

Cooling Towers Made Simple

A field guide to cooling towers and cooling water

How towers work · Performance testing · Troubleshooting · Water chemistry · Hot, humid and cold climates





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Written in our own words from published engineering sources, listed in the References. All diagrams and charts are original PlantCalcKit artwork; captions say "adapted from" where a drawing follows an idea from a book. No water-treatment company or brand is named or recommended.

This guide is for training and engineering estimates. It does not replace your tower maker's instructions, your water-treatment specialist's advice, the official CTI or ASME test codes, or your plant's safety rules.

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GUIDE

How to use this guide

This guide explains cooling towers and cooling water in plain words. You do not need to be an expert. If you can read a thermometer and follow a recipe, you can follow this book.

Who it is for

- **Plant operators** who run and check the tower every shift.
- **Junior engineers** who must test it, fix it and report on it.
- **Anyone** who wants to know why the tower matters and how to keep it healthy.

How the book is built

The book has four parts. You can read them in order, or jump to the part you need.

Part	What you learn	Chapters
A	How a cooling tower works	1 to 4
B	How to watch, test and fix a tower	5 to 8
C	How to keep the water safe	9 to 12
D	Upkeep, savings and worked examples	13 to 16

At the back you will find a glossary, printable checklists, quick-reference tables, quiz answers and the list of books we used.

Our three example sites

A cooling tower behaves differently in a desert, by a hot sea, or in a cold country. So we follow **one tower** through **three climates**. The tower is the same in all three places: 4 cells, 6,000 m³/h (26,400 US gpm) of water, cooled by 10 °C (18 °F).

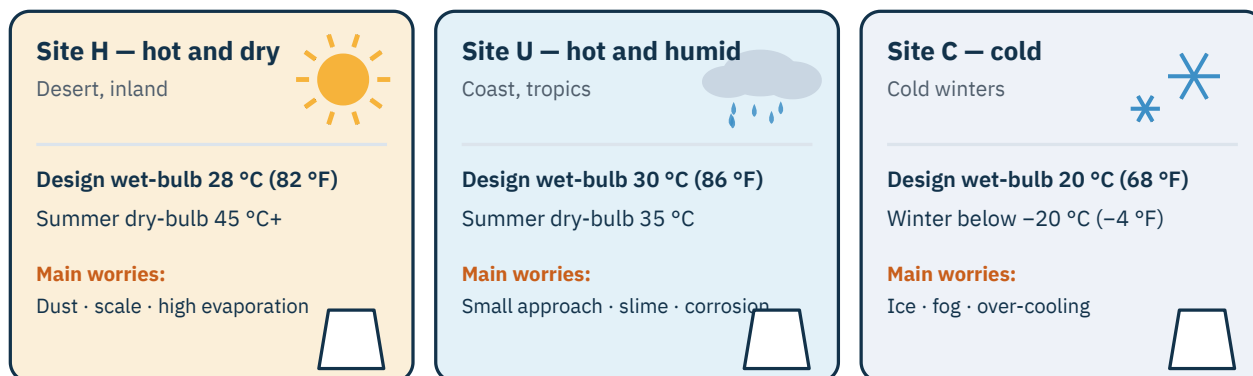


Figure 0.1 — The three example sites used in this guide. Each one uses the same 4-cell tower, cooling 6,000 m³/h (26,400 US gpm) by 10 °C (18 °F).

Site	Climate	Example places	Design wet-bulb	Summer dry-bulb	Main challenges
Site H — hot and dry	Desert, inland	Southern Punjab and Sindh, Gulf interior, Arizona	28 °C (82 °F)	45 °C (113 °F) and above	High evaporation, dust, hard well water, scale
Site U — hot and humid	Coastal, tropical	Karachi, Gulf coast, Singapore, Houston	30 °C (86 °F)	35 °C (95 °F)	Small approach, slime and algae, high chloride, corrosion
Site C — cold	Cold winters	Northern Europe, Canada, northern China	20 °C (68 °F) in summer	Below -20 °C (-4 °F) in winter	Ice, fog, freezing basins, low winter evaporation

You will meet these sites again and again. Look for the climate box in each chapter.

The boxes you will see

- **Try it** — which PlantCalcKit calculator to use, which option to pick, and why.
- **Climate box** — how the topic changes at Site H, Site U and Site C.
- **Watch out** — a common mistake or a safety point.
- **Quick quiz** — five short questions at the end of each chapter. Answers are in Appendix D.
- **Field check** — what a reading you see may mean, and the first thing to check. These are possible causes, not a final diagnosis.
- **One-minute shift check** — three things to look at on every shift, why they matter, and when to act or report. The alarm limits always come from your plant's own approved procedures.
- **Engineer's calculation corner** — a calculation with its inputs, formula, steps, result and assumptions, so you can check it or repeat it for your own tower.

Units

We use SI units first, with US units in brackets. For example: 32 °C (90 °F), 1,000 m³/h (4,400 US gpm). Appendix C has a conversion table.

Where the facts come from

Every fact in this guide comes from published engineering books and codes. We explain them in our own words. We do not copy their text, tables or figures. Drawings in this book are our own. When a drawing is based on an idea from a book, its caption says **"adapted from"** and names the book. The full list of sources is at the end of the book.

The main books are:

- *Cooling Tower Fundamentals*, 2nd edition, SPX Cooling Technologies (ed. J. C. Hensley), 2009.
- *Perry's Chemical Engineers' Handbook*, 7th edition, Section 12 (cooling towers).
- *GPSA Engineering Data Book*, Section 11 (cooling towers) and Section 18 (utilities and water treatment).
- *Betz Handbook of Industrial Water Conditioning* (cooling water chapters).
- H. M. Herro and R. D. Port, *The Nalco Guide to Cooling Water System Failure Analysis*, 1993.
- Cooling Technology Institute (CTI) test code ATC-105 and guideline PTG-156.

Water treatment is described with general names only, such as "scale inhibitor" or "corrosion inhibitor". We do not name or recommend any company or brand.

The PlantCalcKit calculators

PlantCalcKit makes Excel calculators that do the sums in this book for you. Each one shows its working, checks your inputs, and prints a report.

Calculator	What it does	Link
Cooling Tower Water Balance	Evaporation, drift, blowdown, makeup, cycles, water cost	plantcalckit.com/tools/cooling-tower-water-balance
Cooling Tower Performance Test	Tower capability from a test, cell by cell, with fault hints	plantcalckit.com/tools/cooling-tower-performance-test
Cooling Water Chemistry and Cycles	Scaling and corrosion indices, safe cycles, acid feed, treatment cost	plantcalckit.com/tools/cooling-water-chemistry
Cooling Tower Thermal Rating and Upgrade	What the tower will do in summer, with a fan off, or after an upgrade	plantcalckit.com/tools/cooling-tower-thermal-rating

Watch out: This guide helps you understand and check your tower. It does not replace the instructions of your tower maker, your water treatment specialist, or your plant's safety rules.

Part A

How cooling towers work

CHAPTER 1

Why plants need cooling towers

Every plant makes heat it does not want. Where water is available, a cooling tower is often the lowest-cost way to throw that heat into the air — but the best choice for each site depends on water, power cost, space, climate and local rules.

1.1 Where plant heat comes from

Machines and processes get hot when they work. Here are some common examples:

- A **steam turbine** sends its exhaust steam to a condenser. Cooling water turns that steam back into water.
- A **compressor** squeezes gas. The gas gets hot and must be cooled between stages.
- A **chemical reactor** gives off heat while it makes the product.
- **Pumps, gearboxes and motors** need cool oil and cool bearings.
- An **air-conditioning chiller** moves heat out of a building and into its condenser water.

If this heat is not removed, the machines slow down, the product drops, and equipment can fail.

1.2 Water carries the heat

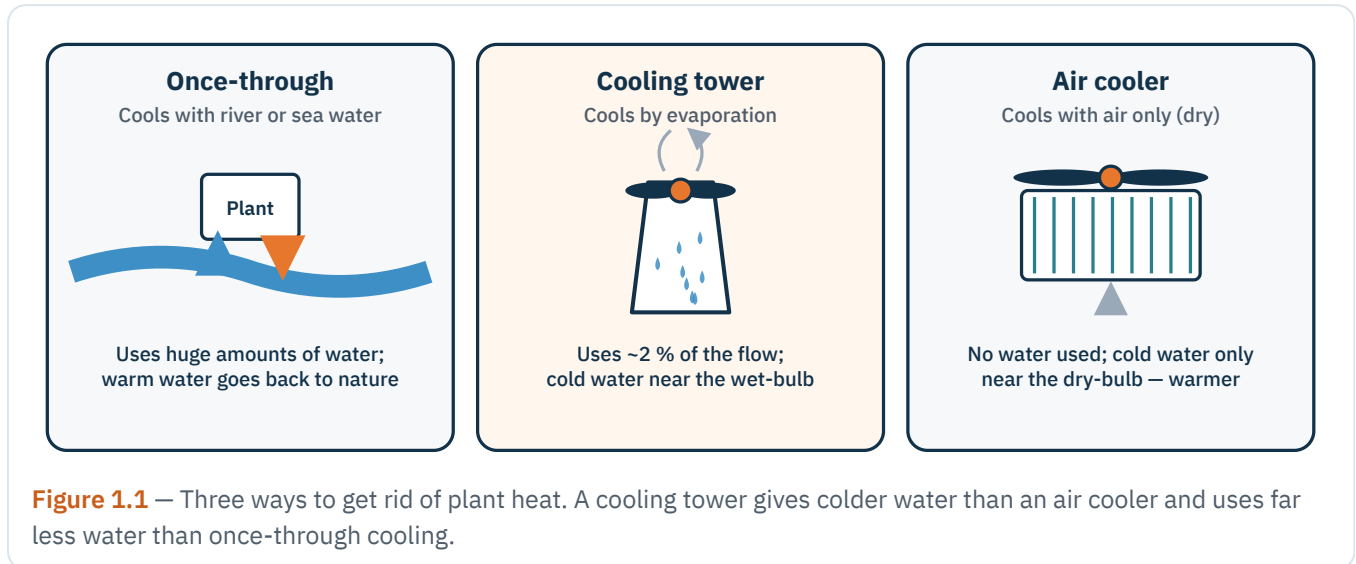
Water is a very good carrier of heat. One kilogram of water must take in 4.19 kJ to warm up by 1 °C (1 °F needs about 1 Btu per pound). That is more than almost any other cheap liquid.

So plants pump cool water through **heat exchangers**. The water picks up heat and comes back warm. Then something must cool it again.

1.3 Three ways to get rid of the heat

Method	How it works	Good points	Weak points
Once-through	Take water from a river, lake or sea, use it once, send it back warmer	Simple, no tower	Needs huge amounts of water; warm water harms rivers and fish; often not allowed
Dry cooling (air cooler, radiator)	Air blows over finned tubes; no water touches the air	No water used	Water can only be cooled to near the dry-bulb air temperature, so it stays warm in hot weather; large and costly

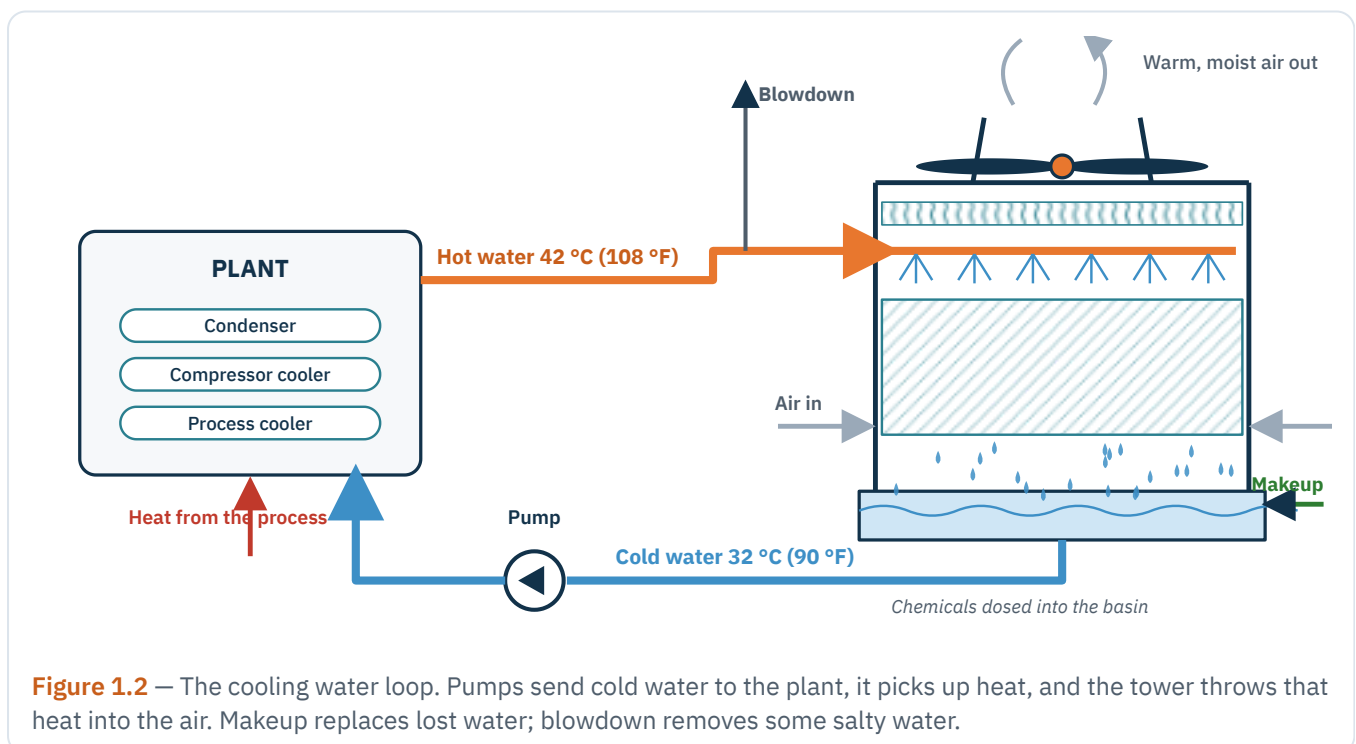
Method	How it works	Good points	Weak points
Cooling tower (open recirculating)	Warm water falls through moving air; a little water evaporates and carries the heat away	Cools water below the air temperature; uses only 1–2 % of the flow	Water is lost to evaporation; minerals concentrate; needs water treatment



The cooling tower wins in most plants. It can cool water close to the **wet-bulb temperature**, which is lower than the air temperature. Chapter 2 explains why.

1.4 The cooling water loop

A typical plant loop has five parts:



1. **Cold water basin** under the tower holds the cooled water.
2. **Pumps** send the cold water to the plant.
3. **Heat exchangers** (condensers, coolers) pass the plant heat into the water.
4. **Return line** brings the warm water back to the top of the tower.
5. **Tower** cools the water as it falls, and it lands in the basin again.

Three streams keep the loop in balance:

- **Evaporation** leaves as vapour and carries most of the heat.
- **Blowdown** is a small stream we drain on purpose to stop minerals building up.
- **Makeup** is fresh water added to replace what was lost.

We study these streams in Chapter 9.

1.5 Open and closed loops

- An **open loop** sends the plant water itself over the tower. This is the most common type in industry. The water touches the air, so dust and oxygen get in.
- A **closed loop** keeps the plant water inside tubes. A tower or evaporative cooler sprays water over the outside of those tubes. The inside water stays clean, but the cost is higher.

This book is mainly about open loops, because they are the most common and need the most care.

1.6 What a tower costs to run

A cooling tower looks simple, but it costs money every hour:

- **Fan power.** Fans in a large tower may use 0.5–1 % of the heat they remove as electricity.
- **Pump power.** The pumps lift the water to the top of the tower and push it through the plant.
- **Water.** Makeup water must be bought, pumped or treated.
- **Chemicals.** Treatment chemicals stop scale, corrosion and slime.
- **Blowdown disposal.** The drained water may need treatment before it leaves the site.
- **Lost production.** This is often the biggest cost. If the cold water is 1 °C warmer than it should be, condensers lose vacuum and compressors work harder.

Watch out: Many plants watch the pumps and fans but forget the water temperature. A tower that is a few degrees too warm can cost more in lost output than all its running costs together.

1.7 Why every degree is worth money

The cold water temperature is not just a number on a screen. It decides how well many machines in the plant work.

Equipment cooled	What warmer water does	Typical effect
Chiller condenser (air-conditioning, process chilling)	The compressor must push against a higher pressure	Chiller makers often quote about 2–3 % more compressor power for each 1 °C warmer condenser water
Steam turbine condenser (power plants, large drives)	Back-pressure rises, so the turbine makes less power from the same steam	A measurable loss in output; the turbine maker's correction curve gives the figure
Gas compressor intercoolers (fertilizer, refineries, air separation)	Gas enters the next stage warmer, so the machine handles less gas and uses more power	In hot summers many plants cut production for this reason
Reactors and product coolers	Product leaves warmer; side reactions or vapour losses rise	Lower yield, more flaring, off-spec product
Lube oil and bearing coolers	Oil runs hotter and thinner	Trips and wear on big machines

So a tower that is 2 °C (3.6 °F) worse than it should be can cost more in lost output each year than all its own running costs. That is the main reason this book spends so much time on monitoring, testing and troubleshooting.

1.8 Safety around a cooling tower

A cooling tower looks quiet, but it has many hazards. Everyone who works on or near one should know them before reading further.

Hazard	Where you meet it	How to stay safe
Rotating fan	Fan deck, inside the plenum	Lock out and tag out the motor; wait for the fan to stop; lock the fan against wind turning it
Falls	Fan deck, ladders, slippery wet decks	Use handrails and harnesses; never walk on fill or wet wood without boards
Drowning	Deep basins and sumps	Never work alone over water; use covers and ladders
Confined space	Inside cells, plenums, sumps	Follow your permit system; test the air; have a standby person
Chemicals	Acid, biocide and inhibitor tanks	Wear goggles, gloves and an apron; keep an eyewash nearby
Legionella	Drift and spray, cleaning work	Keep treatment steady; wear a respirator when cleaning (Chapter 11.10)
Ice	Cold climates	Keep people away from falling ice; never break ice with fans running (Chapter 13.11)
Electricity	Motors, heaters, control panels	Only trained people open panels; isolate before work

The golden rule: **if a job needs you to go inside the tower, the fan must be locked off – every time.**

🕒 ONE-MINUTE SHIFT CHECK

Check	Why it matters	Act or report when
Cold water temperature	It is what the plant receives	It is above the plant limit, or rising for no clear reason
Number of fans and pumps running	Tells you how much cooling is available	A fan or pump has stopped without a planned reason
Basin level	Low level can starve the pumps	Level is falling, or water is running from the overflow

Use the alarm and action limits in your plant's approved procedures. This book does not set them.

✿ CLIMATE CORNER

why the climate matters

- **Site H (hot and dry):** The air is very hot, but its wet-bulb is much lower than its dry-bulb. A tower works very well here. Dry coolers would struggle.
- **Site U (hot and humid):** The wet-bulb is high, so the tower cannot cool the water as far. The plant must accept warmer cooling water, or buy a bigger tower.
- **Site C (cold):** The tower easily makes cold water in winter. The worry is ice, not heat.

▶ TRY IT WITH PLANTCALCKIT

Use the **Cooling Tower Water Balance** calculator to see how much water your tower loses each hour and what it costs per year. Enter the flow, the hot and cold water temperatures and the cycles. The calculator does the rest. plantcalckit.com/tools/cooling-tower-water-balance

? QUICK QUIZ 1

1. Name two machines in a plant that need cooling water.
2. Why is once-through cooling often not allowed?
3. What does a cooling tower use to carry heat away?
4. Which three water streams keep a cooling loop in balance?
5. Why can a warm cooling tower cost more than its own running costs?

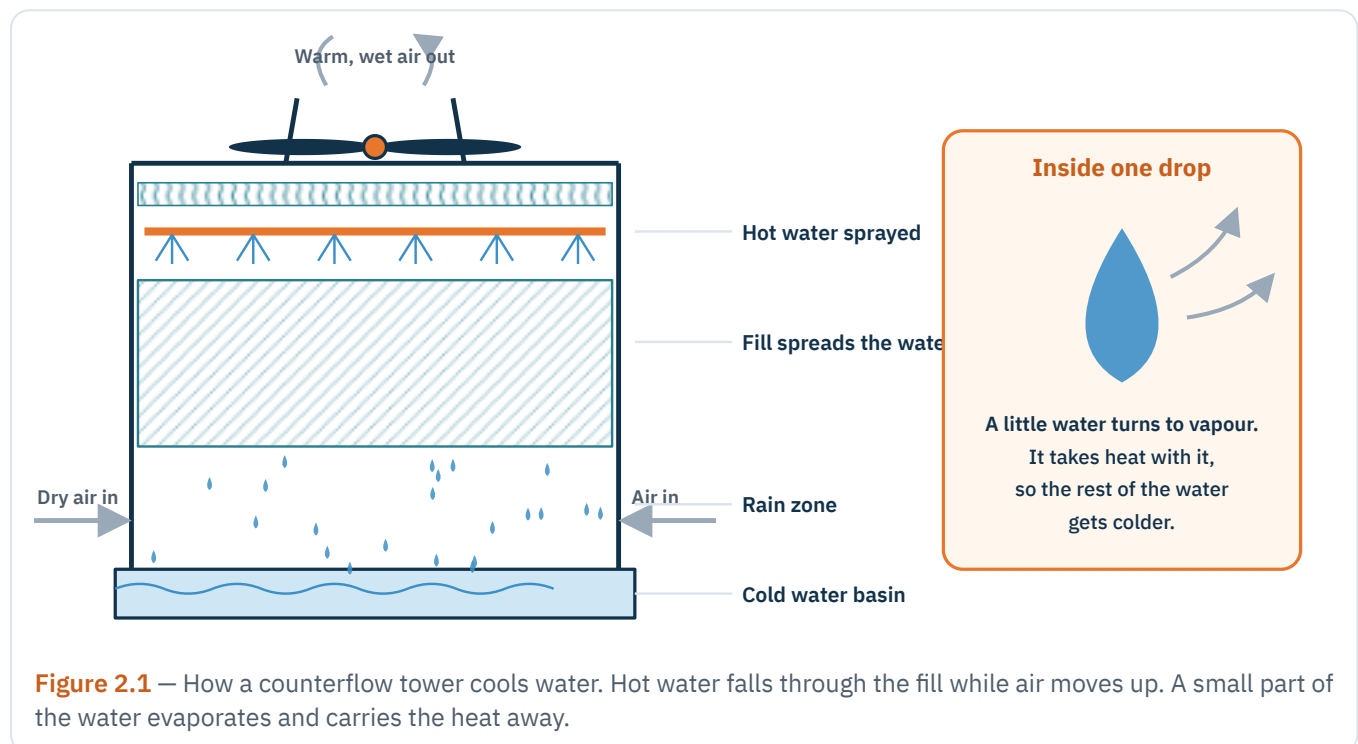
CHAPTER 2

How a cooling tower works

A cooling tower cools water mainly by evaporating a small part of it, so the coldest it can ever make the water is the wet-bulb temperature of the air.

2.1 Cooling by evaporation

Think of a hot day. You sweat, a breeze blows, and you feel cool. The sweat takes heat from your skin when it turns into vapour. A fan makes it work faster because it brings dry air to your skin and carries the damp air away.



A cooling tower does the same thing on a giant scale:

- Warm water is spread out into thin films and small drops.
- A fan (or a tall chimney) pulls air through the falling water.
- A small part of the water evaporates.
- Each kilogram of water that evaporates takes about 2,400 kJ of heat with it (about 1,000 Btu per pound).
- The rest of the water is left cooler and falls into the basin.

To evaporate 1 kg of water takes almost 600 times more heat than warming 1 kg of water by 1 °C. That is why evaporating only 1–2 % of the water is enough to cool all of it by about 10 °C.

2.2 Two kinds of heat move into the air

Air picks up heat from the water in two ways:

Where the heat goes (one example: air at 26 °C, 50 % humidity)



Based on the worked example in SPX, *Cooling Tower Fundamentals* (2009), Sect. I-D.

Figure 2.2 — Most of the cooling comes from evaporation. Only a small part comes from warming the air (adapted from the example in SPX 2009, Sect. I-D).

1. **Latent heat** — the heat carried by the water vapour. This is the big one.
2. **Sensible heat** — the air simply gets warmer, like air over a hot stove.

Cooling Tower Fundamentals (SPX, 2009, Sect. I-D) traces one kilogram of air through a tower. The water is cooled from about 29 °C to 21 °C (85 °F to 70 °F). The air comes in at about 26 °C (78 °F) and 50 % humidity. It leaves almost saturated. About **nine-tenths of the heat** left the water by evaporation. The air's dry-bulb temperature rose by less than 2 °C (3.3 °F) even though the water cooled by 8 °C (15 °F). So the air carried the heat away mostly as moisture, not as extra warmth.

This also shows something surprising. The water left the tower **colder than the air** that came in. A dry cooler can never do that.

2.3 Dry-bulb and wet-bulb temperature

- The **dry-bulb temperature** is the normal air temperature on a thermometer.
- The **wet-bulb temperature** is read by a thermometer whose bulb is wrapped in a wet cloth, with air blowing over it. Water evaporates from the cloth and cools the bulb. The drier the air, the more it cools.

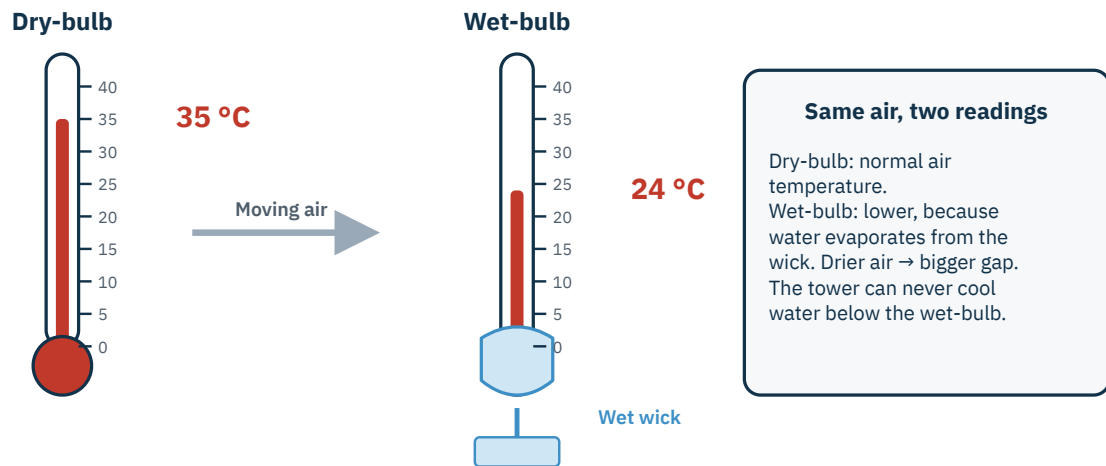


Figure 2.3 — A dry-bulb and a wet-bulb thermometer in the same air. The wet-bulb is the lowest temperature a cooling tower could ever reach.

When the air is fully saturated (100 % humidity), nothing can evaporate, and the wet-bulb equals the dry-bulb. When the air is dry, the wet-bulb is much lower.

Air	Dry-bulb	Humidity	Wet-bulb (about)
Desert afternoon (Site H)	45 °C (113 °F)	15 %	24 °C (75 °F)
Humid coast (Site U)	35 °C (95 °F)	70 %	30 °C (86 °F)
Cool summer day (Site C)	25 °C (77 °F)	60 %	19.5 °C (67 °F)

The wet-bulb sets the practical limit. In normal operation, water in a cooling tower gets close to the entering wet-bulb, but not below it. (In unusual cases, such as very light water loading, theory allows a little less, but for normal plant work treat the entering wet-bulb as the limit.) **That is why towers are designed on the wet-bulb, not the dry-bulb** (SPX 2009, Sect. I-E-1).

Two instruments read the wet-bulb:

- A **sling psychrometer**: two thermometers, one dry and one wet, whirled by hand.
- A **mechanically aspirated psychrometer**: a small fan pulls air over the wet bulb at about 5 m/s (1,000 ft/min). This is the type used for tower tests. Use distilled water on the wick.

2.4 Range and approach

Two numbers describe what any tower is doing:

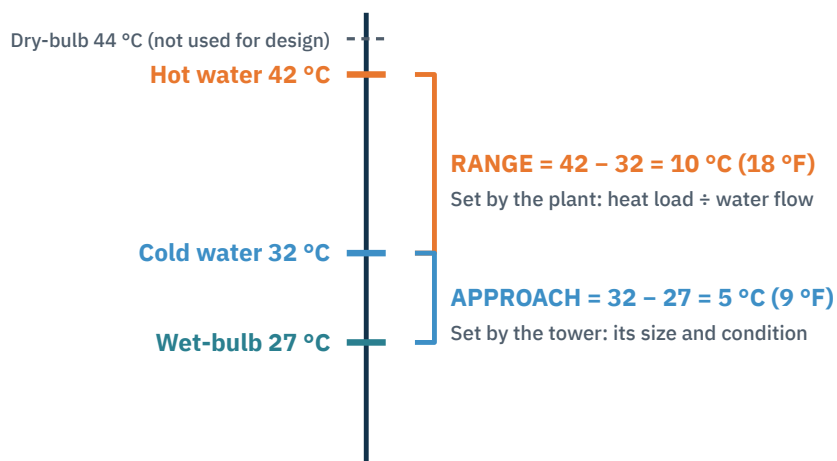


Figure 2.4 — Range and approach for the example tower at Site H. The plant sets the range; the tower size and condition set the approach.

- **Range** = hot water temperature – cold water temperature. This is how much the tower cools the water.
- **Approach** = cold water temperature – wet-bulb temperature. This is how close the tower gets to the limit.

Example: hot water 42 °C, cold water 32 °C, wet-bulb 27 °C.

- Range = $42 - 32 = 10\text{ °C}$ (18 °F)
- Approach = $32 - 27 = 5\text{ °C}$ (9 °F)

As a simple starting rule, the **range** is set mostly by the plant: by how much heat it sends and how much water flows. The **approach** depends mostly on the tower: its size and its condition. A bigger or better tower gives a smaller approach. But the approach also changes with the wet-bulb, the water flow, the air flow and the heat load — so a bigger approach does not always mean the tower got worse.

A third number puts them together:

- **Effectiveness** = $\text{range} \div (\text{range} + \text{approach}) \times 100\%$. In the example: $10 \div 15 = 67\%$. It is a simple indicator of how close the water gets to the wet-bulb limit.

Watch out — effectiveness is not capability. A tower showing 67 % effectiveness may be working exactly as designed. Effectiveness only tells you how close the water gets to the wet-bulb limit. To know whether the tower meets its design guarantee, compare the readings with the maker's performance curves at the same conditions, or run a formal test (Chapters 6 and 7). See the worked example in 2.11.

2.5 Heat load

The heat the tower must remove is:

$$\text{Heat load (kW)} = \text{water flow (kg/s)} \times 4.19 \times \text{range (}^{\circ}\text{C)}$$

For 6,000 m³/h of water (about 1,660 kg/s) and a 10 °C range:

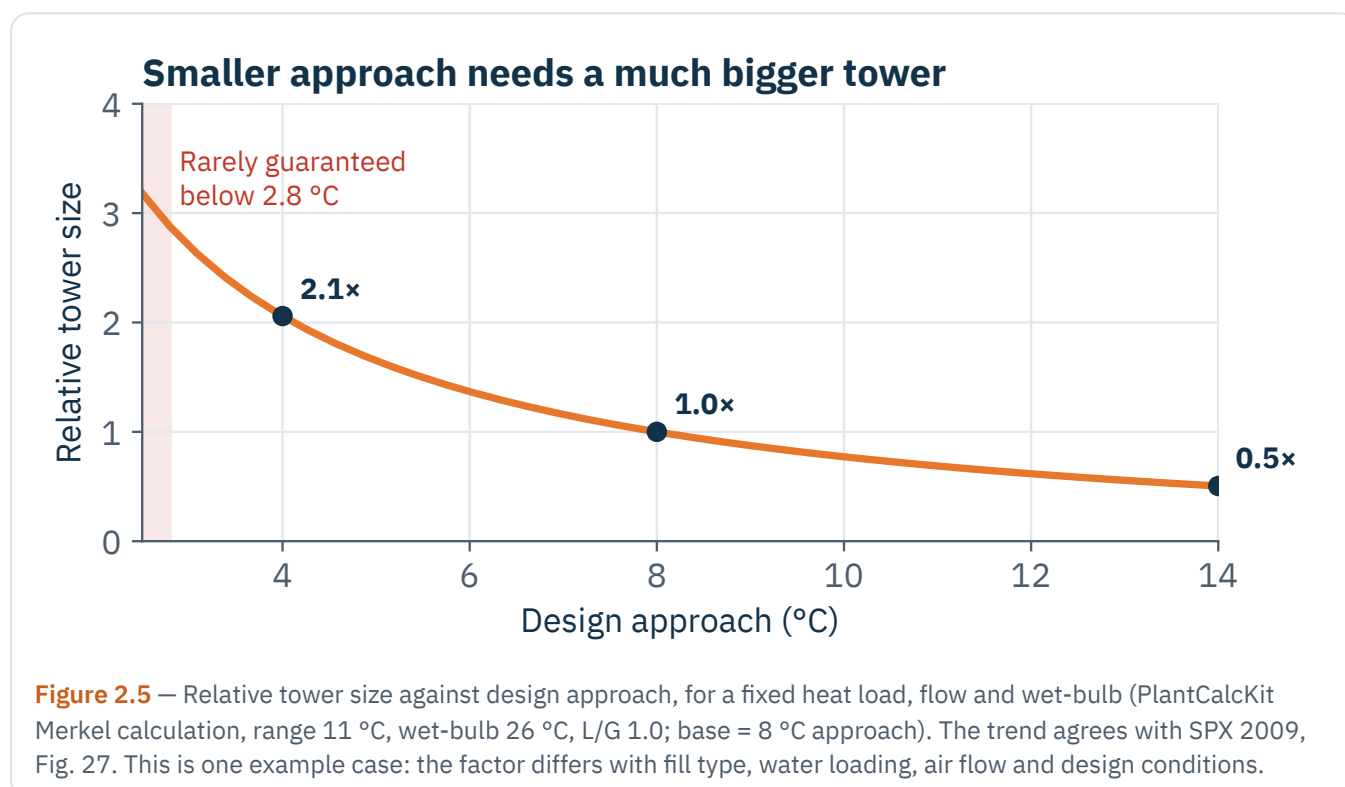
$$\text{Heat load} = 1,660 \times 4.19 \times 10 \approx \mathbf{69,600 \text{ kW}}$$
 (about 70 MW, or 237 million Btu/h).

In US units: heat load (Btu/h) = gpm × 500 × range (°F).

The **size and cost of a tower grow with the heat load** (SPX 2009, Sect. I-E-3). So the plant must state its heat load correctly. Too low, and the tower is too small. Too high, and money is wasted.

2.6 Why small approaches cost so much

The closer you want the cold water to the wet-bulb, the bigger the tower must be. The curve gets very steep at small approaches.



Design approach	Relative tower size (about)
14 °C (25 °F)	0.6
8 °C (15 °F)	1.0 (base)
4 °C (7 °F)	2.0
below 2.8 °C (5 °F)	very large; not normally guaranteed

Values read from the trend in SPX 2009, Fig. 27 (in °F, rounded). These numbers are for one example set of design conditions. In that example, halving the approach roughly doubles the tower. The real factor for your tower depends on the fill, the water loading, the air flow and the design conditions, so treat them as a trend, not a rule. Makers do not usually guarantee approaches below 2.8 °C (5 °F). This is not because it is impossible, but because small errors in measuring become too large at that point (SPX 2009, Sect. I-E-4; Perry, 7th ed., §12).

For a fixed heat load, a **larger range with less water** also gives a smaller, cheaper tower (SPX 2009, Fig. 28).

2.7 L/G and the tower characteristic (KaV/L)

Engineers use two more numbers to describe how a tower works inside.

L/G is the mass of water divided by the mass of dry air going through the tower. Most mechanical draft towers run between **0.75 and 1.5** (Perry, 7th ed., §12).

- More air (lower L/G) means colder water but more fan power.
- More water (higher L/G) means warmer water.

KaV/L is called the **tower characteristic**. It measures how much cooling surface and contact the tower gives to each kilogram of water. Values are usually **0.5 to 2.5** (Perry, 7th ed., §12).

- K is how fast heat and vapour move from water to air.
- a is the wet surface area per cubic metre of fill.
- V is the fill volume.
- L is the water flow.

These ranges are for orientation only. Here L/G is on a mass basis (kg of water ÷ kg of dry air) and KaV/L comes from the Merkel method; other books may use other bases. They are **not acceptance criteria**: a tower is judged against its own design and performance curves, not against a typical range.

You do not need to calculate KaV/L by hand. What matters is the idea behind it, called the **Merkel method**. Heat moves from the water to the air because the air right at the water surface is saturated and "richer" in heat than the air passing by. The bigger that difference, the faster the cooling. Engineers add up this driving force from the bottom of the tower to the top. The result is the KaV/L the job **needs**.

Each fill also has a KaV/L it can **give**. It goes down as more water flows per kilogram of air. Where "needed" equals "given", you find the cold water temperature. Chapter 6 and the Thermal Rating calculator use this idea.

2.8 How much water evaporates

A handy rule: **about 1 % of the water flow evaporates for every 6 to 7 °C of range** (about 0.8 % per 10 °F).

Published factors differ a little, because some of the cooling is sensible, not by evaporation:

Source	Evaporation per °C of range	Per °F of range
Perry, 7th ed., §12	0.153 % of flow	0.085 %
Marley, <i>Water Cooling Towers</i>	0.144 %	0.08 %
GPSA Sec. 11 and Branan	0.18 % (all heat by evaporation, upper limit)	0.10 %

For our tower: $6,000 \text{ m}^3/\text{h} \times 10 \text{ °C} \times 0.153 \% = \text{about } \mathbf{92 \text{ m}^3/\text{h}}$ (400 gpm) evaporated.

2.9 Follow one drop of water

It helps to follow one small parcel of water round the loop of our example tower.

1. **At the condenser.** The water picks up heat from the process and leaves at 42 °C (108 °F).
2. **Up the riser.** The pump pushes it up to the top of the tower, about 10–15 m (30–50 ft) above the basin.
3. **Through the nozzle.** The nozzle breaks the stream into a spray. Thousands of drops now meet the rising air.
4. **Over the fill.** The water spreads into thin films or splashes from bar to bar. This is where most of the cooling happens. The water spends only a few seconds here.
5. **Through the rain zone.** The drops fall freely for the last metre or two and meet the coldest, freshest air.
6. **In the basin.** The water lands at 32 °C (90 °F). It has lost 10 °C in a few seconds.
7. **Back to the plant.** The pump sends it back to the condenser to pick up more heat.

On the way, about **1.5 kg of every 100 kg** of water has turned into vapour and left with the air. That small amount carried away most of the heat.

A plant cooling system usually holds about 10–15 minutes of flow (Betz training material). So the same water goes round the loop **about 100 times a day**. Each trip leaves a little more salt behind, which is why the water chemistry in Part C matters so much.

2.10 Reading a psychrometric chart, simply

A **psychrometric chart** is a map of moist air. Engineers use it to see what happens to the air inside a tower. You do not need to draw one, but it helps to read one.

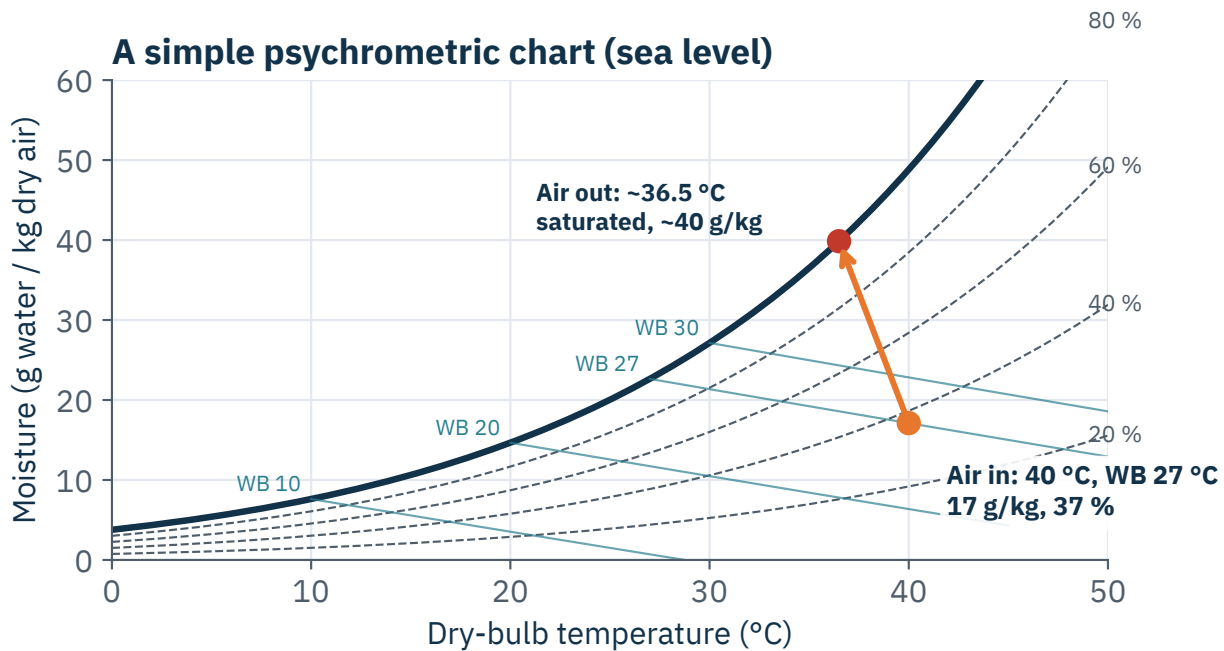


Figure 2.6 — A simplified psychrometric chart with the path of the air through the tower at Site H on a summer afternoon. Calculated with standard psychrometric equations (ASHRAE Fundamentals).

- The **bottom axis** is the dry-bulb temperature.
- The **side axis** is the moisture in the air, in grams of water per kilogram of dry air (g/kg).
- The **top curved line** is the **saturation line**. Air on this line holds all the water it can. Its relative humidity is 100 %, and its dry-bulb and wet-bulb are equal.
- The **sloping lines** are lines of equal wet-bulb. Moving along one of them, the air's total heat (enthalpy) hardly changes.
- Curves below the saturation line show **relative humidity**: 80 %, 60 %, 40 %, 20 %.

What happens in the tower at Site H on a summer afternoon:

Point	Dry-bulb	Wet-bulb	Moisture	Relative humidity
Air entering	40 °C (104 °F)	27 °C (81 °F)	about 17 g/kg	about 37 %
Air leaving	about 36.5 °C (98 °F)	about 36.5 °C	about 40 g/kg	about 100 %

Three lessons from this example:

- The leaving air is **nearly saturated**. That is why towers make a visible plume on cool or humid days.
- The leaving air is **cooler than the entering air** at Site H. Hot, dry air gives up some of its own heat to the water, and that heat also leaves as vapour. Evaporation is doing all the work.
- Each kilogram of air picks up about 23 g of water. For a 10 °C range, the tower needs roughly one kilogram of air for each kilogram of water. This is the L/G ratio of about 1.3 we met in section 2.7.

The numbers above come from standard psychrometric equations (ASHRAE Fundamentals), the same ones used in the PlantCalcKit calculators.

Watch out: Relative humidity alone does not tell you how well a tower will cool. Air at 70 % humidity and 30 °C has a wet-bulb of about 26 °C. Air at 30 % humidity and 45 °C has a wet-bulb of about 30 °C. The second air feels drier, but it gives *warmer* cold water. Always use the wet-bulb.

2.11 Worked example: is the tower performing well?

Let us work through a real question, step by step. On a summer afternoon at Site U, the shift log shows:

Reading	Value
Hot water	42 °C (107.6 °F)
Cold water	34 °C (93.2 °F)
Wet-bulb (at the air inlets)	28 °C (82.4 °F)
Circulating water flow	6,000 m ³ /h (26,400 US gpm)
Fans	all four running at full speed

Step 1 — Range and approach.

- Range = 42 – 34 = **8 °C** (14.4 °F)
- Approach = 34 – 28 = **6 °C** (10.8 °F)

Step 2 — Heat load. Flow = 6,000 × 1,000 ÷ 3,600 ≈ 1,667 kg/s. Heat load = 1,667 × 4.19 × 8 ≈ **55.9 MW** (about 191 million Btu/h).

Step 3 — Effectiveness. 8 ÷ (8 + 6) = **57 %**. This number on its own does **not** tell us whether the tower is good or bad.

Step 4 — What should the tower give? This is the real question. We need the expected cold water for **these** conditions: wet-bulb 28 °C, range 8 °C, full flow, all fans running. We read it from the maker's performance curves (Chapter 6.7). For our example tower the curves give about **32 °C**.

Step 5 — Compare. Cold water deviation = 34 – 32 = **+2 °C**. The tower is giving water about 2 °C warmer than expected.

Step 6 — What does that mean? A rough estimate with the performance-curve method shows the tower is behaving like a tower of only about **70 %** of its design capability. But before anyone says "the tower is bad", check:

1. Are the instruments right? Check the wet-bulb wick, the cold water sensor and the flow meter.
2. Was the wet-bulb measured at the inlets, not in the exit air or in the sun?

3. Are the conditions steady, and inside the limits for a fair comparison (Chapter 6.4)?
4. Do the walk-round checks show a fault: blocked nozzles, a slow fan, damaged fill (Chapter 8)?

These readings describe how the tower is running today. They do **not** prove whether it meets its design guarantee. For that, you need a proper test with corrected readings, compared with the maker's curves (Chapters 6 and 7).

The calculator does the rest. The **Cooling Tower Performance Test** calculator takes the same readings, checks them against the test limits, corrects for fan power and gives the capability with both methods. plantcalckit.com/tools/cooling-tower-performance-test

✓ FIELD CHECK

range and approach

What you see	What it may mean	First thing to check
Cold water rising	Higher wet-bulb, more heat load, or less tower capability	Compare wet-bulb, heat load and cells in service with yesterday
Approach rising at similar weather and load	Poorer air–water contact	Fans running? Nozzles, fill and water spread
Range falling	Less plant heat, or more water flow	Check the real process load and the circulating flow
Approach very small (below about 2.8 °C)	Often a sensor error	Check the wet-bulb wick and the cold water sensor

These are possible causes to check, not a final diagnosis.

🕒 ONE-MINUTE SHIFT CHECK

Check	Why it matters	Act or report when
Range	Shows the heat load	It changes a lot without a plant change
Approach	Shows how close the tower gets to the wet-bulb	It grows at similar weather and load
Wet-bulb reading	Every other number depends on it	The wick is dry or dirty, or the reading looks odd

Use the alarm and action limits in your plant's approved procedures. This book does not set them.

* ❄️ CLIMATE CORNER

range, approach and evaporation at our three sites

	Site H (hot, dry)	Site U (hot, humid)	Site C (cold, summer)
Design wet-bulb	28 °C	30 °C	20 °C
Approach chosen	5 °C	4.5 °C	6 °C
Cold water	33 °C	34.5 °C	26 °C
Hot water (10 °C range)	43 °C	44.5 °C	36 °C
Share of heat by evaporation	Highest (dry air takes much vapour)	High	Lower in winter: cold air takes more heat as sensible warmth

At Site C in winter, much of the cooling is sensible. Evaporation can fall to about 60 % of the summer value (Betz Handbook, ch. 31: evaporation factor 0.75–1.0, down to 0.6 in cold weather).

▶ TRY IT WITH PLANTCALCKIT

The **Cooling Tower Water Balance** calculator lets you pick the evaporation factor:

- **Perry 0.153 %/°C** — good everyday choice for summer operation.
- **Marley 0.144 %/°C** — slightly lower; use if your tower maker uses it.
- **GPSA / Branan 0.18 %/°C** — assumes all cooling is by evaporation. It gives the highest evaporation estimate. That makes it a cautious first estimate of makeup for early budgets. It is not "safe" for every calculation: for example, it overstates the cycles you work out from a measured blowdown. For design work, use the method your tower maker uses, and write down which factor and assumptions you chose.
- **Custom** — enter a factor you measured on site (see Chapter 9 field check).

The **Thermal Rating** calculator works out KaV/L and L/G from your design data.

plantcalckit.com/tools/cooling-tower-thermal-rating

? QUICK QUIZ 2

1. Why can a cooling tower cool water below the air temperature?
2. Hot water 40 °C, cold water 31 °C, wet-bulb 26 °C. What are the range and the approach?
3. Which number does the tower decide, range or approach?
4. About how much water evaporates for a 10 °C range?
5. Why do tower makers not guarantee approaches below 2.8 °C (5 °F)?

CHAPTER 3

Types and parts of cooling towers

Most industrial towers are mechanical draft towers with film or splash fill, and every one of them is built from the same dozen parts.

3.1 How air is moved

Type	How the air moves	Where it is used	Watch points
Atmospheric (spray) tower	Wind and the spray itself pull air in	Very small, old units	Depends on the wind; not used where steady cold water is needed
Natural draft (hyperbolic)	A tall concrete shell. Warm, moist air inside is lighter than the air outside, so it rises like smoke in a chimney	Large power stations	No fans to run, but very costly to build; works best in humid climates; needs the dry-bulb too
Fan-assisted natural draft (hybrid)	A shorter shell plus fans that run at peak times	Large sites wanting less height and less fan power	Fans may only run in summer
Mechanical draft — induced	Fan on top pulls air through and blows it out upward fast	Most industrial towers, from very small to very large	Fast exit air (3–4 times the inlet speed) carries the plume away, so less air comes back in
Mechanical draft — forced	Fan at the side or bottom blows air in	Small towers, indoor units with ducts	Slow exit air, so much more recirculation ; fans can ice in winter; centrifugal blower fans often need more power than propeller fans for the same air flow (how much more depends on the fan and the tower's air resistance)

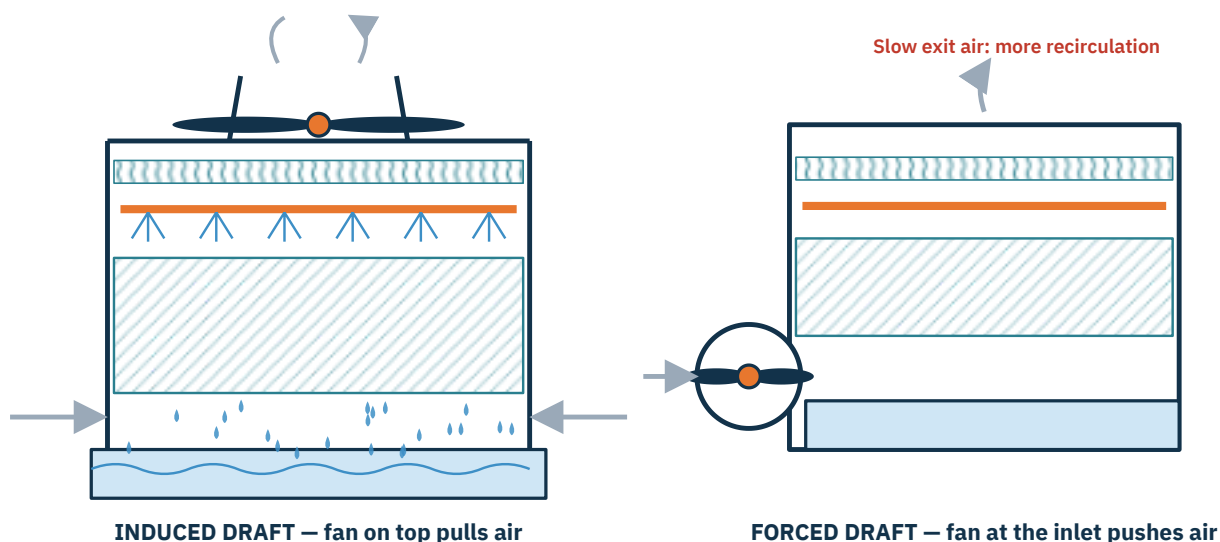
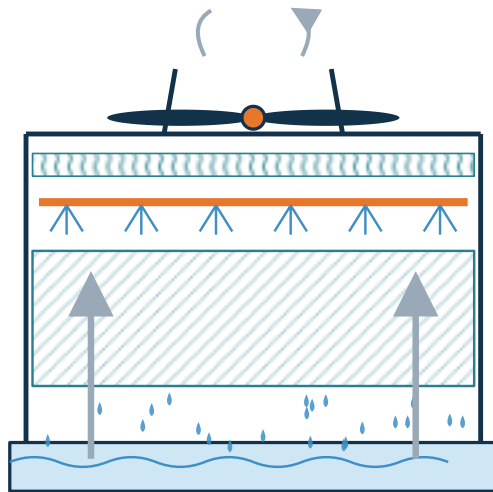


Figure 3.1 — Induced draft (left) pulls air out at high speed, so less warm air comes back in. Forced draft (right) pushes air in; its slow exit air recirculates more easily, and the fan can ice up in winter (adapted from SPX 2009, Sect. I-B).

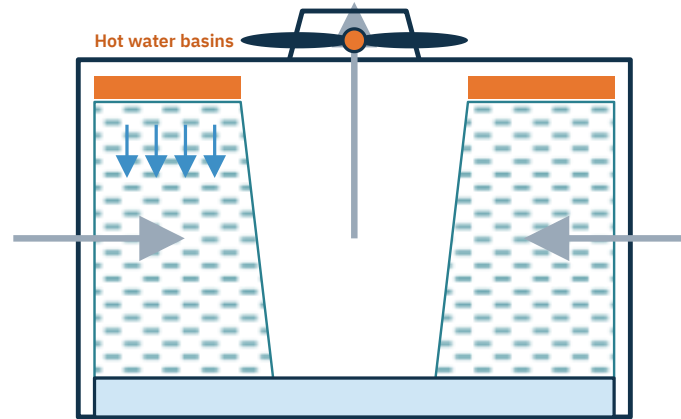
Source: SPX 2009, Sect. I-B.

3.2 How air and water meet

- **Counterflow:** air moves **up** while water falls **down**. Water is sprayed by nozzles from pipes. The tower is enclosed, so less sunlight gets in and less algae grows. It may need more pump head because of the spray system.
- **Crossflow:** air moves **sideways** through the fill while water falls down. Water flows by gravity from open hot-water basins on top, through holes in the basin floor. The basins are easy to see and clean while the tower runs. Sunlight on open basins can grow algae, so covers are often fitted.
- **Double-flow crossflow** has air inlets on two sides with one fan between them. **Single-flow** has one inlet. It suits sites where air can come from one side only, and it can face the prevailing wind.



COUNTERFLOW — air goes up, water comes down



CROSSFLOW — air goes across falling water

Figure 3.2 — Counterflow (left) and crossflow (right) towers. Crossflow towers use open hot-water basins that are easy to inspect; counterflow towers use spray nozzles under the fill deck.

3.3 Other ways to classify towers

- **Field-erected** towers are built on site. All large towers are of this kind.
- **Factory-assembled** (packaged) towers arrive almost complete, in one or a few modules.
- **Rectangular (in-line)** towers are a row of cells. Round and octagonal towers group the fans near the centre. Round towers are less affected by wind and recirculation and need less site piping (SPX 2009, Fig. 39).
- **Wet, dry and hybrid:** most towers are wet (evaporative). A dry tower has finned coils and no evaporation. Hybrid towers mix the two to save water or to stop the visible plume.

3.4 The parts of a tower, from bottom to top

1. Cold water basin. It collects the cooled water and acts as the foundation. Concrete is used for large towers; wood, steel or fibreglass for factory towers. Dirt washed out of the air settles here, so the basin must be easy to drain and clean. The floor should slope towards a sump or drain.

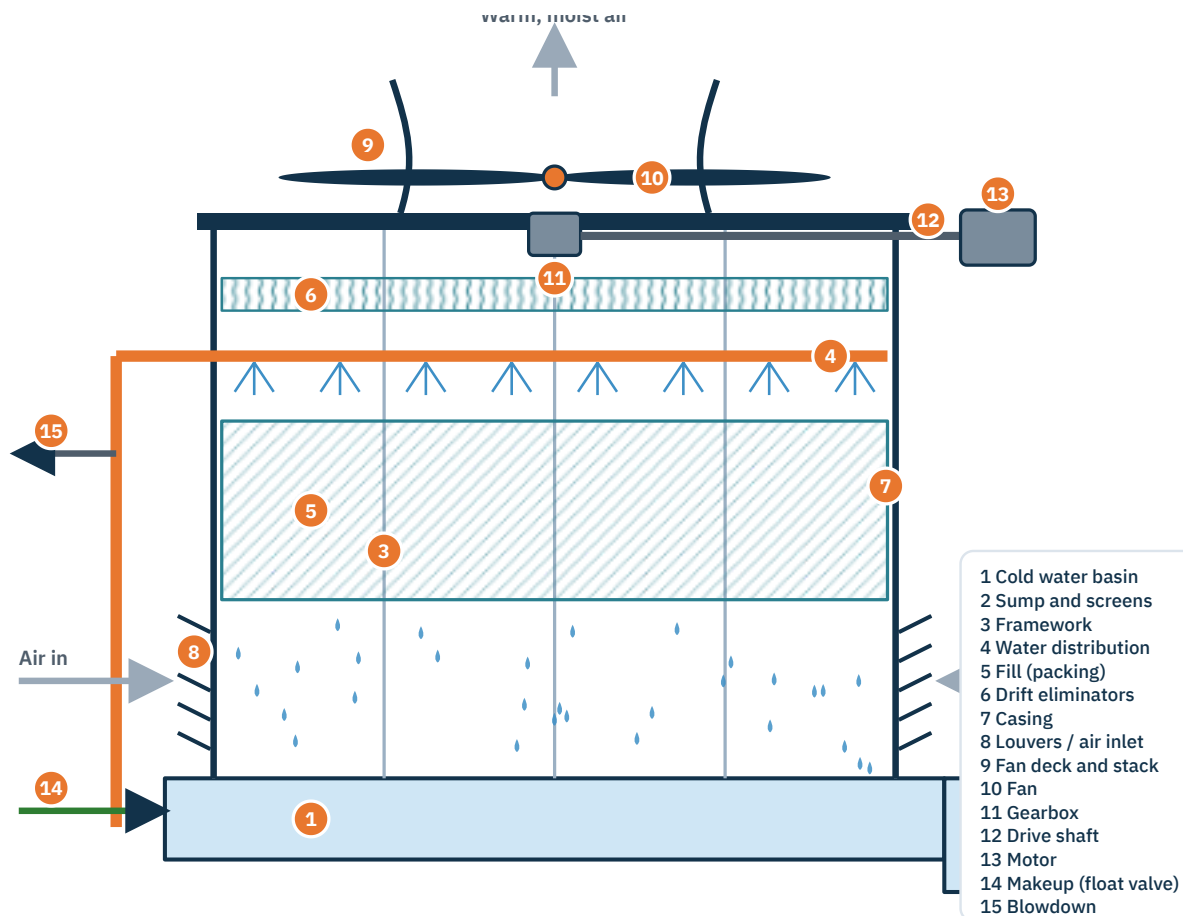


Figure 3.3 — The main parts of an induced-draft counterflow cell. The numbers match the list in section 3.4 (our drawing, adapted from the component descriptions in SPX 2009, Sections II and III).

2. Sump and screens. The sump feeds the pumps. Water should enter the sump slowly (below about 1 m/s, 3 ft/s). Screens of about 12 mm ($\frac{1}{2}$ in) mesh stop debris. Fit two sets so one can be cleaned while the other works (SPX 2009, Sect. II-B).

3. Framework. Columns and beams hold the fill, fans and pipes. Common materials are pultruded fiberglass (FRP), treated wood, concrete and galvanised or stainless steel.

4. Water distribution system. It spreads hot water evenly over the fill.

- **Gravity type** (crossflow): open basins with nozzles or holes in the floor. Easy to inspect, clean and balance.
- **Pressure spray type** (counterflow): pipes and spray nozzles. More likely to clog and harder to clean, but it adds some cooling.
- **Flow-control valves** balance the water between cells and let one basin be shut for cleaning.
- A **riser** (one per cell is common) brings water up from the supply header.

5. Fill (packing). The heart of the tower. It makes the water spread out and stay in contact with the air for longer.

Fill type	How it works	Good for	Weak points
Splash fill (bars or grids)	Water drops from level to level and breaks into droplets	Dirty water, high solids, fibres, oils	Needs more height; bars must stay level , or water runs to the low end and channels
Film fill (thin PVC sheets)	Water spreads into a thin film on closely spaced sheets	Clean water; most cooling per cubic metre	Blocks easily with debris, scale, slime or oil; needs very even water and air

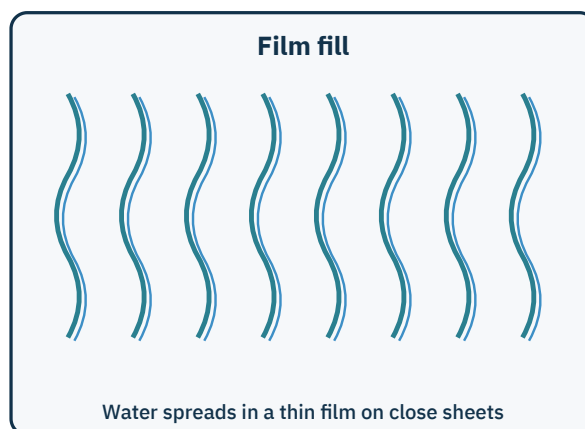
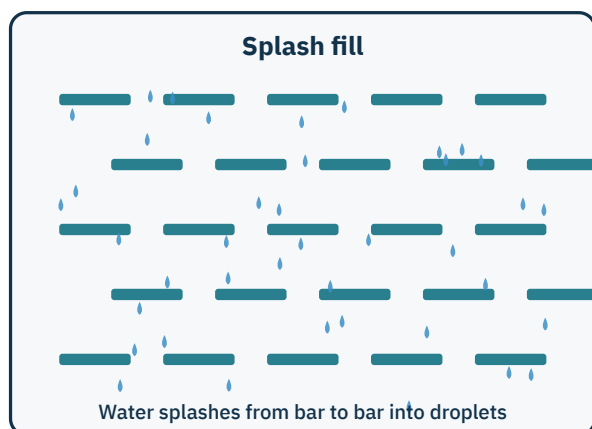


Figure 3.4 — Splash fill (left) tolerates dirty water. Film fill (right) cools more in less space but blocks easily with debris, scale or slime.

SPX (2009, Sect. II-H) advises: **do not use close-spaced film fill where the water can become dirty with debris**. Wider-spaced "clog-resistant" film fills exist, but they cool less.

6. Drift eliminators. Blades or honeycomb that force the leaving air to change direction. The small water drops ("drift") hit the blades and run back into the tower. Drift is circulating water, chemicals and all, so it can spot cars and buildings and cause ice. Modern eliminators keep drift to about **0.001 % to 0.008 %** of the water flow (SPX 2009, Sect. II-I). Older towers may lose 0.1–0.2 %.

7. Casing. The outer walls. They keep water in, form the air path for the fan and carry wind load. Usually fibreglass panels, steel or concrete.

8. Louvers. Sloped blades on the air inlets of crossflow towers. They keep water from splashing out, even out the air flow, and help in winter. Some film fills have louvers moulded into the sheets.

9. Fan deck and fan cylinder (stack). The deck is the top floor and walkway. The cylinder around the fan is shaped for smooth air flow with a small gap at the blade tips. A taller **velocity recovery** stack (flared at the top) turns some air speed back into pressure, giving more air for the same power.

10. Fan. Big towers use **propeller fans** with 4–12 blades, from about 0.6 m to over 10 m in diameter. Blades are aluminium or fibreglass. On larger fans the blade angle (**pitch**) can be set, so the fan draws the right power. **Automatic variable-pitch** fans change the angle while running. **Centrifugal (blower) fans** are used on small, indoor or ducted towers.

11. Speed reducer. Motors turn fast; big fans must turn slowly. Most towers use a right-angle **gearbox**. For continuous duty its bearings are chosen for a long life (about 100,000 hours, SPX 2009, Sect. III-C). Small towers often use **V-belts** (up to about 37 kW, 50 hp). Keep the oil level right and belts tight.

12. Drive shaft. Connects the motor (outside the air stream) to the gearbox. It spins at motor speed (often about 1,500–1,800 rpm), so it must be **balanced** and resist corrosion. Flexible couplings at both ends allow small misalignment. A guard holds the shaft if a coupling fails.

13. Motor. Usually a three-phase, totally enclosed motor, fitted with drain holes. **Two-speed** motors and **variable frequency drives (VFDs)** save energy and help in cold weather. A 1.15 service-factor motor runs cooler and lasts longer. Space heaters keep idle motors dry.

14. Makeup, overflow and blowdown. A float valve or level probes control makeup water. The overflow must be able to pass the full makeup flow if the valve sticks. Blowdown is often taken from the hot-water riser, where it is easy to control.

15. Access and safety. Ladders, stairs, handrails, doors into each cell, fan guards on short fan cylinders, and **vibration switches** that stop a fan if it starts to shake (SPX 2009, Sect. II-L and VI-I).

3.5 Materials and water quality

SPX (2009, Sect. I-G) gives a "normal" water for standard tower materials. These are guide values for choosing tower materials, not operating limits for your plant. Your real limits depend on the metals in the whole system, the treatment programme, the cycles and your maker's and treatment adviser's advice. Outside these guide values, materials need a review:

- pH between 6 and 8
- Chloride (as NaCl) below 750 mg/L
- Sulfate below 1,200 mg/L
- Sodium bicarbonate below 200 mg/L
- Temperature below about 50 °C (120 °F)
- Chlorine dosed now and then, with free chlorine **not above 1 mg/L**

Wood towers should not see hot water above about 60 °C (140 °F). Water low in calcium (negative saturation index) can eat away concrete. Wood and plastics tolerate poor water well; carbon steel does not.

3.6 Closed-circuit coolers and evaporative condensers

In an ordinary (open) tower the plant water itself falls through the fill. Some systems cannot accept that. The water may be too valuable, too clean, or it may pick up dirt and oxygen. For these, makers build two close cousins of the cooling tower.

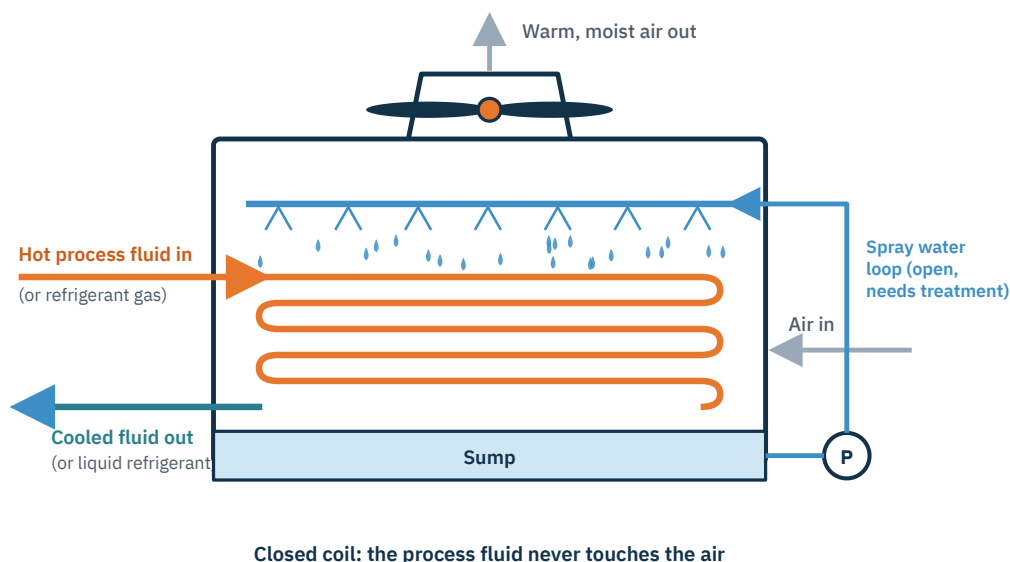


Figure 3.5 — A closed-circuit cooler (fluid cooler). The process fluid stays clean inside the coil; only the spray water is open to the air. An evaporative condenser is the same, with refrigerant condensing inside the coil.

- **Closed-circuit cooler (fluid cooler).** The plant fluid flows inside a coil of tubes. A separate spray water system wets the outside of the coil, and a fan blows air over it. The spray water evaporates and cools the coil. The plant fluid never touches the air.
- **Evaporative condenser.** The same idea, but a refrigerant (such as ammonia) condenses inside the coil. It is common in cold stores, ice plants and food factories.

Feature	Open tower	Closed-circuit cooler
Plant water	Exposed to air, dirt and oxygen	Stays clean inside the coil
Size for the same duty	Smaller, cheaper	Larger and more costly
Approach	Can be closer	Wider, because heat must pass through the tube wall
Water treatment	Treat the whole system	Treat only the small spray-water circuit, but the coil outside scales easily
Winter	Ice control needed	The coil can run dry in winter (no evaporation, no ice) if the fluid has antifreeze

The spray water of a closed-circuit cooler needs the same care as any tower water: bleed, scale control and biocide. Scale on the outside of the coil is the most common reason these units lose capacity.

✓ FIELD CHECK

parts you can see

What you see	What it may mean	First thing to check
Dry patches on the fill	Blocked or missing nozzles	Hot water basin or spray header, nozzles
Water splashing out of the air inlets	Wind, high flow, or damaged louvers	Louvers, flow rate, wind direction
Mist or droplets above the fan stack	Damaged or missing drift eliminators	Eliminators: gaps, sagging, missing panels
Green growth on decks	Sunlight on open hot water basins	Basin covers; biocide control

These are possible causes to check, not a final diagnosis.

* CLIMATE CORNER

choosing a tower type

- **Site H (hot and dry):** Natural draft towers work poorly in dry, hot air and at high altitude, so mechanical draft is usual. Dust storms block film fill; consider clog-resistant fill, inlet screens and side-stream filters.
- **Site U (hot and humid):** Natural draft towers are used mainly for very large loads. Whether one suits a site depends on the whole climate (air temperature and humidity together), the shell size and the water temperatures — humidity alone does not decide it. Most towers at Site U are mechanical draft. Algae grow fast in sunlight, so cover open hot-water basins. Salty air and brackish water call for stainless or silicon-bronze bolts.
- **Site C (cold):** Induced draft is preferred because the fan sits in warm exit air and does not ice up. Two-speed motors or VFDs make winter control much easier. Other possible winter measures include inlet louvers or wind walls, a hot-water bypass to the basin for start-up, and basin heaters. Choose them with the tower maker and follow the maker's winter operating procedure.

► TRY IT WITH PLANTCALCKIT

Before testing or rerating a tower, collect its datasheet: type, number of cells, design flow, hot and cold water, design wet-bulb, fan power and fill type. The **Thermal Rating** and **Performance Test** calculators ask for exactly these values. plantcalckit.com/tools/cooling-tower-performance-test

? QUICK QUIZ 3

1. In a counterflow tower, which way does the air move?
2. Why is film fill a poor choice for dirty water?
3. What job do drift eliminators do?
4. Why must splash bars stay level?
5. Why is an induced draft tower less affected by recirculation than a forced draft tower?

Enjoyed the free sample?

The full guide continues with 13 more chapters: performance monitoring, CTI-aligned performance testing, reading test results, a complete troubleshooting guide, the water balance, cooling water chemistry parameter by parameter, scale, corrosion, fouling and microbes, treatment and dosing, mechanical upkeep, saving energy and water, worked examples for all three climates, small versus industrial towers and the economics of size, sustainability, a glossary, printable checklists and quick-reference tables.

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