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ROLE OF PLANT BUILDINGS IN A POWER STATION ACTING AS BARRIER TO THE WIND AFFECTING THE NATURAL DRAFT COOLING TOWER PERFORMANCE

Ghulam Amur, Brian Milton, John Reizes, Jafar Madadnia, Simon Beecham, Peter Brady, and Homa Koosha

Faculty of Engineering University of Technology Sydney
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(Ghulam.Amur@uts.edu.au)

Abstract

The effect of wind on the performance of a cooling tower has been investigated taking into consideration plant buildings and the presence of another tower. The results include measurements from a full scale tower, wind tunnel testing and numerical simulations. It has been found from these data that the plant buildings can significantly improve tower performance depending on the wind direction relative to the buildings. However, surprisingly, when the wind is blowing from the direction of the second cooling tower, the performance of the first cooling tower drops. This paper presents some results which demonstrate the importance of buildings in predicting cooling tower performance.

Introduction

The performance of natural draft cooling towers depends heavily on weather conditions. This includes the ambient temperature and humidity, which affect the density of atmospheric air and its ability to absorb water vapour. Winds, on the other hand, create uneven pressure distributions at the tower inlet and outlet thereby affecting the velocity distribution within the tower and the overall mass flow rate. Although atmospheric air temperatures and humidity can not be controlled, the adverse consequences of wind can be mitigated to some extent by the use of suitable barriers. Little information is available on wind effects on the cooling tower performance [6] and remedial barriers [4, 5]. In most studies the effect of wind has been reported in terms of variation in the approach temperature, often called approach and defined as the difference between the outlet cooling water temperature of the tower and the wet bulb temperature of the incoming air. Unfortunately, the accompanying information does not include any indication as to whether there were any obstructions to the wind due to plant buildings and other topographical features.

The approach temperature of an isolated tower has been found to increase whenever there is any wind; indicating an increase in the outlet cooling water temperature. A 1K rise in that temperature has been reported when wind speed increases from 2 to 4ms^{-1} [9]. In another study changes in approach temperatures by up to 14K were observed in dry cooling towers for wind speeds up to 15ms^{-1} and 4K in wet towers for wind speeds up to 12.5ms^{-1} [6].

It is therefore necessary that while investigating the effects of wind on the natural draft cooling towers, the role of buildings in creating a barrier to the wind before it reaches the towers need to be studied in detail.

The present study therefore included the installation of instrumentation in a wet cooling tower at Mt Piper Power Station in NSW. Arrays of thermocouples and anemometers were installed in the tower and a remote data collection system was developed for data acquisition. The turbine load, the volumetric flow rate through the tower and water temperatures were obtained from the control room data acquisition system. The mass flow rate of air was calculated by integrating the anemometer data.

A 1/1000 isothermal scaled model of the tower was developed for wind tunnel testing. A duct was attached to the top of the model tower so that the flow rate of air could be controlled by an external fan. The performance of the tower was evaluated in terms of the pressure loss through the model tower. The surrounding buildings and the second tower were also reduced to the same scale and mounted on a turntable in similar positions to those in the full scale power station as may be seen in Figure 1 below.

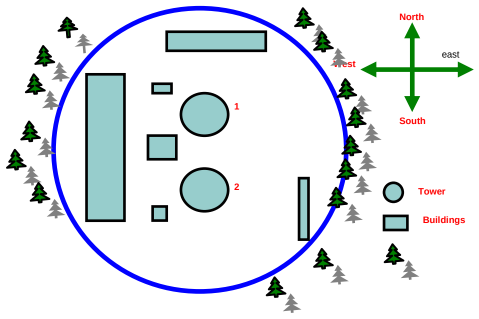

Figure 1: Cooling Tower Layout in relation to Plant Buildings.

The study was further extended by constructing a 2D numerical model of the plant to gain an understanding of the wind flow patterns around the cooling tower area in relation to the other plant buildings.

Full scale measurements

The instruments for data collections at the tower were installed above the cooling tower fill. These included calibrated anemometers and thermocouples installed on ropes extending from the centre to the outer surface of the tower at approximately 30^o around the tower azimuth. In addition, the cooling water temperatures entering and leaving the tower and dry bulb and wet temperatures were also recorded. The data were collected at a frequency of 2000Hz and averaged over 5 minute intervals on a 24 hour cycle. The wind speed and direction and air temperature data was measured at 10 meters height at the metrological station situated 500 meters from the cooling tower and outside the plant buildings. The power generation data was obtained from the plant control room data.

Tower performance with wind from plant building side

For a typical day when the wind direction and the output of the turbine were reasonably constant the data are given in Figure 2.

Although the wind speed at the plant reached velocities up to 10m/s, reliable data were only available for wind speeds up to

4*m/s*. Since there is wind direction and the power demand fluctuate during the day, the data to be used were obtained from records on a day during which wind direction and the power remained fairly constant. This leads to a more reliable correlation between the wind and the approach. Unfortunately, data at constant wind direction and power were only available for wind speed up to $4ms^{-1}$.

It can be seen in the Figure 2 that when the wind blows from the building side the approach temperature decreased from 13*K* to about 10 K as the wind speed increases. A decrease of about 3*K* has been obtained when plant buildings act as barrier to the wind blowing towards the tower. As a result the water leaving the tower could be 3K lower than when there is no wind. This condition is in direct contradiction to some of the previous studies in which the approach increased with the wind speed [6]. This is supported by *Dreyer et alia* [10], who studied evaporative natural draft cooling towers. They found that the approach temperature decreased from 14*K* to 12*K* when the wind speed increased from 0 to 6 ms^{-1}; regrettably, they do not mention whether there were any barriers in front of the tower. One possible explanation is that not only do buildings shield the tower intake, thereby reducing any velocity distribution; the wind also provides suction at the tower outlet, thereby increasing the available pressure drop and the resulting air mass flow rate through the tower. It follows that a judicious placement of power station buildings can actually have a favourable influence on the performance of cooling towers during windy periods.

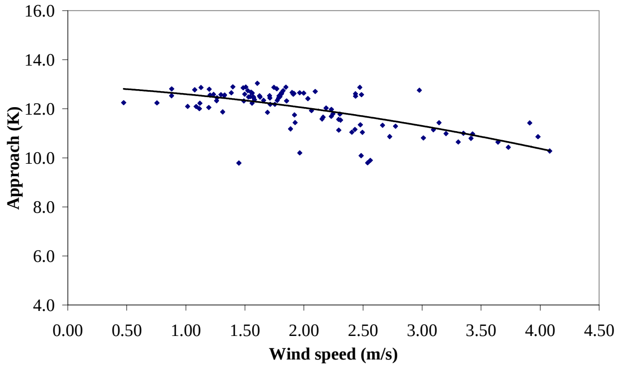

Figure: 2 Effect of wind on tower approach temperature. (Wind from plant building side)

Wind from the direction of the second cooling tower

A wind from the direction of the second tower has been found in this work to increase the approach temperature as can be seen in Figure 3. There is considerable scatter in the data in Figure 3, however, the line of best fit of the approach temperature has a minimum of approximately 6*K* when there is a wind of $0.5ms^{-1}$, to a maximum of approximately 12*K* at a wind speed of $2.8ms^{-1}$. Beyond that velocity there is a slight decrease but the approach temperature remains well above its zero velocity value. Since the two towers are of the same size, and they are completely open at ground level, the second tower does not provide any shielding for the other tower at ground level. Further, the wake from the second tower would reduce the suction effect at the top of the first tower. The result is a decreased air mass flow rate with a consequent reduction in the performance represented by a substantial increase in the approach temperature. Unfortunately this phenomenon cannot be fully investigated in wind tunnel tests because the flow through the model tower is provided by an external fan, but could be modelled numerically.

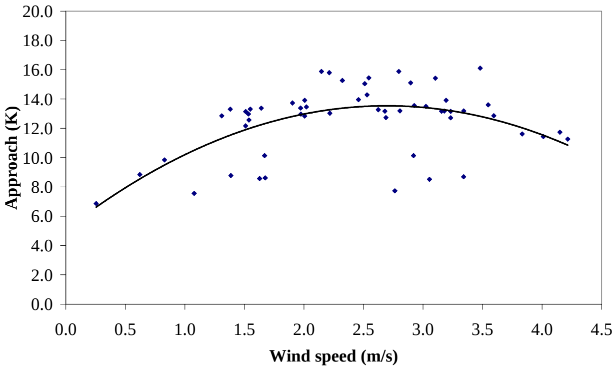

Figure: 3 Effect of wind on tower approach temperature. (Wind from second cooling tower side)

Wind tunnel results

A 1/1000 scale model of the tower was tested in the wind tunnel together with all the buildings and the second tower placed at the correct positions relative to the tower as may be seen in Figure 1. Tests were carried out at different velocity ratios, *VR*, defined as the ratio of the velocity at the tower throat to the wind velocity, and some of those are reported in Figure 4. The effect has been described in terms of the inlet pressure loss coefficient (C_{Pi}) of the tower as a function of the velocity ratio (V_r).

C_{pi} is defined as

$$C_{pi} = \frac{\Delta p_o}{0.5\rho V_{ct}^2},$$

in which, C_{pi}, is pressure loss coefficient at the inlet;
Δp_o is the pressure loss in the tower;
V_{ct}, is the velocity inside the cooling tower; and
ρ, is the density of air.

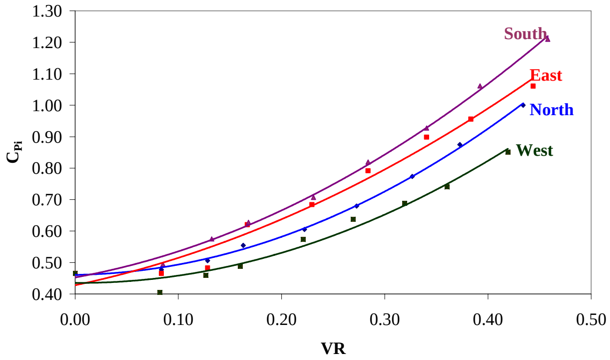

Figure: 4 Variation of C_{Pi} with building and tower obstruction.

As may be seen in Figure 4, C_{pi} is much larger with a value of about 1.20 when the wind reaches the tower from the south, which is the second cooling tower side, than its value of about 0.45 when there is no wind. This loss of performance is accompanied by the fact that it has been reported that in windy conditions, when in tandem arrangement, the pressure fluctuation on the downstream tower can be as high as 40% [2]. However, C_{Pi} is approximately 0.90 when the wind blows from the boiler house side buildings; which is about 33% lower than that obtained when the wind blows from the south or second cooling tower side for a similar velocity ratio. Surprisingly, when the wind blows from the east where there is no obstruction in the path of the oncoming wind (see in Figure 1) there is a lesser loss of performance that when the wind blows from the south and the cooling tower is sheltered by the second cooling tower. The minimum loss of performance occurs when the cooling tower is protected by the massive boiler house building which lies to its west. The northerly approach is also protected by the water treatment building which, however, is smaller than the boiler house so that it gives less protection.

It should be noted that C_{pi} really only represents the inlet losses of the model tower and these are always increased when the wind blows. Because the development of a hot small scale cooling tower model is not really possible, a cold model is used, thereby not allowing the wind effects at the top of the tower to be modelled at all. Thus, the effects of wind suction mentioned in the discussion concerning the full scale plant cannot be reproduced, which means that the improved performance shown in Figure 2 is not seen in the model results.

The model results qualitatively indicate that the tower performance is differently affected when the wind blows from different directions and that this is due the different obstructions present. Surprisingly, the second cooling tower has by far the major effect on the tower performance as can be seen in the full scale and wind tunnel results. It seems that sheltering the inlet reduces C_{pi} so that all other effects being equal it is expected that a reduction in C_{pi} will lead to an improvement in the tower performance. Thus, wind tunnel test on remedial devices designed to improve the inlet flow to the cooling tower will still yield valuable information, but the surrounding buildings need to be included in the model.

Numerical simulations

A two-dimensional numerical simulation of the wind tunnel model has been performed to improve the understanding of wind flow around the cooling tower area in the presence of plant buildings. Although the numerical model studies are in a preliminary stage and have not yet been completely validated, they are given here for information to indicate that the flow pattern is greatly affected by the arrangement of the surrounding buildings and complement the physical modelling results.

The commercial code CFDACE was used to perform the numerical work. The wind tunnel physical arrangement has been simulated in this work. The numerical model was prepared using a total number of 175000 mesh points on an unstructured grid. Since it was expected that the flow would not be steady, a transient solution was sought with a time step of $10^{-4}s$ and an upwind differencing scheme was used on the advective terms in the Navier-Stokes Equation and a central differencing scheme used on the other terms. The κ-ε turbulence model was used. At the inlet, a uniform velocity of 11 m/s was used. At each time step convergence of the velocity and pressure residuals were reduced to 10^{-6} of their initial values. Since the work is still in the progress there are several refinements in the process of being included, the full details would be available after validation. These results here are presented for an indicative purpose only.

The preliminary results may be seen in the Figures 5 to 7 (wind from the small building direction) and Figures 8 to 10 (wind blows from the second tower direction) at various times. In agreement with the full scale and the wind tunnel results, it can be seen that the small building provides shelter to the first cooling tower whereas when the wind is blowing from the second cooling tower there is no shelter. The exact effect of the obstructions need to be averaged overall a long period, however, the general pattern does not change enormously as may be seen in the Figures 5 to 10.

The high stream of air caused by the upstream building affects the eastern side of the second tower. The detached boundary layer on the eastern side of the large building results in a low velocity stream around the western side of the second tower.

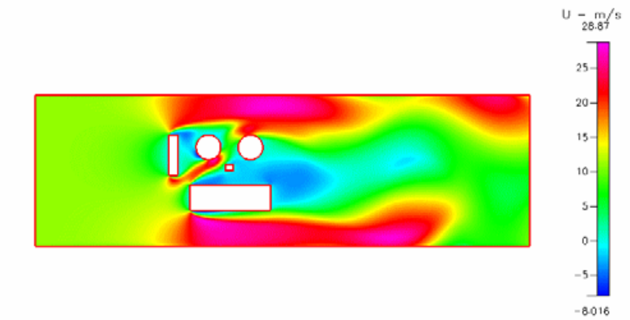

Figure 5: Flow pattern when the wind blows from the direction of a building.

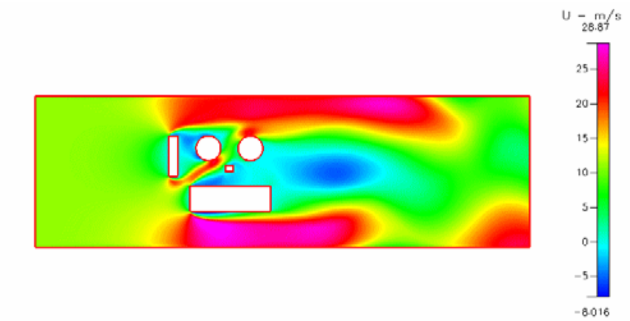

Figure 6: Flow pattern when the wind blows from the direction of a building.

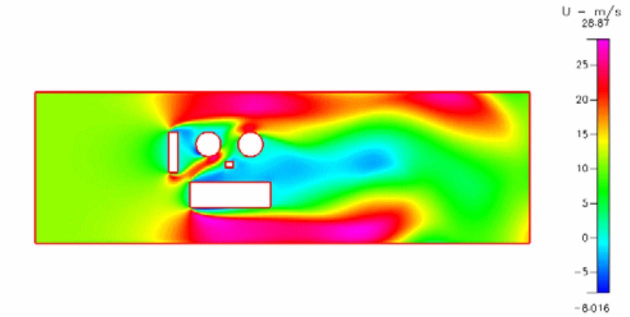

Figure 7: Flow pattern when the wind blows from the direction of a building.

In the second case of wind from the south, as shown in Figures 8 to 10, the two towers are arranged in tandem with a building on the down stream side of the two towers and the large boiler building on one side of both towers. In this case both towers are affected by the wind with the upstream tower having higher surrounding velocity than the down stream tower. However, the upstream tower provides some little shelter to the down stream tower. Although the up stream tower provides some shelter to the down stream tower, the flow pattern created by the large building in fact increases the wind speed on the second tower.

The simulation results, although not yet validated, support the full scale and wind tunnel results in the sense that the tower performs better when the plant buildings provide shelter from the wind. The interaction of the flows around the cooling towers and buildings is much more easily understood from the numerical calculations and their effects quantified. However, it should be understood that a cooling tower in isolation is not an adequate model for the evaluation of its performance in windy conditions without taking account of nearby buildings.

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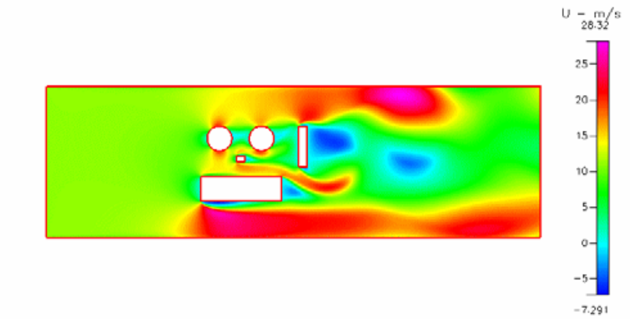

Figure 8: Flow pattern when the wind blows from the direction of the second cooling tower.

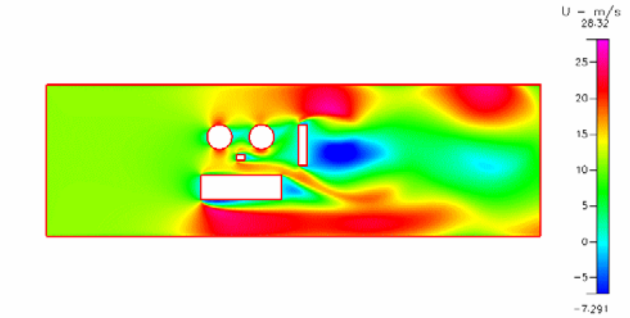

Figure 9: Flow pattern when the wind blows from the direction of the second cooling tower.

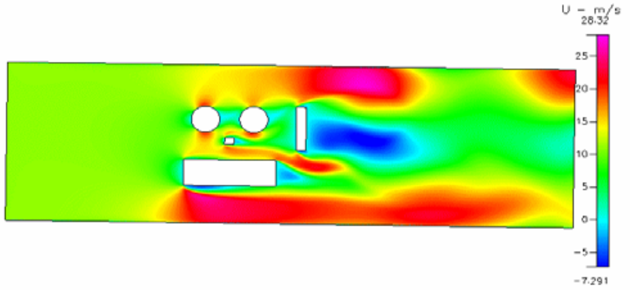

Figure 10: Flow pattern when the wind blows from the direction of the second cooling tower.

Conclusion

The performance of natural draft cooling towers is significantly affected by wind. The plant buildings depending upon the orientation can significantly help to improve the cooling tower performance by sheltering the tower from wind. The effect depends upon the size and orientation and arrangements of the buildings.

The tower performance is reduced when the wind blows from the direction of a second tower or from a direction without any buildings to shelter the tower.

Acknowledgements

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