TECHNOLOGY FACTSHEET

TNO

HIGH TEMPERATURE AIR SOURCE HEAT PUMP (SUPPLY TEMPERATURE 65°C TO 80°C)

Date of factsheet	29-7-2020
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Sector	Households
ETS / Non-ETS	Non-ETS
Type of Technology	Emission reduction
Description	This factsheet describes an air source heat pump used for heating a dwelling. It considers an air source heat pump with a supply temperature ranging from 65 °C to 80 °C that works in combination with traditional wet radiators in homes. This technology is also called a high temperature air-to-water heat pump. There are different supply temperatures for residential heat pumps depending on type of refrigerant and refrigerant cycle (for instance single or cascade systems). Regular residential air source heat pumps typically supply heat at a temperature of up to 55°C (Khoa Xuan Le et al. (2019). This however does not work efficiently with traditional wet radiators in homes that are usually designed for an inlet temperature of 75°C and a return temperature of 65°C (Khoa Xuan Le et al. (2019). High temperature heat pumps can achieve these temperatures; typically these heat pumps reach a temperature of 65 °C up to 80 °C (Carbon Trust and Rawlings Support Services, 2016). This temperature level is sufficient for space heating and domestic hot water. No (significant) adjustments to the heating system in the dwelling are required in that case. The working principle of a heat pump is a reversed refrigeration cycle (see also Staffell et al., 2012). An air source heat pump extracts heat from the outside air (ambient heat) using an evaporator where a refrigerant flows through that absorbs heat. After evaporation, an electric driven compressor increases the pressure, after which the refrigerant condenses back to a liquid (within the condenser) to release heat to a heat exchanger. An expander makes the refrigerant ready for heat absorption. Heat released (within the condenser) is transferred to the dwelling. The transport medium for heat in the dwelling is water (e.g. wet radiators or underfloor heating). The efficiency of a heat pump is expressed as the coefficient of performance (COP): the ratio between heat output and electricity input. The COP depends on the temperature difference between supply temperature and heat source, in technical terms the temperature difference between heat source and heat sink. The higher the temperature lift, the lower the COP. For instance, in winter, there is a larger temperature lift, resulting in a lower COP. At a certain point the temperature difference will be too great for the heat pump to operate (efficiently) and the heat pump has to be stopped. For most air source heat pumps this will occur at temperatures in the range of –15°C to -20°C (Forsén, 2005). At that point auxiliary heating is required.
TRL level 2020	TRL 9
	The European Heat Pump Association report (2018) indicates that 'normal' heat pumps provide temperatures up to 80°C and can use energy sources from renewable and waste sources with temperatures up to 40°C. These are commercially available. (EHPA, 2018).

TECHNICAL DIMENSIONS

	Functional Unit		Value and Range								
Capacity	kWth		11								
			6			-			16		
Potential			Current			2030			2050		
			-			-			-		
			Min	–	Max	Min	–	Max	Min	–	Max
Market share		%	-			-			-		
			Min	–	Max	Min	–	Max	Min	–	Max

Capacity utlization factor		1
Full-load running hours per year		1,100
Unit of Activity	GJth/year	45
Technical lifetime (years)	15 to 20	
Progress ratio		
Hourly profile	Yes	
Explanation	The typical thermal capacity of a high temperature air source heat pump used by a household is between 6 and 16 kWth (Carbon Trust and Rawlings Support Services, 2016). Values outside this range are possible. Khoa Xuan Le et al. (2019) mentiones a capacity of 11kWth. From a field trial using the Daikin high temperature heat pump of 11kWth, it was concluded that heat pump should be properly sized, comparable to gas-fired boiler capacity, in order to provide thermal comfort at the same time as a gas boiler (Shah & Hewitt, 2015). There are currently no statistics available on the number of high temperature (supply T >65 °C) air source heat pumps used by households in the Netherlands (It is very small at present). At the end of 2019, there were in total 119.692 air-water heat pumps used by households in the Netherlands (CBS, 2020). Almost all of these heat pumps operate at lower temperatures (note that dwellings frequently use a gas boiler for high T heat demand - a hybrid heating system). The future market share of residential heat pumps is uncertain. It depends on technical and system innovations (competitiveness with other heating options) and stimulation through energy policies. It is uncertain whether home owners would opt more often for low or high temperature heating systems in the future; this depends for instance on house renovation possibilities. Annual full load hours of a heat pump depend on the heat demand (profile) of a dwelling and the thermal capacity of the heat pump. If we assume a dwelling with 45 GJ as final heat demand and a heat pump with a capacity of 11kWth, then there are around 1100 full load hours. These are full load hours are for space heating and hot tapwater combined. The lifetime of a high temperature heat pump is expected to be similar to that of a regular low temperature heat pump which is about 15 to 20 years (Carbon Trust and Rawlings Support Services, 2016).	

COSTS

	Euro per Functional Unit	Current			2030			2050		
Year of Euro	2015									
Investment costs	€ / kWth	1,052			842			736		
		631	–	1,473	505	–	1,178	442	–	1,031
Other costs per year	€ / kWth	-			-			-		
		Min	–	Max	Min	–	Max	Min	–	Max
Fixed operational costs per year (excl. fuel costs)	€ / kWth	21			17			15		
		11	–	105	8	–	84	7	–	74
Variable costs per year	€ / kWh	-			-			-		
		Min	–	Max	Min	–	Max	Min	–	Max

Costs explanation	Cost unit: Euros2015/kWthermal In case costs were not expressed per kWth in the source, the reported costs in the source were divided by the typical capacity of the heat pump (i.e. 11 kWth, which is an assumption, see 'Capacity'). The table above presents costs excluding VAT. In case VAT was included in the source, VAT in the associated country was subtracted. Explanation per source: A review study conducted by Carbon Trust found that product purchasing cost (CAPEX) of high temperature heat pumps are higher than standard heat pumps by 20-35% (Carbon Trust and Rawlings Support Services, 2016).The difference is to some extent related to the technology itself, and the temperatures reached. For cascade systems (which can achieve supply temperatures of up to 80°C), there is a premium related to the fact that they effectively comprise two heat pumps, including two compressors, additional heat exchangers etc. The increase in total heating system investment compared to low temperature heating systems is compensated to some extent by the reduced need for replacing heat emitters (radiators). The additional heating system investment costs based on fully installed system costs is estimated at 10-20% (Carbon Trust and Rawlings Support Services, 2016). The fully installed costs for high temperature air source heat pumps identified in the review ranges from £6,000 to £14,000 (Carbon Trust and Rawlings Support Services, 2016). Heat pumps that reach 80 °C or higher are more expensive (total investment > 9,000 £) than the ones that reach 65°C or higher. According to Carbon Trust the installation costs amounts to £2,000 to £5,000 (Carbon Trust and Rawlings Support Services, 2016). Domestic hot water cylinder & accessories cost amount to £0 to £2,000 (Carbon Trust and Rawlings Support Services, 2016). Note: In the UK (in 2016) there is a reduced VAT rate for electricity, natural gas and district heating (for dwellings), a number of energy-saving domestic installations and goods, LPG and heating oil (for domestic use only) and some renovation and repairs of private dwellings. Taking this reduced VAT into account, 5% of investment costs were subtracted (instead of the standard UK VAT rate of 20%). Costs were converted to euros using an average exchange rate (conversion factor) of 0,82 from Euro (EUR2015) to British pound sterling (GBP2015). Daikin Altherma HT is a cascading system that can reach temperatures of 80 °C and comes in three capacities: 11, 14 and 16 kWth (Daikin, 2017; Daikin, 2019). The fully installed system costs of these are (approximately) 10.000 euros including 21% VAT. Fixed operational costs: Maintenance costs vary from £100 per year to £1,000 per year (typically £200 per year) (Carbon Trust and Rawlings Support Services, 2016).

	Projections: Based on costs reduction factors for heat pumps mentioned in a factsheet made by IEA (IEA ETSAP, 2013) the installed costs of heat pumps in 2030 are projected to be 20-30% lower (compared to 2013). For 2050, a cost decrease of 30-40% is projected (IEA ETSAP, 2013). Because the costs reduction projection is compared to 2013 we take the minimum cost reduction percentage mentioned in each case (so we assume a 20% reduction in 2030 and 30% reduction in 2050) and use these reductions on the 2030 and 2050 costs in table above. For comparison: EHPA (2019) reports that at current market growth levels the European heat pump sales will double every 8 – 10 years which should result in a cost reduction of approximately 22% by 2024 and approx. 39% by 2030, both compared to 2019 (EHPA, 2019). Combining both sources gives a cost reduction range of 20-40% by 2030.

ENERGY IN- AND OUTPUTS

	Energy carrier	Unit	Current			2030			2050		
Energy carriers (per unit of main output)	*Main output:* Heat	GJ		-1.00			-1.00			-1.00	
			-1.00	–	-1.00	-1.00	–	-1.00	-1.00	–	-1.00
	Ambient heat	GJ		0.52			0.63			0.65	
			0.02	–	0.52	0.25	–	0.63	0.30	–	0.65
	Electricity	GJ		0.48			0.37			0.35	
			0.48	–	0.98	0.37	–	0.75	0.35	–	0.70
		GJ		-			-			-	
			Min	–	Max	Min	–	Max	Min	–	Max

Energy in- and Outputs explanation	In the table energy in- and ouputs ranges related to the annual (seasonal) average COP (SCOP) or SPF values (seasonal performance factor) are given. The efficiency of a heat pump is expressed as the coefficient of performance (COP), which is the ratio between heat output and electricity input, and it depends on the difference between heat supply temperature and source temperature, in other words the temperature lift. For example, a COP of 3 means that 1 unit of electricity is used in order to produce 3 units of heat and 2 units are ambient heat. The higher the temperature lift the lower the COP. For instance, in winter, the temperature lift is larger, resulting in a lower COP. High temperature heat pumps have lower COPs compared to low temperature heat pumps since the temperature lift is higher. Whilst 'standard' high temperature residential heat pumps have been specifically designed for high supply temperatures, the designs of regular low temperature residential heat pumps (supply T <55 °C) are increasingly being improved to reach 60-65°C at a reasonable efficiency (Carbon Trust and Rawlings Support Services, 2016). The European Heat Pump Association (EHPA) writes that increasingly often heat pumps provide hot water at 65°C in an efficient manner (EHPA, 2019). Based on the sources found, the total SPF-range for high temperature air-water heat pumps (supply T above 65°C) ranges between 1,02 and 2,07 . The total COP-range is 2,2 to 4. Explanation by source: Khoa Xuan Le et al. (2019) studied the performance of an air-water high temperature heat pump that could deliver heat at 80 °C under 3 conditions: 1. direct mode, 2. storage mode and 3. combined mode. They found that direct mode (without storage in a tank) had the highest overall SPF. The values reported in their study come from field trails in Northern Ireland with a 11 kWth heat pump with nominal COP of 2,5. The SPF value reported for direct mode is 2,06. For mode 2 it is 1,49 overall and for mode 3 it is 1,83 overall (overall refers to a seasonal system performance factor in which storage loss is included). A study by Watanabe et al. (2017) obtained experimental results, in which the heating COP reaches 4,0 when the hot water temperature is 80 °C and the source water temperature is 26 °C, and the heating COP reaches 4,0 when the hot water temperature is 65 °C and the source water temperature is 8 °C. (Watanabe et al., 2017). No SPF values reported by this source.
	Daikin Altherma HT is a cascading system that can reach temperatures of 80 °C and comes in three capacities: 11, 14 and 16 kWth (Daikin, 2019). The manufacturer reports that the SPF of the 11 kWth system for space heating at a delivery T of 55 °C (internal operating T of 25-80°C) is 2,65, that of the 14 kWth system is 2,66 and that of the 16 kWth system is 2,61 (Daikin, 2019). The COP of this heat pump can reach up to 3,08 (Daikin, 2019). Shah & Hewitt (2015) found that during a five-month operation testing the 11 kWth Daikin heat pump had a SPF of 2,07 on average (Shah & Hewitt, 2015). Performance testing occurred during winter period (from 26/11/2014 to 10/02/2015) which also included the coldest days of the year. During this period the COP (in direct mode meaning without tank storage) varied within the range 1.82 to 2.38 with an average of 2.07. According to a review study conducted by Carbon Trust (2016) there is a lack of in-use performance data, but there are lab test results available (Carbon Trust and Rawlings Support Services, 2016). Comparing standardized test results between low and high temperature heat pumps gives an idea of the differences in performance. The study indicates lab test COPs ranging from 2,2 to 3,1 for the air source heat pump studied at an outside air temperature of 7 °C and at a 65 °C delivery temperature. Too few results were obtained for the SCOP (in the study refered to as the "SSHEE") at 65°C to indicate a value, but results at 55°C (at an air temperature of 7 °C) indicate SCOP values from 1,02 to 1,35 for air source heat pumps. It can be expected that the SCOP at a delivery T of 65°C is even lower, but here we assume the same SCOP (between 1,02 and 1,35). This results seems somewhat on the low side, considering it is only slightly higher than electrical resistance heating (COP=1). We do take these results into account to estimate the SPF-range in the table above. Projections (targets): Based on COP improvement percentages mentioned by IEA (IEA ETSAP, 2013) the COPs in 2030 are projected to be 30-50% higher compared to 2013. For 2050, an increase of 40 to 60% compared to 2013 is projected (IEA ETSAP, 2013). Because this is compared to 2013 we take the minimum percentage improvement in each case (so above we show 30% improvement in 2030 and 40% in 2050, both compared to 2020).

MATERIAL FLOWS (OPTIONAL)

	Material	Unit	Current			2030			2050		
Material flows				-			-			-	
			Min	–	Max	Min	–	Max	Min	–	Max
				-			-			-	
			Min	–	Max	Min	–	Max	Min	–	Max
Material flows explanation											

EMISSIONS (Non-fuel/energy-related emissions or emissions reductions (e.g. CCS)

	Substance	Unit	Current			2030			2050		
Emissions				-			-			-	
			Min	–	Max	Min	–	Max	Min	–	Max
				-			-			-	
			Min	–	Max	Min	–	Max	Min	–	Max
				-			-			-	
			Min	–	Max	Min	–	Max	Min	–	Max
				-			-			-	
			Min	–	Max	Min	–	Max	Min	–	Max
Emissions explanation											

OTHER

Parameter	Unit	Current			2030			2050		
Modified radiators (occasional)	Euro2015/dwelling		1,042			-			-	
		347	–	1,736	Min	–	Max	Min	–	Max
			-			-			-	
		Min	–	Max	Min	–	Max	Min	–	Max
			-			-			-	
		Min	–	Max	Min	–	Max	Min	–	Max
			-			-			-	
		Min	–	Max	Min	–	Max	Min	–	Max

Explanation	Application of high temperature heat pumps do not (necessarily) require (major) renovation of the building envelope; they can be installed in existing dwellings with existing heat distribution systems using wet radiators (Carbon Trust and Rawlings Support Services, 2016). Small changes to existing radiators may still be needed (Carbon Trust and Rawlings Support Services, 2016). Costs for these modified radiators amount to £300 to £1.500 (347-1.737 euros) (Carbon Trust and Rawlings Support Services, 2016). This modification is not always needed. Some types of heat pumps are specifically designed to be combined with existing radiators. Note: Because of high heat demand in winter and consequently high peak electricity use of the heat pump, the grid connection may need to be reinforced. Indicative grid reinforcement costs (not included in costs section above) are as follows (based on CE, 2018 factsheet conventional air source heat pump): Adjustments electrical meter box: approximately 200 euros (one-time). Increased size of grid connection: 700 euros per year (depending on capacity of heat pump, but perhaps not needed for cases with very good insulation) (CE, 2018).

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