BEST PRACTICES BOOK

Challenging Industrial Waste Heat Recovery

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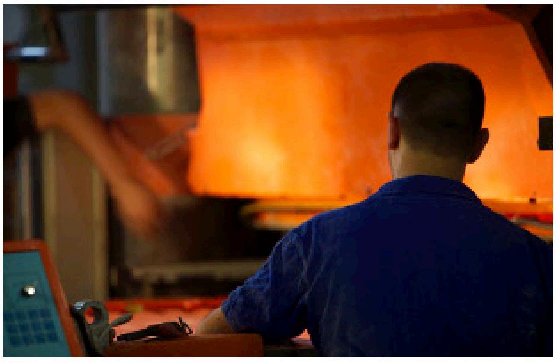


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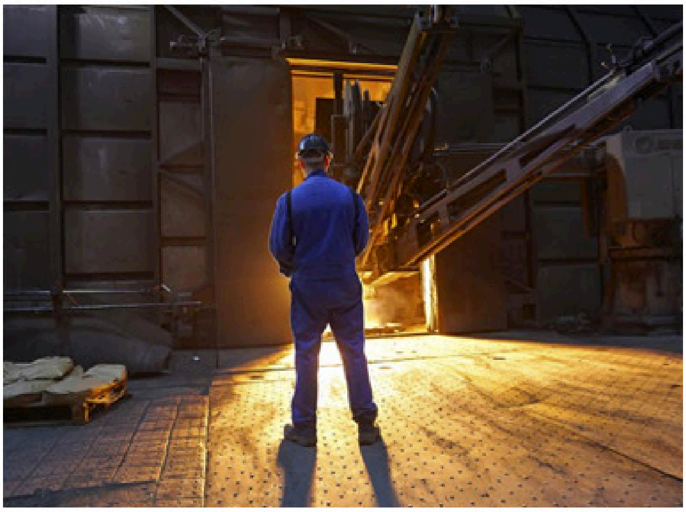


Introduction

The ETEKINA project has expanded the opportunity for waste heat recovery in challenging industrial scenarios, reducing the primary energy needed for energy intensive processes across three different sectors. Namely aluminium diecasting (Fagor Ederlan), speciality steel production (Metal Ravne) and ceramics manufacture (Atlas Concorde). Waste heat is defined as any heat produced by a machine or as a by-product of an industrial process that is lost to atmosphere and has the potential to be captured or reused. Waste heat recovery solutions are implemented to reduce primary energy use, reduce emissions and provide a more energy efficient process. Throughout this project, a subset of heat exchangers known as heat pipe-base heat exchangers have been developed and installed to recover waste heat where installing traditional technology would be too challenging. The life of this project is approaching its end but hopefully the experiences gained here can be applied to future waste heat recovery developments in the right hands. The best practices presented are based upon experiences gained from modelling, designing, installing, testing and operating heat pipe heat exchangers.

Why HPHEs over traditional technology

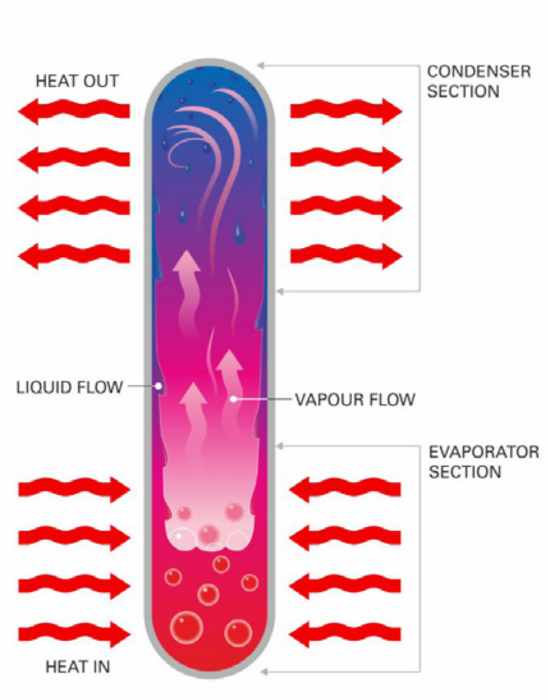


Figure 1 Heat Pipe Principle

A heat pipe heat exchanger consists of many heat pipes that are assembled in a predefined arrangement. Each heat pipe operates as an individual heat exchanger. A heat pipe is a hermetically sealed tube charged with a small amount of working fluid at saturation state. A heat pipe transfers the heat from one end to the other one by two-phase heat transfer. When the heat pipe is exposed to a heat source, the working fluid boils and the vapour flows to the other end which is called a condenser where it condenses and releases the heat to a heat sink. Then the condensate returns to the evaporator by gravity in gravity assisted heat pipes (thermosyphons) or by capillary force through a wick structure in wicked heat pipes. Heat pipes feature uniform surface temperature due to the two-phase heat transfer. In addition, they offer fast response and capability of transferring large amount of heat for long distance without any moving parts. Incorporating heat pipe technology within heat exchangers offers additional features and utilises of heat pipe advantages. HPHEs offers full isolation between the heat source stream and heat sink stream, leading to a risk-free of cross contamination between the two streams. Furthermore, HPHEs offers flexible maintenance as failure of one heat pipe does not impact the performance of the other heat pipes and can be replaced during the regular scheduled maintenance. Further advantages of HPHEs are design flexibility with low maintenance and long-life span which can reach 20 years, Therefore, HPHE technology has been utilised in industry where conventional heat exchangers fail. For instance, HPHEs have been utilised in challenging exhaust streams due to their fouling conditions, corrosive composition, and high temperature.

1. Demo site 1 – Fagor Ederlan

1.1. Introduction

In the use case **Fagor Ederlan,** the aluminium parts receive three heat treatment process: first, the parts are heated at 540°C in a Solution Heat Treatment Furnace (SHTF); next, they are immersed into a Quenching Tank (QT) to be cooled down quickly to 40°C and afterwards, they are heated up at 160°C in an Ageing Heat Treatment Furnace (AHTF). Both furnaces (solution and ageing) are roller-hearth continuous type with natural gas fired heating. The knuckles to be treated cross the furnaces introduced in baskets that are moved by the rollers.

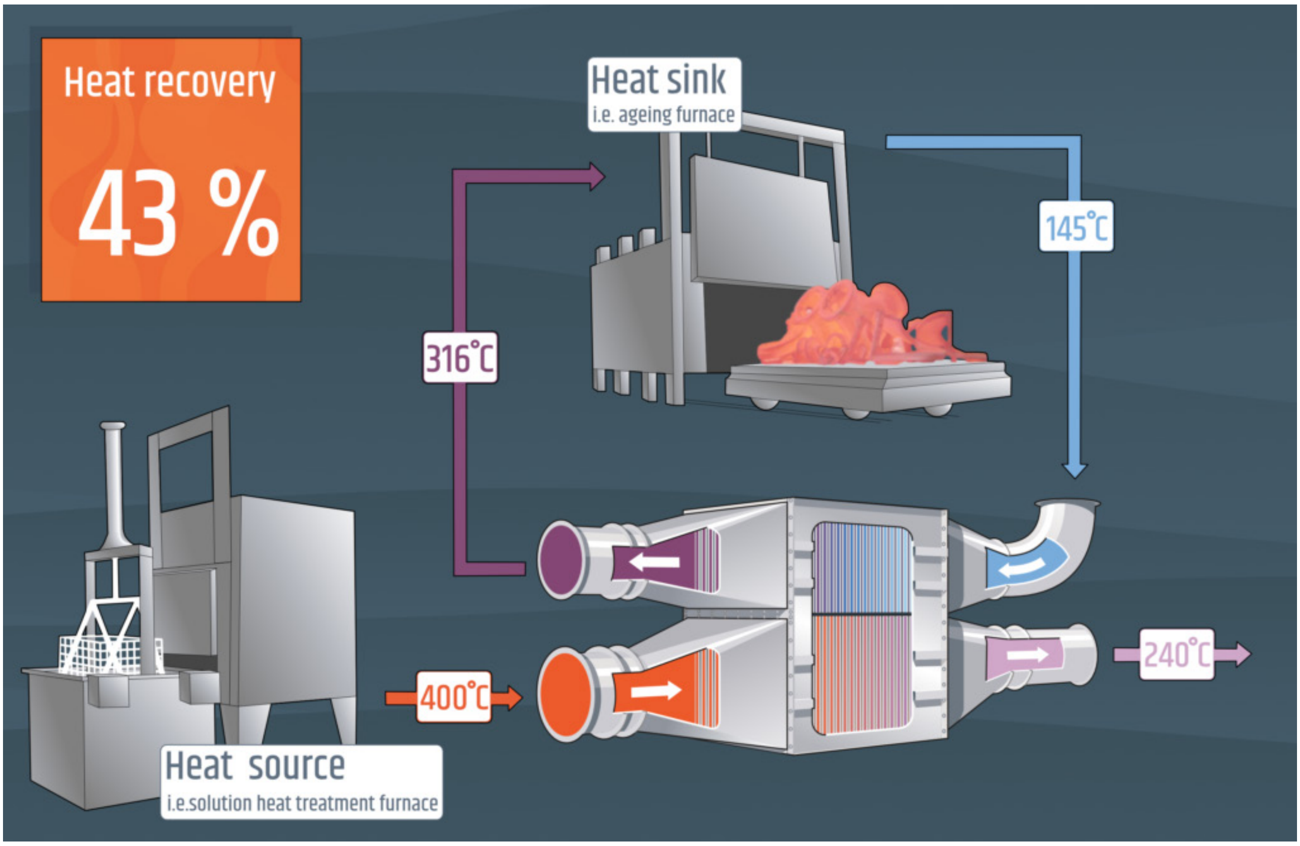


Figure 2 Schematic and objectives of the ETEKINA Project at Fagor Ederlan

The goal of the designed and mounted WHR system is to capture the waste thermal energy delivered by the solution furnace exhaust fumes and transfer it by a HPHE to a recirculation stream that heats up the ageing furnace. In Fig. 1 the layout of the WHR system based on HPHE applied in thermal treatment furnaces of aluminium automotive parts, developed as demo site 1 in ETEKINA project is shown together with the process temperature profile.

Figure 3 HPHE installed on platform

1.2. Installation & commissioning

Simplified P&IDs

The Waste heat recovery system is composed of three main elements, the solution heat treatment furnace, the ageing heat treatment furnaces and the HPHE. The energy contained in the exhaust of the SHTF is absorbed by the HPHE unit which transfers it to the AHTF via a close air flow loop. The system can be operated in various mode:

- Full bypass of the HPHE system (setting prior to the ETEKINA Project)
- Pre-Heating mode, this mode is used to preheat all the system prior to the Waste Heat Recovery mode to ensure that the correct temperature is fed to the AHTF.
- Waste Heat Recovery Mode, the energy from the exhaust of the SHTF is transferred via the HPHE to the AHTF
- HPHE Bypass Mode. This mode is used in case of an increase in the HPHE working temperature which could cause an overheating of the Heat Pipe. The condenser section continues to run to ensure that the Heat Pipes cool down while the exhaust is bypassed to atmosphere until the Heat Pipe are under the maximum allowed temperature.

A simplified Piping and Instrumentation diagram of the installation can be seen below:

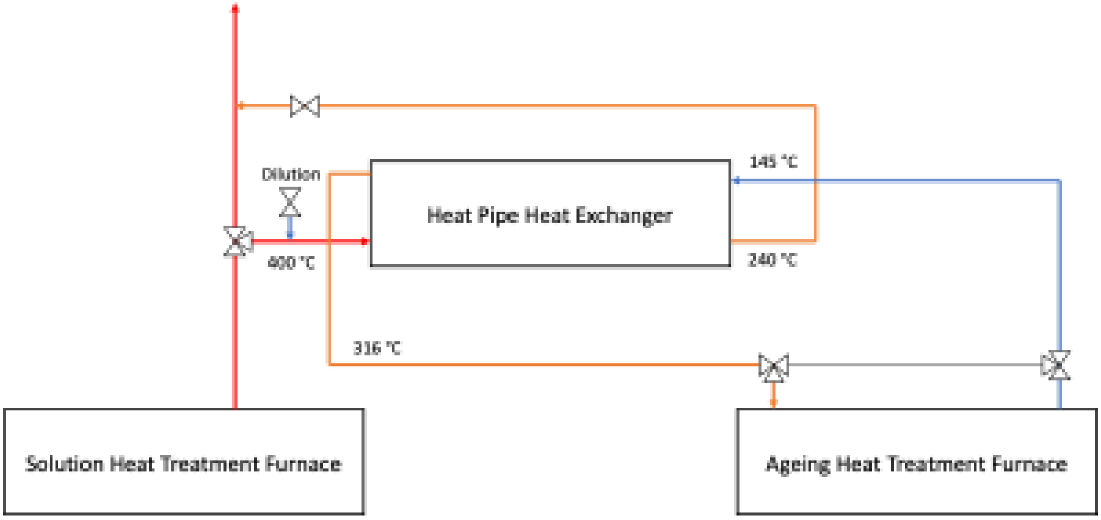


Figure 4 Simplified P&ID, demo case 1

Summarise key findings

The installed waste heat recovery system key findings can be, in the case of Fagor Ederlan, summarised in three sections:

Energy recovery

The system was able to recover, on a reference day, up to 98.3 kW, above the design conditions. However, the power transferred to the condenser section of the HPHE was 63.6 kW. It was concluded that the different in energy between the two streams is due to the lack of insulation on most of the HPHE and the valves used on the system. In this regard, it was decided to insulate the totality of the system to reduce the thermal losses and improve the efficiency of the system.

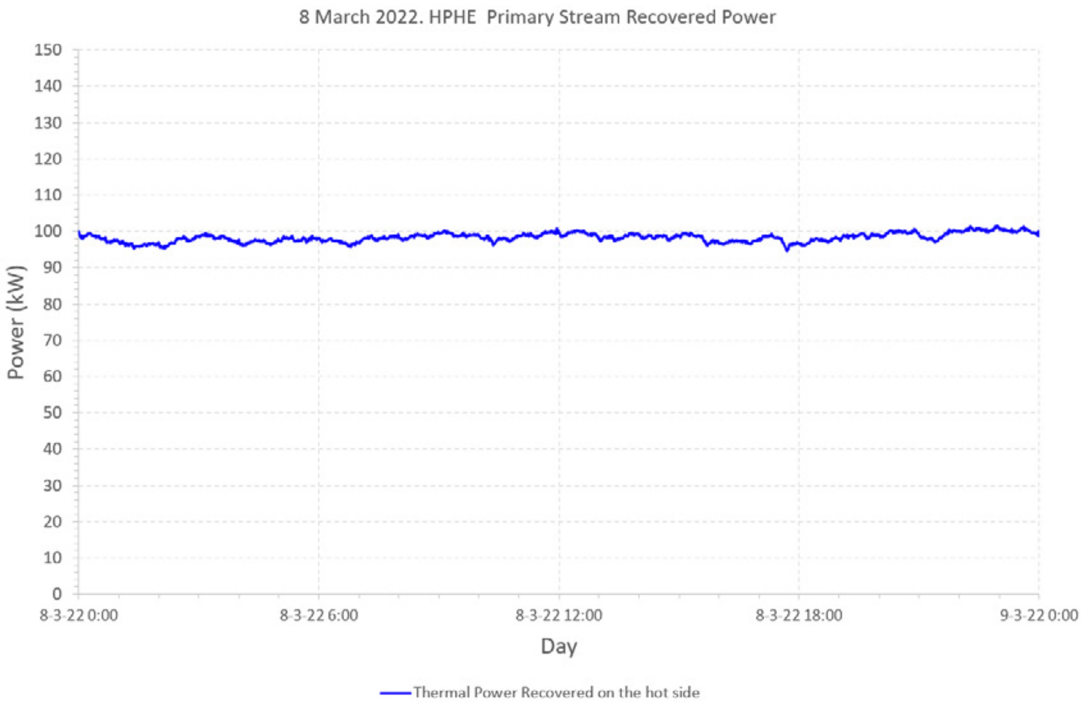


Figure 5 Thermal Powered recovered on a reference day

Energy efficiency

The energy efficiency of the system was calculated based on the amount of heat absorbed from the primary stream referenced on 25°C. It was calculated to average 48 % of the heat available in the stream which surpasses the target of 40 %, the objective of the ETEKINA project. In this regard, the installation of this system is a success.

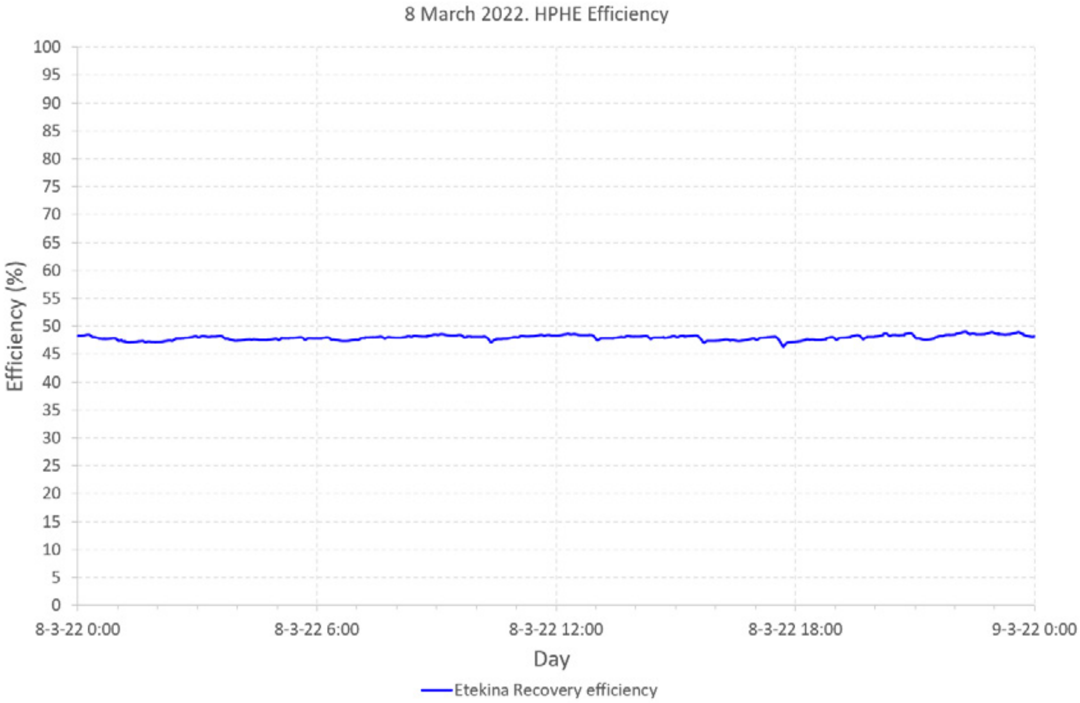


Figure 6 Energy efficiency calculated on a reference day

Natural gas and Greenhouse gas emission saving

The heat recovered from the HPHE was used in the Ageing Heat Treatment Furnace to reduce the load on the gas burners, thus reducing the amount of natural gas consumed and the amount of CO_2 or greenhouse gas rejected to the environment. Using the HPHE system drastically reduced the amount of natural gas consumed. From the commissioning in October 2021 to March 2022, the total natural gas consumption reduction is estimated at 15 836 Nm3 which represent a cost saving of 11,805 € (64 €/MWh). Reducing the gas consumption of furnaces in energy intensive process became a strategic goal for industries as price gas continues to soar.

On the other side, reducing the natural gas consumption also reduce the greenhouse gas emission which is another challenge that high demanding industry is facing. In this regard, the HPHE system was successful by reducing the emissions of those gasses by almost 34 tons in tested period.

It is expected that based on the current annual production time of the Fagor Ederlan plant, the annual saving in natural gas and in greenhouse gases emissions will be 42,500 Nm3 and 90 tons respectively.

Return on Investment

The system installed at Fagor Ederlan is a prototype which increases the cost on installations and monitoring as part of a research project. In this regard, the approach for the ROI need to be carried out using the return of experience of the project and the minimisation of the monitoring and simplification of the P&ID. A vital element would also be the total insulation of the system to ensure that no heat is lost in the secondary circuit of the system.

The finalised ROI for such an installation in a commercial situation would be at 39 Months with the gas price in 2021 and 19 Months using the gas price of 2022. However, as gas prices continue to increase, the ROI cost of the HPHE system will continue to drastically decrease over the year.

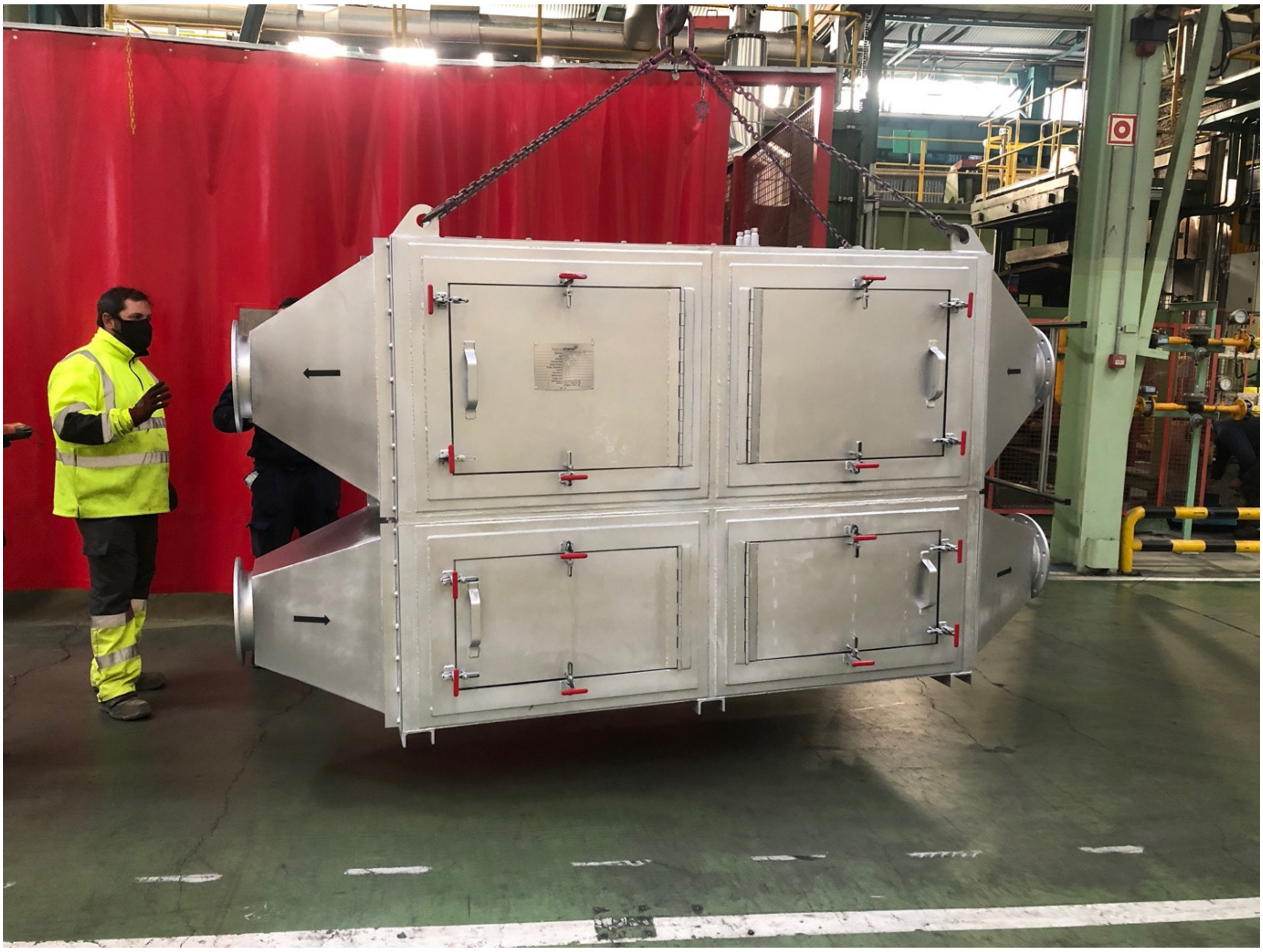


Figure 7 HPHE unit during installation at Fagor Ederlan

1.3. Lessons learned of Demo site 1

The lessons learned from this installation can be summarised as follow:

- An efficient insulation of the HPHE system can increase the overall efficiency of the system and should always be considered when installing a Waste Heat Recovery unit, in particular for this scale (<250 kW)
- Use of industrial thermal energy storage to provide a continues power to the aging furnaces. This will allow for a smoother operation of the furnace while using a variable energy source.
- Optimisation of the system design is key to an efficient system. The oversizing of components leads to losses in efficiency. The main energy consumer in the system are the circulation fans, oversizing these fans leads to a decrease in the efficiency of the ETEKINA system. Sizing the fans to the application will improve the performance of the system.
- Ensuring that the diverter valves are not leaking, i.e. sealing properly shut, to ensure that the working temperature of the HPHE unit can be achieved, which will increase the amount of heat recovered from the system.
- The distance between the furnaces and the HPHE need to be reduced to improve the energy efficiency, decrease the load on the fans (lower pressure drops) and decrease the materials necessary to connected the furnaces to the HPHE.
- Modifying the control system to ensure that the recovery mode have priority over the use of the burners in the aging furnace.
- Condensation can occur when the system temperature is under the Dew Point of the exhaust. It is vital that this point is not reach to prevent the corrosion on the heat pipes, thus reducing the need for maintenance. By ensuring that the system runs continuously, this issue can be avoided. However, this will only be achieved by limiting the use of the bypass valve.
- Communication is key, in this regard, a close collaboration by all the partners involved in such a project need to be very well established. Links between the technology providers, installers, end users and furnace manufacturers need to be established prior to the design phase to ensure that no issues will arise during the project implementation.

2. Demo site 2 – SIJ Metal Ravne

2.1. Introduction

SIJ Metal Ravne Ltd. is a producer of specialist steels, based in Slovenia. It forms part of the SIJ Group which are one of the top five Slovenian industrial group.

The furnace targeted for the ETEKINA system is a heat treatment furnace. The aim of the system is to recover 400 kW from the current exhaust stream. The recovered heat will be then used to provide pre-heated air to the burners and district hot water for the plant and surrounding district heating. The use of a dual heat sink for the waste heat recovery system has never been implemented before, hence the strategic aspect of this demo site to the ETEKINA Project. The success of this demo site can highlight the many applications where the ETEKINA system can be implemented and the variety of heat sink to be used.

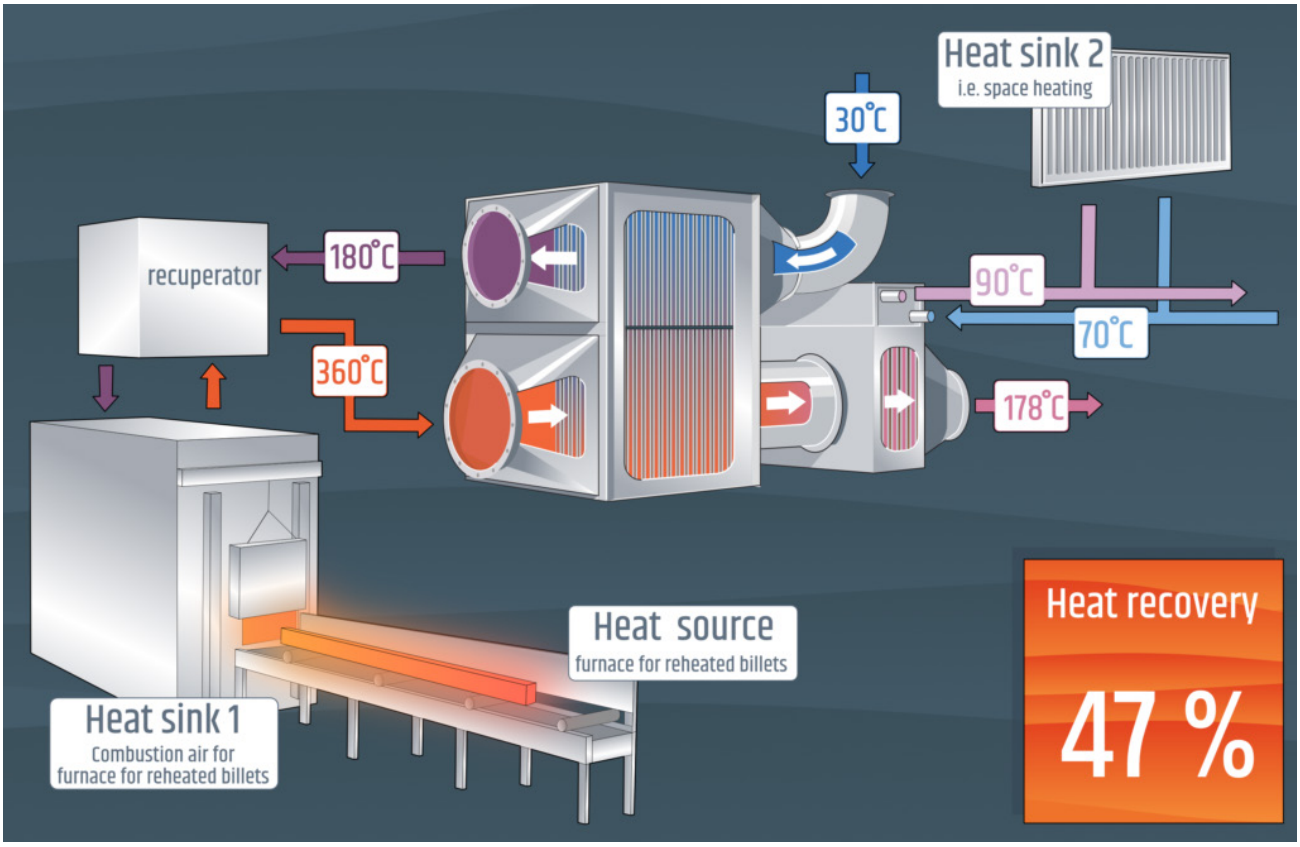


Figure 8 Schematic and objectives of the ETEKINA Project at SIJ Metal Ravne

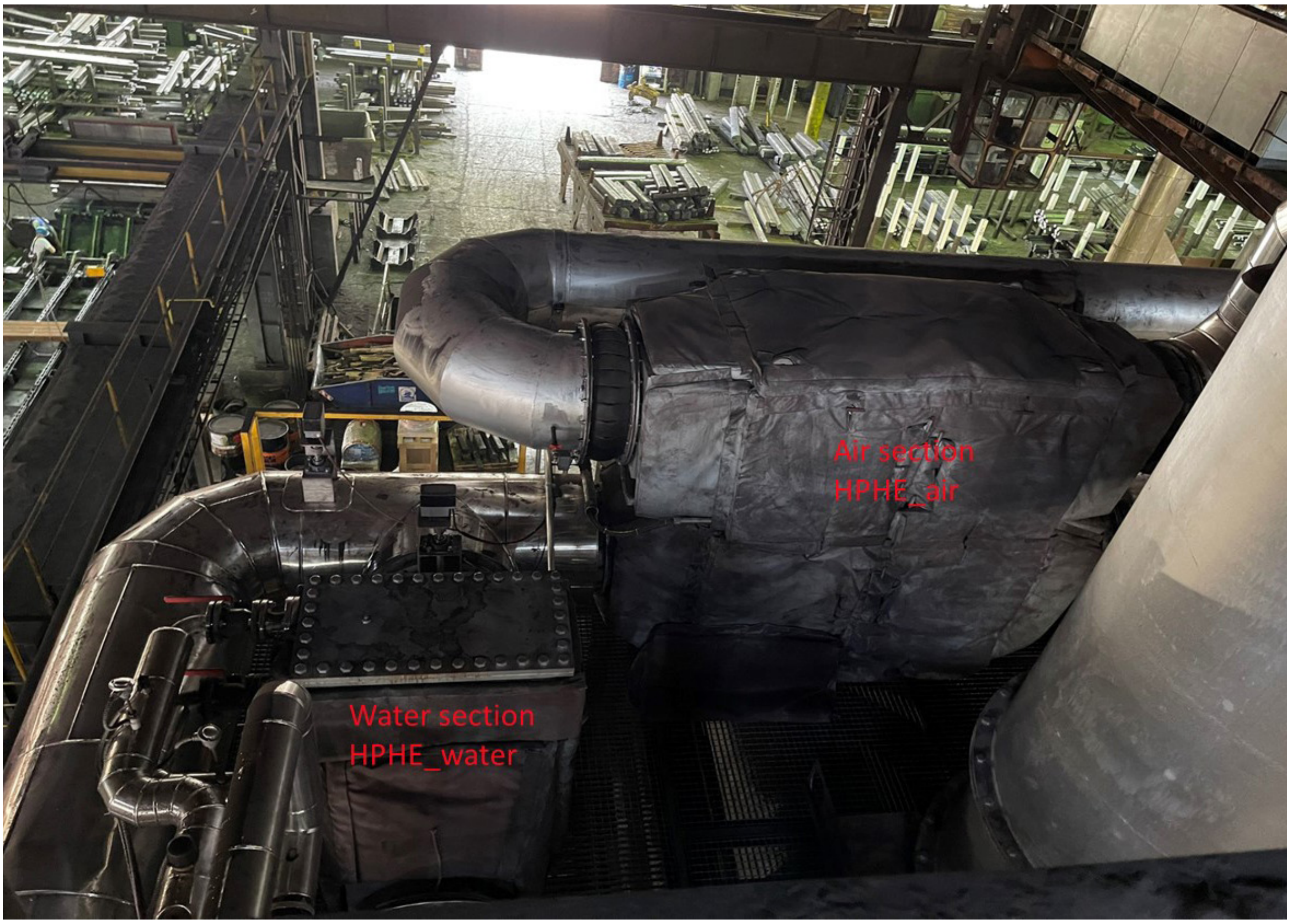


Figure 9 Installed Dual Heat Sink HPHE at SIJ Metal Ravne

2.2. Installation & commissioning

Simplified P&IDs

The heat treatment furnace where the ETEKINA system is applied is the Alino furnace, used to preheat steel billets. A heat recovery system is already in used in the furnace to preheat the air to the burner called the Recuperator. The exhaust gases of the furnace go through the Recuperator. The exhaust then goes through the Dual heat sink HPHE system via a bypass valve. The majority of the heat contained in the exhaust is recovered to preheat the air fed to the Recuperator while the remaining heat is used to heat water for sanitary and office building heating. By using the dual sink methods, the energy recovery potential of the exhaust can be exploited to its fullest while decreasing natural gas consumption and greenhouse gas emissions.

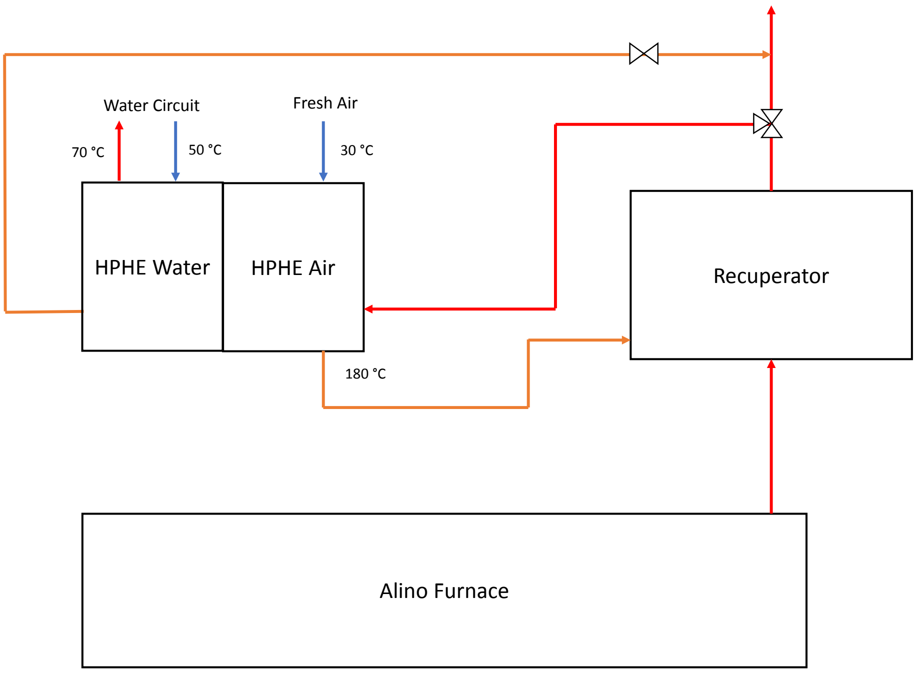


Figure 10 Simplified P&ID Demo case 2

Summarise key findings

The installed waste heat recovery system key finding can be, in the case of SIJ Metal Ravne, summarised in three sections:

Energy recovery

The designed system aimed to recover up to 400 MW of thermal power at the exhaust side. From an exhaust at 350°C for a flow rate of 6150 Kg/h. The Air heat sink section was able to recover up to 200 kW during a reference day from the exhaust side as can be seen below:

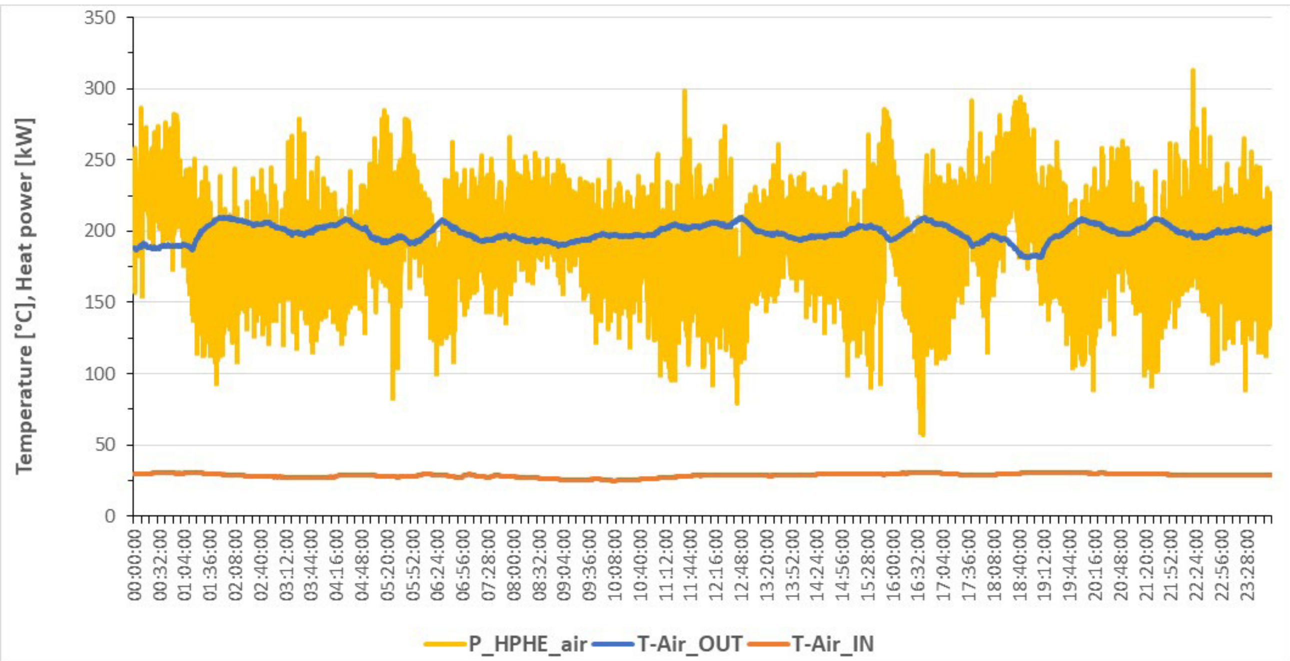


Figure 11 Heat Recovery of the Air section during a reference day

The water section was able to recover up to 130 kW during a reference day.

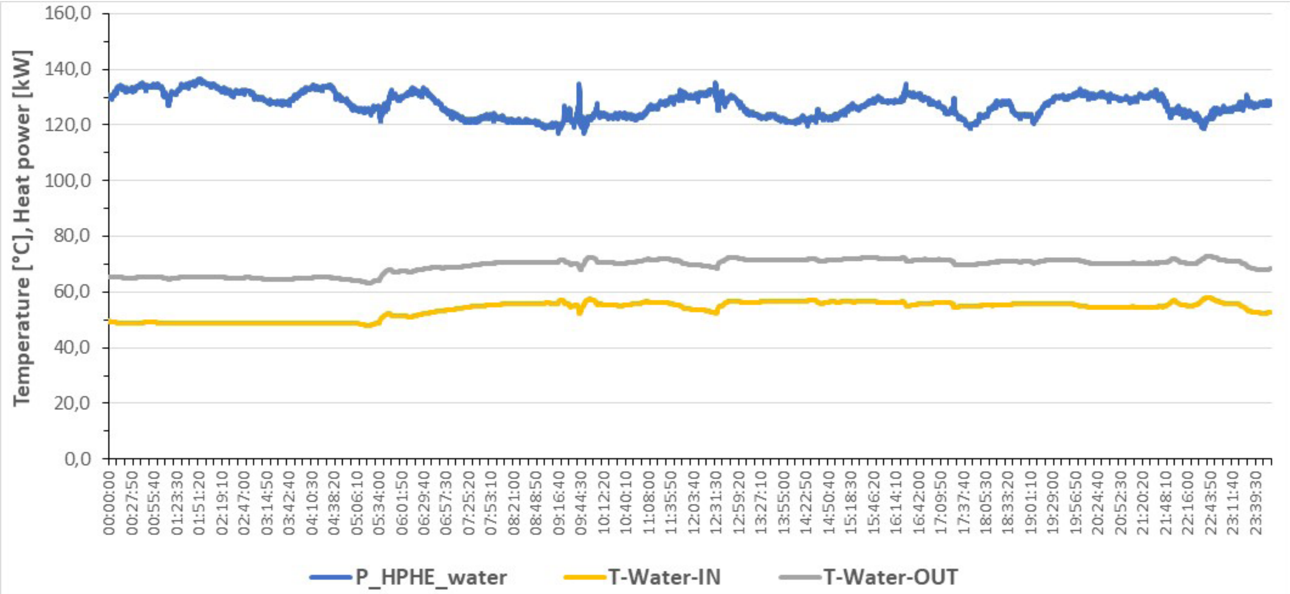


Figure 12 Heat Recovery of the Water section during a reference day

In this regard, the total amount of energy recovered from the system on a reference day is 330 kW. Dissimilarity between the design conditions and the experimental test can be seen. The decrease in power recovered can be explained by a lower temperature output to the water side due to restriction in the DHW heat characteristic which lead to a decrease from 90°C (design condition) to 70°C (operating temperature). Also, the use of the dilution valve to reduce the temperature of the heat pipe in order to achieve a lower temperature lead to a decrease in the energy recovered. However, the HPHE was able to absorb more than 47 % of the waste energy contained in the exhaust which is above the targeted value for the ETEKINA Project.

Over the selected testing period (November 2021 to end of March 2022), the system was able to recover up to 895 MWh. The water section recovered 364 MWh while the air section recovered 531 MWh on an effective operation time of 2804 h.

Energy efficiency

The energy efficiency of the system on a reference day is above the targeted value for the ETEKINA project as mentioned previously. The obtain value was 47 % efficiency. The fluctuation in the energy efficiency below can be explained by the use of the fresh air dilution valve. Optimising the use of this valve could lead to an increase in the system efficiency.

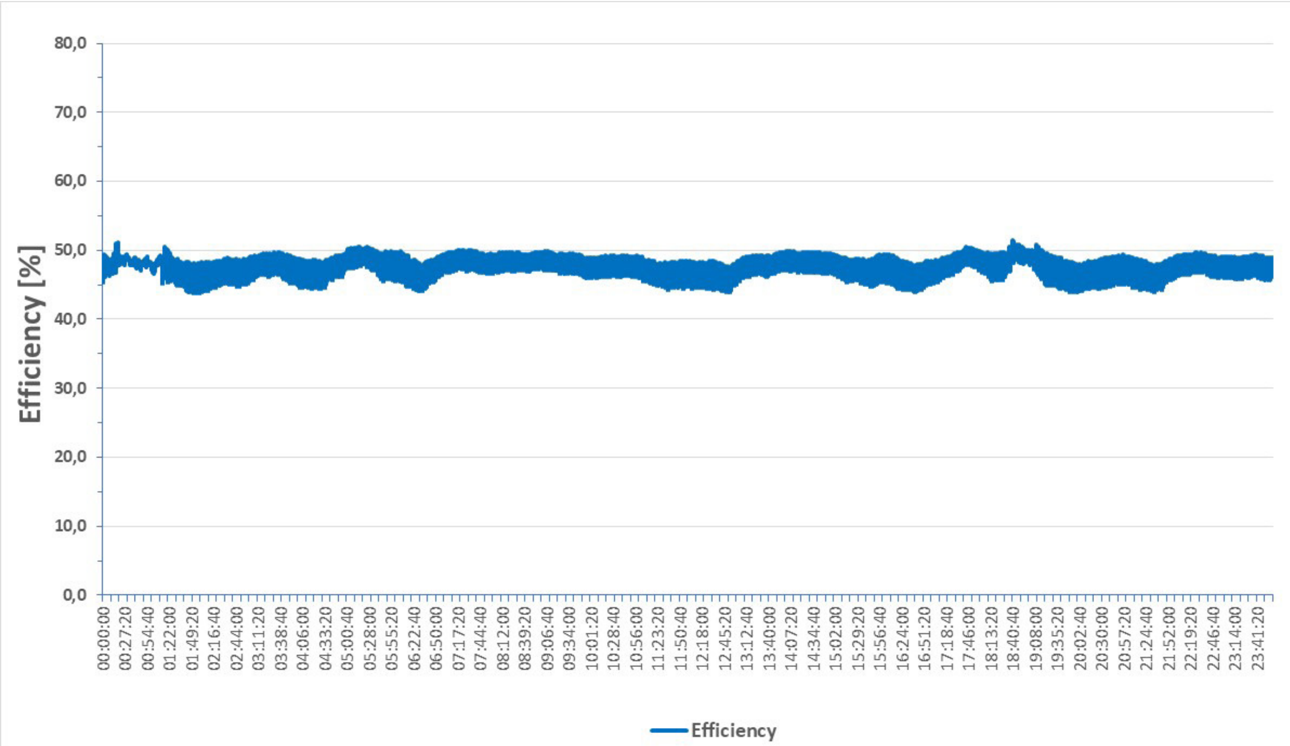


Figure 13 Efficiency of the Dual Heat Sink HPHE on a reference day

Natural gas and Greenhouse gas emission saving

Natural gas prices have been varying substantially over 2021 and 2022. In this regards, two gas prices have been selected for the economical case of the system. A price of 0.313 €/Sm³ for the 2021 period and 0.615 €/Sm³ for the 2022 period have been selected. In terms of volume saved by the system, the total saving in natural gas from feed preheated air to the burners has been estimated to be 56 428 Sm³ which correspond to an economical saving of 57 118 € using the prices mentioned previously.

In terms of CO_2 savings, the total amount of greenhouse gas emissions saved is 106 tons over the test period.

A table summarising the cost, gas and greenhouse gas emissions saving can be seen below:

Table 1 Dual Heat Sink HPHE saving over the test period

		Heat recovery	Natural gas savings	Economic effect (savings)	CO₂ Reduction	
		MWh	**Sm³**	**EUR**	**t CO_2**	**EUR**
Nov. 2021	Air	91	9582	3004	18	1354
	Water	68		4392		
	TOTAL	**158**	**9 582**	**7 396**	**18**	**1 354**
Dec. 2021	Air	94	9965	3124	19	1408
	Water	63		4118		
	TOTAL	**158**	**9 965**	**7 242**	**19**	**1 408**
Jan. 2022	Air	139	14713	9053	28	2079
	Water	89		7603		
	TOTAL	**229**	**14 713**	**16 656**	**28**	**2 079**
Feb. 2022	Air	123	12984	7988	24	1835
	Water	81		6857		
	TOTAL	**204**	**12 984**	**14 845**	**24**	**1 835**
Mar. 2022	Air	87	9184	5651	17	1298
	Water	63		5328		
	TOTAL	**150**	**9 184**	**10 979**	**17**	**1 298**
2021-2022	Air	534	56428	28820	106	7974
	Water	364	0	28298	0	0
	TOTAL	**898**	**56 428**	**57 118**	**106**	**7 974**

The estimated operation time of the system for the water side and the air side is 5 750 hours and 8 050 hours, respectively per year. The expect energy recovered for the water side is 753 MWh/year and 1677 MWk/year for the air section. In this regard, the expected greenhouse gas emissions reduction is 334 t CO_2/year. The total cost saving of the system is anticipated at 198 050 €/year.

Return on Investment

Similar to the installation in the aluminium sector, this installation is a prototype which lead to higher cost in installation, monitoring and data collection. The values collected during the testing period can be projected to a yearly production. Using the figures mentioned prior, it is estimated that the ROI, based on a cost saving of 198 050 €/year, will be less than 10 months.

2.3. Lessons learned of Demo site 2

Similar lessons were learned in this installation such as the importance of insulation for an efficient system, high end valve, size fan ect. Due to the challenging location of the HPHE unit which is located at a high level, it was vital to have an excellent communication between the RTD, technology provider and the demo site to ensure that no issues arise during the installation of the system. Indeed, limited space was available for installation and increasing the platform size can lead to an increase in the overall cost of the installation, thus a lower ROI.

For a unit that provide hot water, it is important to clearly identify the need of the plant in terms of hot water consumption and the level of the water. It is also useful to approach local company or domestic area to investigate the potential of district heating at communal level. By doing so, the end user can recover some cost via the supply of district hot water to the surrounding hot water consumer, thus, lowering the ROI and maximise the heat recovery of the unit, thus reducing the greenhouse gas emissions.

3. Demo site 3 – Ceramiche Atlas Concorde

3.1. Introduction

Ceramiche Atlas Concorde Spa produce ceramic products in Italy. Here was found the largest installed HPHE. Exhausts from the continuous roller kilns were used to heat air used in the drying process.

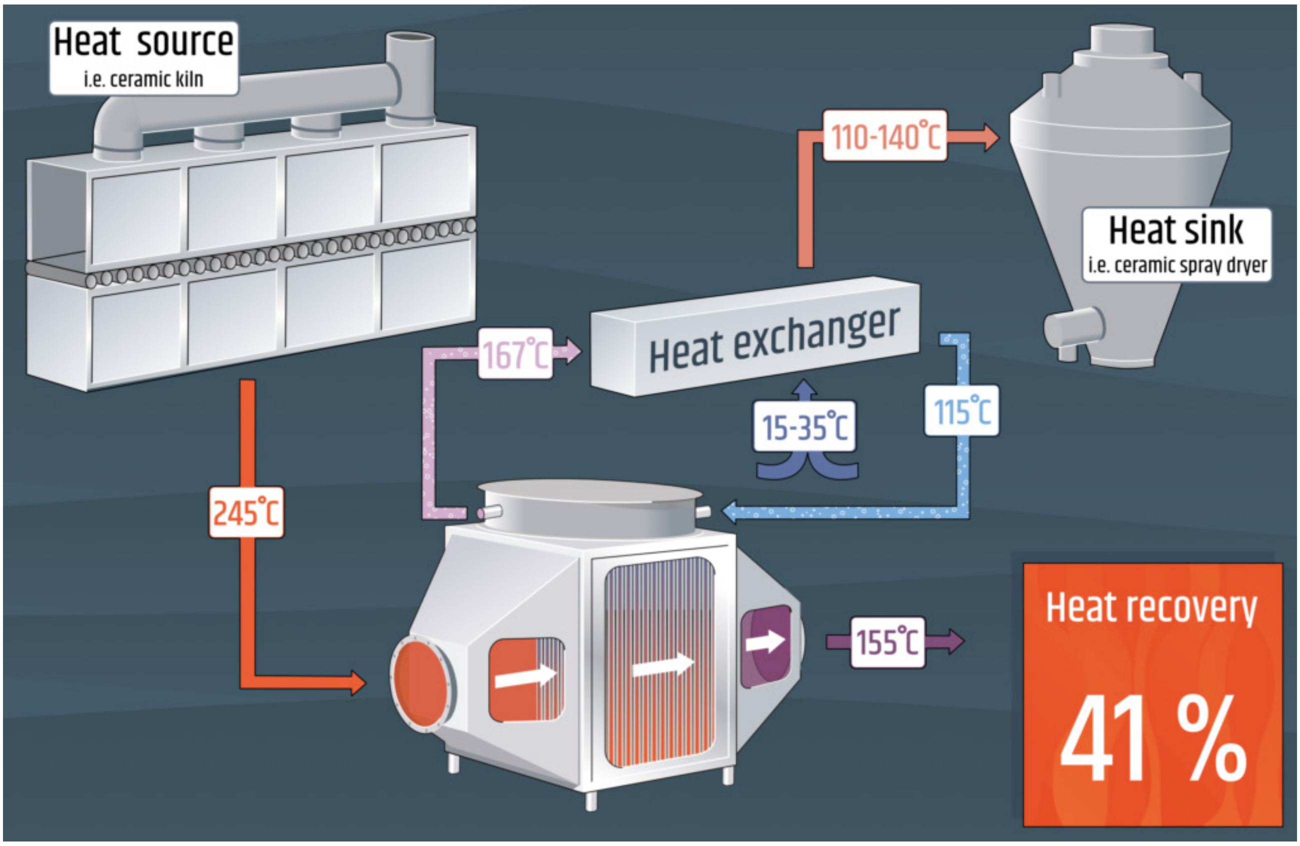


Figure 14 Schematic and objectives of the ETEKINA Project at Atlas Concorde

Figure 15 Installed HPHE at Atlas Concorde

3.2. Installation & commissioning

Simplified P&IDs

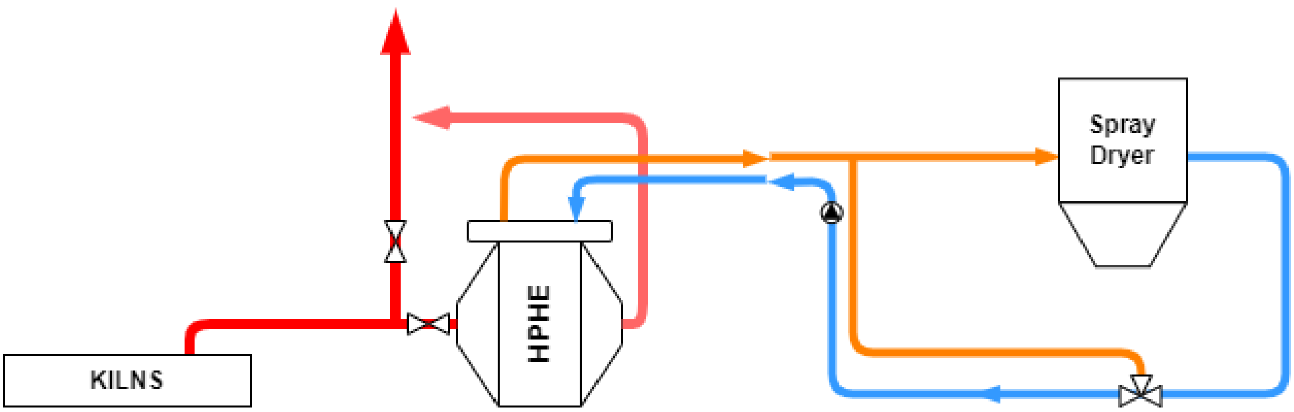


Figure 16 Simplified P&ID of the HPHE system

The HPHE system is connected to the stack of two ceramics kiln. The heat is then transferred to the heat sink via the Heat Pipe Heat Exchanger. The heat sink used in this demo site is a pressurised water circuit that supply hot water to two heat exchangers, providing hot pre-heating air to the spray drier burner. As for all demo sites, a bypass is installed to ensure that the system can be isolated during maintenance. A schematic of the P&ID developed during this project can be seen in Figure 13.

Summarise key findings

Energy recovery

The energy recovery of the HPHE during the operation varied due to the tile batch system that is used during the manufacturing process. Indeed, a variety of materials are fired in the kiln; changes in the exhaust in terms of flow rate and temperatures were observed. The thermal recovery observed during a reference day on the ceramic's demos case varied from 600 kW to 700 kW, inline with the thermal design of the unit. The energy efficiency target of the ETEKINA unit is 40 %, it was noted that the efficiency of the system is always above the ETEKINA target as shown below.

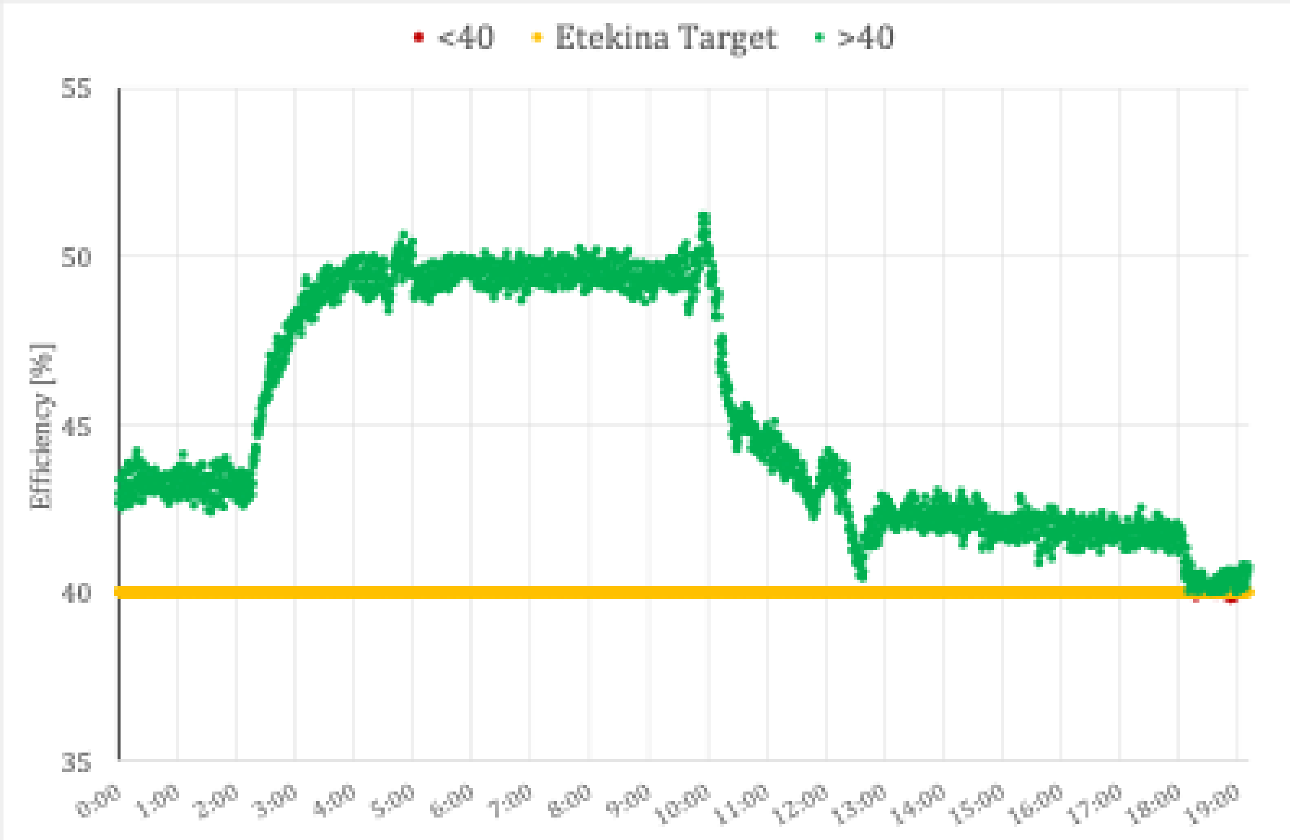


Figure 17 Energy efficiency of the HPHE system at Atlas Concorde

Natural gas and Greenhouse gas emission saving

The system installed in Concorde resulted in a substantial CO_2 reduction due to the large size of the system. Similarly, the reduction in natural gas was also substantial. As gas price market is soaring, it is important for large energy consumers such as the tile ceramic sector that the consumption of energy is reduce. Installing the ETEKINA until will provide an edge on the market by cutting production prices and to remain competitive on a global market. The CO_2 emissions saving is also a vital element for intensive energy industry. Tackling climate change is the main challenges today, in this regard, reducing greenhouse gas emissions by heavy industry is a vital element to this effort.

Return on Investment

The return on investment of the unit was based on two main parameters, the gas price set at 97 €/MWh. The second parameter is the CO_2 tax credit set at 79 €/t. In this regard, the HPHE unit managed, within the first five months of the project to save 90 k€ in Natural Gas consumption. Similarly, for the CO_2 tax credit, a total of 15 k€ were saved during the first five months of the project. Based on the energy recovered in the first five months of the project, it is expected that the total amount of heat recovered per year, based on the current operation of the unit is approximatively 2,5 GWh, while the greenhouse gas emissions is expected to be 0.5 $ktCO_2$/y. it is expected that the Return On Investment of the ETEKINA installation at the Ceramic demo site is less than 3 years.

4. Best Practices

The Return Of Experience of the ETEKINA project is laid out in best practices that should be followed when dealing with waste heat recovery project on a large scale such as the ETEKINA project. Each best practice has been selected to be relevant to what was accomplished during the project as part of the most challenging tasks.

Data Collection and waste heat recovery survey

One of the vital elements of a waste heat recovery project is the assessment of the waste heat recovery sources in the industrial plant. The potential waste heat recovery will drive the investment cost and the Return On Investment of the ETEKINA system. In this regard, it is vital that site surveys are done in a strict manner. Data such as temperature levels, flow rates, gas composition, pressure drops allowed, footprint available for the installations, complexity of piping, distance from the heat source to the heat sink and others are clearly identified through a data capture form that need to be completed and signed off by the end user using up to date data. Any deviation between the data capture form and the actual exhaust condition can lead to a diminished performance and lower ROI. Approaching specialist institutes in data collection and survey can be beneficial for the end user if the knowledge is not available in house.

Our advice
- Provide accurate data set on the exhaust characteristics.
- Anticipate any deviations from the actual exhaust values.
- Survey the site for potential location and estimate the cost of linking the heat source to the heat sink.
- Monitoring campaign need to carried out before any installations.

Caution
- Using historical data can be misleading.
- Data need to be recorded over a few cycles to ensure that the exhaust remain within the operating conditions of the system.

Our Experience
Data capture forms were a vital element of the project that took some iterations to complete. The completion of those forms was done through Technical Visit at the various demo sites, presentation to the end users of the solution to ensure that the technology is well understood and numerous iterations between the HPHE designers, manufacturers, system designers, RTDs, end users and operators to validate the forms. Joining forces from all the actors in the project was necessary for an efficient design and most importantly, a well-planned installation and commissioning.

Best practice on modelling

In the design stage, waste heat recovery systems are often designed by using static calculations related to the nominal condition of the system. Simulation can help to investigate the complex fluid dynamic phenomena involved in these systems and for analysing the integration between each component of the circuit. Simulations are very helpful to analyse the thermal response of the system under certain fluctuations. Different configurations for a solution can be investigated with the simulation.

Our advice

- Define exactly which is the aim of the simulation
- Use a 0D/1D approach for the investigation of a multicomponent system
- Include for each component its real geometry and fluid dynamic features.

Caution

- Validate the numerical model against experiments to have a reliable tool.
- Be aware of including all heat transfer mechanisms within the numerical model.

Our Experience

In ETEKINA, we developed a numerical model of the entire waste heat recovery system in the ceramic case. The numerical model includes all the main components of the system: primary side (waste heat source and piping), HPHE, secondary side (pump/compressor, tank, piping, valves etc), control strategy. The numerical model enables the prediction of the thermal fluid dynamic behaviour of the system (temperatures, pressures, flow rates…) and the evaluation of the best solution that maximizes the energy recovery and, thus, increases the energy efficiency of the industrial process. The numerical model has been used in ETEKINA to develop and tune a control strategy for maintaining the parameters of the system in the desired range.

Best practice on design of HPHE

HPHE design rely heavily on the contributions from the RTDs, the end users and the data capture forms as the system design is bespoke. Every installation is unique due to the exhaust, the footprint and other parameters. It is important to ensure that the end user is satisfied with the design. A HPHE cannot be designed without fully understanding the heat streams conditions and the thermal process. Therefore, the data capture form is an essential step. The HPHE design is evaluated from various aspects such as HPHE size, weight, footprint, cost, availability of the heat sink, compatibility between HPHE materials and heat source and heat sink streams Many iterations of the design can occur until a good agreement between all the involved partner is reached. Involving the ensure user in the design of the unit will also give them a good understanding of what is being installed and how to operate and maintain it. The HPHE design considers various “what if” scenarios. Based on the worst-case scenarios that might happen, several risk mitigation and safety precautions are taken.

Our advice

- Involvement in the design is key to a satisfied end user.
- The design iteration can be challenging but it is vital for a good system operation.
- Every installation is unique and bespoke allowing proper time for design will increase the impact of the system.

Caution

- Cutting corners in the design will only lead to poor system efficiency and a dissatisfied end user.
- Every installation is unique, trying to create a generic design for various site is not advised.

Our Experience

The Design of the HPHEs in ETEKINA was challenging due to the dissimilarity between the exhaust characteristics and heat sink requirements of each sites. Challenges included high temperature and high flow rate exhaust streams, fouling, high pressure heat sink, fluctuating flow rate and temperature of exhaust stream with variant heat sink load, and space limitations. However, by working closely with all the involved partners, the ETEKINA project managed to produce units for all the sites with satisfied end users and a technology that can operates safely. Involvement of the end users and the operators is a vital element of system design. Understanding of the requirements for each site in relation to local and national regulations is also an important aspect of a successful design. Each HPHE was designed to provide the optimum thermal performance at the lowest cost possible and to meet the end user requirements on the same time.

Best practice on installation

The installation of the system is the most crucial moment of any projects. During the installation, a few issues can arise such as non-alignment, different dimensions, weights, connections, unit positioning, and other issues. In this regard, it important that the installation is planned prior to the unit arrival on site and that installation guidelines are prepared for the operators to follow during the mechanical installation of the system. As the unit are large in size, proper manutention needs to be in place as well as risk assessments. It is important that all operators are trained on the installation prior to the work being carried out and that the technology provider is present during the process to avoid any issues. I.e. The direction of the flow in the HPHE is vital, the technology provider needs to ensure that the system is properly placed.

Our advice

- Prepare guidelines for the installation of the unit on site.
- Risk assessments.
- Training of installers.
- Technology providers on site before opening the crate to ensure no damage is done and that the unit is placed properly.

Caution

- Untrained installer can place wrongly the unit which can cause delays to the project.

Our Experience
In the ETEKINA Project, the technical coordinator, responsible on behalf of the technology provider was present during the mechanical commissioning of the unit on site. This prevented any issues in the installation of the system. Prior to the HPHE installation, all the sub system such as sensors, valve, fan etc. were tested by the end user to avoid any delays to the thermal commissioning. HPHE Manuals were also provided to the end user. Plant design and other 3D software were used to ensure the HPHE will be installed safely, correctly, and meets the end user requirements. A Balance Of Plant design was also prepared and approved by the coordination and the end users.
As the RTDs and end users were responsible for the design of the connections to the heat source and heat sink, no serious issues aroused during the installation of the systems.

Best practice on commissioning

Hot commissioning is a process that need to follow strict guideline and be witnessed by the technology provider, the end user and the RTD. A document needs to be prepared before the commissioning outlining the process that need to be followed to ensure that no damage is done to the system. In this regard, after the mechanical commissioning, the end user should not start the system without the technology provider. Once commissioned by the technology provider, a document certifying the operation of the system need to be prepared and shared by the technology provider to the RTD and the end user. Proceeding step by step by ramping up the temperature and the flow rates during the commissioning while monitoring the HPHE temperature and flow rate is vital.

Our advice
- Have the technology provider present physically during commissioning

Caution
- Do not use the full load immediately, ramping up the exhaust is vital to ensure the system is safe from any damage

Our Experience
The Hot commissioning test was carried out in each site by the technology provider, the technical coordinator, the RTD and the end user. A commissioning document was sent to the end user outlining the different steps to ensure a safe commissioning. Each system was commissioned by firstly ensuring flow rate in the condenser is present to safely remove the heat, once done, the ramping up of the exhaust flow rate and temperature can start until the full load is achieved. Then, the system will operate at max load. Once the technology provider and the technical coordinator of the project are satisfied with the performance, the system can be considered commissioned and is handed over to the end user control system.

Best practice on system operation

The operational conditions of heat exchangers are mainly relying on a set of parameters such as pressure, temperature, flow rates and energy transferred from the primary to the secondary stream. Other considerations need to be accounted such as fouling, leakages, mechanical damages etc. Operating parameters, safety parameters and critical parameters need to be identified prior to operation and provided by the technology provider based on end user requirements.

Our advice

- Involved partners needs to be fully committed to this task to ensure that the system operates within the boundaries.

Caution

- Proper identification of safety operating parameters.

Our Experience

During the ETEKINA project, a control strategy for the operation of the HPHE was defined in collaboration with the end users, RTDs and the technology provider. This operating parameters and control strategy included, shut down procedure, start up procedure and emergency procedure based on parameters such as maximum heat pipe temperature, maximum pressure in the circuit, operating temperatures of the Heat Pipes, energy recovered, operating flow rates ect. This was then translated in a PLC controller.

Best practice on maintenance

Maintenance of heat exchanger allow for an extended longevity of the system which is key for the Return On Investment of waste heat recovery system. In this regard, it is important that technology providers and RTD provide to the end user maintenance schedule documents and frequency of maintenance.

Our advice

- Ensure that the end user have all the information's from the technology provider on maintenance schedule and practices.

Caution

- Low maintenance translates into a low lifespan and higher running cost.

Our Experience

HPHE do not require heavy maintenance compare to more traditional heat exchanger such as shell and tube heat exchanger. The maintenance of HPHEs consist of visits to be carried out during maintenance shutdown to ensure that no blockage in the tube bundle is present as well as leakages from the tube plate. To ensure that all the pipes are working in the system, a continues maintenance monitoring can be put in place. If the energy efficiency of the system decreases, then, some heat pipes in the system are not functioning which mean replacement are needed. However, the system can still function until the next shutdown.

Best practice on exploitation and dissemination

Developing new technology and ideas is vital for a project but it needs to be able to reach the correct beneficiaries and potential customers. Convincing new practices for waste heat recovery is challenging as more traditional heat exchanger are already well deployed and know by the industry. In this regards, dissemination and exploitation strategy are key to a successful project when it comes to waste heat recovery technology. Approaching potential industry early in the project, providing visualisation tool and software, participating to international events, publishing scientific papers and participating to conferences are part of the best practices in a research project.

Our advice

- Participate to large scale industrial event.
- Approaching industry institution early in the project.
- Scientific publications and validations.

Caution

- Events need to be done at the benefit of the all consortium with the approval of partner.

Our Experience

In ETEKINA, research institute and universities published substantial scientific publications to disseminate the activities of the project as well as the participation to international conferences on energy efficiency. A visualisation tool was also developed to potential end user can design their own system prior to approaching the relevant project partners. Participation from the Media Partner of the project to various symposium, industry conferences and networking events allowed to disseminate the result of ETEKINA.

Best practice on system optimisation

System optimisation is an important part of the commissioning and installation process. Indeed, most of the issues with the system will occur after some months of exploitation. Opportunities for efficiency improvement can be detected after a certain period. In this regard, monitoring the system after installation and for at least one year can provide insight on what needs to be optimised (ie. Insulation materials, fan size, flow rates and temperatures, use of the dilution or bypass system etc.)

Our advice

- Monitor the system for no less than a year to identify potential improvement.

Caution

- Improvement needs to be carried out within the boundaries set by the end user and the technology provider.

Our Experience

After the ETEKINA HPHE installation occurred, some potential improvements in the system operation were detected. Indeed, in demo case 1, the efficiency of the system was increased by insulating the HPHE, Valve, end other piping system. The control strategy was also change to increase system efficiency by prioritising heat recovery mode over the burners. In demo case 3, a better use of the dilution valve was also implemented to ensure a higher temperature at the inlet of the burners.

Best practice on ensuring project completion

For ensuring a success project completion, different phases have to be successfully completed: definition phase (data capture and design), implementation phase (piping, electric, components) and HPHE unit manufacturing), components integration and WHR system commissioning phase, its validation phase and monitoring phase. To achieved those phases, different working groups are involved whose action require to be very well coordinated. The commitment of all of them and a good and fluent collaboration under the coordination of WHR responsible is necessary.

Our advice

- In every new WHR installation, a project management that represents the end-user and who is the responsible of the WHR installation should coordinate all the involved groups (technology provider, RTDs and installation designers, control developers, mechanical & electrical installers, production manager, quality manager) and their intervention timing.
- Each involved group should have a responsible member who interacts with the installation project manager
- Regularly scheduled managing meeting should be planned for a close monitoring of the progress of the WHR implementation
- Involved working groups needs to be fully committed with the WHR project

Caution

- The implementation in a production line is under unforeseen situations out of the WHR project control (i.e productivity needs that eliminate the stops-timing planned for the WHR system implementation, maintenance activities arisen that interfere with the planned WHR system monitoring, etc.) and all the involved groups may have to adapt to the arisen new situations

Our Experience

In ETEKINA, each demo site installation responsible has interact with all the involved groups with a close collaboration of the Scientific Coordinator, WP4-leader, technology provider and RTD-s. Many unforeseen issues have been arisen due to the production needs, COVID-19 situation, difficulties to coordinate the different availability of the involved working groups, etc, But by regular meetings and by a close communication and the commitment of all the involved partners, the three WHR projects have been successfully completed.

5. Conclusion

All the units of the ETEKINA Project successfully achieved the goal according to the KPIs set at the beginning of the project by exceeding a 40 % efficiency on each demo site. The use of HPHE in industrial setting to recover heat from various exhaust to a large range of heat sink has been validated through the results of the ETEKINA Project.

Lessons were learned on the management, design, installation and commissioning of the project which can be implemented to future installation to further decrease the Return On Investment. As gas prices are soaring due to tensions on the European gas market, it is a good opportunity to now invest in improving efficiency in heavy industries such as metal, aluminium, tiles and other energy demanding sectors. Also, by installing Heat Pipe Heat Exchanger, a drastic reduction in Greenhouse gas emissions was noted. As climate change impact our daily life, it is now more important than ever to decrease the CO_2 emissions generated by energy intensive industry.

To develop and disseminate this technology to the industry, the replicability tool developed by Ikerlan will allow the future development of HPHE within a wide range of industry as end users can tailor the HPHE design to suite the exhaust and the heat sink prior to contacting the relevant consortium member for a complete installation. This tool can be used during energy efficiency audit to investigate the heat recovery potential of all the exhaust in the plant.

Finally, the Return On Experience that this project acquired throughout the development of the prototype and the installation and commissioning of the unit summarised in this document and in the public report will be a valuable asset for the implementation of this technology to a broader range of application with the support of RTDs, end users and technology provider.

The impact of each demo site has been classified based on energy consumption, environmental impact, planning expenditures, performance impact, economic and administrative impact. Each category is rated from one to five.

Table 2 Impact rating of ETEKINA Demo site

	Energy consumption	Environmental impact	Planning expenditures	Performance impact	Economic impact	Administrative impact
Demo site 1	★★★★	★★★★	★★★	★★★★	★★★	★★★★
Demo site 2	★★★★★	★★★★★	★★★★	★★★★★	★★★★★	★★★★
Demo site 3	★★★★★	★★★★★	★★★★	★★★★★	★★★★★	★★★★

Each site performed very well with an advantage to larger unit due to the economy of scale of HPHE unit. Indeed, the capital cost of a larger unit are higher but the energy recovered is substantially higher, for this reason site such as Concorde or SIJ Metal Ravne are at an advantage.

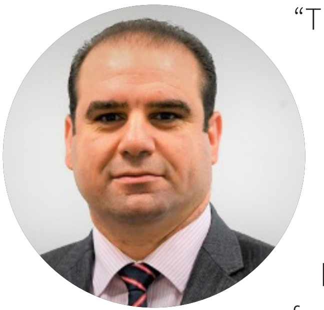
The environmental impact of all the sites is very higher as large amount of CO_2 were saved from the implementation of the ETEKINA unit. By pushing the limits of HPHE and improving the operation and design of the recovery system, the environmental impact will be greater to the extend of removing any high temperature exhaust gases.

By reducing carbon footprint and by demonstrating that the HPHE technology is essential for a green transition and reduction of gas consumption, it is hoped that the impact on regulations and norms for HPHE installation will be reduced to allow for a rapid and efficient deployment of the technology to a large number of industrial sites. It is vital that this administrative implications of HPHE installations are eased mainly due to the rising cost of natural gas, to ensure that industries in Europe remain competitive will reducing the carbon footprint of those industries.

Finally, the economic impact of HPHE system can be clearly shown has being an asset for heavy industries due to the low ROI compared to similar waste heat recovery solution such as ORC or traditional heat exchanger. Indeed, the efficiency of HPHE alongside the low maintenance cost and high reliability place this technology as a strategic investment for industrial company in need of reducing cost and green house gas emissions

Voices from the ETEKINA Consortium

The ETEKINA project started four years ago. What was your intention for the project? What started you on this idea?



"The idea of putting the ETEKINA project together was really just to demonstrate the importance and the potential of the heat pipe technology and how it can be used to recover waste heat from very challenging streams that other conventional systems couldn't manage to recover and reuse the heat that is being recovered in the plant itself. This then leads to reducing the plant's carbon footprint and reducing the energy demand and enhancing the plant energy efficiency in general. I do also think that ETEKINA is contributing by enhancing the efficiency of these systems, using the right technology that will facilitate that. The target for ETEKINA was 40 percent recovery of the available heat that is being wasted from the exhaust streams. I am pleased to say that after four years and having installed the three units, the consortium managed to get the 40 percent as the minimum. We are actually above that in all three demo cases. This is something that is a pleasure to report, and it is a success for the whole consortium. The other intention was to deliver a high TRL heat pipe heat exchanger design that can be delivered directly to the wider industrial community. In addition to that, the involved RTDs in this project have developed system modelling capabilities that can help any interested industry in modelling various waste heat recovery options to achieve the highest thermal efficiency possible."

Prof. Hussam Jouhara,
Technical coordinator of the ETEKINA Project,
Brunel University London.

Do you have a long-term vision? Will heat pipe technology make a change in energy-intensive industries?

"These industries do want to reduce their high energy consumption. But to invest in new energy-saving technologies, they need to see concrete examples, success stories. ETEKINA will provide them with three success stories: in the non-ferrous metal sector, represented by Fagor Ederlan, in the ceramic sector, represented by Atlas Concorde in Italy and in the steel sector, represented by Metal Ravne in Slovenia."

Bakartxo Egilegor,
Project Coordinator, IKERLAN

Dr. Nieto, as you were not only contributing to the project as an expert in developing energy management platforms and heat recovery solutions but also took over the coordinating role from your colleague Bakartxo Egilegor – how was it to supervise a consortium of 10 partners in five countries and three demonstration sites?

"I would say Bakartxo did the hardest work to have a successful project at the end. There were a lot of issues she had to overcome such as delays, Covid-19, different problems in the demo cases, etc. When I took the coordination of the project, all the 3 HPHEs were commissioned and running. In any case, it is always a challenge to coordinate such a huge consortium and I think the biggest challenge we will need to face now is the last reporting period and the final review meeting with the EC. Fortunately, we can say we have a successful project in the end which is really great!"

Dr. Nerea Nieto,
Project Coordinator, IKERLAN

Do you think you will adapt heat pipe heat exchangers (HPHEs) also in other factories of your organisation?

"I think that we would not take part in this project if we hadn't seen this opportunity. I see the usefulness of an incentive, in the case of the ETEKINA project, which has European funding. This is something new in the tile sector and we wouldn't have been able to go down this road unless we received financial backing from the European Union. What we hope to achieve is a technological maturity to allow us to continue this work. This means ensuring the technology is reliable, safe and efficient in the factory context."

Luca Manzini,
Energy Manager at Gruppo Concorde

The EU is very concerned about energy efficiency and CO_2 reduction. How could ETEKINA contribute to EU goals?

"The steel industry is one of the biggest consumers of energy in Slovenia as well as in Europe. We are therefore one of the biggest producers of CO_2 emissions, too. We release about 800 kilograms of CO_2 per ton of steel produced. Considering this, the ETEKINA project is an important asset for us, as we expect to reduce our CO_2 emissions by about 4 %. Of course, this reduction can only be achieved at the facility where we will implement the heat pipe technology, not across the whole company."

Kristijan Plesnik,
Energy Manager at SIJ Metal Ravne

ETEKINA
Thermal energy recovery

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