

Cooling Tower Efficiency

Ensuring Best Efficiency For Your Cooling Tower Project

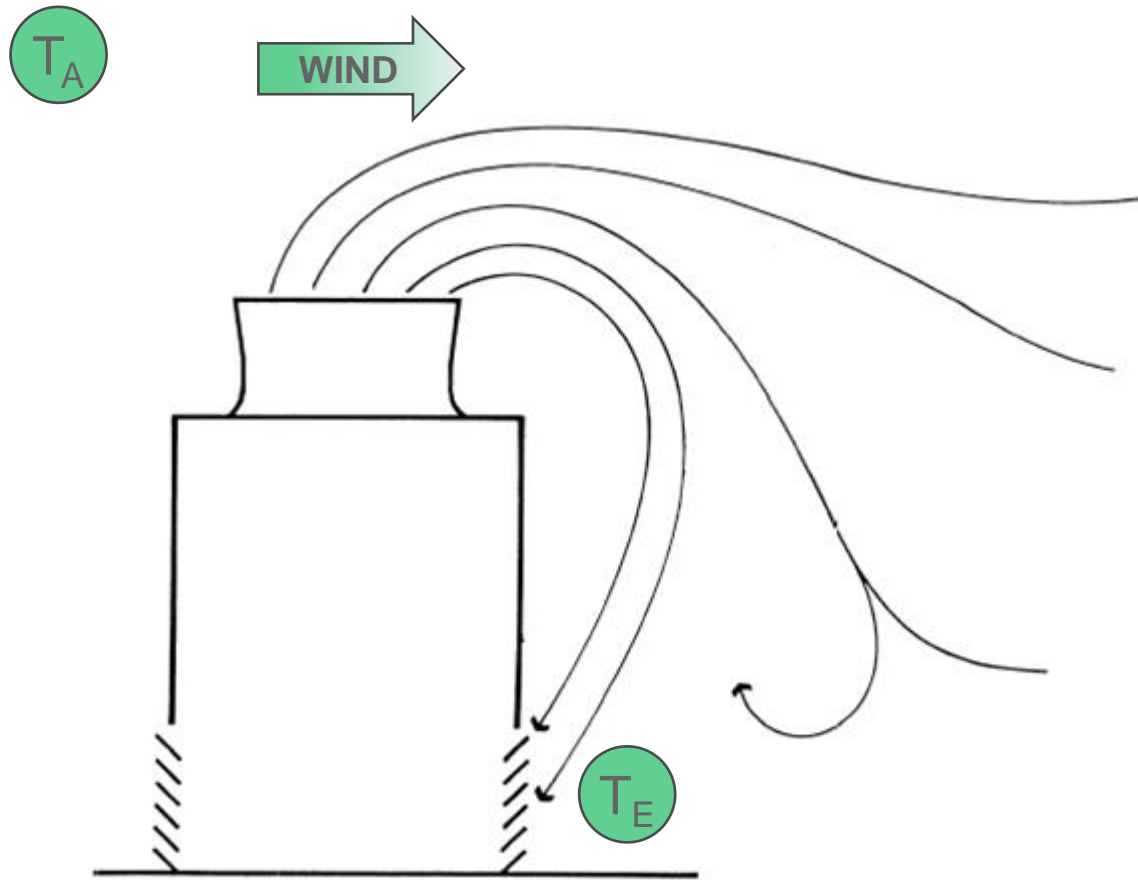
- Recirculation & interference
 - Types of Tower
 - Wind direction
- Air inlet space requirements
 - Walls / Enclosures / Existing structures
 - Available plan area
- Factors in cooling tower sizing
 - Applicable fill area
 - Heatload vs. approach
- Variable flow for energy savings
 - Applicable f



- Recirculation & Interference

Recirculation

It is wet bulb at the tower air inlet which matters



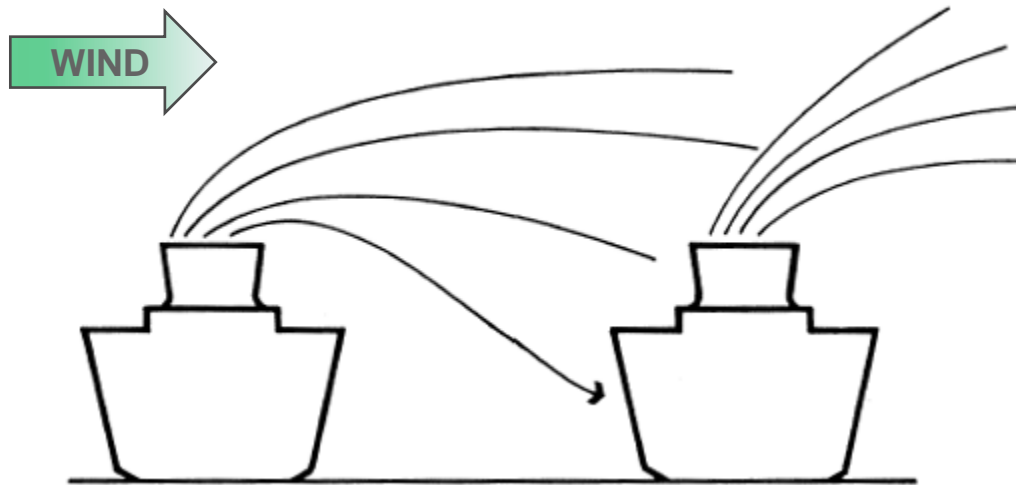
T_A – Ambient wet bulb is a general number which could apply anywhere in the site vicinity

T_E – Entering wet bulb is the temperature entering the tower, taking into consideration location specific factors, such as saturated air from the tower discharge, being induced back into the air inlets

Important to specify entering wet bulb to suppliers

Interference

It is wet bulb at the tower air inlet which matters



Local heat sources up wind of the cooling tower can elevate the wet bulb temperature of the air entering the tower, thereby affecting its performance. This could be an existing cooling tower, or another source of heat. This phenomenon is called “interference”.

Important to specify entering wet bulb to suppliers

Recirculation

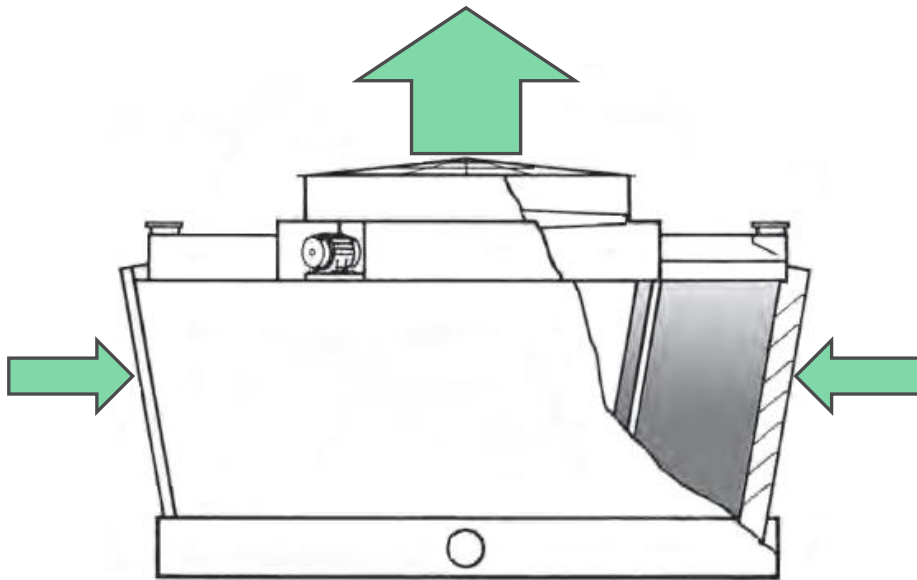
Factors that determine the amount of recirculation:

- **Discharge velocity** – recirculation is reduced by higher discharge velocities, which propel the discharge air away from the tower. The discharge air is warmer than the ambient air, so it will rise away from the tower naturally, once it is beyond the influence of air currents in the vicinity of the tower.
- **Air inlet velocity** – recirculation is increased by higher air inlet velocities, which create a low pressure area around the air inlet. This can draw the discharge air back into the tower inlet.
- **Tower orientation** – a long multi-cell tower installation will recirculate less when installed with the multiple fans in line with the prevailing wind direction. In this orientation, the separate tower plumes concentrate together into one plume of higher buoyancy. Also, a cooling tower which discharges horizontally should be oriented to discharge in the downwind direction of the prevailing wind, to prevent discharge air being drawn back to the air inlet side of the tower.
- **Enclosures & surrounding structures** – enclosures or surrounding buildings can encourage recirculation, especially if the tower is completely surrounded. This forces the incoming air to pass near the discharge air, increasing the risk of mixing. Also when combined with wind, low pressure areas form below the edges of non-streamlined obstacles.

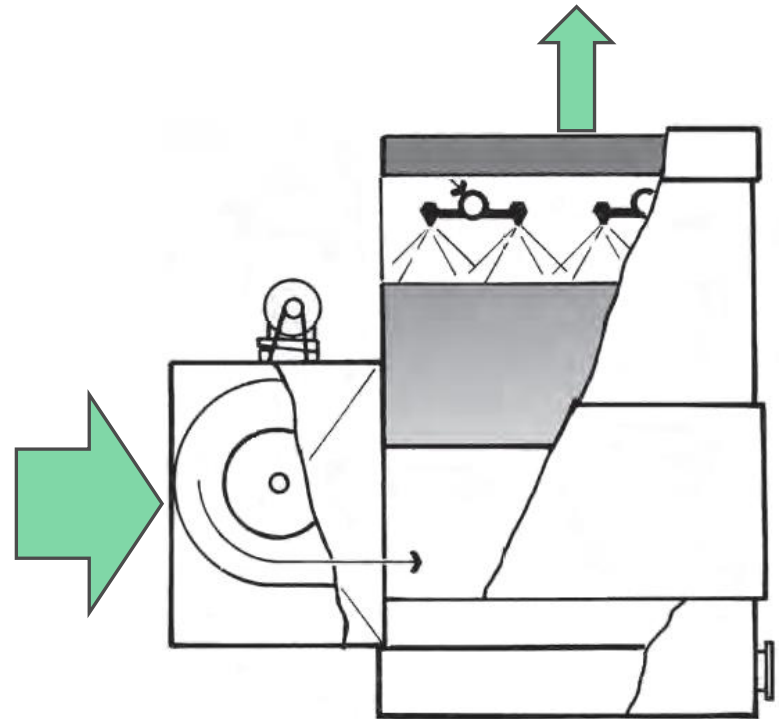
Almost all towers will recirculate some amount, some of the time

Recirculation – Types of Tower

- **Induced Draught** – Discharge air is propelled out of the tower at approx. 10m/s, while fresh air is drawn into the intakes at less than 3.5m/s. This velocity relationship gives reasonable assurance that the tower will be subjected to very little self-imposed recirculation. However, external influences could still cause recirculation.



- **Forced Draught** – Velocity relationships are reversed, so intake velocity is more like 10m/s, discharge less than 3.5m/s. The high intake velocity causes a low pressure area around the air intake, which can draw the low velocity discharge air back into the tower.

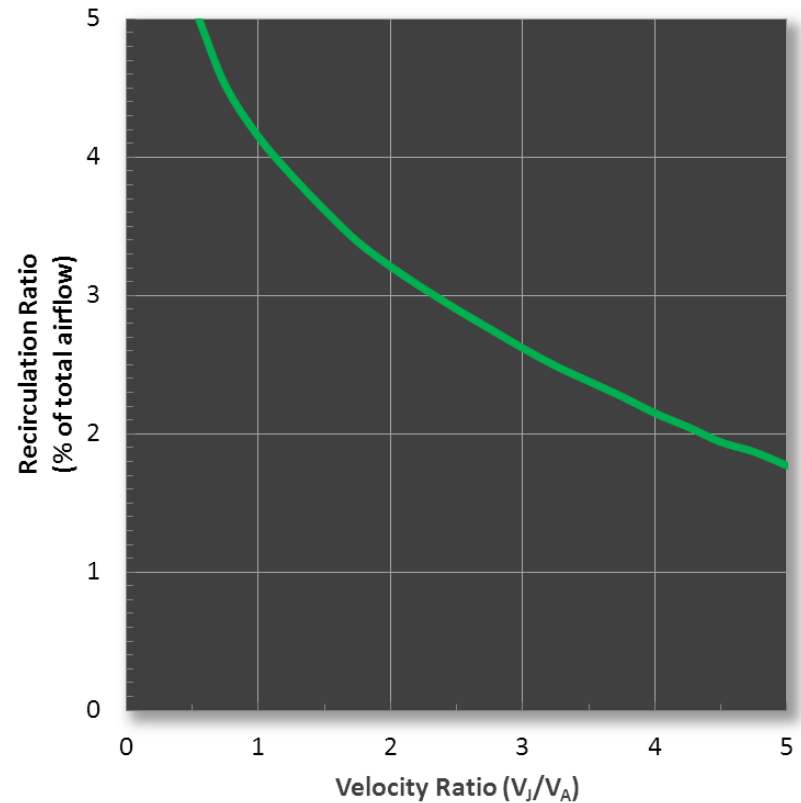
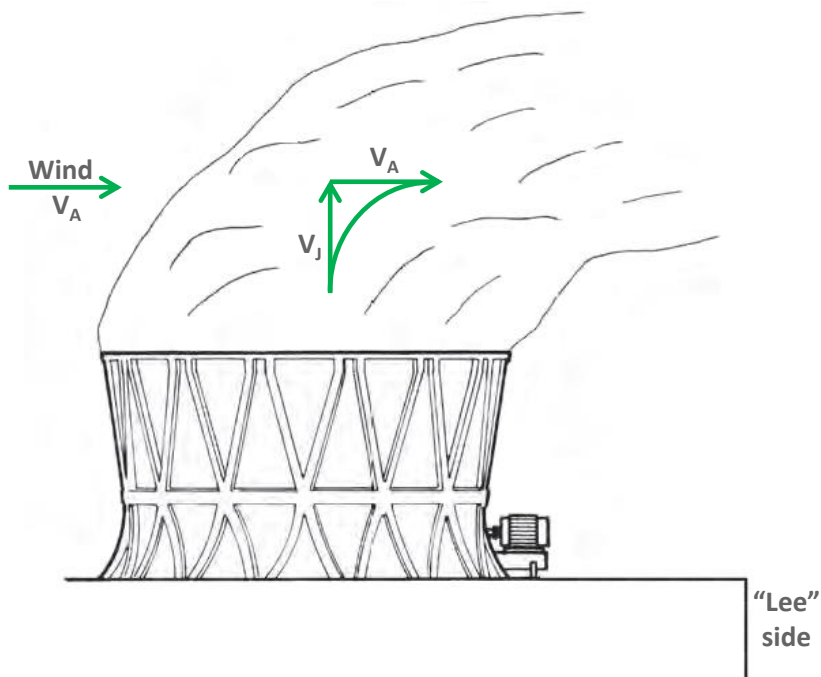


If recirculation is a major concern, consider the type of cooling tower you propose as the solution

Recirculation – Effects of Wind

Wind, depending on its speed and direction (prevailing wind direction vs. air inlet face orientation), tends to magnify a cooling tower's potential to recirculate:

- Creates low pressure area on “lee” side of cooling tower
- Bends the exiting plume

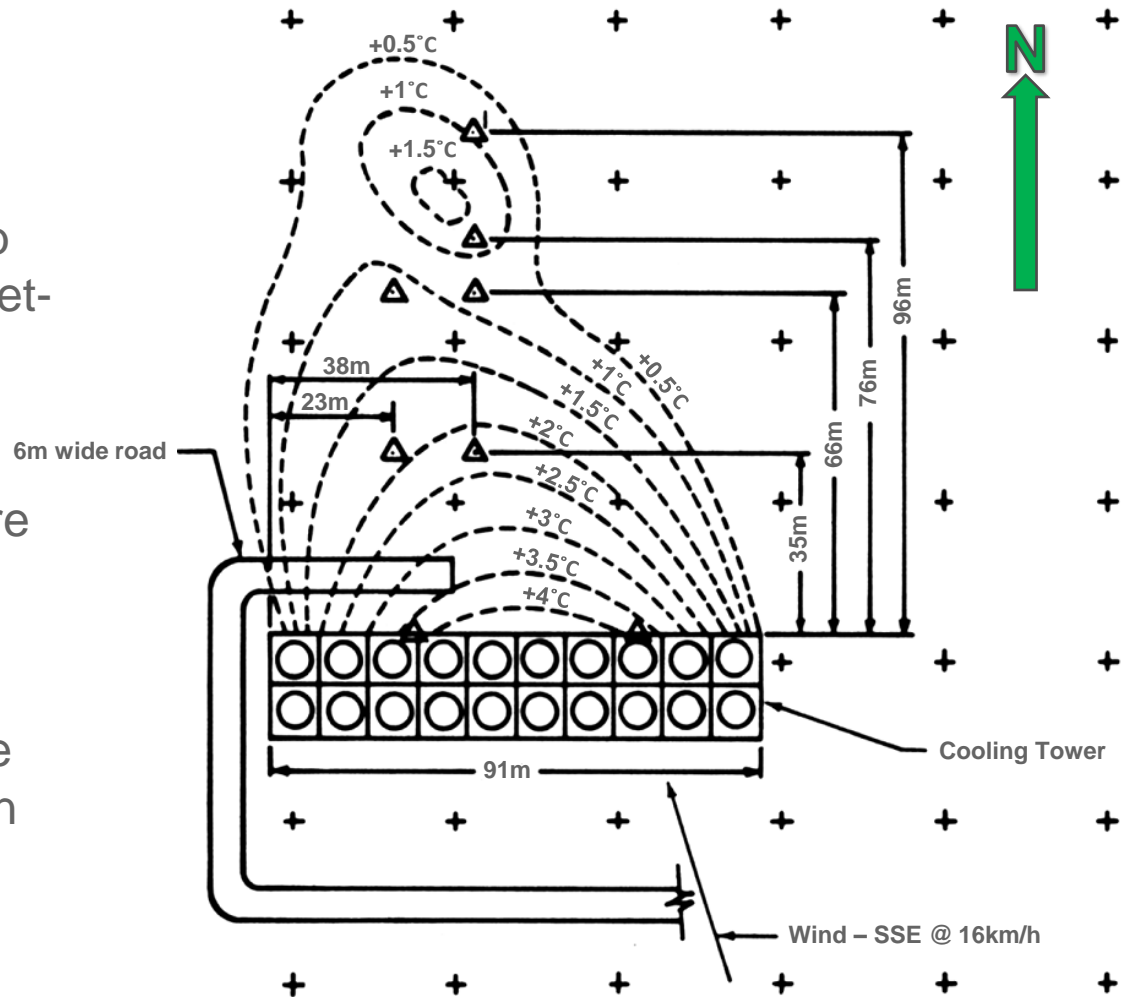


For a fixed tower air discharge velocity, an increase in wind results in an exponential increase in recirculation potential

Scale of recirculation's effect on entering wet bulb

Lines of constant temperature difference show downwind wet-bulb increase over ambient wet-bulb.

Effects of recirculation are exaggerated on larger multi-cell towers. On a single-cell packaged cooling tower, it would be unusual to see more than 1°C difference at the air inlet.

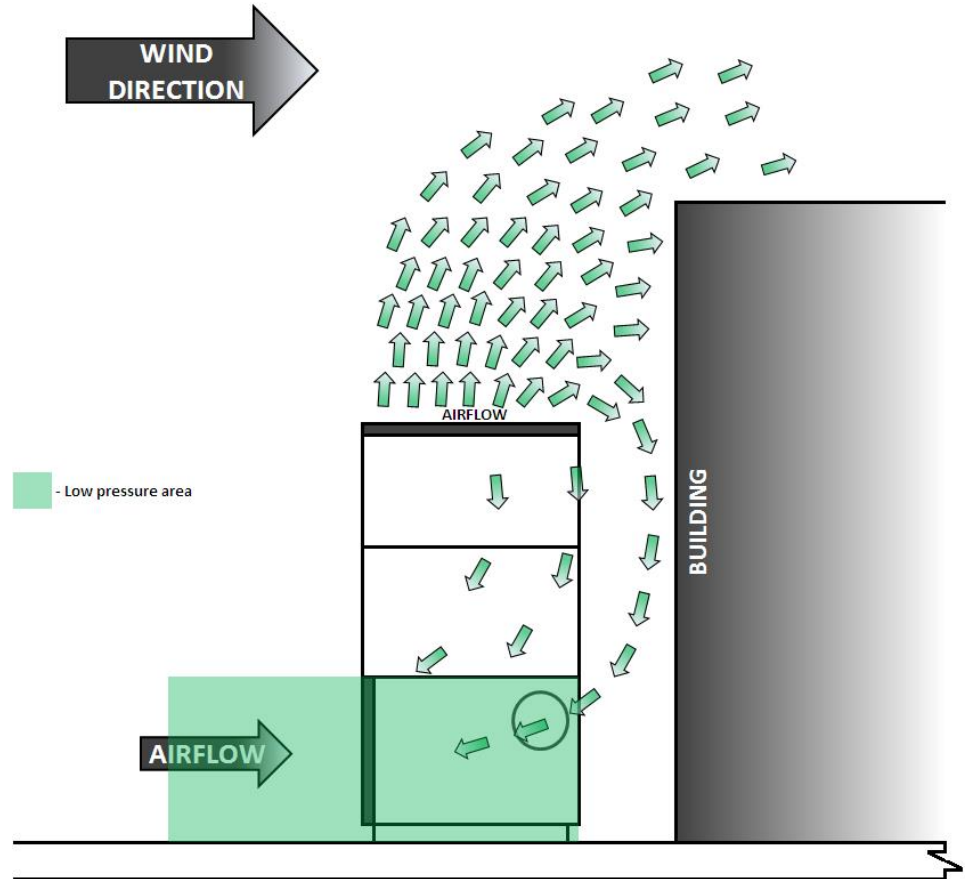


Although this is an extreme case, size of tower dramatically effects how much recirculation can occur

Siting's effect on recirculation – forced draught

When siting a cooling tower next to a building, wind direction and discharge elevation need to be considered to avoid recirculation.

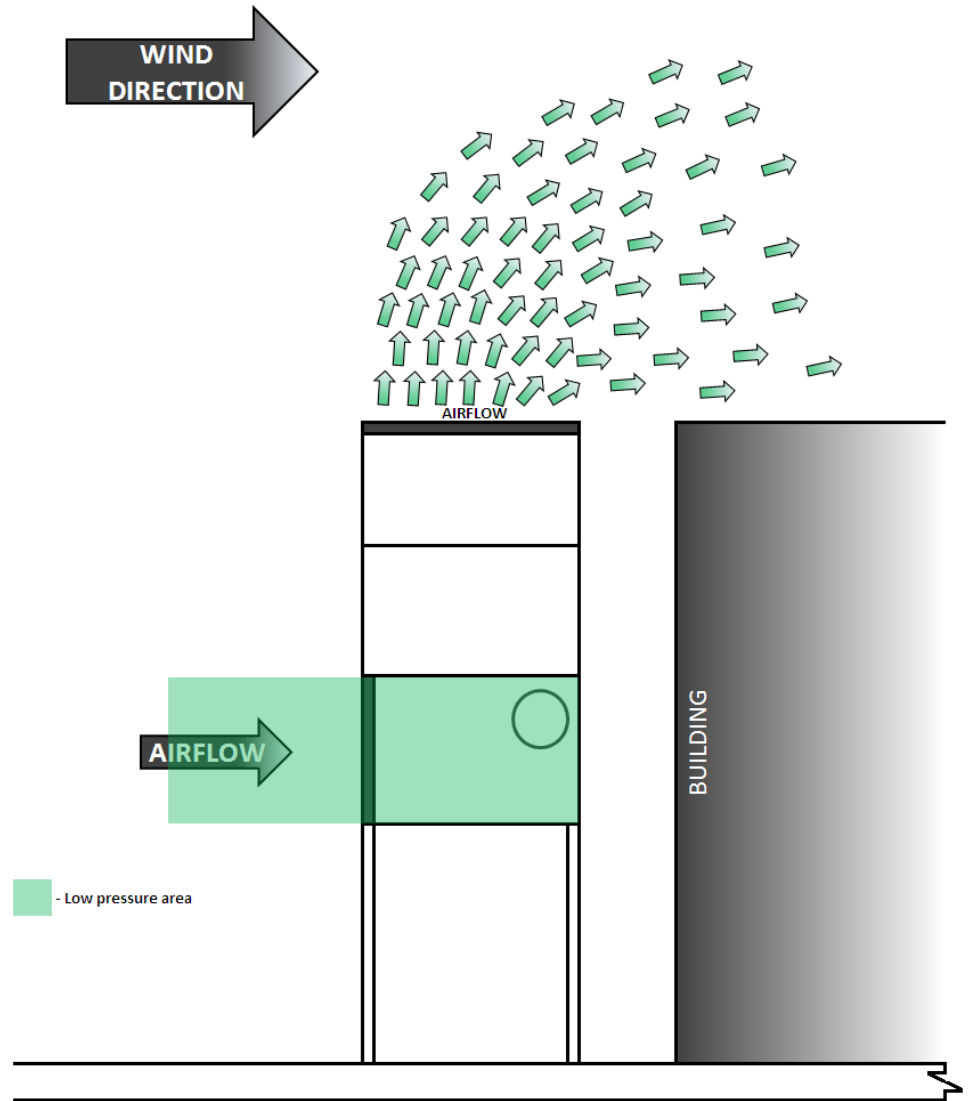
The higher building elevation, and low discharge velocity encourages the air back down towards the low pressure area around the air inlet, created by the high inlet velocity of a forced draught configuration.



This phenomenon is more common with forced draught towers due to the air inlet/discharge velocity relationship

Siting's effect on recirculation – forced draught

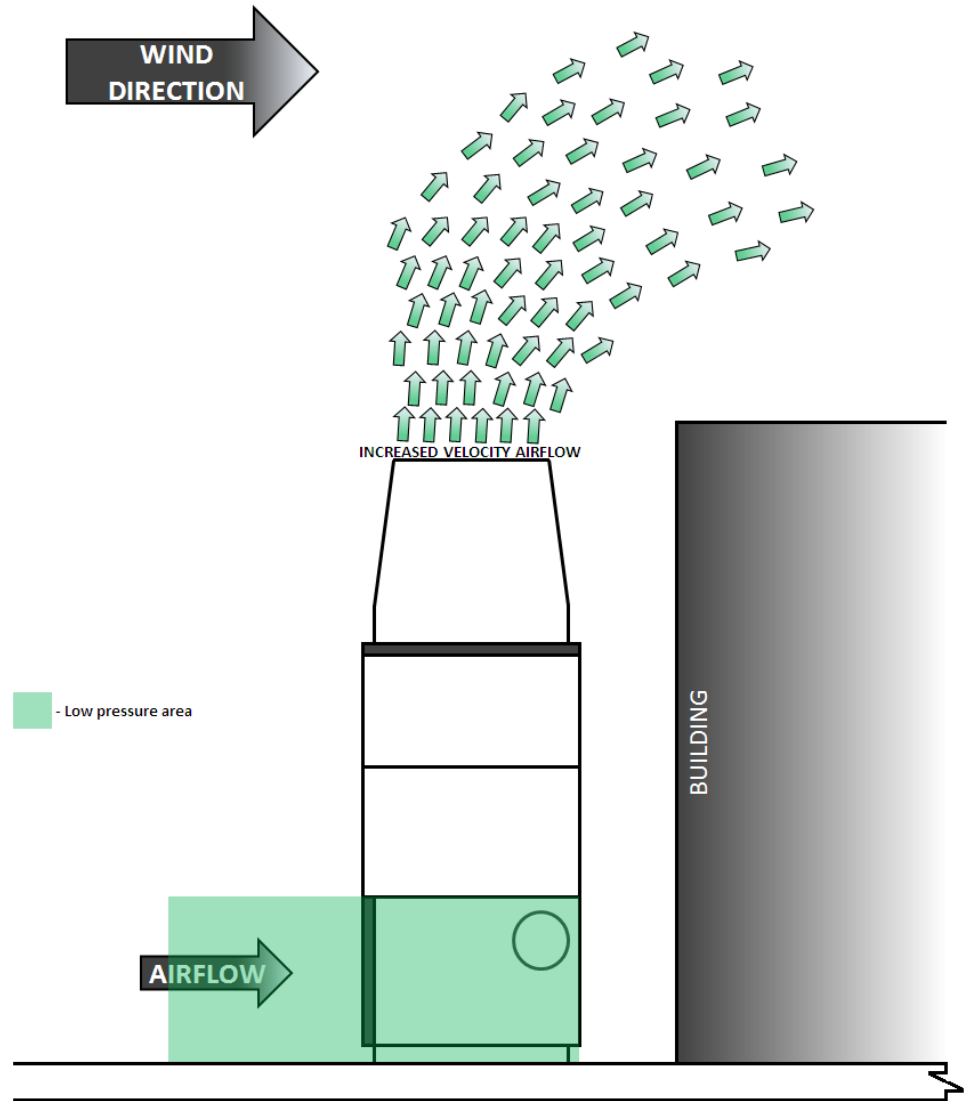
Solution – Raising the cooling tower on supporting steelwork so that the discharge elevation is level with the building. The wind carries the air directly over the building.



Ensure you also consider maintenance implications when raising a cooling tower above grade

Siting's effect on recirculation – forced draught

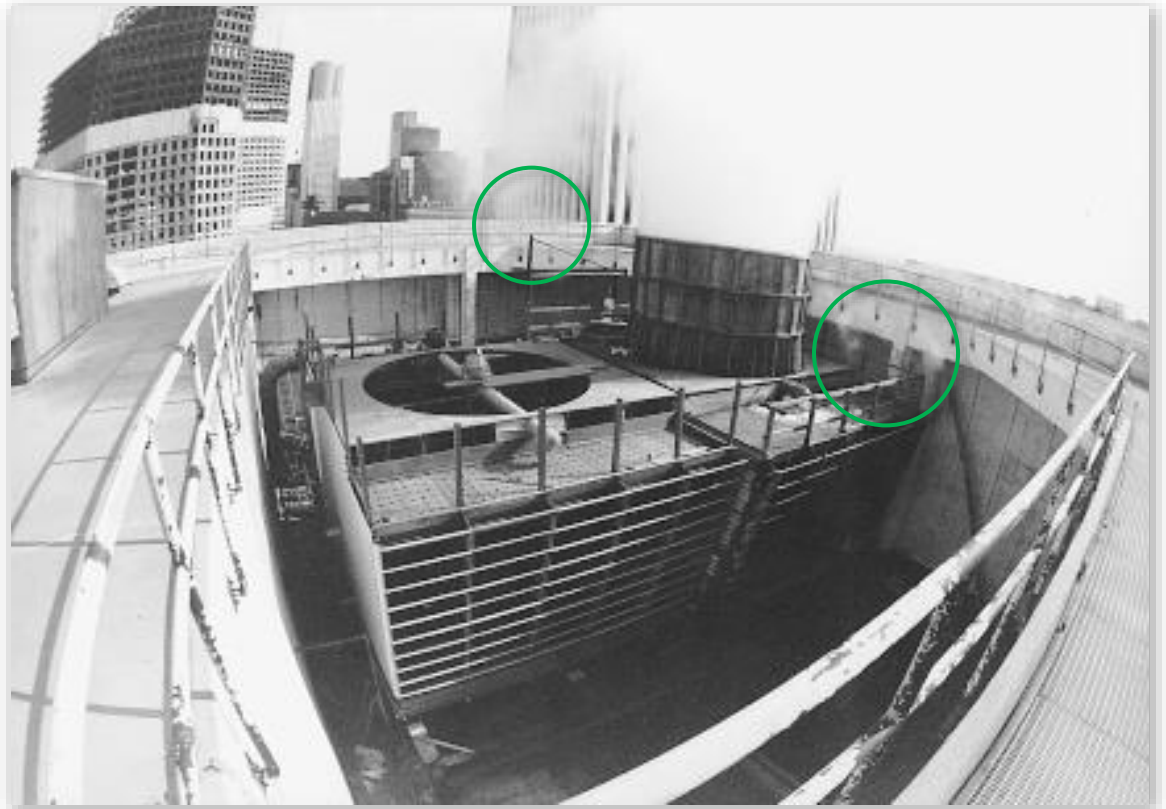
Alternative – Adding a tapered discharge duct increases the velocity and elevation of the exiting air, preventing it from being drawn back down into the tower inlet.



Recirculation – induced draught

This induced draught cooling tower has been installed inside a “well”, surrounded on all 4 sides. This type of location will invite serious recirculation, because the incoming air has to pass right by the discharge air to get into the well.

A fan stack has been added to the cell on the right to try to increase the discharge elevation, but you can still see the warm discharge plume being drawn down towards the air inlets.

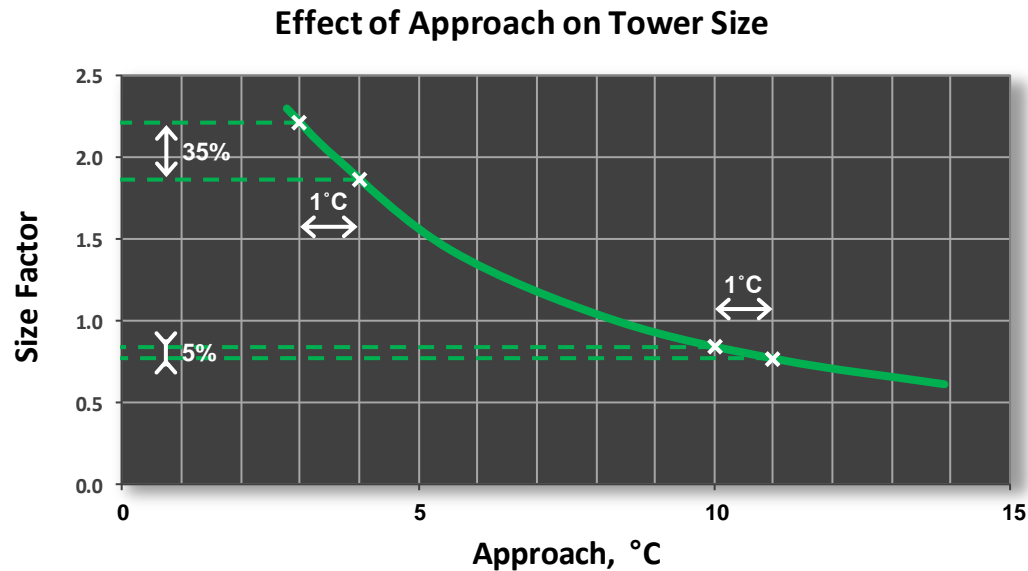


External influences can adversely affect induced draught towers too, they are not immune to recirculation

Incorporating recirculation into design wet bulb

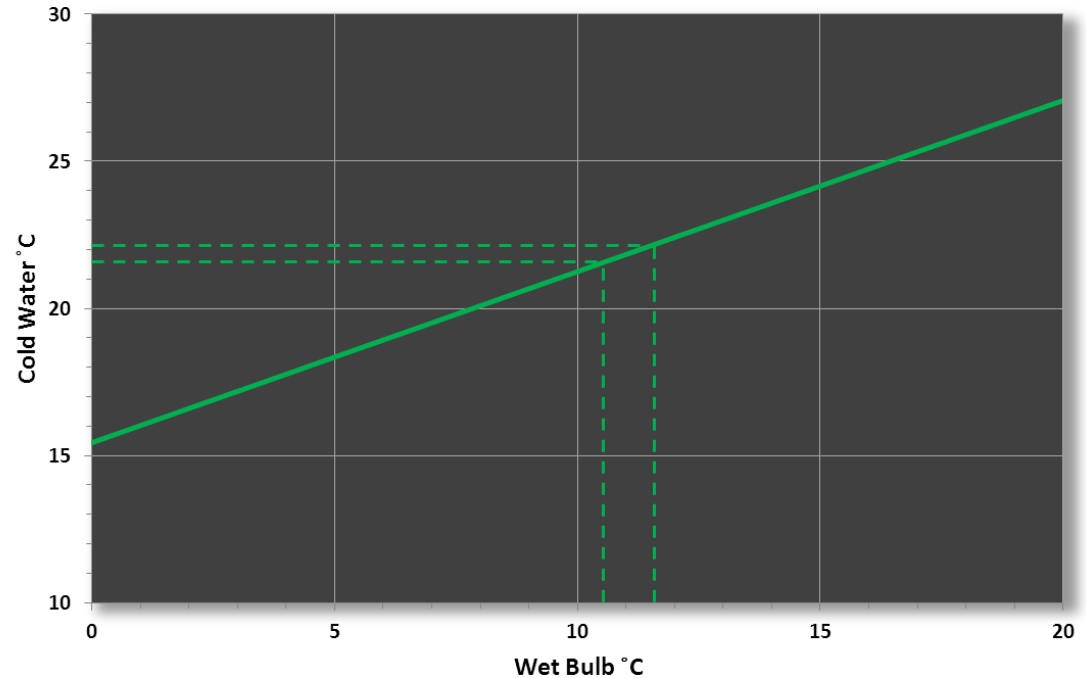
If adjusting the siting of the tower is not possible, an estimation can be made in the tower design for recirculation or interference by increasing the design wet bulb.

At higher approach temperatures, the effects of a 1°C increase in WB would not cause as much of an impact on tower size. But at low approaches, a 1°C increase could effect the tower size by 30-40%.



Recirculation effect on process cold water temperature

- As a rule of thumb, a 1°C rise in wet bulb will result in a 0.5°C rise in cold water temperature.
- How critical this much of a rise in CWT is, will depend on the process the cooling tower is serving.
- For HVAC, a 0.5°C rise in CWT equates to approx. 2% chiller inefficiency



Example –

- 1000 ton water cooled chiller & cooling tower installation
- 450kW total installed motor power
- \$0.15 / kWh

Difference in energy cost per year caused by 0.5°C higher CWT from tower - \$7,884!

What seems like a minor siting issue could lead to significant increases in performance / running costs

Mistakes others have made



- Air Inlet Space Requirements

Air Inlet Space Requirements

Air Flow

Considering the following assumptions...

- Fixed heat load
- Fixed water flow
- Fixed wet bulb temperature

...the cold water temperature produced by a cooling tower is totally dependent upon the quantity of entering air.

Static Pressure

The measure of a system's resistance to a given flow of air. It results from changes in airflow direction and restrictions in the system (which increase air velocity), such as:

- Fill
- Drift Eliminators
- Piping
- Structure

These combine to produce a total net static pressure which determines the fan motor power applied.

If something should happen to cause an increase in the static pressure, air flow through the tower will decrease, and a higher cold water temperature will result.

Air Inlet Space Requirements

Tower Type / Orientation

- How many faces of the tower have air inlets?
- How will the air inlets be oriented?
- What obstacles surround the tower?
- Are there any potential sources of interference nearby?
- What is the prevailing wind direction?
- Are there any noise sensitive directions?



Different towers can have 1, 2, 3 or 4 air inlet sides

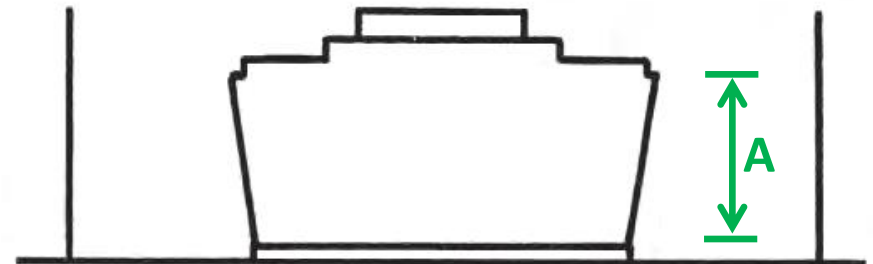
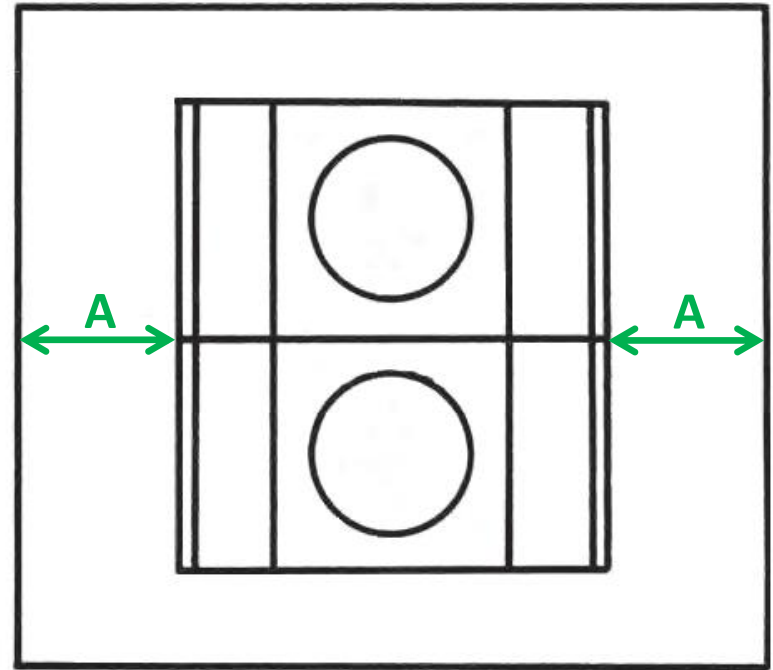
Air Inlet Space Requirements – Walls / Enclosures

- Air restrictions are a form of interference since they interfere with the free flow of air into the cooling tower.
- Due to the effect that air restrictions can have on the air velocity entering the tower, they can also intensify recirculation.

Which of these 2 effects is of greatest concern depends on the type of tower.

Rules of Thumb – Induced Draught Crossflow Tower

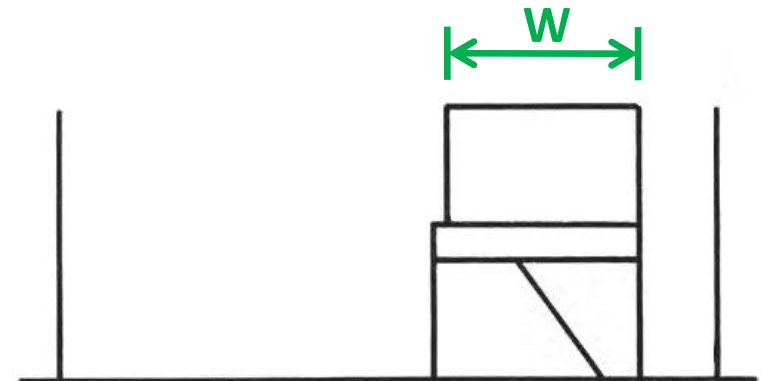
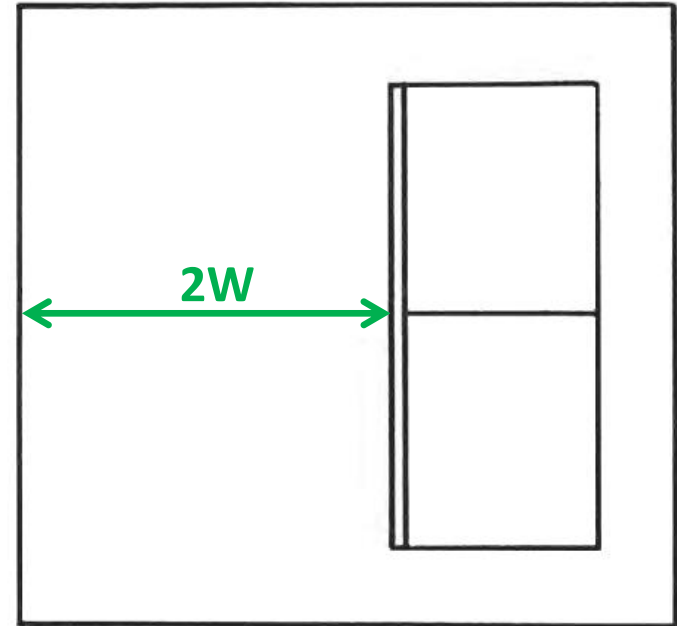
- In approximate terms, the distance from air inlet to nearest enclosure wall should be the same dimension as the air inlet height of the tower.
- Induced draught towers develop less total static pressure than forced draught towers.
 - more sensitive to the impact of external air losses
 - ***air inlet clearances must be governed by their potential to add system air losses***
- With minimum clearances as shown, the maximum possible downward air velocity will not exceed the lowest velocity component of the tower, the air inlet face.
- Since pressure is a direct function of velocity, the added air loss can be considered negligible.
- Although the downward movement of air has effectively moved the tower inlet closer to the discharge, the 3:1 ratio between discharge and inlet velocities has been maintained, so the chance of recirculation has only slightly increased.



Rule applies to 1 or 2 cell towers only. For towers with more than 2 cells, add 15% to the dimension for every extra cell

Rules of Thumb – Forced Draught Tower

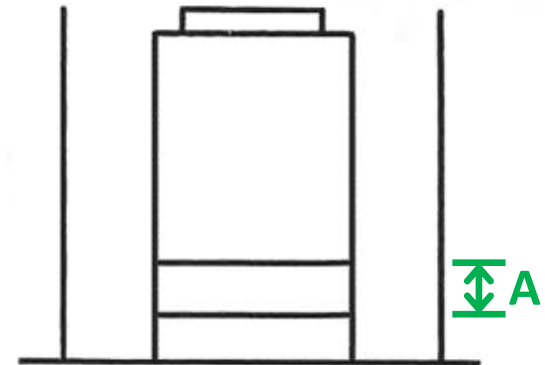
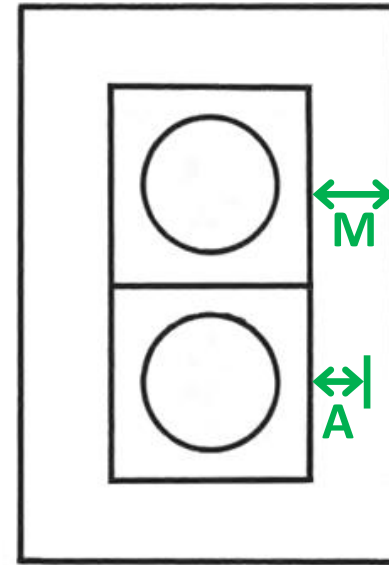
- In approximate terms, the distance from air inlet to nearest enclosure wall should be double the width dimension of the cooling tower.
- Forced draught towers have a relatively high internal static pressure, so the impact of a small amount of air loss is of less importance.
- However, because a forced draft tower is more prone to recirculating, ***the air inlet clearances must be determined by their potential to contribute to recirculation.***
- With the minimum dimensions shown, we ensure an upward discharge velocity at least twice that of the downward velocity into the enclosure.
- Although a greater out/in velocity differential is better in order to reduce the possibility of self-imposed recirculation, increasing the overall enclosure area more than this becomes impractical – and does nothing to improve the situation further.
- A tapered discharge duct would be an additional recommendation to reduce the recirculation potential.



Rule applies to 1 or 2 cell towers only. For towers with more than 2 cells, add 15% to the dimension for every extra cell

Rules of Thumb – Induced Draught Counterflow Tower

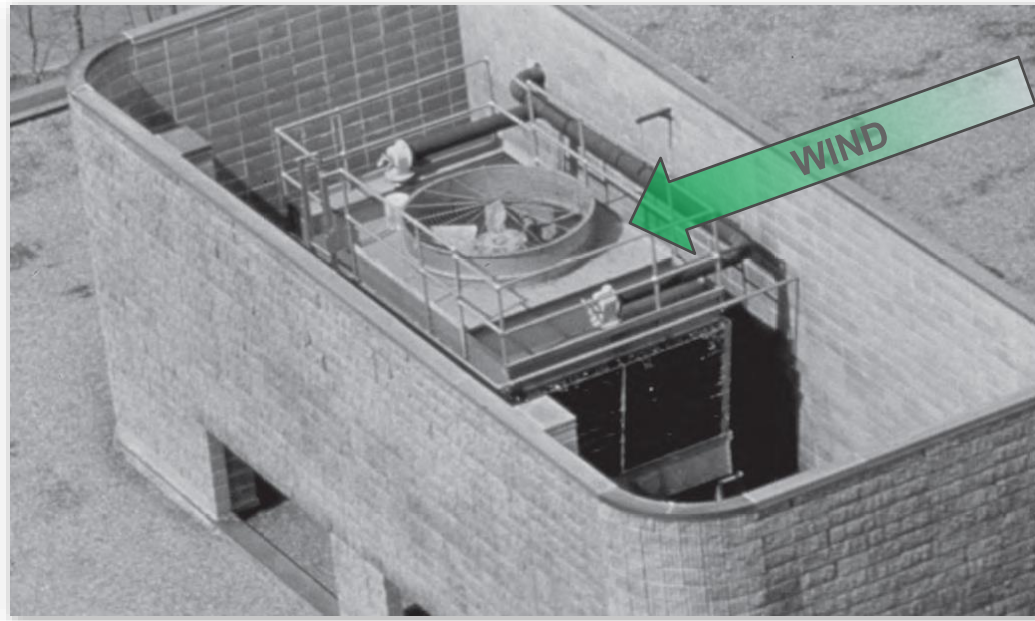
- In theory, the same rule applies as per an induced draught crossflow – distance to nearest wall should be equal or greater than air inlet height
- Because this distance is so much smaller typically on an induced draught counterflow, maintenance access becomes the deciding factor, not airflow.
- Typical maintenance access for this type of tower would be a minimum of 1000mm. Under normal circumstances, more than this would be given to allow for comfortable working.



Rule applies to 1 or 2 cell towers only. For towers with more than 2 cells, add 15% to the dimension for every extra cell

Rules of Thumb - General

- To minimise recirculation, enclosure walls must be equal to, or less than, the elevation of the tower's point of air discharge
- Depressing a tower in an enclosure will increase recirculation considerably
- Openings can be included in the walls to “ventilate” the enclosure. Caution should be taken as this is nowhere near as effective as having correct air inlet space.
- Also, with a prevailing wind in the direction shown, a low pressure area would form on the lee side of the enclosure, promoting recirculation.



Any enclosures with questionable air flow should be reviewed by the cooling tower supplier

Air Inlet Space Requirements – Calculation Method

- Enclosure velocity is the rate at which air needs to be drawn down in between the enclosure walls and the cooling tower air inlets, to supply it with as much air as it needs to perform the cooling duty.
- This velocity is calculated from the amount of air needed by the tower, and the amount of air available in the surrounding enclosure.
- If this air inlet velocity is increased because the enclosure is too small, this increases the external static pressure on the tower, and causes a drop in performance.
- In a space critical project, the cooling tower supplier should assume an enclosure velocity of anything less than ~1.5 m/s to be negligible – or in other words if the velocity does not rise above 1.5 m/s, there is no performance impact on the tower.
- Some suppliers will work on the basis of between 1.5 - 2.0 m/s negligible enclosure velocity, which can reduce the accuracy of the performance estimate.
- Supplier calculation's are typically based on a specific model operating at 100% capacity, with a nominal flowrate at “standard” temperatures.

On selections where air inlet space requirements are restricted, if there is extra capacity in the tower, or different operating temps from the standard temps used by the supplier in their calculations, the supplier may be able to give you a reduced space requirement.

Specify a negligible enclosure velocity of 1.5 m/s on space critical projects, to ensure full tower performance

- Factors in Cooling Tower Sizing

Applicable Fill Area

Counterflow

Fill area = Net effective plan area



Crossflow

Fill area = Net effective face area



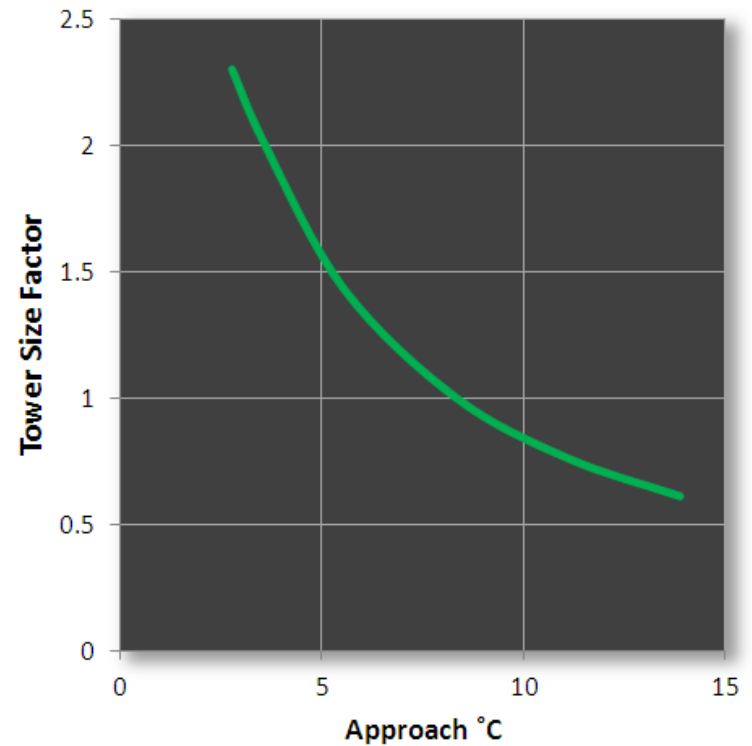
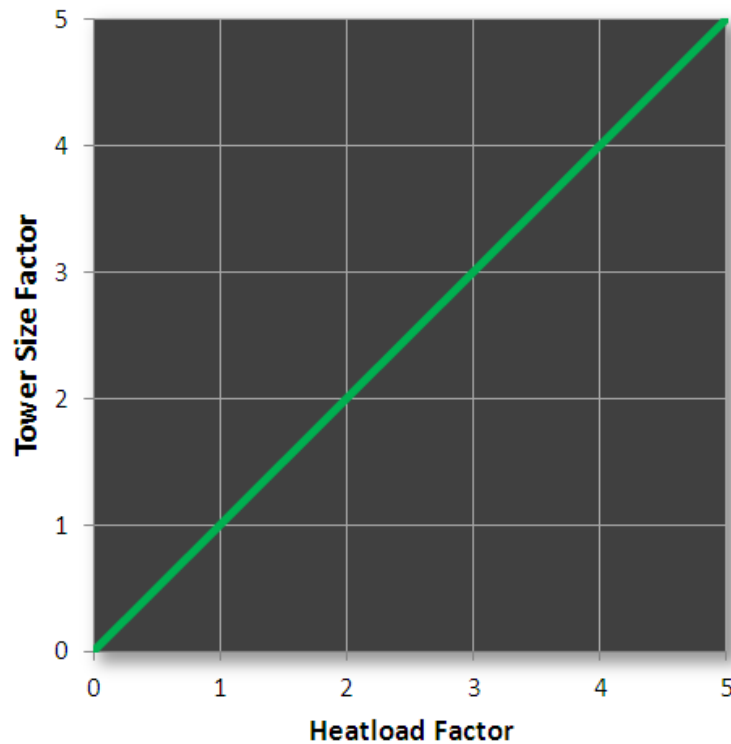
Relative Importance In Tower Performance

1. For each fill type the total air volume is fixed
2. Optimum (economic) fill velocity varies little
3. Therefore fan kW per m² varies little
4. Therefore: Fill area is the most important factor in tower performance
5. Fill height, fan power etc. are relatively minor factors

Any significant difference in fill area is likely to mean a difference in performance

Heat Load vs. Approach

- Tower size varies directly with heat load
- Tower size varies exponentially with approach



Heat Load vs. Approach

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- Tower size varies exponentially with approach

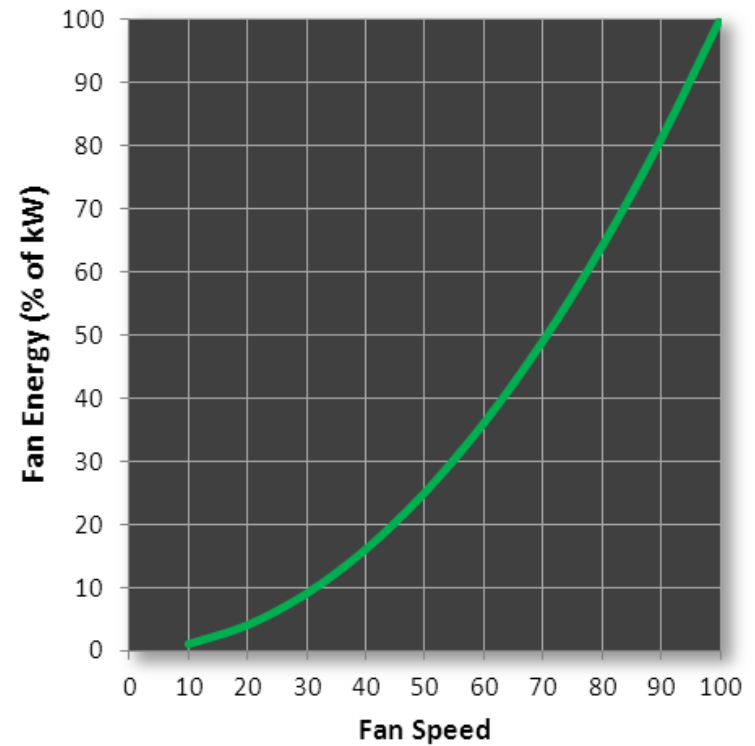
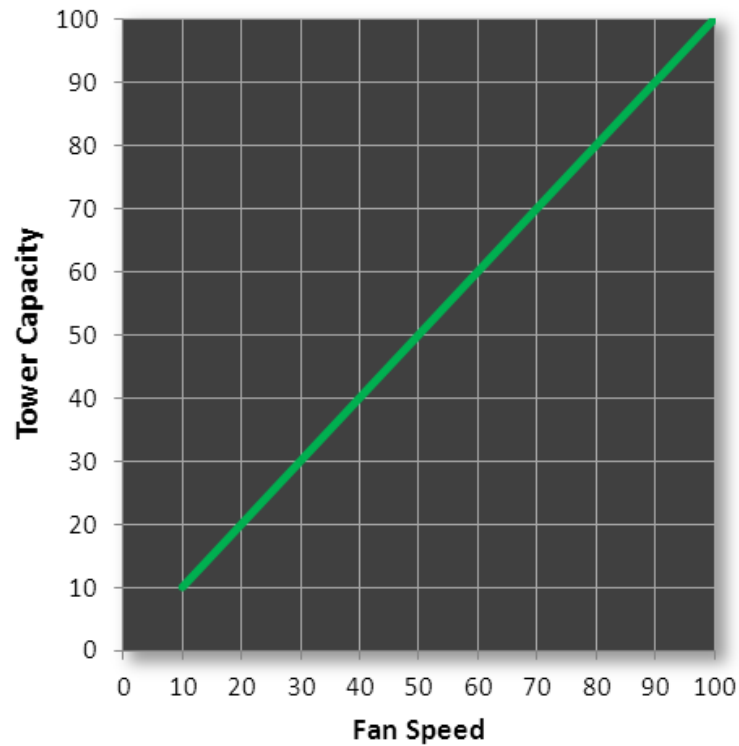
WHY IS THIS IMPORTANT?

- A customer will sometimes want to include extra installed capacity for contingency / future expansion – this has a proportional effect on the tower size
 - Will the variable load involve variable flow rates – is tower capable?
- Cold water and wet bulb temperatures have a critical effect on tower size
 - Are all the company's bidding using the same design WB?
 - How critical is the CWT to the customer – can we make significant savings on tower cost with limited effect on CWT?

- Variable Flow For Energy Savings

Tower Capacity vs. Tower Energy

- Tower capacity varies directly with fan speed
- Tower fan energy varies with the cube of the speed ratio



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WHY IS THIS IMPORTANT?

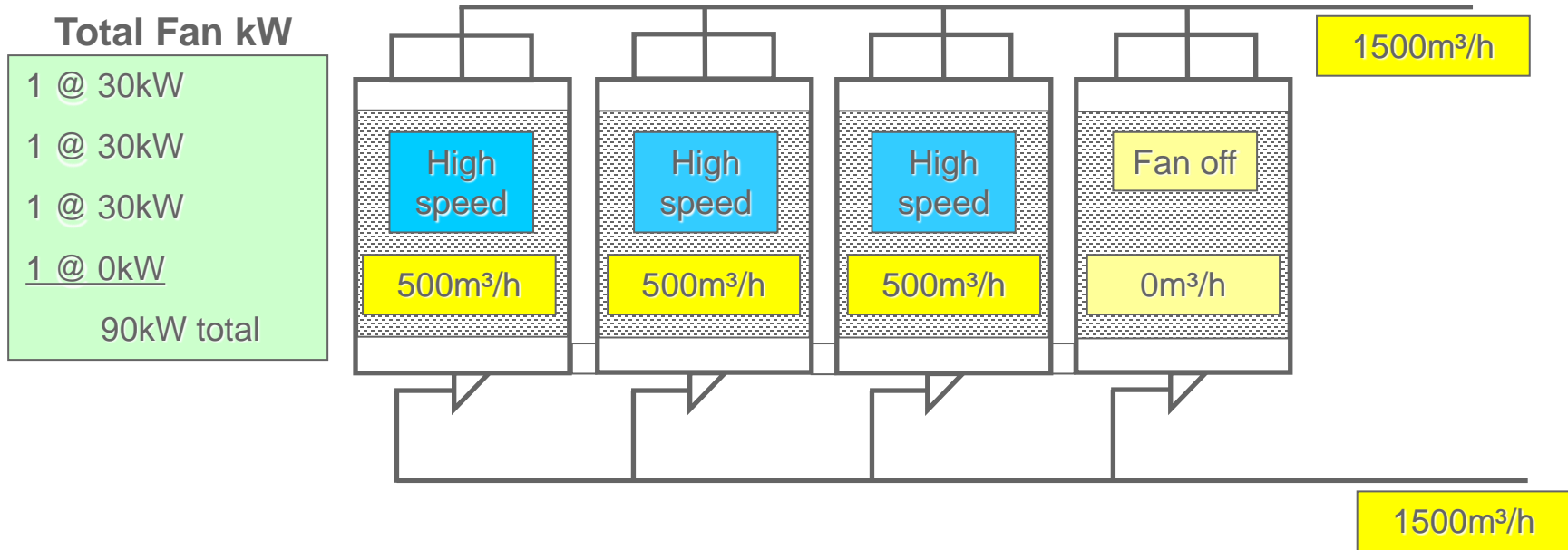
- If the customer has a variable load, the percentage of total load on the tower will equal the required percentage speed of the fans
 - 75% speed provides 75% performance
 - 50% speed provides 50% performance
- Reducing the fan speed gives excellent power cost savings
 - 100% speed : $1.00^3 = 100\%$ kW
 - 75% speed : $0.75^3 = 42.2\%$ kW
 - 50% speed : $0.50^3 = 12.5\%$ kW

Traditional Example – 75% Load Chiller Plant

4 chillers and 4-cell tower

2000m³/h, 31-25-20 Select NC8411TAN4 @ 30kW/fan

75% Load – 3 chillers and 3 towers running



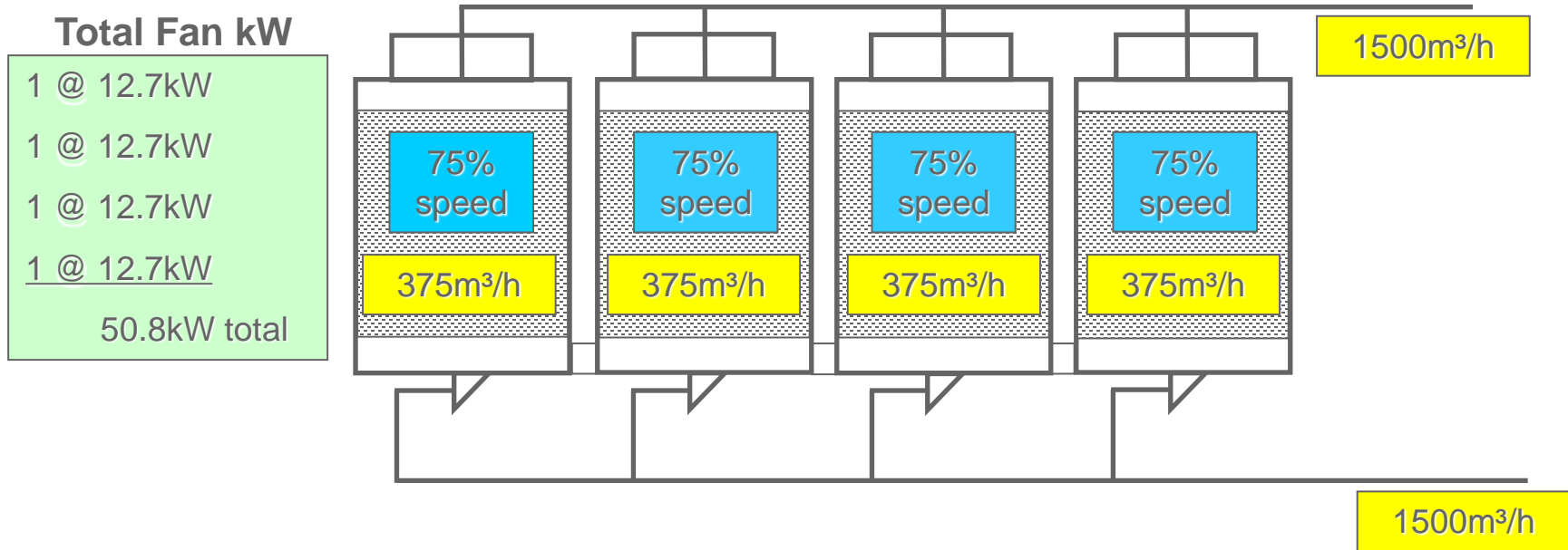
**END RESULTS: 75% OF THE ENERGY @ 75%
LOAD WITH TRADITIONAL APPROACH**

Variable Flow Example – 75% Load Chiller Plant

4 chillers and 4-cell tower

2000m³/h, 31-25-20 Select NC8411TAN4 @ 30kW/fan

Now @ 75% Load – 3 chillers and 4 towers running



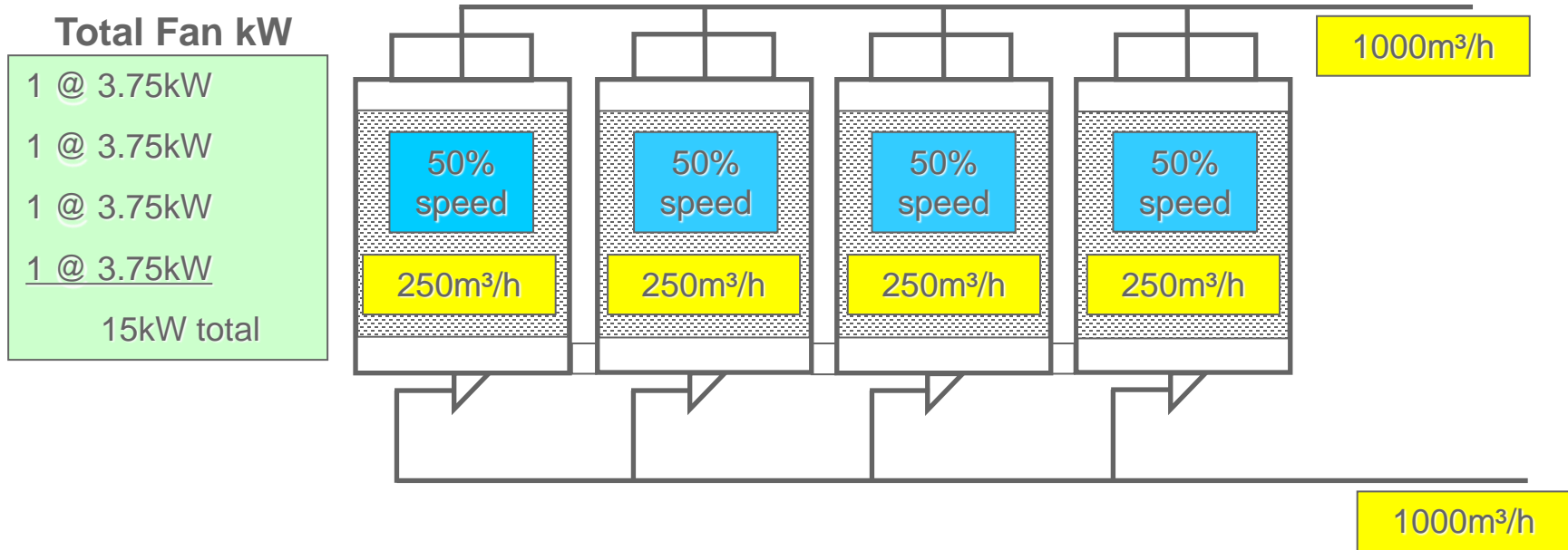
END RESULTS: 50.8/90 = 44% ENERGY SAVINGS VERSUS TRADITIONAL

Variable Flow Example – 50% Load Chiller Plant

4 chillers and 4-cell tower

2000m³/h, 31-25-20 Select NC8411TAN4 @ 30kW/fan

Now @ 50% Load – 2 chillers and 4 towers running



END RESULTS: 15/60 = 75% ENERGY SAVINGS VERSUS TRADITIONAL

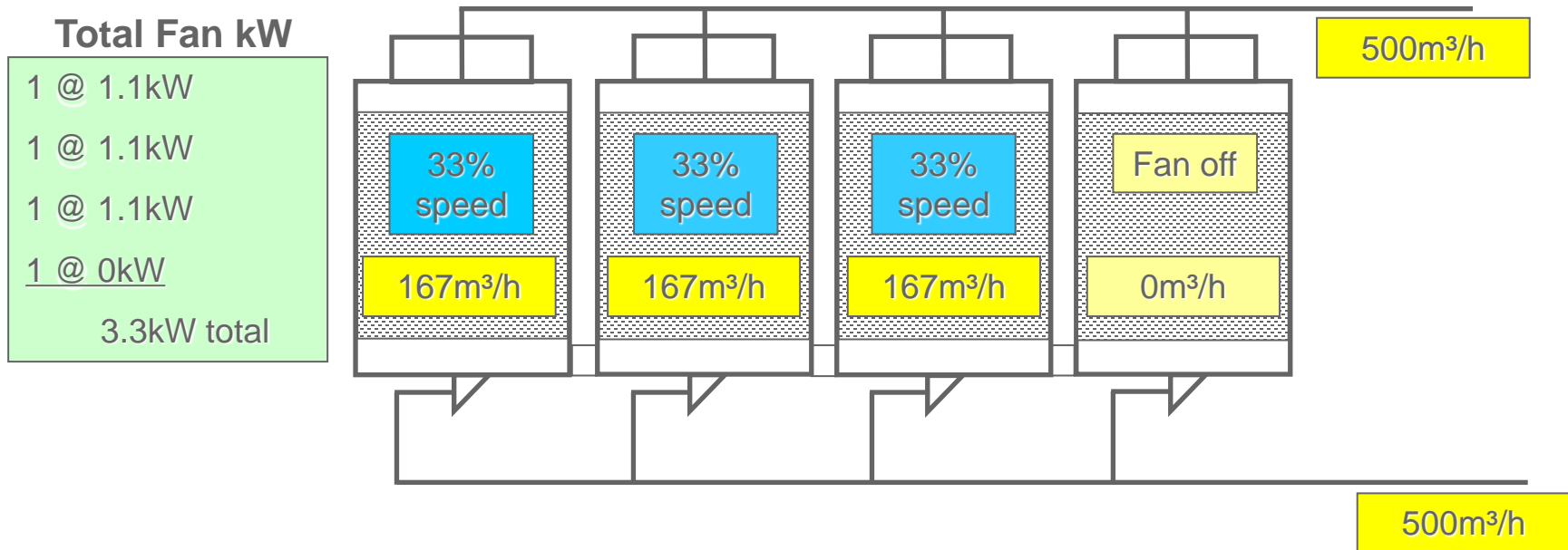
Minimum Flow Example – Chiller Plant

Caution – There are limits as to how low you can go:

4 chillers and 4-cell tower

2000m³/h, 31-25-20 Select NC8411TAN4 @ 30kW/fan

Now @ 25% Load – 1 chillers and 3 towers running



END RESULTS: $3.3/30 = 89\%$ ENERGY SAVINGS VERSUS TRADITIONAL

What's it worth?

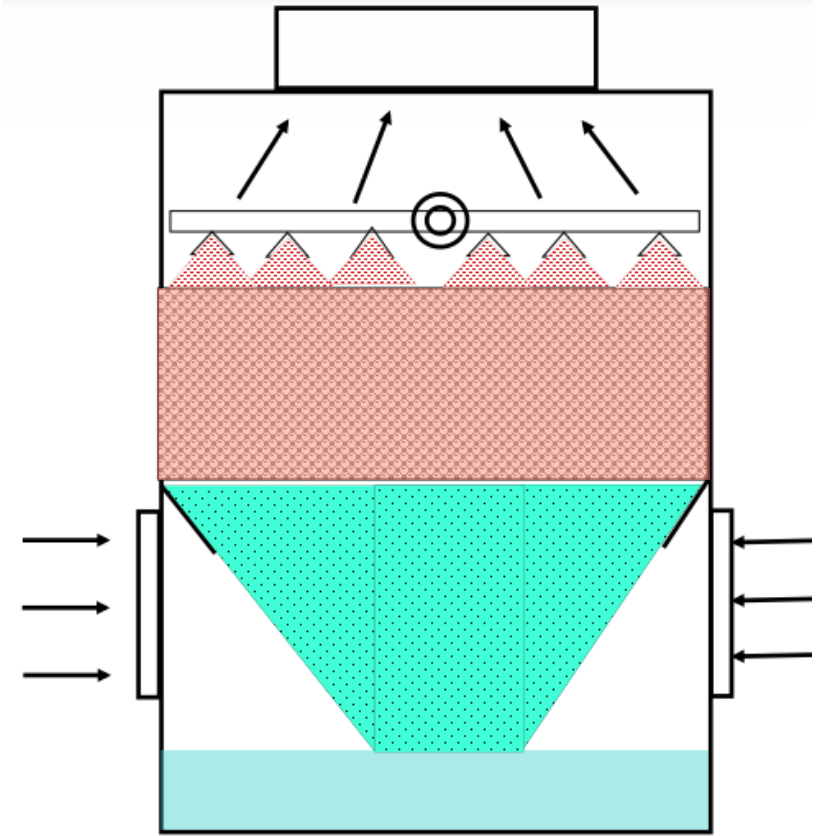
m ³ /h	2000
# of Chillers	4
# of Cooling Towers	4
Cooling Tower kW (ea)	30
Energy Rate	\$0.15 kWh

Operating	Months	Energy Consumption (Traditional)	Energy Consumption (Variable Flow)
4 Chillers online	2	\$ 26,141	\$ 26,141
3 Chillers online	2	\$ 19,605	\$ 11,028
2 Chillers online	2	\$ 13,070	\$ 3,267
1 Chiller online	2	\$ 6,536	\$ 705
0 Chillers online	4	\$ -	\$ -
		\$ 65,352	\$ 41,141
		Energy Savings	\$ 24,211

37% decrease in cooling tower energy consumed

Variable Flow in Counterflow Towers

- No modifications are available for counterflow designs to enhance variable flow performance
- Limited ability to run at low flow rates because the spray system is pressurised



Fan on High Speed

Implementing Variable Flow in Counterflow Designs

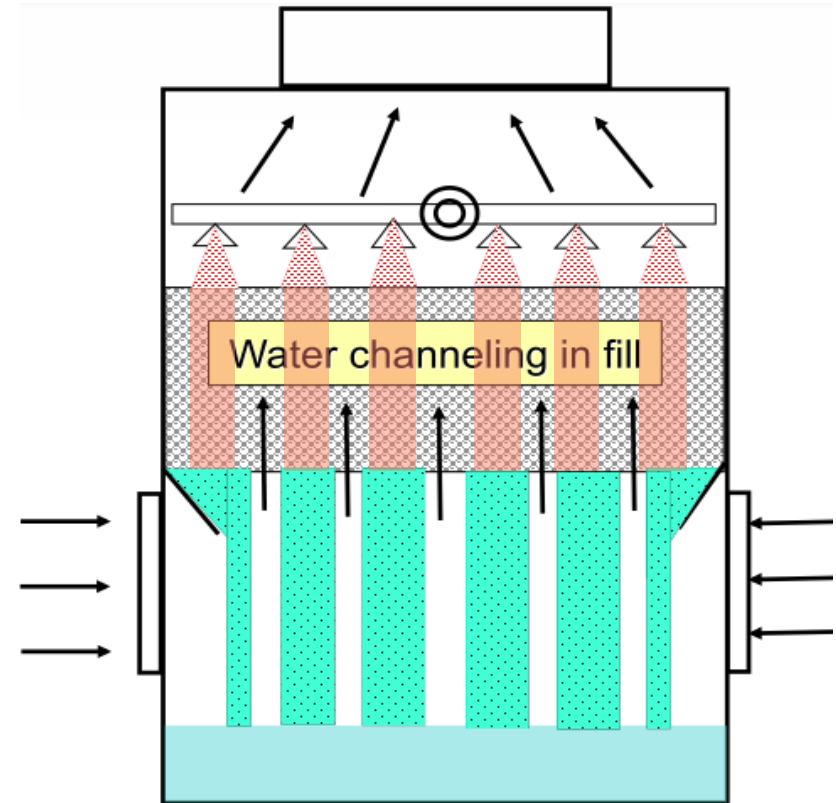
Variable Flow in Counterflow Towers

If you reduce flow too much (**generally more than 30%**), you get uneven water loading:

- Lower air-side pressure drop in fill sections with less water
- More air in drier sections
- Less air in wetter sections

...resulting in:

- Reduced thermal performance
- Greater risk of fill scaling



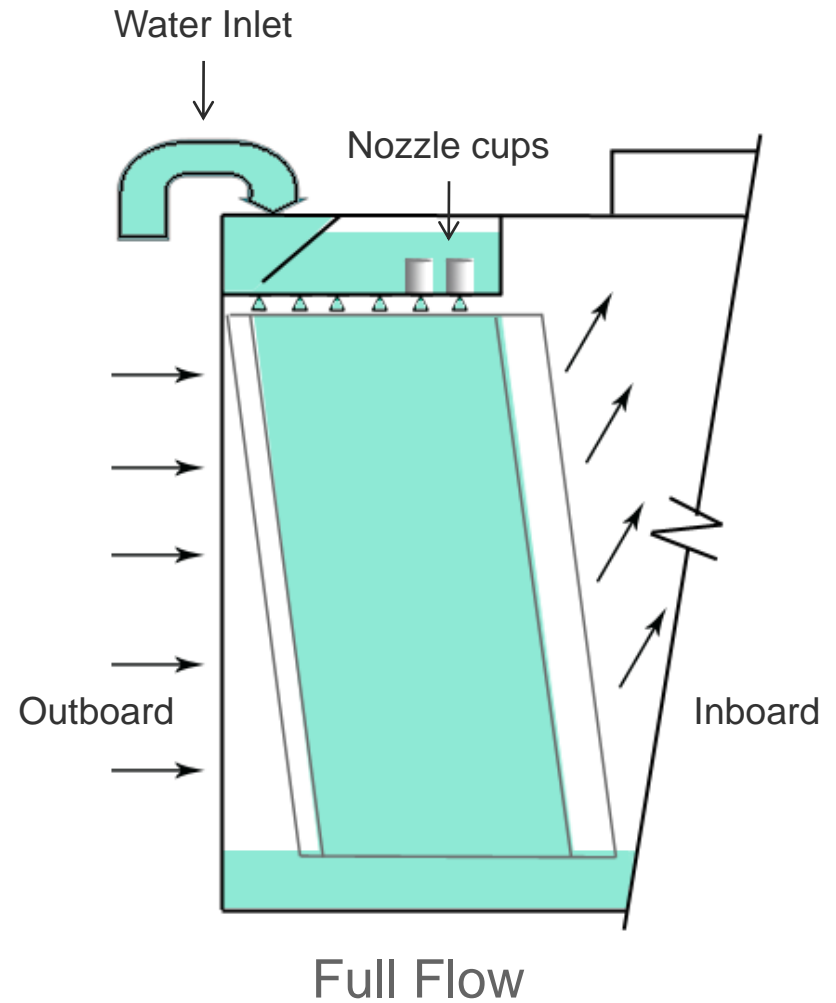
Reduced flow rate

Implementing Variable Flow in Counterflow Designs

Variable Flow for Crossflow Towers

FULL FLOW EXAMPLE

- Water overflows nozzle cups
- Entire fill volume is in use
- Nozzle cups have no effect



Implementing Variable Flow in Crossflow Designs

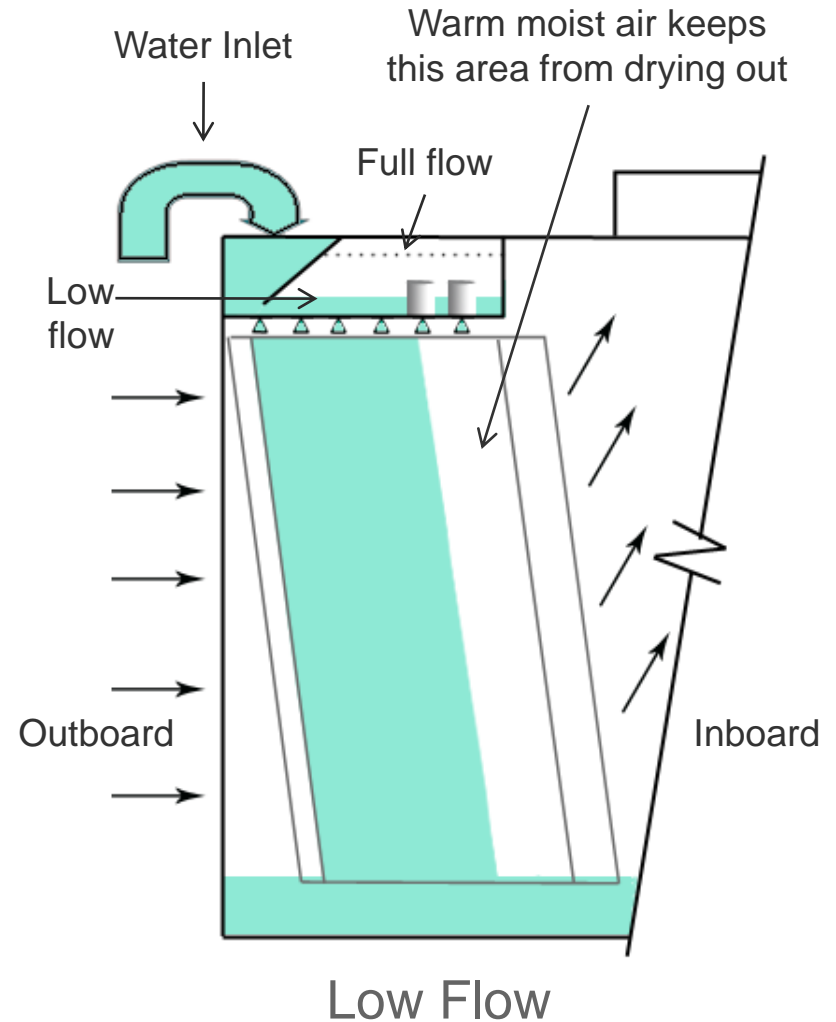
Variable Flow for Crossflow Towers

LOW FLOW EXAMPLE

- Reduced flow in basin
- No water flows over cup
- All water is on air inlet of fill
- Rear of fill remains 'wet'

Benefits

- Eliminates risk of scaling
- Uniform air-side pressure drop
- Prevents air channeling



Implementing Variable Flow in Crossflow Designs