Gas driven Absorption Heat Pumps in domestic heating

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In the near future, Gas driven Absorption Heat Pumps could achieve relevant market penetration and play an important role in reducing CO_2 emissions from space heating and DHW production in existing residential buildings – where gas boiler is the leading technology – thanks to peculiar features and margins for cost and size reduction.

Keywords: Heat pump, domestic heating, absorption, energy efficiency, renewable energy, global warming mitigation

Introduction

Decarbonization of the building sector is clearly a top priority of national and international policies on climate change mitigation. According to the scientific community, even if we completely stop emitting greenhouse gases right now, global warming will continue to happen for at least several more decades [1–2]. Moreover, it is not possible to immediately switch to a zero-carbon energy system. Concerning the building sector and heating demand, a possible long-term strategy consists in one or a combination of the following measures, each one bringing its own issues:

- Green electricity and electrical heat pumps: national electricity grids have not yet the capacity, both in terms of power generation and distribution, to hold the load of a fully electrified heating sector [3–4];
- Energy efficient buildings: most of the stock of existing buildings in Europe has a high-temperature heat distribution system (radiators) [5]; furthermore, the building renovation rate is still very low: 1% on the average.
- Green or blue hydrogen replacing natural gas fuel: a switch to a hydrogen-based energy system, which implies H_2 production, storage, and distribution, requires large investments. Moreover, hydrogen is likely to supply the transport and the industrial sectors with a higher priority as compared to the building sector, making quite unlikely, in short and medium term, a scenario dominated by hydrogen fuelled boilers for domestic heating.

For these reasons, the Gas-driven Absorption Heat Pump (GdAHP) is presented in this paper as an alternative and viable heating technology that can contribute to the decarbonization of the building sector both in the medium and long term.

Potential of Gas-driven Absorption Heat Pumps in the EU

As pointed out in [6], GdAHPs can provide consistent CO_2 savings with respect to the condensing boiler and compete with both full electrical (EHP+AEH) and hybrid (EHP+CB) air-source electrical heat pumps. For example, focusing on the EU average and warm climate and considering primarily lightly renovated buildings, where the air-source electrical heat pump is the current replacement technology, CO_2 savings ($kgCO_2/y$) and relative variation compared to the condensing boiler are shown in **Table 1**.

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Considering the above results, two main considerations arise.

(1) In the medium term, Gas driven Absorption Heat Pumps (GdAHP) could play an important role in reducing the CO_2 emissions for space heating and domestic hot water production in existing buildings: they can replace gas boilers while exploiting the existing gas networks and operating efficiently, even with a high-temperature heat distribution system (radiators) and if air sourced.

(2) In the long term, thanks to the transition of European gas market towards bio-methane and hydrogen (as pure gases or mixed with fossil methane) [7–8], GdAHPs can benefit from the decreased carbon intensity of a cleaner gaseous fuel mix. The target of such policy is increasing the share of renewable energy, reducing emissions in the urban context, and exploiting these energy carriers as a seasonal storage of the summer over-production of renewable electricity, in an increasingly likely scenario of massive deployment of photovoltaics [9–10]. In this scenario, on the one hand GdAHPs will maintain its competitiveness in terms of CO_2 savings with respect to electrical heat pump, on the other hand they make a more efficient use of valuable and expensive gas mixtures with respect to gas boilers.

State of the art of Absorption technology in heating sector

Although absorption is a mature technology, its presence in the heating sector is still marginal, with mainly one manufacturer of ammonia-water heat pumps on the market. Such company has proven their feasibility and reliability by means of thousands of installations in the commercial sector.

Reliability is a precondition for the spreading of GdAHPs in the residential heating sector: considering ammonia /water absorption units, the ammonia sealed circuit must operate with no maintenance for thousands of hours per year, for at least ten years. On the other hand, the current market of GdAHPs does not have a suitable scale to boost their industrialization and the resulting cost reduction.

Ammonia has been inherently a further limit to such industrialization, as it requires steel components and rules out most of the available products in the field of refrigeration, which are either made of copper alloys, or have sizes suitable for large industrial plants. As a result, the heat exchangers of the ammonia circuit have been so far realized in-house by the few manufacturers engaged in the development of this technology.

To achieve a consistent market penetration and obtain the expected impact on CO_2 emissions, the challenge is to make air-source, ammonia-water, GdAHP a safe, compact, and cost-effective product.

Small capacity Gas-driven Absorption Heat Pump

Aiming at demonstrating the possibility of overcoming such a challenge, a compact 8 kW-rated GdAHP prototype is under development at the Department of Energy of Politecnico di Milano.

Our project follows a specific path with the purpose of reducing heat pump cost and dimensions without penalising efficiency:

- Components must come from large series production, in particular the heat exchangers. This approach is made possible by a relatively recent development in the manufacturing process of plate heat exchangers (PHE), the fusion-bonding technology, which allows seamless assembly of 100% stainless steel PHEs
- Compact dimensions of the heat pump, which must be comparable to those of a standard domestic condensing boiler – 500 mm wide, 400 mm deep, 850 mm high – with ammonia charge well below 2 kg. Such small dimensions, and the choice of a configuration with indirect expansion – that is, with a remote air to brine heat exchanger – can allow the internal wall-hung installation of the GdAHP in small flats, greatly expanding its potential market.
- Variable refrigerant and ammonia-water solution valves are used to tune the GdAHP operation to the wide range of thermal loads and ambient conditions related to heating and DHW production, maximizing performances.

Table 1. *CO_2 savings ($kgCO_2/y$) and relative variation compared to the condensing boiler for lightly renovated buildings in EU, source: [6].*

	Average climate		Warm climate	
EHP+AEH	1 337	(–44%)	1 678	(–58%)
EHP+CB	1 120	(–37%)	1 264	(–44%)
GdAHP	917	(–30%)	1 016	(–35%)

Some pictures, showing the main components and dimensions of the sealed circuit – which is the heart of the prototype – are shown in **Figure 1** (most of the valves and transducers installed on the prototype are related to the laboratory activity, and would not be present on a commercial product).

The compactness we could achieve is due to the wide use of PHEs and the special design of the generator and the solution pump, which are new developments.

The prototype has been tested in an accredited laboratory in compliance to standard EN 12309-6:2014 [11].

The main performance indicator resulting from the application of the Standard is the Gas Utilization Efficiency (GUE), which is the ratio between the effective heating capacity and the gas input, measured under specific working conditions, defined by the EN 12309-6:2014 and reported in **Table 2** for high temperature application and average climate. Based on the measured values of GUE, the Seasonal Gas Utilization Efficiency (SGUE), i.e., the weighted average value over the heating season of the GUE can be calculated. The measured GUE (based on the NCV) of the developed prototype over the five test conditions is reported in **Figure 2**, while the resulting SGUE is 1.58.

In the light of the reported results, some remarks can be made about the potential benefits of our prototype (and GdAHPs in general):

- Unlike existing GdAHPs on the market and some condensing boilers, the developed prototype can be partialized down to 15% of its rated power without compromising performance, thanks to the use of variable valves;
- Unlike compression heat pumps, performances remain high even at large temperature lifts;
- The high SGUE shows good prospective annual savings in terms of gas consumption and emissions compared to gas boilers, the technology that the GdAHPs aim to replace.

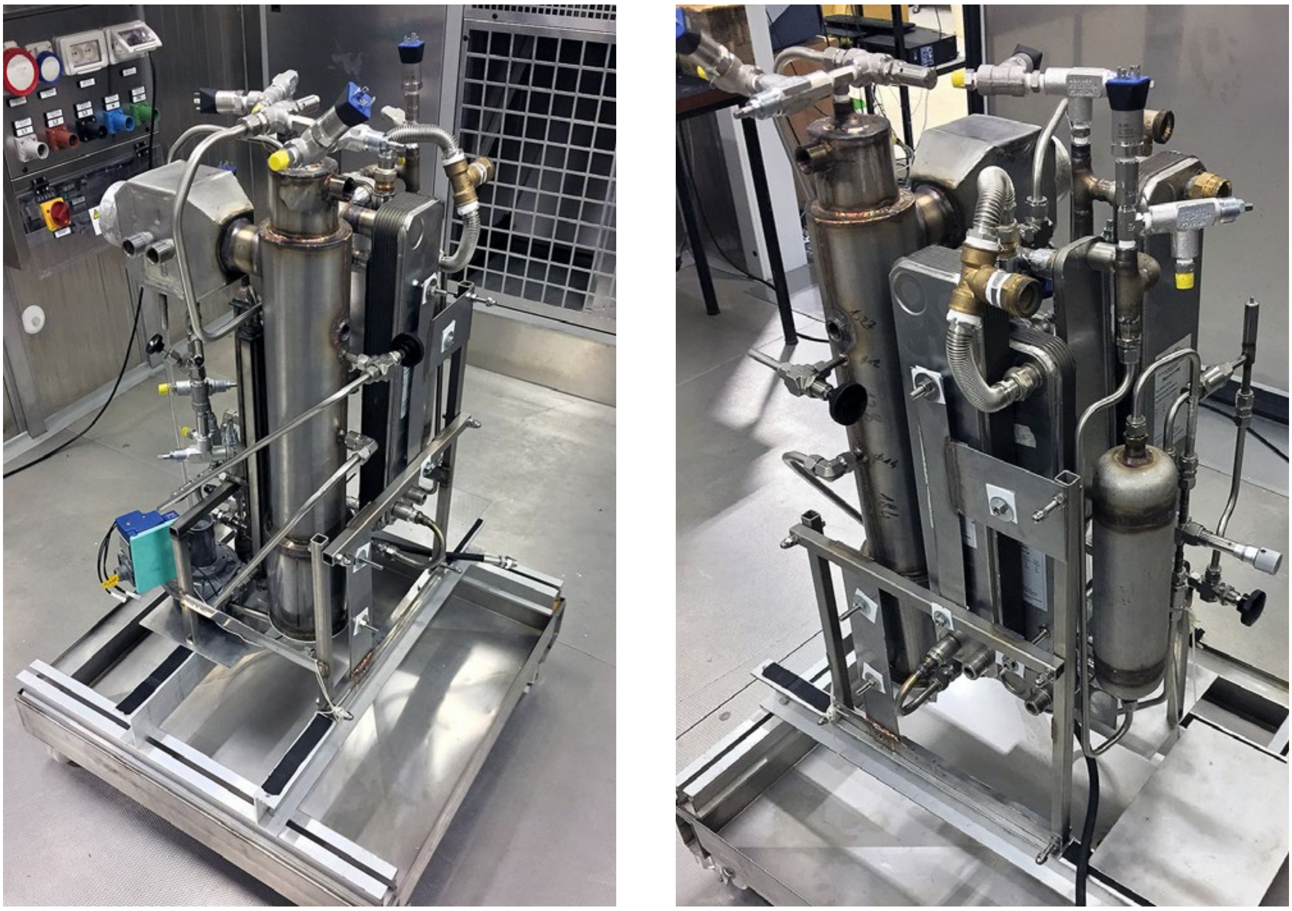

Figure 1. View of two sides of the GdAHP prototype, showing the assembly of components.

Table 2. Test conditions for the measurement of the GUE for the average climate and high temperature application.

Load	Heating capacity kW	Tair dry bulb °C	Tair wet bulb °C	Twater in °C	Twater out °C
100%	8.00	−10	−11	42	55
88%	7.04	−7	−8	40	52
54%	4.32	2	1	33	42
35%	2.80	7	6	29	36
15%	1.20	12	11	25	30

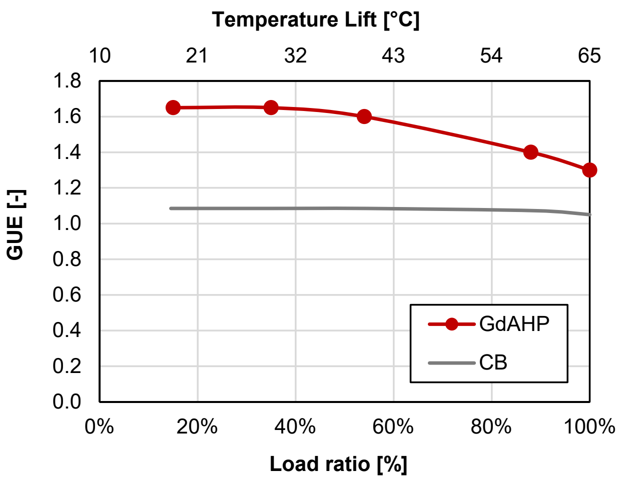

Figure 2. Measured values of GUE based on the conditions reported in Table 2 as function of the thermal lift and comparison with the corresponding efficiency of a condensing boiler.

Conclusions

Gas-driven Absorption Heat Pump is an alternative and viable heating technology that can contribute to the decarbonization of the building sector in the medium and long term. In principle, in the EU average and warm climate and in lightly renovated buildings, where the air-source electrical heat pump is the current replacement technology, GdAHPs can provide consistent CO_2 savings with respect to the condensing boiler and compete with both full electrical (EHP+AEH) and hybrid EHPs (EHP+CB).

However, more efforts are required to make GdAHPs safe, compact and cost-effective products, capable to occupy consistent market shares while achieving the expected impact on CO_2 emissions.

The prototype under development presents some distinguishing features that contribute to make GdAHPs viable for a large deployment in residential buildings:

- It uses stainless steel PHEs that can be manufactured in large series;
- Its dimensions, except for the external air heat exchanger, are comparable to those of a standard domestic condensing boiler – 500 mm wide, 400 mm deep, 850 mm high – and the ammonia charge is well below 2 kg;
- Its experimental performances are quite promising, with a calculated SGUE of 1.58, thanks to the use of variable valves that allow to optimize its operation over a wide range of thermal loads and ambient conditions. ■

References

[1] Peters GP, Andrew RM, Boden T, Canadell JG, Ciais P, Le Quéré C, Marland G, Raupach MR, Wilson C. The challenge to keep global warming below 2 °C. *Nature Climate Change* 2000;**3**:4–6

[2] Budzianowski WM. Time delay of global warming. *International Journal of Global Warming* 2011;**3**,3:289-306.

[3] Love J, Smith AZP, Watson S, Oikonomou E, Summerfield A, Gleeson C, Biddulph P, Fong Chiu L, Wingfield J, Martin C, Stone A, Lowe R. The addition of heat pump electricity load profiles to GB electricity demand: Evidence from a heat pump field trial. *Applied Energy* 2017;**204**:332-342.

[4] Fawcett T, Eyre N, Layberry R. Heat pumps and global residential heating. Proceedings of ECEEE Summer Study on energy efficiency: First fuel now; 2015; 6-321-15.

[5] Peeters L, Van der Veken J, Hens H, Helsen L, D'haeseleer W. Control of heating systems in residential buildings: current practice. *Energy and Buildings* 2008;**40**:1446-1455.

[6] Scoccia R, Toppi T, Aprile M, Motta M. Absorption and compression heat pump systems for space heating and DHW in European buildings: Energy, environmental and economic analysis. *Journal of Building Engineering* 2018;**16**:94-105.

[7] Van Nuffel L., Gorenstein Dedecca J., Yearwood J., Smit T., Bünger U., Altmann M., Fischer C., Michalski J., Raksha T., Zerhusen J., De Vita A. 2019. Impact of the use of the biomethane and hydrogen potential on trans-European infrastructure. Final Report for European Commission.

[8] POST- UK Parliamentary Office of Science and Technology. 2017. POSTNOTE 565, Decarbonising the Gas Network.

[9] MISE. 2020. Piano Nazionale Integrato per l'Energia e il Clima (PNIEC2030).

[10] European Commission. 2018. A Clean Planet for all - A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy. In-depth analysis in support of the Commission Communication COM(2018) 773.

[11] EN 12309-6:2014 Gas-fired sorption appliances for heating and/or cooling with a net heat input not exceeding 70 kW. Calculation of seasonal performances.