DESIGNING RESIDENTIAL HEAT PUMPS TO ACCELERATE THE ENERGY TRANSITION

DR. BRUNO Y. K. DE CARVALHO, STEVEN PACKIARAJAH

As the energy transition needs flexible, energy efficient and sustainable heating solutions, new research by Honeywell and Imperial College London's Dr Danny Pudjianto demonstrates the potential impact of heat pumps, evaluating the possible cost benefits on the whole energy system and the energy efficiency impact of different refrigerant solutions.

Honeywell

TABLE OF CONTENTS

FOREWORD

Investment decisions about how energy systems need to change as the world moves towards a low-carbon existence are typically made by many market participants, including exploration and production resource companies, power station operators, network providers, as well as building owners and developers. But crucially these decisions about the energy transition are informed by supply and demand - including the influence of incentives which have been laid out by governments to meet policy objectives on energy, air quality and economic growth.

To make sure the right objectives are being set, governments and businesses need to have detailed and reliable evidence of what can be achieved in terms of this fundamental change to the way we operate and live. Questions, such as which new technologies need to be nurtured and what the impact on the energy system will be, need to be addressed.

The electrification of heat is often used as the broader term to describe the rapid and large-scale switching of residential heating using (mainly) gas boilers to (mostly) heat pumps powered by electricity. Although we need to decarbonise heating in order to achieve society's Net Zero hopes, this brings with it challenges for the energy system – especially for power generation and the electricity grid.

To be able to look at this complex puzzle holistically, Dr Pudjianto has developed an Integrated Whole Energy System model, which analyses the UK energy system and cost implications of various decarbonisation options. In this paper they apply this to model the value of advanced heat pump technologies, analysing the benefits in systems with different levels of heat electrification.

Whole system modelling is crucial for capturing time and location interactions in low carbon systems, delivering the least cost system whilst meeting the carbon target and maintaining system security. This whole-system approach has been used in studies commissioned by many organisations, including EU DG Energy, the Climate Change Committee, and the Carbon Trust.

Refrigerants are a critical component of a heat pump and are the driving force behind the system's energy efficiency, cost and sustainability. The Coefficient of Performance (COP) will differ depending upon the refrigerant that is used in each heat pump design and application.

Even relatively small improvements in heat pump efficiency can reduce the annual and peak electricity demand resulting in less energy system infrastructure and operation costs, reducing residual carbon emissions and offsetting costs. In this report we compare the energy efficiency of upgraded HFO and Propane heat pump systems to assess the COP delivered by each technology across a range of ambient temperatures.

EXECUTIVE SUMMARY

- A range of technologies will be required to achieve the ambitious targets set out in **REpowerEU** and to **accelerate Europe's journey to net zero.**

- Heating and cooling of buildings across the EU accounts for **40% of energy usage** and **36% of carbon emissions.**

- Heat pumps are on average **three times more efficient than traditional fossil fuel boilers** – helping to reduce fossil fuel use, improve air quality and create millions of new jobs. In addition, heat pumps could help to save up to 30% to 40% on a household's energy costs by 2030.

- Achieving these targets, however, means **having the right heat pump technology available for each building type.** This is often a function of the refrigerant used in the heat pump.

- Heat pumps using fluorinated gas-based refrigerants such as **Hydrofluoroolefins (HFOs) are the preferred solution for deployment in buildings such as large apartment blocks,** which make up the majority of homes across Europe. Alternative heat pump technologies, for instance those relying on **propane or ammonia are often unsuitable on safety or efficiency grounds or due to space constraints** which are a challenge of installing heat pumps in areas of high residential unit density.

- Ensuring the availability of suitable heat pumps to meet the differing needs of EU homeowners and businesses, depending on their location and building type, is important both to maximise the cost, energy and emissions reductions from those dwellings and workplaces but also in terms of the aggregate effect on the energy system.

- Even **relatively small improvements in heat pump efficiency can reduce the annual and peak electricity demand** resulting in less energy system infrastructure and operation costs, reducing residual carbon emissions and offsetting costs.

- HFO refrigerants are a critical part of heat pump technology and offer practical, flexible solutions across most property types, in both indoor and outdoor applications. HFO heat pumps have **higher energy efficiency, lower total cost and are safer for use,** especially in densely urbanized areas or buildings.

- If similar energy and cost savings from mass deployment of heat pumps to those modelled by Dr Pudjianto were realised across Europe, it could result in **billions of euros in cost savings,** enhancing Europe's ability to reach its 2030 and ultimately 2050 decarbonisation targets.

THE ROLE OF HEAT PUMPS IN DELIVERING ENERGY TRANSITION

Rapid heat pump deployment is key to REPowerEU, the European Commission's plan to rapidly make Europe independent from Russian fossil fuels well before 2030. The strategy seeks to diversify energy supplies, boost renewable energy and enhance energy savings. Europe has a target of delivering 60 million heat pumps by 2030 and the UK is seeking to install 600,000 heat pumps every year from 2028. Rapid Heat Pump deployment by 2030 also helps build the momentum required to achieve our region's 2050 Net Zero ambition, because nearly 50% of Europe's Final Energy Demand is used for Heating.

This will require a significant acceleration of the pace of installation of heat pumps, however. At the end of 2022 there were 19.9 million heat pumps installed across the EU. The 60 million target set out in REPowerEU translates to 6 million installations each year across the region, double the number installed in 2022.

A key area of focus is tackling the energy requirements of over 131 million European homes and buildings. Homes and Buildings across Europe are responsible for around 40% of energy consumption and 36% of greenhouse gas emissions.

3x heat pumps are on average three times more efficient than traditional fossil fuel boilers.

The heat pump sector is the biggest positive contributor to the increase in renewable energy production for heating and cooling across Europe, with heat pumps being on average three times more efficient than traditional fossil fuel boilers – helping to reduce fossil fuel use, improve air quality and create millions of new jobs. In addition, heat pumps could help to save up to 30% to 40% on a household's energy costs by 2030 (Keeping Heat Pumps Rolling [7]).

Achieving these objectives and realising the potential cost savings, energy efficiency and emissions reductions is a complex and large-scale undertaking. It involves not only the installation of heat pumps as standard across all new builds, but a massive retrofitting programme across Europe. As indicated, buildings account for 36% of the EU's total carbon dioxide (CO2) emissions and three quarters of the existing building stock will still be with us by 2050. (https://www.bpie.eu/wp-content/uploads/2022/12/How-to-stay-warm-and-save-energy_final-report.pdf)

These buildings literally come in all shapes and sizes and their locations range from semi-detached houses in regions with milder weather, such as Ireland, to apartment blocks in hotter regions such as southern Spain or Italy.

The energy usage patterns, building risk assessments and even the difference in the amount of space available in which to install a heat pump all needs to be considered when determining the appropriate solution. Regional variations in planning regulations also need to be factored in.

These criteria have important implications for the technology that can be deployed and will determine which is the most suitable type of refrigerant to be used in the heat pump required for each dwelling.

Apartments make up 46% of residential units in the EU, for instance. In many cases the lack of outdoor space and stricter safety requirements, given part of the system will need to be inside the apartment itself, could rule out the use of certain refrigerants.

SYSTEM-WIDE COST BENEFITS OF HEAT PUMP TECHNOLOGIES – ANALYSIS BY IMPERIAL'S DR PUDJIANTO

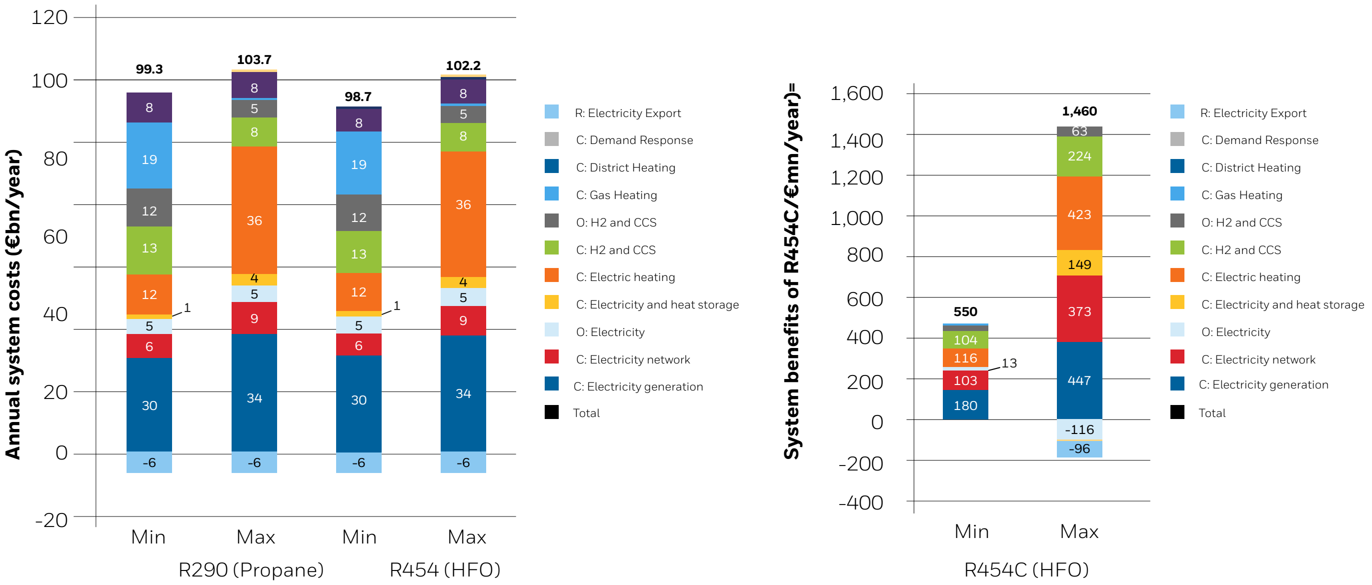
For the analysis, the Integrated Whole System Approach was used to model the value of advanced heat pump technologies, analysing the benefits in systems with different levels of heat electrification. Two extreme scenarios are used: (i) deep electrification, where most of the heat demand is decarbonised through electrification, and (ii) hydrogen for heating, where on-gas grid customers will keep using gas (hydrogen) heating – this will be around 20M domestic customers while other customers will be supplied by electric heating and district heating.

Even relatively small Improvements in heat pump efficiency can reduce the annual and peak electricity demand resulting in less energy system infrastructure and operation costs, reducing residual carbon emissions and offsetting costs. Dr Pudjianto estimates that in the UK's relatively mild climate just a 3.5% difference in the efficiency of the Air-to-Water Heat Pumps deployed to replace gas boilers has a cost implication of:

- **€180M – €448M** per year for the additional electricity generating assets required to be added to the UK energy system
- **€100M – €374M** per year worth of extra investment needed in the electricity distribution network
- **Up to €572M** per year for the increased heating appliance capacities required
- **€51M – €302M** per year additional hydrogen production and storage investment

The figures above are the savings obtained by using HFO instead of propane (R290).

In total this has a financial implication of ~€584M/year for the future UK energy system in even a Hydrogen Heating scenario. In a deep electrification scenario – which many commentators deem more plausible due to the pressing need for hydrogen in more hard-to-abate sectors than residential heating – there is a financial implication of **€1.4B/Year** (Pudjianto, D. [8]).



Whole system benefit of R454C: 0.6 – 1.4 €bn/year

* Benefits relative to the results of R290 (Propane)

Fig.1 UK Annual Costs and System Benefits of R454C based heat pumps with a 3.5% energy efficiency advantage over R290 based heat pumps.

For the private sector, its share of the €1.4B/Year is opportunity lost for investment in further sustainability and decarbonisation projects; and for the public sector, its share of the €1.4B/Year is money that could be spent on other priorities, such as fuel poverty or education.

Across Europe, gas infrastructure is less embedded than in the UK, making the deep electrification scenario even more likely. If these heat pump efficiency implications are further multiplied across the 27 EU nations, this will likely have a multi-billion Euro impact on Europe’s ability to reach its 2030 and ultimately 2050 decarbonisation targets.

THE ROLE OF REFRIGERANT TECHNOLOGY

Fluorinated gases such as Hydrofluoroolefins (HFOs) are widely used in electrified applications such as air conditioning, commercial fridges, freezers and refrigerated transportation. These F-Gases, as they are known, are often the refrigerant of choice because low Global Warming Potential HFOs, frequently achieve a much greater cooling capacity while using less energy than alternatives such as ammonia, Propane and CO2.

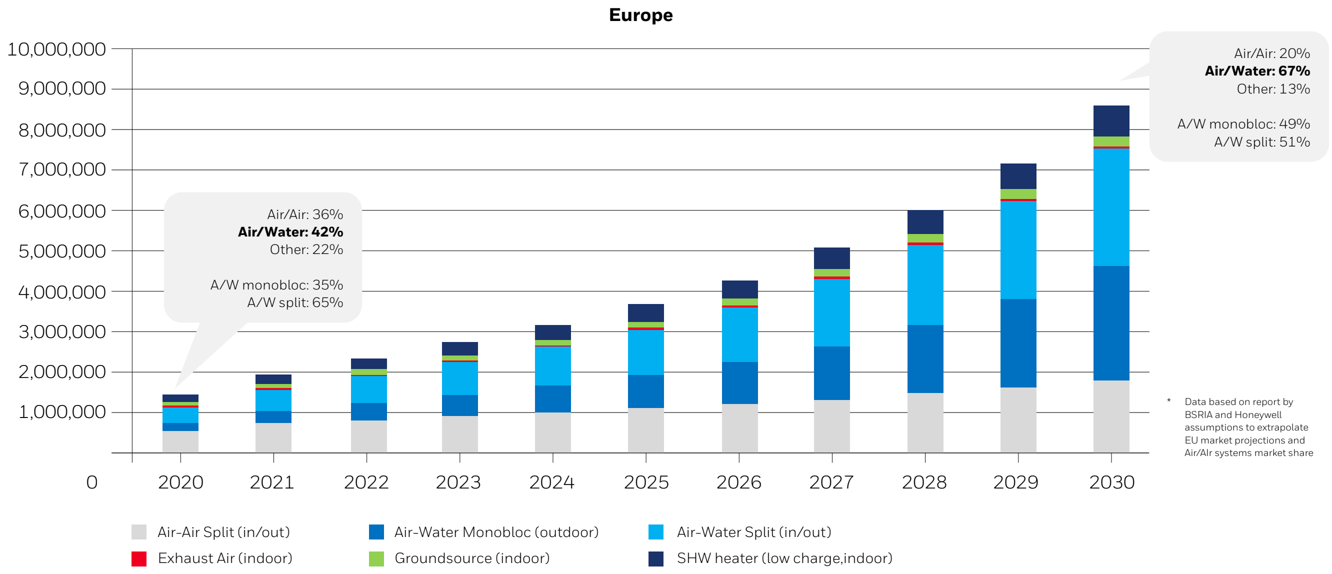
HFOs have proven, in some instances, to be the only viable option in situations where other alternatives – such as propane, ammonia or CO2-based solutions – were unsuitable on grounds of safety, emissions, noise or energy use. This is an important point as these alternatives, which are often described as “natural refrigerants” are the only available alternatives to HFOs.

Unlike alternatives, HFO refrigerants offer solutions across most heat pump applications, property types and system sizes – from residential and district heating, to commercial and industrial and can be used in both indoor and outdoor applications. HFOs have higher energy efficiency, lower total cost of ownership and are safe for use in heat pumps, even in densely urbanized areas or buildings.

Similarly, the use of HFO heat pumps supports the green energy transition by reducing the reliance on fossil fuel heating systems, which is a core pillar of REPowerEU, the European Commission’s plan to rapidly make Europe independent from Russian fossil fuels well before 2030.

In contrast, propane requires ongoing dependence upon oil & gas production, which is contrary to REPowerEU goals and aspirations. Similarly, one unit of electricity used by a heat pump delivers three to five units of heat on average over the heating session. By recovering industrial waste heat, HFO heat pumps can also create district heating networks for towns and cities with lower carbon footprints. All of these elements have the potential to drastically transform the broader energy system.

For easier integration into hydronic heating systems, particularly as the renovation market grows to replace boilers, many residential heat pumps will be Air-to-Water systems. By 2030, Air-to-Water heat pumps may account for 67% of the residential market. Over 50% of the market may also be split system types, requiring refrigerant to flow inside of the residential building.



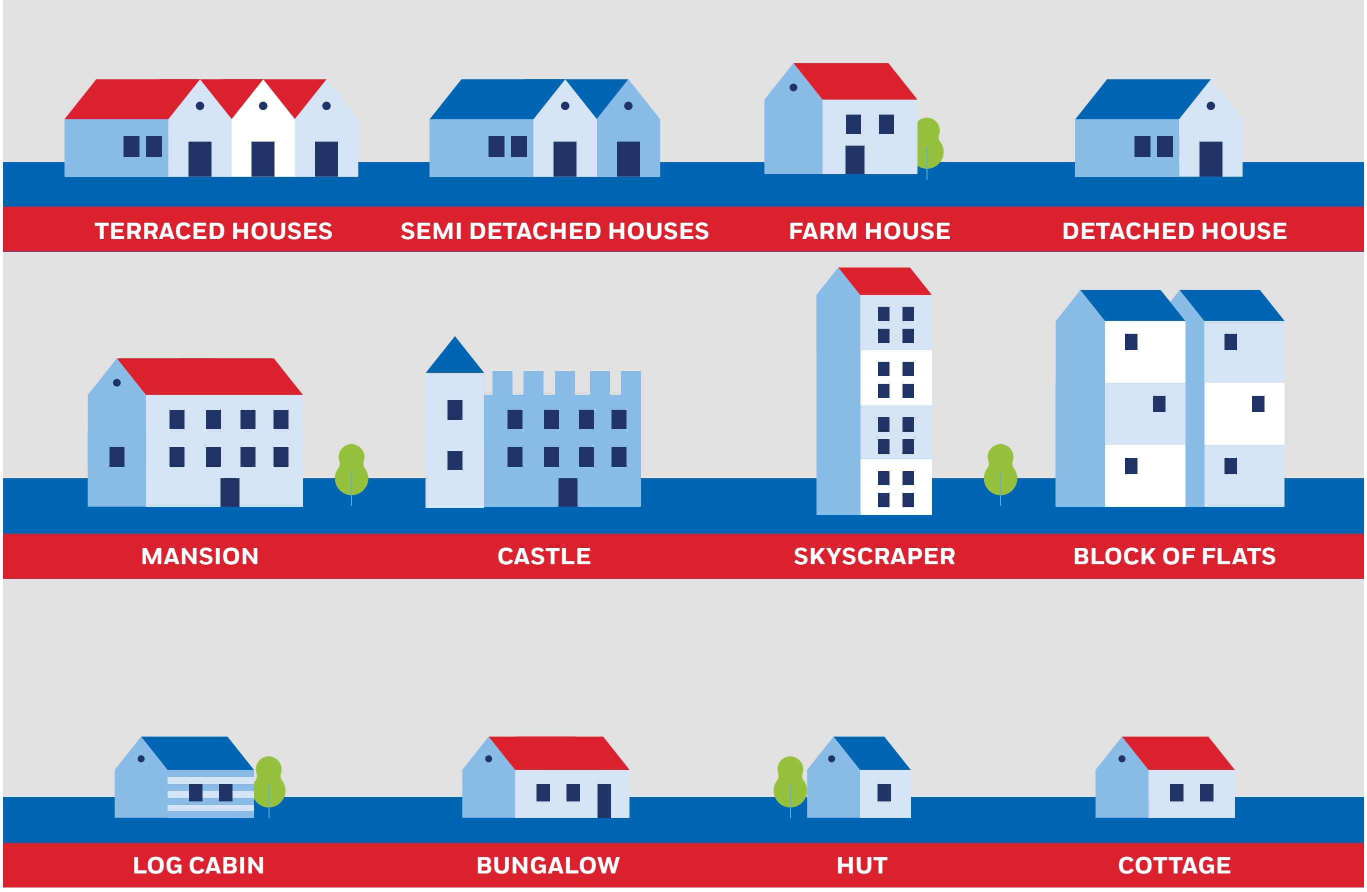
* Data based on report by BSRIA and Honeywell assumptions to extrapolate EU market projections and Air/AIr systems market share

Fig.2 Estimated European Heat Pump market growth by type

The role of HFOs

HFO refrigerants are a critical part of heat pump technology, and offer practical, flexible solutions across most property types, in both indoor and outdoor applications. HFO heat pumps have higher energy efficiency, lower total cost and are safer for use, especially in densely urbanized areas or buildings.

Types of Houses



This kind of application becomes clear in a market like Spain where around 65% of housing stock are high rise and small apartments. In such applications alternative refrigerant use, such as highly explosive propane (R290), will most likely not be possible in many cases, due to equipment standard limitation of the installation capacity for indoor use or local risk assessment requirements. Highly flammable refrigerants such as propane are classed by the industry ASHRAE standard as A3, whereas as mildly flammable HFOs are classed as A2L. A2L refrigerants are less likely to form flammable concentrations due to their better Lower Flammability Limits; A2L refrigerants are harder to ignite, because they require a higher ignition energy; A2Ls have less severe ignition events, because they are less reactive and have a lower combustion energy – thus there is intrinsically a three-layer safety mechanism with A2L HFO refrigerants.

HFO versatility also makes them a critical factor for developing the next generation of even more energy efficient heat pumps – because they are engineered solutions, HFOs have a unique scope for optimising heat pump technology, providing lower cost heat pump solutions for end customers.

Without HFO heat pumps, heat pump options will be limited and the rate of roll out too slow, significantly impacting the EU's goal to decarbonize 40% of residential buildings by 2030 (Keeping Heat Pumps Rolling [7]).

COMPARING ENERGY EFFICIENCY OF UPGRADED HFO AND PROPANE HEAT PUMP SYSTEMS

The use of some HFO refrigerants in residential and commercial heat pump systems may require redesigns to achieve comparable performance to an R32 system. Due to lower capacities and refrigerant glide the heat exchanger should be properly designed to mitigate these losses. The Whole Energy System analysis earlier compared the heat pump performance of HFO blend R454C and R290 (propane). Honeywell offers HFO refrigerants, such as R1234yf, R454C, R455A, R471A and R1234ze(E), for residential and commercial heating that can provide different benefits and are suitable for a variety of application requirements

Thermodynamic cycle comparisons

To evaluate the potential of R454C, R455A and R1234yf in a heat pump system a thermodynamic cycle comparison was made using the conditions shown in Table 1. This cycle assumes the use of a suction-line – liquid line heat exchanger (SLHX) and liquid receiver for the HFO refrigerants as it has been observed that they may benefit from both the further subcooling provided by this component and the possibility of operating with a flooded evaporator which can decrease the likelihood of pinching. R410A, R32 and R290 use a basic cycle (compressor, condenser, expansion device, evaporator).

The cycle assumes an air to water heat pump (AWHP) system with a condenser refrigerant dew temperature of 56°C, except for R455A where the bubble temperature of 50°C was used to maintain at least 3 K at the condenser outlet and make it like R454C, which has a bubble temperature of 49.9°C. Because zeotropic refrigerants can benefit from matching the glide with the water temperature lift their pinching is mostly dependent on the bubble temperature, while azeotropic refrigerants can pinch on the saturated vapor point for a counterflow arrangement. The cycles also have an evaporator outlet temperature of 5°C with a compressor suction superheat of 5 K. These cycle parameters are assumed for an operating condition of A7W55 based on EN14511 [1] to guarantee no pinching in either heat exchanger. Pressure drops and heat losses are neglected in this analysis.

Table 1 Residential and commercial heat pump thermodynamic cycle conditions

PARAMETER	VALUE
Compressor suction superheat	5 K
SLHX effectiveness (HFO blends)	0.325
Compressor isentropic efficiency	0.70
Compressor volumetric efficiency	0.95
Condenser dew temperature (except R455A)	56°C
Condenser bubble temperature (R455A)	50°C
Condenser outlet subcooling (HFO blends)	0 K
Condenser outlet subcooling (other)	5 K
Condenser capacity	8 kW
Evaporator outlet temperature	5°C

These cycle assumptions should provide an optimal comparison between the refrigerants operating in an AWHP. The resulting performance comparison is shown in Table 3. Using R410A as a baseline if the systems are properly optimized for R454C and R455A it should be possible to match or exceed the performance of R410A. Due to the greater compressor displacement required for R454C and R455A a redesigned compressor would be beneficial to provide good isentropic efficiencies when operating under a range of heating conditions. Heat exchangers may also need larger surface areas and optimal circuitry to minimize pressure drop and pinching from glide. An optimally designed brazed-plate heat exchanger could be used for the SLHX which should allow operating with a flooded evaporator reducing the negative effects of pinching due to the positive refrigerant temperature increase caused by its glide.

Table 2 also shows the main issue with R32 heat pump systems: its high discharge temperature which require an unconventional discharge superheat expansion device control or implementing a vapor injection cycle. Also due to its GWP of 675 R32 will eventually be phased out for most heat pump applications.

Table 2 Residential and commercial heat pump thermodynamic cycle performance comparison

Refrig.	GWP (Flamm.)	COP_n	v_d	$P_{ratio.n}$	m_n	T_{disc}
	(-)	(%)	(%)	(%)	(%)	(°C)
R410A		100.0	100.0	100.0	100.0	99.3
R32	675 (A2L)	103.7	88.7	100.7	64.1	125.8
R454C	146 (A2L)	110.2	147.7	90.2	120.1	78.6
R455A	146 (A2L)	112.3	138.4	89.2	115.6	80.1
R1234yf	1 (A2L)	102.7	250.7	107.9	146.2	67.6
R290	4 (A3)	106.2	171.8	93.4	58.9	79.3

Refrig.: Refrigerant name

GWP(Flamm.): Global Warming Potential and Toxicity/Flammability Classification

COP_n: Coefficient of Performance

v_d: Displacement Volume

$P_{ratio.n}$: Pressure Ratio

m_n: Mass Flow Rate

T_{disc}: Discharge Temperature

Evaporator improvements example for R455A

Some redesign on the evaporator to compensate for the glide from this refrigerant as shown in figure 1 can enhance the performance of R455A in heat pump applications. Assuming R455A has a dew temperature of 4°C, at constant pressure its respective bubble temperature is -7.95°C, yielding a glide of 11.95°C. Due to the glide if the outside air was 7°C this refrigerant would need lower average evaporation temperatures than 4°C to be able to absorb heat from the air throughout the evaporator and provide 3°C of superheat. On the other hand, azeotropic refrigerants could be exactly at an evaporation temperature of 4°C with outlet superheat of 3°C.

The main concern with regards to glide and evaporator design is that the flow orientations have a greater performance impact for zeotropic refrigerants. Because the evaporation temperature rises with quality these zeotropic blends can benefit from a cross-counter flow as shown by the air temperature example in figure 1. This configuration mitigates pinching on the evaporator and guarantees a more uniform temperature gradient between air and refrigerant.

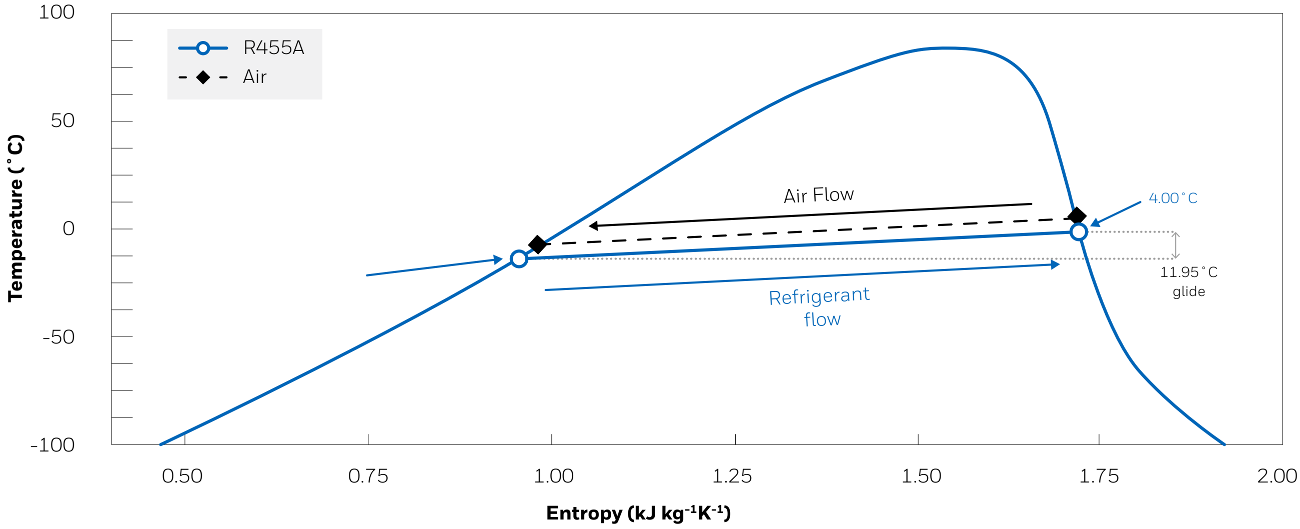


Fig.2 T-s diagram of R455A showing glide at a fixed dew temperature of 4°C

To model and design the evaporator a proprietary software was used (GenesymTM [2]). Refrigerant thermophysical properties are calculated with REFPROP v9.1 [3] (Lemmon et al., 2013) using modified mixture interaction parameters for R455A.

The EN14511-1:2022 [1] rating condition A7W35 was used to evaluate the different coils with a fixed face velocity of 1.0 m/s at 101.3 kPa. The dehumidification process was accounted for by using an enthalpy gradient-based heat transfer calculation with wet fin enhanced effectiveness. The refrigerant inlet enthalpy was defined based on a condenser outlet at 1.6 MPa and 31°C, which equates to a dew temperature of 41°C for R455A, while the baseline R410A system used a saturation temperature of 40°C. The refrigerant outlet superheat as 3.0°C for the R410A baseline. The R455A system performance calculations assumed a SLHX with effectiveness of 32.5%, a value that was estimated based on experimental measurements for an off-the-shelf system. The optimization was performed with fixed heat exchanger height, fins, and tube geometries. The heat exchangers tubes per row, row number and circuitry were the focus of this optimization. To estimate the effect on performance of the evaporator a fixed isentropic efficiency of 70% was used to calculate the compressor power and the losses on connecting lines and heat transfer on the compressor shell were neglected. Capacity was calculated as the sum of evaporator capacity and compressor power with the mass flow rate adjusted to fix it at 8 kW.

Table 3 shows the optimal design for the evaporator with R455A (Fig. 4) compared with the baseline R410A design (Figure 3). To achieve 4.6% COP improvement over the R410A baseline using the following modifications were done to the evaporator: the number of rows was increased to 3 which increased the benefits of a counterflow configuration, the number of circuits was increased to 8 to mitigate the greater pressure drop, the number of tubes per row was increased to 32 to allow for an equal number of tubes per circuit and the evaporator superheat was decreased to 0 K assuming the SLHX would guarantee the superheat required to allow a safe compressor operation and since zeotropic blends benefit from lower superheat as it reduces pinching effects. The overall heat transfer area was increased by approximately 60% over the baseline R410A evaporator.

The biggest incremental improvement came from switching to a counterflow configuration over parallel flow (+3.2% increase in COP). Further details on how the model optimization was done can be found in Carvalho et al. [4].

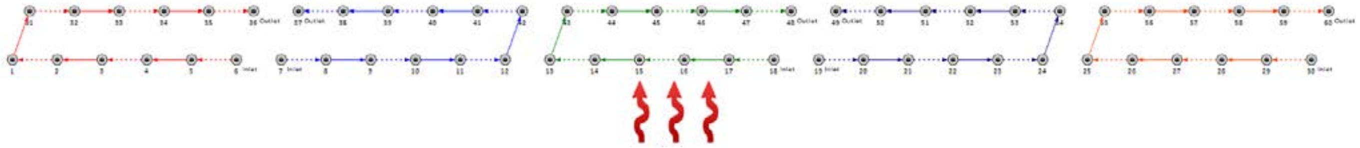


Fig.3 Baseline R410A evaporator coil

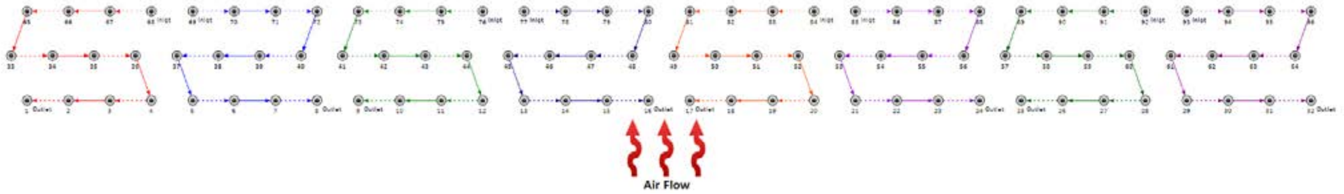


Fig.4 Optimized R455A evaporator coil

Table 3 Evaporator optimization results

Refrigerant		R410A	R455A
Flow config.	[m]	PF	CF
Tubes per row	[-]	30	32
Number of rows	[-]	2	3
Circuits	[-]	5	8
Evaporator superheat	[°C]	3	1
COP	[%]	100.0	104.6
Compressor power	[%]	100	95.6
Mass flow rate	[%]	100.0	108.5
Average sat. temperature	[°C]	1.39	1.07
Refrigerant pressure drop	[kPa]	34.3	20.9
Dew temperature drop	[°C]	1.3	1.1
Average effective glide	[°C]	0.08	7.22
Air side pressure drop	[Pa]	20.2	30.3

This brief analysis on the use HFO refrigerants in the commercial and residential heat pump applications show that adoption of these fluids over R410A or R32 may require redesigns on a component and system level to achieve comparable performance.

AWHP model comparison between R454C, R1234yf and R290 upgraded systems

Air to water heat pump (AWHP) applications represent a significant share of the European residential heating market thus to better understand the importance of R454C as a refrigerant for these systems a model comparison was performed using VapCyc and CoilDesigner software by CEEE from the University of Maryland [5,6]. These software tools allowed for the optimization of the outdoor coils while using the same compressor isentropic/volumetric efficiencies and the same geometry of a concentric tube refrigerant-water heat exchanger that was calibrated to match the performance of brazed plate heat exchangers currently used in AWHP. The models were initially calibrated against catalogue data from heat pump manufacturers and the outdoor coils were upgraded to achieve the best performance. Table 4 shows the main parameters used in this analysis.

Table 4 AWHP system model parameters for a comparison between R454C, R1234yf and R290

Parameter	Value
Compressor suction superheat	5 K
SLHX effectiveness (R454C and R1234yf)	0.325
Compressor isentropic efficiency	0.67-0.70
Compressor volumetric efficiency	0.95
Residence heating load curve	10 kW @ -15°C, 0 kW @ 16°C
Domestic hot water load	2.5 kW
Condenser outlet subcooling (R454C and R1234yf)	0 K
Condenser outlet subcooling (R290)	5 K
Condenser heat transfer area	1.8 m2
Evaporator outlet temperature	5°C

The same compressor efficiency curves were used for all three refrigerants assuming a properly optimized compressor geometry and the compressor speeds were allowed to be controlled between 30 and 120 Hz to match the heating demand. A linear heating load was assumed with 10 kW at -15°C and 0 kW at 16°C, additionally above 16°C a constant domestic hot water heating load of 2.5 kW was defined. The models simulated the systems as the outdoor air temperature varied from -15°C up to 40°C and calculated the delivered capacities and the resulting COP. The R454C system makes use of a receiver and suction line-liquid line heat exchanger to use its refrigerant glide in its favour by shifting the subcooling out of the condenser and the higher temperature evaporation out of its evaporator. This allows for further improvements in performance for refrigerants with glide, such as R454C and R455A. This cycle architecture was also implemented with R1234yf, but its benefit is not as significant. R290 system may make use of such cycle, although this has not been observed in systems on the market and safe charge limitations due to high flammability prevent the use of certain components with propane.

Figure 5 shows the resulting COP values for the three systems evaluated in the model. Across all ambient temperature ranges both R454C and R1234yf systems can outperform the R290 system, especially for lower load conditions and domestic hot water heating. The overall average improvement in efficiency of R454C and R1234yf over R290 was 8.7% and 8.9%, respectively. These model predictions indicate that both R454C and R1234yf if used with properly designed systems may outperform propane in AWHP applications. The use of more sophisticated cycle architectures and component improvements without the same stringent refrigerant charge restrictions than R290 could lead to even greater performance for HFO refrigerants.

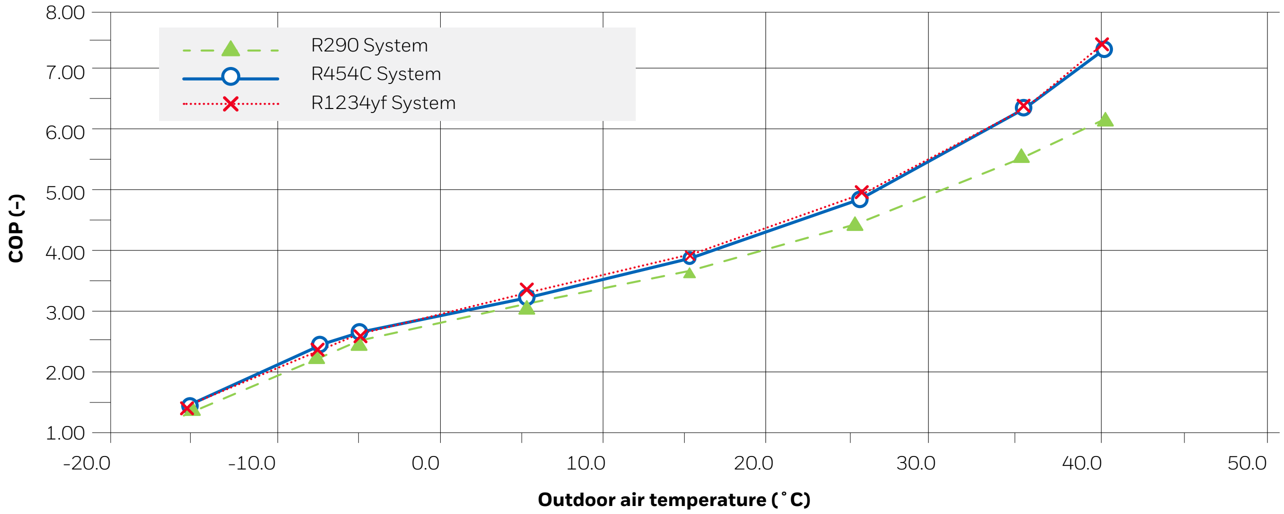


Fig.5 AWHP COP of R454C, R1234yf and R290 systems

REGULATORY LANDSCAPE

1. Revised EU F-Gas proposal – Outcome allows European businesses to choose the right refrigerant to suit their needs

On October 5th, 2023, the European Union provisionally agreed on the revision of the existing F-Gas Regulation No. 517/2014. This law covers the placing on the market and export of F-gases and equipment containing F-gases.

At its core is containment (the prevention of emissions of F-gases from existing equipment) by requiring checks, proper servicing, and recovery of the gases at the end of the equipment's life. The Regulation also set specific targets to reduce the use of HFCs (Hydrofluorocarbons) across Europe and to thereby contribute to overall lower emissions. The Regulation will now be finalised and voted on by the European Parliament and Council in the coming months.

> **"HFOs were 'purpose built' to facilitate emissions reductions as they require less energy compared to alternative solutions such as those based on CO^2, hydrocarbons or ammonia."**

The read from Honeywell's perspective to the outcome of this agreed proposal is a largely positive one as the limited number of full F-gases bans included are conditional on safety requirements and a review of these bans. The feasibility of the phase out for the consumption of HFCs to zero in 2050 will also be subject of a review in 2040.

The European Union has not agreed to ban all F-gases immediately or without due caution.

Rather, the EU has set ambitious targets to reduce the use of HFCs across Europe and to prompt businesses to turn to lower emission F-gases, in a realistic and practical manner with proposed phase downs over a long timeframe.

The GWP limitations for residential applications are as follows:

- All Monoblocs: <150GWP from 2027
- Single Split <3kg: <750GWP from 2025
- Split A-W <12kw: <150GWP from 2027
- Split A-A <12kw: <150GWP from 2029
- Split >12kw: <750GWP from 2029

The agreed potential full F-Gas bans have significant conditions attached.

These include a built-in review by 2030 to evaluate the availability, energy efficiency, cost, safety, and reliability of potential alternatives. This review will include an assessment as to whether bans can be applied to certain applications. Most of the bans also include the language 'except when required to meet safety requirements, enabling exemptions where they do not.'

Honeywell has been progressively adapting its portfolio to market needs regulatory trends, so we are well placed to comply with and support our customers' ability to comply with this latest revision – Honeywell offers the largest portfolio of sustainable <150 GWP HFO refrigerants for Residential Heating.

Furthermore, we plan to keep on working to show that HFOs are the best solution to deliver climate neutral and energy efficient benefits in applications such as chillers, air conditioning units, heat pumps and mobile air-conditioning. HFOs were 'purpose built' to facilitate emissions reductions as they require less energy compared to alternative solutions such as those based on CO2, hydrocarbons or ammonia.

2. PFAS restriction proposal – science supports HFO exclusion from scope

Why HFOs should be excluded from PFAS restrictions

The European Chemicals Agency (ECHA) are considering a proposal for a broad restriction of around 10,000, so called PFAS substances. HFOs are only included in this proposal purely because of their chemical structure - they do not meet the primary criteria for restriction and should be excluded from scope.

What are PFAS?

PFAS are a very large and very diverse family of chemicals. The Organisation for Economic Cooperation and Development (OECD) currently defines about 10,000 materials as PFAS – but concludes that its own definition and the term PFAS "is broad, general and non-specific and does not inform whether a compound is harmful and is not a basis for regulation."

The use of PFAS are indispensable in important sectors such as automotive and aerospace, as well as for critical healthcare applications such as medical devices and pharmaceutical packaging. In addition, some PFAS are demonstrably contributing to tackling some of the world's biggest challenges – such as the fight against climate change and are contributing positively towards the EU's goals of decarbonisation, as set out by the EU Green Deal, and REPowerEU by improving energy efficiency.

Science, facts and evidence support HFOs exclusion from restriction

HFOs are included in this proposal purely because of their chemical structure. They do not meet the primary criteria for restriction, as they are not persistent, not bio-accumulative and are not toxic; so, they should be excluded from scope. Key facts to support this include:

- **They are not PERSISTENT.** They break down in the atmosphere within 15 days and do not persist in the environment.
- **They are not BIOACCUMULATIVE.** They are not retained for long periods in the human body or other biological systems.
- **They are not TOXIC.** They are not considered toxic according to The European Chemicals Agency (ECHA) guidelines.
- **HFOs have LOW GLOBAL WARMING POTENTIAL** (<1) and are an important technology in the fight against climate change.
- HFOs are **SAFER IN USE** than many of the alternative solutions such as hydrocarbons, ammonia and carbon dioxide due to their low flammability, low toxicity and lower operating pressures.
- HFOs provide **LOWER ENERGY CONSUMPTION** than alternatives in many systems. This ultimately leads to lower overall emissions. Their continued use is critical to achieve REPowerEU and other decarbonisation goals.

HFOS & TFA – Health and environmental claims v scientific fact

HFOs are designed to be a safe, transformative and indispensable technology which help tackle some of the EU's biggest climate, energy and economic challenges – enabling businesses, communities and people to thrive. Claims that HFOs are harmful, as per the ECHA proposal, because they degrade into Trifluoroacetic (TFA), are contradicted by scientific analysis and fact.

While TFA salt can enter the environment as a breakdown product of some HFOs – the amounts are well below the threshold for concern with respect to human and environmental health according to UNEP.

Trifluoroacetic acid (TFA) salt is a naturally occurring substance, which has been present in our environment for thousands of years with no indication of impact on human health. TFA can be formed as a breakdown product of some HFOs, the yield of which varies by specific HFO compound – with some only producing a very small amount of TFA.

HFOS ARE SAFE WITH NO HEALTH AND ENVIRONMENTAL IMPACT, ACCORDING TO EUROPEAN CHEMICALS AGENCY (ECHA) GUIDELINES

- HFOs are safe for intended use, enable greater energy efficiency than the refrigerants they replace, are non-persistent and have low Global Warming Potential (GWP).
- They are used in closed loop systems with little to no consumer exposure.
- They offer direct and indirect energy efficiency benefits for a variety of commercial cooling and heating applications in buildings, supermarkets and vehicles.
- TFA is formed in the atmospheric degradation processes for some HFC and HFO fluorinated gases.
- According to UNEP "TFA has biological properties that differ significantly from the longer chain PFAS and inclusion of TFA in this larger group of chemicals for regulation would not have any scientific justification, based on the risk assessment of TFA."
- For most HFC/HFO refrigerants, degradation yields into TFA are small, resulting in small increases in overall TFA concentrations by comparison with pre-existing TFA levels.
- Only a few commercialized fluorinated gases decompose into fractions of TFA over 30% (including, HFO-1234yf, HFC-227ea, HFC-134a).
- In 2000, the concentration of TFA in the world's oceans stood at two one hundred millionths of one per cent (0.00000002%). If HFOs were fully adopted across all applications, the maximum concentration of TFA would reach just 0.000000025% by 2100.

TFA HAS BEEN PRESENT IN THE ENVIRONMENT FOR THOUSANDS OF YEARS WITH NO INDICATION OF IMPACT ON HUMAN HEALTH

- There is evidence that the quantity of TFA measured in the oceans are mostly of natural origin.
- Manmade sources of TFA come from various industries: pharma, pesticides, herbicides, intentional production (as a reagent in analytical chemistry such as COVID-19 testing) or fluorocarbons.
- TFA is not classified as a carcinogen, mutagen or repro- developmental toxicant per the Globally Harmonized System of Classification and Labelling of Chemicals (GHS) guideline.
- Per the recent peer-reviewed publication, the human health risk of TFA from drinking water or food is negligible.
- The European Food Safety Authority (EFSA) has assessed the human health risks from exposure to TFA arising from pesticide applications. They identified no concerns.

Current levels of TFA in the rainwater in Germany are 26 times lower than the German Environment Agency's (UBA) health-based target level.

CONCLUSION

- Even relatively small Improvements in heat pump efficiency can reduce the annual and peak electricity demand resulting in less energy system infrastructure and operation costs.
- Equipment standard limitation of the installation capacity for indoor use and local risk assessment requirements means the technical feasibility of HFO refrigerants are needed to help decarbonise residential heating.
- The use of some HFO refrigerants in residential and commercial heat pump systems may require redesigns to achieve comparable performance to an R32 system.
- Some redesign on the evaporator to compensate for the glide from the refrigerant can enhance the performance of HFO blends in heat pump applications.
- HFO blends can also make use of a liquid receiver and suction line-liquid line heat exchanger to use refrigerant glide in their favour by shifting the subcooling out of the condenser and the higher temperature evaporation out of the evaporator. This allows for further improvements in performance for refrigerants with glide, such as R454C and R455A.
- The model predictions indicate that R454C (and R455A) and R1234yf if used with properly designed systems can outperform propane in AWHP applications.
- Aligned with the GWP limitations in the proposed EU F-gas revision, Honeywell offers the largest portfolio of sustainable <150 GWP HFO refrigerants for Residential Heating. With a view to the impact assessment by 2030 to assess any proposed bans, Honeywell will continue to invest in HFO technologies and advocate for the benefits HFOs bring to society and to European climate goals.
- Science supports the argument that HFOs should be outside the scope of EU PFAS restriction, and Honeywell is submitting evidence and data to support this.

For more information:
https://hwll.co/m1wt7vwf

Solstice® HFO Refrigerants:
https://hwll.co/gqu4f77n

REFERENCES

1. Danish Standards Association, 2022. Test methods and standards for air conditioners, liquid chilling packages and heat pumps (EN 14511-2:2022/09).
2. Genesym [Computer software]. (2022). Honeywell International.
3. Lemmon E.W., Huber, M.L., McLinden, M.O., 2013. NIST Reference fluid thermodynamic and transport properties - REFPROP 9.1, NIST Standard Database 23.
4. de Carvalho, B. Y. K., Sethi, A., Hulse, R.., 2023. Low GWP Refrigerants for Residential Heat Pump Applications: Evaporator Optimization and Cycle Improvements. Proceedings of the 26th International Congress of Refrigeration, Paris, France
5. Vapcyc [Computer software]. (2023). Refrieved from: https://ceee.umd.edu/software/vapcyc
6. CoilDesigner [Computer software]. (2023). Refrieved from: https://ceee.umd.edu/software/coildesigner
7. Keeping Heat Pumps Rolling [Factsheet]. (2023). Honeywell International.
8. Pudjianto, D., 2023. Value of Advanced Heat Pump Technologies in the Future UK Energy System. Imperial College London's Dr Danny Pudjianto worked on this project on an independent basis via Imperial Consultants.
9. Zhao, K., Vijayaraghavan, K., Downes, R., Cush, M., Zhuang, Y., Connolly, R., Shi, S., Kristanovich, F., Gupta, J., 2023. ENVIRONMENTAL MODELING OF TRIFLUOROACETIC ACID (TFA) ORIGINATING FROM HYDROFLUOROLEFINS. Ramboll.

Honeywell