TRI-HP PROJECT

Trigeneration systems based on heat pumps with natural refrigerants and multiple renewable sources

Experimental results of dual source heat exchanger.

Deliverable number: D4.6

Version 1.0

Funded by the European Union's Horizon 2020 research and innovation programme under grant agreement N. 814888. The sole responsibility for the content of this paper lies with the authors. It does not necessarily reflect the opinion of the European Commission (EC). The EC is not responsible for any use that may be made of the information it contains.

This page is intentionally left blank

Project Acronym:	TRI-HP
Project URL:	http://www.tri-hp.eu
Responsible partner:	TECNALIA
Deliverable nature:	Report (R)
Dissemination level:	Public (PU)
Contractual Delivery Date:	June 30, 2020
Actual Delivery Date	December 29, 2020
Number of pages:	17
Keywords:	Dual source heat exchanger, experimental results, propane heat pump
Authors:	Laura Alonso (TECNALIA), Xabier Peña (TECNALIA)
Collaborators:	None
Review:	Daniel Carbonell (SPF-HSR)
Approval:	Daniel Carbonell (SPF-HSR)

Revision History

Date	Version	Changes
December 29, 2020	v1.0	Version with preliminary results submitted to EC

TRI-HP CONSORTIUM

SPF Institut für Solartechnik	Oberseestrasse 10 CH-8640 Rapperswil, Switzerland	Coordinator : Dr. Daniel Carbonell Dani.Carbonell@spf.ch
tecnalia Inspiring Business	Área Anardi, 5. E-20730 Azpeitia (Gipuzkoa), Spain	Mr. Andoni Diaz de Mendibil andoni.diazdemendibil@tecnalia. com
cadena	Murtenstrasse 116, CH-3202, Frauenkappelen, Switzerland	Mr. Raphael Gerber raphael.gerber@cadena.ch
IREC 10 years Shaping Energy for a Sustainable Future	Jardins de les Dones de Negre 1 2ªpl. 08930 Sant Adrià de Besòs (Barcelona)	Dr. Jaume Salom jsalom@irec.cat
Alfa Laval	Box 74, 22100 Lund, Sweden	Mr. Mats Nilsson MatsR.Nilsson@alfalaval.com
ILAG swiss quality coatings	Hämmerli 1, CH-8855, Wangen, Switzerland	Mrs. Stephanie Raisch stephanie.raisch@ilag.ch
Institut für sozial-ökologische Forschung	Hamburger Allee 45, Frankfurt am Main, 60486, Germany	Dr. Immanuel Stiess stiess@isoe.de
NTNU Norwegian University of Science and Technology	Kolbjørn Hejes vei 1D (B249), No-034 Trondheim, Norway	Dr. Alireza Zendehboudi alireza.zendehboudi@ntnu.no
Danish Technological Institute	Kongsvang Allé 29, 8000 Aarhus C, Denmark	Mr. Claus Bischoff clb@teknologisk.dk
Hochschule Karlsruhe Technik und Wirtschaft University of Applied Sciences IKKU Institute of Refrigeration, Air-Conditioning and Environmental Engineering	Moltkestr. 30, 76133 Karlsruhe, Germany	Dr. Prof. Michael Kauffeld Michael.Kauffeld@hs-karlsruhe.de
REHVA Federation of European Heating, Ventilation and Air Conditioning Associations	Rue Washington 40, 1050 Brussels, Belgium	Ms. Anita Derjanecz ad@rehva.eu
GR/ E.F.C. Equipos Frigorificos Compactos, S.L.	C/Zuaznabar 8 Pol. Ind. Ugaldetxo, Oiartzun, 20180, Spain	Mr. Gabriel Cruz g.cruz@equiposfrigorificoscompactos.com

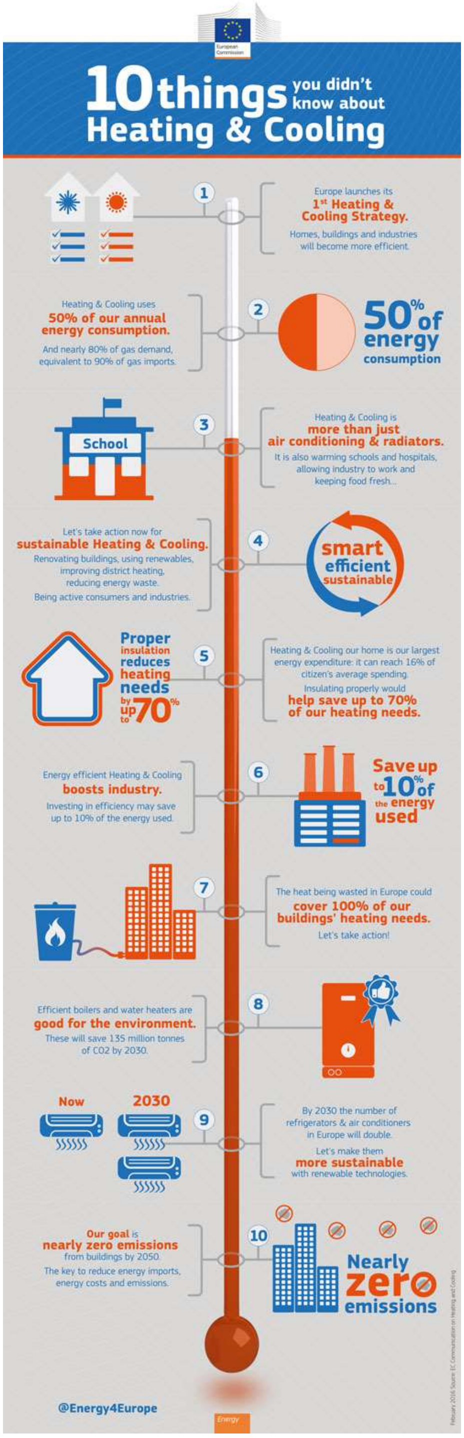
CONTENT

EXECUTIVE SUMMARY

TRI-HP EU project is aiming to develop trigeneration integrated solutions that combine heating, cooling and electricity generation, based on heat pumps running with natural refrigerants and using multiple renewable energy sources.
This deliverable presents the design of the R290 dual source heat pump (DSHP) prototype. The designed heat pump is reversible, includes a variable speed compressor, and a desuperheater (DSH) for domestic hot water (DHW) preparation. Its main innovation is the inclusion of a dual source heat exchanger (DSHX); able to work with water, air or both; in evaporator and condenser modes.
The deliverable provides a justification of the commissioning of the test bench and testing campaign of the DSHX, starting from the design conditions previously set in the project.

1. INTRODUCTION

Heating and cooling needs for domestic applications, industry and tertiary sector account for a 50% of the final energy consumption in the EU[1]. Heating and cooling use 80% of EU's gas demand and 90% of the gas imports. This is translated into large CO_2 emissions to the atmosphere and a large impact on global warming.



Our societal needs keep increasing, and so does the installed capacity for heating and cooling production, but we cannot increase the impact these have on our planet. If the current technologies are kept (84% of heating and cooling comes from fossil fuels) the EU will be far from its climate and energy goals. More efficient technologies must be applied to cover heating and cooling demands, substituting boilers and inefficient air conditioning units with by high efficiency heat pumps which utilize as energy coming from renewable sources[1]. At the same time, the energy demand should be reduced by:

- improved design and construction of buildings,
- implementation of insulation during renovations,
- item intelligent controls and information management.

The most widely spread heat pumps for heating and cooling are vapour compression systems. Such systems need a refrigerant to work. The first refrigerants used (XIX century and 1st decades of XX century) were natural refrigerants, i.e. the substances available at the time. The developments in the 30s and 40s of the XX century in the field of chemistry led to the spread of CFC and HCFC, which were very safe and good refrigerants (at least from the performance point of view). However, it was proved that these substances were causing the depletion of the ozone layer, and their worldwide phase-out was agreed for 2040 thanks to Montreal Protocol (1987)[2]. A similar path is being followed by HFC, which contribute importantly to global warming (in some cases several thousand times more than CO2). The Kigali Amendment to Montreal Protocol (2016)[3], which came into effect January 1st 2019, has the aim of reducing the use of HFC by 2050 to 80% of the levels at 1990. Additional measures are currently applied in Europe, such as F-Gas Regulation[4].

Even though the chemical industry is suggesting a new family of synthetic refrigerant, HFO, to substitute HFC, many research institutes and manufacturers support the return to natural refrigerants, which are well known and predictable.
All the aforementioned points are dealt with in TRI-HP project. In particular, this deliverable D4.6 details the design of the R290 dual-source heat pump, including the following information:

[1] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the regions. An EU Strategy on Heating and Cooling (2016)
[2] http://www.un.org/es/events/ozoneday/background.shtml
[3] https://www.unenvironment.org/news-and-stories/press-release/world-takes-stand-against\\-powerful-greenhouse-gases-implementation
[4] https://ec.europa.eu/clima/policies/f-gas/legislation_en

2. EXPERIMENTAL APPARATUS AND PROCEDURES

In this section, an overview of the experimental test bench and testing procedures is presented.

First, the DSHX test bench is described. As the DSHX is a part of the heat pump, the complete refrigerant cycle is required in order to test the unit in condenser/evaporator modes, and the test bench is designed in order to do that.

Second, the R290 related security installation is described. R290 is a flammable refrigerant (A3 classification) which requires special security procedures in order to charge/discharge and test refrigeration equipment. A special R290 gas detection and extraction security installation has been designed and installed in the laboratory, in order to be able to work with R290 equipment.

Then, the installation of the test bench in the climatic chamber is explained. This allows to test the unit in the different design modes:
- Heating air-water
- Heating brine-water
- Heating air/brine-water
- Cooling air-water
- Cooling brine-water
- Cooling air/brine-water

In the following subsections, the testing procedure and the planned testing conditions are presented. The testing has been carried out following specific technical standards for the testing heat pumping equipment.

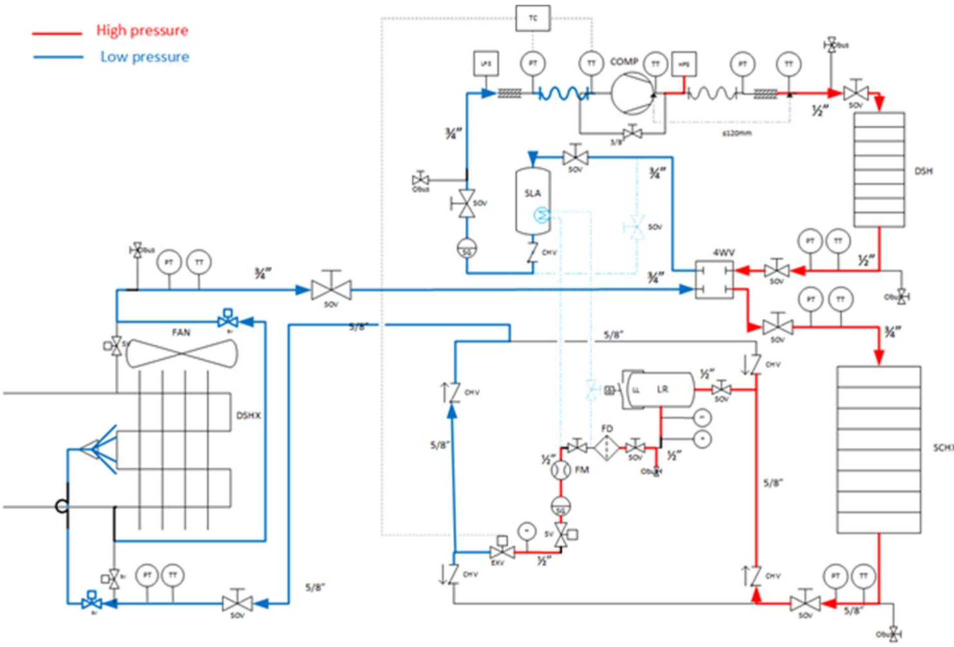
Finally, the commissioning of the unit is described, explaining the technical problems faced and solved.

2.1 DUAL SOURCE HEAT EXCHANGER TEST BENCH

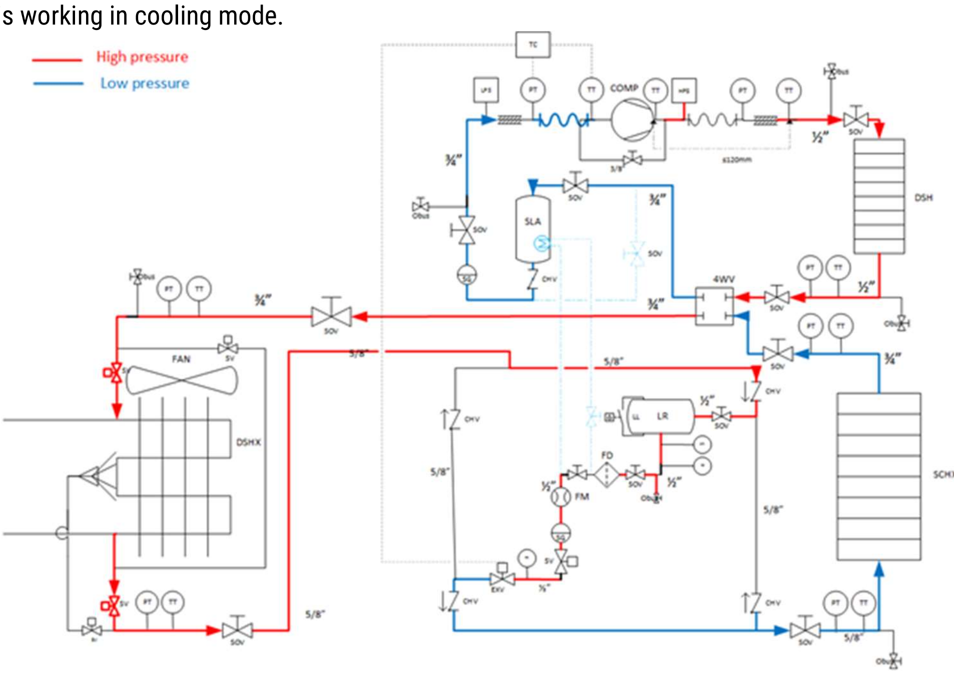
The dual source test bench implemented for testing the DSHX was designed and manufactured considering all requirements for the Dual source HP, permitting testing not only the DSHX but as well the requirement of some auxiliary elements such as the SLA (Suction line accumulator), desuperheater (DSH), and IHX (Internal Heat Exchanger).

The refrigerant circuit has been designed taking into account the reversibility of the cycle, and the inclusion of the DSHX. In the demand side, the inclusion of a DSH has been decided in order to make use of the high compressor discharge temperatures for DHW generation. At the compressor discharge, the refrigerant passes always through the desuperheater, and then it is sent to the four-way valve. The direction of the refrigerant at this point depends on the working mode of the heat pump.

When the heat pump is working in heating mode, the refrigerant is sent to the SCHX from the four-way-valve, which will be working as a condenser. After condensing, the refrigerant goes to the liquid receiver and then expands through the electronic expansion valve. Then it is sent to the DSHX, where it evaporates. Finally, returning through the four-way valve, the refrigerant goes to the suction accumulator, and back to the compressor. Figure XX shows the direction of the refrigerant flow when the heat pump is working in heating mode.



When the heat pump is working in cooling mode, the refrigerant is sent to the DSHX from the four-way-valve, which will be working as a condenser. After condensing, the refrigerant goes to the liquid receiver and then expands through the electronic expansion valve. Then it is sent to the SCHX, where it evaporates. Finally, returning through the four-way valve, the refrigerant goes to the suction accumulator, and back to the compressor. Figure XX shows the direction of the refrigerant flow when the heat pump is working in cooling mode.



The circuit between the DSHX and the SCHX includes several check valves, in order to assure the correct circulation of the refrigerant in both working modes, going first to the liquid receiver and then to the expansion valve. A filter drier, Coriolis flow meter and sight glass are included after the liquid receiver and before the expansion valve.

The physical configuration of the DSHX makes it necessary to include four solenoid valves, which open and close depending on the working mode of the heat pump. These are necessary because there are two different inlets to the DSHX on the refrigerant side depending on the working mode, and one common outlet for both working modes. More details are included in D4.2[1]. For the Dual Source HX two possible sources/sinks have been taken into account (ground and air), for the two working modes (heating or cooling mode). As already mentioned in D4.2, the brine+water mixture coming from the geothermal boreholes flows through the internal tube of the coaxial tube coil, meanwhile the refrigerant flows in the passage formed in between the internal and external tube of the coaxial tube coil, finally the air flows through the fins of the mentioned coil.

In the following figure the P&ID of the whole Dual source test bench could be seen including all the sensors and the water circuits as well. More details are included in D5.2.

[1] D4.2 Design of dual source heat exchanger.

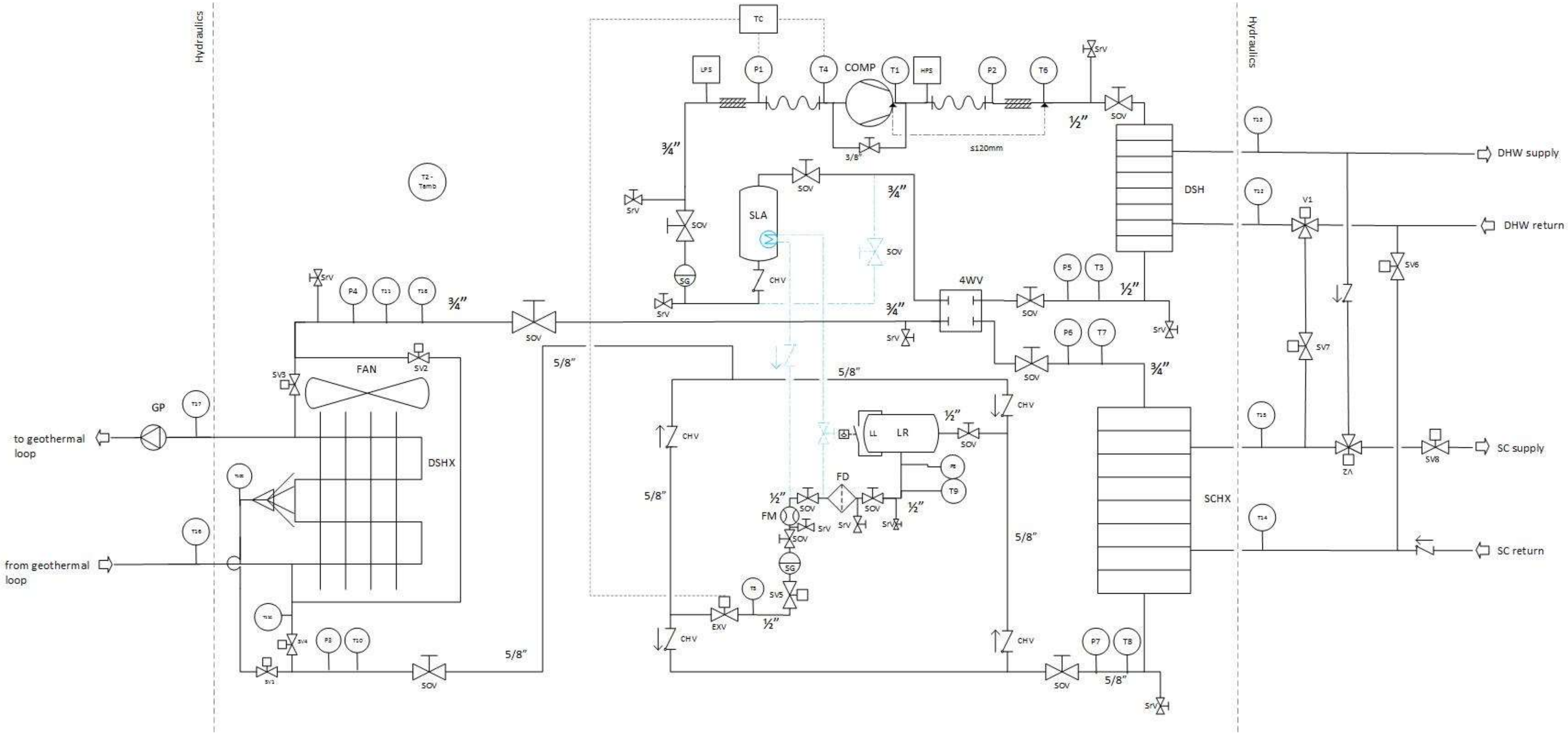


Figure 1. DSHX test bench P&ID.

2.2 PROPANE RELATED SECURITY INSTALLATION

The security installation of the Tecnalia's lab is prepared for a maximum of 10 kg of R290, having two working zones:

- Zone 01: Propane charging area: The preparation area, where gas will be charged and discharged into the air conditioning units to be tested, is located inside the test lab, next to one of the walls. It is an open area of a closed diaphanous premises, without important outdoor air supply. The estimated area for the loading area is about 30 square meters. The mechanical ventilation system only goes into operation when gas leaks occur. In the gas charging area, in addition to the indicated measurements, a portable Ex fan is available intended to reduce the concentration in case of gas leakage during filling of the test machine. In addition, the refrigerant bottle, after charging, will be returned to the supplier, so it will not be stored in the laboratory.
- Zone 02: Climatic Chamber: This is a watertight chamber of 40 square meters and 220 cubic meters, which has the option of being divided into two separate zones. Inside the chamber there are two air conditioning equipment to simulate the different temperature and humidity conditions to which equipment is tested, one per zone. The system does not provide outdoor air. The camera has 4 safety valves with openings to equalize pressures indoors and outdoors.

The gas detection system is continuously monitoring the facility.
The system has been configured with two alarm levels, complying with the requirements of UNE 202007:2006 IN

- Level 1 Pre-alarm "high concentration"; it is activated when a concentration of C3H8 equal to or greater than 12% of LEL (Lower Explosive Limit) is reached in any of the detectors. The detection plant lights up the indication. PRE-ALARM in red. The system activates the optical-acoustic warning and mechanical leak extraction ventilation.
- Level 2 Alarm "very high concentration"; it is activated when a concentration of C3H8 equal to or greater than 20% of LEL is reached in any of the detectors. The red ALARM indication of the sensor to which it corresponds is illuminated in the detection unit. The system activates the warning optical-acoustic and mechanical ventilation of leak extraction (if they were not already), and cuts off the power supply of the installation that energizes the climatic chamber, disabling all electrical/mechanical ignition sources located next to the exhaust sources, leaving only the detection unit with voltage (has Ex characteristics), the extraction system (has Ex characteristics), the alarm system, located outside the risk zone according to zone extension calculation and emergency lighting (has Ex characteristics). The cut-off points of the electrical installation are also outside the hazardous area, according to calculation.

Figure 2. Leak detection main board and location in Tecnalia's laboratory.

Figure 3. Leak detection sensor and location in Charging zone prepared with the air extraction system.

Figure 4. Leak detection sensor and location inside Climatic chamber.

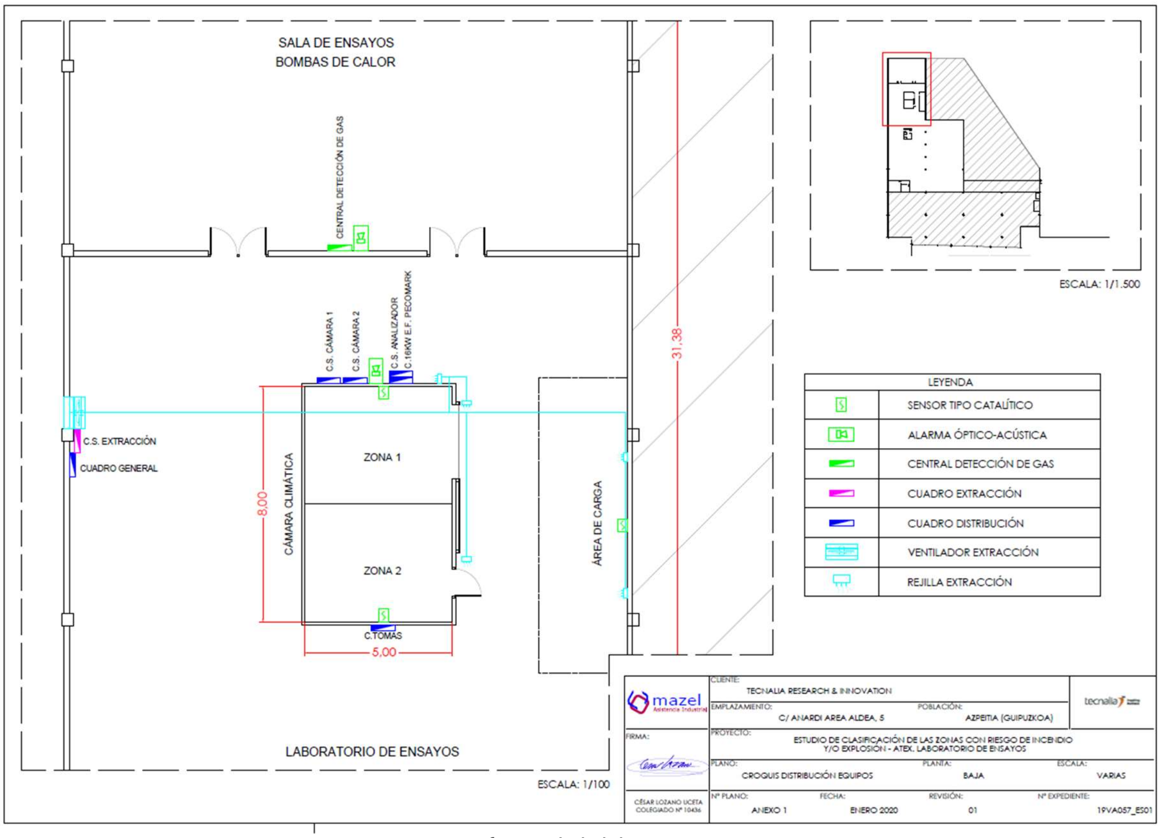


Figure 5. Drawing of Tecnalia's laboratory Layout.

2.3 INSTALLATION IN THE CLIMATIC CHAMBER

The DSHP has been experimentally tested inside the climatic chamber in the laboratory.

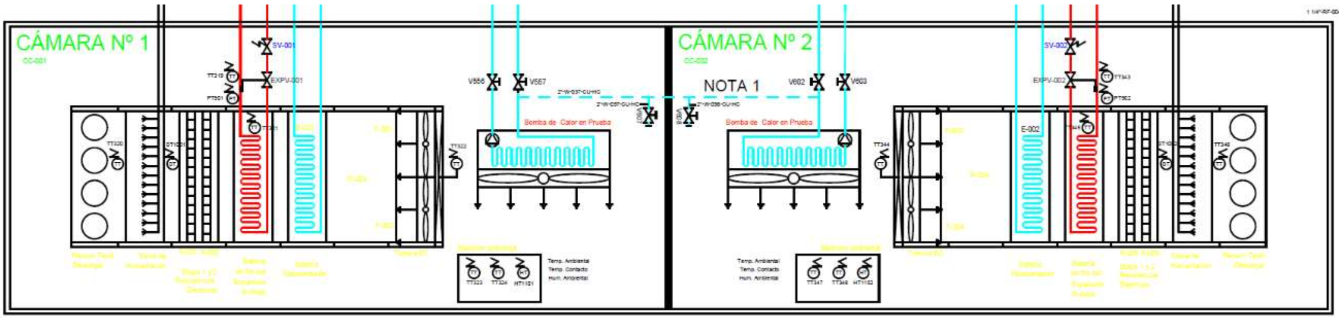


Figure 6. Hydraulic circuit of the climatic chamber.

Figure 6 shows the hydraulic circuit of the climatic chamber. As shown in the figure, it can be partitioned in two chambers which work in different conditions simultaneously, or on the contrary can work as a unique chamber if the tested unit requires it (because of capacity or size). For that purpose, the climatic chamber has two symmetric dissipation and energy producing systems, which can work at the same conditions when the chamber is unique, or separately at independent conditions when it is separated in two chambers.

The DSHX test bench has been located in Chamber number one (from now on, Chamber1), which contains the following dissipation and energy producing equipment:

- 5 impulsion pumps. Impulsion pump number 2 (from now on Pump2), is the one which is linked to the demand side of the HP, and will provide flow rate to the SCHX (in heating, cooling, DWH modes) and the desuperheater (in heating, heating+DHW, cooling+DHW modes).
- 3 heat exchangers.
- A buffer tank of 885 liters.

Figure 7 shows the scheme of Chamber1, where the DSHX test bench has been installed.

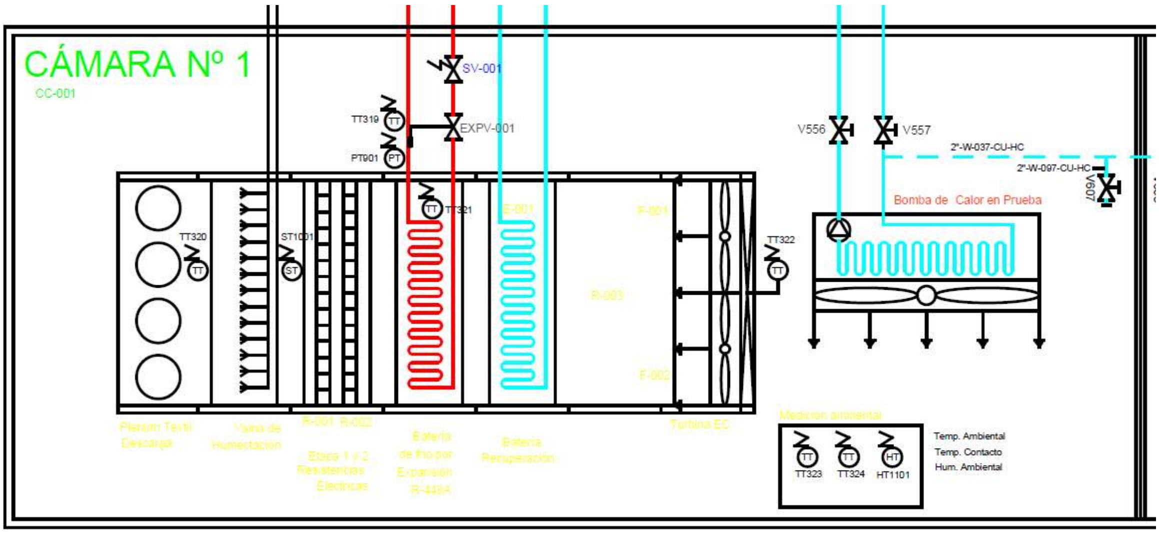


Figure 7. Scheme of Chamber1.

In order to reach to the desired testing conditions in Chamber1, an Air Handling Unit (AHU) will be used. The AHU comprises different heat exchanging coils. In the AHU, two fans blow the air coming from the chamber through the heat exchanging coils, until it is expelled uniformly through hoppers. The air is treated in the different heat exchanging coils, achieving the desired conditions.

As the DSHX can work with air or water/brine, it needs to be connected to another source/sink of heat. A connection with Chamber2 has been made, providing a brine flow rate to the DSHX. The conditions of the source/sink are controlled from Chamber2. The connections of the DSHX test bench with both climatic chambers' circuits is shown in Figure 8. Air conditions and demand side conditions are controlled from Chamber1, and DSHX source/sink conditions are controlled from Chamber2. A buffer tank of 250 L has been installed between the test bench and the demand side circuit, in order to gain stability.

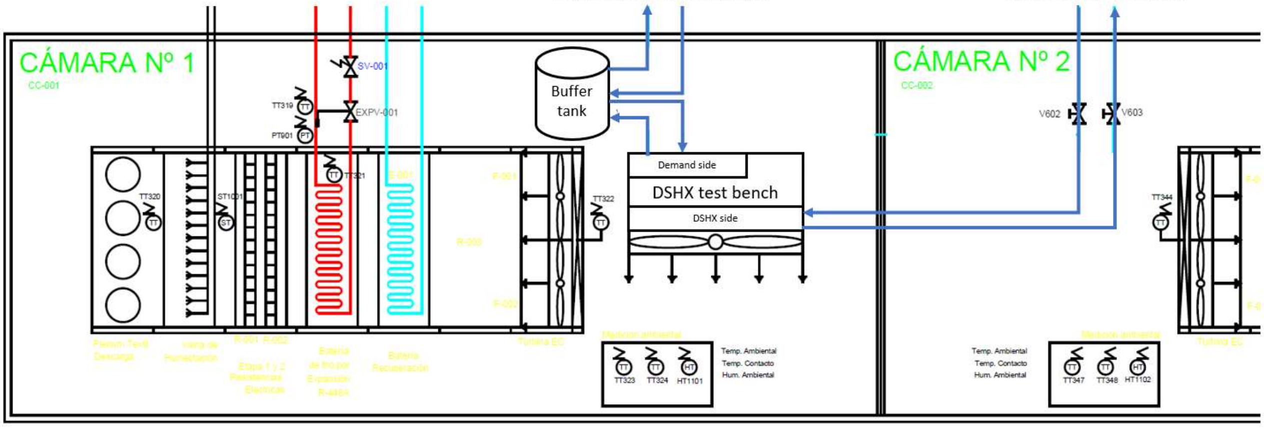


Figure 8. Scheme of the DSHX test bench installed in the climatic chamber.

Figure 9. DSHX test bench installed inside the climatic chamber.

Inside Chamber1 there are two sensors, an NTC sensor for measuring ambient dry bulb temperature, and a relative humidity sensor. Besides these two sensors, the additional metering instrumentation shown in Table XX has been included for the testing of the unit.

Table 1. Instrumentation in the climatic chamber.

Instrumentation	Type/Brand
4 dry bulb temperature sensors in aspiration of DSHX	PT100
2 dry bulb temperature sensors in aspiration of DSHX	PT100
4 temperature sensors for control of the impulsion and return temperature of the water to the demand side/brine to the DSHX side	PT100
2 anemometers (one in aspiration, the other in impulsion of the DSHX) to measure air velocity	Kimo
2 relative humidity sensors (one in aspiration, the other in impulsion of the DSHX)	Pego

During the initial tests, the PIDs of the climatic chamber have been adjusted in order to get the maximum possible stability in the measurements.

2.4 TESTING PROCEDURE

As explained above, the DSHX test bench comprises the complete refrigeration cycle of a reversible heat pumps, in order to be able to test the different design modes of the DSHX. For the testing procedure the following European Standard has been used: EN 14511 Air conditioners, liquid chilling packages and heat pumps for space heating and cooling and process chillers, with electrically driven compressors. Part 3: Test methods [1].

The heating/cooling capacity of the heat pumps has to be determined according to the direct method applied to the water heat exchanger, by determining the water flow rate and the inlet/outlet temperatures to this component.

For tests in steady-state conditions, the heating/cooling capacity is determined by the following equation:

$$P_{H-C}(W) = q \times \rho \times Cp \times \Delta t$$

Where:

q: volume flow rate, expressed in m3/s;
ρ: density, expressed in kg/m3;
C_p: specific heat at constant pressure, expressed in J/(kgK);
ΔT: difference between outlet and inlet temperatures, expressed in K.

In the case of transient conditions (tests in which defrost cycles occur), the average heating capacity shall be determined using the integrated capacity and the elapsed time corresponding to the total number of complete cycles that occur over the data collection period.

The capacity shall include the correction due to the heat output of indoor and/or outdoor fans and/or pumps. If the liquid part is not an integral part of the unit, the capacity correction shall be:

- Substracted from the measured heating capacity.
- Added to the measured cooling capacity.

Taking this into account, the COP/EER values are obtained by dividing the heating/cooling capacity and the electrical power consumed by the unit.

$$COP(-) = \frac{P_H}{P_{absorbed}}$$

$$EER(-) = \frac{P_C}{P_{absorbed}}$$

According to EN 14511, the testing procedure consists in three principal periods:

- A preconditioning period, where the test room reconditioning apparatus and the heat pump under test shall start and operate in certain stability conditions.
- A stability period.
- A data acquisition period. Its duration differs depending on of the heat pump is working in steady-state or in transient regime.

Figure 10 shows the low chart of test procedure according to EN 14511, showing how each test can end up in steady-state or transient regime, and the corresponding testing times in each of the regimes.

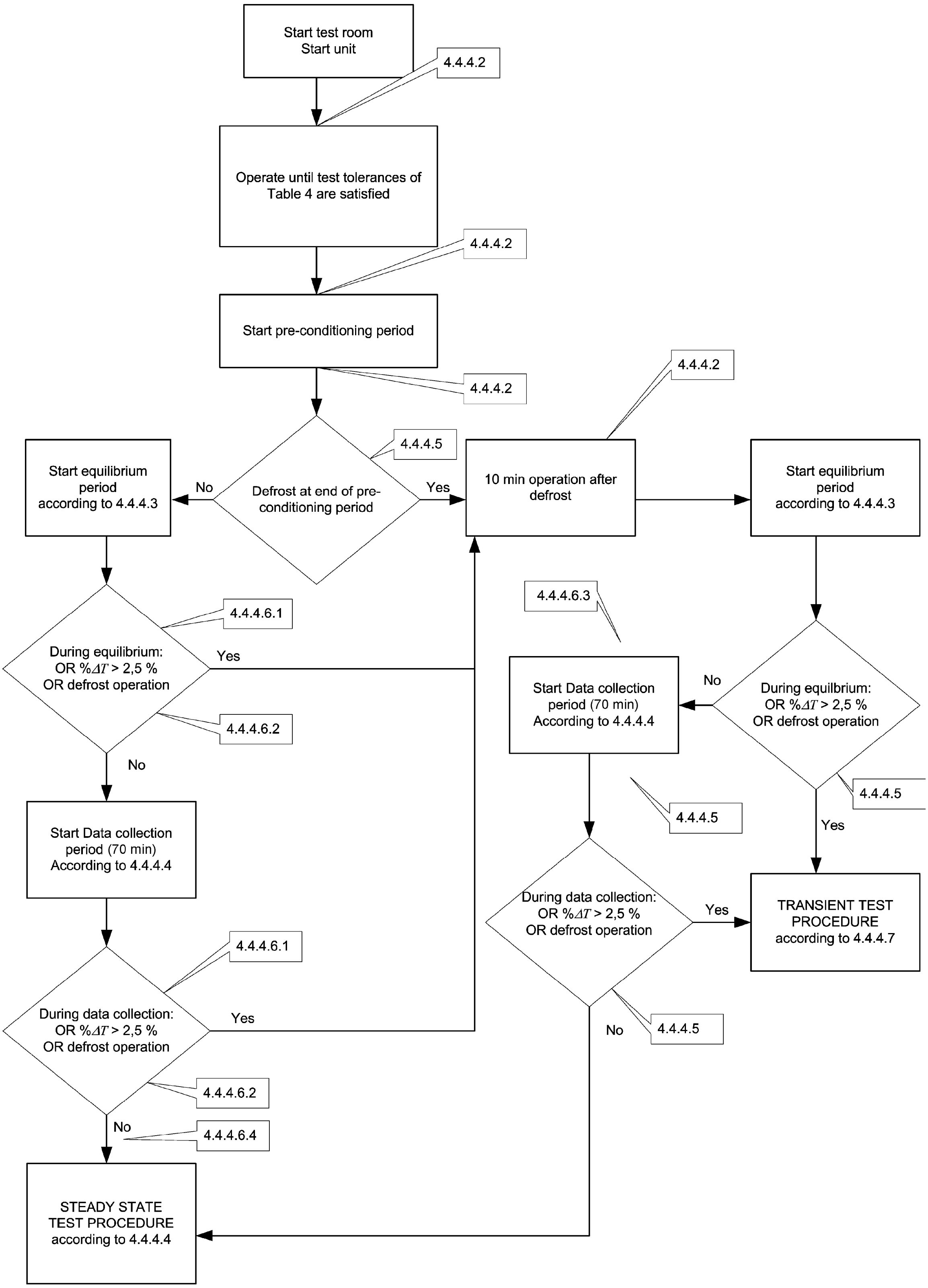


Figure 10. Flow chart of test procedure according to EN 14511.

In the data acquisition period, data have been continuously registered every 2 seconds, in steady-state and transient tests. In steady-state regime tests the heating/cooling capacity has been measured during a period of 30 minutes.

2.5 TEST CONDITIONS

The testing of the DSHX are firstly focused on the design conditions. Those were established at the beginning of the project (see D1.1[5]) and are shown in Table 2.

Table 2. Reference design conditions for the dual-source heat pump.

Heat exchanger	Source	Operation mode	Temperature (°C) Inlet to HP / Outlet from HP
External heat exchanger	Ground	Heating	0 / -3
		Cooling	25 / 30
	Air	Heating	7
		Cooling	35
Space conditioning heat exchanger		Heating	40 / 45
		Cooling	12 / 7
Desuperheater		DHW	70

The first set of experimental conditions are based on those design conditions, except for the DHW generation conditions. Those conditions are complemented by other testing conditions, varying the air and brine temperature in the DSHX. The temperature on the demand side is maintained constant and corresponds to the design conditions, generation at 40-45°C (medium temperature level). In the design conditions, testing at different compressor frequencies is done.
Table 3 shows the experimental testing points conditions, for the independent testing of the following modes of the DSHX:

- Heating brine-water
- Heating air-water
- Cooling brine-water
- Cooling air-water

The conditions of load are:

- Nominal load: compressor at 70 Hz.
- Partial load I: compressor at 90 Hz.
- Partial load I: compressor at 50 Hz.
- Partial load I: compressor at 30 Hz.

Table 3. Testing conditions of the DSHX working independently with brine or air.

Mode	Source/Sink	Source/Sink inlet dry bulb T (°C)	Source/Sink inlet wet bulb T (°C)	Demand inlet T (°C)	Load
Heating	Brine	0	-	40	Nominal
					Part load I
					Part load II
					Part load III
		10			Nominal
		15			Nominal
		5			Nominal
	Air	7	6		Nominal
					Part load I
					Part load II
					Part load III
		12	11		Nominal
		2	1		Nominal

[5] D1.1 Energy demands for multi-family buildings in different climatic zones.

Cooling	Brine	25	-	12	Nominal
					Part load I
					Part load II
					Part load III
		20			Nominal
		15			Nominal
		10			Nominal
	Air	35			Nominal
					Part load I
					Part load II
					Part load III
		27			Nominal
		46			Nominal

After these set of tests, testing with the DSHX working at the same time with brine and air will be developed.

2.6 COMMISIONING

As preliminary phase of the commissioning of the system in Tecnalia's lab it was prepared a Dual-source HX's test bench verification protocol for checking critical points after its construction process in GRV-EFC. A series of functional checks have been carried out before sending the prototype to the Thermal Equipment and Systems Laboratory of TECNALIA.
Both parties (GRV-EFC and TECNALIA) have signed this document after the functional checking are completed.

Table 1. Dual-source HP Verification Protocol.

Dual-source HP Verification Protocol	**Responsible**	**Done**	**Date**	**Requisites**	**Comments**
Pressure / leak test	GRV-EFC	☑	28/08/2020	34 bar pressure	
Control Panel Verification	GRV-EFC	☑	28/08/2020		
Temperature measurements checking (NTC, T-type thermocouples & Pt-100)		☑	28/08/2020	Tecnalia present	Checklist included.
Pressure measurements checking		☑	21/08/2020	Tecnalia present	Checklist included.
Coriolis Flow meter measurement checking		☑	21/08/2020	Tecnalia present	Measurement 0 kg/s checked.

Solenoid valves commands checking		☑	21/08/2020	Tecnalia present	
Four-way-valve commands checking		☑	21/08/2020	Tecnalia present	Valve acts when excited.
Check communication between PLC and SEC		☑	21/08/2020	Tecnalia present	
Check readings from SEC / PLC		☑	28/08/2020	Tecnalia present	
High pressure switch (HPS) checking		☑	21/08/2020	Tecnalia present	Power-off when 26 bar is reached, restart again when 20 bar is reached.
Low pressure switch (LPS) checking		☑	28/08/2020	Tecnalia present	Power-off when 0,9 bar is reached, restart again when 1,9 bar is reached.
Double-checking of all the check-valves.		☑	21/08/2020	Tecnalia present	
Hydraulic circuit valves commands checking (solenoids and 3-way-valves)		☑	21/08/2020	Tecnalia present	3WV needed repositioning. Done.
Double-checking of all the check-valves in the hydraulic circuit.		☑	21/08/2020	Tecnalia present	
Fan inverter checking.		☑	21/08/2020	Tecnalia present	The inverter and fan are checked at 12 Hz. and 50Hz. (Max. Flow). The direction of airflow is checked, the fan works in suction mode, as it should.
Dual HP Verification Protocol checked by both parties (GRV-EFC & TECNALIA)	GRV-EFC TECNALIA	☑	31/08/2020	Include checklist	

First of all, the NTC type temperature Sensors provided directly by Emerson (T4, T5, T6, T10, T11) have been measured at 0ºC, introducing them in iced water, giving measurements with a deviation in the range of 0.5K.

Figure 1. Temperature sensors submerged in iced water.

Table 2. Temperature measurements checking, 1st checking campaign.

Temperature sensor	Type	Measurement (ºC)
T8	Type T thermocouple	28.2
T9	Type T thermocouple	28.3
T10C	Type T thermocouple	28.4
T11C	Type T thermocouple	28.3
T12	Type T thermocouple	26.8
T13	Type T thermocouple	26.9
T14	Type T thermocouple	26.5
T25	Type T thermocouple	No measurement
T16	Type T thermocouple	26.4
T17	Type T thermocouple	26.9
T3	Type T thermocouple	No measurement
T7	Type T thermocouple	26.6
T10	NTC (Emerson)	26.9
T11	NTC (Emerson)	27.2
T18	Transient NTC until Emerson NTC's reception	27
T1	Transient NTC until Emerson NTC's reception	25.83
T2	Transient NTC until Emerson NTC's reception	26.19
T4	NTC (Emerson)	26.45
T5	NTC (Emerson)	29.81
T6	NTC (Emerson)	26.54

Table 3. Temperature measurements checking, 2nd checking campaign.

Temperature sensor	Type	Measurement (ºC)
T8	Type T thermocouple	29.9
T9	Type T thermocouple	30.1
T10C	Type T thermocouple	No measurement
T11C	Type T thermocouple	29.8
T12	Type T thermocouple	30.1

T13	Type T thermocouple	30.4
T14	Type T thermocouple	30
T25	Type T thermocouple	30.1
T16	Type T thermocouple	29
T17	Type T thermocouple	29.4
T3	Type T thermocouple	29.4
T7	Type T thermocouple	29.3
T10	NTC (Emerson)	27.2
T11	NTC (Emerson)	27
T18	Transient NTC until Emerson NTC's reception	26.7
T4	NTC (Emerson)	26.5
T5	NTC (Emerson)	29.8
T6	NTC (Emerson)	26.5

Table 3. Temperature measurements checking, 3rd checking campaign

Temperature sensor	Type	Measurement (°C)
T1	NTC (Emerson)	21.6
T2	NTC (Emerson)	21.7
T18	NTC (Emerson)	21.7
T10C	Type T thermocouple	26.3

As can be seen the T1, T2, T18 lastly received NTC type temperature Sensors, provided by a local distributor ordered by EFC using the same reference as the ones directly received by Emerson, have a considerable deviation respect to the new contact thermocouple. The T1, T2 and T18 sensors have been introduced in iced water as well as T10 (as reference); and as can be seen the value of T10 is around 0°C, while the values of T1, T2 and T18 have a deviation of around 5K.

Figure 2. Measurements of T1, T2, T18 and T10 (ref.) submerged in iced water.

As T1 and T2 are needed for the control of SEC, two other NTC sensors from the circuit which had been checked correctly in the beginning (T10, T11) are included in those positions. Then, to complete the sensors which are missing (T10, T11, T10C and T18), four T-type thermocouples are prepared, checked and positioned in their corresponding place in the circuit.

In addition pressure transducers checking have been carried out at around 9 bar directly connected to the PLC and SEC respectively, mentioned pressure transducers were previously checked by Tecnalia individually against their calibrated pressure sensor giving proper measurements.

Table 4. Pressure transducers checking.

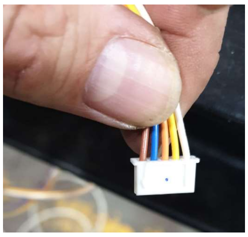
Pressure transducer	Measured pressure (bar)	Comments

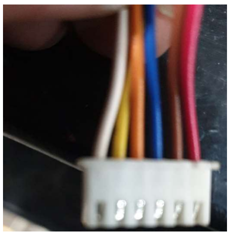
P1	5.28	Reading through SEC. Check it again when SEC is configured in Tecnalia.
P2	14.6	Reading through SEC. Check it again when SEC is configured in Tecnalia.
P3	8.84	
P4	8.83	
P5	8.84	
P6	8.80	
P7	8.79	
P8	8.80	

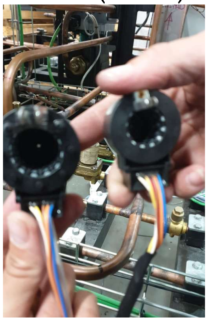
After receiving the test bench in Tecnalia a lot of problems were deleted and solved. Firstly 2 Emerson drive replacements should be carried out, the first received drive was a non-dissipation drive and then one that was not compatible with the compressor we have, this was finally replaced by the current one (model ED3018BU-V2-B).

Likewise, with regard to the compressor we also receive the following communication from Emerson regarding the model that we have installed on our equipment:
"And to mention already, when you move from lab testing to field testing also the compressor has to be replaced to be fully CE-compliant.
YH0461U-9X9 is declared as unprotected compressor and when you move to field test and introduce the unit in European market, the protected version YH0461U-9E9 is needed. Both compressors are physical identical, for the protected version additional tests to check the protection by the drive are done and covered by CE-declaration. Tests are still ongoing and we are confident to complete this by end of this year."

Regarding the expansion valve 2 valves were received with their corresponding coils the EXM-B0E 800402M with its coil EXM-24U #800415M (6 wires, which as you mentioned is incorrect for the SEC 12V) and the EXL-B1G 800406M with its coil EXL-125 800407M (5 wires 12V Correct for the SEC), see the attached figures. As can be seen the coil of the B0E was not compatible with the SEC (6 pins). When detecting this problem and not receiving any delivery response from the correct coil for the B0E, EXM-125 #800403M (12VDC), it was decided to install the only valve model that we had compatible with the SEC i.e. the EXL-B1G 800406M with the EXL-125 800407M coil (12VDC).







Also, regarding the sec firmware at first we received the 600A that had to be updated by the 600F since the 600A was detected as incorrect not having the possibility to match the YH0461U-9X9 to the SEC and the ED3018BU-V2-B drive.

In addition, after first preliminary testing campaign it was detected that the expansion valves body EXM-B0E 800402M, was damaged and that it is not opening or closing according to the sequence send by the SEC controller, the valve was sent already damaged by Emerson or during the welding process carried out by GRVEFC. The substitution of the valve was performed after around one month waiting for the mentioned component due to Emerson supplier.

The PLC control developed by GRVEFC which is the Master having the Emerson's SEC controller as slave, was not communicating properly with the SEC during the first testing campaign, a fine tuning was required from GRVEFC technicians in the programmed control algorithm of the PLC.

On the other hand, the refrigerant was migrated to the DSHX during the cooling mode Testing campaign, in which the system was correctly working and the DSHX acts as condenser properly. When we move to heating mode campaign having the liquid in the DSHX was problematic, therefore a liquid transfer was carried out from DSHX to the Liquid receiver. In addition, it was detected that the refrigerant charge required for heating mode was higher than the required for cooling mode, therefore 1kg was added to the DSHX test bench in order to perform properly the rest of the testing points.

In addition due to the unexpected pressure drop in the water side of the Plate heat exchangers supplied by the consortium partner Alfa-Laval an extra water pump was set in series with the laboratories one in order to achieve the required flow rate in the Space conditioning and DHW production sides.

The last issue which stops the Heating testing campaign was due to a malfunctioning of a the solenoid valve SV4 it was not closing properly its way and therefore a mixing and re-expansion of the biphasic refrigerant coming form the expansion valve was produced. The valve was substituted by the same valve model EVR-15 5/8"S 32F(L)1228, provided by Danfoss, which is designed therotetically for working with propane but anyway according to the last tests it seems that is allowing the refrigerant to pass through it as well.

All the mentioned problems and mainly the last one delayed the perform of the whole testing campaign mainly in the heating mode.

3. DATA REDUCTION

In Section 2.4, the testing requirements of EN 14511 have been presented. As we have the complete refrigerant cycle, heating/cooling capacities of the unit and COP/EER are calculated for each of the measurement conditions.

However, the objective of the experimental campaign is the thermal characterization of the DSHX working as an evaporator/condenser and with different working fluids: air, brine or both exchanging heat with the refrigerant. For that reason, the DSHX has been completely monitored during the experimental testing.

As shown in Figure 1, the DSHX includes the following temperature and pressure sensors:

- T10 & T10C: Inlet temperature to the DSHX (Heating mode).
- T11C, T11 & T18: Inlet temperature to the DSHX (Heating mode).
- P3: Inlet pressure to the DSHX (Heating mode).
- P4: Outlet pressure to the DSHX (Heating mode).
- T16: Inlet brine temperature to DSHX
- T17: Outlet brine temperature to DSHX

These measurements are complemented with the ones included in the climatic chamber brine circuit and air:

- Inlet brine temperature to DSHX
- Outlet brine temperature to DSHX
- Inlet air temperature to DSHX
- Outlet air temperature to DSHX
- Inlet air relative humidity to DSHX
- Inlet air relative humidity to DSHX

The registered measurements, along with the refrigerant flow rate obtained with a Coriolis flow meter, serves for the determination of the heat exchange capacities, LMTD values and U values for the heat exchanger as a whole, and for each of the parts of the DSHX:

- Heating mode:
  - Evaporating part
  - Superheating part
- Cooling mode:
  - Desuperheating part
  - Condensing part
  - Subcooling part

Total heat exchange capacities have been calculated in the refrigerant side, brine side and air side, calculated for the DSHX working in heating or cooling mode as:

$$P_{DSHX}(W) = m_r \times \Delta h$$

Where:

q: volume flow rate, expressed in kg/s;
Δh: difference between outlet and inlet enthalpies, expressed in kJ/kgK.

The logarithmic mean temperature difference is calculated, and the total heat transfer coefficient, U_{total}, is calculated as:

$$U_{total}\left(\frac{kW}{m^2K}\right) = \frac{P_{DSHX}}{A \times LMTD}$$

Where:

P_{DSHX}: heat exchange capacity, expressed in kW;
A: heat exchange area, expressed in m^2;
LMTD: logarithmic mean temperature difference, expressed in K.

LMTD and U values have been calculated for each of the parts of the DSHX as well. The following figures represent the heat exchange parts of the DSHX in each of the working modes:

- Heating: DSHX works as an evaporator.
- Cooling: DSHX works as a condenser.

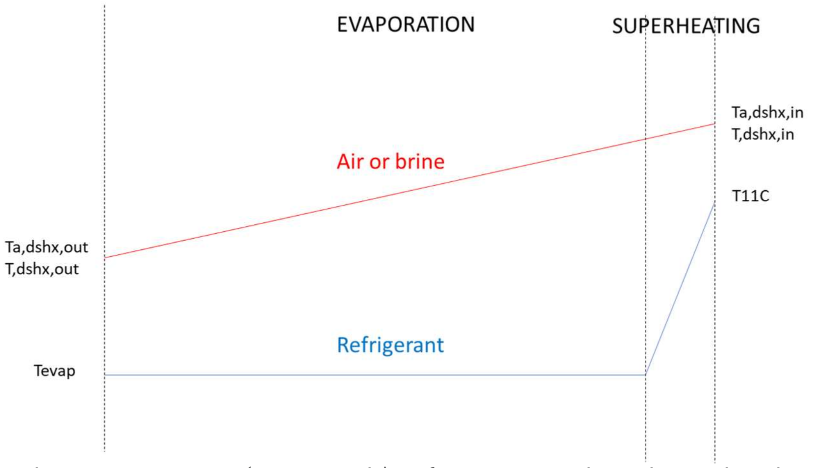


Figure 11. DSHX working as an evaporator (Heating mode). Refrigerant can exchange heat with air, brine or both at the same time.

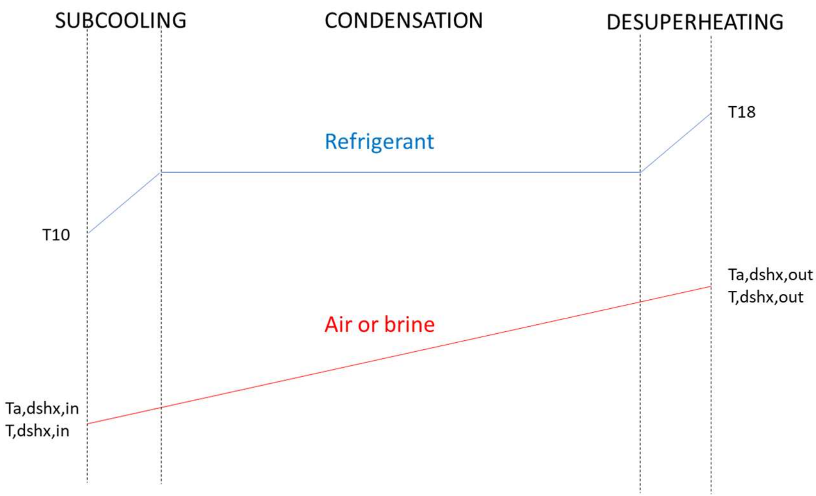


Figure 12. DSHX working as a condenser (Cooling mode). Refrigerant can exchange heat with air, brine or both at the same time.

4. EXPERIMENTAL RESULTS AND DISCUSSION

As mentioned previously due to the problems during the commissioning and all the component substitution which involves, refrigerant extraction, substitution of the component, new welding works, new pressure test vacuum and refrigerant recharge procedure, certain delay in the testing period are produced. In the following table the results of the cooling test properly performed could be seen.

					Test results															
Test Configuration					DSHX (Air)			Demand			Refrigerant			Capacity & COP/EER						
			T_air	T_in_w	T_in_air	T_out_air	HR_in_air	T_in_w	T_out_w	v_w	Cond. Temp	Evap. Temp	SH	Q_useful	Incert. Q_useful		El. Consumption	COP/EER_Lab	Incert. COP/EER	
Date	Comp. Speed (rpm)	SH Setpoint	ºC	ºC	ºC	ºC	%	ºC	ºC	m3/h	ºC	ºC	K	kW	±	%	kW		±	%
COOLING					Copiar datos correspondientes de la pestaña Data_COOLING															
04/12/2020	4200	10	35	12	36.05	40.64	43.47	12.77	6.11	1.20	43.90	-2.42	10.11	9.36	0.87	9.3%	3.21	2.92	0.27	9.3%
10/12/2020	4200	13	27	12	27.01	33.05	59.16	12.24	5.89	1.19	36.67	-5.06	13.21	8.81	0.47	5.3%	2.94	3.00	0.16	5.3%
11/12/2020	4200	13	46	12	45.92	52.28	30.03	12.20	5.87	1.19	54.62	-2.88	13.07	8.77	0.83	9.5%	3.64	2.41	0.23	9.5%
11/12/2020	5400	13	35	12	34.83	42.32	44.46	11.96	4.61	1.19	46.16	-5.59	13.13	10.16	0.73	7.2%	4.10	2.48	0.18	7.3%
14/12/2020	5400	13	35	12	34.59	42.41	0.00	12.18	4.54	1.13	46.28	-5.74	13.11	10.11	0.51	5.0%	4.30	2.35	0.12	5.1%

On the other hand, some tests were performed in Heating mode as well but taking into account the previously explained refrigerant mixture problems due to the malfunctioning of solenoid valve SV4, the results obtained in heating mode are not yet as conclusive as expected.

					Test results															
Test Configuration					DSHX (Air)			Demand			Refrigerant			Capacity & COP/EER						
			T_air	T_in_w	T_in_air	T_out_air	HR_in_air	T_in_w	T_out_w	v_w	Cond. Temp	Evap. Temp	SH	Q_useful	Incert. Q_useful		El. Consumption	COP/EER_Lab	Incert. COP/EER	
Date	Comp. Speed (rpm)	SH Setpoint	ºC	ºC	ºC	ºC	%	ºC	ºC	m3/h	ºC	ºC	K	kW	±	%	kW		±	%
HEATING					Copiar datos correspondientes de la pestaña Data_HEATING															
18/12/2020	4750	11	6	40	5.92	2.38	66.32	39.02	44.44	1.87	45.47	-9.50	11.21	11.70	0.72	6.2%	3.82	3.06	0.19	6.2%
21/12/2020	4200	11	11	40	11.66	7.88	66.05	39.99	45.33	1.89	46.57	-4.22	11.08	11.62	0.66	5.7%	3.53	3.29	0.19	5.8%
21/12/2020	3000	8	11	40	12.34	10.53	67.99	40.16	43.54	1.89	42.58	-12.33	8.13	7.37	0.6	8.1%	2.54	2.90	0.24	8.3%

6. CONCLUDING REMARKS

Further experimental campaigns fulfilling all the proposed test points should be developed during the beginning of 2021 in order to obtain definitive conclusions about the DSHX working in both heating and cooling modes and with geothermal and aerothermal heat source/sink.

The problems related to refrigerant mixture should be solved in order to obtain definitive conclusions for the further development of the second prototype including the redesigned DSHX.

REFERENCES

[1] EN 14511 Air conditioners, liquid chilling packages and heat pumps for space heating and cooling and process chillers, with electrically driven compressors.

TRI-HP PROJECT

Trigeneration systems based on heat pumps with natural refrigerants and multiple renewable sources

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N. 814888.