Generation systems – heat pumps

Heating, Ventilation and Air Conditioning Systems
A.A. 2024/25

Jacopo Vivian

14/5/2025

Generation systems

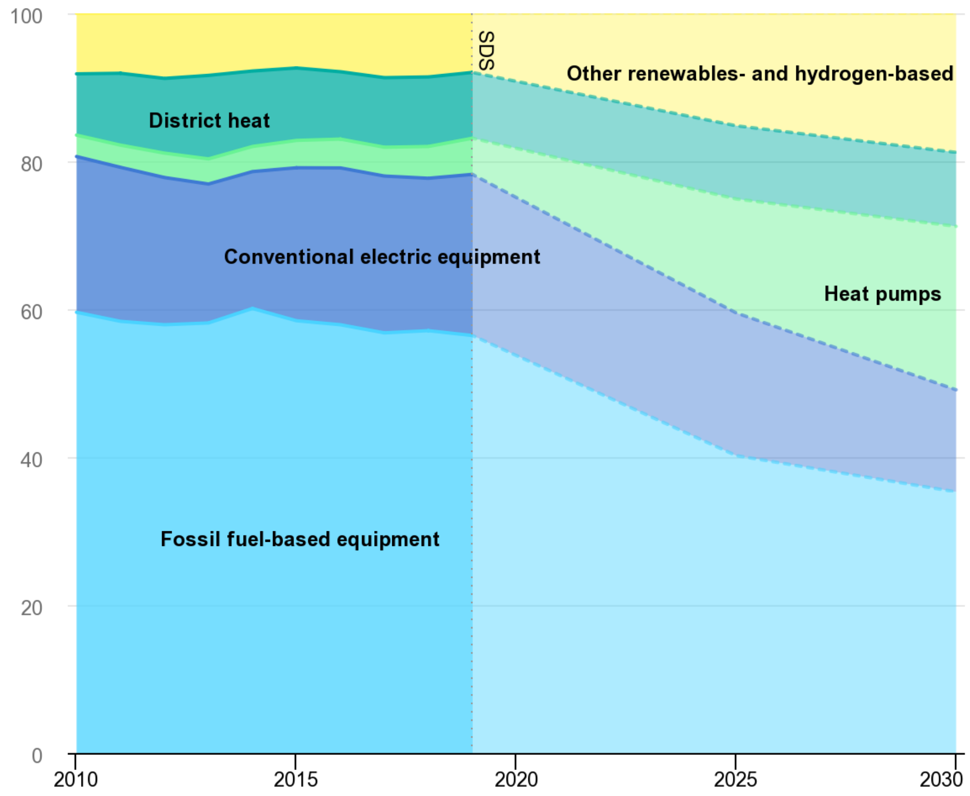
Energy conservation law

Energy is not «created», energy is just converted from one form to another.

Generation systems

Electrification of end uses

Electrification of the heating sector helps achieve decarbonization targets because «clean» electricity can be produced locally with renewable energy sources such as PV systems.



[source: IEA, 2020]

Heat pumps

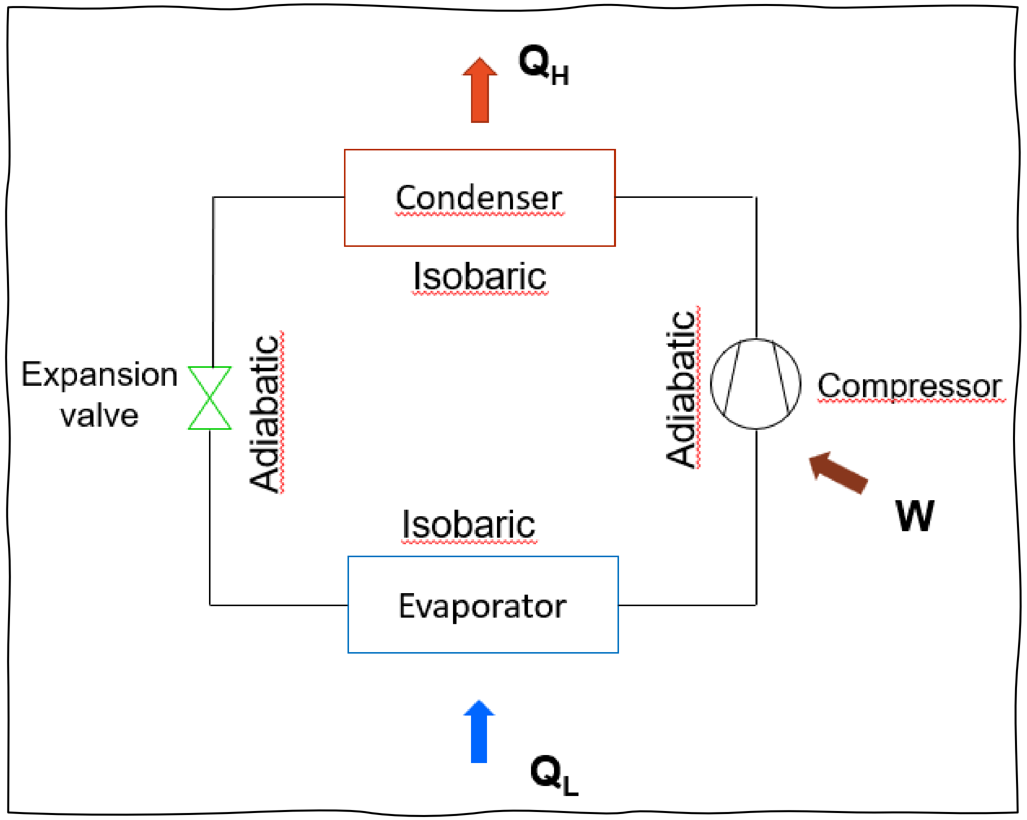
Heat sources and sinks

The heat sink is the heating system where the heat carrier fluid is water (e.g. hydronic system that supplies radiators, fan coils, AHUs).

Type	Heat source
Air-to-water	Outdoor air Exhaust air (from building ventilation system)
Water-to-water	Ground Groundwater (from well) Waste heat (from process heat) Surface water (from lake, river, sea, etc)

Heat pumps

Working principle



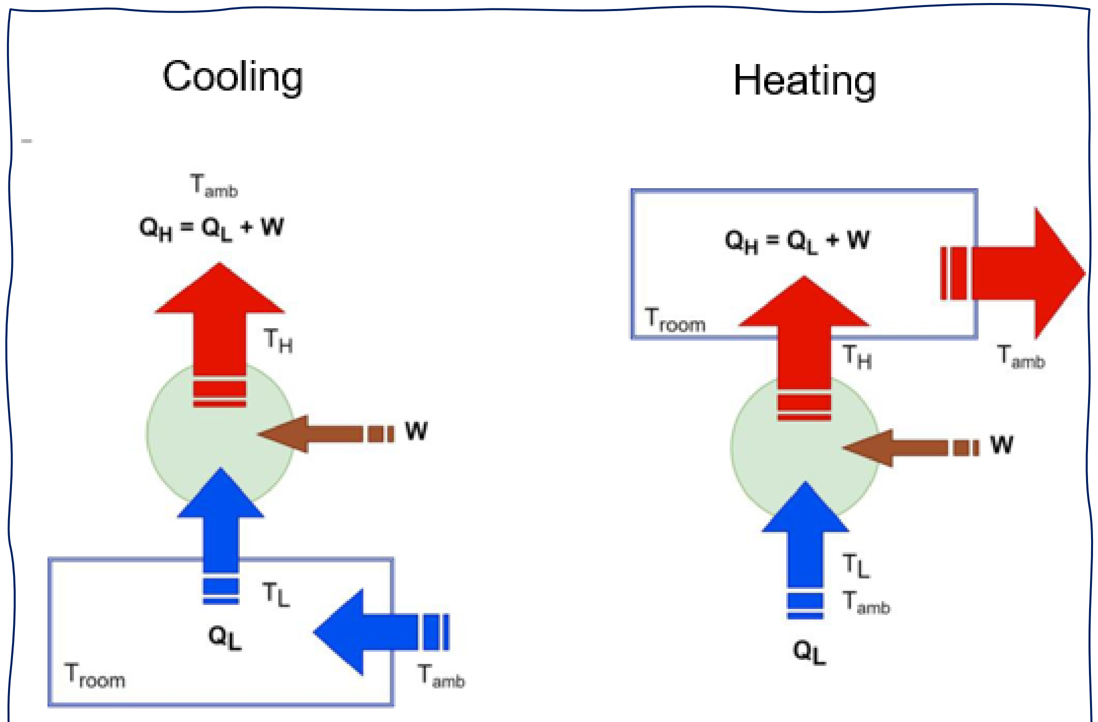


Figure 3a: refrigeration process

Figure 3b: heat pump process

Heat pumps

Heat sources and sinks

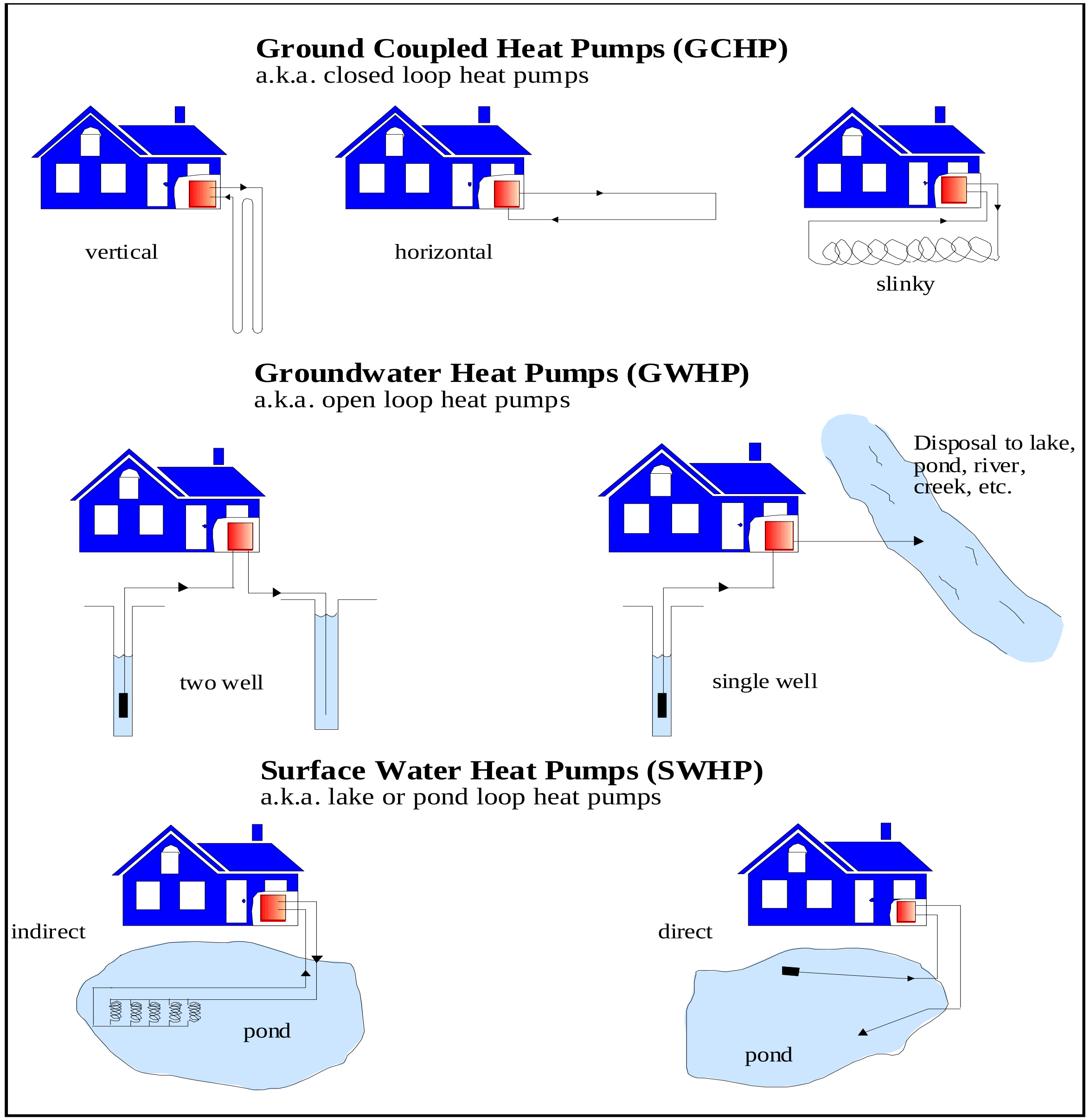
The heat sink is the indoor air or a heating system using air as heat carrier fluid.

Type	Heat source
Air-to-air	Outdoor air Exhaust air (from building ventilation system)
Water-to-air	Ground Groundwater (from well) Waste heat (from process heat) Surface water (from lake, river, sea, etc)

Heat pumps

Heat sources and sinks

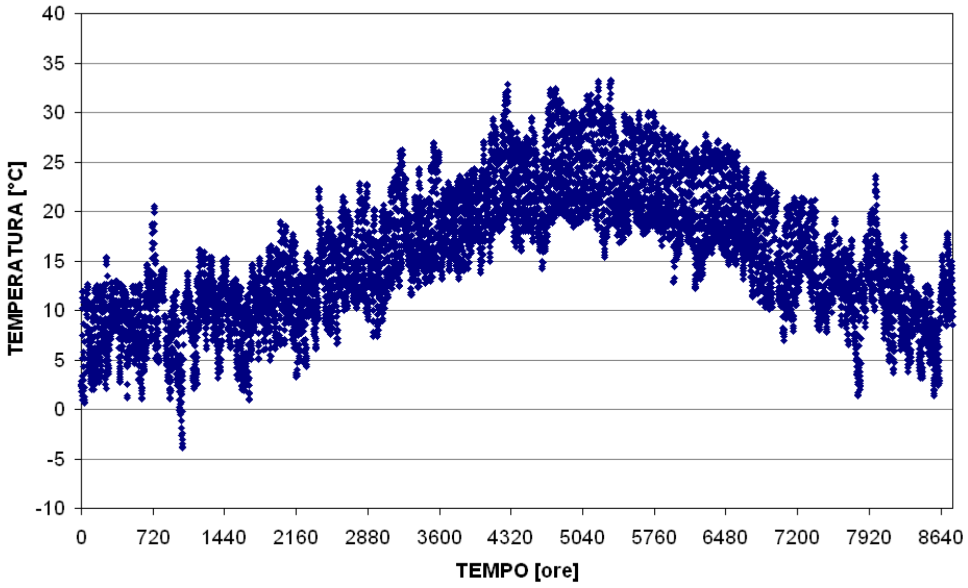
Ground-coupled or ground-source HPs rely on a **closed loop** to extract heat, whereas groundwater HPs rely on an **open loop**.

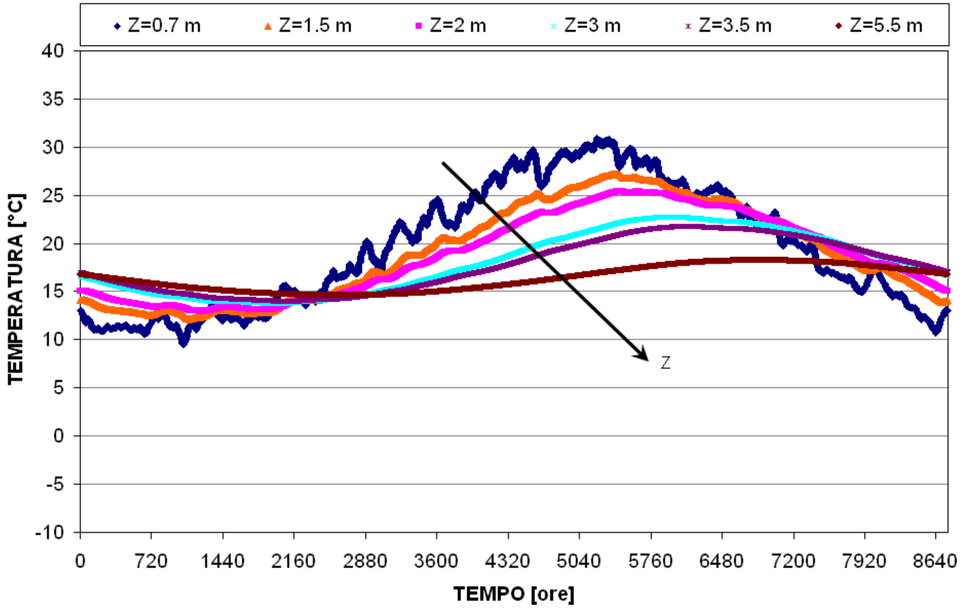


Heat pumps

Air vs ground as heat source

Ground temperature is like a filtered air temperature (smoothed and delayed signal depending on depth) → warmer in winter, and colder is summer!





Heat pumps

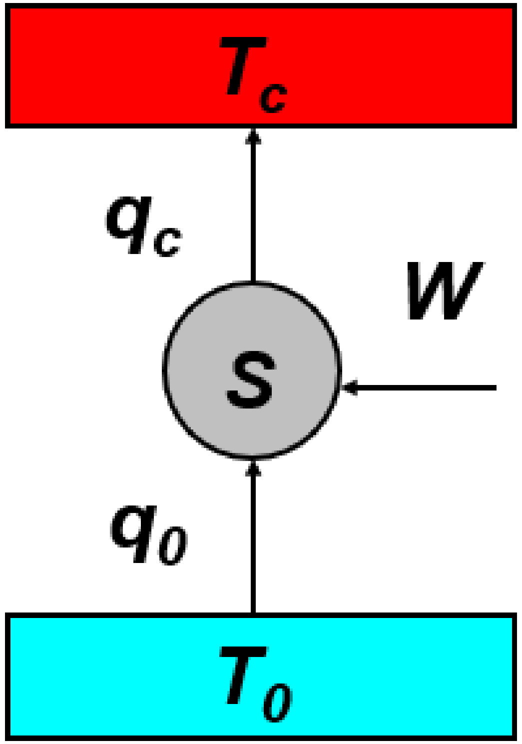
Performance

The efficiency is measured by the Coefficient of Performance (COP).

$$COP = \frac{q_c}{W}$$

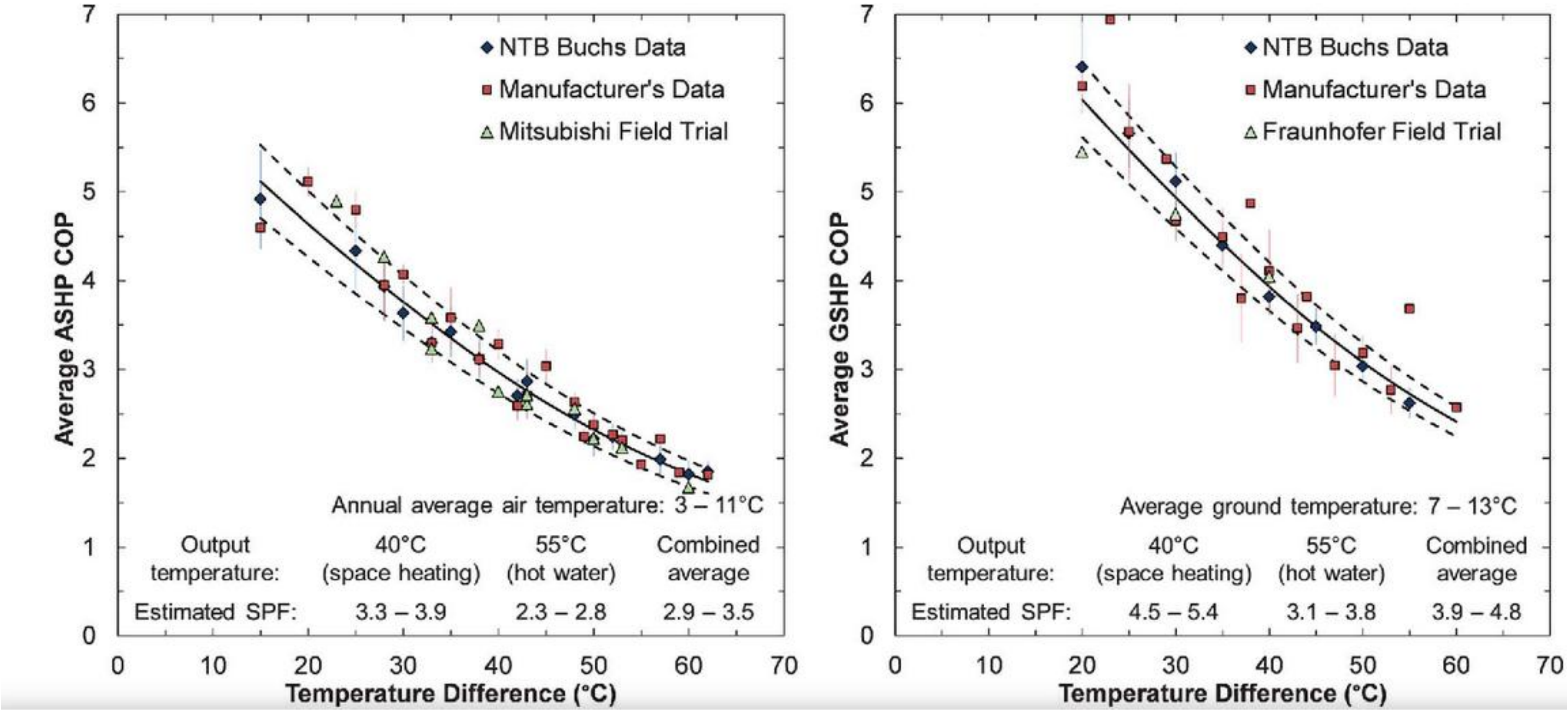
The maximum COP increases as long as the temperature difference between warm heat sink and the cold heat source drops.

$$COP = \frac{T_c}{T_c - T_0}$$



Heat pumps

Performance

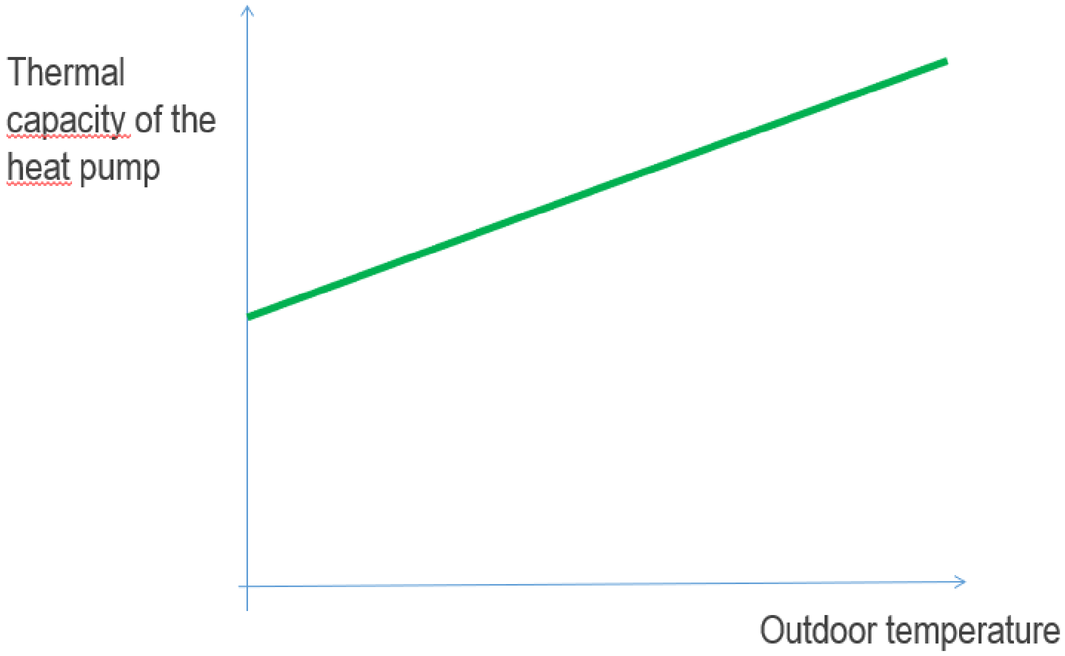


[source: Staffell et al]

Sizing of air-to-water heat pumps

Thermal capacity of a heat pump

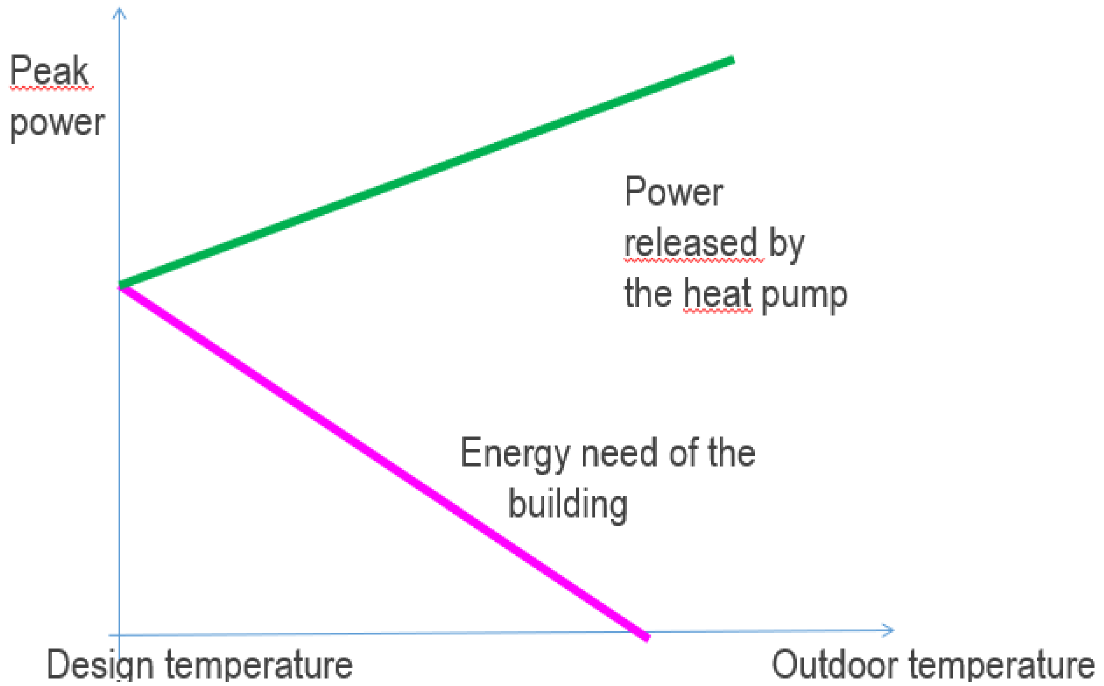
The thermal capacity of a heat pump (i.e. the thermal power supplied from the heat pump condenser to the building) decreases with decreasing external air temperature, whereas the heat load of the building (the required thermal energy to keep indoor thermal comfort) increases.



Sizing of air-to-water heat pumps

Heat pump only

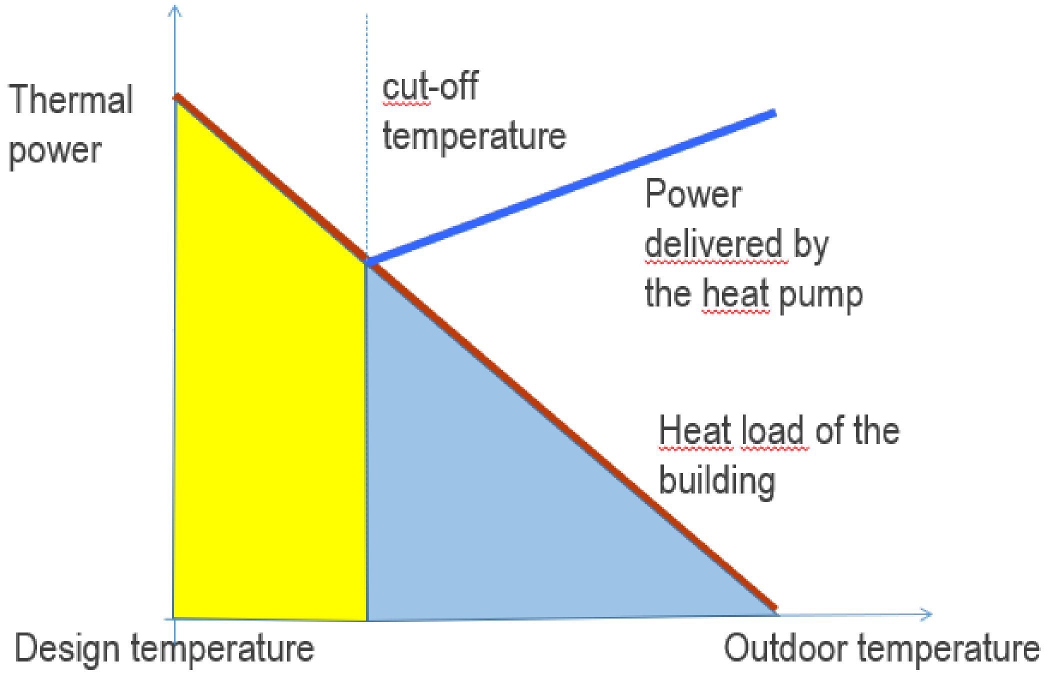
- The heat pump is sized based on the peak load in **outdoor design conditions**.
- This is ok for new or deeply retrofitted buildings, with limited peak load and low supply temperature required by the heating system (radiant systems, fan-coils, active beams).



Sizing of air-to-water heat pumps

Alternate operation with gas boiler

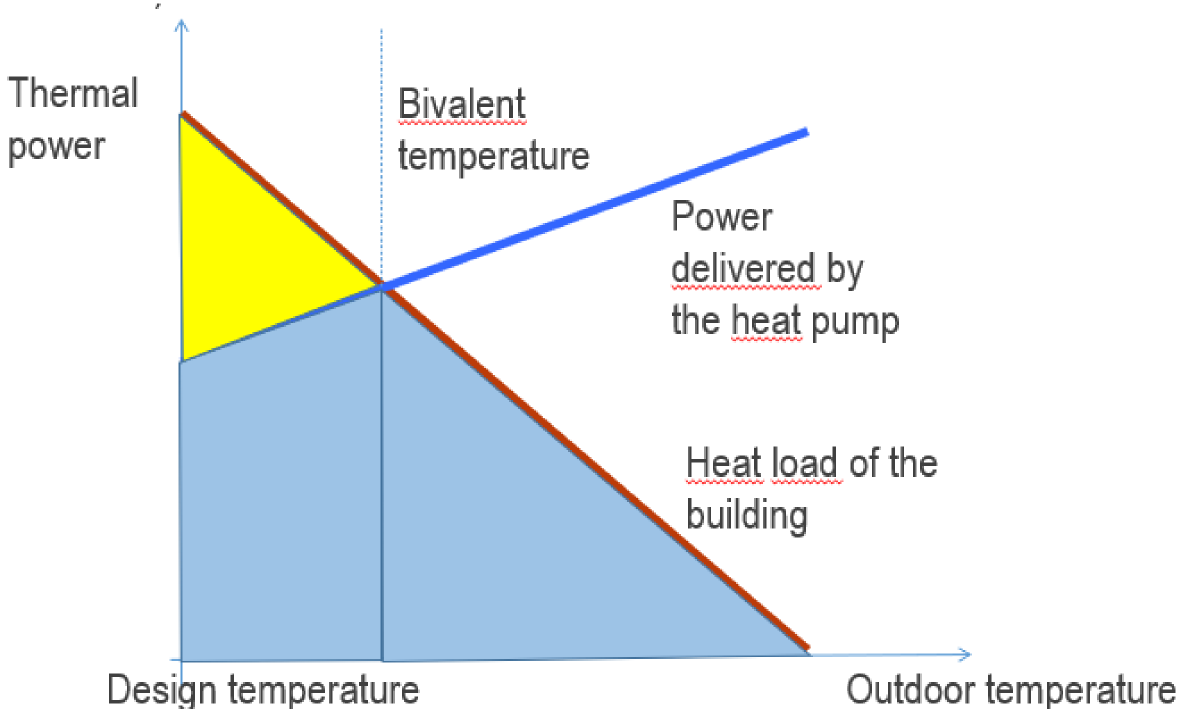
- The heat pump is sized based on the heat load corresponding to the **cut-off temperature**.
- This is ok for buildings with moderate retrofit, with significant peak load and high supply temperature required by the heating system (radiators).
- Below the cut-off temperature the heat pump switches off and the heat load is entirely supplied by the gas boiler.



Sizing of air-to-water heat pumps

Parallel operation with gas boiler

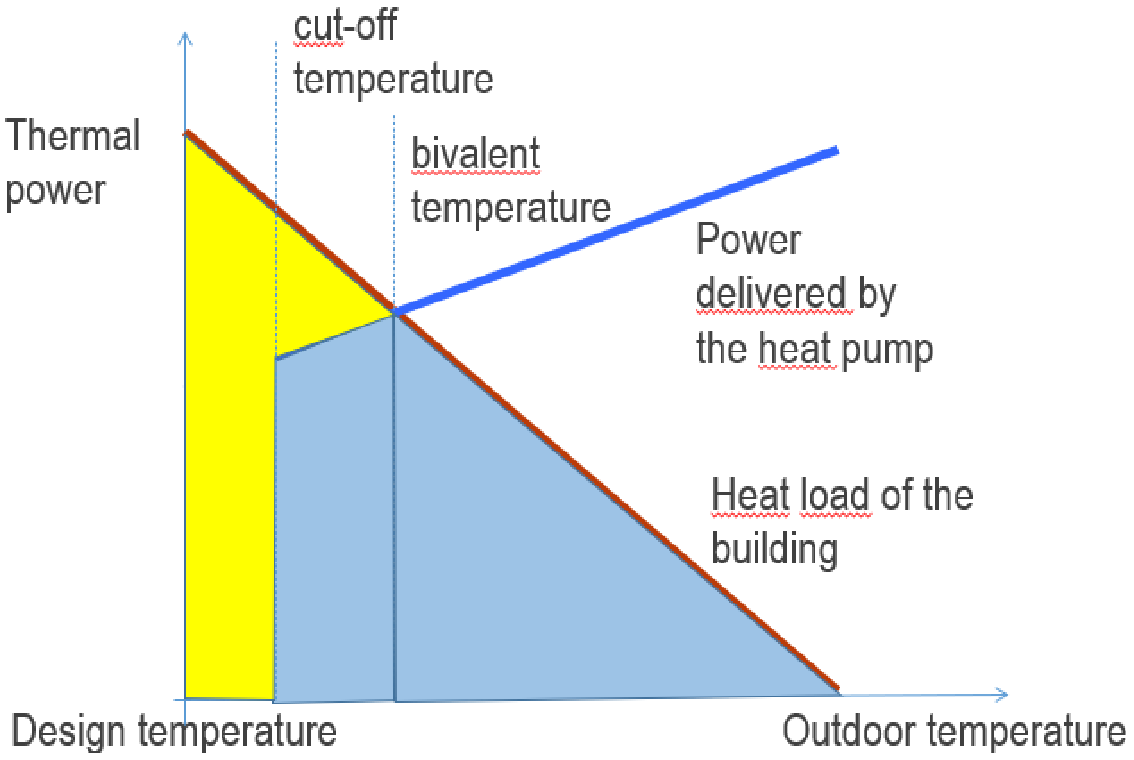
- The heat pump is sized based on the heat load corresponding to the **bivalent temperature**.
- This is ok for buildings with moderate retrofit, with significant peak load and high supply temperature required by the heating system (radiators).
- Below the bivalent temperature the heat pump and the gas boiler work in parallel.



Sizing of air-to-water heat pumps

Partially parallel operation with gas boiler

- The heat pump is sized based on the heat load corresponding to the **bivalent temperature**.
- Below the bivalent temperature the heat pump and the gas boiler work together in parallel operation.
- Below the cut-off temperature the heat pump switches off and the gas boiler works.

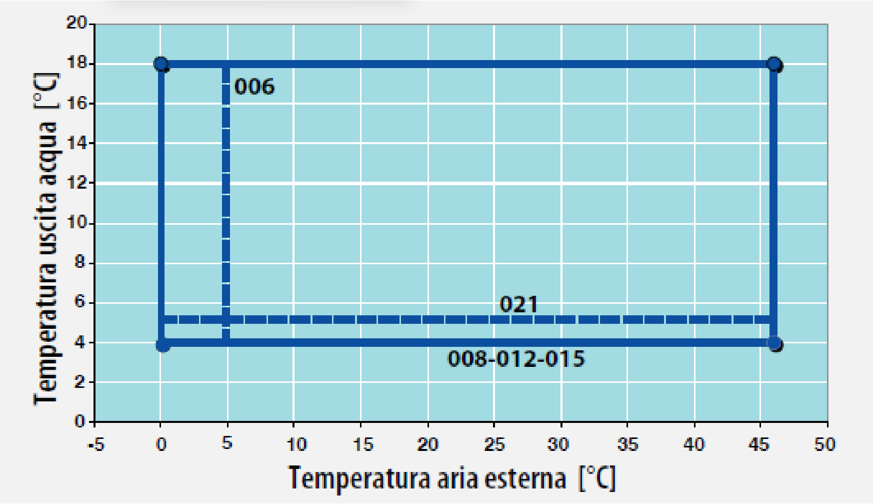


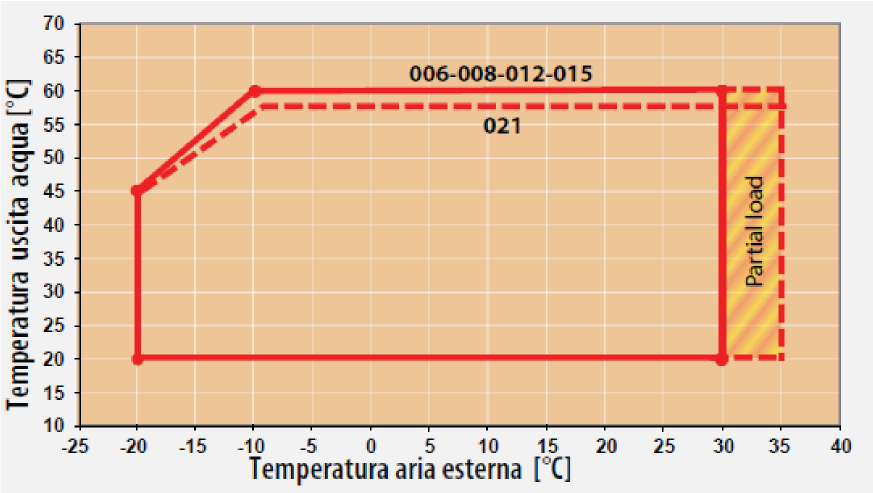
Sizing of air-to-water heat pumps

Operation range

The heat pump model must be suitable for the desired operating conditions, i.e. the design point must be inside the operating range provided by the heat pump manufacturer.

The operating range depends on the interaction between components (mainly the compressor) and the refrigerant.



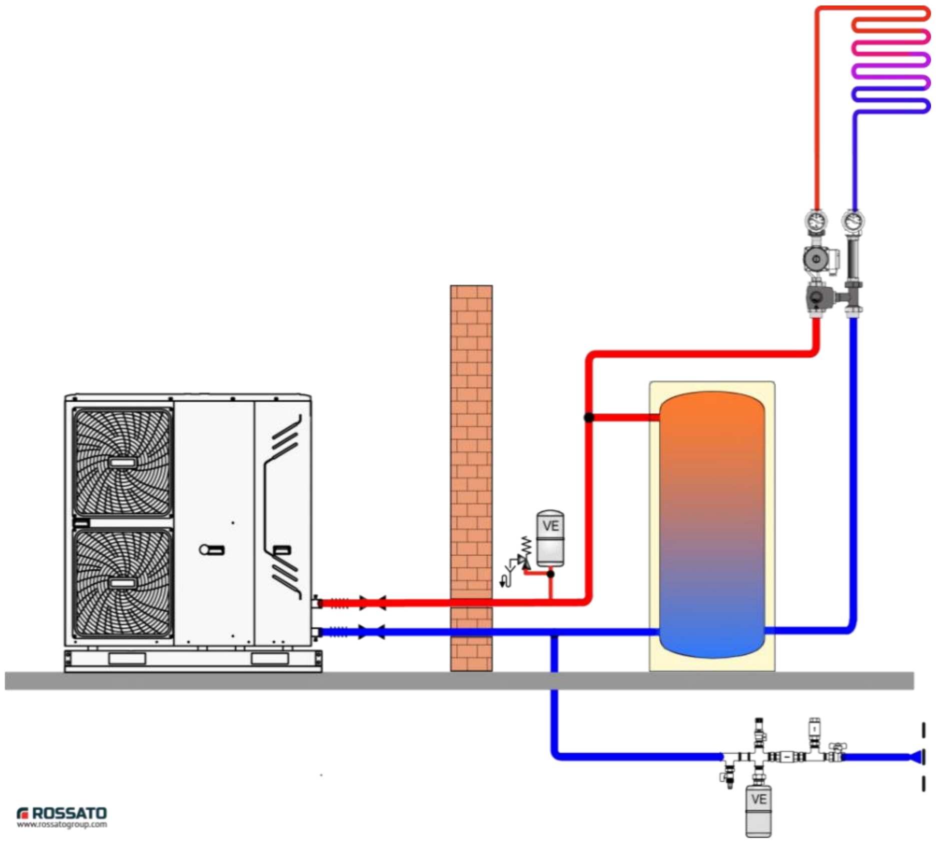


Types of air-to-water heat pumps

Mono-bloc heat pumps

The whole machine is outdoor.

- It is a cheap solution.
- Hydronic system (heat and cold distribution) directly connected to the outdoor machine.
- Antifreeze solution must be designed for the water of the hydronic system.



[source: Rossato]

Types of air-to-water heat pumps

Mono-bloc heat pumps

The whole machine is outdoor.

1. Evaporatore rivestito con alette ondulate per aumentare l'efficienza
2. Ventilatore DC ad alta efficienza
3. Compressore inverter doppio rotore ad alta efficienza
4. Inverter
5. Condensatore

[source: Viessmann]

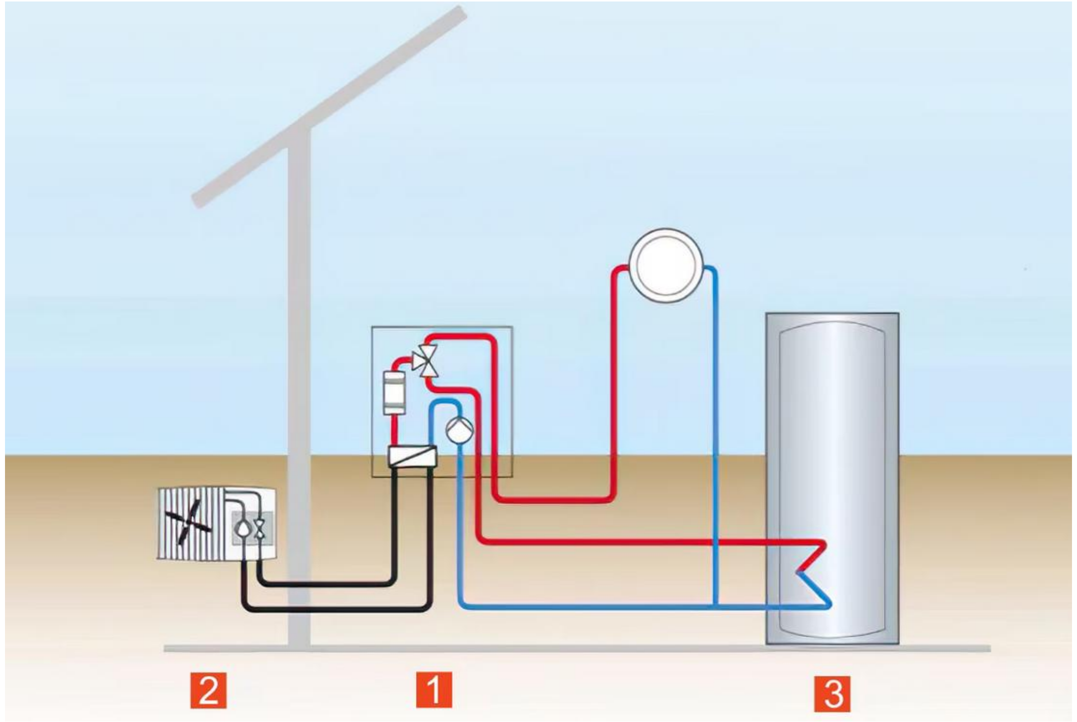
Types of air-to-water heat pumps

Split heat pumps

Split heat pumps are characterised by their separation into a quiet indoor unit and an air handling outdoor unit.

More efficient solution.

Possibile plug&play solutions with integrated hydronic kit.



[source: Viessmann]

Types of air-to-water heat pumps

Split heat pumps

Split heat pumps are characterised by their separation into a quiet indoor unit and an air handling outdoor unit.

More efficient solution.

Possibile plug&play solutions with integrated hydronic kit.

[source: Eneren]

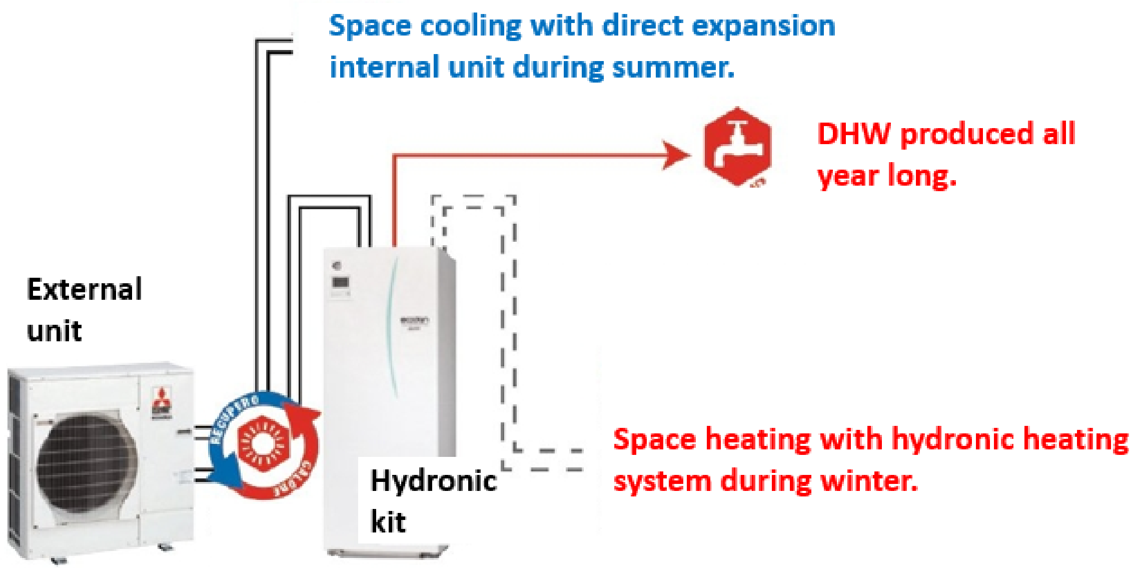
Types of air-to-water heat pumps

Mixed solution

The external unit can provide heating and cooling.

A hydronic kit allows to generate DHW (with a tank) all over the year and warm water for the heating system during winter.

In summer the system works as a direct expansion cooling system, through indoor terminal units.

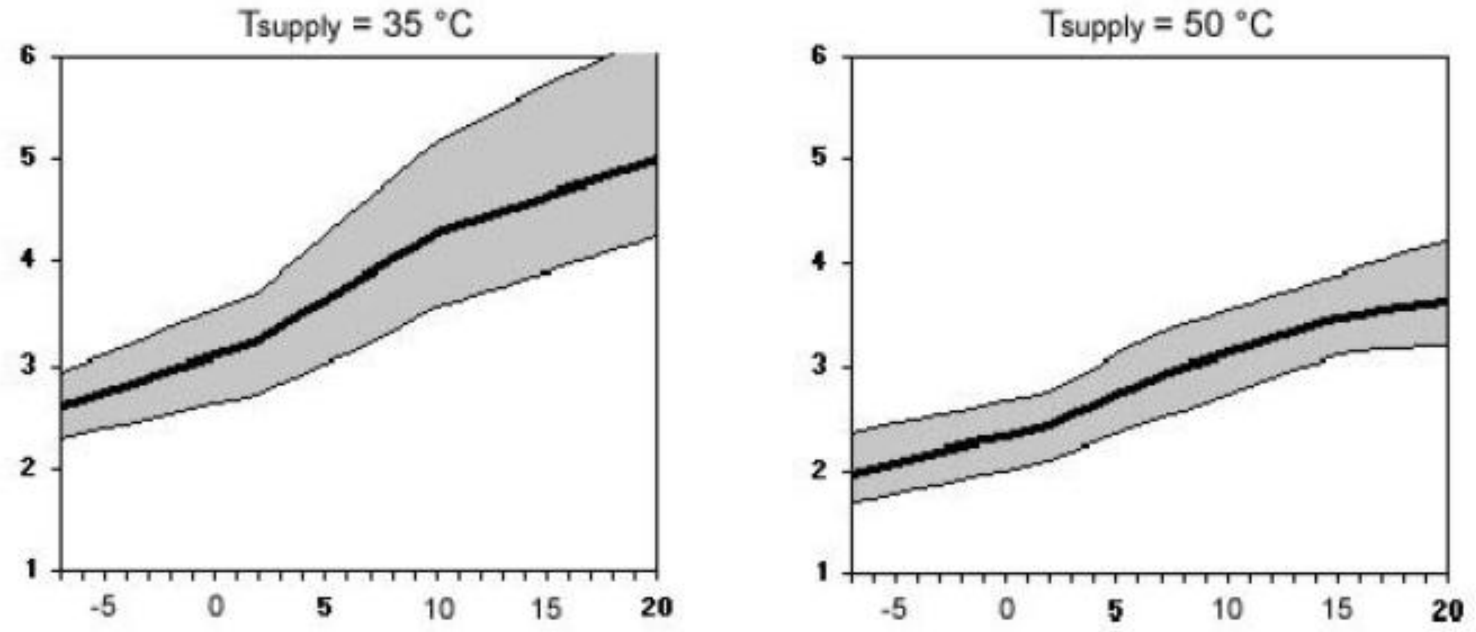


[source: Eneren]

Air-to-water heat pumps

Performance

Not only the capacity but also the efficiency is severely affected by the outdoor temperature.



COP

Outdoor air temperature [°C]

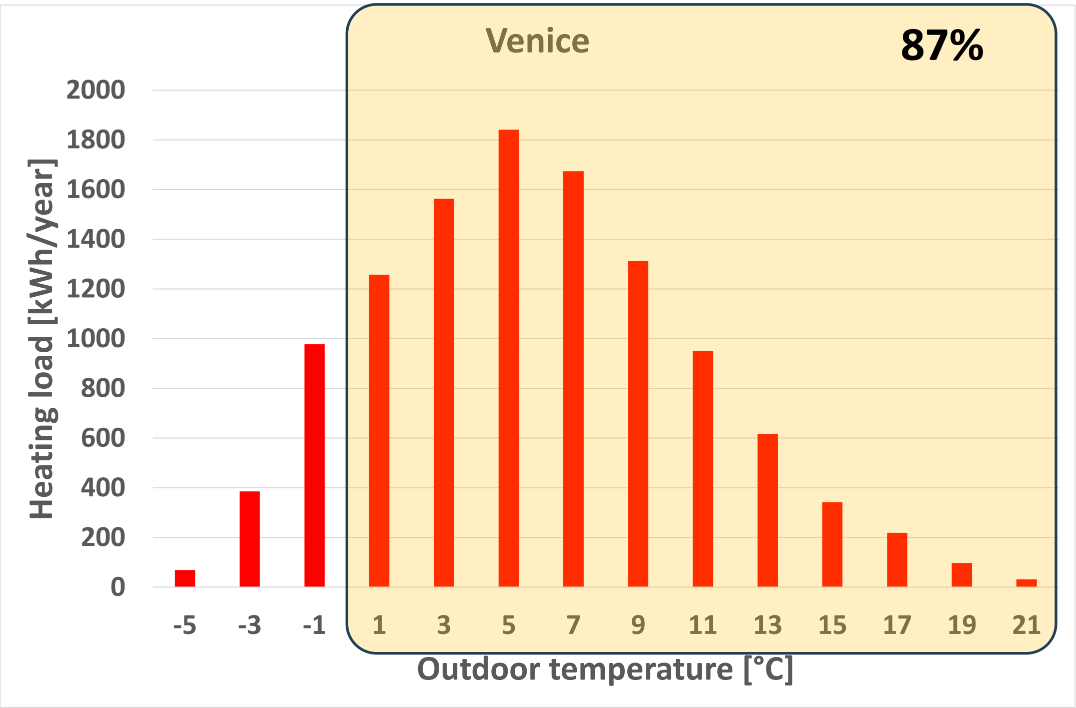
Outdoor air temperature [°C]

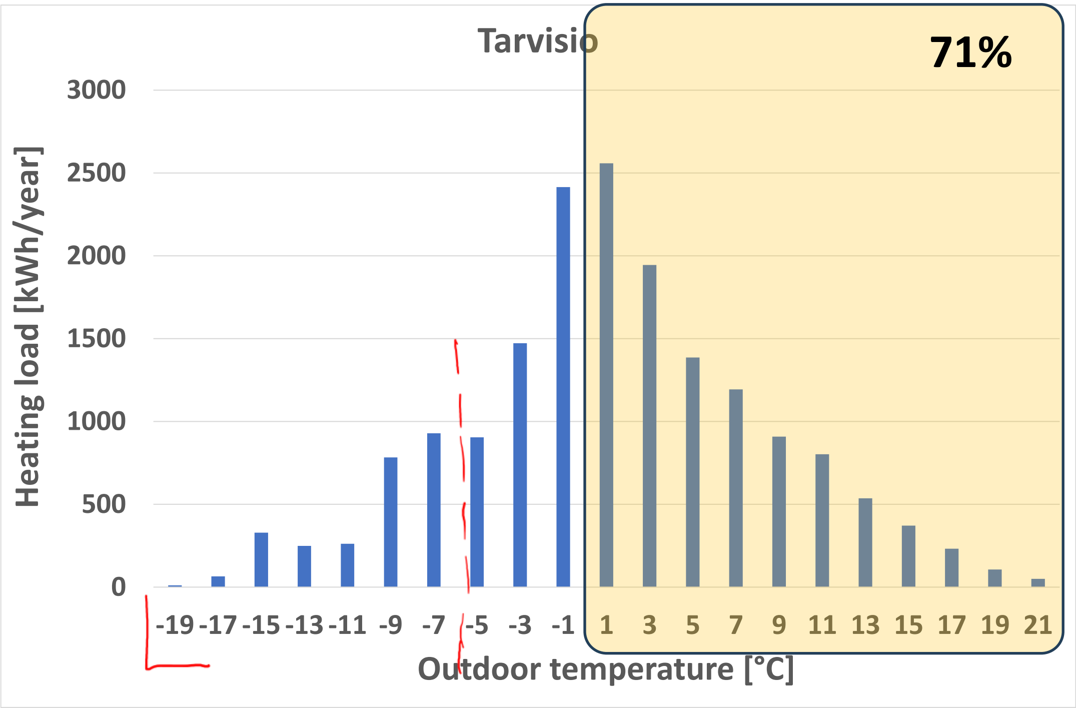
[source: Winthertur Toss]

Air-to-water heat pumps

Performance

Not only the capacity but also the efficiency is severely affected by the outdoor temperature.





Air-to-water heat pumps

Performance

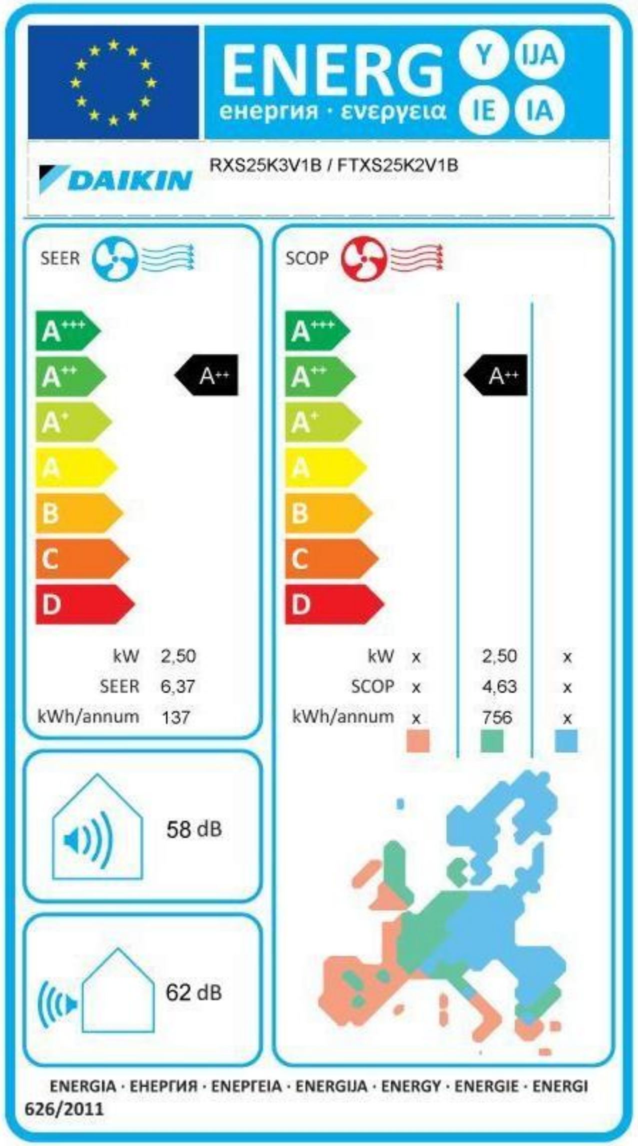
The declared performance by heat pump manufacturers follows reference standards:

- **EN 14825** (product standard): seasonal COP and EER (SCOP and SEER) are defined based on a standardized load profile in 3 different climates in Europe. It is useful to compare different heat pumps. It does not represent the efficiency for the specific building.
- Italian standard **UNI/TS 11300-4** (system standard): it is used to evaluate the seasonal performance of the heat pump of the considered building using a Seasonal Performance Factor (SPF)

Air-to-water heat pumps

Performance

Example of technical datasheet and energy performance label according to EN 14825.



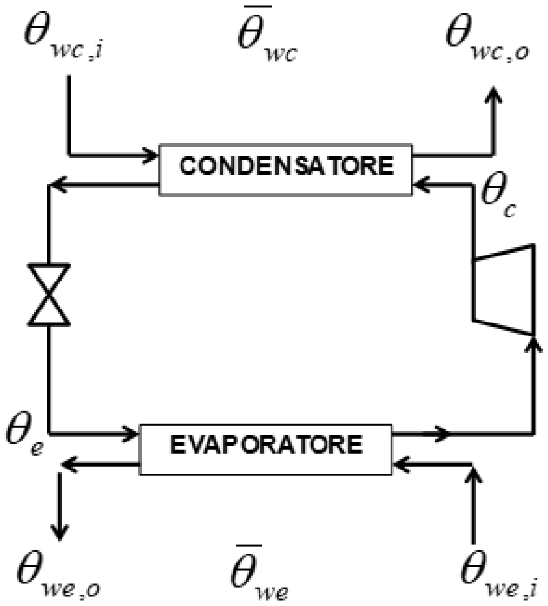
RATED TECHNICAL DATA

MCI			006HM	008HM	012HM	015HO	015HM	021HO
Power supply		V-ph-Hz	230 - 1 - 50	230 - 1 - 50	230 - 1 - 50	400 - 3 - 50	230 - 1 - 50	400 - 3 - 50
Cooling capacity	(1)(E)	kW	4,73	5,84	10,2	13,0	13,0	18,6
Total power input	(1)(E)	kW	1,58	1,96	3,46	4,47	4,42	6,00
EER	(1)(E)		3,00	2,98	2,96	2,91	2,95	3,10
SEER	(2)(E)		4,19	3,85	3,98	4,88	4,30	4,51
Water flow	(1)	l/h	810	992	1750	2237	2237	3201
Available pressure head - LP pumps	(1)(E)	kPa	65	66	76	66	66	74
Heating capacity	(3)(E)	kW	5,76	7,36	12,9	14,5	14,0	20,0
Total power input	(3)(E)	kW	1,89	2,31	4,26	4,39	4,32	6,06
COP	(3)(E)		3,05	3,19	3,03	3,30	3,23	3,30
SCOP	(2)(E)		3,37	2,84	2,95	3,33	3,25	2,90
Heating energy efficiency class	(4)		A++	A+	A+	A++	A++	A+
Water flow	(3)	l/h	996	1281	2238	2439	2439	3470
Available pressure head - LP pumps	(3)(E)	kPa	60	55	72	58	60	74
Cooling capacity	(5)(E)	kW	7,04	7,84	13,5	16,0	16,0	25,8
Total power input	(5)(E)	kW	1,90	1,96	3,70	4,20	4,17	6,79
EER	(5)(E)		3,70	3,99	3,66	3,81	3,85	3,80
Heating capacity	(6)(E)	kW	5,76	7,16	11,9	15,0	14,5	21,1
Total power input	(6)(E)	kW	1,35	1,80	3,00	3,57	3,54	5,15
COP	(6)(E)		4,28	3,97	3,95	4,20	4,09	4,10
Maximum current absorption		A	11,0	15,0	21,0	11,0	23,0	16,0
Compressors / circuits			1 / 1					
Expansion vessel volume		dm^3	2	2	3	3	3	8
Sound power level	(7)(E)	dB(A)	64	65	68	69	69	74
Transport weight - unit with pump		kg	61	69	104	116	112	199
Operating weight - unit with pump		kg	61	69	104	116	112	199

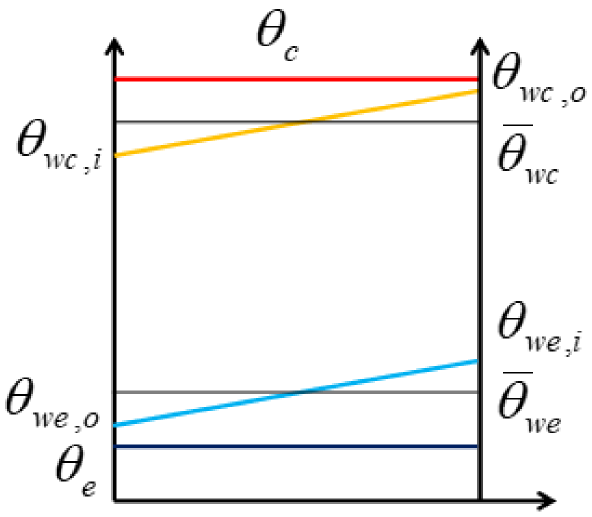
Air-to-water heat pumps

Performance

Carnot efficiency can be used as a simple method to obtain COP in different operating conditions from those declared by the manufacturer.



$$\theta_c = \bar{\theta}_{wc} + \Delta\theta_c$$



$$\theta_e = \bar{\theta}_{we} - \Delta\theta_e$$

Condensing heat released to water fluid

$\Delta\theta_c$ = + 5°C related to the average water temperature

Evaporation absorbing heat from the water

$\Delta\theta_e$ = - 5°C related to the average water temperature

Condensing heat released to the air (fin coil)

$\Delta\theta_c$ = + 15°C related to the outdoor air temperature

Evaporation absorbing heat from the air (fin coil)

$\Delta\theta_e$ = - 10°C related to the outdoor air temperature

Air-to-water heat pumps

Performance

Carnot efficiency can be used as a simple method to obtain COP in different operating conditions from those declared by the manufacturer.

Example

Declared value of the COP: 4

t outdoor air= 7°C

t water supply = 35°C

Let's suppose that the water based heating system works between 42°C (supply water temperature) and 38°C (return water temperature). Hence the average water temperature is 40°C. Outdoor air temperature is 3°C.

The operating conditions for the declared COP are:

t ev. = 7°C – 10°C = -3°C = 270 K

t cond. = 35°C + 5°C = 40°C = 313 K

$$COP_{nominal}^{*} = \frac{313}{313 - 270} = 7,3$$

Actual conditions:

t ev. = 3°C – 10°C = - 7°C = 266 K

t cond. = 40°C + 5°C = 45°C = 318 K

$$COP_{actual}^{*} = \frac{318}{318 - 266} = 6,1$$

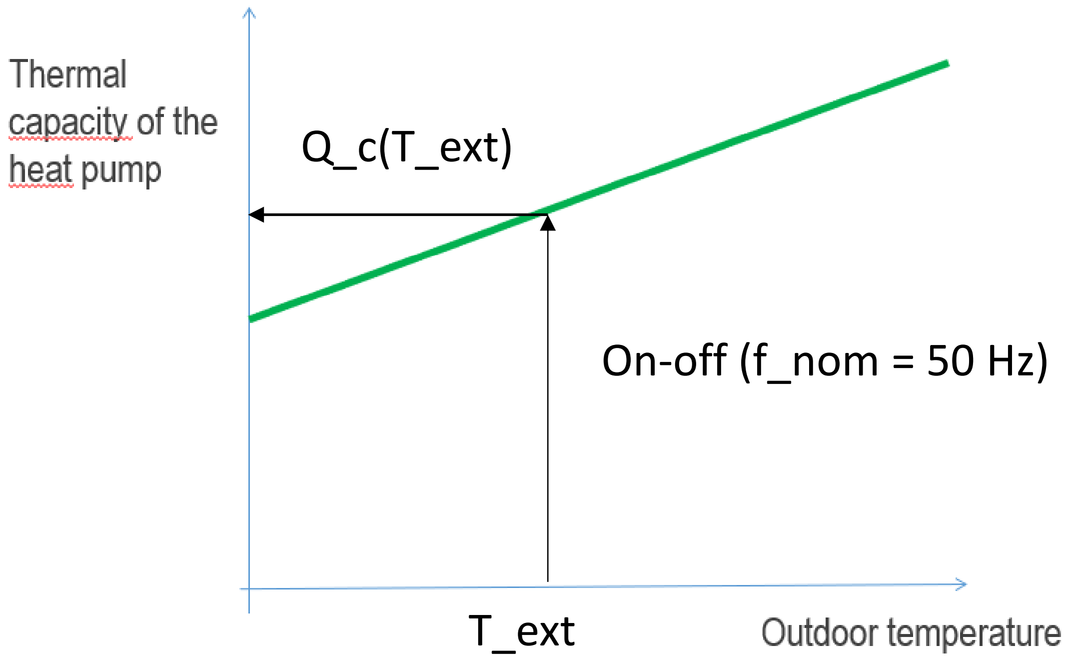
$$COP_{actual} = \frac{COP_{nominal} \cdot COP_{actual}^{*}}{COP_{nominal}^{*}}$$

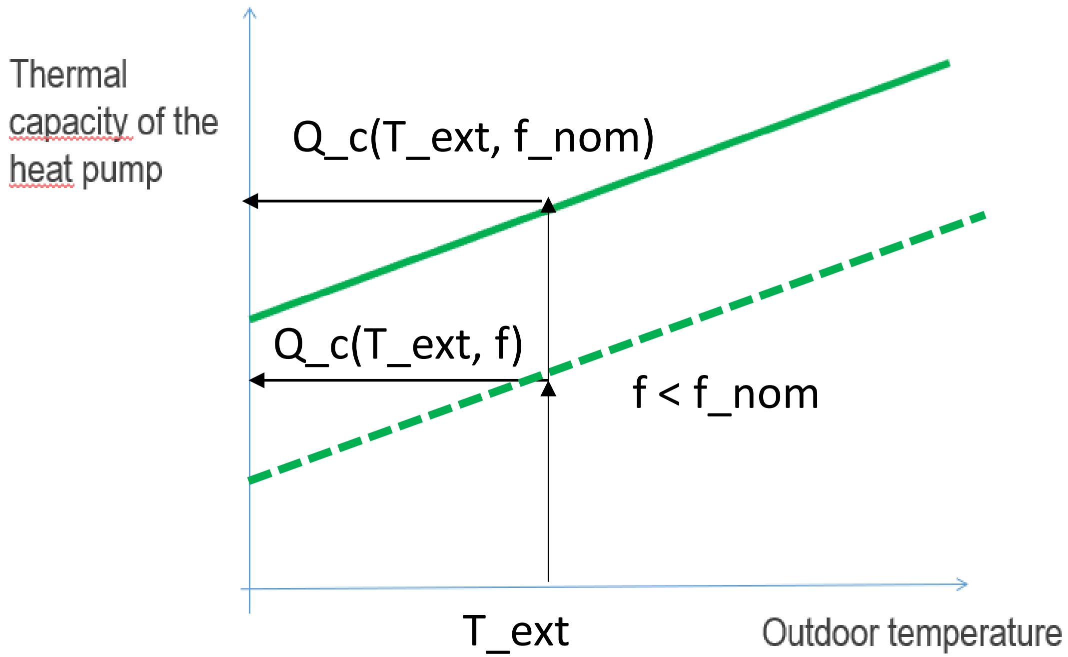
$$= \frac{4 \cdot 6,1}{7,3} = 3,4$$

Air-to-water heat pumps

Performance

Inverter-driven vs on-off heat pumps.

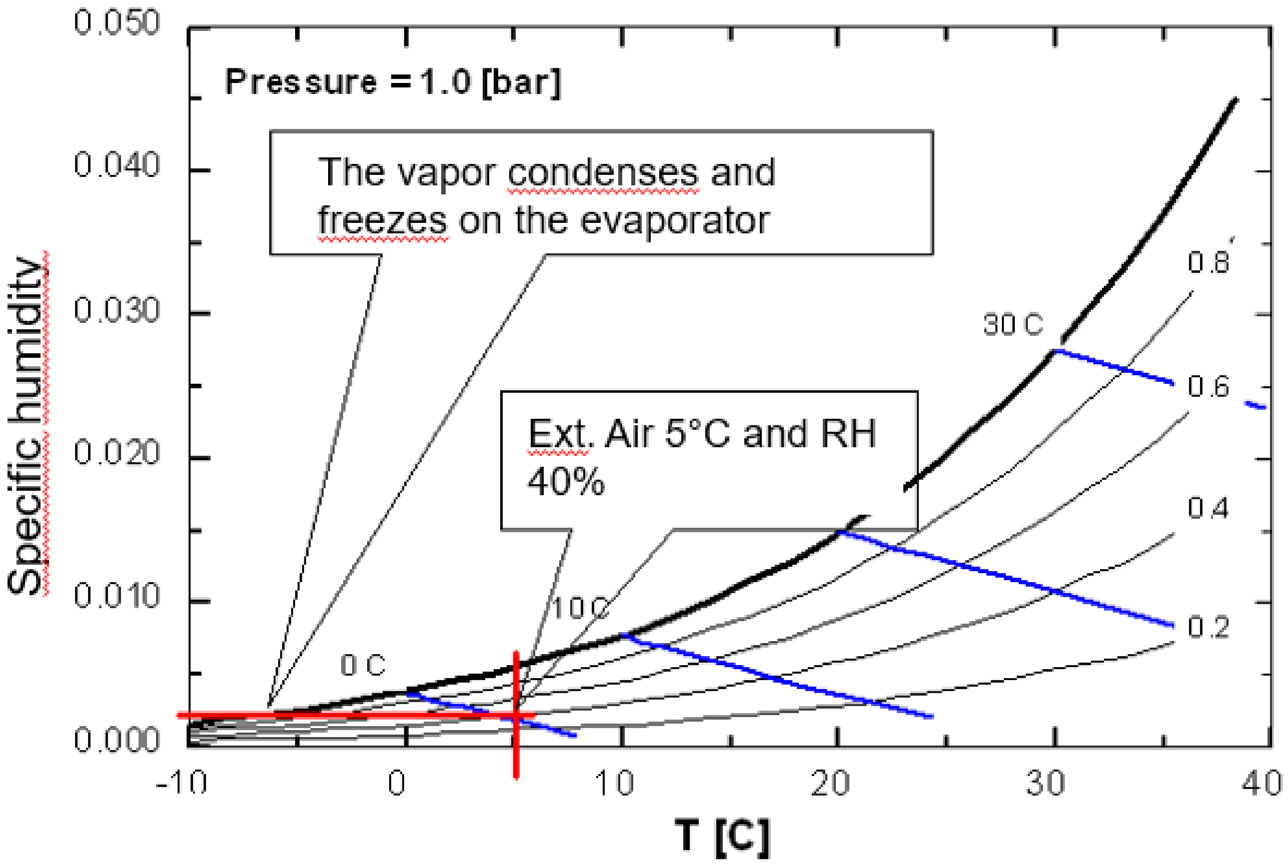




Air-to-water heat pumps

Performance

- When outside air is cooled at the evaporator, water vapor condenses and there may be frost formation.
- If allowed to accumulate, frost inhibits heat transfer; therefore, the outdoor coil must be defrosted periodically.



Air-to-water heat pumps

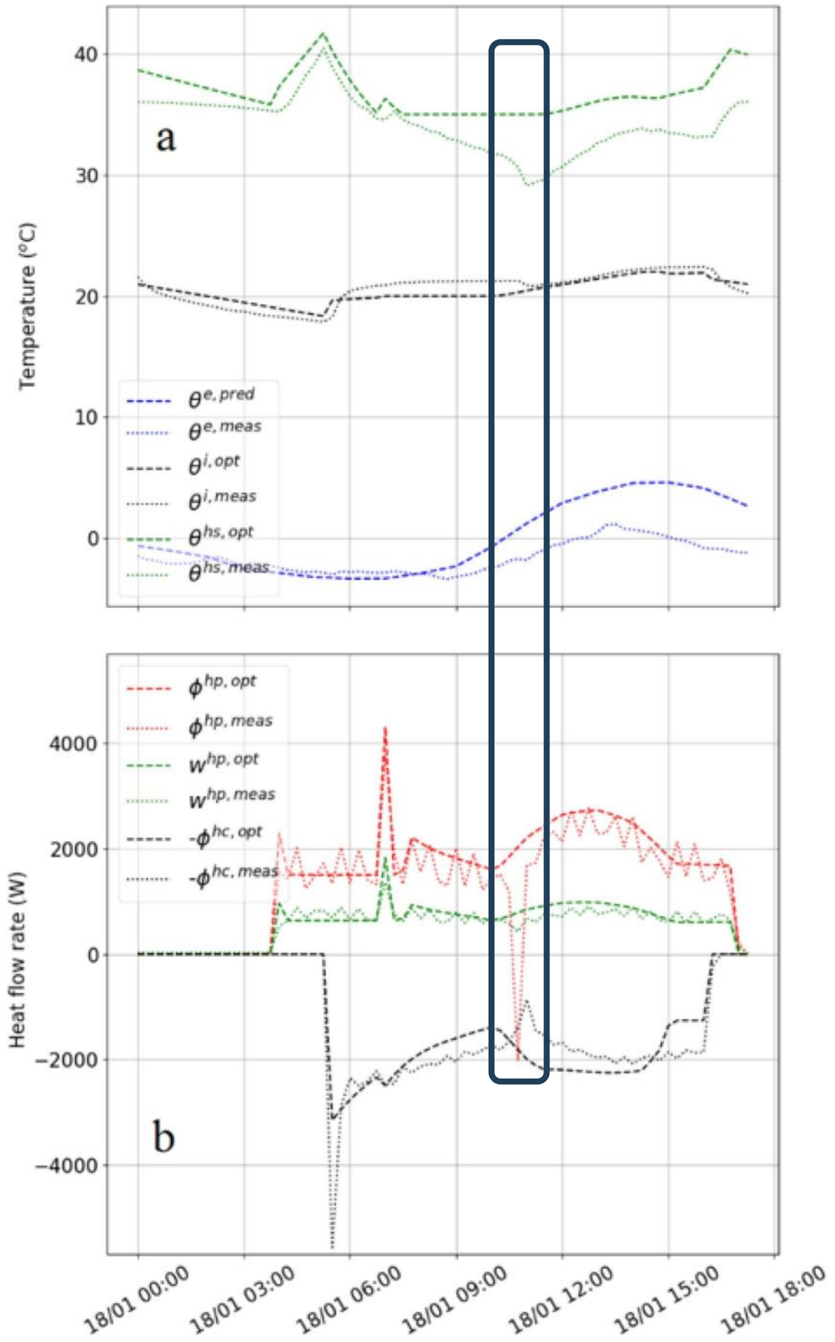
Performance

- When outside air is cooled at the evaporator, water vapor condenses and there may be frost formation.
- If allowed to accumulate, frost inhibits heat transfer; therefore, the outdoor coil must be defrosted periodically.

Air-to-water heat pumps

Performance

- Most systems defrost by reversing the cycle.
- Another method of defrosting is spraying heated water over an outdoor coil. The water can be heated by the refrigerant or by auxiliaries.



References

- ASHRAE Handbook – 2020 HVAC Systems and Equipment (SI Edition)
- Staffel et al, A review of domestic heat pumps.