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Winter is Coming.
Where are the Heat Pumps?

Assessing heat pump viability in residential buildings – a multifaceted perspective

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Executive Summary

The imperative to forge a path towards cost-effective decarbonisation has never been more pressing. And in that regard, an up-close look at the heating of our building stock is indispensable. Pathways towards a cost-effective decarbonisation of the building stock all consistently point in the direction of a common outcome: combined with demand reduction, a massive deployment of heat pumps is needed, complemented by district heating.

Building performance policies, coupled with the energy crisis and heightened awareness of the energy transition, have spurred a surge in heat pump sales across Europe. While this rapid momentum is notably pronounced in new constructions, the transition is still gaining traction in existing buildings. This paper summarises the research findings obtained for Flanders, Belgium by the Smart Energy and Built Environment Unit of EnergyVille/VITO and offers evidence-based insights into five pivotal elements that influence the viability of heat pump deployment in residential buildings.

Favourable market conditions for heat pump rollout in existing buildings

Initial investment cost is a crucial deciding factor when it comes to purchasing a heat pump, and it depends on three main elements: the capacity of the heat pump, the type of heat source, and the installation cost. Furthermore crucial for the investment cost in existing buildings is whether the existing heat distribution system suffices for proper operation or not.

Another particularly influential factor for the rollout of heat pumps is the relationship between electricity and fossil fuel prices. This price ratio varies significantly–both over time and from country to country, as it is highly dependent on the geopolitical context and policies. For a price ratio of 4.5—on average in line with prices in Flanders between 2015 and now—it is not interesting, in terms of operational costs, for buildings with any insulation level to operate a heat pump. In general, the tipping point for the profitability of operating a modern heat pump in the Belgian context occurs at electricity-to-gas price ratios below 2.5.

Technical feasibility

The technical feasibility of heat pumps is well-established, as they operate on the principles of thermodynamics and have been proven effective for both heating and cooling applications. Advances in technology have led to the development of highly efficient and reliable heat pump systems, making them a technically viable and sustainable option for residential, commercial and industrial heating and cooling needs.

The possibility of installing a fully electric heat pump is mainly determined by the energy performance of the building and the design temperature regime of the delivery system. Lowering the supply temperature of the hydronic heating system can also allow for a low-temperature system, thus decreasing the cost of the heat pump.

Contribution of a PV system

Heat pumps require a substantial amount of electricity to operate, which often leads to the suggestion of installing solar photovoltaic (PV) panels to cover the heat pump electricity consumption. The context of energy market reform has, however, turned the economic sense of combining heat pumps with PV panels into a somewhat more subtle question. With low feed-in tariffs and a shift to capacity-based network charges, it is important to maximise self-consumption of this combination of technologies.

Our research finds that the self-consumption is low—due to both a seasonal and time-of-day mismatch of the heating demand and the PV production. An average load cover factor of just under 10% was found for typical Belgian heating profiles. By using intelligent control that responds to the thermal buffer capacity of buildings, the electricity demand can be shifted by a few hours in well-insulated buildings in order to improve the match with local PV production. The coverage of heat demand by PV in this case is still limited to approximately 15 to 20%.

Role of the heat pump in cost-optimal renovation

The assessment of the cost-effectiveness of various energy performance levels of 135 reference buildings allowed for a comparison between heat pumps and condensing gas boilers in terms of cost-optimality and cost-effectiveness. Running calculations for the theoretical EPC approach showed that the total lifecycle cost for the heat pumps decreases for the lower energy price ratios and is about the same as for gas boiler solutions for a ratio around 2.5. In this case, heat pumps are part of the cost-optimal solutions.

The picture is quite different when looking at the estimated "real" consumption, where the total cost of the current state is always lower than that of solutions with a heat pump, especially for badly insulated buildings. This because the "real" current consumption is much lower than the EPC-calculated consumption for low energy performance levels. The differences in "real" use and EPC-calculated use are a result of two effects. The prebound effect, under which occupants of badly performing buildings reduce their energy use below standard comfort levels to save money. And the rebound effect, under which occupants consume more energy after renovation to improve their comfort compared to before.

When improving the buildings performance towards 100 or even 200 kWh/m^2, heat pumps do become the most cost-effective system for the lower energy price ratios. Thus, while lower price ratios are vital, deciding factors beyond purely financial considerations—such as regulation and comfort, or value increase—are equally needed to justify the viability of heat pumps.

Grid impact

Heat pumps can assist the grid if smart control is used, and the system is designed for both efficiency and flexibility. However, when such smart control is not in place, heat pumps – just like other large loads, such as electric vehicle charging–may create congestion and power quality problems in the local grid. Cumulatively, in the electricity system of a region or country, they may lead to increased demand for electricity production and distribution capacity. When proposing decarbonisation policies focused on the electrification of heating, it is therefore important to consider the potential impacts on the security of supply and grid stability. Something which equally entails that grid operators need to stay up to date and foresee scenarios that reflect ambitious policies for heating electrification, even more so in the face of the parallel electrification of mobility.

Key recommendations to accelerate the rollout of heat pumps

Fact-based information, benefits and applications of the rollout of heat pumps are needed to support both policymaking and implementation on the ground. This position paper therefore concludes with the following six key recommendations to accelerate the rollout of heat pumps in residential buildings.

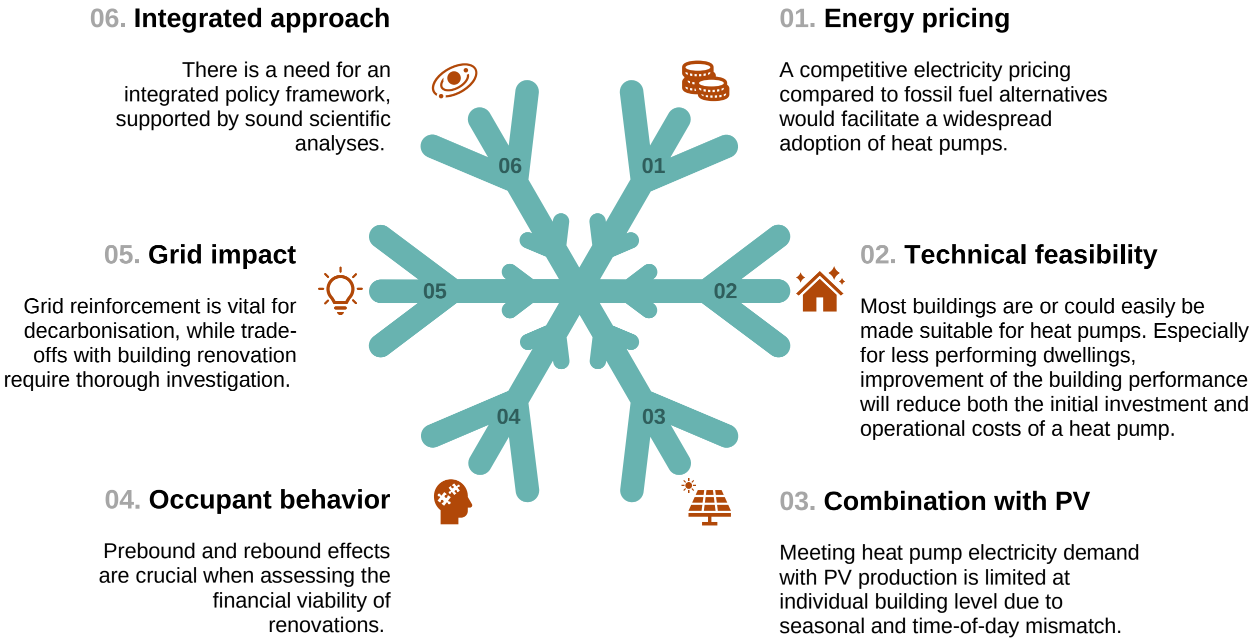

Figure 1: Recommendations to expedite the deployment of heat pumps in residential buildings[1].

[1] Designed by PresentationGO: Free PowerPoint templates and Google Slides themes - PresentationGO

Introduction

Backdrop

There is no beating about the bush in the latest report by the United Nations' Intergovernmental Panel on Climate Change (IPCC): in the face of the escalating challenges posed by climate change, the imperative to forge a path towards cost-effective decarbonisation has never been more pressing [1]. Hand in hand with the need for urgent and impactful measures, go strategic choices that consider an integrated societal approach. And in that regard, an up-close look at the heating of our building stock is indispensable—both in terms of the role different technologies can and should play, and in terms of the balancing act between demand reduction and decarbonising our heat supply.

In the autumn of 2022, EnergyVille launched PATHS2050 — The Power of Perspective, an online platform which offers key insights into achieving a cost-effective decarbonisation of Belgium across an array of different sectors. And, when looking at the results of the currently explored scenarios for the building stock, we see they all consistently point in the direction of a common outcome, regardless of the scenario considered: combined with demand reduction, a massive deployment of heat pumps is needed, complemented by district heating.[2]

The combination of the above thus incentivised the EnergyVille/VITO research team of the 'Smart Energy & Built Environment' Unit to summarise their own substantial research efforts regarding the support of policies and the implementation of projects involving heat pumps. This position paper is the fruit of their labour.

The rise of the heat pump

Heat pumps are a mature technology that, in recent years, has consistently been improved to allow for versatile individual and collective applications in the residential sector. Meanwhile, given that they are very efficient in delivering heat, they are considered to be of paramount importance to decarbonise building stock heating. As a result—within the framework of the EU's commitment to rapidly reduce dependence on (Russian) fossil fuels and fast forward the green transition[3]—we see that policies at both Member State and EU level, coupled with the energy crisis and heightened awareness of the energy transition, have recently moved heat pumps to the forefront of the energy transition.

On a Member State level, heat pump rollout is being facilitated throughout Europe with policies such as bans on gas connections to the grid for new homes in the Netherlands and Flanders[4], mandatory shares of renewable energy in heating systems in Germany[5], and greenhouse gas emission limits to new heating systems in France[6].

Belgium, for example, has recently witnessed a rapid acceleration in the rollout of heat pumps—albeit one which currently seems to be prominently confined to new constructions, with the transition still gaining traction in existing buildings. This acceleration can be attributed to a potent cocktail of the energy crisis, an increased awareness of the energy transition and newly introduced building related policies. In Flanders specifically, the

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[2] EnergyVille Paths 2050: https://perspective2050.energyville.be/residential-commercial

[3] REPowerEU: https://neighbourhood-enlargement.ec.europa.eu/news/repowereu-plan-rapidly-reduce-dependence-russian-fossil-fuels-and-fast-forward-green-transition-2022-05-18_en

[4] In the Netherlands, a ban on the connection to a gas network for new-build homes has been in force since 2018. https://www.iea.org/policies/12207-gas-act-no-mandatory-connection-of-new-buildings-to-gas-grid Also in Flanders there is a general ban on gas connections for new buildings from 2025. https://www.vlaanderen.be/nieuwe-verwarmingsinstallatie-kiezen/geen-aardgasaansluitingen-meer-bij-nieuwe-grote-projecten

[5] Germany intended to effectively ban new gas boilers as of 2024, by requiring new heaters to operate with at least 65% renewable energy, limiting the options to heat pumps, biomass and district heating. After facing strong opposition, this ban was eventually linked to municipal heat plans, and thus postponed to 2026 for large cities and 2028 for smaller cities. Source: https://www.cleanenergywire.org/factsheets/qa-germany-debates-phaseout-fossil-fuel-heating-systems

[6] In France, a 2022 decree requires that the level of greenhouse gas emissions from a new heating or domestic hot water production equipment must be less than 300 gCO2eq / kWh NCV. This de facto sets the end of new coal- and fuel oil-powered heating devices in residential buildings. https://climate-laws.org/document/decree-no-2022-8-relating-to-the-minimum-environmental-performance-result-concerning-the-installation-of-heating-or-domestic-hot-water-production-equipment-in-a-building_de0d

"Warmteplan 2025" (Heat Plan 2025) foresees financial support for the installation of heat pumps, as well as the phasing out of oil boilers and the banning of gas connections in new buildings [6]. Because of all of these factors, sales of heat pumps and heat pump boilers saw an increase of no less than 140% in the first half of 2023 compared to the previous year, with heat pumps representing a quarter of all heating system sales.[7] Thus, while it remains of utmost importance to acknowledge that the uptake in existing buildings is still running at too slow a pace, this rapid acceleration in new constructions is hard to miss. And the same accelerating trend is noticeable on a European level, where sales data from 16 European countries show a 38% increase in heat pump sales in 2022, outpacing the 34% rise in annual sales of 2021 [7], [8].

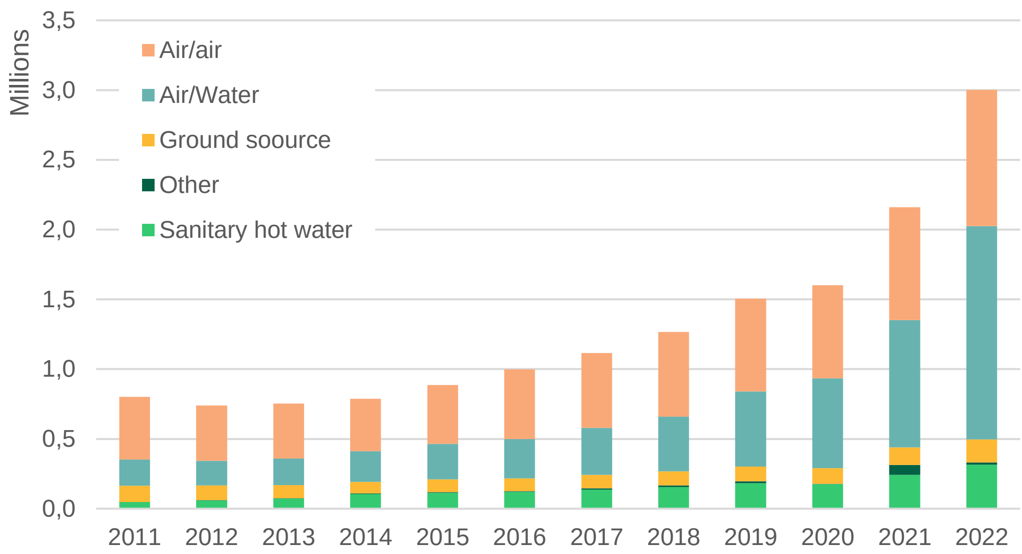

Figure 2: European heat pump sales development by type ("Air/air counts heat pumps with a primary heating function). Source: Adapted from EHPA [8]

At the same time, on an EU level, the European Commission recently initiated a call for evidence and public consultation to establish a dedicated Heat Pump Action Plan[8]—an initiative that aims to further accelerate the heat pump deployment in Europe by focusing on legislation, financing, communication and skill building, as well as by setting up a Heat Pump Accelerator platform that will bring all relevant stakeholders together. With this plan, the European Commission's objective is to install at least 10 million additional heat pumps by 2027.

Bumps in the road

While the public consultation for the Heat Pump Action Plan has consolidated the common understanding that heat pumps will play a significant role in achieving the climate and energy goals of the European Union, it has equally highlighted the fact that substantial effort will be required to sufficiently accelerate the deployment of heat pumps.

Indeed, the bumps in the road are currently still manifold. Grid readiness, building readiness, lower upfront and operational costs, affordability and skilled workers are but some of the main aspects requiring our immediate attention, as identified in the public consultation. At the same time, the lack of reliable and easily accessible information, among others, can be an important factor hampering acceptance of the technology.

[7] (in Dutch) https://www.infowarmtepomp.be/nl/nieuws/verkoop-warmtepompen-stijgt-met-140procent-1-op-4-geplaatste-warmtegeneratoren-is-een-warmtepomp-n-60/

[8] European Commission, Heat Pump Action Plan Initiative: https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/13771-Heat-pumps-action-plan-to-accelerate-roll-out-across-the-EU_en

The need for a compass

In short, more evidence as well as clearer communication are needed to both strengthen policies and promote acceptance and market uptake. All stakeholders across Europe—including policymakers and citizens—could benefit from a compass in the shape and form of more transparent and trustworthy information on which to base their decisions:

Under which circumstances does the installation of heat pumps make sense—from a technical, economic and broader societal point of view? Which buildings should be prioritized to adopt heat pumps? What is the role of energy efficient renovation? Which policies are required to expedite deployment, while at the same time ensuring that the necessary complementary measures—such as energy efficiency improvements—are concurrently addressed?

A thorough and fact-based analysis can assist in comprehending crucial issues and identifying possible measures to mitigate them. This position paper aims to bring insights to the table that contribute to achieving these objectives.

Research basis for this position paper

For the most part framed within the Flemish context, our research has—up until now—only been made available in Dutch. This present position paper therefore aims to broaden our reach. It focuses on the individual building perspective as the main building block to achieve the broader targets, and compiles findings of our research to address five pivotal elements that influence the viability of heat pump deployment in residential buildings, offering evidence-based insights into each.

The supporting material and results for the analysis presented in this paper have been based on the following studies carried out by EnergyVille/VITO:

- **PATHS 2050—The Power of Perspective: 2022-2023 scenarios towards a carbon-neutral Belgium by 2050** [9]**:** This EnergyVille/VITO study aimed to obtain deeper insights into the effectiveness, efficiency and costs of potential innovation pathways to achieving 2050 carbon-neutrality in Belgium. It explored what a future Belgian energy system could look like when decisions are based on system cost minimization, with a holistic view using a highly detailed energy system model—the EnergyVille TIMES model for Belgium (TIMES-BE). The study results can be explored in an interactive way for various sectors, and examined scenarios and sensitivity runs: PATHS2050 | Energy outlook (energyville.be)
- **Hybrid heat pumps in existing dwellings** [10]**:** This EnergyVille/VITO study commissioned by the Flemish Energy and Climate Agency (VEKA) was finalised in March 2023. It was based on simulations of four residential unit typologies, three sizes and six variations of insulation level of the building envelope. The simulations examined the proportion of heat supplied by the heat pump or by the gas boiler part of the hybrid system, switching between electricity and gas depending on the most economically advantageous regime for each time step. Scenarios before and after any renovation were examined to take into account the effect of an oversized distribution system after renovation. Our results were presented in a decision matrix that shows the proportion of the demand covered by the heat pump for different insulation levels before and after renovation. The study also analysed the influence of parameters such as the electricity over gas price ratio, dynamic tariffs, the sizing of radiators, the heating regime, as well as photovoltaic self-consumption: Onderzoek naar beleidsmaatregelen omtrent hybride warmtepompen in bestaande woongebouwen | VEKA
- **Cost-effectiveness of heat pumps in Flemish homes** [11]: Following the sharp increase in energy prices at the end of 2022, this EnergyVille/VITO factcheck examined the impact of energy prices on heat pump cost-effectiveness in existing Flemish buildings. The study assessed cost-effectiveness by means of a simplified computation of the payback time, understood as the difference in investment cost divided by the annual difference in energy cost for the electric heat pump compared to a reference condensing gas boiler: Fact check: how do energy prices affect the cost-effectiveness of heat pumps for existing homes? | EnergyVille
- **The fastest way to A (in Dutch: De snelste weg naar A)** [12]: This position paper from January 2022 investigated which renovation measures lead to a level A energy performance label in the most cost-optimal way, as this is the ambition set by the Flemish government in the Long-Term Renovation Strategy for 2050. Using a data-driven approach, a large set of representative dwellings for the Flemish building

stock were analysed—both in their current state, and under several renovation scenarios. EnergyVille/VITO's EBECS tool[9]—an acronym for EnergyVille Building Calculation Service—allowed for the performance of these analyses, as it is capable of calculating energy performance as well as investment costs of renovation scenarios. For our January 2022 position paper, the most optimal renovation packages were identified both in terms of lowest investment cost, as well as lowest total cost of ownership: Position Paper: De snelste weg naar A: Optimale renovatiemaatregelen in het kader van de Vlaamse 2050 doelstellingen voor woningen | EnergyVille

- **Cost-optimal renovation for existing Flemish dwellings**: This study commissioned by the Flemish Energy and Climate Agency (VEKA)—contributing to the refinement of its Long-Term Renovation Strategy for 2050—was finalised in May 2023. Using an approach similar to the one we applied to our 'The fastest way to A' study, we examined the energy performance levels that can be reached in a cost-optimal and cost-effective way. Here, the methodology for calculating cost-optimal levels of minimum energy performance requirements was followed, as laid out in Article 5 of the Energy Performance of Buildings Directive (EPBD) and in its Delegated Regulation 244/2012 [13], [14]. Thus, maintenance, replacement and disposal costs were also included here, as well as carbon costs for the macroeconomic analysis. This allowed us to identify a pareto front of cost-effective solutions for reducing the energy performance of different building variants representing the Flemish building stock.

NOTE: While the studies underlying this position paper are mostly related to the Flemish building stock and context, it is important to realise that valuable insights can be drawn for other European countries that share similar challenges —either technical, regulatory or market-related. Furthermore, the methods and models used to derive these results can be easily altered to analyse other contexts.

[9] EnergyVille EBECS tool: https://www.energyville.be/en/research/ebecs-tool

1. Favourable market conditions for heat pump rollout in existing buildings

1.1. Investment cost

The investment cost is a crucial deciding factor when it comes to purchasing a heat pump, as it directly impacts the overall affordability of the system. High initial costs may deter potential buyers, limiting the adoption of this sustainable heating solution. Additionally, considering the long-term savings in energy bills, evaluating the investment cost helps assess the return on investment and economic feasibility of the heat pump over its lifecycle.

The investment cost of a heat pump depends on three main factors:

- The capacity of the heat pump: the range of heat pump capacities easily accessible on the market is limited, while generally the price increases with the capacity.
- The type of heat source: air-source heat pumps are cheaper than ground-source heat pumps in terms of the investment cost, even though the latter have better performance during operation.
- The labour cost of the installation: this depends on the installer's hourly wage, but also on the number of hours needed for the installation, on the number of components to connect, and on the equipment needed. Ground-source heat pumps generally have a significantly more expensive installation, because they involve underground piping and drilling.

The price, particularly regarding installation costs, varies significantly from country to country. 1Table 1 shows a 2022 price range for different heat pump systems for Belgium, based on expert opinion and various literature sources. In comparison, the installation cost of a condensing gas boiler in Belgium ranges between 2 000 and 6 000€. The technology perspectives analysis of IEA in 2023 also highlights that while the market price of heat pumps varies a lot per region and heat pump type, this variation is primarily dependent on the labour costs of the installation, where the largest potential exists for lowering the costs [15]. Contrarily, for components such as the heat exchanger and compressor, which are the most expensive components of the system, manufacturing cost reductions are less likely, given that those have been mass manufactured for a while [15].

1System	Investment (incl. installation)	Seasonal coefficient of performance (SCOP)
Air-air heat pump	3 500–8 000 €	3.2–4.5
Air-water heat pump	7 000–15 000 €	3.5–4.5
Ground-water (vertical) heat pump	11 000–25 000 €	4.5–5.5

Table 1: Overview of investment cost (in Belgium, 2022) and performance of different types of heat pumps, based on expert opinion and various literature sources.

Accessories and additional options, such as for instance the possibility to use the heat pump for cooling on top of heating, may incur additional costs. In case of an air-air heat pump, a separate system for the preparation of domestic hot water needs to be foreseen. Furthermore, depending on the heat pump type and the heat requirements, the existing heat distribution system may be insufficient for proper operation. For instance, common heat pumps work with low-temperature hydronic systems (see Section 2). In case the heat distribution system needs to be replaced, expanded or modified, additional costs and disruption in the building should be foreseen. However, the hybrid heat pump study showed that often the existing distribution system is sufficient, as it is in many cases over-dimensioned due to prior renovation works or initial oversizing.

1.2. Energy prices

One of the most influential factors for the rollout of heat pumps is the evolution of energy prices. As the conventional systems for space heating in most European countries are fossil fuel burners, such as gas and heating oil boilers[10], the relationship between electricity and fossil fuel prices is a crucial deciding factor. This price ratio varies significantly over time and from country to country, as it is highly dependent on the geopolitical context and policies. Figure 3 shows how the ratio significantly differs between European countries, and how it generally decreased after the recent energy crisis. Among other factors, energy taxation can contribute significantly to the resulting price ratio, and it varies widely among European countries [16].

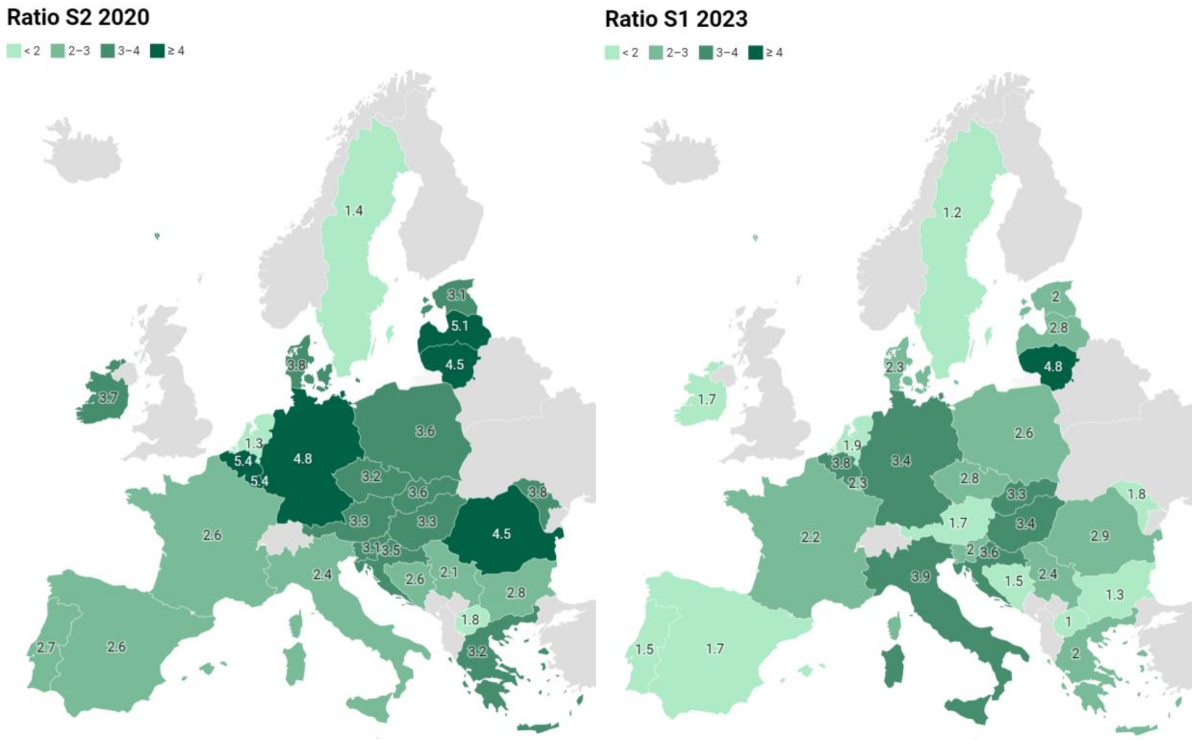

Figure 3: Visualisation of electricity-to-gas price ratio for household consumers before the recent energy crisis and in the last semester. Own visualisation based on Eurostat data for prices with all taxes and levies and for consumption bands DC: 2 500–5 000 kWh for electricity and G2: 20–200 GJ for gas.

In the previous paper "**Cost-effectiveness of heat pumps in Flemish homes**" [11], EnergyVille/VITO investigated the payback time of different heat pumps under various price scenarios to assess in simple terms the profitability for the building owner. The expected lifecycle of a heat pump is generally considered around 15 years. As such, a payback time shorter than 15 years is desired by the one purchasing the heat pump, so that a return on investment is obtained before the heat pump needs to be replaced. The simple calculation demonstrated that the seasonal coefficient of performance (SCOP) of the heat pump has a considerable influence on the payback time, as shown in Figure 4. As the SCOP lowers to the level of the electricity-to-gas price ratio, the payback time dramatically increases. Therefore, to shorten the payback period, one could increase the SCOP, by means of reducing the output temperature of the emission system and reducing heat demand in general.

[10] Eurostat: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Energy_consumption_in_households

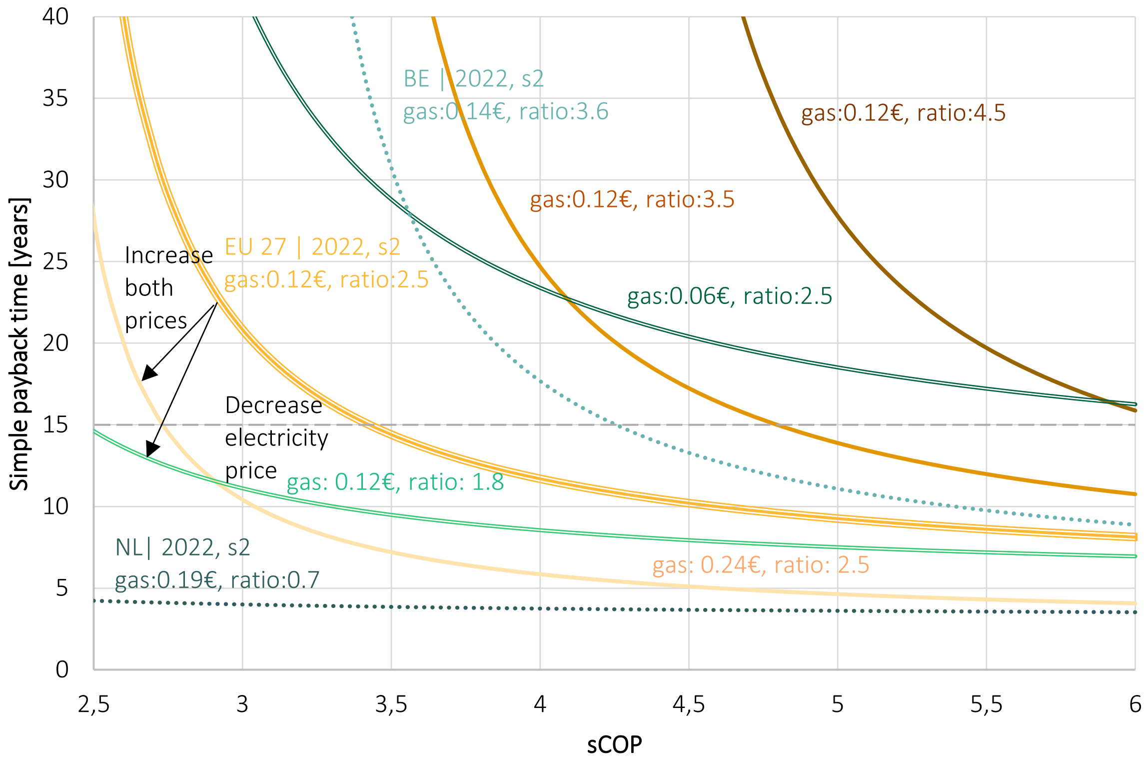

Figure 4: Payback time in function of SCOP for different price scenarios. Results for 8000€ difference in investment cost between heat pump and gas boiler, and a space heating demand of 12000 kWh/year.[11]

The hybrid heat pump study investigated in more detail the influence of different electricity-to-gas price ratios on the space heating operation of a hybrid heat pump system in Flanders. The hybrid system combines an existing or new gas boiler with an air-water heat pump. A controller decides at every moment which of the two components provides the required heat at the lowest cost, depending on the energy prices, the heating requirement and outside temperature—which determine the efficiency of the heat pump. The hybrid heat pump study used dynamic simulations to analyse the extent to which it is more economical to operate the heat pump component for different prices.

The results show that for a price ratio of 4.5—on average in line with prices in Flanders between 2015 and 2023—it is not interesting in terms of operational costs for buildings with any insulation level to install a heat pump or have a hybrid system running in heat pump mode. This is demonstrated in Table 2 for terraced buildings as an example, where the percentage of heat delivered by the heat pump part of a hybrid system is shown. On the contrary, at a ratio of 1.8, the preferred operation of the heat pump over the gas boiler for most of the time is self-evident, even for poorly insulated homes. In general, the tipping point for the profitability of operating a modern heat pump in the Belgian context is for electricity-to-gas price ratios **below 2.5** for most dwellings. Only for dwellings with very high insulation quality the operation in heat pump mode is still preferred up to a price ratio of 3.5. It should be highlighted, however, that this assessment only focuses on the operational costs. Installation costs for heat pumps can be significant, especially for buildings with low insulation quality and thus higher required capacity, and should be taken into account in decision making.

[11] The simple payback time is expresses as the difference in investment cost between the reference case of a gas boiler and the heat pump, divided by the difference in annual energy costs. These energy costs are the heat demand multiplied by the energy price and divided by the system efficiency of either the gas boiler or heat pump (SCOP).

price ratio elec/gas = 4.5						
insulation	a	b	c	d	e	f
a	0.13					
b	0.13	0.10				
c	0.13	0.10	0.08			
d	0.14	0.11	0.09	0.07		
e	0.15	0.12	0.09	0.07	0.06	
f	0.19	0.14	0.11	0.09	0.08	0.06

price ratio elec/gas = 3.5						
insulation	a	b	c	d	e	f
a	0.93					
b	0.93	0.71				
c	0.93	0.71	0.42			
d	0.95	0.76	0.47	0.28		
e	0.96	0.78	0.49	0.31	0.25	
f	0.98	0.85	0.60	0.40	0.33	0.23

price ratio elec/gas = 2.5						
insulation	a	b	c	d	e	f
a	1.00					
b	1.00	1.00				
c	1.00	1.00	0.93			
d	1.00	1.00	0.96	0.74		
e	1.00	1.00	0.98	0.78	0.68	
f	1.00	1.00	1.00	0.90	0.83	0.62

price ratio elec/gas = 1.8						
insulation	a	b	c	d	e	f
a	1.00					
b	1.00	1.00				
c	1.00	1.00	1.00			
d	1.00	1.00	1.00	0.97		
e	1.00	1.00	1.00	0.99	0.94	
f	1.00	1.00	1.00	1.00	1.00	0.90

Table 2: Influence of electricity/gas retail price ratio on the decision matrix for medium-sized terraced buildings, with oversizing factor of 1.3 and 18°C indoor temperature setting. The decision matrix shows the proportion of heat supplied by the heat pump in a year for different insulation levels, as explained in footnote 12.

The ratio of energy prices is also decisive considering the total lifecycle cost of the system for the owner, as already presented. Given that gas boilers currently require a lower initial investment, and looking from the perspective of a building owner, a low electricity-to-gas price ratio is required to compensate for the difference in the initial investment over the years. This is particularly important for better insulated dwellings where the energy demand is relatively low and therefore also the savings in operational cost are smaller. For poorly insulated dwellings, attention should be paid to the actual consumption compared to the estimated one, since households in such buildings tend to lower their comfort level and thus consume less energy than required to heat the building to standard comfort. In this case, the savings during operation by using a heat pump will once more be lower than expected.

From these studies we can conclude that to make heat pumps economically viable for the owner, and therefore increase the rate of heat decarbonisation, lower investment cost (e.g., through subsidies) are appropriate. At the same time, higher gas prices compared to electricity for the end consumer are needed to keep the operation of heat pumps more economical. Energy taxation reform, such as shifting levies and taxes from electricity to fossil fuels, could be an approach to align incentives with societal goals [16]. However, affordability for vulnerable consumer groups should be taken care of when such reforms are made. Social energy tariffs, on the other hand, can have a perverse effect when they artificially increase the electricity to gas price ratio, leading to a preference of fossil fuel boilers over heat pumps. The new ETS Directive has in the meantime created an Emissions Trading System 2 that will put a carbon price on fuel combustion in buildings starting from 2027-28.[13] The system is expected to reduce the electricity-to-gas price ratio. However, this "polluter pays" principle will also have to be accompanied by a policy mix that ensures lower-income households are not disproportionately hurt, and that those with higher incomes effectively invest in emission reduction renovation measures.

[12] Each number in the decision matrix shows the proportion of heat supplied by the heat pump of the hybrid system in a year, which is based on the economically best option in each time step. The building envelope insulation level in the rows indicates the situation before renovation, while the insulation level in the columns indicates the situation after renovation. Therefore, the diagonal gives the buildings in their original state. Moving horizontally to the left one finds the result for the same building after renovation to a higher insulation level.

[13] Emissions Trading System 2: https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/ets-2-buildings-road-transport-and-additional-sectors_en

2. Technical feasibility

The technical feasibility of heat pumps is well-established, as they operate on the principles of thermodynamics and have been proven effective for both heating and cooling applications. Advances in technology have led to the development of highly efficient and reliable heat pump systems, making them a technically viable and sustainable option for residential, commercial and industrial heating and cooling needs.

The possibility of installing a fully electric heat pump is mainly determined by two parameters:

- The energy performance of the building: this parameter largely determines the required design heat load, from which the necessary power of the space heating generation system can be estimated.
- The design temperature regime of the delivery system: based on the design heat capacity (and associated temperature regime) of the hydronic delivery system for space heating, one can assess whether low-temperature supply is possible for the required design heat load of the house. Low-temperature heat pumps are cheaper and more efficient than their high-temperature counterparts.

The combination of these two parameters is crucial to determine the feasibility of different system designs. Understanding in which cases the design load is exceedingly high, or the operating conditions are suboptimal, such as conditions requiring too high supply temperatures, can help avoid unnecessarily expensive applications of heat pump technology.

The hybrid heat pump study showed that a heat pump is feasible in most dwellings. Figure 5 shows that the required heat pump capacities for buildings with up to a medium degree of insulation (according to the definition of the hybrid heat pump study) are commonly available on the market (green band). For the least insulated ones, a hybrid system is better suited.

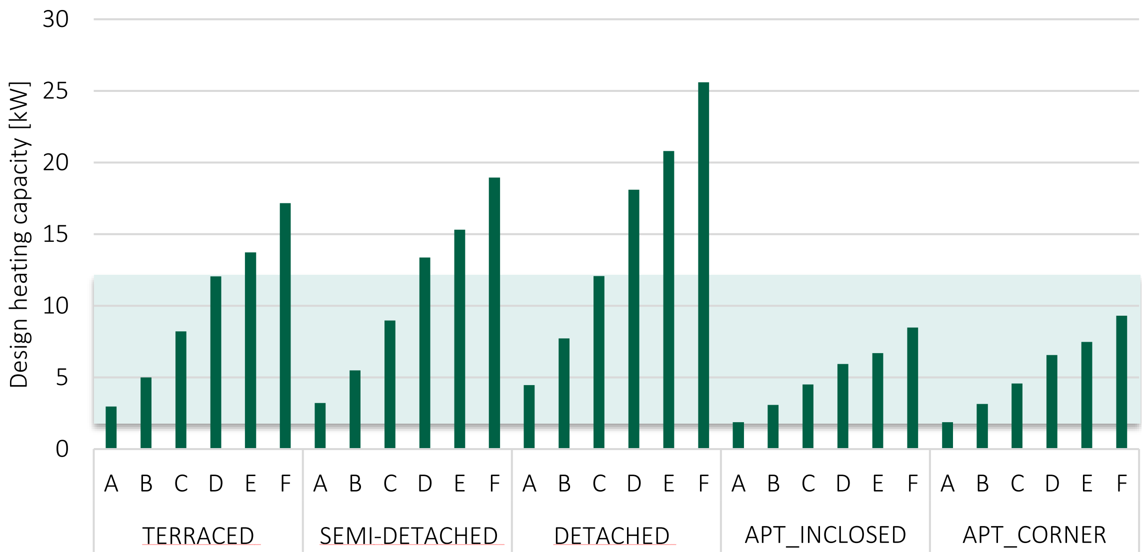

Figure 5: Design capacity for the different housing types and insulation qualities in the hybrid heat pump study. The green band indicates the capacities for fully electric heat pumps commonly available on the market, based on a limited market research.

2.1. Building performance

The thermal performance of the building determines its heat requirements, and thus influences the required capacity of the heating system and its technical feasibility. It is particularly important to correctly size the heat pump. In contrast to fossil fuel boilers, heat pumps suffer from cycling (frequent on/off behaviour) that reduces their lifetime, so they should not be oversized. It can be advantageous to improve the energy performance of the building in order to reduce the heat requirements and allow for a cheaper heat pump, and at the same time lower consumption and operational costs, as well as minimise impact on the grid. Taking into account potential renovation obligations and national long-term objectives, such as those in Flanders, it is in some cases mandatory and in any case advisable that the poorly insulated homes additionally improve their building energy performance when they change the heating system.

Upgrading the building energy performance includes measures such as improving the thermal insulation and airtightness of the building envelope. At the same time, it is advisable to insist on the provision of appropriate energy efficient ventilation and to provide the necessary shading to increase summer comfort as well. Depending on the renovation works carried out, adjustments of the emission system should be considered, allowing it to operate at low temperatures (see also the next section).

Renovation costs can in many cases be significant. Financing this investment can therefore be an issue for many households. The cost-optimal renovation further depends on energy prices, which can determine whether certain systems and measures lead to lower total costs of ownership in the long term. Section 4 further discusses the issue of cost-optimal renovation and the role of heat pumps. The economic aspect of building renovation aside, other benefits such as thermal comfort and indoor air quality improvements should be taken into account in a broader vision on renovation. Secondary benefits for the owner, such as a higher real estate value, also matter. On the other hand, possible constraints may be related to the limited experience or availability of trained professionals, and the intrusive character of an extensive renovation.

As already mentioned, fully electric heat pumps in less performing buildings are more expensive than hybrid systems because of larger needed capacities of the heat pump. However, for policies that aim to prioritise emission reduction, they can still be an interesting option, provided financial support is foreseen to cover the difference. The impacts of a full or partial electrification need to be considered, as highlighted in Section 5. In any case, the decarbonisation of the housing stock must be supported by emission reductions in the electricity production.

2.2. Heat distribution system

Most heat pumps, with the exception of air-to-air systems, are usually connected to a hydronic heat distribution system. This is also the heat distribution system present in most existing buildings using gas or fuel oil boilers in Europe. However, in many existing buildings that are not well-insulated, this heat emission system requires high water temperatures in order to be able to meet the large heat requirements needed to ensure the desired comfort level. Such high-temperature distribution system usually consists in traditional high-temperature radiators, where the design supply temperature is commonly 70°C to 90°C. With current technology, regular heat pumps can supply water up to approximately 55°C with acceptable efficiency. At higher supply temperatures, the efficiency drops rapidly, as shown in Figure 6. Therefore, they are more appropriately combined with low-temperature heat distribution systems, such as under-floor heating and low-temperature radiators.

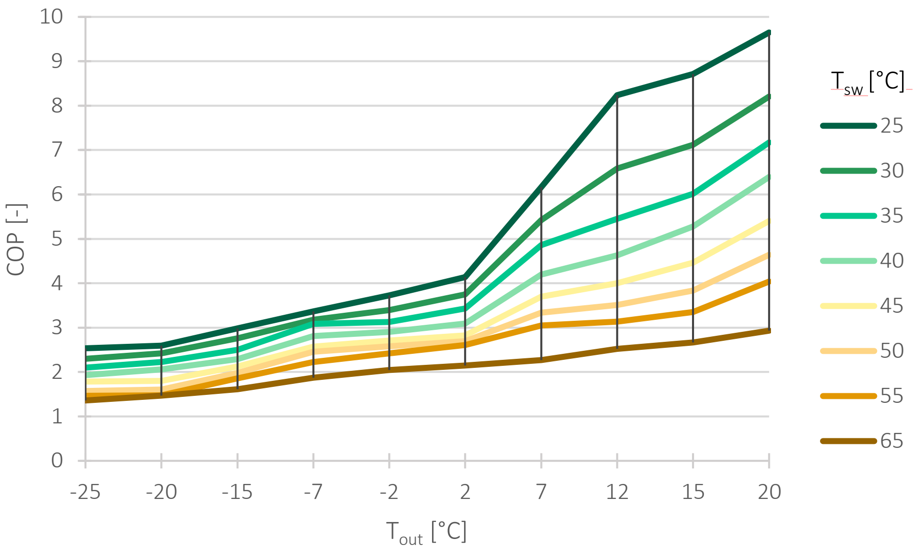

Figure 6: Coefficient of performance (COP) of air-to-water heat pump in function of departure temperature (T_{sw}) and outside temperature (T_{out}), as simulated in the hybrid heat pump study.

Low temperature heating could nevertheless still be possible with an existing emission system. A detailed assessment could be performed, requiring some expertise and assumptions. An easy way to assess in practice whether the current emission system can work with low temperatures is the so-called 50°C test. It consists in testing whether sufficient comfort can be provided by the existing boiler in a cold month, when the boiler is set to produce water at 50°C. In this way, occupants can estimate whether a low-temperature heat pump could sufficiently cater for their needs.

Emission systems are often over-dimensioned, either because of their initial installation or during renovation works that already lowered the heat demand. Therefore, it can be the case that existing radiators are sufficient to deliver the necessary heat at lower supply temperature without any changes, or with small adjustments. The hybrid heat pump study showed that an over-dimensioning of 30% to 45% (with reference to the heating needs of the original state of the building) can already mean that most houses with medium to low thermal insulation can be heated with a (hybrid) heat pump using the existing emission system. As the building is renovated and the heating needs decrease, the emission system becomes even more over-dimensioned and capable to supply the required heat. It is possible to further increase the heat delivery of an existing system with lower supply temperature by increasing the heat transfer area, for example replacing or adding radiators. Furthermore, booster technology may provide a cheap option, whereby the convective heat dissipation is increased with dedicated mini fans (see for example Figure 7). Especially for convectors, this can be a necessary adaptation as such technology often does not provide sufficient power at low regime temperatures due to the heat transfer mechanism that consists predominantly of natural convection. A nearby power supply and cabling need to be available for the added devices.

Figure 7: Mini fans for use on existing radiators and convectors (source: SpeedComfort).

Another way to allow for low-temperature heating while reusing the existing emission system is by reducing the required heat load. Improving the building performance, as explained in the previous section, lowers the heat requirements, which could be covered by a low-temperature system. Easier improvements, such as replacement of the windows or roof insulation may already be sufficient, depending on the case.

When heating with low temperature is not possible, other solutions may be used. High-temperature heat pumps can achieve temperatures between 60-80°C, albeit with a loss of efficiency at the highest temperatures. Furthermore, they are more expensive than the regular low-temperature heat pumps. Hybrid systems are another option, whereby the gas boiler ensures the required temperatures are reached. These are generally cheaper than fully electric heat pumps because of the lower required capacity of the heat pump component, which is usually added to an existing gas boiler.

3. Contribution of a PV system

Heat pumps, fully electric or hybrid, require an important amount of electricity to operate. To reduce the cost of operation, the installation of solar photovoltaic (PV) panels on homes made economic sense for the homeowners when reversing meters were in use or feed-in tariffs were still high. Currently, policies to financially support small scale PV have subsided in many countries, while the progressive electrification of heating and private transport begins to create electricity network challenges (see also Section 5). Reforms towards more cost-reflective distribution network tariffs are being explored by regulators around Europe [17], of which the new capacity tariff in Flanders, in vigour since the beginning of 2023, is an example. The economic sense of combining heat pumps with PV panels has become a more subtle question in this context, depending to a large extent on the local tariffs and subsidies.

With low feed-in tariffs and a shift to capacity-based network charges, it is important to maximise self-consumption of this combination of technologies. The following figures, taken from the hybrid heat pump study, show the heat pump electricity demand profile installed in a typical well-insulated Flemish large, terraced house over a year (Figure 8) and during a cold week (Figure). Overlayed on these graphs is the electricity generation of a large (10 kWp) south-oriented PV system. It is common and financially interesting to make maximum use of the roof area, up to the allowed maximum of 10 kWp in Flanders.

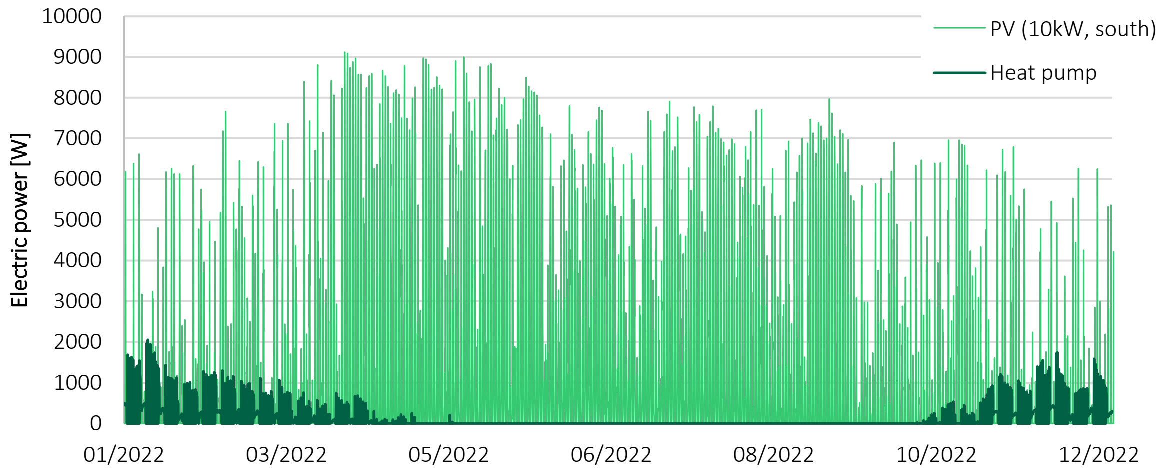

Figure 8: Yearly electricity demand of the heat pump for a typical well-insulated Flemish large, terraced house with high thermal insulation and local PV production (10 kWp installation, south oriented).

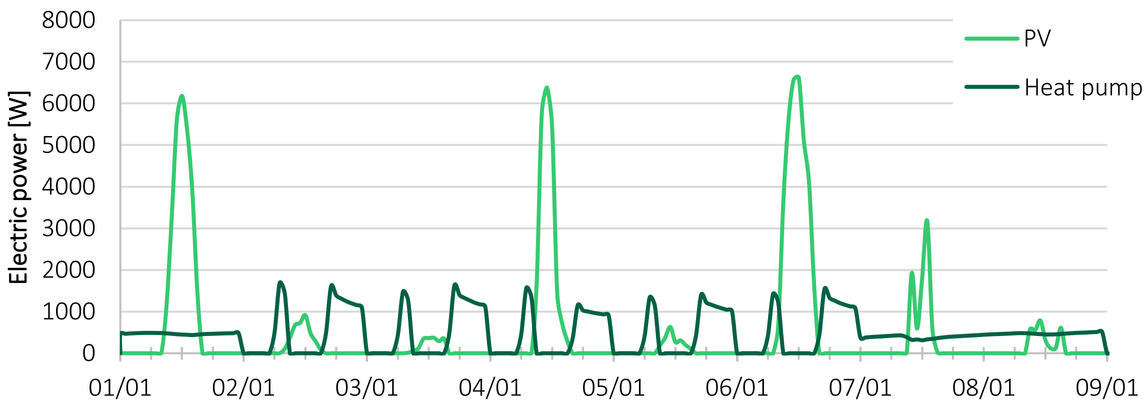

Figure 9: Detail of a cold winter week—Electricity demand of the heat pump for a typical well-insulated Flemish large, terraced house with high thermal insulation and local PV production (10 kWp installation, south oriented).

As the figures demonstrate, self-consumption in such climate is low, both due to a seasonal and time-of-day mismatch of the heating demand and the PV generation. The typical thermostat settings for a working family require heating when the sun is not yet up, or already down in winter. The hybrid heat pump study found an average load cover factor (proportion of load covered by the PV) of just under 10% for typical heating profiles, taking into account only the heat pump load for space heating, showing that the contribution of PV can be very limited for this use. A PV system oriented east or west would match to a somewhat larger extent the usual patterns of consumption of a working family that is not at home during the day, but it would also produce less energy in total.

Other research has previously demonstrated that by using intelligent control that responds to the thermal buffer capacity of buildings, the electricity demand can be shifted by a few hours in well-insulated buildings in order to improve the match with local PV production. In this case, the coverage of heat demand by PV is still limited to approximately 15 to 20% [2], [3].

In the case of domestic hot water, for which heat demand is almost constant throughout the year, and for which a storage vessel that can be preheated is often used, a higher cover factor can be obtained (up to more than 60%). Furthermore, in warmer climates where heat pumps to a substantial extent may be used for cooling purposes, a higher cover factor can be expected, as the need for cooling often coincides with sunny summer days. This is however not the case for Belgian dwellings, as active cooling doesn't noticeably improve self-consumption [3].

Electric storage could offer a partial solution to increase self-consumption on a daily basis and allow for a better integration of renewable energy technologies. While battery storage prices have significantly decreased in the last years, economic profitability still depends on many parameters, including the solar irradiance of the location, the electricity demand, future prices and tariff development [18]. Furthermore, given the large seasonal mismatch between generation and production, a more efficient approach would be to optimise self-consumption at the level of building clusters rather than individual dwellings. In this way, one can make use of different demand profiles, including non-residential loads, which, combined, could follow more closely the potentially available local renewable electricity production. Large seasonal storage could play a significant role in this case. This additionally highlights that dynamic calculation methods that reflect the real energy flows are needed to better inform policymakers on these issues. Policymakers should furthermore not forget that all technologies, including batteries [19], PV [20], as well as heat pumps [21], are associated with certain social and environmental impacts during their production and disposal. Such impacts need to be considered carefully from a societal perspective when designing policies in a holistic way.

4. Role of the heat pump in cost-optimal renovation

The latest proposal for a revision of the Energy Performance of Buildings Directive (EPBD)[14] foresees Minimum Energy Performance Standards (MEPS) to ensure a higher renovation rate of existing buildings, with the aim to achieve a fully decarbonised building stock by 2050. Member States would have to share their roadmap with targets and policies to achieve this goal in their National Building Renovation Plans, which will replace the previous Long-Term Renovation Strategies. EnergyVille/VITO supported the Flemish government in the analysis of cost-optimal energy performance levels for the renovation of existing buildings, to inform the further development of its Long-Term Renovation Strategies [22]. The methodology for calculating cost-optimal levels of minimum energy performance requirements was followed, as laid out in Article 5 of the EPBD (2010/31/EU and revision 2018/844)[13] and Delegated Regulation 244/2012 [14]. Both a financial calculation and a macroeconomic calculation were made, where the latter excludes taxes, VAT, charges and subsidies, but includes the carbon cost.[15]

This study calculates the lifecycle costs and resulting energy performance level of different renovation packages for 135 reference buildings[16], following the approach in the position paper 'The fastest way to A'[17]. The aim is primarily to assess the cost-effectiveness of minimum energy performance requirements, but with such calculations it is also possible to compare different renovation measures or system options. It is therefore interesting to see how heat pumps compare to condensing gas boilers in terms of cost-optimality and cost-effectiveness (cost-optimal: lowest lifecycle cost, cost-effective: lifecycle cost lower than the original building state). For this study, the SCOP of the heat pumps was considered fixed at a conservative 3.6. With an improved performance, depending on the building type and heat pump, reduced operational costs can be expected. Furthermore, the preferred renovations can also be identified.

The calculations for the study include a sensitivity analysis to compare the results for energy use calculated according to the EPC methodology (Flemish energy performance assessment methodology for existing buildings) and estimated “real” use. Real use was estimated as a proportion of the EPC-calculated energy use, depending on the energy performance level, based on a study of real consumption in Flanders[18]. This is a simplified approach to provide a first estimate. More research is needed to establish an accurate method to take into account the effects that lead to the differences between estimated and real energy use.

Furthermore, a sensitivity assessment was also done for different energy price scenarios. In the original study, a low, medium and high projection of future prices (stabilisation after 2025) was used, in accordance with the approach taken for the cost-optimal level calculations for Flemish new-built residential buildings in 2023 [23]. However, the price ratio between electricity and gas in those scenarios only varies from 4 to 5 and does not yield significant differences when comparing heat pumps to condensing gas boilers. Additionally, the gas price remains rather low for all scenarios (between 0.05€ and 0.13€ per kWh, with electricity respectively from 0.26€ to 0.50€ per kWh, all charges and distribution costs included). Therefore, the results presented here make use of the prices shown in Figure 10. A 2% yearly increase was assumed for the 30-year calculation period, similar to the approach in the hybrid heat pump study. The indicated prices include all components, taxes and levies.

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[14] https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en

[15] Assumed as linearly increasing from 50€/ton CO2 in 2020 to 350€/ton CO2 in 2050, according to the EnergyVille Paths 2050 assumptions [17].

[16] The reference buildings include detached, semi-detached and terraced dwellings, split in 5 age classes (based on the TABULA classification), and each split in three sizes and 3 insulation quality levels (based on available data from the Flemish EPC database of 2016). Furthermore, two types of apartments are included, an enclosed and an exposed type, each split in three sizes (based on the Flemish EPC database of 2016).

[17] https://www.energyville.be/pers/position-paper-de-snelste-weg-naar-optimale-renovatiemaatregelen-het-kader-van-de-vlaamse-2050

[18] Correction factors for real energy use for heating are applied to the calculated EPC heating demand per energy performance level. These factors were based on the findings of research that compared real consumption with the calculated energy performance score for about 86 000 Belgian households. Source: [26]

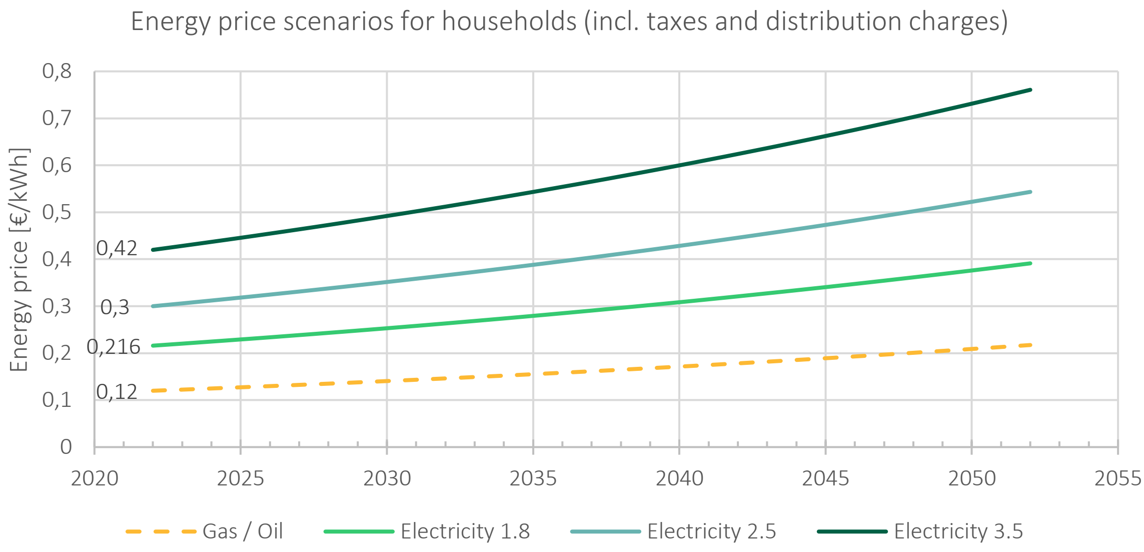

Figure 10: Energy price scenarios used for cost-optimal renovation analysis. Price evolution for gas/oil and electricity (energy component and distribution cost) over the evaluation period for three energy price ratio scenarios (1.8, 2.5 and 3.5).

Results of the analysis are given in the following two figures, for an example semi-detached reference building with average size and average insulation quality, for all three price scenarios and respectively the EPC-calculated energy use (Figure 11) and the adjusted "real" use (Figure 12). The achievable energy performance score is plotted against the total lifecycle cost of each renovation package, highlighting the original heating system, the packages with a heat pump and with a condensing gas boiler. Here, the results of the financial analysis are shown as total cost. The results were similar for the macroeconomic costs, leading to the same conclusions, therefore they are not repeated here. However, note that the standard emission factors of the EPC methodology were used for electricity, namely 333 gCO2/kWh. More realistic values moving towards a decarbonised electricity supply could produce different results. This effect will be studied in a follow-up EnergyVille/VITO publication. Additionally, the effect of embodied carbon emissions will be addressed.

It is clear from Figure 11 that the total lifecycle cost for the heat pumps decreases for the lower price ratios and is about the same as for gas boiler solutions for a ratio around 2.5. The impact is larger for the older, less performing buildings, where some packages with heat pumps have a lower total cost than the current situation and even begin to be the cost-optimal choice more often than condensing gas boilers. However, even for a ratio of 3.5, heat pumps lead to cost-effective solutions (total lifecycle cost lower than the current situation) for older buildings, according to the ECP-calculated results. Furthermore, there is a wide variation among all renovation packages with heat pumps, as different other renovation measures are included. This will be further assessed in the following set of figures.

Also very noticeable is the contribution of PV panels, which is always considered positive under this assessment (see shift in cloud of results particularly noticeable in the 2006-2012 period and in the yellow dots representing the heating system in the original state and sole addition of PV). This is because PV investment costs have dropped in recent years, but also because the EPC methodology takes PV production entirely into account in the calculation of the energy score. For the calculation of energy costs, it was assumed that 30% of PV production was self-consumed over the year for all heating purposes.

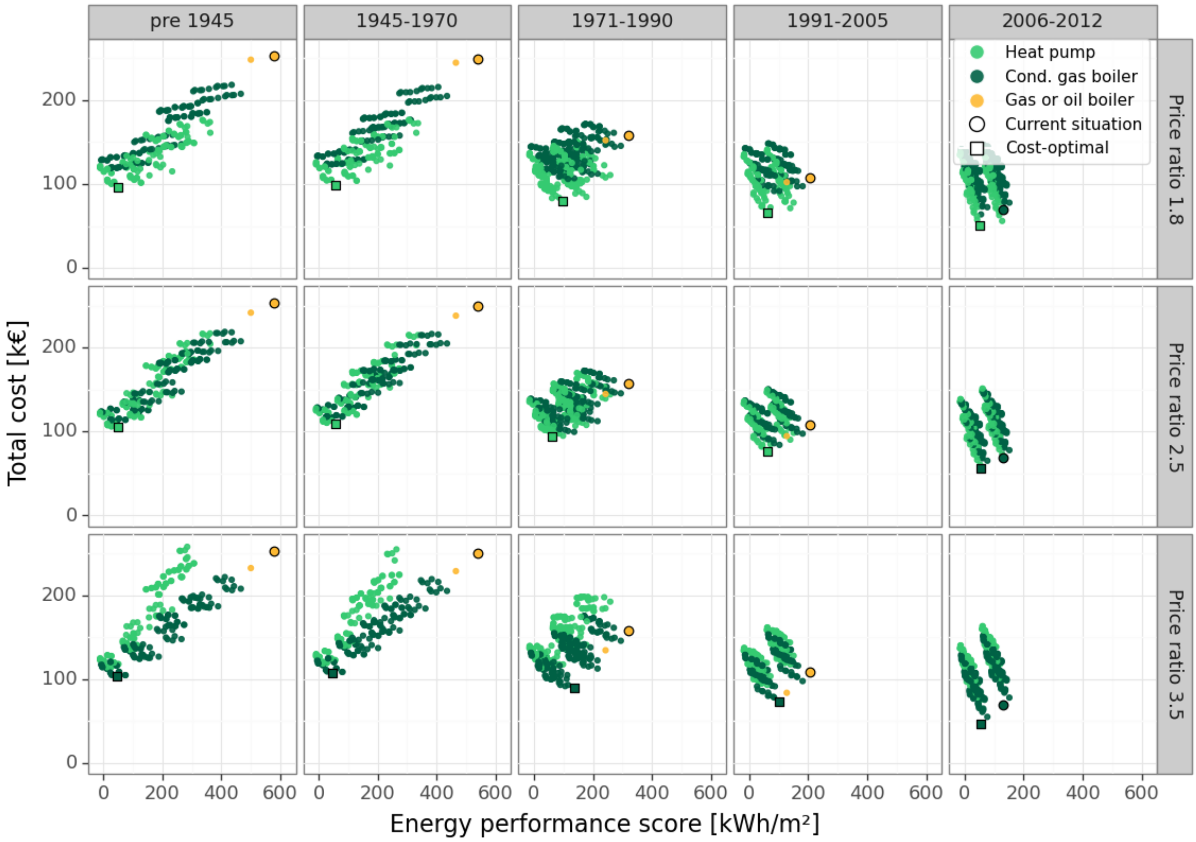

Figure 11: Mapping of the cost and performance of different renovation packages for semi-detached dwellings of average size and insulation quality and five construction periods (columns). The rows compare different price ratio scenarios. The resulting total cost is based on energy demand calculated with the EPC methodology.

The picture is quite different when looking at the estimated "real" consumption. With the simplified approached used to estimate the "real" consumption, the total cost of the current state is always lower than that of solutions with a heat pump (or even condensing gas boiler), because the "real" current consumption is much lower than the EPC-calculated consumption for low energy performance levels. When the energy performance improves, the "real" consumption is closer to the EPC-calculated consumption. These effects deliver less reduction of the costs compared to the estimations based on the EPC calculation, especially for badly insulated buildings. The differences in "real" use and EPC-calculated use are a result of two effects. The prebound effect, under which occupants of badly performing buildings reduce their energy use below standard comfort levels to save money. And the rebound effect, under which occupants consume more energy after renovation to improve their comfort compared to before. Within this context, it is worth noting that while the cost savings may be more limited than expected, the comfort gains and value increase can be significant. This also highlights that better estimates of real energy use compared to the one estimated by the EPC methodology are needed.

Considering these adjusted estimates of "real" consumption, even for a low price ratio, it often remains more cost-effective to keep the original heating system and building envelope and only add PV panels. This is because the energy savings from energy efficiency improvements may be limited due to the aforementioned pre- and re-bound effects. Again, when taking a decision of renovating the dwelling or not, the comfort and related health improvements should be considered here, as well as potential hinderance. The important contribution of PV in the calculation of the energy performance score of buildings is further highlighted here, which discounts the entire annual production of renewables without considering seasonal or hourly variations in the self-consumption.

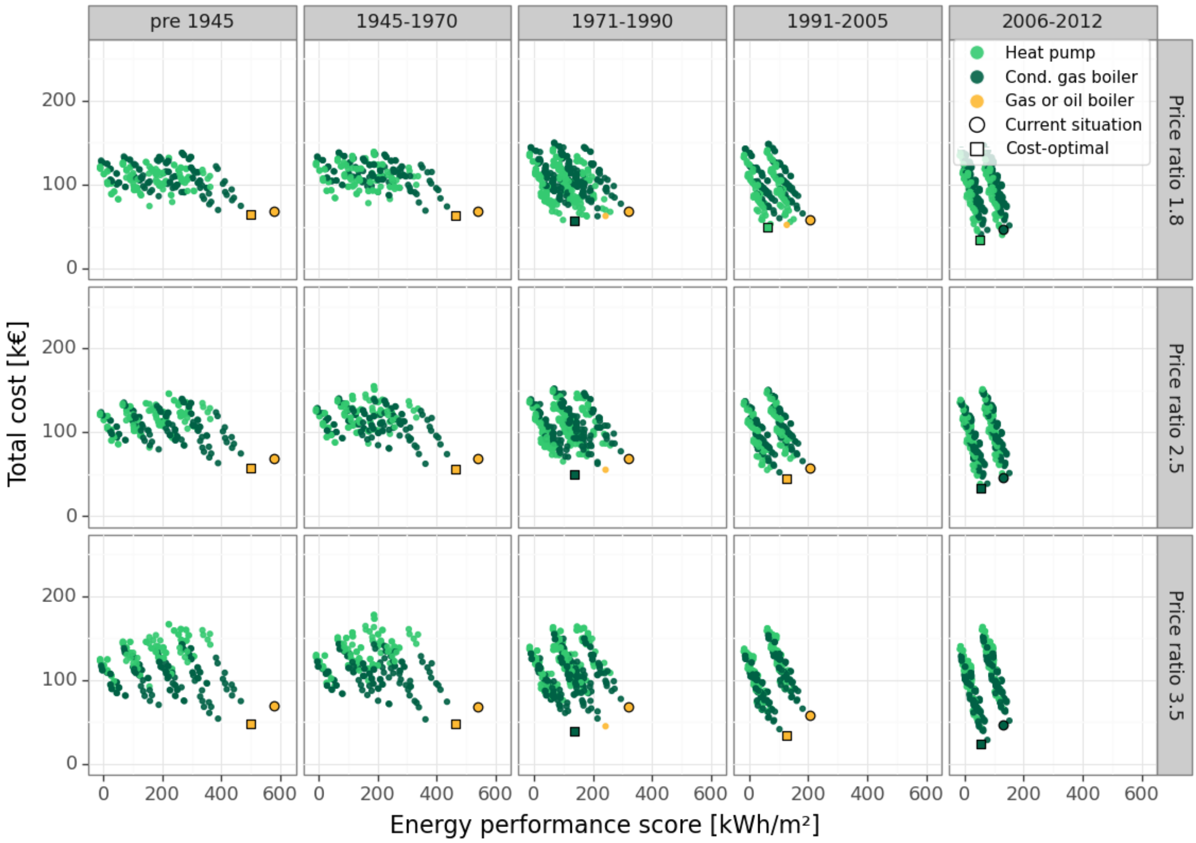

Figure 12: Mapping of the cost and performance of different renovation packages for semi-detached dwellings of average size and insulation quality and five construction periods (columns). The rows compare different price ratio scenarios. The resulting total cost is based on energy demand calculated with the EPC methodology, but the demand is corrected to represent real consumption[18].

Exploring the performance of various renovation packages across different scenarios provides an interesting avenue for further investigation. Figure 13 and Figure present a more detailed view of a subset of the previous results where the different renovation packages are highlighted according to the measures they contain, focusing on the ones that include a heat pump. Here, for simplicity's sake, we do not distinguish between light and heavier renovations of the different building elements. Furthermore, we do not highlight the renovation measures concerning window replacement and ventilation because of their relatively smaller impact on both energy performance and cost, as well as to keep the figures clearer.

First, we may notice that a price ratio change (corresponding to an electricity price change, as the gas price is kept to the same level), has an impact on the relative contribution of measures. While the largest difference regards the comparison of gas boilers and heat pumps, within the heat pump packages some measures are more interesting when the electricity price is higher. We can notice in both figures that, for the newer building type, the cases without the main renovation measures (depicted as ●) are the most cost-optimal amongst the heat pump solutions, with a larger difference when the electricity price is low. Concerning the older building type, even though the packages without renovation are not cost-optimal, they nevertheless shift downwards in cost significantly as the electricity price decreases. This indicates that low electricity price may dissuade investments in renovation, but also that heat pumps can be implemented without the need for additional renovation in relatively newer buildings. For the older buildings, it is generally more cost-effective to have some renovations done. This last observation strongly depends on whether the EPC-calculated or estimated "real" energy demand is used. For the latter, the total cost differences between non-renovated and renovated cases are reduced due to the prebound and rebound effects. Again, costs aside, comfort improvements and renovation hinderance also need to be considered in the decision-making.

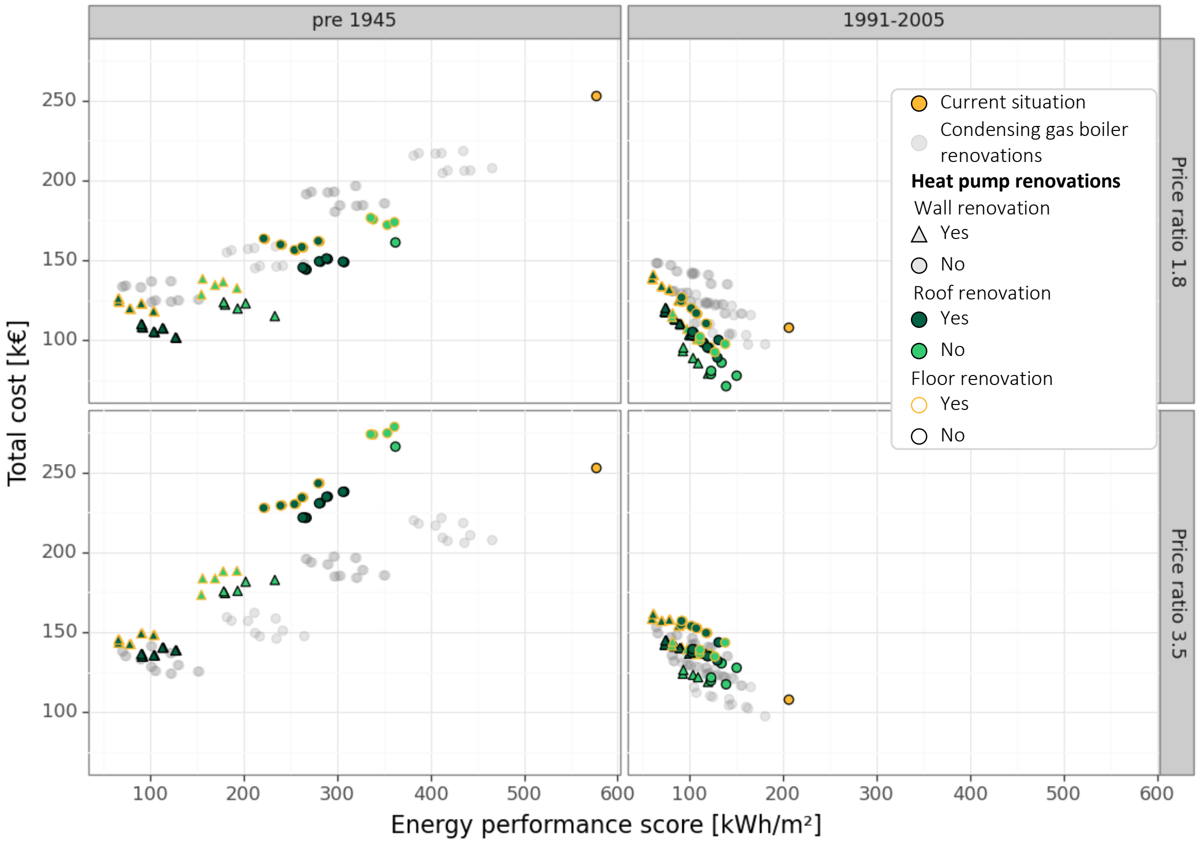

Figure 13: Detailed view of renovation packages for semi-detached dwellings of average size and insulation quality and two construction periods (columns). The rows compare different price ratio scenarios. The different shapes, fill colours and border colours highlight the presence of specific renovation measures in each package including a heat pump, while renovations with gas boilers are all greyed out. Renovation packages with PV have been removed to allow focus on the other renovation measures. The resulting total cost is based on energy demand calculated with the EPC methodology.

Concerning the individual renovation measures, wall renovations (depicted as △) are generally always in the pareto front, as they offer a large performance improvement with a slight reduction of total cost. Roof insulation (depicted in the colour ●) is a clear improvement for older buildings, for which those packages are in the pareto front, but considering "real" energy use they might not end up as cost-optimal. For newer buildings, on the other hand, the additional investment cost doesn't always seem to pay off. Finally, ground floor insulation (depicted in the edge colour ○) is only present high in the pareto fronts in combination with all other renovations (depicted as ▲), indicating that while they do lead to an improvement of the energy performance, the additional cost is relatively large.

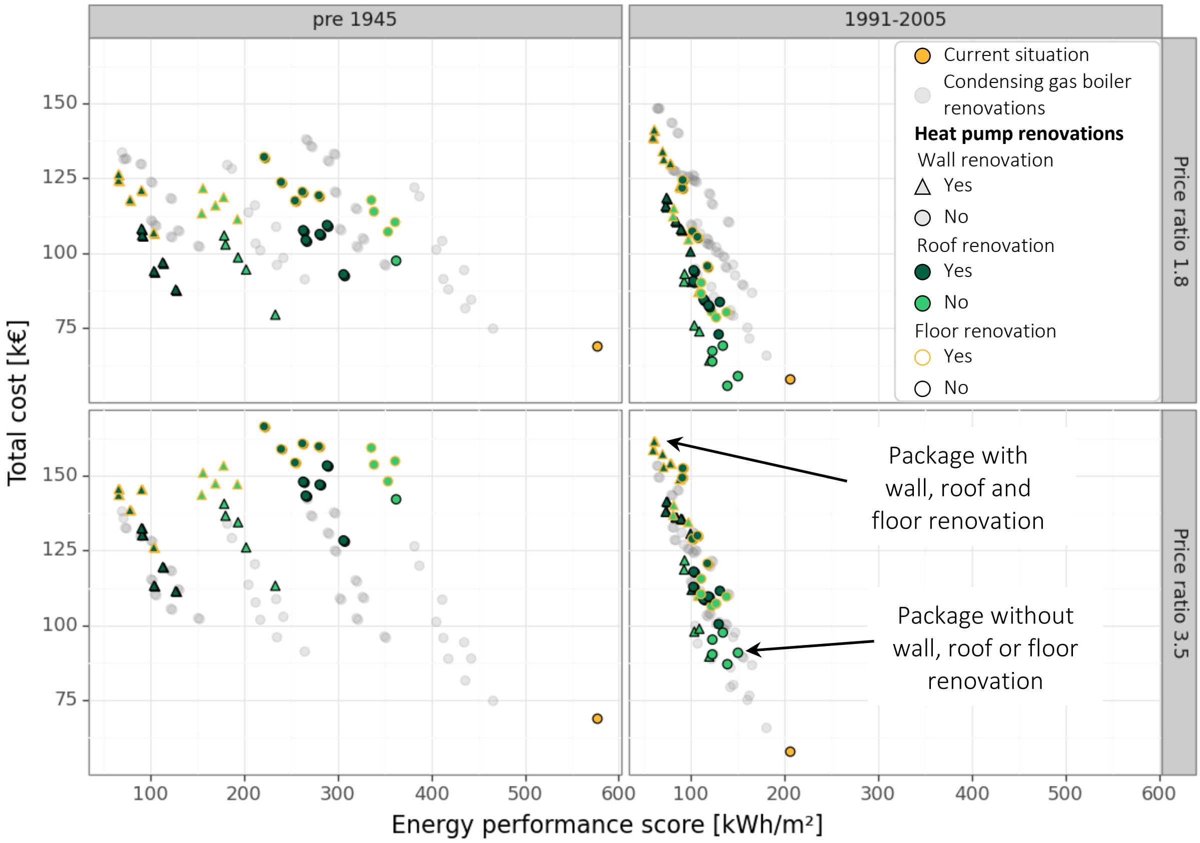

Figure 14: Detailed view of renovation packages for semi-detached dwellings of average size and insulation quality and two construction periods (columns). The rows compare different price ratio scenarios. The different shapes, fill colours and border colours highlight the presence of specific renovation measures in each package, including a heat pump, while renovations with gas boilers are all greyed out. Renovation packages with PV have been removed to allow focus on the other renovation measures. The resulting total cost is based on energy demand calculated with the EPC methodology, but the demand is corrected to represent real consumption[18].

5. Grid impact

Heat pumps, like other thermostatically controlled loads, can assist the grid if smart control is used and the system is designed for both efficiency and flexibility [4]. However, when such smart control is not in place, heat pumps—just like other large loads, such as electric vehicle charging—may create congestion and power quality problems in the local grid. Cumulatively, in the electricity system of a region or country they may lead to increased demand for electricity production and distribution capacity. The opposite is also possible, namely grid congestion because of too much injection from renewable electricity production that is not absorbed by local needs. The Netherlands is an example of a country where the electricity distribution grid already suffers from congestion, leading to waiting lists for the connection of new solar projects and large heat pump systems.

The impact of an individual heat pump is, however, difficult to estimate. The heat demand, which depends on the building size and energy performance, as well as on the dimensioning of the system, both play a role in the required capacity of the heat pump. Furthermore, the presence of a ventilation system with heat recovery and the heat pump system itself also influence the resulting power requirements in time. For instance, a hybrid configuration with gas boiler, the presence of back-up electric elements, solar thermal assistance or a buffer storage tank may play a role. The actual use, in terms of temperature settings, is also a parameter that has an impact on the shape of the electricity demand profile.

The cumulative impact on the local grid of several heat pumps in a neighbourhood further depends on many factors, including the grid configuration and dimensioning, and the existing loading of the network. In general, neighbourhoods with larger uninsulated buildings will have larger issues if all buildings are equipped with a heat pump, because of the generally higher required capacities. However, the simultaneity[19] of the loads is also important. As already explained, the load profile of heat pumps depends on the individual systems and temperature settings. However, as there is a large dependence on the outdoor temperature, generally high simultaneity is expected between heat demand of buildings in the same neighbourhood, region or country. The simultaneity of loads diminishes as the number of loads increases. As shown in Figure , for fully electric heat pumps, the simultaneity can be as high as 75% in a small rural neighbourhood connected to one distribution feeder, considering Belgian residential buildings [5]. This value tends to about 50-60% for a sufficiently large number of households. Looking at the simultaneity of the total household load, this is about 30-40% when a building has a heat pump, compared to around 20% for the usual electrical loads (for large numbers of consumers). These values, however, don't include potential effects due to active flexibility management. Research has shown that it can be possible to reduce the peak demand of heat pumps with active demand response in buildings with a minimum level of insulation [4]. However, at the moment, these effects are not yet realisable on a large scale. Furthermore, simultaneity factors for hybrid systems couldn't be found in the literature.

[19] Simultaneity factor of 0.6 or 60%, for example, indicates that the simultaneous peak of all loads is 60% of the theoretical peak where all loads have their peak at the same time.

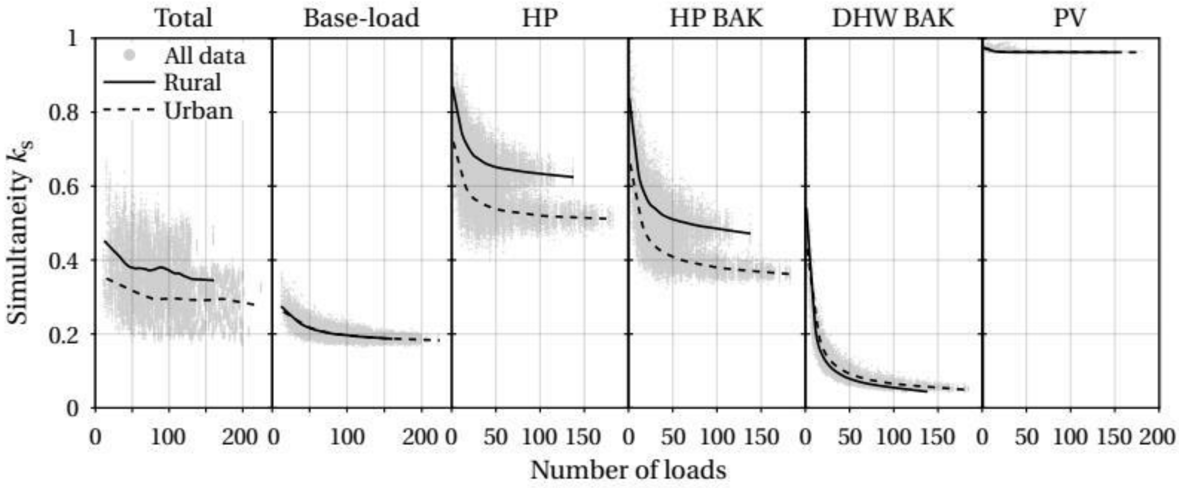

Figure 15: Simultaneity factors k_s for different load types, calculated on a 30-min basis. Grey points represent all simulated data points, and the lines represent the fit for rural and urban distribution islands separately. The HP *graph represents the simultaneity factor of the main heat pump load, while factors for the electric back-up elements are also given separately. (Source: Protopapadaki, 2018* [5]*).*

To assess the impact at region or country level, one can make a first estimate based on the total installed capacity of heat pumps and simultaneity factors as those mentioned before. The timing of the simultaneous peak demand is then an additional factor to take into consideration, especially as this may coincide with the peak demand for the remaining electricity consumption in the country. For electric heat pumps in a climate similar to Belgium, peak power demand is in winter, when the highest heating demand is found. Furthermore, for air-sourced heat pumps, the efficiency drops when the outdoor temperature decreases, further increasing the electrical demand. The same is illustrated by Elia, the Belgian electricity system operator, for 200 synthetic climate years in Figure 16.

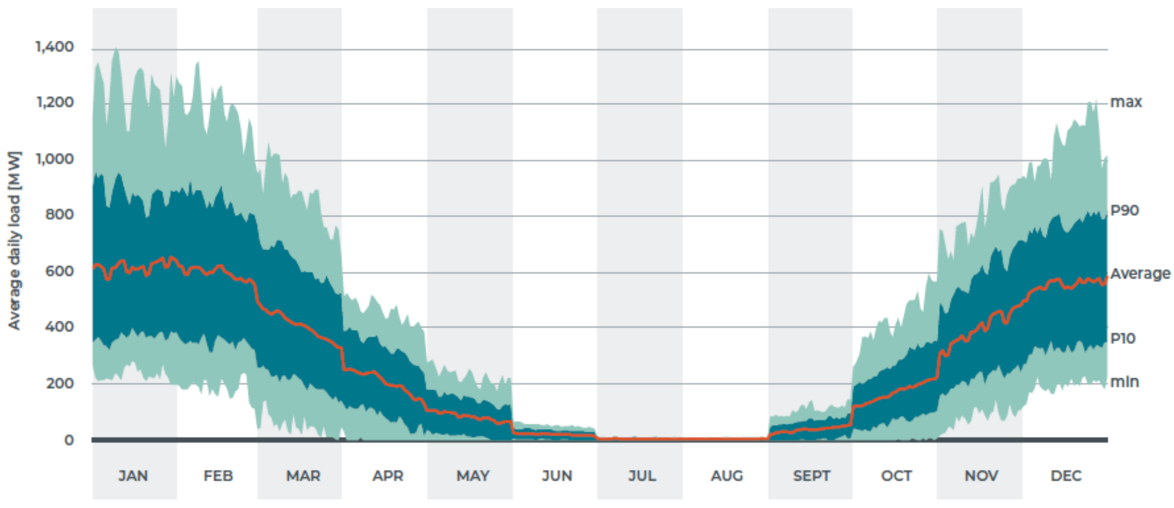

Figure 16: Distribution of the expected average daily electricity consumption of heat pumps in 2030 (central scenario). Source: Elia Adequacy and Flexibility study 2024-2034 [24]

To estimate the impact on the grid, estimates of the evolution of the installed number of heat pumps and their capacity in Flanders were made in the hybrid heat pump study. Figure gives an overview of this evolution for a selection of integration scenarios of fully electric and hybrid heat pumps. Different scenarios were developed, based on the simulation results for different energy price ratios: the replacement of heating systems with either fully electric or hybrid heat pumps in the different insulation levels was determined based on the proportion of heat pump use compared to the gas boiler use. Here, we show one of those scenarios denoted as Mix. Additionally, an All-full-electric case, an All-hybrid case and a special renovation case (Reno) were examined. The latter considers replacement of heating systems only when a deep retrofit is made, resulting in much fewer replacements in total, but also in smaller capacity due to the better insulation.

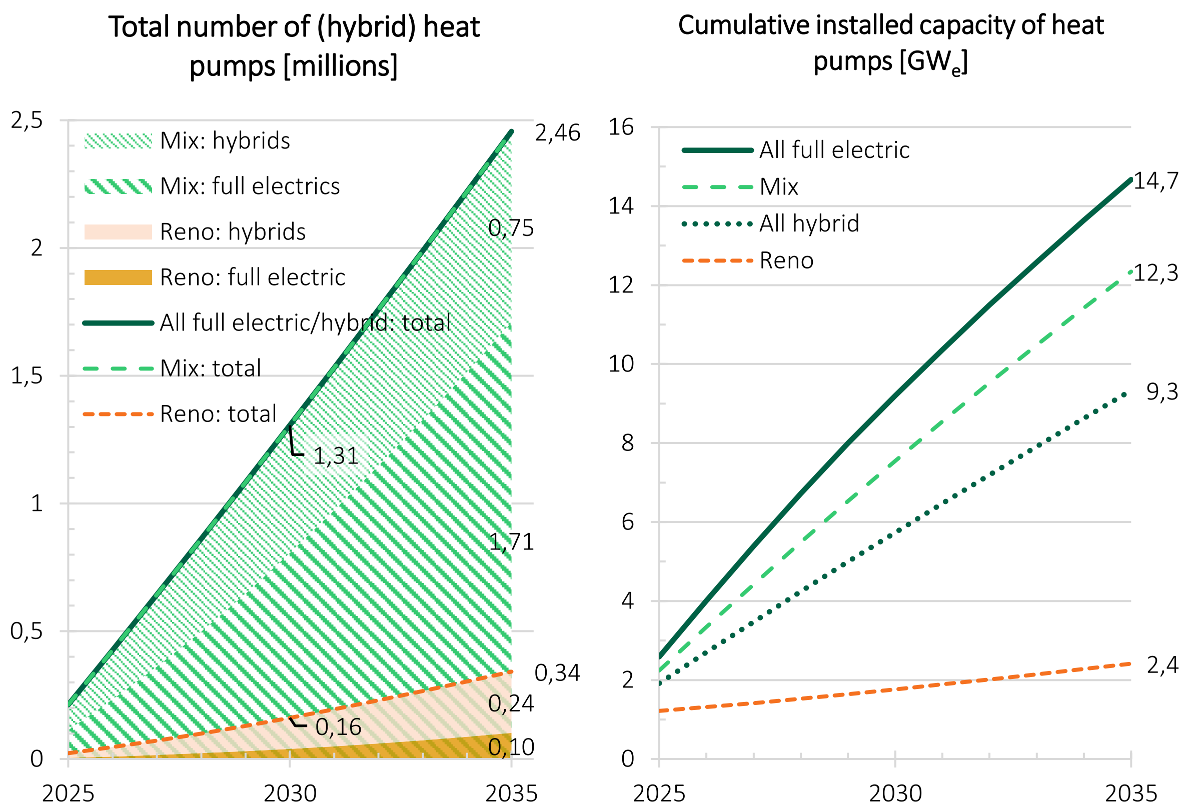

Figure 17: Estimation of the total number of residential heat pumps in Flanders (left) and the related installed capacity (right) for different scenarios of heat pump implementation, according to the hybrid heat pump study.

As a comparison, the EnergyVille/VITO PATHS2050 study [20]suggests 1.5 million heat pumps should be installed in homes and commercial buildings by 2030 in Belgium, to reach climate neutrality by 2050. Given that the Flemish building stock makes up about 60% of the total Belgian building stock, and that commercial buildings are only a very small part of this total, this translates roughly into 0.9 million heat pumps in Flemish homes by 2030.[21] This highlights that for Belgium to reach a carbon neutral future in 2050 (what the PATHS2050 scenarios aim to reach), the basic Reno case where heat pumps are only installed when deep renovations are made, is clearly not sufficient.

Furthermore, it is important when proposing decarbonisation policies focused on the electrification of heating, to take into account the potential impacts on the security of supply and grid stability. This also entails that grid operators need to stay up to date and foresee scenarios that reflect ambitious policies for heating electrification, even more so in the face of the parallel electrification of mobility. In Belgium, transmission grid operator Elia assumes in its 'Adequacy and flexibility study[22]' of 2023 a penetration rate of 19% by 2030, up from just 3.6% assumed in its study two years earlier [24]. For 2035, a penetration of 27% of heat pumps in residential buildings is assumed, or 1.8 million heat pumps. This is still substantially less than the best scenario in the hybrid heat pump

[20] EnergyVille Paths 2050: https://perspective2050.energyville.be/

[21] EnergyVille Paths 2050: https://perspective2050.energyville.be/residential-commercial

[22] Elia publishes its adequacy and flexibility study for the period 2022-2032: https://www.elia.be/en/news/press-releases/2021/06/20210625_elia-publishes-its-adequacy-and-flexibility-study-for-the-period-2022-2032

study, but also more ambitious than the lowest scenario (Reno), given that the hybrid heat pump study only looks at the Flemish region. Furthermore, in the 2023 study on the capacity of the low-voltage distribution network in Flanders, the Flemish energy regulator (VREG) considered 1.6 million heat pumps in 2035 for the most ambitious scenario, and only 0.25 million in the low penetration scenario [25].

The choice between hybrid or electric heat pumps has an impact on the estimated peak consumption, since the hybrid ones would result in a lower total peak. However, prioritizing fully electric heat pumps in well-insulated buildings is also important as they contribute more to the reduction of fossil fuel consumption and carbon emissions. Challenges for the electricity grid are also to be expected when hybrid heat pumps are rolled out, albeit to a lesser extent. On the other hand, a rollout of hybrid heat pumps may mean that the gas network will be maintained for longer in certain places, resulting in a higher cost for the end users who are still customers of the gas distribution network. Further, some countries already intend to ban new systems that use fossil fuels altogether, in which case hybrid heat pumps would not be an option.

Conclusions

Heat pumps are at the forefront of the energy transition in Europe. And unsurprisingly so, given their potential towards decarbonisation, their highly efficient performance and their versatile applications. The European Commission's upcoming Heat Pump Action Plan initiative [23]is set to accelerate their deployment, and so are various policies already undertaken in several European Member States.

Despite that, more fact-based information concerning the technology, its benefits and its applications are needed to support both policymaking and implementation on the ground. This paper summarises the research findings obtained for Flanders, Belgium by the Smart Energy and Built Environment Unit of EnergyVille/VITO, and concludes with the following six key recommendations to accelerate the rollout of heat pumps in residential buildings.

1. **A competitive electricity pricing compared to fossil fuel alternatives would facilitate a widespread adoption of heat pumps.**

Our research indicates that competitive electricity pricing, in comparison to fossil fuel alternatives such as natural gas, can enhance the economic viability of heat pumps for homeowners. While the higher initial investment cost of heat pumps compared to gas boilers is a significant factor to consider, their increased efficiency does allow for a potential offset against this difference in initial investment cost, and this within a few years because of their reduced operational costs.

Indeed, in a climate and building stock similar to that of Flanders, a required electricity-to-gas price ratio of 2.5 or lower would render heat pumps economically competitive against gas boilers. Additionally, a lower electricity price could enable heat pump installations without additional renovations in some newer building types, thus contributing to reduced overall energy demand and emissions.

Any energy taxation reform should be complemented by a careful assessment of alternative and complementary policy measures—including tax reform, renovation obligations, fossil fuel bans or other financial incentives such as tax breaks or subsidies—all considered together to achieve an optimal societal outcome. Especially, a targeted approach to vulnerable households is required, and relevant measures should be integrated to address a just transition.

2. **Most buildings are or could easily be made suitable for heat pumps. Especially for less performing dwellings, improvement of the building performance will reduce both the initial investment and operational costs of a heat pump.**

From a technical point of view, our findings show that most buildings are already suitable for heat pumps, or could easily be made to be so after some simple adaptations or limited renovation. The possibility of installing a fully electric heat pump is mainly determined by the energy performance of the building and the temperature regime of the heat delivery system. Therefore, an improvement of the building performance can help reduce the heating demand—limiting the size and thus the price of the heat pump. In newer buildings, renovations which only replace the existing heating system with a heat pump already reduce the lifecycle cost compared to a standard gas boiler. In older, less performing dwellings, for heat pumps to make sense from a technical point of view, moderate interventions such as replacing the windows and the roof insulation can, in many cases, be sufficient. However, for heat pumps to make sense from a lifecycle cost perspective, a deeper renovation—including, for instance, the addition of wall insulation—would be recommended.

On the other hand, lowering the supply temperature of the hydronic heating system can also allow for a low-temperature system, thus decreasing the cost of the heat pump. This upgrade of the emission system can be achieved through booster technology or simply with additional emission elements. Where these solutions are not sufficient, high-temperature heat pumps are available—albeit at a higher cost.

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[23] Heat pumps action plan: https://energy.ec.europa.eu/news/heat-pumps-action-plan-online-consultation-launched-commission-accelerate-roll-out-across-eu-2023-06-07_en

For buildings with very high thermal needs, hybrid systems that combine a heat pump and a gas boiler are another option. Although it does have to be noted that while they help improve energy efficiency without the need for renovation, in the future they may still have to be replaced by fully electric heat pumps—depending on the long-term policies applied in each country.

3. **Meeting heat pump electricity demand with PV production is limited at individual building level due to seasonal and time-of-day mismatch.**

Analysis of a PV production profile and a heat pump electricity demand profile shows that there is both a seasonal and a time-of-day mismatch for a Belgium-like climate and latitude, leading to the fact that PV production can only cover the heat pump load for space heating for around 10%. The load cover factor is much higher for domestic hot water production if a storage vessel is used.

In warmer climates with significant cooling needs, heat pumps can indeed be a good combination with PV, as more coincidence of the demand and production can be expected. However, when it comes to heating-dominated countries, such as Belgium, the assumption sometimes included in energy performance assessments that PV can contribute 100% to the energy supply is misleading—at least in terms of self-consumption. To improve the absorption of local renewable energy production, optimisation at the level of multiple buildings—whereby the variable needs of different users can be combined—would be more beneficial than optimisation at an individual building level.

4. **Prebound and rebound effects are crucial when assessing the financial viability of renovations.**

Regarding cost-optimal renovation, our findings show that when examining the total cost over a period of 30 years, the outcomes depend significantly on the energy price assumptions. Here again, the retail electricity-to-gas price ratio needs to drop below 2.5 for heat pumps to topple condensing gas boilers and become part of the cost-optimal renovation packages.

However, real energy use—especially in buildings with limited or no insulation—has been shown to be much lower than the one estimated by the energy performance calculation method based on asset rating. A more realistic estimate of the energy saving potential—one taking into account prebound and rebound effects—is therefore important when assessing the financial viability of renovations and heat pump installations. In this case, the price difference between fossil fuels and electricity plays an even bigger role, as the potential energy savings are more limited.

At the same time, for policy makers and building owners to be able to make better informed decisions, more knowledge and evidence is required about the patterns of energy use before and after renovation, as well as about the co-benefits that energy renovation offers.

5. **Grid reinforcement is vital for decarbonisation, while trade-offs with building renovation require thorough investigation.**

While conducting a detailed assessment of the impact of heat pumps on the electricity grid proves challenging, it is feasible to estimate the evolving total number of heat pumps and the anticipated peak demand for a country or region. The extent of impact on the grid is contingent on policies, energy prices and the influence of both on heat pump adoption across residential building sectors.

In the context of Flanders, projections suggest an installation of 0.35 million to 2.4 million heat pumps by 2035—subject to market conditions and policy ambitions. Currently, grid adequacy studies in Belgium do not encompass more ambitious scenarios, despite the imperative of meeting European and national climate targets. Realizing these targets, however, would necessitate expedited and scaled grid expansions. Acknowledging that investments in thermal insulation can diminish peak demand by reducing required heat pump capacity, we see that a trade-off emerges between renovation spending and investment in grid reinforcement and generation capacity. Investigating this trade-off at a localized level—considering neighbourhood-specific needs—is essential to be able to devise tailored transition pathways.

6. There is a need for an integrated policy framework, supported by sound scientific analyses.

While heat pumps may be technically feasible for many buildings in Flanders and Europe, the uptake of the technology in existing buildings remains slow. Aspects influencing this uptake are related to awareness and acceptance, to financing or to supply chain challenges such as a higher demand than offer for heat pumps, instability of material prices and a lack of qualified installers. To achieve climate objectives, however, heat pump deployment needs to be accelerated.

Energy policy for the decarbonisation of the building stock therefore requires a broadly integrated framework that unifies technological, economic, social and context-related factors. An optimal package of combined policies and regulations to bolster the roll-out of heat pumps should be context-specific and potentially combine both global measures such as energy taxation reform, and local measures such as investment support. Along with assistance for vulnerable households, a balanced policy package would also reduce the need to subsidise those that are able to invest. Based on a solid scientific foundation, such packages should be developed—taking into account trade-offs between building envelope renovation and heat pump installation, and considering opportunities found in collective approaches to renovation.

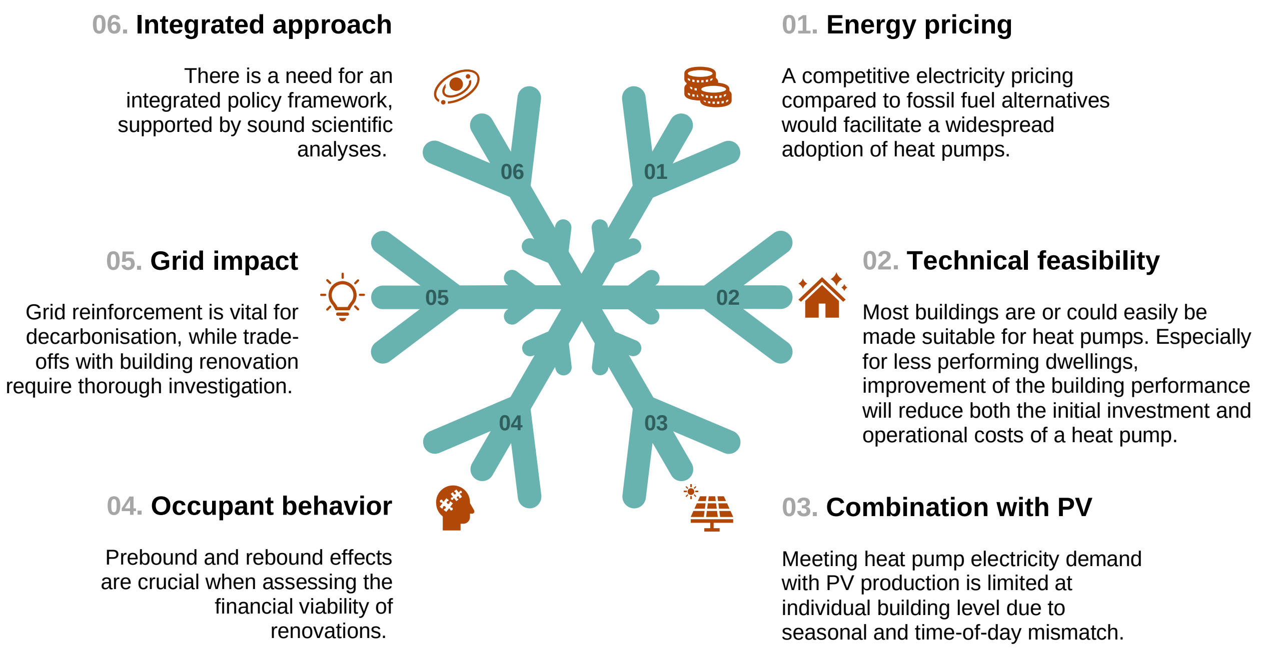

Figure 1: Recommendations to expedite the deployment of heat pumps in residential buildings.

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