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Domestic Heat Pumps Using Hydrocarbons: Current Status and Market Overview in Europe

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Governments are promoting the shift to electrically-driven heat pumps for domestic heating and hot water, while also regulating the use of environmentally-damaging fluids. Natural refrigerants, particularly hydrocarbons (HCs), are gaining attention due to their low toxicity, and excellent thermophysical characteristics, despite being flammable. HCs are seen as sustainable long-term alternatives to synthetic fluids. This article is based on a Technical Brief with the same title published by the International Institute of Refrigeration [1], which explores the current use of HCs in domestic heat pumps, their advantages and limitations compared to other options, and prospects for broader adoption.

Introduction

Global warming and climate change require a phase-out of fossil fuels. The residential sector is particularly important to decarbonise as it is responsible for one-third of all the global warming emissions in Europe. A significant portion of the emissions of this sector comes from heating, which is mainly powered by fossil fuels. In Europe, efforts to reduce emissions include the electrification of these systems, particularly through Domestic Heat Pumps (DHPs), which are seen as the natural alternative.

The EU aims to install a total of 30 million DHPs by 2030. This is part of the broader goal to reduce greenhouse gas emissions by 55% by 2030. The use of DHPs has increased significantly in recent years, with air-to-air and air-to-water models becoming more popular. Despite a decline in global sales in 2023 and 2024, DHP market share is expected to continue to rise if the decarbonization objectives are maintained.

By 2040, DHPs are expected to be the leading heating and cooling technology worldwide. However, there are challenges regarding the refrigerants used in DHPs, as many are harmful to the environment. Low Global Warming Potential (GWP) refrigerants are required to meet the Kigali Amendment and European F-gas regulations. In Europe, the F-gas regulation will forbid installations of heat pumps with any F-gases in small systems (<12 kW) from 2035, unless required by safety concerns. Among the options, HCs are promising if their flammability is managed properly.

This article summarizes the overview of the current possibilities of using HC refrigerants for DHPs supplied in the Technical Brief [1]. First, a motivation for the selection of HCs as the most suitable refrigerant for this application is given, followed by the main characteristics of DHPs when using HCs, including their charge limits. Next, an overview of the commercially available HPs using HCs and their possibilities in the framework of the EU F-Gas regulation 2024/573 is presented (EU Parliament and Council, 2024). It concludes with considerations of possible technological evolutions that could extend the application range of HCs in HPs.

Why HCs?

HCs, have excellent thermodynamic properties compared to other refrigerants; they have a high isentropic COP, work at low pressure ratios, which benefits the compressor efficiency, have a low discharge temperature which is translated in a wider operation map and have a high heat transfer coefficient which allows a competitive cost of the heat exchangers. From the environmental point of view, other than their negligible GWP, since they are naturally occurring fluids whose interactions in the environment are very well known, thus no unexpected effects can be expected from their widespread use.

Regarding flammability, new standards have been approved in the last years, such as EN IEC 60335-2-40, in order to ensure their safe application. EN 378 is also currently being revised. These standards offer a variety of flammability risk mitigation concepts (RMCs) that can be applied to DHPs, according to system type, installation location, refrigerant charge, etc. Essentially, these RMCs include approaches to reduce leakage, avoidance of potential sources of ignition, airflow to disperse leaks, and provision of user and operator information.

Perspective of Hcs as Refrigerants

Heat Pumps Currently Available

Regarding R290 DHPs, as of 2022, HP Keymark database included about 420 products using R290 refrigerant. DHPs can be categorised by their source and sink mediums: air to water (ATW), liquid to water (LTW), and air to air (ATA).

ATW systems: Typically used for space heating and domestic hot water (DHW), these systems include outdoor monoblock units with almost no restrictions when they are placed outdoors. Split systems may also be used, but can be limited by refrigerant charge and capacity depending on design. They have become a key alternative to gas boilers, gaining significant market share due to their simplicity. In the HP Keymark database of 2022, 203 R290 ATW DHPs were listed, compared to 1,095 HFC ATW products. Looking at Figure 1, ATW performance data shows that many R290 /models outperform R410A and R32 models in Seasonal Coefficient of Performance (SCOP). Additionally, the refrigerant charge tends to increase with Nominal Heating Capacity (NHC), with R290 models offering high capacities with no more than 1 kg of refrigerant. Specific charge for the best models is around 50 g/kW.

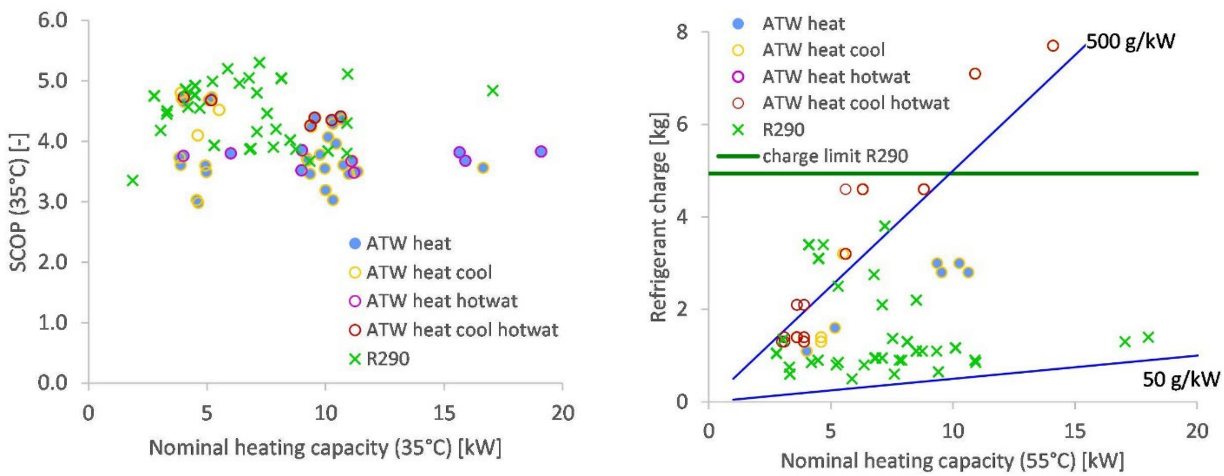


Figure 1. Left) SCOP as a function of nominal capacity for ATW HPs depending on the used refrigerant. Right) Refrigerant charge as a function of the nominal capacity for ATW HPs depending on the used refrigerant [1]

LTW systems: These heat pumps are less common than ATA or ATW models. In the HP Keymark database [8], 127 LTW models use R290, compared to 408 HFC LTW products. Figure 2 shows that R290 HP models have a higher SCOP than models with other refrigerants, independently of (NHC). Refrigerant charges for LTW are typically lower than ATW units; for this typology, it is common to find specific charges of 25 g/kW.

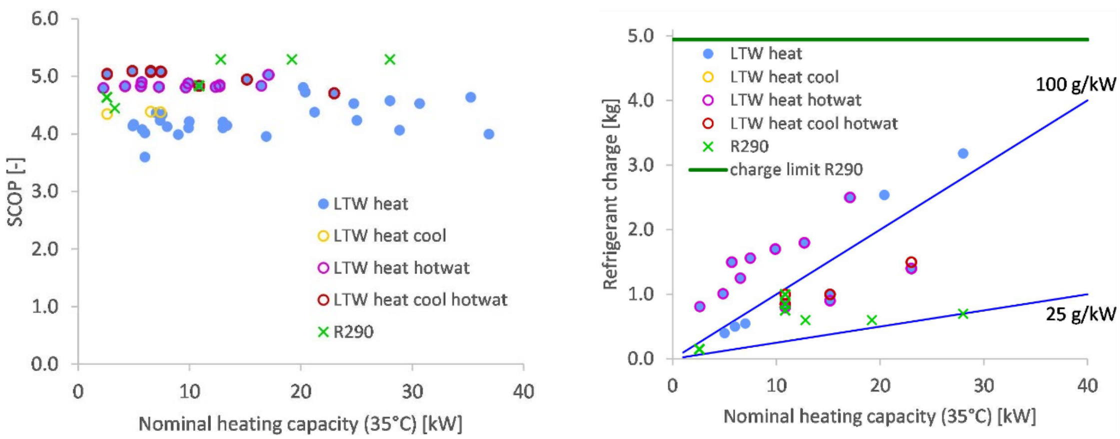


Figure 2. Left) SCOP is a function of nominal capacity for LTW HPs depending on the used refrigerant. Right) Refrigerant charge as a function of the nominal capacity for LTW HPs, depending on the used refrigerant [1]

ATA systems: These are dominant in the market nowadays. Their typical capacities are under 12 kW and are primarily dominated by R410A and R32. In fact, a recent study [2] reviewed over 2,500 reversible ATA heat pumps, showing that less than 1% used R290. The study also presents an analysis of charge limits for R290 depending on the capacity (see Figure 3) based on the limits imposed by EN IEC 60335-2-40:2024 and performing quite conservative assumptions arrives to the conclusion that the use of HCs – particularly R290 and R1270 – is broadly feasible in high- efficiency reversible models for NCCs up to 12 kW.

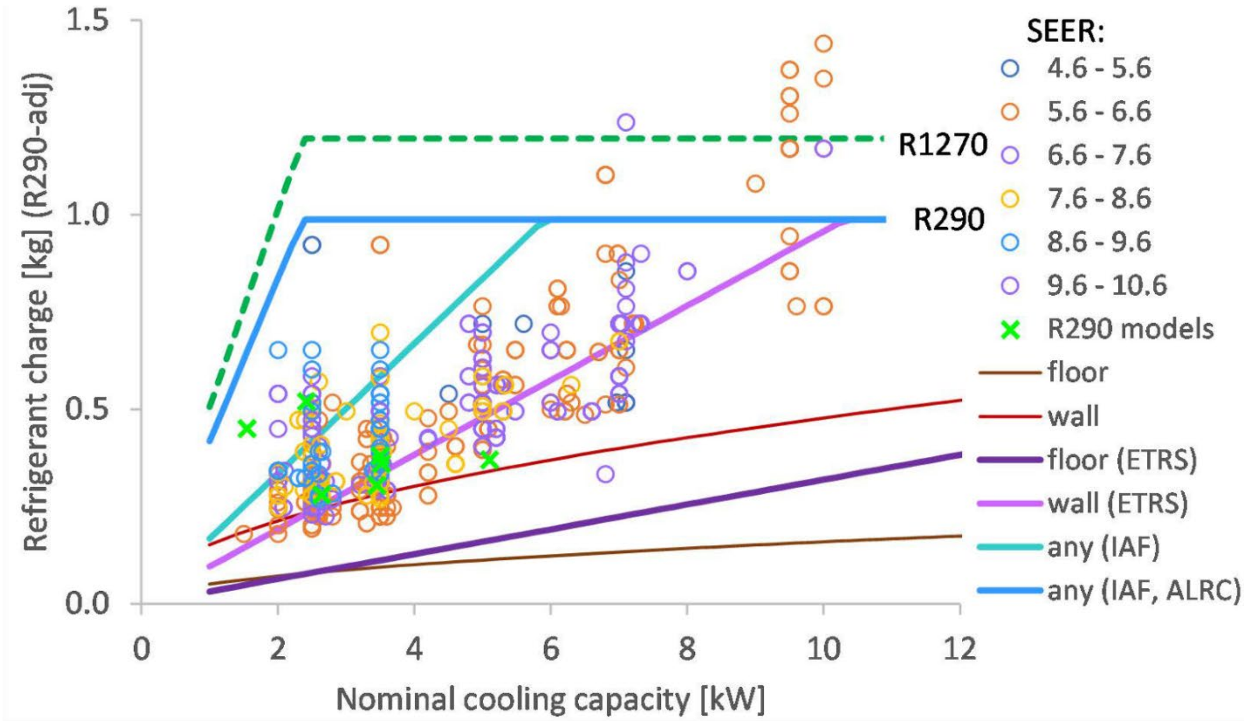


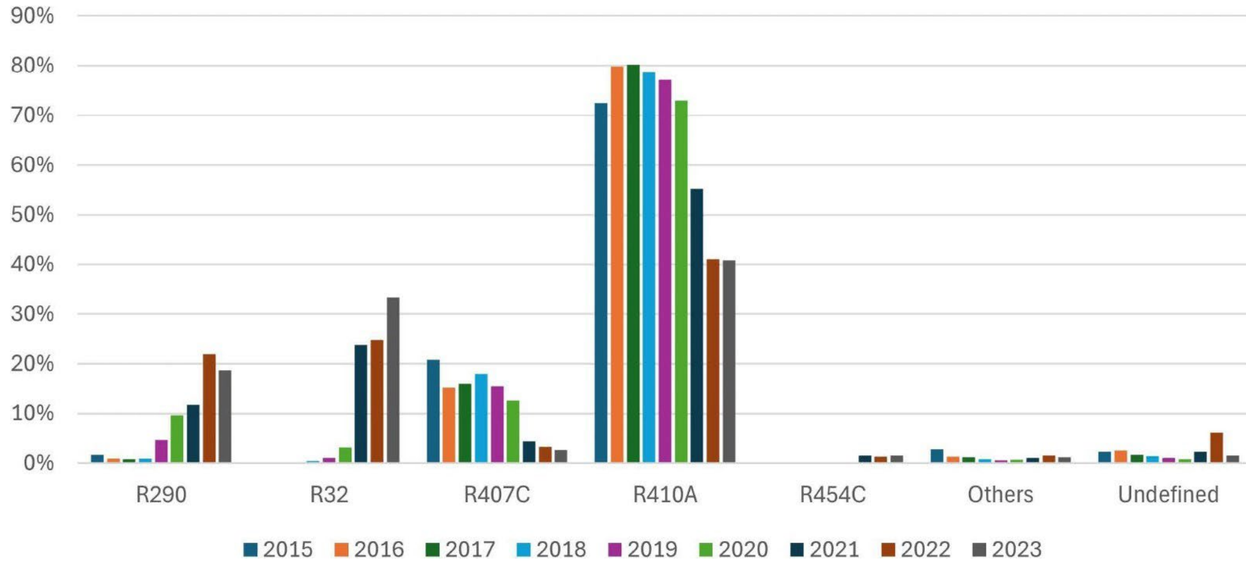
Figure 3. Allowable charge of R290 if different safety precautions are followed, superimposed with charge-adjusted catalogue data [1]

Regarding the price of the units, large-scale cost analyses presented in [2] showed that using DHP based on R290 is generally neutral compared to other refrigerants, with advantages in terms of reduced material mass, manufacturing emissions associated to the components but also to the refrigerant itself, and charge amount and cost. This statement is also verified by performing a market study through pages like Idealo. In markets outside Europe, such as China and India, R290-based systems are being introduced more widely, with several large manufacturers developing R290 reversible AC/HPs.

Market Penetration

In the previous subsection, the number of HP models available was analysed; now, the sales of heat pumps depending on the refrigerant is going to be studied to measure the penetration of HCs based on limited data from the German market according to the BEG funding scheme (Bundesförderung energieeffiziente Gebäude)[1].

From 2015 to 2023, the share of R290 refrigerants in subsidized HPs grew to about 20% by 2022. This share was even higher for monoblock ATW systems. However, in 2023, R290's share dropped, while R32-equipped systems continued to grow. One reason for these dynamics could be found in the different shares of R290 depending on the HP type, which was not reflected in that classification, see Figure 4.



Annual change	R407C	R410A	R290	R32	Comment
2017-2018	+1.8%	-1.7%	+0.1%	+0.3%	
2018-2019	-2.3%	-1.4%	+3.6%	+0.8%	Intro of several new R290 DHPs on the (subsidized) market
2019-2020	-2.9%	-4.3%	+5.2%	+2.1%	Intro of several new R290 and R32 DHPs on the (subsidized) market
2020-2021	-8.3%	-17.7%	+2.1%	+20.6%	New funding scheme in 2021 (BEG) incl. ATA DHPs
2021-2022	-1.1%	-14.1%	+10.1%	+1.0%	Intro of new R290 HPs, new funding scheme in 2021 (BEG) incl. ATA DHPs
2022-2023	-0.5%	-0.3%	-3.1%	+8.6%	Simplified access of (multi-)split DHPs (mainly R32) to subsidization; supply issues for R290 DHPs

Figure 4. Evolution of the dynamics of shares of refrigerants wanted by house owners in Germany as well as annual changes and reasons for shifts between refrigerants [1]

Hydrocarbons Under The Perspective of The EU F-Gas Regulation

Within the 2024 EU F-gas regulation, there are a series of bans for various RACHP (Refrigerant, Air Conditioning and Heat Pump) equipment types. Those related to DHPs are listed in Table 1. Orange shading indicates the difficulty in achieving charge limits for the larger capacity systems of AC&HP equipment, assuming non-mandatory limits in safety standards, whilst green shading implies that charge requirements are broadly achievable with R290. Except for items 8(e), “Other self-contained AC&HPs,” and 9(f), “AC&HP split systems > 12 kW”, it is expected that all equipment categories can be mostly satisfied with HCs.

Table 1 Comparison of required HC charges and values permitted by standards [1].

Year	Annex IV item[1]	Equipment category	Limitation[2]	R290 permitted[3] [kg]	
				IEC 60355-2-40	EN 378-1
2025	9(a)	Single split AC&HPs with < 3kg	No GWP > 750	1	1.5, 2.5
2027	8(b)	Plug-in room, monoblock AC, and self-contained HPs ≤ 12 kW	No GWP > 150 (or No GWP > 750)	1.0, 5.0	1.5, 5.0
2027	8(d)	Monoblock and self-contained AC&HPs, > 12 kW and ≤ 50 kW	No GWP > 150 (or No GWP > 750)	1.0, 5.0	1.5, 5.0
2029	9(b)	AC&HP split ATW systems ≤ 12 kW	No GWP > 150	1	1.5, 2.5, 5.0
2029	9(c)	AC&HP split ATA systems ≤ 12 kW	No GWP > 150	1	1.5, 2.5
2029	9(e)	AC&HP split ATA systems ≥ 12 kW	No GWP > 750	1	1.5, 2.5
2030	8(e)	Other self-contained AC&HPs	No GWP > 150 (or No GWP > 750)	1.0, 5.0	1.5, 5.0
2032	8(c)	Plug-in room, monoblock AC, and self-contained HPs ≤ 12 kW	No F-gases (or No GWP > 750)	1.0, 5.0	1.5, 5.0
2033	9(f)	AC&HP split systems > 12 kW	No GWP > 150	1	1.5, 2.5
2035	9(d)	AC&HP split systems ≤ 12 kW	No F-gases (or No GWP > 750)	1	1.5, 2.5

[1] The letter in parentheses refers to successive POM bans for each Annex IV item listed within Regulation 2024/573.
[2] Text in parentheses ("or No GWP > 750") refers to the condition "...except when required to meet safety requirements."
[3] Actual value depends upon system architecture (EN IEC 60355-2-40) or access class/system location classification (EN 378-1).

Possible Evolution to Widen The Application Range of Hydrocarbons

Wider implementation of HPs working with HCs depends critically on safety issues, and that point is strongly related to refrigerant charge reduction. In addition to more common R&D activities focused on improving HP efficiency and flexibility, refrigerant charge optimization will be a major research topic in future developments.

In that sense, strategies such as using condensers and evaporators with smaller internal volumes [3][4][5][6], minimizing liquid line lengths, and reducing oil in compressors [7] have shown potential for reducing refrigerant charge. Prototypes have demonstrated very low specific charges, as low as 10 g/kW, but the variety in results found in the literature suggests that further improvements are possible. However, most of these approaches still must address durability and feasibility issues before reaching the market.

As it has been explained, it is necessary to review the design criteria of all DHP system components to include the refrigerant charge as a design factor. But also, other aspects contributing to safety, like an analysis of the charge limit in the standards, total system response to external fires, effect of the overall housing design on room concentrations, methods to determine releasable charge, etc., must also be considered.

Conclusions

Hydrocarbons (HCs) are gaining renewed interest as refrigerants for DHPs as they are considered one of the safer environmental alternatives. While HCs are highly flammable and require careful safety considerations, revised international and European standards are now allowing their use in larger systems with larger charges, promoting the shift from synthetic fluids to HCs.

The sales of DHPs with HC-refrigerant (mainly using R290) are increasing, and they represented almost 20% of the German market in 2023. Many HP manufacturers are currently offering HCs DHP in their catalogs. Compressors and heat exchanger manufacturers are also optimizing their designs for HCs in such a way that the range of available products and applications is expected to grow in the next years.

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