
HEAT PUMP TRAINING PROGRAM

From basic physics to troubleshooting a running plant. Ten vendor-neutral courses with worked examples, P&IDs, quizzes and glossaries, written for Indian conditions.

10

courses

95

lessons

104

diagrams & P&IDs

3

levels

LEVEL 1

Foundations

LEVEL 2

Application & design

LEVEL 3

Field practice

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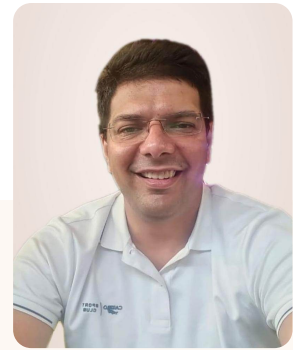
An open knowledge-sharing program

sunnivaencon.com

ABOUT THE AUTHOR

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It started as an instinct. In 2012 I wanted to do something in energy conservation. That was the whole of it. There was no plan to build machines, and no plan to build them in India. Both came later.

Kashyap founded Sunniva Encon in 2012 to work on energy conservation. The company now designs and builds heat pumps at its own factory in Asangaon, Maharashtra, with its office in Mumbai, and supplies hot water, space heating and process heat systems across India, including remote, high-altitude sites.

Over these years he has seen heat pumps chosen, sized, installed and serviced in every kind of Indian condition, and seen how often good machines are let down by poor selection, rushed installation or missing maintenance. Most of those problems come from knowledge that is not widely taught.

This program is his answer: an open, vendor-neutral course that shares that knowledge with students, technicians, installers, consultants and facility teams. It teaches the technology, not a brand. The lessons carry no product names or sales claims; Sunniva's part is only to make the material available.

- Founder Director, Sunniva Encon LLP, since 2012
- More than 5,000 heat pump installations across India
- Own heat pump factory in Asangaon, Maharashtra, built for 2,000 machines a year
- Nationwide service network reaching sites as remote as Leh

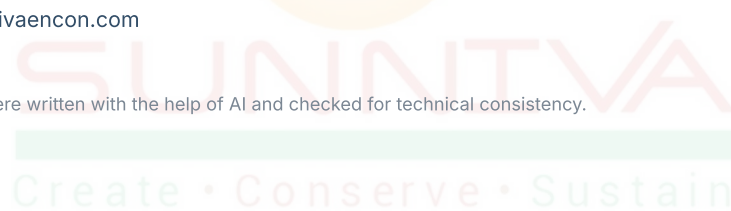
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Course 1 — Heat, Energy and Refrigeration Basics

Powered by Sunniva. This is a Level 1 Foundations course for everyone: students, new technicians, plumbers and facility staff. No prior engineering study is needed. After this course you will be able to: (1) explain the difference between heat and temperature and convert between kW, kcal/h, TR and BTU/h; (2) calculate the heat needed to warm water or change its phase; (3) read a refrigerant pressure and know its saturation temperature; (4) explain why a heat pump delivers more heat than the electricity it uses.

1.1 Heat vs temperature: what we are really moving

Key idea: Temperature tells us how hot something is; heat is the energy that flows because of a temperature difference.

Temperature is a measure of how fast the molecules in a substance are moving. We measure it in degrees Celsius (°C) or kelvin (K). A thermometer reads temperature, not heat.

Heat is energy in transit. It always flows from a hotter body to a colder body, on its own. We measure heat in joules (J), kilojoules (kJ) or kilowatt-hours (kWh).

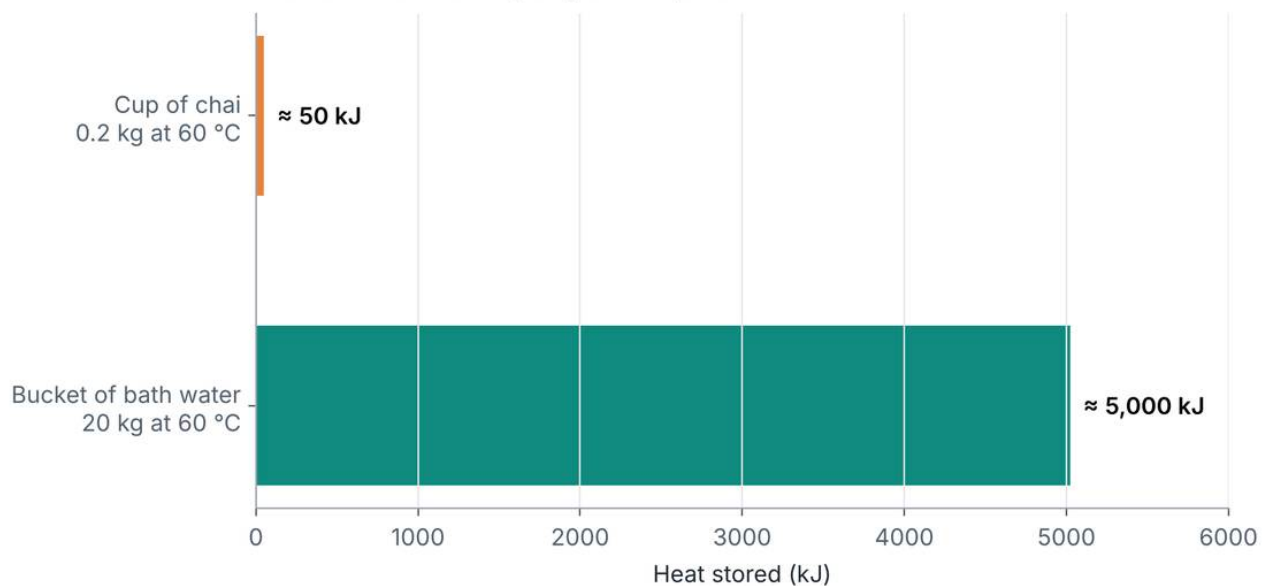
Think of a cup of chai and a full bucket of bath water, both at 60 °C. They have the same temperature. But the bucket holds far more heat, because it has far more water.

A heat pump does not "make" heat. It moves heat from a cooler place, like outdoor air, into a warmer place, like a hot water tank. That is why we always ask: how much heat, at what temperature?

The kelvin scale starts at absolute zero, the coldest possible temperature. 0 K = -273.15 °C. A temperature *difference* of 1 K is the same size as 1 °C.

Same temperature, very different amounts of heat

Heat stored relative to 0 °C, using $Q = m \times c_p \times \Delta T$. A thermometer reads 60 °C in both. The bucket holds 100 times more heat.



Same temperature, very different amounts of heat

Quantity	What it tells you	Unit (SI)	Measured with
Temperature	How hot or cold	°C or K	Thermometer, sensor
Heat (energy)	How much energy moved	kJ, kWh	Calculated or heat meter
Heat rate (power)	How fast energy moves	kW	Calculated or heat meter

Worked example — heat stored in a bucket vs a cup

$$Q = m \times c_p \times \Delta T$$

- Water specific heat, $c_p = 4.186 \text{ kJ/kg}\cdot\text{K}$ (typical value near room temperature).
- Cup: $Q = 0.2 \times 4.186 \times (60 - 0) = 50.2 \text{ kJ}$.
- Bucket: $Q = 20 \times 4.186 \times (60 - 0) = 5,023 \text{ kJ}$.
- Same temperature, but the bucket holds 100 times more heat.

Remember

- Temperature is a level; heat is a quantity of energy.
- Heat flows naturally from hot to cold only.
- A temperature difference of 1 K equals a difference of 1 °C.
- A heat pump moves heat; it does not create it.

Common mistake: Saying "this geyser has more temperature". Say it has a higher temperature, or more heat stored.



1.2 Units that matter: kW, kcal/h, TR, BTU/h and converting between them

Key idea: All heating and cooling capacities are rates of energy flow, and they convert to kW with a few fixed numbers.

Capacity means how much heat a machine moves per unit time. The SI unit is the kilowatt (kW). One kW means one kilojoule every second.

In India you will still meet older units on nameplates and quotations. Cooling is often quoted in tons of refrigeration (TR). Boilers are often quoted in kcal/h. Imported equipment may use BTU/h (British thermal units per hour).

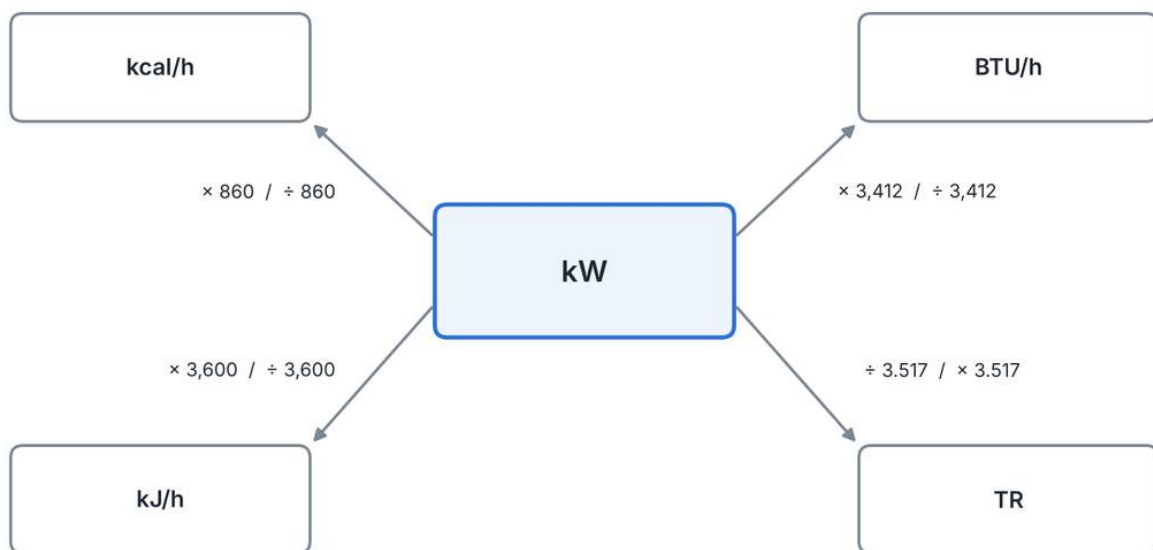
One TR is the heat needed to melt one short ton of ice in 24 hours. It is a cooling rate, not a weight. A "1.5 ton AC" removes about 5.3 kW of heat.

Energy (kWh) and power (kW) are different. Power is the rate. Energy is power multiplied by time. A 2 kW heater running 3 hours uses 6 kWh.

From	To kW multiply by	Notes
1 kcal/h	0.001163	1 kW = 860 kcal/h
1 TR	3.517	1 TR = 12,000 BTU/h = 3,024 kcal/h
1 BTU/h	0.000293	1 kW = 3,412 BTU/h
1 HP (motor power)	0.746	Mechanical/electrical power, not heat capacity

Convert any capacity unit through kW

Multiply going out from kW, divide coming back



Examples: 10 kW = 8,600 kcal/h = 34,120 BTU/h = 2.84 TR. A 1.5 TR AC moves about 5.3 kW.

Convert any capacity unit through kW

Worked example — compare a boiler and a heat pump quote

A hotel in Pune has an old boiler rated 1,00,000 kcal/h. A new quote gives a heat pump in kW. What kW matches?

$$P_{kW} = \frac{P_{kcal/h}}{860}$$

- $P = 1,00,000 \div 860 = 116.3$ kW.
- In TR terms: $116.3 \div 3.517 = 33.1$ TR.
- In BTU/h: $116.3 \times 3,412 = 3,96,800$ BTU/h (about 4 lakh BTU/h).

Remember

- Convert everything to kW first, then compare.
- 1 TR = 3.517 kW; 1 kW = 860 kcal/h; 1 kW = 3,412 BTU/h.
- kW is a rate (power); kWh is an amount (energy).
- HP on a compressor is motor power, not heating capacity.

Field tip: When a customer says "2 ton", ask whether that is cooling capacity or compressor motor HP. They are not the same.



1.3 Sensible and latent heat

Key idea: Sensible heat changes temperature; latent heat changes phase (solid, liquid, gas) without changing temperature.

When you heat water on a stove from 25 °C to 100 °C, the thermometer rises. That heat is called sensible heat, because you can "sense" it on a thermometer.

Once water reaches 100 °C at sea level, it starts boiling. The flame keeps adding heat, but the temperature stays at 100 °C until all the water turns to steam. That hidden heat is called latent heat.

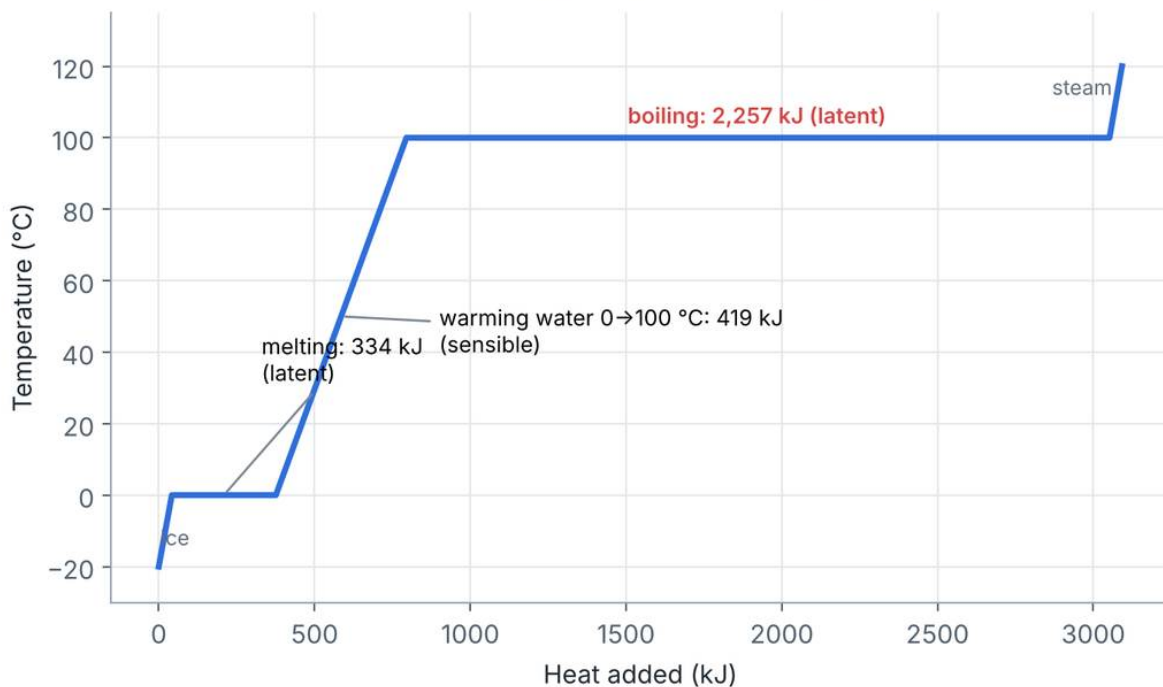
Latent heat is large. Turning 1 kg of boiling water into steam needs about 2,257 kJ. Warming the same kg from 0 °C to 100 °C needs only about 419 kJ.

A clay matka cools water using latent heat. A little water seeps through the clay and evaporates. Evaporation takes latent heat from the remaining water, so it gets cooler.

Refrigeration and heat pumps depend on latent heat. The refrigerant absorbs a lot of heat when it evaporates and gives it back when it condenses.

Heating curve of 1 kg of water at sea level

Sloped parts = sensible heat (temperature rises). Flat parts = latent heat (phase changes, temperature stays).



Heating curve of 1 kg of water

Property of water (typical, 1 atm)	Value
Specific heat of liquid water	4.186 kJ/kg·K
Specific heat of ice	about 2.1 kJ/kg·K
Latent heat of fusion (melting ice)	about 334 kJ/kg
Latent heat of vaporisation at 100 °C	about 2,257 kJ/kg

Worked example — warming a 100 L geyser in Bengaluru

Cold water comes in at 25 °C. We want 60 °C. 100 L of water is about 100 kg.

$$Q = m \times c_p \times \Delta T$$

- $Q = 100 \times 4.186 \times (60 - 25) = 14,651 \text{ kJ}.$

- Convert to kWh: $14,651 \div 3,600 = 4.07$ kWh.
- With an electric element (close to 100% efficient) at an example rate of ₹9/kWh: $4.07 \times 9 =$ about ₹37.
- If that same 100 kg were boiled to steam, it would need another $100 \times 2,257 = 2,25,700$ kJ (62.7 kWh). Latent heat is big.

Remember

- Sensible heat shows on a thermometer; latent heat does not.
- $Q = m \times c_p \times \Delta T$ for sensible heat; $Q = m \times h_{fg}$ for latent heat.
- Evaporation absorbs heat; condensation releases it.
- Refrigerants carry heat mainly as latent heat.

Field tip: 1 kWh warms about 860 L of water by 1 K. That is a handy check on any hot water calculation.



1.4 Conduction, convection and radiation

Key idea: Heat travels in three ways: through solids by conduction, with moving fluids by convection, and as infrared waves by radiation.

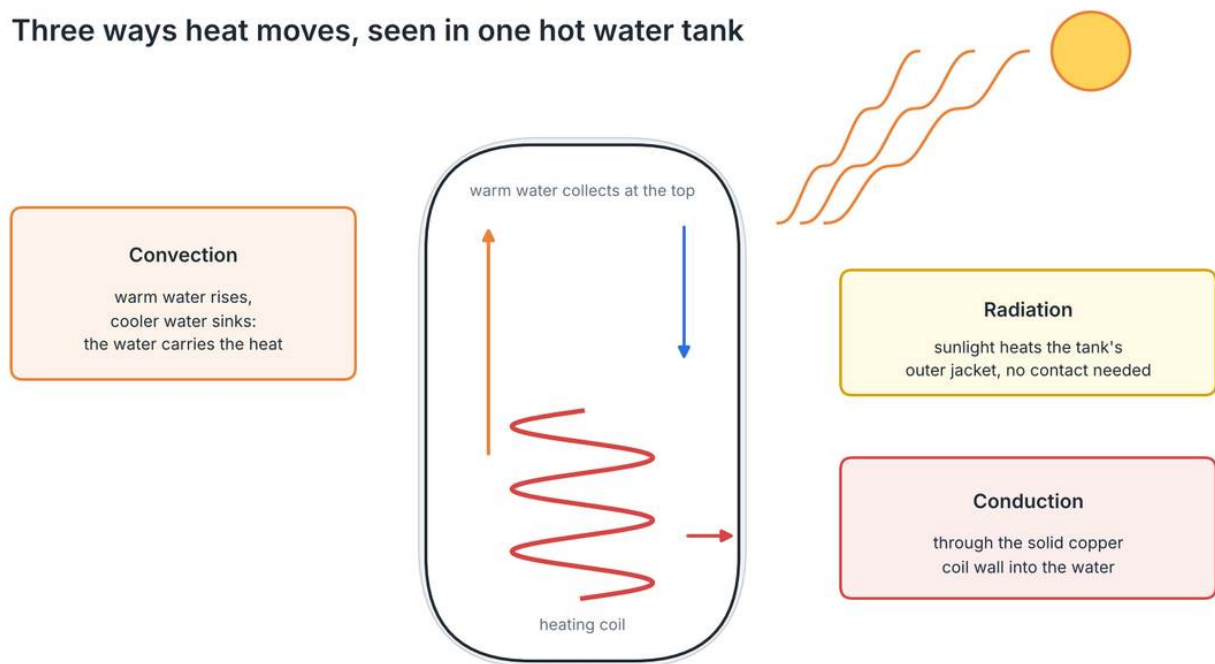
Conduction is heat passing through a material, molecule to molecule. A steel spoon in hot chai gets hot at the handle. Copper and aluminium conduct well, which is why heat exchangers use them.

Convection is heat carried by a moving fluid, such as air or water. Natural convection happens on its own: hot water rises in a geyser tank. Forced convection uses a fan or pump, like the fan on an outdoor unit.

Radiation is heat travelling as infrared waves. It needs no medium. You feel it from the sun on a terrace, or from a hot tandoor wall.

Insulation works by slowing conduction. Materials like PUF (polyurethane foam) and nitrile rubber trap tiny pockets of still gas. Still air and gas conduct heat poorly.

Three ways heat moves, seen in one hot water tank



Conduction, convection and radiation in a hot water tank

Material	Thermal conductivity, W/m·K (typical)	Use
Copper	about 390	Tubes, heat exchangers
Aluminium	about 200	Fins
Carbon steel	about 50	Tanks, pipes
Stainless steel	about 15	Tanks, plate heat exchangers
Water	about 0.6	Heat transfer fluid
Still air	about 0.026	Trapped in insulation
PUF insulation	about 0.022–0.030	Tank and pipe insulation

Worked example — heat loss through a pipe wall vs insulation (conduction)

Compare 1 m² of 2 mm steel with 1 m² of 25 mm PUF, each with a 40 K temperature difference.

$$Q = \frac{k \times A \times \Delta T}{t}$$

- Steel: $Q = (50 \times 1 \times 40) \div 0.002 = 10,00,000 \text{ W}$. In practice, the air film outside limits this, but steel offers almost no resistance.
- PUF: $Q = (0.025 \times 1 \times 40) \div 0.025 = 40 \text{ W}$.
- The insulation cuts conduction by a factor of tens of thousands. This is why uninsulated hot pipes waste so much energy.

Remember

- Conduction: through solids. Convection: by moving fluid. Radiation: by infrared waves.
- Good conductors (copper, aluminium) go where we want heat to pass.
- Insulation works by trapping still gas.
- Fans and pumps turn natural convection into faster forced convection.

Common mistake: Leaving pipe joints, valves and pump bodies uninsulated. Small bare areas lose a surprising share of heat.



1.5 The laws of thermodynamics in plain words

Key idea: Energy is never created or destroyed, and heat only flows from cold to hot if we spend work to push it.

Thermodynamics is the science of heat, work and energy. Four laws are usually listed, numbered zero to three. For heat pump work, the first two matter most.

Zeroth law. If two bodies are each at the same temperature as a third, they are at the same temperature as each other. This is why thermometers work.

First law (conservation of energy). Energy can change form but cannot be created or destroyed. In a heat pump: heat delivered = heat taken from the source + electrical work put in.

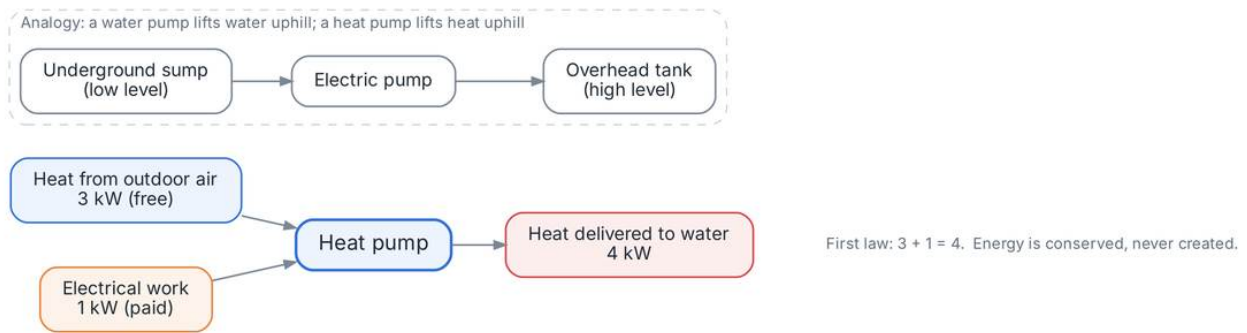
Second law. Heat flows naturally from hot to cold. To move heat from cold to hot, you must supply work. A fridge needs electricity to push heat out of the cold cabinet into the warmer kitchen.

The second law also sets a ceiling. No real machine can beat the ideal Carnot cycle, a theoretical perfect cycle. Real machines reach only part of that limit.

Third law. As a substance approaches absolute zero (0 K), its disorder approaches a minimum. It rarely matters in field work.

Think of a water pump lifting water from a sump to an overhead tank. Water flows down by itself. Lifting it up needs a pump and electricity. A heat pump "lifts" heat in the same way.

Energy balance of a heat pump



Energy balance of a heat pump

Law	Plain words	What it means for a heat pump
Zeroth	Equal temperatures are in balance	Sensors and thermometers can be trusted
First	Energy is conserved	Heat out = heat in + work in
Second	Heat flows hot to cold unless work is added	Compressor work is needed; there is a maximum COP
Third	Absolute zero is a limit	Temperatures in K are always positive

Worked example — ideal (Carnot) heating COP for a Chennai hot water job

Source: outdoor air at 30 °C. Sink: water at 60 °C. Convert to kelvin first.

$$COP_{Carnot,heating} = \frac{T_{hot}}{T_{hot} - T_{cold}}$$

- $T_{hot} = 60 + 273 = 333 \text{ K}$; $T_{cold} = 30 + 273 = 303 \text{ K}$.
- $COP_{Carnot} = 333 \div (333 - 303) = 333 \div 30 = 11.1$.
- Real air-source heat pumps at these conditions typically reach COP 3.5–4.5, about 30–40% of Carnot.

Remember

- First law: heat delivered = source heat + electrical input.
- Second law: moving heat uphill always costs work.
- Smaller temperature lift means higher possible COP.
- Always use kelvin in Carnot formulas.

Common mistake: Using °C in the Carnot formula. $60 \div 30 = 2$ is wrong; $333 \div 30 = 11.1$ is right.



1.6 Pressure, boiling point and saturation

Key idea: The temperature at which a liquid boils depends on pressure; higher pressure means a higher boiling point.

Pressure is force per unit area. We use bar. Atmospheric pressure at sea level is about 1.013 bar.

Gauges usually read gauge pressure (bar g), which is pressure above atmosphere. Absolute pressure (bar a) is gauge pressure plus atmospheric pressure. Refrigerant tables use absolute pressure.

A pressure cooker is the best example. The weight holds the pressure at about 1 bar above atmosphere. Water then boils at about 120 °C instead of 100 °C, so food cooks faster.

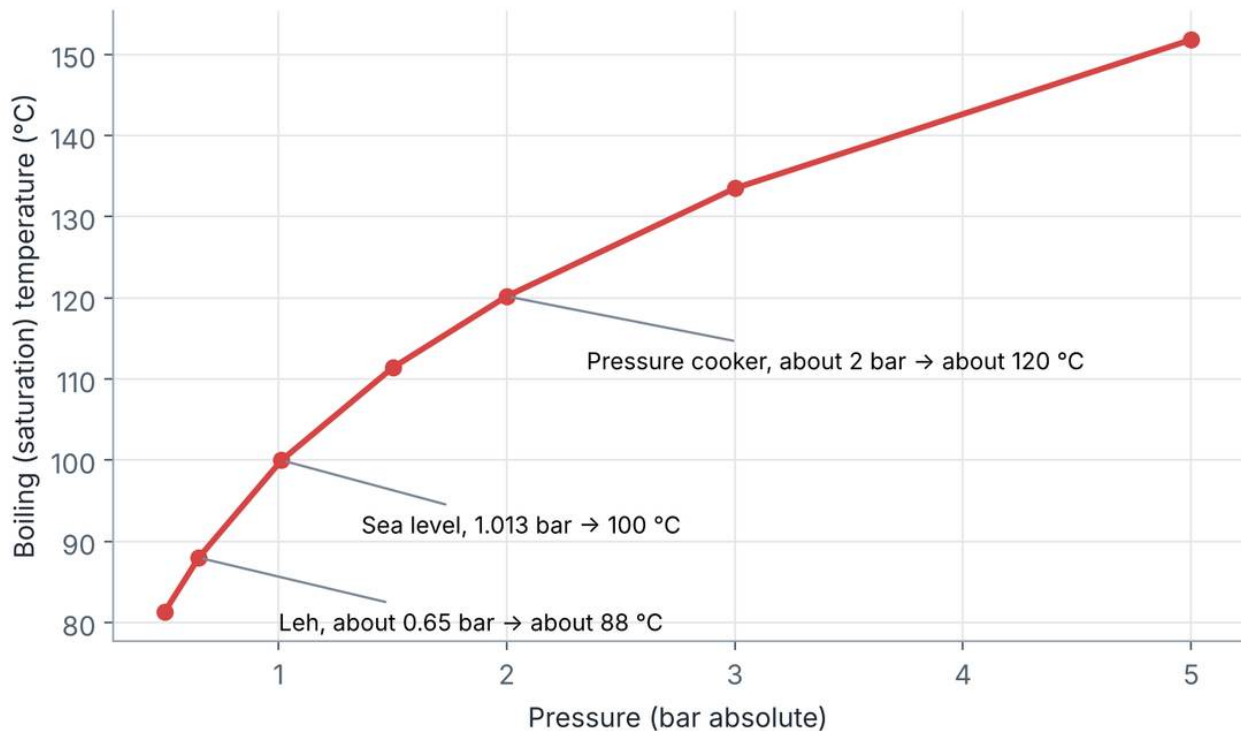
At high altitude, the opposite happens. In Leh (about 3,500 m), air pressure is lower and water boils at about 88 °C (typical). Dal takes longer to cook.

"Saturation" means liquid and vapour are together in balance. At a given pressure, there is only one saturation temperature. If you know one, you know the other. This is the most useful fact in refrigeration.

Below the saturation temperature the liquid is "subcooled". Above it the vapour is "superheated". Technicians measure both to check a system.

Water boils at a lower temperature when pressure is lower

Typical steam-table values. Pressure in bar absolute.



Boiling point of water vs pressure

Situation	Absolute pressure (typical)	Water boils at (typical)
Leh, about 3,500 m	0.65 bar a	about 88 °C
Sea level (Mumbai, Chennai)	1.013 bar a	100 °C
Pressure cooker	about 2.0 bar a	about 120 °C
Small steam boiler	5 bar a	about 152 °C

Worked example — gauge to absolute pressure

A gauge on a system in Kolkata reads 7 bar g. What is the absolute pressure?

$$P_{abs} = P_{gauge} + P_{atm}$$

- $P_{abs} = 7 + 1.013 = 8.01 \text{ bar a.}$
- Use 8.0 bar a when reading a refrigerant pressure–temperature table.

Remember

- Higher pressure raises the boiling point; lower pressure lowers it.
- At saturation, pressure fixes temperature and temperature fixes pressure.
- bar a = bar g + about 1.013 (at sea level).
- Subcooled liquid is below saturation; superheated vapour is above it.

Field tip: Check whether your gauge or app shows bar g or bar a before reading a saturation table.



1.7 Refrigerants and phase change

Key idea: A refrigerant is a fluid chosen to boil at low temperature and condense at high temperature, carrying heat as latent heat.

A refrigerant is the working fluid inside a heat pump or AC. It is picked so that it boils well below room temperature at a moderate pressure. It condenses at a useful high temperature when compressed.

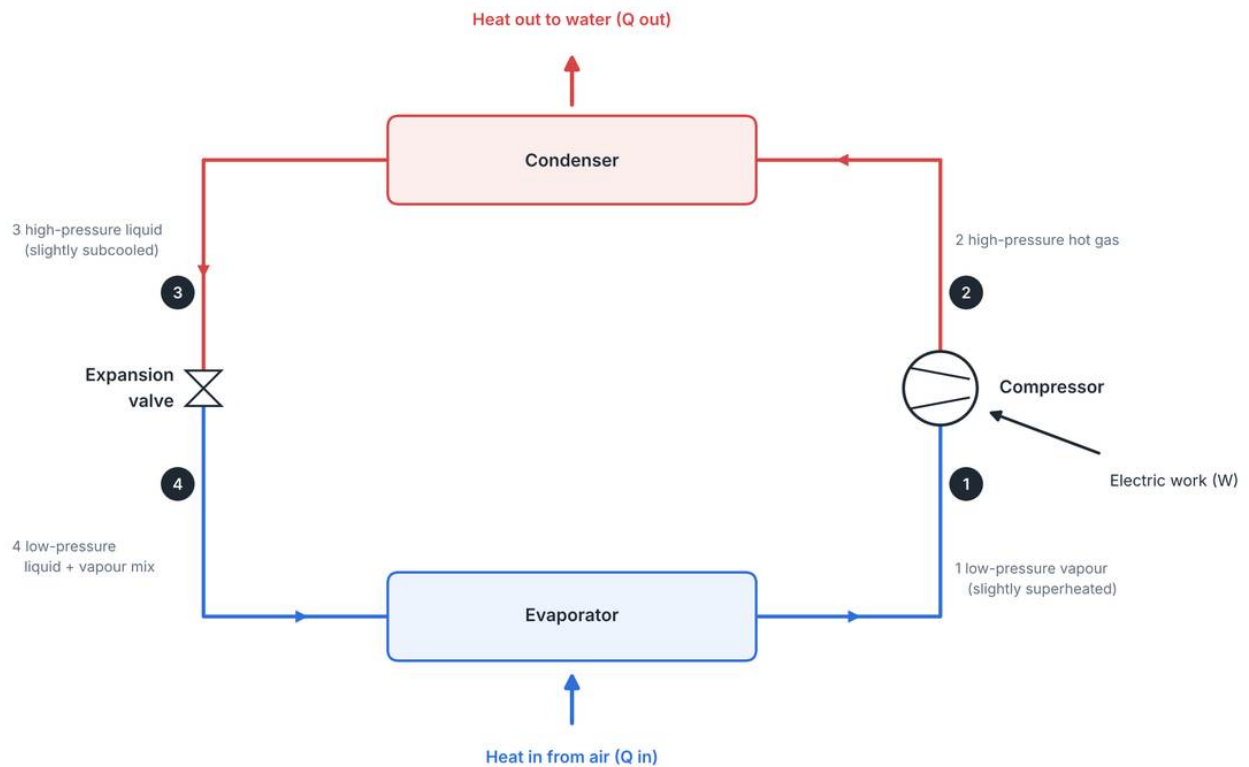
The basic cycle has four parts. The evaporator absorbs heat as the refrigerant boils. The compressor raises its pressure and temperature. The condenser releases heat as it condenses. The expansion valve drops the pressure again.

Think of a fridge. Inside, the refrigerant boils and takes heat from your food. At the back, it condenses and you feel warm air. A heat pump water heater uses that warm "back side" to heat water.

Refrigerants differ in pressure, efficiency, flammability and climate impact. GWP (global warming potential) compares a gas's warming effect to CO₂ over 100 years. Safety class (from ISO 817 / ASHRAE 34) rates toxicity (A low, B high) and flammability (1 none, 2L mild, 2, 3 high).

The vapour compression cycle: four parts, one loop

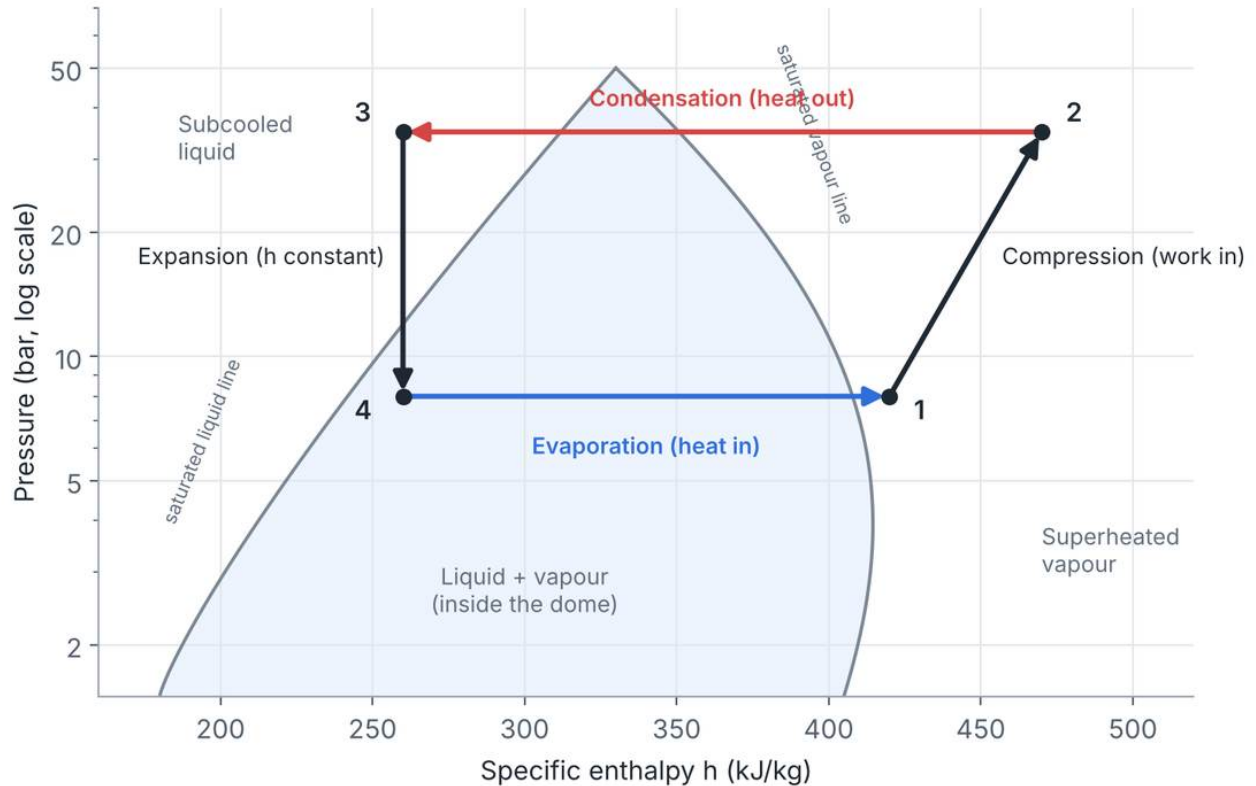
High-pressure side red, low-pressure side blue. Numbers are the four state points.



The vapour compression cycle

The same cycle on a pressure–enthalpy (P-h) diagram

Illustrative values, not tied to one refrigerant



The cycle on a P-h diagram

Refrigerant	Type	GWP (100-yr, IPCC AR4)	Safety class	Sat. pressure at 0 °C (bar a, typical)	Sat. pressure at 40 °C (bar a, typical)
R134a	HFC	1,430	A1	about 2.9	about 10.2
R410A	HFC blend	2,088	A1	about 8.0	about 24.2
R32	HFC	675	A2L	about 8.1	about 24.8
R290 (propane)	Natural (HC)	3	A3	about 4.7	about 13.7
R744 (CO ₂)	Natural	1	A1	about 34.9	Above critical point (31 °C)

Worked example — refrigerant flow needed for 10 kW of heating

In the condenser, each kg of refrigerant gives up heat equal to its enthalpy drop. Assume a typical drop of 200 kJ/kg for this example.

$$\dot{m} = \frac{Q}{\Delta h}$$

- $Q = 10 \text{ kW} = 10 \text{ kJ/s}$.
- $\dot{m} = 10 \div 200 = 0.05 \text{ kg/s}$.
- Per hour: $0.05 \times 3,600 = 180 \text{ kg/h}$ of refrigerant circulating.

Remember

- Evaporator: refrigerant boils and absorbs heat. Condenser: refrigerant condenses and releases heat.
- The compressor sets the two pressures; the expansion valve separates them.
- Low GWP and correct safety class matter as much as efficiency.
- Never mix refrigerants or top up with a different one.

Common mistake: Charging a flammable refrigerant (A2L or A3) with tools and procedures meant only for A1 gases. Use rated tools and follow the safety procedure.



1.8 Air and humidity: dew point, wet-bulb, relative humidity

Key idea: Air always carries some water vapour, and how much it can hold depends on its temperature.

Air is a mix of dry air and water vapour. Warm air can hold more vapour than cold air. This matters for air-source heat pumps, because their outdoor coil works with humid air.

Relative humidity (RH) is how much vapour the air holds compared with the most it could hold at that temperature. 100% RH means the air is saturated. Mumbai in the monsoon often sits near 80–90% RH.

Dew point is the temperature at which air starts to condense water if cooled. A cold glass of water "sweats" because its surface is below the dew point of the room air.

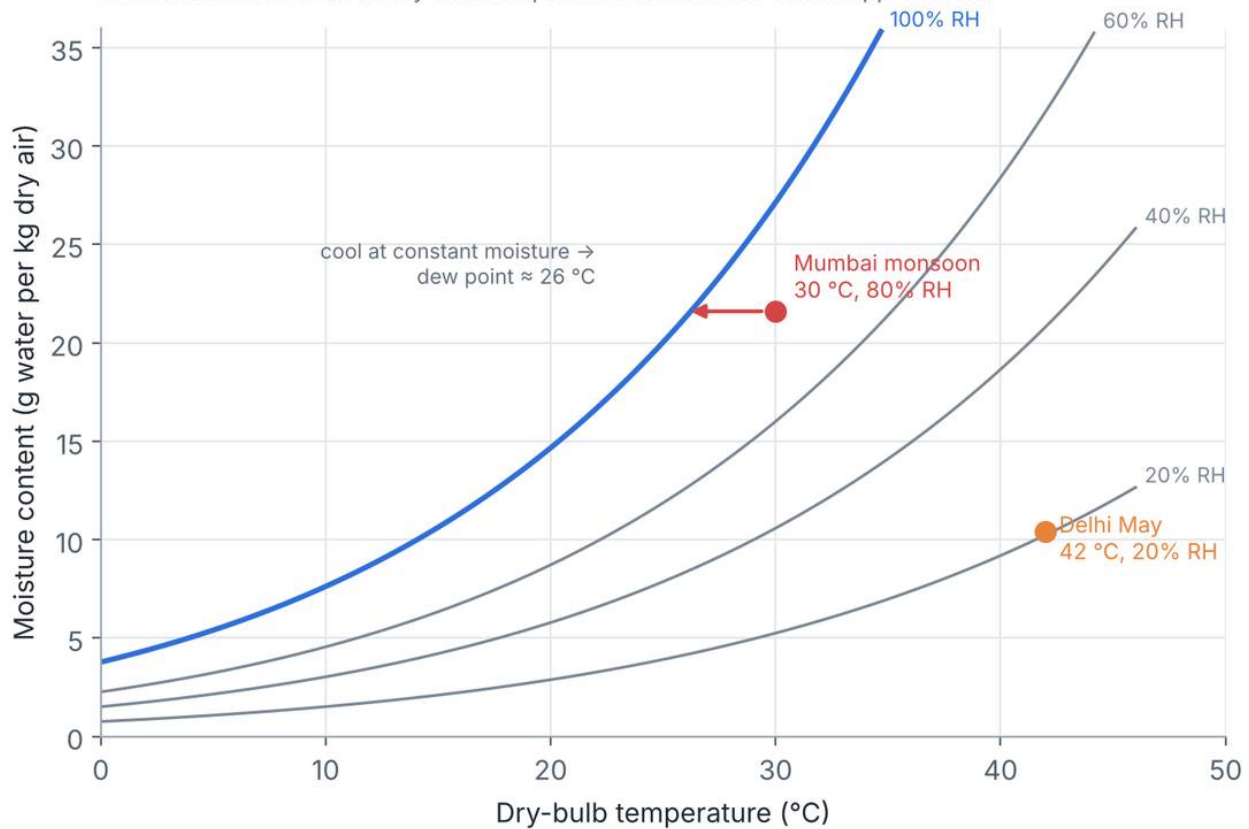
Dry-bulb temperature is the normal air temperature from a thermometer. Wet-bulb temperature is read from a thermometer with a wet wick in moving air. Evaporation from the wick cools it, so wet-bulb is lower unless the air is saturated.

A desert cooler works on this principle. It can cool air close to the wet-bulb temperature. That is why coolers work well in dry Jaipur and poorly in humid Kolkata.

For a heat pump, when the outdoor coil is below the dew point, water drips off it. If the coil surface falls below 0 °C, that water freezes as frost. The unit must then defrost.

Simplified psychrometric chart

Moisture content of air vs dry-bulb temperature at sea level. Values approximate.



Simplified psychrometric chart

Term	Meaning	How measured
Dry-bulb temperature	Normal air temperature	Ordinary thermometer
Wet-bulb temperature	Lowest temperature reachable by evaporating water into the air	Thermometer with wet wick, moving air
Relative humidity (RH)	Vapour held ÷ maximum possible at that temperature, in %	Hygrometer, sensor
Dew point	Temperature at which condensation starts	Calculated, or chilled-mirror meter

Worked example — dew point for Mumbai monsoon air

Air is 30 °C at 80% RH. Use a typical saturation vapour pressure for water at 30 °C of 4.25 kPa.

$$p_v = RH \times p_{sat}(T_{db})$$

- $p_v = 0.80 \times 4.25 = 3.40$ kPa.
- Find the temperature where $p_{sat} = 3.40$ kPa. From steam tables this is about 26 °C.
- So any surface below about 26 °C will drip water. An outdoor coil at 20 °C will condense heavily in Mumbai.

Remember

- Warm air holds more water vapour than cold air.
- RH is a ratio; dew point tells you the actual moisture.
- Wet-bulb $\leq$ dry-bulb, equal only at 100% RH.
- Coil below dew point $\rightarrow$ condensate; coil below 0 °C $\rightarrow$ frost.

Field tip: Always plan a condensate drain for air-source heat pumps. In humid coastal cities they can drain several litres per hour (typical).



1.9 Energy, power and efficiency: why COP can exceed 100%

Key idea: A heat pump's COP is heat delivered divided by electricity used, and it exceeds 1 because most of the heat comes free from the air.

Efficiency is useful output divided by input. An electric geyser element turns almost all electricity into heat, so it is close to 100% efficient. A gas burner loses some heat up the flue, so it is typically 80–90%.

A heat pump is different. It does not turn electricity into heat. It uses electricity to move heat from the air into water. So the heat delivered is larger than the electricity used.

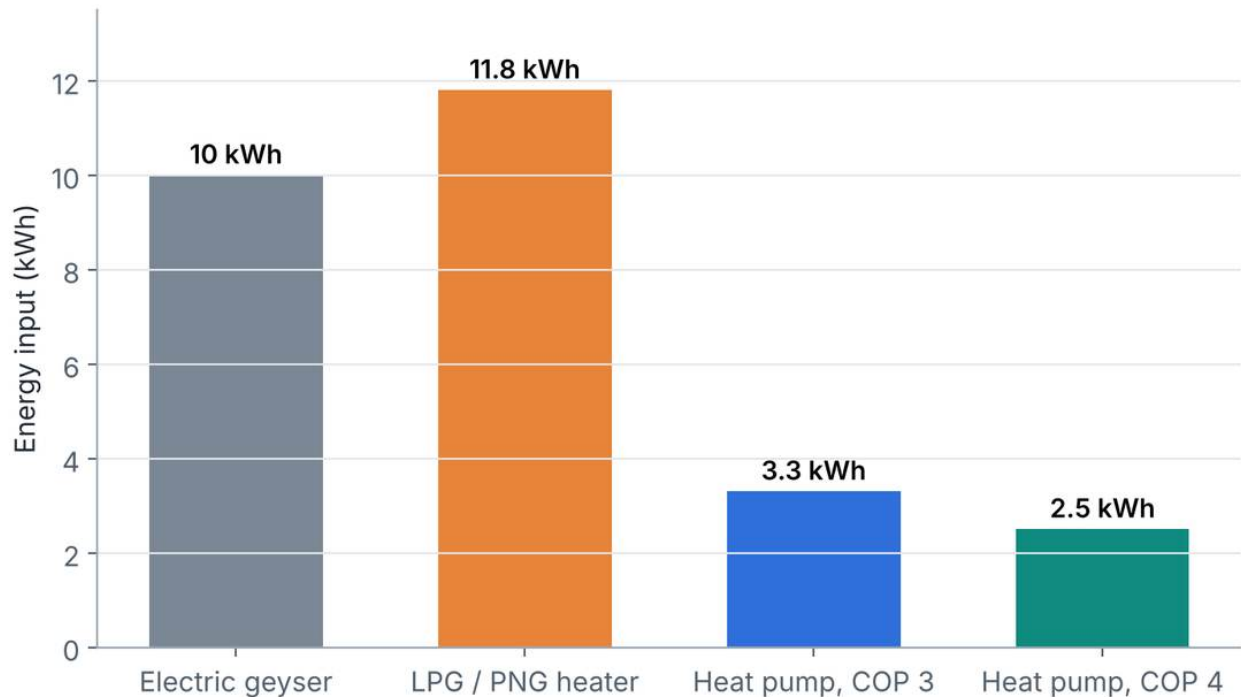
COP (coefficient of performance) is heat delivered ÷ electrical input, both in kW. COP 4 means 4 kW of heat for 1 kW of electricity. Expressed as a percentage, that is 400%.

COP is not fixed. It falls when the source is colder or the water is hotter, because the "lift" is bigger. A heat pump making 55 °C water from 35 °C air in Nagpur will show a higher COP than one making 65 °C water from 10 °C air in Shimla.

No law is broken. By the first law, heat delivered = heat from air + electricity. The extra comes from the environment, which is warmed by the sun.

Energy you pay for to get 10 kWh of hot water

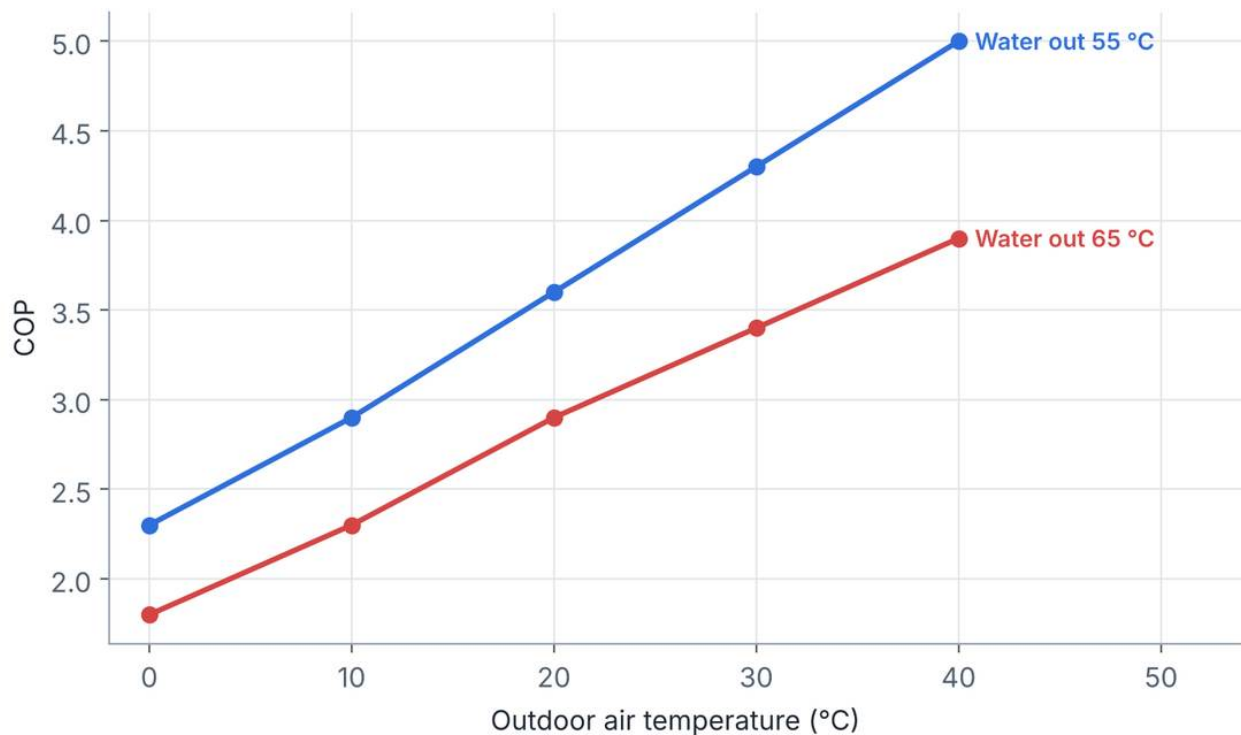
Typical efficiencies: electric 100%, LPG/PNG heater 85%. Heat pump at COP 3 and COP 4.



Energy input for 10 kWh of hot water

COP falls as the outdoor air gets colder

Typical, illustrative values. Real machines vary; use the datasheet.



COP vs outdoor air temperature

Heating method	Efficiency or COP (typical)	Heat delivered per 1 unit of input
Electric geyser element	about 95–100%	about 1 kWh
LPG or PNG water heater	about 80–90%	about 0.8–0.9 kWh of fuel energy
Diesel boiler	about 80–88%	about 0.8–0.88 kWh of fuel energy
Air-source heat pump, hot water at 55–60 °C	COP about 3–4.5	about 3–4.5 kWh

Worked example — daily cost to heat 1,000 L for a hostel in Hyderabad

Heat 1,000 L from 25 °C to 60 °C. Example rates: electricity ₹9/kWh, LPG ₹100/kg. LPG energy content about 12.8 kWh/kg (typical net value); burner efficiency 85% (typical).

$$Q = m \times c_p \times \Delta T, \quad E_{elec} = \frac{Q}{COP}$$

- $Q = 1,000 \times 4.186 \times 35 = 1,46,510 \text{ kJ} = 1,46,510 \div 3,600 = 40.7 \text{ kWh}$ of heat.
- Electric geyser (about 100%): $40.7 \text{ kWh} \times ₹9 = ₹366$ per day.
- LPG: fuel energy = $40.7 \div 0.85 = 47.9 \text{ kWh}$; LPG mass = $47.9 \div 12.8 = 3.74 \text{ kg}$; cost = $3.74 \times ₹100 = ₹374$ per day.
- Heat pump at COP 4: electricity = $40.7 \div 4 = 10.2 \text{ kWh}$; cost = $10.2 \times ₹9 = ₹92$ per day.
- Saving vs electric geyser: about ₹274 per day, about ₹1 lakh per year at 365 days.

Remember

- $COP = \text{heat delivered (kW)} \div \text{electrical input (kW)}$.
- COP above 1 does not break physics; the extra heat comes from the air.
- COP falls as the temperature lift grows.
- Always compare running cost on the same heat demand in kWh.

Common mistake: Quoting one COP figure without its conditions. Always state source temperature and water outlet temperature with the COP.

Quiz 1

1. A cup of tea and a bucket of water are both at 60 °C. Which statement is true?
 - A. Both hold the same heat
 - B. The bucket holds more heat
 - C. The cup holds more heat
 - D. Neither holds any heat
2. 1 TR is approximately equal to:
 - A. 1 kW
 - B. 2.5 kW
 - C. 3.517 kW
 - D. 12 kW
3. A boiler rated 86,000 kcal/h has a capacity of about:
 - A. 10 kW
 - B. 100 kW
 - C. 860 kW
 - D. 1,000 kW
4. While water is boiling at a steady 100 °C, the heat being added is called:
 - A. Sensible heat
 - B. Radiant heat
 - C. Latent heat
 - D. Specific heat
5. Hot water rising to the top of a storage tank is an example of:
 - A. Conduction
 - B. Natural convection
 - C. Radiation
 - D. Forced convection
6. Which law says heat cannot flow from cold to hot without work?
 - A. Zeroth law
 - B. First law
 - C. Second law
 - D. Third law
7. A gauge reads 5 bar g at sea level. The absolute pressure is about:
 - A. 4 bar a
 - B. 5 bar a
 - C. 6 bar a
 - D. 10 bar a
8. In the vapour compression cycle, where does the refrigerant release heat?
 - A. Evaporator
 - B. Condenser
 - C. Expansion valve
 - D. Suction line
9. Water drips from an outdoor coil when the coil surface is:
 - A. Above the dry-bulb temperature
 - B. Above the wet-bulb temperature
 - C. Below the dew point
 - D. Exactly at 0 °C only
10. A heat pump delivers 12 kW of heat using 3 kW of electricity. Its COP is:

- A. 0.25
- B. 3
- C. 4
- D. 9

Answer key

1. **B** — Same temperature, but the bucket has far more mass, so far more heat.
2. **C** — $1 \text{ TR} = 12,000 \text{ BTU/h} = 3.517 \text{ kW}$.
3. **B** — $86,000 \div 860 = 100 \text{ kW}$.
4. **C** — Heat that changes phase without changing temperature is latent heat.
5. **B** — Warm water is lighter and rises on its own; no pump is involved.
6. **C** — The second law sets the direction of heat flow and the need for work.
7. **C** — $5 + 1.013 \approx 6 \text{ bar a}$.
8. **B** — The refrigerant condenses in the condenser and gives up its latent heat.
9. **C** — Condensation starts when a surface is below the dew point of the air.
10. **C** — $\text{COP} = 12 \div 3 = 4$.



Glossary

Term	Meaning
Absolute pressure (bar a)	Pressure measured from a perfect vacuum; gauge pressure + atmospheric pressure
BTU/h	British thermal units per hour; 1 kW = 3,412 BTU/h
Carnot COP	Highest COP possible in theory between two temperatures, using kelvin
Condensation	Change from vapour to liquid; releases latent heat
Condenser	Heat exchanger where refrigerant condenses and gives heat to water or air
Conduction	Heat transfer through a solid, molecule to molecule
Convection	Heat carried by a moving fluid (natural or forced)
COP	Coefficient of performance: heat delivered ÷ electrical input
Dew point	Temperature at which air starts to condense water when cooled
Dry-bulb temperature	Normal air temperature read on a thermometer
Enthalpy	Total heat content of a fluid per kg, in kJ/kg
Evaporation	Change from liquid to vapour; absorbs latent heat
Evaporator	Heat exchanger where refrigerant boils and absorbs heat
Expansion valve	Device that drops refrigerant pressure between condenser and evaporator
Gauge pressure (bar g)	Pressure above atmospheric pressure
GWP	Global warming potential, compared with CO ₂ over 100 years
Heat	Energy that flows because of a temperature difference (kJ, kWh)
kcal/h	Kilocalories per hour; 1 kW = 860 kcal/h
Kelvin (K)	Absolute temperature scale; 0 K = -273.15 °C
kW / kWh	Power (rate of energy) / energy (power × time)
Latent heat	Heat that changes phase without changing temperature
P-h diagram	Pressure–enthalpy chart used to draw a refrigeration cycle
Radiation	Heat transfer by infrared waves, needing no medium
Refrigerant	Working fluid that boils and condenses to carry heat in a cycle
Relative humidity (RH)	Water vapour in air as a % of the maximum it can hold at that temperature
Saturation temperature	Boiling/condensing temperature at a given pressure
Sensible heat	Heat that changes temperature
Specific heat (c _p)	Heat needed to raise 1 kg by 1 K; water ≈ 4.186 kJ/kg·K
Subcooling	Liquid cooled below its saturation temperature
Superheat	Vapour heated above its saturation temperature
Temperature	Measure of how hot or cold something is (°C or K)
TR (ton of refrigeration)	Cooling rate of 3.517 kW (12,000 BTU/h)
Wet-bulb temperature	Temperature of a wetted thermometer in moving air; ≤ dry-bulb

Course 2 — How a Heat Pump Works

Powered by Sunniva. This is a Level 1 Foundations course for everyone: technicians, engineers, sales staff, consultants and curious owners. No prior refrigeration knowledge is needed. After this course you will be able to:

- explain in plain words how a heat pump moves heat from a cold place to a warm place;
- name every main part of the refrigerant circuit and say what it does;
- read a pressure–enthalpy (P-h) diagram and estimate COP from it;
- explain why COP falls as temperature lift rises, and why air-source units need defrost.

2.1 Moving heat uphill: the core idea

Key idea: A heat pump does not make heat; it moves heat that already exists from a colder place to a warmer place, using a small amount of electricity to do the work.

Heat flows naturally from hot to cold. A cup of chai cools down in a room; it never heats itself up. To make heat flow the other way, "uphill", we must spend work. A water pump does the same for water: it lifts water from a sump to an overhead tank.

Your home fridge is a heat pump. It pulls heat out of the food and throws it out at the back grille. Touch that grille and you feel the heat. A water heating heat pump does the same job, but we keep the warm side and use it.

Air at 25 °C in Chennai still holds a lot of heat. Even air at 0 °C in Shimla holds heat, because "cold" only means "less heat". The heat pump collects this low-grade heat and lifts it to a useful temperature, such as 55 °C for bathing water.

Coefficient of performance (COP) is the useful heat delivered divided by the electricity used. An electric geyser element has a COP of about 1. A heat pump typically delivers a COP of 3 to 5 for water heating.

What goes out to the water = heat from the source + electrical work



Energy flow through a heat pump

Heating method	Typical efficiency or COP	Energy bought for 10 kWh of heat
Electric geyser (resistance element)	about 1.0	about 10 kWh electricity
LPG water heater	about 0.8–0.9 (typical)	about 0.9 kg LPG per 10 kWh (typical)
Heat pump (water heating)	about 3–5 (typical)	about 2–3.3 kWh electricity

Worked example — heating 500 L of water in Pune from 25 °C to 55 °C.

$$Q = m c_p \Delta T \quad E_{elec} = \frac{Q}{COP}$$

- Mass of water $m = 500$ kg. Specific heat $c_p = 4.186$ kJ/kg·K. $\Delta T = 55 - 25 = 30$ K.
- $Q = 500 \times 4.186 \times 30 = 62,790$ kJ. Divide by 3,600 to get kWh: $Q \approx 17.4$ kWh.
- Electric geyser (COP ≈ 1): 17.4 kWh $\times$ ₹9/kWh (example rate) $\approx$ ₹157.
- Heat pump at COP 3.5: $17.4 \div 3.5 \approx 5.0$ kWh $\times$ ₹9 $\approx$ ₹45.
- Heat taken free from the air: $17.4 - 5.0 = 12.4$ kWh.

Remember

- A heat pump moves heat; it does not create it.
- Heat out = heat from source + electrical work.
- COP = useful heat $\div$ electricity used.

- Even cold air contains usable heat.

Field tip: When explaining to a customer, point to the hot grille behind their fridge. It is the easiest demonstration you have.



2.2 The vapour compression cycle, step by step

Key idea: A refrigerant boils to absorb heat at low pressure, is compressed, then condenses to release heat at high pressure, and the cycle repeats.

A **refrigerant** is a fluid chosen because it boils at a low temperature. Water boils at 100 °C at sea level. In a pressure cooker, the higher pressure makes water boil at about 120 °C. Pressure sets the boiling point. A heat pump uses this rule: low pressure for boiling cold, high pressure for condensing hot.

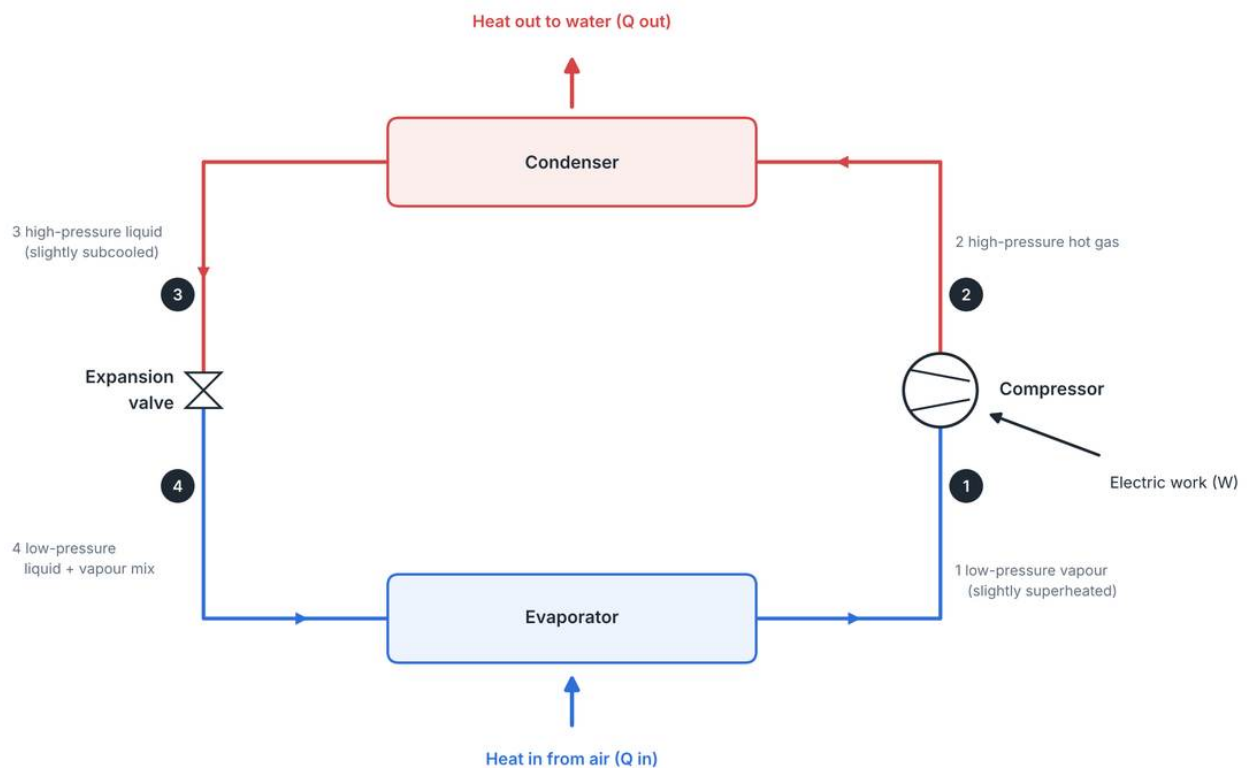
The cycle has four parts. Follow one kilogram of refrigerant around the loop.

1. **Evaporation (1 → 2).** Cold, low-pressure liquid enters the **evaporator**. It boils by taking heat from outdoor air or water. It leaves as a slightly **superheated** vapour, meaning a few degrees warmer than its boiling point.
2. **Compression (2 → 3).** The **compressor** squeezes the vapour. Pressure and temperature rise sharply. Hot gas at perhaps 70–100 °C (typical) leaves the compressor.
3. **Condensation (3 → 4).** The hot gas enters the **condenser**. It gives its heat to the water and turns back into liquid. It leaves slightly **subcooled**, meaning a few degrees below its condensing point.
4. **Expansion (4 → 1).** The liquid passes through an **expansion device**. Pressure drops suddenly. Part of the liquid flashes to vapour and the mix becomes very cold. It returns to the evaporator.

Sweat cools your skin the same way: as it evaporates, it takes heat from you. Evaporation always absorbs heat.

The vapour compression cycle, step by step

High-pressure side red, low-pressure side blue. Numbers are the four state points.



The vapour compression cycle

Point	Location	Pressure	Phase	Typical temperature (water heating, 25 °C air)
1	Compressor suction	Low	Superheated vapour	about 15–20 °C
2	Compressor discharge	High	Hot superheated gas	about 70–100 °C
3	Condenser outlet	High	Subcooled liquid	about 50–55 °C
4	Evaporator inlet	Low	Cold liquid-vapour mix	about 10–15 °C

(Values are typical and depend on refrigerant and conditions.)

Worked example — energy balance on a unit.

$$Q_{cond} = Q_{evap} + W_{comp}$$

- A unit draws $W = 3$ kW at the compressor.
- Its evaporator absorbs $Q_{evap} = 9$ kW from air.
- Condenser output $Q_{cond} = 9 + 3 = 12$ kW.
- $COP = 12 \div 3 = 4.0$.

Remember

- Pressure controls the boiling point of the refrigerant.
- Low side absorbs heat; high side rejects heat.
- Four parts: evaporator, compressor, condenser, expansion device.
- Superheat protects the compressor; subcooling protects the expansion device.

Common mistake: Calling the hot discharge gas "the water temperature". Discharge gas is much hotter than the water it heats.



2.3 Compressors: rotary, scroll, reciprocating, screw, inverter

Key idea: The compressor is the heart of the heat pump; its type sets capacity range, efficiency, noise and how well it handles part load.

The compressor raises the refrigerant's pressure. Most heat pump compressors are **hermetic**, meaning motor and pump are sealed in one welded shell. The motor is cooled by the suction gas flowing over it.

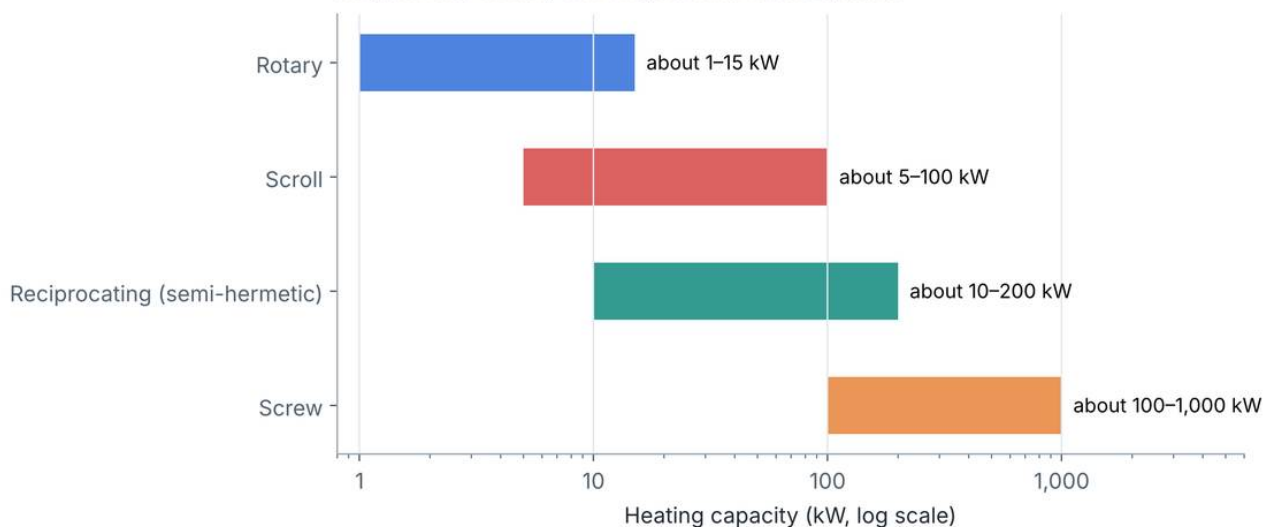
Rotary compressors use a rolling piston inside a cylinder. They are small, cheap and common in split ACs and small heat pumps. **Scroll** compressors use two spiral scrolls, one fixed and one orbiting. Gas is trapped and squeezed toward the centre. Scrolls are quiet, efficient and reliable in the mid range.

Reciprocating compressors use pistons, like a car engine. They are rugged and easy to repair but noisier. **Screw** compressors use two meshing rotors. They suit large industrial capacities.

Inverter is not a separate pump type. It is a drive that changes the motor speed. Rotary and scroll compressors are often inverter-driven. A fixed-speed compressor runs at full speed or stops. An inverter compressor slows down to match the load, like a car cruising instead of braking and accelerating.

Typical heating capacity per compressor type

Ranges overlap and vary with refrigerant and maker. Log scale.



Typical capacity range per compressor type

Type	Typical capacity per compressor	Strengths	Limits	Common use
Rotary	about 1–15 kW	Compact, low cost	Less efficient at large sizes	Domestic water heaters, splits
Scroll	about 5–100 kW	Quiet, efficient, few moving parts	Not field-repairable (hermetic)	Domestic to commercial units
Reciprocating	about 10–200 kW	Rugged, repairable (semi-hermetic)	Noise, vibration, valve wear	Older and industrial plants
Screw	about 100 kW and above	Large capacity, continuous duty	High cost, oil management	Industrial process heat
Inverter drive (on rotary/scroll)	—	Matches load, soft start, better part-load COP	Electronics sensitive to voltage and heat	Variable-load applications

Remember

- Most heat pump compressors are hermetic and suction-gas cooled.
- Rotary for small, scroll for mid, screw for large.
- Inverter is a speed control, not a pump design.
- Liquid entering the compressor ("slugging") can break it; superheat prevents this.

Field tip: Check supply voltage at the compressor terminals under load. Low voltage in rural feeders is a common cause of trips and burnt windings.



2.4 The evaporator: collecting heat

Key idea: The evaporator is where cold boiling refrigerant picks up heat from the source — outdoor air, water or ground loop.

In an **air-to-water** heat pump, the evaporator is a **finned-tube coil**. Copper tubes carry refrigerant; thin aluminium fins add surface area. A **fan** pulls outdoor air through the fins. The air leaves a few degrees colder.

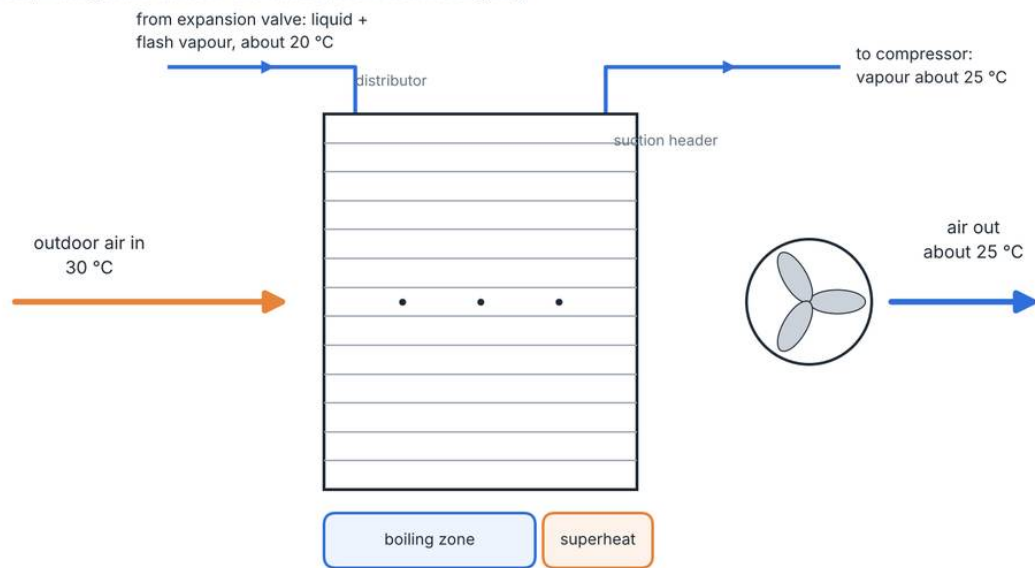
Inside the tubes the refrigerant boils at a nearly constant temperature. This is the **evaporating temperature**, usually several degrees below air temperature. The difference is called the **approach** or temperature difference (TD). Typical air-coil TD is about 6–12 K.

Near the outlet all liquid has boiled away. The vapour then warms a few degrees more. This extra warming is the **superheat**. A small superheat proves no liquid will reach the compressor.

In water-source or ground-source units, the evaporator is a plate or shell-and-tube heat exchanger instead of a coil. The principle is the same.

Inside a finned-coil evaporator

Air gives up heat; refrigerant boils in the tubes, then warms slightly



Create • Conserve • Sustain
Inside a finned-coil evaporator

Evaporator issue	Effect	Check
Dusty or blocked fins	Less air, lower evaporating pressure, lower COP	Clean with low-pressure water from inside out
Fan slow or failed	Low suction pressure, frost, LP trip	Fan current, blades, capacitor
Bent fins	Reduced airflow	Comb fins straight
Too little refrigerant	High superheat, low capacity	Superheat and pressures

Worked example — air flow needed for an 8 kW evaporator, air cooled by 5 K.

$$\dot{V} = \frac{Q}{\rho c_p \Delta T}$$

- $Q = 8$ kW. Air density $\rho \approx 1.2$ kg/m³. $c_p \approx 1.005$ kJ/kg·K. $\Delta T = 5$ K.
- $V = 8 \div (1.2 \times 1.005 \times 5) = 8 \div 6.03 \approx 1.33$ m³/s.
- In m³/h: $1.33 \times 3,600 \approx 4,780$ m³/h.

Remember

- The evaporator absorbs heat by boiling refrigerant.
- More surface and more airflow mean higher evaporating temperature and better COP.
- Superheat at the outlet protects the compressor.
- Keep coils clean, especially in dusty or coastal Indian sites.

Common mistake: Installing the outdoor unit in a closed duct or pit. The cold discharge air recirculates and the unit "breathes its own exhaust".



2.5 The condenser and heat exchangers: plate, shell-and-tube, tube-in-tube, coil-in-tank

Key idea: The condenser hands the refrigerant's heat to the water; its type decides size, water-side pressure drop and how well it tolerates scale.

In the condenser, hot refrigerant gas gives up heat in three zones. First it **desuperheats** (hot gas cools to condensing temperature). Next it **condenses** (gas turns to liquid at constant temperature). Last it **subcools** (liquid cools a few degrees more).

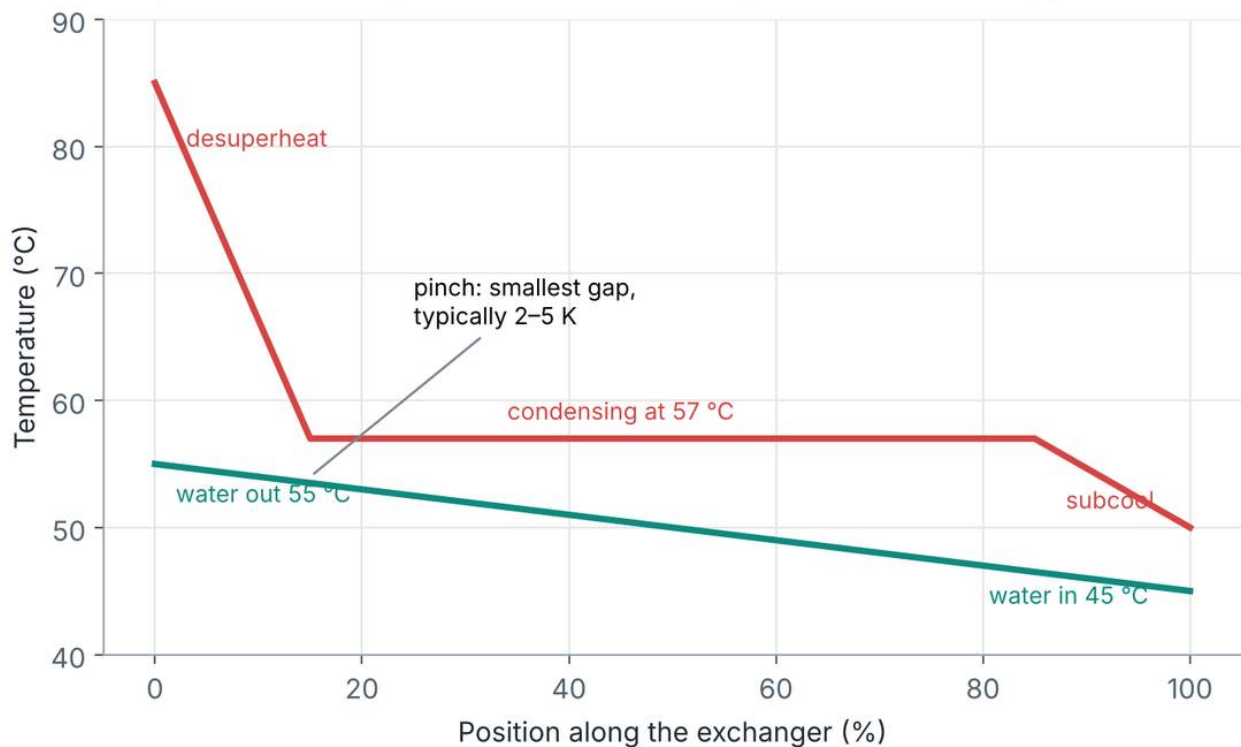
Water and refrigerant should flow in opposite directions. This is **counterflow**. It lets the water leave hotter and keeps the temperature difference even along the length.

Four types are common:

- **Brazed plate heat exchanger (BPHE):** stacked stainless plates brazed together. Very compact and efficient. Narrow channels can scale or block with hard water.
- **Shell-and-tube:** water in tubes, refrigerant in the shell (or the reverse). Bulky but tolerant of dirt and easy to clean mechanically.
- **Tube-in-tube (coaxial):** one tube inside another. Simple and robust, often used in pool heaters and small units.
- **Coil-in-tank:** a copper coil wrapped on or immersed in the storage tank. No water pump needed. Slower heat transfer.

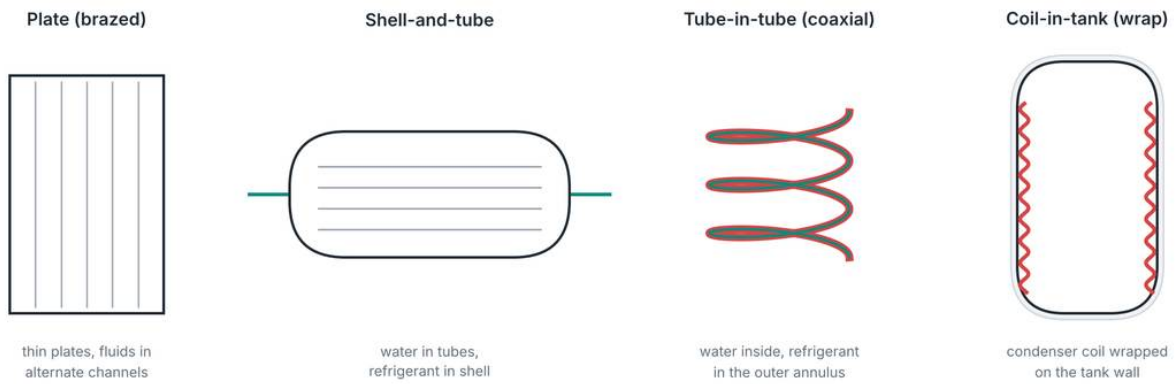
Temperatures along a counterflow condenser

Refrigerant enters as hot gas, condenses at constant temperature, then subcools. Typical values.



Temperatures along a counterflow condenser

Four common heat exchanger types



Four common heat exchanger types

Type	Compactness	Scale tolerance	Cleaning	Typical use
Brazed plate	Very high	Low	Chemical descaling only	Domestic, commercial, process
Shell-and-tube	Low	High	Mechanical (rod) and chemical	Large commercial, industrial
Tube-in-tube	Medium	Medium	Chemical	Pool heaters, small units
Coil-in-tank	— (part of tank)	Medium	Hard to reach	Small domestic all-in-one

Worked example — water flow through a 10 kW condenser with 5 K rise.

$$\dot{m} = \frac{Q}{c_p \Delta T}$$

- $Q = 10 \text{ kW}$. $c_p = 4.186 \text{ kJ/kg} \cdot \text{K}$. $\Delta T = 5 \text{ K}$.
- $\dot{m} = 10 \div (4.186 \times 5) = 0.478 \text{ kg/s}$.
- $0.478 \text{ kg/s} \times 3,600 \approx 1,720 \text{ kg/h} \approx 1,720 \text{ LPH}$.

Remember

- Condensers work in three zones: desuperheat, condense, subcool.
- Counterflow gives the best temperatures.
- Plate exchangers are compact but scale-sensitive.
- Water flow must match the design ΔT .

Field tip: Many Indian borewell and municipal supplies are hard. Use a strainer and softener, and descale plate exchangers on schedule.

2.6 Expansion devices: capillary, TXV, EEV

Key idea: The expansion device drops the refrigerant from high to low pressure and meters just enough flow to keep the evaporator full without flooding the compressor.

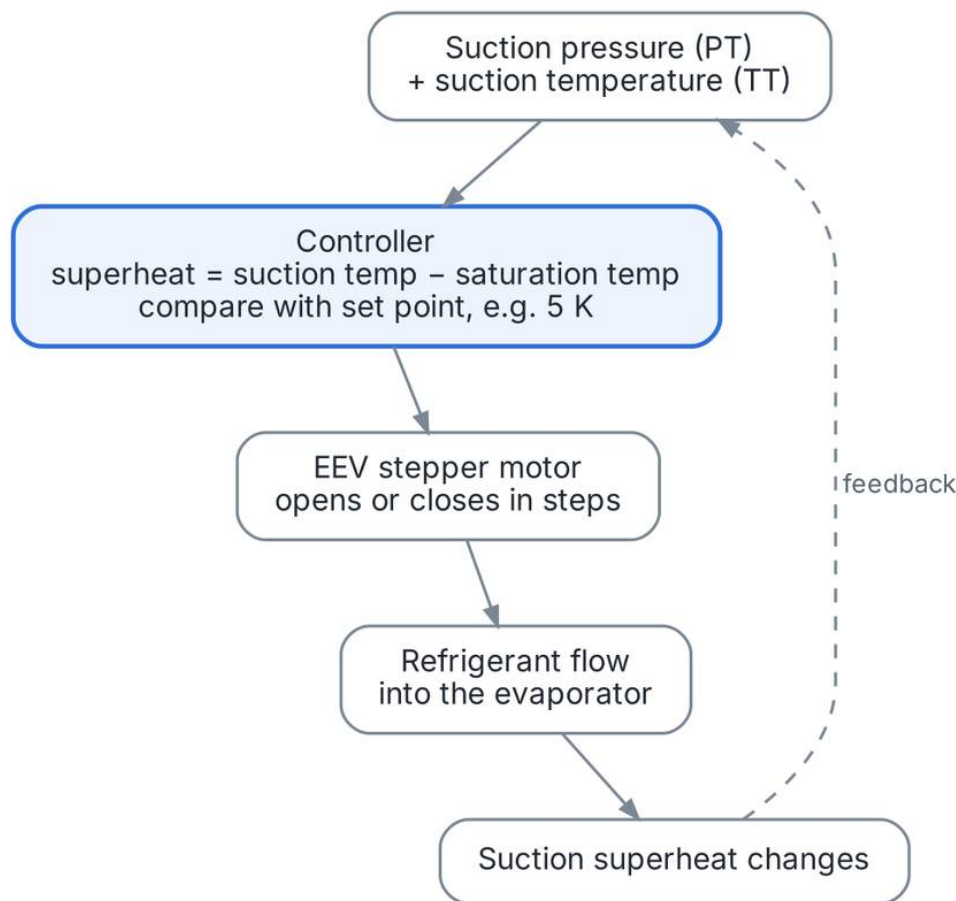
The expansion device sits between condenser and evaporator. It works like the nozzle on a garden hose. A small opening holds back pressure and lets a controlled flow through.

Capillary tube: a long thin copper tube with a fixed bore. Cheap, no moving parts. It cannot adjust to changing load, so it suits small units with steady conditions, like fridges.

Thermostatic expansion valve (TXV): a mechanical valve with a **sensing bulb** clamped on the suction line. If superheat rises, the bulb pressure opens the valve more. If superheat falls, it closes. It self-adjusts within its design range.

Electronic expansion valve (EEV): a valve moved by a **stepper motor**. A controller reads suction temperature and pressure, calculates superheat and sets the valve position. It responds fast and works over a wide range. Most inverter heat pumps use an EEV.

How an electronic expansion valve (EEV) holds superheat



EEV superheat control loop

Device	Adjusts to load?	Cost	Typical use
Capillary tube	No (fixed)	Lowest	Small fixed-speed units
TXV	Yes, mechanically	Medium	Fixed-speed commercial units
EEV	Yes, electronically, wide range	Highest	Inverter units, wide operating range

Worked example — measuring superheat in the field.

$$SH = T_{suction\ line} - T_{sat}(P_{suction})$$

- Suction gauge reads a pressure whose saturation temperature (from the refrigerant P-T chart) is 2 °C.
- Clamp thermometer on suction line near the compressor reads 8 °C.
- Superheat = 8 – 2 = 6 K. This is within a typical target of about 4–8 K.

Subcooling is measured the same way on the liquid line: saturation temperature at discharge pressure minus liquid line temperature.

Remember

- The expansion device creates the low-pressure side.
- Capillary is fixed; TXV and EEV adjust.
- EEVs control superheat using sensors and a controller.
- Superheat too low risks liquid return; too high wastes evaporator surface.

Common mistake: Judging refrigerant charge from pressure alone. Always check superheat and subcooling too.



2.7 Controls, sensors and safety devices

Key idea: Sensors tell the controller what the circuit is doing, and safety devices stop the unit before anything is damaged.

The **controller** is the unit's brain, usually a microprocessor board. It reads sensors, runs the compressor, fan, pump and valves, and logs faults.

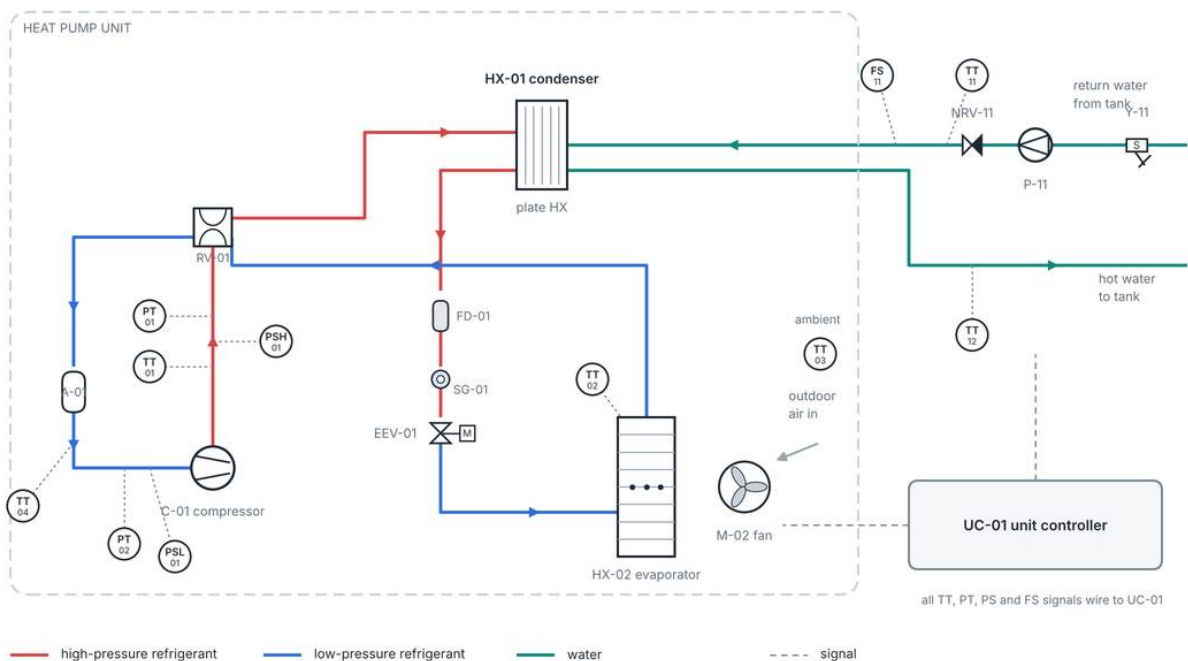
Temperature sensors are usually **NTC thermistors**. NTC means negative temperature coefficient: resistance falls as temperature rises. They are placed on water inlet and outlet, discharge, suction, coil and outdoor air.

Pressure transmitters give a continuous pressure reading. **Pressure switches** are on-off safety devices. The **high-pressure switch (HP)** opens if discharge pressure is too high, for example when water flow stops. The **low-pressure switch (LP)** opens if suction pressure is too low, for example on gas leak or heavy frost.

The **4-way reversing valve** swaps the roles of the two heat exchangers. It is used for defrost and, in some units, for cooling mode. A **flow switch** proves water is flowing before the compressor may start.

Air-to-water heat pump: refrigerant circuit P&ID

Heating mode. Hot side red, cold side blue, water teal, dashed = signal to controller UC-01



P&ID: refrigerant circuit of an air-to-water heat pump

Device	Tag	What it protects or measures	Typical action
High-pressure switch	PSH	Overpressure on discharge side	Stops compressor; often manual reset
Low-pressure switch	PSL	Low suction pressure (leak, frost, low airflow)	Stops compressor; auto reset with lockout after repeats
Discharge temp sensor	TT	Compressor overheating	Reduces speed or stops compressor
Water flow switch	FS	No-flow condition in condenser	Prevents compressor start
Coil temp sensor	TT	Frost on evaporator	Starts and ends defrost
Water outlet sensor	TT	Setpoint control, anti-freeze	Modulates or stops
Crankcase heater	—	Refrigerant migrating into oil when off	Heats compressor sump

Pressure switch set-points depend on refrigerant and design. Always use the value on the unit nameplate or service manual.

Remember

- Sensors measure; switches protect; the controller decides.

- HP switch trips are usually caused by no or low water flow.
- LP switch trips are usually caused by leaks, frost or poor airflow.
- Never bypass a safety switch to "get the unit running".

Field tip: Before replacing a "faulty" NTC sensor, measure its resistance and compare with the table in the service manual at the actual temperature.



2.8 Reading a pressure–enthalpy (P-h) diagram

Key idea: The P-h diagram is a map of the refrigerant; the cycle drawn on it shows every state and lets you read heat and work directly as horizontal distances.

Enthalpy (h) is the heat content of one kilogram of refrigerant, in kJ/kg. On a P-h diagram, enthalpy runs along the bottom (x-axis). Pressure runs up the side (y-axis), usually on a log scale.

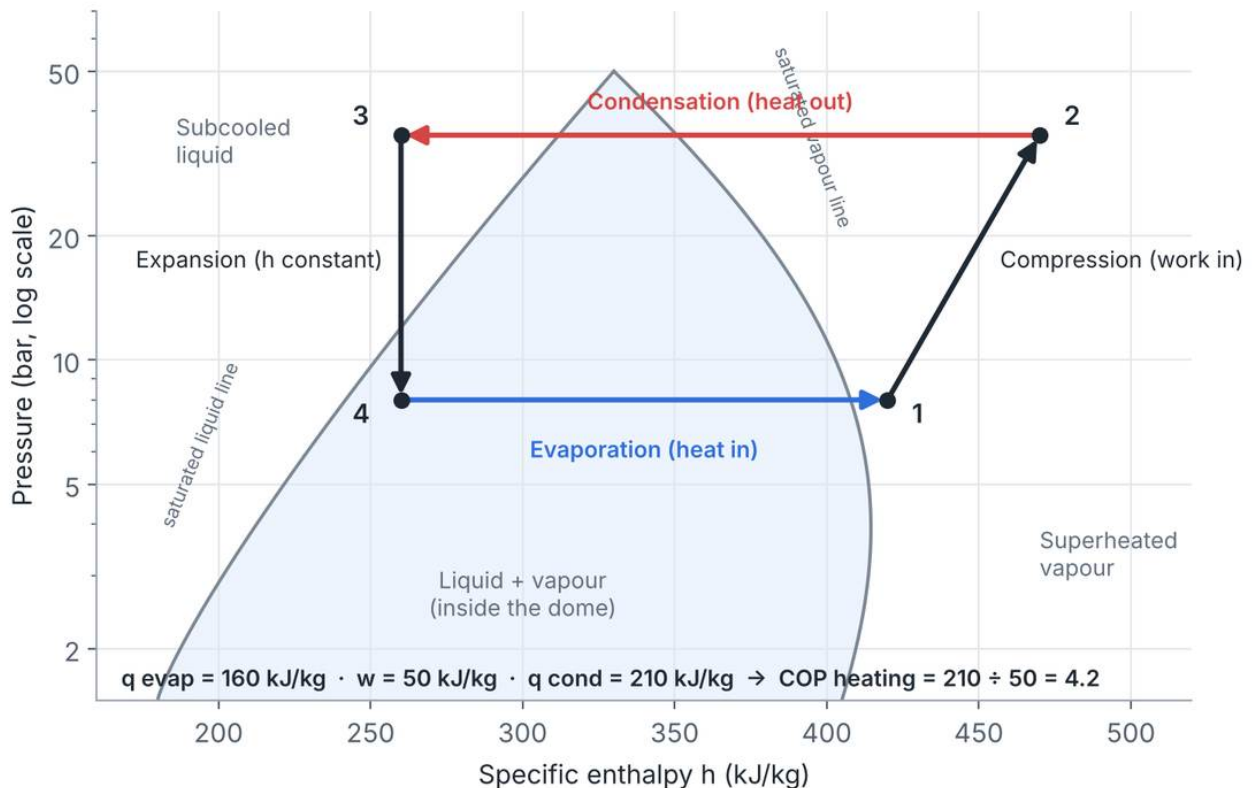
A dome-shaped curve sits in the middle. Left of the dome is liquid. Inside it is a liquid–vapour mix. Right of it is vapour. The left edge is the **saturated liquid line**; the right edge is the **saturated vapour line**.

The cycle draws as a rough box:

- **4 → 1, evaporation:** horizontal line at low pressure, moving right. The length is heat absorbed.
- **1 → 2, compression:** a line going up and to the right. The horizontal shift is compressor work.
- **2 → 3, condensation:** horizontal line at high pressure, moving left. The length is heat delivered.
- **3 → 4, expansion:** a vertical line straight down. Enthalpy does not change.

Reading a P-h diagram: the cycle and its energy

Illustrative values, not tied to one refrigerant



P-h diagram with the cycle and its energy

Worked example — COP from a P-h diagram (illustrative enthalpies).

$$COP_{heating} = \frac{h_2 - h_3}{h_2 - h_1}$$

- Read from the diagram: $h_1 = 420$ kJ/kg, $h_2 = 470$ kJ/kg, $h_3 = h_4 = 260$ kJ/kg.
- Heat delivered $q_{cond} = 470 - 260 = 210$ kJ/kg.
- Compressor work $w = 470 - 420 = 50$ kJ/kg.
- $COP = 210 \div 50 = 4.2$.
- Check: $q_{evap} = 420 - 260 = 160$ kJ/kg, and $160 + 50 = 210$. The balance holds.

Mass flow for a 12 kW unit: $m = 12 \div 210 \approx 0.057 \text{ kg/s}$.

Remember

- Horizontal = pressure constant; vertical = enthalpy constant.
- Evaporation and condensation are horizontal lines.
- Expansion is vertical: no energy added or removed.
- $\text{COP} = \text{condenser enthalpy change} \div \text{compressor enthalpy change}$.

Field tip: Keep a P-h chart and P-T chart for each refrigerant you service. Gauge readings mean nothing without them.



2.9 What drives COP: temperature lift and operating conditions

Key idea: COP depends mostly on temperature lift — the gap between the source temperature and the delivery temperature; the smaller the lift, the higher the COP.

Temperature lift is condensing temperature minus evaporating temperature. A small lift is like pumping water up one floor. A big lift is like pumping it up to the tenth floor. The higher the climb, the more work per litre.

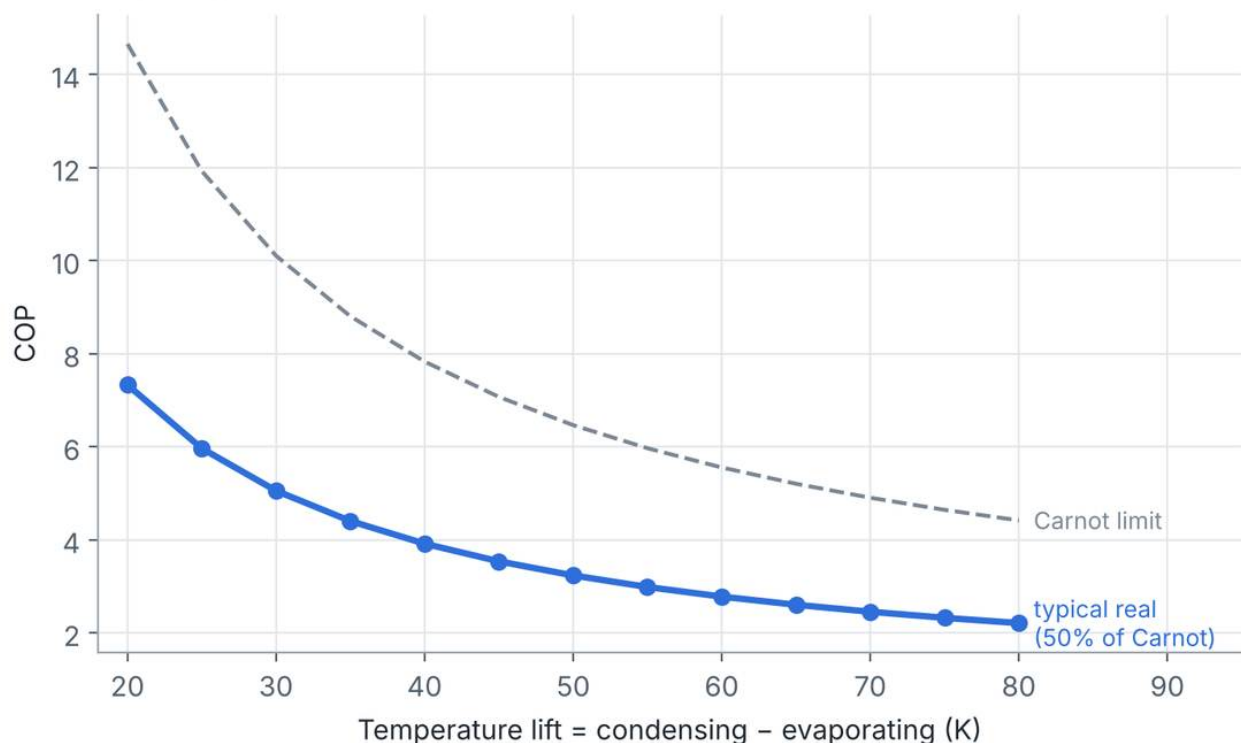
Physics sets a ceiling called the **Carnot COP**. It uses absolute temperatures in kelvin ($^{\circ}\text{C} + 273.15$). Real heat pumps typically reach about 40–60% of Carnot COP, because of compressor losses, heat exchanger temperature differences and pressure drops.

So COP rises when:

- the source is warmer (summer air in Chennai beats winter air in Delhi);
- the delivery water is cooler (45 °C needs less lift than 65 °C);
- heat exchangers are clean and correctly sized (smaller approach temperatures);
- water and air flows are correct.

Smaller temperature lift, higher COP

Evaporating at 0 °C. Real COP taken as 50% of the Carnot limit (illustrative).



COP vs temperature lift

Temperature lift (K)	Condensing temp (°C)	Carnot COP	Approx. real COP (50% of Carnot)
20	20	14.7	7.3
30	30	10.1	5.1
40	40	7.8	3.9
50	50	6.5	3.2
60	60	5.6	2.8
70	70	4.9	2.5

All rows assume an evaporating temperature of 0 °C, so condensing temperature equals the lift.

Worked example — same unit, Chennai summer vs Delhi winter, water at 55 °C.

$$COP_{Carnot} = \frac{T_{cond}}{T_{cond} - T_{evap}} \quad (T \text{ in kelvin})$$

- Assume condensing at 60 °C (5 K above water) = 333.15 K.
- Chennai, air 32 °C, evaporating about 24 °C = 297.15 K. Lift = 36 K. Carnot COP = 333.15 ÷ 36 ≈ 9.3. Real at 50% ≈ 4.6.
- Delhi winter, air 8 °C, evaporating about 0 °C = 273.15 K. Lift = 60 K. Carnot COP = 333.15 ÷ 60 ≈ 5.6. Real at 50% ≈ 2.8.
- Daily 17.4 kWh of heat (from lesson 2.1): Chennai 17.4 ÷ 4.6 ≈ 3.8 kWh ≈ ₹34; Delhi 17.4 ÷ 2.8 ≈ 6.2 kWh ≈ ₹56 (₹9/kWh example rate).

Remember

- Lift is the main driver of COP.
- Lower the delivery temperature whenever the application allows.
- Carnot COP is a ceiling; real units reach about half of it (typical).
- Always quote COP with its test conditions (air and water temperatures).

Common mistake: Comparing two units' COPs measured at different conditions. A COP without its air and water temperatures is meaningless.



2.10 Defrost and low-ambient operation

Key idea: When outdoor air is cold and humid, frost forms on the evaporator; the unit must periodically melt it, and at very low temperatures capacity and COP both fall.

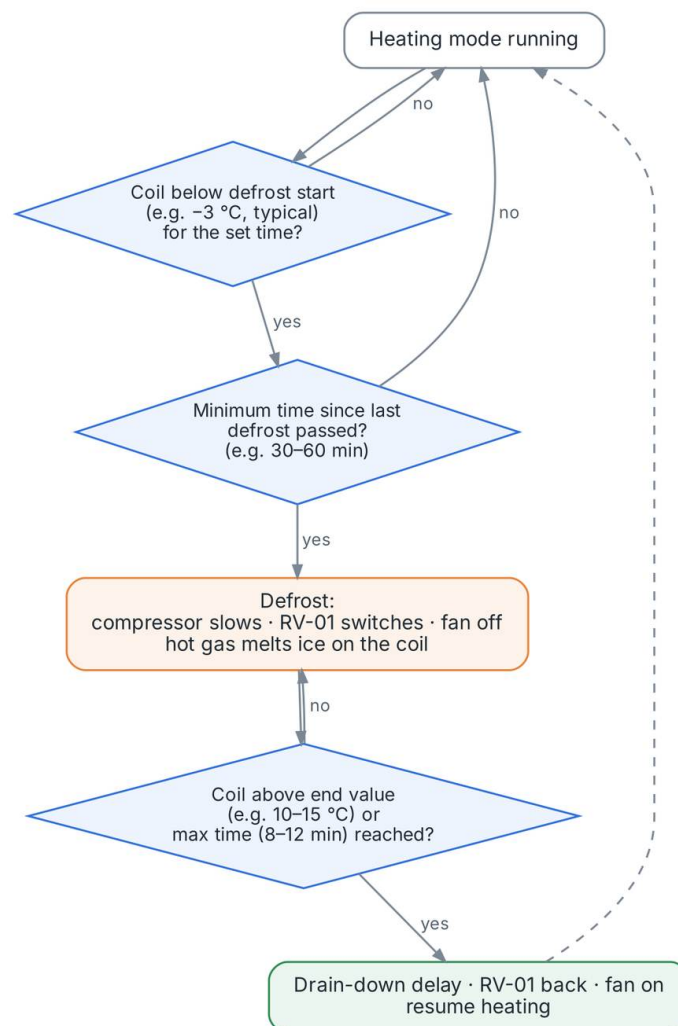
When the coil surface goes below 0 °C, moisture in the air freezes on the fins. Frost blocks airflow, like ice in an old freezer. Suction pressure falls and capacity drops.

Frosting is worst with outdoor air around –5 °C to +7 °C and high humidity (typical). In very dry, very cold air there is less moisture, so less frost. In India this matters in north Indian winters, hill stations and humid winter mornings; it rarely matters in coastal south India.

Reverse-cycle defrost is the most common method. The 4-way valve switches, so hot gas goes to the outdoor coil and melts the frost. The fan stops so heat stays on the coil. Heat is briefly taken from the water side. **Hot-gas bypass defrost** sends some discharge gas directly to the evaporator without reversing.

The controller starts defrost using coil temperature, time since last defrost, and sometimes the coil-to-air temperature difference. It ends defrost when the coil is warm enough or after a maximum time. Good logic defrosts only when needed.

How a defrost cycle is triggered and ended (typical settings)



How a defrost cycle starts and ends

Low-ambient challenge	Effect	Design response
Frost on coil	Lower airflow and capacity	Defrost logic, wide fin spacing
Low suction pressure	High compression ratio, hot discharge	EVI (enhanced vapour injection) or two-stage compressor
Refrigerant migration when off	Oil dilution, liquid at start	Crankcase heater
Melt water freezing at base	Ice builds up, blocks drain	Base-pan heater, raised mounting
Water pipes freezing	Burst pipes, damaged exchanger	Anti-freeze pump run, glycol, trace heating

Enhanced vapour injection (EVI) injects extra vapour mid-way through compression. It cools the compressor and restores capacity at low ambient.

Remember

- Frost forms when the coil is below 0 °C and the air is humid.
- Reverse-cycle defrost uses the 4-way valve to send hot gas to the coil.
- Defrost uses energy, so it should run only when needed.
- Capacity and COP fall as outdoor air gets colder.

Field tip: Mount outdoor units on a stand above snow and melt-water level, and keep the drain path clear of ice.



Quiz 2

1. A heat pump delivers 12 kW of heat and draws 3 kW. What is its COP?
 - A) 0.25
 - B) 3
 - C) 4
 - D) 9
2. Where does the refrigerant absorb heat?
 - A) Condenser
 - B) Evaporator
 - C) Compressor
 - D) Expansion valve
3. What happens to the refrigerant in the expansion device?
 - A) Pressure rises
 - B) It condenses
 - C) Pressure drops and part of it flashes
 - D) It is superheated
4. Which compressor type is most common in mid-size units of about 5–100 kW?
 - A) Screw
 - B) Scroll
 - C) Centrifugal
 - D) Capillary
5. "Inverter" in a heat pump means:
 - A) A type of evaporator
 - B) A variable-speed drive for the compressor
 - C) A reversing valve
 - D) A safety switch
6. Suction line is 9 °C and saturation temperature at suction pressure is 3 °C. Superheat is:
 - A) 3 K
 - B) 6 K
 - C) 9 K
 - D) 12 K
7. The most likely cause of a high-pressure switch trip in water heating is:
 - A) Dirty outdoor coil
 - B) Low water flow through the condenser
 - C) Low ambient air
 - D) Too much superheat
8. On a P-h diagram, the expansion process is:
 - A) A horizontal line
 - B) A vertical line
 - C) A curve to the right
 - D) A loop
9. Which change raises COP the most?
 - A) Raising water set-point from 45 °C to 60 °C
 - B) Lowering temperature lift
 - C) Running the fan slower
 - D) Blocking the coil
10. During reverse-cycle defrost:
 - A) Hot gas is sent to the outdoor coil and the fan stops

- B) The water pump is switched off permanently
- C) The compressor runs backward
- D) Cold air melts the frost

Answer key

1. C — $\text{COP} = 12 \div 3 = 4$.
 2. B — The evaporator boils refrigerant, absorbing heat from the source.
 3. C — The device drops pressure, so some liquid flashes to vapour and cools.
 4. B — Scroll compressors dominate the mid range.
 5. B — An inverter changes compressor motor speed to match load.
 6. B — $9 - 3 = 6 \text{ K}$.
 7. B — No or low water flow means heat is not removed, so discharge pressure rises.
 8. B — Expansion happens at constant enthalpy, so it is a vertical line.
 9. B — COP rises as lift falls; the other options increase lift or reduce heat transfer.
 10. A — The 4-way valve sends hot gas to the outdoor coil; the fan stops to keep heat on the coil.
-



Glossary

Term	Meaning
Heat pump	Machine that moves heat from a cold source to a warmer sink using work
COP	Coefficient of performance: useful heat ÷ electricity used
Refrigerant	Working fluid that boils and condenses in the circuit
Evaporator	Heat exchanger where refrigerant boils and absorbs heat
Condenser	Heat exchanger where refrigerant condenses and releases heat
Compressor	Pump that raises refrigerant pressure and temperature
Expansion device	Restriction that drops refrigerant pressure (capillary, TXV, EEV)
TXV	Thermostatic expansion valve, controlled by a suction-line bulb
EEV	Electronic expansion valve, moved by a stepper motor and controller
Superheat	Vapour temperature above its saturation temperature
Subcooling	Liquid temperature below its saturation temperature
Saturation temperature	Boiling or condensing temperature at a given pressure
Enthalpy	Heat content per kg of refrigerant, kJ/kg
P-h diagram	Chart of pressure vs enthalpy used to plot the cycle
Temperature lift	Condensing temperature minus evaporating temperature
Carnot COP	Theoretical maximum COP from absolute temperatures
Approach	Temperature gap between refrigerant and air or water in an exchanger
Counterflow	Two fluids flowing in opposite directions in an exchanger
BPHE	Brazed plate heat exchanger
Hermetic compressor	Motor and compressor sealed in one welded shell
Inverter	Variable-speed drive for the compressor motor
4-way reversing valve	Valve that swaps high and low sides for defrost or cooling
NTC thermistor	Temperature sensor whose resistance falls as temperature rises
HP / LP switch	High- and low-pressure safety switches
Defrost	Melting frost from the evaporator coil
EVI	Enhanced vapour injection, improves low-ambient capacity
Crankcase heater	Heater that keeps refrigerant out of compressor oil when off

Course 3 — Types of Heat Pumps

Powered by Sunniva. This Level 1 Foundations course is for everyone: technicians, engineers, sales and service staff, consultants and students. No prior knowledge beyond Course 1 and 2 is needed. After this course you will be able to:

- Name any heat pump by its heat source and heat sink, and say where it fits.
- Sketch a simple system schematic for air-to-water, water-to-water, ground-source and air-to-air machines.
- Explain the difference between monoblock and split construction, and between standard and high-temperature machines.
- Compare a heat pump with a solar water heater, a boiler and an electric geyser on running cost for an Indian site.

3.1 Classifying by heat source and heat sink

Key idea: Every heat pump is named "source-to-sink" — where it takes heat from, and where it delivers heat to.

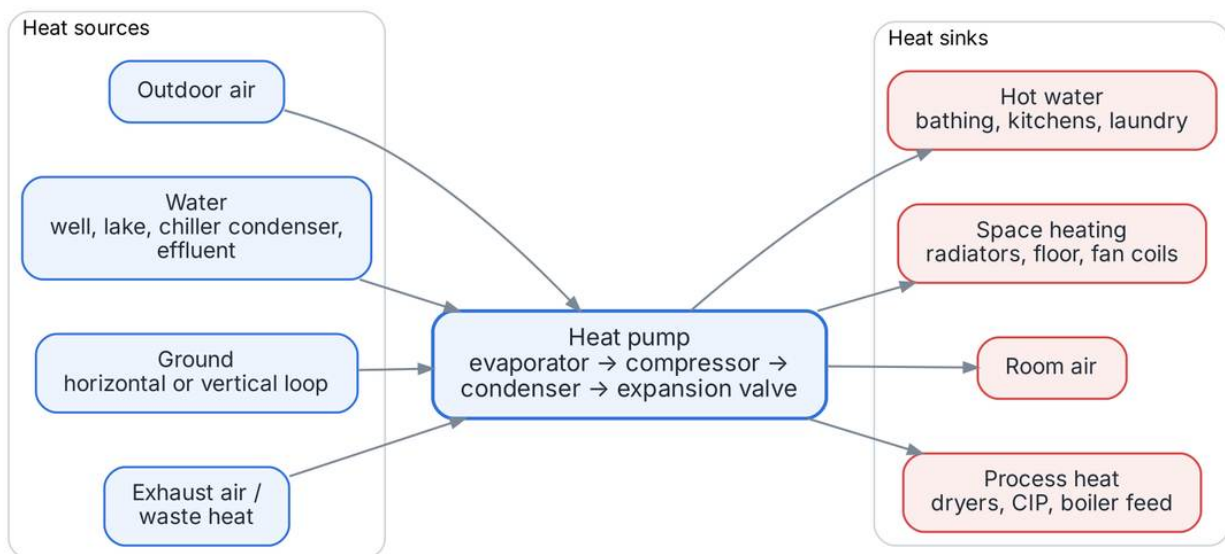
A heat pump moves heat from a cooler place to a warmer place. The place it takes heat from is the **heat source**. The place it delivers heat to is the **heat sink**.

Think of a fridge. It takes heat from the food (source) and throws it out at the back grille into kitchen air (sink). A heat pump works the same way, but we use the hot side on purpose.

The name follows a simple rule: source first, sink second. An "air-to-water" heat pump takes heat from outdoor air and heats water. A "water-to-water" heat pump takes heat from one water stream and heats another.

The three common sources are air, water and ground. The three common sinks are water, air and process (a product, a dryer, or steam).

Heat pumps are named by where heat comes from and where it goes



Heat pumps named by source and sink

Type	Heat source	Heat sink	Typical Indian use
Air-to-water	Outdoor air	Water	Hotel, hostel, hospital hot water
Water-to-water	Water stream (well, chiller condenser, effluent)	Water	Waste-heat recovery in factories
Ground-source (brine-to-water)	Ground via a buried loop	Water	Cold regions, very large buildings
Air-to-air	Outdoor air	Indoor air	Room AC with heating mode, VRF
Exhaust air-to-water	Warm exhaust air	Water	Kitchens, laundries, dryers

Remember

- Name = source first, sink second.
- Sources: air, water, ground, waste heat.
- Sinks: water, air, process.
- A warmer source means less work for the compressor and a higher COP.

Field tip: On a site visit, first ask "what warm stream is already being thrown away?" It may be a better source than outdoor air.



3.2 Air-to-water heat pumps

Key idea: An air-to-water heat pump pulls heat from outdoor air with a fan and coil, and puts it into water through a plate or tube heat exchanger.

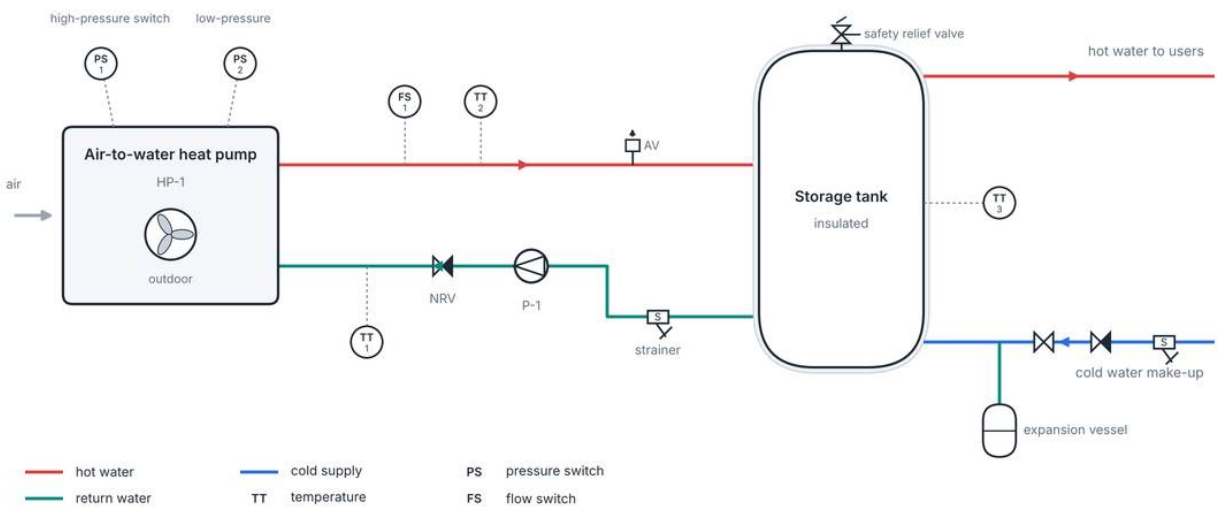
This is the most common heat pump for hot water in India. It needs no well, no borehole and no waste stream. It needs only outdoor air and a place with good airflow.

The fan blows outdoor air across the **evaporator** (a finned coil where the refrigerant boils and absorbs heat). The **compressor** raises refrigerant pressure and temperature. The **condenser** (a plate or shell-and-tube heat exchanger) gives this heat to the water. The **expansion valve** drops the pressure so the cycle can repeat.

Most of India is warm, so air is a good source for most of the year. In Chennai or Mumbai, outdoor air is 25–35 °C almost all year. In Delhi winter nights it can drop to 5 °C, and in Leh to well below 0 °C. COP falls as air gets colder.

Air-to-water heat pump with storage tank (P&ID)

Packaged unit outdoors; water loop to an insulated tank; hot water drawn from the top



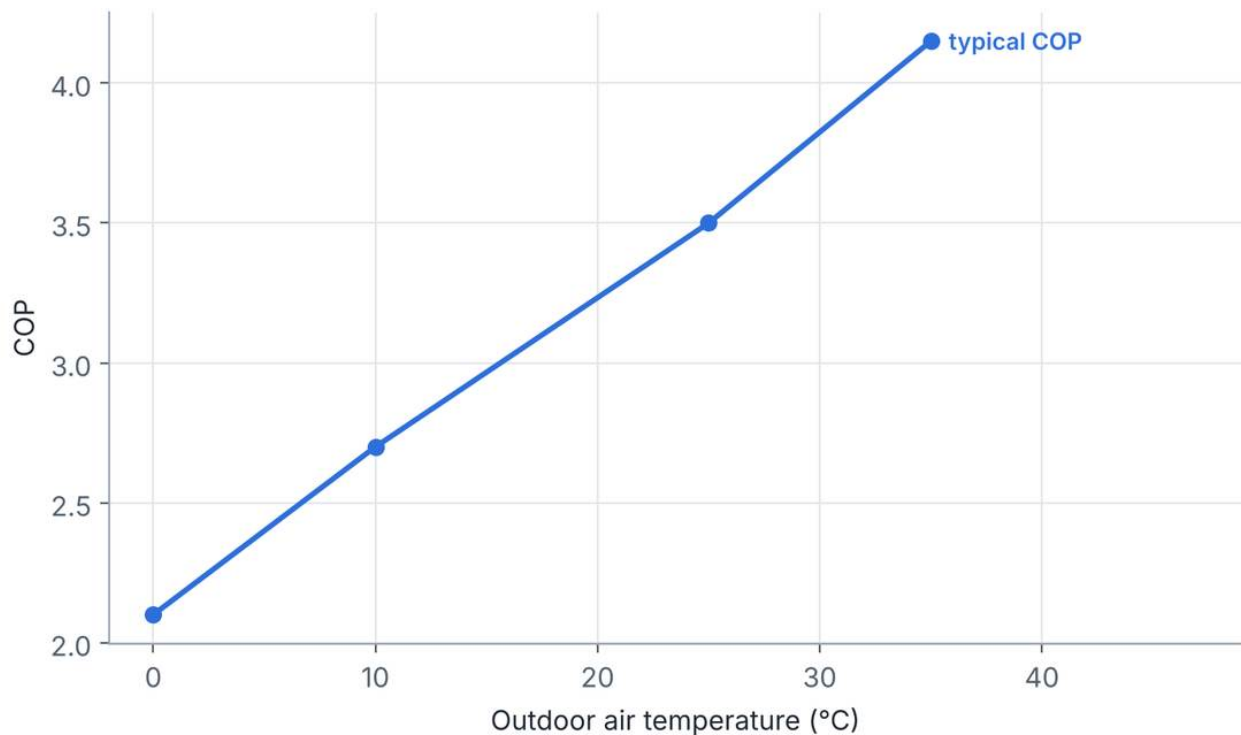
P&ID: air-to-water heat pump with storage tank

Outdoor air (°C)	Typical COP, water to 55 °C	Notes
35	3.8–4.5	Summer, coastal cities
25	3.2–3.8	Most Indian plains, average
10	2.4–3.0	North India winter
0	1.8–2.4	Hill stations; defrost needed

(All values typical; check the machine's datasheet.)

Air-to-water COP at 55 °C water, by outdoor temperature

Typical, illustrative values. Real machines vary; use the datasheet.



Air-to-water COP by outdoor temperature

Worked example — Hotel hot water in Pune

A hotel needs 1,000 L of water heated from 25 °C to 55 °C each day. Compare an electric geyser and an air-to-water heat pump (typical COP 3.5). Example electricity rate ₹9/kWh.

$$Q = \frac{m \cdot c_p \cdot \Delta T}{3600}$$

- $m = 1,000 \text{ kg}$, $c_p = 4.186 \text{ kJ/kg} \cdot \text{K}$, $\Delta T = 30 \text{ K}$
- $Q = 1,000 \times 4.186 \times 30 \div 3,600 = 34.9 \text{ kWh}$ of heat per day
- Electric geyser (about 98 % efficient): $34.9 \div 0.98 = 35.6 \text{ kWh} \rightarrow 35.6 \times ₹9 = ₹320$ per day
- Heat pump: $34.9 \div 3.5 = 10.0 \text{ kWh} \rightarrow 10.0 \times ₹9 = ₹90$ per day
- Saving: about ₹230 per day, or roughly ₹84,000 per year.

Remember

- Source = outdoor air; sink = water.
- Needs free airflow; do not box the unit in.
- COP falls in cold weather; below about 5 °C, the coil may frost and need defrost.
- Best fit for most Indian hot-water jobs.

Common mistake: Installing the unit in a closed basement or shaft. It recirculates its own cold exhaust air and COP collapses.

3.3 Water-to-water and waste-heat recovery heat pumps

Key idea: A water-to-water heat pump takes heat from a warm water stream that is already available and lifts it to a useful temperature.

Many factories and buildings throw heat away. A chiller rejects heat at its cooling tower at about 32–37 °C. Laundries drain warm water. Dairies and pharma plants have warm effluent and condenser water.

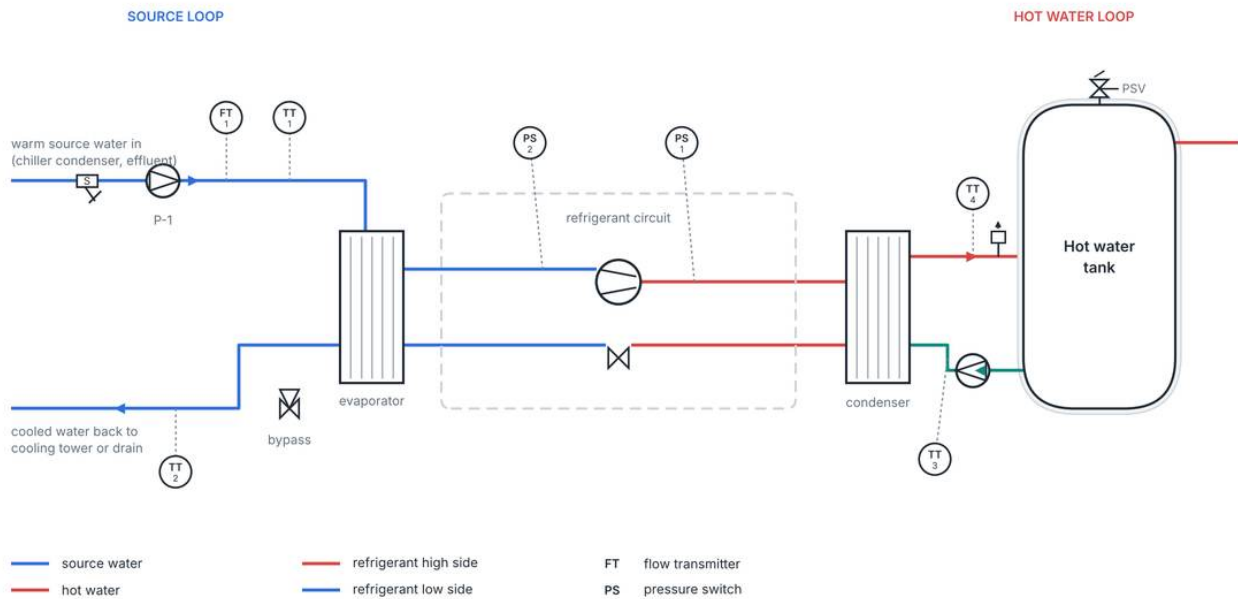
These streams are too cool to use directly. A water-to-water heat pump lifts them to 55–80 °C. Because the source is warm and steady, COP is high, typically 4–6.

Both sides are water, so the machine is compact. The evaporator and condenser are both plate or shell-and-tube heat exchangers. There is no fan and no defrost.

Every cooling tower and drain carries heat away to be wasted. A waste-heat heat pump catches that heat and puts it back to work.

Water-to-water heat pump recovering waste heat (P&ID)

Warm source water is cooled in the evaporator; the condenser heats a hot water tank



P&ID: water-to-water heat pump recovering waste heat

Waste-heat source	Typical temperature (°C)	Typical hot-water output (°C)
Chiller condenser water	30–37	55–65
Air compressor cooling water	35–50	60–75
Laundry / dyeing drain	30–45	55–70
Process effluent	25–40	55–65
Borewell water	25–30	50–60

(All values typical.)

Worked example — Chiller heat recovery in a Chennai hospital

Condenser water flows at 20 m³/h, cooled from 37 °C to 32 °C. A water-to-water heat pump (typical COP 5) uses this heat.

$$Q_{source} = \dot{V} \times 1.163 \times \Delta T \quad Q_{hot} = Q_{source} \times \frac{COP}{COP - 1}$$

- 1.163 kWh/m³·K is the heat capacity of water.
- Q source = 20 × 1.163 × 5 = 116 kW
- Q hot = 116 × 5 ÷ 4 = 145 kW of hot water heat

- Electrical input $W = 145 - 116 = 29 \text{ kW}$
- Bonus: the cooling tower now rejects 116 kW less heat, saving fan power and make-up water.

Remember

- Warm, steady source → high COP.
- No fan, no defrost, compact.
- Check source flow and temperature over a full day, not one reading.
- Use a strainer and a plate HX that suits the water quality.

Field tip: Indian borewell and effluent water is often hard or dirty. Fit a strainer and consider an intermediate plate heat exchanger to protect the evaporator.



3.4 Ground-source heat pumps

Key idea: A ground-source heat pump uses the steady temperature of the earth, reached through a buried pipe loop filled with water or brine.

A few metres below the surface, ground temperature stays almost the same all year. It is close to the area's average annual air temperature. In most of the Indian plains this is about 24–30 °C. In Leh or Shimla it is much colder, typically 5–15 °C.

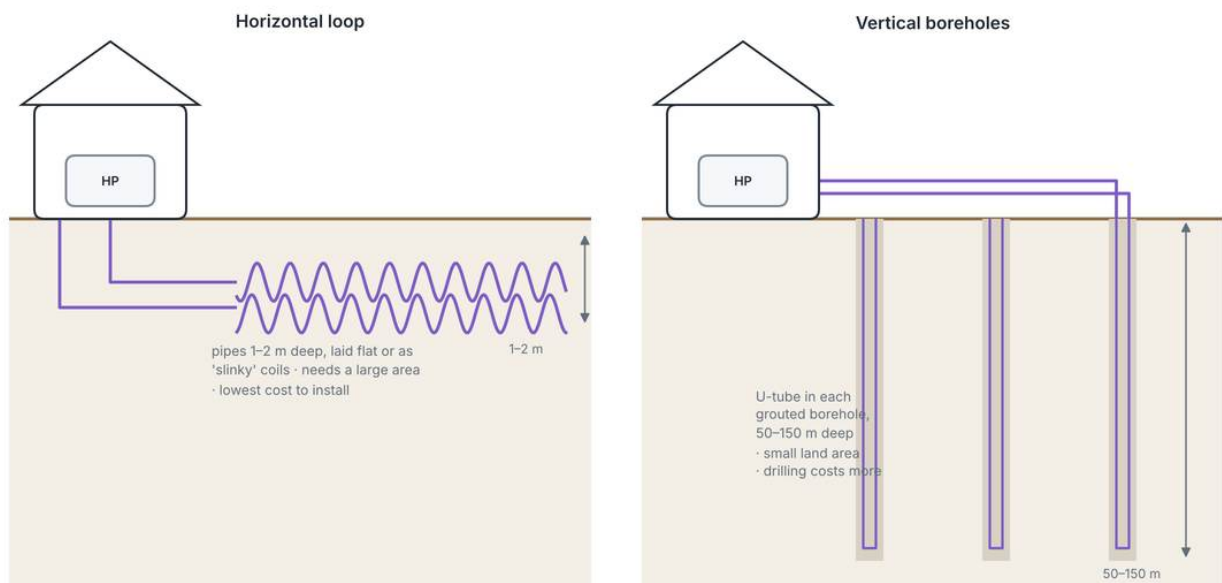
A plastic (HDPE) pipe loop is buried in the ground. Water or **brine** (water with antifreeze, such as glycol) circulates through it. It picks up heat from the soil and carries it to the heat pump's evaporator.

There are two main loop types. A **horizontal loop** is laid in trenches about 1–2 m deep and needs a large open area. A **vertical loop** uses boreholes, typically 50–150 m deep, and needs little land.

In hot Indian climates, ground-source is mostly used for cooling, where the ground absorbs condenser heat. For heating, it pays off most in cold regions where air is very cold in winter.

Ground loops: horizontal vs vertical

Same building and heat pump; the loop is the difference



Both loops: circulation pump, expansion vessel, air vent and TT on loop supply and return, inside the plant room.

Ground loops: horizontal vs vertical

Feature	Horizontal loop	Vertical loop
Depth	1–2 m	50–150 m (typical)
Land needed	Large	Small
Installation cost	Lower (trenching)	Higher (drilling)
Ground temperature stability	Varies a little with season	Very stable
Typical heat extraction	10–25 W per m ² of land	30–60 W per m of borehole

(Heat extraction depends strongly on soil and moisture; values typical.)

Worked example — Borehole length for a Shimla guest house

Heating need is 10 kW. Heat pump COP is 4. Soil allows a typical 40 W per metre of borehole.

$$Q_{\text{ground}} = Q_{\text{heat}} \times \frac{\text{COP} - 1}{\text{COP}} \quad L = \frac{Q_{\text{ground}}}{q}$$

- $Q_{\text{ground}} = 10 \times 3 \div 4 = 7.5 \text{ kW} = 7,500 \text{ W}$
- $L = 7,500 \div 40 = 188 \text{ m of borehole}$

- Practical layout: two boreholes of about 95 m each.

Remember

- Ground stays near the annual average air temperature.
- Horizontal = shallow, large area; vertical = deep, small area.
- Highest first cost of all types; lowest variation in COP.
- Best fit in cold regions, or for large combined heating and cooling.

Common mistake: Undersizing the loop. The ground slowly cools (or heats) over years and COP drops season after season.



3.5 Air-to-air and heat-recovery air conditioning

Key idea: Every room air conditioner is an air-to-air heat pump; a reversing valve lets many of them heat as well as cool.

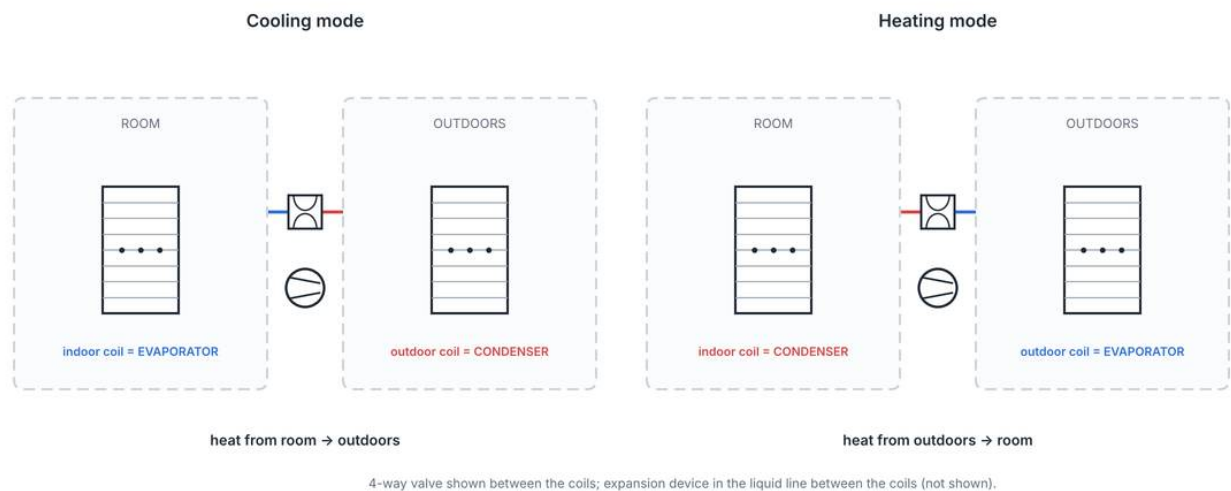
In cooling mode, an AC takes heat from room air and throws it outdoors. In heating mode, a **four-way reversing valve** swaps the flow. The outdoor coil becomes the evaporator and the indoor coil becomes the condenser.

Heating-mode ACs are useful in north Indian winters. They give 2.5–4 kW of heat per kW of power, typically, versus 1 kW from an oil-filled or fan heater.

Larger buildings use **VRF** (variable refrigerant flow) systems. One outdoor unit serves many indoor units. A **heat-recovery VRF** can cool some rooms and heat others at the same time. It moves heat from the server room to the reception, for example.

A simpler form of heat recovery is a **desuperheater**. This small heat exchanger on the hot discharge gas of an AC or chiller makes free hot water while the unit cools.

Air-to-air heat pump: the 4-way valve swaps the coils' jobs



Air-to-air heat pump in cooling and heating mode

Feature	Room AC (heat pump mode)	Heat-recovery VRF	Desuperheater
Heats	Room air	Some rooms, while cooling others	Water
Typical size	1–2.5 TR	8–60 TR outdoor units	Fraction of chiller rating
Main benefit	Low-cost winter heating	Moves heat between zones	Free hot water while cooling

(1 TR = 3.517 kW of cooling.)

Remember

- An AC is a heat pump; the reversing valve gives heating.
- Heat-recovery VRF heats and cools different rooms at once.
- A desuperheater recovers some condenser heat as hot water.
- Air-to-air heats air, not water.

Field tip: In heating mode the outdoor coil can frost in cold, humid weather. Short pauses for defrost are normal, not a fault.

3.6 Monoblock vs split construction

Key idea: In a monoblock, the whole refrigerant circuit is sealed in one outdoor box; in a split, refrigerant pipes run between an outdoor and an indoor unit.

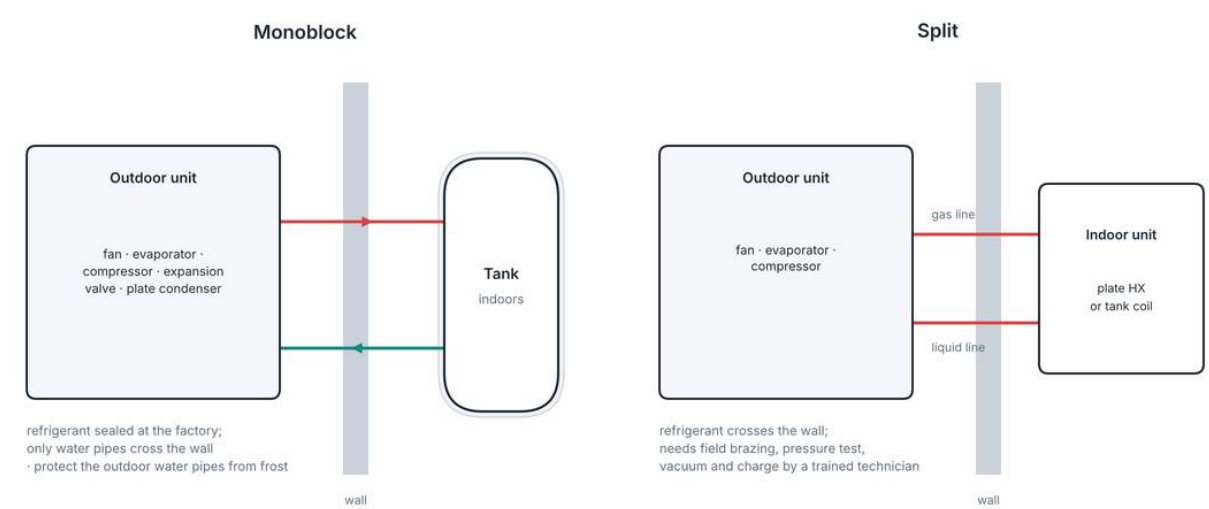
A **monoblock** (also called packaged) heat pump has compressor, evaporator, condenser and valves in one unit. The factory charges and tests it. On site, the installer only connects water pipes and power.

A **split** heat pump has two parts. The outdoor unit holds the fan, coil and usually the compressor. The indoor unit holds the water heat exchanger (and sometimes the tank). Copper refrigerant lines join them.

The split needs field brazing, nitrogen pressure test, vacuum and refrigerant charging. This needs a trained refrigeration technician. The monoblock avoids this, so leak risk on site is lower.

The monoblock's weakness is that water pipes run outdoors. In cold regions they can freeze, so glycol or trace heating is needed. In most of India this is not a problem, but in cold, high-altitude regions such as Leh and Shimla it is a real risk; see lesson 4.9.

Monoblock vs split: what crosses the wall



Monoblock vs split

Feature	Monoblock	Split
Refrigerant work on site	None	Brazing, pressure test, vacuum, charge
Leak risk on site	Low	Higher
What crosses the wall	Water pipes	Refrigerant pipes
Freeze risk	Water pipes outdoors (cold regions)	Low; water stays indoors
Indoor space	Only tank	Indoor unit + tank
Service	Mostly at the outdoor unit	Two locations
Typical sizes	Small to very large	Mostly small domestic

Remember

- Monoblock: factory-sealed, water connections only.
- Split: refrigerant lines, needs a trained technician.
- Monoblock is the usual choice for commercial and industrial jobs.
- Split suits homes where only small pipes can enter the building.

Common mistake: On a split, skipping the deep vacuum. Moisture left in the lines causes acid, ice at the expansion valve and compressor failure.

3.7 High-temperature heat pumps (80–120 °C) and refrigerant choice

Key idea: To deliver 80–120 °C, a heat pump needs a refrigerant that can condense at high temperature, and a warm source to keep the lift small.

Standard heat pumps deliver water up to about 55–65 °C. Many industries need more: pasteurisation, dyeing, CIP (clean-in-place) washing, drying and boiler feed water. A **high-temperature heat pump** (HTHP) delivers 80–120 °C.

Every refrigerant has a **critical temperature**. Above it, the gas cannot be condensed into liquid. To condense at 100 °C, the refrigerant's critical temperature must be well above 100 °C.

The **temperature lift** is the gap between source and sink temperature. A bigger lift means a lower COP. So HTHPs work best with a warm source, such as 40–60 °C waste water.

Think of a pressure cooker. Raising the pressure lets water stay liquid above 100 °C. A heat pump refrigerant also needs high pressure to condense at high temperature, and every refrigerant has its own limit.

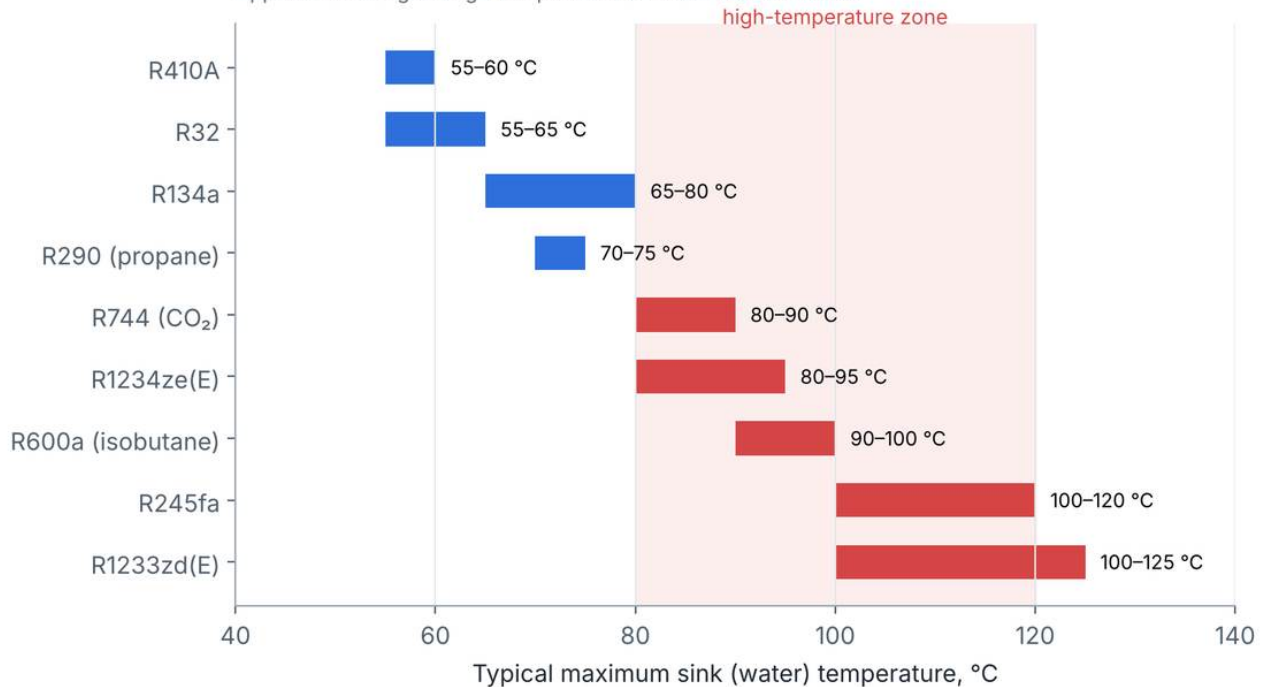
Refrigerant	Type	Critical temp. (°C, approx.)	GWP (approx.)	Typical max. sink temp.	Notes
R410A	HFC blend	71	~2,090	55–60 °C	Common in older units
R32	HFC	78	~675	55–65 °C	Mildly flammable (A2L)
R134a	HFC	101	~1,430	65–80 °C	Widely used, being phased down
R290 (propane)	Natural (HC)	97	~3	70–75 °C	Flammable (A3); small charge
R744 (CO ₂)	Natural	31	1	80–90 °C (transcritical)	Very high pressure; best with cold inlet water
R1234ze(E)	HFO	109	<1	80–95 °C	Mildly flammable (A2L)
R600a (isobutane)	Natural (HC)	135	~3	90–100 °C	Flammable (A3)
R245fa	HFC	154	~1,030	100–120 °C	Low pressure
R1233zd(E)	HFO	166	~1	100–120+ °C	Low pressure, non-flammable

(Values approximate; GWP figures vary by IPCC report. Check the refrigerant datasheet.)



Typical maximum water temperature by refrigerant

Approximate ranges. High-temperature zone 80–120 °C shaded.



Typical maximum water temperature by refrigerant

Worked example — Why lift matters (ideal COP)

Compare lifting heat to 90 °C from 40 °C waste water versus from 25 °C outdoor air. Real machines achieve typically 35–45 % of the Carnot COP calculated from source and sink temperatures.

$$COP_{Carnot} = \frac{T_{sink}}{T_{sink} - T_{source}} \quad (T \text{ in kelvin})$$

- From 40 °C water: $363 \div (363 - 313) = 363 \div 50 = 7.3 \rightarrow$ real about 40 % $\rightarrow$ COP $\approx$ 2.9
- From 25 °C air: $363 \div (363 - 298) = 363 \div 65 = 5.6 \rightarrow$ real about 40 % $\rightarrow$ COP $\approx$ 2.2
- The warm source gives about 30 % more heat per kWh.

Remember

- HTHP = 80–120 °C output for industry.
- Refrigerant critical temperature sets the upper limit.
- Smaller lift $\rightarrow$ higher COP; pair HTHPs with warm waste heat.
- Low-GWP options: R290, R744, R600a, HFOs; note flammability class.

Common mistake: Promising 90 °C from a standard R410A or R32 machine. Its refrigerant cannot condense that hot.

3.8 Simultaneous heating and cooling

Key idea: A heat pump always produces cooling at the evaporator and heating at the condenser; using both at once nearly doubles the useful output for the same power.

A normal hot-water heat pump throws its cold side away to outdoor air. A normal chiller throws its hot side away at the cooling tower. A **simultaneous heating and cooling** heat pump uses both sides.

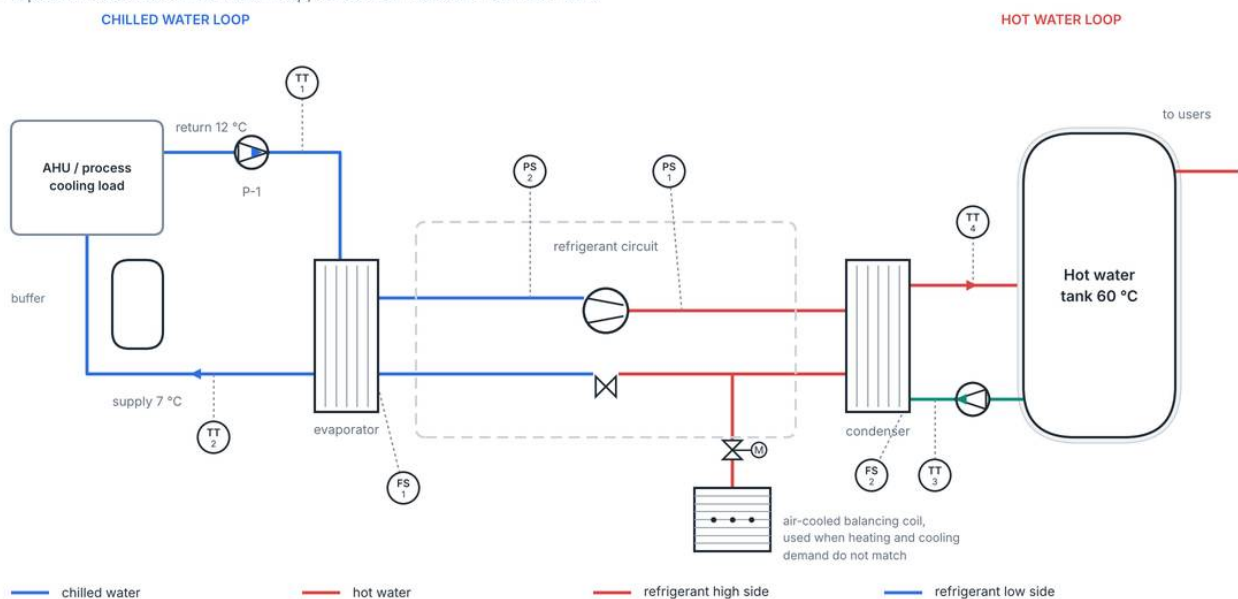
The evaporator chills water, typically to 7 °C supply and 12 °C return. The condenser heats water, typically to 55–65 °C. Both are put to work.

Good matches in India: hotels (AC plus bathing water), dairies (milk chilling plus CIP hot water), hospitals, food plants and pharma units.

When demand on one side drops, a **balancing coil** (an air-cooled coil) or the cooling tower rejects or picks up the extra heat. This keeps the machine running safely.

One heat pump, two useful outputs: chilled water and hot water (P&ID)

Evaporator cools the chilled water loop; condenser heats the hot water tank



P&ID: simultaneous heating and cooling

Worked example — Dairy in Anand, Gujarat

Power input $W = 10$ kW. Cooling output $Q_c = 20$ kW (milk chilling). Heating output $Q_h = 30$ kW (hot water at about 60 °C; 75–85 °C CIP water needs a booster or a high-temperature unit).

$$Q_h = Q_c + W \quad COP_{total} = \frac{Q_h + Q_c}{W}$$

- Check: $20 + 10 = 30$ kW ✓
- Heating-only COP = $30 \div 10 = 3.0$
- Total COP = $(30 + 20) \div 10 = 5.0$
- Daily for 10 h: 100 kWh power $\times$ ₹9 = ₹900 gives 300 kWh heat plus 200 kWh cooling.

Remember

- Evaporator = cooling, condenser = heating; use both.
- Total COP = (heating + cooling) $\div$ power, often 4.5–6 (typical, 7 °C chilled / 55–65 °C hot water).
- Best where heating and cooling are needed at the same hours.
- Plan a balancing coil or tower for mismatched loads.

Field tip: Log the hourly heating and cooling loads first. If they never overlap, a storage tank or two separate machines may be better.



3.9 Heat pumps vs solar water heaters, boilers and geysers: where each fits

Key idea: Each hot-water technology has a place; choose by running cost, reliability of supply, space and temperature needed.

An **electric geyser** turns 1 kWh of electricity into about 1 kWh of heat. It is cheap to buy and suits small, occasional use. Running cost is high for large volumes.

A **solar water heater** uses sunlight on flat-plate or evacuated-tube collectors. Fuel is free, but output depends on sunshine. It needs roof space and a backup for cloudy days and monsoon.

A **boiler** burns LPG, PNG, diesel or biomass. It can reach high temperatures and steam quickly. Fuel cost, emissions, safety and fuel handling are the drawbacks.

A **heat pump** gives 3–4 kWh of heat per kWh of power, typically. It works day and night, in any weather. First cost is higher than a geyser, but running cost is the lowest of the electric options.

Worked example — Cost of 1 kWh of useful heat (example fuel rates)

Example rates: electricity ₹9/kWh, LPG ₹100/kg, PNG ₹75/scm, diesel ₹100/L. Typical heating values: LPG ≈ 12.8 kWh/kg, PNG ≈ 10 kWh/scm, diesel ≈ 10 kWh/L.

$$\text{Cost per useful kWh} = \frac{\text{Fuel price}}{\text{Heating value} \times \text{Efficiency}}$$

- Electric geyser: ₹9 ÷ (1 × 0.98) = ₹9.2
- LPG boiler: ₹100 ÷ (12.8 × 0.85) = ₹9.2
- PNG boiler: ₹75 ÷ (10 × 0.85) = ₹8.8
- Diesel boiler: ₹100 ÷ (10 × 0.82) = ₹12.2
- Heat pump (COP 3.5): ₹9 ÷ 3.5 = ₹2.6

Cost of one useful kWh of heat

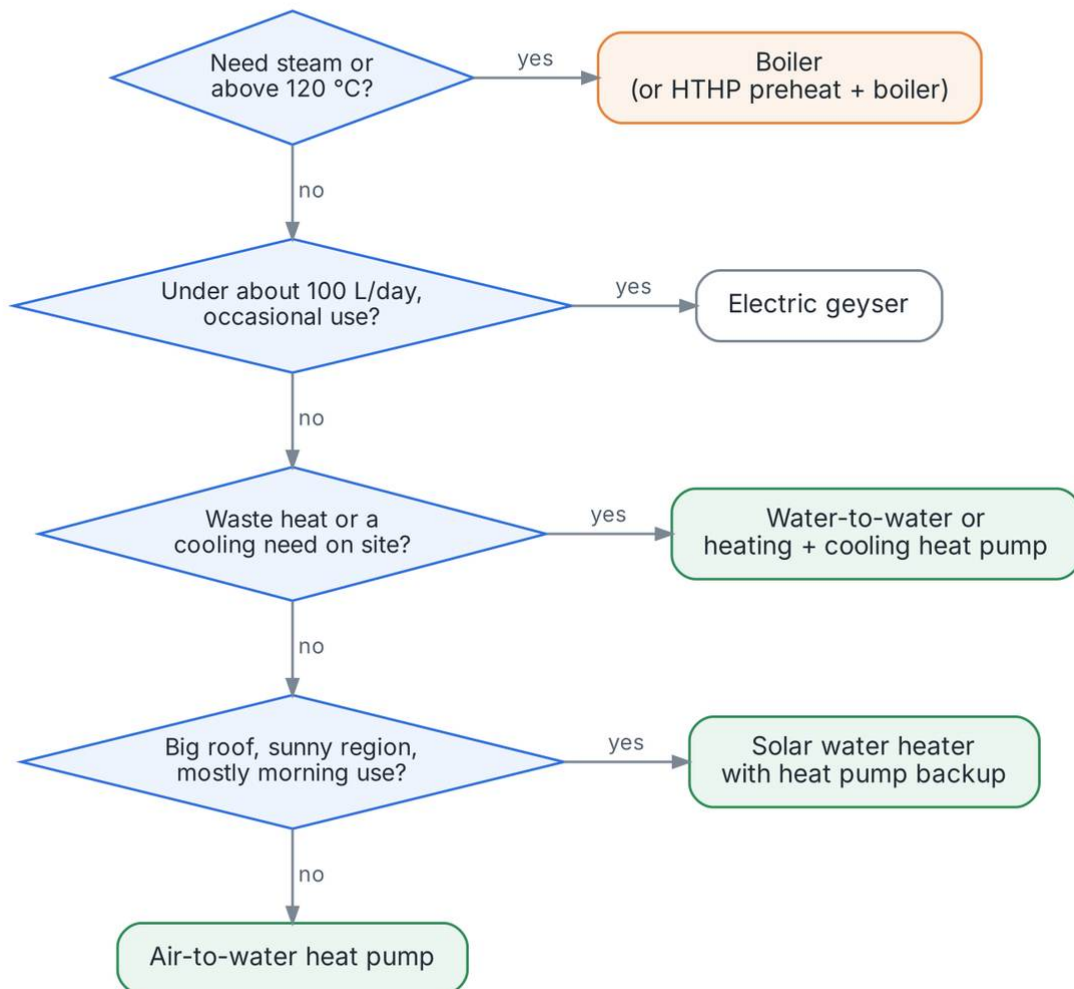
Example rates: electricity ₹9/kWh, LPG ₹100/kg, PNG ₹75/scm, diesel ₹100/L; typical efficiencies.



Cost of one useful kWh of heat

Technology	Typical efficiency / COP	Max. temp. (typical)	Works at night / monsoon	Best fit
Electric geyser	0.95–0.99	60–75 °C	Yes	Homes, small daily use
Solar water heater	Depends on sun	50–70 °C	No, needs backup	Sunny sites with roof space, morning use
LPG / PNG / diesel boiler	0.80–0.90	Steam / >100 °C	Yes	Steam, very high temperature
Heat pump	COP 3–4.5	55–65 °C standard; 80–120 °C high-temp	Yes	Large daily hot water, process heat to 90 °C
Solar + heat pump	Combined	55–65 °C	Yes	Lowest running cost, good space

Which hot water system fits?



Which hot water system fits?

Remember

- Geyser: cheap to buy, costly to run.
- Solar: free fuel, but weather-dependent; always needs backup.
- Boiler: for steam and very high temperatures.
- Heat pump: lowest running cost for most hot-water jobs up to 90 °C.
- Solar plus heat pump is a strong combination.

Common mistake: Comparing only purchase price. Over 5–10 years, running cost is usually far bigger than first cost.

Quiz 3

1. A heat pump that takes heat from a chiller's condenser water and makes hot water is called:
 - A. Air-to-water
 - B. Water-to-water
 - C. Air-to-air
 - D. Ground-source
2. In heat pump names, the first word describes the:
 - A. Refrigerant
 - B. Heat sink
 - C. Heat source
 - D. Compressor type
3. Why does an air-to-water heat pump's COP drop in winter?
 - A. Water gets hotter
 - B. The temperature lift increases
 - C. The fan stops
 - D. The refrigerant changes
4. A vertical ground loop typically uses boreholes of:
 - A. 1–2 m
 - B. 5–10 m
 - C. 50–150 m
 - D. 500–1,000 m
5. In an air-to-air heat pump, which part switches between cooling and heating?
 - A. Expansion valve
 - B. Four-way reversing valve
 - C. Filter drier
 - D. Flow switch
6. Which statement about a monoblock heat pump is true?
 - A. Refrigerant lines are brazed on site
 - B. Only water pipes and power are connected on site
 - C. It cannot be used for commercial jobs
 - D. It has no compressor
7. What mainly limits the maximum sink temperature of a refrigerant?
 - A. Its colour
 - B. Its critical temperature
 - C. Its oil type
 - D. Its cylinder size
8. A machine uses 10 kW to give 30 kW cooling and 40 kW heating at the same time. Total COP is:
 - A. 3
 - B. 4
 - C. 7
 - D. 10
9. With example rates (electricity ₹9/kWh), useful heat from a heat pump at COP 3.5 costs about:
 - A. ₹0.9/kWh
 - B. ₹2.6/kWh
 - C. ₹9.2/kWh
 - D. ₹12.2/kWh
10. A solar water heater on its own is not enough because:
 - A. It cannot heat above 30 °C

- B. It needs diesel
- C. Output depends on sunshine, so it needs backup
- D. It uses refrigerant

Answer key

1. B — Both source (condenser water) and sink (hot water) are water.
2. C — The name is always source first, sink second.
3. B — Colder air means a larger gap to the water temperature, so the compressor works harder.
4. C — Vertical boreholes are typically 50–150 m deep.
5. B — The reversing valve swaps the roles of the indoor and outdoor coils.
6. B — The refrigerant circuit is sealed and charged at the factory.
7. B — Above the critical temperature, the refrigerant cannot condense.
8. C — $(40 + 30) \div 10 = 7$.
9. B — $₹9 \div 3.5 \approx ₹2.6$.
10. C — Cloudy days, monsoon and night use need a backup heater.



Glossary

Term	Meaning
Heat source	The place or medium a heat pump takes heat from (air, water, ground, waste heat).
Heat sink	The place or medium a heat pump delivers heat to (water, air, process).
Air-to-water	Heat pump that takes heat from outdoor air and heats water.
Water-to-water	Heat pump that takes heat from one water stream and heats another.
Ground-source heat pump	Heat pump that uses the ground as its source through a buried loop.
Brine	Water mixed with antifreeze (for example glycol) used in ground or cold loops.
Horizontal loop	Ground loop laid in trenches about 1–2 m deep.
Vertical loop	Ground loop placed in boreholes, typically 50–150 m deep.
Air-to-air	Heat pump that heats or cools air directly, such as a room AC.
Four-way reversing valve	Valve that swaps an air-to-air heat pump between cooling and heating.
VRF	Variable refrigerant flow: one outdoor unit serving many indoor units.
Heat-recovery VRF	VRF that heats some rooms and cools others at the same time.
Desuperheater	Small heat exchanger that recovers heat from hot discharge gas to make hot water.
Monoblock	Heat pump with the full refrigerant circuit sealed in one unit; water connected on site.
Split	Heat pump with outdoor and indoor units joined by refrigerant pipes.
High-temperature heat pump (HTHP)	Heat pump delivering about 80–120 °C.
Critical temperature	Temperature above which a refrigerant cannot be condensed to liquid.
Temperature lift	Difference between sink and source temperatures; bigger lift lowers COP.
GWP	Global warming potential: warming effect of a gas compared with CO ₂ .
Carnot COP	The ideal, highest possible COP between two temperatures.
Simultaneous heating and cooling	Using a heat pump's cold and hot sides at the same time.
Balancing coil	Air coil that rejects or absorbs extra heat when heating and cooling loads do not match.
Waste heat	Heat currently thrown away, such as chiller condenser water or warm drain.
Solar water heater	System that heats water with sunlight using flat-plate or evacuated-tube collectors.
Electric geyser	Resistance water heater; about 1 kWh heat per kWh of electricity.

Create • Conserve • Sustain

Course 4 — Applications and Heat Load Calculation

Diagram specs are given in [DIAGRAM ...] blocks; build them as Docs widgets per topic.diagram / topic.charts. -->

Powered by Sunniva. This Level 2 (Application and Design) course is for consultants, designers and facility teams who select and size heat pumps for real buildings and plants. After it you will be able to: (1) estimate daily hot water demand for homes, hotels, hostels and hospitals; (2) turn that demand into a load profile, storage volume and heat pump capacity; (3) calculate pool and building heat losses; and (4) judge where heat pumps suit industrial, drying and cold-climate jobs.

4.1 Where heat pumps fit: domestic, commercial, industrial

Key idea: A heat pump fits any job that needs a steady supply of heat below about 80 °C, and it fits best when the temperature lift is small.

A heat pump moves heat from a low-temperature source (air, water or ground) to a higher-temperature sink (hot water or air). It does not burn fuel. It uses electricity to drive a compressor, like a fridge, but using the heat it rejects instead of the cold it makes.

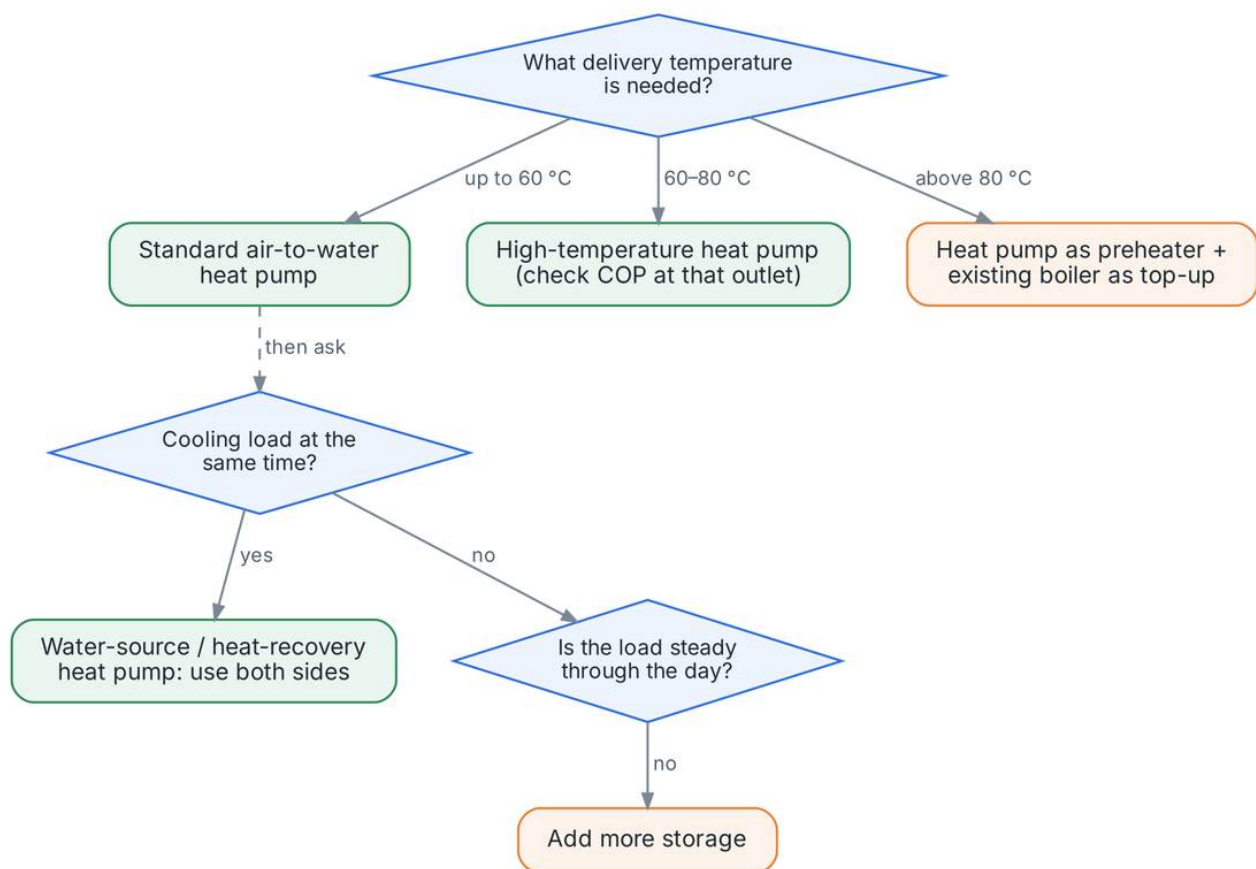
The key number is the temperature lift. Lift is the difference between the source temperature and the delivery temperature. A small lift means a high COP. COP (coefficient of performance) is heat delivered divided by electricity used.

Think of a pressure cooker. Raising water from 25 °C to 45 °C is easy. Pushing it to 95 °C takes far more effort. Heat pumps behave the same way.

Segment	Typical uses	Typical delivery temperature	Fit
Domestic	Bathing, kitchen, underfloor heating	45–60 °C	Very good
Commercial	Hotels, hostels, hospitals, gyms, laundries, pools	28–65 °C	Very good
Industrial (low temp)	Washing, CIP, boiler feed preheat, dyeing	50–80 °C	Good with high-temperature units
Industrial (high temp)	Steam, frying, sterilising	Above 100 °C	Preheat only, or specialist systems



Is a heat pump a good fit?



Is a heat pump a good fit?

Remember

- Lift drives COP: keep delivery temperature as low as the process allows.
- Domestic and commercial hot water up to 60 °C is the natural home of heat pumps.
- Above about 80 °C, use the heat pump as a preheater.
- A site that needs heating and cooling together is the best case of all.

Field tip: Always ask the client "What temperature do you really need at the tap or process?" The answer is often 10–15 °C lower than the boiler setting.

4.2 Estimating hot water demand: per person, per room, per bed

Key idea: Daily hot water demand equals the number of users multiplied by a typical litres-per-user figure, always stated at a reference temperature.

Demand figures mean nothing without a temperature. "50 litres per person" at 60 °C is about 88 litres at 45 °C (cold water 25 °C), because hot water gets mixed with cold at the tap. Always write the temperature next to the litres.

Use the figures below as starting points. Measure actual use on existing sites whenever you can. Water meters on the hot line are cheap and settle arguments.

Typical daily hot water demand (stored at 60 °C, cold water at about 25 °C). These are typical values, not standards.

Building / user	Unit	Typical L/day at 60 °C
Home, economy	per person	30–40
Home, comfortable	per person	40–60
Hostel / dormitory	per bed	30–50
Hotel, budget	per room	70–100
Hotel, mid-range	per room	100–150
Hotel, luxury / resort	per room	150–250
Hospital, wards only	per bed	70–100
Hospital, incl. kitchen and laundry	per bed	100–160
Restaurant / canteen	per meal	4–8
Gym / sports shower	per shower	15–25
Staff (offices, factories)	per person	5–10

Convert between temperatures with an energy balance. Hot water at temperature T_1 mixed with cold water gives the same energy as a larger volume at a lower temperature.

Worked example — convert demand to another temperature

A spec asks for 80 L per person at 45 °C. Cold water is 25 °C. What is the volume at 60 °C?

$$V_{60} = V_{45} \times \frac{T_{45} - T_c}{T_{60} - T_c}$$

- $V_{60} = 80 \times (45 - 25) \div (60 - 25)$
- $V_{60} = 80 \times 20 \div 35 = 45.7$ L per person at 60 °C

Worked example — daily energy for an apartment block

A block has 40 flats with 4 people each. Use 45 L/person/day at 60 °C. Winter cold water in Bengaluru is about 20 °C.

$$Q \text{ (kWh)} = \frac{V \text{ (L)} \times 4.186 \times \Delta T}{3600} = V \times \Delta T \times 0.001163$$

- Volume = $40 \times 4 \times 45 = 7,200$ L/day
- $\Delta T = 60 - 20 = 40$ K
- $Q = 7,200 \times 40 \times 0.001163 = 335$ kWh/day

Remember

- Always state litres together with a temperature.
- 1 litre heated by 1 K needs 0.001163 kWh.
- Use typical tables only as a first estimate; meter real use where possible.
- Design for the coldest inlet water, usually the winter month.

Common mistake: Mixing 45 °C demand figures with a 60 °C storage design. This undersizes the system by 40% or more.

4.3 Daily load profiles and peak demand

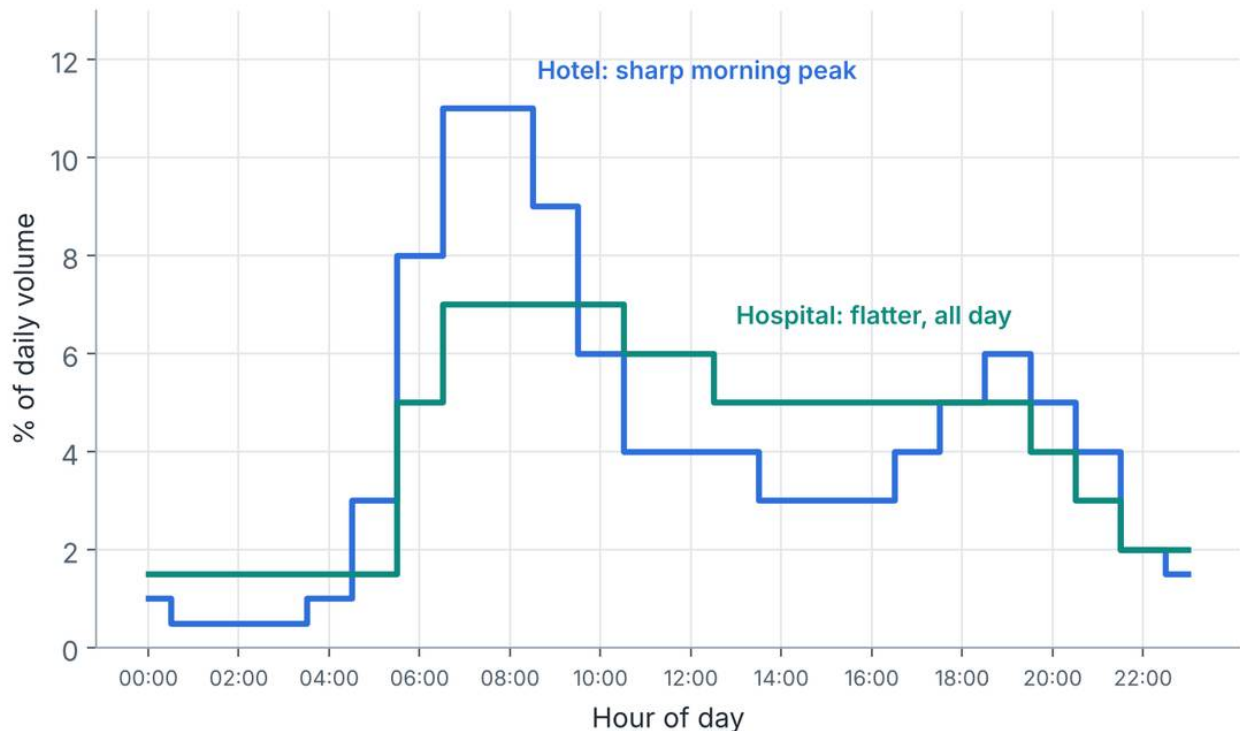
Key idea: The daily total sets the heat pump size; the peak hours set the storage size.

A load profile shows how much hot water is drawn in each hour of the day. Hotels and hostels have sharp morning peaks. Hospitals draw more evenly through the day.

A heat pump heats slowly but steadily. A storage tank is like an overhead water tank: it fills slowly and can be emptied quickly. The tank covers the peak while the heat pump catches up.

Typical daily hot water draw by hour

Share of the day's total, % per hour. Illustrative typical profiles.



Typical daily hot water draw by hour

There is a trade-off. A bigger tank lets you use a smaller heat pump that runs longer. A smaller tank needs a bigger heat pump that can follow the peak.

Design choice	Heat pump	Storage	Suits
Large storage	Smaller, runs 16–20 h	30–50% of daily volume	Hotels, hostels with sharp peaks
Medium storage	Medium, runs 12–16 h	20–30% of daily volume	Most commercial jobs
Small storage	Large, follows load	10–15% of daily volume	Hospitals, process with even draw

Worked example — storage for a peak period

A hostel uses 6,000 L/day at 60 °C. Cold water is 25 °C. The morning peak (6–9 am) takes 35% of the day. The heat pump delivers 20 kW. Usable storage fraction is 0.75 (the bottom of the tank mixes with incoming cold water).

$$V_{store} = \frac{V_{peak} - V_{recovery}}{f_{usable}}, \quad V_{recovery} = \frac{P_{HP} \times t}{\Delta T \times 0.001163}$$

- Peak draw = $0.35 \times 6,000 = 2,100$ L
- Recovery in 3 h = $20 \times 3 \div (35 \times 0.001163) = 60 \div 0.0407 = 1,474$ L
- Net from tank = $2,100 - 1,474 = 626$ L

- Storage = $626 \div 0.75 = 835 \text{ L}$ → select 1,000 L

Remember

- Daily kWh ÷ running hours = heat pump capacity.
- Peak period draw minus recovery = storage need.
- Only about 70–80% of a tank is usable hot water.
- Hostels have the sharpest peaks; hospitals the flattest.

Field tip: Ask the client for check-in/check-out times, shift changes and laundry hours. These create the real peaks.



4.4 Hotels, hostels and hospitals

Key idea: These three building types differ mainly in their peak pattern, their required temperatures and their hygiene rules.

Hotels have morning and evening peaks. Their kitchens and laundries add large daytime loads. Guests expect hot water in seconds, so a recirculation loop is needed.

Hostels have short, very sharp peaks. Two hundred students may shower in 90 minutes. Storage must be generous.

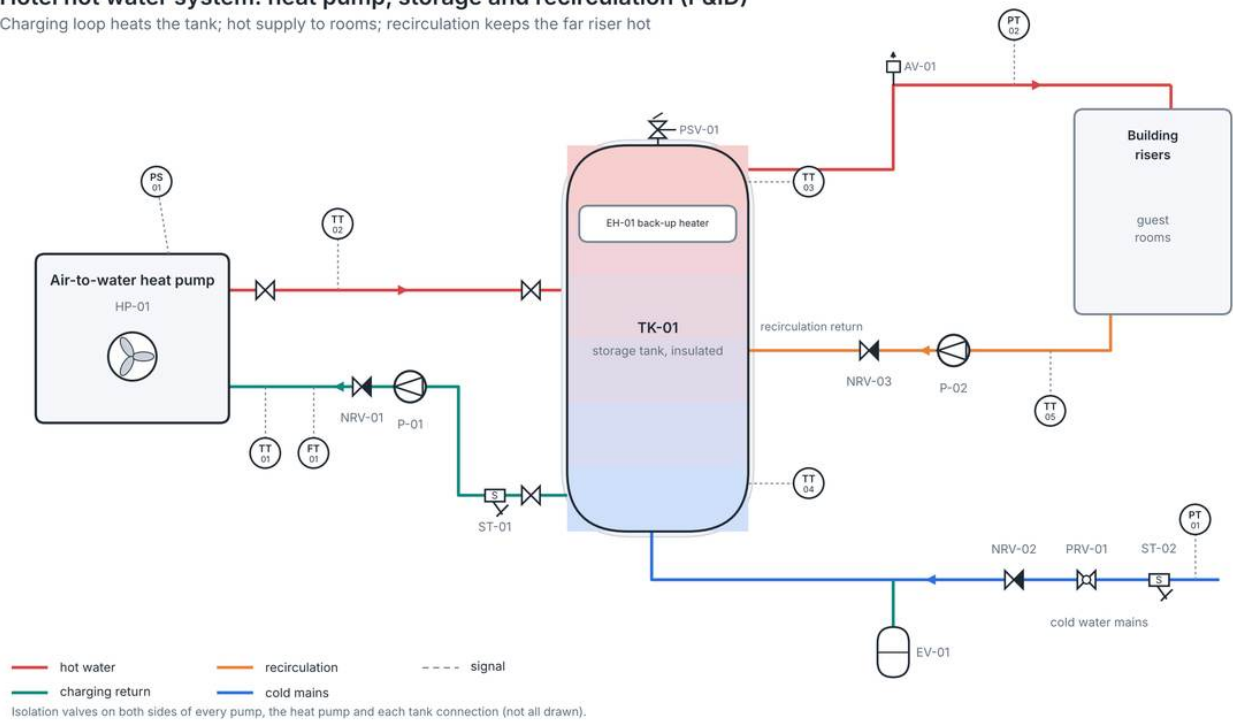
Hospitals need water hot enough to control Legionella. Legionella is a bacterium that grows in warm stagnant water between about 25 °C and 45 °C. Common practice is to store at 60 °C or above and keep the return loop at 50 °C or above. Follow your local code and the hospital's infection-control team.

Item	Hotel	Hostel	Hospital
Peak shape	Morning + evening	Very sharp morning	Spread over the day
Storage temperature	55–60 °C	55–60 °C	60 °C or more
Recirculation loop	Yes	Usually	Yes, mandatory in practice
Special loads	Kitchen, laundry, spa	Mess kitchen	Laundry, CSSD, kitchen
Back-up heating	Electric or existing boiler	Electric	Always provide redundancy

High-temperature points need boosters. A dishwasher final rinse needs about 82 °C. Do not raise the whole system to that temperature. Use a local booster heater instead.

Hotel hot water system: heat pump, storage and recirculation (P&ID)

Charging loop heats the tank; hot supply to rooms; recirculation keeps the far riser hot



P&ID: hotel hot water system with storage and recirculation

Remember

- Hotels: two peaks plus kitchen and laundry.
- Hostels: one very sharp peak, so big storage.
- Hospitals: hygiene first — 60 °C storage, 50 °C or more on return, redundancy.
- Use local boosters for 80 °C+ points, not the whole system.

Common mistake: Forgetting the recirculation loop heat loss. On large hotels it can add 10–20% to the daily load.

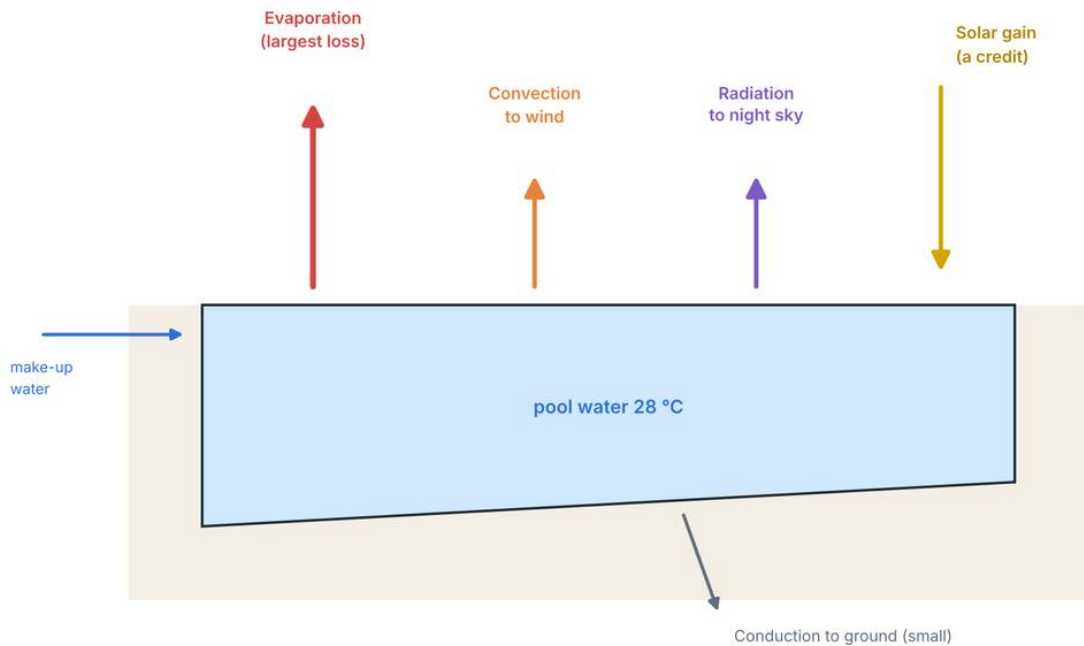
4.5 Swimming pools: heat-loss calculation

Key idea: A pool loses heat mainly by evaporation, so a cover saves more energy than any other measure.

A pool loses heat four ways. Evaporation is water turning to vapour at the surface. Convection is warm water heating the air that blows across it. Radiation is heat lost to the cold sky. Conduction is heat lost through walls and floor to the ground.

Evaporation is usually half or more of the total. It depends on the vapour-pressure difference between water and air, and on wind speed. A matka cools water the same way, by evaporation.

Where a pool loses its heat



Where a pool loses its heat

Widely used empirical formulas:

$$Q_{\text{evap}} = A (p_w - p_a) (0.089 + 0.0782 V) \quad [\text{kW}; A \text{ m}^2, p \text{ kPa}, V \text{ m/s}]$$

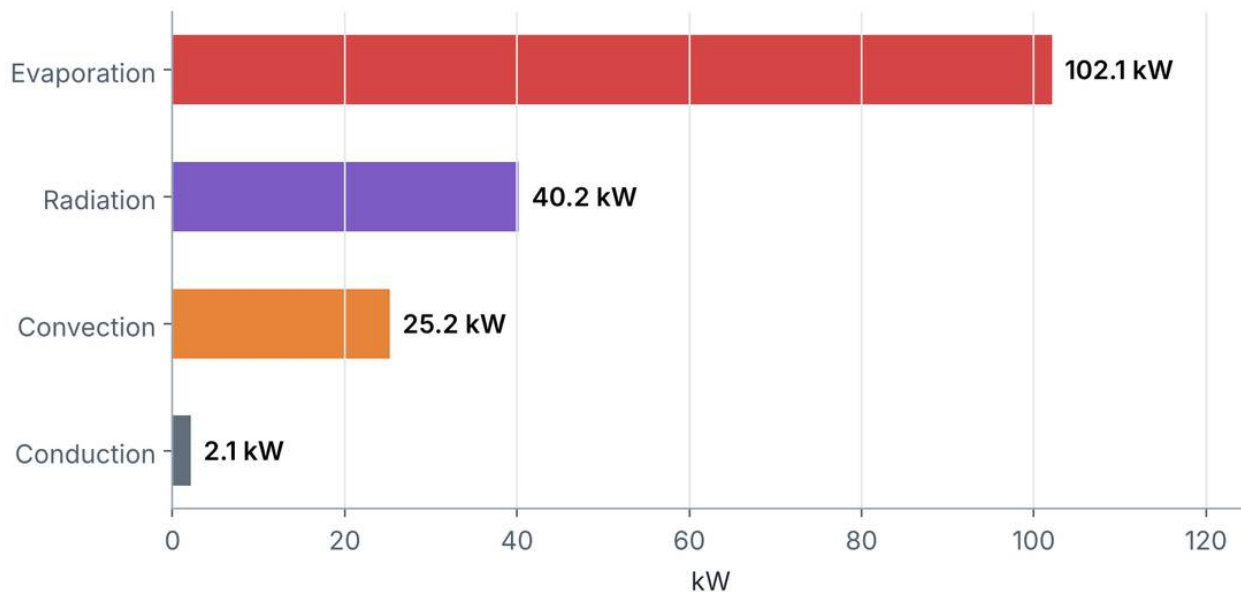
$$Q_{\text{conv}} = h A (T_w - T_a), \quad Q_{\text{rad}} = \varepsilon \sigma A (T_w^4 - T_{\text{sky}}^4), \quad Q_{\text{cond}} = U A_{\text{shell}} (T_w - T_{\text{ground}})$$

- p_w = saturation vapour pressure at water temperature; p_a = actual vapour pressure of air.
- h = surface heat transfer coefficient, typical 5–10 W/m²K in light wind.
- ε = emissivity of water, about 0.95; $\sigma = 5.67 \times 10^{-8}$ W/m²K⁴.
- T_{sky} is often 10–15 K below air temperature on clear nights (typical).

Saturation vapour pressure	kPa
10 °C	1.23
14 °C	1.60
20 °C	2.34
26 °C	3.36
28 °C	3.78
30 °C	4.25

Delhi pool, uncovered: heat loss in the January design hour

Worked example from lesson 4.10. 25 m × 12 m pool at 28 °C.



Delhi pool heat loss in the design hour

The full worked example is in Lesson 4.10.

Remember

- Evaporation is usually the biggest loss.
- A night cover typically cuts evaporation by 80–90%.
- Wind shelter (walls, hedges) reduces evaporation and convection.
- Indoor pools lose far less heat but need dehumidification.

Field tip: Measure wind at the water surface, not on the roof. Boundary walls often cut it to under 1 m/s.

4.6 Space heating: building heat loss

Key idea: Building heat loss equals fabric loss through walls, roof, floor and windows plus ventilation loss, both proportional to the indoor–outdoor temperature difference.

Heat leaks through every surface. The U-value tells how fast. U-value is the heat flow in watts through 1 m² for each 1 K of temperature difference (W/m²K). Lower U means better insulation.

Air leaking in and out also carries heat. We count it as air changes per hour (ACH). One ACH means the full room volume is replaced every hour.

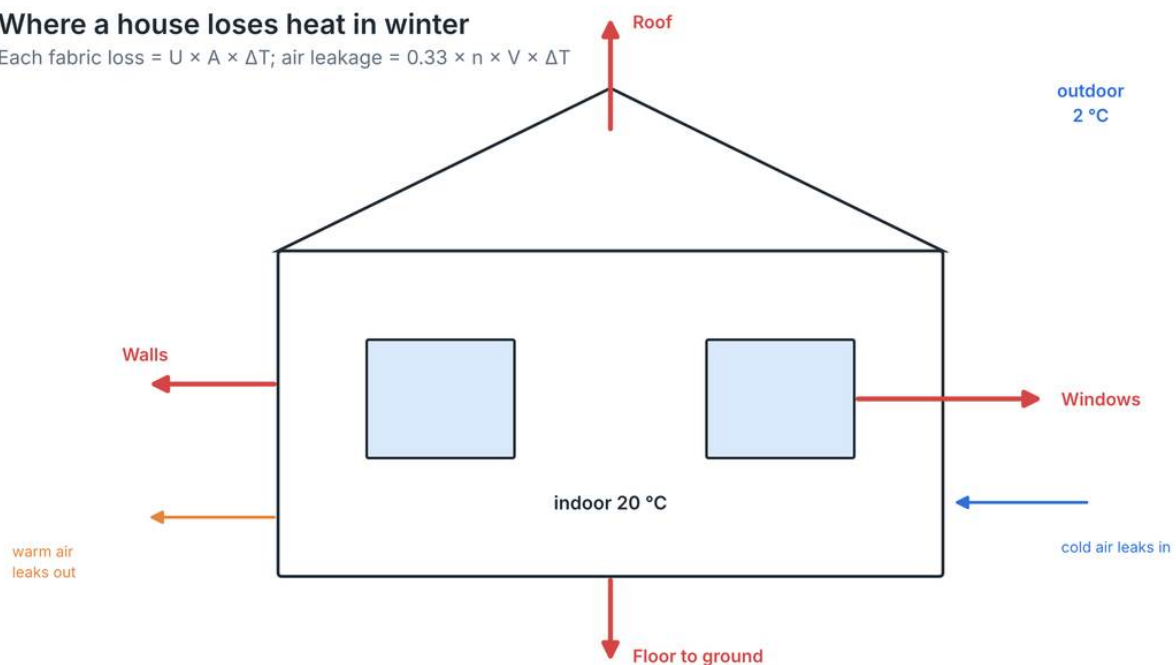
$$Q_{fabric} = \sum U A \Delta T, \quad Q_{vent} = 0.33 n V \Delta T \quad [\text{W}]$$

- 0.33 = density × specific heat of air ÷ 3600, in Wh/m³K.
- n = air changes per hour; V = room volume in m³.

Element (typical Indian construction)	Typical U (W/m ² K)
230 mm brick wall, plastered	1.9–2.2
230 mm brick wall + 50 mm insulation	0.5–0.6
150 mm RCC roof, no insulation	2.8–3.3
RCC roof + 50 mm insulation	0.5–0.7
Single glazing, aluminium frame	5.5–6.0
Double glazing, uPVC frame	2.5–3.0

Where a house loses heat in winter

Each fabric loss = $U \times A \times \Delta T$; air leakage = $0.33 \times n \times V \times \Delta T$



Where a house loses heat in winter

Worked example — 120 m² house in Chandigarh

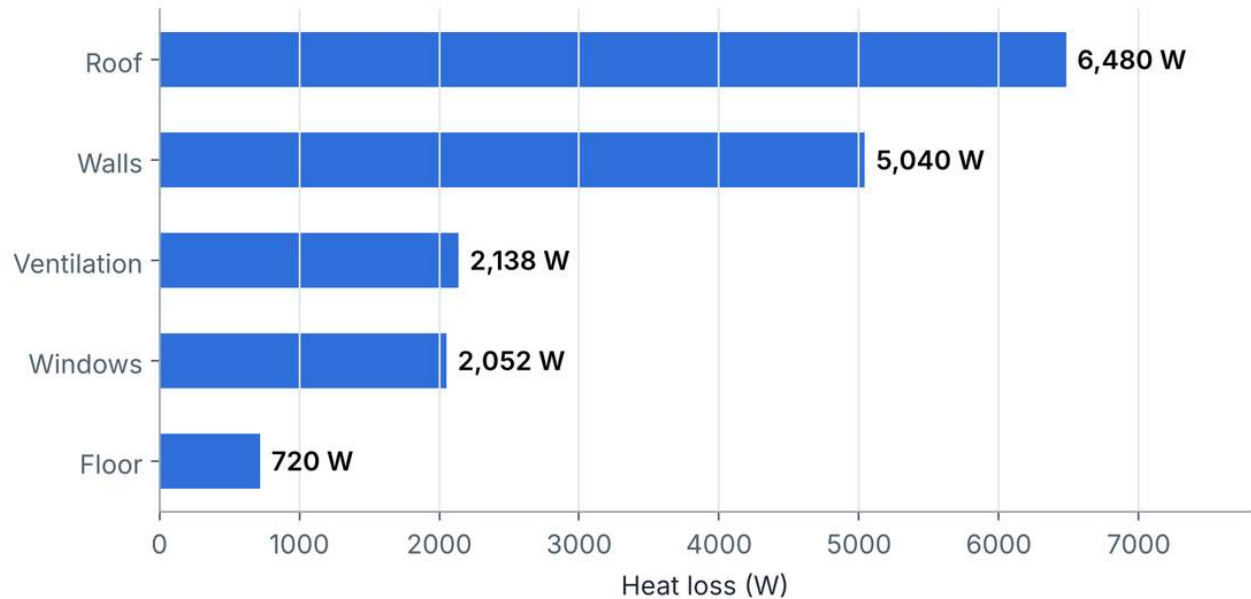
Design outdoor 3 °C, indoor 21 °C, $\Delta T = 18$ K. Ground below floor about 15 °C. Height 3 m, n = 1.0 ACH.

- Walls: $2.0 \times 140 \text{ m}^2 \times 18 = 5,040 \text{ W}$
- Windows: $5.7 \times 20 \text{ m}^2 \times 18 = 2,052 \text{ W}$
- Roof: $3.0 \times 120 \text{ m}^2 \times 18 = 6,480 \text{ W}$

- Floor: $1.0 \times 120 \text{ m}^2 \times 6 = 720 \text{ W}$
- Ventilation: $0.33 \times 1.0 \times 360 \text{ m}^3 \times 18 = 2,138 \text{ W}$
- Total = $16,430 \text{ W} \approx 16.4 \text{ kW} \rightarrow$ with 10% margin, about 18 kW
- With 50 mm roof insulation ($U = 0.6$), roof loss drops to 1,296 W and total to about 11.2 kW.

Chandigarh house: winter heat loss by element

Worked example in lesson 4.6. Total about 16.4 kW.



Chandigarh house heat loss by element

Low flow temperatures raise COP. Underfloor heating works at 30–40 °C. Fan coils work at 40–50 °C. Old radiators may need 55–65 °C. Weather compensation lowers the flow temperature on milder days and saves energy.

Remember

- Roof losses dominate in Indian flat-roof houses.
- Insulate first, then size the heat pump.
- Use low flow temperatures: underfloor 30–40 °C is ideal.
- Design at the local winter design temperature, not the average.

Common mistake: Sizing from "watts per m²" rules of thumb without checking the roof. An uninsulated RCC roof can double the load.

4.7 Industrial process heat: dairy, food, pharma, textiles

Key idea: Many factory processes need hot water at 50–80 °C, which a heat pump can supply far more cheaply than a boiler.

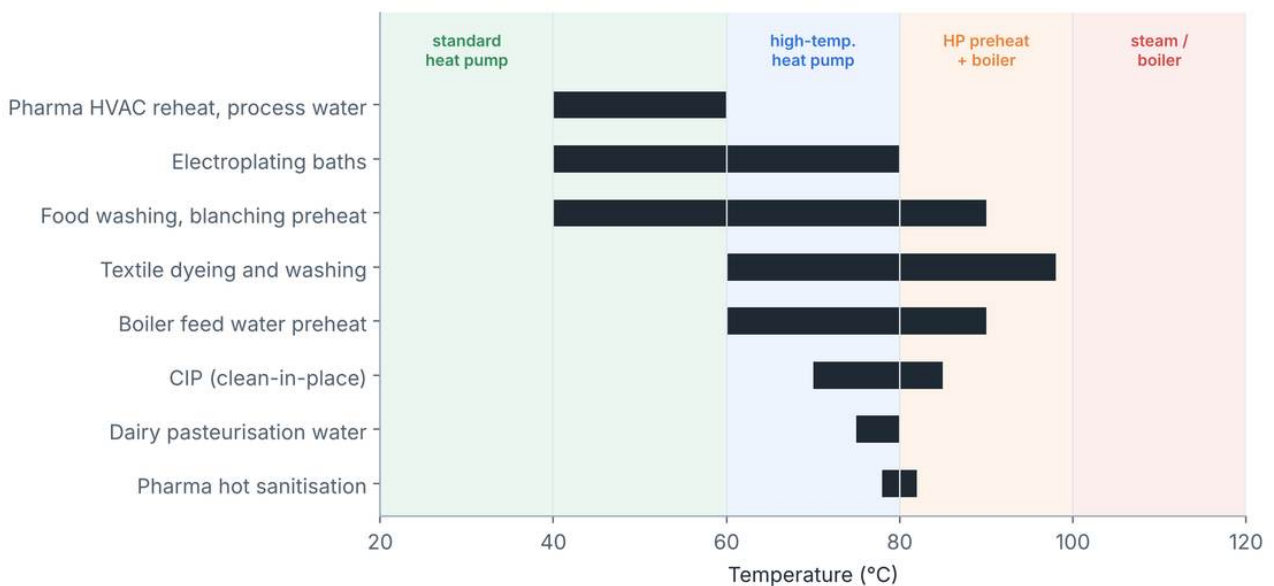
Most factories run boilers at steam pressure for jobs that need only hot water. Each conversion from steam to hot water wastes energy. A heat pump can supply that hot water directly.

The best sites need heating and cooling together. A dairy chills milk to about 4 °C and also washes equipment at 70–80 °C. One heat pump can do both: the cold side chills, the hot side heats.

Industry	Process	Typical temperature
Dairy	Pasteurisation (HTST)	72 °C hold, water at 75–80 °C
Dairy / food	CIP (clean-in-place)	70–85 °C
Food	Washing, blanching preheat	40–90 °C
Pharma	Purified water hot sanitisation	About 80 °C
Pharma	HVAC reheat, process water	40–60 °C
Textiles	Dyeing, washing	60–98 °C
All	Boiler feed water preheat	60–90 °C
Electroplating	Bath heating	40–80 °C

Process temperatures and which heating fits

Typical process temperature ranges against the heating that suits them



Process temperatures and which heating fits

Worked example — dairy CIP hot water

A dairy uses 10,000 L/day of CIP water at 75 °C, heated from 30 °C. Today a diesel boiler (80% efficient) does this. Use example rates: diesel ₹100/L at about 10 kWh/L; electricity ₹9/kWh. Heat pump COP at 75 °C outlet, typical 2.8.

$$Q = V \times \Delta T \times 0.001163, \quad \text{Fuel} = \frac{Q}{CV \times \eta}, \quad E_{HP} = \frac{Q}{COP}$$

- $Q = 10,000 \times 45 \times 0.001163 = 523 \text{ kWh/day}$
- Diesel = $523 \div (10 \times 0.80) = 65.4 \text{ L} \rightarrow ₹6,540/\text{day}$
- Heat pump electricity = $523 \div 2.8 = 187 \text{ kWh} \rightarrow ₹1,683/\text{day}$
- Saving $\approx ₹4,857/\text{day}$, before any value from cooling

Remember

- Hot water up to 80 °C is heat pump territory.
- Combined heating and cooling gives the highest overall value.
- Use the heat pump as a preheater for steam boilers above 80 °C.
- Waste heat (chiller condensers, compressor cooling) is an ideal source.

Field tip: Walk the plant with an IR thermometer. Find where steam is used to make hot water — that is your first project.



4.8 Drying and dehumidification

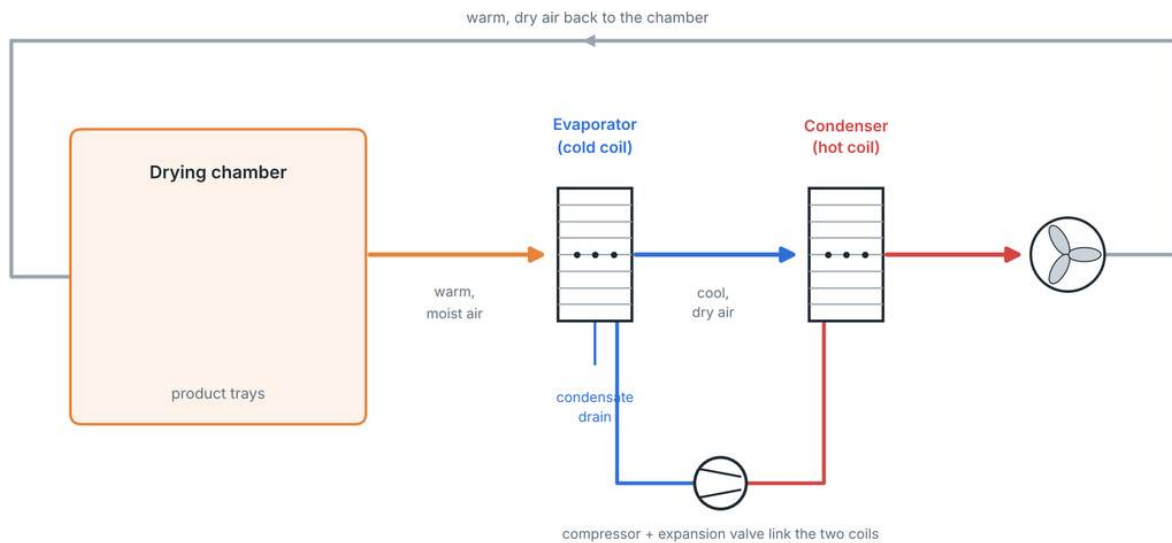
Key idea: A heat pump dryer removes water by cooling air below its dew point and reuses the heat, so it uses far less energy than a heater-and-vent dryer.

Drying needs two things: heat to evaporate water, and a way to remove the vapour. A conventional dryer heats air, passes it over the product and vents it outside. The heat leaves with the air.

A heat pump dryer runs in a closed loop. Moist air passes over the cold evaporator. Its moisture condenses and drains away. The same air is reheated on the condenser and sent back over the product. The dew point is the temperature at which air becomes saturated and water starts to condense.

Closed-loop heat pump dryer

The same air goes round: the evaporator removes water, the condenser reheats the air



Closed-loop heat pump dryer

The key performance figure is SMER (specific moisture extraction rate). It is kilograms of water removed per kWh of electricity.

Dryer type	Typical SMER (kg/kWh)	Typical air temperature
Electric heater, open vent	0.3–0.9	50–80 °C
Heat pump, closed loop	1.0–4.0	35–65 °C

Low drying temperatures protect colour, aroma and nutrients. This suits spices, fruits, herbs, fish and some pharma products.

Worked example — fruit slices

A batch of 500 kg fresh fruit slices at 80% moisture (wet basis) is dried to 10%. Latent heat of water is about 0.68 kWh/kg. Heat pump SMER is 2.5 kg/kWh; a heater dryer is 0.6 kg/kWh.

$$m_{dry} = m_{wet}(1 - x_{wet}), \quad m_{final} = \frac{m_{dry}}{1 - x_{final}}, \quad m_{water} = m_{wet} - m_{final}$$

- Dry solids = $500 \times 0.20 = 100$ kg
- Final mass = $100 \div 0.90 = 111.1$ kg
- Water removed = $500 - 111.1 = 388.9$ kg
- Heat pump: $388.9 \div 2.5 = 156$ kWh $\rightarrow$ ₹1,404
- Heater dryer: $388.9 \div 0.6 = 648$ kWh $\rightarrow$ ₹5,832

- Over a 20 h batch, the dryer must remove 19.4 kg/h on average.

Remember

- Size a dryer by water removed per hour, not by product weight.
- SMER compares dryers fairly.
- Closed-loop heat pump dryers work at gentle temperatures.
- Moisture removal is fastest at the start of a batch.

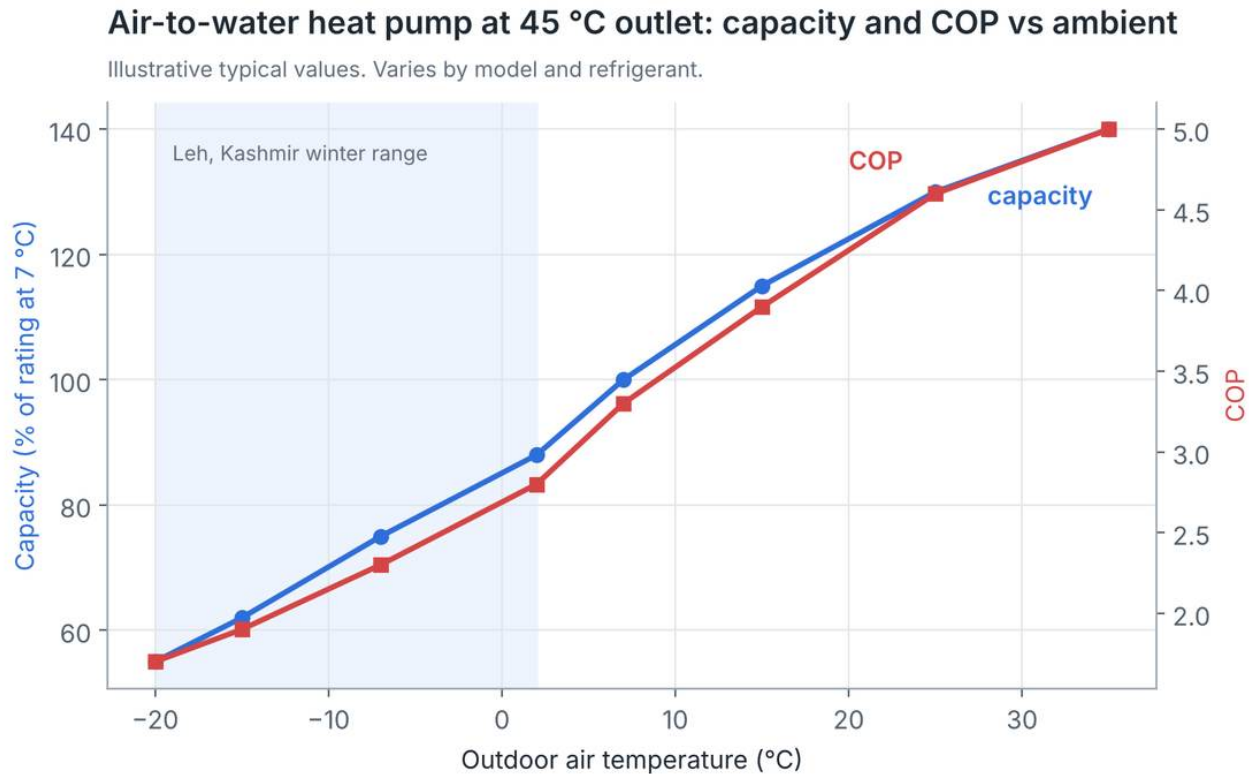
Common mistake: Sizing on average moisture removal. The first hours remove water two to three times faster than the average.



4.9 Cold climates and high altitude

Key idea: In cold air, an air-source heat pump loses capacity and COP and must defrost; at altitude, thinner air reduces airflow mass and boils water at lower temperatures.

As outdoor air gets colder, the evaporator has less heat to pick up. Capacity falls and COP falls. Below about 5 °C with humid air, ice forms on the coil. The unit must defrost, usually by briefly reversing the cycle.



Capacity and COP vs ambient at 45 °C outlet

Place (typical)	Altitude	Typical winter low	Notes
Delhi	~220 m	3–7 °C	Light frost risk, fog
Shimla	~2,200 m	–2 to 2 °C	Defrost frequent
Srinagar	~1,600 m	–5 to –2 °C	Glycol advisable
Leh	~3,500 m	–15 to –25 °C	Low-ambient design, glycol, back-up

Design rules for cold sites:

- Size at the local design low, not at the rated 7 °C point.
- Choose units built for low ambient (for example, vapour injection or CO₂ cycles).
- Protect water circuits with glycol (antifreeze) or drain-down. About 30% ethylene glycol protects to roughly –15 °C; about 40% to roughly –24 °C (typical).
- Glycol lowers heat transfer and raises pumping power; allow 5–10% derating (typical).
- Keep snow and ice away from the coil and condensate drains.

At altitude the air is thinner. At about 3,500 m air density is roughly 70% of sea level. A fan moves the same volume but less mass, so coil capacity falls. Water boils at about 88–89 °C at that height, so keep vent and relief settings in mind.

Worked example — derating at Leh

A heat pump gives 20 kW at 7 °C ambient at sea level. At Leh, design ambient is –15 °C. Use capacity factor 0.62 (from the chart), altitude factor 0.90 and glycol factor 0.95 (typical assumptions; check maker data).

$$P_{site} = P_{rated} \times f_{ambient} \times f_{altitude} \times f_{glycol}$$

- $P = 20 \times 0.62 \times 0.90 \times 0.95 = 10.6 \text{ kW}$
- A 20 kW-rated unit gives only about 10.6 kW at Leh. Size accordingly.

Remember

- Capacity and COP both fall as ambient falls.
- Defrost cycles take a share of every cold hour.
- Altitude reduces air mass flow and boiling point.
- Always protect water circuits from freezing.

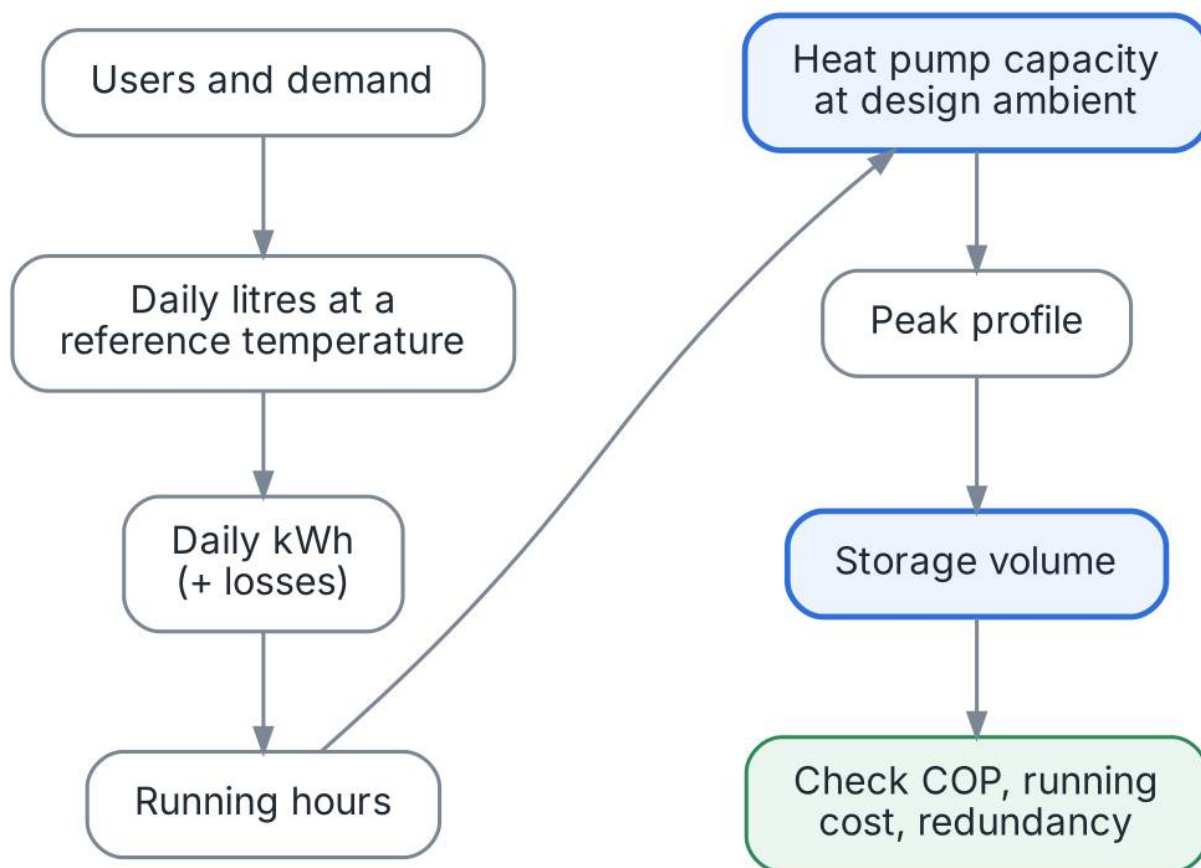
Field tip: Raise outdoor units at least 300–500 mm above expected snow level and keep the condensate drain heated.



4.10 Worked examples, start to finish

Key idea: Every sizing job follows the same path — demand, energy, losses, running hours, capacity, storage — and checks the result against design conditions.

Sizing in eight steps



Sizing in eight steps

Case A — 60-room mid-range hotel in Pune

Step 1. Demand. Design at 100% occupancy (typical 2 guests per room). Storage at 60 °C.

Load	Basis (typical)	L/day at 60 °C
Guest rooms	60 rooms × 140 L	8,400
Restaurant	150 meals × 6 L	900
Staff	20 × 10 L	200
Total		9,500

Laundry is assumed outsourced. Add it if done in-house.

Step 2. Daily energy. Pune winter cold water is about 20 °C, so $\Delta T = 40$ K.

$$Q = V \times \Delta T \times 0.001163$$

- $Q = 9,500 \times 40 \times 0.001163 = 442$ kWh/day

- Add 15% for tank and recirculation losses: $442 \times 1.15 = 508 \text{ kWh} \rightarrow$ use 510 kWh/day

Step 3. Heat pump capacity. Allow 16 running hours a day. This leaves margin for peaks and service.

$$P_{HP} = \frac{Q_{day}}{t_{run}}$$

- $P = 510 \div 16 = 31.9 \text{ kW} \rightarrow$ select about 32 kW at the winter design ambient (about 10–12 °C early morning in Pune)

Step 4. Storage. From the profile in 4.3, 6–9 am takes 30% of the day.

- Peak draw = $0.30 \times 9,500 = 2,850 \text{ L}$
- Recovery in 3 h = $32 \times 3 \div (40 \times 0.001163) = 96 \div 0.0465 = 2,064 \text{ L}$
- Net from tank = $2,850 - 2,064 = 786 \text{ L} \rightarrow \div 0.75 \text{ usable} = 1,048 \text{ L}$
- Check against the rule of 20–30% of daily volume (1,900–2,850 L). Select 2,000 L to cover group check-outs and full-house days.

Step 5. Running cost (example rates). COP at 60 °C outlet, typical 3.0. LPG net calorific value about 12.8 kWh/kg, boiler efficiency 85%.

- Heat pump: $510 \div 3.0 = 170 \text{ kWh} \times ₹9 = ₹1,530/\text{day}$
- LPG: $510 \div (12.8 \times 0.85) = 46.9 \text{ kg} \times ₹100 = ₹4,690/\text{day}$

Result: about 32 kW heat pump capacity at design ambient, 2,000 L storage at 60 °C, with recirculation loop and electric back-up.

Case B — 25 m × 12 m outdoor pool in Delhi, January

Step 1. Data.

- Area A = 300 m²; average depth 1.5 m; volume 450 m³
- Water 28 °C; daily mean air 14 °C; RH 70%; wind at surface 0.5 m/s (walled)
- Ground about 18 °C; shell area = $300 + 2 \times (25 + 12) \times 1.5 = 411 \text{ m}^2$
- Pool used 12 h uncovered; covered 12 h at night
- Solar gain ignored for design (Delhi winter fog days)

Step 2. Evaporation (uncovered).

- p_w at 28 °C = 3.78 kPa; $p_a = 0.70 \times 1.60 = 1.12 \text{ kPa}$; $\Delta p = 2.66 \text{ kPa}$
- $Q_{\text{evap}} = 300 \times 2.66 \times (0.089 + 0.0782 \times 0.5) = 300 \times 2.66 \times 0.128 = 102.1 \text{ kW}$

Step 3. Convection. $h = 6 \text{ W/m}^2\text{K}$ (typical, light wind).

- $Q_{\text{conv}} = 6 \times 300 \times (28 - 14) = 25,200 \text{ W} = 25.2 \text{ kW}$

Step 4. Radiation. $T_w = 301 \text{ K}$; $T_{\text{sky}} \approx 14 - 12 = 2 \text{ °C} = 275 \text{ K}$.

- $Q_{\text{rad}} = 0.95 \times 5.67 \times 10^{-8} \times 300 \times (301^4 - 275^4)$
- $= 0.95 \times 5.67 \times 10^{-8} \times 300 \times (8.209 - 5.719) \times 10^9 = 40.2 \text{ kW}$

Step 5. Conduction. $U \approx 0.5 \text{ W/m}^2\text{K}$ to ground (typical, uninsulated).

- $Q_{\text{cond}} = 0.5 \times 411 \times (28 - 18) = 2,055 \text{ W} = 2.1 \text{ kW}$

Step 6. Totals.

Loss	Uncovered (kW)	Covered (kW, typical cover effect)
Evaporation	102.1	10.2 (~90%)
Convection	25.2	12.6 (~50%)
Radiation	40.2	20.1 (~50%)
Conduction	2.1	2.1
Total	169.6	45.0

- Daily loss = $12 \times 169.6 + 12 \times 45.0 = 2,035 + 540 = 2,575 \text{ kWh}$
- Make-up water: about 2 m³/day evaporated, heated from 15 °C: $2,000 \times 13 \times 0.001163 = 30 \text{ kWh}$
- Add 5% for pipe and filter losses: $(2,575 + 30) \times 1.05 = 2,735 \text{ kWh/day}$

Step 7. Capacity. Allow 20 running hours (defrost and filtration margin).

- $P = 2,735 \div 20 = 137 \text{ kW}$ at design ambient (night lows 6–8 °C)

- Pool heat pumps are often rated at higher ambient. The nameplate at that rating will be larger; check output at 7–10 °C air.
- Without a cover: $24 \times 169.6 \times 1.05 \approx 4,270$ kWh/day → about 215 kW. The cover saves over a third of the plant.

Step 8. Initial heat-up.

- $Q = 450,000 \text{ L} \times (28 - 15) \times 0.001163 = 6,804$ kWh
- With the cover on 24 h, about 90 kW is spare after losses → about 75 h, or 3–4 days.

Step 9. Running cost (example). Typical pool COP 4.0 at these conditions.

- $2,735 \div 4.0 = 684$ kWh $\times$ ₹9 = ₹6,156/day

Result: about 137 kW heat pump capacity at Delhi January design conditions, with a mandatory night cover.

Remember

- Follow the same path every time: demand → kWh → hours → kW → storage.
- State every assumption (occupancy, temperatures, wind, cover).
- Check capacity at the design ambient, not the catalogue rating.
- Covers and insulation cut plant size more cheaply than bigger machines.

Common mistake: Sizing a pool heat pump from the heat-up energy alone. The daily loss sets the size; heat-up just sets how long you wait.



Quiz 4

1. Which figure mainly decides the heat pump capacity for a hot water system?
 - A. Peak hourly draw B. Daily energy ÷ running hours C. Tank volume D. Pipe size
2. 80 L at 45 °C with cold water at 25 °C equals how much at 60 °C?
 - A. 46 L B. 60 L C. 80 L D. 107 L
3. Energy to heat 1,000 L by 40 K is about:
 - A. 4.6 kWh B. 23 kWh C. 46.5 kWh D. 167 kWh
4. Which building usually has the flattest daily hot water profile?
 - A. Hostel B. Hotel C. Hospital D. Gym
5. Typical minimum return-loop temperature for Legionella control is:
 - A. 35 °C B. 40 °C C. 50 °C D. 70 °C
6. The largest heat loss from an outdoor pool is usually:
 - A. Conduction B. Radiation C. Convection D. Evaporation
7. A pool cover mainly saves energy by cutting:
 - A. Conduction B. Evaporation C. Solar gain D. Pump power
8. Ventilation heat loss in watts is:
 - A. $0.33 n V \Delta T$ B. $U A \Delta T$ C. $4.186 V \Delta T$ D. $\epsilon \sigma A T^4$
9. SMER in a dryer means:
 - A. kWh per kg product B. kg water removed per kWh C. Air flow per kW D. Drying time per batch
10. At high altitude an air-source heat pump loses capacity mainly because:
 - A. Water boils hotter B. Air density is lower C. Electricity is weaker D. Refrigerant leaks

Answer key

1. B — Daily kWh spread over running hours sets the kW; peaks set storage.
2. A — $80 \times (45 - 25) \div (60 - 25) = 45.7$ L.
3. C — $1,000 \times 40 \times 0.001163 = 46.5$ kWh.
4. C — Hospitals run round the clock, so draw is spread out.
5. C — Common practice keeps the return at 50 °C or above.
6. D — Evaporation is usually half or more of the total.
7. B — Covers stop vapour leaving the surface.
8. A — $0.33 \text{ Wh/m}^3\text{K} \times \text{air changes} \times \text{volume} \times \Delta T$.
9. B — Specific moisture extraction rate, kg/kWh.
10. B — Less air mass passes over the coil for the same fan volume.

Glossary

Term	Meaning
ACH (air changes per hour)	Number of times a room's air volume is replaced in one hour
CIP (clean-in-place)	Cleaning process equipment with hot solutions without dismantling it
COP	Heat delivered ÷ electricity used
Defrost	Removing ice from the outdoor coil, usually by reversing the cycle briefly
Dew point	Temperature at which air becomes saturated and water condenses
Design ambient	Outdoor temperature used for sizing, usually a cold winter value
Emissivity (ε)	How well a surface radiates heat compared with a perfect radiator
Glycol	Antifreeze added to water circuits to prevent freezing
Legionella	Bacteria that grow in warm stagnant water and cause lung infection
Load profile	How demand varies hour by hour over a day
Make-up water	Fresh water added to replace evaporation and backwash losses
Recirculation loop	Pipe loop that keeps hot water moving so it reaches taps quickly
Recovery	Hot water the heat pump produces during a draw period
SMER	Specific moisture extraction rate: kg water removed per kWh
Temperature lift	Difference between source and delivery temperature
U-value	Heat flow through 1 m ² per 1 K difference, W/m ² K
Usable fraction	Share of tank volume available at useful temperature, typically 0.7–0.8
Vapour pressure	Pressure exerted by water vapour; drives evaporation
Weather compensation	Control that lowers heating flow temperature on milder days



Course 5 — Selection and System Design

Powered by Sunniva. This Level 2 course is for consultants, MEP designers and senior technicians who select heat pumps and design the systems around them. After it you will be able to: (1) read a datasheet and correct its ratings to your site conditions; (2) size a heat pump and storage tank together for a real hot water load; (3) choose between direct, indirect, buffered, hybrid and cascaded layouts and draw them as P&IDs; (4) specify water treatment, materials and the electrical supply.

5.1 Reading a datasheet: rating conditions and what they hide

Key idea: A datasheet capacity is true only at the exact air and water temperatures it was tested at.

A datasheet is like a car's mileage figure. It is measured under fixed, gentle conditions, and real roads give less. A heat pump's heating capacity (kW of heat delivered) and COP (coefficient of performance: heat out divided by electricity in) change with outdoor air temperature and the water temperature you ask for.

Every rating should state its rating condition: the ambient dry-bulb (DB) temperature, the wet-bulb (WB) temperature (which tells humidity), and the water inlet and outlet temperatures. If a sheet gives a capacity without these, you cannot compare it with anything.

Common rating points used by manufacturers (typical, they vary by standard and product type):

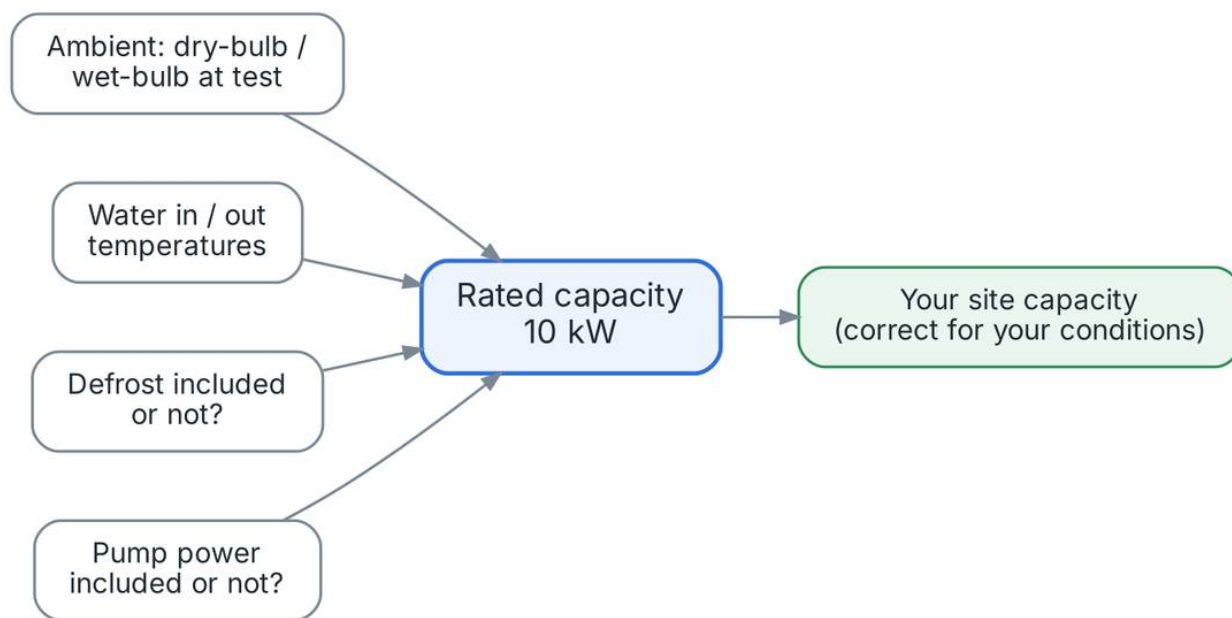
Rating style	Ambient DB / WB	Water	Typical use
Mild "domestic hot water" point	20 °C / 15 °C	15 °C in → 55 °C	Hot water heat pumps
Space-heating low temperature	7 °C / 6 °C	30 °C in → 35 °C out	Underfloor heating
Space-heating medium temperature	7 °C / 6 °C	40 °C in → 45 °C out	Radiators, fan coils
Cold climate check	-7 °C / -8 °C	30 → 35 °C	Winter capacity

What datasheets often hide:

- **Defrost losses.** Ratings at 20 °C have no frost. Below about 7 °C with high humidity, the evaporator frosts and defrost cycles cut average output (typical 5–15 %).
- **Heat-up vs. steady state.** A "15 → 55 °C" rating is an average over a heat-up. Reheating a tank already at 45 °C gives a lower COP.
- **Pump and fan power.** Check whether COP includes the water pump power. Some sheets exclude it.
- **Maximum vs. nominal.** Inverter units list a nominal and a maximum capacity. Size on the capacity at your condition, not the maximum.
- **Sound level.** Sound pressure (dB(A) at a distance) and sound power are different numbers. Sound power is always the larger.

Create • Conserve • Sustain

What sits behind one capacity number



What sits behind one capacity number

Worked example — correcting a datasheet COP for site water temperature

A unit is rated 10 kW, COP 4.2 at 20 °C ambient, water 15 → 55 °C. Your site in Shimla needs 60 °C water at 5 °C ambient. Use the manufacturer's correction table. If none exists, a Carnot-ratio estimate gives a rough direction.

$$COP_{Carnot} = \frac{T_{hot}}{T_{hot} - T_{cold}} \quad (K), \quad COP_{site} \approx COP_{rated} \times \frac{COP_{Carnot,site}}{COP_{Carnot,rated}}$$

Rated: $T_{hot} \approx 55$ °C average-to-final. Use average water 35 °C = 308 K; $T_{cold} = 293$ K → Carnot = 308/15 = 20.5. Site: average water 37.5 °C = 310.5 K; $T_{cold} = 278$ K → Carnot = 310.5/32.5 = 9.6. $COP_{site} \approx 4.2 \times 9.6/20.5 \approx 2.0$. This is a rough, conservative estimate. Always prefer the manufacturer's own performance table.

Remember

- No rating condition, no comparison.
- Capacity and COP fall when ambient falls or water temperature rises.
- Ask whether defrost and pump power are included.
- Size on capacity at the design condition, not the maximum.

Common mistake: Comparing one brand's 20 °C rating with another brand's 7 °C rating.

5.2 Capacity vs ambient: derating

Key idea: As outdoor air gets colder, an air-source heat pump delivers less heat, so you size at the coldest design ambient.

An air-source heat pump picks up heat from the air. Colder air holds less heat for the evaporator to collect, and the compressor pumps less refrigerant mass because suction gas is less dense. Cold air simply has less heat to give, so the machine picks up less.

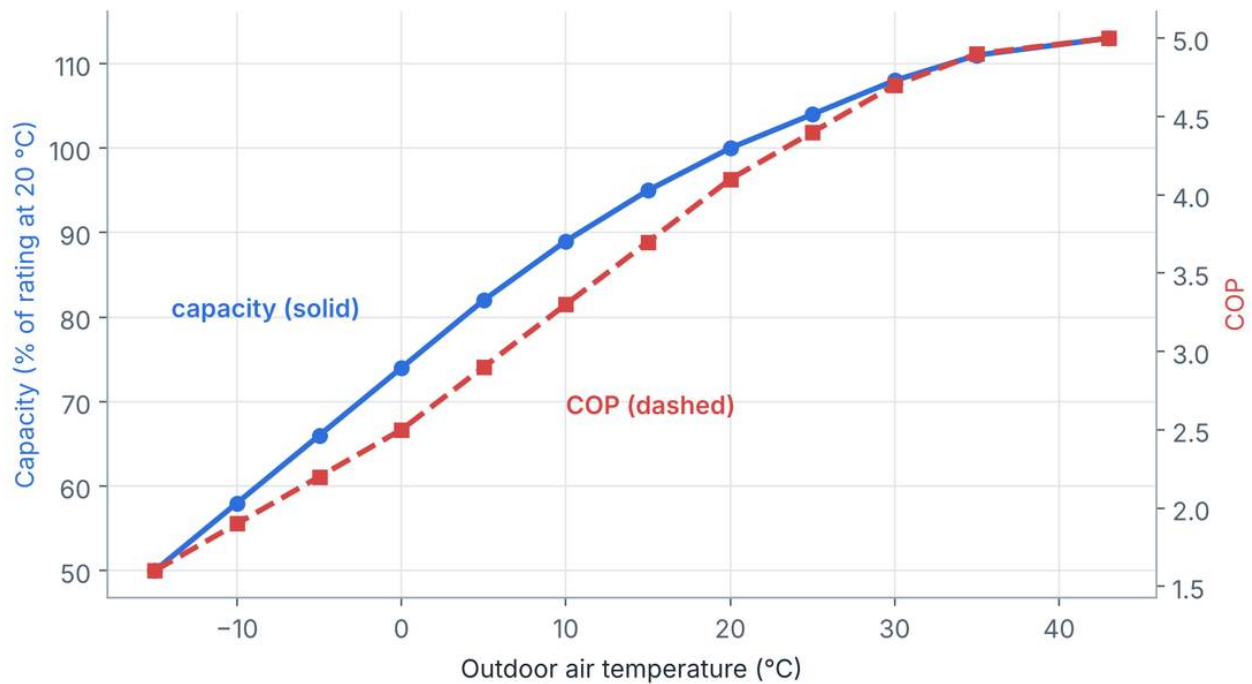
Derating means reducing the rated capacity to the real capacity at your design ambient. The design ambient is the low outdoor temperature you design for, for example the typical winter morning low at your site.

Typical Indian design ambients (illustrative, check local climate data):

City	Typical winter design ambient	Note
Chennai	18–20 °C	Little derating
Mumbai	15–17 °C	Little derating
Bengaluru	12–14 °C	Mild
Delhi	4–6 °C	Moderate, fog/frost mornings
Shimla	–2 to 2 °C	Strong derating, defrost
Leh	–20 to –15 °C	Needs cold-climate (EVI) unit

Capacity and COP vs ambient at 55 °C water

Generic, illustrative. Defrost dip around 0–5 °C not shown. Use the maker's tables.



Capacity and COP vs ambient at 55 °C water

Worked example — derating for Delhi winter

A unit is rated 20 kW at 20 °C. Its table shows 82 % capacity at 5 °C with 55 °C water. Defrost loss is taken as 8 % (typical).

$$Q_{site} = Q_{rated} \times f_{ambient} \times (1 - f_{defrost})$$

$Q_{site} = 20 \times 0.82 \times (1 - 0.08) = 20 \times 0.82 \times 0.92 = 15.1$ kW. The "20 kW" machine is a 15 kW machine on a Delhi January morning.

Remember

- Size at design ambient, not at rating ambient.

- Capacity and COP both fall with ambient.
- Add defrost loss below about 7 °C in humid air.
- In hot climates the unit has spare capacity in summer.

Field tip: Ask for the full capacity table, not the brochure single point.

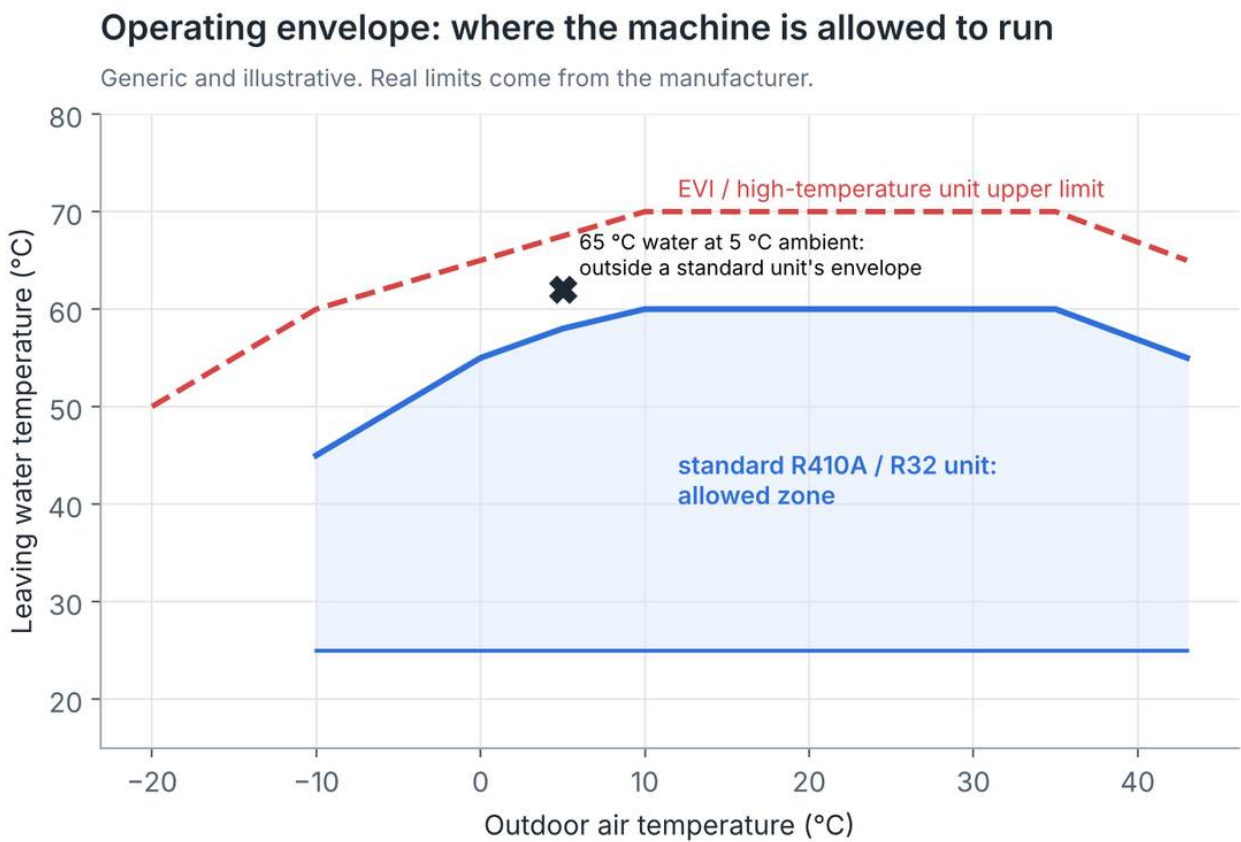


5.3 The operating envelope

Key idea: The operating envelope is the map of ambient and water temperatures in which the compressor can run safely.

Every compressor has limits. If the water is too hot or the air too cold, the discharge temperature and pressure climb too high. The unit then trips on high pressure (HP) or high discharge temperature. The envelope shows the allowed area.

Read it like a road map. X-axis is ambient air temperature. Y-axis is leaving water temperature (LWT), the hot water temperature leaving the heat pump. Inside the shaded area the unit runs. Outside it, it stops or limits itself.



Operating envelope (generic, illustrative)

Envelope edge	What happens if you cross it
Top (water too hot)	High-pressure trip, high discharge temperature
Left (air too cold)	Low suction pressure, low-pressure trip, poor oil return
Right (air too hot)	High condensing pressure; unit may limit capacity
Bottom (water too cold at start)	Low head pressure; some units need a minimum water temperature

Worked example — will it run?

Project in Shimla: design ambient -2°C , required 60°C water. On the generic envelope, the upper boundary at -2°C is about 53°C . $60^{\circ}\text{C} > 53^{\circ}\text{C}$, so the standard unit is outside the envelope. Options: choose an EVI (enhanced vapour injection) or high-temperature unit, or heat to 50°C and top up with an electric or boiler stage.

Remember

- Plot your design point (ambient, LWT) on the envelope before selecting.
- Check both winter and summer corners.
- The envelope tightens at low ambient.
- EVI and CO₂ machines widen the envelope.

Common mistake: Setting the controller to 60 °C on a unit whose envelope ends at 55 °C, then blaming HP trips on the gas charge.



5.4 Sizing: capacity, running hours and storage trade-off

Key idea: Hot water sizing is a trade-off — a bigger tank lets a smaller heat pump run longer hours.

Hot water demand is peaky. A hotel uses most of its water 6–9 am and 7–10 pm. A geyser meets a peak with high power. A heat pump meets it with stored hot water, filled slowly over many hours. The tank is a battery of heat.

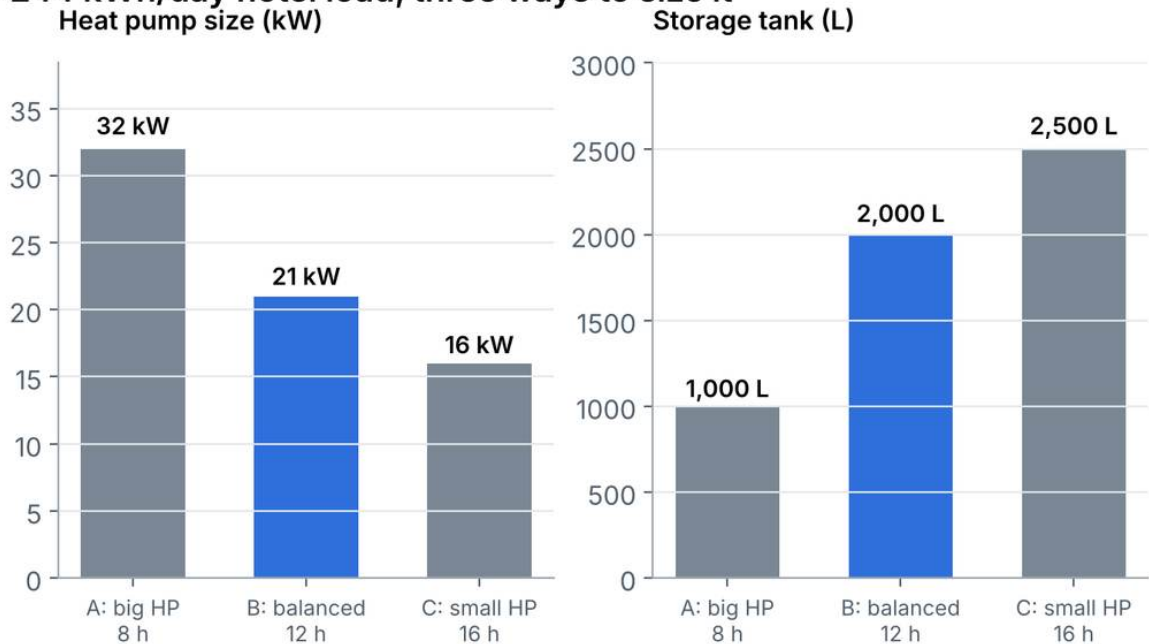
Three steps:

1. Find daily hot water energy.
2. Choose running hours (typically 8–16 h per day for hot water; more hours means a smaller unit).
3. Size storage to cover the peak that the heat pump cannot meet in real time.

$$E_{day} = \frac{V \times c_p \times \Delta T}{3600} \text{ [kWh]}, \quad c_p = 4.186 \text{ kJ/kg} \cdot \text{K}, \quad 1 \text{ L} \approx 1 \text{ kg}$$

$$Q_{HP} = \frac{E_{day}}{h_{run}}, \quad V_{tank} \approx \frac{(E_{peak} - Q_{HP} t_{peak}) \times 3600}{c_p \Delta T \eta_{usable}}$$

Same 244 kWh/day hotel load, three ways to size it



Running cost is the same if COP is equal; option B (highlighted) usually balances cost, space and recovery.

Three ways to size the same hotel load

Worked example — 40-room hotel in Pune

Load: 40 rooms × 2 guests × 60 L at 60 °C = 4,800 L/day plus kitchen 1,200 L = 6,000 L/day. Cold water 25 °C (typical Pune winter). $\Delta T = 35 \text{ K}$. $E_{day} = 6,000 \times 4.186 \times 35 / 3600 = 244 \text{ kWh/day}$. Morning peak: 50 % of daily use in 3 hours = 122 kWh. Usable fraction of tank (stratification and mixing) $\eta = 0.8$ (typical 0.75–0.9).

Option	Running hours	HP size	HP output in 3 h peak	Energy tank must hold	Tank volume
A — big HP	8 h	$244/8 = 30.5 \text{ kW} \rightarrow 32 \text{ kW}$	96 kWh	$122 - 96 = 26 \text{ kWh}$	$26 \times 3600 / (4.186 \times 35 \times 0.8) \approx 800 \text{ L} \rightarrow 1,000 \text{ L}$
B — balanced	12 h	$244/12 = 20.3 \text{ kW} \rightarrow 21 \text{ kW}$	63 kWh	59 kWh	$\approx 1,800 \text{ L} \rightarrow 2,000 \text{ L}$
C — small HP	16 h	$244/16 = 15.3 \text{ kW} \rightarrow 16 \text{ kW}$	48 kWh	74 kWh	$\approx 2,260 \text{ L} \rightarrow 2,500 \text{ L}$

Running cost is the same for all three if COP is equal: $244 \text{ kWh} \div \text{COP } 3.8 = 64 \text{ kWh electricity/day} \times ₹9 = ₹578/\text{day}$ (example rate). Option B is usually best: moderate tank, room to recover if a second peak comes early, and some spare hours for derating. Check: the evening peak must be recovered in the hours between peaks. Option C needs $74 \text{ kWh} \div 16 \text{ kW} \approx 4.6 \text{ h}$ refill time — fine if peaks are 10 h apart.

Remember

- Energy per day sets total work; running hours set machine size.
- Storage covers what the machine cannot deliver during the peak.
- Leave 20–30 % spare hours for derating and defrost.
- Check recovery time between peaks.

Field tip: Ask the client for water meter readings, not guesses; hotels often use 40–80 L per guest at 60 °C.



5.5 Storage tank sizing and stratification

Key idea: A stratified tank keeps hot water on top and cold at the bottom, so you can draw more usable hot water from the same volume.

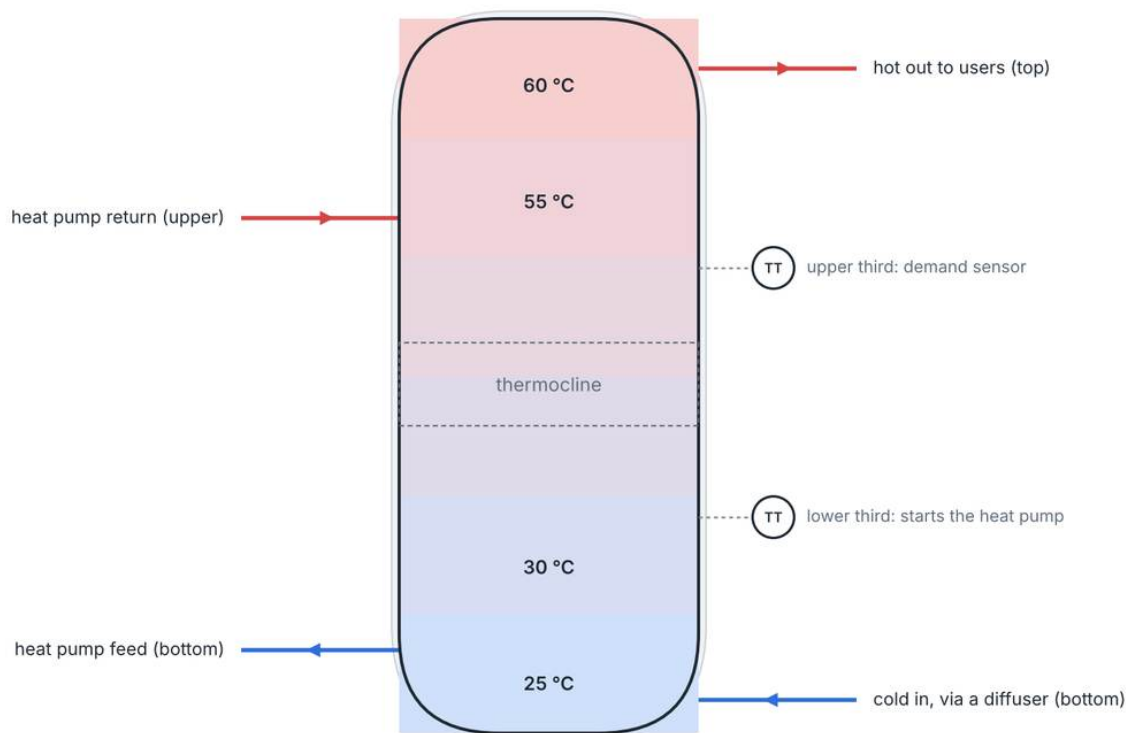
Hot water is lighter than cold. Left still, it forms layers: hot at the top, cold at the bottom, with a thin mixing zone between called the thermocline. This is stratification. Stir the tank and the layers mix, and the effect is lost.

Good stratification means the heat pump gets cold water from the bottom, which raises its COP. The user gets hot water from the top at full temperature until the tank is almost empty.

How to keep stratification:

- Bring cold make-up in at the bottom through a diffuser, at low velocity (typical under 0.3 m/s at inlet).
- Take hot draw-off from the top.
- Return heat pump hot water to the top; take heat pump feed from the bottom.
- Prefer tall vertical tanks (height:diameter around 2:1 to 3:1).
- Avoid recirculation return lines dumping into the middle at high flow.

Stratified storage tank: keep hot on top, cold at the bottom



Stratified storage tank

Item	Typical value
Usable fraction, well stratified	0.8–0.9
Usable fraction, mixed tank	0.6–0.7
Storage temperature	55–60 °C
Legionella control	Store ≥ 60 °C, periodic pasteurisation cycle above 60 °C
Tank insulation	50–100 mm PUF, typical loss target < 1 °C per 12 h

Worked example — standing loss check

A 2,000 L tank at 60 °C in a 20 °C plant room loses heat at 2.0 W/K (UA, typical for well-insulated tank).

$$Q_{loss} = UA \times (T_{tank} - T_{room})$$

$Q_{loss} = 2.0 \times (60 - 20) = 80 \text{ W} = 1.92 \text{ kWh/day}$. Cost = $1.92 \div \text{COP } 3.8 \times ₹9 \approx ₹4.5/\text{day}$. Good insulation makes standing losses minor.

Remember

- Hot in at top, cold in at bottom, slowly.
- Tall tanks stratify better.
- Place the HP start sensor in the lower third.
- Store at 60 °C or run pasteurisation for Legionella safety.

Common mistake: A high-flow recirculation pump that mixes the whole tank and kills stratification.



5.6 Direct vs indirect heating

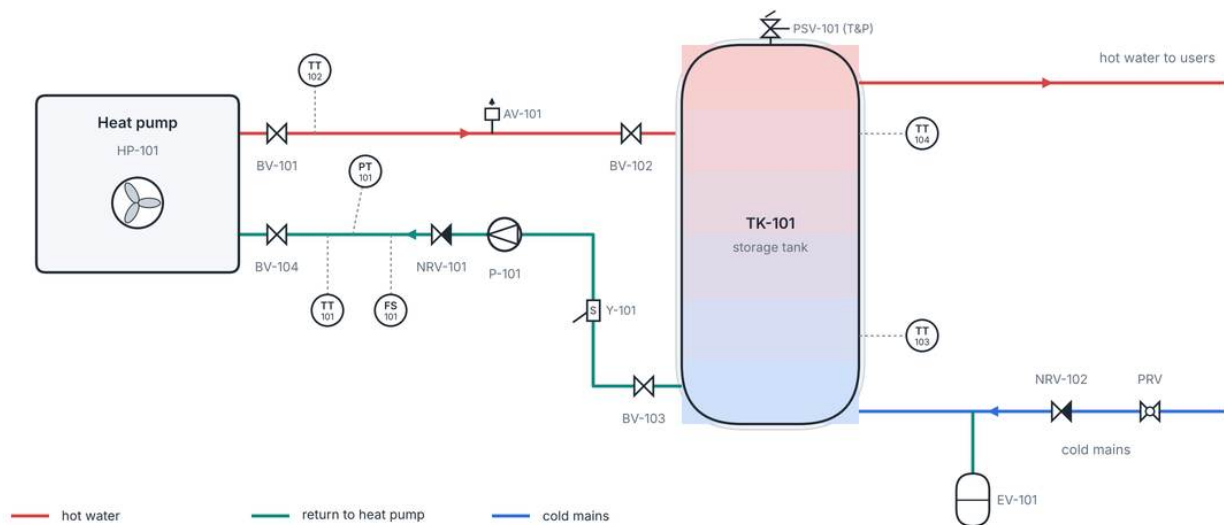
Key idea: Direct heating passes the user's water through the heat pump condenser; indirect heating keeps it in a separate loop through a heat exchanger.

In a direct system, the potable (drinking-quality) or process water flows straight through the heat pump's condenser. It is simple and has no exchanger losses. But hard or dirty water scales the condenser.

In an indirect system, the heat pump heats a closed loop of clean, treated water. A plate heat exchanger (PHE) or tank coil transfers heat to the user water. This protects the heat pump, at the cost of a 3–5 K approach (temperature lost across the exchanger) and an extra pump.

P&ID 1: direct heating

Tank water passes straight through the heat pump's condenser

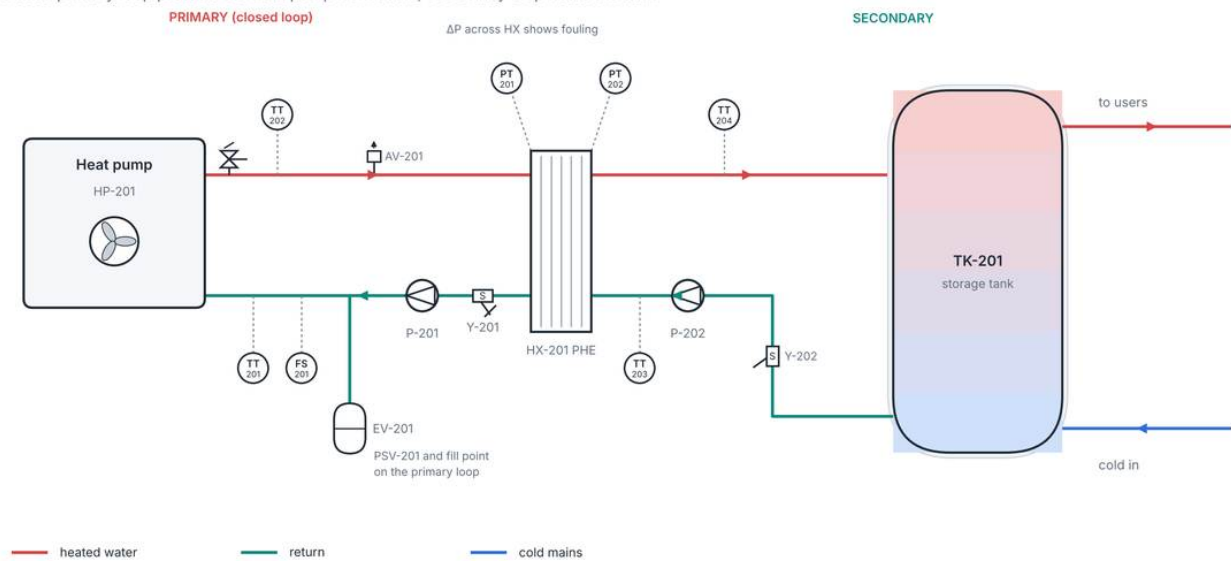


P&ID 1: direct heating

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P&ID 2: indirect heating through a plate heat exchanger

Closed primary loop protects the heat pump from scale; secondary loop heats the tank



P&ID 2: indirect heating through a plate heat exchanger

Factor	Direct	Indirect (PHE)
Efficiency	Best — no approach loss	COP lower by typical 5–10 %
Cost	Lower	Extra PHE, pump, controls
Scaling risk to HP	High with hard water	Low — closed treated loop
Maintenance	Descale HP condenser	Descale PHE (easy to open/CIP)
Best for	Soft water, RO water, small domestic	Hard water, process fluids, pools, hygiene

Worked example — approach penalty

Need 58 °C user water. PHE approach 4 K → primary must make 62 °C. If the envelope limit is 60 °C at design ambient, indirect fails while direct (58 °C) works. Either pick a higher-temperature unit or a closer-approach PHE (2 K, more plates).

Remember

- Direct is simpler and more efficient; indirect protects the machine.
- Use indirect when TDS/hardness is high or the fluid is not clean water.
- Add the PHE approach to the HP leaving water temperature.
- Fit isolation valves on both PHE sides for cleaning.

Field tip: Above about 150–200 mg/L hardness (as CaCO_3), plan indirect or softening from day one.

5.7 Hydraulics: piping, pumps, buffer tanks, flow rates

Key idea: The heat pump needs a steady, correct water flow — get the flow wrong and nothing else matters.

Flow rate links capacity and temperature rise:

$$\dot{V} [\text{m}^3/\text{h}] = \frac{Q [\text{kW}] \times 3600}{\rho c_p \Delta T} \approx \frac{0.86 Q}{\Delta T}$$

Most heat pumps want a ΔT of about 5 K across the condenser (typical 3–7 K). Too low a flow raises condensing temperature and trips on HP. Too high a flow wastes pump power and erodes pipes.

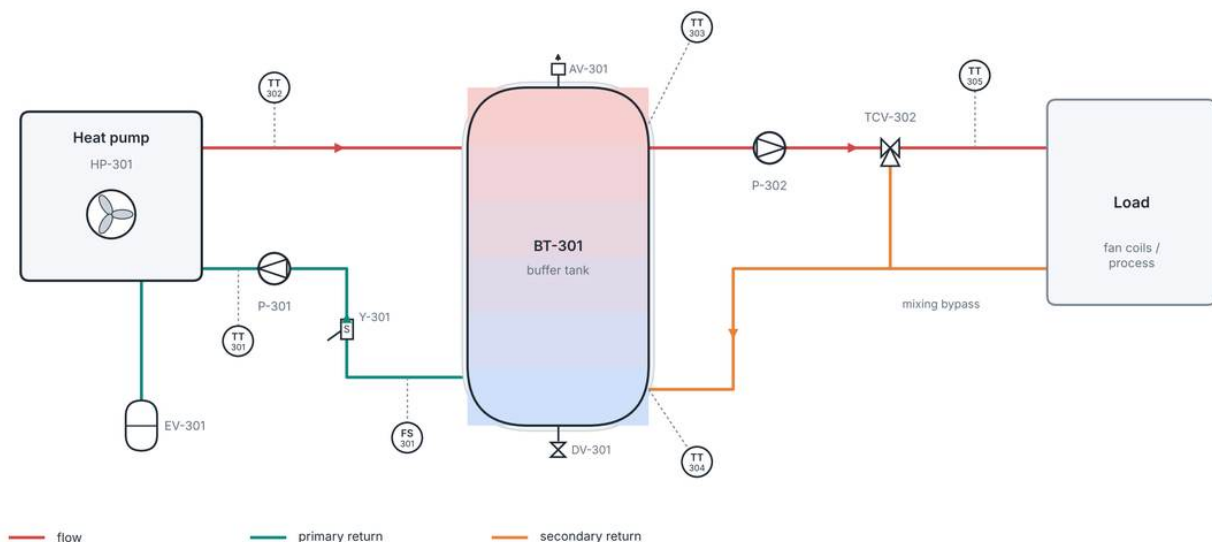
Pipe velocity guide (typical): 0.6–1.2 m/s for small pipes, up to 1.5–2.0 m/s for larger mains. Keep below about 2.5 m/s to limit noise and erosion.

A buffer tank adds water volume. It is used when (a) the system water volume is too small, causing short cycling (frequent stop-starts), (b) defrost needs heat stored, or (c) primary and secondary flows differ. The buffer then acts as a hydraulic separator: primary pump (HP side) and secondary pump (load side) work independently.

Minimum water volume rule of thumb: typical 5–10 L per kW for inverter units, 10–20 L per kW for on/off units. Check the manufacturer's figure.

P&ID 3: buffer tank, primary and secondary circuits

Heat pump flow and load flow are separated, so each pump can run at its own rate



P&ID 3: buffer tank, primary and secondary circuits

Capacity	Flow at ΔT 5 K	Typical pipe (copper/PPR/steel)
5 kW	0.86 m ³ /h (860 LPH)	22 mm Cu / 25 mm PPR / DN20
10 kW	1.72 m ³ /h	28 mm Cu / 32 mm PPR / DN25
20 kW	3.44 m ³ /h	35 mm Cu / 40 mm PPR / DN32
40 kW	6.9 m ³ /h	50 mm PPR / DN40
80 kW	13.8 m ³ /h	DN50–DN65

Worked example — pump for a 30 kW unit

Flow = $0.86 \times 30 / 5 = 5.16 \text{ m}^3/\text{h}$. Pipe DN40 (ID $\approx 41 \text{ mm}$): area = 0.00132 m^2 ; velocity = $5.16/3600/0.00132 = 1.09 \text{ m/s}$ — fine. Head: condenser 3.5 m (from datasheet), pipe 30 m equivalent $\times 0.03 \text{ m/m} = 0.9 \text{ m}$, strainer + valves 1.5 m $\rightarrow 5.9 \text{ m}$; add 15 % margin $\rightarrow$ about 6.8 m. Select a pump for $5.2 \text{ m}^3/\text{h}$ at about 7 m head: shaft power $\approx 212 \text{ W}$ (hydraulic power $\approx 96 \text{ W}$) at 45 % pump efficiency.

$$P_{shaft} = \frac{\rho g H \dot{V}}{\eta} = \frac{1000 \times 9.81 \times 6.8 \times 5.16/3600}{0.45} \approx 212 \text{ W}$$

Remember

- Set flow for $\Delta T \approx 5 \text{ K}$ across the heat pump.
- Fit a strainer before the heat pump and a flow switch at its inlet.
- Use a buffer when water volume is small or flows differ.
- Air vents at high points, drains at low points.
- Where load-side demand swings widely (hotel recirculation, fan-coil loops), fit the secondary pump with a variable frequency drive (VFD): pump power falls roughly with the cube of speed, so running at part load saves far more energy than throttling a valve.

Common mistake: Undersized pipe from the client's old geyser line — the flow switch never makes.



5.8 Hybrid systems with solar thermal and boilers

Key idea: In a hybrid system, the cheapest heat source runs first and the heat pump or boiler tops up.

Solar thermal collectors (flat plate or evacuated tube) give free heat on sunny days. A heat pump gives heat at low running cost any time. A boiler (LPG, PNG or diesel) gives high temperature quickly and acts as backup.

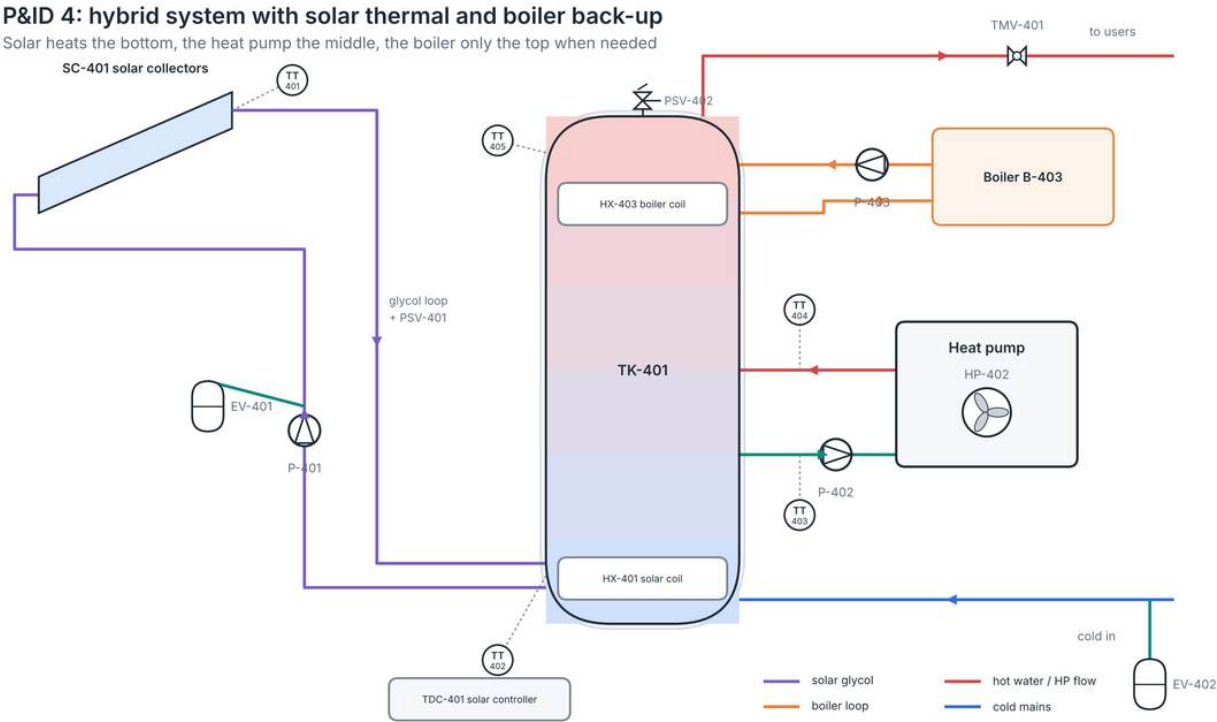
The usual order: solar preheats the bottom of the tank, the heat pump lifts water to 50–55 °C, and the boiler or electric heater tops up only for peaks, pasteurisation, or a heat pump failure.

Running cost per kWh of heat delivered (example rates):

Source	Example price	Efficiency	Cost per kWh heat
Solar thermal	free	—	≈ ₹0 (plus pump power)
Heat pump COP 3.5	₹9/kWh	350 %	₹2.6
PNG boiler	₹75/scm, ~10.5 kWh/scm (typical)	88 %	₹8.1
LPG boiler	₹100/kg, ~12.8 kWh/kg (typical)	88 %	₹8.9
Diesel boiler	₹100/L, ~10 kWh/L (typical)	85 %	₹11.8
Electric heater	₹9/kWh	~100 %	₹9.0

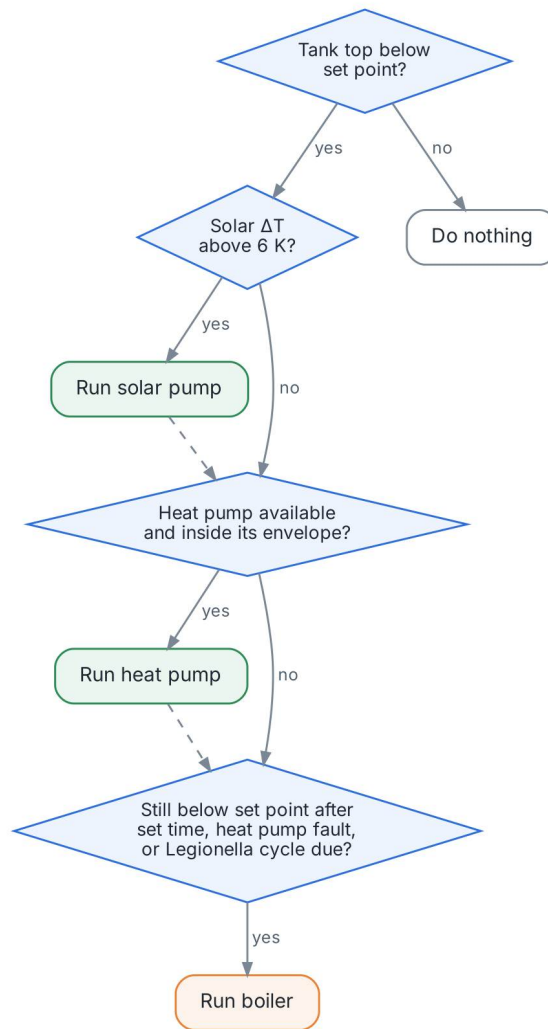
P&ID 4: hybrid system with solar thermal and boiler back-up

Solar heats the bottom, the heat pump the middle, the boiler only the top when needed



P&ID 4: hybrid with solar thermal and boiler back-up

Hybrid control: cheapest heat first



Hybrid control: cheapest heat first

Worked example — annual saving of adding a heat pump to an LPG boiler (Bengaluru hostel)

Load 150 kWh/day heat, 365 days = 54,750 kWh/year. Solar covers 40 % (typical in Bengaluru with good array) = 21,900 kWh. Remaining 32,850 kWh. LPG only: $32,850 \times ₹8.9 = ₹2.92$ lakh/year. HP covers 90 % of remainder, LPG 10 %: HP $29,565 \times ₹2.6 = ₹76,900$; LPG $3,285 \times ₹8.9 = ₹29,200$. Total ₹1.06 lakh. Saving $\approx ₹1.86$ lakh/year (example rates).

Remember

- Solar first, heat pump second, boiler last.
- Keep each source in its own tank zone to protect stratification.
- Solar heats the bottom, which lowers HP COP — size HP return accordingly.
- Use a TMV on outlet when sources can overheat the tank.

Field tip: Interlock so the boiler cannot run while the HP is meeting setpoint; check controller priorities at commissioning.

5.9 Multiple units: cascading and redundancy

Key idea: Several smaller heat pumps in cascade give better part-load efficiency and keep hot water flowing if one unit fails.

Cascading means connecting several heat pumps to one header and switching them on in stages as demand rises. A master controller rotates the lead unit to share running hours equally.

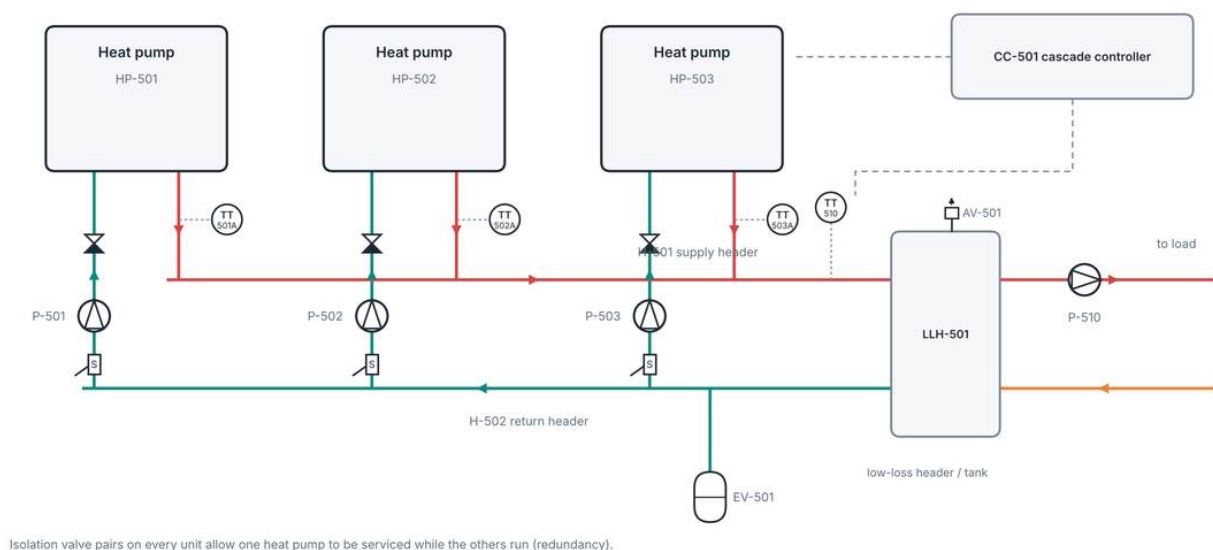
Redundancy is the spare capacity you keep for failure. N+1 means one more unit than needed. For a hospital or hotel, losing hot water is not acceptable, so N+1 is common.

Header design:

- Use a common supply and return header with reverse-return piping, or a low-loss header, so each unit gets equal flow.
- Each unit has its own pump (or motorised valve), NRV, isolation valves, strainer and flow switch.
- Size header velocity low (typical ≤ 0.6 m/s) so it acts as a hydraulic separator.

P&ID 5: three heat pumps in cascade on a common header

Each unit has its own pump and non-return valve; one controller stages them



P&ID 5: three heat pumps in cascade

Arrangement	Pros	Cons
One large unit	Low capital, simple	No backup, poor part-load
2 × 50 %	Some backup (50 %)	Half output on failure
3 × 50 % (N+1)	Full output with one down	Higher capital
4 × 33 % (N+1)	Fine staging, full backup	More pipework, controls

Worked example — redundancy choice for a 120 kW hospital load

Design load 120 kW at design ambient. Option 1: 3 × 40 kW (N). One failure → 80 kW = 67 % output. Option 2: 4 × 40 kW (N+1). One failure → 120 kW = 100 %. Extra capital is one unit; for a hospital, choose N+1.

Remember

- Cascade for part-load efficiency and resilience.
- Equal flow to each unit: reverse return or individual pumps with balancing.
- NRV on every unit to stop back-flow through idle units.
- Rotate lead unit to equalise hours.

Common mistake: No NRV on idle units — hot water bypasses back through them and the header never reaches setpoint.

5.10 Water quality and material selection

Key idea: Bad water kills heat exchangers faster than anything else, so match materials and treatment to the site water.

Indian water ranges from soft rainwater to borewell water with TDS above 1,500 mg/L. Hardness (calcium and magnesium) forms scale on hot surfaces. Scale is a thermal blanket: a 1 mm layer can cut heat transfer noticeably and raise condensing pressure.

Key terms:

- TDS (total dissolved solids): all dissolved salts, mg/L (ppm).
- Hardness: calcium + magnesium, expressed as mg/L CaCO_3 .
- Chlorides: attack stainless steel (pitting), especially when hot.
- pH: acidity; below about 6.5 corrodes copper, above about 9 encourages scale.

Typical guide values for water passing through a brazed plate or coaxial condenser (check manufacturer):

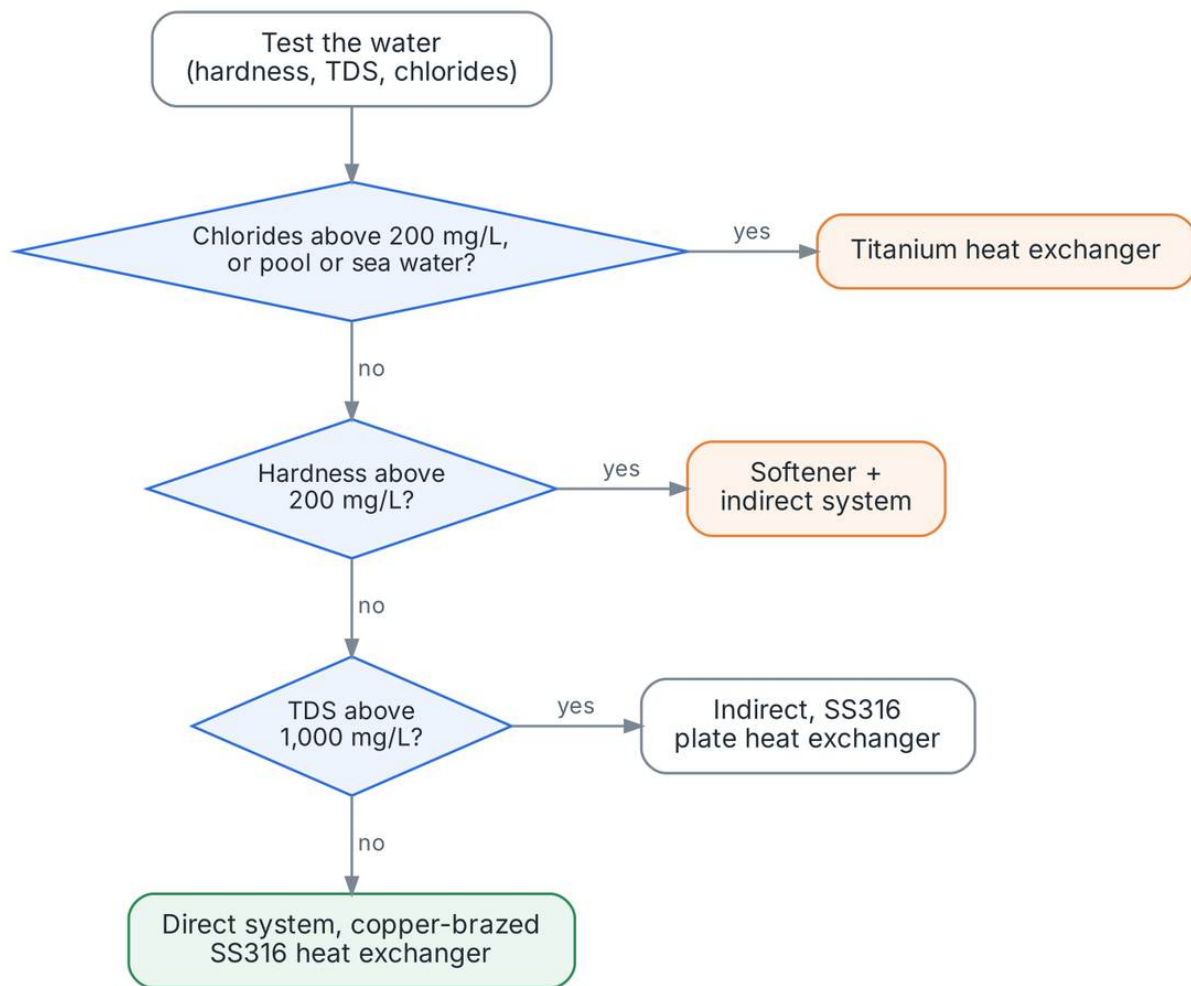
Parameter	Typical acceptable	Comment
pH	7.0–9.0	
Total hardness	< 150–200 mg/L as CaCO_3	Soften above this
TDS	< 500 mg/L (preferred), up to ~1,000 with care	
Chlorides	< 100–200 mg/L for SS304	SS316 or titanium above
Free chlorine	< 0.5–1 mg/L	Pools need care
Iron	< 0.2 mg/L	Fouling

Material selection:

Water type	Condenser material
Soft / RO municipal	Copper-brazed SS316 plate or copper coaxial
Hard borewell	Indirect loop + softener; SS316 PHE on user side
Swimming pool (chlorinated)	Titanium coil
Sea / brackish water	Titanium
Process with ammonia contact	Nickel-brazed or fully welded SS (no copper)



Choose materials from a water test (typical limits)



Choose materials from a water test

Worked example — scale penalty

A unit in Jaipur on borewell water (hardness 450 mg/L) builds scale. Condensing temperature rises 4 K. Rule of thumb: COP falls roughly 2–3 % per K of extra lift (typical). COP drops from 3.5 to about $3.5 \times (1 - 0.025 \times 4) = 3.15$. On 200 kWh heat/day: electricity rises from 57.1 to 63.5 kWh/day = $6.4 \text{ kWh} \times ₹9 = ₹58/\text{day} \approx ₹21,000/\text{year}$, before the cost of a failed condenser.

Remember

- Test the water before selecting: pH, hardness, TDS, chlorides, iron.
- Pools and sea water need titanium.
- High hardness → softener and/or indirect loop.
- Plan CIP (clean-in-place) connections on PHEs.

Field tip: Carry a TDS pen and a hardness strip kit to every site survey.

5.11 Electrical design: supply, protection, starting current

Key idea: The electrical supply must handle the heat pump's running current, its starting current and the local voltage swings.

Heat pumps up to about 5–7 kW heating output are often single phase (230 V). Larger units are usually three phase (415 V). Check the nameplate for rated input current, maximum running current (at the hottest/most loaded condition), and locked rotor amps (LRA), the current a fixed-speed compressor draws for a moment at start.

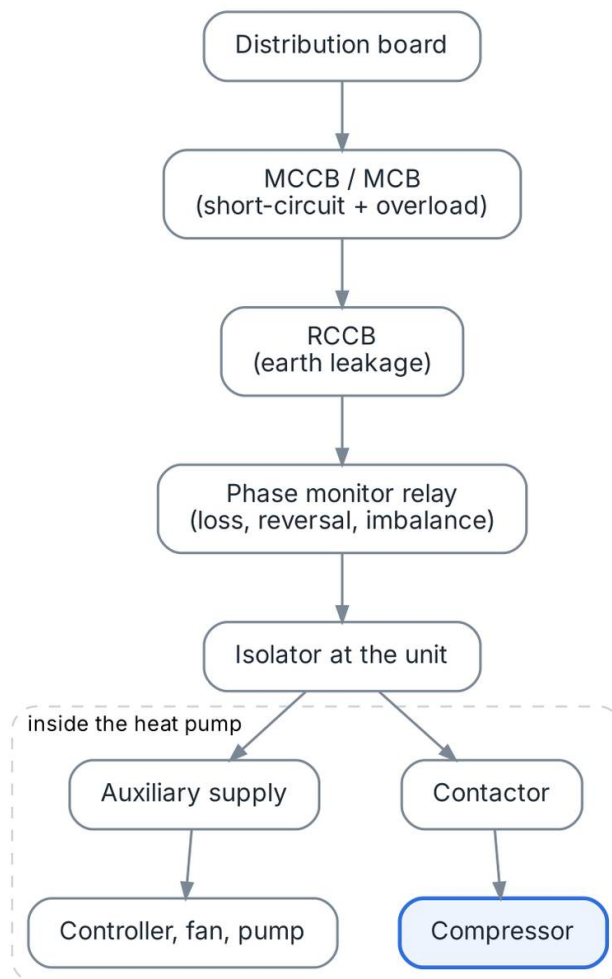
Starting current:

- A fixed-speed scroll compressor on direct-on-line (DOL) start can draw 5–7 times running current for a fraction of a second.
- Soft starters reduce this to typical 2–3 times.
- Inverter compressors ramp up gently; inrush stays near running current.

Indian supply issues: voltage can sag to 180–200 V on single phase in rural areas, and phases can be unbalanced. Use a phase-failure and phase-sequence relay, and a voltage monitor or stabiliser sized for the starting kVA where supply is weak.

Protection chain (typical): incoming MCB/MCCB → RCCB/RCBO (earth leakage, 30 mA for personnel protection or 100–300 mA for equipment per local practice) → contactor → overload relay or compressor motor protector. Fit a local isolator next to the outdoor unit. Earth properly — test earth resistance.

Electrical supply to a heat pump: single-line view



Electrical supply: single-line view

Unit heating output	Typical supply	Typical running current (indicative)
3–5 kW	1-phase 230 V	4–7 A
10 kW	3-phase 415 V	4–6 A per phase
25 kW	3-phase 415 V	10–14 A per phase
50 kW	3-phase 415 V	20–28 A per phase

Worked example — cable and MCB for a 25 kW (heat) unit

COP at design 3.0 → electrical input 25/3.0 = 8.3 kW. Max running input (hot day, high water) say 10 kW, pf 0.9.

$$I = \frac{P}{\sqrt{3} V \cos \phi}$$

$I = 10,000 / (1.732 \times 415 \times 0.9) = 15.5$ A. Choose a 20 A C-curve or D-curve MCB (D-curve if DOL start with high LRA). Cable: 4 mm² copper, 4-core armoured, typical for runs up to about 30 m; check voltage drop (keep under 3–5 %) and derating for grouping and ambient. Starting check (fixed speed, LRA $6 \times 15.5 \approx 93$ A): transformer/DG must accept this dip. With a soft starter, about 40 A.

Remember

- Size cable on maximum running current, not nominal.
- Check LRA against DG and weak grid supply.
- Phase monitor + RCCB + local isolator on every installation.
- Voltage drop under 3–5 % at full load.

Common mistake: Running a DOL unit on a small DG set sized only for running kW — it stalls at every start.



Quiz 5

1. A datasheet lists 10 kW at 20 °C DB / 15 °C WB, water 15 → 55 °C. At 5 °C ambient you should expect: A) more than 10 kW B) exactly 10 kW C) less than 10 kW D) the same kW but lower COP only
2. The main purpose of an operating envelope is to show: A) noise levels B) safe ambient and water temperature combinations C) refrigerant charge D) pump head
3. Daily hot water energy for 3,000 L heated by 35 K is about: A) 61 kWh B) 122 kWh C) 244 kWh D) 35 kWh
4. Increasing running hours from 8 to 16 h for the same daily load generally: A) doubles the HP size B) halves the HP size but needs more storage C) needs no storage D) halves running cost
5. In a well stratified tank, the heat pump should take its feed from: A) the top B) the middle C) the bottom D) the hot outlet
6. Indirect heating via a PHE is preferred when: A) water is RO-treated and soft B) water is hard or the fluid is not clean water C) maximum COP is the only goal D) the site has no space
7. Flow for a 20 kW heat pump at ΔT 5 K is about: A) 0.86 m³/h B) 1.7 m³/h C) 3.4 m³/h D) 6.9 m³/h
8. In a hybrid solar + HP + boiler system, the normal operating priority is: A) boiler, HP, solar B) HP, boiler, solar C) solar, HP, boiler D) all together
9. In a cascade of heat pumps on a common header, each unit needs a non-return valve mainly to: A) reduce noise B) stop flow bypassing back through idle units C) raise COP D) meter energy
10. For a swimming pool with chlorinated water, the best condenser material is: A) copper B) SS304 C) titanium D) mild steel

Answer key

1. C — capacity falls as ambient air gets colder.
2. B — it maps where the compressor can run without tripping.
3. B — $3,000 \times 4.186 \times 35 / 3600 \approx 122$ kWh.
4. B — same energy over twice the hours halves kW; storage must cover more of the peak.
5. C — cold bottom water gives the best COP and keeps layers.
6. B — the closed primary loop protects the heat pump.
7. C — $0.86 \times 20 / 5 = 3.44$ m³/h.
8. C — cheapest heat first; boiler only tops up.
9. B — without NRVs, water short-circuits through stopped units.
10. C — titanium resists chloride attack.



Glossary

Term	Meaning
Rating condition	The ambient and water temperatures at which a datasheet value was measured
Dry-bulb (DB) / Wet-bulb (WB)	Air temperature / temperature that also reflects humidity
COP	Heat delivered divided by electrical input
Derating	Reducing rated capacity to actual capacity at site conditions
Design ambient	The low outdoor temperature the system is designed to work at
Defrost	Melting ice off the outdoor coil, which briefly stops heating
Operating envelope	Map of allowed ambient vs leaving water temperatures
LWT	Leaving water temperature from the heat pump
EVI	Enhanced vapour injection, a compressor feature for cold climates and high water temperatures
Stratification	Hot water layer on top of cold in a still tank
Thermocline	The mixing zone between hot and cold layers
Usable fraction	Share of tank volume delivered at useful temperature
Direct heating	User water flows through the heat pump condenser
Indirect heating	A closed loop heats user water through a heat exchanger
PHE	Plate heat exchanger
Approach	Temperature difference between the two fluids at the exchanger end
Buffer tank	Extra water volume that prevents short cycling and separates circuits
Short cycling	Frequent stops and starts that wear the compressor
Hydraulic separator / low-loss header	Device that lets primary and secondary flows run independently
Cascade	Several units staged on one header
N+1	One more unit than needed, for redundancy
TDS	Total dissolved solids in water, mg/L
Hardness	Calcium and magnesium content, as mg/L CaCO ₃
CIP	Clean-in-place connections for descaling
LRA	Locked rotor amps, the momentary starting current
DOL	Direct-on-line motor starting
RCCB	Residual current circuit breaker for earth leakage protection
P&ID	Piping and instrumentation diagram
TT / PT / FT / FS	Temperature transmitter / pressure transmitter / flow transmitter / flow switch

Course 6 — Economics, Energy and Sustainability

Powered by Sunniva. This Level 2 course is for building owners, energy consultants and finance teams who must judge whether a heat pump makes financial and environmental sense. After it you will be able to: (1) compare the cost of heat from any fuel on a fair, per-useful-kWh basis; (2) calculate simple payback, ROI and lifecycle cost; (3) estimate CO₂ savings and the value of solar PV and time-of-day tariffs; and (4) put these numbers into a clear business case for management.

6.1 How to compare running costs fairly

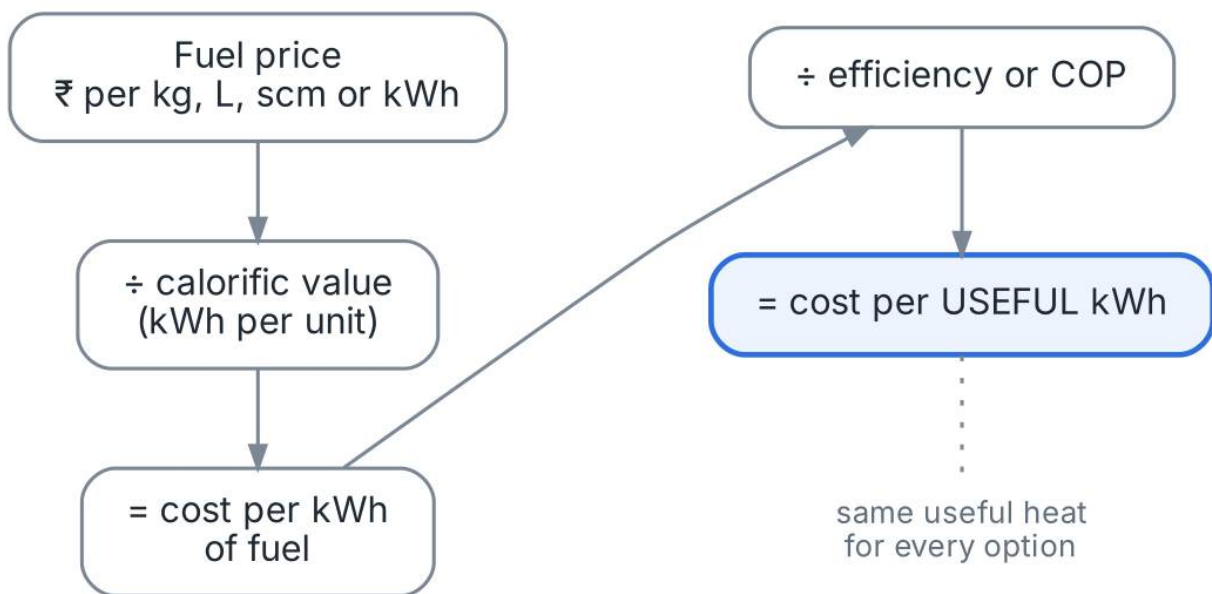
Key idea: compare fuels by the cost of one unit of useful heat delivered, not by the price on the bill.

A litre of diesel and a unit of electricity are not the same thing. Each contains a different amount of energy. Each appliance also wastes a different share of it.

Think of buying rice. A 5 kg bag at ₹300 and a 2 kg bag at ₹140 cannot be compared by bag price. You divide by weight first. Heat works the same way, but you also subtract what spills on the floor.

Useful heat is the energy that actually reaches the water, air or process. It is measured in kWh (kilowatt-hour, 3.6 MJ). Calorific value is the energy contained in one unit of fuel. Efficiency is the share of that energy that becomes useful heat. For a heat pump we use COP (coefficient of performance): useful heat out divided by electricity in.

Four steps to a fair running-cost comparison



Four steps to a fair running-cost comparison

Rule	Why it matters
Use the same useful heat demand for every option	Otherwise you compare different jobs
Use net calorific value (NCV) consistently	Gross values flatter combustion efficiency
Use seasonal efficiency, not peak test efficiency	Boilers cycle; heat pump COP changes with weather
Include standby and distribution losses	Long pipes and hot tanks lose heat all day
Include maintenance, not only fuel	Burners, chimneys and filters cost money
Use the real tariff, including fixed and demand charges	The average ₹/kWh can differ from the energy rate

Net calorific value (NCV) excludes the heat locked in water vapour in the flue gas. Gross calorific value (GCV) includes it. Mixing the two can shift results by about 10%.

Worked example — what does one useful kWh cost from an electric geyser?

$$\text{Cost per useful kWh} = \frac{\text{Fuel price per unit}}{\text{Energy per unit} \times \text{Efficiency}}$$

1. Electricity price (example): ₹9/kWh. Energy per unit: 1 kWh.
2. Typical electric resistance efficiency including tank losses: 0.95.
3. Cost per useful kWh = $9 \div (1 \times 0.95) = ₹9.47$.

Remember

- Divide price by energy content, then by efficiency.
- Keep one useful heat demand for all options.
- Use seasonal, real-world efficiency figures.
- Add maintenance and fixed charges before deciding.

Common mistake: comparing ₹/kWh of electricity with ₹/kg of LPG directly, without converting both to useful kWh.



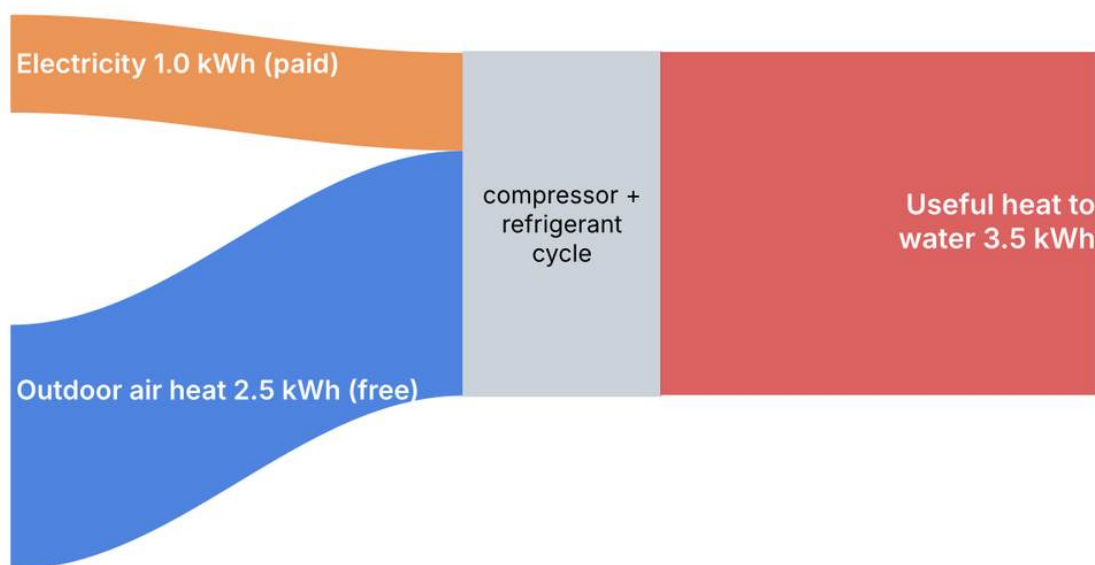
6.2 Cost per useful kWh: electricity, LPG, PNG, diesel, biomass

Key idea: a heat pump turns 1 kWh of electricity into about 3–4 kWh of useful heat, so its cost per useful kWh is a fraction of the tariff.

A heat pump does not create heat by burning. It moves heat already present in the outside air into water, like a fridge, but using the heat it rejects instead of the cold it makes. The electricity drives the compressor; the ambient air supplies the rest.

Combustion appliances can never deliver more heat than the fuel contains. Their efficiency is always below 100%. A heat pump's COP is above 1 because the free ambient heat is not on the bill.

Where a heat pump's heat comes from (COP 3.5)



Where a heat pump's heat comes from

Typical reference values used in this course

Energy source	Example price	Typical NCV	Energy per unit (kWh)	Typical efficiency / COP
Electricity (resistance geyser)	₹9/kWh	—	1.0 per kWh	0.95
Electricity (air-source heat pump, hot water 55–60 °C)	₹9/kWh	—	1.0 per kWh	COP 3.5 (typical range 3–4.5)
LPG	₹100/kg	~46 MJ/kg	~12.8 per kg	0.85
PNG (piped natural gas)	₹75/scm	~34 MJ/scm	~9.5 per scm	0.85
Diesel (HSD)	₹100/L	~36 MJ/L	~10.0 per L	0.80
Biomass briquettes	₹8/kg (example)	~15 MJ/kg	~4.2 per kg	0.70

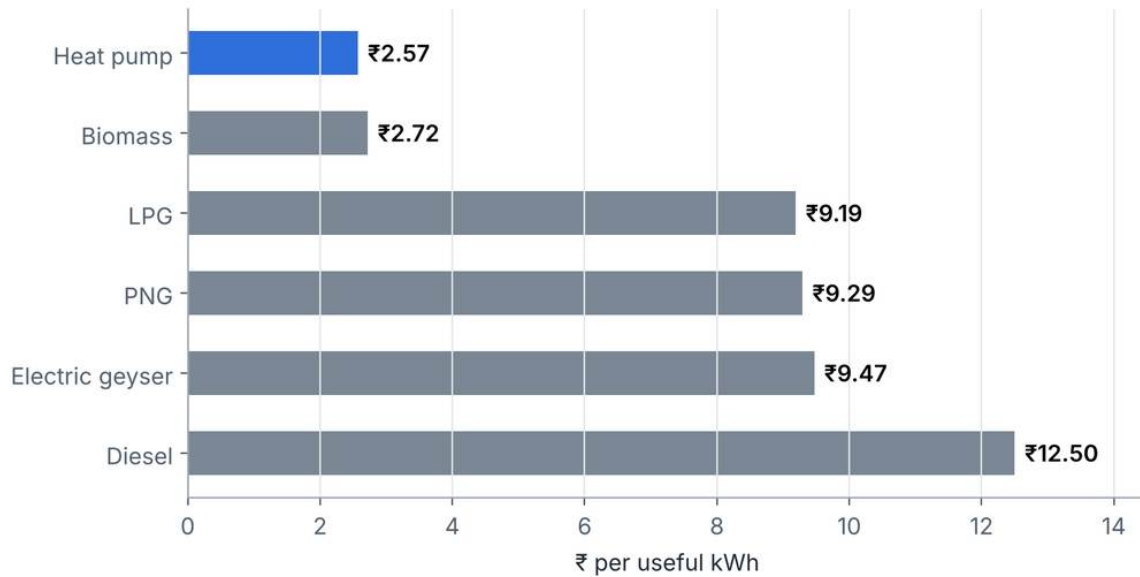
scm means standard cubic metre, the gas volume at reference conditions. HSD means high-speed diesel. Biomass values vary widely with moisture content.

Cost per useful kWh (example rates, typical efficiencies)

Source	Cost per kWh of fuel	÷ efficiency	Cost per useful kWh
Heat pump (COP 3.5)	₹9.00	3.5	₹2.57
Biomass briquettes	₹1.90	0.70	₹2.72
LPG	₹7.81	0.85	₹9.19
PNG	₹7.89	0.85	₹9.29
Electric resistance geyser	₹9.00	0.95	₹9.47
Diesel	₹10.00	0.80	₹12.50

Cost of one useful kWh of heat

Example rates (electricity ₹9/kWh, LPG ₹100/kg, PNG ₹75/scm, diesel ₹100/L, biomass ₹8/kg), typical efficiencies.



Cost of one useful kWh of heat

Biomass looks cheap on fuel alone. It needs storage space, manual feeding, ash removal and emission control. Its supply and moisture also vary by season, which affects real efficiency.

Worked example — LPG in a Chennai hostel kitchen water heater

$$\text{Cost per useful kWh}_{\text{LPG}} = \frac{100}{12.8 \times 0.85}$$

1. Energy in 1 kg LPG $\approx 46 \text{ MJ} \div 3.6 = 12.8 \text{ kWh}$.
2. Cost per kWh of fuel = $\text{₹}100 \div 12.8 = \text{₹}7.81$.
3. Divide by efficiency 0.85: $\text{₹}7.81 \div 0.85 = \text{₹}9.19$ per useful kWh.
4. Heat pump: $\text{₹}9 \div 3.5 = \text{₹}2.57$. The heat pump heat costs about 28% of LPG heat.

Remember

- Heat pump cost per useful kWh = tariff $\div$ COP.
- At typical COP, heat pump heat costs roughly a quarter to a third of LPG, PNG or diesel heat.
- Biomass can be cheap but carries hidden handling costs.
- Recalculate whenever fuel prices change.

Field tip: ask for the last 12 months of fuel bills. Real consumption beats any estimate.

6.3 Payback, ROI and lifecycle cost

Key idea: a heat pump costs more to buy but less to run, so judge it over its whole life, not on purchase price.

Simple payback is the number of years the yearly saving takes to repay the extra investment. ROI (return on investment) is the yearly saving as a percentage of investment. Lifecycle cost adds up purchase, energy, maintenance and replacement over the equipment's life.

It is like choosing between a cheap two-wheeler that drinks petrol and a costlier efficient one. After a few years the efficient one has paid for its extra price.

Lifecycle cost often uses NPV (net present value). NPV discounts future savings because ₹1 next year is worth less than ₹1 today. The discount rate is usually the company's cost of capital.

Worked example — hotel in Bengaluru replacing LPG for hot water

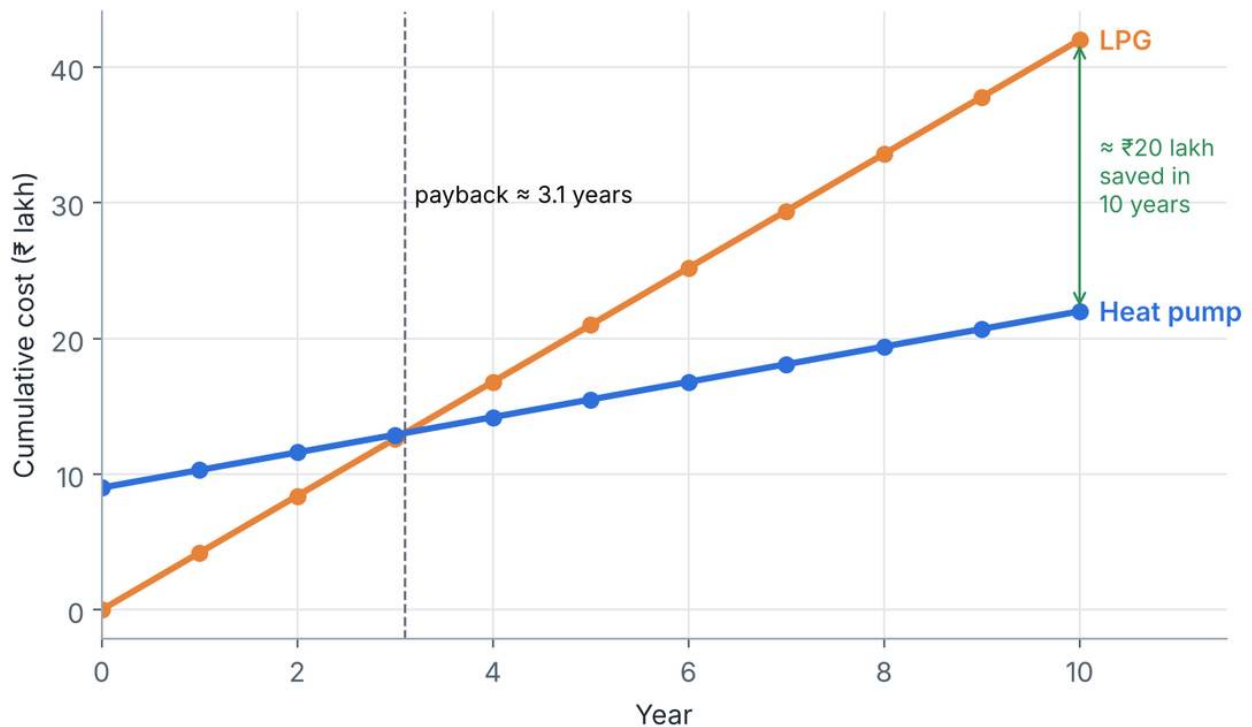
Demand: 3,000 litres per day heated from 25 °C to 60 °C, every day.

$$Q = m \cdot c_p \cdot \Delta T \quad \text{Simple payback} = \frac{\text{Extra capital cost}}{\text{Net annual saving}}$$

1. Daily heat: $Q = 3,000 \text{ kg} \times 4.186 \text{ kJ/kg} \cdot \text{K} \times 35 \text{ K} = 439,530 \text{ kJ} \div 3,600 = 122 \text{ kWh/day}$.
2. Yearly heat: $122 \times 365 \approx 44,560 \text{ kWh}$.
3. LPG: $44,560 \div (12.8 \times 0.85) \approx 4,096 \text{ kg} \times ₹100 = ₹4.10 \text{ lakh}$. Add maintenance ₹10,000 (example). Total $\approx ₹4.20 \text{ lakh/yr}$.
4. Heat pump at COP 3.5: $44,560 \div 3.5 \approx 12,730 \text{ kWh} \times ₹9 = ₹1.15 \text{ lakh}$. Add maintenance ₹15,000 (example). Total $\approx ₹1.30 \text{ lakh/yr}$.
5. Net annual saving $\approx ₹4.20 - ₹1.30 = ₹2.90 \text{ lakh}$.
6. Installed heat pump system (example): ₹9.0 lakh. Simple payback = $9.0 \div 2.90 \approx 3.1 \text{ years}$.
7. Simple ROI = $2.90 \div 9.0 \approx 32\% \text{ per year}$.
8. NPV over 10 years at 10% discount rate: annuity factor = $(1 - 1.1^{-10}) \div 0.1 = 6.145$. NPV = $2.90 \times 6.145 - 9.0 \approx ₹8.8 \text{ lakh}$.

Cumulative cost: LPG boiler vs heat pump (example)

₹ lakh. Heat pump costs more on day one and less every year after.



Cumulative cost: LPG boiler vs heat pump

Measure	What it tells you	Weakness
Simple payback	How fast the money comes back	Ignores savings after payback and time value of money
Simple ROI	Yearly return on capital	Same as above
NPV	Value created today, in ₹	Needs a discount rate assumption
IRR (internal rate of return)	The discount rate at which NPV = 0	Harder to explain; can mislead on small projects
Lifecycle cost	Total cost of ownership	Needs life and replacement assumptions

Remember

- Payback = extra capital ÷ net annual saving.
- Include maintenance on both sides.
- NPV shows value; payback shows speed.
- Test the result with higher and lower fuel prices (sensitivity).

Common mistake: using the heat pump's full price when the old boiler must be replaced anyway. Use only the extra (incremental) cost in that case.



6.4 Electricity tariffs and time-of-day operation

Key idea: with a hot water tank, a heat pump can run when electricity is cheapest, cutting running cost further.

Many Indian commercial and industrial tariffs have time-of-day (ToD) rates. ToD means the energy rate changes by hour. Peak hours cost more; off-peak or solar hours may cost less. The exact hours and percentages differ by state and change often.

A hot water tank works like a battery for heat. You fill it when power is cheap and draw from it when needed. The heat pump heats the tank in cheap hours; the building uses the hot water later.

Bills also contain fixed or demand charges. Demand charge is billed on maximum kVA (kilovolt-ampere) drawn, per month. Starting several large machines together can raise it.

Example time-of-day tariff and when to run the heat pump

Example rates, $\pm 20\%$ around ₹9/kWh. Actual hours and rates vary by state.



Example time-of-day tariff and run windows

Choice	Effect on cost	Effect on COP
Run in daytime (warm air)	Normal or solar-hour rate	Higher COP
Run at night off-peak	Lower rate	Lower COP in winter, as air is colder
Avoid evening peak	Avoids peak surcharge	Neutral
Stagger compressor starts	Lower demand charge	Neutral

In hot climates such as Chennai, night COP falls only slightly. In Delhi or Dehradun winters, night air can be 5–10 °C colder than afternoon air. That can cancel part of the off-peak saving.

Worked example — shifting the Bengaluru hotel load

$$\text{Daily saving} = E_{\text{daily}} \times (\text{Peak rate} - \text{Off-peak rate})$$

- Daily heat pump electricity: $12,730 \div 365 \approx 35$ kWh.
- Example rates: peak ₹10.8 (+20%), off-peak ₹7.2 (–20%).
- All at peak: $35 \times 10.8 = ₹378$. All off-peak: $35 \times 7.2 = ₹252$.
- Daily saving = ₹126. Yearly $\approx ₹46,000$, before any COP change.

Remember

- Storage tanks let heat pumps follow cheap tariff hours.

- Check the current state tariff order for ToD hours.
- Balance cheaper night rates against lower night COP.
- Watch demand charges, not only energy charges.

Field tip: size the tank to cover the peak-hour draw so the heat pump can stay off during peak.



6.5 Calculating CO₂ savings

Key idea: CO₂ per useful kWh = emission factor of the energy source ÷ efficiency or COP.

An emission factor is the CO₂ released per unit of energy used. For grid electricity it is the CO₂ from power stations per kWh delivered. India's grid factor is approximately 0.7 kg CO₂/kWh because much power comes from coal. It is falling as solar and wind grow.

Because a heat pump divides the grid factor by its COP, it emits less CO₂ per useful kWh than LPG or diesel; against PNG it breaks even at about COP 3, so it wins when its seasonal COP is above about 3 or as the grid gets cleaner.

Typical emission factors (approximate)

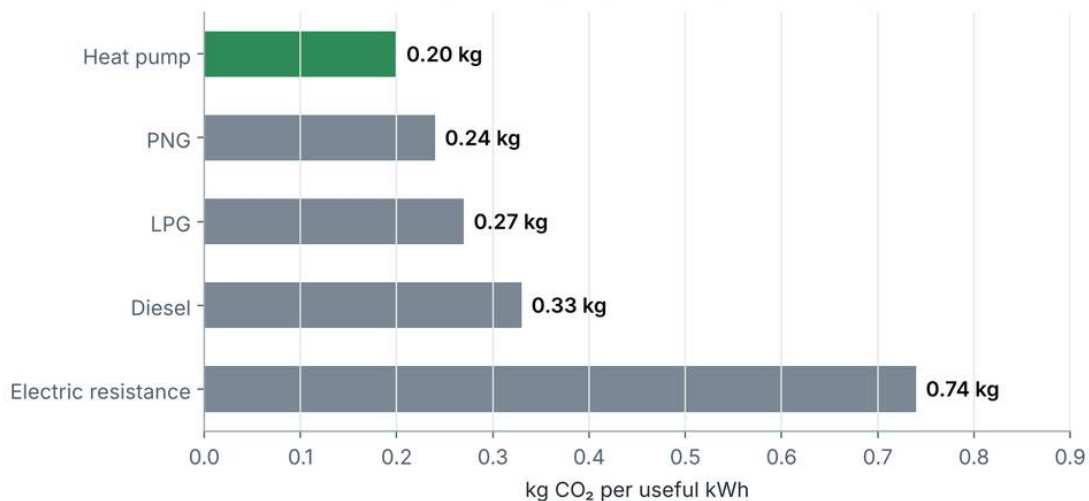
Source	Per unit	Per kWh of fuel (NCV)
Grid electricity (India, approximate)	0.7 kg/kWh	0.70 kg
LPG	~2.98 kg/kg	~0.23 kg
PNG / natural gas	~1.9 kg/scm	~0.20 kg
Diesel	~2.68 kg/L	~0.27 kg
Biomass (sustainably sourced)	Treated as near-zero net CO ₂	~0 (biogenic)

CO₂ per useful kWh (typical)

Source	Factor ÷ efficiency	kg CO ₂ per useful kWh
Heat pump, COP 3.5	0.70 ÷ 3.5	0.20
PNG boiler	0.20 ÷ 0.85	0.24
LPG boiler	0.23 ÷ 0.85	0.27
Diesel boiler	0.27 ÷ 0.80	0.33
Electric resistance	0.70 ÷ 0.95	0.74

CO₂ per useful kWh of heat

Typical values; Indian grid taken as about 0.7 kg CO₂/kWh. With rooftop solar the heat pump falls close to zero in solar hours.



CO₂ per useful kWh of heat

Worked example — hotel in Goa replacing a diesel boiler

Demand: 2,000 L/day from 25 °C to 60 °C.

$$\text{CO}_2 = \text{Energy used} \times \text{Emission factor}$$

1. Daily heat = 2,000 × 4.186 × 35 ÷ 3,600 = 81.4 kWh. Yearly ≈ 29,720 kWh.

2. Diesel: $29,720 \div (10.0 \times 0.80) \approx 3,715 \text{ L}$. $\text{CO}_2 = 3,715 \times 2.68 \approx 9.96 \text{ t/yr}$.
3. Heat pump: $29,720 \div 3.5 \approx 8,490 \text{ kWh}$. $\text{CO}_2 = 8,490 \times 0.7 \approx 5.94 \text{ t/yr}$.
4. Saving $\approx 4.0 \text{ t CO}_2$ per year, about 40%.
5. Cost bonus: diesel ₹3.72 lakh vs heat pump ₹0.76 lakh per year (example rates).

Remember

- Use an approximate grid factor of 0.7 kg/kWh and state it.
- Divide the factor by COP or efficiency.
- Heat pumps beat electric geysers by about 3–4 times on CO_2 .
- Savings grow as the grid gets cleaner.

Common mistake: comparing a heat pump with an electric geyser using fuel factors. Both use the grid; the COP alone drives the saving.



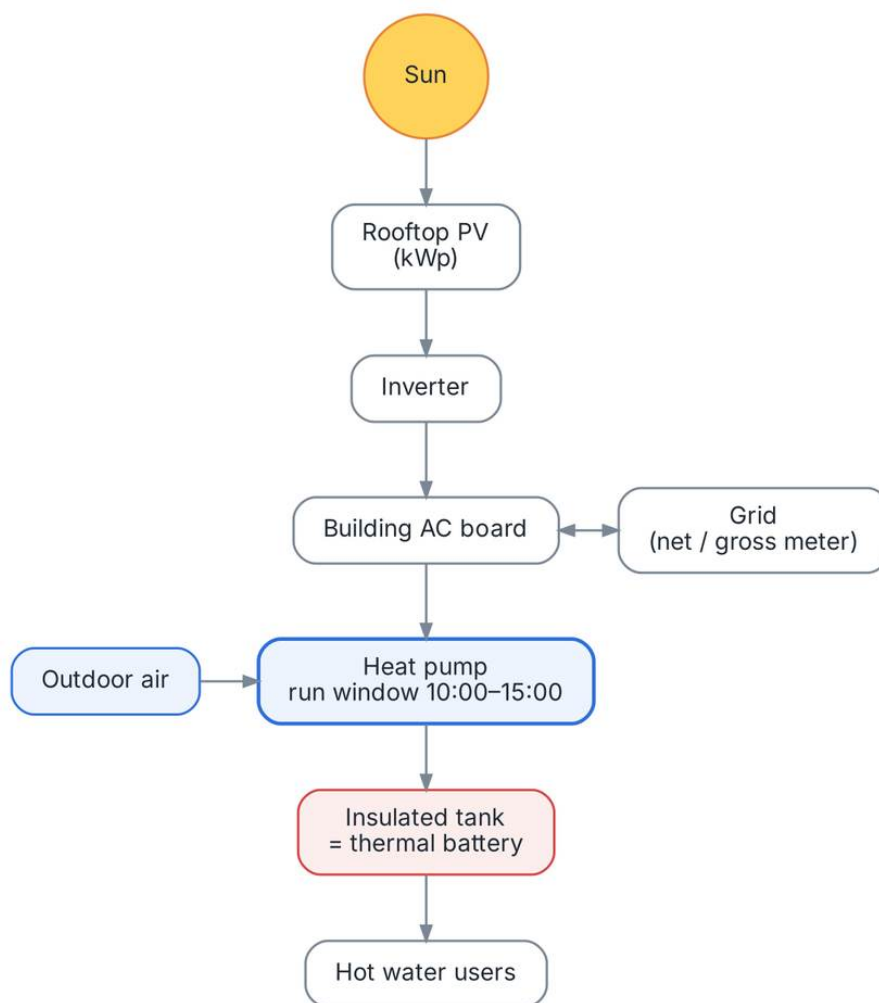
6.6 Pairing heat pumps with rooftop solar PV

Key idea: solar PV plus a heat pump plus a hot water tank stores sunshine as hot water, which is cheaper than storing it in batteries.

Rooftop solar PV (photovoltaic) panels turn sunlight into electricity. Their rating is in kWp (kilowatt-peak), the output under standard test light. In most of India, 1 kWp typically produces about 4–5 kWh per day, averaged over the year.

PV makes power at midday. Hot water is often needed in the morning and evening. A well-insulated tank bridges the gap. Heat from a heat pump in the tank is a "thermal battery" that costs far less per kWh stored than a lithium battery.

Rooftop solar runs the heat pump; the tank stores the heat for evening



Rooftop solar with a heat pump and tank

Metering type	How it works (general)	Best heat pump strategy
Net metering	Exported units offset imported units	Daytime running still preferred; check state caps
Gross metering	All PV is sold at a fixed tariff	Heat pump simply buys from grid
Self-consumption only	No export credit	Run heat pump in solar hours to avoid wasting PV

Rules on net and gross metering vary by state and DISCOM (distribution company). Check the current regulation before you size the system.

Worked example — sizing PV for the Bengaluru hotel heat pump

$$\text{PV size (kWp)} = \frac{\text{Daily heat pump electricity (kWh)}}{\text{Specific yield (kWh/kWp/day)}}$$

1. Daily heat pump use ≈ 35 kWh.
2. Typical yield in Bengaluru ≈ 4.5 kWh/kWp/day.
3. PV size = $35 \div 4.5 \approx 7.8 \rightarrow$ choose 8 kWp.
4. Roof area at a typical $8\text{--}10$ m²/kWp: about $65\text{--}80$ m² of shade-free roof.
5. Yearly PV energy $\approx 8 \times 4.5 \times 365 \approx 13,140$ kWh. At ₹9/kWh that is $\approx$ ₹1.18 lakh/yr avoided.
6. Example PV cost ₹50,000/kWp $\rightarrow$ ₹4.0 lakh. Simple payback ≈ 3.4 years.

Remember

- 1 kWp gives typically 4–5 kWh/day in India.
- Run the heat pump in solar hours and store heat in the tank.
- Thermal storage is cheaper than battery storage.
- Check state metering rules before sizing.

Field tip: keep PV panels clean. Dust in dry cities can cut output noticeably within a few weeks.



6.7 Green building ratings and incentives (IGBC, GRIHA, LEED)

Key idea: green building ratings reward efficient hot water, low-carbon energy, good refrigerants and measured performance, and heat pumps support all four.

A green building rating is a voluntary scorecard. Points are given for energy, water, materials, indoor quality and site. Higher scores earn higher levels of certification.

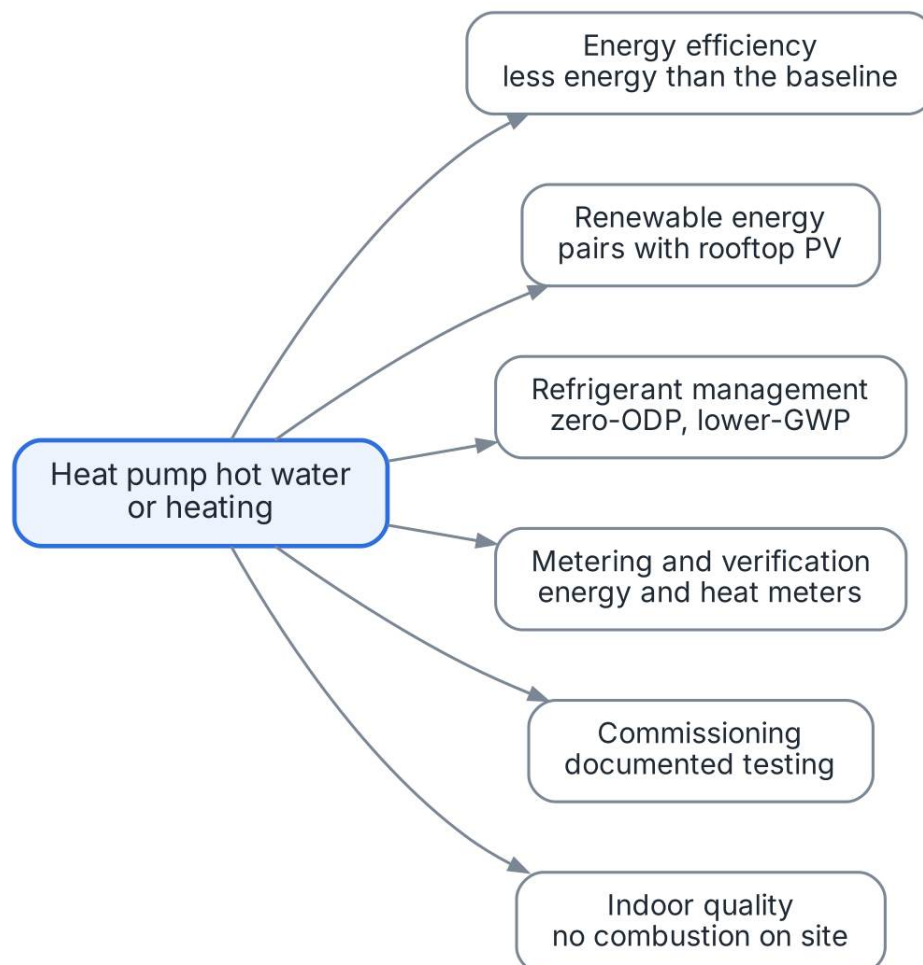
Three systems are common in India:

Rating system	Run by	Typical use in India
IGBC	Indian Green Building Council, part of CII (Confederation of Indian Industry)	Homes, offices, factories, townships and more
GRIHA	GRIHA Council, set up with TERI and supported by MNRE	Widely used for government and public buildings
LEED	US Green Building Council (USGBC), certified through GBCI	Multinational offices and export-oriented facilities

GRIHA stands for Green Rating for Integrated Habitat Assessment. TERI is The Energy and Resources Institute. MNRE is the Ministry of New and Renewable Energy. LEED stands for Leadership in Energy and Environmental Design.

India also has the Energy Conservation Building Code (ECBC) from the Bureau of Energy Efficiency (BEE). Rating systems often use it as a reference for minimum energy performance.

Where heat pumps help in green building ratings



Where heat pumps help in green building ratings

How heat pumps typically help (general themes, not credit numbers)

- **Energy performance:** lower energy than a baseline electric or fuel-fired water heater.
- **Renewable integration:** easy to run from on-site solar PV.
- **Refrigerants:** ratings favour zero ODP (ozone depletion potential) and lower GWP (global warming potential) refrigerants.
- **Measurement:** sub-metering of electricity and heat output supports performance credits.
- **Commissioning:** documented testing and handover records.
- **No on-site combustion:** no flue gases or fuel storage on the premises.

Incentives. Some states and urban local bodies have offered benefits for rated buildings. Examples include extra floor area ratio or property tax rebates. These schemes change often, so always check the current local rules. Tax treatment of energy-saving equipment should be confirmed with a tax adviser.

Remember

- IGBC, GRIHA and LEED are voluntary rating systems.
- Heat pumps help with energy, renewables, refrigerants and metering.
- Provide data: COP, refrigerant type, GWP and meter readings.
- Check current local incentives; they vary by city and state.

Field tip: give the project's green building consultant a one-page data sheet early. Late data often means lost points.



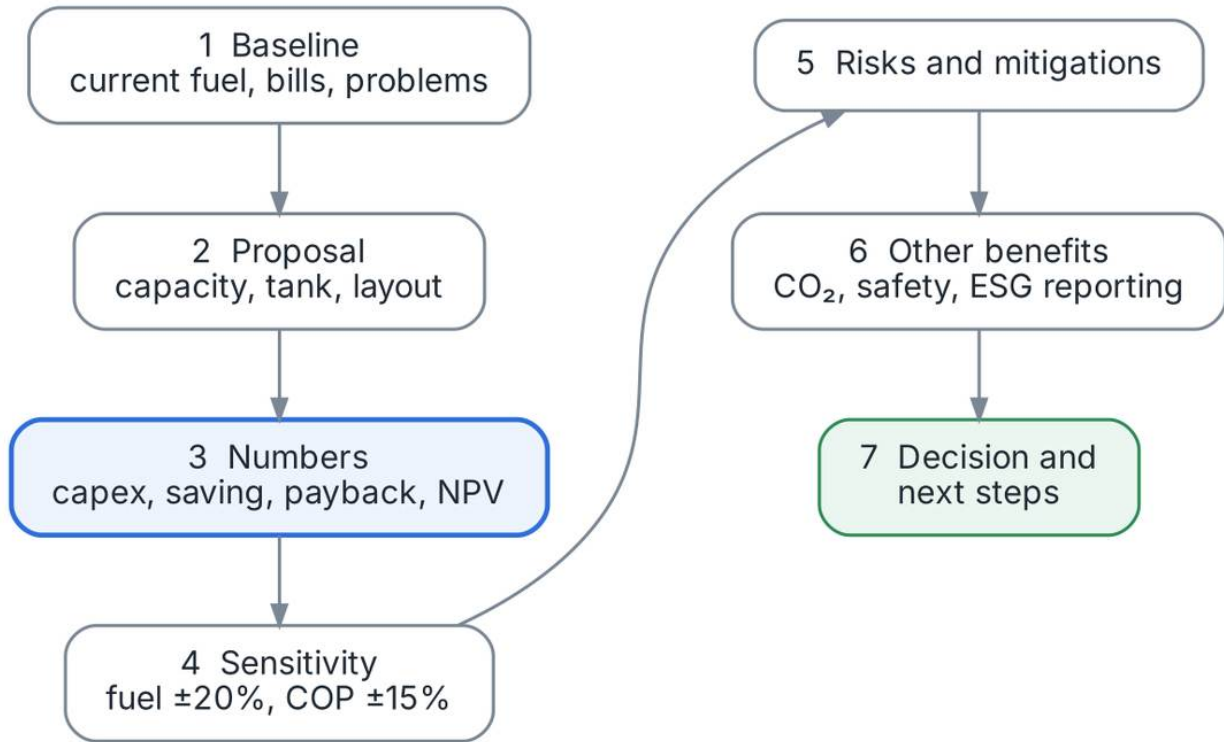
6.8 Building the business case for management

Key idea: a good business case shows the money, the risks and the non-money benefits on one page, with honest assumptions.

Management wants clear answers. How much? How fast does it pay back? What could go wrong? What else do we gain?

Present one recommended option plus the "do nothing" baseline. Show every assumption so a finance team can check it.

Structure of a heat pump business case



Structure of a heat pump business case

Section	What to include
Baseline	12 months of fuel bills, hot water demand, current problems
Proposal	Capacity, tank size, location, backup plan
Financials	Capex, annual saving, payback, ROI, NPV
Sensitivity	Results at ±20% fuel price and ±15% COP
Risks	Power cuts, water quality, space, maintenance skills
Benefits	CO ₂ saved, no fuel storage, safer kitchens, ESG (environmental, social, governance) reporting
Ask	Budget, approval date, project timeline

Worked example — sensitivity table for the Bengaluru hotel

$$\text{Payback} = \frac{9.0}{S_{\text{LPG}} - S_{\text{HP}}}$$

Base: LPG cost ₹4.20 lakh/yr, heat pump cost ₹1.30 lakh/yr, capex ₹9.0 lakh.

Case	LPG cost/yr	Heat pump cost/yr	Saving/yr	Payback
Base	₹4.20 L	₹1.30 L	₹2.90 L	3.1 yr
LPG price -20%	₹3.38 L	₹1.30 L	₹2.08 L	4.3 yr
LPG price +20%	₹5.02 L	₹1.30 L	₹3.72 L	2.4 yr
COP 3.0 instead of 3.5	₹4.20 L	₹1.49 L	₹2.71 L	3.3 yr

LPG $\pm 20\%$ applies to the fuel part (₹4.10 L) only; maintenance stays ₹0.10 L. At COP 3.0, electricity = $44,560 \div 3.0 \times ₹9 \approx ₹1.34$ L, plus ₹0.15 L maintenance.

Remember

- Always compare against "do nothing".
- Show every assumption and its source.
- Include a sensitivity table; it builds trust.
- Add non-money benefits such as CO₂ and safety.
- Finish with a clear request and timeline.

Common mistake: presenting only the best case. One surprise later can sink trust in every future project.



Quiz 6

1. What is the fair basis for comparing heating fuels?
 - A. Price per unit on the bill B. Cost per useful kWh delivered C. Calorific value only D. Appliance purchase price
2. At ₹9/kWh and COP 3.5, what is the heat pump's cost per useful kWh?
 - A. ₹9.00 B. ₹31.50 C. ₹2.57 D. ₹5.50
3. 1 kg of LPG contains about how much energy (NCV)?
 - A. 1.0 kWh B. 4.2 kWh C. 12.8 kWh D. 46 kWh
4. Simple payback equals:
 - A. Annual saving ÷ capex B. Extra capex ÷ net annual saving C. Capex × discount rate D. Fuel cost ÷ COP
5. Why does NPV discount future savings?
 - A. Equipment wears out B. Money today is worth more than money later C. Tariffs always fall D. Tax rules require it
6. Under a ToD tariff, the main role of a hot water tank is to:
 - A. Raise COP B. Let the heat pump run in cheaper hours C. Reduce water hardness D. Remove the need for a pump
7. Using an approximate grid factor of 0.7 kg CO₂/kWh and COP 3.5, CO₂ per useful kWh is about:
 - A. 0.20 kg B. 0.70 kg C. 2.45 kg D. 0.05 kg
8. In India, 1 kWp of rooftop PV typically produces per day:
 - A. 0.5–1 kWh B. 4–5 kWh C. 10–12 kWh D. 24 kWh
9. Which of these is NOT an Indian-origin green building rating?
 - A. IGBC B. GRIHA C. LEED D. None of these
10. What should a business case always be compared against?
 - A. The cheapest heat pump B. The "do nothing" baseline C. A competitor's quote D. Last year's budget

Answer key

1. B — Different fuels hold different energy and appliances waste different amounts.
2. C — $₹9 \div 3.5 = ₹2.57$.
3. C — About $46 \text{ MJ/kg} \div 3.6 \approx 12.8 \text{ kWh}$.
4. B — Years for the net saving to repay the extra investment.
5. B — The time value of money; the discount rate reflects the cost of capital.
6. B — Stored hot water lets the heat pump avoid peak hours.
7. A — $0.7 \div 3.5 = 0.20 \text{ kg}$.
8. B — Typical average yield across most of India.
9. C — LEED is run by the US Green Building Council.
10. B — Savings only mean something relative to what happens if nothing changes.

Glossary

Term	Meaning
Useful heat	Heat that actually reaches the water, air or process
kWh	Kilowatt-hour; 3.6 MJ of energy
Calorific value	Energy contained in one unit of fuel
NCV / GCV	Net / gross calorific value; NCV excludes heat in flue water vapour
Efficiency	Useful heat out ÷ fuel energy in, for combustion or resistance heaters
COP	Coefficient of performance; useful heat out ÷ electricity in
Seasonal efficiency	Average efficiency over a year of real operation
scm	Standard cubic metre of gas at reference conditions
Simple payback	Extra capital ÷ net annual saving, in years
ROI	Return on investment; annual saving as % of capital
NPV	Net present value; discounted future savings minus capital
IRR	Internal rate of return; discount rate at which NPV = 0
Lifecycle cost	Total cost of owning equipment over its life
Sensitivity analysis	Re-running results with changed assumptions
ToD tariff	Time-of-day tariff; energy rate varies by hour
Demand charge	Charge based on maximum kVA drawn in a billing period
Emission factor	CO ₂ released per unit of energy used
kWp	Kilowatt-peak; PV rating under standard test conditions
Net / gross metering	PV export rules: offset imports, or sell all generation
Thermal storage	Storing energy as hot water for later use
IGBC / GRIHA / LEED	Green building rating systems used in India
ECBC	Energy Conservation Building Code issued by BEE
ODP / GWP	Ozone depletion potential / global warming potential of a refrigerant
ESG	Environmental, social and governance reporting

Course 7 — Installation Practice

Powered by Sunniva. This Level 3 Field Practice course is for installers, plumbers and electricians who put heat pumps on site. It assumes you know the basic refrigeration cycle and hydronic terms from earlier courses. After it you will be able to: (1) survey a site and spot problems before the truck arrives; (2) lay out, size and fit the water side with the right valves, strainers and vessels; (3) braze, pressure-test, evacuate and charge a split system safely; (4) wire, earth and commission a unit and avoid the ten most common installation mistakes.

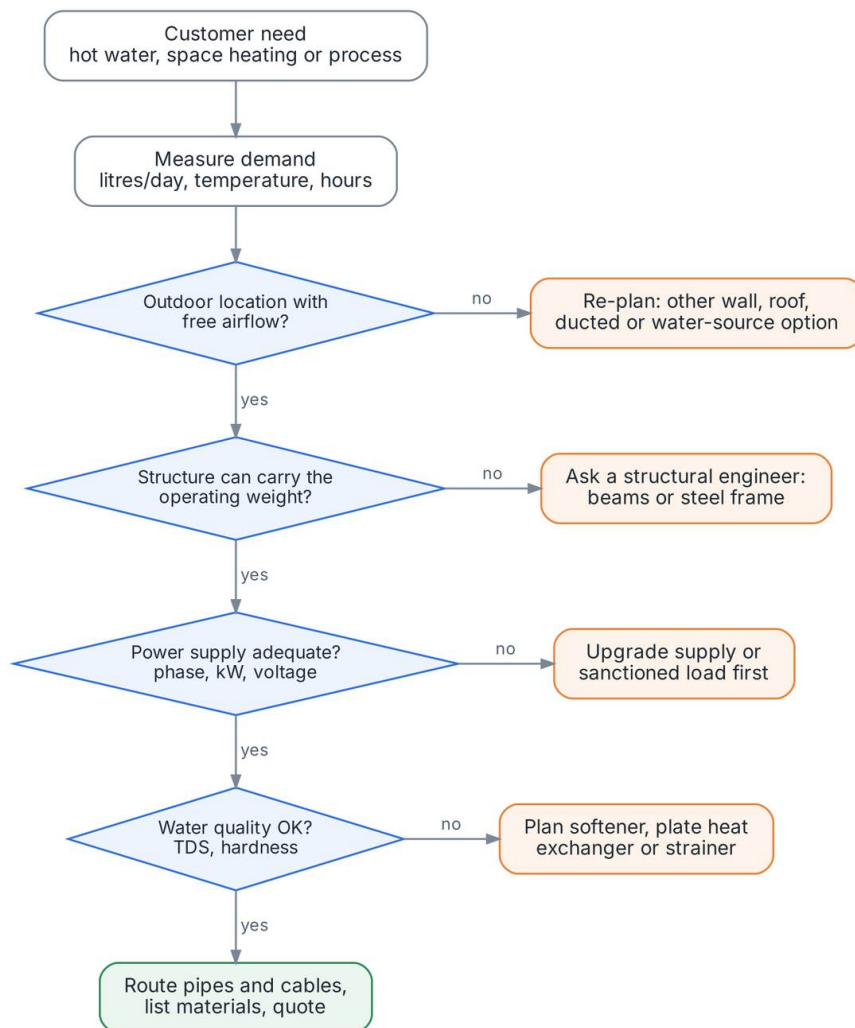
7.1 The site survey checklist

Key idea: Most installation problems are decided at the site survey, long before the first pipe is cut.

A site survey is a planned visit to check the location, services and access before quoting or installing. Think of it like a tailor taking measurements. Cut the cloth without measuring and no stitching can save the suit.

Carry a tape, a camera, a clamp meter, a TDS meter (total dissolved solids; it does not measure hardness) and a hardness test-strip kit and a compass app. Photograph everything. Your photos settle arguments later.

Site survey: the questions to answer before quoting



Site survey: the questions to answer before quoting

Site survey checklist

Demand and use

- ☐ Application confirmed (domestic hot water, space heating, pool, process)
- ☐ Daily hot water volume (litres/day) and peak hour draw
- ☐ Required supply temperature (°C) and existing heater type (geyser, LPG, diesel boiler)
- ☐ Operating hours and any night-tariff or solar-hour preference

Location

- ☐ Proposed unit position photographed from four sides
- ☐ Clearances measured against the manufacturer's manual (front, rear, sides, top)
- ☐ No recirculation risk (fan outlet not facing a wall within ~1.5–3 m, typical)
- ☐ Distance to bedrooms, neighbours and boundary noted (noise)
- ☐ Prevailing wind, dust, salt air (coast) and direct rain exposure noted
- ☐ Crane, lift or staircase access for the unit and its weight checked

Structure

- ☐ Floor or roof type (RCC slab, sheet, ground) recorded
- ☐ Operating weight of unit plus tank known; structural check asked for if on a roof
- ☐ Space for plinth or steel frame and condensate drain run

Water side

- ☐ Incoming water TDS (ppm) and hardness measured; source noted (municipal, borewell, tanker)
- ☐ Supply pressure (bar) measured at the nearest point
- ☐ Pipe route length, number of bends, rise and fall measured
- ☐ Existing tank volume, material and condition checked
- ☐ Drain point for safety valve, strainer flushing and condensate located

Electrical

- ☐ Supply type (single-phase 230 V / three-phase 415 V) and sanctioned load
- ☐ Voltage measured at the DB (phase-neutral and phase-phase, under load if possible)
- ☐ Distance from DB to unit for cable sizing
- ☐ Earth pit available and tested; neutral-earth voltage measured
- ☐ Space for a local isolator next to the unit

Safety and approvals

- ☐ Safe working-at-height plan for roofs (harness anchor, edge protection)
- ☐ Society or landlord permission for roof or façade work
- ☐ Hot work (brazing) permit needed? Fire extinguisher plan

Remember

- Measure, do not guess: TDS, voltage, distances and clearances.
- Photograph every survey point; attach photos to the job file.
- Check structure and power before promising a location.
- Plan drains (safety valve, condensate, flushing) at survey time.

Field tip: Measure the voltage at 7 pm as well as at noon. Evening peak sags in many Indian towns can trip compressors.

7.2 Location, airflow, clearances and noise

Key idea: An air-source heat pump is only as good as the air it can breathe, so give it free inlet air and let the outlet air escape.

An air-to-water heat pump pulls heat from outdoor air through its finned coil (evaporator). If the cold discharge air loops back to the inlet, the coil sees colder air. This is called recirculation. Output and COP (coefficient of performance, heat out ÷ electricity in) fall, and defrost becomes more frequent.

It is like a person breathing their own exhaled air in a closed lift. Each breath is worse than the last.

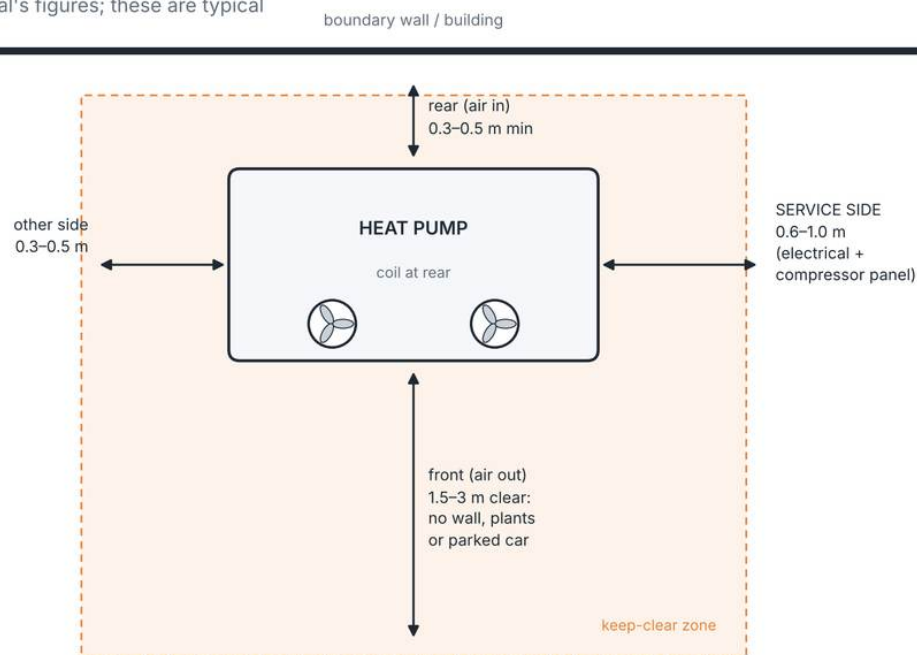
Typical clearances

Always use the manufacturer's manual. The figures below are typical starting points only.

Side	Typical minimum clearance	Why
Air inlet (coil side, rear)	0.3–0.5 m	Coil must draw air evenly
Air outlet (fan side, front)	1.5–3 m clear	Stop discharge air bouncing back
Service side (electrical / compressor panel)	0.6–1.0 m	Technician must open panel and work
Other side	0.3–0.5 m	Airflow and pipe access
Top (vertical fan units)	2–3 m open sky; no roof slab just above	Hot / cold air must rise away
Between two units side by side	0.5–1.0 m typical	Avoid one unit breathing the other's air

Clearances around an outdoor unit (plan view, typical values)

Always use the manual's figures; these are typical



Vertical-discharge units: keep 2–3 m open above. Mark the zone with floor paint at handover.

Clearances around an outdoor unit (plan view)

Noise

Sound pressure level (dB(A), what the ear hears at a point) falls with distance. In open space it drops about 6 dB each time the distance doubles. Hard surfaces near the unit reflect sound back and add to the level.

Placement	Typical addition
Free-standing in open space	0 dB
Against one wall	about +3 dB
In a corner (two walls)	about +6 dB
In a corner under a slab (three surfaces)	about +9 dB

India's Noise Pollution (Regulation and Control) Rules set residential-area limits of 55 dB(A) by day and 45 dB(A) at night. Keep units away from bedroom windows, both yours and the neighbour's.

Worked example — noise at a neighbour's window

A unit's datasheet gives 60 dB(A) at 1 m. It is placed in a corner in a Pune housing society. The neighbour's bedroom window is 8 m away.

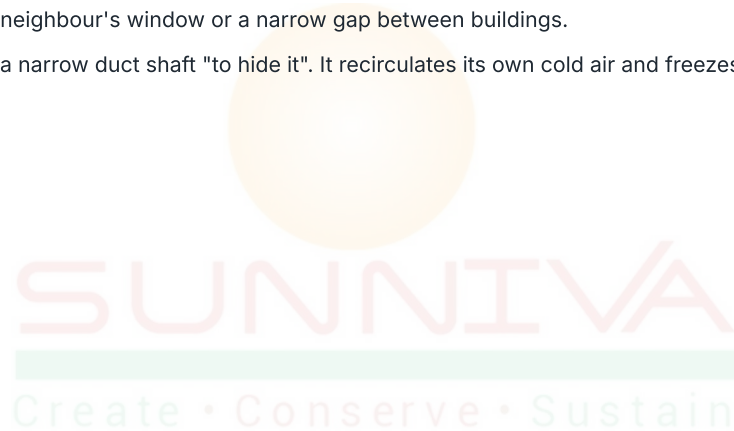
$$L_p(r) = L_p(1 \text{ m}) - 20 \log_{10} \left(\frac{r}{1 \text{ m}} \right) + \text{reflection}$$

1. Distance loss: $20 \times \log_{10}(8) = 20 \times 0.90 = 18 \text{ dB}$.
2. Free-field level: $60 - 18 = 42 \text{ dB(A)}$.
3. Corner reflection: $+6 \text{ dB} \rightarrow 48 \text{ dB(A)}$.
4. Night limit is 45 dB(A). This location fails at night.
5. Moving the unit out of the corner to a single wall: $42 + 3 = 45 \text{ dB(A)}$. Borderline. Better to add distance or run quiet-mode at night.

Remember

- Keep the outlet path clear; recirculation kills COP.
- Use the manual's clearances; the table above is typical only.
- Corners and slabs amplify noise; distance reduces it.
- Do not face the fan outlet towards a neighbour's window or a narrow gap between buildings.

Common mistake: Tucking the unit into a narrow duct shaft "to hide it". It recirculates its own cold air and freezes up.



7.3 Foundations, anti-vibration mounts and service access

Key idea: A solid, level base plus correct anti-vibration mounts stops noise, cracked pipes and early compressor failure.

The heat pump has a compressor and fans that vibrate. A rigid bolt to a thin slab turns the whole roof into a loudspeaker. Anti-vibration (AV) mounts are rubber pads or springs that stop vibration passing into the structure.

Foundations

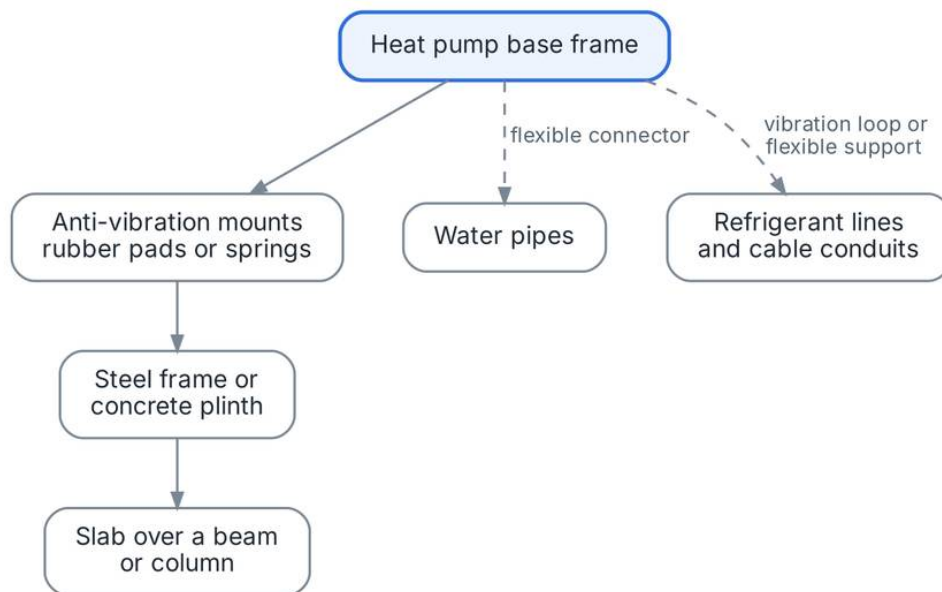
- Ground mounting: a concrete plinth 100–150 mm above finished ground (typical). It keeps the unit above splash water and flooding.
- Roof mounting: place the unit on a steel frame or plinth that sits over beams or columns, not mid-span on a thin slab. Ask a structural engineer for heavy units.
- Level within the manual's tolerance (often a few mm per metre). An unlevel unit can hold water in its drain pan and strain pipe joints.
- In high-wind or cyclone areas (Odisha, coastal Andhra, Gujarat coast) bolt the unit or frame down.
- In snow areas (Leh, Kashmir, upper Himachal) raise the unit above expected snow depth so the coil and drain stay clear.

Anti-vibration mounts

Mount type	Typical static deflection	Use
Ribbed rubber / neoprene pad	2–5 mm	Small and medium units on ground or strong slab
Rubber-in-shear mount	5–10 mm	Medium units on roofs
Spring mount (with restraint)	15–25 mm	Large units on light structures, near bedrooms

Static deflection (δ) is how far the mount squashes under the unit's weight. More deflection means a lower natural frequency and better isolation.

Vibration isolation chain: nothing rigid between the unit and the building



Vibration isolation chain

Worked example — will a rubber pad isolate the compressor?

A unit sits on rubber pads that deflect 3 mm. The compressor runs at 2,900 rpm (48 Hz).

$$f_n \approx \frac{15.8}{\sqrt{\delta_{\text{mm}}}} \text{ Hz} \quad T = \frac{1}{r^2 - 1}, \quad r = \frac{f}{f_n}$$

1. Natural frequency: $15.8 \div \sqrt{3} = 15.8 \div 1.73 = 9.1 \text{ Hz}$.
2. Frequency ratio: $r = 48 \div 9.1 = 5.3$.
3. Transmissibility: $T = 1 \div (5.3^2 - 1) = 1 \div 27.1 = 0.037$, so about 4% passes through.
4. Isolation $\approx 96\%$. Good.
5. Now an inverter compressor slowing to 20 Hz: $r = 20 \div 9.1 = 2.2$; $T = 1 \div (4.84 - 1) = 0.26$. Only 74% isolation. On a light roof near bedrooms, softer (spring) mounts help.

Isolation only works when r is above about 1.4 ($\sqrt{2}$). Near $r = 1$ the mount makes vibration worse (resonance).

Service access

Leave room to open every panel, remove the compressor and pull the fan. Keep isolation valves, strainers and the electrical isolator reachable without a ladder where possible. On roofs, provide a safe walkway and a fixed anchor for a harness.

Remember

- Plinth or frame on beams, not on a thin mid-span slab.
- Mounts must deflect enough; check isolation at low inverter speed too.
- Bolt down in windy areas; raise above snow in cold regions.
- Flexible connectors on all pipes leaving the unit.

Field tip: Use a spirit level on two axes before tightening mount bolts, then recheck after the unit is filled with water.



7.4 Water piping layout and sizing

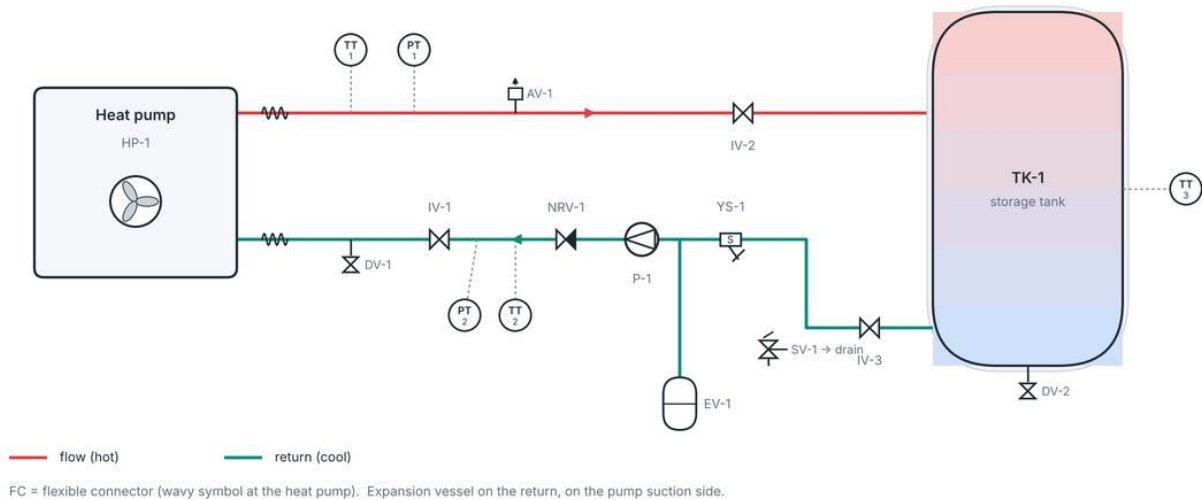
Key idea: The water side must carry the right flow at a sensible velocity, with every component in its correct place.

Flow rate is how much water passes per hour (m³/h or LPH, litres per hour). Velocity is how fast it moves in the pipe (m/s). Too fast is noisy and erodes fittings. Too slow lets air and dirt settle, and the pipe costs more than needed.

A typical heat pump circuit runs at a temperature difference (ΔT) of about 5 K between flow and return. The heat carried depends on flow and ΔT .

Typical installation P&ID: heat pump to storage tank (closed loop)

Flow: heat pump → tank → strainer → pump → non-return valve → heat pump



Typical installation P&ID: heat pump to storage tank

Flow direction: heat pump → flow pipe → tank coil / tank → return pipe → strainer → pump → non-return valve → heat pump.

Tag	Item	Purpose
HP-1	Heat pump	Heat source
TK-1	Storage tank	Stores hot water, buffers load
IV-1/2/3	Isolation valve (ball valve)	Isolate unit or tank for service
FC-1/2	Flexible connector	Stop vibration reaching pipes; allow small movement
YS-1	Y-strainer	Catch dirt and scale before pump and heat exchanger
P-1	Circulation pump	Moves water around the loop
NRV-1	Non-return valve	Stops reverse flow when pump stops
EV-1	Expansion vessel	Absorbs water expansion as it heats
SV-1	Safety (relief) valve	Opens if pressure rises above set point
AV-1	Automatic air vent	Releases trapped air at high point
DV-1/2	Drain valve	Empty and flush the system
TT-1/2/3	Temperature transmitter / test point	Read flow, return and tank temperatures
PT-1/2	Pressure transmitter / gauge point	Read pressure; across strainer and unit shows blockage

Typical pipe sizing table

Water flow at typical velocities of 0.7–1.5 m/s, based on typical internal diameters of medium-grade steel pipe. Copper and PPR (polypropylene random copolymer) pipes have different internal diameters, so check the maker's chart. These are typical guides, not design values.

Nominal size	Typical ID (mm)	Flow at 0.7 m/s (m³/h)	Flow at 1.5 m/s (m³/h)	Approx. heat at ΔT 5 K, upper flow (kW)
DN15 (½")	16	0.5	1.1	6
DN20 (¾")	22	0.9	2.0	11
DN25 (1")	27	1.5	3.2	18
DN32 (1¼")	36	2.6	5.5	32
DN40 (1½")	42	3.5	7.5	43
DN50 (2")	53	5.6	12.0	70
DN65 (2½")	69	9.4	20.1	117
DN80 (3")	81	13.0	27.8	160
DN100 (4")	105	21.9	47.0	270

Small pipes near homes are best kept at the lower end of velocity for quiet running.

Worked example — size the pipe for a 30 kW heat pump at a Bengaluru hotel

The unit heats at 30 kW with ΔT = 5 K.

$$\dot{V} \text{ (m}^3\text{/h)} = \frac{Q \text{ (kW)}}{1.163 \times \Delta T \text{ (K)}} \quad v = \frac{\dot{V}}{3600 \times \frac{\pi}{4} d^2}$$

- Flow: $30 \div (1.163 \times 5) = 30 \div 5.815 = 5.16 \text{ m}^3\text{/h}$ (5,160 LPH).
- Try DN32 (ID 0.036 m): area = $0.7854 \times 0.036^2 = 0.00102 \text{ m}^2$. Velocity = $5.16 \div (3,600 \times 0.00102) = 1.41 \text{ m/s}$. Upper end, possible but noisier.
- Try DN40 (ID 0.042 m): area = $0.7854 \times 0.042^2 = 0.00139 \text{ m}^2$. Velocity = $5.16 \div (3,600 \times 0.00139) = 1.03 \text{ m/s}$. Comfortable.
- Choose DN40 for the main run. The unit's own connection may be smaller; reduce only at the unit.

(1.163 is the heat in Wh needed to warm 1 litre of water by 1 K.)

Remember

- Flow = kW ÷ (1.163 × ΔT); then pick a pipe for about 0.7–1.5 m/s.
- Strainer and pump on the return, before the heat pump.
- Air vents at high points, drains at low points.
- Fit TT and PT points on flow and return for commissioning.

Common mistake: Matching the main pipe to the unit's small connection size. Over a long run that starves the unit of flow and trips it on high pressure.

Create • Conserve • Sustain

7.5 Valves, strainers, expansion vessels and air vents

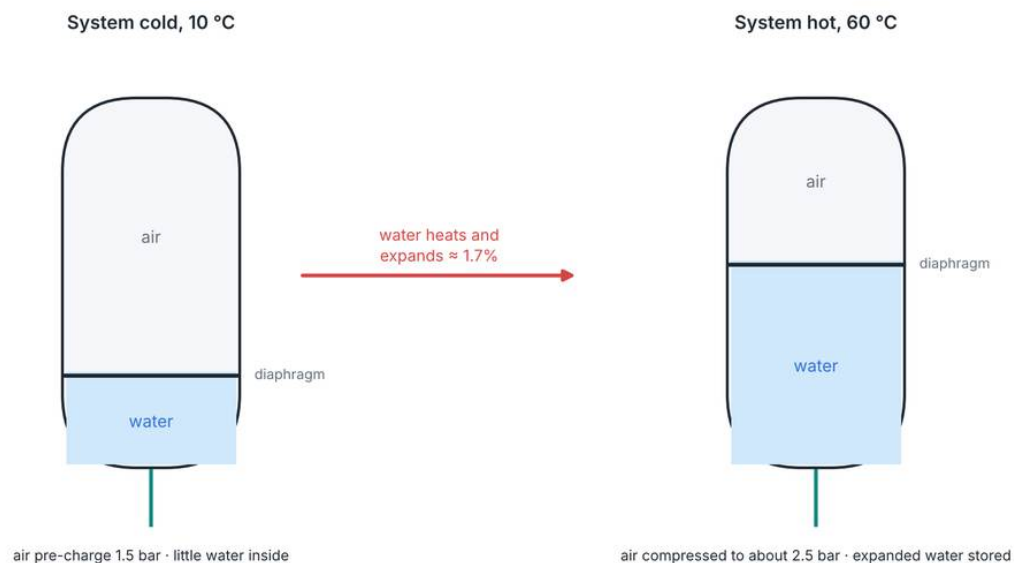
Key idea: Each small fitting protects the heat pump from a specific enemy: dirt, air, pressure or backflow.

Component	Protects against	Where it goes	Typical spec
Ball valve (isolation)	Draining the whole system for service	Both sides of unit, pump, strainer	Full-bore, same size as pipe
Y-strainer	Dirt, scale, welding slag	Return, before pump and heat pump	Mesh typically 0.5–1 mm (follow manual)
Non-return valve (NRV)	Reverse flow, thermosiphon	After pump	Low-pressure-drop type
Expansion vessel	Pressure rise as water heats	Return side, near pump suction	Sized to system volume; pre-charged
Safety valve	Over-pressure	On the closed circuit, no valve between it and the heat source	Set below the weakest component's rating
Auto air vent	Air locks, noise, poor flow	Every high point	With isolating valve for replacement
Drain valve	Cannot empty or flush	Every low point	Hose-union type
Flexible connector	Vibration and pipe stress	At unit inlet and outlet	Rated for temperature and pressure

A Y-strainer is a Y-shaped fitting with a mesh basket that catches dirt. In Indian borewell and tanker water, scale and sand are common. A blocked strainer is the top cause of low-flow trips.

An expansion vessel is a steel tank with a rubber diaphragm. One side has air at a set pre-charge pressure; the other side takes system water. It works like a pressure cooker's weight in reverse: it gives the water room to grow instead of venting it.

Expansion vessel: how it absorbs expanding water



Expansion vessel cold vs hot

Worked example — size an expansion vessel

Closed heating loop in a Delhi school: system water 500 L, fill at 10 °C, maximum 60 °C. Pre-charge 1.5 bar(g). Safety valve 3 bar(g), so final working pressure is kept at 2.5 bar(g). Water expands about 1.7% from 10 to 60 °C (from density 999.7 to 983.2 kg/m³).

$$V_{EV} = \frac{e \times V_{sys}}{1 - \frac{p_i}{p_f}} \quad (p \text{ in bar absolute})$$

1. Expansion volume: $0.0168 \times 500 = 8.4 \text{ L}$.
2. Absolute pressures: $p_i = 1.5 + 1 = 2.5 \text{ bar(a)}$; $p_f = 2.5 + 1 = 3.5 \text{ bar(a)}$.
3. Acceptance factor: $1 - 2.5 \div 3.5 = 0.286$.
4. Vessel: $8.4 \div 0.286 = 29.4 \text{ L}$.
5. Choose the next size up: 35 L.

Check pre-charge with a tyre gauge before filling. Set it to about the static fill pressure at the vessel.

Remember

- Strainer before the pump and heat pump; clean it after the first week.
- Never put an isolation valve between the heat source and its safety valve.
- Size the expansion vessel from system volume; check pre-charge before filling.
- Air vents at every high point; bleed again after first run.

Field tip: Fit a pressure gauge on each side of the strainer. When the difference grows, it is time to clean the mesh.



7.6 Insulation of pipes and tanks

Key idea: Heat you pay to make should reach the tap, not warm the terrace.

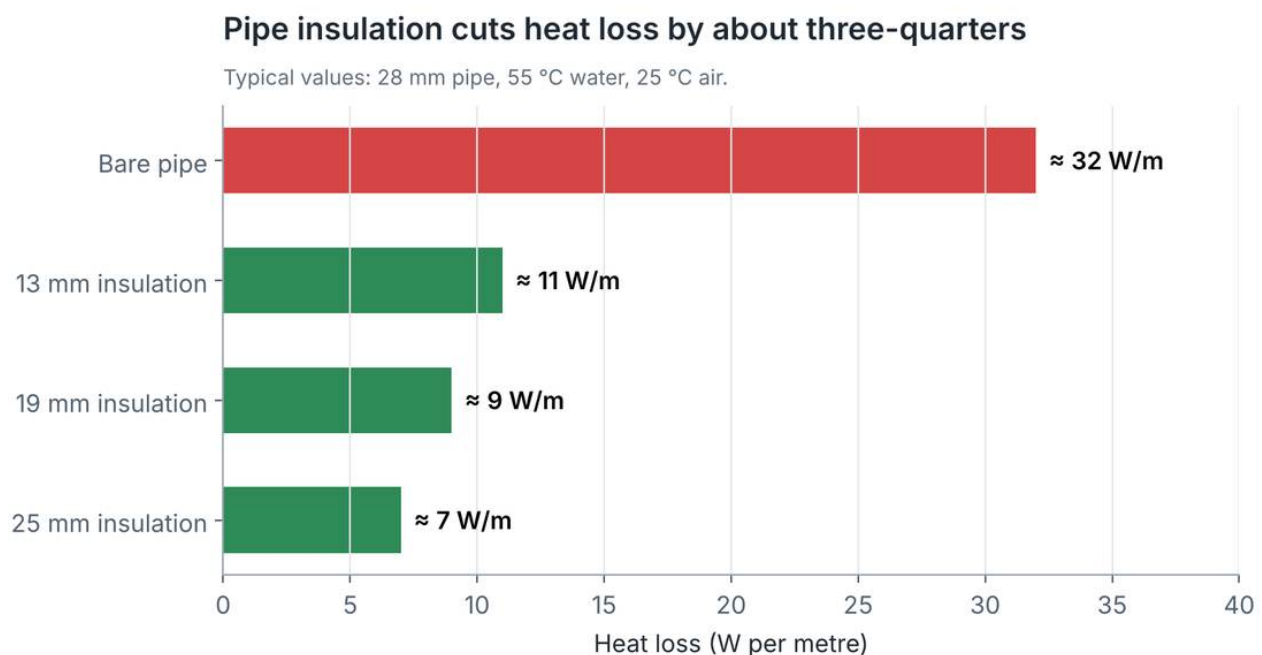
Insulation slows heat flow through pipe and tank walls. The common material is closed-cell elastomeric foam (nitrile rubber tube). Closed cells resist water uptake, which matters in Indian monsoons. Glass wool and PUF (polyurethane foam) are used on tanks.

It works like the wall of a vacuum flask: it keeps hot water hot by slowing the heat leaving it.

Pipe service	Typical insulation thickness	Notes
Hot water / heating, indoor	13–19 mm	Thicker for larger pipes
Hot water / heating, outdoor	19–25 mm	UV protection essential
Chilled water / cooling	19–32 mm	Must be vapour-sealed to stop sweating
Refrigerant lines (split units)	9–19 mm on both lines	Separate tubes for each line
Storage tanks	50–100 mm PUF or equivalent	Cover top and nozzles too

Outdoor protection

Sunlight breaks down most foam in one or two summers. Outdoors, cover it with aluminium cladding, UV-resistant paint or tape. Seal all joints with the maker's adhesive, not just plastic tape.



Heat loss: bare vs insulated pipe

Worked example — what does bare pipe cost?

A Jaipur hostel has 20 m of 28 mm hot water pipe on the terrace at 55 °C, with air at 25 °C. Typical losses are about 32 W/m bare and 9 W/m with 19 mm insulation. Circulation runs 12 h a day. Heat pump COP 3.5. Electricity ₹9/kWh (example rate).

$$E_{loss} = q \times L \times t \quad \text{Electricity} = \frac{E_{loss}}{COP}$$

1. Bare loss: $32 \times 20 \times 12 = 7,680 \text{ Wh} = 7.7 \text{ kWh/day}$ of heat.
2. Insulated loss: $9 \times 20 \times 12 = 2,160 \text{ Wh} = 2.2 \text{ kWh/day}$.
3. Heat saved: $7.7 - 2.2 = 5.5 \text{ kWh/day}$.
4. Electricity saved: $5.5 \div 3.5 = 1.57 \text{ kWh/day}$.
5. Money saved: $1.57 \times 9 = ₹14/\text{day}$, about ₹5,100 a year, from roughly 20 m of insulation.

Remember

- Insulate every hot pipe, valve body and tank nozzle.
- Outdoors, foam must have UV protection.
- Chilled pipes need a continuous vapour seal or they drip.
- Keep insulation dry; wet insulation works poorly.

Common mistake: Leaving valves, strainers and pump bodies bare. A bare DN40 valve can lose as much as a metre or more of bare pipe.



7.7 Refrigerant piping for split units: brazing, nitrogen purge, pressure test

Key idea: Clean, dry, leak-free copper joints made under nitrogen are the foundation of a reliable split system.

A split heat pump has the compressor or the water heat exchanger in separate units joined by refrigerant pipes. Those pipes must stay clean and dry inside. Moisture and oxide scale cause acid, blocked expansion valves and burnt compressors.

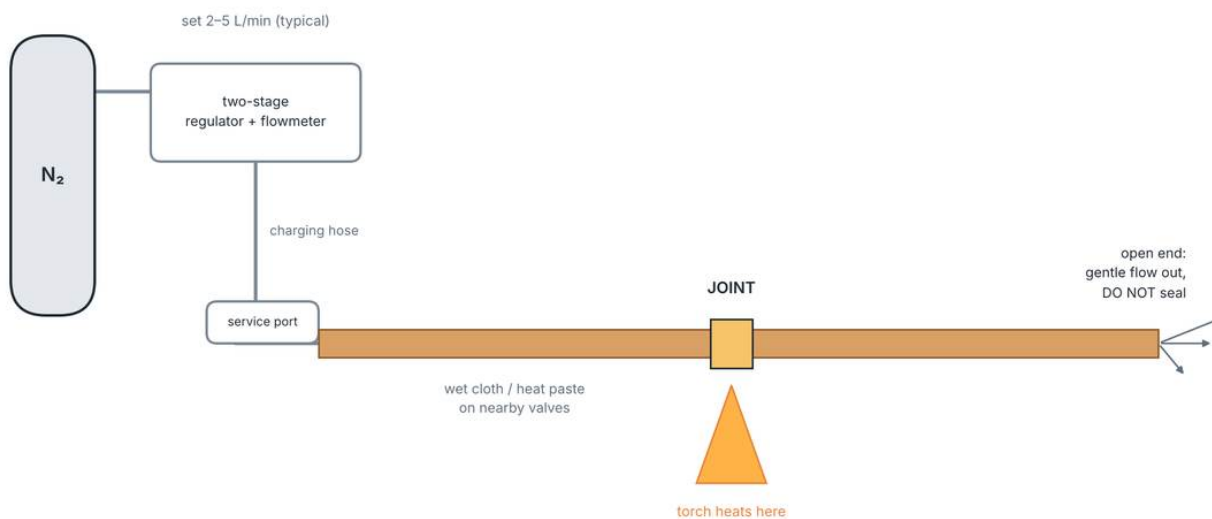
Brazing is joining copper at high temperature (above 450 °C) using a filler rod. Copper-to-copper joints commonly use copper-phosphorus rods; copper-to-brass or steel needs a silver rod with flux. Hot copper reacts with air and forms black oxide flakes inside the pipe. Flowing nitrogen through the pipe while brazing pushes the air out and stops this.

Safety first

- Use only oxygen-free dry nitrogen (OFN). Never use oxygen or compressed air: oxygen with oil can explode.
- Always use a nitrogen regulator. A full cylinder can be above 150 bar.
- Keep a fire extinguisher and a wet cloth or heat shield at the joint. Protect valves and sensors from heat.
- Work in ventilated space. Nitrogen displaces oxygen in closed rooms.
- Recover any refrigerant first; never braise a pipe that holds refrigerant.

Brazing with a nitrogen purge

Low nitrogen flow keeps oxygen out, so no black oxide scale forms inside the pipe



Sequence: purge about 1 minute → keep low flow while brazing → keep flowing until the joint cools below about 200 °C → stop.

Brazing with a nitrogen purge

Sequence: purge for about a minute to displace air → keep low flow while brazing → keep flowing until the joint cools below about 200 °C (no colour) → stop.

Good practice

- Cut copper with a tube cutter, not a hacksaw. Ream the burr. Cap pipe ends until joined.
- Use refrigeration-grade copper (cleaned and capped). Plumbing copper is not dry inside.
- Bend with a bender; keep bend radius per the tool. Avoid kinks.
- Support pipes with clamps at typical intervals of 1–1.5 m. Insulate each line separately.
- For long vertical rises on suction lines, follow the manual on oil traps.

Pressure test

After brazing, test with dry nitrogen before evacuation.

1. Pressurise in stages (for example, 5 bar, then higher). Check for gross leaks at each stage.
2. Reach the test pressure in the manual. For R32 and R410A systems this is often around 38–42 bar on the high side (typical; always follow the manual and never exceed the unit's rated pressure).
3. Soap-test every joint and flare.
4. Hold. Typical practice is a few hours minimum and 24 h for larger systems. Record pressure and ambient temperature at start and end.
5. Pressure changes about 1% for every 3 °C change in temperature at these pressures. Correct for this before calling a leak.

Worked example — temperature-corrected hold test

A split system in Lucknow is pressurised to 40.0 bar(g) at 6 pm at 32 °C. Next morning at 24 °C it reads 39.0 bar(g). Is it leaking?

$$\frac{p_2}{p_1} = \frac{T_2}{T_1} \quad (\text{absolute values})$$

1. $p_1 = 40.0 + 1 = 41.0 \text{ bar(a)}$; $T_1 = 32 + 273 = 305 \text{ K}$; $T_2 = 24 + 273 = 297 \text{ K}$.
2. Expected $p_2 = 41.0 \times 297 \div 305 = 39.9 \text{ bar(a)} = 38.9 \text{ bar(g)}$.
3. Measured 39.0 bar(g). The drop is explained by cooling. No leak indicated.

Remember

- Braze only with nitrogen flowing; never with oxygen or air in the pipe.
- Always regulate nitrogen; never connect a cylinder directly.
- Pressure-test before vacuum; vacuum does not find small leaks well.
- Correct the hold-test result for temperature.

Common mistake: Brazing without nitrogen "because it is a short pipe". The black scale goes straight to the expansion valve and compressor.



7.8 Evacuation and charging

Key idea: Pull a deep, steady vacuum to remove air and moisture, then charge the exact refrigerant weight the system needs.

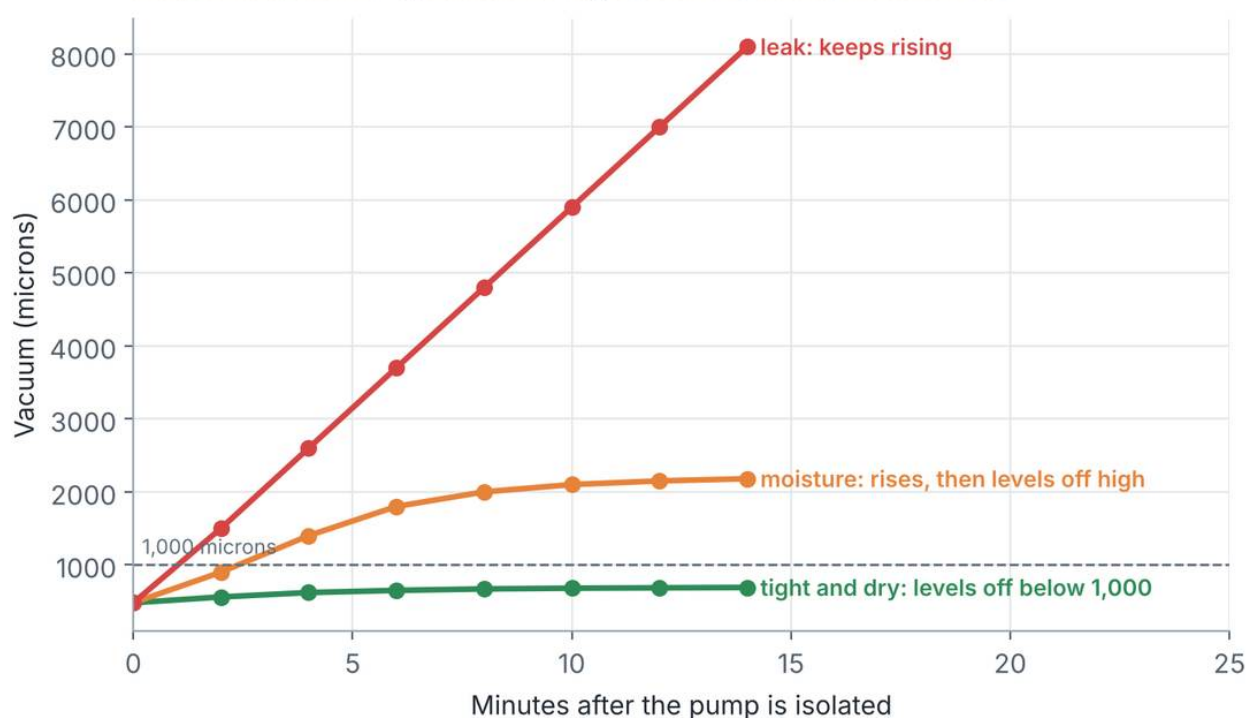
Evacuation means removing air and water vapour from the refrigerant circuit with a vacuum pump. Water boils at very low pressure, so a deep vacuum makes moisture boil off and get pumped away. A micron gauge measures vacuum in microns of mercury (1 micron $\approx$ 0.133 Pa). The manifold's compound gauge is not accurate enough for this.

Evacuation steps

1. Remove Schrader cores with a core tool and use short, large-bore hoses for speed.
2. Connect the micron gauge as far from the pump as possible, ideally at the system.
3. Run a two-stage vacuum pump with fresh oil.
4. Pull down to the target. A common field target is 500 microns or lower (typical; follow the manual).
5. Isolate the pump and do a decay test, typically 10–15 minutes.
6. If the gauge rises and levels off below about 1,000 microns, the system is dry and tight. If it keeps rising steadily, there is a leak. If it rises and stops high, moisture remains: evacuate further.

Reading a vacuum decay test

Pump isolated at 0 min. Typical curves. Target below 500 microns before the test.



Reading a vacuum decay test

Charging

- Charge by weight on a digital scale. Do not charge "by pressure" or "by feel of the suction line".
- Many split units are pre-charged for a set pipe length. Add extra charge per metre beyond it, as the manual states.
- Blends such as R410A and R407C must be charged as liquid. R32 is a single refrigerant, but liquid charging is still the normal practice.
- R32 and R290 are flammable (A2L and A3 safety classes). Use tools rated for them, remove ignition sources, and ventilate. R290 needs specific training.
- Record the charge on the unit label and in the commissioning sheet.

Refrigerant	Safety class	Charge as	Notes
R410A	A1 (non-flammable)	Liquid	High pressure blend
R32	A2L (mildly flammable)	Liquid (normal practice)	Single component
R407C	A1	Liquid	Large glide blend
R134a	A1	Liquid or vapour	Lower pressure
R290 (propane)	A3 (highly flammable)	Per manual only	Special training and tools

Worked example — additional charge

A split unit in Kolkata is pre-charged for 7.5 m of pipe. The actual pipe run is 15 m. The manual says add 20 g per metre (example value) for the liquid line size used.

$$m_{add} = (L_{actual} - L_{pre}) \times g/m$$

1. Extra length: $15 - 7.5 = 7.5$ m.
2. Extra charge: $7.5 \times 20 = 150$ g.
3. Weigh in 150 g as liquid, slowly, through the suction service port with the unit running (or as the manual says).

Remember

- Use a micron gauge; pressure test first, then vacuum.
- Target and decay test tell you dry, wet or leaking.
- Charge by weight; blends as liquid.
- Treat R32 and R290 as flammable: right tools, no sparks.

Field tip: Change vacuum pump oil after every wet system. Milky oil cannot pull a deep vacuum.



7.9 Electrical wiring and earthing

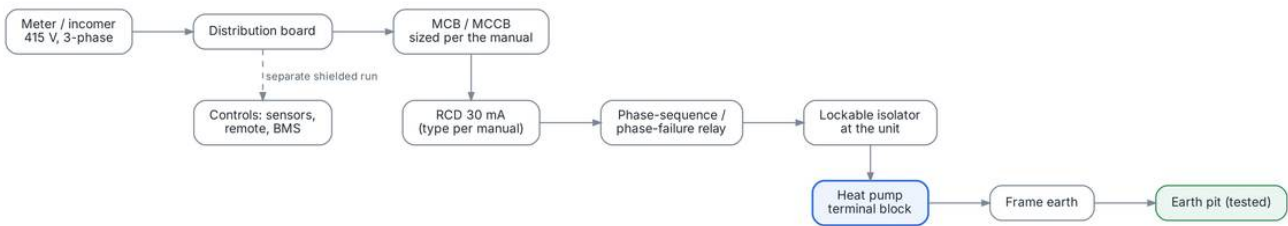
Key idea: Correct supply, protection and earthing keep the installer, the user and the compressor safe.

A heat pump draws high current, has a compressor motor and often an inverter drive. Undersized cables, missing earths and wrong protection cause trips, burnt terminals and electric shock. All electrical work must follow the Indian Electricity Rules / CEA regulations and the earthing code IS 3043, and be done by a licensed electrician.

Main items

- **Dedicated circuit** from the distribution board (DB) with its own breaker.
- **MCB** (miniature circuit breaker) rated for the unit. Motor loads often need C or D curve; follow the manual's MOCP (maximum over-current protection) value.
- **RCD / RCCB** (residual current device), typically 30 mA for personal protection. Inverter units may need a Type B or another type the manufacturer specifies.
- **Local isolator** within sight of the unit, lockable for service.
- **Phase sequence** check on three-phase units. Scroll compressors run backwards on the wrong sequence, get noisy and fail.
- **Earthing**: a low-resistance earth conductor to the unit frame and a tested earth pit. Bond metal pipework.
- **Control and sensor cables** run separately from power cables, or shielded, to avoid noise.
- **Glands and drip loops**: cables enter from below with a drip loop so rain does not run into the panel.

Three-phase supply to a heat pump: single-line view



Three-phase supply: single-line view

Check	Typical acceptable value	Tool
Supply voltage, single-phase	230 V ± 10%	Multimeter
Supply voltage, three-phase	415 V ± 10%, phase imbalance under ~2%	Multimeter
Neutral-earth voltage	Under ~2 V (typical good practice)	Multimeter
Earth resistance	As low as practical; follow local inspector (a few ohms or less is common)	Earth tester
Insulation resistance of compressor	Above 1 MΩ typical (check manual)	Insulation tester (megger)
Voltage drop along cable	Within ~3–5% typical	Calculation / measurement

Worked example — current and breaker for a three-phase unit

A unit in Ahmedabad draws 10 kW electrical input at full load on a 415 V supply, power factor 0.9.

$$I = \frac{P}{\sqrt{3} V \cos \varphi}$$

1. $I = 10,000 \div (1.732 \times 415 \times 0.9) = 10,000 \div 647 = 15.5$ A per phase.
2. Breaker: next standard size above full-load current, but not above the manual's MOCP. A 20 A C/D-curve MCB is a typical choice.
3. Cable: 4 mm² copper is a typical choice for 20 A on a short run. Check voltage drop on runs over about 30 m and upsize if needed.
4. Confirm with the nameplate maximum current, which can be higher than the rated current.

Remember

- Dedicated circuit, correct MCB, RCD and lockable isolator.
- Check phase sequence before first start on three-phase units.

- Test earth resistance and insulation resistance; record the values.
- Separate control cables from power cables.

Common mistake: Using the neutral as earth, or no earth at all. The frame can become live and the electronics fail.



7.10 Condensate drainage

Key idea: An air-source heat pump makes a lot of water from humid air and defrost, and it must drain away freely.

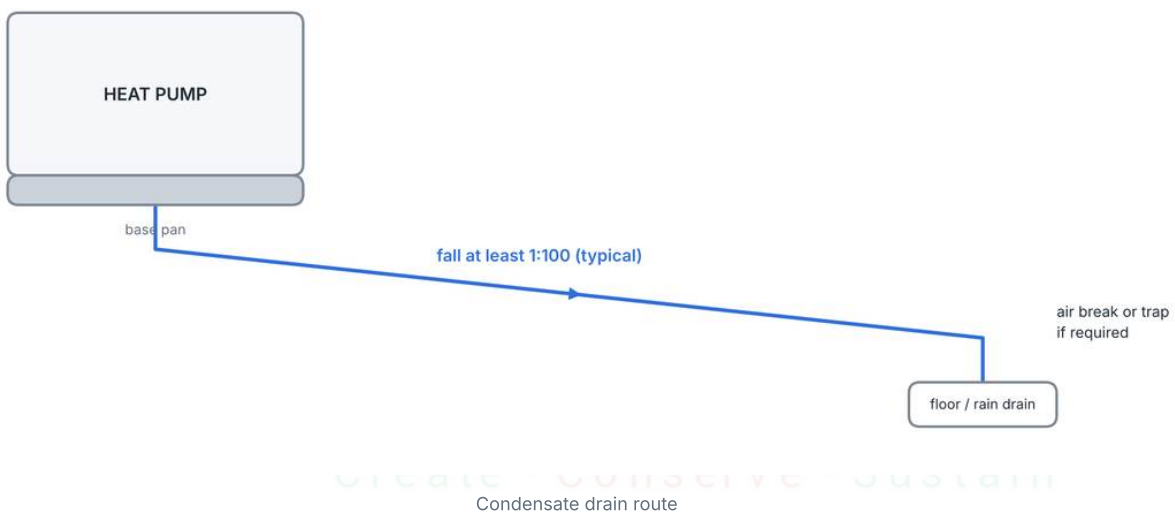
When outdoor air passes over the cold coil, its moisture condenses, just as a cold bottle from the fridge "sweats" on a humid day. In defrost, the ice on the coil melts and drains too. In coastal humid cities like Mumbai, Chennai and Kochi, the volume is large.

Good practice

- Drain from the unit base pan with the fitting supplied. Do not block base holes.
- Lay the drain pipe with a fall of at least 1:100 (1 cm per metre, typical) to a drain point, never to a walkway.
- Use a trap or air break where the manual requires it, and where draining into a sewer to stop smells.
- On roofs, route to the rainwater outlet. Water on the slab causes dampness and moss.
- In cold regions (Leh, Spiti, Kashmir, upper Himachal) drains can freeze. Keep them short and steep, and use a drain heater where the manual requires it. Ice blocking the base pan can damage the coil.
- Condensate is close to distilled water. It is soft but may carry dust and metals, so it is not drinking water. It can be reused for gardening.

Condensate drain: keep it falling all the way (side view)

Cold regions: a short, steep run with a drain heater; avoid long horizontal sections that freeze.



Worked example — how much water?

A large air-source unit in Chennai moves 10,000 m³/h of air. Air enters at a humidity ratio of 20 g/kg (moisture per kg of dry air) and leaves at 18.5 g/kg. Air density is about 1.15 kg/m³.

$$\dot{m}_{water} = \dot{V}_{air} \times \rho_{air} \times (W_{in} - W_{out})$$

1. Air mass: 10,000 × 1.15 = 11,500 kg/h.
2. Moisture removed: 11,500 × (0.020 – 0.0185) = 17 kg/h.
3. About 17 litres per hour, roughly 400 litres in a 24-hour day. This needs a proper drain, not a bucket.

Remember

- Plan the drain at survey time; it can be many litres per hour.
- Keep a steady fall to an approved drain; never onto walkways.
- In cold regions protect the drain from freezing.
- Keep base pan holes clear of debris and leaves.

Field tip: Pour a bucket of water into the base pan at commissioning and watch where it goes.

7.11 The ten most common installation mistakes

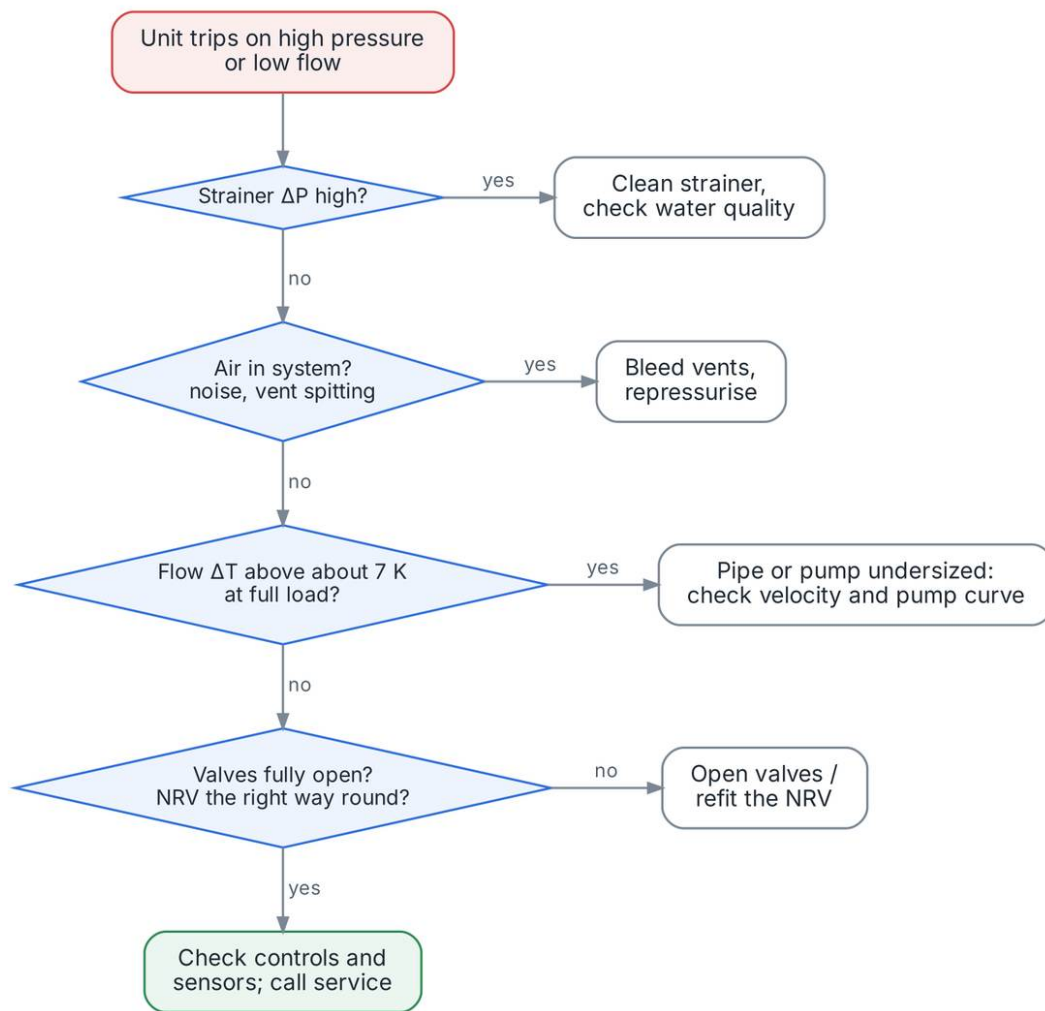
Key idea: Most early heat pump failures come from a short list of avoidable installation mistakes.

Learn this list and check it on every job. Each mistake has a clear symptom and an easy prevention.

#	Mistake	Symptom	Prevention
1	Unit boxed in, outlet facing a wall	Low output, frequent defrost, icing	Respect clearances; keep outlet path clear
2	Pipe too small for the flow	High-pressure or flow trips, noise	Size for 0.7–1.5 m/s; do not copy unit stub size
3	No strainer, or never cleaned	Low flow, blocked plate heat exchanger	Y-strainer on return; clean after first week
4	Air trapped in the circuit	Gurgling, pump noise, flow alarm	Air vents at high points; bleed after first run
5	Expansion vessel missing, wrong size or flat	Safety valve dripping, pressure swings	Size from system volume; check pre-charge
6	Brazing without nitrogen	Blocked expansion valve, compressor failure	Always flow OFN while brazing
7	Poor vacuum / no decay test	Moisture, acid, high discharge temperature	Micron gauge, 500 microns typical, decay test
8	Wrong charge (by guess)	Low COP, high or low pressure trips	Charge by weight per manual
9	Weak supply, no earth, wrong phase sequence	Trips, burnt terminals, reverse-running compressor	Proper cable, MCB, RCD, earth, phase check
10	No or poor insulation and no UV cover	Heat loss, sweating, foam crumbling	Insulate fully; clad outdoors



From a trip back to its installation cause



From a trip back to its installation cause

Commissioning record (minimum)

Record these values at handover: supply voltage, running current, flow and return temperatures (TT-1, TT-2), system pressure (PT-1, PT-2), strainer pressure difference, refrigerant charge (split units), earth resistance and insulation resistance. Leave a copy with the customer.

Remember

- Clearances, pipe size, strainer and air vents fix most water-side trips.
- Nitrogen, vacuum and weighed charge fix most refrigerant-side failures.
- Earth, protection and phase sequence fix most electrical failures.
- Record commissioning values; they are your baseline for future service.

Field tip: Revisit after one week: clean the strainer, bleed the air and recheck pressure. It prevents most callbacks.

Quiz 7

1. During a site survey, which tool gives a quick indication of dissolved salts (TDS)?
 - A. Clamp meter B. TDS meter C. Micron gauge D. Megger
2. Discharge air recirculating back to the coil inlet will:
 - A. Raise COP B. Lower output and increase defrost C. Have no effect D. Reduce noise only
3. A unit gives 60 dB(A) at 1 m. Ignoring reflections, roughly what is the level at 4 m?
 - A. 54 dB(A) B. 48 dB(A) C. 45 dB(A) D. 30 dB(A)
4. Anti-vibration mounts isolate well only when the forcing frequency divided by the natural frequency is:
 - A. Exactly 1 B. Below 1 C. Above about 1.4 D. Zero
5. A 20 kW heat pump runs at ΔT 5 K. The water flow is about:
 - A. 1.2 m³/h B. 3.4 m³/h C. 6.9 m³/h D. 17 m³/h
6. Where should the Y-strainer go in a heat pump water circuit?
 - A. On the flow pipe after the tank B. On the return, before the pump and heat pump C. On the drain line D. Only on the cold water inlet of the house
7. Which gas must flow through copper pipe during brazing?
 - A. Oxygen B. Compressed air C. Oxygen-free dry nitrogen D. Refrigerant
8. After isolating the vacuum pump, the micron gauge keeps rising steadily without levelling. This means:
 - A. The system is dry B. There is a leak C. The gauge is new D. The charge is correct
9. Why must the phase sequence be checked on a three-phase scroll compressor unit?
 - A. To reduce the electricity bill B. A scroll can run backwards and fail on wrong sequence C. To set the thermostat D. It is only needed for single-phase units
10. Outdoor elastomeric foam insulation without UV protection will typically:
 - A. Last forever B. Crack and crumble within a few summers C. Improve with sunlight D. Turn into a vapour barrier

Answer key

1. **B** — A TDS meter reads total dissolved salts; use a hardness kit for hardness.
2. **B** — The coil sees colder air, so output and COP fall and defrost happens more often.
3. **B** — 4 m is two doublings of distance: $60 - 6 - 6 = 48$ dB(A).
4. **C** — Isolation needs a ratio above $\sqrt{2}$ (about 1.4); near 1 is resonance.
5. **B** — $20 \div (1.163 \times 5) = 3.4$ m³/h.
6. **B** — It protects the pump and the heat pump's heat exchanger from dirt.
7. **C** — OFN displaces air and prevents oxide scale; oxygen and air are dangerous or useless.
8. **B** — A steady, non-levelling rise points to a leak; a rise that levels high points to moisture.
9. **B** — Scroll compressors run backwards on reversed phases, are noisy and get damaged.
10. **B** — Sunlight degrades most foams; cladding or UV paint is needed outdoors.

Glossary

Term	Meaning
Acceptance factor	Fraction of an expansion vessel's volume that can take water; $1 - p_i/p_f$ in absolute pressure
Air vent (automatic)	Valve at a high point that releases trapped air from the water circuit
Anti-vibration (AV) mount	Rubber or spring support that stops vibration passing to the structure
Brazing	Joining metals above 450 °C with a filler rod that melts below the base metal
COP	Coefficient of performance: heat delivered ÷ electricity used
dB(A)	A-weighted sound level, close to how the human ear hears loudness
Decay test	Watching vacuum after isolating the pump to check for leaks or moisture
Evacuation	Removing air and moisture from a refrigerant circuit with a vacuum pump
Expansion vessel	Diaphragm tank that absorbs water expansion in a closed circuit
Flexible connector	Braided or rubber pipe section that absorbs vibration and movement
Isolation valve	Valve (often a ball valve) used to shut off a section for service
MCB	Miniature circuit breaker: protects a circuit from overload and short circuit
Micron gauge	Instrument that measures deep vacuum in microns of mercury
Non-return valve (NRV)	Valve that allows flow in one direction only
OFN	Oxygen-free (dry) nitrogen used for purging and pressure testing
P&ID	Piping and instrumentation diagram: schematic of pipes, valves and instruments with tags
Phase sequence	Order of the three phases (R-Y-B); sets the rotation direction of three-phase motors
Pre-charge	Air or nitrogen pressure set in an expansion vessel before filling
PT	Pressure transmitter or pressure test point
RCD / RCCB	Residual current device: trips when current leaks to earth
Recirculation	Discharge air from the unit flowing back into its own inlet
Safety valve	Valve that opens automatically above a set pressure
Site survey	Visit to check location, structure, power, water and access before quoting
Static deflection	How far a mount compresses under the unit's weight
TDS	Total dissolved solids in water, in ppm
Transmissibility	Fraction of vibration force that passes through a mount
TT	Temperature transmitter or temperature test point
Velocity (pipe)	Speed of water in a pipe, in m/s; typically 0.7–1.5 m/s for heat pump circuits
Y-strainer	Y-shaped fitting with a mesh that catches dirt in the water flow

Course 8 — Commissioning and Performance Testing

Powered by Sunniva. This Level 3 course is for installers and service engineers who start up air-to-water heat pumps and prove they work. It assumes you already know the refrigeration cycle and basic hydronic piping. After this course you will be able to:

- Run a full pre-commissioning check and a safe first start-up.
- Place test instruments correctly and take reliable site readings.
- Calculate actual heating capacity and COP from temperature, flow and power readings.
- Measure superheat and subcooling, read a factory test report, and hand the system over properly.

8.1 Pre-commissioning checks

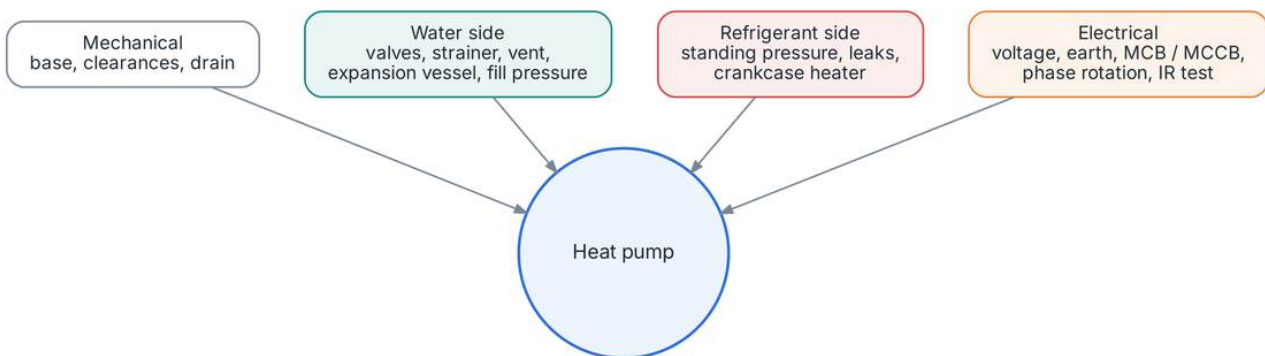
Key idea: Most start-up failures are caused by things that could have been found with the power still off.

Commissioning means proving that an installed system works as designed. Pre-commissioning is everything you check before the compressor runs for the first time. Think of it like checking oil, water and tyres before a long drive on the highway.

Problems found now cost a few minutes. The same problems found after start-up can cost a compressor. A dry pump, a closed valve or a reversed phase can cause damage within minutes.

Work in four groups: mechanical, water side, refrigerant side and electrical. Tick each item only after you have seen it yourself, not because someone told you.

Four zones to check before first start



Four zones to check before first start

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Commissioning checklist

Mechanical

- ☐ Unit sits level on a firm base or frame, with anti-vibration pads fitted.
- ☐ Air clearances around the coil and fan match the installation manual.
- ☐ No air short-circuit: discharge air cannot return to the coil inlet.
- ☐ Condensate and defrost drain is free and slopes away from the unit.
- ☐ All transport brackets and packing inside the unit are removed.

Water side

- ☐ Piping is flushed clean before connecting to the heat pump.
- ☐ Strainer is fitted on the inlet to the heat pump and its mesh is clean.
- ☐ All isolation valves on the heat pump circuit are open.
- ☐ Air vents are fitted at high points and the system is fully vented.
- ☐ Closed system: cold fill pressure is set (typical 1.5–2.0 bar) and the expansion vessel pre-charge is checked.
- ☐ Water side pressure test passed (typical 1.5 × working pressure, held with no drop).
- ☐ Water quality is checked: hardness and TDS recorded; softener or treatment fitted where water is hard.

- ☐ Circulating pump turns freely and rotates in the correct direction.
- ☐ Flow switch is fitted in the correct direction and wired.
- ☐ Pipes and fittings outdoors are insulated and UV protected.

Refrigerant side

- ☐ Monoblock: standing pressure on the gauges is present (unit not empty).
- ☐ Split: nitrogen pressure test passed, vacuum below 500 micron (typical), charge as per manual.
- ☐ No oil stains at brazed joints, valves or flare nuts.
- ☐ Service valves are fully open (split units) and caps refitted.

Electrical

- ☐ Supply voltage at the unit terminals is within $\pm 10\%$ of nameplate (typical).
- ☐ Three-phase: voltage imbalance between phases is below 2% (typical).
- ☐ Phase sequence is correct (phase rotation meter or controller check).
- ☐ Cable size, MCB/MCCB rating and RCCB match the manual.
- ☐ Earth is connected and earth continuity is checked.
- ☐ Insulation resistance of compressor windings to earth is above 1 M Ω (500 V tester, typical minimum).
- ☐ All terminal screws are tightened, including inside the control panel.
- ☐ Crankcase heater has been energised for the time stated in the manual (typical 12–24 hours).

Check	Typical value	Why it matters
Closed-loop fill pressure (cold)	1.5–2.0 bar	Prevents air entry and pump cavitation
Insulation resistance	> 1 M Ω	Detects wet or damaged motor windings
Supply voltage	$\pm 10\%$ of nameplate	Low voltage overheats the compressor motor
Voltage imbalance (3-phase)	< 2%	Imbalance causes high current in one winding
Crankcase heater on before start	12–24 h	Drives liquid refrigerant out of the oil

Remember

- Never start a heat pump with closed water valves or an unvented circuit.
- Wrong phase sequence can damage a scroll compressor within minutes.
- Measure insulation resistance before first power-up, not after a fault.
- Record every reading; the checklist becomes part of the handover file.

Common mistake: Skipping the crankcase heater wait on a cold morning. Liquid refrigerant in the oil can wash out the bearings at first start.

Create • Conserve • Sustain

8.2 First start-up sequence

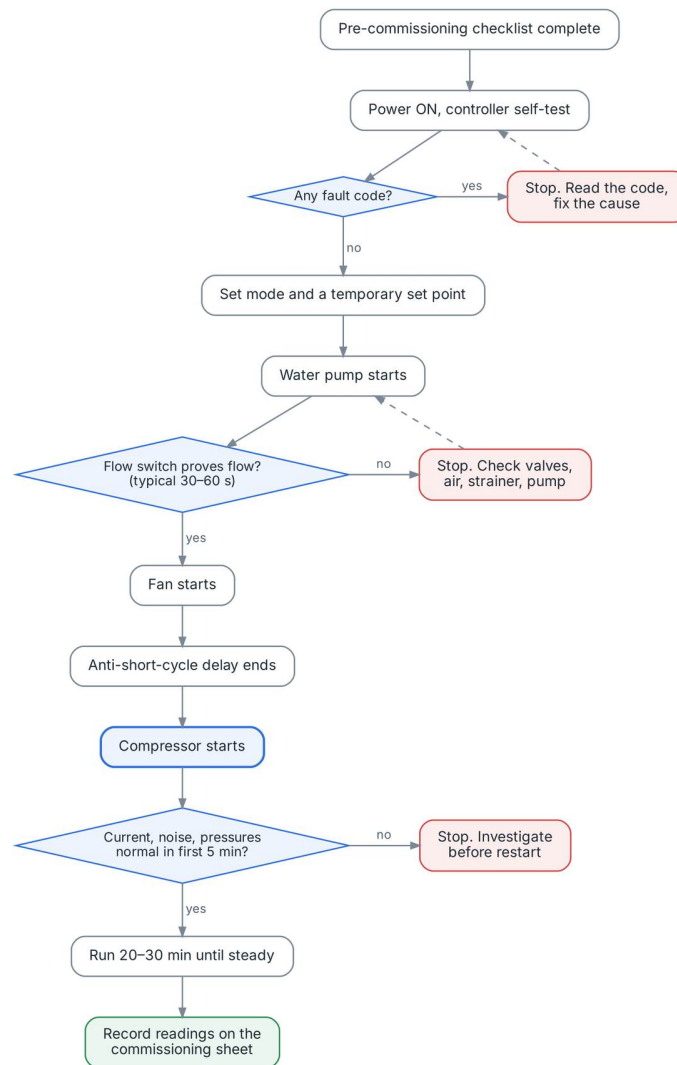
Key idea: A heat pump starts in a fixed order — water first, then air, then the compressor — and each step must prove itself before the next.

The controller follows a sequence of interlocks. An interlock is a condition that must be true before the next step is allowed. It is like a pressure cooker: the lid must lock before pressure can build.

Your job at first start is to watch each step happen. If a step does not happen, stop and find out why. Do not bypass a safety to "just see it run".

Typical order: the water pump starts, the flow switch proves flow, the fan starts, then the compressor starts after its anti-short-cycle delay. An anti-short-cycle timer is a minimum off time (typical 3 minutes) that protects the compressor from rapid restarts.

First start-up, step by step



First start-up, step by step



Step	What to watch	Normal sign
Pump start	Pump sound, pressure gauge	Steady hum, small rise in pressure
Flow proven	Flow switch, controller display	No flow alarm
Fan start	Rotation, vibration	Smooth, correct direction
Compressor start	Clamp meter on compressor lead	Inrush then settles near rated current
First 5 minutes	Suction and discharge pressure	Suction falls, discharge rises steadily
20–30 minutes	Water ΔT , superheat	Readings stable within ± 0.5 K

Remember

- Water flow must be proven before the compressor is allowed to run.
- Never jumper the flow switch or high-pressure switch to get a start.
- Measure starting and running current on every phase.
- Take performance readings only after the system is steady.

Field tip: Keep your hand near the isolator for the first compressor start. Any metallic knocking or a loud hum without rotation means switch off at once.



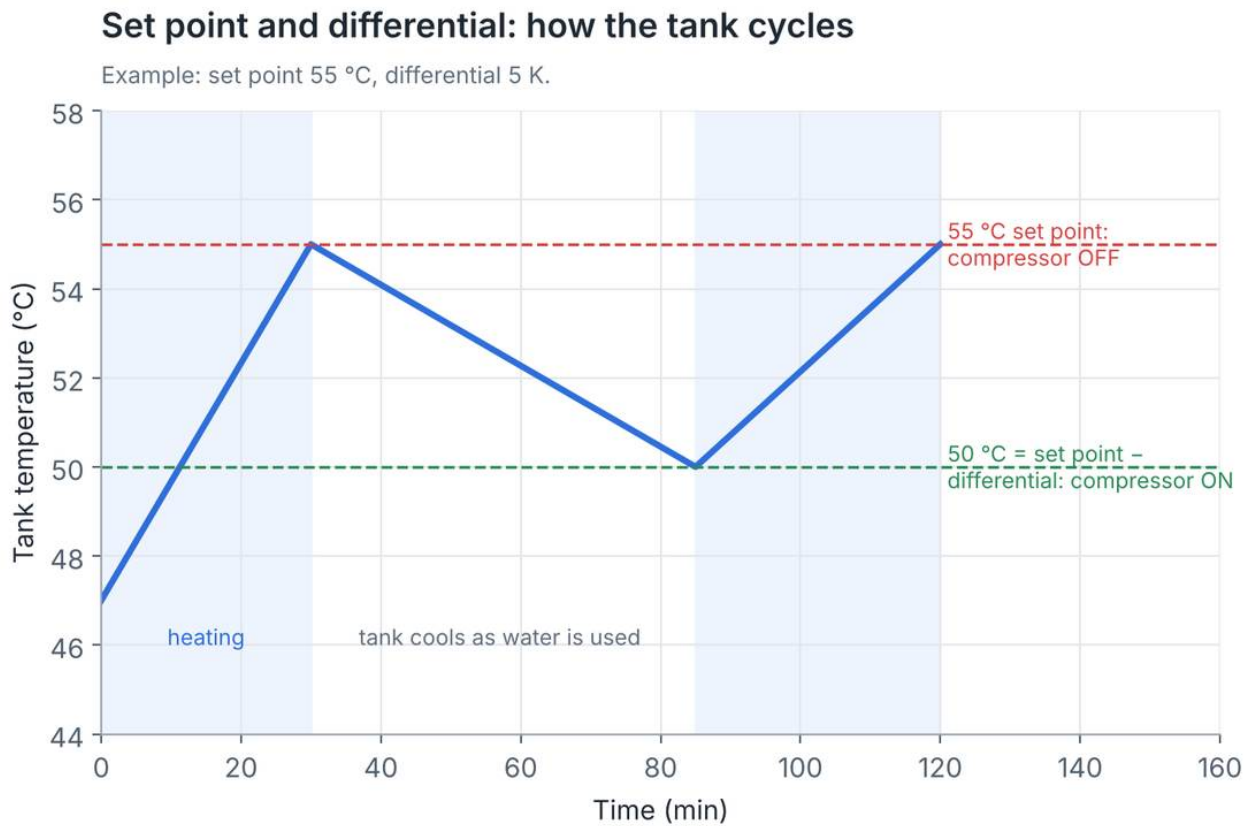
8.3 Controller setup and set points

Key idea: The controller decides how the heat pump behaves; wrong set points can make a good machine look bad.

The controller is the brain of the unit. It reads sensors and switches the pump, fan, compressor and valves. Setting it up means telling it what the site needs.

A set point is the target temperature, for example 55 °C hot water. A differential (also called hysteresis) is the band around the set point. The unit stops at the set point and restarts when the water falls by the differential. A fridge works the same way: the compressor stops when cold, and restarts after it warms a little.

A very small differential causes short cycling, which means frequent stops and starts. Short cycling wears the compressor and wastes energy. A very large differential lets the water get too cold before restart.



Set point and differential

Parameter	What it does	Typical setting
Hot water set point	Target water temperature	50–55 °C for domestic and commercial hot water
Space heating set point	Target flow temperature	35–45 °C (floor heating lower, radiators higher)
Differential	Restart band below set point	3–5 K
Anti-short-cycle timer	Minimum compressor off time	3 minutes
Pump overrun	Pump runs after compressor stops	1–3 minutes
Defrost start	Coil temperature that triggers defrost	As per manual; depends on refrigerant and coil
Anti-legionella cycle	Periodic high-temperature cycle	60 °C or above, weekly (where required)
Max outlet water limit	Protects against over-temperature	Below the unit's operating envelope limit
Clock and schedules	Sets cheap-tariff or working hours	Match site timings

Indian practice: many commercial sites (hotels, hostels, hospitals) need hot water mainly at 5–9 am and 6–10 pm. Use schedules so the tank is hot before these peaks. In Bengaluru or Pune winters, the morning ambient can drop to 10–15 °C, so allow extra heating time.

Remember

- Set the set point to what the user needs, not the maximum the unit can reach.
- A differential of 3–5 K is typical; smaller values cause short cycling.
- Higher water temperature means lower COP — every few degrees matter.
- Record all final controller settings on the commissioning sheet.

Common mistake: Leaving factory test settings in place. Always check set points, schedules and the clock before handover.



8.4 Measuring temperature, pressure, flow and power

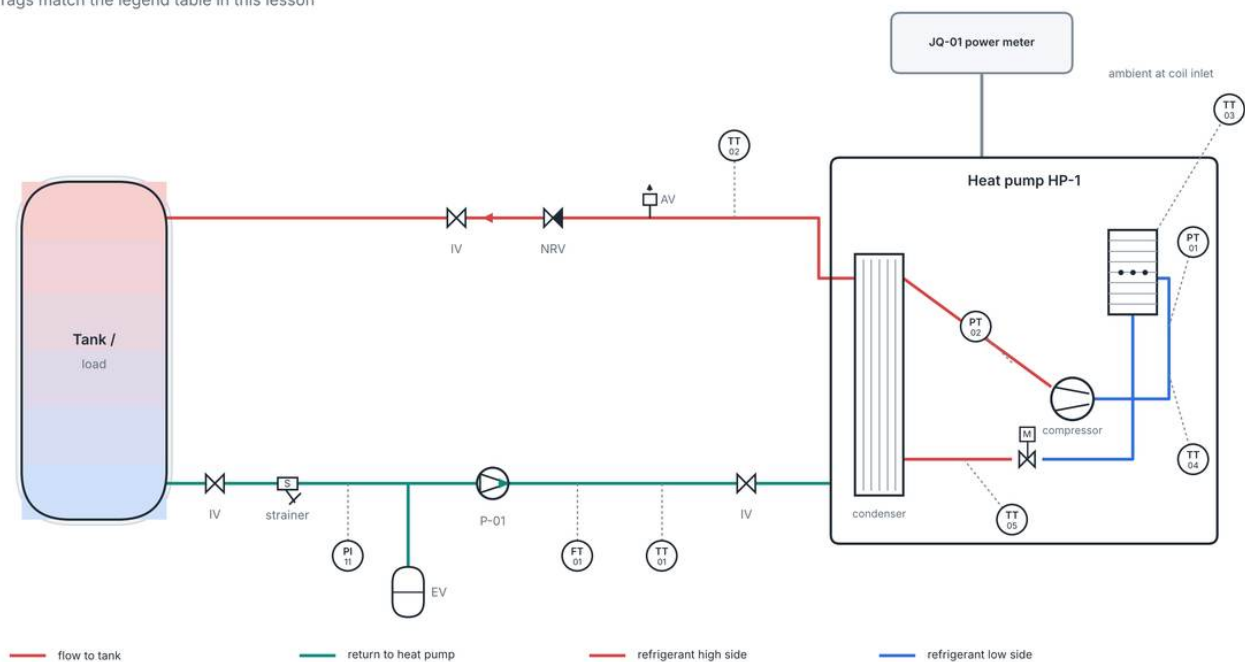
Key idea: A capacity or COP figure is only as good as the four measurements behind it — temperature, flow, pressure and power.

To prove performance on site you need a measured heat output and a measured electrical input. Heat output comes from water flow and temperature rise. Electrical input comes from a power meter.

Each instrument must sit in the right place. A temperature sensor placed after a mixing tee, or a flow meter right after a bend, gives a wrong reading. The P&ID below shows where every test instrument goes. A P&ID (piping and instrumentation diagram) is a drawing that shows pipes, valves and instruments with standard symbols and tags.

Where the test instruments go (P&ID)

Tags match the legend table in this lesson



P&ID: where the test instruments go

Legend (table under the diagram):

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Tag / symbol	Meaning	Where it goes
TT-01	Temperature transmitter, inlet water	Pipe into heat pump, after pump and flow meter, close to unit
TT-02	Temperature transmitter, outlet water	Pipe out of heat pump, before any tee or mixing
TT-03	Ambient air temperature	Shaded, at the air inlet of the coil, not in exhaust air
TT-04	Suction line temperature	Suction pipe near compressor, insulated over sensor
TT-05	Liquid line temperature	Liquid pipe after condenser, insulated over sensor
FT-01	Flow transmitter / flow meter	Straight pipe run on inlet side
PT-01	Suction pressure	Suction service port
PT-02	Discharge pressure	Discharge / high-side service port
PI-11	Water pressure gauge	Return line, near pump suction
JQ-01	Power and energy meter	Electrical supply feeding the whole unit
P-01	Circulating pump	Return line to heat pump
IV	Isolation valve	Both sides of heat pump
NRV	Non-return valve	Flow line, prevents back-flow
AV	Automatic air vent	High point of circuit
EV	Expansion vessel	Return line, pump suction side
Strainer	Y-strainer	Before pump and heat pump inlet

Measurement	Instrument	Typical accuracy needed	Placement rule
Water temperature	PT100 Class A or calibrated thermistor in a thermowell	$\pm 0.2\text{ }^{\circ}\text{C}$ or better	Immersed in flow, thermowell filled with paste
Air temperature	Shaded probe	$\pm 0.5\text{ }^{\circ}\text{C}$	At coil inlet, out of sun
Water flow	Electromagnetic or ultrasonic flow meter	$\pm 1\text{--}2\%$	Straight run, typical 10 D upstream and 5 D downstream
Refrigerant pressure	Digital manifold	$\pm 0.5\%$ of full scale	Service ports, hoses purged
Refrigerant pipe temperature	Clamp probe	$\pm 0.5\text{ }^{\circ}\text{C}$	Clean pipe, insulated over probe
Electrical power	True-RMS power meter (kW, kWh)	$\pm 1\%$	On the unit supply, all phases

Why $\pm 0.2\text{ }^{\circ}\text{C}$ matters: with a 5 K water ΔT , an error of $0.2\text{ }^{\circ}\text{C}$ on each sensor can shift ΔT by 0.4 K. That is an 8% error in capacity before you even start.

Remember

- Measure the water ΔT with matched, calibrated sensors, not the unit's own display alone.
- Ultrasonic clamp-on meters need a straight pipe and correct pipe data.
- Measure power with a true-RMS meter on all phases; amps alone are not watts.
- Place the ambient probe where the coil actually breathes, in shade.

Field tip: Swap the two water probes into the same bucket of water before testing. If they differ, note the offset and correct for it.

8.5 Calculating actual capacity and COP on site

Key idea: Capacity is water flow × specific heat × temperature rise; COP is that capacity divided by electrical input.

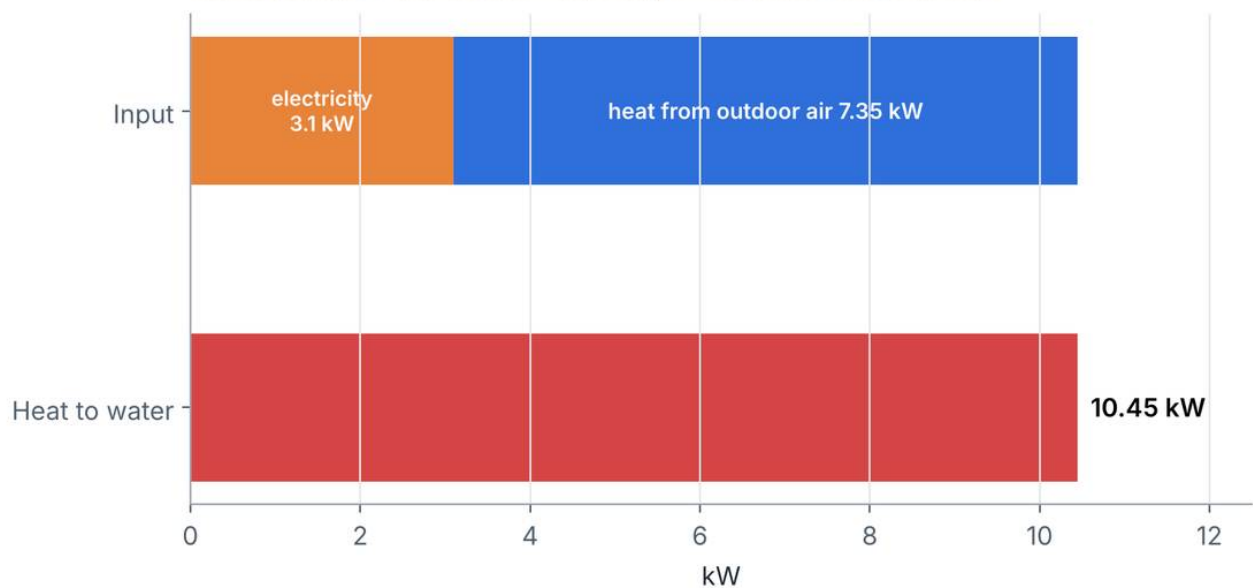
Heating capacity is the heat the unit puts into the water, in kW. Specific heat (cp) is the energy needed to warm 1 kg of a substance by 1 K. For water it is about 4.18 kJ/kg·K.

COP (coefficient of performance) is heat out divided by electricity in. A COP of 3.5 means 3.5 kW of heat for every 1 kW of electricity. The extra heat comes free from the outdoor air.

An electric geyser has a COP of about 1. That is why a heat pump can cut water heating electricity by two-thirds or more.

Energy balance from site readings

Worked example 1: heat to water = electricity in + heat taken from outdoor air.



Energy balance from site readings

$$Q = \dot{m} \times c_p \times \Delta T$$

$$\text{COP} = \frac{Q}{P_{\text{electrical}}}$$

Shortcut for water (flow in LPH):

$$Q \text{ (kW)} = \frac{\text{Flow (LPH)} \times \Delta T \text{ (K)}}{860}$$

Worked example 1 — Circulating heat pump at a hotel in Pune

Site readings after 30 minutes of steady running. Ambient (TT-03) 28 °C. Inlet water (TT-01) 50.0 °C. Outlet water (TT-02) 55.0 °C. Flow (FT-01) 1.8 m³/h. Power meter (JQ-01) 3.10 kW.

Step 1 — mass flow. 1.8 m³/h = 1800 L/h. Water at this temperature is close to 1 kg/L.

$$\dot{m} = \frac{1800 \text{ kg/h}}{3600 \text{ s/h}} = 0.50 \text{ kg/s}$$

Step 2 — temperature rise.

$$\Delta T = 55.0 - 50.0 = 5.0 \text{ K}$$

Step 3 — capacity.

$$Q = 0.50 \times 4.18 \times 5.0 = 10.45 \text{ kW}$$

Check with the shortcut: $1800 \times 5 / 860 = 10.47 \text{ kW}$. Same answer.

Step 4 — COP.

$$\text{COP} = \frac{10.45}{3.10} = 3.37$$

Step 5 — compare. Look up the manufacturer's data at 28 °C ambient and 55 °C outlet, not the headline rating. If the data shows about 10.5 kW and COP 3.4 at these conditions, the unit is performing as expected.

Step 6 — what it saves (example rate ₹9/kWh). Over 8 running hours the unit delivers $10.45 \times 8 = 83.6 \text{ kWh}$ of heat for $3.10 \times 8 = 24.8 \text{ kWh}$ of electricity. That costs $24.8 \times 9 = ₹223$. An electric geyser would use about 83.6 kWh, costing about ₹752.

Worked example 2 — Tank heat-up method at a home in Bengaluru

When no flow meter is available, time a tank heat-up. A 500 L tank is heated from 25 °C to 55 °C in 1.5 hours. The energy meter shows 4.2 kWh used.

$$Q_{\text{energy}} = m \times c_p \times \Delta T = 500 \times 4.18 \times 30 = 62\,700 \text{ kJ}$$

$$62\,700 \text{ kJ} \div 3600 = 17.4 \text{ kWh}$$

$$\text{Average capacity} = \frac{17.4 \text{ kWh}}{1.5 \text{ h}} = 11.6 \text{ kW}$$

$$\text{Average COP} = \frac{17.4}{4.2} = 4.1$$

This method ignores tank heat loss and assumes the tank is well mixed. It gives a fair average, not an exact figure. Make sure no water is drawn off during the test.

Error source	Effect on result	How to avoid
Probes not matched	ΔT wrong, capacity off by 5–10%	Bucket test, note offset
Reading during defrost or start-up	Capacity too low	Wait for steady state
Flow meter in turbulent spot	Flow wrong	Use straight pipe run
Measuring amps, not kW	Power wrong (power factor ignored)	Use a true-RMS power meter
Comparing to rating at different conditions	False "underperforming" claim	Compare at the same ambient and water temperature

Remember

- $Q = \dot{m} \cdot c_p \cdot \Delta T$; for water, $\text{kW} = \text{LPH} \times \Delta T / 860$.
- Always compare site results with data at the same ambient and water temperatures.
- Take readings only in steady state, never during defrost.
- Small ΔT errors make big capacity errors; calibrate probes.

Common mistake: Using the nameplate input power instead of the measured power. Nameplate values are at rating conditions, not today's site conditions.

8.6 Superheat and subcooling

Key idea: Superheat tells you if the evaporator is fed correctly; subcooling tells you if the condenser side has the right charge.

Saturation temperature is the temperature at which refrigerant boils or condenses at a given pressure. You read it from the pressure-temperature (P-T) chart or the digital manifold. A pressure cooker shows the same idea: higher pressure, higher boiling point.

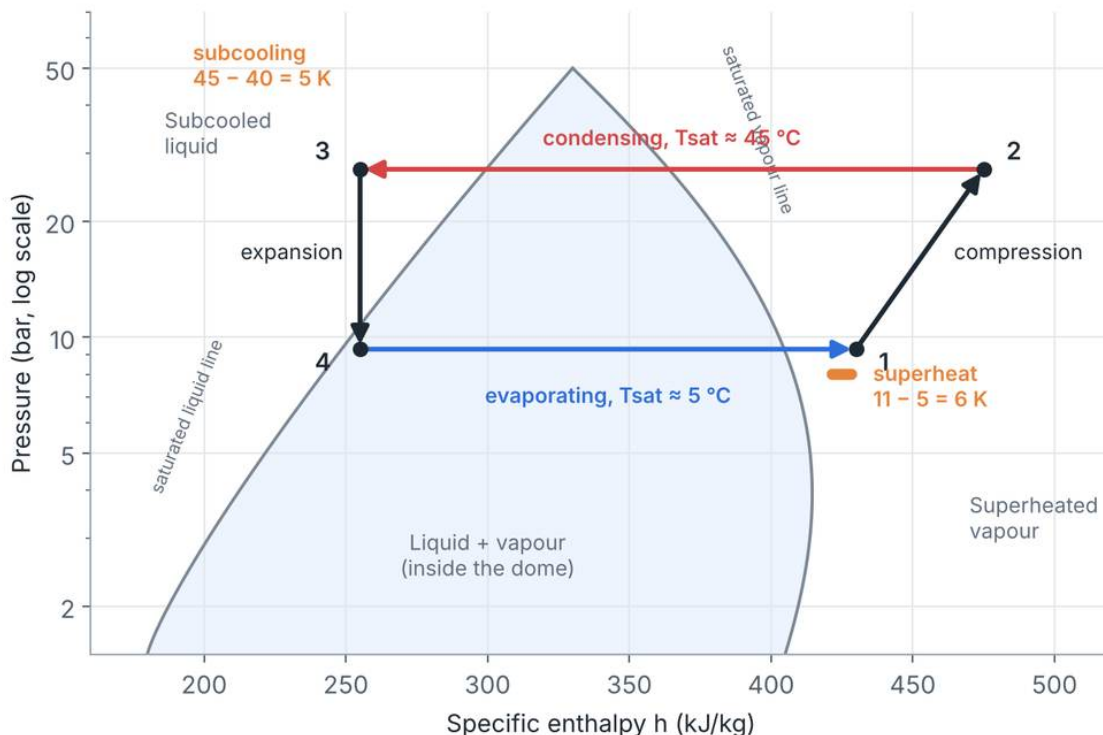
Superheat is the suction line temperature minus the evaporating saturation temperature. It proves that only vapour reaches the compressor. Too little superheat risks liquid entering the compressor. Too much means the evaporator is starved, often from low charge or a faulty expansion valve.

Subcooling is the condensing saturation temperature minus the liquid line temperature. It proves the expansion valve receives solid liquid. Low subcooling often means undercharge. High subcooling often means overcharge or a restriction.

A P-h diagram plots pressure (vertical) against enthalpy (horizontal). Enthalpy is the heat content per kg of refrigerant. The dome shape is the saturation curve. Superheat sits just right of the dome on the low-pressure line. Subcooling sits just left of the dome on the high-pressure line.

Superheat and subcooling on the P-h diagram

R410A worked example: suction 9.3 bar abs at 11 °C; high side 27.3 bar abs, liquid line at 40 °C. Sketch, not to scale.



Superheat and subcooling on the P-h diagram

Worked example — R410A unit in Chennai, steady running

Readings: suction gauge 8.3 bar(g); suction line temperature (TT-04) 11 °C. Discharge-side gauge 26.3 bar(g); liquid line temperature (TT-05) 40 °C.

Step 1 — convert gauge to absolute pressure (add about 1 bar).

$$P_{abs} = P_{gauge} + 1.0$$

Suction: $8.3 + 1.0 = 9.3$ bar abs. High side: $26.3 + 1.0 = 27.3$ bar abs.

Step 2 — read saturation temperatures from the R410A P-T chart. At 9.3 bar abs, $T_{sat} \approx 5^\circ\text{C}$. At 27.3 bar abs, $T_{sat} \approx 45^\circ\text{C}$. (Most digital manifolds do this for you once the refrigerant is selected.)

Step 3 — superheat.

$$SH = T_{suction\ line} - T_{sat, evap} = 11 - 5 = 6\ K$$

Step 4 — subcooling.

$$SC = T_{sat, cond} - T_{liquid\ line} = 45 - 40 = 5\ K$$

Step 5 — judge. Both values fall in the typical range below. The charge and expansion valve are working normally.

Reading	Typical range	Too low means	Too high means
Superheat (EXV/TXV systems)	4–8 K	Flooding risk, liquid to compressor	Starved evaporator, low charge, valve fault
Subcooling	3–8 K	Undercharge, flash gas at valve	Overcharge, restriction, condenser flooded

Always use the target values in the installation manual where given. Fixed-orifice and capillary systems behave differently from electronic expansion valves.

Remember

- Superheat = suction line temp – evaporating saturation temp.
- Subcooling = condensing saturation temp – liquid line temp.
- Convert gauge to absolute pressure if your chart is in absolute.
- Measure on clean pipe with the probe insulated, in steady state.

Common mistake: Adding refrigerant because suction pressure "looks low" on a cold morning. Check superheat and subcooling first; low ambient alone lowers suction pressure.



8.7 Reading a factory performance test report

Key idea: A factory test report proves each unit met its design performance under controlled conditions; learn to read every column.

Before dispatch, good factories run each unit, or a sample, on a test bench. The bench controls the air and water conditions and records performance. The record is called a performance test report.

On site, this report is your baseline. If site readings differ a lot from the report at similar conditions, something has changed — installation, water flow, charge or supply voltage.

Sample performance test record (generic)

Refrigerant: R410A. Unit type: air-to-water heat pump, rated 20 kW heating at 20 °C ambient, 40 → 45 °C water. Tolerance: ±5% on capacity and COP (typical; the real figure is set in the test specification).

Test no.	Ambient DB (°C)	Ambient RH (%)	Water in (°C)	Water out (°C)	Flow (m³/h)	Capacity (kW)	Voltage (V)	Current (A)	Input power (kW)	COP	Suction P (bar g)	Discharge P (bar g)	SH (K)	SC (K)	Result
T1	20	65	40.0	45.0	3.44	20.0	415	7.4	4.65	4.30	9.8	29.5	6	5	Pass
T2	7	85	41.0	45.0	3.44	16.0	415	7.7	4.85	3.30	6.0	29.5	5	4	Pass
T3	35	45	50.0	55.5	3.44	22.0	412	9.5	5.95	3.70	12.5	37.0	7	5	Pass

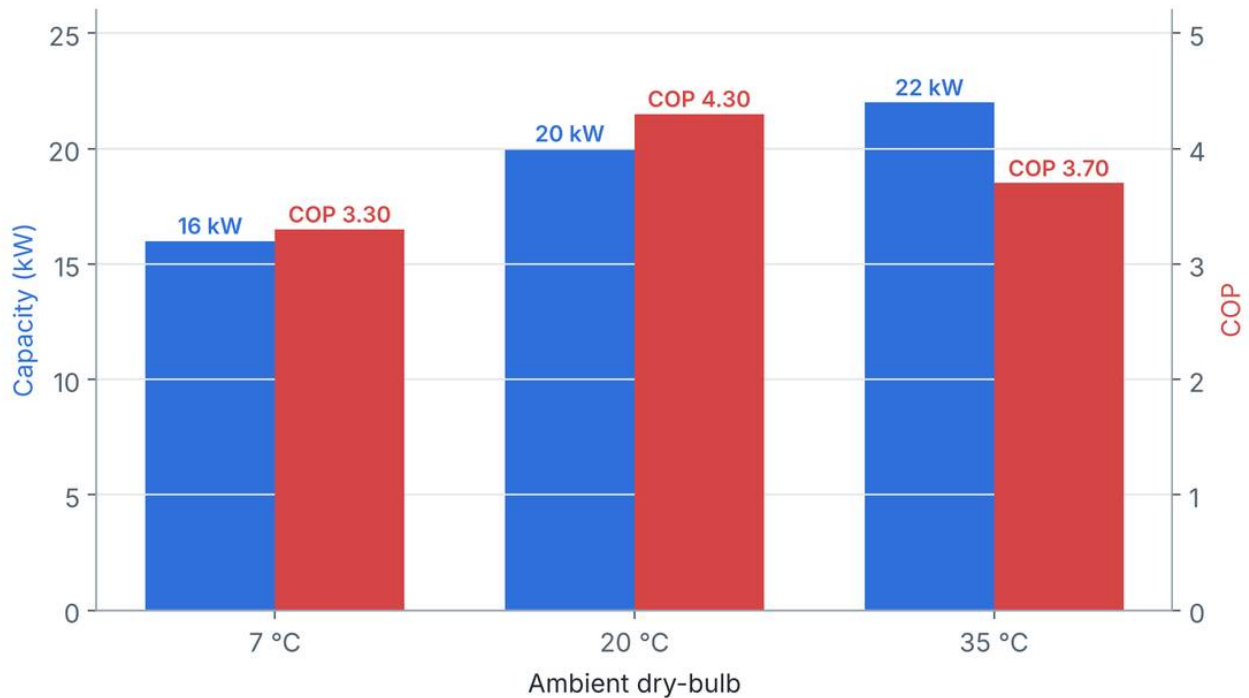
How the numbers fit: Capacity = Flow (LPH) × ΔT / 860. For T1: $3440 \times 5.0 / 860 = 20.0$ kW. COP = $20.0 / 4.65 = 4.30$.

Column	What it means	What to look for
Test no.	Test point identifier	Each rating condition has its own row
Ambient DB	Dry-bulb air temperature at coil inlet	Defines the test condition
Ambient RH	Relative humidity of inlet air	High RH at low ambient means frost and defrost
Water in / out	Water temperatures at unit inlet and outlet	ΔT should match the design (here about 4–5.5 K)
Flow	Water flow rate through the condenser	Site flow should be close to this
Capacity	Heat delivered, from flow × cp × ΔT	Compare with rated value ± tolerance
Voltage	Supply voltage during test	Results apply at this voltage
Current	Running current per phase	Site current should be similar at similar conditions
Input power	Measured electrical input in kW	Includes compressor, fan and controls (check if pump is included)
COP	Capacity ÷ input power	Falls with lower ambient and higher water temperature
Suction P / Discharge P	Refrigerant pressures (gauge)	Baseline for site gauge readings
SH / SC	Superheat and subcooling	Baseline for charge checks
Result	Pass or fail against tolerance	Any fail must be explained and retested

Other items on a good report: unit serial number, refrigerant type and charge, test date, bench instrument calibration reference, tester name and signature, and electrical safety tests (insulation resistance, earth continuity, high-voltage test).

Factory test: capacity and COP at three ambient conditions

From the sample test report. COP at 35 °C is lower than at 20 °C because the water is hotter (55.5 vs 45 °C).



Factory test: capacity and COP at three ambients

Remember

- A test result only means something together with its test conditions.
- Check that capacity = flow × ΔT / 860 on the report; the numbers must agree.
- Confirm whether input power includes the water pump.
- Keep a copy of the report in the site file as the performance baseline.

Field tip: When a customer complains of low output, compare the site readings with the factory row closest to today's ambient and water temperature.

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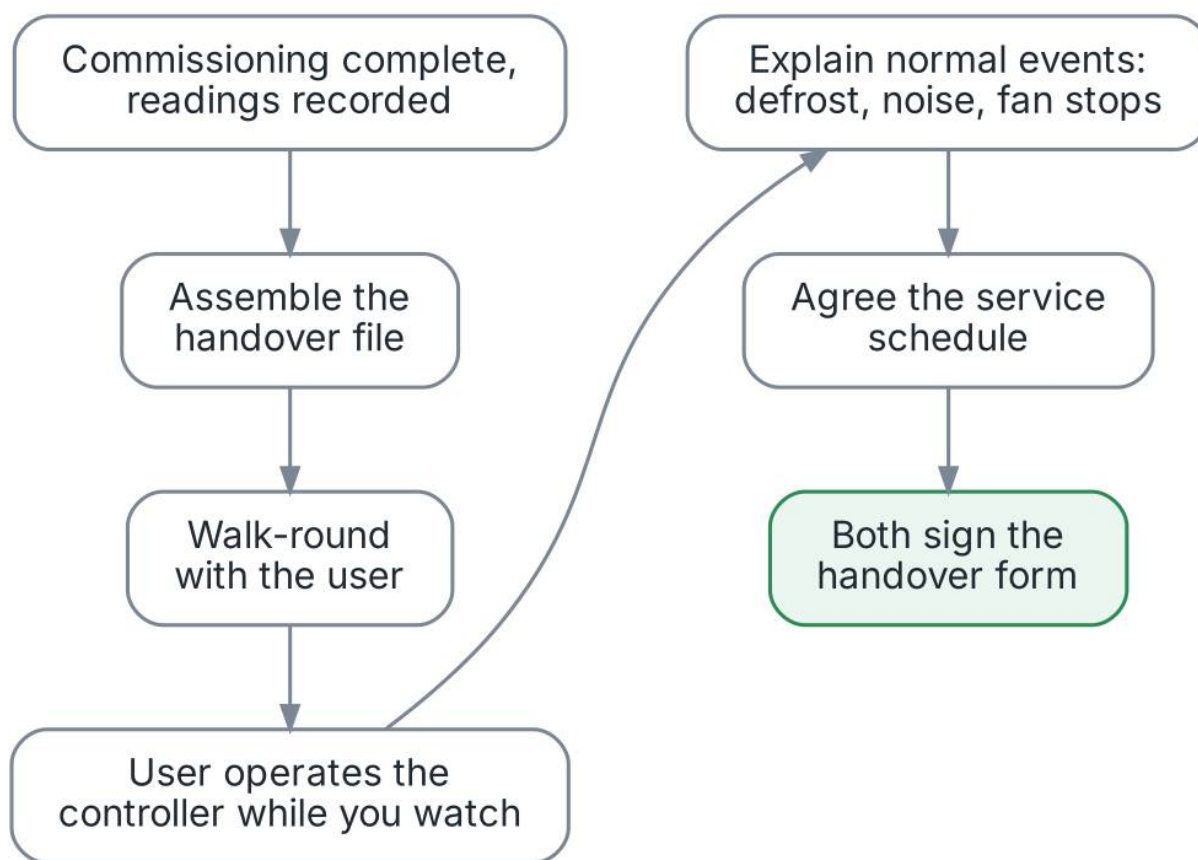
8.8 Handover: documents and user training

Key idea: The job is not finished until the user knows how to operate the system and has every document they need.

Handover is the formal transfer of the system to the owner or operator. A good handover prevents most "nuisance" service calls. Many early complaints come from users who do not understand defrost, schedules or set points.

Train the person who will actually operate the system — the hotel maintenance man, the hostel warden, or the homeowner. Show, then ask them to do it while you watch.

Handover in seven steps



Handover in seven steps

Document	Contents	Who keeps it
Commissioning report	Checklist, readings, capacity, COP, SH/SC, settings	Owner and installer
Factory performance test report	Bench test results for this serial number	Owner
Installation and user manual	Operation, safety, fault codes	Owner, near the unit
As-built schematic / P&ID	Actual piping, valves, sensors, electrical feed	Owner and service team
Controller settings sheet	Set points, differential, schedules, limits	Owner and installer
Warranty card and registration	Serial number, start date, conditions	Owner
Service schedule	Filter, strainer, coil, water quality checks	Owner
Contact details	Service phone, email, QR code if any	Posted on or near unit

User training topics:

- Switching on and off, changing set point and schedule.
- What defrost is: the fan stops and steam may rise from the coil — this is normal.
- Normal sounds, and which sounds mean "call service".
- Reading and noting fault codes before calling.
- Simple care: keep the coil clear of leaves, dust and stored items; clean the strainer as advised.
- Water quality: where water is hard, maintain the softener to prevent scale.
- Safety: do not open panels; isolator location; keep children away from the unit.

Remember

- Hand over a complete file: commissioning report, test report, manuals, settings and warranty.
- Train the real operator and have them practise.
- Explain defrost and normal noises to avoid false complaints.
- Get a signed handover form with the date; warranty usually starts here.

Field tip: Take a photo of the final controller settings and the commissioning sheet, and send it to the owner the same day.



Quiz 8

1. Before the first start of a compressor with a crankcase heater, the heater should typically be energised for:
 - A. 5 minutes B. 30 minutes C. 12–24 hours D. It is not needed
2. In the start-up sequence, the compressor is allowed to start only after:
 - A. The fan reaches full speed only B. Water flow is proven by the flow switch C. The tank reaches set point D. Defrost ends
3. A heat pump runs with 2400 LPH flow and a 5 K water temperature rise. Its capacity is about:
 - A. 4.8 kW B. 9.6 kW C. 14.0 kW D. 20.0 kW
4. The same unit uses 4.0 kW of electrical power. Its COP is:
 - A. 2.5 B. 3.0 C. 3.5 D. 4.0
5. Where should the ambient temperature sensor be placed?
 - A. In the fan exhaust air B. On the roof in direct sun C. Shaded, at the coil air inlet D. Inside the control panel
6. Suction saturation temperature is 4 °C and suction line temperature is 10 °C. Superheat is:
 - A. 4 K B. 6 K C. 10 K D. 14 K
7. Low subcooling with high superheat most often indicates:
 - A. Overcharge B. Undercharge C. Too much water flow D. Correct charge
8. Why is a ± 0.2 °C sensor error important in capacity testing?
 - A. It is not important B. With a 5 K ΔT it can cause about 8% capacity error C. It only affects COP, not capacity D. It only matters above 60 °C
9. On a factory test report, the most important thing to check alongside capacity is:
 - A. The colour of the unit B. The test conditions (ambient and water temperatures) C. The tester's handwriting D. The packing list
10. A very small controller differential (for example 1 K) usually causes:
 - A. Higher COP B. Short cycling C. Lower water temperature D. Longer defrost

Answer key

1. C — Liquid refrigerant must be driven out of the oil; typical 12–24 h.
 2. B — Running without flow causes high pressure trips and heat exchanger damage.
 3. C — $2400 \times 5 / 860 = 13.95 \approx 14.0$ kW.
 4. C — $14.0 / 4.0 = 3.5$.
 5. C — It must read the air the coil actually draws in, without sun heating it.
 6. B — $10 - 4 = 6$ K.
 7. B — Not enough refrigerant starves the evaporator and leaves little liquid in the condenser.
 8. B — Two 0.2 °C errors can shift ΔT by 0.4 K, which is 8% of 5 K.
 9. B — Capacity and COP change with conditions; a number without its conditions is meaningless.
 10. B — The unit reaches set point and restarts too often, wearing the compressor.
-

Glossary

Term	Meaning
Commissioning	Proving that an installed system works as designed and recording the results
Pre-commissioning	Checks done before the first start-up, with the compressor off
Interlock	A condition that must be met before the next step is allowed
Anti-short-cycle timer	Minimum compressor off time, typically 3 minutes
Set point	Target temperature the controller works towards
Differential (hysteresis)	Temperature band between switch-off and restart
Short cycling	Frequent compressor starts and stops
P&ID	Piping and instrumentation diagram, using standard symbols and tags
TT / PT / FT	Temperature, pressure and flow transmitter (ISA tags)
JQ	Power/energy meter tag (power totaliser)
Heating capacity (Q)	Heat delivered to the water, in kW
Specific heat (cp)	Energy to raise 1 kg by 1 K; water $\approx 4.18 \text{ kJ/kg}\cdot\text{K}$
ΔT	Temperature difference, here outlet minus inlet water
COP	Coefficient of performance: heat out $\div$ electricity in
Steady state	Running condition where readings no longer change
Saturation temperature	Boiling or condensing temperature at a given pressure
Superheat	Suction line temperature minus evaporating saturation temperature
Subcooling	Condensing saturation temperature minus liquid line temperature
P-h diagram	Chart of refrigerant pressure against enthalpy
Enthalpy	Heat content of refrigerant per kg, kJ/kg
Gauge vs absolute pressure	Absolute = gauge + about 1 bar (atmospheric)
Insulation resistance	Resistance between motor windings and earth; typical minimum 1 M Ω
True-RMS power meter	Meter that measures real power in kW, accounting for power factor
Performance test report	Factory record of a unit's tested capacity, power and COP
Handover	Formal transfer of the system and documents to the owner
Defrost	Cycle that melts frost from the outdoor coil

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Course 9 — Service, Maintenance and Troubleshooting

Powered by Sunniva. This Level 3 course is for service technicians who already know the refrigeration cycle and heat pump components. After it you will be able to: (1) plan and record preventive maintenance for air-source and water-source heat pumps; (2) clean coils, descale plate heat exchangers and control water quality; (3) follow a systematic method to find faults, including high-pressure and low-pressure trips; and (4) trace compressor, leak, electrical and control faults to their root cause.

9.1 Preventive maintenance schedule and service records

Key idea: A heat pump that is checked on a fixed schedule and logged every time rarely fails without warning.

Preventive maintenance (PM) means planned checks done before something breaks. Breakdown maintenance means repairing after a failure. PM costs less because small problems such as a dirty filter are fixed before they trip the compressor.

Think of a pressure cooker. You check the gasket and the whistle before cooking, not after the lid blows. A heat pump works the same way. Most failures start as a slow drift in a pressure, temperature or current.

A service record is the written history of a unit. Each visit you note readings, work done and parts changed. Over months the record shows trends, like a slowly rising discharge temperature, that a single visit cannot.

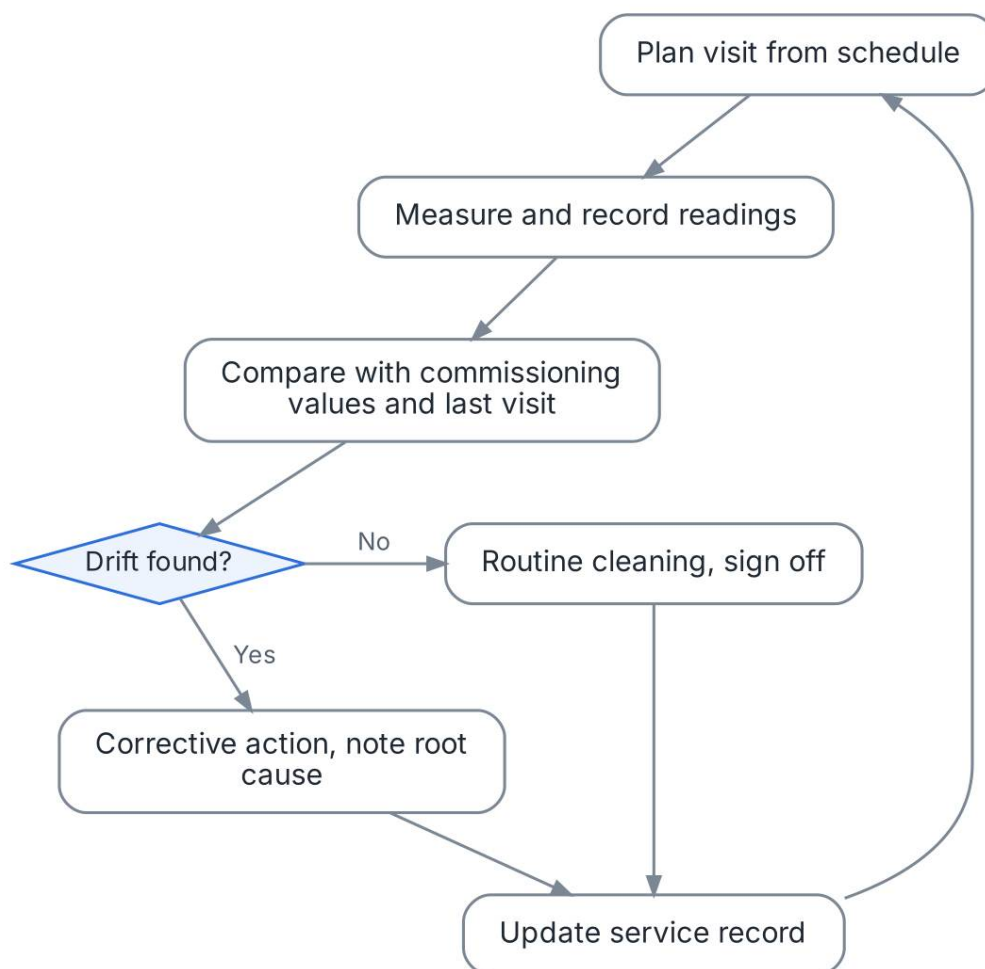
PM schedule

Frequency	Who	Check	What "good" looks like
Daily	Operator	Unit running, no alarms on controller	No active alarm; set point reached
Daily	Operator	Supply and return water temperature	Difference (ΔT) typically 3–7 °C
Daily	Operator	Unusual noise, vibration, water drips	None
Monthly	Technician	Clean Y-strainer on water inlet	Mesh clear; pressure drop back to normal
Monthly	Technician	Clean air-coil fins (light wash)	Fins clear of dust, leaves, lint
Monthly	Technician	Condensate drain and tray	Free-flowing, no algae
Monthly	Technician	Water system pressure and air vents	Pressure as commissioned; no trapped air
Quarterly	Technician	Suction and discharge pressures, superheat, subcooling	Within commissioning values
Quarterly	Technician	Compressor and fan current on each phase	Within nameplate; phases balanced within about 2–3 %
Quarterly	Technician	Tighten electrical terminals, inspect contactors	No burnt marks, no pitting
Quarterly	Technician	Leak check on brazed joints and flare nuts	No oil stains, detector silent
Quarterly	Technician	Water quality test (hardness, TDS, pH)	Within limits of lesson 9.3
Yearly	Technician	Descale plate heat exchanger (more often in hard water)	Approach temperature back to commissioning value
Yearly	Technician	Deep coil clean with coil cleaner	Full air flow restored
Yearly	Technician	Insulation resistance test of compressor and fan motors	Above 1 M Ω minimum at 500 V DC (healthy compressors usually read well above 2 M Ω ; follow the manufacturer's manual)
Yearly	Technician	Calibrate or verify sensors and safety switches	Readings match reference instrument; HP/LP switches trip at set point
Yearly	Technician	Expansion vessel pre-charge, safety valve, pump bearings	Pre-charge as designed; valve not passing

What a service record must contain

Field	Example
Date, site, unit serial	12-03-2026, Hotel, Pune, serial XXXX
Ambient and water temperatures	Ambient 34 °C; water in 48 °C, out 54 °C
Suction and discharge pressure (R410A)	15.0 bar(g) / 35.0 bar(g)
Superheat and subcooling	6 K / 5 K
Compressor current (R/Y/B)	18.2 / 18.4 / 18.1 A
Alarms in log since last visit	None
Work done, parts used	Strainer cleaned; coil washed
Next action	Descale PHE at next quarterly visit

The preventive maintenance cycle



The preventive maintenance cycle

Remember

- PM is planned; breakdown repair is unplanned and costs more.
- Record readings every visit so you can see trends.
- Compare against commissioning values, not just "looks fine".
- Hard water and dusty sites need shorter intervals.

Field tip: Photograph the controller's alarm log and the nameplate at every visit and attach them to the record.

9.2 Cleaning coils and heat exchangers; descaling

Key idea: Dirt on the air side and scale on the water side both act like a blanket, so the heat pump must work harder to move the same heat.

An air coil (finned tube heat exchanger) picks up dust, cotton lint, leaves and oily kitchen fumes. A plate heat exchanger (PHE) is a stack of thin pressed plates; refrigerant flows on one side and water on the other. Scale is a hard layer of calcium and magnesium salts left by hard water when it is heated.

Look inside an old geyser in Delhi or Chennai and you will see white rock on the element. The same rock forms in the PHE water channels. Even a thin layer of scale cuts heat transfer noticeably, because scale conducts heat far worse than steel.

Cleaning the air coil

1. Isolate power and lock out.
2. Brush or vacuum loose dirt from the air-inlet side.
3. Spray coil cleaner (non-acidic, safe for aluminium and copper) and wait for the time on the label.
4. Rinse with low-pressure water from the air-outlet side towards the inlet (back-flush), so dirt goes out the way it came in.
5. Straighten bent fins with a fin comb.

Never use a high-pressure jet close to the fins. It flattens them and blocks air flow.

Descaling a plate heat exchanger

Descaling means circulating a mild acid solution through the water side to dissolve scale. Use a descaling solution suited to stainless steel plates and copper brazing; follow the chemical supplier's strength and time. Typical practice is a weak acid such as citric acid or a proprietary inhibited descaler.

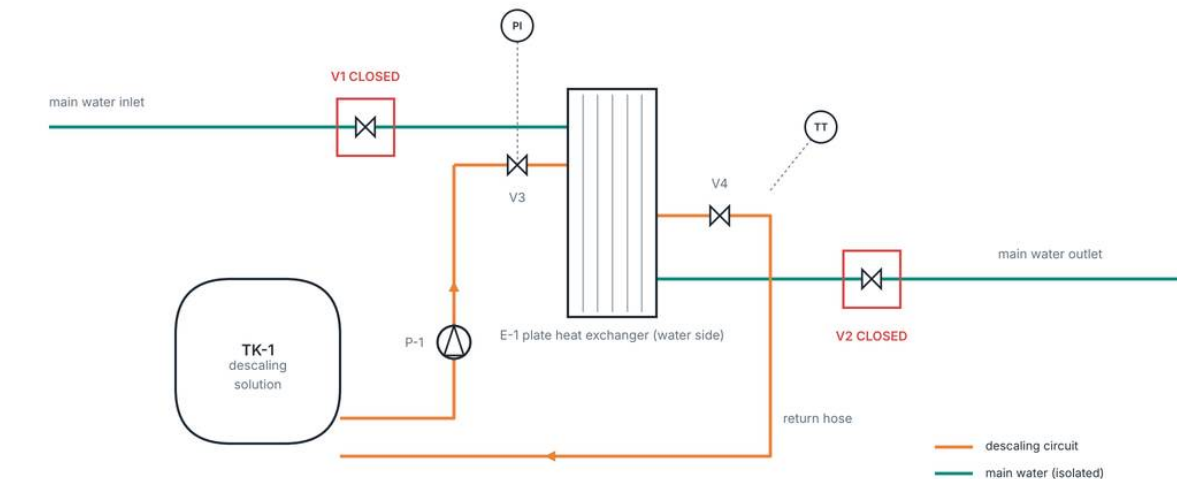
Steps:

1. Switch off the heat pump and the system pump. Isolate power.
2. Close isolation valves V1 and V2 on the main water lines.
3. Connect hoses from the descaling pump to service valves V3 (inlet) and V4 (outlet) on the PHE.
4. Fill the tank with descaling solution. Circulate against the normal flow direction (back-flush) for better scale removal.
5. Watch for foaming. Foaming means the acid is still reacting with scale. When foaming stops and pH stays steady, scale is dissolved.
6. Drain the solution into a container for neutralisation. Never drain acid into a garden or open drain.
7. Flush with clean water until the outlet pH is neutral (about 7).
8. Neutralise if the chemical supplier says so, flush again, reconnect, vent air and restart.
9. Record the approach temperature before and after.

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Descaling circuit for a plate heat exchanger (P&ID)

Main valves V1 and V2 closed; acid solution circulates through the service valves V3 and V4



Circulate in the direction opposite to normal flow; flush with clean water afterwards and neutralise the solution.

P&ID: descaling circuit for a plate heat exchanger

Legend: TK tank; P pump; V1/V2 isolation ball valves (closed during descaling); V3/V4 service (flushing) valves; E-1 plate heat exchanger; PI pressure indicator; TT temperature transmitter; arrows show back-flush direction (opposite to normal flow).

Item	Symptom of fouling	Clean when
Air coil (heating mode)	Low suction pressure, more frequent defrost	Visibly dirty, or suction falls versus record
Air coil (cooling / heat rejection)	High discharge pressure	Discharge pressure rises versus record
Water-side PHE (condenser)	High discharge pressure, approach temperature rising	Approach rises by about 2–3 K over commissioning (typical)
Water-side PHE (evaporator)	Low suction, freeze-protection alarms	Approach rises over commissioning
Y-strainer	Low flow, flow switch trips	Pressure drop across it rises

Worked example — Is the condenser PHE scaled?

Approach temperature is the difference between the refrigerant condensing temperature and the leaving water temperature.

$$\text{Approach} = T_{\text{cond}} - T_{\text{water,out}}$$

At commissioning in Ahmedabad: condensing temperature 58 °C, water out 55 °C. Approach = 58 – 55 = 3 K.

One year later, same load: condensing temperature 63 °C, water out 55 °C. Approach = 63 – 55 = 8 K.

The approach has grown by 5 K. Higher condensing temperature means higher compressor work. Descale the PHE.

Remember

- Back-flush coils from outlet side to inlet side, at low pressure.
- Descale against normal flow direction, then flush to neutral pH.
- Use chemicals compatible with stainless steel, copper and brazing.
- Track approach temperature to know when to descale.

Common mistake: Leaving the main isolation valves open, so acid flows into the whole building's pipework.

9.3 Water treatment and scale prevention

Key idea: Most water-side problems in Indian sites come from hard, dirty or corrosive water, and they are cheaper to prevent than to clean.

Water quality is measured by a few simple numbers. Hardness is the amount of dissolved calcium and magnesium, given as mg/L (ppm) of CaCO_3 . TDS (total dissolved solids) is all dissolved salts in mg/L. pH shows whether water is acidic (below 7) or alkaline (above 7).

Borewell water in many parts of India is hard. Hardness of several hundred mg/L is common in places like Rajasthan, Gujarat and parts of Bengaluru. A kettle used with such water gets a white crust; a heat pump gets the same crust inside its PHE, and fast, because the water is hot.

Scale forms faster at higher temperatures. That is why hot-water heat pumps above about 55 °C are most at risk. Open systems, where fresh make-up water is added all the time, bring in new hardness every day.

Typical water quality guide for heat pump circuits

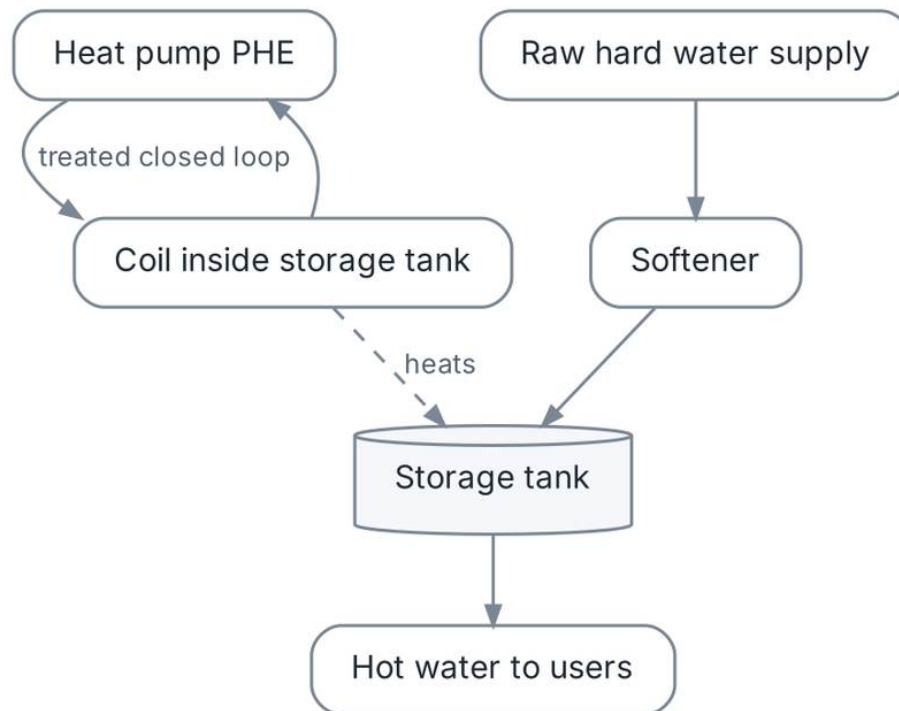
Parameter	Typical target (closed loop)	Why it matters
pH	7.5–9.0	Low pH corrodes copper; very high pH can attack aluminium and brazing
Total hardness	Below about 100–150 mg/L as CaCO_3 for hot water service (typical)	Scale on PHE
TDS	Below about 500 mg/L (typical)	Scale and corrosion
Chlorides	As low as practical; typically below about 200 mg/L for stainless steel at heat pump temperatures	Pitting of stainless plates
Suspended solids	Filtered by strainer, mesh typically 0.5–1 mm	Blocking of PHE channels

These are typical values. Always use the limits in the unit's manual where available.

Ways to prevent scale

Method	How it works	Good for	Limits
Closed loop with indirect PHE	Hard water never touches the heat pump PHE	Most sites with hard water	Needs a second heat exchanger in the tank
Water softener (ion exchange)	Swaps calcium and magnesium for sodium	Domestic and hotel hot water	Needs regular salt and regeneration
Reverse osmosis (RO)	Removes most dissolved salts	Small flows, very bad water	Wastes water; RO water can be corrosive, so adjust pH
Polyphosphate dosing	Keeps hardness in suspension	Moderate hardness	Must be food-safe for drinking water
Lower hot water set point	Less scaling at lower temperature	Where use allows	Check hygiene needs (legionella)
Y-strainer and dirt separator	Catches sand and rust	All systems	Must be cleaned monthly

A closed loop protects the heat pump from hard water



A closed loop protects the heat pump from hard water

Worked example — How much scale comes in?

A hotel in Jaipur uses 5,000 L of hot water a day. Hardness is 300 mg/L as CaCO_3 . If even a tenth of this hardness drops out as scale:

$$m_{\text{scale}} = V \times H \times f$$

$V = 5,000 \text{ L}$, $H = 300 \text{ mg/L}$, $f = 0.1 \text{ m} = 5,000 \times 300 \times 0.1 = 150,000 \text{ mg} = 150 \text{ g per day}$.

Over a year: $150 \text{ g} \times 365 \approx 55 \text{ kg}$ of potential scale. Even if most leaves with the water, some will settle in the PHE. This is why open systems on hard water need a softener or an indirect loop.

Remember

- Test hardness, TDS and pH at commissioning and every quarter.
- Hot water above about 55 °C scales fastest.
- An indirect closed loop is the best protection on hard water.
- Clean strainers monthly.

Field tip: Carry a simple hardness test kit and TDS meter; a reading takes two minutes.

9.4 A systematic troubleshooting method

Key idea: Find faults by measuring and comparing, not by guessing and replacing parts.

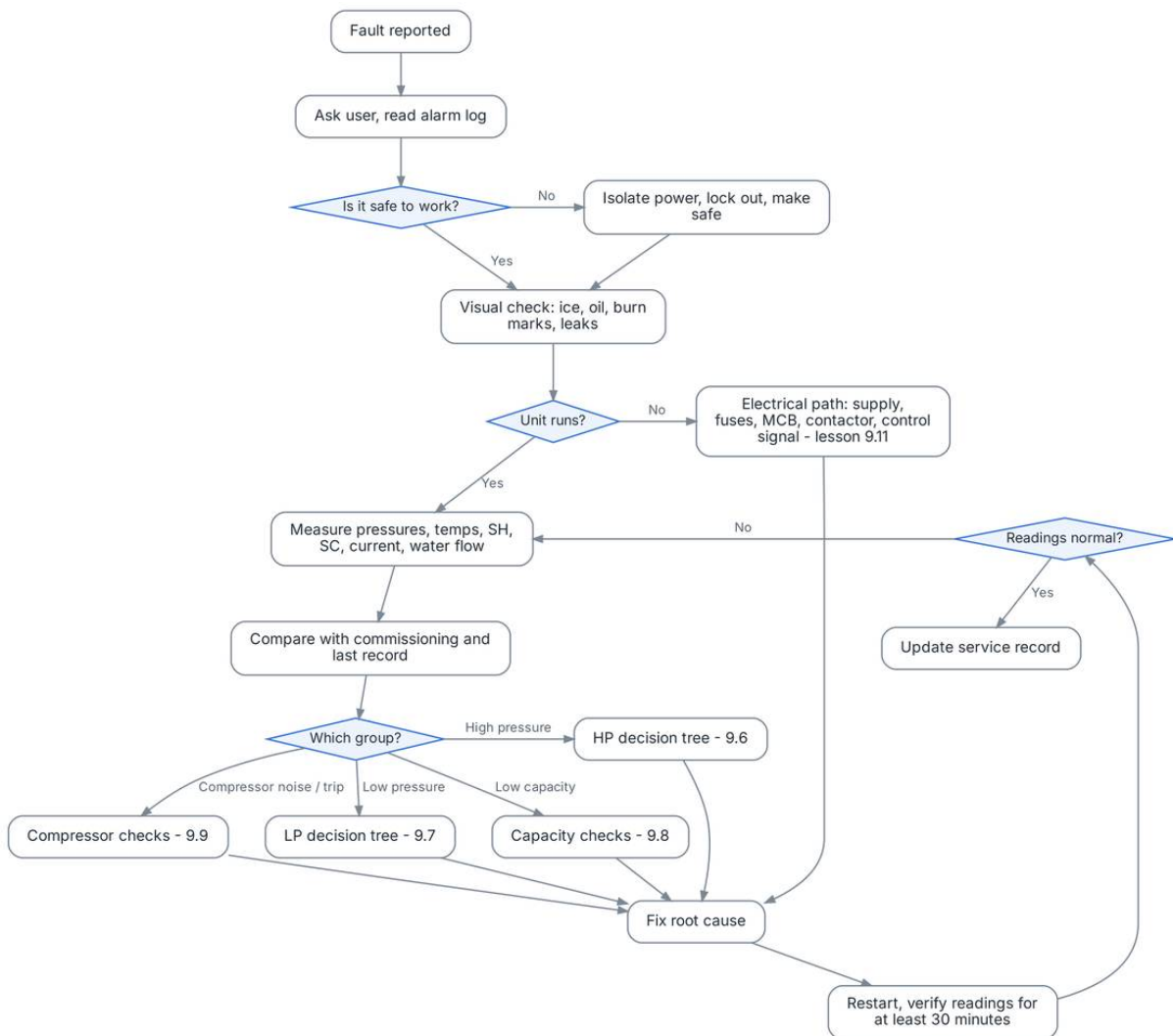
Troubleshooting is the process of finding the root cause of a fault. A root cause is the first thing that went wrong; a symptom is what you see. A tripped compressor is a symptom. A blocked strainer that starved the condenser of water may be the root cause.

A good doctor asks questions, takes temperature and pulse, then decides. A good technician does the same. Replacing parts until it works is expensive, and the real cause often returns.

Six steps

1. **Listen and gather.** Ask the user what happened, when, and what changed. Read the alarm log.
2. **Observe safely.** Look, listen, smell. Check for ice, oil stains, burnt smells, water leaks.
3. **Measure.** Pressures, temperatures, superheat, subcooling, currents, voltages, water flow.
4. **Compare.** Against commissioning values, the manual, and the previous service record.
5. **Isolate the cause.** Use the decision trees in lessons 9.6 and 9.7. Test one idea at a time.
6. **Fix, verify, record.** Repair the root cause, run the unit, confirm readings, write it down.

A systematic fault-finding method



A systematic fault-finding method

Normal reading guide (typical, air-to-water heat pump with R32 or R410A)

Reading	Typical normal range	Note
Superheat at compressor suction	4–8 K	Depends on expansion valve setting
Subcooling at condenser outlet	3–8 K	Depends on charge and design
Water ΔT across condenser	3–7 K	Lower means high flow; higher means low flow
Discharge temperature	Typically below about 100–110 °C	Very high means overheating compressor
Phase current imbalance	Within about 2–3 %	Higher points to supply or motor problem

Refrigerant pressures depend on the refrigerant and temperatures, so always convert pressure to saturation temperature with a P-T chart or gauge scale.

Worked example — Is this superheat normal?

Superheat is the suction line temperature minus the evaporating saturation temperature.

$$SH = T_{suction} - T_{sat}(P_{suction})$$

Suction pressure reads 7.5 bar(g). From the P-T chart for the refrigerant, saturation is 2 °C (example). Suction line temperature is 14 °C. $SH = 14 - 2 = 12$ K.

This is higher than the typical 4–8 K. The evaporator is starved: suspect low charge, a blocked filter-drier, or a faulty expansion valve.

Remember

- Symptom is not cause; keep asking "why".
- Measure before you touch anything.
- Change one thing at a time and re-measure.
- Always verify and record after the fix.

Common mistake: Adding refrigerant just because suction pressure is low, without checking superheat, subcooling and air or water flow first.



9.5 Reading fault codes and controller logs

Key idea: A fault code tells you which protection acted, not why it acted.

A controller is the electronic board that runs the heat pump. It reads sensors and switches, and stops the unit when a value goes out of range. It then shows a fault code (a short code on the display) and usually stores it in a log with date, time and readings.

Each manufacturer uses its own codes. Always look up codes in that unit's service manual. This lesson explains the general categories, which are similar across makes.

A fault code is like the warning light on a car dashboard. The oil light says oil pressure is low. It does not say whether the oil is leaking or the pump is worn. You still need to investigate.

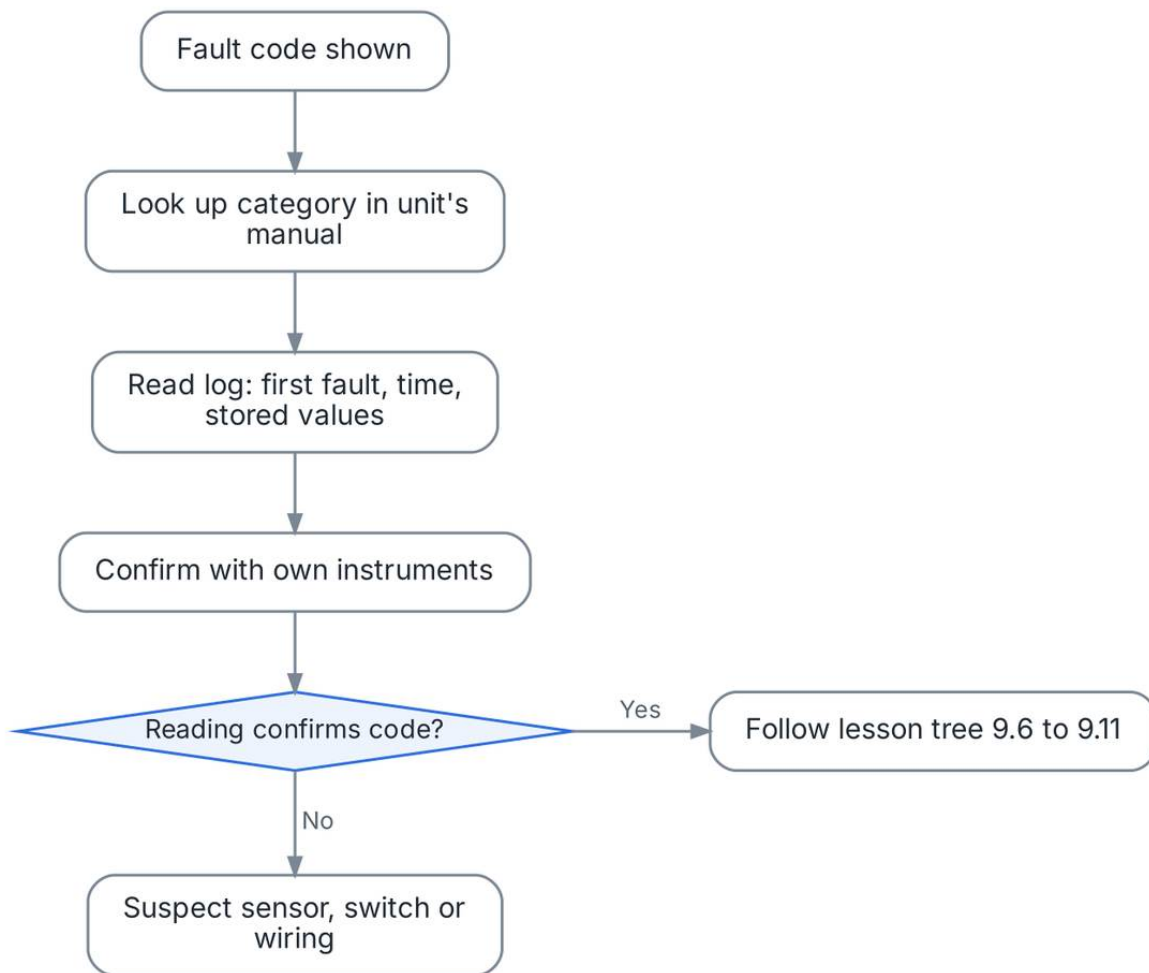
Generic fault categories

Category	What it means	Typical first checks
High-pressure protection	HP switch or sensor saw too high discharge pressure	Water/air flow at condenser, scale, overcharge, non-condensables (9.6)
Low-pressure protection	LP switch or sensor saw too low suction pressure	Evaporator air/water flow, ice, low charge, expansion valve (9.7)
High discharge temperature	Compressor outlet too hot	Low charge, high superheat, high compression ratio
Water flow fault	Flow switch open or flow too low	Pump, strainer, air lock, closed valve
Freeze protection	Water or refrigerant near 0 °C in evaporator	Low flow, low set point, low charge
Sensor fault	Sensor open or short circuit	Wiring, connector, sensor resistance vs table
Communication fault	Boards or display not talking	Cable, connector, earthing, interference
Compressor overcurrent / overload	Current too high or motor too hot	Voltage, phase loss, locked rotor, high pressure
Phase / voltage fault	Missing phase, wrong sequence, voltage out of range	Supply, phase sequence relay, cables
Inverter / drive fault	Drive detected internal or motor problem	Supply, heat sink, motor windings, drive cooling fan
Defrost fault	Defrost took too long or did not end	Defrost sensor, reversing valve, ice build-up

How to use the log

1. Note the first fault in a sequence. Later faults are often knock-on effects.
2. Note the time pattern: same time each day points to a load, a supply dip or a timer.
3. Read stored values at trip time if available: pressures, temperatures, current.
4. Check how often the fault repeats. Some controllers lock the unit after a set number of trips.

From fault code to root cause



From fault code to root cause

Remember

- Codes differ by make; always use the unit's own manual.
- A code names the protection, not the cause.
- The first fault in the log is usually the most useful.
- Confirm with your own gauges and meters.

Field tip: Never reset a fault repeatedly to "see if it clears"; each reset can stress the compressor.

9.6 High-pressure trips

Key idea: A high-pressure trip almost always means heat is not being removed from the condenser fast enough.

The high-pressure (HP) switch is a safety switch on the discharge line. It opens when discharge pressure crosses a set limit and stops the compressor. Its job is to protect the compressor, pipes and people from over-pressure.

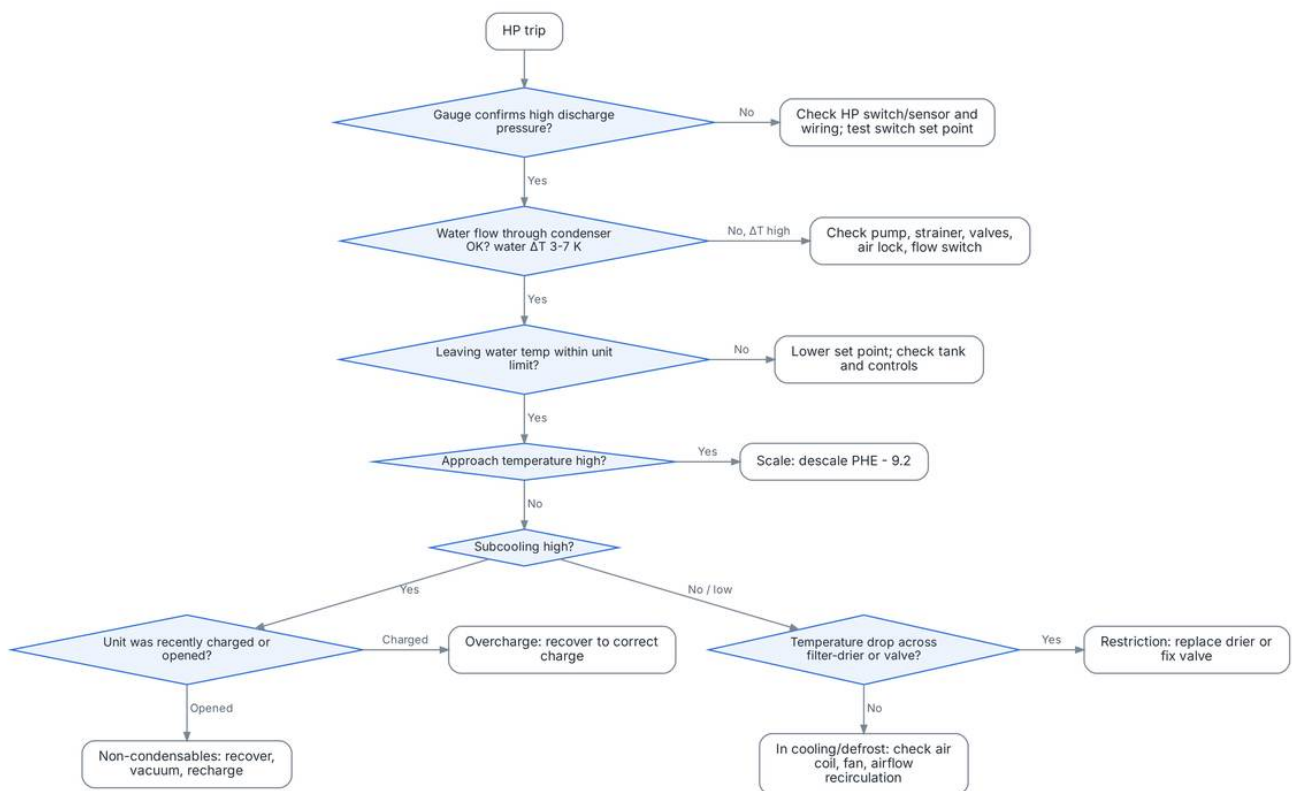
Think of a pressure cooker on a high flame with a blocked vent. Pressure keeps rising because heat goes in but cannot leave. In a heat pump the condenser is the vent. If it cannot reject heat, pressure rises.

In heating mode, the condenser is the water-side PHE. In cooling or defrost mode, the air coil acts as the condenser. So always ask which heat exchanger is the condenser at the moment of the trip.

Main causes

- Low water flow through the condenser (pump fault, blocked strainer, closed valve, air lock).
- Scale on the PHE water side.
- Water set point too high for the unit, or return water too hot.
- Overcharge of refrigerant.
- Non-condensable gases (air or nitrogen) in the circuit.
- Restriction after the condenser, which backs up liquid.
- In cooling/defrost: dirty air coil, failed fan, hot air recirculation.
- Faulty HP switch or pressure sensor.

High-pressure trip: decision tree



High-pressure trip: decision tree

Symptom → cause → check → fix (high pressure)

Symptom	Likely cause	Check	Fix
HP trip, water ΔT high (over about 8 K)	Low water flow	Strainer, pump, valves, air vents	Clean strainer, vent air, repair pump
HP trip after months of good running, ΔT normal	Scale on PHE	Approach temperature vs commissioning	Descale PHE
HP trip, high subcooling, after a recharge	Overcharge	Weigh charge vs nameplate	Recover excess
HP high, pressure does not match temperature when off	Non-condensables	Standing pressure vs ambient saturation	Recover, vacuum, weigh in fresh charge
HP trip in cooling, fan running slow or off	Fan motor or capacitor failure	Fan current, capacitor value	Replace capacitor or motor
Trip but gauge shows normal pressure	Faulty switch or sensor	Compare sensor with gauge	Replace switch or sensor

Worked example — Is the water flow too low?

A 20 kW heat pump in Indore heats water. Supply 55 °C, return 45 °C. Find the actual flow.

$$Q = \dot{m} \times c_p \times \Delta T \Rightarrow \dot{m} = \frac{Q}{c_p \times \Delta T}$$

$Q = 20 \text{ kW}$, $c_p = 4.19 \text{ kJ/kg}\cdot\text{K}$, $\Delta T = 55 - 45 = 10 \text{ K}$ $\dot{m} = 20 \div (4.19 \times 10) = 0.477 \text{ kg/s}$ $0.477 \text{ kg/s} \times 3,600 = 1,718 \text{ kg/h} \approx 1,720 \text{ LPH}$.

For a 5 K design ΔT the flow should be about 3,440 LPH. The flow is half of design. Clean the strainer and check the pump before blaming refrigerant.

Remember

- First ask: which coil is the condenser right now?
- Check water flow and ΔT before touching refrigerant.
- Rising approach temperature means scale.
- Overcharge and air in the system both raise subcooling and head pressure.

Common mistake: Raising the HP switch set point to stop the trips. This removes the safety and can burst components.



9.7 Low-pressure trips

Key idea: A low-pressure trip means the evaporator is not getting enough heat or enough refrigerant.

The low-pressure (LP) switch sits on the suction line. It opens when suction pressure falls too low. This protects the compressor from running without enough refrigerant and the evaporator from freezing.

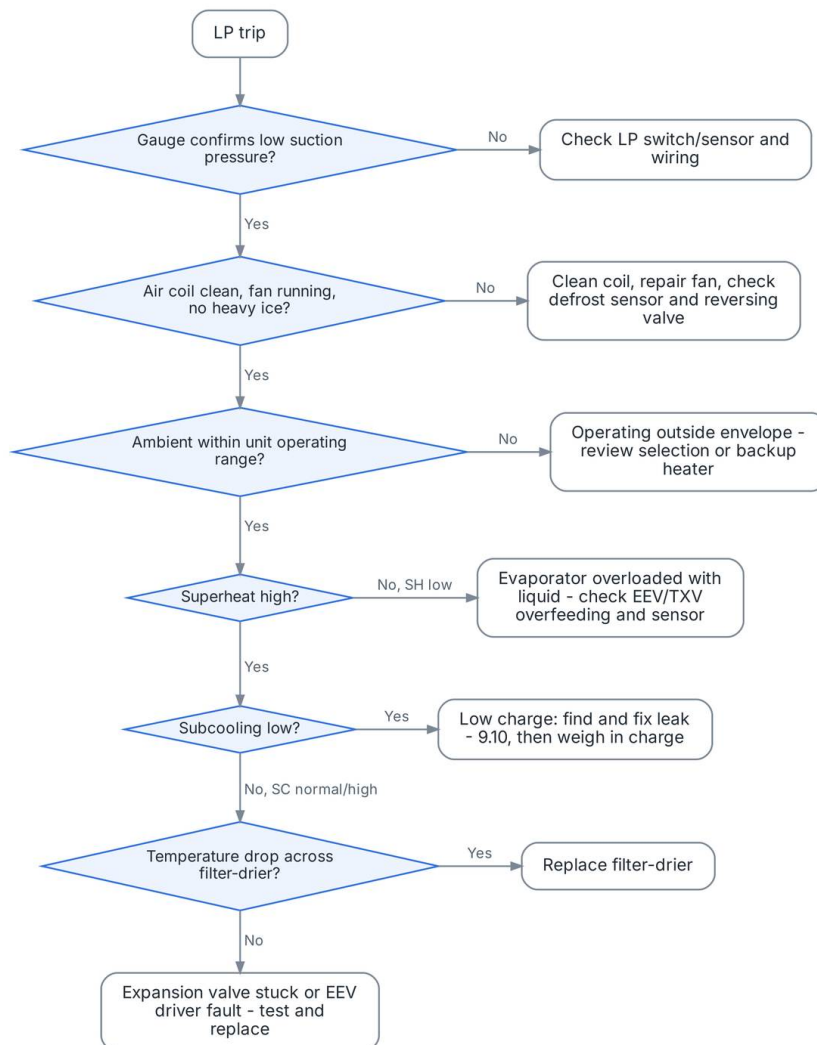
Imagine drinking through a straw from an almost empty glass. You suck harder and harder, but little comes. A starved evaporator is the same: the compressor pulls suction pressure down because too little vapour is coming in.

In heating mode the evaporator is the air coil. In cooling mode on a reversible unit, it is the water-side PHE.

Main causes

- Low air flow over the air coil: dirt, ice, failed fan.
- Heavy frosting without proper defrost.
- Very low ambient temperature beyond the unit's operating range.
- Low refrigerant charge (leak).
- Blocked filter-drier or strainer in the liquid line.
- Expansion valve stuck closed or faulty (or EEV driver fault).
- In cooling: low chilled water flow, low set point, frozen PHE.
- Faulty LP switch or sensor.

Low-pressure trip: decision tree



Low-pressure trip: decision tree

Symptom → cause → check → fix (low pressure)

Symptom	Likely cause	Check	Fix
LP trip, high SH, low SC, oil stains	Refrigerant leak	Leak test (9.10)	Repair leak, vacuum, weigh in charge
LP trip, high SH, normal SC, cold or frosty drier	Blocked filter-drier	Temperature drop across drier over about 2 K	Replace drier
LP trip, high SH, normal SC, drier warm	Expansion valve stuck closed	Valve response, EEV coil and driver	Replace valve or coil/driver
LP trip in heating, coil fully iced	Defrost failure	Defrost sensor, reversing valve, defrost logic	Replace sensor or valve
LP trip, coil dirty, fan slow	Low air flow	Fan current, coil condition	Clean coil, repair fan
LP trip in cooling, chilled water ΔT high	Low water flow at evaporator	Strainer, pump, valves	Restore flow

Worked example — Check the drier

Liquid line temperature before the filter-drier: 38 °C. After it: 33 °C.

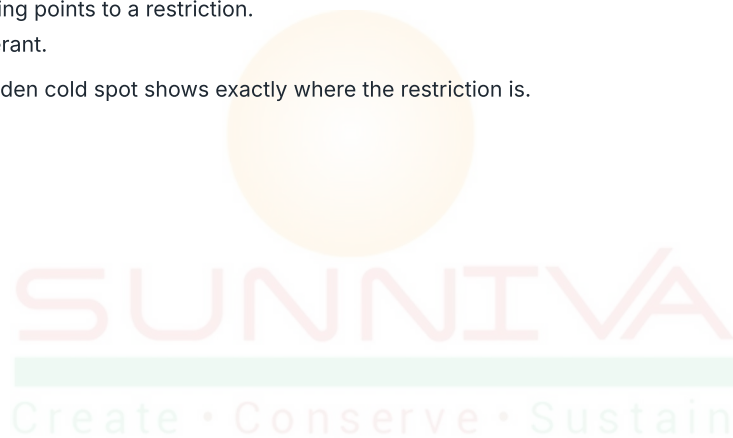
$$\Delta T_{drier} = T_{in} - T_{out}$$

$\Delta T = 38 - 33 = 5$ K. A healthy drier shows almost no drop (typically below about 1–2 K). A 5 K drop means it is blocked and the liquid is flashing. Replace the drier.

Remember

- First ask: which coil is the evaporator right now?
- High superheat plus low subcooling usually means low charge.
- High superheat with normal subcooling points to a restriction.
- Check air flow and ice before refrigerant.

Field tip: Feel along the liquid line; a sudden cold spot shows exactly where the restriction is.



9.8 Low capacity and falling COP

Key idea: When capacity or COP falls, the cause is usually one of three: poor heat transfer, wrong charge, or a tired compressor.

Capacity is the heat output in kW. COP (coefficient of performance) is heat output divided by electrical input. A unit with COP 4 gives 4 kWh of heat for 1 kWh of electricity.

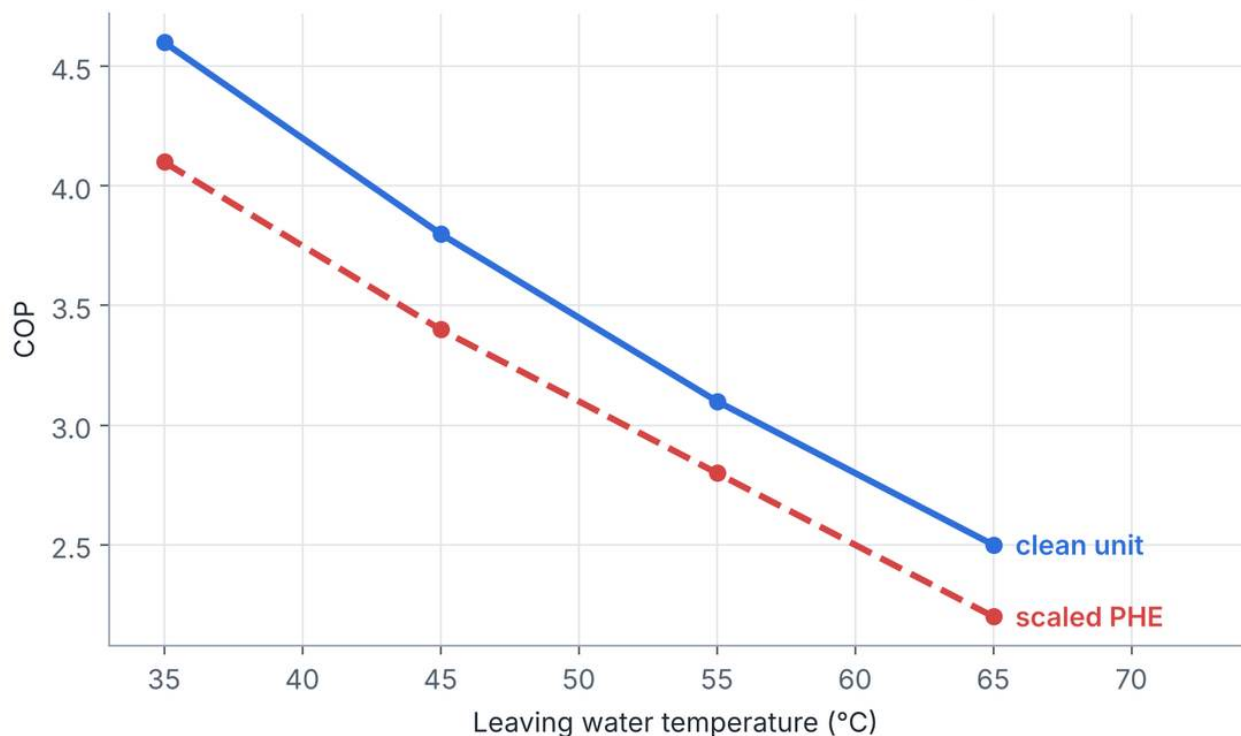
Falling COP often shows up first in the electricity bill, not as a fault code. The unit keeps running but heats slower and costs more. Like a fridge with a dirty back grill, it still cools but runs much longer.

Main causes

- Dirty air coil or scaled PHE.
- Low or high refrigerant charge.
- Wrong water flow (too low or too high).
- Expansion valve badly set or faulty.
- Compressor wear: leaking valves or scroll tips cause low compression.
- Reversing valve leaking hot gas internally into suction.
- Wrong set point or poor controls (short cycling).
- Unit running outside its design conditions (very cold or very hot water).

Scale costs efficiency at every water temperature

Illustrative values, not test data. Scaled PHE raises condensing temperature by about 5 K.



COP vs leaving water temperature, clean vs scaled

Symptom → cause → check → fix (capacity and COP)

Symptom	Likely cause	Check	Fix
Slow heat-up, high discharge pressure, rising approach	Scaled PHE	Approach temperature	Descale
Slow heat-up, low suction, high SH	Low charge	SH, SC, leak test	Fix leak, recharge by weight
Low current, small pressure difference, normal charge	Compressor wear / internal leak	Compression ratio, current vs data	Replace compressor (find root cause first)
Suction line warm in heating, both reversing valve outlets similar temperature	Reversing valve leaking	Temperatures at valve ports	Replace reversing valve
Frequent start-stop	Short cycling: small buffer, tight differential	Controller log of starts per hour	Adjust differential, add buffer volume
COP low only on very cold mornings	Normal effect of low ambient	Compare with manufacturer data	Expected; check defrost and backup

Worked example — Measure field COP

A heat pump at a hostel in Bhopal. Water flow 2,000 LPH, in 45 °C, out 52 °C. Input power measured 4.2 kW.

$$Q = \dot{m} \times c_p \times \Delta T, \quad COP = \frac{Q}{P_{in}}$$

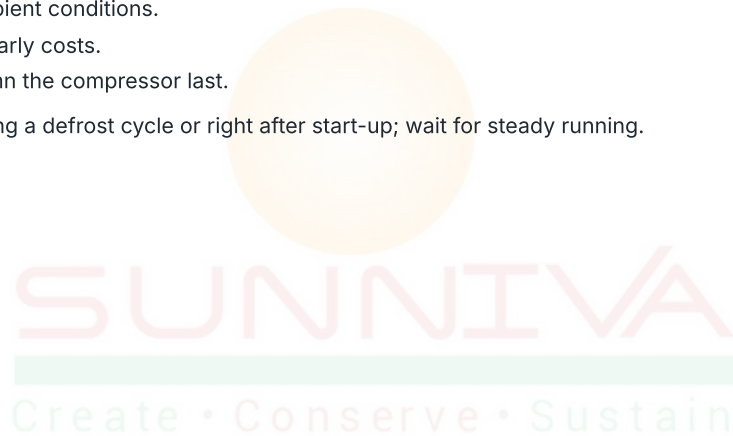
$\dot{m} = 2,000 \div 3,600 = 0.556 \text{ kg/s}$ $Q = 0.556 \times 4.19 \times (52 - 45) = 0.556 \times 4.19 \times 7 = 16.3 \text{ kW}$ $COP = 16.3 \div 4.2 = 3.9$

If commissioning COP at the same conditions was 4.3, the drop is about 9 %. Daily cost impact for 10 hours at the example rate of ₹9/kWh: Input at COP 4.3 = $16.3 \div 4.3 = 3.79 \text{ kW}$; at COP 3.9 = 4.2 kW. Extra = $0.41 \text{ kW} \times 10 \text{ h} \times ₹9 = ₹37$ per day, about ₹13,500 per year.

Remember

- COP = heat out ÷ power in; measure both.
- Compare at the same water and ambient conditions.
- Small COP losses add up to large yearly costs.
- Clean heat exchangers first; condemn the compressor last.

Common mistake: Measuring COP during a defrost cycle or right after start-up; wait for steady running.



9.9 Compressor failures and their root causes

Key idea: Compressors rarely fail on their own; they are usually killed by something else in the system.

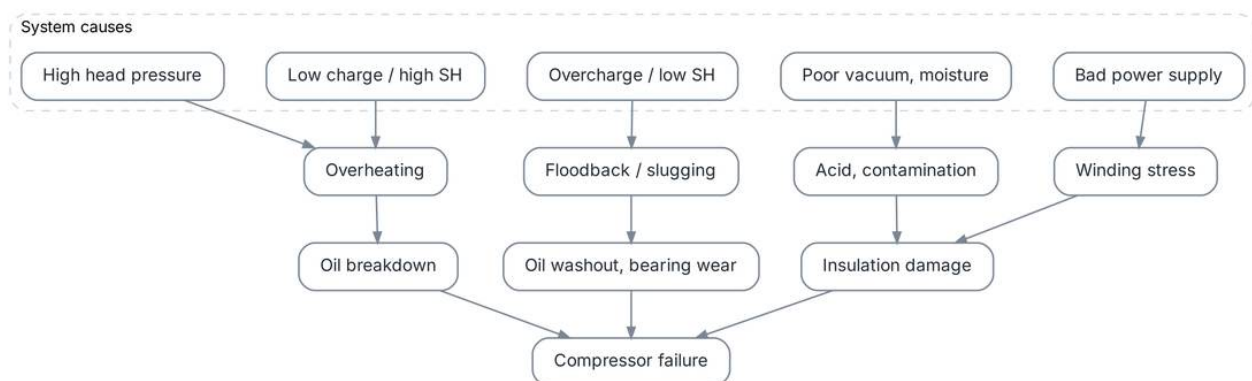
The compressor is the heart of the heat pump. When it fails, replacing it without finding the root cause often leads to a second failure within weeks. Always ask what made it fail.

Like a motorbike engine seized because the oil ran out, the engine is the victim, not the cause. The same is true for compressors.

Main failure types

Failure	What happens	Common root causes
Liquid floodback	Liquid refrigerant enters the compressor and washes oil away	Low superheat, overcharge, faulty expansion valve, low evaporator air or water flow
Liquid slugging	A slug of liquid enters the compression chamber; mechanical damage	Refrigerant migration during off cycle, no crankcase heater, poor piping
Overheating	Motor and oil get too hot; oil breaks down	Low charge, high superheat, high discharge pressure, high compression ratio
Oil loss	Bearings run dry	Oil trapped in system, long pipes without oil return, leaks, floodback
Electrical burnout	Motor windings short to each other or to earth	Voltage imbalance, single phasing, overheating, moisture and acid in system
Contamination	Moisture, air or debris cause acid and wear	Poor evacuation, open system left too long, no drier, brazing without nitrogen

How system faults kill compressors



How system faults kill compressors

Checks before condemning a compressor

Check	How	Typical result for healthy compressor
Winding resistance (single-phase: C-S, C-R, S-R; three-phase: between each pair)	Multimeter, power isolated	Three-phase windings equal within a few percent; single-phase S-R = C-S + C-R
Insulation resistance to earth	Insulation tester at 500 V DC	Above 1 MΩ minimum at 500 V DC (healthy compressors usually read well above 2 MΩ; follow the manufacturer's manual)
Running current	Clamp meter on each phase	Within nameplate RLA, balanced
Compression	Pressure difference when running	Normal discharge-suction difference for conditions
Oil condition	Sample or acid test kit	Clear, no burnt smell, acid test negative

After a burnout

1. Recover refrigerant; do not vent.
2. Test oil for acid.
3. Replace compressor and filter-drier; fit a suction line filter-drier if acid is present.
4. Pressure test with dry nitrogen; evacuate deeply (lesson 9.10).
5. Weigh in correct charge.
6. Check acid again after running; change drier again if needed.

Worked example — Voltage imbalance

Measured line voltages: 410 V, 400 V, 385 V.

$$\text{Imbalance (\%)} = \frac{\text{max deviation from average}}{\text{average}} \times 100$$

Average = $(410 + 400 + 385) \div 3 = 398.3$ V Maximum deviation = $398.3 - 385 = 13.3$ V Imbalance = $13.3 \div 398.3 \times 100 = 3.3$ %

Voltage imbalance above about 2 % is generally considered harmful to motors; the current imbalance it causes is several times larger. Get the supply checked before fitting a new compressor.

Remember

- The compressor is usually the victim, not the culprit.
- Floodback and overheating are the two biggest killers.
- Check windings, insulation, current and oil before condemning.
- After a burnout, clean the system or the new compressor will fail too.

Common mistake: Replacing a burnt compressor without changing the filter-drier and testing for acid.



9.10 Leak detection and repair

Key idea: Find the leak, fix it properly, then prove the system is tight and dry before charging.

A refrigerant leak lowers charge, cuts capacity and can let air and moisture in. Many refrigerants are greenhouse gases, and some, like R32 and R290, are flammable to different degrees. So leaks matter for performance, safety and environment.

Common leak points are brazed joints, flare nuts, Schrader valve cores, service valve stems, capillary tubes rubbing on the frame, and vibration cracks. Brazing leaks are often caused by poor joint clearance, overheating or not using nitrogen purge.

Leak detection methods

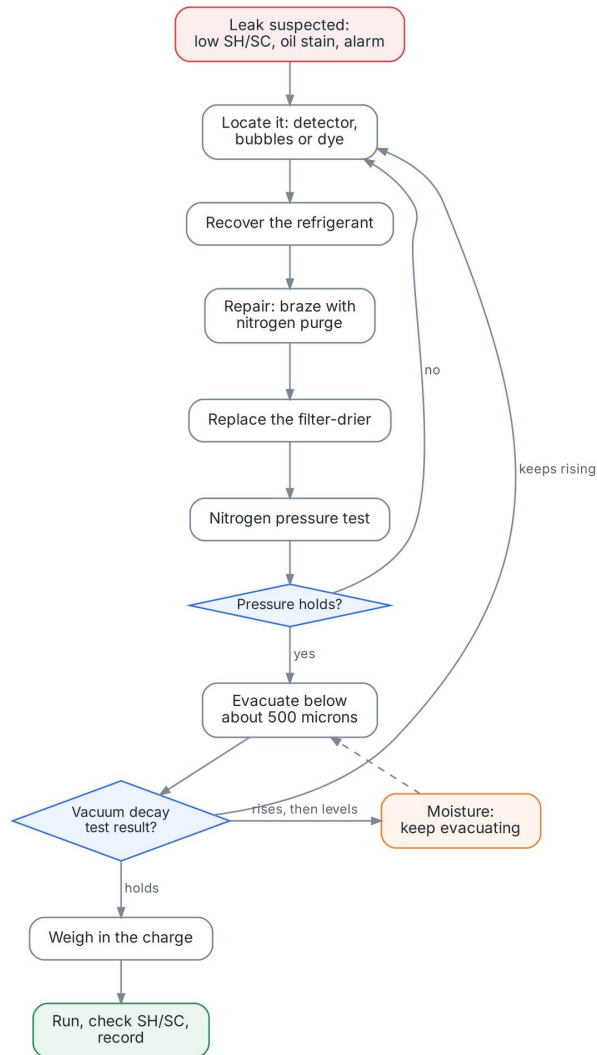
Method	How it works	Good for	Limit
Visual / oil stain	Refrigerant carries oil out; joint looks wet or dusty	First quick check	Small leaks may not show
Soap bubbles	Bubbles form at leak	Pinpointing on accessible joints	Slow; needs pressure in system
Electronic detector	Sensor senses refrigerant	Searching wide areas	Wind and other gases confuse it
UV dye	Dye glows under UV light	Intermittent leaks	Dye must be compatible with oil
Nitrogen pressure test	Fill with dry nitrogen, watch pressure	Proving tightness after repair	Allow for temperature change
Nitrogen + tracer (95/5 nitrogen-hydrogen)	Detector finds hydrogen	Very small leaks	Needs suitable detector
Vacuum hold (decay) test	Pressure rise while under vacuum	Proves tight and dry	Moisture also causes rise

Repair procedure

1. Recover refrigerant into a recovery cylinder. Never vent it.
2. Make the repair. Braze with dry nitrogen flowing through the pipe to stop oxide scale forming inside.
3. Replace the filter-drier whenever the system is opened.
4. Pressure test with dry nitrogen to the test pressure in the manual. Hold and watch for drop (correct for temperature).
5. Release nitrogen and evacuate to a deep vacuum. A common target is below 500 microns (about 0.67 mbar absolute).
6. Isolate the pump and do a decay test. If pressure keeps rising, there is a leak; if it rises then levels off, there is still moisture.
7. Weigh in the charge by weight from the nameplate, as liquid where the refrigerant is a blend.
8. Run, check SH and SC, leak test again, record.

Create • Conserve • Sustain

Leak repair sequence



Leak repair sequence

Worked example — Correcting a nitrogen test for temperature

Nitrogen test pressure set at 30 bar(g) at 25 °C in the morning in Kolkata. In the afternoon the reading is 30.8 bar(g) at 32 °C. Is it holding?

Use absolute pressure and absolute temperature (gas law, constant volume).

$$\frac{P_2}{P_1} = \frac{T_2}{T_1}$$

$P_1 = 30 + 1.013 = 31.0$ bar abs; $T_1 = 25 + 273 = 298$ K; $T_2 = 32 + 273 = 305$ K. P_2 expected = $31.0 \times 305 \div 298 = 31.7$ bar abs = 30.7 bar(g).

Reading 30.8 bar(g) $\approx$ expected 30.7 bar(g). The rise is only from heat; the system is holding.

Remember

- Recover, never vent.
- Braze with nitrogen flowing; change the drier.
- Prove tightness with nitrogen, then dryness with vacuum.
- Charge by weight.

Common mistake: "Topping up" a leaking unit every season instead of finding and fixing the leak.

9.11 Electrical and control faults

Key idea: Many "refrigeration" faults are really electrical or control faults, so check power, signals and sensors early.

The electrical side has two parts. The power circuit carries high current to the compressor, fans and pump through MCBs (miniature circuit breakers), contactors and drives. The control circuit carries small signals from sensors, switches and the controller.

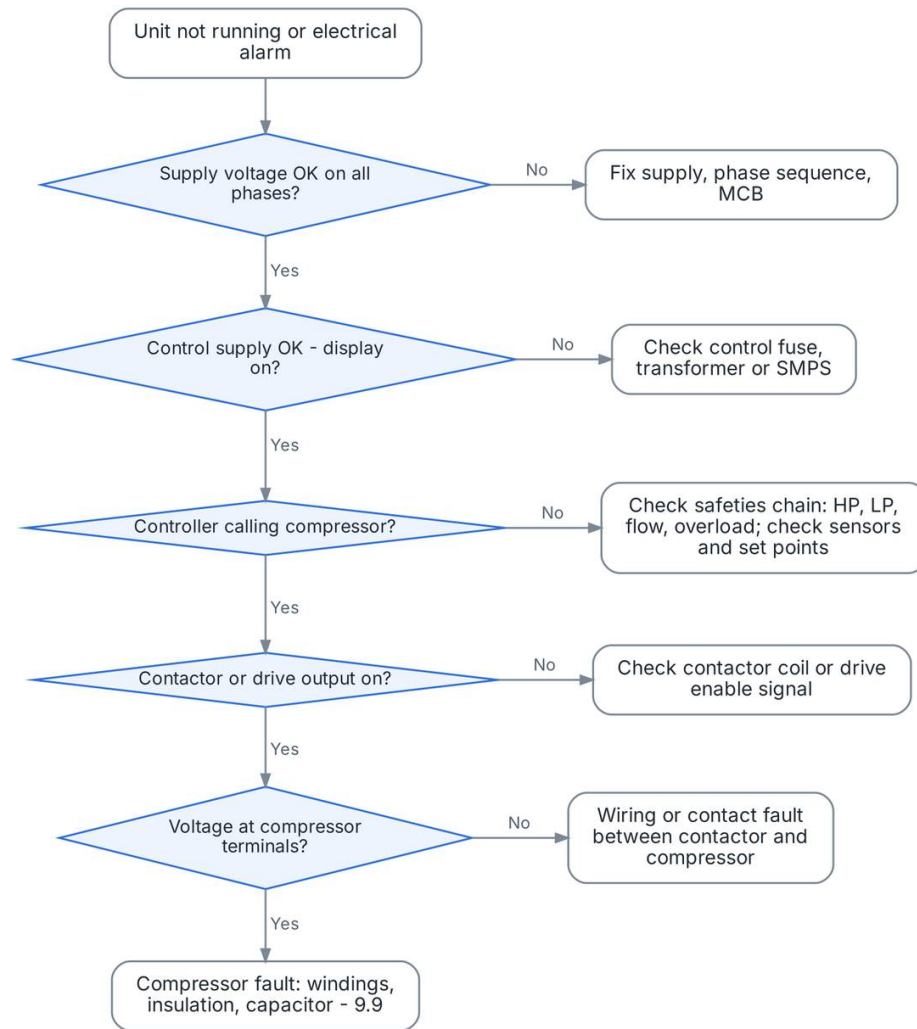
Indian sites often face voltage swings, missing phases and loose terminals from heat and vibration. A loose terminal heats up like a bad plug on an iron, until it burns.

Safety first: Isolate, lock out and prove dead with a tested voltage tester before touching terminals. Capacitors and inverter drives can hold dangerous charge after power is off; wait the time stated on the drive and measure.

Common electrical and control faults

Symptom	Likely cause	Check	Fix
Unit dead, no display	No supply, tripped MCB, blown control fuse, failed transformer/SMPS	Voltage at incoming terminals and control supply	Restore supply, find why it tripped, replace fuse/PSU
Phase fault alarm	Missing phase or wrong phase sequence	Voltage each phase, phase sequence meter	Fix supply; swap two phases if sequence wrong (fixed-speed scroll)
Compressor hums, will not start (single-phase)	Failed run/start capacitor, low voltage, seized rotor	Capacitor μ F vs rating, voltage at start	Replace capacitor; check voltage; condemn if seized
Contactor chatters	Low coil voltage, loose control wire	Coil voltage, terminals	Tighten, fix supply to coil
Burnt contactor contacts	Normal wear, frequent starts, low voltage	Inspect contacts, starts per hour	Replace contactor; reduce short cycling
Sensor fault code	Open or short sensor, damp connector	Sensor resistance vs temperature table	Dry, re-terminate or replace sensor
Wrong temperature shown	Sensor out of pocket, poor contact	Compare with reference thermometer	Refit with paste and insulation; replace
Communication fault	Loose cable, poor earth, interference from power cables	Cable continuity, routing, shield earthing	Re-route away from power cables, earth shield at one end
Inverter drive trip	Supply problem, overheated drive, motor fault	Heat sink fan, ambient, motor winding test	Clean and cool drive; fix supply; follow drive manual
Flow switch fault but water flowing	Paddle stuck, switch misadjusted	Switch contact operation	Clean, adjust or replace
Earth leakage (RCCB) trips	Insulation failure, water in junction box	Insulation test on each motor and heater	Dry out or replace faulty part

Basic electrical fault-finding path



Basic electrical fault-finding path

Worked example — Check an NTC sensor

An NTC (negative temperature coefficient) thermistor's resistance falls as temperature rises. Many heat pump sensors are 10 kΩ at 25 °C (typical), but the table depends on the sensor.

Water is at 40 °C (measured with a reference thermometer). The sensor's resistance table shows about 5.3 kΩ at 40 °C for a typical 10 kΩ B3950 sensor. The meter reads 5.2 kΩ: the sensor is good.

If the meter reads infinity (open circuit) or near zero (short), the sensor or its wire has failed. Always use the resistance table for the actual sensor fitted.

$$R(T) = R_{25} \exp \left[B \left(\frac{1}{T} - \frac{1}{298.15} \right) \right]$$

With $R_{25} = 10 \text{ k}\Omega$, $B = 3950 \text{ K}$, $T = 313.15 \text{ K}$: $1/313.15 - 1/298.15 = 0.0031934 - 0.0033540 = -0.0001606$ $B \times (-0.0001606) = -0.6345$ $R = 10 \times e^{(-0.6345)} = 10 \times 0.530 = 5.3 \text{ k}\Omega$.

Remember

- Isolate, lock out and prove dead before touching terminals.
- Check supply and phases early in any fault.
- Test sensors against their resistance table.
- Keep signal cables away from power cables.

Field tip: Tighten all power terminals at every quarterly visit; heat and vibration loosen them.

Quiz 9

1. Which of these is a quarterly task rather than a daily one?
 - A. Checking for active alarms
 - B. Measuring superheat and subcooling
 - C. Listening for unusual noise
 - D. Reading supply and return water temperature
2. During descaling of a PHE, the main isolation valves should be:
 - A. Open, so acid cleans the whole system
 - B. Closed, with the descaling pump connected to the service valves
 - C. Half open
 - D. Removed
3. The approach temperature of a water-side condenser rises from 3 K to 8 K at the same load. The most likely cause is:
 - A. Overcharge
 - B. Scale on the water side
 - C. Faulty LP switch
 - D. Low ambient temperature
4. Which water setup best protects a heat pump PHE on very hard borewell water?
 - A. Open system with no treatment
 - B. Higher hot-water set point
 - C. Indirect closed loop with a coil in the storage tank
 - D. Removing the strainer
5. A fault code shows "high-pressure protection". What does it tell you?
 - A. The exact root cause
 - B. Which protection acted, not why
 - C. That the compressor has failed
 - D. That the refrigerant is low
6. A heat pump in heating mode trips on HP. Water ΔT across the condenser is 11 K (design 5 K). First action?
 - A. Recover some refrigerant
 - B. Raise the HP switch set point
 - C. Check strainer, pump and valves for low water flow
 - D. Replace the compressor
7. LP trip with high superheat and low subcooling most likely means:
 - A. Overcharge
 - B. Low refrigerant charge
 - C. Scaled condenser
 - D. High water flow
8. Measured flow 2,000 LPH, ΔT 7 K, input 4.2 kW. Field COP is about:
 - A. 2.5
 - B. 3.9
 - C. 5.2
 - D. 16.3
9. Which is the most common root cause of compressor liquid floodback?
 - A. High superheat
 - B. Low superheat from overfeeding or low evaporator air/water flow
 - C. High supply voltage
 - D. Clean coils
10. After a leak repair, the vacuum decay test shows pressure rising and then levelling off. This means:

- A. A leak is still present
- B. Moisture is still in the system; keep evacuating
- C. The system is ready to charge
- D. The gauge is faulty

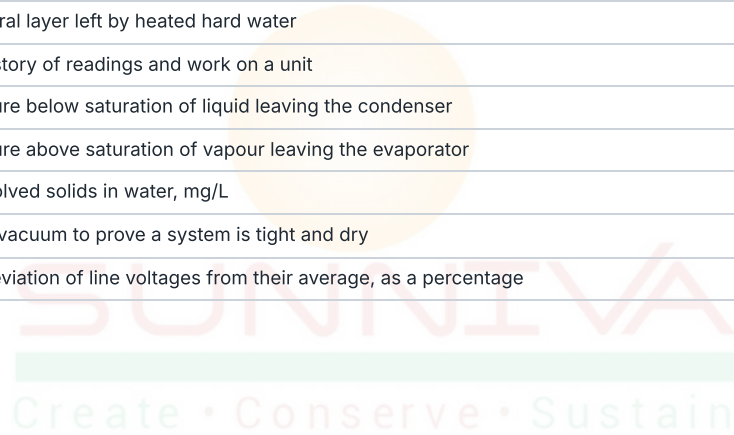
Answer key

1. **B** — Superheat and subcooling need gauges and a technician; daily checks are done by operators.
2. **B** — Closing V1/V2 keeps acid in the PHE only, circulated through service valves.
3. **B** — A growing approach at the same load is the classic sign of water-side scale.
4. **C** — Hard water never reaches the heat pump PHE in an indirect closed loop.
5. **B** — Codes name the protection; the cause must be found by measuring.
6. **C** — A high ΔT means low flow, the most common HP trip cause in heating.
7. **B** — A starved evaporator (high SH) with little liquid in the condenser (low SC) points to low charge.
8. **B** — $Q = 0.556 \times 4.19 \times 7 = 16.3 \text{ kW}$; $16.3 \div 4.2 \approx 3.9$.
9. **B** — Low superheat means liquid leaves the evaporator and reaches the compressor.
10. **B** — A rise that stops shows moisture boiling off; a continued rise would mean a leak.



Glossary

Term	Meaning
Approach temperature	Difference between refrigerant saturation temperature and leaving water temperature in a heat exchanger
Back-flush	Flushing a coil or PHE in the direction opposite to normal flow
Breakdown maintenance	Repair done after a failure
COP	Coefficient of performance: heat output divided by electrical input
Contactors	Electrically operated switch that starts motors
Descaling	Removing mineral scale using a mild acid solution
EEV / TXV	Electronic or thermostatic expansion valve; meters refrigerant into the evaporator
Filter-drier	Liquid line component that removes moisture and dirt
Floodback	Liquid refrigerant returning to the compressor
Hardness	Dissolved calcium and magnesium, as mg/L CaCO ₃
HP / LP switch	High- and low-pressure safety switches
Insulation resistance	Resistance between windings and earth, tested at 500 V DC
Non-condensables	Air or nitrogen trapped in a refrigerant circuit
NTC thermistor	Temperature sensor whose resistance falls as temperature rises
PHE	Plate heat exchanger
Preventive maintenance (PM)	Planned checks done before failure
Root cause	The first fault in a chain that led to the symptom
Scale	Hard mineral layer left by heated hard water
Service record	Written history of readings and work on a unit
Subcooling (SC)	Temperature below saturation of liquid leaving the condenser
Superheat (SH)	Temperature above saturation of vapour leaving the evaporator
TDS	Total dissolved solids in water, mg/L
Vacuum decay test	Holding a vacuum to prove a system is tight and dry
Voltage imbalance	Largest deviation of line voltages from their average, as a percentage



Course 10 — Safety, Refrigerants and Standards

Powered by Sunniva. This Level 3 course is for everyone who works in the field: installers, service technicians, commissioning engineers and supervisors. After it you will be able to (1) isolate and lock out a heat pump safely before work, (2) handle pressure, brazing and flammable or high-pressure refrigerants without putting yourself or the site at risk, (3) read a refrigerant's safety class and choose the right handling rules, and (4) explain the phase-down rules and the test standards behind a heat pump's rated figures.

10.1 Electrical safety and lock-out/tag-out

Key idea: Never trust a switch — isolate, lock, tag and prove the circuit dead before you touch it.

A heat pump runs on 230 V single-phase or 415 V three-phase supply. Both can kill. Current through the chest of only tens of milliamps can stop the heart.

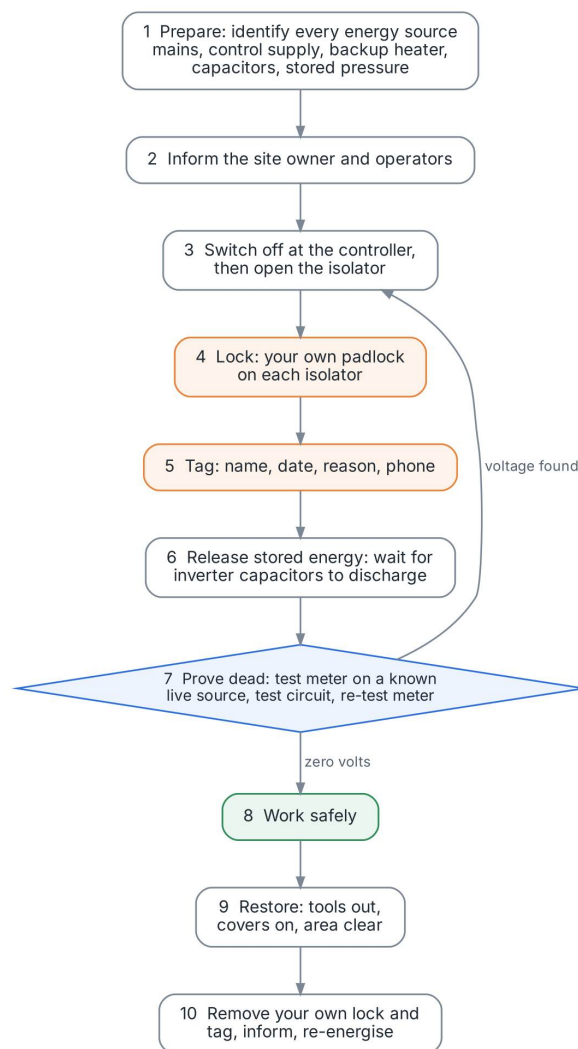
Lock-out/tag-out (LOTO) is a written routine that keeps a machine switched off while someone works on it. "Lock-out" means a personal padlock on the isolator. "Tag-out" means a label saying who is working and why.

Think of LOTO like keeping the gas cylinder valve shut and the regulator removed while you repair the stove. Turning the knob off is not enough.

Inverter drives add one more hazard. Their DC bus capacitors (energy-storing parts inside the drive) can hold a lethal charge for several minutes after power-off. Wait the time printed on the drive label, then measure.



Lock-out / tag-out in ten steps



Lock-out / tag-out in ten steps

Hazard	Where in a heat pump	Control
Mains voltage	Terminal block, contactors, inverter input	Isolate, lock, test
Stored DC charge	Inverter / VFD capacitors	Wait the labelled time, measure DC bus
Backfeed	Second supply for backup heater or pump	Isolate every source
Earth fault	Damaged cable, wet panel	RCD/RCCB, earth continuity test
Moving parts	Fan blades, pump couplings	Lock out before reaching in

Remember

- Every person working fits their own lock; one lock per person.
- "Test before touch": prove your meter works before and after testing the circuit.
- Inverter capacitors stay live after switch-off; wait and measure.
- Check for second supplies such as backup heaters and external pumps.
- Only the person who fitted a lock removes it.

Common mistake: Trusting the controller "OFF" button — it stops the compressor but the control board and terminals stay live.

10.2 Pressure, brazing and fire safety

Key idea: Refrigerant circuits store energy as pressure, and brazing adds open flame — control both before you start.

A refrigerant circuit is a sealed pressure vessel. High-side pressure is typically 15–25 bar on R134a systems and 25–40 bar on R410A/R32 heat pumps and can exceed 100 bar on CO₂ systems. A loose flare or a cut pipe under pressure can whip, freeze skin or blow oil into eyes.

A pressure cooker is a good comparison. You never open the lid while it is whistling; you let pressure fall first. Treat every circuit the same way.

Brazing joins copper pipes with a filler rod at roughly 600–800 °C (typical). Blow dry nitrogen (oxygen-free nitrogen, OFN) through the pipe at low flow while brazing. This stops black copper oxide forming inside, which later blocks filters and expansion valves.

Never braise a circuit that still holds refrigerant or oil. Heat can raise pressure, and some refrigerants break down into toxic acids in a flame.

Nitrogen purge while brazing



Nitrogen purge while brazing

Test	Purpose	Typical medium	Note
Strength / pressure test	Prove joints hold design pressure	Dry nitrogen	Use regulator and relief valve; never oxygen or compressed air
Leak test (standing)	Find leaks	Dry nitrogen, sometimes with trace gas	Hold for a set time, correct for temperature
Evacuation	Remove air and moisture	Vacuum pump	Typical target below 500 micron

Worked example — pressure change with temperature during a standing test

A circuit is filled with nitrogen to 30 bar(g) at 25 °C in Chennai. Next morning it reads 29.2 bar(g) at 20 °C. Is it leaking?

$$\frac{P_2}{T_2} = \frac{P_1}{T_1} \quad (\text{absolute pressure, kelvin})$$

- $P_1 = 30 + 1 = 31 \text{ bar(a)}$; $T_1 = 298 \text{ K}$; $T_2 = 293 \text{ K}$.
- Expected $P_2 = 31 \times 293 / 298 = 30.48 \text{ bar(a)} = 29.48 \text{ bar(g)}$.
- Measured 29.2 bar(g) is 0.28 bar lower than expected — a small leak is likely. Re-check joints with soap solution.

Fire safety on site

- Hot-work permit where the site requires it.
- Keep a dry-powder or CO₂ extinguisher within reach.
- Remove or shield combustibles; use a heat mat.
- Stay 30 minutes after brazing to watch for smouldering (typical site rule).

Remember

- Recover refrigerant and depressurise before cutting or brazing.
- Always flow nitrogen while brazing; never use oxygen to pressure test.
- Use a regulator on every nitrogen cylinder.
- Correct standing-test readings for temperature.

Field tip: Wear safety glasses and gloves for all refrigerant work — liquid refrigerant flashing on skin causes frostbite in seconds.

10.3 Refrigerant safety classes: A1, A2L, A3

Key idea: A refrigerant's safety class — a letter for toxicity and a number for flammability — tells you how carefully to handle it.

ISO 817 and ASHRAE Standard 34 classify refrigerants with a two-part code. The letter shows toxicity: A is lower toxicity, B is higher toxicity. The number shows flammability: 1 no flame propagation, 2L lower flammability with slow burning speed, 2 flammable, 3 higher flammability.

So R32 is "A2L": low toxicity, mildly flammable. R717 (ammonia) is "B2L": higher toxicity, mildly flammable.

GWP (global warming potential) compares how much heat a gas traps over 100 years with CO₂, which is 1. AR4 and AR5 are two IPCC assessment reports; they give slightly different values.

Refrigerant safety classes (ISO 817 / ASHRAE 34)

Flammability ↓ / Toxicity →	A lower toxicity	B higher toxicity
3 higher flammability	R290 (propane) R600a (isobutane)	—
2 flammable	R152a	—
2L lower flammability	R32, R1234yf, R1234ze(E)	R717 (ammonia)
1 no flame propagation	R134a, R410A, R407C, R513A, R744 (CO ₂)	R123

Refrigerant safety classes

Flammability \ Toxicity	A — lower toxicity	B — higher toxicity
3 — higher flammability	R290 (propane), R600a	—
2 — flammable	R152a	—
2L — lower flammability	R32, R1234yf, R1234ze(E)	R717 (ammonia)
1 — no flame propagation	R134a, R410A, R407C, R513A, R744 (CO ₂)	R123

Read the class as two parts: the letter is toxicity, the number is flammability.

Refrigerant comparison (GWP values approximate, 100-year)

Refrigerant	Type	GWP AR4 (approx.)	GWP AR5 (approx.)	Safety class	Typical use
R134a	HFC	1430	1300	A1	Chillers, high-temperature heat pumps, car AC (older)
R410A	HFC blend	2090	1920	A1	Split AC, air-to-water heat pumps (older designs)
R407C	HFC blend	1770	1620	A1	Retrofit of R22 systems, water chillers
R32	HFC	675	677	A2L	Split AC, modern air-to-water heat pumps
R513A	HFO/HFC blend	~630	~570	A1	R134a replacement in chillers
R1234yf	HFO	~4	<1	A2L	Car AC, some chillers
R1234ze(E)	HFO	~7	<1	A2L	Chillers, high-temperature heat pumps
R290	Hydrocarbon	3	~3	A3	Monobloc heat pumps, small commercial units
R744 (CO ₂)	Natural	1	1	A1	Hot water heat pumps, supermarket refrigeration
R717 (ammonia)	Natural	0	0	B2L	Industrial refrigeration, large heat pumps

Remember

- Letter = toxicity (A lower, B higher); number = flammability (1, 2L, 2, 3).
- A2L refrigerants burn slowly but still need ignition control.
- Low GWP often means some flammability or high pressure — a trade-off.
- Check the nameplate class before you choose tools or work method.

Common mistake: Assuming "A1" means harmless — any refrigerant displaces oxygen in a small closed room.



10.4 Working with flammable refrigerants (R290 and others)

Key idea: With A3 and A2L refrigerants, keep gas below its lower flammable limit and keep every ignition source away.

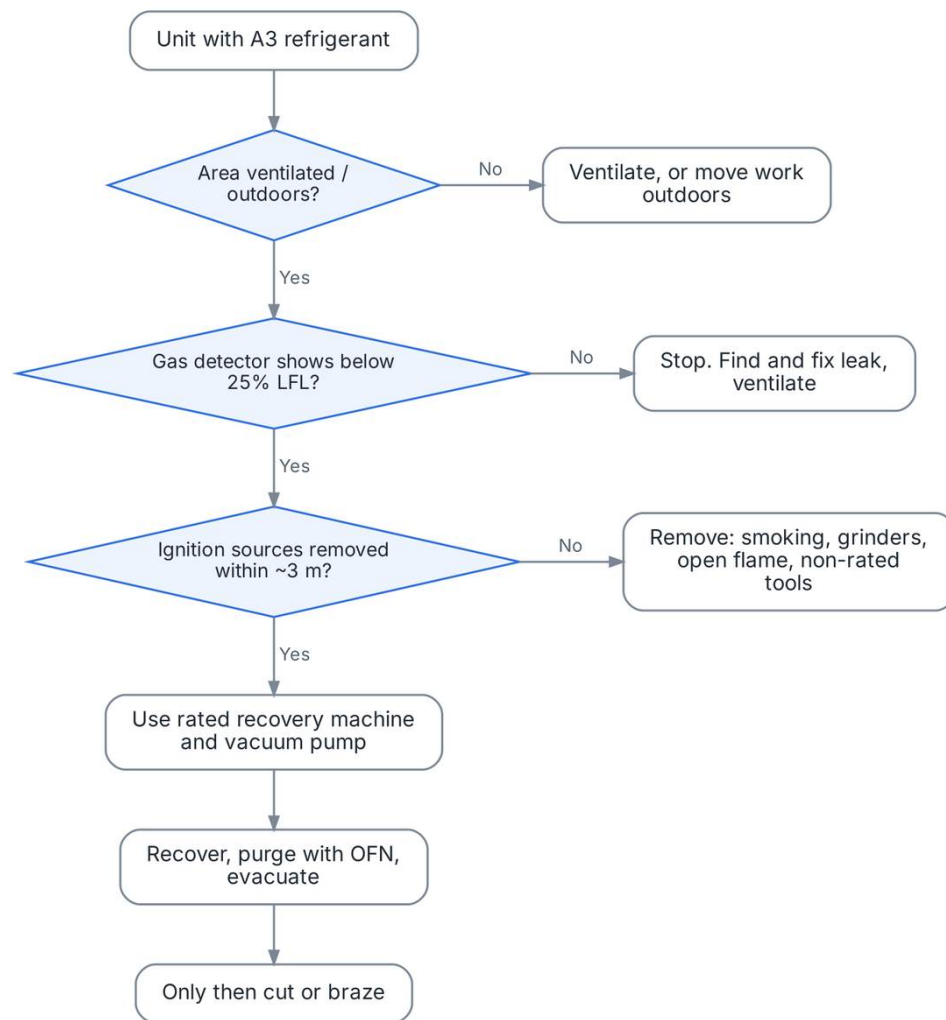
R290 is propane, the same gas family as LPG. It has excellent efficiency and very low GWP. But a leak can form a burnable mixture with air.

The lower flammability limit (LFL) is the lowest gas-in-air concentration that can burn. For R290 it is about 2.1 % by volume (typical value). Below LFL the mix is too lean to burn.

Propane is heavier than air. Like LPG from a leaking cylinder, it collects at floor level and in pits.

Charge size limits exist in product and installation standards. Indoor parts usually carry small charges; larger charges sit outdoors in monobloc units. Follow the manufacturer's limits.

Before opening an R290 (A3) circuit



Before opening an R290 (A3) circuit

Rule	R290 (A3)	R32 (A2L)
Gas detector	Always, set for hydrocarbons	Always, suitable sensor
Tools	Spark-free recovery unit and vacuum pump	Rated for A2L
Ventilation	Essential; gas sinks to floor	Essential
Brazing	Only after recovery and nitrogen purge	Same
Cylinder	Marked for flammable gas, red band or label	Flammable label

Remember

- Use a calibrated gas detector before and during work.
- No smoking, no open flame, no sparking tools in the work zone.
- Recover and purge with nitrogen before any hot work.
- Store and transport cylinders upright, ventilated, away from heat.
- Respect the manufacturer's charge limits.

Field tip: Keep the gas detector at ankle height — propane settles low.



10.5 CO₂ (R744) systems

Key idea: CO₂ is non-flammable and has GWP 1, but it runs at very high pressure and often above its critical point.

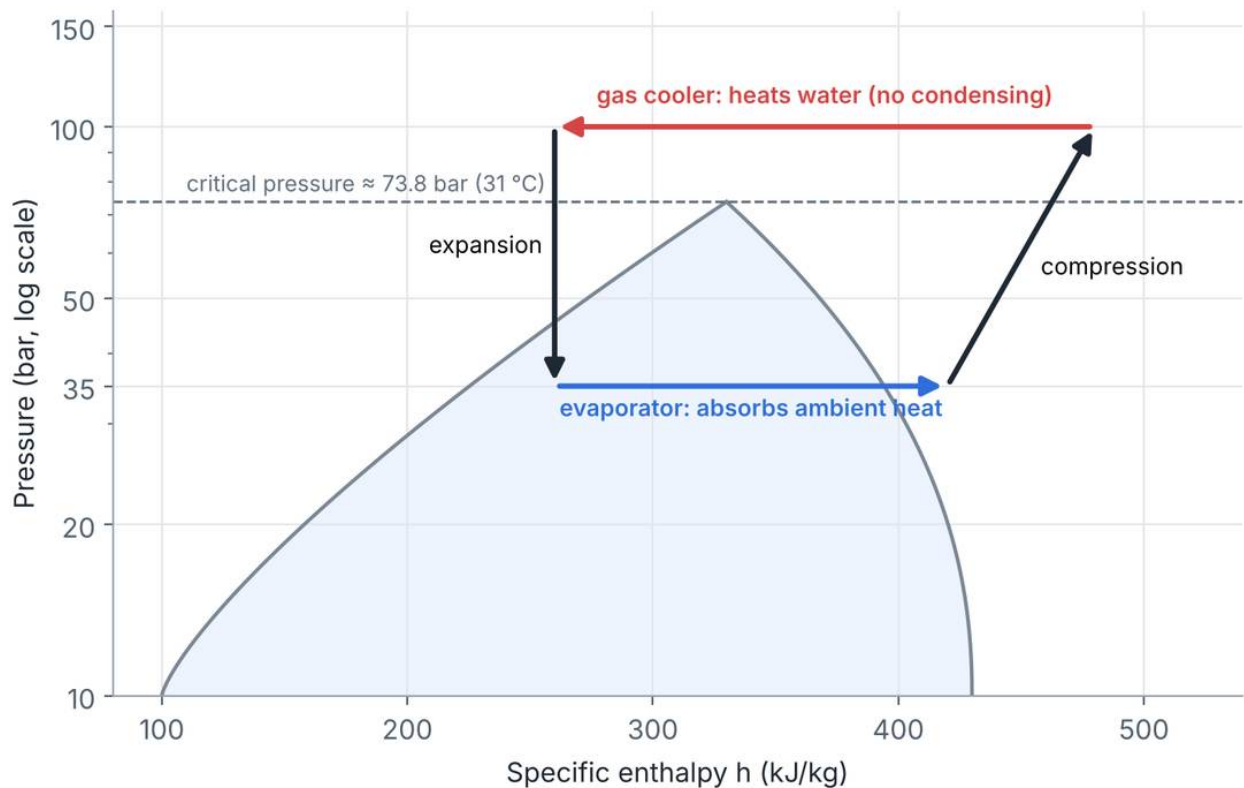
CO₂'s critical point is about 31 °C and 73.8 bar. Above this point there is no separate liquid and vapour. Heat is rejected in a "gas cooler" instead of a condenser.

This is called a transcritical cycle. Because the hot gas cools over a wide temperature glide, CO₂ heats water very well from a cold inlet to 65–90 °C. That suits sanitary hot water.

Typical pressures (approximate): gas cooler side 80–130 bar, evaporator side 25–45 bar. Standstill pressure on a warm Indian day can exceed 60 bar.

CO₂ (R744) transcritical cycle

Sketch, not to scale. Heat rejection happens above the critical point, in a gas cooler.



CO₂ transcritical cycle

Property	R744 (CO ₂)	R410A (for comparison, typical)
Safety class	A1	A1
GWP	1	~2000
High-side pressure	80–130 bar	25–35 bar
Critical temperature	~31 °C	~71 °C
Best use	Hot water, large water temperature lift	Space heating and cooling

Safety: high pressure needs rated pipes, fittings and gauges. CO₂ is heavier than air and displaces oxygen in pits and plant rooms. Dry ice can form when liquid CO₂ is vented quickly, blocking lines.

Remember

- Use gauges and hoses rated for CO₂ pressures.
- Vent CO₂ slowly to avoid dry ice formation.
- Fit a CO₂ detector in enclosed plant rooms.

- Efficiency depends strongly on cold water inlet temperature.

Common mistake: Using a standard HFC manifold on a CO₂ system — it is not rated for the pressure.



10.6 Recovery, recycling and disposal of refrigerants

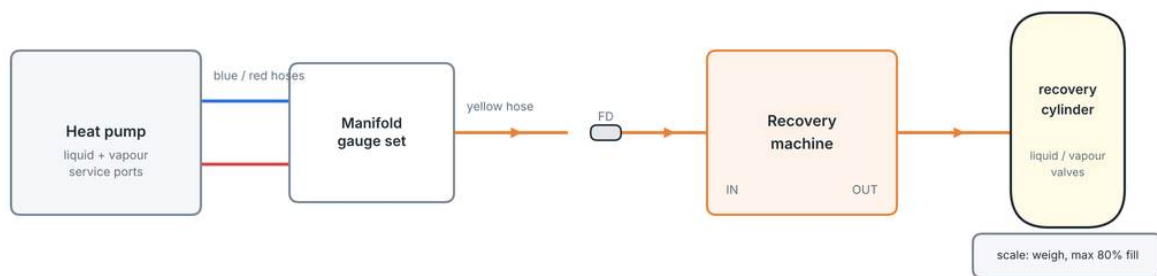
Key idea: Refrigerant is never vented — it is recovered into a rated cylinder, then recycled, reclaimed or destroyed.

Recovery means removing refrigerant from a system into a cylinder. Recycling means cleaning it on site (oil and moisture removal) for reuse in the same owner's system. Reclaim means reprocessing it at a facility to new-product purity. Destruction means breaking it down in an approved plant.

Venting HFCs harms the climate. Venting hydrocarbons creates a fire risk. Recover everything except where a procedure specifically permits controlled venting of hydrocarbons outdoors.

Connecting a recovery machine

Recover into a dedicated cylinder on a scale; never fill above 80%



Connecting a recovery machine

Recover liquid first (faster), then vapour. The cylinder sits on a scale. Use a cylinder rated and labelled for the refrigerant.

Worked example — maximum safe fill of a recovery cylinder

A recovery cylinder has a water capacity of 12 L. You recover R32 with liquid density about 0.96 kg/L (typical at room temperature). Use the 80 % fill rule.

$$m_{\max} = V_{\text{water}} \times \rho_{\text{liquid}} \times 0.8$$

- $m_{\max} = 12 \times 0.96 \times 0.8 = 9.2$ kg (approximately).
- If the empty cylinder (tare) weighs 9 kg, stop recovery at 18.2 kg gross on the scale.

Step	Action
1	Identify refrigerant from nameplate; never mix types in one cylinder
2	Weigh empty cylinder, evacuate it
3	Connect as diagram; purge hose air
4	Recover liquid, then vapour, to the target vacuum
5	Close valves, label cylinder: refrigerant, weight, date, site
6	Record in service log; send for reclaim or destruction

Remember

- One refrigerant per cylinder; label it.
- Never fill beyond 80 % of liquid capacity.
- Use a recovery machine rated for the refrigerant class (A2L/A3).
- Keep records of quantities recovered.

Field tip: Chill the recovery cylinder (shade, wet cloth) in Indian summers — a cooler cylinder speeds recovery.

10.7 The Kigali Amendment, HFC phase-down and the India Cooling Action Plan

Key idea: World rules now cut HFC use step by step, so low-GWP and natural refrigerants are the long-term direction.

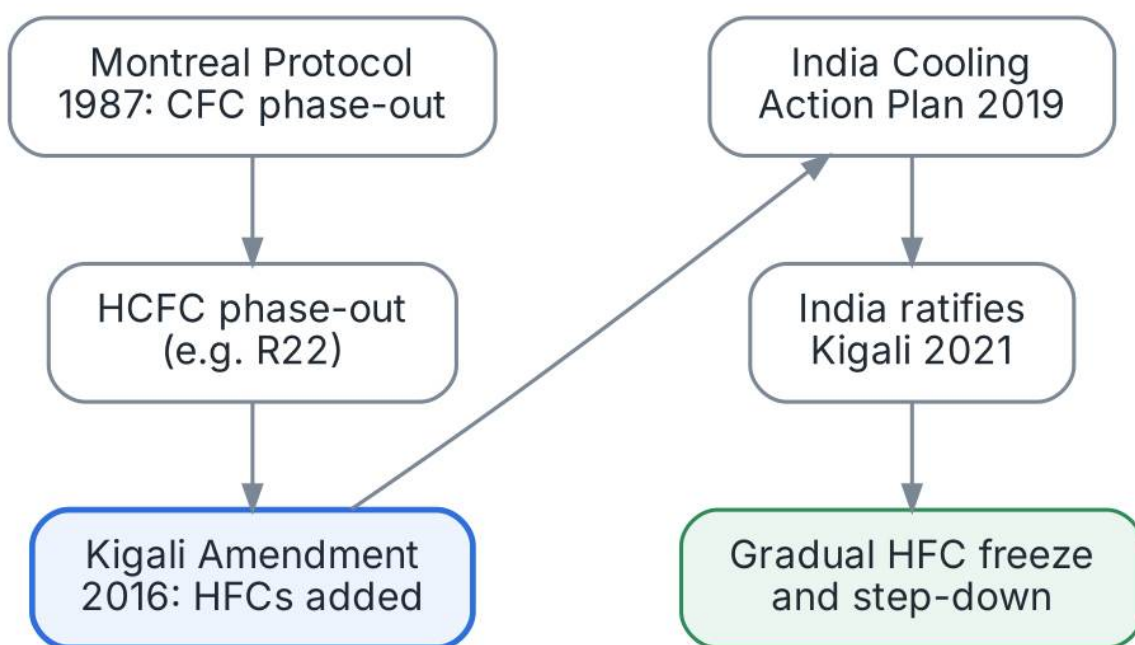
The Montreal Protocol (1987) is the treaty that phased out ozone-depleting gases like CFCs and HCFCs (e.g. R22). It is often called the most successful environmental treaty.

The Kigali Amendment (agreed in 2016 in Kigali, Rwanda) added HFCs to the Montreal Protocol. HFCs do not harm ozone but are strong greenhouse gases. Countries agreed to freeze, then gradually reduce, HFC production and use.

Countries are grouped with different timelines. Developed countries started first. India is in a group of developing countries with a later freeze and slower reduction. India ratified the amendment in 2021.

The India Cooling Action Plan (ICAP), released by the Ministry of Environment, Forest and Climate Change in 2019, looks 20 years ahead. It aims to reduce cooling demand and refrigerant demand, improve efficiency, and train and certify service technicians.

From ozone to climate: the refrigerant rules



From ozone to climate: the refrigerant rules

Gas family	Example	Ozone harm	Climate impact	Status direction
CFC	R12	High	Very high	Phased out
HCFC	R22	Moderate	High	Being phased out
HFC	R134a, R410A	None	High	Phase-down under Kigali
HFO	R1234yf	None	Very low	Growing
Natural	R290, R744, R717	None	Very low	Growing

Remember

- Montreal handled ozone; Kigali extended it to HFCs for climate.
- India follows a later, gradual HFC timeline.
- ICAP stresses efficiency, lower demand and technician training.
- Skills for A2L, A3 and CO₂ will be in steady demand.

Field tip: Good recovery and leak-free installation are the technician's direct contribution to the phase-down.

10.8 Test and rating standards: BIS, EN 14511, EN 16147, ISO 13256, AHRI

Key idea: A rated capacity or COP only means something if you know which standard and which test conditions produced it.

A test standard fixes how a unit is measured: air and water temperatures, flow, tolerance and instruments. Two units can only be compared fairly when tested to the same standard at the same conditions.

Think of a car's fuel mileage. A highway figure and a city figure differ for the same car. Heat pump COP changes the same way with source and sink temperatures.

How a standard becomes a datasheet number



How a standard becomes a datasheet number

Standard	Body / region	What it covers (general)
BIS (Indian Standards)	Bureau of Indian Standards, India	Indian standards for safety and performance of air conditioners, heat pumps and electrical appliances; some products need BIS certification
EN 14511	European (CEN)	Rating of capacity and COP/EER of air conditioners, chillers and heat pumps (air and water sources) at defined conditions
EN 16147	European (CEN)	Testing of heat pumps for domestic hot water, including tapping cycles and water heating COP
ISO 13256	International (ISO)	Rating of water-source and ground-source (brine) heat pumps
AHRI standards	Air-Conditioning, Heating, and Refrigeration Institute, USA	Performance rating of HVAC and heat pump equipment; certification directory in North America
ISO 817 / ASHRAE 34	ISO / ASHRAE	Refrigerant designation and safety classification (from 10.3)
ISO 5149 / EN 378	ISO / CEN	Safety and environmental requirements for refrigerating systems and heat pumps

Condition shorthand: "A7/W35" means outdoor air 7 °C, water leaving at 35 °C. "W10/W35" means source water 10 °C, leaving water 35 °C. "B0/W35" means brine 0 °C.

Worked example — reading a rating

A datasheet says: heating capacity 10 kW, power input 2.5 kW at A7/W35, and 9 kW, 3.2 kW at A7/W55.

$$COP = \frac{Q_{heat}}{P_{electric}}$$

- At A7/W35: $COP = 10 / 2.5 = 4.0$.
- At A7/W55: $COP = 9 / 3.2 = 2.8$.
- For hot water at 55 °C in Pune, use COP 2.8, not 4.0. At ₹9/kWh (example rate), 100 kWh of heat costs $100 / 2.8 \times 9 = ₹321$, not ₹225.

Remember

- Always quote the test condition with any COP.
- EN 14511 for space heating/cooling ratings; EN 16147 for domestic hot water.
- ISO 13256 for water- and ground-source units.
- Check whether BIS certification applies to the product in India.

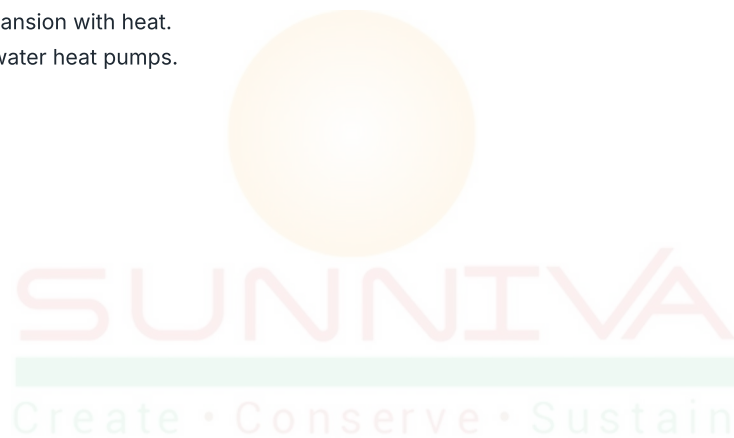
Common mistake: Comparing one unit's A7/W35 COP with another unit's A7/W55 COP.

Quiz 10

1. What is the correct order in LOTO? A) Lock, isolate, test, tag B) Isolate, lock, tag, prove dead C) Test, tag, isolate, lock D) Tag, isolate, work, lock
2. Why wait after switching off an inverter heat pump? A) Fan must stop cooling B) DC bus capacitors hold charge C) Refrigerant must settle D) Controller must save data
3. Which gas is used to pressure test a refrigerant circuit? A) Oxygen B) Compressed air C) Dry nitrogen D) LPG
4. In "A2L", what does "A" mean? A) Approved B) Lower toxicity C) Air-cooled D) High flammability
5. Which refrigerant is class A3? A) R32 B) R744 C) R290 D) R134a
6. Which refrigerant is B2L? A) R717 B) R410A C) R1234yf D) R513A
7. Where does leaked R290 collect? A) Ceiling B) Evenly in room C) Floor level and pits D) Outside only
8. Approximate critical temperature of CO₂? A) 0 °C B) 31 °C C) 71 °C D) 100 °C
9. Maximum liquid fill of a recovery cylinder? A) 50 % B) 80 % C) 95 % D) 100 %
10. Which standard covers domestic hot water heat pump testing? A) EN 16147 B) ISO 13256 C) ISO 817 D) EN 378

Answer key

1. B — isolate first, then lock, tag and prove dead before work.
2. B — inverter capacitors stay charged after power-off.
3. C — dry nitrogen is inert and dry; oxygen and air are dangerous.
4. B — A = lower toxicity class.
5. C — R290 (propane) is higher flammability, A3.
6. A — ammonia is higher toxicity and lower flammability.
7. C — propane is heavier than air.
8. B — about 31 °C (at about 73.8 bar).
9. B — 80 % leaves room for liquid expansion with heat.
10. A — EN 16147 covers domestic hot water heat pumps.



Glossary

Term	Meaning
LOTO	Lock-out/tag-out: personal lock and label that keep equipment isolated during work
DC bus capacitor	Energy-storing part in an inverter drive that stays charged after power-off
RCD / RCCB	Device that trips when current leaks to earth
OFN	Oxygen-free (dry) nitrogen used for purging and pressure testing
Brazing	Joining metals with a filler rod above about 450 °C
Safety class	ISO 817 / ASHRAE 34 code: toxicity letter plus flammability number
A2L	Lower toxicity, lower flammability with slow burning speed
LFL	Lower flammability limit: lowest gas-in-air concentration that can burn
GWP	Global warming potential, compared with CO ₂ = 1 over 100 years
AR4 / AR5	IPCC assessment reports giving GWP values
Transcritical	Cycle with heat rejection above the critical point
Gas cooler	Heat exchanger replacing the condenser in a transcritical CO ₂ cycle
Critical point	Temperature/pressure above which liquid and vapour cannot be told apart
Recovery	Removing refrigerant from a system into a cylinder
Recycling	On-site cleaning of recovered refrigerant for reuse
Reclaim	Reprocessing refrigerant at a facility to new-product purity
Kigali Amendment	2016 addition to the Montreal Protocol to phase down HFCs
ICAP	India Cooling Action Plan, 20-year national cooling roadmap
EN 14511	European standard for rating heat pump and AC capacity and efficiency
EN 16147	European standard for testing domestic hot water heat pumps
ISO 13256	International standard for rating water- and ground-source heat pumps
COP	Coefficient of performance: heat output divided by electrical input





THANK YOU.

Thank you for learning with us. Questions, corrections and suggestions for the next edition are welcome.

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