Technology Collaboration Programme
by iea

Heat Pumping Technologies
MAGAZINE
Heat Pumps Unleashing Flexibility and Sector Coupling
Vol.42 No.1/2024
A HEAT PUMP CENTER PRODUCT

Topical Article

Efficiency and Flexibility: A UK Perspective on Heat Pumps in the Electricity System

DOI: 10.23697/9159-2985

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This article raises the question of what the 'optimal' performance of a heat pump looks like as we transition to a decarbonised, flexible electricity system. As the system boundary is widened from heat pump efficiency to whole electricity system efficiency, we reflect on how heat pump and heating system design may evolve to result in the lowest system costs. The article is set in a UK context, but many of the issues raised are relevant to other countries with current or planned large-scale heat pump uptake.

Introduction

UK policy on building decarbonisation relies heavily on heat pump deployment - in 2021, the UK government set a target of installing 600,000 heat pumps per year by 2028. Achieving this target will require decreases in capital costs and running costs, as well as overcoming a number of other barriers [1]. Running costs depend on electricity tariffs as well as building and heat pump efficiency, leading to a drive to improve the Seasonal Coefficient Of Performance (SCOP) of heat pumps in order to increase affordability for households. To maximise SCOP, the current best practice involves running the heat pump constantly through the heating season, using weather compensation control to adjust the required flow temperature. Some installers also advocate designing out buffer vessels, as hydraulic separation between the heat pump circuit and space heating circuits reduces efficiency in principle. Our sizing calculations (and running cost predictions) tend to be based on steady-state heat loss, corresponding to constant operation[1].

[1] The heat pump design standard used in the UK, MIS3005D, also allows for intermittent operation but the authors have not encountered this option being used for sizing domestic systems.

Meanwhile, there is a growing awareness of what the future electricity system will look like. In the UK, supply will be dominated by wind power, and demand will peak in winter evenings (as it does today), but the electrification of heat, transport and industry will change the demand profile, including the potential introduction of a new winter morning peak created by heat pumps (see Figure 1). In the future, it is likely that we will operate heat pumps flexibly to manage the hourly variability of electricity demand both on a national and local scale and thus to support system operation. A national expert workshop held in 2023, which brought together stakeholders from the heat pump industry, electricity sector and other parts of the system, found there a broad consensus that heat pump flexibility will be widespread by 2035, the year by which the UK electricity system is planned to be fully decarbonised [2].

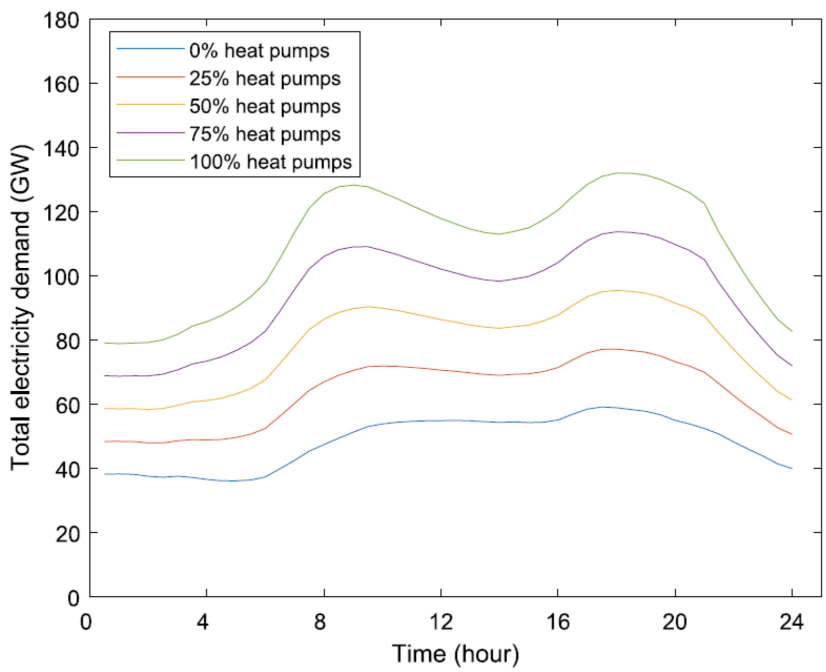

Figure 1: Predicted effect of heat pump penetration on half-hourly British electricity demand on a very cold winter day. Figure from [3].

How, therefore, do we reconcile the above two perspectives: on the one hand of, maximally efficient heat pumps running at a constant output, and on the other hand of heat pumps as part of a dynamic electricity system, turning on/off/up/down according to the requirements of the system? More specifically, what needs to change in order to move from the first way of defining ideal heat pump operation to the second?

In this article we focus on some of the technical aspects of this transition; there also exist important social, economic and governance aspects of introducing heat pump flexibility which need to be addressed.

Redefining efficiency

Historically, for good reasons, heat pump efficiency – SPF, COP, SCOP – has drawn the system boundary around the heat pump, plus backup heating. This makes sense when each unit of electricity used costs the same amount, and it is desirable to minimise the total cost by getting as much heat out of the system as possible for each unit of electricity used.

These metrics, however, will not represent the value of the heat pump's operation in the future electricity system, in which the ability of the heat pump to modify its load and to defer or front-load its operation will be worth money. For example, a recent UK trial has investigated preheating homes during periods of low-cost electricity and then switching heat pumps off during expensive periods. This will decrease heating system efficiency – requiring higher flow temperatures during the preheating times and potentially during recovery after an 'off' period. Electricity use is likely to increase, and yet within the context of the whole electricity system, the heat pump's performance is 'better' or 'more useful' than it would have been under constant operation due to the value of load shifting to the system.

Unlike other countries in which utilities carry out direct load control of heat pumps, the UK is taking a market-driven approach to flexibility. Customers will be incentivised to run their heat pumps flexibly through half-hourly electricity pricing structures. Variable half-hourly pricing will lead to a different cost-optimal way to run a heat pump than is currently the case under fixed unit pricing. It is not yet clear exactly how different the electricity price will be throughout a single day, but if the price signal is great enough, then a different set of operational characteristics will be desirable in a heat pump compared to simply running efficiently at constant output. This is discussed next.

Modifying heating system capability

A future in which electricity prices vary half hourly and heat pumps regularly translate price signals into different modes of operation may lead to heat pump and heating system designs being different from those of today. Firstly, extra storage may be needed. The UK's building stock is old and leaky compared to those in other European countries, yet most buildings are eligible for a subsidy on heat pump retrofit. Experts currently agree that space heating load can be shifted 1-3 hours in the majority of homes without thermal discomfort (and hot water up to 12 hours); it is also likely that building fabric efficiency upgrades in the years from now to 2035 will proceed much more slowly than the heat pump roll-out. Therefore, the amount of thermal storage available from building fabric alone is unlikely to increase in the coming years. The 1-3 hours of storage available in most homes is helpful for evening demand peak smoothing but is not usually long enough to match demand to variable wind supply (which varies on a timescales from daily to weekly rather than hourly). Batteries and thermal storage can significantly extend the load-shifting potential of heat pumps, and it may be that these become much more common aspects of heat pump installations as the need for flexibility increases.

Heating system responsiveness may also become more important so that when heat pumps respond to low prices and ramp up their output, or recover from a period of no/lower operation by increasing their output to restore an internal temperature, this can be done quickly. Increased responsiveness may occur by increasing flow temperature or change in component specification (e.g. size of radiators, use of fan-assisted radiators for faster heat transfer); again, the incentive structure for electricity pricing will determine what is the most cost-effective configuration of heat pump equipment and operation. This may, in turn, affect the sizing methodology and even the performance testing regime.

Enhancing heat pump control

Different heat pumps use different control logic, but in general, the control is designed to maintain a steady state internal temperature (and sufficient hot water). For example, in our previous work, one UK heat pump expert could not find a way to program an off period into their controller as the heat pump's control was set to run all winter unless the outdoor temperature exceeded a threshold - its algorithms were designed to maintain a certain flow temperature [4].

Adapting control functionality to deal with turning up/down, or off and back on, should be fairly straightforward. There are decisions to be made as to whether to constrain the flow temperature when heat pumps resume operation after an off period, in order to not create new electricity peaks. However, these could, in theory, be simply implemented in firmware updates to the heat pump.

It has also been shown in previous work that if a heat pump installation has not been carried out with flexibility in mind, it is easily possible for components in the heating system to override or negate attempted flexibility from the heat pump. We have identified buffer tanks calling for heat during high-price periods [4], and others have found thermostatic radiator valves blocking attempts to preheat spaces before high-price periods. Again, these issues might be solved by changes to the heat pump controller's software so that the heat pump or smart home controller can take into account other system components, as well as requests from the electricity system to flex its load. As our energy system becomes more complex, this simply reflects the need to think about the efficiency of the wider system and not allow the optimising of individual components to lead to wider system inefficiencies.

Conclusion

We are moving from a world in which the key performance metric, representing the lowest cost way of running heat pumps, is *heat pump* efficiency to one in which it is *whole energy system* efficiency. The latter will combine heat pump efficiency, flexibility capability, and other factors such as resilience. There will be a trade-off involved between these factors in order to reach the most efficient and, therefore least-cost solution - this trade-off will affect heating system design and operation. This article is not intended to give all the answers but to open up the debate as to how heat pumps and their associated heating system components may have to change and how heating system design and retrofit can best facilitate flexible operation.

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