Heat Pumping Technologies

MAGAZINE

Heat Pumps Revolutionizing Retrofits: Scaling Up Deployment with Innovative Solutions and Overcoming Barriers

Vol.42 Issue 3/2024
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In this Issue

Welcome to Issue 3 of Heat Pumping Technologies Magazine!

In this third edition, we dive into a transformative and highly relevant theme: **"Heat Pumps Revolutionizing Retrofits: Scaling Up Deployment with Innovative Solutions and Overcoming Barriers."** This issue focuses on the pivotal role heat pumps play in retrofitting existing buildings, accelerating the transition to sustainable heating systems, and breaking through the challenges that still hinder widespread adoption.

From cutting-edge technologies to strategic integration and policy insights, this issue is packed with invaluable perspectives for industry professionals, policymakers, researchers, and enthusiasts alike.

We kick off with the **Foreword**, titled **“Scaling up heat pump retrofits: what do we need to do,”** which sets the stage for actionable strategies to boost deployment. In the **Column**, **“A Review of the Barriers that Remain Today for Heat Pump Widespread Deployment,”** we analyze the obstacles that stand in the way of scaling heat pumps and discuss how to overcome them.

Our **Topical Articles** delve into innovative solutions:

- **"Speeding Up the Roll-Out of Heat Pumps with Lessons from Archetypal Outcome-Led Packaged Retrofit Solutions"** explores practical frameworks to accelerate deployment.
- **"Early-stage Guidance on Heat Pump Retrofit for Non-domestic Buildings: Interim Results from HPT Annex 60"** offers a glimpse into the evolving strategies for retrofitting larger-scale facilities.

In the **Non-Topical Articles**, we broaden the focus with groundbreaking insights:

- **"Creating an Investment Climate for Clean District Heating"** examines financial mechanisms to support heat pump expansion.
- **"R744 Heat Pumps with Ejectors for Heating and/or Cooling: Opportunities, Challenges, and Results"** highlights the potential of natural refrigerants.

- **"When the Electric Car Moves In - Coordinated Control of Heat Pumps and Electric Car Charging"** explores the intersection of heat pumps and electrification.

In the **National Market Section**, we spotlight **Italy** with an exclusive **"Heat Pump Market Report,"** providing a detailed look at one of Europe's leading markets for heat pump adoption.

This edition encapsulates the challenges, opportunities, and innovative solutions shaping the future of heat pump technology in retrofits. Whether you're a seasoned expert or new to the field, this issue is sure to inspire and inform.

Enjoy your reading!
Metkel Yebiyo, Editor
Heat Pump Centre, The central communication activity of the Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP)

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Foreword

Scaling up Heat Pump Retrofit: What Do We Need to Do?

By Dr. Peter Mallaburn, Energy Institute, University College London and Operating Agent, IEA HPT TCP Annex 60.

The IEA[1] estimates that 85% of our buildings at home and work will need to be net zero by 2050. With heating accounting for over 50% of carbon emissions, heat pumps are expected to make a very significant contribution to this. Many governments are developing policies to accelerate heat pump deployment, and this policy pressure can only get more intense as more and more countries adopt net zero targets.

New buildings can be decarbonised relatively easily by banning fossil fuelled heating in the building codes. But 80-95% of the buildings we use today will still be around in 2050, and only 0.2% of these go through a "deep" renovation each year[2] which is when the heating system is most likely to get changed. This is nowhere near fast enough. So why is there such a mismatch between aspiration and actuality?

A large part of the answer is that retrofitting complex technologies like HVAC systems is really, really hard. Unfortunately, policymakers tend to frame the problem in cost terms: heat pumps are more expensive, so overcome this barrier with a grant and problem solved. Policy is littered with examples of this misguided neoclassical thinking.

There are parallels to the domestic condensing boiler story[3] in the late 1990s. Policymakers at the time focused on demand-side cost barriers, mainly using grants. But the key barrier

[1] IEA (2023): Net Zero by 2050: a roadmap for the global energy sector.
[2] EC (2020): A renovation wave for Europe – greening our buildings, creating jobs, improving lives. COM/2020/662 final. European Commission, Brussels.
[3] CREDS (2020): The story of condensing boiler market transformation – a briefing note for BEIS.

was on the supply-side, with installers struggling to cope with a (slightly) more complex installation procedure. Once this was recognised, installers were retrained, and the problem was solved. It took 5 years, from 2001 to 2006, to ban conventional boilers in the UK.

But heat pump retrofit is an order of magnitude more complex, with barriers across the technology chain[4]. The situation is particularly difficult in commercial and public buildings, where each site is essentially a bespoke retrofit project.

So what's the answer?

- First, I think it is important, particularly for policymakers, to accept that different parts of the market will need different solutions rather than a one-size-fits-all approach.
- Second, look for retrofit projects that are easier than others and start there. Prestige offices, the public sector, and richer householders all seem to have stronger value drivers.
- Finally, design programmes to exploit and amplify this value, creating success stories, and at the same time build capacity and confidence on both the demand and supply-sides.

If we get this demand-led approach right, the ideal outcome is that the supply-side of the market will start to chase the value of heat pumps without government subsidy and do the heavy lifting on the more intractable sectors. Policy measures will still be needed, but these will change as the market transforms.

My own HPT TCP Annex 60 is applying this approach to large non-domestic heat pumps. Here a key part of the problem is that organisations simply don't have the guidance they need on the best heat pump system for their building. Annex 60 is basically building a web app for key decision-makers that walks them through the various system options, how they might perform and where to go for some real-world case studies. Roger Hitchin goes into a lot more detail on Annex 60 in the article below.

IEA TCPs are designed to tackle this sort of technology deployment challenge, and I am pleased to see the articles in this Magazine each taking a valuable perspective. I look forward to seeing how the conversation develops.

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[4] IEA (2022): The future of heat pumps.

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Column

A Review of the Barriers that Remain Today for Heat Pump Widespread Deployment

By Frédéric Genest, Research Engineer and Technical Advisor, CanmetENERGY, Natural Resources Canada

Heat pumps have been identified as the heating technology of choice for the efficient electrification and decarbonization of heating. They have been part of the toolkit of the HVAC industry for many decades, and their capabilities and potential applications are well known. However, their use is not yet fully widespread: This column explores some of the barriers that the industry still faces today.

The capital costs of heat pump systems, especially when compared to fuel-fired boilers or electric resistance heating, can represent a significant barrier to more widespread adoption. For example, the cost of a typical ground-coupled heat exchanger (with grouted vertical boreholes) is a major roadblock to overcome when projects enter the value engineering phase, and only about 10% of ground-source heat pump systems considered at schematic design survive the bidding process. While optimizing strategies can help, another possible answer to this is standing columns wells, a lesser-known ground-coupled heat exchanger technology with a significant presence in the New England region (USA). They can deliver the same thermal performance with reduced capital costs and a smaller footprint on the ground. These characteristics allow them to be successfully installed in dense urban areas (a notable example is New York, NY, USA). Consequently, they have been the subject of increased research over the last decade to develop more accessible design tools and to have a better understanding of their suitability, benefits, and limitations. These research initiatives are now bearing fruit, leading to greater awareness and an eventual increase in the adoption of the technology across North America.

Another barrier is found in cold, heating-dominated climates, such as those of Canada, northern USA, and Alaska. In these areas, commonly available air-source heat pumps tend to experience significant capacity and efficiency degradations at colder outdoor temperatures, limiting the energy and emission savings benefits of the technology. In certain regions, ambient temperatures may drop below the operating range specified by the manufacturer, further limiting system operations. Combined, these facts resulted in low seasonal operation and performance, making this technology much less attractive since supplemental heating is needed to handle the design heating load.

Fortunately, cold-climate heat pumps (CCHP) have recently become available and are gaining a significant market share with each passing year. While the initial design of CCHP resulted from various technology innovations implemented in large and small VRF systems, many air-to-air and air-to-water CCHPs are also benefiting from the advent of HFO refrigerants and the growing interest in natural refrigerants, which allow for even wider operating ranges and performance. Furthermore, in support of the development of these products, two recent US Department of Energy Cold Climate Challenges (the first for residential heat pumps, the second focusing on rooftop units) invited manufacturers to develop prototypes able to operate at even lower outdoor temperatures with high levels of performance. The first challenge concluded earlier in 2024, and participating manufacturers are already announcing new product lines based on the results. All in all, the availability of CCHPs in various configurations is steadily increasing worldwide, with many products now able to provide sufficient and efficient heating during most, if not all, of the heating season in non-arctic climates.

A third barrier for heat pumps is the lack of easy compatibility between heat pumps and some HVAC systems found in existing buildings. For instance, the hydronic heating systems of buildings in North America have historically been designed with a peak supply temperature higher than 80 °C, while 60 °C appears to be the norm for Europe. Most conventional heat pumps (e.g., those using R410A) are generally only able to provide significant volume of hot water up to about 45 °C, limiting the potential applications. As such, retrofitting heat pumps in buildings with high temperature hydronic distribution is generally impossible without some “design gymnastics”, for example, using the heat pump only when a loop operating conditions are reset to a low-enough supply temperature. An alternate strategy is thus to replace parts of the existing system (namely heating coils and space heating terminals) with units operating at temperatures more compatible with the one supplied by those heat pumps. However, such replacements are generally disruptive to building operations, often done at high costs, and thus only as part of deep retrofit projects. Today, with the research and development done in the field of high-temperature heat pumps for the industrial sector and, again, the advent of HFO refrigerants and natural refrigerants, a growing number of heat pumps offer the potential for direct “plug-&-play” into existing hydronic systems. High-temperature air-to-water models, with a maximum supply temperature of 60 °C available even at -20 °C outdoor temperature, and water-to-water models, able to achieve higher than 80 °C while producing chilled water, are now part of the standard product catalog of many large and small equipment manufacturers.

Following this review, we may wonder, “What barriers still remain?” An important one is a lack of general awareness of the broad range of products currently available, their capabilities, and the “new” potential applications. The dissemination of technical guidance and training for the selection, design, and operation of these systems, as well as the realization of demonstration projects and the publication of case studies, are critical activities that are currently picking up momentum. Within the IEA itself, various recent and current annexes of the HPT TCP aim exactly at achieving that. And we only need to look to the latest market news across the globe to see that trade journals, major equipment manufacturers, trade and technical associations, government agencies, and more are providing free webinars, publishing technical articles, guidance, and developing training on the electrification of heating with heat pumps. The conclusion is clear: The heat pump revolution is currently happening, but it is still in its infancy, and our continued efforts are needed to create lasting changes.

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Topical Article

Speeding Up the Roll-Out of Heat Pumps With Lessons from Archetypal Outcome-Led Packaged Retrofit Solutions

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Jon Warren, Head of innovation and policy, Energiesprong UK

Heat pump deployment in the UK is well behind targets. Energiesprong UK has been exploring deep retrofit with heat pumps in non-traditionally built homes which has been challenging but insightful. We have tested different retrofit packages in several prominent archetypes, which represent 200k properties in the UK. The lessons learned and solutions developed offer the potential for a step-change in scale, helping contribute to a retrofit ecosystem capable of delivering 1m homes a year.

UK context

To meet UK climate change targets, the government set a target in 2021 to install 600,000 low-carbon heat pumps annually by 2028.[1] In 2023, there were 36,799 MCS-certified installations of heat pumps.[2]

[1] UK Government 2023, "Research briefing on heat pumps", https://post.parliament.uk/research-briefings/post-pn-0699/ accessed on 24.10.24.

[2] Carbon Brief, "Analysis: Surge in heat pumps and solar drives record for UK homes in 2023", https://www.carbonbrief.org/analysis-surge-in-heat-pumps-and-solar-drives-record-for-uk-homes-in-2023/, accessed on 24.10.24.

While this is a 20% increase on the previous year, it is still far below what's needed. Yet with the repeated refrains of "retrofitting one home a minute" and "every home is suitable for a heat pump", we could be forgiven for expecting endless graphs of exponential heat pump market growth and deployment. So, what's holding us back?

The UK's big heat pump challenges

1. **Affordability**

Despite numerous case studies showing heat pump effectiveness, public opinion remains divided with "heat pumps work" and "heat pumps don't work" articles in equal measure in mainstream media. Many UK homeowners can access a £7,500 subsidy, covering much of the upfront cost for homes requiring minimal new pipework and radiators.

Operational costs are the bigger concern. Properly installed heat pump systems where gas has been removed can deliver savings, but these can quickly be blighted by a cold weather snap or tariff changes. Negative consumer feedback often lacks proper analysis. Poor assumptions about insulation or installation can lead to higher-than-expected costs.

2. **Maximising efficiency requires careful design for different homes**

Homes, even of similar types, can have significantly variable heat pump installations, affecting efficiency by over 20%[3]. Unlike gas boilers, heat pumps are sensitive to temperature and flow control, and cost-saving measures during installation can hurt performance. Accurate heat-loss models are essential, but real-world testing has shown unexpected deviations. Building data sets around the most pertinent factors to successful heat pump retrofit for particular types of homes can reap dividends in terms of outcomes, allowing repeated successful installations and more predictable performance.

3. **The shift to modern methods of construction is not happening quickly enough**

While digital solutions exist, heat pump installation remains craft-based. Kits of parts, modular systems and pre-fabrication are limited, as are the skills for implementing them. Stop-start government funding has left housing providers unable to commit to long-term programmes, meaning the numbers do not stack up for the supply chain to invest. Barriers like fragmented supply chains, skills shortages, financing issues, and planning constraints further slow the adoption of modern retrofit methods.

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[3] https://es.catapult.org.uk/wp-content/uploads/2023/03/EoH-Interim-Heat-Pump-Performance-Data-Analysis-Report-1.pdf accessed on 24.10.24

A better retrofit market: taking a systemic approach to tackle these challenges together

So, even with generous upfront subsidies, heat pumps remain a confusing and weak proposition for many. Very few providers can deliver a holistic solution that considers the context of the wider house and energy system, which limits assurances of performance and confidence that outcomes will be sustained.

Our approach has been to create an integrated retrofit approach designed in more detail for particular types of homes. Ongoing performance monitoring provides assurance to funders who can provide finance at better rates, necessary to enable deployment at massive scale.

Energiesprong is an outcome-led retrofit movement with teams across Europe working in their respective countries to create the conditions for a home refurbishment market that delivers comfortable, affordable, and desirable net-zero homes.

It aims to create scale by:

- Allowing a portion of the renovation costs to be repaid through energy bill savings, supported by a long-term performance guarantee
- Ensuring high-quality refurbishments with the use of industrialised components and circular or bio-based materials
- Achieving shorter renovation times through improved processes and techniques
- Developing a product that appeals to people.

Common archetypes have formed the starting point of the first markets in several countries, as shown in Figure 1. We take a technology-agnostic approach but there is a strong focus on using integrated solutions (including a heat pump!) that offer rapid installation and high quality, underpinned by a performance guarantee.

Figure1: Energiesprong retrofits in Arnhem, the Netherlands. Credit: Energiesprong Global Alliance

In the UK, we picked social housing as our starting market as landlords' long-term maintenance plans mean the business case makes the most sense.

It is also populated by several housing archetypes that particularly suit our focus on industrialised whole house retrofit (as shown in Figure 2), including those built after the war under the Emergency Factory Made Housing Programme and solid brick council homes built between 1920 - 1940. These are the homes where deep retrofit has the biggest impact in terms of achieving net-zero emissions, reducing fuel poverty, and achieving much-needed aesthetic regeneration.

Figure 2: 1960s cross-wall homes owned by Nottingham City Council were the first homes in the UK to undergo an Energiesprong retrofit. Credit: Energiesprong UK

Categorising UK archetypes by age – not all homes need a deep retrofit

Not all homes need deep retrofits to meet decarbonisation goals. With lower battery costs and better understanding of heat pumps, millions of homes can be rapidly decarbonised, especially if long-term plans are uncertain. In some cases, the embodied carbon and capital costs make deep retrofits impractical.

Categorising homes by archetype helps in selecting the right solutions. Homes built after 1972 have some energy conservation measures, with significant updates in 1984, 1995, and 2002. The 2006 update to Part L introduced the SAP system for energy assessments.

Homes built after 2006 likely only need heat pumps and solar panels without further insulation. Homes built between 1984 and 2006 may need some adjustments but generally won't require solid wall insulation if they have cavities.

What we have learned: common archetypes have many similar traits, but there are common variations.

Countries often have clusters of similar homes or archetypes, typically defined by construction method or period (e.g., solid brick vs. cavity walls, terraced vs. detached) as shown in Table 1. Even within these, sub-archetypes like mid or end terraces may require different retrofitting approaches.

Table 1: Common similarities and common differences table

Common similarities	Common differences
Form/size/layout	Extensions and porches
Structure	Plot size/shape/pitch
Wall construction	External cladding/insulation
Structural condition	Asbestos
Defects	Occupants!
Services layout	
Energy measures and heating system	

Similarities

During construction, pattern books guided designs, offering variants in size or number of bedrooms. Mid and end-of-terrace options could be built, and options to create flats within the same form were often provided. Estate planners would then roll these out to match the local housing needs. Structurally, the homes would be very similar, using concrete or steel structural frames connected to concrete, steel, or brick walls with steel, asbestos, or traditional tile roofs. Table 2 shows these typical non-traditional property characteristics.

These homes perform similarly, except for slight differences due to orientation and solar gain.

Table 2: Typical non-traditional property characteristics

Structure	Walls	Roof
Concrete (pre-cast) Concrete (poured in-situ) Steel Timber	Concrete (pre-cast) Concrete (poured in-situ) Steel clad	Steel Asbestos panels Concrete (tile)

With homes built at similar times, maintenance issues often compound at the same time. Budget cuts in social housing have led to widespread problems – with drainage, rising damp, and electrical compliance issues prevalent in most of our non-traditional schemes. Archetype-related issues, such as structural corrosion or roof replacement, can complicate retrofits, adding high remediation costs. While these are not HP performance issues - and perhaps strengthen the case for a holistic retrofit - they cannot be ignored when designing a retrofit for 15-30 years, and the high capital costs of remediation can often torpedo the best business case.

Originally designed with coal fireplaces and little insulation, many homes have undergone multiple energy efficiency upgrades, including loft and cavity wall insulation, conversion to gas heating, and double glazing. These homes, largely in social ownership, have benefited from subsidised schemes, making their energy standards relatively uniform.

Differences

Extensions, ranging from unheated spaces to bathroom pods and porches, vary widely, even on the same street. While non-traditional homes are strikingly similar across London suburbs and northern UK towns, plot sizes and slopes differ, meaning outdoor space for heat pumps is not always available.

Non-traditional homes often have varying cladding, either for aesthetics or insulation. Upgrades usually require removing the old layer to attach new systems. Asbestos, used in roofs and chimneys, frequently poses challenges during retrofits, with unexpected finds causing delays.

While these homes may lack kerb appeal and energy efficiency, they offer larger spaces compared to modern builds. Their size makes them popular with both residents and housing managers, especially for housing larger families. Heating systems must cater to diverse occupants, though social landlords match homes to occupancy.

How are we putting these lessons into practice?

Creating a 'retrofit catalogue'

We're compiling our archetypal work to date to test 'packaged solutions' that work for each non-traditional archetype. The aim is to bring together what we know about common pitfalls on design and construction, prioritisation of the many trade-offs that are made during the design process (as shown in Figure 3), and learning from real-world monitoring of 200 homes that have been retrofitted (as shown in Figure 4).

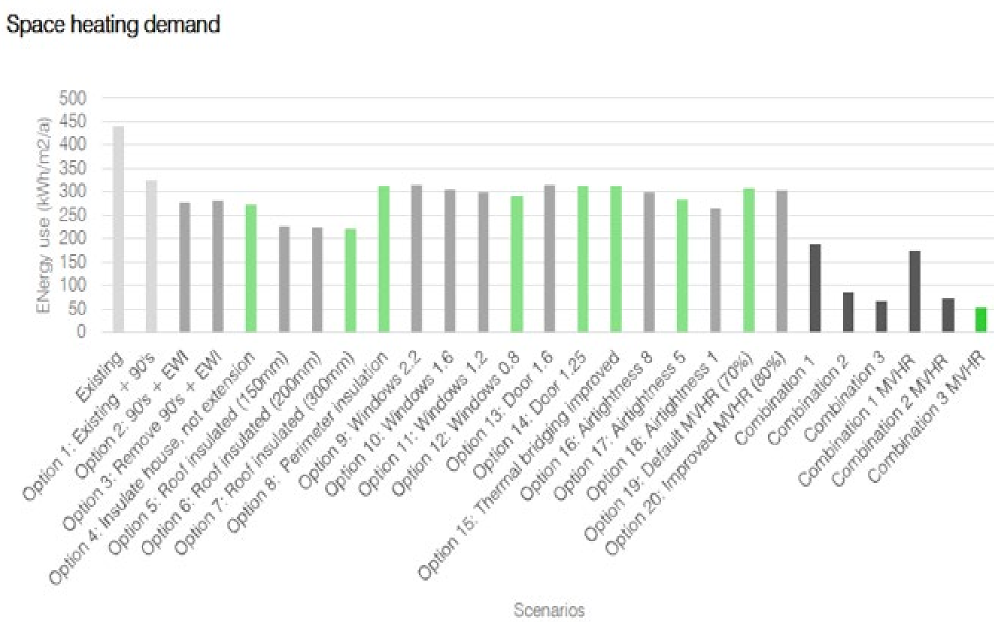

Figure 3 Modelling different retrofit scenarios in the design process

Figure 3: Modelling different retrofit scenarios in the design process

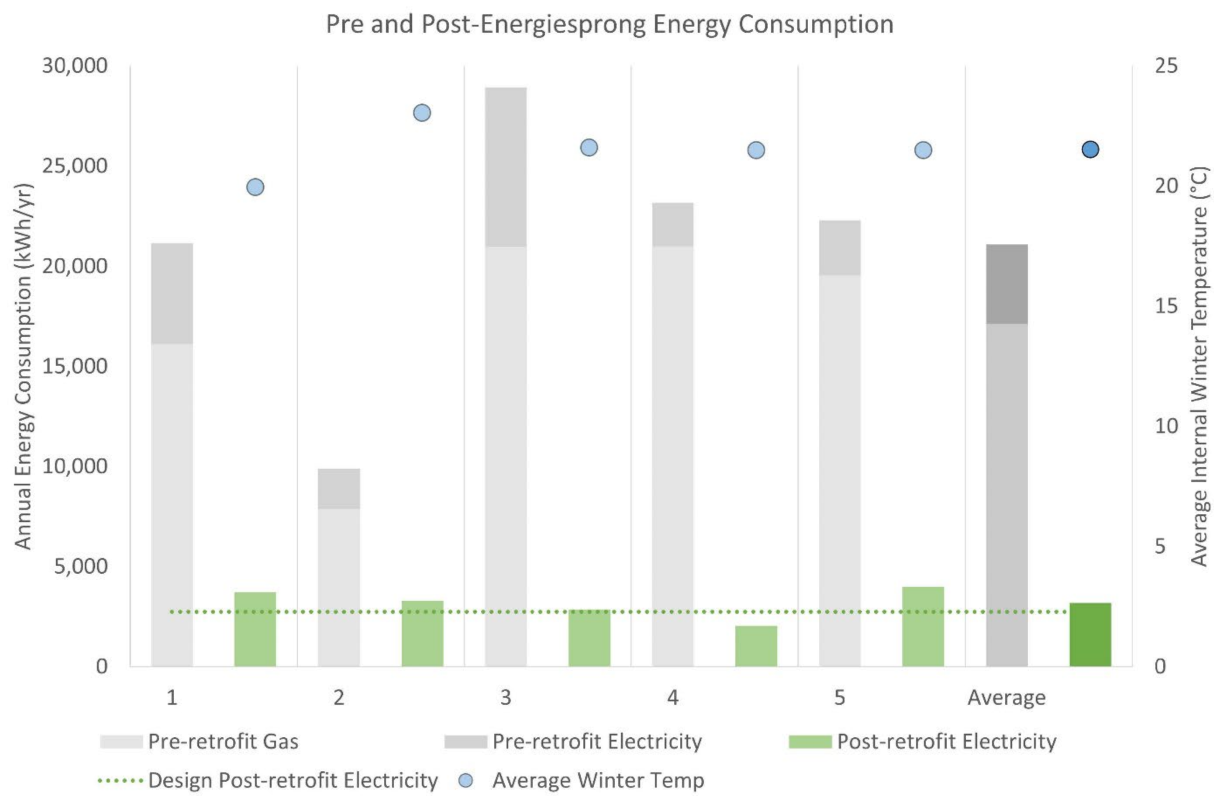

Figure 4: First cohort of Energiesprong pilot performance.

Figure 5 Packaged solutions under test.

Our UK Government funded work via the DESNZ Heat Pump Ready project is bringing all this thinking together by exploring the match between packaged solutions (shown in Figure 5) and four key UK archetypes. Designs will be tested at two sites, and further exploration of real-world performance variability and delivery risks will be explored to create design blueprints for four archetypes that represent 200k homes.

Building on this concept, the Transform-ER project expands this approach even further, building a new data platform that will be able to create a net-zero pathway for properties by analysing the best solutions for different archetypes and providing a pre-qualified pipeline. Transform-ER (Transform.Engage.Retrofit) is an Innovate UK-funded project that is tackling retrofit's biggest barriers to scale - enabling one million home upgrades every year by 2030.

Innovative manufacturers are designing and testing new components that will be added to the platform and matched with UK homes. The platform will initially tackle 300,000 homes in alpha/beta phases before scaling up to support a wider retrofit system capable of tackling one million homes per year. New contracting models and finance options will also be developed and rolled out.

We will be sharing insights and resources from these projects, where appropriate, with the wider sector to ensure that lessons are learned and built upon, all with the aim of nurturing a retrofit ecosystem that can deliver home energy refurbishments at the speed and scale we require for the UK's net zero targets.

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Topical Article

Early-stage Guidance on Heat Pump Retrofit for Non-Domestic Buildings: Interim Results from HPT Annex 60

DOI:10.23697/xjt0-9197

By Roger Hitchin, UK Alternate delegate, UK

This article outlines early-stage guidance from HPT Annex 60 on retrofitting heat pump systems in non-domestic buildings. It presents an interactive tool designed to assist decision-makers by filtering over 25 possible configurations based on building constraints and priorities. The tool also connects users to case studies and system descriptions, supporting informed decisions amidst sparse data and evolving market conditions.

Introduction

We all know that we need to decarbonize the heating in all our buildings, most of which have already been built. This is as true for nondomestic buildings as it is for dwellings, yet they have received less attention in terms of policy measures or technical guidance, despite typically accounting for around one-third of national heating energy. Existing non-domestic buildings pose different problems to dwellings but also offer additional opportunities.

The aim of Annex 60, “Retrofitting Heat Pump Systems in Large Non-domestic Buildings” [1] is to provide early-stage guidance to building owners and their advisors on the types of heat pump retrofit that best suit the circumstances of their buildings and their cost and carbon reduction priorities. This will be provided by an interactive tool that first filters the 25 or so different possible system configurations to match constraints identified by the tool user and selects a short-list suggested as being worth investigating in detail. The shortlist will be linked to a database of case studies that illustrate existing retrofits that most closely match the circumstances of the tool user. It is intended to make this accessible on the Technology Collaboration Programme website, where it can be updated as new information becomes available.

With policies to phase out fossil fuel heating becoming more widespread, consideration of retrofitting a heat pump system is likely to be triggered either by an existing boiler (or other heat generator) approaching the end of its life, by a heating system needing to be replaced for similar reasons, or by the substantial refurbishment of a building perhaps for a change in use. If the average life of a boiler is about 15 years, the annual replacement rate is about 7% of the installed stock (perhaps slightly fewer if there is an incentive for life extension). Based on typical reported lifetimes, major changes to systems might occur at about half this rate. These rates are significantly higher than the estimates of the order of 1% per year for deep energy renovation. In most cases, the heat distribution system will be in good order, and systems that retain it will tend to be favoured.

Interim results

The first stage of the Annex was a literature review. This revealed that there was hardly any published guidance on retrofitting heat pumps to non-domestic buildings, though that is now starting to change [2,3,4,5,6]. There are also very few statistics on existing markets, probably because the markets are still in the very early stages of development. In the UK, for example, annual sales of heat pumps into non-domestic buildings are probably about 2000 units per year, of which about 2/3 are believed to be in existing buildings – an even smaller market penetration rate than for dwellings. They appear to be predominantly installed in two niche markets: public buildings (where financial incentives exist for a limited number of buildings) and in a specific part of the office market, where major refurbishment can be justified by expected rental increases - these “class A offices” typically require very good energy performance and sustainability ratings that favour the use of heat pumps.

The Annex has collectively collected over 100 case studies, but these vary considerably in the amount of information that is available. The term “case studies” is used in the Annex to serve several functions: to provide reassurance to tool users that others have successfully carried out retrofits in circumstances similar to their own; to provide a degree of insight into the costs and performances of systems; and to provide detailed insight into the performance of a few example installations. Most of the current case studies satisfy the first of purposes, but few have much information about actual performance. The number of “deep dive” studies is small.

The most common market sectors in the case study collection are offices, schools, and “arts. leisure, community, and religion” but this is probably not representative of the market: in particular, the retail, hospitality (hotels), and health sectors may be under-represented. It is likely that the distributions will be different in different countries. Figure 1 shows the distribution of system types in the case studies. In the absence of statistics, this is not necessarily representative of the market mix. By far, the most common system is air-to-water, of which a significant (and possibly under-reported) proportion are either bivalent systems or systems with heat pumps that can produce flow temperatures close to those that would be supplied from an oil or gas boiler. These have the obvious advantage of reducing or eliminating the need to replace heat emitters, which is a potentially expensive and disruptive action that interferes with the activities carried out in the building. Bivalent systems provide some reassurance to building owners who have concerns about being completely dependent on the heat pump system: they also appear to offer good carbon savings relative to capital cost. This is, however, contingent on their being designed and operated in a way that restricts the use of fossil fuel to “top-up” operations. We do not have sufficient data to reliably map system types against building sectors.

Other relatively common types of system are the ground source (sometimes bivalent) and the modification of air conditioning systems to provide heating. In many countries, the largest market for heat pumps is as reversible room air conditioners: these are considered to be out of scope for the Annex, but variable refrigerant flow (VRF) or water-loop systems (WLHP) are in scope. In the case study portfolio, there are similar numbers of polyvalent (4- or 6-pipe) chillers and VRF systems. VRF systems have the advantage that they can be implemented floor by floor in buildings where the duration and timing of leases for each floor varies. Case studies that only provide service hot water are shown separately, but stand-alone water heating installed alongside a separate space heating or cooling systems is not distinguished from a combined system.

Figure 1 shows 13 types of system, but the guidance tool includes twice this number, selected from over 200 theoretically possible configurations. The identification of which options look promising for a specific building depends on many factors: the priorities of and constraints facing the decision maker, the location of the building (including its climate and electricity supply), the levels and patterns of heat demand, and the level of planned system refurbishment (if any). The nature of the existing heat distribution system will often be an important factor: unless it needs to be replaced for other reasons, modifying or replacing it is an avoidable cost, and (if it is satisfactory) its design is a good proxy indication of many of the system design requirements.

The tool is intended to provide its users with early-stage guidance through this maze by using their responses to questions to filter out options that have serious constraints or do not match their priorities and concerns. This will leave a “short list” (of variable length) of options on which to focus a more detailed assessment. It will provide some generic relative guidance: for example, “Option A will usually be more expensive than option B but will abate more carbon emissions.” This is intended to allow them to have a focused discussion with their design consultants or equipment suppliers. It is likely to be useful, for example, to decision makers in smaller businesses who may be considering what would normally be a boiler for boiler replacement but are aware that regulation or sustainability concerns require them to consider a heat pump instead. These decision makers probably do not have immediate access to specialist system designers and may wish to become better-informed ahead of detailed discussions with suppliers, installers, and designers. They are probably not contemplating major building or system refurbishment, though the tool should also be useful if they are.

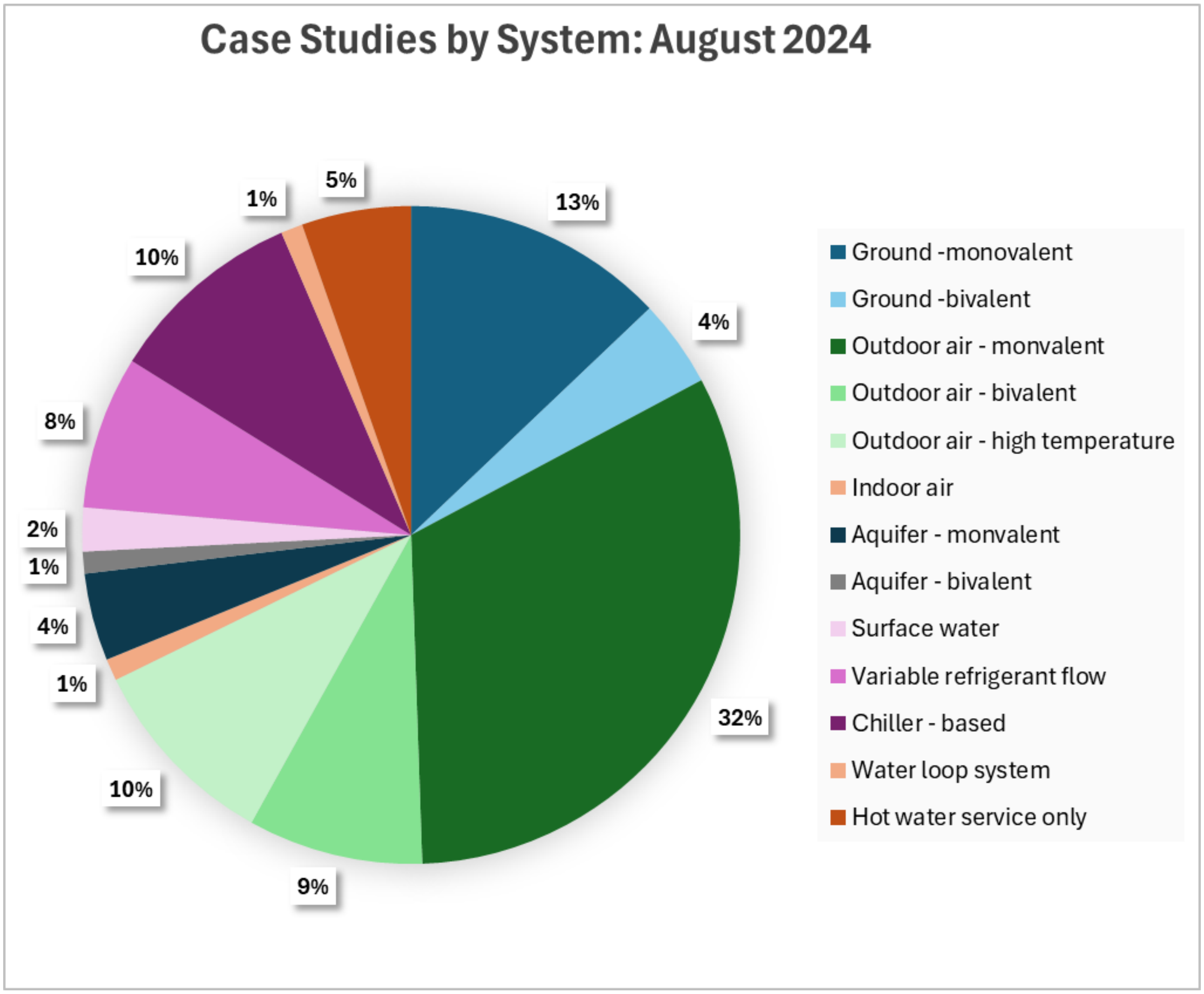

Figure 1: Distribution of system types in the case studies

The basic structure of the tool is shown in Figure 2: the logic module handles the short-listing process and links to a database of case studies and also to a set of generic descriptions of each type of system. The shortlist of suggested system options provides links to these for those systems that are suggested. If they prefer, tool users can interrogate the case study and system description databases directly, for example, before answering the questions for the guidance module.

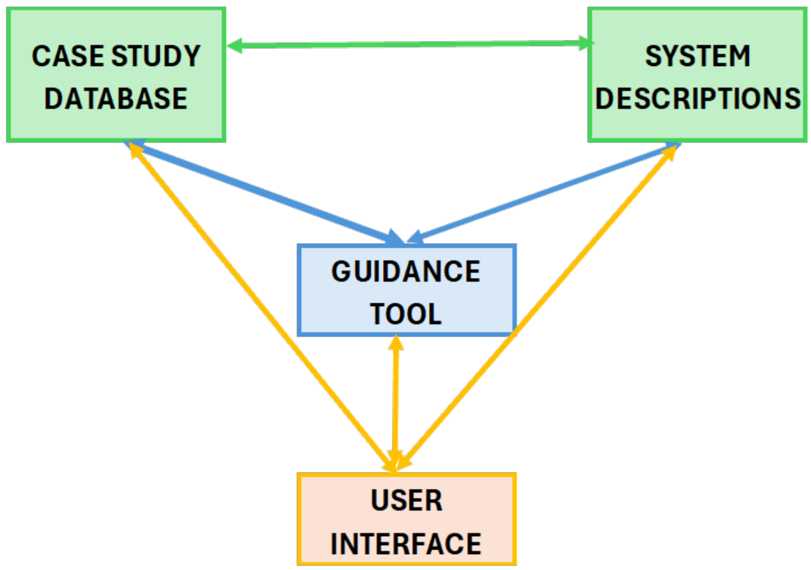

Figure 2: basic structure of the tool

Figure 3 provides an overview of the logic process: the initial long-list - currently of 27 system options - is filtered by question responses – currently 12 to 14 questions (in some cases, the response to a question leads to additional ones) to produce the shortlist. Some questions will allow a "don't know" response, which will generate advice to either seek more information or explore the options for both "yes" and "no" responses.

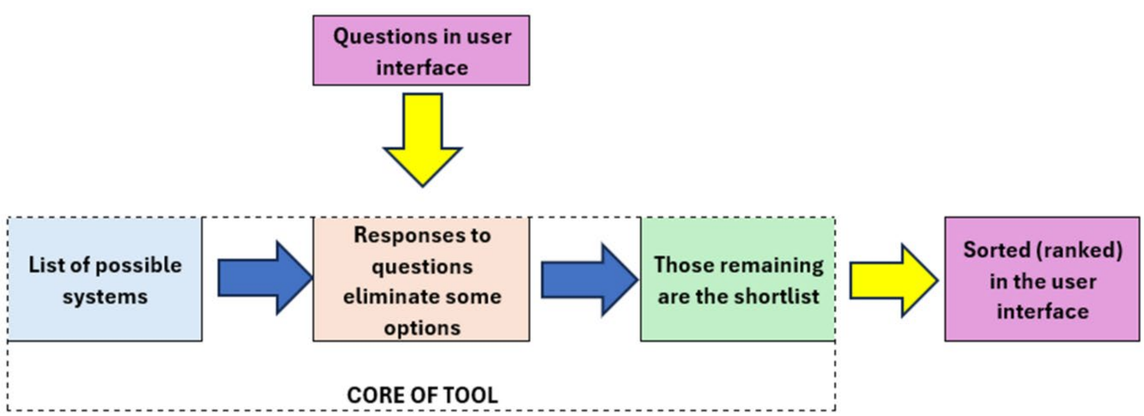

Figure 3. Overview of the logic process:

The ranking process is proving to be one of the more challenging aspects of the project because data is sparse and consistent comparison between data for different system/building combinations is difficult. Ideally, comparisons would be based on technico-economic studies of different options for the same building, but these have proved to be difficult to obtain, even anonymously.

The best means of presenting the results to tool users is also still to be agreed upon. Figure 4 shows one graphical possibility. The chart shows the relative performance of a set of systems for three metrics: capital cost (blue), carbon abatement (orange), and capital cost per unit of carbon abated (grey). The longer the bar, the better the performance. Alternatively, the tool user could be asked to prioritise their criteria.

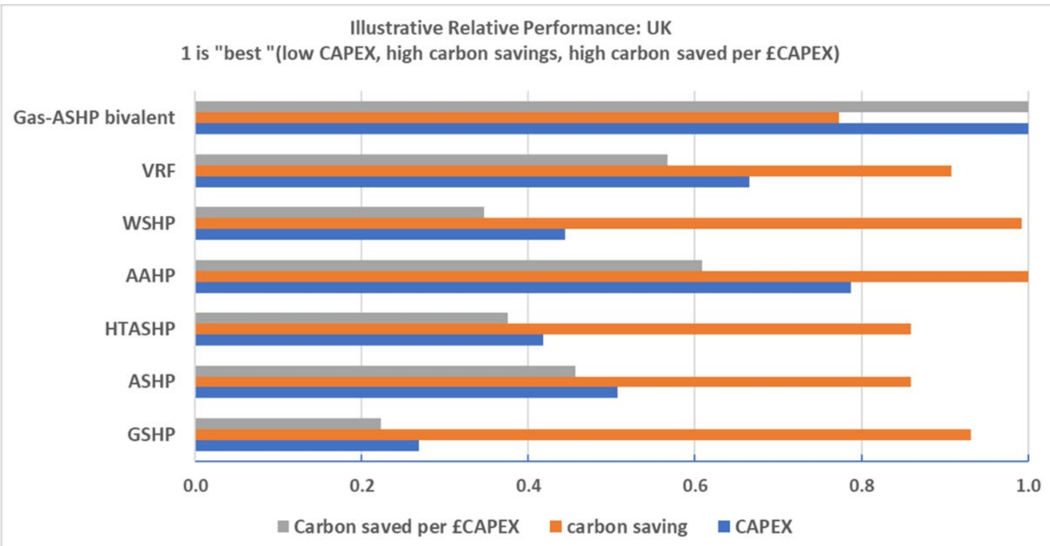

Figure 4: Relative performance of a set of systems for three metrics: capital cost (blue), carbon abatement (orange), and capital cost per unit of carbon abated (grey)

Discussion

The project has been more demanding than expected, partly because less information and experience is available than had been expected. It is hoped to extend the project for a year, but, even so, it is clear that market experience on which guidance can be based will remain in short supply. There is a longer-term need to collect and collate experience as the market develops.

Other outstanding questions include:

- How much does the guidance need to be specific to countries or regions with different energy supply systems, climates, and regulatory frameworks? Canada, for example, contains regions that differ substantially in some of these respects – making its substantial contributions to the project difficult to generalize.

- Who are the decision-makers? Small businesses may be run by a few individuals who have many other business decisions to address, but larger organizations are likely to have multilevel management hierarchies, each level of which needs to give approval.

More generally, and outside the formal scope of the project, the shortage of market information means that policymakers are poorly placed to consider policy instruments focused on the sector.

Meanwhile, the guidance tool and databases will form a framework whose value will increase as it becomes better populated and feedback from its use is used to develop its content and procedures further.

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Non-Topical Article

Creating an Investment Climate for Clean District Heating

DOI:10.23697/0gg6-2p26

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Scotland's journey to decarbonize heating highlights challenges and solutions for sustainable energy transitions. By integrating large heat pumps, addressing electricity costs, and fostering collaboration, Scotland aims to expand heat networks to 10% by 2035. Key recommendations include confidence in heat sales, commercial viability, and a unified national vision, serving as a roadmap for global net-zero goals.

Introduction

As countries worldwide confront the urgent need to transition away from fossil fuels, Scotland's experience offers valuable lessons for any nation pursuing sustainable energy solutions. With rising fuel poverty and pressing climate legislation, Scotland's journey to decarbonize its heating sector is increasingly urgent. The country aims to significantly expand heat networks; an essential component in reducing carbon emissions and enhancing energy resilience.

Whilst many countries have achieved district heating from combustion sources, Scotland and the UK chose gas. On one hand, a blank canvas. On the other a legacy fuel that continues to offer a cheap counter-factual. Scotland must overcome this and strategise a way ahead to a district heating landscape not underpinned by combustion but harnessing ambient and waste heat with large heat pumps.

Scotland’s reliance on gas heating must diminish rapidly. This transition, signposted by one of the most impressive district heating schemes in the world from a sustainability perspective, has stalled. Figure 1 is of Queens Quay near Glasgow, which is the first and last such facility, which commenced in 2017.

Whilst it is recognised that a “Just Transition” presents an opportunity to foster sustainable and affordable heat networks, generating significant socio-economic benefits and commercial prospects for a Net Zero Scotland, the underlying policy and commercial landscape remains incompatible with subsidy free development. The UK aims to reduce fossil fuel dependence, as the heating sector contributes 37% of annual carbon emissions. Creating the circumstances whereby heat networks are a low-cost, low-carbon solution is critical for urban decarbonization. However, current policies hinder optimal deployment rather than enhance. This article outlines three thematic areas for simple, effective policy shifts to enhance heat network viability. At little or no cost to either the Scottish or UK Government.

A critical aspect of this transition is the recognition that future district heating systems must rely less on traditional heat sources, such as combusting domestic waste, and instead embrace cleaner alternatives. Much of the market activity craves success in this first activity, but it will be short-lived and stunted in capacity. The policy upheaval must be through the lens of total decarbonisation and sustainability. This shift will necessitate the integration of large-scale heat pumps, which utilize renewable electricity to provide low-carbon heating. Consequently, electricity policy becomes a pivotal theme in the successful deployment of heat networks. Effective electricity pricing and infrastructure will be crucial in making low-carbon heat accessible and economically viable for consumers.

Scotland's ambitious targets to increase the proportion of heat supplied by these networks from under 2% to 8% by 2030, and closer to 10% by 2035, demonstrate a commitment to creating a more sustainable and affordable heating landscape. However, the challenges faced in this transition underscore the importance of heat related policy design and regulatory frameworks. This is mirrored by world class deployment of on- and offshore wind, but currently, the linkages are missing, with almost all generated power fed into a grid, which subsequently layers on legacy policy costs, making feed-in rates balloon from approx. €80/MWh to closer to €300/MWh for power purchase even just a few kilometres away.

For countries seeking to implement similar initiatives, Scotland's experience highlights the necessity of fostering collaboration between government bodies, industry stakeholders, and communities. But more importantly, is the close interplay between electricity generation and heat production. By prioritizing clear communication, economic viability, and integrated planning, nations can cultivate a robust environment for heat network development. As we delve into the proposed policy shifts and strategic recommendations, the lessons being learned in Scotland (there is a long way to go) can serve as a roadmap for other countries aiming to achieve their own net-zero ambitions in a sustainable manner.

Figure 1: Photo of Queens Quay near Glasgow, which is the first and last such facility - commenced in 2017

Focal points:

To accelerate the deployment of large-scale heat networks in Scotland's urban areas, we identified three critical themes:

1. Confidence around offtaker heat sales
2. Commercial viability when compared to the status quo
3. Communication of a vision for clean district heating based on a national integrated plan

From these discussions, we have compiled a series of pragmatic 'asks' directed toward the Scottish and UK Governments. Recognizing that policy and regulation in this area require a joined-up approach, we emphasize the need for Scotland to adopt a "Whole Systems" Energy Planning framework.

The interdependencies between various energy vectors, such as the increasing pressure on the electricity grid, can be effectively addressed through large-scale district heating schemes. Isolated planning will lead to higher costs for both public and private sector bill payers in Scotland.

We strongly advocate for treating heat networks as a new utility, integral to the national and regional integrated energy design and planning processes led by the new National Energy Systems Operator (NESO) and Regional Energy Strategies (RESPs). This approach would empower heat network developers and operators to adopt existing utility rights, facilitating effective multi-vector energy planning essential for a successful energy transition.

Current state of play

Currently, there are a limited number of operational district heating schemes in Scotland. These have been primarily established by local authorities or Universities and other public sector estates. Subsequent schemes are unable to secure commercial partners for construction with the demise of funding models either associated with gas CHP, subsidised biomass, or subsidised heat pumps. Examples of large-scale, mixed offtaker, low-carbon schemes receiving minimal state incentives are scarce.

While significant progress has been made in early-stage feasibility, regulatory development, and consultation, the transition remains sluggish. Many projects are deemed unattractive, presenting high-risk investment opportunities. Where appealing projects do exist, they are often limited in scale and heavily subsidized to meet necessary financial benchmarks. Overall, progress on project delivery falls short of the required levels, indicating that current Scottish Government policy interventions are not meeting ambitions. The limited market activity in Energy from Waste plants should be set against the reality of both a moratorium on new planning consents for such facilities whilst the sustainability criteria are reviewed and a limited volume of feedstock versus long-term heat demand.

What needs to change?

In a nutshell, it needs to be commercially viable to make clean heat with big heat pumps.

The barriers to rapid adoption in Scotland primarily reside in policy rather than technology. This article proposes several landscape adjustments to achieve the desired progress.

The Scottish Government is collaborating with the UK Government to address various policy and regulatory challenges across the wider energy sector, however, it should be said though that currently, the collaboration seems to focus more on the deployment of more renewable electricity generation rather than the mutually beneficial harnessing of already existing but curtailed electricity generation by ultra-flexible resources to make clean heat.

1. Confidence of offtaker heat sales

As simple as it may seem, the certainty of sales of clean heat is not yet where our society is at versus a highly regulated and successful gas network. For heat networks to be financially viable, a sufficient number of customers must commit to their adoption, creating a predictable demand stretching forwards several decades. This collective action is vital for reducing commercial risk and attracting private sector investment. However, without clear public policy and regulation identifying heat networks as the preferred solution in specific areas, this collective action is unlikely to occur.

We propose the following key "asks":

- All Governments should clarify the shift away from gas for heating buildings with a backstop date for replacement gas boiler sales.
- Governments must explicitly state that heat networks are the preferred solution for heating in denser urban areas, provided a “credible offer” is available at a “fair price.”
- Public sector buildings should be prioritized for connection to district heating where such offers exist, and any funding allocated to Local Authorities, Higher Education, or Healthcare must support district heating connections when located within heat network zones.
- New properties in or near heat network zones should be mandated to connect to these networks, with planning consents allowing for a transition to heat network consumption within ten years.

Defining a “fair price” within 25% of average retail gas prices would help create confidence in the district heat market, ultimately driving billions in private investment and creating employment while reducing costs and health problems associated with poor air quality.

2. Commercial Viability Compared to Status Quo

Establishing a low-risk, high-certainty capital investment environment is essential, but it must be paired with effective cost management strategies to ensure competitive heat pricing. The likely use of large-scale heat pumps for low-carbon heat means that electricity pricing is the most significant factor affecting market viability.

Recognizing that electricity policy is a reserved matter for the UK Government, a coordinated approach is necessary. Proposed measures include:

Option A: Custom Electricity Tariff for Heat Pump Operators

Implementing a new support scheme to provide operators of commercial scale heat pumps with significantly lower electricity tariffs estimated to be 67% to 75% below current prices, could create a favorable environment for heat networks. This would facilitate competitive pricing without being classified as a subsidy. This is probably the primary message to other European neighbours; ***if you want clean district heating, manage the supply and price of the electricity market to make projects viable.***Option B: Reducing Risk of Private Electricity Transmission

Option A requires a UK Government policy shift. Thinking within the policy boundaries of Scotland; Underwriting the utilization of existing high-voltage transmission infrastructure for clean heat facilities would lower barriers to entry for heat network developers. This could involve mandating side offtake from new transmission hubs in planning consents and fostering collaboration between the electricity sector and heat network developers.

Figure 2 - Whitelees near Glasgow. Largest land-based windfarm in Europe but power costs 4x as much just 200m down the road due to outdated pricing policies. Reducing deployment costs is another essential step for the Scottish Government, which has devolved authority in areas like clean air, planning, and heat. Effective coordination in these domains will yield positive outcomes for district heat network deployment.

A strong message must be to any Government though; “don’t try and fix the cost of all electricity. To make clean heat viable, just correct the cost of electricity for the decarbonisation mission. This will be simpler and quicker and more likely to be achieved.

Figure 2: Photo of Whitelees near Glasgow. Largest land-based windfarm in Europe, where power costs are 4x just 200m down the road.

Figure 3: Photo of Ammonia heat pump harvesting heat from the Clyde estuary

3. Communication of a vision and plan for clean district heating

Finally, effective communication is vital for fostering stakeholder engagement and ensuring a cohesive strategy for transitioning to clean heat. The following actions are recommended:

- The UK Government should clearly communicate its intention to phase out natural gas as the primary heating solution for UK buildings over the next two decades. This statement would provide direction for investment in low-carbon heat solutions.
- The Scottish Government should publish a detailed strategy outlining a timeline and plan for achieving heat network uptake objectives by 2035. This includes communication tools and stakeholder engagement to ensure wide understanding and broad support for the transition. Awareness of individual domestic heat pumps is creating a vacuum for those in properties not suited to these, but without clarity that heat networks will be provided. Creating this publicity without the economics being resolved to somewhere close to gas is clearly not a good plan.
- Establishing a formal, representative industry group focused on clean district heating will allow effective engagement in heat network policy, facilitating billions in inward investment for decarbonization efforts. Across Europe, there is no forum

dedicated to clean district heating unencumbered by other industry segments. This creates a lack of a well-tuned sounding board for Governments.
- A pan-cabinet awareness session should be arranged to ensure that all parts of the Scottish Government understand their roles in this transition, creating a unified approach across diverse portfolios.

Clear and strategic messaging will be critical to garnering support for clean heat initiatives, emphasizing the benefits of clean district heating over individual heat pump systems. Figure 3 shows the Queens Quay river source heat pump which has proven the technical case using a natural working fluid, ammonia. The economic case remains to be achieved without subsidies.

Lastly, it is imperative that sustainability is at the heart of a heat pump paradigm. Synthetic working fluids might be technically established, but they are totally unnecessary in this segment and bring a wealth of worrying sustainability weaknesses, whether atmospheric or oceanic. The last thing we want are cleaner homes but dirtier drinking water.

Conclusion

The transition to sustainable heat networks in Scotland and the lessons being learned provides an instructive model for other nations. By implementing simple policy shifts that focus on enhancing confidence, commercial viability, and effective communication, governments can create a robust environment for heat network growth funded privately. This collective effort will not only help achieve ambitious net-zero targets but also drive economic growth and improve public health outcomes. As the world faces mounting environmental challenges, embracing these strategies will be essential for realizing a sustainable energy future.

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Non-Topical Article

When the Electric Car Moves In - Coordinated Control of Heat Pumps and Electric Car Charging

DOI:10.23697/mgf2-tx64

By Markus Lindahl, Lars-Henrik Björnsson, Jan Ekman, RISE Research Institutes of Sweden

There is an ongoing electrification of the Swedish society, bringing new challenges and opportunities for electricity use in our homes. One of the most exciting developments is the integration of electric cars into the household energy systems. Results from ongoing research by RISE show that homeowners in Sweden with heat pumps and electric cars can save significant costs per year through coordinated and optimized control of their heat pumps and car charging. This coordinated control can help reduce the strain on the power grid, while households avoid high peak tariffs and reduce their electricity costs.

Electrification of the energy system

Sweden is undergoing a significant electrification process aimed at creating a more sustainable energy system. This shift is expected to increase the need for a more flexible electricity usage. However, the energy transition, urbanization, and an aging power grid have led to capacity issues in parts of the power grid. To address this, more and more Swedish grid operators are introducing "peak tariffs". These tariffs, which will become mandatory in Sweden by 2027, base part of the grid fee on the household's highest power peaks during the month and aim to incentivise the user to spread out their electricity usage to avoid peak loads that can lead to problems in the power system.

Simultaneously, household energy consumption and power demand are influenced by the ongoing electrification of the vehicle fleet, as the electric cars are typically charged at home. This shift will increase the household electricity consumption and risk of high power peaks if multiple large electricity consumers are used simultaneously, particularly in homes with both electric vehicle charging and heat pumps. This is a new aspect for households to consider, and they may not necessarily have the knowledge or awareness of coordinated control and its potential impact on their daily habits. Until now, most Swedish households have not had to consider when they use electricity or whether several large power consumers are running simultaneously. But as peak tariffs become more common and the electricity prices fluctuate more, households are receiving clear signals that power issues are something they need to consider, which can significantly impact their electricity bills.

To reduce power peaks and keep costs down, the homeowners' need for a flexible electricity usage is increasing, especially for those with both electric heating and an electric vehicle. These households are becoming more common. As of September 2024, there were 630,000 rechargeable cars in Sweden, and it is expected that there will be about 2.5 million rechargeable vehicles by 2030. At the same time, 800,000 of Sweden's approximately 2 million single-family homes are heated with a heat pump connected to a hydronic heating system. One advantage of electric loads related to heating and electric vehicle charging is that they can be shifted in time within certain limits, offering the potential for lower power peaks.

Coordinating heat pumps and EV charging

For single-family homes with hourly electricity pricing and a network fee based on the home’s power peaks, control strategies that focus solely on electricity prices risk leading to higher network fees due to high power peaks. Similarly, a strategy that focuses only on minimizing power peaks may result in unnecessarily high electricity consumption during hours with high electricity prices. Therefore, the study has focused on the potential of a control strategy that considers both components. Costs are kept down by maintaining low power peaks while simultaneously shifting the electricity consumption of the heat pump and car charging to hours with low electricity prices.

The economic potential of a smart control has been evaluated through simulations. The case study developed was based on a fictional 160m^2 single-family building located in Norrköping on the Swedish east coast, 150 km south of Stockholm. The villa is assumed to have a heating demand of 9 kW during the coldest hour of the year, which in the base case is met by an 8kW ground source heat pump that also produces the domestic hot water. When the heat output from the compressor is insufficient, the heat pump’s auxiliary heater kicks in to cover the remaining heating needs. In each scenario, we modelled households with electric cars that follow their unique driving patterns and are charged at home every night using an 11kW charger. The car usage is based on real-world data collected with GPS for 1-3 months from about 400 passenger cars representative for Swedish driving.

The developed control strategy for combined heat pump operation and electric car charging starts by scheduling the heat pump's heating of the house, followed by scheduling the car charging. The heat pump is controlled so that the house's heating is shifted to hours with low electricity prices, while the total electrical power remains below previous maximum values for the current month. Since heating flexibility depends on the house's thermal inertia and varies from house to house, the study assumes a house that can choose the cheapest hours to meet its heating needs within an eight-hour window. The fact that the house can handle periods of up to eight hours does not mean that these periods are always eight hours. The control algorithm determines the period length, from one to eight hours, for each period. The study also assumes that the electric car is plugged in in the evening and fully charged every night. Other household electricity and the heat pump's production of domestic hot water are not controlled and are considered as a base load.

Potential for cost savings

The left part of Figure 1 shows the total electricity costs for the simulated 400 households, presented for two scenarios: one with active control (red) and one without active control (blue). The results are based on data from 2021 and a grid fee from Göteborg Energi. As expected, a longer annual driving distance leads to higher costs due to increased electricity consumption. The figure on the right illustrates the annual savings, calculated as the difference between the two scenarios, with the average savings potential amounting to approximately $470 per year, which correspond to 20% of the total annual electricity costs for the villa. Note that for households with the same annual driving distance, savings can vary by up to 40%, primarily due to daily driving patterns. Spreading driving over many days provides greater flexibility in charging, enabling higher cost savings compared to fewer days with more intensive driving and charging. About 70% of the savings, or $330, relate to avoiding costs associated with peak tariffs, while 30% relate to savings achieved by shifting consumption to hours with lower electricity prices, which averaged around $140 per year. The savings potential is shown as the difference between two extremes, either no control strategy at all or a fairly advanced strategy. In the case without any control, the electric car is charged at high power (11kW) as soon as the driver get home in the afternoon. Part of the savings can be achieved through simpler control strategies, such as reducing the power of the electric car charger or starting the charging after midnight.

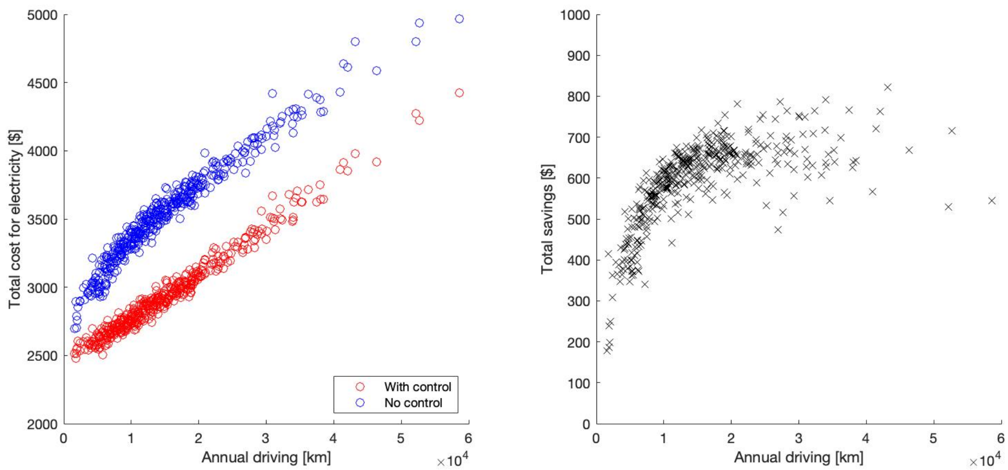

Figure 1. Left: Total annual cost per household for electricity price and power tariff, sorted by annual mileage, for the scenario with active control (red) and without control (blue). Right: Annual total cost savings, sorted by annual mileage.

The annual savings from coordinated control increase with the driving distance up to about 10,000 km per year, after which they level off. Part of the explanation is that a significant portion of the savings consists of reduced peak tariff costs, which do not decrease further with additional mileage. Variations in electricity prices between different years also play a significant role in the results. For example, 2022 had higher electricity prices compared to 2021 and 2023, leading to savings from coordinated control being about 40% higher in 2022 compared to the other years.

To simulate a villa with an exhaust air heat pump, the maximum compressor output of the heat pump was reduced to 3 kW, resulting in an increase in total electricity costs, mainly due to higher energy consumption associated with increased use of the auxiliary heater. However, the smaller heat pump also offered fewer opportunities for savings through active control. This is because longer operating hours at higher outputs reduce the flexibility to shift electricity consumption to periods with lower prices and make it harder to keep the power peaks down. The same trend of reduced savings potential was observed when the house's P-design (i.e. heating demand in the coldest hour of the year) was increased by 30% to represent a house with higher heating demand but with the same heat pump. Reducing the house's P-design by 30%, however, only provided a small additional savings potential, which can be interpreted as the heat pump in the base case already having significant flexibility to schedule heating.

Social aspects affect the saving potential

Behavior related to heating and electric car charging significantly affects the potential for savings from coordinated control. For households, coordinated control introduces new aspects to consider in daily life. Previously, most people did not have to think about when they use electricity, but with power tariffs and varying electricity prices, this is becoming increasingly important to keep the costs low.

We have seen a clear technical potential for coordinated control in the study, but it must be understood in its social context. Households' practices, norms, and expectations play a crucial role in how the technology can be implemented and used effectively. Expectations for an available, fully charged electric car and norms around indoor temperature can challenge the possibilities for flexibility.

Coordinated control of heat pumps and electric car charging offers a promising solution for managing peak electricity demand and reducing energy costs in single-family homes. However, realizing this potential requires increased awareness and knowledge among households, as well as technical solutions that are user-friendly and adapted to their needs and daily practices.

In the future, we can expect more households to prioritize and plan their electricity use to reduce peak demand and electricity costs. With the right support and information, coordinated control can become an important part of a sustainable and efficient energy system.

About the project

This article is based on findings from the ongoing Swedish research project "When the Electric Car Moves in! - The Social and Technical Potential with Coordinated Control of Heat Pumps and Electric Car Charging in single-family Homes" which has been funded by the Swedish Energy Agency, and is being carried out in collaboration with researchers from RISE Research Institutes of Sweden and Dalarna University along with industry partners.

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Non-Topical Article

R744 Heat Pumps with Ejectors for Heating and/or Cooling: Opportunities, Challenges, and Results

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R744 heat pumps with ejectors are driving decarbonization in sectors needing heating and cooling, such as hotels, hospitals, schools, food processing, district heating/cooling, etc. Traditionally reliant on fossil-fuelled heating and separate cooling systems, these sectors benefit from R744 heat pumps integrated with thermal storage, boosting efficiency and supporting demand response to lower peak energy use. This study explores the opportunities and challenges of deploying R744 heat pumps with ejectors, comparing energy performance to systems without ejectors in a Mexico City hotel, and presenting test data from the Schaufler Academy in Germany.

1. Introduction

In the late 1980s, Gustav Lorentzen revolutionized refrigeration technology by advancing modern R744 (CO_2) systems, enabling its use in heat pumps and refrigeration [1]. R744, known for being non-toxic, non-flammable, odorless, and colorless, has become popular as a refrigerant due to its low global warming potential (GWP) of 1 and zero ozone depletion potential (ODP). Its low critical temperature of 31.1°C enables heat rejection in the supercritical region, making it particularly effective for applications needing high temperature increases, such as hot water production [2]. Innovations in compressors, heat exchangers, and ejectors have expanded R744 heat pump technology across residential, commercial, and industrial sectors [3]. R744 heat pumps offer efficient heating and cooling, supporting decarbonization goals and serving as a sustainable alternative to fossil fuel-based systems. They also provide potential long-term cost savings through improved energy efficiency. Ejectors play a critical role in recovering expansion work, boosting system efficiency, and reducing costs [4]. This study explores the challenges and benefits of deploying R744 heat pumps with ejectors in commercial and industrial settings, with case studies from a hotel in Mexico City and the SCHAUFLER Academy illustrating system performance with and without ejectors.

2.1 Commercial and industrial heat pumps

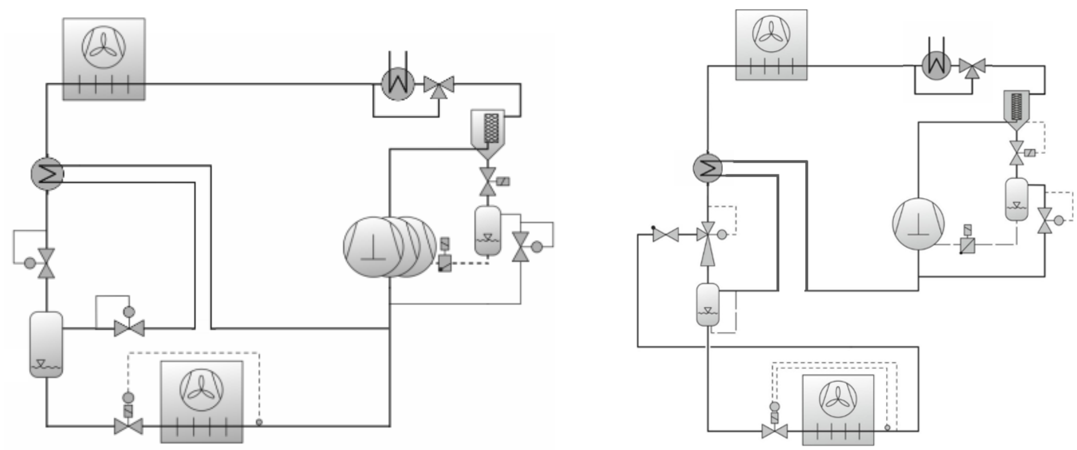
As sustainability becomes a global priority, transforming heat generation across sectors is essential. Traditional fossil-fuel heating systems contribute heavily to environmental impact, which is why R744 heat pumps are now widely adopted for decarbonizing and electrifying heating in commercial and industrial settings. These systems provide sustainable heating and cooling for various sectors, using multiple reciprocating compressors in parallel to handle loads from 40 kW to 3 MW per rack. By leveraging renewable sources like air or water, these heat pumps operate efficiently with high COPs. Ejectors are increasingly used to enhance R744 heat pump efficiency, supporting energy-saving, improved efficiency, and sustainable energy goals.

2.2 Adjustable ejectors

Simon et al. [5] describe an ejector as a jet pump-like device that recovers expansion energy typically lost during throttling to compress another fluid, enhancing system efficiency without extra electrical input. Utilizing R744's thermodynamic properties and the Venturi effect, ejectors create a pressure lift. Optimal performance relies on the pressure hub (difference between ejector outlet and suction inlet pressures) and the entrainment ratio (suction-to-motive nozzle mass flow ratio). Adjustable, variable-geometry ejectors allow precise load adaptation and operate from 800 to 9500 kg/h mass flow. Models like the HDV-E95, delivering 286.4 kW, effectively replace high-pressure valves and improve COP across various load conditions.

2.3 R744 heat pump installed in a Mexico City hotel

This study compares the impact of adjustable ejectors on an air-to-water and water-to-water R744 heat pump system with a flash-gas bypass (FGB) system, as shown in Figure 1. Installed at a luxury Mexico City hotel in July 2022 and manufactured by ICE-SQUARE, the R744 heat pump delivers 250 kW of heating and 180 kW of cooling. Key components include three Bitzer transcritical compressors, evaporators, a heat recovery system, an air-cooled gas cooler, flash gas tank, control valves, and a low-pressure oil management system. Cooling is achieved via direct expansion of R744, while heating is provided through de-superheating in the heat recovery heat exchanger. The system heats water from 25°C to 65°C and cools it from 12°C to 7°C, with separate 10,000-liter thermal storage tanks for heated and chilled water. These tanks reduce peak demand costs by storing water for pools, jacuzzis, hot water, and air conditioning across 54 rooms and common areas (Figure 2).



(a) **(b)**

Figure 1: Simplified schematics showing (a) flash-gas bypass system, and (b) ejector low-lift system

Figure 2: R744 heat pump system and the water thermal storage tanks

Since the heat pump operates transcritically, high motive nozzle energy is expected, making ejector impact on efficiency significant. Energy efficiency and setup comparisons between both systems are analyzed, with ejector low-lift system behavior demonstrated per Table 1 parameters.

Table 1: R744 heat pump operating conditions

Cond.	t_{amb} [°C]	$t_{gc,\ out}$ [°C]	to [°C]	$t_{WaterIn}$ [°C]	$t_{WaterOut}$ [°C]	Qo_{AirCon} [kW]	$\dot{Q}_{Heat}$ [kW]
A	35.0	37.0	3	25	65	180	250
B	32.0	34.0	3	25	65	144	250
C	29.0	32.0	3	25	65	108	250
D	26.0	28.0	3	25	65	72	250
E	20.0	22.0	10	25	65	0	250

The heat recovery water return temperature is 25°C, with a supply temperature of 65°C and a pinch point of 2K. Suction line, evaporator, and IHX flash gas superheat are set to 5K. Peak heating capacity remains consistent across conditions, with an evaporating temperature of 3°C for scenarios A, B, C, and D, assuming a room temperature of 20°C. Ambient temperature varies, and gas cooler outlet temperature is set 2K above ambient. High pressure adjusts for maximum energy efficiency. Cooling capacity for part-load operation is interpolated linearly between 35°C and 20°C, with free cooling applied at 20°C ambient. Operating condition E uses only air for cooling, setting the evaporating temperature at 10°C.

The ejector system operates as a flash gas bypass or ejector low-lift system based on conditions. COPCool calculations consider only the required air conditioning cooling capacity (Qo_{AirCon}). Total cooling capacity (Qo_{Tot}) includes both the evaporator for air conditioning and the evaporator in the gas cooler frame, as shown in Table 2. FGB calculations use BITZER R744 software, with ejector performance estimated through an advanced, low-lift ejector model in development and refining [5]. Performance uncertainty meets EN12900:2013 standards [6].

Table 2: System setup and performance for investigated operating conditions

	pDif [bara]	pc [bara]	$t_{gc, out}$ [°C]	t_M [°C]	f_{Comp1} [Hz]	Displ. [m^3/h]	Pe [kW]	UT [%]	$Qo_{Tot.}$ [kW]	COP_{Cool} [-]	COP_{Heat} [-]
A (FGB)	44.0	92.0	37.0	-	69	59.9	73.9	-	182.8	2.44	3.38
B (FGB)	44.0	92.0	34.0	-	57	55.6	68.3	-	188.8	2.11	3.66
C (FGB)	44.0	92.0	31.0	-	50	53.1	65.2	-	194.2	1.66	3.83
D (FGB)	44.0	94.0	28.0	-	42	50.2	63.1	43	194.3	1.14	3.96
E (FGB)	50.0	94.0	22.0	-	27	44.8	56.1	30	237.0	-	4.47
A (Ejec)	44.0	90.0	37.0	35.7	52	53.8	63.3	88	185.9	2.84	3.96
B (Ejec)	42.5	92.0	34.0	32.0	43	50.6	61.6	73	192.5	2.34	4.06
C (Ejec)	40.5	92.0	31.0	28.8	43	50.6	61.9	57	195.8	1.74	4.04
D (Ejec/ FGB)	44.0	94.0	28.0	27.1	42	50.2	63.1	43	194.3	1.14	3.96
E (Ejec/ FGB)	50.0	94.0	22.0	21.7	27	44.8	56.1	30	237.0	-	4.47

The ejector system requires one HDV-E95 ejector and one HDV-E30, with the latter only needed for operating condition A. Table 2 presents the system's performance. "Utilization" refers to the needle position in the motive nozzle, where 100% means fully open and 30% means 70% closed. Ejector operation is defined by evaporating temperature and diffusor outlet pressure (pDif). The system uses the same compressors as the FGB system: two 4FTE-30K and one 4HTE-20K, with one 4FTE-30K, using a frequency inverter, operating at 60 Hz in Mexico.

For condition A, COPCool is 2.44 for the FGB system and 2.84 for the ejector system; COPHeat is 3.38 for FGB and 3.96 with ejector, yielding a 16.7% efficiency gain. The ejectors boost compressor suction pressure, increasing density, with combined compressor displacement at 53.8 m^3/h for the ejector system versus 59.9 m^3/h for FGB. Heating capacity of 250 kW is consistently met.

Condition B shows a 10.9% COP improvement. Lower gas cooler outlet temperature results in more liquid refrigerant exiting the ejector, necessitating a higher entrainment ratio, reducing pressure lift and efficiency gains.

For condition C, COP improves by 5.3%. Lower pressure hub reduces displacement difference between ejector and FGB systems; the high 67% entrainment ratio is theoretically feasible but requires field verification.

Conditions D and E demand high entrainment ratios, preventing stable stand-alone low-lift operation. Alternatives include FGB mode, using a three-way valve to raise gas cooler outlet temperature, or a pump to return liquid refrigerant to the flash tank. The ejector functions as a high-pressure valve, with 43% and 30% utilization in conditions D and E, respectively, enabling varied part-load operation.

2.4 SCHAUFLER Academy

R744 compressor operating conditions in refrigeration systems are influenced by numerous factors, with system concept playing a key role. For manufacturers, ensuring safe compressor operation is essential. BITZER enhances compressor safety and efficiency by integrating innovative designs and technologies into R744 compressors. Additionally, application-specific guidance, training, and mathematical modeling during planning increase reliability. The SCHAUFLER Academy in Germany provides training on natural refrigerants and serves as a testing ground for practical measurements. This study focuses on a water-to-water R744 heat pump with an ejector in a low-lift application, enabling comparison between ejector and flash gas bypass (FGB) operation modes for district heating.

The subject of this work is a water-to-water R744 heat pump with ejector, as illustrated in Figure 3. The system is designed as a low-lift application with an ejector. The operation can be switched to standard FGB operation to compare the efficiencies of two different operation modes, especially with a focus on heat pumps for district heating. A simplified schematic of the system design discussed is shown in Figure 4.

Figure 3: R744 heat pump system in the SCHAUFLER Academy

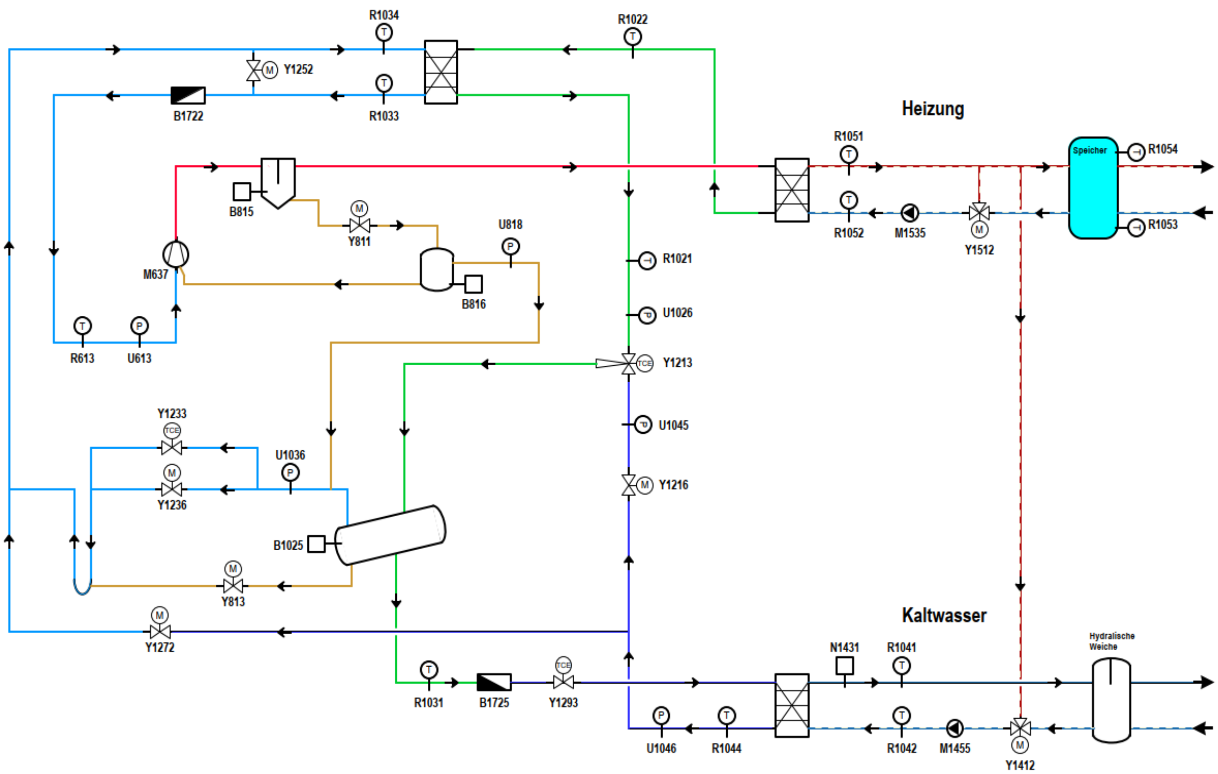


Figure 4: Simplified diagram of the R744 heat pump system in the SCHAUFLER Academy

Figure 5 shows an example of operation at partial load in conditions as steady as possible. The compressor ran constantly at an operating frequency of 41 Hz.

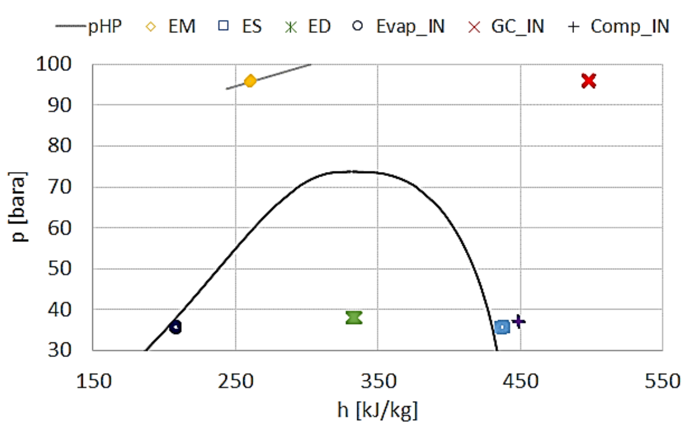


Figure 5: Example of a measurement taken over 60 minutes

Table 3 outlines operating conditions with low motive mass flow temperature and reduced nozzle area, averaging 51 ± 4%. Key performance metrics show a pressure lift of 2.7 ± 0.7 bar and an entrainment ratio of 0.689 ± 4.5%. The ejector's diffusor outlet enthalpy averages 332.8 kJ/kg, with vapor quality at 0.565 ± 1.7%. Approximately 6.3% of liquid mass flow is missing, causing a -1.2 kJ/s imbalance around the medium pressure vessel, suggesting a potential liquid level rise, though unlogged. At this point, the average efficiency is 21%, as shown in Figure 6, relating entrainment and efficiency to pressure lift.

Table 3: Overview of the discussed part load operating conditions

State point	abbreviation	unit	p [bara]	t [°C]	h [kJ/kg]
Compressor in	Comp_IN	[-]	38.1 ± 0.4 bar	15.0 ± 0.3 K	448.8 ± 0.9
Gas cooler in	GC_IN	[-]	-	94.3 ± 0.5 K	498.0 ± 0.8
Ejector motive in	EM	[-]	96.0 ± 0.5 bar	26.1 ± 0.3 K	260.6 ± 0.8
Ejector suction in	ES	[-]	35.5 ± 0.6 bar	4.6 ± 1.6 K	437.6 ± 2.5
Ejector diffusor out	ED	[-]	38.1 ± 0.4 bar	-	332.8 ± 2.1
Evaporator in	Evap_IN	[-]	-	-	208.5 ± 0.9

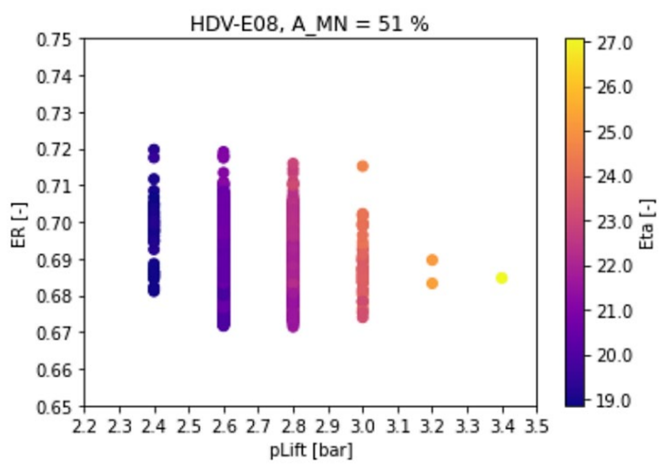


Figure 6: Entrainment and efficiency as a function of pressure lift as derived and discussed

In practice, this means that for such operating points, a liquid pump must be used, as suggested by [7]. The extent to which such operating conditions can be detected in practice and what corrective measures should be taken are the subject of further investigations.

Conclusions

This paper analyzes the energy efficiency of an R744 heat pump with and without ejectors in a Mexico City hotel and evaluates an R744 heat pump with an ejector at the SCHAUFLER Academy in Germany. Results show that adjustable ejectors can enhance system COP, improve energy efficiency, and lower compressor power use and displacement. In Mexico City, high ambient temperatures enable a 16.7% COP boost at 35.0 °C, with a 10.2% reduction in compressor displacement. However, low ambient temperatures challenge stable ejector operation due to increased entrainment needs. Tests at the Academy indicate that heat pump performance with a low-lift ejector depends on suction mass flow and entrainment, especially under varying heat sink temperatures. Matching compressor and ejector mass flow rates, or operating frequency and ejector opening, is essential.

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National Market

Italy: Heat Pump Market Report

DOI:10.23697/65cr-4397

Maurizio Pieve, Raniero Trinchieri, ENEA, Marco Dall'Ombra, Federico Musazzi, Assoclima, ITALY

An updated overview of the Italian heat pump market is described in this article, ranging over the last 15 years, during which its position in the European context was maintained among the highest. Despite the recent slowdown, the heat pump sector is very lively, since familiarity with these machines is spreading even among the non-specialist public. Looking to the future, it is crucial that the reliability of investments in heat pumps, both on the manufacturers' and final user sides, is guaranteed. This can be achieved by a more stable framework of incentives aimed at the renewal of domestic heating and cooling systems. Additionally, economic support tools are needed to contain the effects of price fluctuations in electricity prices on international markets.

Introduction

During the presentation of the annual review regarding statistical data on space heating and cooling equipment at Mostra Convegno Expocomfort held in Milan last spring, [1] the president of Assoclima, Maurizio Marchesini, commented on the results, noting that 2023 was a year contrasted and characterized by a series of challenges. The market was, in fact, characterized by two very distinct trends: the residential sector, after the sensational growth in 2022 induced by the incentive called "Superbonus 110" and by concerns related to the availability of gas due to the conflict between Russia and Ukraine, suffered heavily over the unexpected and confusing cut of incentives in 2023, which affected the sales of residential heat pumps, also generating difficulties in related systems, such as terminal units. According to Assoclima, despite the challenges encountered, the future prospects for heat pumps remain positive. The residential sector will have to face the problem of high levels of product stock present in the distribution route, but this does not compromise the enthusiasm for the future of technology. Indeed, at all levels, especially those governing the policies of the coming decades, the primary role of heat pump technology for the decarbonization of residential space heating and cooling and beyond is now undisputed.

The Italian heat pump market
Looking at the national market during the past 15 years and beyond, all the space heating and cooling equipment sales, including cooling-only units, DHW, and hybrid systems, show the trend in Figure 1 [2, 3].

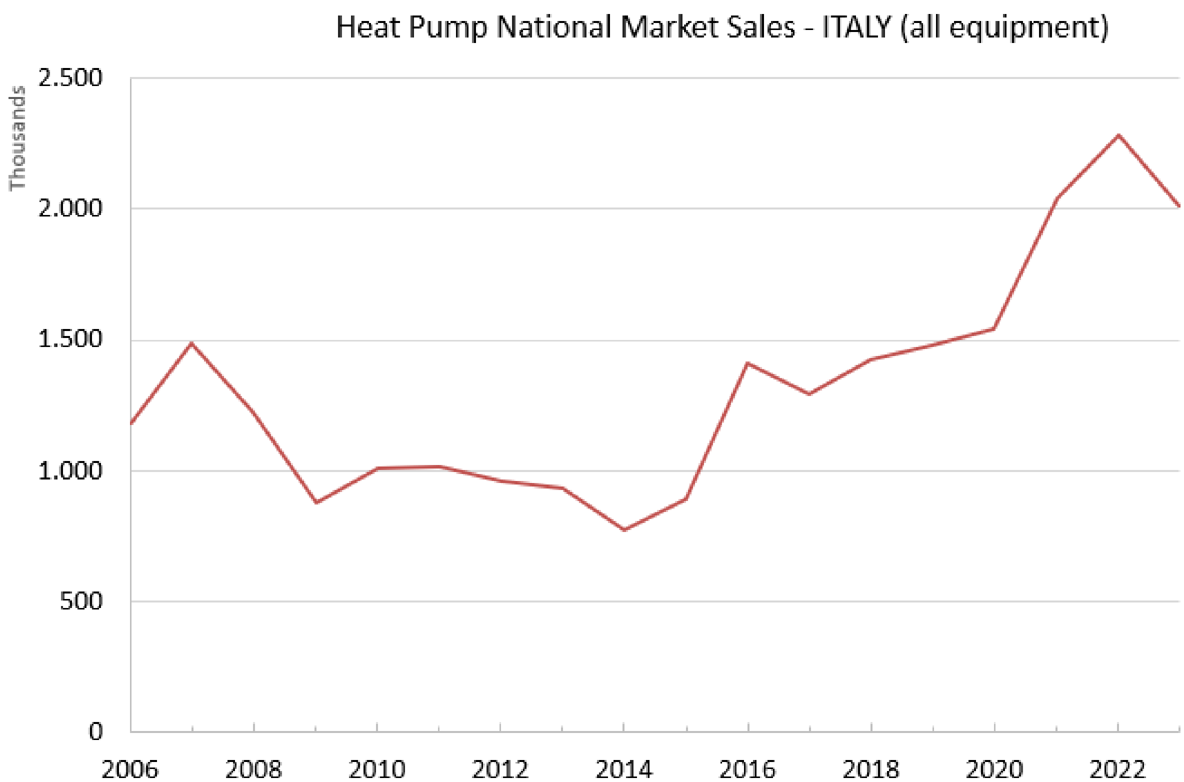

Figure. 1: Annual sales of air conditioning components, including reversible and cooling-only equipment

As detailed in a previous report on the Italian market [4], when considering the heat pumps used as the main system for space heating, the contribution of the air-to-air heat pumps share is considerably reduced since a percentage of only about 10% is taken into account.

After such a statistical correction, the Italian HP (primary heating only) market appears as Figure 2 shows [2, 3, 5].

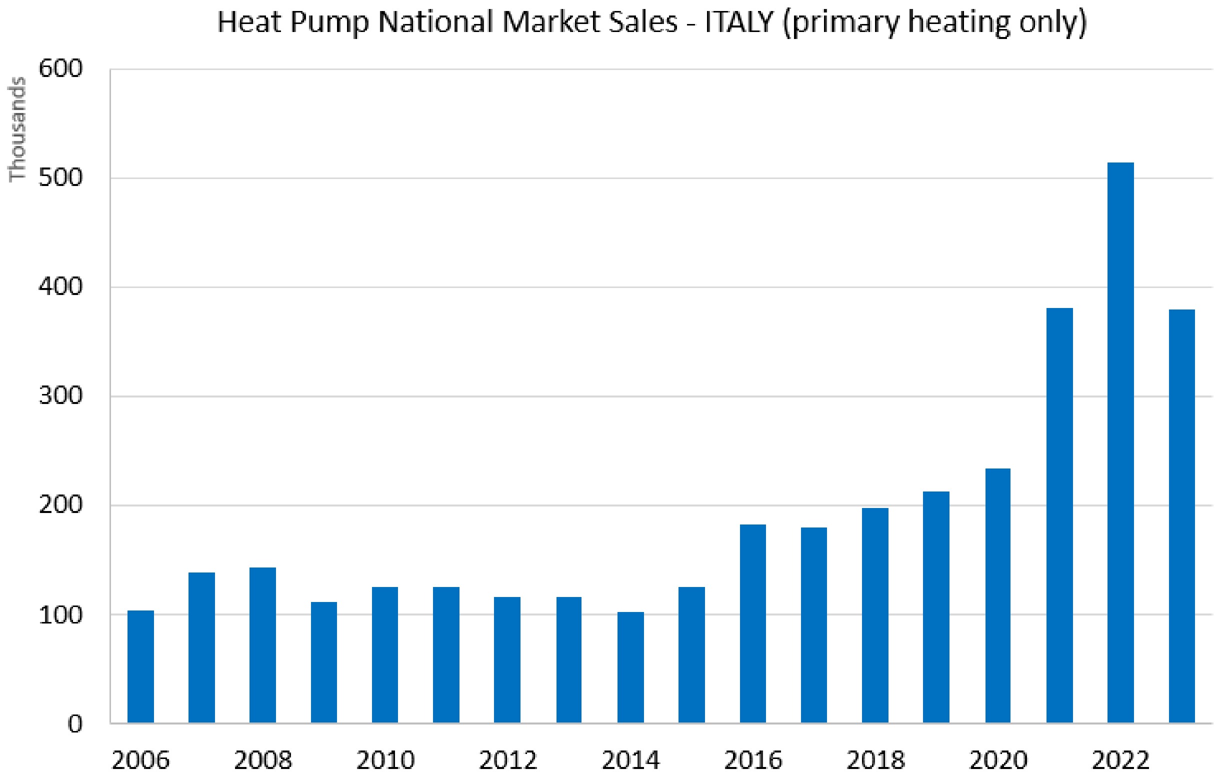

Figure 2: Annual sales of heat pumps for heating service in Italy – 2006-2023

Over the last ten years, the average annual sales of heat pumps have been around 250,000, peaking in 2022 at about 513,000. The first relevant boost came in 2014, when a special tariff was introduced, available only to residential users adopting a heat pump as the main heating system. A progressive sales growth until 2020 is probably also attributable to increasingly hotter summers, which drove sales of air-to-air machines, almost all usable in heat pump mode as well. After that, aiming at responding to the economic crisis due to pandemics, a measure named Super Ecobonus (or Superbonus 110) was introduced, regarding all-round building renovations, including space heating equipment [6]. This measure caused the sales of heating systems to soar and, proportionally, heat pumps even more. Naturally, this surge was followed by a rebound the following year, when the incentive measures were progressively reduced and then cancelled. The share of heat pumps considered as a whole, over the total space heating equipment sales, passed from an average value of about 12% during the first half of the 2010s up to more than 26% in the last 5 years.

Not only air-to-air machines

In addition to air-air, which represents the majority of sales on the market, it is interesting to observe the trend of other types in recent years. Figure 3 [2, 3, 5] compares the shares of

2016 vs 2023, from which the main relevant result is the increasing percentage of non-air-to-air equipment.

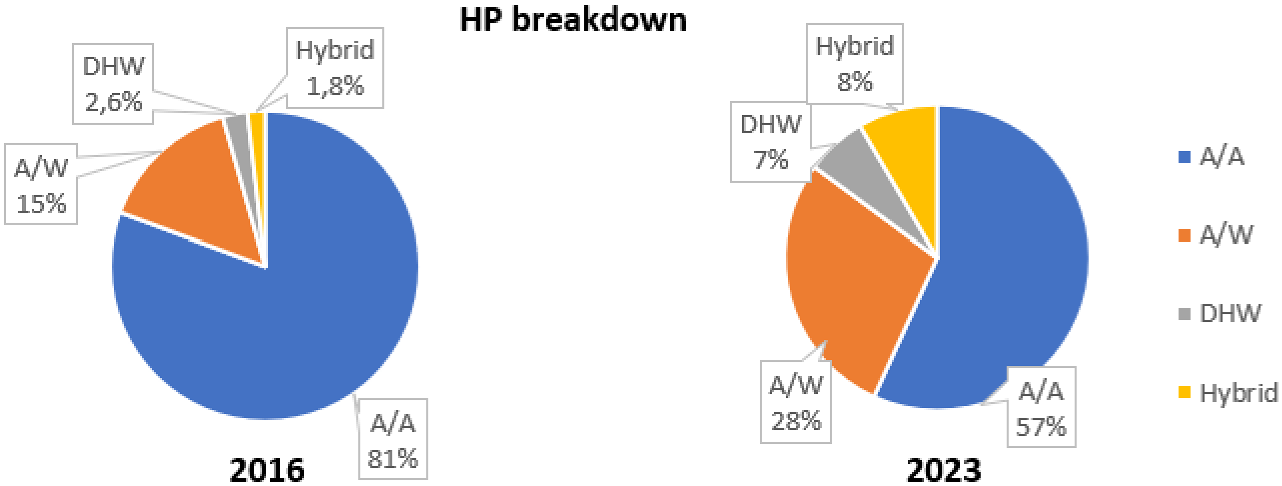

Figure 3: Breakdown of heat pump sales for space heating and DHW production in 2016 and 2023

Figure 4 [2, 3] shows a more detailed breakdown of such machines, i.e., air-to-water, domestic hot water production, and hybrid heat pumps. Sales of the latter were driven both by the incentives of recent years and, above all, by greater confidence among installers and designers with machines similar to boilers. Moreover, they were easier to accept for end users who came from an old system with a gas boiler.

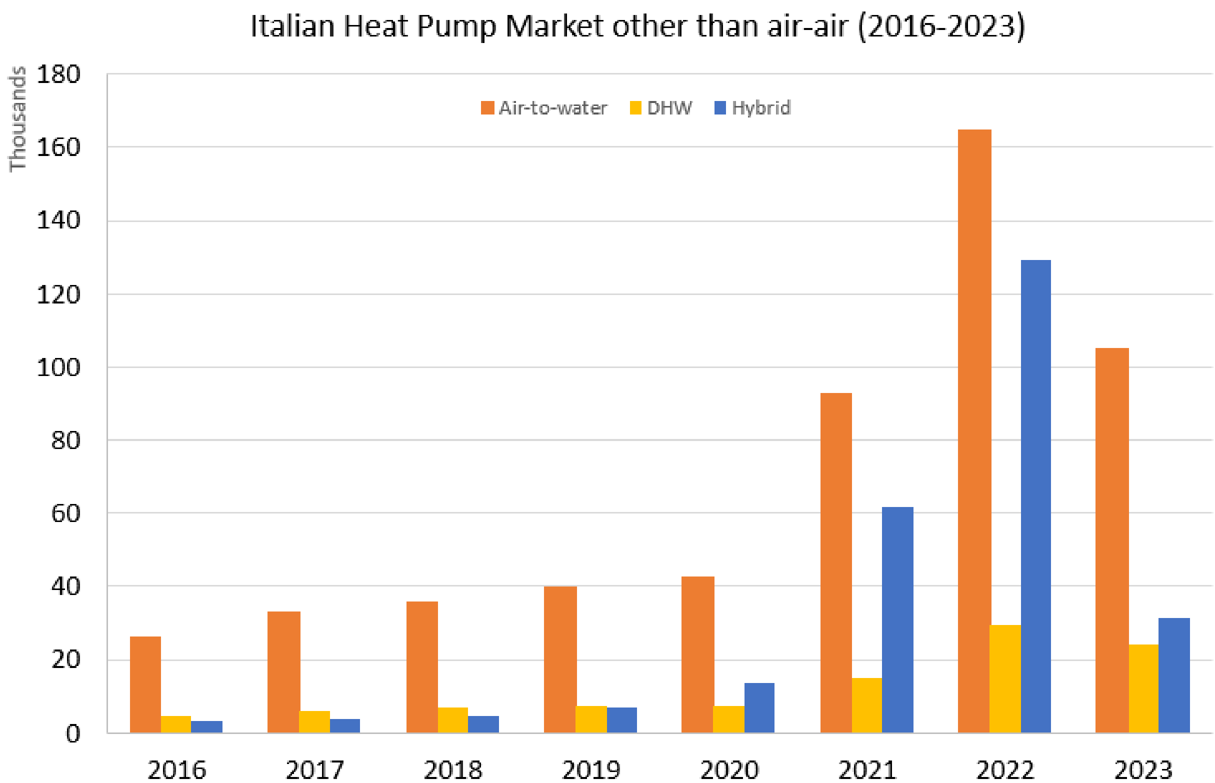

Figure 4: Italian heat pump market for air-to-water, DHW, and hybrid heat pumps

At the European level, for several years, the Italian heat pump market has been firmly placed among the highest positions: in the last 15 years, it has been almost always the second largest market, with a share between 13% and 18%. In 2023, Italy lost a position due to the drastic reduction in sales, better explained before after an impressive peak in 2022; in 2023, sales returned to levels very close to 2021. The most recent composition by country in the EU and by type, according to EHPA [5], is shown in Figure 5.

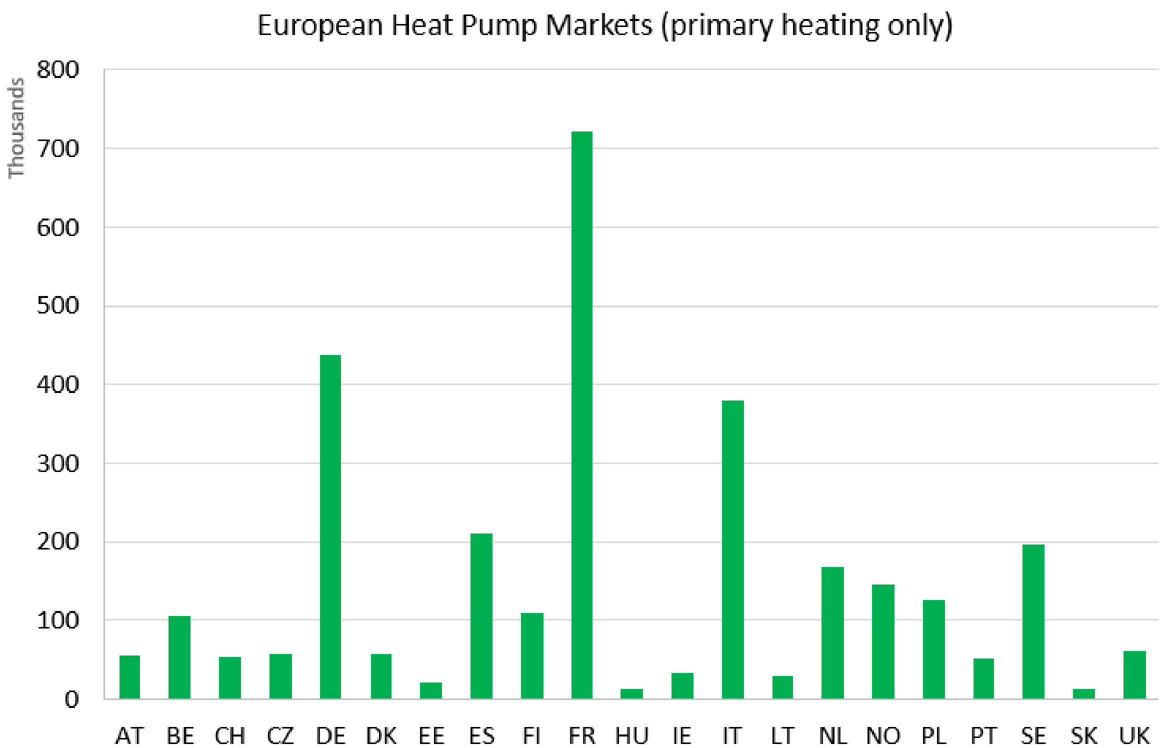

Figure 5: Heat pump market in Europe in 2023 according to EHPA statistics

Incentives and barriers

For some years now, heat pumps have benefited from the main tax incentives reserved by the legislation for high-efficiency systems to achieve energy savings. This means heat pumps have been recognized as a strategic technology in the energy requalification of buildings, and for this reason, they are encouraged, alternatively, through the following tools:

- Ecobonus, i.e., the tax deduction equal to 65% of the expenses incurred for replacing existing space heating systems with heat pumps; between 2021 and 2023, this particular incentive had been strengthened, reaching up to a deduction rate of 110%, under particular conditions regarding the overall renovation of the building. Currently, the percentage of the tax credit has been decreased to 70% for 2024 and 65% for 2025. For low-income households, a mechanism is set up to integrate the sums not covered by the incentives.
- “Conto Termico 2.0” (Thermal Account 2.0), introduced in 2016 for interventions aiming at producing thermal energy from renewable sources and for increasing energy efficiency; the incentive is calculated based on the thermal energy produced.
- “White certificates” incentive, one of the oldest, provides a grant proportional to the energy saving arising from an efficiency improvement, differentiated depending on the final use and sector.

In a previous heat pump report [4], one of the main bottlenecks in the flow of steps necessary to increase the diffusion of heat pumps on the market had been identified in installers, still largely anchored to the world of boilers and reluctant to renew their culture towards more complex machines. Currently, this is still a crucial point, combined with the lack of stability of incentives: the recent experience of the Superbonus 110, which left as an important consequence a great uncertainty even among final users, has taught that it is essential to guarantee continuity, stability, and coherence of the incentives in relation to the energy efficiency that entails the use of a heat pump compared to existing alternatives.

Conclusions

The Italian heat pump market is lively, despite the trend of last year, which marked a setback following the drastic reduction of incentives and turned out to be perhaps too generous. In a country that boasts a very strong tradition of production and export of this technology, the trends of the last decade give rise to hope, with an average of about 250,000 units sold annually, even if much remains to be done, especially in the diffusion of culture in a broader sense, in overcoming old patterns linked to fossil fuels, and in giving stability of incentives.

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