DAIKIN

WHITE PAPER:

IS “FREE COOLING” RIGHT FOR MY APPLICATION?

EVALUATING PROS AND CONS OF CHILLER-MOUNTED INTEGRATED WATER-SIDE ECONOMIZER SYSTEMS

As businesses embrace environmental initiatives to combat climate change, facility managers and building operators are feeling pressure to increase building efficiency, reducing energy consumption and operating costs.

"Free cooling," the process of allowing the building load to bypass mechanical cooling and exchange its heat with lower temperature outdoor air, is an environmentally favorable approach that helps reduce operating costs. Free cooling can take two different forms: air-side economizers that directly exchange cool outdoor air with the building or water-side economizers that use cool outdoor air to cool the chilled water used to cool the building. One emerging solution increasingly available in the marketplace is integrated water-side economizers mounted on air-cooled chillers, sometimes referred to as "free cooling chillers" because the energy use is so low relative to mechanical cooling that it is almost negligible. While not truly "free," such systems can offer significant energy savings in the correct application. The purpose of this paper is to evaluate the applications in which these chiller-mounted solutions are the most beneficial.

To evaluate different water-side economizer efficiency levels, Daikin simulated multiple different building environments representing light internal winter-time loads and high internal winter-time loads, with varying ventilation rates, to help determine the feasibility and value of free cooling in these settings. The simulation incorporated building data from several climates and geographical locations to factor in weather variation across the United States.

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The results of the simulation demonstrate that the benefits of integrated free cooling can be significant in the right applications and climate conditions. Building type and climate dramatically impact the viability of free cooling, favoring applications in cooler climates and applications with high wintertime loads and lower ventilation rates.

1 THE RISE OF THE INTEGRATED WATER-SIDE ECONOMIZER

Before integral mounting of economizer coils on air-cooled chillers was commonly available, some systems were designed to use separate dry coolers in order to subject the building heat to the cool outdoor air. In fact, many systems are still designed this way today. Both solutions offer different advantages and the discussion on what applications make sense for integrated free cooling cannot be properly had without first understanding the nuances between the two competing designs.

THE OLD WAY: STAND-ALONE DRY COOLERS AND CHILLERS

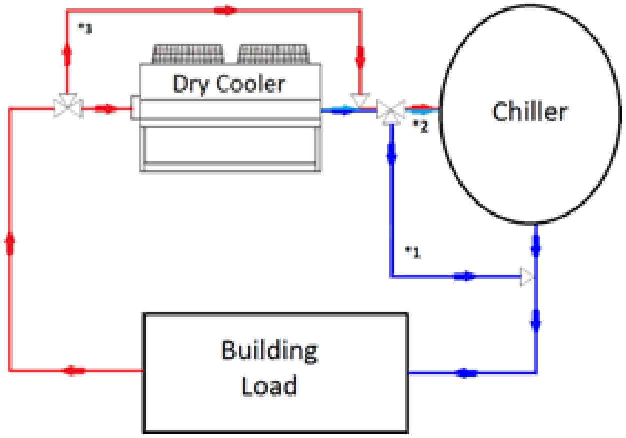
A dry cooler is a stand-alone, fluid-to-air heat exchanger that receives the building cooling loop glycol directly, then exchanges the heat with the outdoor air to cool the loop glycol before returning it to the building or routing through the chiller, as seen in Figure 1. In warmer ambient conditions where the dry cooler is unable to cool the fluid completely, the fluid flows through the chiller to receive mechanical cooling. To control the fluid flow path, the three way valves connecting the building cooling water loop to the chiller and fluid cooler open or close, allowing the flow to bypass the dry cooler or chiller when appropriate, which helps manage pressure drop.

THE NEW WAY: INTEGRATED FREE COOLING

Similar in concept to a dry cooler, integrated free cooling uses glycol to air coils, but unlike dry coolers, these coils are typically attached to the chiller on the outside of the primary condenser coil, to cool the process fluid using low temperature ambient air, as seen in Figure 2.

FIGURE 1: DRY COOLER TYPICAL PIPING IN SERIES

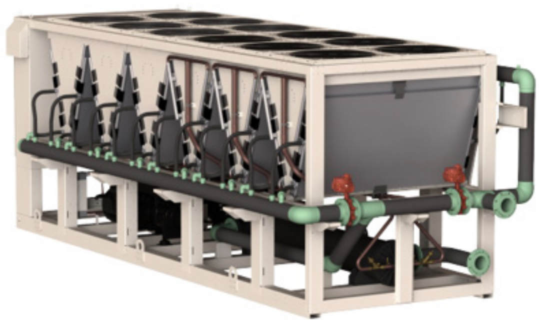
*1 - Dry Cooler meets building load and bypasses Chiller
*2 - Dry Cooler partially meets building load, uses Chiller to cool remaining load
*3 - Bypass Dry Cooler, Chiller used to meet full building load



Integrated free cooling chillers typically operate in one of three "modes." In mechanical cooling mode, the unit functions just like a normal air-cooled chiller, cooling the glycol using the refrigeration cycle. This is done when the ambient temperature is above the leaving glycol temperature. As shown in Figure 3, in the second mode of operation, "hybrid mode," glycol is diverted first through the air coils where it is partially cooled, and then diverted into the evaporator where it is further cooled to meet the design fluid temperature setpoint. Hybrid mode is used when the ambient temperature is below the entering fluid temperature, but not low enough to achieve 100% free cooling. Because hybrid mode operates in mild ambient temperatures, it can often represent the greatest number of run hours.

This means that optimizing operation during hybrid mode is crucial for maximizing system efficiency and achieving the best return on investment. The third mode, 100% free cooling mode, takes place when ambient temperatures are well below the leaving fluid temperature setpoint, often 20-30°F lower, depending on the particular system design. In this mode, all the cooling of the glycol is achieved through the use of the coils and the compressors are turned off. This means kW draw is very low in this mode given the condenser fans and glycol pumps are the only power draws required. Efficiency is often an order of magnitude higher than mechanical cooling.

FIGURE 2: PHYSICAL IMAGE OF CHILLER WITH INTEGRATED WATER-SIDE ECONOMIZER "FREE COOLING" SOLUTION



Integrated coils also take up less space than a separate dry cooler, making them appealing to jobsites where space is limited. However, when not in free cooling mode, the integrated fluid coil causes air-flow restriction across the primary condenser refrigerant coil and therefore derates the chiller performance. The impact on chiller efficiency can be significant (in the range of 5 to 10 percent).

Additionally, all integrated free cooling chillers are not created equal. It is important to choose an integrated free cooling chiller in which both the design and manufacturing are done by the factory. Some manufacturers rely on third party modification shops to transform their standard chillers into integrated free cooling chillers, with varying levels of success and robustness. Getting an integrated free cooling chiller that is designed, manufactured, and reliability tested all under one roof ensures that the components all work together successfully and reliably. Similarly, the in-house solution also ensures that the control logic works seamlessly, and that factory developed AHRI-certified performance prediction software, based on real lab testing, results in a product that can be trusted to perform in the field. While avoiding the mechanical cooling penalty associated with integrated free cooling may seem like the obvious choice, using separate dry coolers comes with its own set of challenges.

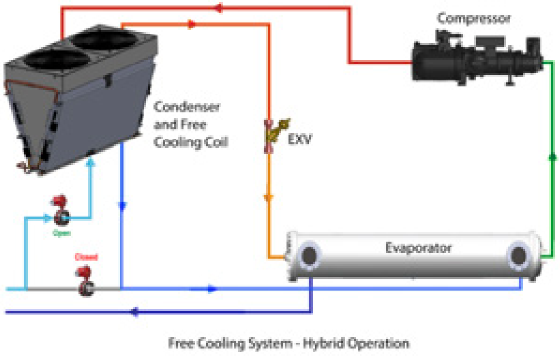
INCREASED FOOTPRINT SIZE

Separate dry coolers require twice the available equipment footprint compared to integrated free cooling due to the additional space required to mount them. In buildings like manufacturing facilities and data centers, maximizing available real estate for revenue generating activities rather than housing HVAC equipment is often a necessity.

HIGHER INSTALLED COSTS

In addition to the footprint challenges, separate dry coolers also mean much higher installation costs than an integrated free cooling chiller, due to the additional piping and wiring connections that must be made to each dry cooler. Both increase installation time and expense for contractors.

FIGURE 3: DIAGRAM OF FREE COOLING GLYCOL AND REFRIGERANT FLOW PATHS



INCREASED PROGRAMMING COSTS

Last, the separate dry cooler option carries the often forgotten but very real cost of custom control sequences that make the separate pieces work together. Of notable difficulty is sequencing during shoulder seasons when some pre-cooling could be done by the dry coolers and the remainder of the cooling done by the chiller, similar to the "hybrid mode" that would be used in an integrated free cooling chiller. Without careful attention to detail and an understanding of the efficiency characteristics of each piece of equipment, these systems may not operate at their theoretical efficiency capability, sacrificing efficiency in order to achieve a more simplified control sequence. Some sequences eliminate "hybrid mode" type operation all together, only enabling the dry coolers when ambient temperature is low enough to achieve 100 percent free cooling, which results in the loss of a significant portion of potential energy-saving operating hours.

Integrated free cooling solves these real-world challenges. The coils are within the footprint of the chiller, meaning no additional real estate is needed. The coils are headered together and piped into the chiller evaporator, meaning there is only one inlet and one outlet connection for contactors to connect to, and everything is powered from the chiller electrical panel. Likely the greatest benefit to integrated free cooling is a repeatable and optimized control sequence, developed by factory engineers who understand chiller efficiency curves and who can customize the operating sequence to improve the efficiency of the combined system. Repeatable and scalable control logic helps avoid costly control mistakes and allows the same proven logic to be used over and over again, eliminating the time, effort, and cost associated with custom site-specific control sequences.

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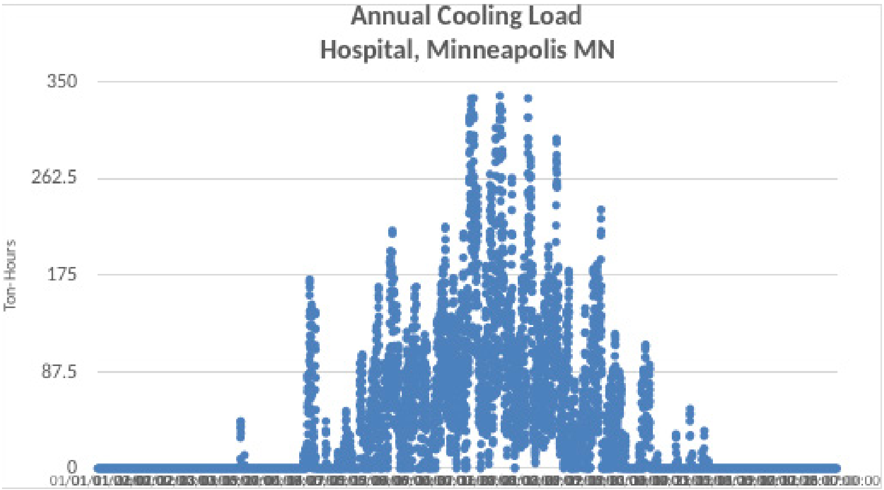
SIMULATING INTEGRATED FREE COOLING ENERGY SAVINGS

To quantify whether integrated free cooling is an attractive solution for different types of applications, Daikin simulated three different building scenarios. The first is a hospital, using the chiller for comfort cooling. The second is a data center using the chillers for server cooling, and the third is a medium-sized office building again using the chiller for comfort cooling. Refer to Table 1 for the details of the modeling data.

The hospital model represents a building with fairly light winter loads, whereas the data center model represents high winter loads. The difference in loads plays a large role in the analysis to determine the effectiveness of free cooling for each application, as does the ventilation rate.

Figure 4 shows the annual hourly chiller load for the Minneapolis, MN hospital model. Note the difference in load between the warmer and cooler months. The chiller will run most in the summer months when there is a sizable cooling load and temperatures are too warm for free cooling. There is little potential for free cooling in the cooler months since the building load is reduced due to significant amounts of cool ventilation air. According to the usage graph, between the months of November and March, it's clear there is essentially no cooling load.

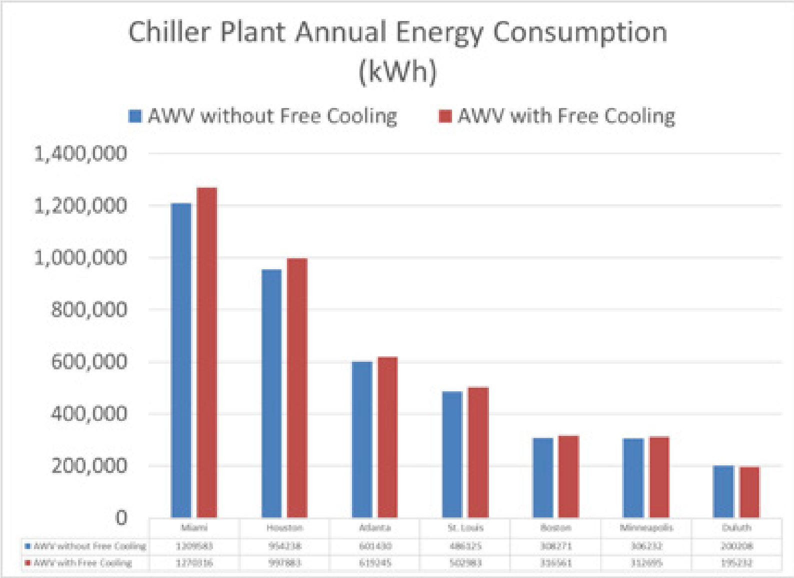
FIGURE 4: HOSPITAL SIMULATION – 350 TON AIR-COOLED SCREW CHILLER COOLING LOAD HOUR



INTEGRATED FREE COOLING OUTCOMES: LIGHT INTERNAL LOADS

In Figure 5, the blue bars represent a standard chiller without integrated free cooling, modeled in the different locations on the X axis. The red bars represent a chiller with an integrated free cooling coil. Comparing the red and blue bars, we see that for this application, free cooling represents an increase in overall energy usage when compared to the blue bars.

FIGURE 5: HOSPITAL SIMULATION – 350 TON AIR-COOLED SCREW CHILLER ENERGY CONSUMPTION

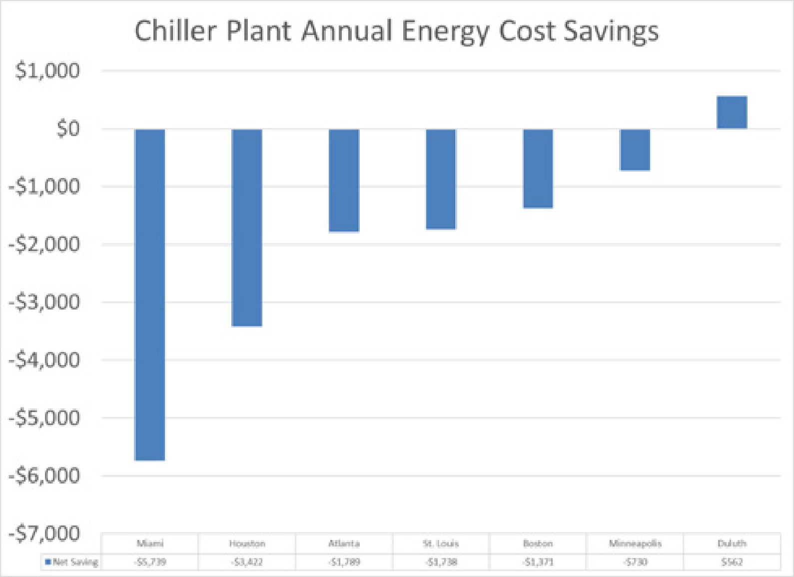


	Miami	Houston	Atlanta	St. Louis	Boston	Minneapolis	Duluth
■ AWV without Free Cooling	1209583	954238	601430	486325	308271	306232	200208
■ AWV with Free Cooling	1270316	997883	619245	502983	316561	312695	195232

Due to high ventilation rates which building codes typically require for hospitals, cool outdoor air is already providing the bulk of the cooling during the colder ambient conditions when hybrid cooling or free cooling would normally be active, meaning there is relatively little load left to remove using the free cooling function. Conversely, in the summertime, the free cooling coils reduce the efficiency of the mechanical cooling such that the net effect is a higher overall energy use, even in cold climates like Duluth. This highlights one key aspect of free cooling, which is that it provides the best benefits when used in conjunction with an application that has higher wintertime run hours, and that also does not have the ability to cost effectively use air-side economizing to meet the wintertime cooling demand.

Figure 6 depicts the savings associated with integrated free cooling when compared to a non-free cooling chiller for each hospital location. Note that none of the locations experienced net savings throughout the year with the inclusion of integrated free cooling. This is due to very low run hours for free cooling due to smaller internal loads in the wintertime that were almost completely offset by the cooling effect from the ventilation air, leaving almost no run hours for the integrated water-side economizer.

FIGURE 6: HOSPITAL SIMULATION – 350 TON AIR-COOLED SCREW CHILLER FREE COOLING ANNUAL SAVINGS



	Miami	Houston	Atlanta	St. Louis	Boston	Minneapolis	Duluth
■ Net Saving	-$5,739	-$3,422	-$1,789	-$1,738	-$1,371	-$730	$562

DATA CENTER SIMULATION

Next, we simulated a relatively small 300T data center using chilled glycol to indirectly cool the servers. As shown in Figure 7, the Minneapolis wintertime load is much higher in a data center application since the load is driven by the electrical load of the servers versus being ambient dependent. Additionally, data centers are generally running warmer chiller water temperatures so more hours of free cooling are available. This trend can be seen by looking at the varying heights of the red and blue bars in Figure 8. We can see that for Miami, because the number of free cooling hours was small, using integrated free cooling resulted in higher energy use because of the derate to mechanical cooling. In all other locations though, integrated free cooling resulted in energy savings, with significant savings noted in moderate to cold climates. For example, in Duluth, we can see the annual energy usage dropped to almost half when using a chiller with integrated water-side economizer, resulting in over $50,000 of annual energy savings. As noted above, it is important to recognize that in the case of data centers, the chilled water loop leaving fluid temperature is often designed for higher temperatures than are normally used for comfort cooling. While a typical comfort cooling application may use 44°F leaving fluid temperature, data centers often use 55°F or higher, with the most common designs in the 60-65°F fluid temperature range. This means that free cooling can engage at a relatively higher ambient temperature than with comfort cooling, leading to a higher number of free cooling operating hours.

FIGURE 7: DATA CENTER SIMULATION – 350 TON AIR-COOLED SCREW CHILLER LOAD HOURS

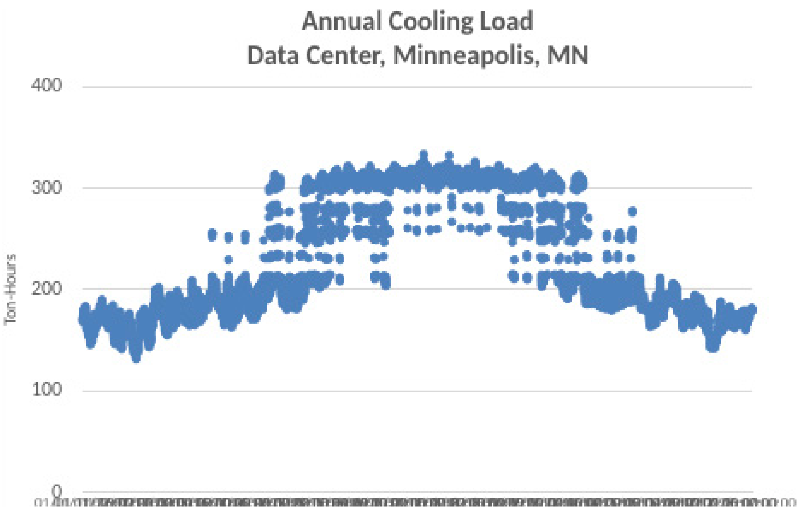
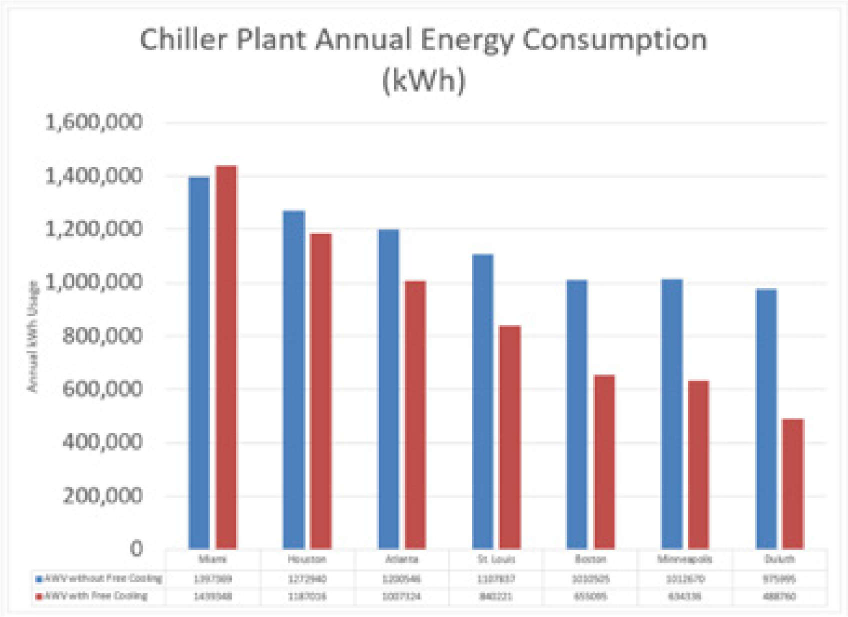
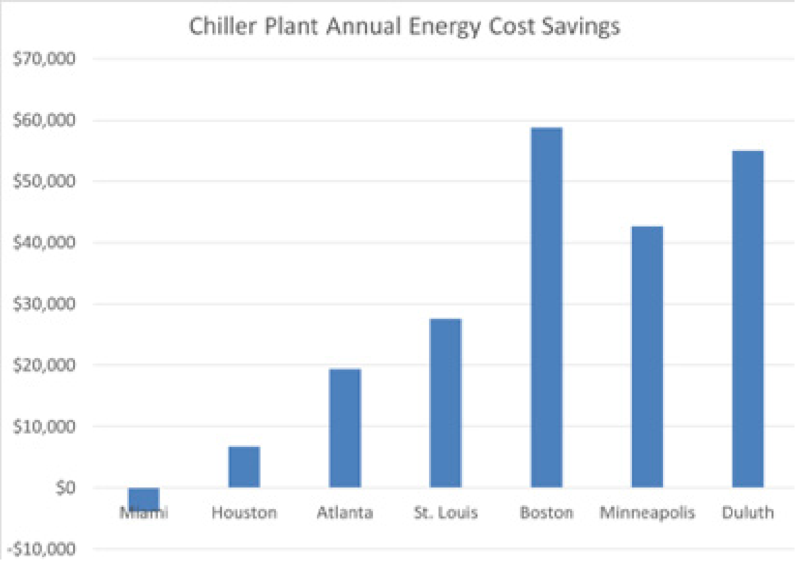


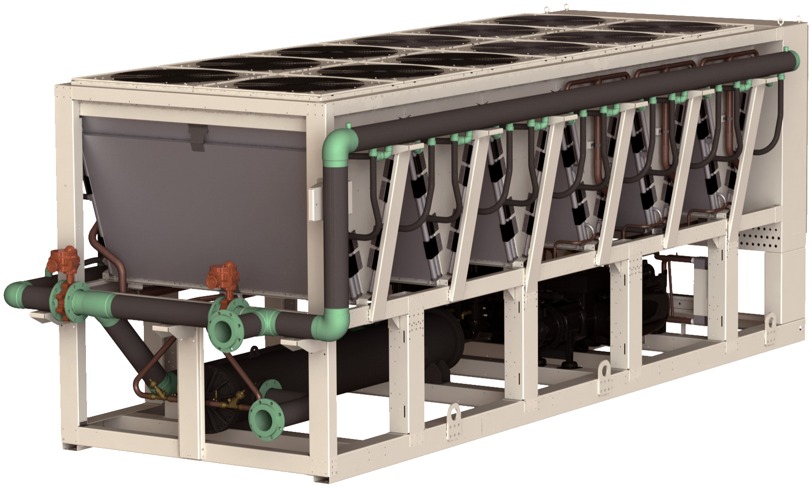
FIGURE 8: DATA CENTER SIMULATION – 350 TON AIR-COOLED SCREW CHILLER ENERGY CONSUMPTON



These results demonstrate that integrated free cooling can result in significant energy savings when applied to the correct application and that for data centers, the energy savings of integrated free cooling during the cooler months far offset the penalty to mechanical cooling efficiency during the warmer months in all but the warmest climates. We can thereby deduce that other applications with similarly high wintertime loads, such as process cooling applications for plastic manufacturing, pharmaceutical production, or food/beverage production, could similarly benefit from integrated free cooling, especially if those applications also use elevated leaving fluid temperatures.

FIGURE 9: DATA CENTER SIMULATION – 350 TON AIR-COOLED SCREW CHILLER FREE COOLING ANNUAL SAVINGS





OFFICE BUILDING SIMULATION

Lastly, we simulated a medium-sized office building with a 600-ton comfort cooling load and ASHRAE standard ventilation rates. In Figure 11, we see that an integrated free cooling chiller can offer energy savings for an office building application when applied in moderate and cold climates. Atlanta was just under break-even, so climates cooler than Atlanta could expect to see some energy savings in an office-building type application. The yearly spend on energy is shown in Figure 12, with the best result being Boston with over $12,000 annual energy savings on this size system. It is also important to recognize that many older buildings and systems may have ventilation rates less than modeled here, so for those older systems, the energy savings could be even more pronounced.

FIGURE 10: OFFICE BUILDING SIMULATION – 500 TON AIR-COOLED SCREW CHILLER COOLING LOAD HOURS

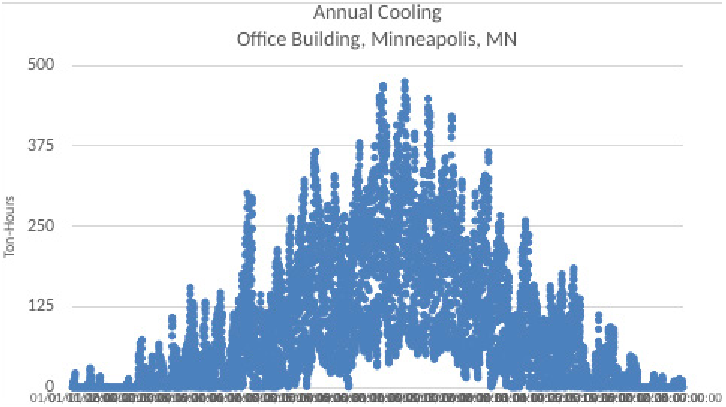


FIGURE 11: ANNUAL ENERGY USE RESULTS FOR A 500-600T OFFICE BUILDING WITH AND WITHOUT INTEGRATED FREE COOLING

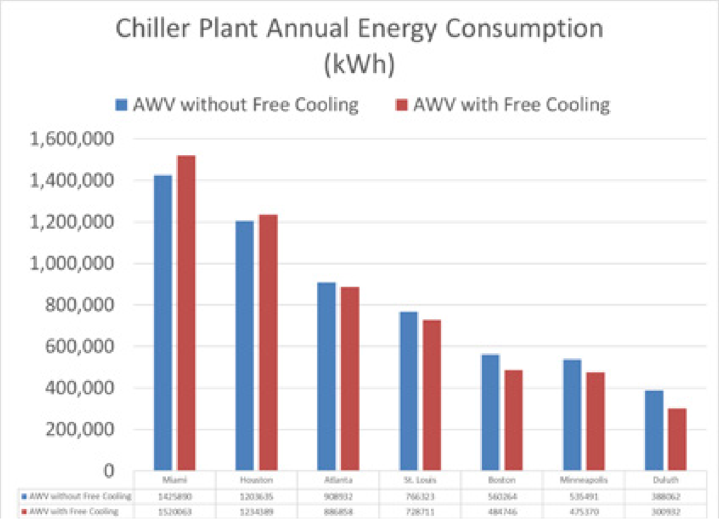
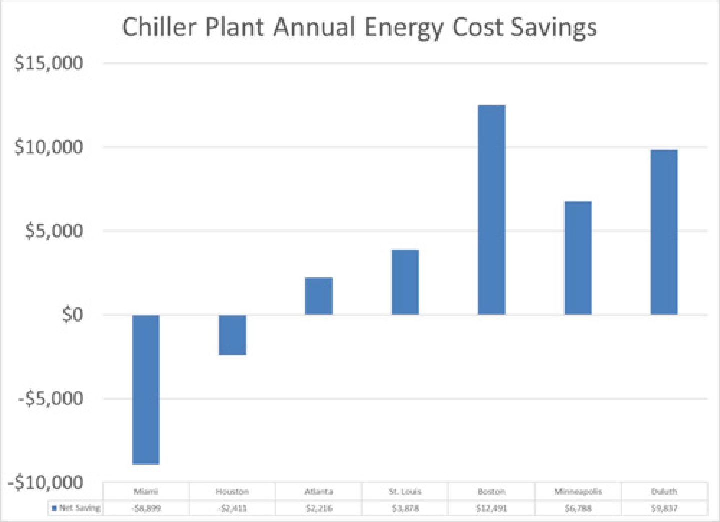


FIGURE 12: YEARLY ENERGY SAVINGS AS A RESULT OF INTEGRATED FREE COOLING



3 SUMMARY

These results demonstrate that integrated free cooling can result in significant energy savings when applied to the correct application and that for data centers, the energy savings of integrated free cooling during the cooler months far offset the penalty to mechanical cooling efficiency during the warmer months in all but the warmest climates. We can thereby deduce that other applications with similarly high wintertime loads, such as process cooling applications for plastic manufacturing, pharmaceutical production, or food/beverage production, could similarly benefit from integrated free cooling, especially if those applications also use elevated leaving fluid temperatures.

METHODOLOGY

To evaluate the impact of integrated free cooling on energy consumption and energy costs, three prototype buildings (hospital, data center, and medium-sized office building), located in seven climate zones, were studied. The U.S. Department of Energy's EnergyPlus (version 8.5) total building energy simulation tool was used to model a chiller plant consisting of commercially available chillers with and without integrated free cooling. The model generated hourly building loads based on TMY-3 (typical meteorological year) weather data and standard ASHRAE 90.1 inputs for building envelope and lighting power densities. See below for additional modeling assumptions.

TABLE 1

MODEL INPUTS

- Electricity rates from U.S. Energy Information Administration Average Price by End-Use
- Free cooling and hybrid operation
  - Based on actual Daikin Pathfinder® AWV chiller performance specifications
  - Pump energy was increased to account for the pressure drop across the integrated free cooling coils

HOSPITAL

- Building cooling load: 350 tons on average
- 350 ton air-cooled screw chiller system with primary variable chilled water pump
- Chilled water temperatures of 55/44°F and 30% Propylene Glycol
- Ventilation rate at design conditions was 38% of supply air flow
- Operating hours of 24 hours per day, seven days per week

DATA CENTER

- Building cooling load: 350 tons on average
- 350 ton air-cooled screw chiller system with primary variable chilled water pump
- Chilled water temperatures of 74/60°F and 30% Propylene Glycol
- Ventilation rate of less than 5% of supply air flow
- Operating hours of 24 hours per day annually

OFFICE

- Building cooling load: 600 tons on average
- (2) 350 ton air-cooled screw chiller system with primary variable chilled water pump
- Chilled water temperatures of 54/44°F and 30% Propylene Glycol
- Ventilation rate of 11% of supply air flow
- Operating hours of 12 hours per day Monday-Friday and 6 hours on Saturday