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A GAS ABSORPTION HEAT PUMP FOR EXISTING RESIDENTIAL BUILDING: HEAT4U PRELIMINARY ACHIEVEMENTS

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ABSTRACT

The efficiency of energy using products becomes more and more important regarding the environmental issues and the impulsion from regulations requirements. To give a specific answer to the existing houses, the HEAT4U European project has been granted by the European Commission, with the objective of developing a gas absorption heat pump (GAHP) as a high efficient solution for heating and domestic hot water (DHW). This gas technology which is using the outside air and natural gas as energy sources combines different advantages compared to electrical heat pumps. Among them, it can deliver high efficiency at low temperatures, it is energy efficient also with high temperature emission systems (i.e. radiators), it does not impact the grids imposing adoption of smart grid approaches, it uses a natural working fluid without global warming potential, and, finally, provides a 30% to 40% energy saving compared to a condensing boiler.

Started since October 2011, the HEAT4U project, led by ROBUR as the main company on the GAHP field, has developed a complete system including a GAHP prototype, system control and all hydraulic means in order to provide energy for both space heating and DHW service. In a first step, the European markets requirements for retrofit applications were analyzed in order to provide an suitable system. This preliminary system has been tested in laboratory conditions in compliance with latest harmonized revisions of test standards (EN12309, EN13203-6). The results of these preliminary prototypes will be detailed in a first part.

Some of these tests have allowed to estimate seasonal performance according to Ecodesign and Labeling directives and also to fill in a performance map model to estimate same performance according to different building models, climate conditions and DHW loads. Despite results were measured on preliminary prototypes, they are already very promising for a retrofit application, where electric heat pumps have lower efficiency and boilers have already reached asymptotic limits.

Finally, five field tests have been deployed in five different countries to complete the objective of demonstration. The first results will be analyzed in the paper.

Now, the successful completion of HEAT4U (ending in October 2014) will offer the opportunity for progressing with the next steps, which consists on gathering conditions for industrialization and commercialization phases, to a successful deployment of GAHP technology in European individual dwellings.

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1 A NEW GAHP WITHIN THE EUROPEAN HEAT4U PROJECT

In Europe, new directives as the Energy Performance of Buildings Directive [1] and the Energy related Product Directive [2] push for deep retrofitting efforts in the residential buildings sector, in order to achieve energy efficiency and renewable energy use targets for 2020 and beyond. Existing houses represent a large share of the building stock and constitute a sector where a large potential to reduce energy use and CO2 emissions lies. They more and more push to use the best technology to produce heat and will promote systems using a part of renewable energy. A Gas Absorption Heat Pump (GAHP) is developed within the European project HEAT4U in order to address the unanswered needs of the existing buildings across Europe that feature high temperature heating systems and demand of domestic hot water. These buildings represent a significant part of the European building stock that today cannot find in alternative technology (biomass, electrical heat pump, solar thermal, micro-CHP) a solution that is environmental compatible, cost efficient and do not impose expensive upfront infrastructural investment for the deployment.

This GAHP technology associates the use of renewable energy with natural gas. Beyond the significant increase in energy efficiency on heating and DHW, this heat pump technology helps to reduce peak electricity consumption and reduces CO2 emissions.

Figure 1: The partners of HEAT4U project

In this context, HEAT4U is an industry led project whose main objective is to develop a GAHP solution to allow a cost-effective use of renewable energy in existing residential building for heating and DHW services. The project is conceived to overcome a number of technological and non-technological barriers which currently prevent HEAT4U main objectives are:

- Development of an appliance with specifications suitable for the residential market (10 – 25 kW);
- Integration of the technology in existing heating and DHW architectures or into pre-fabricated building components, designed for deep retrofitting;
- Development of a decision support system, enabling the assessment of the expected performance in different building operating conditions;
- Field test assessment of the technology in 5 real buildings: dissemination activity to promote the awareness of the benefits of the GAHP technology.

In this paper, an overview of HEAT4U technical results is presented. This gathers experimental results of the GAHP in laboratory conditions, different estimations of GAHP seasonal performance provided by the decision support system developed within the project, and finally the results and the learning of the five field tests deployed around Europe.

Figure 2: Example of installation of a residential GAHP in an existing building

2 LABORATORY TEST RESULTS

2.1 Methodological approach

The primary goal of these tests has been the verification of the GAHP performance according to the revision EN standards which are referenced to by the European Eco-design criteria and Energy labeling criteria [2] (i.e. the prEN12309 series for sorption appliances).

In particular the test protocol used for the GAHP performance assessment in the laboratory is based on the prEN12309-3 [3] and prEN12309-4 [4], developed during the first phase of the HEAT4U project.

2.2 Test results for space heating

Tests for GAHP performance in space heating operation have been carried out both at Politecnico di Milano (POLIMI) and Fraunhofer ISE laboratories. These two laboratories shared the working load, testing the appliance performance over two different sets of operating conditions. Moreover, some operating conditions have been used from both the laboratories, with the purpose of comparing the results and increase their accuracy.

The performances of the preliminary prototypes have been measured according the test conditions proposed by the prEN12309-3 [3] for high temperature appliances. In particular, tests related to a variable outlet temperature control have been performed for the climate conditions warm, average and cold as defined in prEN12309-6 [5] according to European Eco-design [2].

		Warm climate		**Average climate**		**Cold climate**	
PLR	%	64.3	28.6	54.2	34.4	60.5	36.7
Tair	°C	7.0	12.0	2.0	7.0	-7.0	2.0
GUE(NCV)	-	1.53	1.41	1.47	1.39	1.21	1.31

Table 1: Some of the results for high temperature appliance obtained on preliminary prototypes of residential GAHP in some of the most common situations of use.

Where:

- PLR: Part load ratio (building load divided by the design load at a certain outdoor temperature)
- GUE: Gas Utilization Efficiency (effective heating capacity divided by gas consumption)

3 SEASONAL PERFORMANCE SIMULATION

3.1 Modeling tools

In order to get an indication of the performance of the GAHP technology under different climate conditions, load profile, emission system, etc., a Decision Support System has been developed.
This DSS aims to provide realistic estimates of the seasonal performances by means of dynamic simulations of the GAHP and the building load. For this purpose, performance map models have been implemented in TRNSYS which includes both full load and part load behavior of the appliance based on a first experimental characterizations of a prototype of the GAHP.

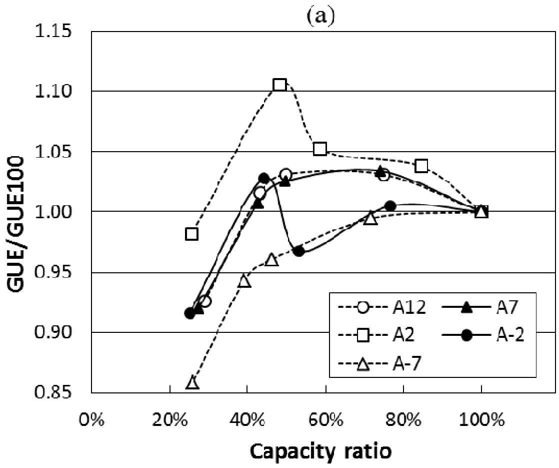

Figure 3: Example of type of performance map model used in the DSS [6]

The required heat is fully delivered by the GAHP. The distribution system (domestic hot water system DHW and comfort heating CH) is directly connected to the appliance. The heat distribution system may constitute of radiators or a floor heating, which differ in the supply temperature and the temperature spread of the heat distribution system.

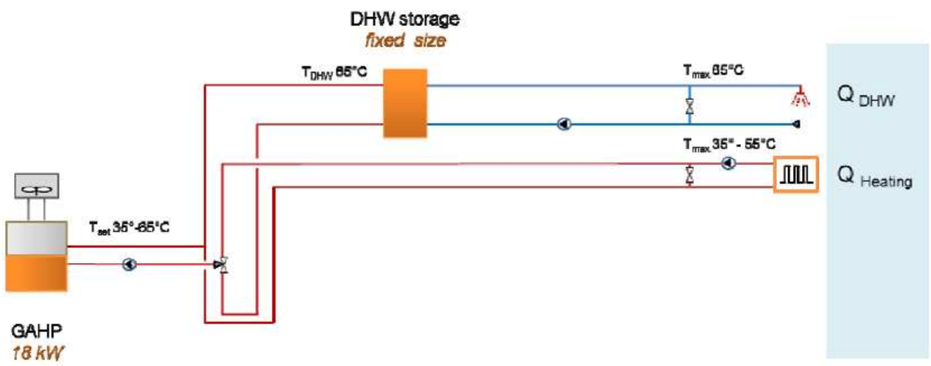

Figure 4: The System configuration of a monovalent GAHP system for domestic hot water preparation and space heating [8]

In parallel of the DSS development process, two simplified methods of simulation have been also developed and their performance results have been compared to the TRNSYS one.

The first one called Fast Performance Calculation Tool (FPCT) has been based on test results made by GDF SUEZ (CRIGEN) on a first GAHP conceptual prototype.[8]

The second one developed later called Modified Bin Method Tool (MBMT) follows from the application of the bin method, as described in prEN15316-4-2 [9]. The bin method suggested by prEN12309-6 [5] has been modified with the purpose of extending its applicability to more general conditions, including different climates, different building insulation levels and different design loads.

3.2 Results and comparison

3.2.1 FPCT vs. TRNSYS

In order to conduct a first plausibility check on these performance predictions, the monovalent system configuration was also implemented in the simulation tool TRNSYS for the average climate (Strasbourg).

System	Simulation Tool	Heating Curve	T_{Out} [°C]	Heat Load [kWh]	DHW load [kWh]	Gas Utilization (NCV) [kWh]	SGUE (NCV) [-]
GAHP	FPCT - LF	No	55	30557	3348	26847	1.26
GAHP	TRNSYS - LF	No	55	30557	3124	27499	1.22
GAHP	TRNSYS- BC	No	55	30930	3575	27538	1.25
GAHP	FPCT - LF	Yes	Average: 41°C	30557	3348	25632	1.32
GAHP	TRNSYS - LF	Yes	Average: 41°C	30557	3118	25842	1.30
GAHP	TRNSYS - BC	Yes	Average: 41°C	29064	3573	24987	1.31
Condensing Boiler	TRNSYS - BC	Yes	Average: 41°C	29215	3103	33328	0.97

Table 2: Comparison of the preliminary results of the FPCT and TRNSYS system simulation for the location of Strasbourg and with T_{Out} either with constant outlet temperature (55°C) or f ollowing the heating curve (LF: Simulation with Load File; BC: Building coupled simulation) [8]

Here, two simulations with the equivalent load file and a more detailed building-coupled simulation were performed. The difference simulation approaches yield very similar results. System performance is better when varying outlet temperature T_{Out} according to a heating curve which leads to a lower average annual outlet temperature. Indeed the two simulations summarized in Table 3 estimate the gain in energy efficiency expected by simply activating the heating curve function on the GAHP control in approximately 6 to 8%.

Further, as a reference simulation the equivalent building was simulated with a condensing boiler as the heat generator (also using a heating curve). When compared to the reference simulation of the gas condensing boiler (with heating curve), a clear advantage can be drawn by the GAHP systems with an increase in energy efficiency of up to 35% compared to a condensing boiler in the same operating conditions.

3.2.2 MBMT vs. TRNSYS

Building	Total floor area (m^2)	External surface (m^2)	Average U-value $W/(m^2\,K)$	Infiltration rate h^{-1}	Window surf. ratio (m^2/m^2)	Climate file
Helsinki 1	200	436	0.61	0.5	5.7%	FI-Helsinki-Kaisani-29980.tm2
Helsinki 2	450	728	0.37	0.3	6.9%	
Strasbourg 1	200	436	0.83	0.5	5.7%	FR-Strasbourg-71900.tm2
Strasbourg 2	450	728	0.51	0.3	6.9%	
Athens 1	200	436	1.59	0.5	5.7%	GR-Athinai-167140.tm2
Athens 2	900	1284	0.64	0.3	5.4%	
Milan 1	200	436	1.02	0.5	5.7%	IT-Milano-Linate-160800.tm2
Milan 2	450	728	0.65	0.3	6.9%	

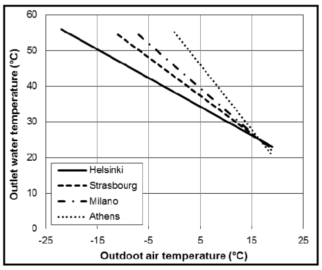

Figure 5: Features of sample buildings and climatic curves associated to the considered buildings [10]

		TRNSYS SIMULATION				MODIFIED BIN METHOD			
	Q_h	E_{aux}	Q_g	SGUE	SAEF	E_{aux}	Q_g	SGUE	SAEF
	MWh	kWh	MWh	-	-	kWh	MWh	-	-
Helsinki 1	31.0	979	24.5	1.27	31.7	985	24.4	1.27	31.5
Helsinki 2	25.3	842	20.6	1.23	30.1	874	20.7	1.22	29.0
Strasbourg 1	23.0	749	17.8	1.30	30.7	745	17.7	1.30	30.9
Strasbourg 2	15.6	598	12.8	1.22	26.1	617	13.0	1.20	25.3
Athens 1	13.1	488	10.0	1.31	26.8	505	10.0	1.31	25.9
Athens 2	9.0	366	7.1	1.26	24.5	399	7.2	1.24	22.5
Milan 1	23.8	730	18.0	1.32	32.6	725	18.0	1.32	32.8
Milan 2	17.4	600	13.8	1.26	29.1	622	14.0	1.24	28.1

Table 3: Seasonal performance calculations according to TRNSYS simulations and MBMT [10]

A specific climatic curve, corresponding to the high temperature application of standard prEN12309, has been defined for each building (see Figure 5). MBMT is verified by comparing its results with the results of a more detailed building and appliance simulation carried out with TRNSYS. Regarding the Table 4, a reasonable agreement between TRNSYS simulations and the modified bin method is found, especially for the calculation of the SGUE.

3.3 Conclusion

These simulations results confirm, emphasize and quantify the importance of using the heating curve in order to maximize system efficiency. The simulation tool developed (DSS) also allows, once loaded with the appropriate performance map models, to estimate seasonal gas efficiency in different climate conditions and building loads. The simulation run performed on the preliminary data show seasonal efficiency always higher than 120% NCV and able to achieve 132% NCV. For the most representative regions in Europe (average climate), improvement in gas energy efficiency (compared to a gas condensing boiler in same operating conditions) are up to 35% (even with high temp radiators).

4 FIELD TEST RESULTS

4.1 Five field tests representative of different climates and typical installation for existing dwellings

Five real field tests have been installed in different geographical installation places.

The main objectives of these field tests were:

- to demonstrate reliable, comfortable and efficient heating and DHW service in different countries and situations representative of the most typical installations for existing buildings;
- to improve the installation guideline and have first feedback from installers;
- to optimize the GAHP System Control,
- to optimize the GAHP Appliance Control,

- to obtain measurements of efficiency in primary energy in real conditions and energy savings compared to the previous installed systems.

Among the five installations, four of them have been deployed into residential dwellings (France - GDF Suez, UK - British Gas, Poland - Flowair and Germany - E.On), while one used a load simulator (Italy - Enea).

Country	FRANCE (GDF SUEZ - GrDF)	GERMANY (E.On)	UK (British Gas)	POLAND (Flowair)	ITALY (Enea)
City	Sainte Genevieve des Bois	Bottrop	Whitley Bay	Gdanks	Anguillara - Rome
Building type	One-family insulated house GAHP installed at the end of the garden (30m from the house) Additional insulation installed in 2013	One-family low insulated house GAHP behind the garage in the garden	Semi Detached with: GAHP at rear behind garage & kitchen extension	One-family low semi insulated house GAHP behind the garage in the garden	3 x One-family low insulated house (VIRTUAL BUILDING) GAHP outside testing laboratory, 2 meters away from the laboratory building
Number of inhabitants	4	3	2	4	N.A.
Year of construction	1920	Ca. 1954	1950	2006	1960/1970
Heated building area [m2]	110	Ca. 140	124	178	297
Specific heat load [W/m2]	-	-		-	46.12 (heating only)
Design load for heating [kW]	12 (estimated)	15 (estimated)	12 (estimated)	14 (estimated)	14 (imposed by control)
Design outdoor temperature of location (℃)	-7	-10	- 3	-18	0
Design supply temperature of heating system (℃)	65	60/45	65	70	60-65
Connection to the gas network	Existing	Existing	Existing	Existing	Existing
Distribution system	8 X 1500 W High temperature radiators	High temperature radiators	11 x Radiators of various sizes, 5 were increased in size for trial.	High temperature radiators	High temperature radiators
Operation mode	Monovalent (with back up boiler as contingency plan)	Monovalent (with back up boiler for contingency)	Monovalent (with back up boiler for contingency)	Bivalent (with peak load boiler)	Monovalent
Output of peak load boiler (if bivalent operation) [kW]	-	-	-	-	N.A.
Alternative / complementary heating system	Gas Condensing Boiler	Gas Condensing Boiler	Gas Condensing Boiler	Gas Condensing Boiler	None

Table 4: Features of the five field test locations

As a general consideration it should be recorded that the 2013-2014 has been a winter warmer than usual. In particular the Field Tests of Poland, Germany, France and UK were affected by higher than usual temperatures. Furthermore, every site significantly overestimated the heating load. As a consequence, only very partial load have been observed during the field trial. To exemplify consider the situation encountered in UK and described in figure 6: UK building as supposed to demand 12 kW @ -7℃ while it provided (by regression) only 8 kW @ -7℃).

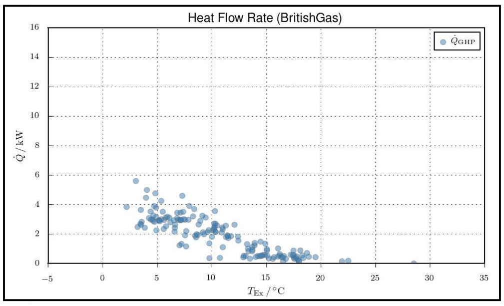

Figure 6 : Heat Flow rate in UK according to external temperature (graph: Fraunhofer ISE)

In addition to the poor building load matching (drastically smaller than anticipated), all Field Tests have also been affected by other external factors:

- late equipment and measurement system commissioning
- reduced duration (late start, anticipated vacation of the building)
- plant unconformities (by-passes, filter cleanliness, etc.)
- optimization of control parameters during field test (outlet temperature, flows, etc.)

If these external factors prevented the direct measure of the seasonal performance, they were an excellent opportunity to complete the optimization work of the GAHP Appliance and GAHP System Control.

The field test program has delivered therefore instrumental information that we would summarize in:

- availability of a protocol for performing field testing of GAHP Appliances;
- data for comparing performance of difference schematics/installation practices;
- demonstrated no need for modification of the emission systems (retrofit is limited to machinery room);
- demonstrated ability to operate in a building fitted with high temperature radiators;
- demonstrated ability to operate under outdoor conditions even at -17°C (in the lab -22℃);
- demonstrated reliable operation with absence of failure or discomfort for end users;
- demonstrated that defrosting cycles are infrequent with transparent effect to end users;
- set of guidelines of good practices for planning, installation and commissioning.

4.2 Performance analysis

Since the performance figures (GUE, AEF) are influenced by some factors as auxiliary drives (circulation pump) and storage or hydraulic circuits energy losses, a specific field test protocol and associated system boundaries have been defined to reflect the impact of different devices on the performance of the system (see here below an example of system boundaries for the French installation).

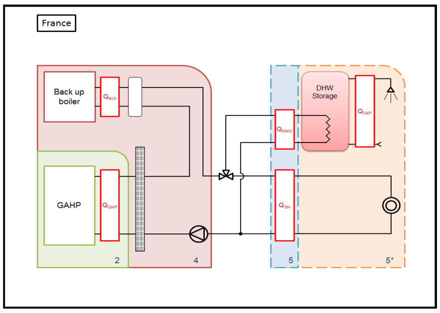

Figure 7: Definition of system boundaries for France (graph: Fraunhofer ISE)

The HEAT4U field test program results demonstrated, despite the extreme partial load conditions in which they were performed, the following achievements:

- Efficient operation in Space Heating mode: 122% to 150% (NCV);
- Efficient operation even in the combined operation (Space Heating and DHW): 111% to 138% (NCV)
- Efficient operation even at very low partial load conditions (lower than 20% of nominal power output) and even when delivering DHW service: up to 127% NCV.

In order to validate these measurements and to generate a neutral benchmark on the same specific applications, during HEAT4U field tests also condensing boilers have been measured for comparison (in several circumstances GAHPs have been deliberately switch-off and the heat demand of the buildings were delivered by condensing boilers). In such similar operating conditions the performance measured on condensing boiler was approximately 85% to 92% GCV.

This large amount of available data makes already possible achieving solid evidence of real energy performance. Despite unexpectedly extreme operating conditions, HEAT4U field tests systematically reported efficiencies of 30% better than a condensing boiler in the same application/circumstances/ conditions. These results demonstrate that the adaptation of the GAHP technology to a residential application has been successfully achieved by providing a solution able to deliver substantial energy saving even while demonstrating at the same time tolerant to significant heat load mismatch.

All inhabitants involved in field test sites have interest in extending field test session to a second year.

5 CONCLUSIONS

HEAT4U Project planned to use a set of tools for provide the evidence of the readiness of the GAHP technology for the residential market.

One of the most effective tools was in particular the Field Test program. This program was designed to collect real life experience in installing commissioning, optimizing and using GAHP systems.

Given the limited number of possible field test sites envisaged by the HEAT4U Project, other tools were planned since the beginning for acquiring solid evidence of the performance of the technology in the expected application (existing residential building in Europe).

These instruments, developed and fine tuned in coordination with the Field Test program are the Labs campaigns and the development of a Simulation Tool. The validation of the simulation tool on the basis of Labs Measurements and Field Test data allows the complete an exhaustive assessment of the energy performance that not even an extremely large field test program would have allowed.

The HEAT4U program has therefore demonstrated, by means of lab testing, simulation and field testing the achieved performance (saving up to 35% compared to a condensing boiler) and reliability of the GAHP technology. The consistency of results between different performance estimate tools deliver solid evidence of the robustness of the evaluations. In addition the extreme partial load conditions during field testing have demonstrated the GAHP technology’s resilience in performance delivery. This is indeed a major objective achieved within HEAT4U.

In consideration of the above performances, their consistency and also of the boundary conditions in which such performances have been delivered, the GAHP technology can therefore be considered suitable and ready for full market deployment in the residential environment and in particular in the existing building stock across Europe.

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