Determining the Proper Wind Sensor Height on a Building Using CFD

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Abstract

On-site meteorological data for air quality modeling must be collected at a power plant. Examination of the site led to the conclusion that no proper location existed on-site for the placement of a standard 10-meter meteorological tower due to local vegetation and buildings and other, nearby structures. Nor was there any off-site location available because the vicinity is built out. The only possible location of the tower is on top of the power plant itself. EPA meteorological guidance recommends that a fluid modeling effort be undertaken to demonstrate the suitability of a site when a tower is located on a building. Computational Fluid Dynamics (CFD) was used to determine the minimum height of the tower required to limit the influence of the building wake on the wind at the sensor.

1.0 Introduction

It is difficult to locate a meteorological tower in an urban area when collecting data for air quality modeling. The tower must be placed in an area free from the influence of wind altering obstacles and shading. An urban area will contain many tall friction elements and siting will be limited due to property ownership and use constraints. For Prevention of Significant Deteriation (PSD) review, it is most appropriate to collect meteorological data at the location of the source undergoing review. However, this can be costly in time and money as it is expensive to install and operate a PSD quality meteorological station and may delay the project under review. That is why many projects use the nearest already operating station for modeling. In some cases, though, the nearest meteorological station is inappropriate for modeling.

The facility in this study is located in an urban area with strict property constraints, rough topography, and tall urban friction elements. The facility in review is a power generation facility operating several large diesel electric generators in Kodiak, Alaska. The nearest meteorological tower is the National Weather Service (NWS) ASOS station located at the Kodiak airport. Even though this facility is only six miles away from the airport, it is evident that significant topographical features will create entirely different climatological signatures in the wind. Figure 1 demonstrates this. Wind at the Kodiak airport aligns frequently along the river valley it is located in, making a northwest wind the most common feature in the windrose. The source facility is located near several tall hills, one of which is directly northwest of the site. It is highly unlikely that the Kodiak airport site is representative of the source site.

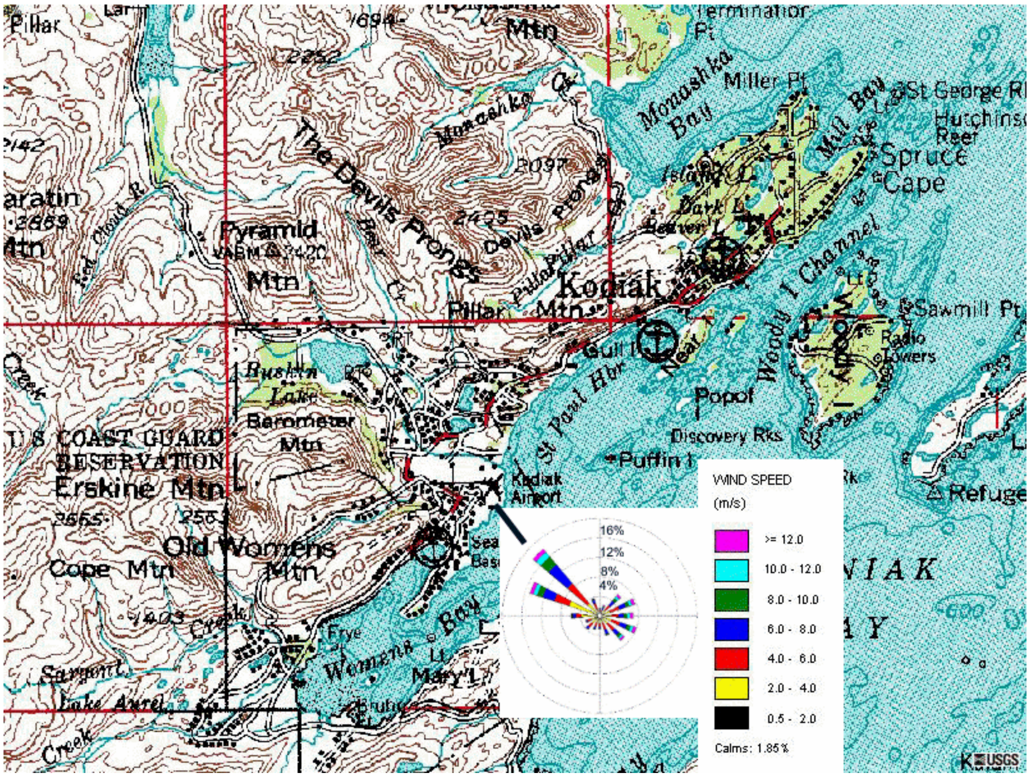

Figure 1: Wind-rose and topography at Kodiak, Alaska.

There is no obvious ideal site for location of a meteorological tower on the facility property. Nor are adjoining properties available. High density of tall vegetation, facility buildings, powerlines and neighboring buildings all contribute to this. Winds at this location are further complicated by a large bridge structure (from Kodiak Island to Near Island) located close by to the west of the facility building.

In these cases, the meteorological guidance allows the facility to make use of a rooftop location for a meteorological tower if it can be demonstrated to be suitable using wind tunnel analyses. Several factors lead to the expectation that a roof location may be the most suitable alternative. These factors are:

- Future source stacks are expected to be located at about the same height above the roof of the plant building as a 10-meter high meteorological tower mounted on the plant roof would be. Sensor height at the same height as the source being studied is desirable in most cases. The stacks may need to be as high as the Good Engineering Practice (GEP) stack height due to the high topography in the region.

- The plant and the surrounding area are located on a steep slope, which will cause increased turbulence at the surface. A taller sensor location is beneficial at limiting the influence of this on the dataset.
- Heavy vegetation and building density in the area may cause the general flow to be detached from the surface layer (known as an urban zero-plane displacement). A higher sensor will be beneficial at limiting the influence of this on the dataset.
- The rooftop location will be nearer to the sources. Any other alternative will probably need to be off site. Significant topographical variation in the area requires the tower to be near to the source to result in a representative dataset.

These factors lead to the conclusion that a meteorological tower mounted on the facility's roof may be the best location for recording winds if wind tunnel modeling demonstrates that the wind at that height will not be significantly altered by the building or structure induced turbulence.

The best location on the plant roof is at the northeast corner of the building. This location is as far east as possible to limit the impacts of the adjacent bridge. It is also as far north as possible to limit the impacts from the strong south winds. North winds don't pose as much risk due to the slope of the land and the high vegetation upwind. A microwave tower is present at this corner, which could be used as the base for the meteorological tower.

Wind tunnel modeling using CFD

Meteorological guidance for meteorological tower locations specifies wind tunnel modeling to demonstrate that a roof location is adequate for a met station. The site is adequate if the wind conditions at the roof location have little deviation from the hourly averaged winds that would occur in the same location if the building did not exist.

Wind tunnel modeling can be costly and proper facilities are rare. Computational Fluid Dynamics (CFD) is essentially a computerized wind tunnel. CFD has been used for micrometeorological studies to study pedestrian comfort, localized pollutant dispersion, odor levels, building wind-loading, and stack exhaust behavior. Though not generally as widely used as wind tunnel modeling, CFD has proven to be as or more accurate than wind tunnel modeling in many studies. A benefit of CFD modeling is that the entire domain can be analyzed for wind speed and direction. In a wind tunnel model a separate sensor is needed for these variables at each individual point of analysis.

CFD modeling was used to analyze the suitability of the region above the plant roof as a meteorological station location. Nine individual CFD modeling runs were performed based on the possible worst case conditions (in terms of the size of building wake). Worst case conditions tend to occur when winds impact the building perpendicular to building faces. Two of these runs were from direct project west (in relation to the faces of the power plant building) at 5 m/s and 10 m/s (wind speeds at 10 meters above the surface at mean sea level) to judge the length of the wake from the bridge structure and the windward building face wake. Two of these runs were out of project north at 4 m/s and 8m/s to judge the influence of the windward edge wake jet at the proposed instrument location. Three of these runs were project south winds at 4m/s, 8m/s, and 12 m/s. Two additional runs were made at 12 m/s from 15 degrees to the east and west of project south to test the sensitivity of the building wake analysis.

Wind speeds were selected based on statistical probability of occurrence at the Kodiak airport. These winds may not be representative of the wind speed climatology at the site, but provide the nearest estimate. Fastest gust speeds observed on record were below 60 mph, or roughly 27 m/s. Highest sustained winds on record were generally below 20 m/s in the winter months. A typical high sustained wind is 10-14 m/s (22-30 mph) occurring roughly 8% of the time. Winds above 14 m/s occur roughly about 2% of the time, most near 14 m/s. Therefore, 12 m/s is chosen as the high wind scenario most likely to cause the building wake to reach higher above the roof and effecting the wind sensor.

Modeling domain and setup

The modeling domain was setup in accordance to guidelines developed by Envirometrics for CFD modeling based on experience with many projects. (See McAlpine and Ruby, 2004 for details of these modeling rules.) The domain included the steep upslope of the hill that the site is located on, simplified in east-west variance to prevent the geometry of the building from becoming too complicated. The center of the domain is the Kodiak plant building. The building envelope, stack bases, and roof vents were the only building features added to the domain. An outline of the building is included in Figure 2, and shows one potential position of the tower, at the northeast corner of the building. This figure does not show the surrounding topography. The main building was modeled as 10 meters high.

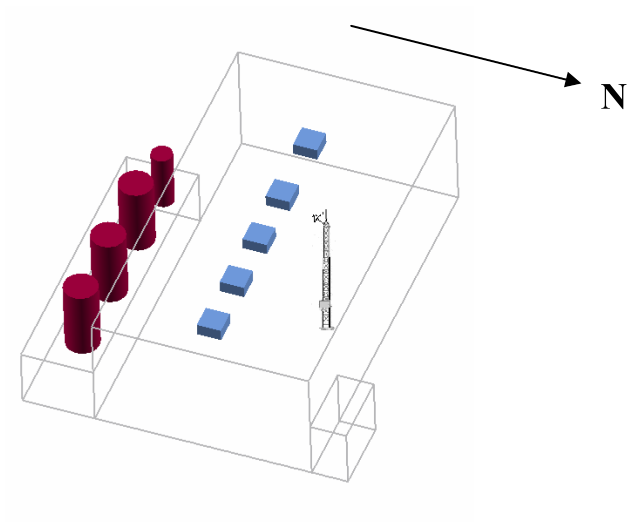

Figure 2: Outline drawing of the geometry used in the model for the facility building. The tower is located on the northeast corner of the plant building. The building vents and bases for the exhaust stacks are included in the geometry.

CFD model construction is somewhat limited in its ability to account for details. When small-scale detail is added to a building the computational cells must be smaller, which exponentially increases the computation time for the model. The bridge was added to the domain, slightly turned in angle to be parallel to the Kodiak building, which greatly simplified constructing the mathematical model. The actual bridge is at about an 8^o angle to the building. The sides of the domain were located 180 meters in distance from the nearest obstacle (building or bridge). This distance is based on the 6*H guideline used by Envirometrics where H is the distance from the lowest point in the domain (0 meters) to the highest obstacle point in the domain (30 meters). The top of the modeling domain was located at 8*H, 240 meters.

The domain was flooded with normal air at 45^o F (280^o K) and 1000 mb in pressure. A vertical wind profile for each wind speed was induced throughout the domain and at the inlets of the domain using a logarithmic profile with a standard friction element height, z_o, of 0.4 meters which corresponds to regions of "fairly level wooded county" or "outskirts of towns." Perhaps a larger friction element height would be warranted considering the tall heights of trees and buildings in the area. However, the strongest winds come in off of the ocean, where friction element heights are near 0 meters, so 0.4 meters was used as a compromise.

The standard wind profile equation used was:

$$U(z) = U_* / k \ \ln(z-d \ /z_o)$$

where the wind velocity U at the height z is given by the friction velocity, U_*, the von Karmon constant k (0.4), the friction element height z_o, and the zero-plane displacement height d (used for urban areas or regions of dense friction elements). No zero-plane displacement height was used in this study despite the tall friction elements nearby to result in more conservative solutions.

The friction velocity for each wind speed was estimated from the standard wind speed at 10 meters, thus making the wind profile dependent only on the friction element height. The resulting wind profile was found to be representative of the natural profile in the area.

The CFD turbulence solver used for this evaluation was the Chen-Kim modified k-epsilon solver, which is modified to account for observations in larger Reynold's number flows and turbulence time-frame scales. It is considered the most suitable model for domains of this size. In general, the most suitable turbulence solver for ambient air quality studies available today is the Large-Eddy Simulation (LES) solver, however implementations are not yet available which allow reasonable computation time. The industry standard model is the simple k-epsilon model, which performs reasonably when compared to wind tunnel tests in most studies published in the literature (reasonable in respect to the level of accuracy needed in most air quality evaluations). It has been widely observed that k-epsilon models tend to underpredict turbulent kinetic energy (TKE) directly upwind of cubes/buildings and overpredict TKE directly downwind of buildings.

Each wind scenario is labeled by the wind initialized at 10 meters above mean sea level (MSL). Incoming winds at higher elevations were assumed to follow the wind profile.

Modeling Results

Project west winds at 5 m/s

The incoming west winds have the potential to influence measurements at the tower position in two ways. First, the wake of the bridge has the potential to reach far downstream, especially during higher velocity winds. Second, the building roof wake zone has the potential of being higher than a 10-meter tower, more likely during higher wind speeds. Since the topography is fairly identical upstream to both project east and west winds, this analysis was used to evaluate the building roof wake zone heights for both east and west winds. Maximum roof wake zone heights are reported for the latitude plane where the tower is proposed and the maximum roof wake zone height at the center of the building.

Wind speeds were measured incoming to the bridge at the same latitude and ground elevation as the power plant building. Incoming winds of 5 m/s at 10 meters above MSL were 6.6 m/s at 10 meters above the surface at that elevation and 7.1 m/s at 20 meters above the surface. Since the building is 10 meters high, the 10 meter tower is 20 meters above the surface.

Wind speed at the tower was about 7.3 m/s, which is 2.8% higher than the undisturbed 20 meter wind. The wind isopleths for this scenario are illustrated in Figure 3. The figure demonstrates wind magnitude along a plane cut into the domain parallel to the face of the power plant front wall and at the latitude of the location of the tower. Wind under the bridge is low because of the influence of a bridge pylon, which is near to the sample plane, but not visible in the picture. North/south component wind speeds were small at the tower, being 0.15 m/s at the anemometer location 10 meters above the roof, resulting in about a 1.5° turn of the wind.

A reasonable method to analyze the wind magnitude is to compare it to that observed at the building stacks. The wind for the stacks was measured at 5 meters above the top of the second stack base from the west, which is about the level of the existing stack openings. Wind was about 7.2 m/s at this point. However, the current location of the stack openings is well within the building wake zone and it is likely that the stacks will need to be raised to a position out of the wake zone.

The wakes were observed by viewing the levels of turbulent kinetic energy (TKE) in the wake. The edges of the wake were assumed to be the regions where a sharp gradient in TKE occurred from higher values of TKE to lower values, similar in magnitude to the overall flow. The wakes were easily seen in the model, and a mean wind speed gradient often followed the TKE gradient, so that the average flow reached velocities comparable to the average flow outside of the wake region.

The height of the roof wake was about 6.5 meters at the north edge of the building where the tower is located, and 7.2 meters high at the center of the building.

The bridge wake mostly dissipated before reaching the west face of the building, as can be seen in Figure 3 (included at the end of the document) by examining the wind profile. While some degree of TKE from the bridge wake does reach the tower location, it is difficult to quantify it as of similar magnitude to the surrounding TKE values from the building. Overall, the bridge influence is trivial for this distance downwind.

Project west winds at 10 m/s

Incoming winds of 10 m/s at 10 meters above MSL were 12.5 m/s at 10 meters above the ground at this latitude and elevation and 13.6 m/s at 20 meters above the ground. Wind speed at the tower was 13.9 m/s, about 2.2% higher than the 20 meter incoming wind. Wind isopleths are plotted for this wind speed in Figure 4.

The building wake zone does get quite high in this case, being nearly 7 meters in height at the north face of the building, and over 11 meters in height at the center of the building. The high central zone of TKE is illustrated in Figure 5, where the ratio of TKE to total KE is shown. A secondary recirculation zone reaches high into the area 10 meters above the building, but is lower along the edge of the building as illustrated in Figure 6. However, Figure 6 shows that the bridge wake may have some interference at the tower. TKE/KE approaches 10% in the area, meaning that some turbulent gusts may be evident in a wind record due to the bridge during high project west winds. Average winds at the tower may be altered slightly due to this, but this is difficult to quantify with the steady state solution provided by CFD analysis.

The north/south component of the wind at the tower level is 0.7 m/s. This is still a small percentage when compared to the 13.9 m/s westerly component, but results in about a 3° turn in the wind. This is mostly due to the influence of the bridge, judging on the illustration of the TKE wake.

Project north winds at 4 m/s

North winds are a bit accelerated in their incoming state because they are originating up hill from the site. For winds incoming down the slope of the hill, measuring wind speed at 10 and 20 meters at a point before the wind reaches the building may not be representative of the wind profile we are studying. The goal is to see the influence of the building compared to no building being present. Therefore, it is more valuable to study the wind at 10 meters and 20 meters above the ground at a location at the same elevation as the building along the slope away from the interference of the building. This measurement location was 50 meters east of the building.

Incoming winds are about 5.2 m/s 20 meters above the ground. Wind speed at the tower was 5.7 m/s. At the general stack area, wind speeds were about 6.2 m/s. An illustration of the recirculation zones and wind vectors are included in Figure 7. The wind was turned about 4º off of the incoming wind.

The roof wake zone approached to about 3.5 to 4 meters above the roof maximum near the tower area.

Project north winds at 8 m/s.

Comparative winds are about 9.9 m/s 20 meters above the ground. Wind speed at the tower was 11.0 m/s. At the general stack area, the wind speed was about 12.1 m/s. An illustration of the recirculation zones and wind vectors are included in Figure 8. Turning of the wind was about 0.77 m/s to the east at the tower, which causes about a 4º turn in the wind.

The roof wake zone approached to about 3.5 to 4 meters above the roof maximum near the tower area.

Project south winds at 4 m/s.

South winds are the most important winds for the tower, as they will strike the building face in such a way as to create the maximum wake zone at a tower location near the north edge of the building. It is likely that strongest winds may actually come from the project southwest as winds are channeled at the surface along the face of the hill and between Kodiak Island and Near Island. Comparative winds were calculated about 50 meters east of the building.

Comparative wind was at about 5.1 m/s at 20 meters. Winds measured at the tower were about 5.5 m/s and at about 5.4 m/s at the stacks. Turning at the tower was about 0.38 m/s to the west, leading to a turn of about 4º.

It was evident that the building wake may be quite large during direct south winds, the worst case scenario. The wake, as illustrated in Figure 9, approaches 7.5 meters in height near the center of the building even during the lower wind speeds. It is obvious that the slope of the hill has a lot of influence on the size of this wake as rising winds carry the turbulence upward.

Project south winds at 8 m/s.

The 8 m/s MSL wind is 10.0 m/s at 20 meters above the base elevation at the tower. Winds measured at the tower were about 11.6 m/s and about 9.8 m/s at the stacks. Turning at the tower was about 0.38 m/s to the west, leading to a turn of about 2 degrees.

This was definitely the worst case scenario modeled. The wake, as illustrated in Figure 10, approaches 10 meters in height near the tower. It is obvious that the slope of the hill influences the size of this wake as rising winds carry the turbulence upward. In response to the wake, a jet of higher velocity wind forms above the wake. As wind gusts, this jet will move up and down as the size of the wake grows and shrinks, leading to some turbulent conditions at the tower sensor. To demonstrate this, velocities were measured at 2 meters above the sensor (12 meters above the roof) and 2 meters below the sensor (8 meters above the roof). Above the sensor the wind speed was about 11.4 m/s. At 2 meters below the sensor the steady state wind speed was 11.9 m/s. As the wake moves up and down with incoming gusts, this jet will move in and out of the tower sensor area. The average should be comparable to the value observed with this steady state solution.

Project south winds at 12 m/s.

Comparative wind was about 14.3 m/s at 20 meters above the surface at the same latitude as the tower. Again, some de-coupling is occurring at higher wind speeds as a displacement height begins to form. This causes a high-speed jet of wind above the de-coupling zone and causes the wind to turn more east-west along the hill below the de-coupling zone. Winds measured at the tower were about 14.3 m/s and about 13.1 m/s at the stacks. Turning at the tower was about 1.4 m/s to the west, leading to a turn of about 5.6 degrees. Winds at the stack were turned about 5 degrees.

Again, wind speeds were measured at different heights at the tower position to demonstrate the gradient in wind speed at the tower. Wind speed at 8 meters above the roof was 13.8 m/s and 12 meters above the roof, 14.6 m/s.

The wind speed wake was illustrated in Figure 11. The turbulent wake approaches a height of 6 meters and a high-speed roof jet is apparent on the windward side of the roof. However, the wake is less defined in this case because of the de-coupling of the high winds from the surface layer.

South wind 12 m/s turned 15º toward the east (project south-southwest wind)

Two wind directions were tested, each 15º off of true south, to demonstrate the dependence of the wake on the angle. With this turning, the de-coupling was found to be muffled, so a worst case strong wind event could be examined, along with the turbulence from winds coming in at an angle.

In this case, wind approaching the site at the same latitude as the tower was 15.1 m/s at 20 meters, turned to about 18º. Observations found that wind tends to turn along the slope of the hill nearer to the surface.

At the tower, wind was 15.5 m/s. The wind was turned about 2.8º from the 18º observed at the wind comparison point. Wind speed at the stacks was 16.9 m/s. The turbulent wake approaches 10 meters in height.

Southwind 12 m/s turned 15º toward the west (project south south-east wind)

In this case wind was approaching the site at 14.9 m/s at 20 meters, turned to about 17º. Observations found that wind tends to turn along the slope of the hill nearer to the surface, but the turning was less severe in this case farther from the slope of the hill. At the tower, wind was 16.5 m/s. The wind was turned about 4.7º from that observed at the comparison wind location. Wind speed at the stacks was about 15 m/s. The turbulent wake height approaches 9 meters.

Analysis

A criteria to determine how acceptable this location is can be based on the frequency of the wind speeds observed from climatological data at the site and the error limits for meteorological data established in the guidance (EPA, 2000). The Kodiak airport meteorological data set from 1985-1992 was analyzed. From these 8 years of data, frequencies of wind speed were derived. This data set is not expected to be representative of the Kodiak plant site due to the influence of the Buskin River valley on the direction of the wind. However, the magnitude of higher wind speeds should be fairly similar because both sites are located on the south shore of the northeast section of the island. The valley will cause a higher frequency of low speed northeast winds due to valley cold drainage.

The wind speeds were distributed into 4 m/s blocks: 2-6 m/s, 6-10 m/s, 10-14 m/s, and >14 m/s. It is estimated that the latter three categories represent the 4 m/s, 8 m/s, and 12 m/s CFD runs respectively. The frequency of occurrence in percent of hours per year is:

2-6 m/s: 57.1%
6-10 m/s: 26.5%
10-14 m/s: 8.3%
> 14 m/s: 1.9%

These values should be considered when reviewing the percent error for each wind case. The winds modeled were worst case conditions intended to demonstrate the largest building wake that can form (by winds perpendicular to building faces). However, winds will only rarely impact the building face directly.

The meteorological guidance states that the performance of a wind sensor must be within 5º of the actual wind direction and 5% of wind speed magnitude in calibration. These values are a useful beginning point to judge the acceptability of the station sensor location. They are necessarily conservative considering that they are meant for measurement accuracy at all measured values. Wind speed and direction can vary greatly over short distances in areas of complex topography so a less conservative approach would be to double these criteria for a wind direction limit of 10º error and wind magnitude error of 10% at the maximum deviation. However, the stricter criteria will be used to weight this analysis considering that the CFD method itself already contains a certain degree of uncertainty when compared to the actual environment.

The goal of tower positioning is to locate the tower at the height at which the wind vector will not vary from what it would be if no building were present. Therefore, the comparative wind vector needs to be at the same height above the ground as the sensor. The wind vector at the sensor was compared to the wind at 20 meters above the ground since the tower is 10 meters tall and posted on the roof of the 10 meter tall building.

Table I outlines the differences in the wind speed and direction for each worst case scenario. Overall, the error is relatively small when compared to the error in the stack region. This tower position is reasonably representative of the incoming 20-meter wind, recalling that the 10 meters tower is placed on top of a 10-meter tall building.

Table I. Wind speeds at 10 m above power plant roof and comparative errors

Worst case project wind scenarios	Tower wind speed: m/s	% difference comparative 20 meter wind speed	wind direction error
W 5 m/s	7.3	2.8 %	1.5º
W 10 m/s	13.9	2.2 %	3º
N 4 m/s	5.7	9.6 %	4º
N 8 m/s	11	11.0 %	4º
S 4 m/s	5.5	7.8 %	4º
S 8 m/s	11.6	16.0 %	2º
S 12 m/s	14.3	0.0 %	5.6º
SSW 12 m/s	15.5	2.6 %	3º
SSE 12 m/s	16.5	10.7 %	5º

In this table wind speeds are taken at the sensor location of a 10 meters tower on top of the power plant roof in the northeast corner. The percent difference in the observed magnitude of the undisturbed wind at 20 meters compared to the magnitude at the tower is listed. The wind direction error is also listed. All magnitude values were positive.

The wind direction error is within the stricter criteria of 5º for all cases except for 5.6º for project south winds at 8 m/s. This value is 12% above the criteria for a wind speed that will occur less than 8.3% of the time. Slight variations in the wind direction found a lower wind direction error for the SSW 12 m/s and SSE 12 m/s cases.

The wind speed error was beyond our stricter criteria for 5 cases. For three of these cases it was more than double the criteria with a maximum of 16% error. Though these high errors again occur for the less frequent higher winds, an alternative should be analyzed.

Due to these errors in magnitude exceeding our criteria, an alternative height of tower was analyzed at 15 meters above the power plant building roof. Wind speeds at the tower sensor were compared to undisturbed incoming winds at 25 meters. The results are listed in the following table.

Table II. Wind speeds at 15 m above power plant roof and comparative errors

Worst case project wind scenarios	Tower wind speed: m/s	% difference comparative 25 meter wind speed	wind direction error
W 5 m/s	7.5	4.2%	0.8º
W 10 m/s	15.5	6.2%	1.6º
N 4 m/s	5.8	6.9%	2.5º
N 8 m/s	11.2	7.7%	2.7º
S 4 m/s	5.6	5.7%	2.7º
S 8 m/s	11.3	6.6%	1.5º
S 12 m/s	15	2.0%	3º
SSW 12 m/s	16.9	6.3%	5.7º
SSE 12 m/s	16.9	6.3%	2.7º

In this table the wind speeds are observed at the sensor location at a 15-meter tower on top of the power plant roof (northeast corner). The percent difference in the observed magnitude of the wind at 25 meters is compared to the magnitude at the tower. The wind direction error is also listed. All error values were positive.

Although 7 cases exceed the stricter criteria of 5%, the exceedance is small at and all within the less strict criteria of 10%. The wind direction error is also much lower for most cases with one exceedance in the SSW 12 m/s case.

One more alternative position was tested to see if the tougher 5% wind speed differential critieria can be met with only a bit more increase in tower height. Therefore, a tower 18 meters tall was analyzed. The results are illustrated in Table III.

The extra 3-meter rise in the tower seems to improve the quality of the observations enough to warrant the extra rise. Now, only 2 wind conditions exceed the stringent 5% criteria for wind speed and all are at or below the 5º criteria for wind direction error. A dramatic drop in wind speed error occurred for the south winds with 15º deviations. Since the majority of the higher winds will be during southerly episodes, and impacting the south face at an angle, this alternative seems the most viable.

This alternative seems to be a reasonable solution for the meteorological tower location. Therefore, a 18-meter tall building posted on the roof of the plant at the northeast corner will be a reasonable approach at gathering a meteorological data set for this site.

Table III. Wind speeds at 18 m above power plant roof and comparative errors

Worst case project wind scenarios	Tower wind speed: m/s	% difference comparative 28 meter wind speed	wind direction error
W 5 m/s	7.6	2.7%	0.6º
W 10 m/s	15.6	5.4%	0.1º
N 4 m/s	5.8	4.3%	0.7º
N 8 m/s	11.3	6.6%	0.6º
S 4 m/s	5.7	5.6%	0.2º
S 8 m/s	11.3	3.7%	0.2º
S 12 m/s	15.4	2.5%	1.4º
SSW 12 m/s	15.9	3.2%	5.0º
SSE 12 m/s	16.2	3.8%	2.0º

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