

Optimum Placement For Air-Cooled Chillers

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Placement of air-cooled chillers matters. For example, often for aesthetic reasons chillers are placed behind architectural screens or at locations invisible to pedestrians. However, this can restrict the flow of ambient air to these chillers. Further, performance of air-cooled condensers can degrade under high ambient temperatures and windy conditions due to recirculation of the hot discharge plumes from the condenser fans back into the chiller air intakes.^{1,2,3}

Wind speed, wind direction, spacing between the chillers, distance from the building, and the height of the building wall and screen wall can affect dispersion of discharge plumes from the chillers and increase the air temperature entering the air-cooled condenser. A computational fluid dynamics (CFD) study was performed to understand the impact of wind speed, wind direction (orientation of chillers with respect to wind direction), spacing between the chillers, and the distance of the chillers from the adjacent building.

The cooling performance of air-cooled condensers is evaluated in terms of airflow patterns, dispersion of discharge plumes surrounding the chillers, and the air temperature distribution at chiller air intakes. The extent of hot discharge plume recirculation into the air intakes and its effect on the chiller performance is

estimated in terms of the rise in the average intake air temperatures.

Virtual Setup

A three-dimensional, steady-state, non-isothermal CFD model of a bank of four air-cooled chillers was developed for this analysis. As shown in *Figure 1*, the chillers are placed adjacent to a three-story building that is 40 ft (12 m) high and 120,000 ft² (11 100 m²). Each chiller is equipped with a total of 16 fans arranged into two rows. The supply airflow rate for each fan is assumed to be 10,000 cfm (4700 L/s), and the air temperature rise (ΔT) across the condenser coils is assumed to be 20°F (11°C). Therefore, each chiller has a heat rejection capacity of about 3,470 MBH (1020 kW).

As shown in *Figure 1c* the air intakes are located on each side of these chillers, and the discharge from

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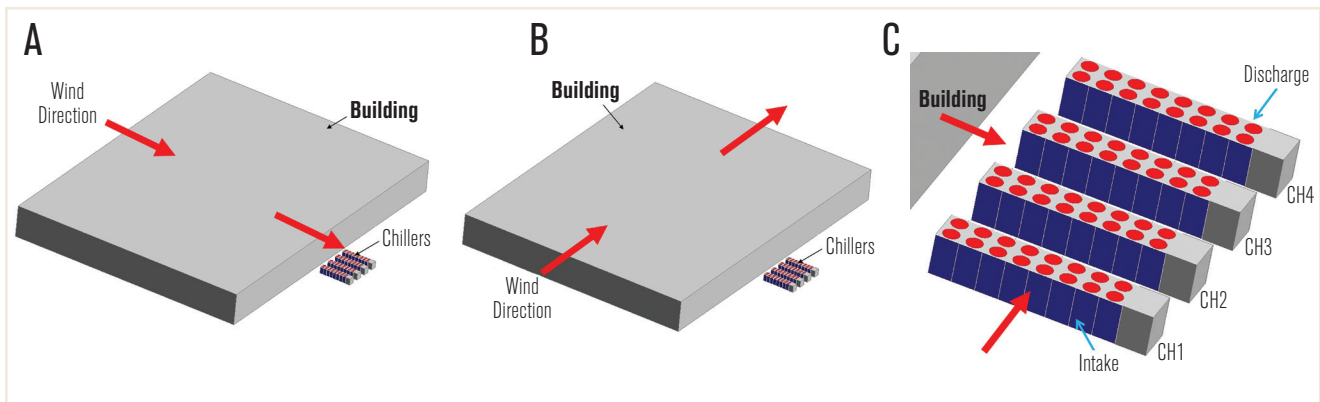


FIGURE 1 CFD models showing A) wind direction parallel to and B) wind direction perpendicular to the air intakes (long dimension) of the chillers, and C) details of the chiller air intakes and discharge.

the condenser fans are located on top of the chillers. For analysis purposes, ambient air temperature was assumed to be 80°F (26.7°C), which represents a typical hot summer 1% design dry-bulb condition for cities such as San Diego.

Wind directions parallel and perpendicular to the air intakes (located on the long dimension) of chillers are analyzed in this study. The wind directions with respect to the orientation of chillers are shown by arrows in *Figure 1*. This can also be referred to as the orientation of chiller air intakes to the prevailing wind direction.

The following cases were analyzed during this study. These analyses were performed systematically by varying only a single parameter at a time.

- Three wind speeds, 5 mph, 10 mph, and 15 mph (8 km/h, 16 km/h, 24 km/h), were analyzed for two wind directions, while keeping the spacing between the chillers at 12 ft (3.7 m) and the distance from the adjacent building at 10 ft (3 m).
- The spacing between the chillers was varied from 6 ft (1.8 m), 8 ft (2.4 m), and 12 ft (3.7 m), while keeping the distance from the adjacent building at 10 ft (3 m), the wind speed at 10 mph (16 km/h), and the wind direction parallel to the air intakes (long dimension) of the chillers.
- The distance of the chillers from the adjacent building was varied from 5 ft (1.5 m), 10 ft (3 m), and 15 ft (4.6 m), while keeping the spacing between the chillers at 12 ft (3.7 m), the wind speed at 10 mph (16 km/h), and the wind direction parallel to the air intakes (long dimension) of the chillers.

Effect of Wind Speed

An increase in the wind speed can result in an increase in the intake air temperatures, which can

potentially degrade the performance of air-cooled chillers. *Figures 2* and *2a* show the temperature distribution at the chiller air intakes and the resulting dispersion of the discharge plume from the top of the chillers, respectively.

In this case when the wind direction is parallel to the air intakes, the chillers are located on the leeward side of the building where the wake zone—a zone of low pressure—is formed. With an increase in the wind speed, the pressure in the wake zone decreases, and the spatial extent of such a low-pressure zone surrounding the chillers increases.

As a result, with the increase in the wind speed, the hot plume rising from the fan exhausts bends downward and entrains into the chiller intakes. As shown in *Figure 2a*, in the case of low wind speed (5 mph [8 km/h]), the hot plume rises vertically upward and away from the chiller intakes. As the wind speed increases from 5 mph (8 km/h) to 15 mph (24 km/h), the discharge plume tends to bend downward and almost reaches the ground, in the case of 15 mph (24 km/h) wind speed.

Although increasing wind speeds can also increase the ambient airflow rate, which can dilute the high-temperature discharge plumes, the bending of the high-temperature plumes toward the chiller air intakes outweighs such dilution effects of high wind conditions.

In all of these cases, the outermost chillers (CH1 and CH4) are less affected than those at the interior locations (CH2 and CH3). Similarly, the air intakes located at the center of a chiller row show the highest intake air temperature and possibly higher performance degradation than those located at the end of the row. With an increase in the wind speed, the highest intake air

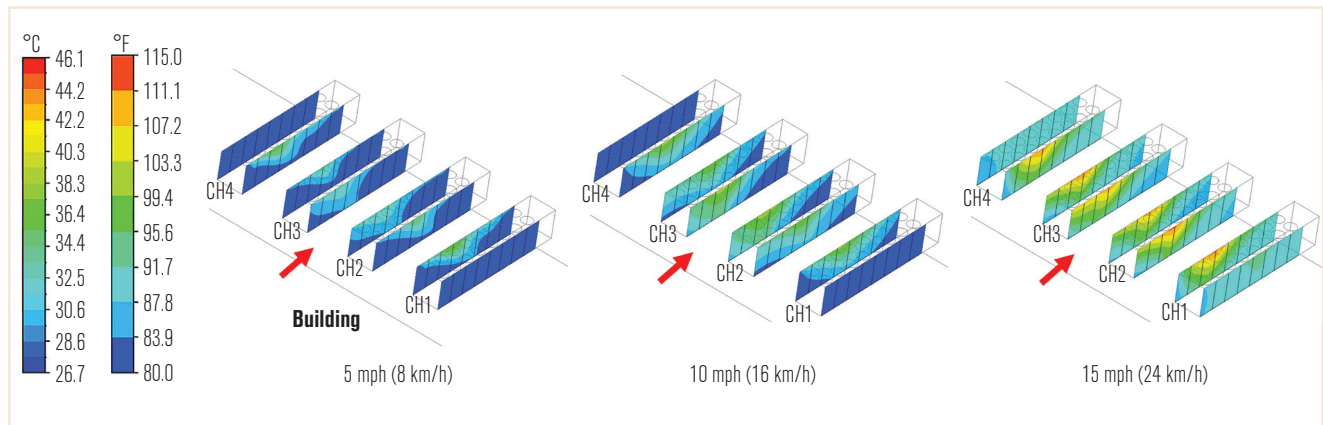


FIGURE 2 Effect of wind speed on the temperature distribution at the air intakes of chillers with parallel wind direction. Increase in the wind speed increases the intake air temperatures, which can potentially degrade the performance of air-cooled chillers. The air intakes at the center of each chiller row show the highest rise in the air temperatures.

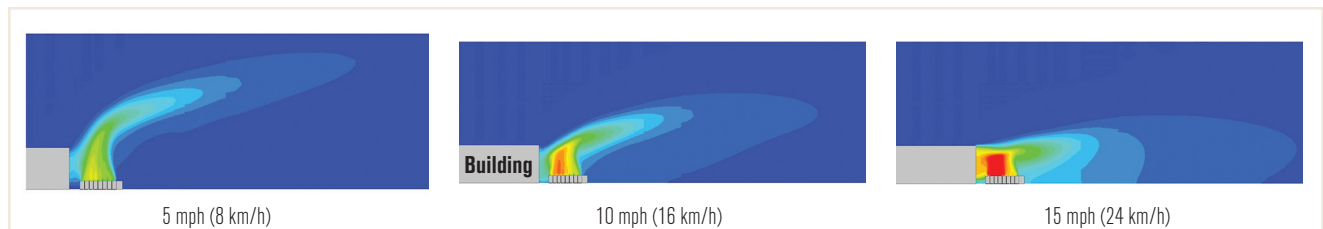


FIGURE 2A Effect of wind speed on the dispersion of hot discharge plume from the chillers with parallel wind direction. With an increase in the wind speed, the hot plume rising from the fan exhausts bends downward and can almost reach the ground at higher wind speeds.

temperature locations move toward the building side. This is because at increasing wind speeds the discharge plumes tend to move backward toward the low-pressure zone and get entrained into the intakes closer to the building.

Effect of Chiller Orientation

When the wind direction is perpendicular to the air intakes (long dimension) of the chillers, an increase in the wind speed also results in an increase in the intake air temperatures (*Figure 3*). In this case, the front intake of the first chiller (CH1) directly faces the incoming wind and, as a result, experiences the lowest intake air temperature. Since the other chillers are located in the wake zone of this first chiller, they experience higher intake air temperatures.

Similar to the previous case at low wind speed (5 mph [8 km/h]), the hot plume moves vertically upward. And, as the wind speed increases, the discharge plume bends downward and almost reaches the ground. For all wind speeds, the interior air intakes (CH2 and CH3) experience relatively higher intake air temperatures than those located at the exterior (CH1 and CH4). While the hot discharge plumes flow in the direction of the

wind, the plumes from the windward-side chillers move over the adjacent chillers, and, therefore, get entrained into the intakes of the leeward-side chillers.

As shown in *Figure 3*, the effect of such cascading plume movement becomes prominent with increasing wind speeds, resulting in higher intake air temperatures, especially for those air intakes (CH2 and CH3) located at the center of each row. Since the wind direction is perpendicular to the long dimension of the chillers, the ambient air can easily enter the chiller aisles from both front and back ends of the chillers. As a result, the temperature distribution on the chiller intakes is quite symmetric: high at the center and low at the front and back end.

Figure 4 shows the effect of wind speed and wind direction on the average intake air temperature of the chillers. These charts show the average intake air temperatures, rather than the distribution of temperature over the intake faces.

Higher intake air temperatures are an indication of higher recirculation of hot discharge plumes into the chiller air intakes and can potentially lead to higher performance degradation. Due to the cascading effect of the hot plume entrainment, the average intake air

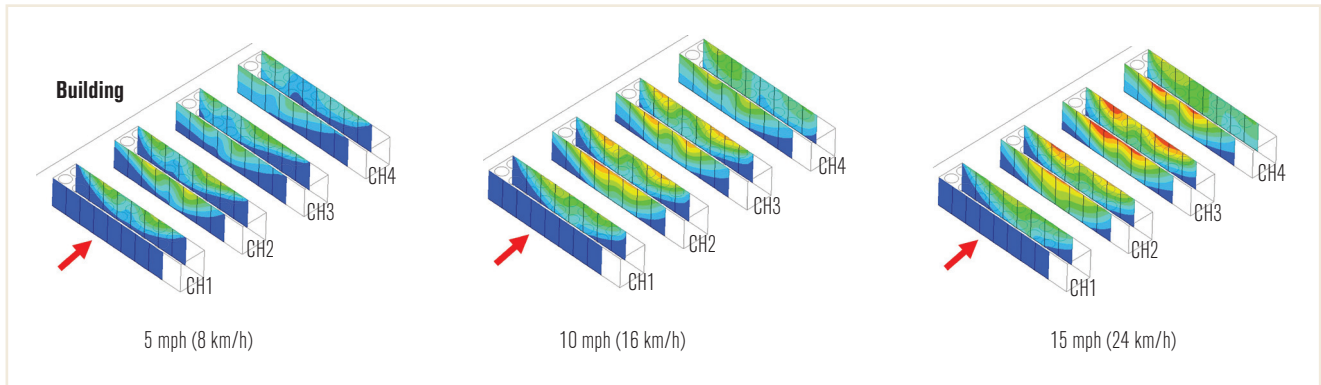


FIGURE 3 Effect of wind speed on the temperature distribution at the air intakes of chillers with perpendicular wind direction. The air intakes directly facing the incoming wind are least affected, whereas the subsequent air intakes show a significant increase in the intake air temperatures.

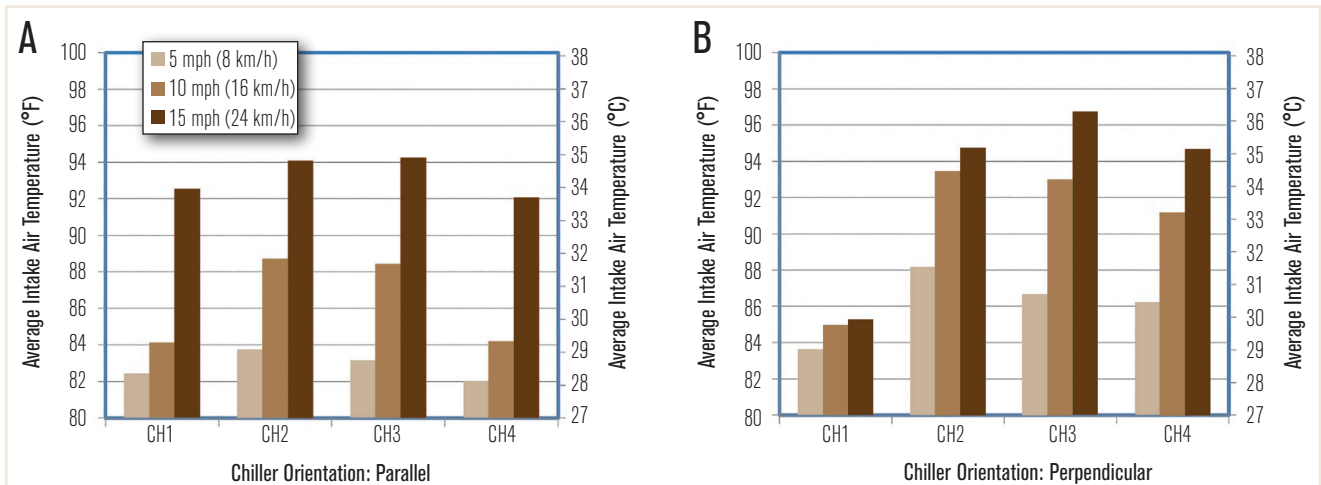


FIGURE 4 Effect of wind speed and chiller orientation on the average intake air temperature. The average intake air temperature rises with wind speed, and it is higher when the wind direction is perpendicular to chiller air intakes (long dimension). In general, interior chillers show higher intake air temperatures than do the exterior chillers.

temperatures are higher when the wind direction is perpendicular to the air intakes.

For both orientations, an increase in the wind speed increases the average intake air temperatures. However, such an increase is significantly higher when the wind speed reaches 15 mph (24 km/h) and the air intakes are parallel to the wind direction (Figure 4a).

On the contrary when the air intakes are oriented perpendicular to the wind direction (Figure 4b), the average intake air temperature increases gradually with increases in the wind speed. In both the cases, interior chillers (CH2 and CH3) show higher intake air temperatures than the exterior (CH1 and CH4) chillers.

Effect of Spacing Between the Chillers

The intake air temperature increases as the spacing between the chillers decreases from 12 ft (3.7 m) to 6 ft (1.8 m). Figure 5 shows the effect of spacing between

the chillers on the temperature distribution at the chiller air intakes. In the case of wider (12 ft [3.7 m]) spacing, the ambient air enters into the chiller aisles from the end located away from the building rather than from the end that is closer to the building. This indicates higher resistance for the air to enter from the building side.

When the spacing between the chillers is reduced, the ambient air cannot reach the center of the chiller aisles, and, thus, promotes the hot discharge plumes to entrain back into the air intakes. This is evident from the higher air temperatures at the top of the chiller intakes as shown in Figure 5. This is further evident in Figure 5a, which shows the temperature of the discharge plume and how it is dispersed at the top of the chillers.

When the chillers are placed 12 ft (3.7 m) apart, the hot discharge plumes are separated from each other

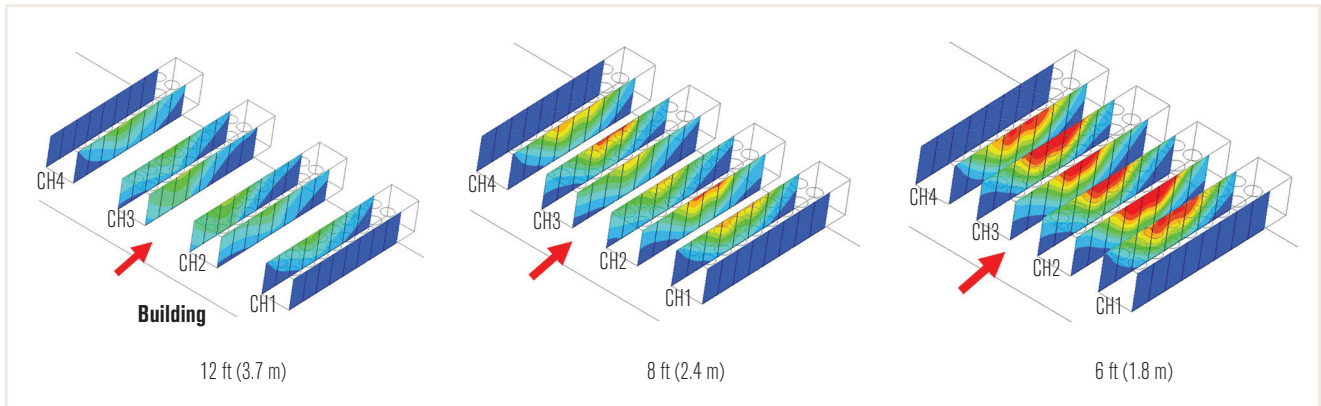


FIGURE 5 Effect of the spacing between the chillers on the temperature distribution at the air intakes of the chillers, showing that the intake air temperature increases as the spacing between the chillers decreases.

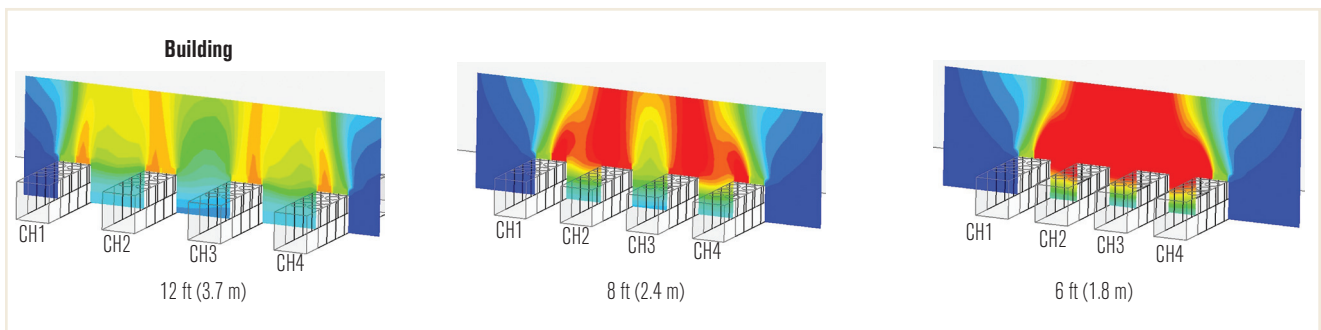


FIGURE 5A Effect of the spacing between the chillers on the dispersion of the hot discharge plumes from the chillers, showing that at wider spacing the hot discharge plumes remain separated and move straight upward. At reduced spacing these plumes come close, preventing ambient air from entering the intakes.

and tend to move straight upward. When the spacing is reduced, these plumes come close to each other and enter deeper into the chiller aisles. This is evident from the increasing temperature inside the aisles (Figure 5a).

Effect of Distance From the Building

The intake air temperature increases as the distance between the building and the chillers decreases. Figure 6 shows the effect of the distance of chillers from the building wall on the temperature distribution on the chiller air intakes. When the chillers are placed closer to the building, they are moved farther into the wake zone—a zone of low pressure. As a result the hot discharge plumes from the chillers move toward the building and saturate the space between the building and the chiller with the hot air (Figure 6a). Moving chillers away from the building creates room for the ambient air to enter from both ends of the chillers and helps lower the intake air temperature.

Figure 7 shows the effect of spacing between the chillers and the distance of the chillers from the building on the average intake air temperature of the chillers. As mentioned before, these charts show the average

intake air temperatures rather than the distribution of air temperature over the intake faces, and indicate the extent of entrainment of hot plumes.

Figure 7a shows that a reduction in the spacing between the chillers increases the average intake air temperature. Reducing the spacing between the chillers from 12 ft (3.7 m) to 6 ft (1.8 m) increases the average rise in the intake air temperature from 6°F (3.3°C) to almost 12°F (6.6°C). When the chiller spacing is reduced to 6 ft (1.8 m), the interior chillers (CH2 and CH3) show a significant increase in the average intake air temperatures.

Figure 7b shows that the intake air temperature decreases as the distance between the building and chillers increases. However, this analysis indicates the effect of increasing distance on the intake air temperature becomes less significant after a distance of 10 ft (3 m). These analyses were performed for a 10 mph (16 km/h) wind speed. It is possible that for higher wind speeds these results may show a different trend. A comparison of these two charts indicates the spacing between the chillers has a more significant impact on the intake air temperatures than the distance of the chillers from the building.

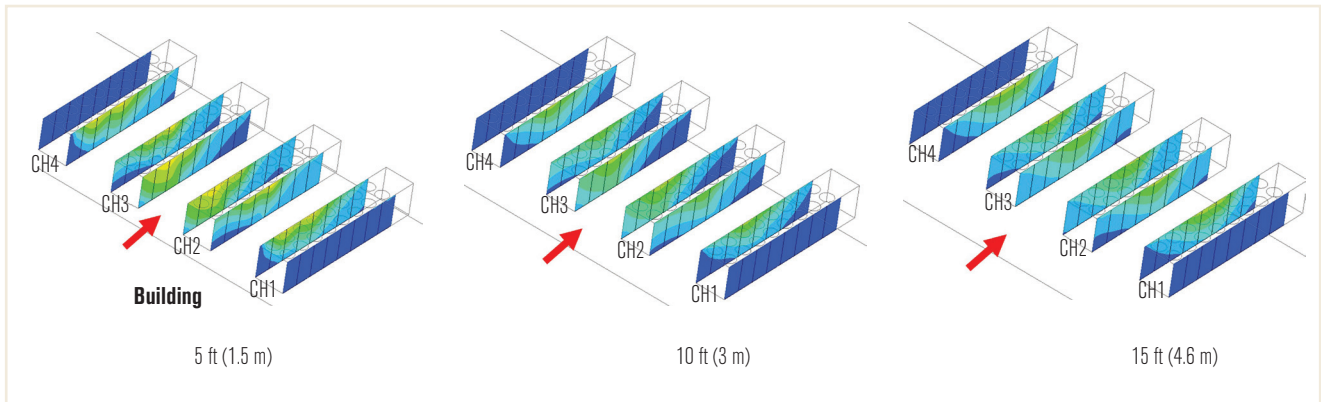


FIGURE 6 Effect of the distance of chillers from the building wall on the temperature distribution at the air intakes, showing that when chillers are moved away from the building the intake air temperature decreases.

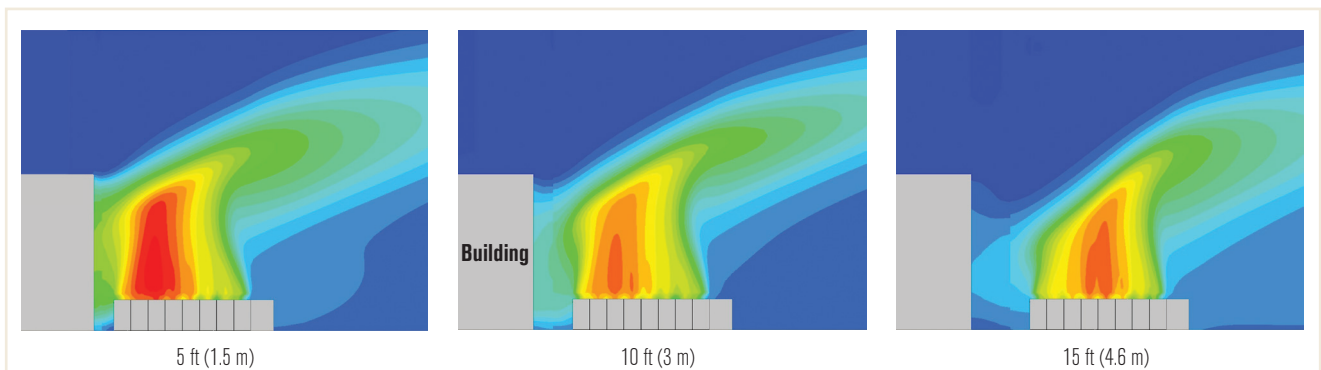


FIGURE 6A Effect of the distance of chillers from the building wall on the temperature distribution around the chillers, showing that when chillers are placed too close to the building, the hot discharge plumes saturate the space between the building and the chiller.

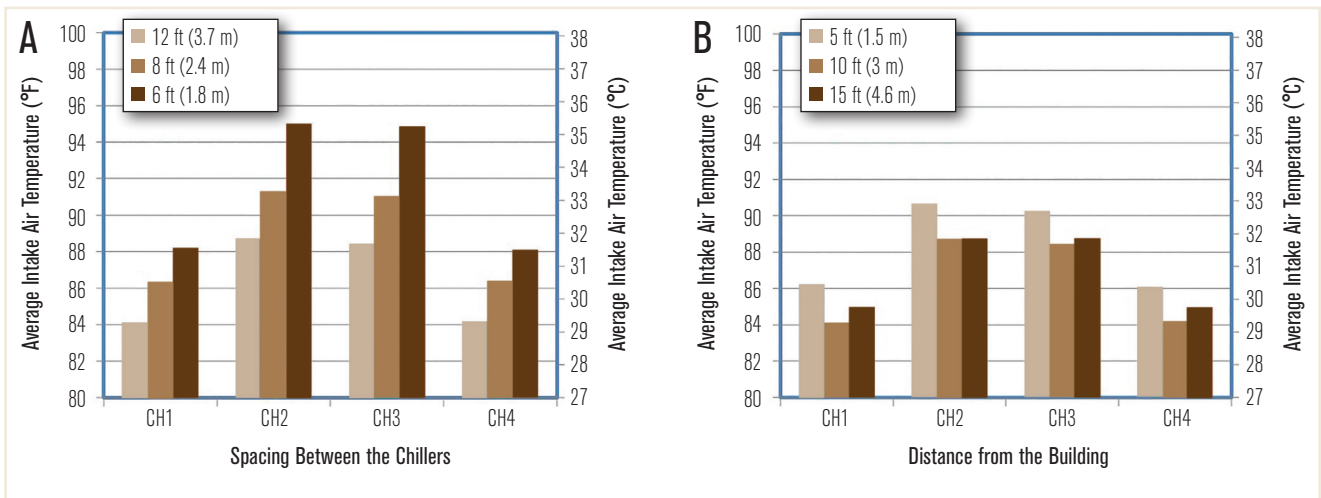


FIGURE 7 Effect of A) spacing between the chillers and B) distance from the building on the average intake air temperature for chillers, showing that the spacing between the chillers has a larger impact on the average intake air temperatures than does the distance of the chillers from the building.

Summary and Conclusions

A CFD analysis of a bank of air-cooled chillers adjacent to a three-story building indicates that an increase in the wind speed increases recirculation of discharge plumes into the chiller intakes, resulting in

higher intake air temperatures.

At lower wind speeds, the discharge plumes tend to move vertically (upward) away from the chillers. However, with increasing wind speeds these plumes can bend downward toward the chiller intakes,

resulting in higher recirculation.

When the chiller intakes are oriented perpendicular to the prevailing wind direction, the discharge plumes from windward-side chillers enter into the following leeward-side chillers, and this cascading effect becomes prominent at higher wind speeds.

This study further indicates that the spacing between the chillers has a larger impact on the recirculation of hot discharge plumes than the distance between the building and the chillers. In real-life situations, the prevailing wind speeds and directions can vary significantly from location to location. Also, the terrain and surrounding structures can affect the local wind speed and direction. Therefore, the extent of discharge plume recirculation can vary in each situation. In such situations CFD analyses can provide valuable insights in optimizing the orientation, spacing, and distance of chillers from adjacent buildings.

Based on the insights from this study, placing the chiller air intakes parallel to the prevailing wind

direction with at least 10 ft (3 m) of spacing between the chillers and at least 10 ft (3 m) away from the adjacent building wall can reduce the adverse recirculation of discharge plumes into the chiller air intakes and also can reduce potential performance degradation.

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