Low valued energy sources UPgrading for buildings and industry uses

LowUP Test Plan for relevant environment 2

Deliverable D4.11

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About LowUP

LowUp – Low valued energy sources UPgrading for buildings and industry uses – is developing efficient alternatives to supply heating and cooling for building and industries, based on the use of renewable free energy and heat recovery from non-valuated residual energy sources that are currently wasted. As a result, these technologies will contribute to reducing significantly CO_2 emissions and primary energy consumption, and increasing the energy efficiency in buildings.

Led by the Spanish firm ACCIONA, the LowUp project gathers 13 partners (3 large companies, 3 research and technology organisations and 7 SMEs) from 7 European countries. During 48 months, the consortium will develop efficient alternatives to supply heating and cooling for buildings and industries based on renewable free energy as well as non-valuated wasted thermal sources:

- 3 technologies will be developed and demonstrated: one heating and one cooling system for buildings, and one heat recovery system for industrial processes.
- The systems will be demonstrated at 4 demo sites: A Pilot Office building in Seville (Acciona Construccion, Spain), a Waste Water Treatment plant in Madrid (Canal de Isabel II & Acciona Water), a Pulp and Paper mill in Setubal (Portugal, The Navigator Company) and a Student Hall in Badajoz (Spain, University of Extremadura).

For more information visit: www.lowup-h2020.eu

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Executive Summary

This report (D4.11 “Test plan for relevant environment 1”) has been elaborated within the LowUP Project (GA #723930) and provides a plan to execute all the activities within the framework of Task 4.4.

After the proper implementation of LowUP technology at emulated test-site scale, Task 4.4 will focus on stable and continuous operation of the LowUP systems in the relevant operational environments. As results, an extensive characterization will be achieved for the calibration and validation of each technology and the whole LowUP system.

The activity will be split into 4 different phases: On-site test and Commissioning, Start-UP of the whole system, characterization of the LowUP system and the Operation and Validation at a system level.

This deliverable (D4.11) aims to bring a the test plan plan of the characterization activity, focused on the relevant environment 2, so that, Madrid, Setúbal and Tecnalia demo sites.

Keywords

Commissioning, operation, validation, characterization, test plan.

List of acronyms and abbreviations

WWTP	Waste Water Treatment Plant
P&ID	Piping and Instrumentation Diagram
WHR	Waste Heat Recovery
HSR	Heat System Recovery
RHeX	Rotating Heat Exchanger (from Pozzi)
HP	Heat Pump

1 Introduction

After the integration of the HRS and HP-GEA systems in the demo sites of Madrid, Setubal and Gipuzkoa, the next step is to carry out the testing, operation and validation of all the technologies that take part in the LowUP project, as well as, the comparison with the results of previous work packages related to systems simulations, manufacturers testing and expected energy consumptions, cooling and heating productions, energy efficiency and cost savings.

Task 4.4 will focus on stable and continuous operation of the LowUP systems in the relevant operational environments. The activity will be split into 4 different phases, with different purposes, as it is shown in figure 1:

Figure 1: Task 4.4 - scheme of content

The activities within the task 4.4 are explained in detail below:

A) On-site test and Commissioning: each component, after being properly installed according to manufacturer indication and specification, will be re-tested individually to achieve power, control, safety, operation and design condition for an operational test site.
B) Start-Up of the whole system: LowUP systems will be driven to achieve their nominal working conditions, before running through limit and modulating conditions, in order to check possible operational gaps, crashes, programming and dimensioning errors, quality of connections and insulation, fault detection system, degree of automation, operation sequence, transitory states, leakages, vibrations, acoustic limits, accessibility for O&M, reliability and robustness of individual technologies, friendliness of user interface, communication limits, etc.
C) Characterization of the LowUP system: once starting-up, each component would be run through working limits, in order to achieve the working curve and verify the results of design and manufacturing, for corrections and improvements.
D) Operation and Validation at a system level: the system will be operating continuously and automatically, reproducing different working conditions and adapting to different scenarios in terms of load profiles, maintenance activities, coordination with existing equipment, economic savings, etc.

This deliverable aims to fulfil the description of objectives C and D, dealing with the operation of the systems at all operation points which are significant to the LowUP industrial application. The objective of the related task in the project (Task 4.4) is the stable and continuous operation of the LowUP system in a geographically relevant operational environment. As results, an extensive characterization will be achieved for the calibration and validation of each technology and the whole LowUP System.

All these activities, belonging to Task 4.4, will be developed in next deliverables. However, the purpose of this deliverable is to establish an action plan, which allows fulfilling all the activities mentioned above for the demo sites of Seville and Badajoz in the time and manner established.

1.1 Relation to other project tasks

This deliverable (D4.11) is comprised of Task T4.4 in WP4. This task will focus on stable and continuous operation of the LowUP system in a geographically relevant operational environment. As results, an extensive characterization will be achieved for the calibration and validation of each technology.

Moreover, next, Table 1 describes in more detail the relationships between the tasks reported in D4.11 and the rest of the project.

Table 1. LowUP tasks that will interact with results derived from D4.11

Task / WP	Relationship
T4.1	This task aims to fulfil all engineering activities necessary for defining and planning the proper implementation of LowUP concepts at relevant test-site scale: • The TECNALIA thermal lab located in the city of Derio, Bizkaia. • The industrial plant of NAVIGATOR paper factory in Setubal, and ACCIONA water treatment plant in Madrid.
T3.4	Subtask 3.4.2.- Dynamic simulation and HIL emulation Generation of the mathematical models of different equipment by use of technical characteristics and manufacturers’ data sheets and attainment of the transfer functions of the equipment will be done in this Task. The results of the characterization test will feed the dynamic models that will be developed that allow intelligent control.

2 Presentation of the system

The HP-LowUP concept is based on an efficient and reliable heat pump-based system, being 100% thermal powered by residual and rejected low-temperature energy sources (below 45ºC), being focused for application at industrial processes with temperatures up to 80 ºC. This temperature upgrading solution is based on the combination of heat recovery technologies, from low valued energy sources such as waste and process rejected heat (20 - 45ºC) and high efficiency-high temperature water-to-water heat pump for the production of process heat between 55-80ºC.

As depicted in Figure 1, HP-LowUP system is composed of the following technologies:

- A sludge/wastewater-to-water or water-to-sludge/process water heat exchangers that can be used as a heat recovery system or as a heat delivery system;
- An electrically driven high-efficiency heat pump.

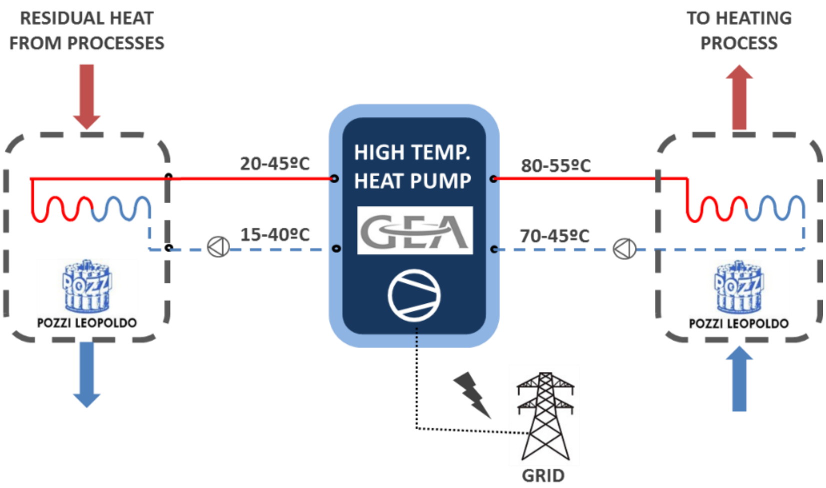

Figure 2: HP-LowUP concept.

These systems are being characterized by different demo sites in order to validate their performance under real operating conditions. The demo sites where the systems are installed are the following:

- Madrid: Heat recovery system (HRS) integrated by Pozzi.
- Setubal: Heat recovery system (HRS) integrated by Pozzi.
- Gipuzkoa: Highly efficient heat pump (HP-LowUP) integrated by GEA.

As a demonstrator deliverable, this document aims to describe the installation and integration process carried out in the test sites that have hosted the technologies.

3 HRS test plan

3.1 RHeX Characterization

In this task, a testing plan for the characterization of the RHeX at Madrid and Setubal facilities has been developed. In order to test the system, different heat loads and operating points need to be tested. The following table shows the variables to be studied, and the selected operation levels for each.

To set the experimental points in a real worksite is difficult because of the variables to be tested can be controllable or uncontrollable.

Table 2. Description of variables to be tested

	Variable	Description
Controllable	**F**: Frequency of the rotor [Hz]	Rotating speed of the rotor of the RHeX. Modifies the thermal transmissivity UA of the heat exchanger. This variable is controlled with the frequency inverter of the motor that drives the rotor. This value will remain steady at **50 Hz**.
	SVF: Sludge volume flow	The flow rate of the sludge containing the waste heat. It flows through the primary circuit. Controlled either with the flow valve or with the frequency inverter of the sludge pump.
	WVF: Water volume flow	The flow rate of water from the RHeX to the dry cooler. It flows through the secondary circuit. Controlled with the frequency inverter of the water pump.
	DTW: Waterside temperature difference	The temperature difference at the secondary circuit (water side) has to be kept at the constant value DT = 5 K, to reproduce the requested operating conditions of the HP evaporator circuit. This condition can be achieved with the HRS control system of the dry cooler's fan, though it
Uncontrollable	**AIT**: Air inlet temperature	The temperature of the air entering into the dry cooler, in other words, outdoor air temperature. This magnitude is expressed as a range since it can take values within a continuous domain. It cannot be controlled, but the working values are estimated from 12°C to 47°C (see D4.5).
	SIT: Sludge inlet temperature	The temperature of the sludge exiting the biodigester and entering the RHeX. It cannot be predicted, though is estimated from 30°C to 50°C.

Based on the engineering of plants in Madrid and Setubal (see D4.5). The considered values for these variables are collected in Table 3.

Table 3. Sets of values for the test variables

Value level	F [Hz]	SVF [l/h]	WVF[l/h]	SIT range [°C]	Mean SIT [°C]	DTW [°C]
1	50Hz	3000	4800	30-35	32.5	5
2		5000	7200	35.1-40	37.5	
3				40.1-45	42.5	
4				45.1-50	47.5	

3.2 Outdoor air temperature

The air inlet temperature, which is the same as outdoor temperature, will fluctuate throughout day and night, and with seasons. The outdoor temperature affects the performance of the HRS, since the heat recovered at the RHeX will be dissipated at the dry cooler, thus, the outdoor temperature limits the heat recovery capacity of the assembly. The characterization of the RHeX does not take into account the outdoor temperature, but it can limit the capacity of the tests and therefore, it acts as a test variable. The tests will have to run cyclically to perform under different outdoor temperature conditions.

3.3 Temperature difference at the secondary circuit

The secondary circuit is connected to the dry cooler, which emulates the thermal load of the HP. For that reason, the load to the thermal has to keep the conditions needed by the HP. One of these conditions is a temperature difference DT = 5 K at the evaporator side. To keep this differential, the dry cooler will be operated by the PLC control, which will regulate the fan speed as a function of the inlet and outlet temperature at the RHeX secondary circuit.

3.4 Table of cases

Each test case is made of the combination of the sets of values of the variables. The operation cases have been made in order to contain all the possible operation points. In the following figure appear the list of cases with their Case ID. The list grows up to **16 cases**.

Table 4. Cases to be tested.

	Controlled Variables		Uncontrolled Variable
Identificador	**SVF[l/min]**	**WVF[l/min]**	**Sludge Inlet T [ºC]**
ID1	50	80	30-35
ID2	83	80	30-35
ID3	50	120	30-35
ID4	83	120	30-35
ID5	50	80	35,1-40
ID6	83	80	35,1-40
ID7	50	120	35,1-40
ID8	83	120	35,1-40
ID9	50	80	40,1-45
ID10	83	80	40,1-45
ID11	50	120	40,1-45
ID12	83	120	40,1-45
ID13	83	120	40,1-45
ID14	50	80	45,1-50
ID15	83	80	45,1-50
ID16	50	120	45,1-50

The strategy behind this operation cases list is to run each case for a period of time so the system can become thermally steady and the environmental conditions won't vary significantly to be considered another operational point. The run time for each case is considered to be **30 min** when the system can reach the thermal balance. Thus, the full cycle of cases can be completed within **8 hours** approximately.

The full cycle will run uninterruptedly through night and day, and along seasons, thus achieving all possible outdoor temperature values. Proceeding this way, it is expected that data from all operational points will be obtained without depending on the environmental conditions.

4 HP test plan

4.1 HP Characterization

In this task, a testing plan for the characterization of the HP at TECNALIA facilities has been developed. In order to characterize the system, different heat loads and operating points need to be tested. In the following table are shown the parameters to be studied, and the selected operation levels for each.

Table 5. Description of variables to be tested

Variable	Description
Tout condenser (°C)	HP outlet setpoint temperature
ΔT Lift (°C)	Difference between Tout at the condenser and Tout at the evaporator.
Tin evaporator (°C)	Temperature to be supplied at the inlet of the evaporator (through the gas boiler in Tecnalia lab)
Q load %	Load ratio of the HP. It has to be achieved by the chiller. The maximum load to be achieved by the HP is a DT=10K at the condenser side.
ΔT (°C)	The thermal difference at the condenser. Related to the load ratio.
Tin condenser (°C)	Inlet temperature at the condenser, to be supplied by the chiller
Flow evap	Water flow at the evaporator. Fixed by the specs of the equipment. It corresponds to DT=5K.
Flow cond	Water flow at the condenser. It corresponds to ΔT (°C) desired to test.
Control strategy	The control system of the HP can operate in two modes: PI and FLOW.

An update has been carried out in the software with which it is possible to test with different possibilities of regulation of the expansion valve. Apart from the **MASS FLOW** mode and the **MANUAL** mode that was already available, the **PI** mode has been added. This will allow seeing the influence of these controls. During the tests, both controls will be tested.

4.2 HP operation constraints

For the operation of the HP, the following restrictions must be kept, according to the features of the device.

- ΔT Lift < 35°C: The temperature lift T_condenser_out (setpoint) – T_evaporator_out cannot exceed 35°C, otherwise can occur overpressure issues.
- ΔT Lift > 20°C: Likewise, if it drops below 20°C, a low-pressure issue can occur.
- T_evaporator_in < 45ºC: The maximum evaporator inlet temperature cannot exceed 45°C.

Trespassing these constraints may be possible in a MANUAL operating mode, in case some extra points are wished to be tested.

4.3 PI operating mode

For the PI operating mode have been chosen the following value sets. The values are based on the engineering of plants in Madrid and Setubal (see D4.5). The considered values for these variables are collected in Table 6.

Table 6. Sets of values for the test variables.

Value level	Tout condenser (°C)	ΔT Lift (°C)	Tin evaporator (°C)	Qload %	ΔT (°C)
1	80	35	45	100	10
2	75	30	40	75	7.5

3	70	25	35	50	5
4	65	20	30	-	-
5	55		25		

Taking into account the HP operating constraints described above, the possible value combination to be tested are summarized in Table 7. The ΔT at the condenser side does not appear but will be included as another variable in the tests.

Table 7. Possible combination of values for the test variables.

	ΔT Lift = Tcond_out - Teva_out														
	100%					75%					50%				
Teva_in/ Tcond_out	**55**	**65**	**70**	**75**	**80**	**55**	**65**	**70**	**75**	**80**	**55**	**65**	**70**	**75**	**80**
25	35					35					35				
30	30					30					30				
35	25	35				25	35				25	35			
40	20	30	35			20	30	35			20	30	35		
45		25	30	35	40		25	30	35	40		25	30	35	40

4.4 MASS FLOW operating mode

For the PI operating mode have been chosen the following value sets. The values are based on the engineering of plants in Madrid and Setubal (see D4.5). The considered values for these variables are collected in Table 8.

Table 8. Sets of values for the test variables.

Value level	Tout condenser (°C)	ΔT Lift (°C)	Tin evaporator (°C)	Qload %	ΔT (°C)
1	80	35	45	100	10
2	75	30	40	75	7.5
3	70	25	35	50	5
4	65	20	30	-	-
5	55		25		

Taking into account the HP operating constraints described above, the possible value combination to be tested are summarized in Table 9Table 7. The ΔT at the condenser side does not appear because it is not restricted but will be included as another variable in the tests.

Table 9. Possible combination of values for the test variables.

	ΔT Lift = Tcond_out - Teva_out					
	100%					
Teva_in/ Tcond_out	**50**	**55**	**60**	**65**	**70**	**75**
20	35					
25		35				
30			35			
35				35		
40					35	
45						35

4.5 Table of cases

Making the different combination possible of the selected levels of the parameters, it can be obtained **48 cases** to be run. Some of the cases have been left out of scope because of device constraints.

In order to achieve a steady-state, or to have the thermal masses of the systems balanced, it has been considered that a running time of 35 minutes is enough good for the measurement.

Table 10. Cases to be tested.

ID	DÍA	TCondenser out	ΔT Lift	Tevaporador in	Qload	ΔT	Type of Control
	dd/mm/aa	ºC	ºC	ºC	%	ºC	Manual
1	3/2/2020	55	30	25	100	10	Manual
2	3/2/2020	55	25	30	100	10	Manual
3	3/2/2020	55	25	30	75	7,5	Manual
4	4/2/2020	55	30	25	75	7,5	Manual
5	4/2/2020	55	30	25	50	5	Manual
6	5/2/2020	55	25	30	50	5	Manual
7	5/2/2020	55	20	35	100	10	Manual
8	5/2/2020	55	20	35	75	7,5	Manual
9	6/2/2020	55	20	35	50	5	Manual
10	10/2/2020	65	30	35	100	10	Manual
11	10/2/2020	65	30	35	75	7,5	Manual
12	10/2/2020	65	30	35	50	5	Manual
13	13/02/2020	65	25	40	75	7,5	Manual
14	13/02/2020	65	25	40	50	5	Manual
15	14/02/2020	65	25	40	100	10	Manual
16	17/02/2020	65	20	45	100	10	Manual
17	17/02/2020	65	20	45	75	7,5	Manual
18	18/02/2020	80	35	45	100	10	Manual
19	18/02/2020	80	35	45	75	7,5	Manual
20	19/02/2020	75	30	45	100	10	Manual
21	19/02/2020	75	30	45	75	7,5	Manual
22	19/02/2020	75	30	45	50	5	Manual
23	20/02/2020	65	20	45	50	5	Manual

24	20/02/2020	80	35	45	50	5	Manual
25	20/02/2020	70	30	40	100	10	Manual
26	**24/02/2020**	50	30	20	100	10	Mass flow
27	**24/02/2020**	60	30	30	100	10	Mass flow
28	**24/02/2020**	55	25	30	50	5	Mass flow
29	**24/02/2020**	55	30	25	50	5	Mass flow
30	**24/02/2020**	65	30	35	50	5	Mass flow
31	**25/02/2020**	55	15	40	50	5	Mass flow
32	**25/02/2020**	55	15	40	75	7,5	PI
33	**25/02/2020**	55	15	40	100	10	PI
34	**25/02/2020**	55	15	40	100	10	Mass flow
35	**25/02/2020**	70	30	40	100	10	PI
36	**25/02/2020**	70	30	40	100	10	Mass flow
37	**25/02/2020**	70	35	35	100	10	PI
38	**25/02/2020**	70	35	35	50	5	PI
39	**26/02/2020**	65	30	35	100	10	PI
40	**26/02/2020**	65	30	35	100	10	Mass flow
41	**26/02/2020**	70	35	45	100	10	PI
42	**26/02/2020**	70	35	45	50	5	PI
43	**26/02/2020**	75	30	45	100	10	PI
44	**26/02/2020**	75	30	45	100	10	Mass flow
45	**27/02/2020**	75	40	35	100	10	PI
46	**27/02/2020**	75	40	35	100	10	Mass Flow
47	**27/02/2020**	75	35	40	100	10	Mass Flow
48	**27/02/2020**	75	35	40	100	10	PI

5 Conclusions

In this document are generated the test cases, and each of them is a combination of values of the variables needed to elaborate on the characterization of the RHeX and the HP.

The tests for the RHeX will be carried out automatically by its autonomous control system which consists of a PC + PLC, and the cases will run in cycle spending 30 min per case, taking a total time of 3 days per each cycle. In that way, it is pretended to collect all the possible operating points, including those that depend on environmental conditions.

The tests for the HP will be carried out at the Tecnalia thermal lab. Each case will be executed by the Tecnalia personnel as a separate experiment.