

# THE EFFECT OF WIND ON THE PERFORMANCE OF MULTIPLE SHORT NATURAL DRAFT DRY COOLING TOWERS

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## ABSTRACT

The layout of multiple natural draft dry cooling towers can have an influence on the performance of the cooling system in concentrated solar power (CSP) plants. Hence, the aim of this study was to investigate the effect of wind on the performance of multiple natural draft dry cooling towers (NDDCTs). Computational fluid dynamics (CFD) modelling was carried out to numerically analyse the performance of two short NDDCTs at different tower spacings, crosswind velocities and wind attack angles (the direction of the wind relative to a line drawn between the centres of the two towers). The results show that the cooling performance of the towers is a strong function of tower spacing and their orientation with respect to the wind direction. The findings of this study are essential for the layout installation of multiple short NDDCTs with respect to the most frequent direction of the crosswind in a specific location.

## 1 INTRODUCTION

Concentrating solar power (CSP) plants are usually located in arid regions with high solar intensity. Water scarcity in these locations makes the application of natural draft dry cooling towers (NDDCT) favorable. With these systems, there is a density difference between the air inside and outside the tower due to the temperature difference, which induces the surrounding air to flow into the tower. The air passes through the heat exchanger bundles and acts as a cooling medium for the hot fluid flow inside the tubes. The size of the cooling tower depends on the power plant generation and cooling capacity and CSP plants with net generation output of a few megawatts often utilize short NDDCTs.

Lu et al. [1] first investigated the effect of wind on the thermal performance of a 15m NDDCT. In their study, it was shown that short NDDCTs are highly susceptible to ambient conditions. In addition, they explored the functionality of internal windbreaks with a view to reducing the crosswind's negative impact on the performance of the short NDDCT. The proposed windbreak enhanced the cooling performance in the windward and leeward sectors of the heat exchangers [2]. Further investigations were carried out on a real scaled 1: 12.5 cooling tower.

Building on this work Li et al. [3] started their investigation by simulating a 20m NDDCT at the Queensland Geothermal

Energy Center of Excellence (QGECE), which they followed up with an experimental study [4]. Later it was proposed that the cooling performance of the NDDCT can be increased by 18% at a certain crosswind speed by optimizing the hot water mass flow rate among the heat exchanger bundles [5]. The effect of ambient temperature on the cooling performance was examined experimentally on the 20m high NDDCT [6]. The unfavorable effect of cold in flow at the top of the cooling tower was observed experimentally.

Of course, as the capacity of CSP power plants is increased, additional cooling is required which necessitates the addition of more NDDCTs. When adding these cooling towers, there is a need to be able to position them correctly so that their performance as a group is maximised. To do this, an understanding of the effect they have on one another is needed, particularly concerning windy conditions. Although much research has been devoted to isolated cooling towers, very few studies have investigated the performance of multiple cooling towers under windy conditions. Each cooling tower in a group may exhibit different characteristics from those of an isolated one. Hence, the aim of this study was to investigate the effect of tower spacing on the performance of two short NDDCTs with horizontally arranged air-cooled heat exchanger at different crosswind velocities and orientations.

## 2 METHODOLOGY

To understand the behaviour of NDDCTs under windy conditions, 3-dimensional CFD simulations were used to investigate the airflow characteristics around the towers and the effect on their performance. The simulations were performed for three tower spacings  $D/8$ ,  $1.6D$ , and  $3.2D$  (where  $D$  is the tower diameter, 12.525m), three different wind attack angles ( $0^\circ$ ,  $45^\circ$ , and  $90^\circ$ ) and several wind velocities (0-8 m/s). A commercial RANS finite volume code (ANSYS FLUENT) was used to carry out these simulations, where the turbulent field was simulated using the realizable  $k-\epsilon$  turbulence model. The realizable  $k-\epsilon$  model has been extensively validated for a wide range of flows including rotating shear flows, boundary layer flows and separated flows and had been shown to be well suited to modelling both short and large NDDCTs [3].

For this study, a cylindrical tower and horizontally arranged air-cooled heat exchanger were examined with the computational domain and boundary conditions shown in Figure

1. The dimensions of the computational domain were selected based on a mesh sensitivity showed the boundaries did not affect the domain flow field. In saying this, the windward tower was placed at the centre of semi-cylinder with a height of 90m and radius of 72m and the leeward tower was located at a rectangular domain with a length of 200m as used in the investigation of a multi-tower system by [7]. For the no-wind condition the towers were placed in a cylindrical domain and for the windy condition a velocity inlet boundary condition was assigned at the windward side (surface of half cylinder) of the domain. The velocity profile applied at this boundary is defined by Eq. 1:

$$U = v_{cw} = \left(\frac{y}{y_{ref}}\right)^a v_{ref} \quad (1)$$

Where  $v_{ref}$  is a reference velocity at a reference height  $y_{ref}=10$  m and the exponent  $m$  is defined as the roughness of the ground and the stability of the atmosphere.

To determine the rate of heat rejected by each cooling tower, the heat exchangers were modelled as a cylindrical porous media with a radiator on its top face such that the heat rejected to the surrounding air ( $q$ ) is given by Eq. 2.

$$q = h(T_{air,d} - T_{ext}) \quad (2)$$

Where  $T_{air,d}$  is the temperature downstream of the heat exchanger (radiator),  $T_{ext}$  is the reference temperature for the liquid. The combination of a porous media zone and radiator boundary condition was used for heat exchanger modelling in short NDDCTs previously [2, 5].

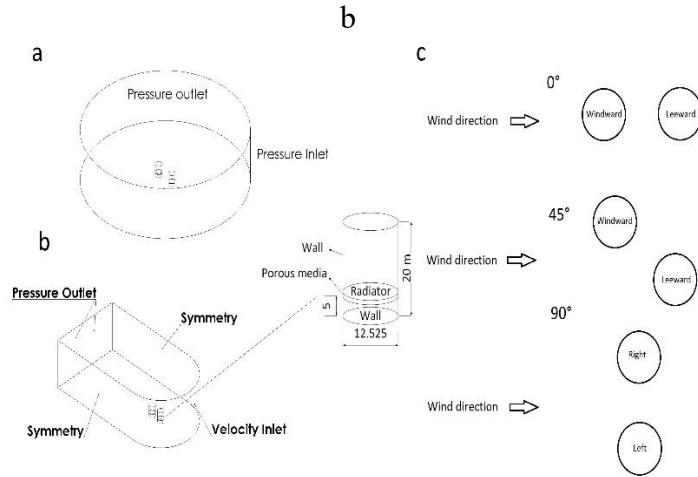


Figure 1: Computational domain and boundary conditions at a) no-wind condition and b) windy c) and towers orientation

## 2.1 Validation

To validate the computational model, numerical results of a single NDDCT were compared with [3] as shown in Figure 2. This compares the normalised cooling capacity of a single tower ( $Q/Q_{nowind}$ ) with those reported by [3]. The results show that

the modeling results are in good agreement with the published work.

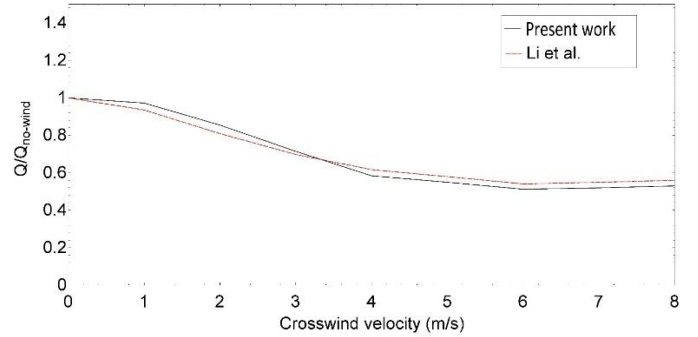


Figure 2: Comparison between present CFD result and [3].

## 3 RESULTS AND DISCUSSION

Having shown that the model was capable of predicting the performance of a single tower it was applied to a multi-tower configuration. In multi-tower systems, the windward tower can act as a windbreak for the next tower. Figure 3 shows the heat rejection rate from both towers at tower spacing of 0.8D, 1.6D, and 3.2Dm, respectively. It is apparent that the heat rejected by the windward tower (the modelled NDDCT rejects 2530kW at the no-wind condition) is significantly reduced while the leeward tower shows an increase in heat rejection rate that can be attributed to it being located in the wake of the first tower. Referring to Figure 3, it is apparent that the heat rejection rate of the leeward tower increases as the towers are placed closer together. The exception to this is when the towers are at 0.8D and there is no-wind (the heat rejection rate for each cooling tower is 2500kW); both towers attempt to draw air under natural convection and their proximity means they “fight” to get sufficient airflow, thus leading to a reduction in their combined cooling capacity.

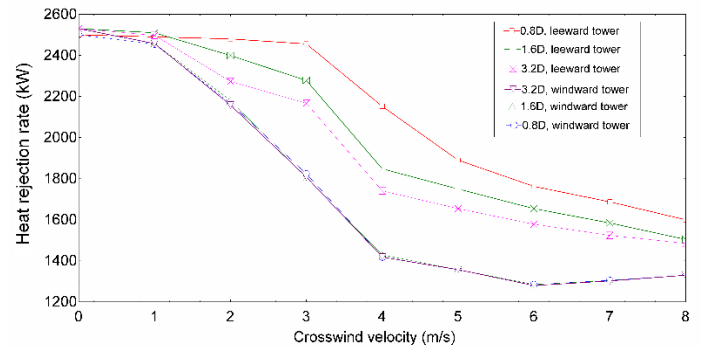


Figure 3: Heat rejection rate from both towers at different tower spacing at wind attack angle of 0°

Exploring this further, Figure 4 presents the heat reject for both towers at different wind speeds in wind attack angles of 45°. It can be seen that the heat rejection of both towers increases as the tower spacing increases at the no-wind condition (the same

as for the  $0^\circ$  wind attack angle). At a wind direction of  $45^\circ$ , the windward tower shows superior performance compared to the leeward tower, especially at low tower spacing. As discussed previously, the high crosswind velocity degrades the performance of a NDDCT. As the flow passes the windward cooling tower, it reaches the contraction between the two towers which results in an increased flow velocity. The increased flow velocity does not allow the cooling air to flow through the lateral side of the heat exchanger bundles, so the local flow rate decreases. At a tower spacing of  $1.6D$  and  $3.2D$  the heat rejection rate of the leeward tower, over the range of crosswind velocities, increased by 4% and 10% compared to the tower spacing of  $0.8D$ . That said the difference in the heat rejection of the two towers becomes effectively negligible at a tower spacing of  $3.2D$ . When the tower spacing increases the interaction of the towers becomes weak and they behave more like individual units.

At a wind attack angle of  $90^\circ$  (Figure 5), the performance of both towers is more or less the same, due to their symmetrical layout. When the towers are placed side by side, a flow blockage occurs in front of these towers meaning little air can flow through the passage between the towers. This forces more air into the windward side of both towers and results in an improvement in performance of these sections. Hence, at tower spacing of  $0.8D$ , the combined heat rejection rate of both towers was 2% higher than the other spacing conditions. The interaction of towers at this wind attack angle completely disappears at tower spacings of  $1.6D$  and  $3.2D$ , and the towers act as individual units.

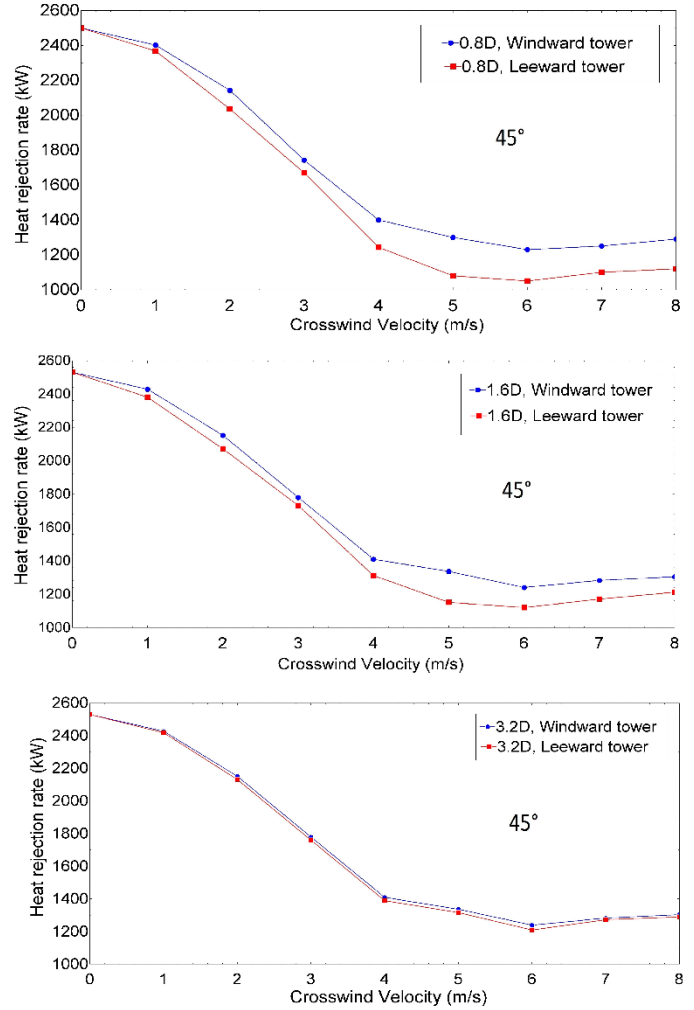


Figure 4: Heat rejection rate from both towers at different tower spacing at wind attack angles of  $45^\circ$

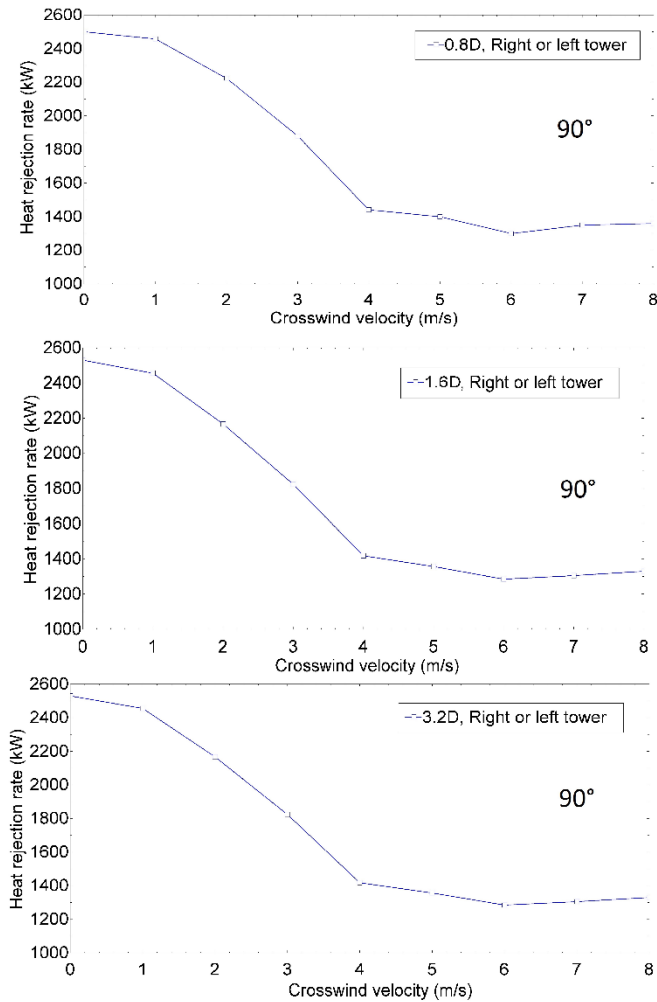


Figure 5: Heat rejection rate from both towers at different tower spacing at wind attack angles of  $90^\circ$

#### 4 CONCLUSION

The performance of two NDDCTs was investigated at various crosswind velocities (0-8 m/s) at different wind attack angles of  $0^\circ$ ,  $45^\circ$ , and  $90^\circ$  with tower spacing variable from 0.8D to 3.2D. The results demonstrated that there is a noticeable interaction between two towers at different towers layouts. At the no-wind condition, the cooling performance of both towers is reduced with a small tower spacing, as this limits the air supply and the airflow across the heat exchangers in both towers.

However, for the windy conditions, the redirection of flow due to the layout of the cooling towers can improve the performance of the towers. At a wind attack angle of  $0^\circ$  the windward tower redirects the wind flow and reduces the local velocity near the leeward tower, thus increasing its cooling capacity. This effect becomes weaker with increasing tower spacing. When the wind is blowing at  $90^\circ$ , there is a performance improvement in both towers at low tower spacing. However, the performance of both towers is almost same as two individual towers at a tower spacing of 1.6D and 3.2D. In all three

arrangements, the towers interact with each other at low tower spacing and can lead to an increase in cooling capacity. The results provide practical insights for the targeted placement of towers in locations with a prevailing wind direction.

#### REFERENCES

- [1] Lu Y, Guan Z, Gurgenci H, Zou Z. Windbreak walls reverse the negative effect of crosswind in short natural draft dry cooling towers into a performance enhancement. *International Journal of Heat and Mass Transfer*. 2013;63:162-70.
- [2] Lu Y, Gurgenci H, Guan Z, He S. The influence of windbreak wall orientation on the cooling performance of small natural draft dry cooling towers. *International Journal of Heat and Mass Transfer*. 2014;79:1059-69.
- [3] Li X, Guan Z, Gurgenci H, Lu Y, He S. Simulation of the UQ Gatton natural draft dry cooling tower. *Applied Thermal Engineering*. 2015.
- [4] Li X, Gurgenci H, Guan Z, Wang X, Duniam S. Measurements of crosswind influence on a natural draft dry cooling tower for a solar thermal power plant. *Applied Energy*. 2017;206:1169-83.
- [5] Li X, Xia L, Gurgenci H, Guan Z. Performance enhancement for the natural draft dry cooling tower under crosswind condition by optimizing the water distribution. *International Journal of Heat and Mass Transfer*. 2017;107:271-80.
- [6] Li X, Duniam S, Gurgenci H, Guan Z, Veeraragavan A. Full scale experimental study of a small natural draft dry cooling tower for concentrating solar thermal power plant. *Applied Energy*. 2017;193:15-27.
- [7] Zhai Z, Fu S. Improving cooling efficiency of dry-cooling towers under cross-wind conditions by using wind-break methods. *Applied Thermal Engineering*. 2006;26:1008-17.