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ACC.04: Guidelines for Wind Mitigation in Air-Cooled Condensers

Original Issue: 09/10/2024
Revision due: 09/10/2027

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Guidelines for Wind Mitigation in Air-Cooled Condensers

Introduction

Naturally occurring wind has been determined by many researchers, consultants and providers / operators of forced-draft Air-Cooled Condensers (ACCs) as the root cause of performance deficiencies and mechanical problems. Regardless of site-specific wind speed and direction, the equipment is typically designed to meet the maximum wind speed of 5 m/s (16 ft/s) normally specified in test codes, and performance specifications are generally met under such conditions. However, air-cooled equipment must operate during much higher wind speeds and gusts, sometimes frequently. During these periods there can be significant deficiencies in condenser vacuum, in some cases tripping the unit. Wind above 5 m/s will affect thermal performance due to airflow distortion entering the windward fans or recirculation that will impact the windward and leeward fans. Wind can also increase the intake of hot air from neighboring heat sources and can add significant stress to the fan blades by causing loading and unloading as the blades rotate, potentially leading to blade failure. Furthermore, these forces can cause motors overloaded above their amperage set point to trip, and gear reducers can also be damaged due to stresses induced by wind.

Mitigation of the detrimental effects of wind can be achieved to some extent by optimizing the initial design and may include installation or subsequent retrofit of appropriately designed structures. Computational fluid dynamics (CFD) modeling as well as well-designed pilot testing can confirm suitable mitigation efforts.

Note: The information contained in this Guideline is believed to be accurate based on available knowledge. It is the responsibility of any user of this Guideline to confirm the accuracy of information herein and to apply the information appropriately to any specific situation.

Effects of Wind on Forced Draft ACCs

Wind can cause reduced ACC performance as well as mechanical equipment degradation. The variability of wind parameters (velocity, direction, duration) introduces challenges to modeling, but wind patterns tend to have consistency on a seasonal / annual basis, so historical data is used to estimate future scenarios. Site-specific issues such as the position of buildings or other structures, the elevation of ACC fans and barriers included in the original ACC design will also influence the effects of wind.

<u>Fan performance and condenser vacuum</u>

Wind can cause significant problems by causing erratic airflow or stalling, resulting in backpressure increase (vacuum deterioration) in the condenser. This effect is most notable when the ambient air temperature is approaching or above the original design temperature along with the steam turbine operating near full load. Under these conditions, a slight increase in backpressure may force a reduction in electricity generation output and can cause the generating unit to trip offline.

During moderate wind speeds the structure of the ACC along with air drawn toward the fans can result in recirculation of the heated exhaust air to the ACC (Figure 1). This is due to the relatively short distance between the discharge point and fan inlets. Recirculation is generally considered to occur on the leeward (downstream) side of the ACC; while this is true at low-to-moderate wind speeds, at higher wind speed such as 15.5 m/s (51 ft/s) recirculation can be predominant on the windward (upstream) side.

As wind speeds exceed 7 m/s (23 ft/s) areas of the fans may become stalled for airflow with the air intake receiving inadequate supply air. Under these conditions, backflow can occur, with hot air being drawn downward through the stalled-flow side and subsequently recirculated as supply air, further reducing cooling effectiveness. At these higher wind speeds, airflow through the windward fans or the second row inward will be most affected and will be significantly reduced. The higher the wind speed, the greater the air flow will be reduced. This pattern has been observed repeatedly on many ACCs.[1-6]

Figures 2 and 3, demonstrated via CFD analysis, represent the effects of wind speed on changes in temperature and airflow through the windward fans with no wind mitigation structures present. Figures 4 and 5 show the difference when appropriately designed wind mitigation structures are in place. Figure 6 shows a side view of CFD modeling with and without wind mitigation structures.[7]

<u>Mechanical equipment degradation</u> `

As the fan rotates around the inlet bell the blades experience variable aerodynamic loading as they move through the non-uniform flow field. This effect has been documented in several reports. This creates an alternating stress on the blades which causes fatigue of blade material resulting in crack initiation at stress points in the blade, eventually resulting in blade failure if not cracks are not discovered in time (Figures 7-9). Fan blades should be inspected during every major outage and blades repaired or replaced. These alternating loads have also caused fatigue failure of blade hardware. Note that failed fan blades can be released and pose a significant safety hazard for personnel underneath the ACC; this area should be isolated from routine traffic and work should be performed only when the unit is offline if possible.

Wind also can cause shifts in motor amperage draw. Depending on fan blade pitch and whether changes have been made to the original design for performance improvement, the motor amp draw could approach or exceed its rated capacity with increases caused by wind. It also should be considered that since changes in air density will cause motor amperage to increase, the fan pitch settings should allow some margin when set in warm weather. Depending on the original setting of the circuit breakers, variation in motor amperage could trip the motors.

Wind can create vibration, which could trip the vibration switch or cause an alarm on continuously monitored equipment. It is possible for alternating loads on fan blades to induce loads on the bearings and gears of the gear reducer.

Identifying the Presence of Wind-Induced Problems

It is relatively routine for ACC operators to observe shifts in backpressure with variations in wind conditions, and for this shift to occur rapidly. Since the major period of performance concern is during hot ambient temperatures when the unit is at risk of generation shortfalls or a turbine trip, operators should maintain vigilance during weather conditions that influence backpressure. However, the distinctives of fan response to wind direction and the issue of recirculation can complicate the picture. CFD modeling can be optimized by correlating the model with actual data where available, improving predictive capability.

Equipment degradation develops much more slowly than performance loss. Although ideally early detection approaches such as vibration monitoring will be employed to identify degradation at an early stage and prevent its progression, there may be no recognition of a problem until failure occurs. The influence of wind on fan blade, gearbox and motor failures should always be a consideration, but analysis is necessary to confirm whether wind appears to be a primary cause or a secondary factor. The position of fans with respect to wind direction and speed, for example, may implicate wind if blade failures are on the outer edge of the windward side of the ACC, but be considered less significant for failures toward the central fans.

Wind Mitigation Approaches

There are a variety of locations and configurations that are used to reduce the effect of wind on ACC performance (Figures 10-16). Screens placed around the upper portion of the air inlet are typically used to reduce or prevent mechanical problems and to limit recirculation. The goal is to create uniform inlet temperature, as close as possible to the ambient air temperature. A comparison between Figures 2 and 4 show with CFD analysis how inlet temperature can be adjusted to achieve better uniformity.

Screens used as wind walls, designed as a cross or cruciform placed under the ACC, block and redirect cross winds which results in improved uniformity of inlet airflow across the fan shrouds (Figures 3 and 5). This essentially adjusts airflow supplied to the fans nearer to the original design condition, as well as reducing windward recirculation.

Figure 5 represents an ACC where windscreens are installed on the upper perimeter as well as a ground-level cruciform structure. These mitigation efforts reduce much of the airflow variation seen in Figure 3. This case was analyzed at 15.5 m/s because significant reduction in performance was taking place when approaching this wind speed.

<u>Initial design</u>

Actions to mitigate wind effects on an ACC may be included in the initial ACC design, particularly where operating goals and expectations are directed toward optimum fuel efficiency and power output under a variety of environmental conditions. Pre-construction wind measurements at the site along with a well-designed CFD analysis that takes into consideration nearby physical structures can be helpful in optimizing these mitigation measures. The effort may include physical structures to manage wind velocity, ACC orientation and specific locations, height, fan bay arrangement, etc. For example, wide, solid peripheral walkways designed with about 0.3 to 0.5 fan diameters have been shown to reduce wind effects (performance degradation as well as vibration) on peripheral fans across a wide range of wind conditions.[2] Measures such as wide walkways will not address all wind-related concerns for a given ACC but are an example of relatively inexpensive initial design features that should provide a positive effect towards wind management.

Fan design can also assist in addressing performance deficiencies under windy conditions. The fan curve and solidity can be selected with consideration of the effects of anticipated wind patterns, including the greater susceptibility of peripheral fans to wind-induced damage as well as performance effects. Reinforced fan blades and/or stronger attachment hardware can be included for peripheral fans wherever modeling indicates a concerning risk of blade damage or failure.

Retrofits

If wind mitigation measures are lacking or inadequate in the original design, retrofitted structures are generally feasible and effective.[8] Detailed CFD analysis with operation-based input will be very helpful in identifying optimal mitigation approaches. Full or partial re-direction of wind may be based on ground-based structures, upward extensions of existing sidewalls to limit recirculation, or downward screens (fixed or movable) to shield fan inlets with a variety of mesh options. A critical retrofit issue is ensuring the structural capacity to avoid excessive stress, particularly during high wind events. While a new design will have this capacity built-in, a retrofit requires a structural evaluation to assure that columns and connections have adequate strength. If an ACC to be retrofitted is structurally inadequate, simple bracing will usually remedy the deficiency.

Quality materials and workmanship are important for a durable installation. Windscreens come in a variety of porosities and are reinforced to withstand the wind loads of the original structural design specification. High velocity winds and gusts involved can quickly destroy screen materials that are not of suitable porosity and rigidity. Windscreen mesh should be treated to withstand degradation from UV rays. Windscreens are custom designed for the column spacing of the equipment. They are typically attached with hooks and ratchets and require no welding or drilling for bolts.

In addition to mitigating wind speed, fan designs that reduce the risk of wind damage with reinforced blades and/or more robust attachment hardware may be retrofitted in areas proven to be susceptible to damage from wind.

Prioritization of mitigation options

Evaluation of the significance of specific wind-induced problems will guide the operator to identify which mitigation efforts will be most cost-effective, and perhaps which steps to take first. Priorities should be considered between equipment damage / risk, performance due to fan stalling, and hot air recirculation. An evaluation should also include any negative effects of wind mitigation equipment, such as any reduction in airflow that might take place during periods of low wind speed. Depending on the cost-benefit, it may not be necessary to install mitigation equipment directed towards all potential wind-related issues.

Evaluating the Effectiveness of Mitigation Efforts

Wind mitigation is normally undertaken to improve condenser vacuum performance and/or to limit equipment degradation and failure. As with the initial evaluation of the need to take wind mitigation steps, determination of the effectiveness of mitigation actions depends on the objectives and anticipated outcomes.

Condenser performance

Fan stalling and hot air recirculation both cause an increase in condensate temperature and consequently a reduction in vacuum, but they potentially can be measured separately by properly-positioned temperature probes. Background temperature measurement prior to the installation of any mitigation equipment is essential to subsequent evaluation efforts. All relevant conditions must be recorded for background under a variety of scenarios to use for comparison (wind speed and direction, operating fans with speed settings, ambient and condensate temperatures, condenser vacuum, steam / condensate flow, finned tube external cleanliness, etc.). The effectiveness of wind mitigation equipment at improving condenser performance can be quickly determined by comparing the condenser vacuum before and after the installation, under similar conditions.

Equipment Degradation / Failure

Physical deterioration of fan blades, gearboxes and motors usually takes place over an extended time frame, weeks-to-months rather than a few days. This potentially provides an opportunity for early detection of blade cracks, pending gearbox failure (vibration, acoustics and oil monitoring) and motor failure (vibration and acoustics). The effectiveness of wind mitigation for limiting equipment degradation will likely be confirmed over a period of years.

Wind Mitigation Program

It may be useful to develop a program to monitor wind effects on a specific ACC and to recommend mitigation actions. A program of this type would be important for initial evaluation of the significance of wind-induced problems, whether equipment was installed with initial ACC construction or not. If and when suitable wind mitigation is installed and effectiveness confirmed, the program could be reduced to a periodic check to ensure that effectiveness is consistently maintained.[9]

Effects of Wind on Induced Draft ACCs

Induced draft ACCs have been increasingly selected over the traditional forced draft design in recent years, due to lower initial costs for purchase and installation. It had been anticipated that the induced draft design would not be as significantly subjected to wind effects because the fans are largely shielded by structural barriers that block airflow to the fan inlet, but there may be cases where wind mitigation is beneficial for optimizing performance in these units.

Conclusions

Wind effects can be a major issue of concern for ACC owner/operators and can result in significant loss of unit efficiency and availability, as well as maintenance expense. An organized approach to evaluating and considering available mitigation options can be of great benefit to the economics of power-generating plants with ACCs. Subject matter experts are available with consulting and wind mitigation suppliers, as well as the original ACC suppliers, to assist in providing technical information to allow an informed decision on actions to be taken, if any.

Note: Presentations discussing this and other issues involved with air cooled condensers can be viewed on the website of the Air Cooled Condenser Users Group at http://acc-usersgroup.org/.

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Figures

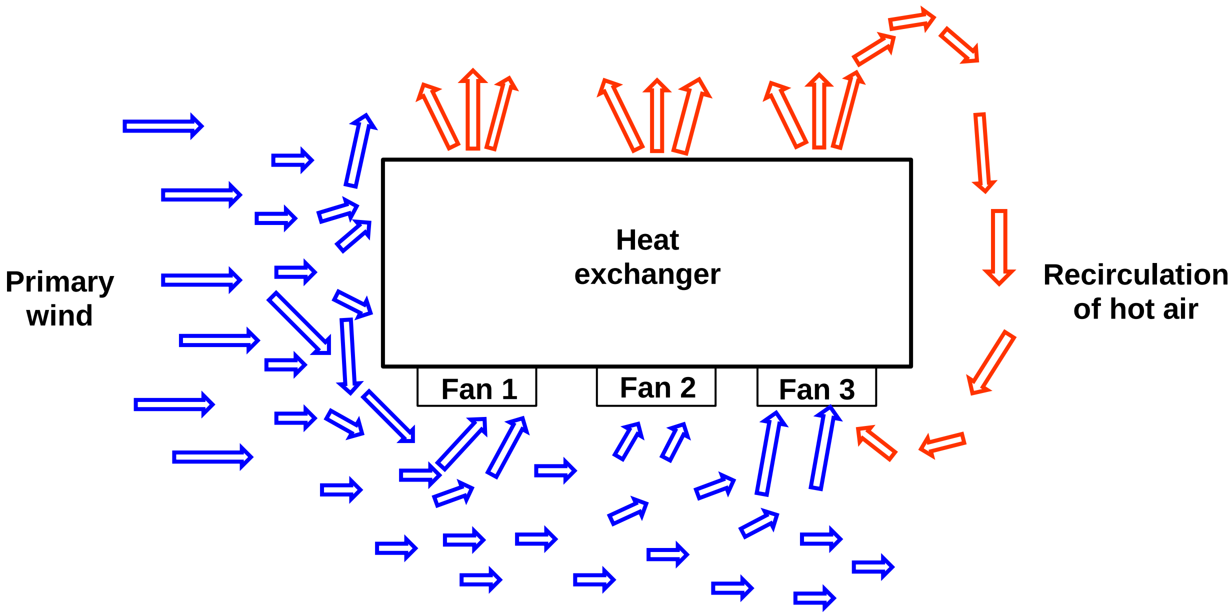

Figure 1: Wind-supported hot air recirculation

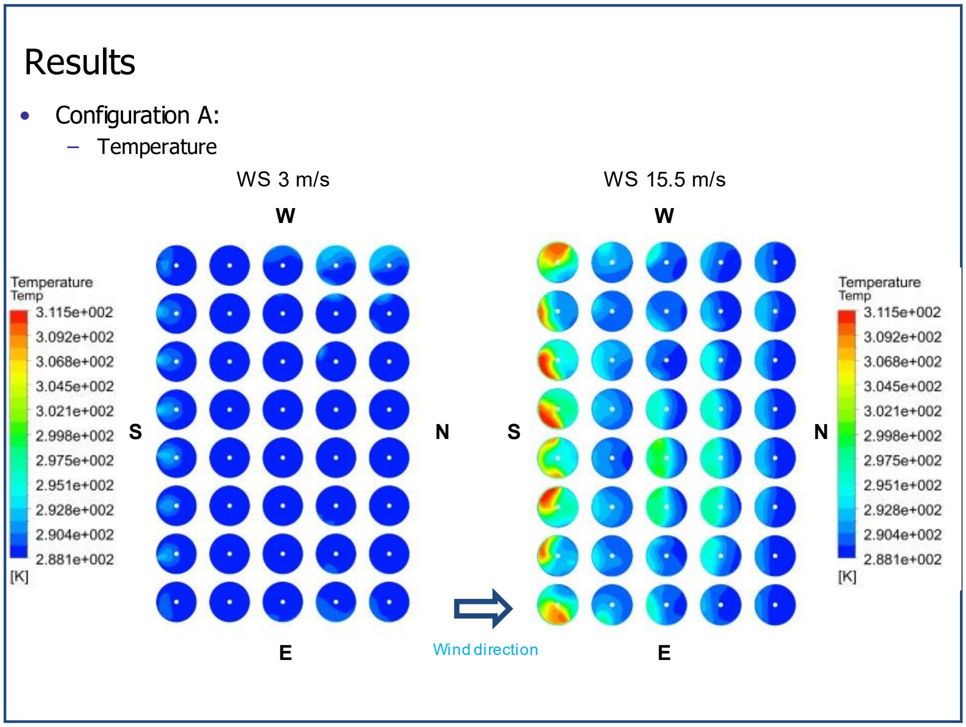

Figure 2: Wind effects on inlet air temperature without wind mitigation features

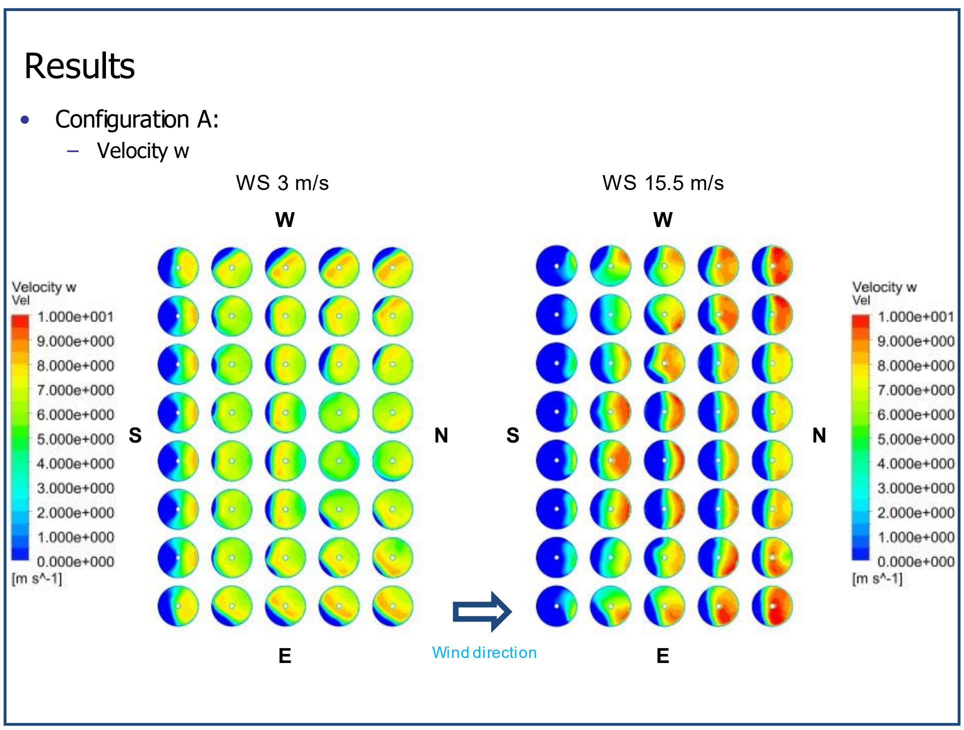

Figure 3: Wind effects on fan air flow velocity without wind mitigation features

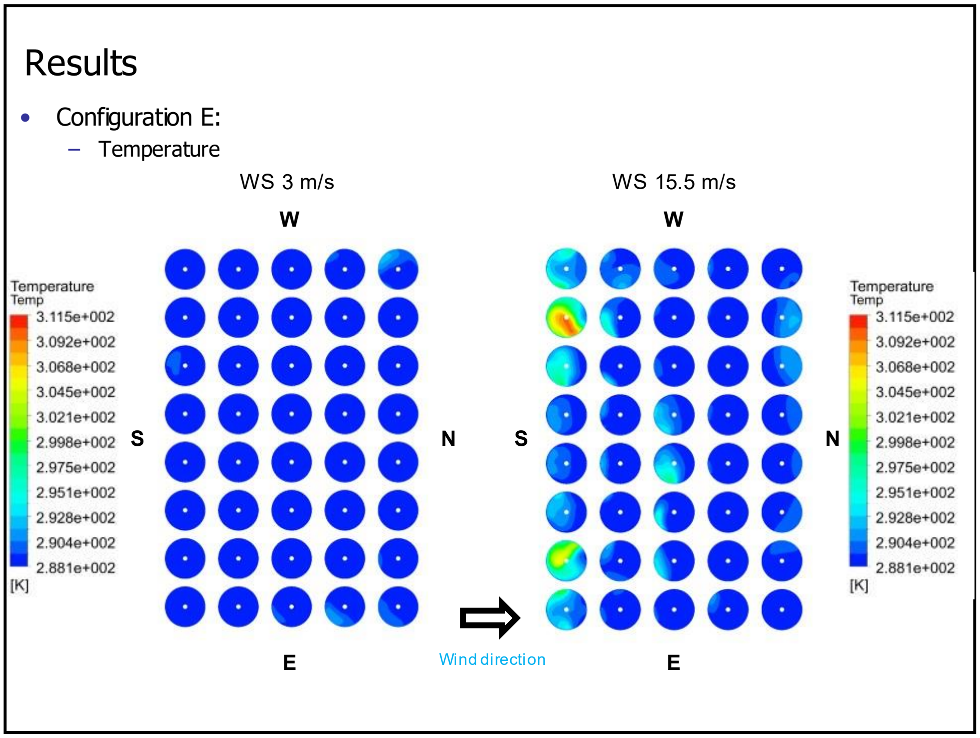

Figure 4: Wind effects on inlet air temperature with wind mitigation features

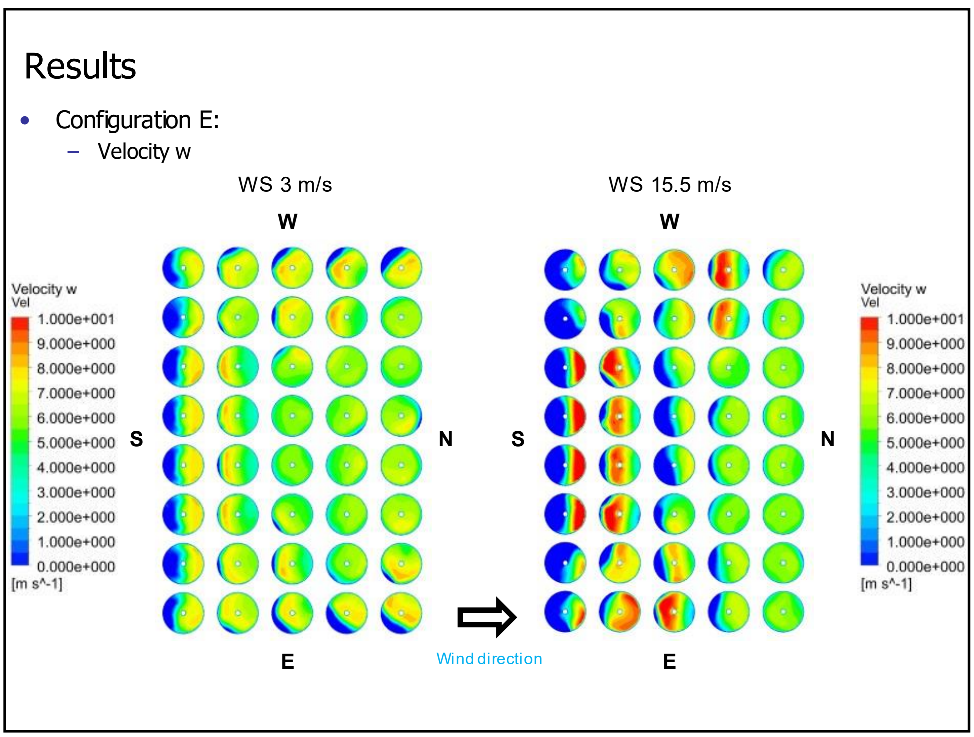

Figure 5: Wind effects on fan air flow velocity with wind mitigation features

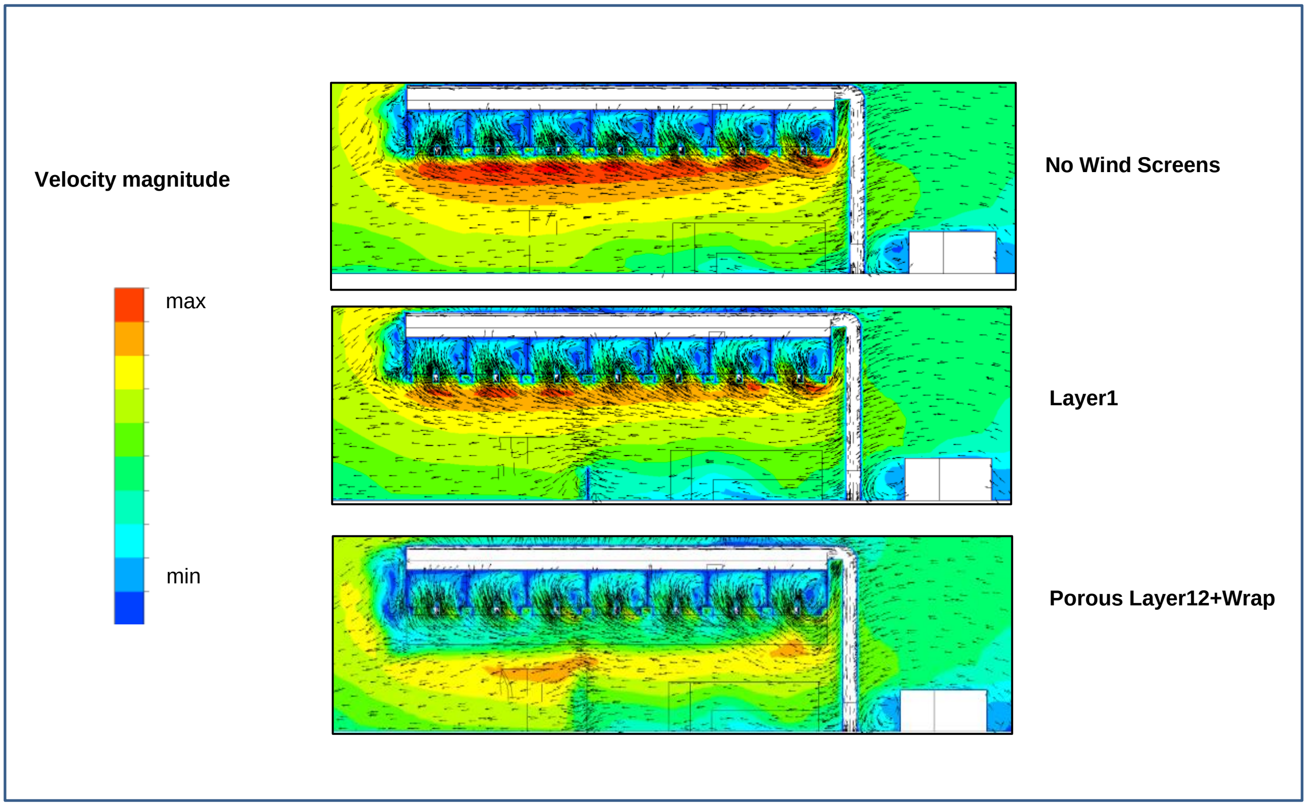

Figure 6: CFD modeling with and without screens

Figure 7: Broken fan blade due to dynamic blade stress

Figure 8: Broken and missing fan blade

Figure 9: Failed fan blade on the ground; this represents a significant potential safety hazard for personnel working underneath the ACC.

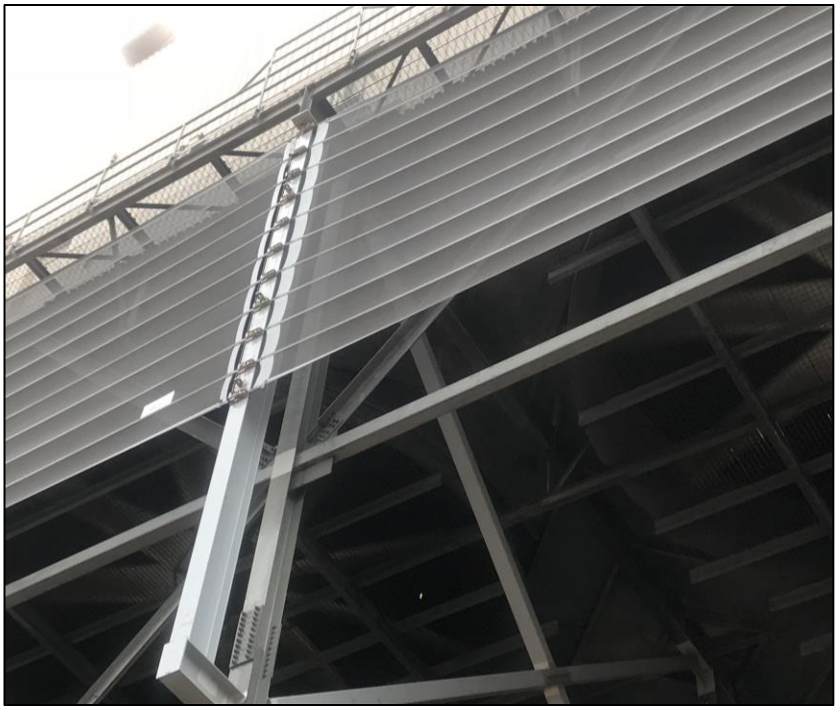

Figure 10: Perimeter screens for fan protection

Figure 11: Perimeter screens to reduce vibrations and fan blade damage

Figure 12: Internal screening to prevent crosswind losses to fan airflow

Figure 13: Screen wall installation

Figure 14: Motorized wind screen designed to reduce fan blade stresses and to allow adjustments as a function of wind speed

Figure 15: Combination of perimeter screen to reduce stress on fan blades and cruciform screens to reduce wind induced performance deficiencies

Figure 16: Wind cross at ground level

Definitions

A-frame: The A-shaped structure defined by a set of finned heat exchange tubes attached to an upper duct.

air cooled condenser (ACC): A steam condensing device that employs air as the steam coolant.

air inleakage (AIL): Air drawn into the vacuum caused by condensing steam, occurs when a point of air entry exists.

backpressure: The vacuum created by condensing steam in a condenser.

CFD: Computational fluid dynamics, the science of using computers to preduct liquid and gas flows based on the governing equations of conservation of mass, momentum and energy.

condensate: Liquid water formed from condensed steam.

dephlegmator: The section in an ACC that is designed to remove non-condensable gases from condensing steam.

finned tubing: Heat exchange tubes for ACCs that have external fins to enhance cooling capacity.

solidity (for a fan blade): The ratio of blade chord length to spacing.

wind screen: A fabric that is composed of an engineered mesh material of varying porosities that has been tested to determine the wind break efficiency that can be translated into the wind loading imposed upon the structure at the design wind speed for the facility.