TECHNOLOGY FACTSHEET

AQUIFER THERMAL ENERGY STORAGE (STORAGE TEMP ±5 TO ±25°C) - INDIVIDUAL SYSTEM

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Sector	Built environment
ETS / Non-ETS	Non-ETS
Type of Technology	Emission reduction
Description	This factsheet describes thermal energy storage in an aquifer (abbreviated ATES), a technique used for heating and cooling of buildings. It describes an individual system for one or multiple buildings ('individual' means there is no heat/cold transport network present to transport heat/cold over large distances such as in district heating). The technology is applicable to buildings with a relatively high cooling demand, which are found in the services sector (e.g. an office or university building). The reason for this is that heat and cold storage must be in balance to retain the heating/cooling capacity of the system. The applicability and energetic performance of ATES strongly depend on site-specific hydrogeological conditions (Department for Business, Energy and Industrial Strategy, 2016). ATES comprises low temperature sensible heat storage in water bearing (e.g. sand) layers in the subsurface (aquifer). Depending on type of system (at least) one or two thermal wells are required for extraction and injection of water (since water is extracted from the subsurface it is called an "open system"). The wells are typically between 30 and 150 meters deep (Agentschap NL, 2011). At a depth of more than 500 meters heat storage would comprise the heat of the interior of the earth, which is called geothermal energy (ECW, 2019). The technology furthermore consists of pipes, pumps and controls. Using heat exchangers, heat is transferred to the heating system in a building. A heat pump is needed to upgrade the temperature to useable levels for space heating. The heat pump is taken into account in this factsheet. The heating/cooling distribution system inside the building (costs and efficiency) is not taken into account in this factsheet. Also, peak supply heating systems (e.g. gas-fired boiler running on winter days) is not taken into account in this factsheet. The overall temperature range of water storage is ± 5 °C to ± 25 °C. In summer, cold water (typically 5 -8 °C) is extracted from the aquifer in order to provide space cooling (Bloemendal et al., 2017). The warmed-up water is returned to the aquifer. The cooling part is essential to regenerate the heat source. The ATES system must be thermally balanced over the year otherwise heating or cooling capacity will deteriorate. In winter the proces is reversed. The stored water (typically 14-18 °C) is supplied to buildings for heating purposes and the cooled water is returned (Bloemendal et al., 2017). A heat pump (water/water heat pump) raises the temperature to the level necessary for space heating. Buildings with ATES are heated using a low temperature heating system using underfloor and/or wall heating. This means that the heat distribution system for space heating inside the building works at a relatively low temperature (supply temperature to heat emitters is in range 30 to 50°C). This requires a well insulated building (i.e. a building with a good energy label). Direct cooling (space cooling without using a heat pump) can be provided by pumping cold water directly through the building. In case there is also a demand for hot tapwater, this needs to be at least 60 °C and can be supplied for instance by a seperate gas boiler, an electric boiler, or a solar water heater.
TRL level 2020	TRL 9 According to a review-report focussed on the UK the TRL of ATES is between 5 and 8 (Department for Business, Energy and Industrial Strategy, 2016). However, ATES is an established technology in (some) other countries in Europe, especially in the Netherlands (TRL=9) where it is commonly used for individual buildings (commercial buildings and apartment blocks). The first ATES installations in the Netherlands were realised in 1995 and by 2015 there were around 2000 of these installations (Bloemendal et al., 2017).

TECHNICAL DIMENSIONS

	Functional Unit		Value and Range								
Capacity	kWth		1,000								
			200			-			10,000		
Potential	NL	GWth	Current			2030			2050		
			-			-			7		
			Min	–	Max	Min	–	Max	7	–	7
Market share	% of total number of buildings in the Netherlands	%	-			-			-		
			Min	–	Max	Min	–	Max	Min	–	Max

Capacity utlization factor	1
Full-load running hours per year	Space Heating: 1.800/Space Cooling: 800 (in the Netherlands)
Unit of Activity	GJth/year — 6,480
Technical lifetime (years)	30
Progress ratio	
Hourly profile	Yes
Explanation	ATES installations generally have a capacity of 0,2 to 10 MW (Wesselink, 2016). A review-report focussed on the UK gives examples of projects with heating capacities ranging from 250kWth to 2MWth and cooling capacities ranging from 400 kW to 3 MW (Department for Business, Energy and Industrial Strategy, 2016). According to Nationaal Warmtepomp Trendrapport (2018) the potential of water/water heat pumps (i.e. ATES) is 7 GWth (Nationaal Warmtepomp Trendrapport, 2018). Worldwide, there are more than 2.800 ATES systems in operation at present, with 99% of them low-temperature-systems (storage temperatures of < 25 °C). 85% of all systems are located in the Netherlands, and a further 10% are found in Sweden, Denmark, and Belgium (Fleuchaus et al., 2018). The number of heating full load hours of the ATES (and the peak demand heating systems) depends on the heat supply profile of the ATES and the heat demand profile of the heat consumer. Similar line of reasoning holds for space cooling. In different countries around the world the ATES technology has 1.200 - 2.800 full load hours per year for heating (IEA, 2007). Depending on country ATES has 600 - 2.000 full load hours per year for cooling (IEA, 2007). Range obtained depends on the different climate conditions in the inventorized countries. IEA presents 1.200 heating full load hours as a (typical) value for the USA, 2.000 for Europe, and 2.800 for Northern Europe and Canada. For cooling an average of 1.300 full load hours per year is given by IEA. Values for the Netherlands (heating: 1800/cooling: 800) are taken from the VESTA model from PBL (PBL, 2017). Generally, the cooling demand is lower than heating demand. In order to retain the heat/cold balance in the soil the excess heat demand has to be supplied with auxiliary heating (a gas-fired boiler or electric boiler). According to Expertise Centrum Warmte (ECW) the technical lifetime of ATES could be more than 30 years (ECW, 2019). According to Agentschap NL, the technical lifetime of the heat sources, pipes and heat exchangers generally is 25 or 30 years (Agenstschap NL, 2011). Pumps, controls and other related equipment is assumed to have a lifespan of 15 years.

COSTS

Year of Euro	2015

	Euro per Functional Unit	Current			2030			2050		
Investment costs	€ / kWth	529			476			404		
		529	–	2,975	476	–	2,678	404	–	2,276
Other costs per year	€ / kWth	-			-			-		
		Min	–	Max	Min	–	Max	Min	–	Max
Fixed operational costs per year (excl. fuel costs)	€ / kWth	16			14			12		
		16	–	90	14	–	80	12	–	68
Variable costs per year	€ / kWh	-			-			-		
		Min	–	Max	Min	–	Max	Min	–	Max

Costs explanation	In the table above, a cost range is shown based on average cost data from multiple sources (see references). The investment (capital) costs consist of the storage system, heat pump and heat exchangers (including transport) pipes. Note that for ATES we refer to capacity in terms of kWth, as for aquifers the size is usually expressed as the (maximum) rate at which heat can be extracted from a well at a single time. - Schüppler et al. (2019) reviewed the capital costs of ATES as reported by several other literature sources and come to a cost-range of 89-1.000 euro/kWth (Schüppler et al., 2019). (NB: Schüppler et al. also state that the evaluation of the economic data is in most cases not transparent or already obsolete.) -Based on a review focussed on the UK the investment costs of an ATES system ranges from 600 to 1.000 £/kWth (Department for Business, Energy and Industrial Strategy, 2016). -According to the International Energy Agency the investment costs of ATES amount to 200 -1.150 (reported average value is 500) euro2005/kWth (IEA, 2007). -IRENA and IEA report an investment cost range of 3400-4500 USD2008/kWth for category 'sensible thermal energy storage' technologies (IEA, 2013a; IRENA, 2013). The ATES technology is included in this cost range (and elabored on in the study) but so are other sensible heat storage technologies. O&M cost (fixed & variable) for 'sensible thermal energy storage' technologies are 120 USD/kW/yr (IEA, 2013a; IRENA, 2013). Fixed operational costs per year amount to 2,5% (for ATES) and 4% (for heat pump) given as percentage of the initial investment (RVO, 2016). IEA and IRENA report 120 USD2008/kWth/year as fixed+variable operational costs (O&M) for sensible thermal energy storage (IEA, 2013; IRENA, 2013). Cost projection: Only a (significant) decrease in costs of heat pumps can be expected. We base our heat pump cost projections for 2030 and 2050 on cost reduction percentages from an IEA factsheet (IEA, 2013b). The installed costs of heat pumps in 2030 are projected to be 20-30% lower compared to 2013. In 2050, costs decreased by 30-40% compared to 2013. Since the IEA costs reduction is compared to 2013 (and for the purpose of this factsheet it needs to be compared to 2020) we take the minimum percentage in each case (so, 20% reduction in 2030 and 30% in 2050). In the calculations we assume that the heat pump comprises 50% of the total investment.

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
	Electricity	GJ		0.37			0.30			0.29	
			0.37	–	0.37	0.30	–	0.30	0.29	–	0.29
	Ambient heat	GJ		0.90			0.97			0.99	
			0.90	–	0.90	0.97	–	0.97	0.99	–	0.99
		GJ		-			-			-	
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*

Energy in- and Outputs explanation

In the table above we show the average annual energy in- and outputs associated to space heating. The energy in- and outputs of the entire ATES system, from heat source to end consumer, depends on a number of assumptions regarding heat losses and the SPF (annual average COP) of the heat pump. These assumptions are as follows:
-Total heat losses associated to heat extraction and seasonal storage of heat in an aquifer is assumed 20% per year.
-The coefficient of performance (COP) of the heat pump is the ratio between electricity input and heat output. The COP depends on the temperature difference between heat source and heat sink. The annual average COP is called seasonal performance factor (SPF). At a temperature difference of 4-8 °C (between extraction and infiltration), the COP of a heat pump ranges between 3 and 5 (Bloemendal et al., 2017). According to Schüppler et al. (2013), the estimated seasonal performance factor (SPF) of the ATES system for heating is 4 (Schüppler et al., 2019). We assume COP=SPF=4 since the source temperature is almost constant over the year.
-Furthermore there is pump energy involved. Typically one uses between 17 and 20 kWhe of pump energy per GJth thermal energy output (Koornneef, J., 2019). We assume 20 kWhe/GJth, this converts to 0,07 GJe/GJth.
With this, the in- and outputs of the system are calculated. The typical (average) system efficiency is 79%.

For comparison:
IRENA indicates a 50 - 90 % ATES system efficiency for heating (IRENA, 2013).
Department for Business, Energy and Industrial Strategy (2016) reports 70-90% ATES system efficiency for heating (efficiency is higher for cold storage) (Department for Business, Energy and Industrial Strategy, 2016).

Note: For ATES cooling a COP of 29 is reported by (Schüppler et al., 2019).

Projection:
Only a (significant) increase in performance of heat pumps can be expected. We base our heat pump COP projections for 2030 and 2050 on improvement percentages from an IEA factsheet (IEA, 2013b). The performances of heat pumps in 2030 are projected to be 30-50% higher compared to 2013 (for cooling 20-40%). In 2050, the performance increased by 40-60% compared to 2013 (for cooling 30-50%). Since the IEA projection is compared to 2013 (and for the purpose of this factsheet it needs to be compared to 2020) we take the minimum percentage in each case (so 30% in 2030 and 40% in 2050 for heating with heat pump).

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**		
			-			-			-	
		Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
			-			-			-	
		Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
			-			-			-	
		Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
			-			-			-	
		Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
Explanation										

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