

# Heat Pumps & Thermal Energy Storage



Source: <https://archive.epa.gov/climatechange/kids/solutions/technologies/geothermal.html>

# Geothermal Power

## Heat Pumps

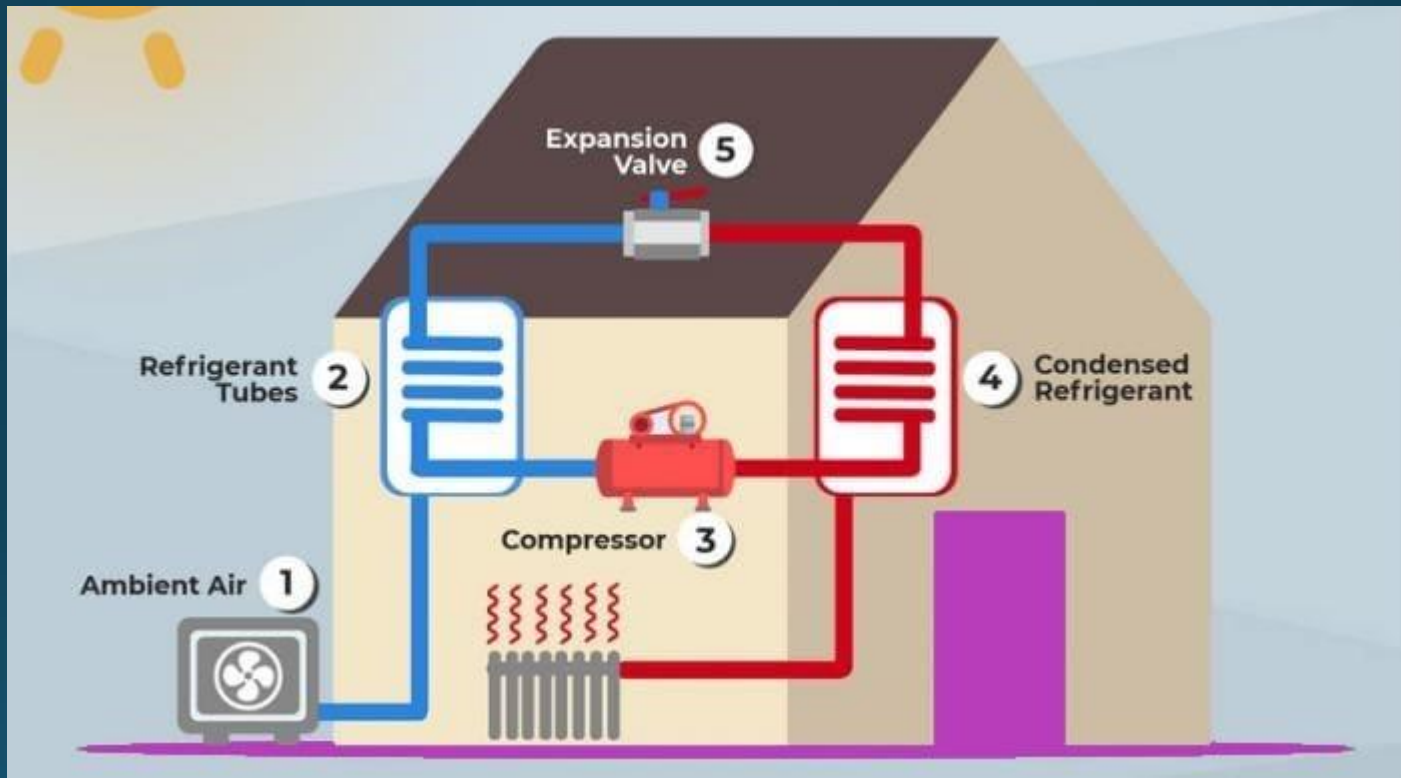
- How does a heat pump work
- Why use heat pumps
- Types of heat pumps
- Heat pump advantages & disadvantages



Source: [www.adrianos.gr](http://www.adrianos.gr)

# Heat Pumps

## What is it?



Source: <https://mechanicalboost.com/heat-pump/>

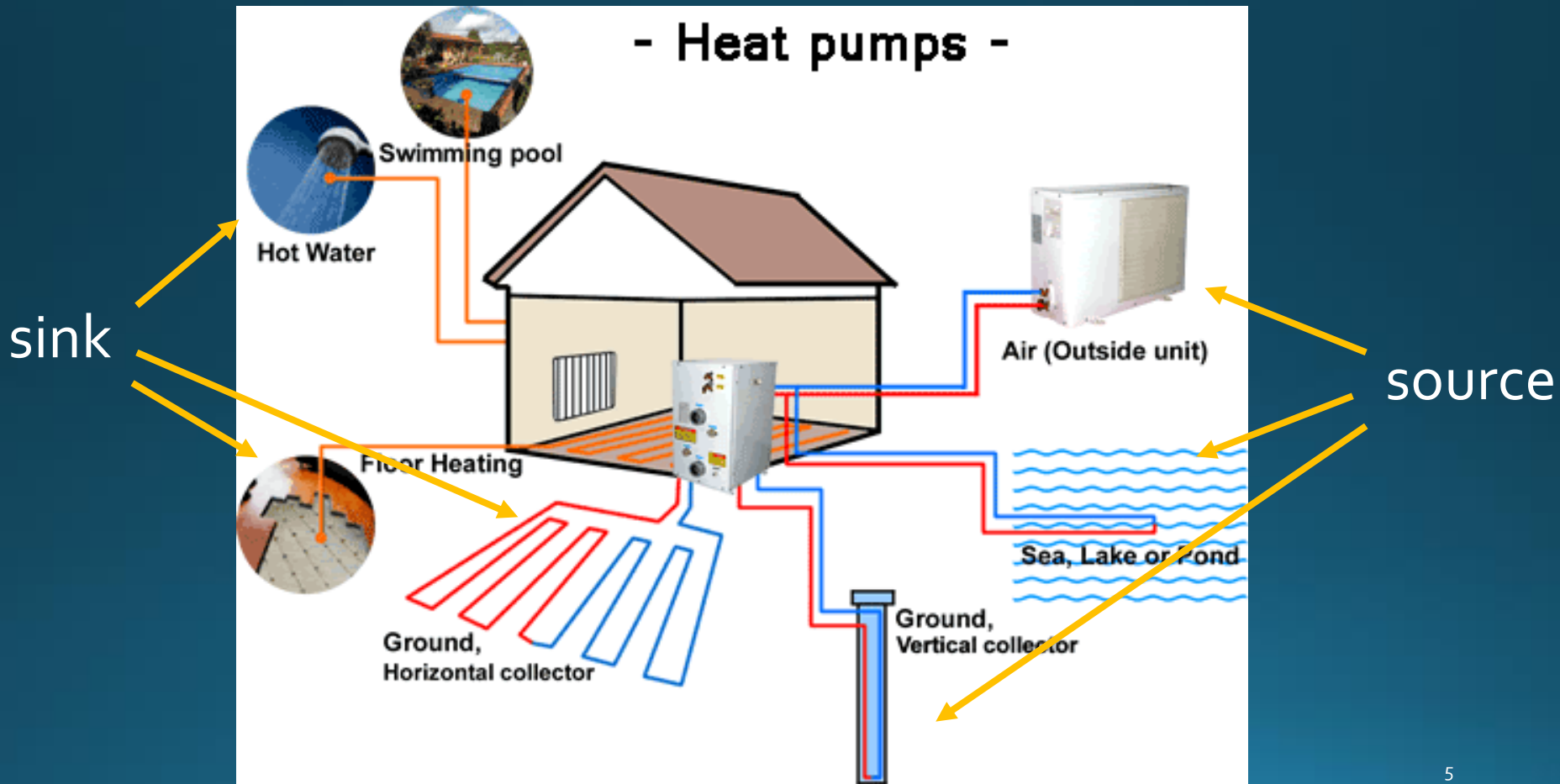
See video: “01 What is a Heat Pump.mp4”

# What is a Heat Pump

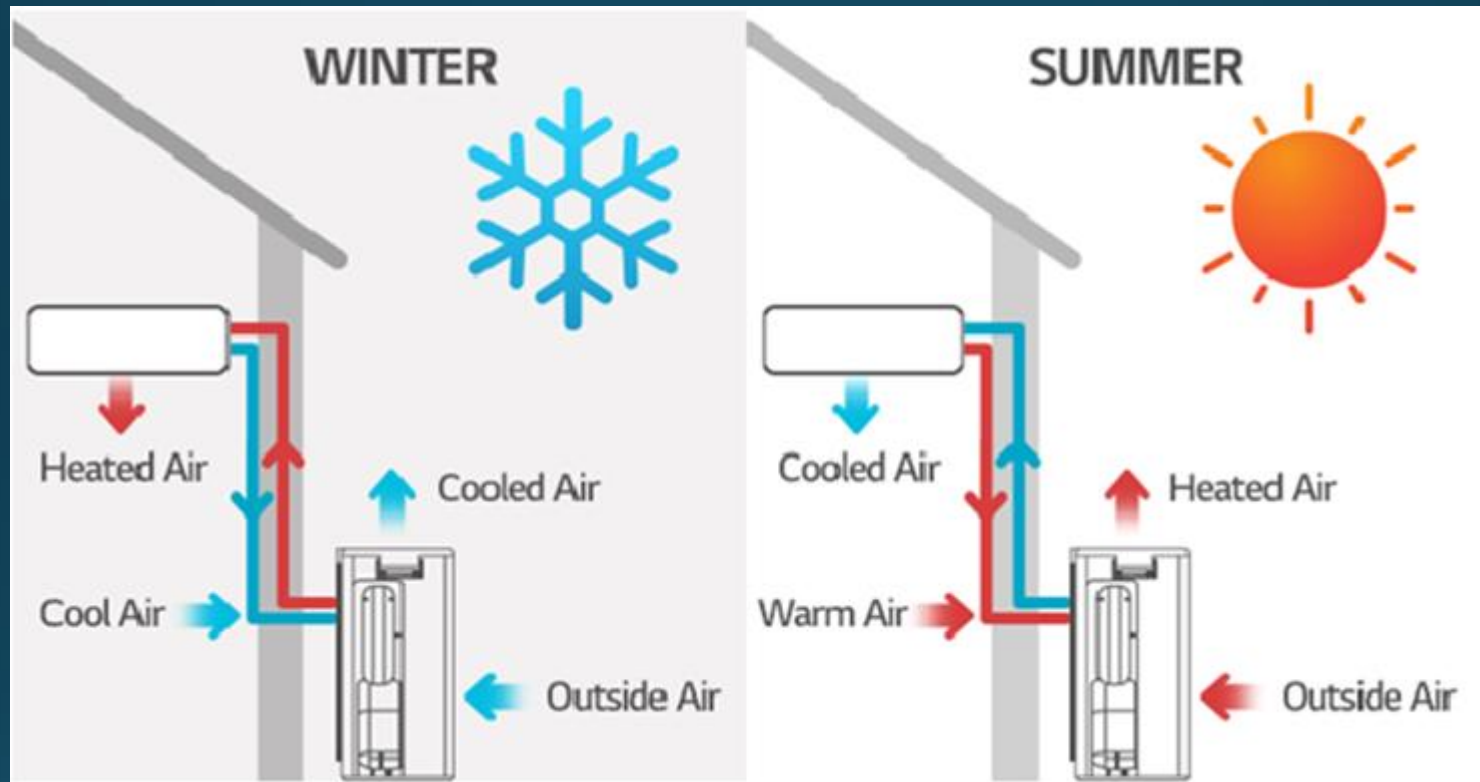


# Why use heat pumps (HP) ?

Heating and cooling from several “sources”



# Heating and cooling with a HP?



Source: <https://www.lghvacstory.com/heat-pumps-the-new-high-tech-energy-source/>

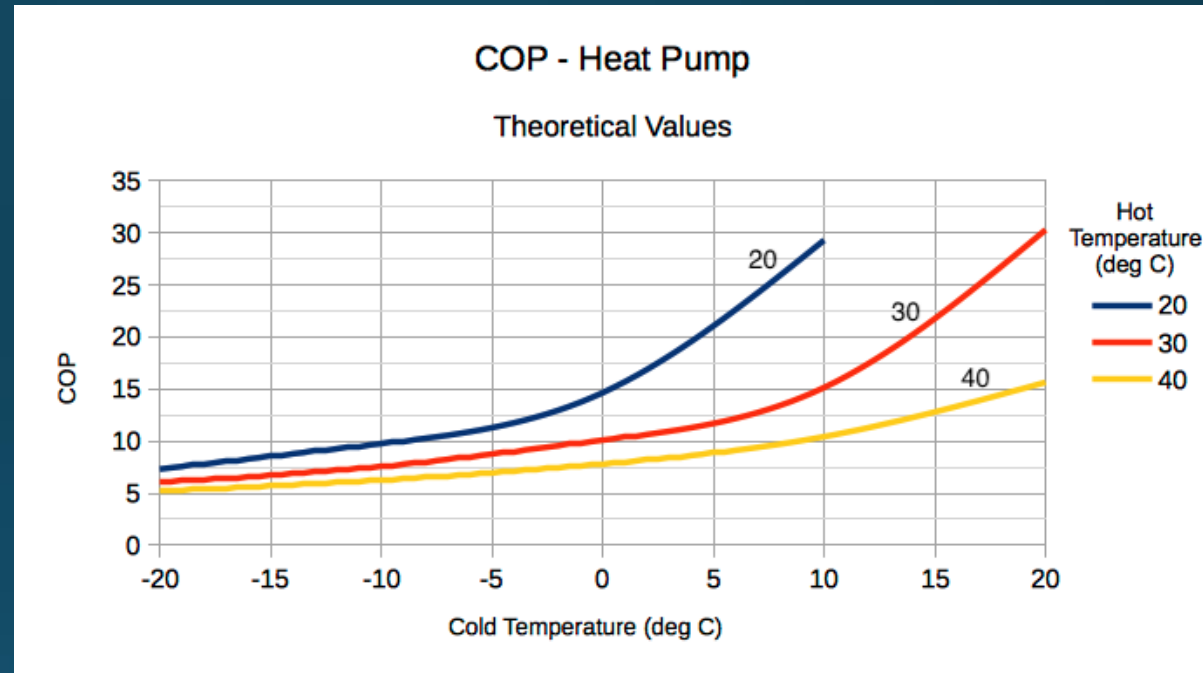
In cool mode, the heat pump utilises the same refrigeration cycle as any typical HVAC equipment. In heat mode, the heat pump uses the same circuit used for cooling, but reverses the refrigerant flow. Reversing the flow of the units refrigeration circuit allows the indoor coil to be used for heating.

# Why use heat pumps (HP) ?

## Efficiency

- Energy Savings specifically Heating Efficiency
- Efficiency is shown in two forms **EER** or **COP**
- **Energy Efficiency Ratio- EER** used for cooling
- **Coefficient of Performance - COP** used for heating

Efficient Gas-fired Heaters typically yield a 82 to 92 range in heating efficiency (COP 0.82 to 0.92) COP Capacity Out / Power In



Source: [https://www.engineeringtoolbox.com/heat-pump-efficiency-ratings-d\\_1117.html](https://www.engineeringtoolbox.com/heat-pump-efficiency-ratings-d_1117.html)

- Electric-resistance Heaters typically yield even more, up to 100 heating efficiency (COP 1.00)
- Heat Pumps typically yield 300 to 400 heating efficiency (COP 3.00 to 4.00 and even higher!)

# Types of HP's (1/6)

- **Water to Water (Water Source HP)**

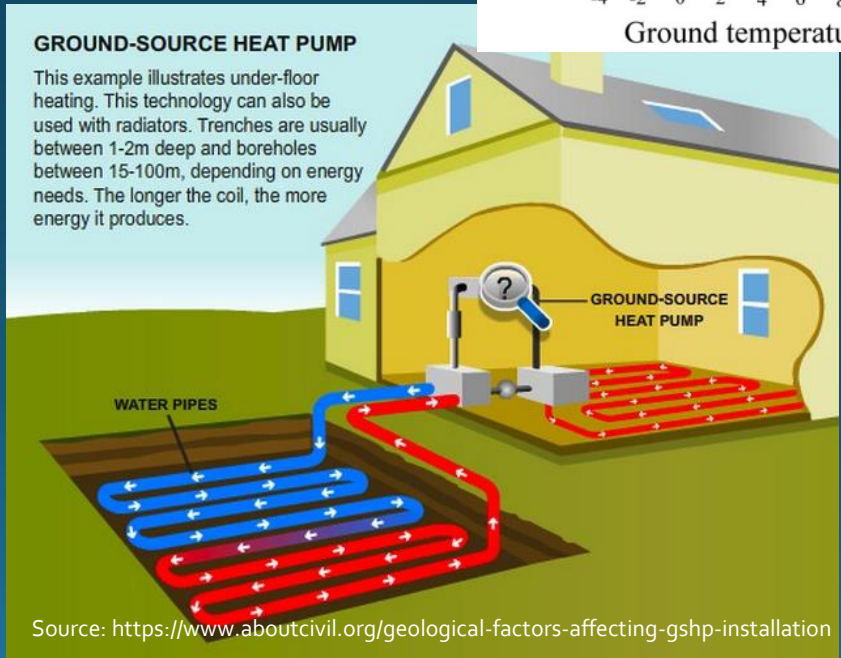
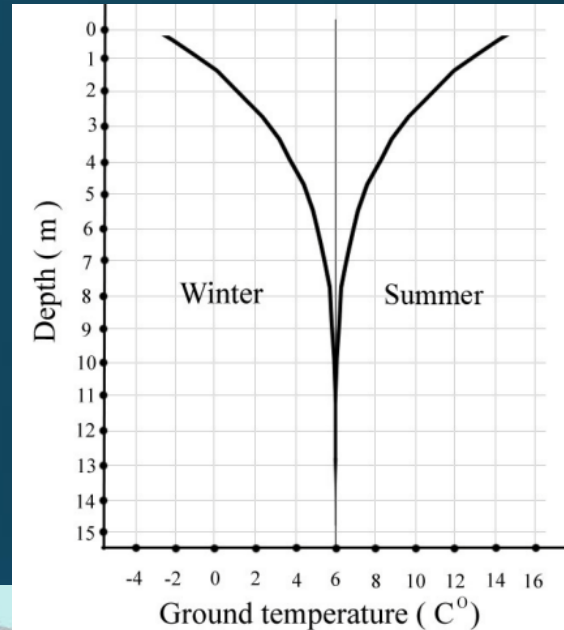
Utilizes two water coils as the condenser and the evaporator

- **Air to Air (ductless)**

Utilizes the typical refrigeration system with two fan coils

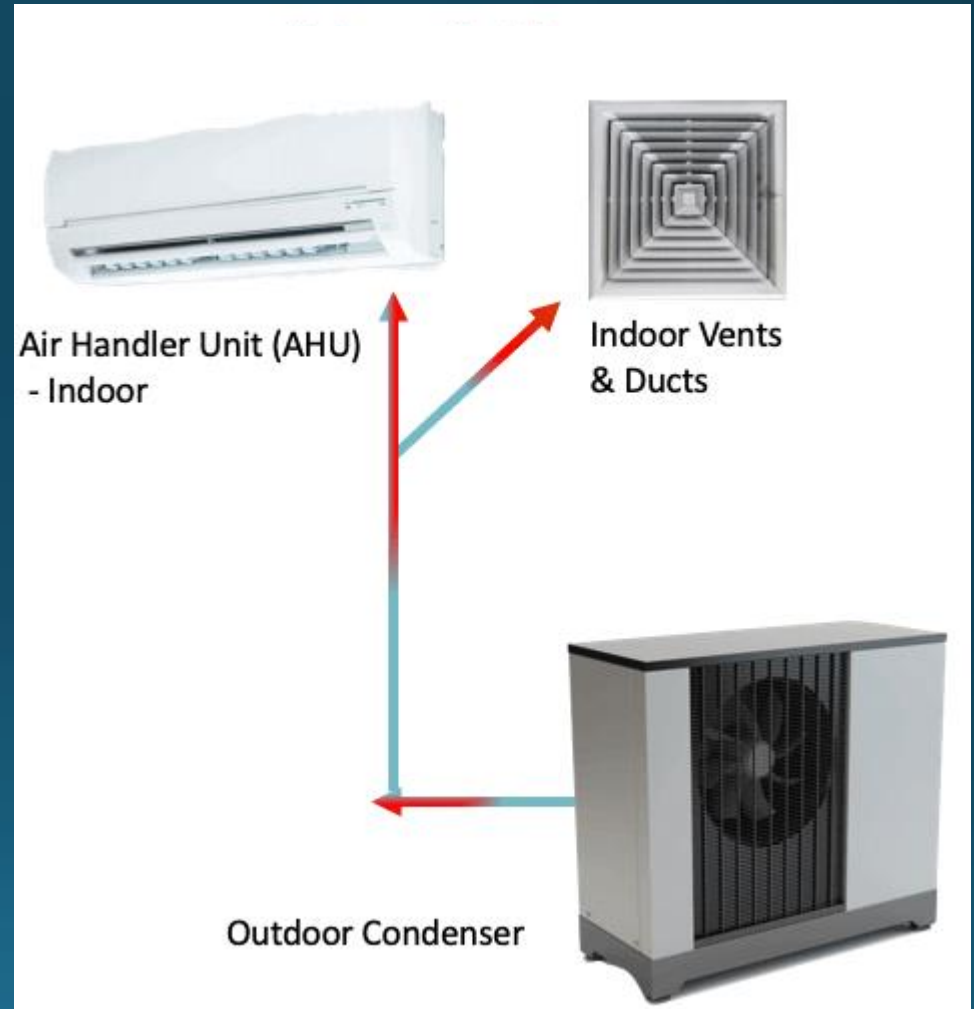
- **Air to Water**

Utilizes a fan coil for the supply air and a water coil for rejecting heat in the cool mode and obtaining heat in the heat mode



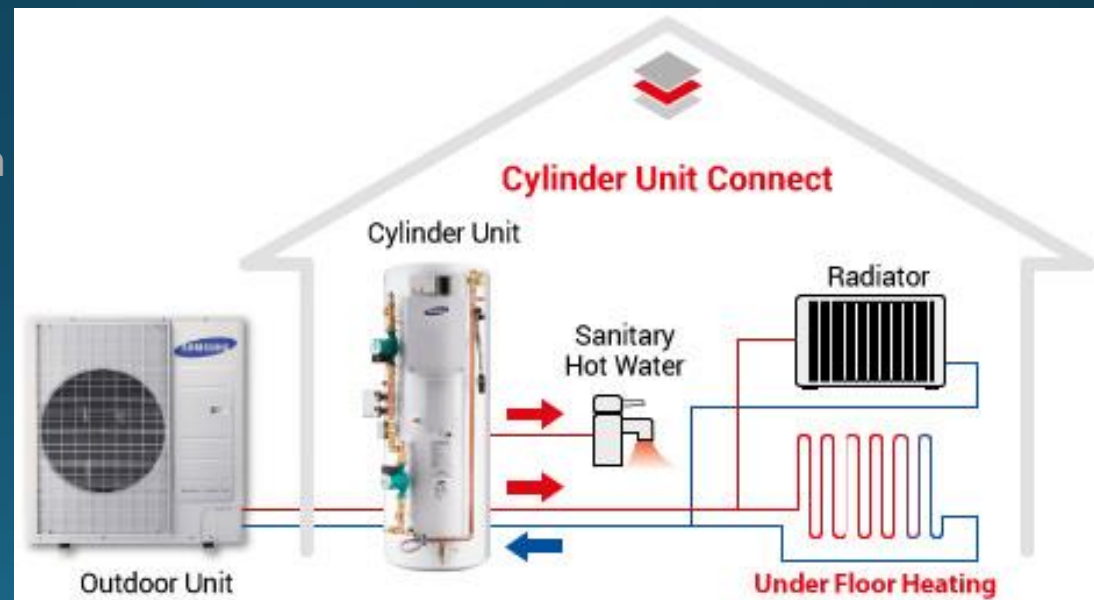
# Types of HP's (2/6)

- Water to Water (Water Source HP)  
Utilizes two water coils as the condenser and the evaporator
- Air to Air (ductless)**  
Utilizes the typical refrigeration system with two fan coils
- Air to Water  
Utilizes a fan coil for the supply air and a water coil for rejecting heat in the cool mode and obtaining heat in the heat mode



# Types of HP's (3/6)

- **Water to Water (Water Source HP)**  
Utilizes two water coils as the condenser and the evaporator
- **Air to Air (ductless)**  
Utilizes the typical refrigeration system with two fan coils
- **Air to Water**  
Utilizes a fan coil for the supply air and a water coil for rejecting heat in the cool mode and obtaining heat in the heat mode



# Types of HP's (4/6)

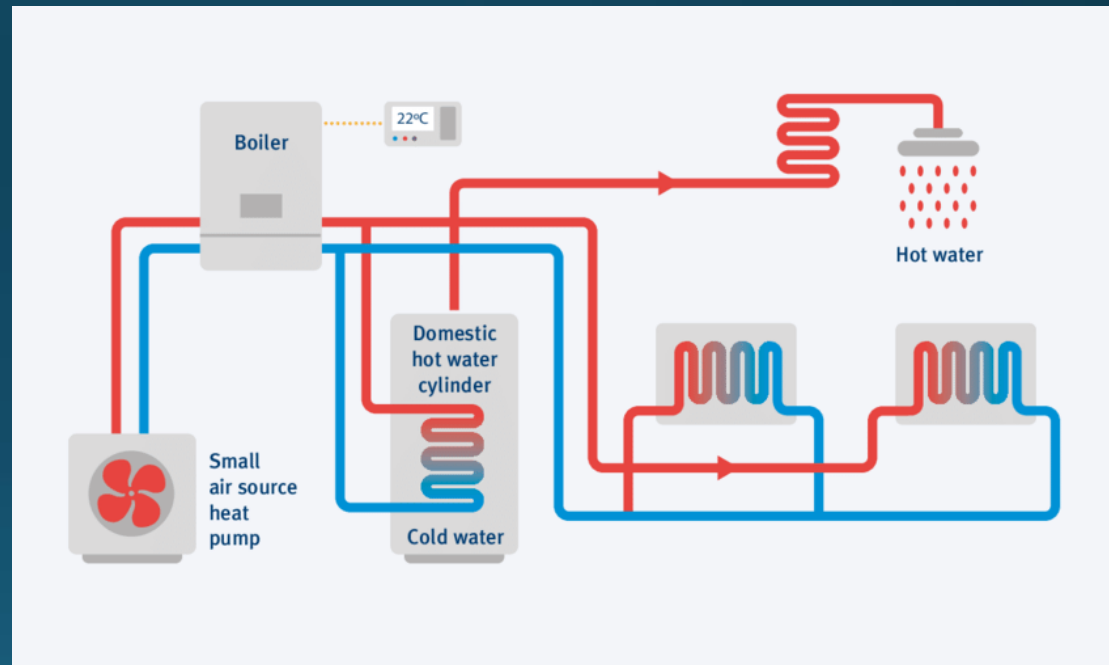
- **Solar Assisted Heat Pump**  
is coupled with a field of hybrid photovoltaic-thermal solar collectors
- Hybrid  
uses a heat pump alongside another heat source. Typically, it describes fitting a heat pump alongside a fossil fuel (gas, oil or LPG) boiler.
- Exhaust Air Heat Pump  
obtains heat from the room's exhaust air and supplies it inside the room or building.



Source: <https://www.knowledge-share.eu/en/patent/solar-assisted-heat-pump/>

# Types of HP's (5/6)

- Solar Assisted Heat Pump is coupled with a field of hybrid photovoltaic-thermal solar collectors
- Hybrid (heating system) uses a heat pump alongside another heat source. Typically, it describes fitting a heat pump alongside a fossil fuel (gas, oil or LPG) boiler.
- Exhaust Air Heat Pump obtains heat from the room's exhaust air and supplies it inside the room or building.



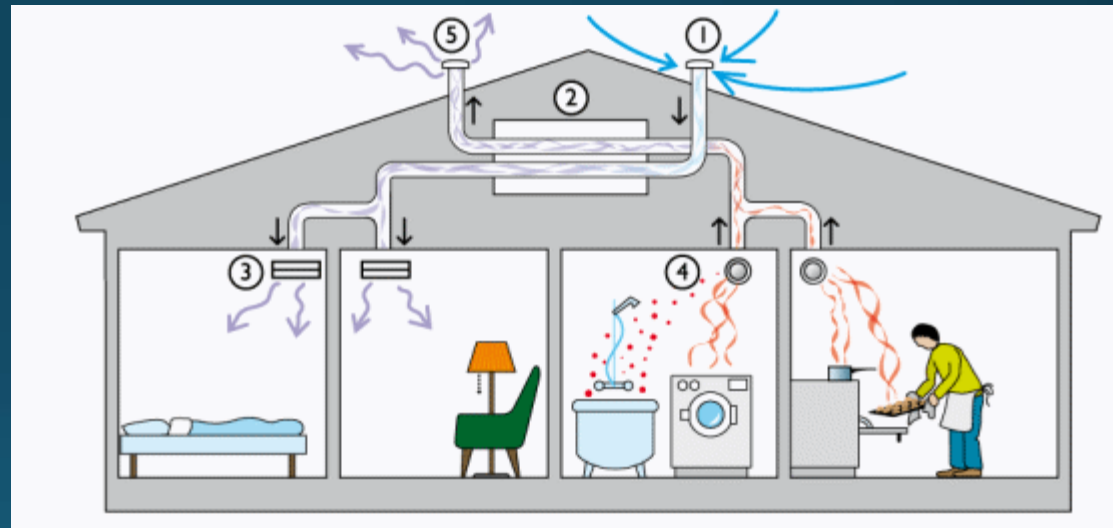
Source:  
[https://www.researchgate.net/publication/345341436\\_Smart\\_and\\_Flexible\\_Electric\\_Heat\\_An\\_Energy\\_Futures\\_Lab\\_Briefing\\_Paper/figures?lo=1](https://www.researchgate.net/publication/345341436_Smart_and_Flexible_Electric_Heat_An_Energy_Futures_Lab_Briefing_Paper/figures?lo=1)

# Types of HP's (6/6)

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- Exhaust Air Heat Pump** obtains heat from the room's exhaust air and supplies it inside the room or building.



Source: <http://www.energimyndigheten.se/en/sustainability/households/other-energy-consumption-in-your-home/ventilation/exhaust-and-supply-air-ventilation-with-heat-recovery-ftx-system/>

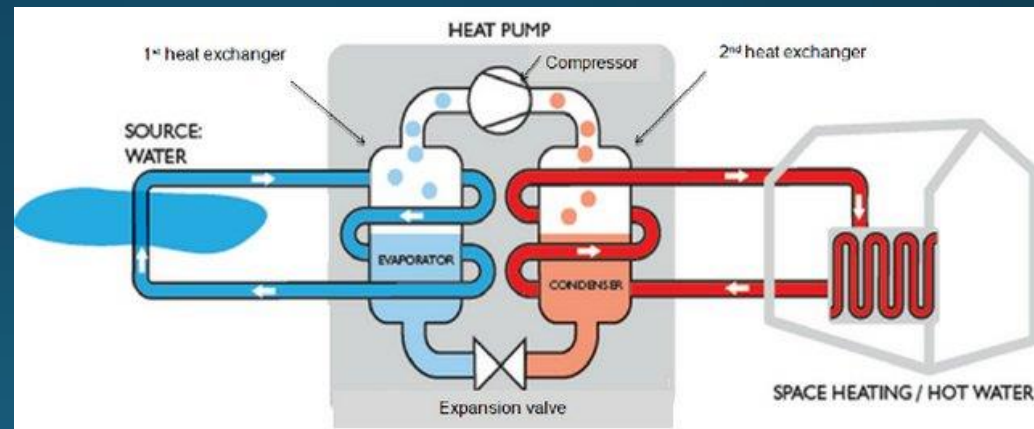
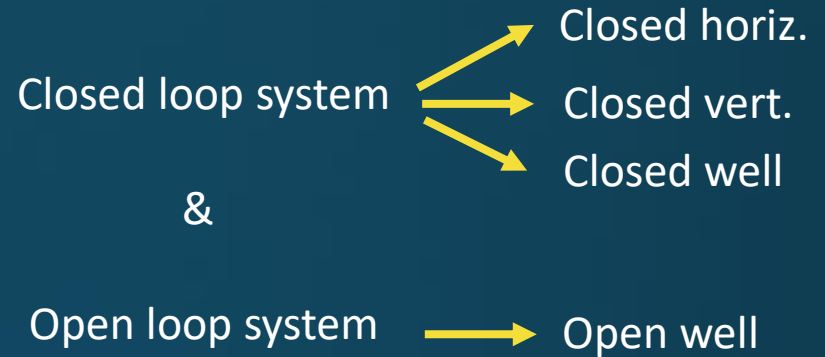
# Types of HP's Water to Water (Water Source HP)

The ground is a heat source in the winter and heat sink in the summer.

A geothermal heat pump on the same day uses a source of 55 deg and a sink of 70 deg (15 deg difference).

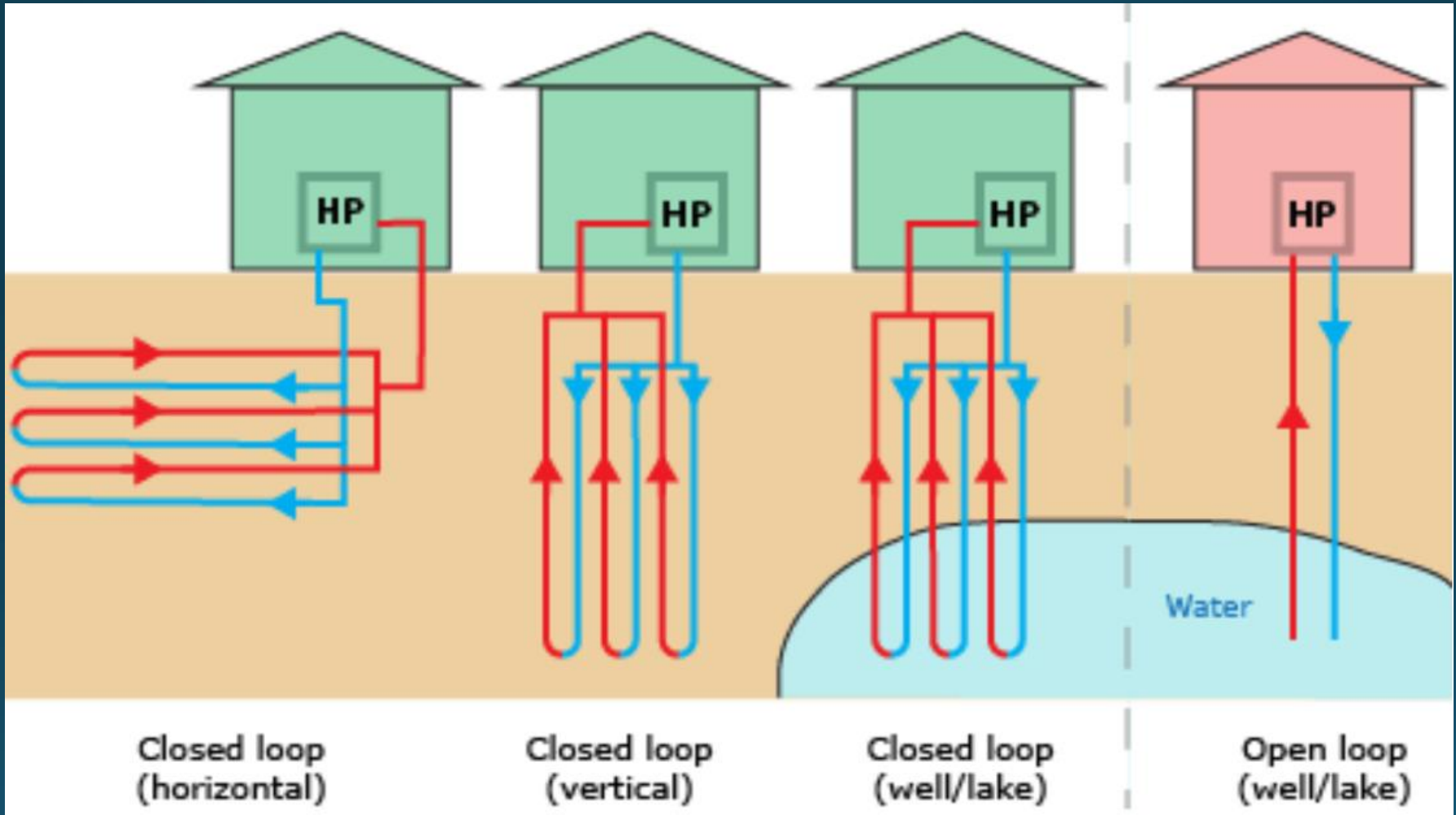
Halving the difference in temperature greatly increases the efficiency.

During the summer season, these pumps process in the reverse direction (i.e., the heat is extracted from the room or building and released into the external cold water). The cooling heat pumps have high efficiency than the heating cycle heat pumps.



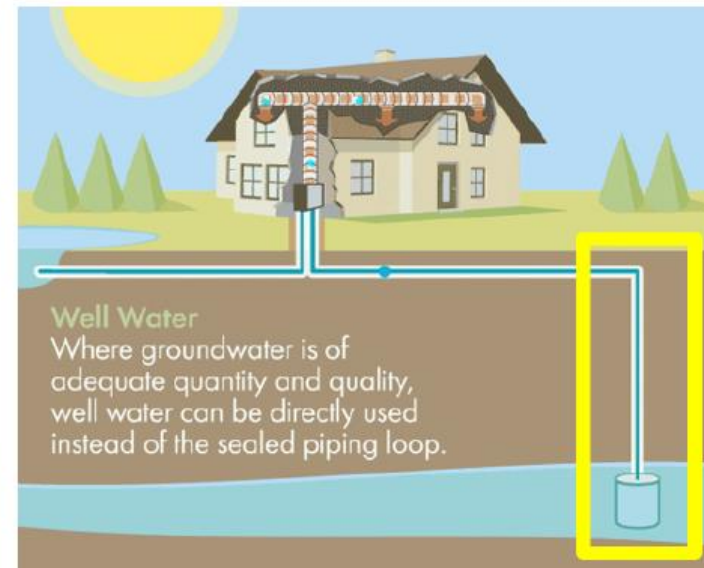
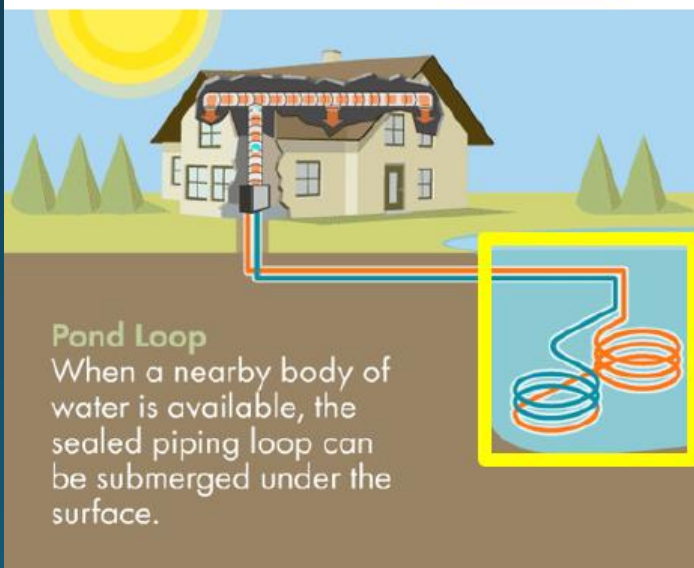
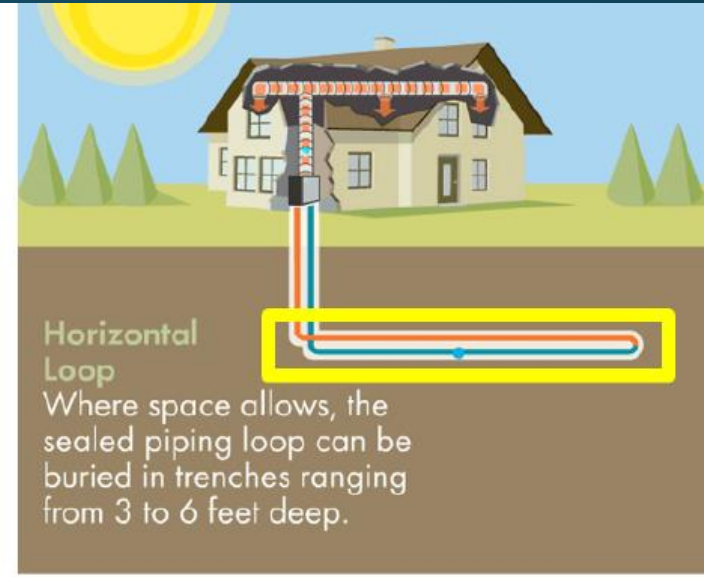
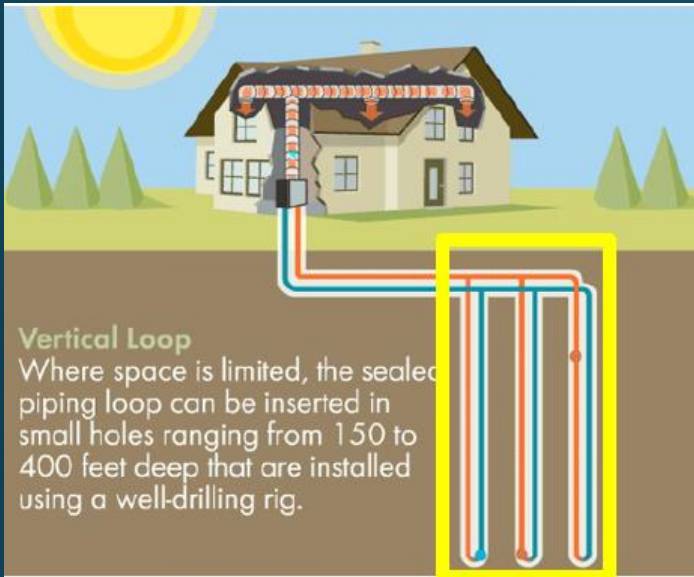
Source:  
[https://www.researchgate.net/publication/286358619\\_A\\_renewable\\_heat\\_solution\\_for\\_water\\_ingress\\_in\\_the\\_Glasgow\\_subway\\_tunnel\\_system/figures?lo=1](https://www.researchgate.net/publication/286358619_A_renewable_heat_solution_for_water_ingress_in_the_Glasgow_subway_tunnel_system/figures?lo=1)

# Types of HP's Water to Water (Water Source HP)



Source: <https://basix.nsw.gov.au/iframe/energy-help/heating-and-cooling/ground-source-heat-pump.html>

# Types of HP's Water to Water (Water Source HP)

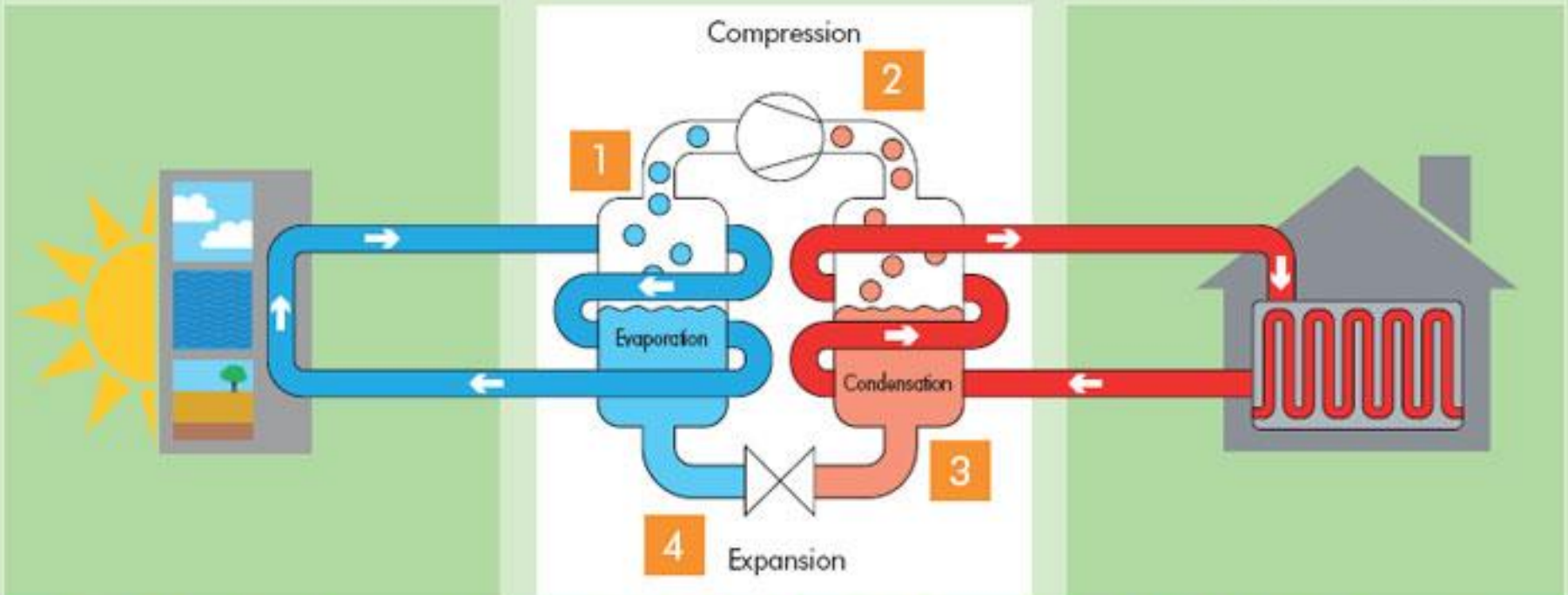


# How does a HP works?

Heat source

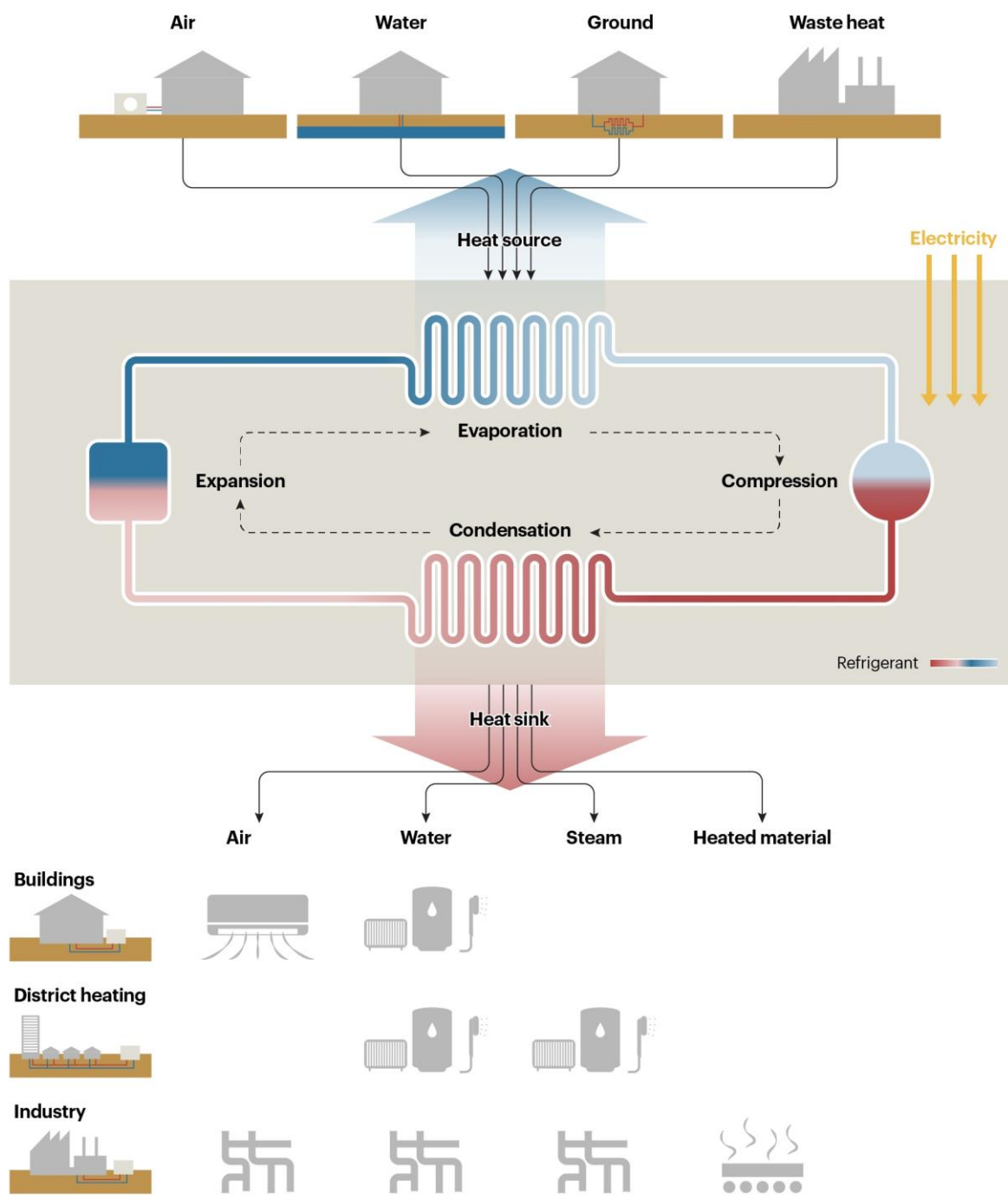
Heat pump

Heat distribution and storage system



**75% free environmental energy + 25% electrical energy = 100% heating energy**

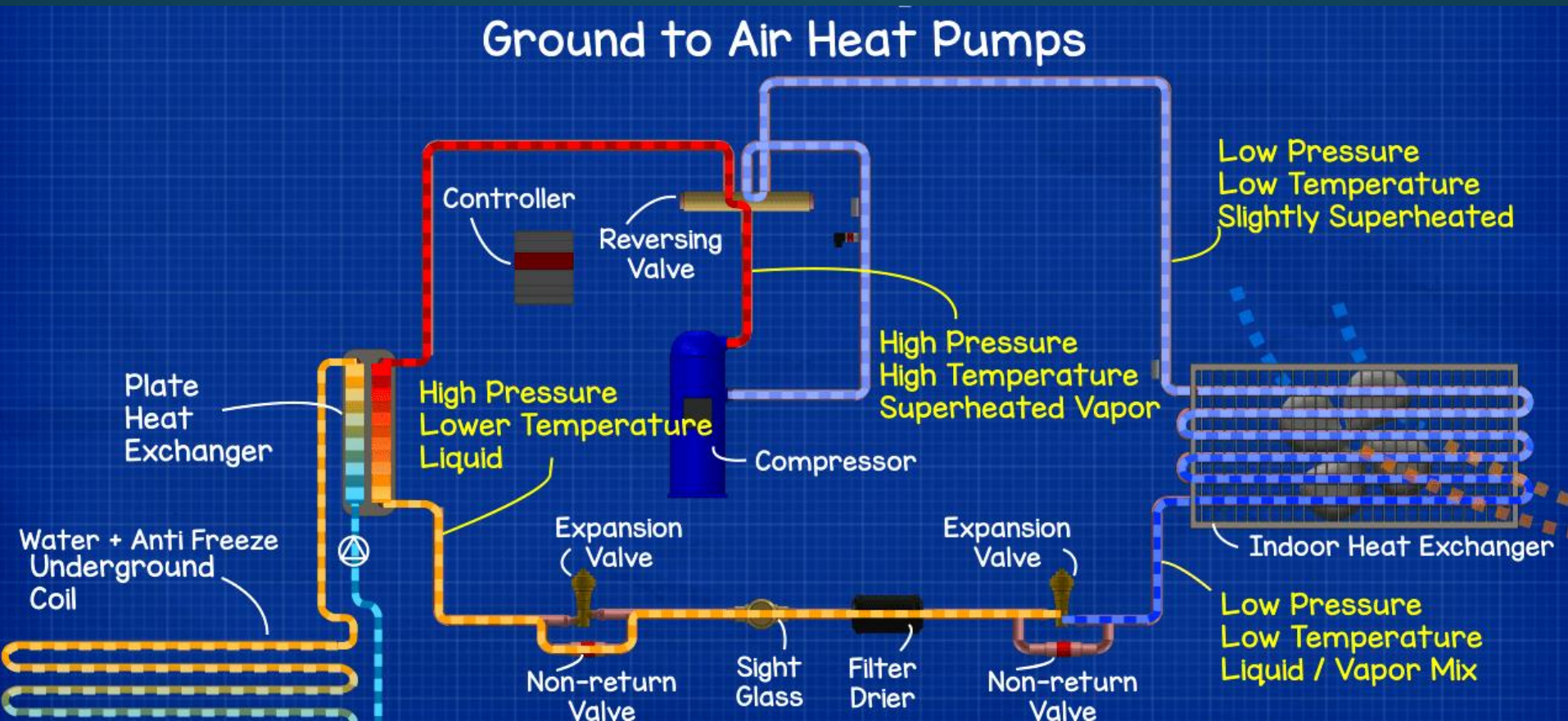
Source: <http://www.pet.ie/how-do-heat-pumps-work.html>



Source:  
<https://iea.imgix.net/2442557e-bfba-4b13-94c6-5114fab94977/HeatPumps.png?auto=compress%2Cformat&fit=min&q=80&rect=0%2C0%2C1890%2C2188>

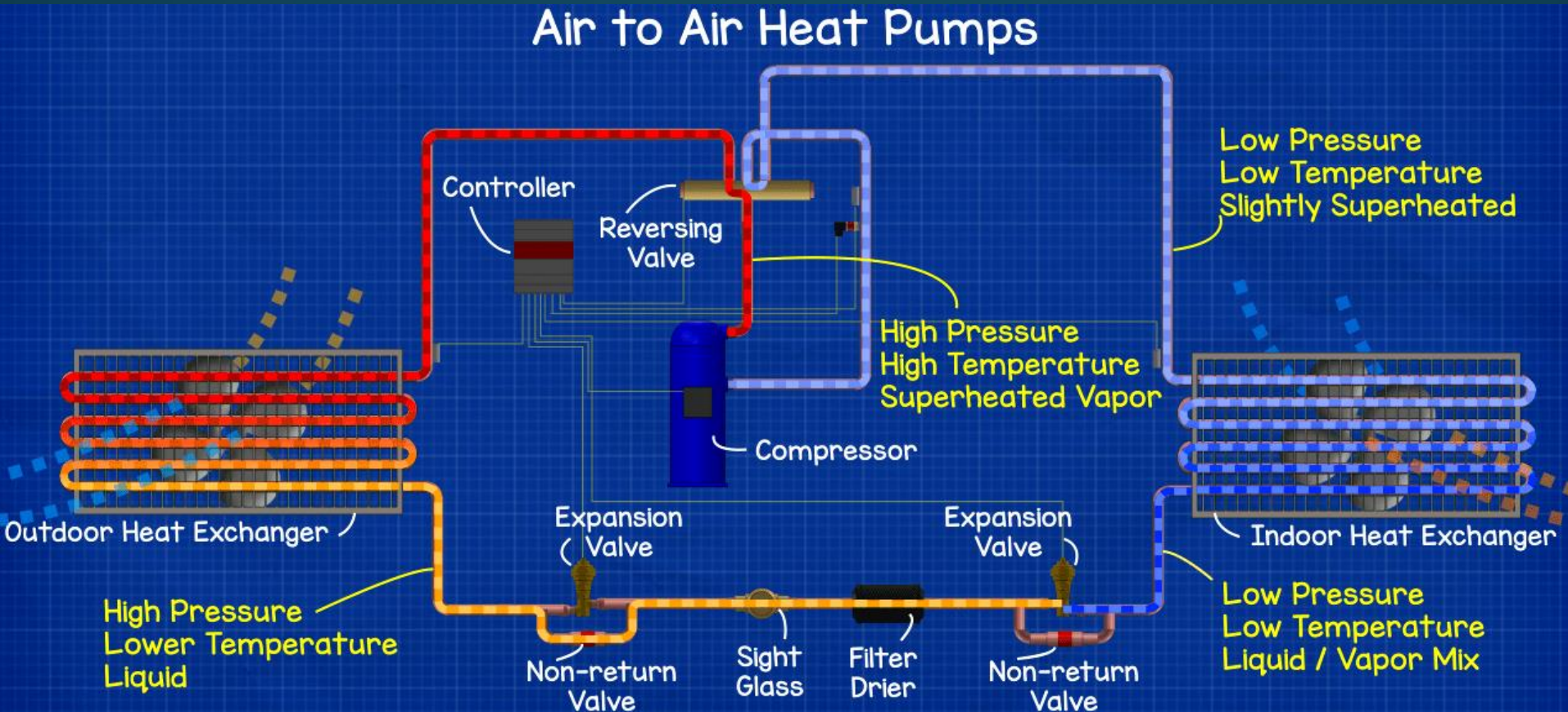
# How does a HP works?

A heat pump is an electrical equipment that delivers heat from a source (low-temperature area) to a sink (high-temperature area). A heat pump works on the heat transfer principle.



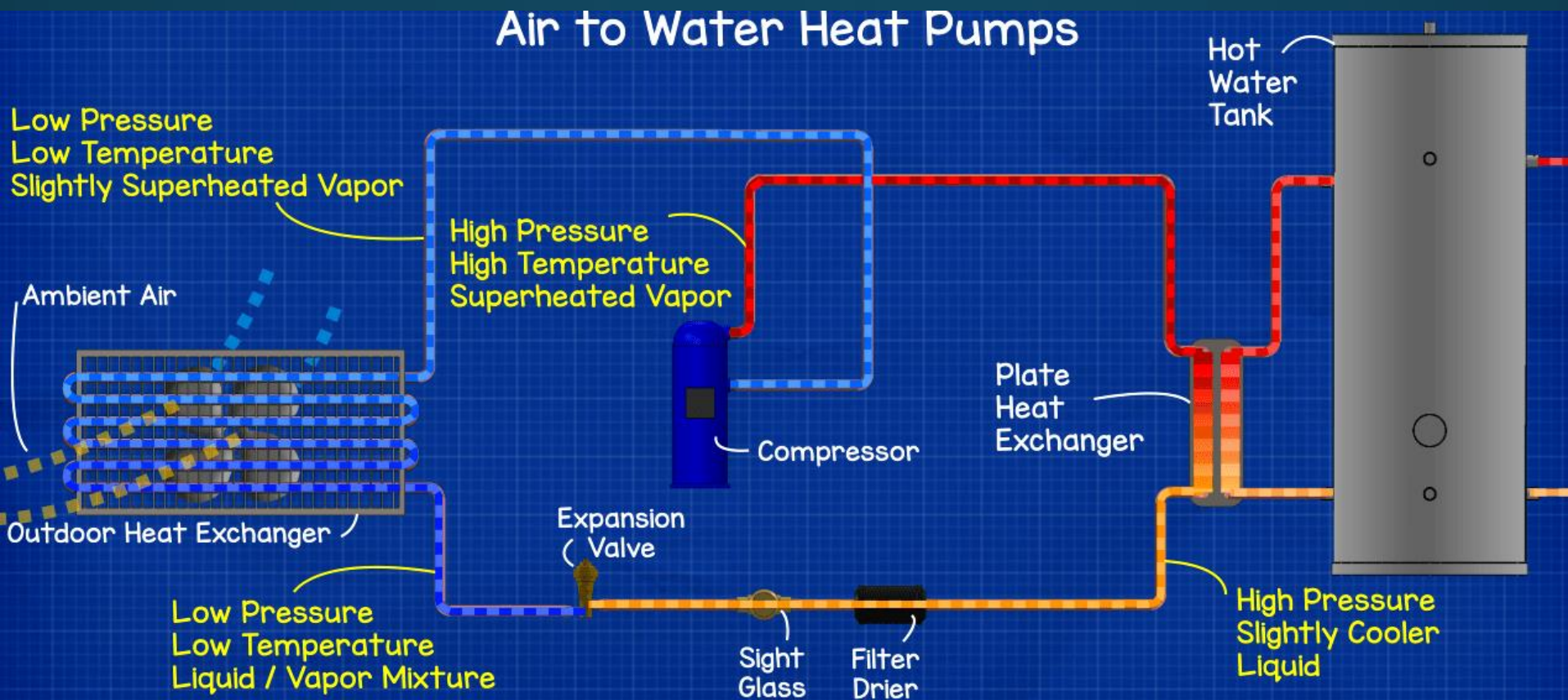
# How does a HP works?

An air source heat pump heats on a moderate winter day using a heat source of 40 deg and a sink of 70 deg (30 deg difference).



# How does a HP works?

A heat pump is an electrical equipment that delivers heat from a source (low-temperature area) to a sink (high-temperature area). A heat pump works on the heat transfer principle.



# Some useful figures and conversions

1 kW (kilowatt) is a unit of **Power** or a rate of energy.

(A typical small electric heater consumes 1 to 2 kW)

There are 3,411 Btu's in 1 kW. i.e. 10kW = 34,110 Btu/hr.

There are 860 kcal/hr in 1 kW

A normal immersion heater uses 3kW when heating

1 kWh (kilowatt hour) is a quantity of energy per time (hour)

1 kWh = 1 unit of electricity = (1 kW use for 1 hour)

A 1 kW heater would use 24 kWh each day.

1 kWh = 3,600 kJ

Note heat pumps are rated by their heat output, not their electrical power input.

# Calculating the power output of a HP

$$G = Z * \Delta\theta * Svc \text{ wat}$$

Where

$G$  = Heat Energy Flux (kW)

$Z$  = Flow rate ( $Ls^{-1}$ )

$\Delta\theta$  = Temperature Drop ( $^{\circ}K$ )

$Svc \text{ wat}$  = Specific heat capacity of water =  $4180 \text{ (JL}^{-1}\text{K}^{-1}\text{)}$

This gives how much heat can be extracted from the groundwater in kW.

Example:

If  $Z=1Ls^{-1}$ , and  $\Delta\theta=4^{\circ}K$  then:

$$G=1Ls^{-1}*4K*4180 \text{ JL}^{-1}\text{K}^{-1}=16.720 \text{ Js}^{-1}=16.7\text{kW.}$$

This is the heat energy flux (heat energy output) from a water flow of  $1Ls^{-1}$ .

# Calculating the power output of a HP

Once the ground heat flux has been derived,  $G = Z * \Delta\theta * Svc\ wat = 16.7$  a value must be worked out for the total heating effect of the process.

$$H = \frac{G}{\left(1 - \frac{1}{COP_H}\right)}$$

Where

H = Total Heating Effect (kW)

G = Heat Energy Flux (kW)

$COP_H$  = Coefficient of Performance (dimensionless)

Example:

If  $COP_H = 4$  then:

$$H = \frac{G}{\left(1 - \frac{1}{COP_H}\right)} = \frac{16.7}{\left(1 - \frac{1}{4}\right)} = \frac{16.7}{\left(\frac{4-1}{4}\right)} = \frac{16.7}{\left(\frac{3}{4}\right)} = 16.7 * \frac{4}{3} = 22.3 \text{ kW}$$

$$COP = \frac{H}{E} = \frac{\text{Heat delivered}}{\text{Electrical power input}}$$

$$E = 22.3\text{kW}/4 = 5.6 \text{ kW}$$

In order to achieve this value of H a constant power supply (E) is required,

# The seasonal performance of heat pumps

The typical seasonal performance factor (SPF) of heat pumps – an indicator of average annual energy performance – has increased steadily since 2010 to nearly **4** today for most space heating applications.

It is common to reach factors of **4.5** and up to **7**, especially in relatively mild climates such as the Mediterranean region and central and southern China. Conversely, in very cold climates such as part of Canada, low outside temperatures could reduce the energy performance of currently available technologies to **3** on average over the winter season.

The transition from non-inverter to inverter technologies in recent decades has boosted efficiency. Today, inverter technologies avoid much of the energy loss that results from the stops and starts of non-inverter units, while also reducing the temperature life for the compressor.

# The seasonal performance of heat pumps

Remember that the SPF of the heating system is different from that of the DHW heating system.

Example calculations by type of heat pump:

The following examples for the different types of heat pump assume heating requirements of 10,000 kWh/year. We also assume that 60% of the energy will be used for the heating and 40% for the DHW. That means 6000 kWh/year for the heating and 4000 kWh/year for the hot water.

Heat pump type	Heating SPF	DHW SPF	Electricity consumption for heating	Electricity consumption for water	Total electricity consumption
Geothermal heat pump	4.0	3.8	6000 kWh/year $4.0 = 1500$ kWh/year	4000 kWh/year $3.8 = 1052$ kWh/year	1500 kWh/year + 1052 kWh/year = 2552 kWh/year
Air source heat pump	2.8	2.4	6000 kWh/year $2.8 = 2143$ kWh/year	4000 kWh/year $2.4 = 1666$ kWh/year	2143 kWh/year + 1666 kWh/year = 3.809 kWh/year
Water source heat pump	4.8	4.5	6000 kWh/year $4.8 = 1250$ kWh/year	4000 kWh/year $4.5 = 888$ kWh/year	1250 kWh/year + 888 kWh/year = 2138 kWh/year

# The cost of electricity consumed by heat pumps

The electricity costs of a heat pump can be calculated as follows:  
 Total electricity consumption of the heat pump x electricity price

Example calculations by type of heat pump:

We assume an electricity price of 21 cents/kWh. In our examples, the resulting electricity costs would be as follows.

Type of heat pump	Annual electricity costs (for heating and hot water)
Geothermal heat pump	$2552 \text{ kWh/year} * 21 \text{ cents/kWh} = 53.592 \text{ cents} = \text{€}535.92$
Air source heat pump	$3809 \text{ kWh/year} * 21 \text{ cents/kWh} = 79.989 \text{ cents} = \text{€}799.89$
Water source heat pump	$2138 \text{ kWh/year} * 21 \text{ cents/kWh} = 44.898 \text{ cents} = \text{€}448.98$

# How to reduce the electricity consumption of heat pumps

- Radiant heating systems, such as underfloor heating, use low flow temperatures so the heat pump uses less electricity as a result.
- Solar thermal technology can cover DHW heating, at least in the summer. This means that you only need to use the heat pump in the winter and thus use less electricity.
- Good insulation of the house is the most effective measure for lowering the required heating output as far as possible and reducing the electricity consumption of heat pumps.
- Correct design and sizing of the heating system.

# Energy efficiency programmes specific to heat pumps

China's Ministry of Environmental Protection established financial subsidies, ranging from £8000 to 3.500 (CNY 7.400 to 29.000) for households purchasing air-source heat pumps in 2020 in Beijing, Tianjin, Shanxi, Hebei and Shandong. Japan's Energy Conservation Plan is a similar scheme.

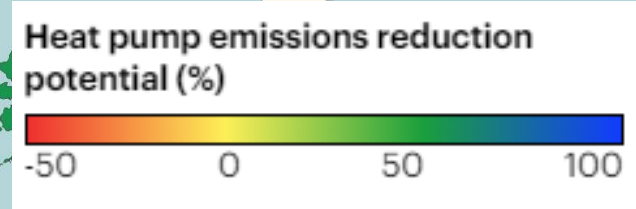
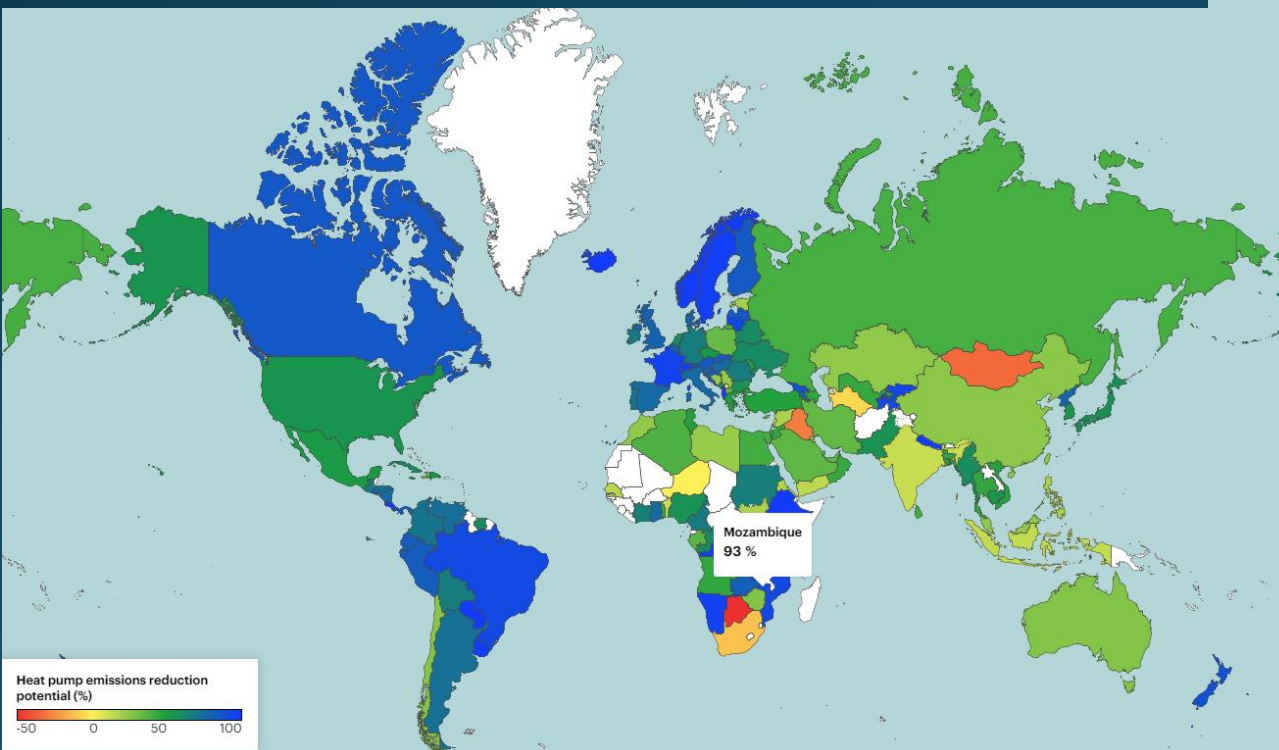
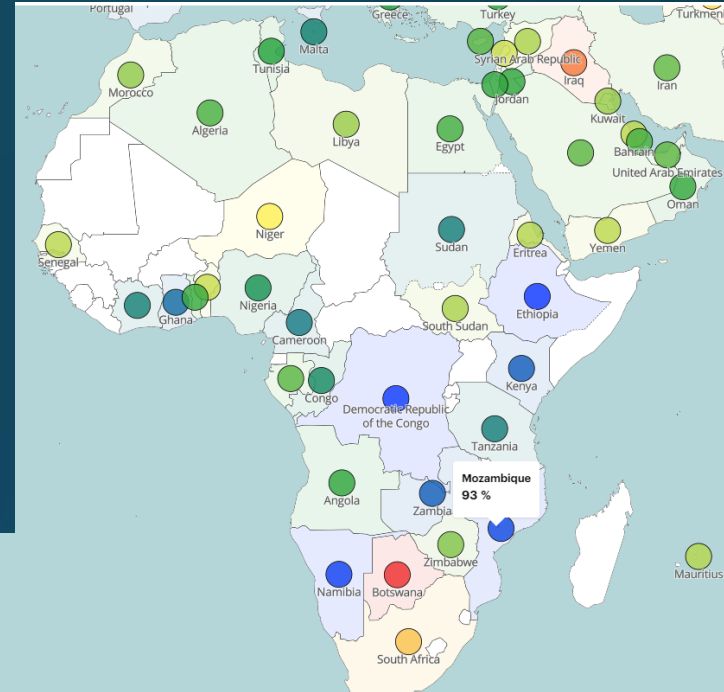
Other programmes specifically target ground-source heat pumps.

The United States recently extended the 26% federal tax credit for new residential ground source heat pump until the end of 2022. In Beijing, 30% of the initial investment cost is also covered by the state. To help achieve its ground-source heat pump deployment target of 700 million m<sup>2</sup>, China has proposed complementary subsidies (CNY 35/m<sup>2</sup> to CNY 70/m<sup>2</sup>) for other areas such as Jilin, Chongqing and Nanjing.

# Pros & Cons of Heat Pumps

## Heat Pump's emissions reduction

Air-source heat pump CO<sub>2</sub> emissions reductions by country relative to the most efficient condensing gas boilers (2020).



Source: <https://www.iea.org/reports/heat-pumps>

# Pros & Cons of Heat Pumps

 Advantages	Disadvantages 
Lower running costs 	 High upfront cost
Less maintenance 	 Fairly difficult to install
Safer than combustion based system 	 Questionable sustainability
Reduce your CO2 emissions 	 Significant work to your house and garden
Provide cooling during summers 	 Cold weather can damage the system
Long life-span, extremely reliable 	 Not entirely carbon neutral, electricity required
Boiler Upgrade Scheme (BUS) 	 Special planning permissions

# Pros & Cons of Heat Pumps

## Pros

One of the advantages of a heat pump is that they use electricity, reducing the need to have access to natural gas or keeping a propane tank.

Because heat pumps use a whole home duct system the warmth produced is evenly distributed throughout the house, reducing the number of cold spots and keeping everyone comfortable.

Efficiency is also a great advantage to a heat pump, particularly ground source heat pumps. Generally, heat pumps put out more cool and warm air by volume than the amount of energy it takes to run them (efficiency). Heat pumps are also more advantageous to maintain because, during the maintenance, the technician will look at both parts of the system to keep everything running smoothly.

### Typical cost of a heat pump



# Pros & Cons of Heat Pumps

## Cons

Heat pumps cost more than furnaces to purchase and install. Longevity is another disadvantage to a heat pump. Clogging issues may arise in GSHP. There are a lot of variables that influence an HVAC system life expectancy, with the biggest one being how often it is used. Because heat pumps are used year-round vs seasonally, they tend to wear out more quickly, usually lasting about 25 years.



# Sizing a Heat Pumps

Choosing the right size heat pump for your home is critical to a well-functioning and efficient heating and cooling system. If your heat pump is too small then it will struggle to keep your home cool and warm. On the other hand, if it is too big it will waste energy by producing too much hot or cool air, cycling on and off constantly, and stressing out the motor. There are a number of factors that go into sizing your unit properly.

- Local climate
- Home square footage
- Window and doors
- Insulation in the home
- How many people are in the home
- Temperature preferences of home residents
- Other appliances that can generate heat
- Existence of resources nearby

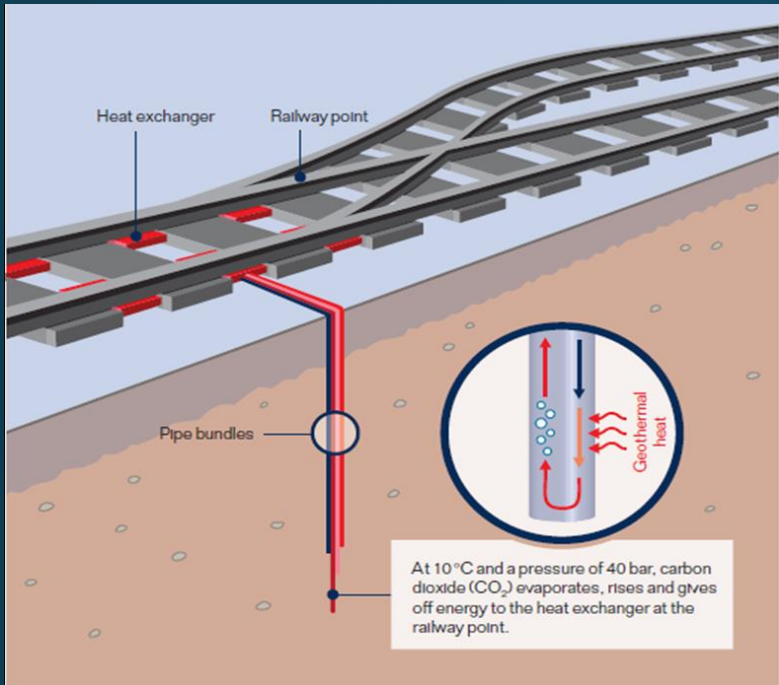
**AirCon NZ Heat Pump Sizing Guide for new and older houses**

Heating [KW]	2.4m Stud Height		2.7m Stud Height		3.0m Stud Height		3.3m Stud Height		3.8m Stud Height	
	new build	old build	new build	old build	new build	old build	new build	old build	new build	old build
20	2.2	2.6	2.4	3.0	2.7	3.3	3.0	3.6	3.4	4.2
25	2.7	3.3	3.0	3.7	3.4	4.1	3.7	4.5	4.3	5.2
30	3.2	4.0	3.6	4.5	4.1	5.0	4.5	5.4	5.1	6.3
35	3.8	4.6	4.3	5.2	4.7	5.8	5.2	6.4	6.0	7.3
40	4.3	5.3	4.9	5.9	5.4	6.6	5.9	7.3	6.8	8.4
45	4.9	5.9	5.5	6.7	6.1	7.4	6.7	8.2	7.7	9.4
50	5.4	6.6	6.1	7.4	6.8	8.3	7.4	9.1	8.6	10.5
55	5.9	7.3	6.7	8.2	7.4	9.1	8.2	10.0	9.4	11.5
60	6.5	7.9	7.3	8.9	8.1	9.9	8.9	10.9	10.3	12.5
65	7.0	8.6	7.9	9.7	8.8	10.7	9.7	11.8	11.1	13.6
70	7.6	9.2	8.5	10.4	9.5	11.6	10.4	12.7	12.0	14.6

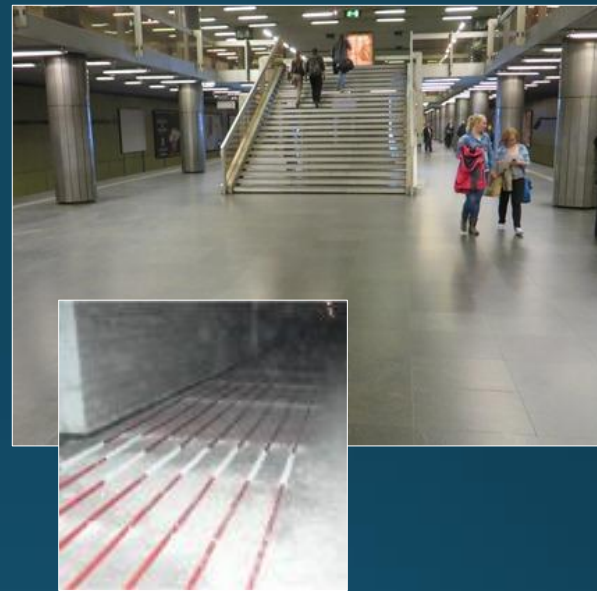
Source: <https://www.hpac.co.nz/tipsandadvice/how-to-choose-the-right-size-heat-pump/>



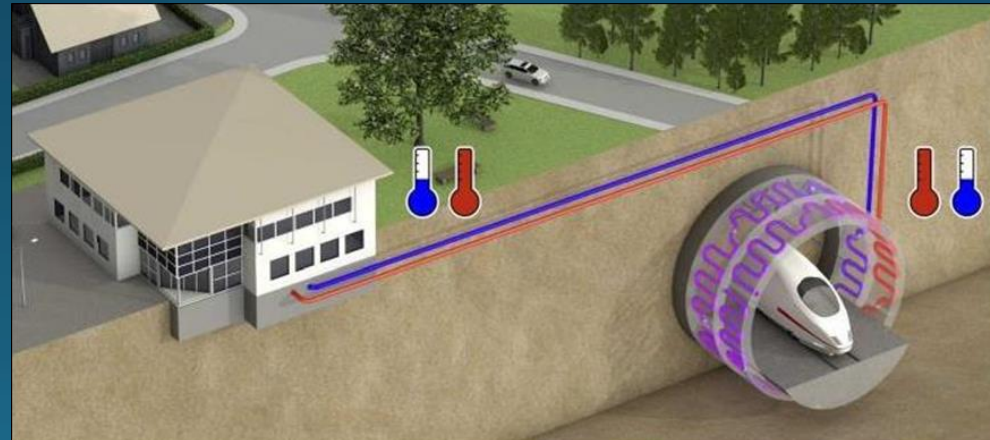
# Other uses of Heat Pumps



Source: Hamburg Port Authority

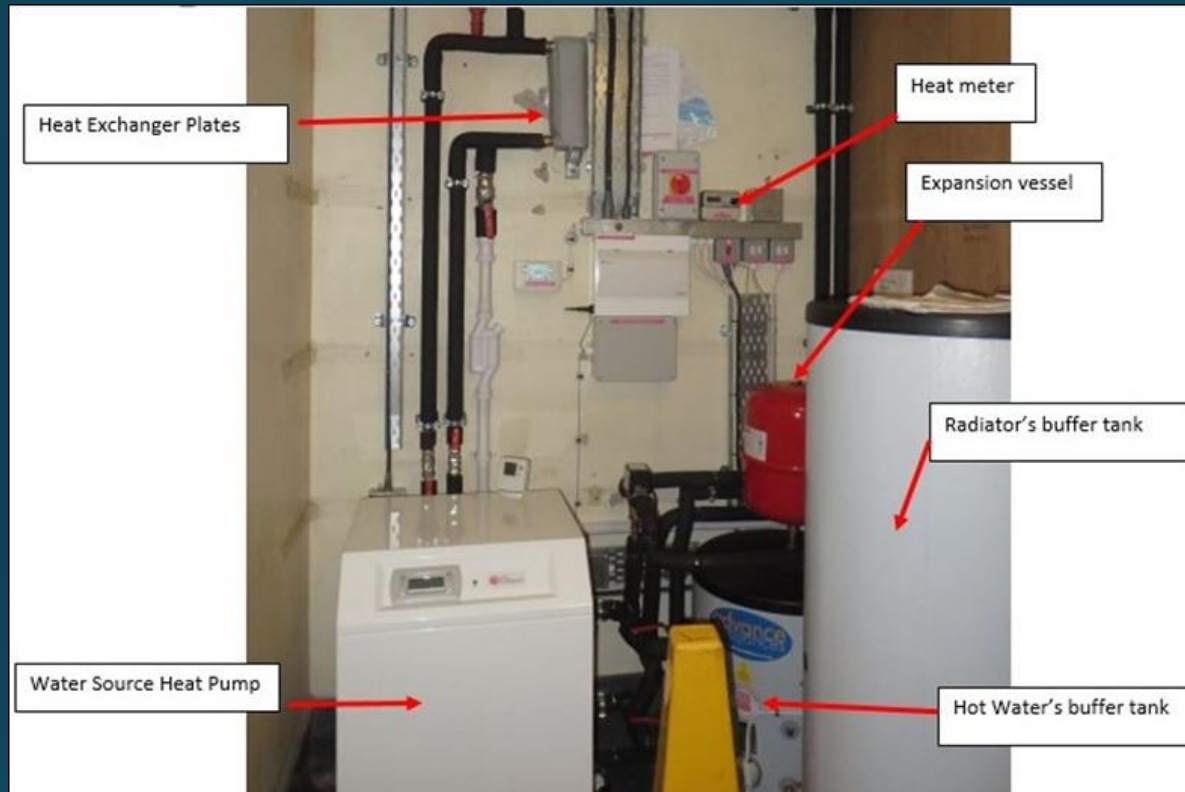


Source: Budapest Metro System



Source: [gshp.org.uk](http://gshp.org.uk)

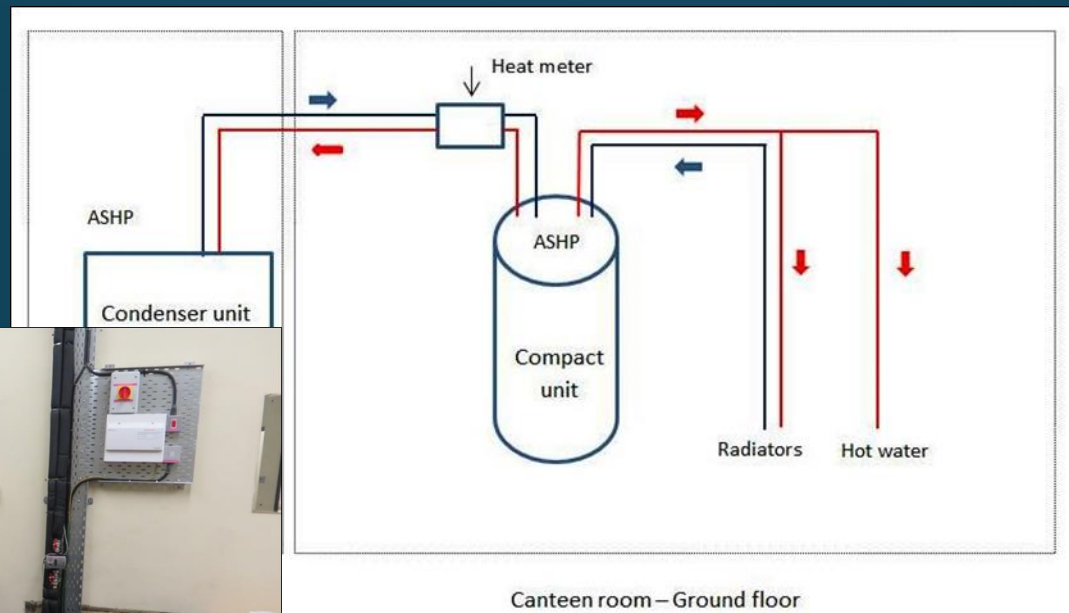
# Case study GSHP



Comparison between an electric fired heating system and a HP system

Heating	Input	Output	Cost / kWh	Cost/day (16h)	Cost / year (210d)	Carbon dioxide factor	By-product
	kW	kW	£	£	£	kgCO <sub>2</sub> /kWh	-
<b>Old system:</b> 4 electric radiators (2kW)	8	8	8X0.12=0.96	0.96X16=15.36	3225.6	0.54	None
<b>New system:</b> WSHP	3	9	3X0.12=0.36	0.36X16=5.76	1209.6	0.17	Cooling

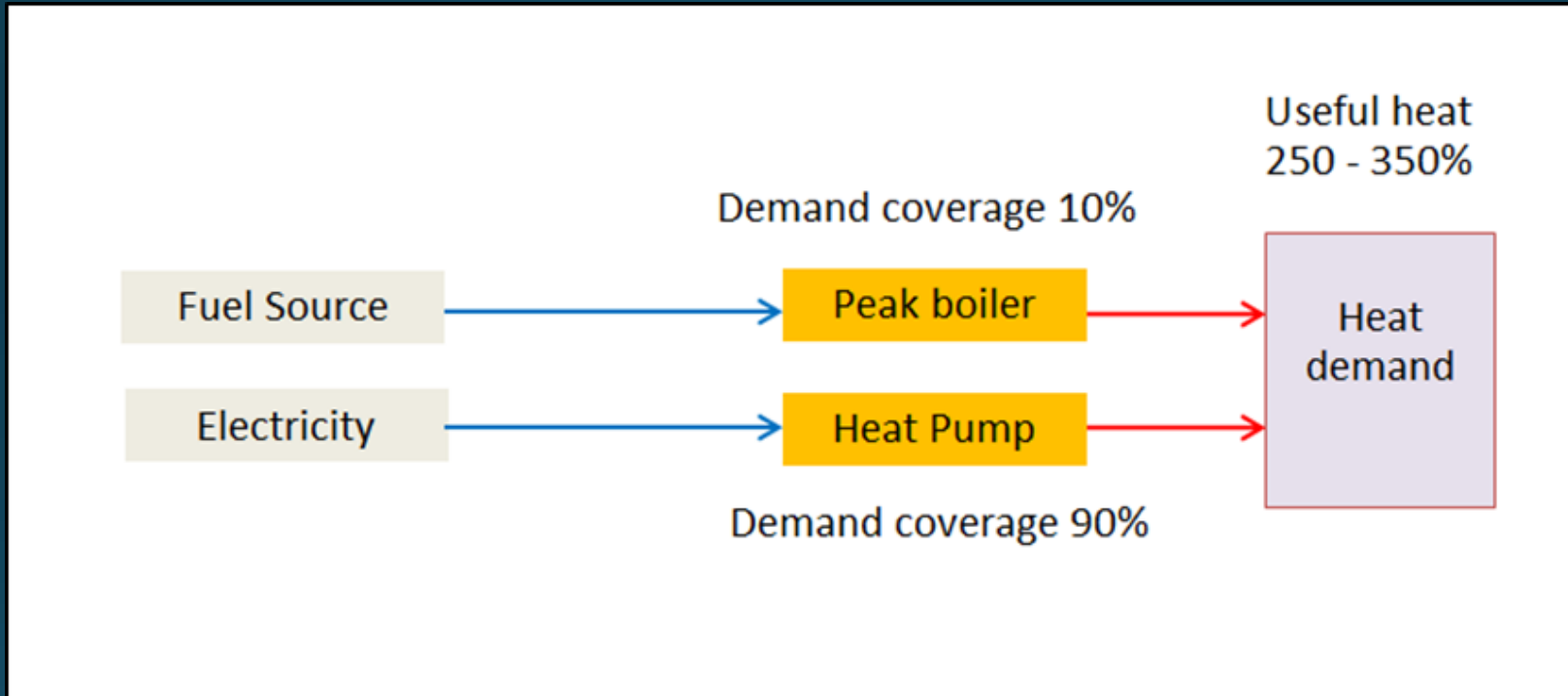
# Case study ASHP



Comparison between an electric fired heating system and a HP system

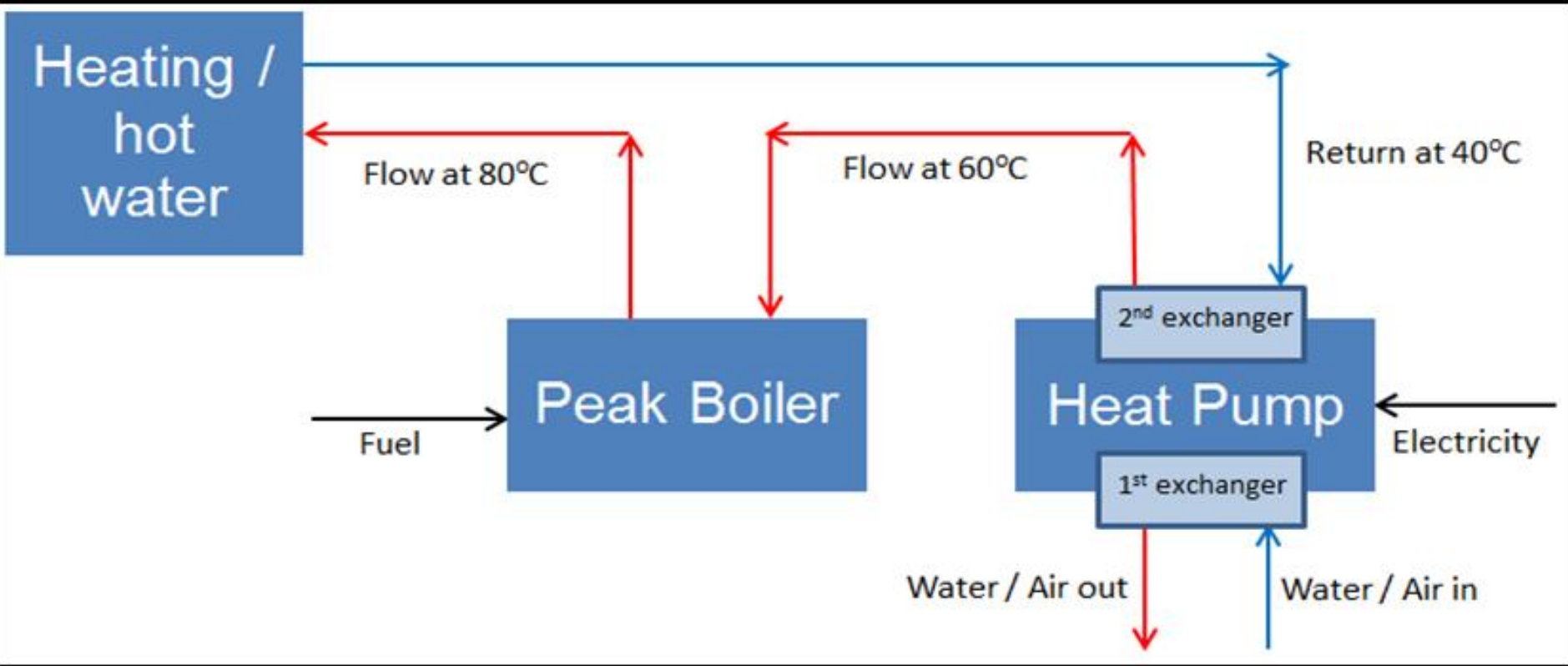
Heating	Input	Output	Cost / kWh	Cost/day (16h)	Cost / year (210d)	Carbon dioxide factor	By-product
	kW	kW	£	£	£	kgCO <sub>2</sub> /kWh	-
<b>Old system:</b> 5 electric radiators (2kW)	10	10	10X0.12=1.2	1.2X16=19.2	4032	0.49	None
<b>New system:</b> ASHP	3	9	3X0.12=0.36	0.36X16=5.76	1209.6	0.21	Cooling

# HP works as an additional heating system (Hybrid)



Heating an old building with a HP and a peak boiler

# HP works as an additional heating system (Hybrid)



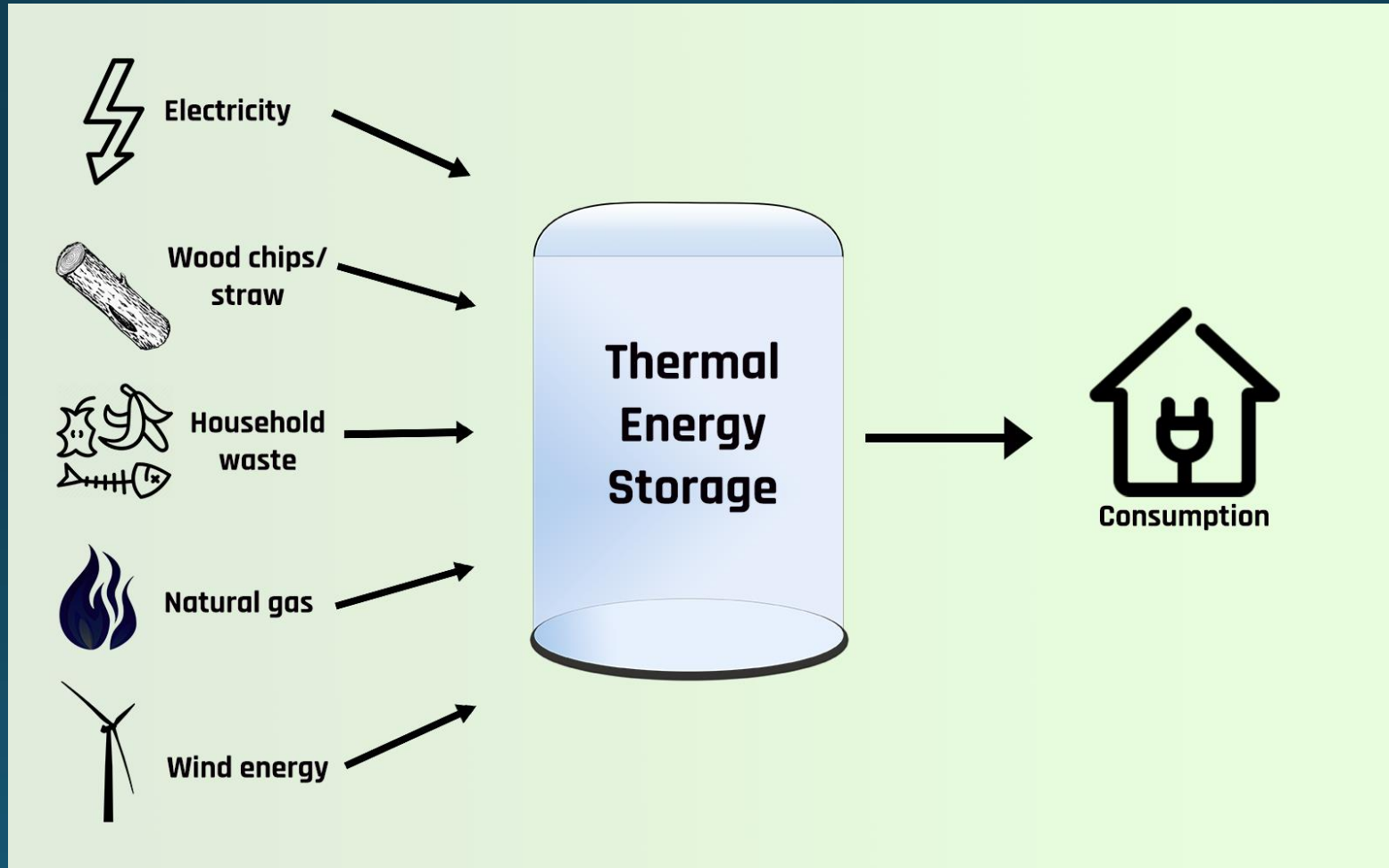
Application in retrofitting

## GSHP cost for an industrial space of 800m<sup>2</sup>

Technology	Equipment	Warranty	Overall cost (Including equipment, installation, commissioning, VAT)	Payback period
Water Source Heat Pump: water sourced system (WSHP)	<ul style="list-style-type: none"> <li>• Three 70kW heat pumps (exchangers)</li> <li>• Three 1000l buffer tanks</li> <li>• One intelligent control system</li> <li>• Approx. 300m insulated pipes (from 15mm to 32mm)</li> <li>• Two circulation pumps</li> </ul>	<p>At 10 years manufacturer's warranty &amp; a full 10-year guarantee on all works carried out</p>	£200.000	9 years

# Thermal Energy Storage (TES)

Thermal energy storage means heating or cooling a medium to use the energy when needed later.



# Why do we need thermal energy storage?

While battery storage technology is developing rapidly, there are alternatives that help meet the challenges of renewable energy intermittence and grid stability.



# Underground Thermal Energy Storage

Underground Thermal Energy Storage (UTES) systems store energy by pumping heat into an underground space, typically using water as storage medium. In general, large-scale underground systems of more than 4,000-5,000 cubic meters are a cost-effective option, while tanks are the smarter alternative for smaller capacity systems.

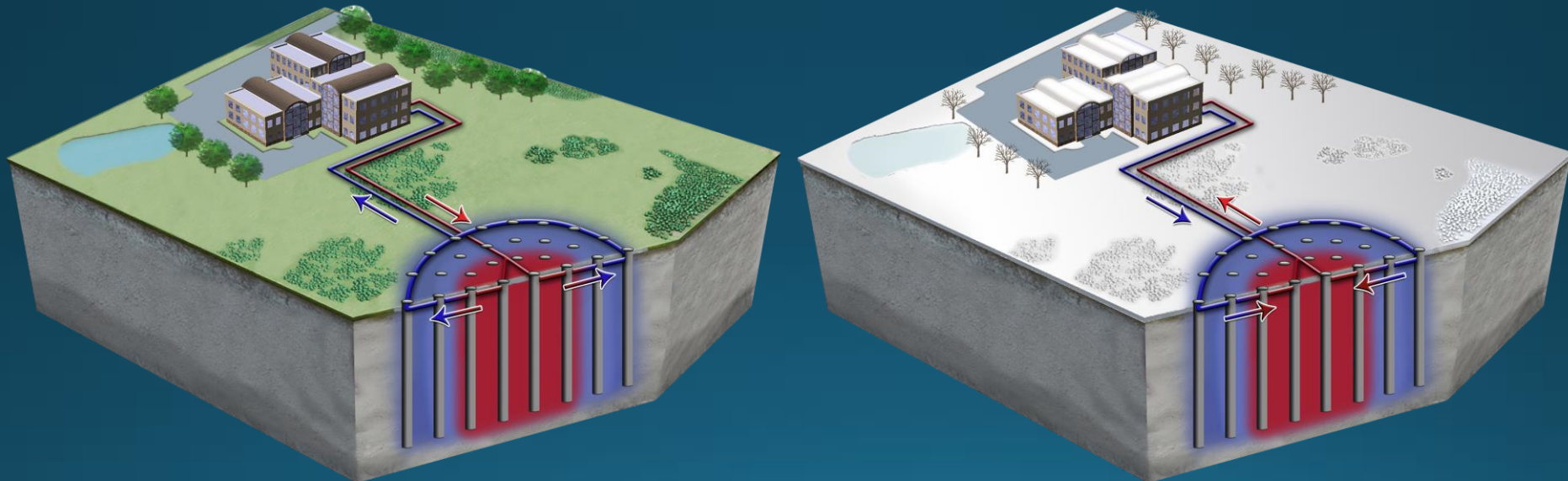


Photo: Johan Frey

## Pit Thermal Energy Storage (PTES)

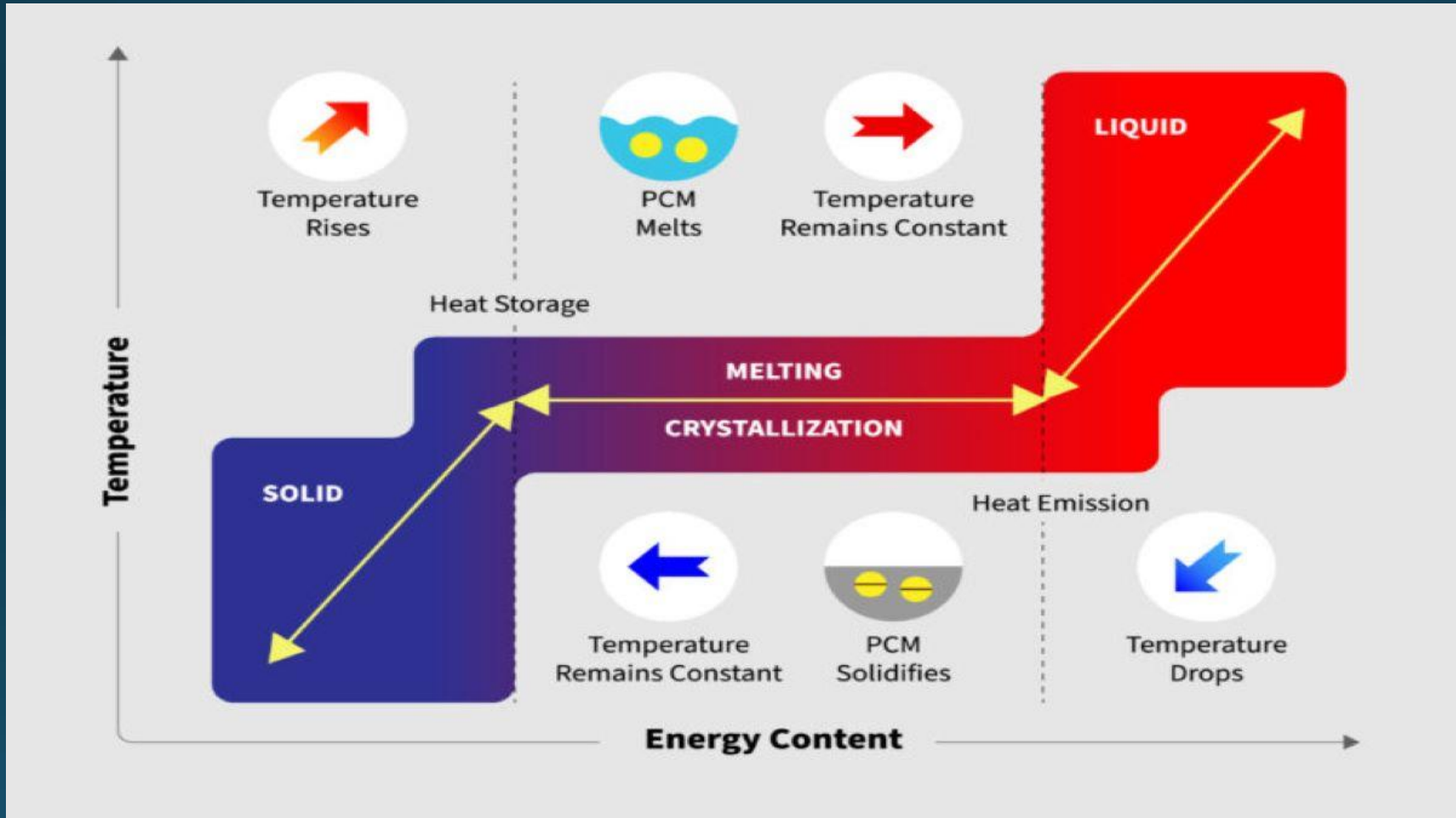
# Underground Thermal Energy Storage

## BTES – Borehole Thermal Energy Storage



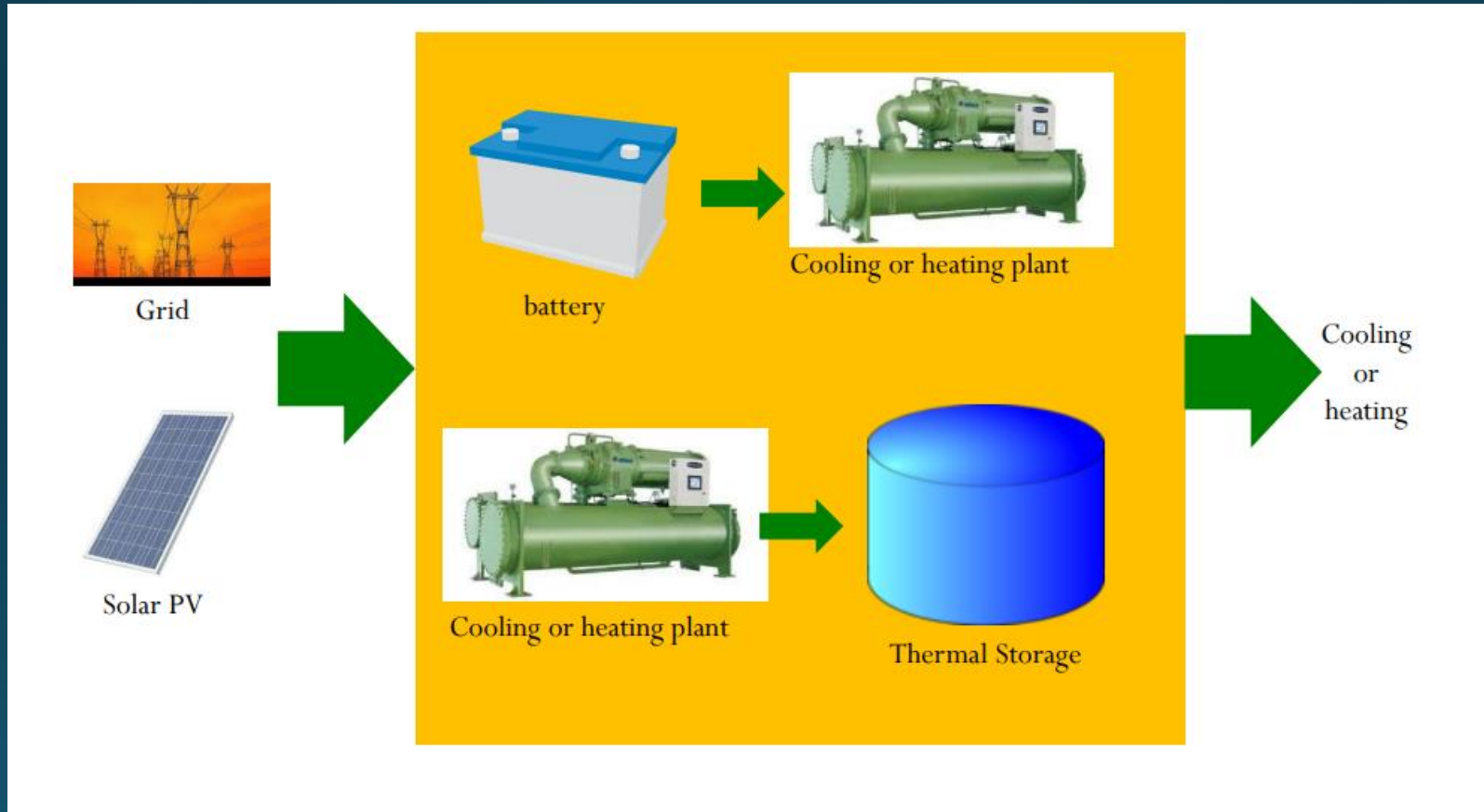
# Geothermal Energy Storage

## Phase changing materials (PCM)



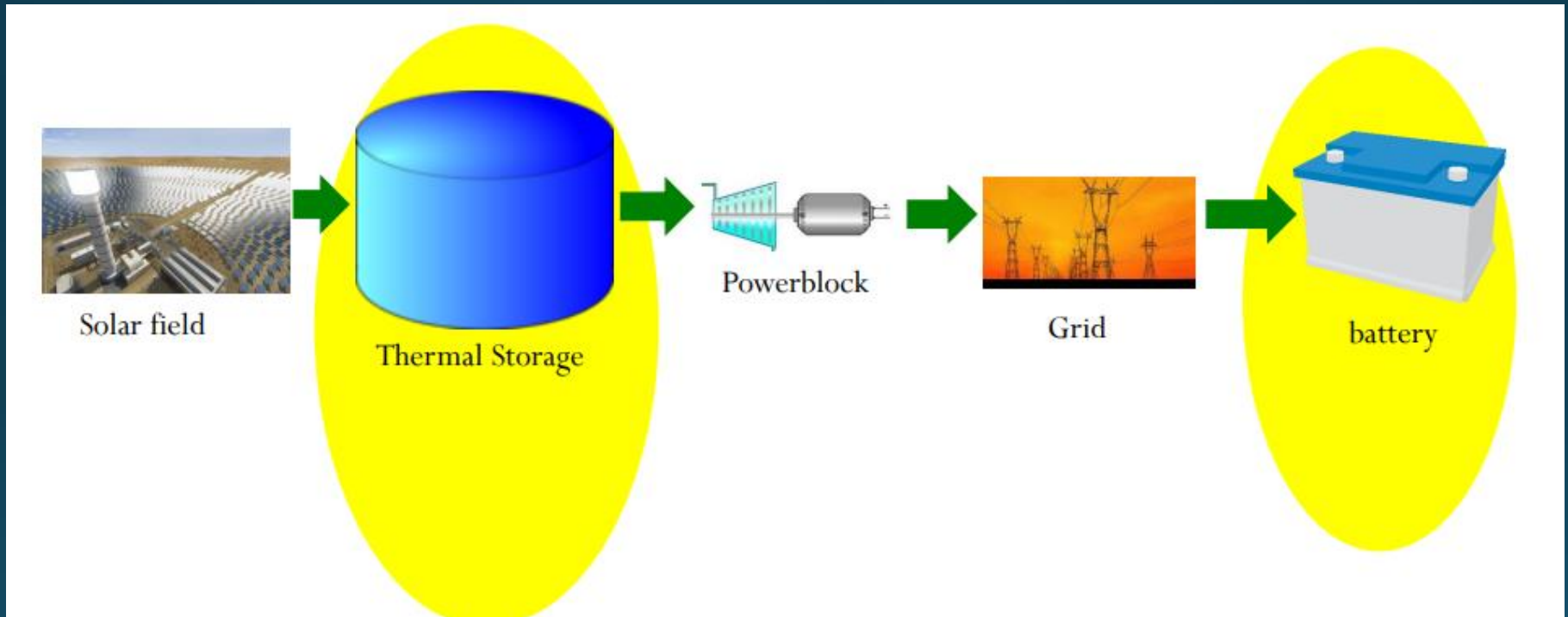
# Thermal Energy Storage

Storing electricity for cooling or heating



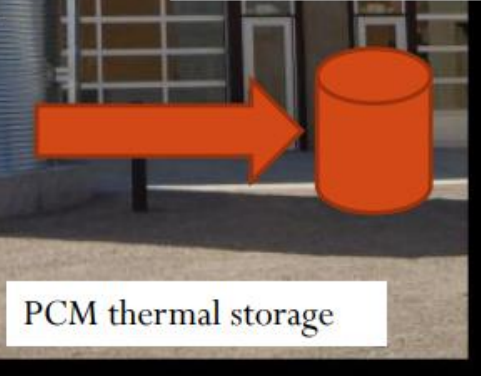
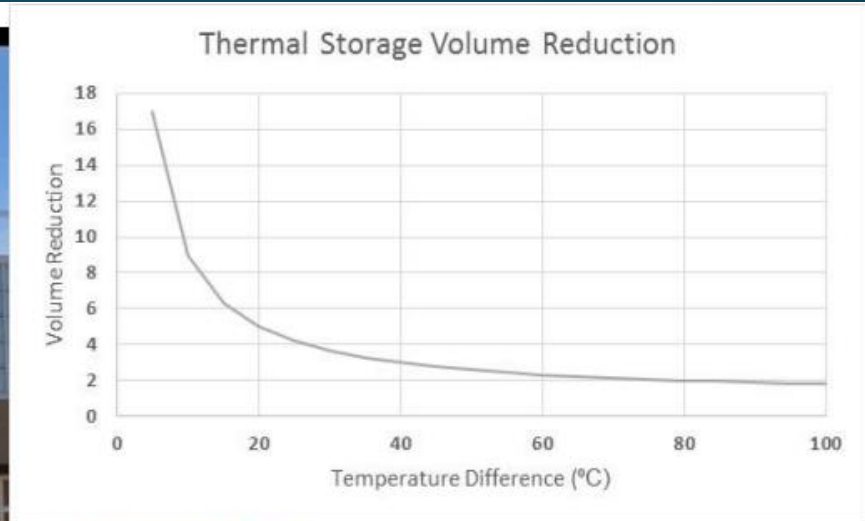
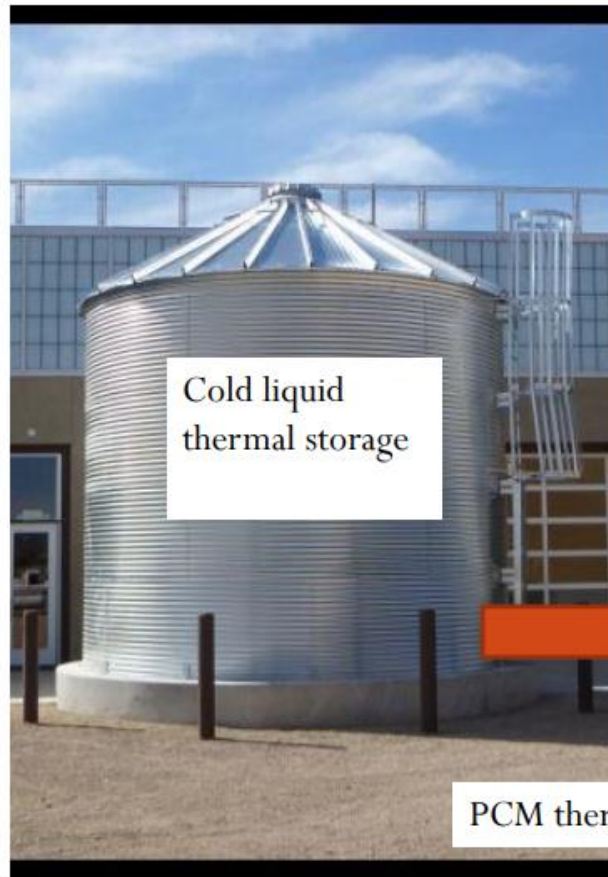
# Thermal Energy Storage

Energy storage for solar power plants



# Thermal Energy Storage

## Volume reduction with PCMs



# Thermal Energy Storage (TES)

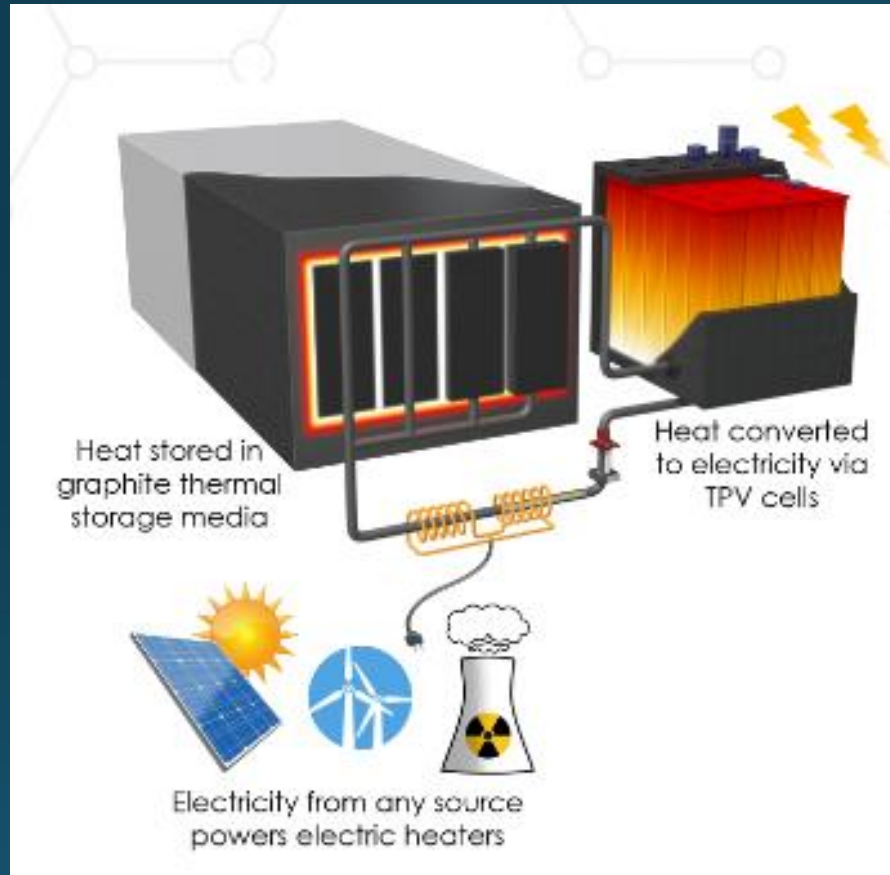
## Economics

- Li ion batteries storage: 760 – 1800 £/kWh
- PCM thermal storage for refrigeration 200 £/kWh

## Advantages

- Cheaper
- Longer life (batteries: 10-15 years / TES: 30 years)
- Higher power capacity
- Can operate at higher ambient temperatures
- Provides backup when heating or cooling generating equipment fails

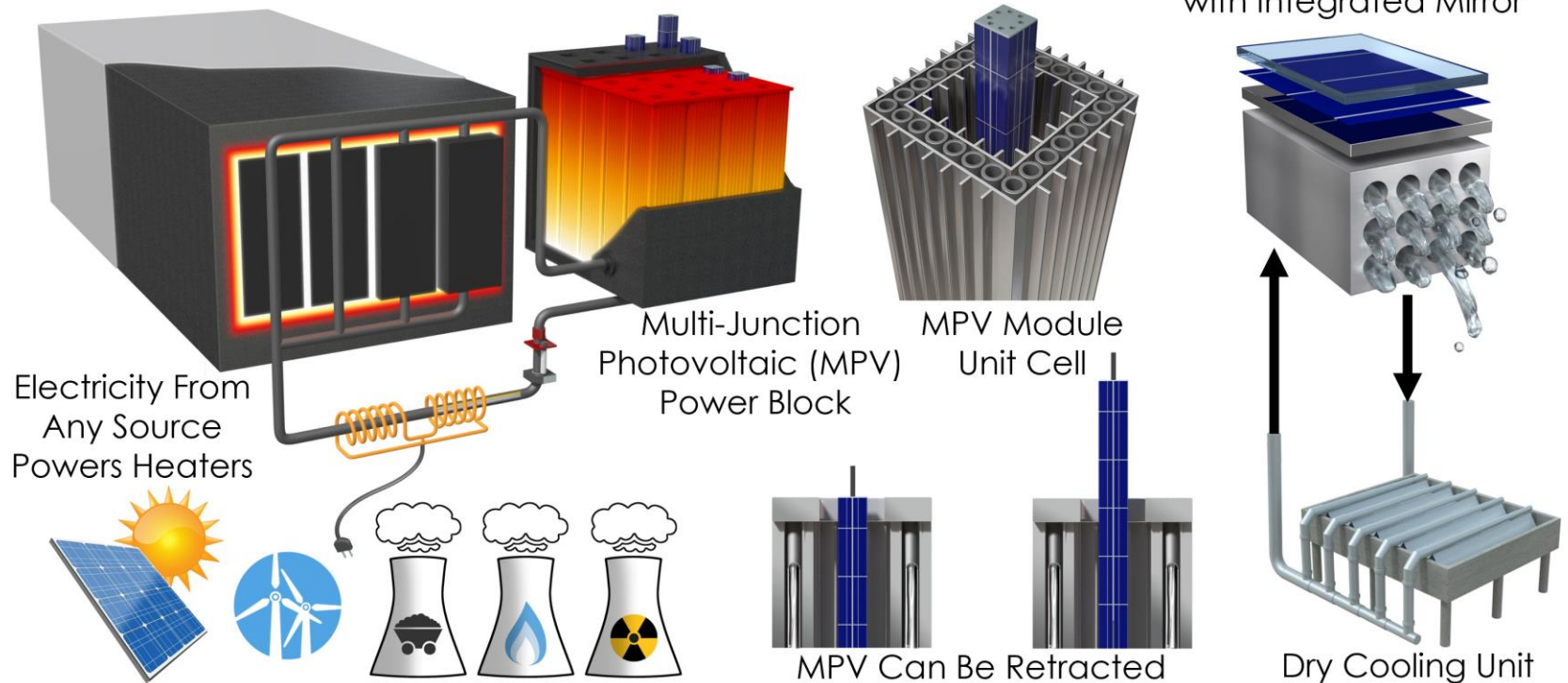
# Thermal Energy Grid Storage (TEGS)



TEGS is a low-cost, long duration, grid-scale energy storage technology. This technology acts like a battery where electricity flows in and out of the system as it charges and discharges.

# Thermal Energy Grid Storage (TEGS)

Electricity → Heat → Electricity



Source: <https://ase.mit.edu/projects/thermal-energy-grid-storage-tegs/>

# Thermal Energy Storage (TES)

