Hybrid Heat Pumps Minimize Emissions and Overall Costs

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Heat pumps are more attractive than (many) conventional heating methods, mainly due to their efficiency. This article describes the impact of heat pumps on the energy chain – not just in residential homes, but also on infrastructure and emissions. Hybrid heat pumps offer advantages in the sense that the carrier can be varied depending on specific circumstances, thereby further improving efficiency and reducing emissions with only limited impact on energy infrastructure costs. This can be achieved by the following means. Switching to gas where heat pump efficiency is poor reduces energy bills and also reduces electric peak load (reducing electricity infrastructure costs). Also, at times when electricity emission factors are poor, a switch can be made to gas as energy carrier. Switching to electricity during periods of abundant availability of clean electricity also reduces emissions. Switching to gas at very low outside temperatures avoids installing low-temperature radiators in existing homes, thereby reducing costs.

Introduction

The most important aim of energy transition is to reduce CO_2 emissions. This article will focus on this aim for the residential heating sector: how can we reduce CO_2 emissions with minimal overall costs, while maintaining the current levels of comfort and security of supply?

Specifically, we will investigate the impact of residential energy decisions on the energy chain as a whole: the costs and emissions of generation, transmission, distribution and appliances. Only by looking at the whole energy chain can sensible choices be made that benefit both customer and society. This research was conducted by the gas infrastructure company Gasunie in cooperation with partners.

Emission reduction as target

Both the EU and its member states individually have set targets to reduce CO_2 emissions due to their impact on global warming. To support these targets, the EU has developed an Emissions Trading System. Emissions in the residential sector do not fall under this scheme, however. National policies have been developed to support emission reduction in this market sector. In this article, emission reduction has been defined as an overall emission reduction, whether or not it falls within ETS.

The residential heating market in the Netherlands is currently mainly supplied by natural gas. The standard used for reliability is a 1-in-50 winter, which means that the infrastructure must be able to cope with the demand

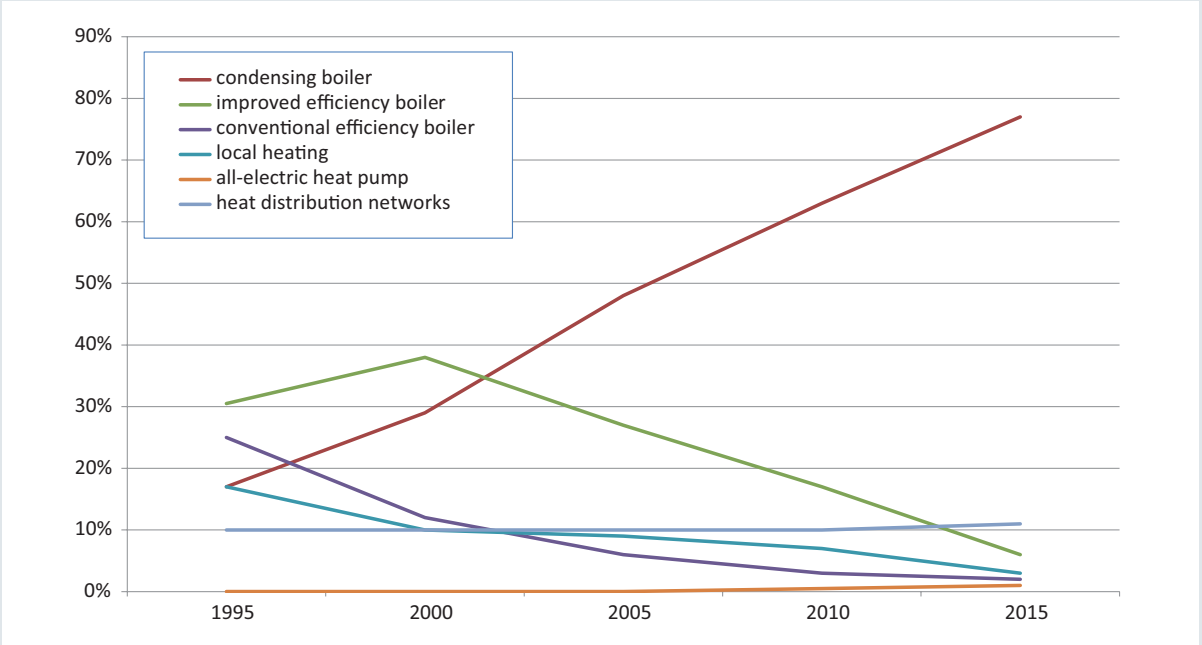

Fig. 1: Market share of heating systems in the residential sector in the Netherlands.

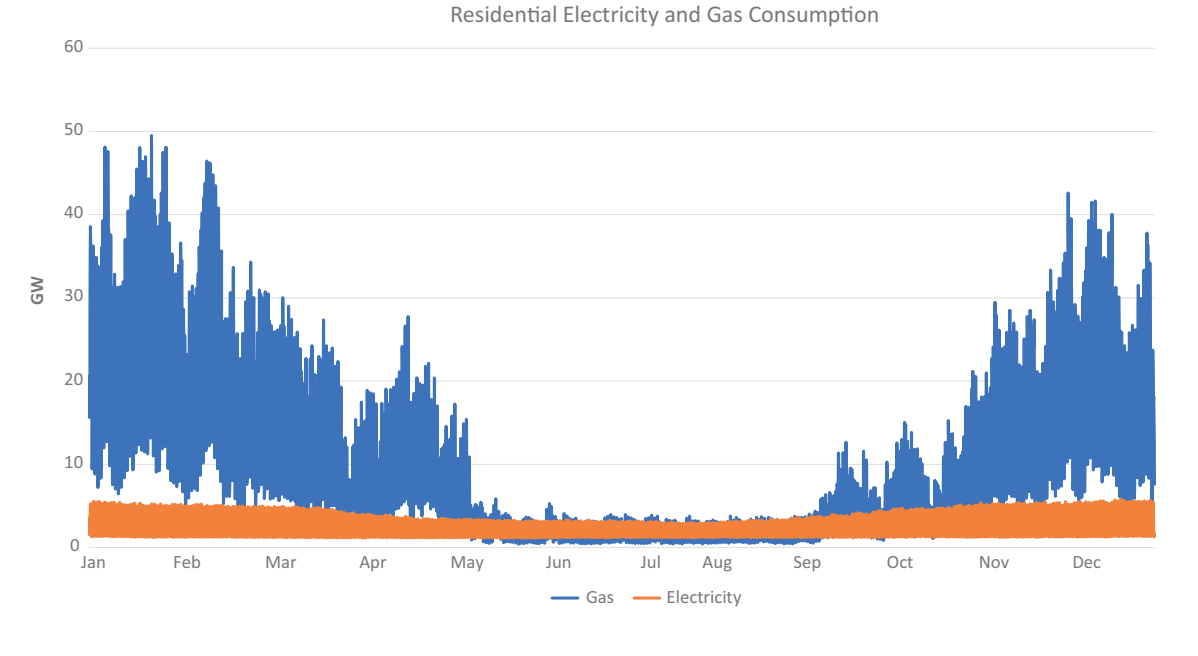

Fig. 2: The peak demand of gas and electricity in the residential sector in the Netherlands. Note the large difference during winter.

of a winter day that happens once in 50 years, with an average effective daily temperature of -17 °C. This study assumes that this standard will also be applied to any other future energy infrastructure for the residential heating market. Results presented in this article are specifically applicable to the Dutch residential heating market, but are also of general value.

Characteristics of the residential heating market

As mentioned previously, residential heating in the Netherlands is almost completely supplied by natural gas. Condensing boilers are currently the most common heating appliances, with an 80 % market share – up from approximately 20 % some 20 years ago (see Figure 1). The market share of heat pumps is currently only 1.5 %, but is increasing. The residential heating market is very temperature-dependent. Figure 2 shows this behavior for 2017. In this winter a peak gas demand of about 50 GW was observed for the residential heating market, with a peak electricity demand of just 5 GW.

In severe winter conditions, with lower temperatures, the peak gas demand will be even higher. Since this is the characteristic demand profile of the residential heating market, any alternative energy carrier taking over this role from natural gas will have to be able to cope with this profile.

In this article we specifically compare a transition from condensing boilers to either all-electric heat pumps or hybrid heat pumps – the first being a mix of air source heat pumps, mainly for existing homes, and ground source heat pumps, mainly for new homes, while the latter are defined as an air source heat pump combined with a condensing boiler. In a hybrid heat pump, both electricity and gas can be used (the choice made can be varied from hour to hour) to generate the required heat for space heating and domestic hot water.

One option for winter months (which have a limited supply of renewable energy in the residential sector, so rely heavily on fossil fuels) is the use of all-electric heat pumps. Unfortunately, the efficiency of air source all-electric heat pumps is heavily dependent on outside air temperatures – see Figure 2. At times of low outside temperatures, heat demand will be highest when the efficiency of the heat pump is low. All-electric heat pumps will greatly increase the required electrical energy load, requiring electricity generation and grids to be expanded. Moreover, homes have to be equipped with underfloor heating when using an all-electric heat pump. This comes at a high cost for existing homes. All the abovementioned reasons put severe limitations on the applicability of air-based heat pumps.

In contrast, hybrid heat pumps can choose between two energy carriers. A smart choice of carrier could reduce the load on electricity generation and grids, and make expansion investments unnecessary. Hybrid heat pumps do not require any changes to home radiators, since they can easily deliver high-temperature water during cold winters – making them an extremely attractive option. They also reduce emissions and costs, as explored in more detail in section 3.

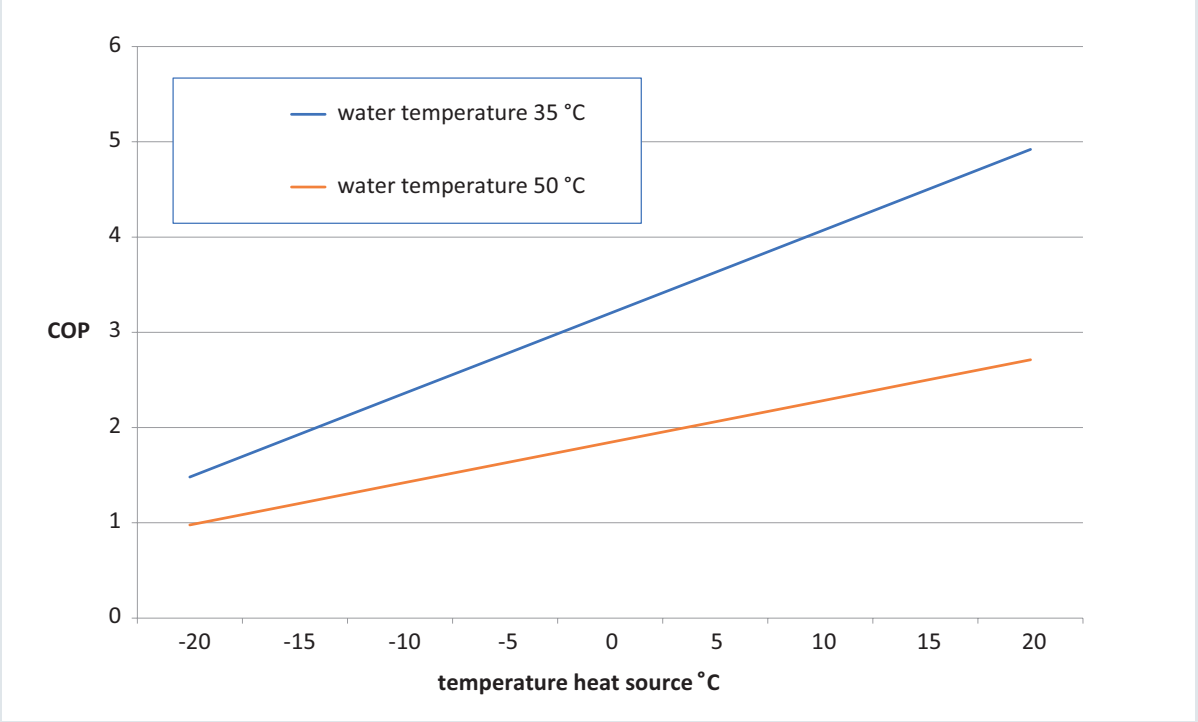

Fig. 3: Figure 3 Efficiency of air-sourced heat pumps.

Figure 3 indicates (using a currently observed emission factor for electricity of 0.586 and for gas of 0.183 kg CO_2/kWh) that with poor efficiency it would be better to use natural gas to achieve lower carbon emissions.

Overall costs

The costs of home refurbishment and changes to heating appliances are important when considering how to reduce CO_2 emissions from residential heating. Infrastructure costs are often overlooked, however. A transition from natural gas to electricity represents a tremendous hidden cost for electricity transportation, distribution and power generation.

An extensive study conducted recently [2] looked at the costs of residential heating. In this study six scenarios are used, consisting of two insulation levels (medium and high) and three heating technologies (condensing boilers, all-electric heat pumps and hybrid heat pumps). The total costs in each scenario were calculated, consisting of energy, infrastructure and home adaptations (such as insulation, radiator surface, ventilation and appliances). Costs are calculated on an annual basis with an expected lifetime of 40 years for infrastructure and insulation and 15 years for appliances. A condensing boiler with a medium insulation level is used as a reference.

The results are shown in Figure 4. The hybrid heat pump/medium insulation scenario is marginally more expensive (+17 %) compared to the current condensing boiler. In contrast, switching to an all-electric scenario more than doubles the cost, in large part due to the excessive infrastructure investments required for the all-electric/medium insulation scenario. This can be explained as follows. Infrastructure reinforcements (and thus costs) are caused by electricity demand under peak conditions on a very cold winter day. Under these temperature conditions, the COP of air source heat pumps becomes very poor (see also Figure 3). A combination of high thermal demand and low efficiency causes an extreme peak in electricity demand and thus a heavy load on the electricity infrastructure. Hybrid systems can be operated in such a way that, in circumstances of high thermal demand, gas will be used as an energy carrier – putting less pressure or no pressure on the electricity grid infrastructure.

Next we investigated the CO_2 emission reductions of all-electric versus hybrid heat pump systems. To arrive at these results, future expected emission factors of 0.25 and 0.17 kg CO_2/kWh were used [2] for electricity and gas respectively. We find that hybrid solutions offer higher emissions reductions than condensing boiler and all-electric solutions (see Figure 5).

Comparing both graphs provides insight into the costs of realizing further emission reductions using a condensing boiler/medium insulation home for comparison. See Table 1.

Taking a home with medium insulation equipped with a condensing boiler as a reference (which is the situation in the Netherlands), it can be seen from Table 1 that the next step in CO_2 emission reduction should be to install a hybrid heat pump and then insulate from here to a further, higher level. That way, the greatest re-

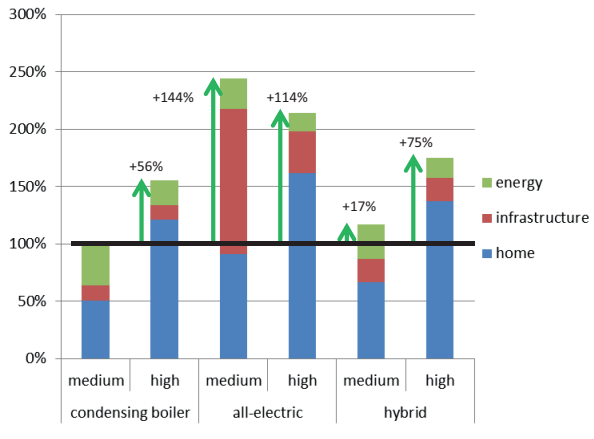

Fig. 4: Costs of insulation and appliances on an annual basis.

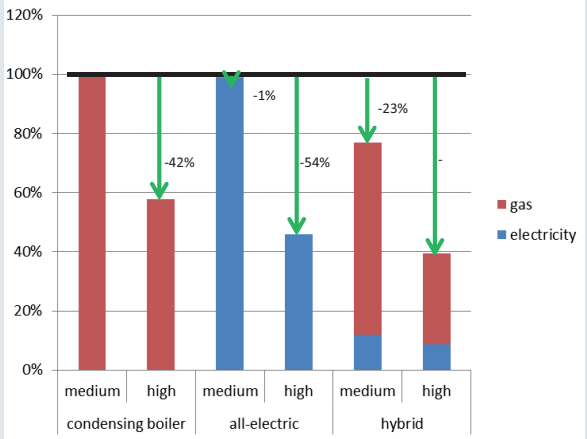

Fig. 5: CO_2 emissions at medium and high insulation levels and three heating appliance technologies.

	Condensing boiler		All-electric heat pump		Hybrid heat pump	
	medium	high	medium	high	medium	high
Costs (€/ton CO_2)	-	€716	€79500	€1149	€411	€676

Table 1: Costs of realizing further emission reductions. "Medium" and "High" refers to the levels of insulation.

duction is achieved for the lowest cost. Looking at the table, it is also very clear that installing an all-electric heat pump in a medium insulation home is extremely expensive (mainly due to high infrastructure costs, which are currently socialized) and barely reduces emissions.

Note, too, that even if the residential sector were part of ETS (which is not the case), current CO_2 prices will never incentivize the residential sector to reduce CO_2 emissions.

Conclusions

Residential space heating and domestic hot water demand represent a large share of energy consumption and greenhouse gas emissions.

Currently, natural gas as the main energy supplier is a low-cost and highly flexible solution in Central European countries. As an alternative energy carrier, electricity cannot offer these advantages since both transport and storage are much more expensive. A combination of energy carriers must therefore be pursued in order to achieve "the best of both worlds". Hybrid appliances are capable of accommodating both gas and electricity as energy carrier and of reducing emissions for the lowest overall costs.

References

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[2] van Melle T, Menkveld M, Oude Lohuis J, de Smidt R, Terlouw W. De systeemkosten van warmte voor woningen. Utrecht, the Netherlands 2015.

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