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Optimizing the Features of a Customizable Air-Cooled Chiller

The use of air-cooled chillers in process and comfort cooling applications has been steadily increasing in recent years. The air-cooled chiller has evolved from a packaged product, with few options, to a fully customizable unit that can be tailored to meet specific application and job site requirements. High-efficiency air-cooled chillers are now approaching equivalent life cycle costs when compared to water-cooled chiller systems.

In order to take full advantage of the various efficiency levels and options available in the next generation of air-cooled chillers, it is more important than ever to understand the major design considerations and how a selection based on one factor can affect another. Decisions regarding energy efficiency, sound performance, and footprint requirements are interdependent. The ideal selection will fully meet the most critical requirement while achieving the best possible result with respect to the other factors. This article will discuss the significant benefits of a configurable product and describe how new modeling programs can help you optimize the air-cooled chiller solution for your customer.

Introduction

Since first introduced, air-cooled chillers have been growing in popularity and are now common in modern systems. Traditionally, these chillers were selected for their all-inclusive construction and the associated savings in installation and maintenance costs resulting from the elimination of the cooling tower and condenser pumps. On some models, even the hydronic accessories (such as the pump and expansion tank) may be included, assembled, and tested in the factory so that they arrive ready to begin operation. These packaged features have made the air-cooled chiller a good choice for schools, hospitals, hotels, retail environments, and offices as well as for cooling process or manufacturing operations.

Advancements in Air-Cooled Chiller (ACC) Technology

Over the years, the simple packaged product described above has evolved to a fully customizable piece of equipment. Technological advancements have resulted in many improvements that have increased efficiency and performance and reduced sound levels while maintaining the lower initial and maintenance costs that made the air-cooled chiller popular. These improvements include:

- Implementation of direct digital controls (DDC) in place of electro-mechanical controls. DDC controls are more accurate, respond faster to changes in conditions, and provide more reliable operation.
- Implementation of trending and energy efficiency software algorithms.
- Design improvement of the compressors for more efficient operation, less internal losses, and quieter operation.
- Removal of capacity restricting unloaders on compressors, such as slide valves. These restrictors reduced refrigerant flow while the compressor operated at full speed, causing an increase in sound levels.
- Implementation of variable speed drives on compressors to reduce operating speed, which provides better capacity control, lower energy consumption, and quieter operation.
- Implementation of variable speed drives on condenser fans, resulting in better chiller efficiency as well as quieter unit operation.
- Design improvements on condenser fans to increase the amount of airflow while reducing energy consumption and decreasing sound levels.
- Design of new condenser coils which utilize aluminum microchannel material, resulting in greater heat transfer, increased surface area and improved efficiencies.

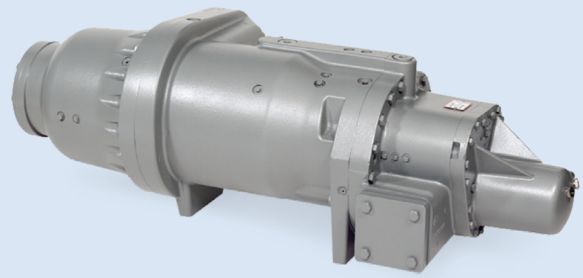
COMPARISON OF SIZE AND WEIGHT OF SCROLL AND SCREW COMPRESSORS

In addition to differences in operation and efficiency, the physical characteristics of these two types of compressors may influence the chiller selection. Shown below are typical size and weight factors to be considered.

Replacement Scroll Compressor (Typical Tandem Configuration)

Capacity: 20 or 25 tons
Approximate Weight: 270 lbs
Approximate Dimensions (in.) (L x W x H): 17 x 14 x 26

Replacement Screw Compressor:



Capacity: 80 or 100 tons
Approximate Weight: 1,875 lbs
Approximate Dimensions (in.) (L x W x H): 50 x 20 x 21

Efficiency and the Future of Air-Cooled Chillers

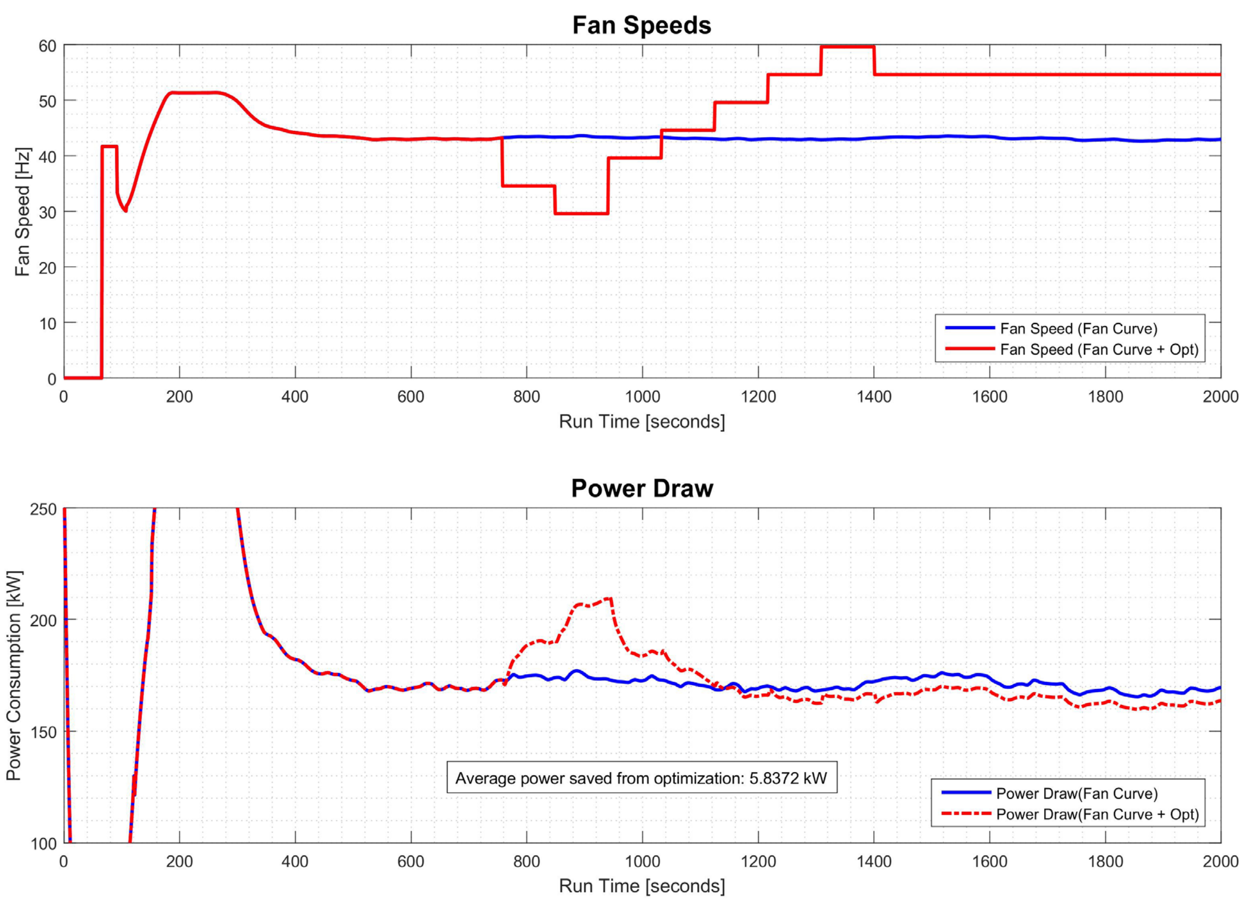
Nearly all chiller plants operate the majority of their hours at load cooling conditions that are lower than the peak design conditions. These part-load operating conditions are often at off-design ambient temperatures.

Water-cooled chiller plant systems consume a large amount of energy. Many owners have installed automatic temperature control systems to optimize the overall energy efficiency of the chiller, tower, and pumps. Since the chiller is the largest energy consumer in the plant, these controls focus on optimizing chiller operation. Additionally, where possible, these controls take advantage of the energy savings afforded by lower wet bulb temperatures.

Next-generation ACC control systems include energy optimization software to accomplish this same type of energy savings. The work performed by the compressor is related to the mass flow of refrigerant as well as the difference in the saturated suction pressure in the evaporator and the saturated condensing pressure in the condenser. This differential pressure is known as lift. Compressor energy consumption becomes interdependent with the condenser fan operation. Increasing the airflow of the condenser fans also increases the amount of heat transfer, which then reduces the condensing pressure. When the airflow of the condenser fans is increased, their energy consumption is elevated. However, lowering the condensing pressure then reduces the energy consumption of the compressor. The next-generation energy optimization software will maintain the lowest overall energy consumption of the compressor and condenser fans by modulating condenser fan airflow. Furthermore, the control system will continue to optimize the energy efficiency of the ACC as the condenser coils become dirty, so the benefit increases over time.

Figure 1 shows data logging plots for actual ACC chiller performance. The upper plot shows condenser fan speed as a function of run time. The lower plot shows total chiller input kW as a function of run time. In each figure, the blue line is standard chiller performance and the red line is chiller performance with self-optimizing control. In the upper figure, the chiller starts and achieves normal, steady-state operation during the interval 0 to 750 seconds. After this point, the self-optimizing control searches for the most efficient fan speed. The lower plot shows that as the optimizing control begins to operate at about 750 seconds, chiller input kW is higher than standard control; but as the optimizing control works to find the best condenser fan speed, the input kW reduces until it is consistently lower than the standard control.

Figure 1 – Optimizing Energy Usage with Fan Control



Some manufacturers offer fans that can be controlled with variable speed fan drive motors. Chiller controls software is being specifically developed to coordinate optimal fan speed for application conditions while also providing refrigerant circuit optimization. This will result in higher part-load efficiency and reduced acoustic levels.

Air-Cooled Chiller Customization

Previous designs of air-cooled chillers often did not offer choices in components, efficiency, and size. Options to control noise were limited to selecting a compressor with or without acoustic treatment. Designers were previously unable to optimize an air-cooled chiller selection to satisfy specific efficiency, sound, and space requirements.

Today's designers have the ability to select their air-cooled chiller based on efficiency, sound, and footprint.

Some examples of customizable features of air-cooled chillers include:

- Ability to select a different evaporator design based on size, first cost, freeze protection, and serviceability
- Capability to select different compressors based on efficiency, first cost, serviceability, efficiency, and life expectancy
- Ability to select different condenser coils based on efficiency, first cost, corrosion resistance, and weight
- Capability to select constant speed or variable speed technology for the compressor and/or fans based on efficiency and first cost
- Ability to choose from multiple footprints for a given capacity in order to optimize efficiency while meeting space requirements

In addition, air-cooled chiller condenser coils are available in different configurations, providing another level of customization. The two most common choices are the aluminum/copper (Al/Cu) and the microchannel heat exchanger (MCHX) coil designs, but other options are available. A brief description of each type of coil follows.

Aluminum/Copper (Al/Cu) Coil

All types of air-cooled condensers typically have used the standard coil construction of aluminum fins with copper tubes.

Customizable Air-Cooled Chiller

MCHX (MICROCHANNEL HEAT EXCHANGER) COILS

A microchannel coil is composed of three key components: The flat microchannel tube, the fins (located between alternating layers of microchannel tubes), and two refrigerant manifolds. These three components are joined together in a single coil using a nitrogen-charged brazing furnace. Overall, the product quality and integrity are maximized as only one uniform braze in the furnace is required.

The microchannel tubes found in the heat exchanger provide excellent heat transfer for the refrigerant. Heat transfer has been improved in the air side as a result of the enhanced surface area contact and the metallurgical bond between tube and fin. The fin design is now optimized to enhance the heat transfer performance. The fin-to-tube bond also reduces thermal resistance between tube and fin, resulting in better heat conduction.

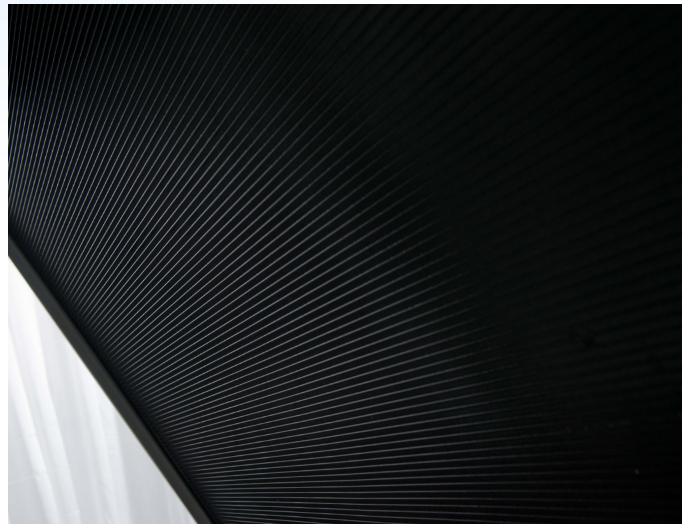
The MCHX coil construction allows for increased levels of structural rigidity. In addition to structural resilience, the physical properties associated with using an all-aluminum construction provide a significant weight advantage when compared to copper tubes.

This advantage can translate into an overall equipment weight reduction that can significantly reduce the cost should the equipment be installed on the roof of a building (e.g., chiller, rooftop, etc.).

In contrast to standard round tube/plate fin (RTPF) aluminum fin/copper tube condenser coils, MCHX coils are constructed with all-aluminum alloys with brazed fin construction. Microchannel heat exchangers generally provide higher thermal performance per unit volume when compared to RTPF designs.

In summary, when compared to traditional coil technology, the MCHX coil offers the following benefits:

- *Improved heat transfer and thermal performance*
- *Increased coil and overall unit efficiencies*
- *Substantial refrigerant charge reduction*
- *Compact size with reduced coil volume*
- *Enhanced structural robustness*



E-coated MCHX coils. During e-coating an extremely durable and flexible epoxy coating is uniformly applied over all coil surfaces for complete isolation from the contaminated environment.

Microchannel Heat Exchanger (MCHX) Coil

The MCHX coil design utilizes several aluminum alloys, in combination with a metallic coating, for construction of the heat exchangers. The alloys are carefully chosen to extend the life of the coil. MCHX coils typically have the highest operating efficiencies and lowest first cost and require the lowest refrigerant volume.

Often, the choice between Al/Cu and MCHX condenser coils is an owner preference based on previous experience with such factors as useful operating life, maintenance, and ease of replacement.

Another less common choice for condenser coil construction is copper/copper (Cu/Cu).

Copper/Copper (Cu/Cu) Coil

Copper fin coils eliminate the bi-metallic bond found on standard coil construction. A copper wavy fin pattern is mechanically bonded to the standard copper tube. A protective Mylar strip installed between the coil assembly and sheet metal coil support pan further protects that coil from galvanic corrosion.

In addition to the choices for the material of the condenser coil, additional corrosion protection is available with a factory-installed pre-coat or epoxy-based coating. These coatings may extend the life of the coils under harsh environmental conditions, such as those found in coastal, industrial, or highly populated urban areas. The corrosion resistance of an epoxy coated condenser coil will be equivalent to a 2000+ hour salt spray test in accordance with ASTM (American Society for Testing and Materials) B-1117 Standard.

IMPORTANCE OF CORROSION PROTECTION

There are numerous condenser coil options for air-cooled chillers, all of which have benefits and disadvantages. However, all condenser coils may be subjected to corrosion due to environmental factors.

Corrosive environments occur not only in coastal or marine climates and industrial areas, but also are present in urban or rural areas, localized microclimates, and combinations of these conditions.

Environmental exposure of air conditioning components can often lead to an undesirable outcome if the correct materials are not applied. In corrosive environments with an unprotected coil, a rapid direct pitting attack of the tube and/or tube-to-manifold joint can occur and may lead to a catastrophic refrigerant leak and system failure.

Condenser coils need to be protected from environments that may lead to localized and/or generalized corrosion. Premature corrosion of heat exchangers, specifically condenser coils, may lead to unexpected performance degradation, poor aesthetics, and possible equipment failure.

In order to minimize these effects, material selection and protection schemes must be considered.

E-coating, available on both aluminum fin coils and MCHX coils, provides superior protection against many corrosive atmospheres. During e-coating, an extremely durable and flexible epoxy coating is uniformly applied over all coil surfaces for complete isolation from the contaminated environment. A consistent coating is achieved through a precisely controlled electrocoating process that bonds a thin, impermeable epoxy coating to the specially prepared coil surfaces.

Pre-coated aluminum fin/copper tube coils have a durable coating applied to the fin stock prior to the fin stamping process. This design offers protection in mildly corrosive coastal environments, but is not recommended in severe industrial or coastal environments.

For more information on coils and corrosion protection, refer to the Carrier Selection Guide:
http://www.utcccs-cdn.com/hvac/docs/1001/Public/08/04-581061-01.pdf

Selecting a Customizable Air-Cooled Chiller

The following example illustrates the factors that must be considered when selecting the customizable features available on the newest ACCs. Consider the owner of a nominal 180-ton, 15-year old ACC that is a candidate for replacement. Most likely, any of today's ACCs will be more efficient and quieter than the existing machine. However, the owner will want to consider the optimized efficiency improvement versus first cost and the desired amount of sound reduction for the specific installation. Additional decisions must be made regarding size, weight, and expected maintenance. All of these choices are interdependent.

The first step in evaluating efficiency is to calculate an approximate operating cost of the existing chiller. Using 5,000 hours per year with an electrical rate of $0.10/kwh, the total energy cost is approximately $50,000 per year, as shown in Table 1. Replacement ACC Option 1A is a standard efficiency, constant speed, scroll compressor ACC, only 4 in. longer and 1% heavier than the existing chiller. Comparing efficiencies, the Integrated Part Load Value (IPLV) of the new chiller is 13% more efficient than the existing chiller.

A simple payback analysis using the IPLV values shows that Option 1A has an operational energy savings of over $6,000 per year. Another possibility would be to select the same type of chiller as Option 1A and add variable frequency drives (VFDs) to the condenser fan system (Option 1B). This option will have the same footprint, but now the IPLV improvement is 37% compared to the existing chiller. The resulting energy savings compared to the existing equipment is now $13,000 per year, which could result in a payback of less than 6 years for Option 1B. The same comparison for Option 1A results in a payback schedule of over 10 years, more than likely not attractive enough to undertake as a replacement.

Another possibility is a high-efficiency ACC that utilizes screw compressors with VFDs. Option 2A has an IPLV that is 61% more efficient than the existing chiller, a very large difference. The analysis now yields an energy savings of almost $20,000 per year. The additional first cost for Option 2A is an extra 20% over the cost of 1A. The payback analysis of energy savings versus first cost now approaches 4 years. Of course, the payback analysis would be different if this job site were a school that is located in the Northeastern United States and the chiller only operates 2,000 hours per year. In that case, the lower operating hours and smaller energy savings might not justify the additional first cost.

Also, consider that an ultra-high efficiency ACC is available. Option 2B has an IPLV improvement of 72% versus the existing chiller. The most efficient and largest chiller will have the greatest first cost, but there may be rebates available from the electric utility to partially offset the additional first costs. Some electrical utilities have rebates approaching 50% of the first cost of the chiller. Based on the analysis of the payback now approaching 2 years, it appears that the owner should probably do everything possible to install the most efficient chiller.

Table 1 – Simple Payback Analysis

SELECTION FACTOR	EXISTING CHILLER	REPLACEMENT OPTIONS*				
		1A	1B	2A	2B	Option 2B with 50% Utility Rebate
Nominal Capacity (Tons)	174	170	170	180	180	180
Approximate First Cost	-	100%	8%	20%	44%	-28%
Full Load Efficiency (EER)	9.7†	5%	5%	7%	19%	19%
IPLV Efficiency (EER)	11.9†	13%	37%	61%	72%	72%
Length (ft-in.)	19-3	19-7	19-7	17-4	25-1	25-1
Length (%)	-	2%	2%	-10%	30%	30%
Weight	12,750	1%	1%	9%	26%	26%
Approximate Yearly Operating Costs	$50,023	-13%	-27%	-38%	-41%	-41%
Simple Payback Analysis (Years)	-	10.51	5.44	4.21	4.70	2.35

*Percent indicates increase or decrease compared to existing chiller.
†Approximate efficiencies of existing chiller at AHRI conditions (44/54 F, 95 F).

LEGEND:
EER – Energy Efficiency Ratio
IPLV – Integrated Part Load Value

However, the evaluation above did not take into account the space requirements of the chiller. Is the existing chiller located at grade, or is it on a roof with a structural steel frame? Options 1A and 1B are 4 in. longer and 1% heavier than the existing ACC. Option 2A, a more efficient choice, is 1 ft and 11 in. shorter but 9% heavier than the existing chiller. Option 2B, the most efficient option, is 26% heavier than the existing chiller. In addition, Option 2B is 6 ft longer. Can the longer chiller fit in the existing footprint? If not, what modifications will be required for the replacement work and what will be the additional cost?

Another factor related to the installation location is ease of maintenance. If the chiller is located on a high roof and the compressor must be replaced, it would be easier and less costly to replace a lighter scroll compressor instead of a heavier screw compressor. Other maintenance considerations may influence the decision. In general, ACCs with screw compressors are more efficient and more robust than scroll compressors. However, the owner may prefer an ACC with 7 or 8 scroll compressors, which would provide greater redundancy in case of failure than an ACC with just 2 screw compressors. In addition, the owner may have reason to consider the skill level required by maintenance personnel when comparing the compressor types and options available.

As noted earlier, the third major design consideration is the desired sound reduction. Technological advancements have made it possible for some manufacturers to offer new highly efficient chillers with low sound ratings. A low sound level may itself be a factor in the decision if required by the application. At the same time, the sound reduction method may be determined by the limitations of space, and in turn can have an impact on the efficiency achieved.

The above sample analysis reveals that there are many possible scenarios for an ACC application. Selecting a new or replacement chiller requires the designer to consider the factors of space and sound as well as first cost and efficiency. The interdependency of these factors requires a method to evaluate the impact that they might have on each other. For a more accurate payback analysis, the designer should utilize actual installation costs, energy modeling, and life cycle costing software.

Balancing Major Design Considerations

As described in the previous section, the customizable features of the new air-cooled chillers provide options to optimize efficiency, sound, or footprint. However, these options are interdependent, and maximizing one feature may affect another even more critical factor. For example, choosing to maximize energy efficiency may result in a unit with a larger footprint. Therefore, it is important to identify the most important design considerations for a specific project and understand how to select a chiller to maximize the critical factor and meet the other requirements with the best performance possible.

The three main design factors that are interconnected are efficiency, sound, and space. When considering space, in addition to the location and footprint of the chiller, the designer must evaluate the effect of sound barriers or architectural barriers on efficiency.

Efficiency

While lower installation and maintenance costs remain significant benefits to the selection of air-cooled chillers, improvements in efficiency are largely responsible for the increase in the use of these chillers. Air-cooled chiller (ACC) systems are often winning the life cycle cost battle when compared to water-cooled chiller (WCC) systems. The ACC systems have lower initial costs, lower maintenance costs, and much lower water costs, all of which have become significant factors in some parts of the country. Over the years, ACC efficiencies have greatly increased with the implementation of newer technologies. In a like-for-like efficiency comparison of just the chiller, WCCs are still 30 to 50% more efficient compared to ACCs; however, the additional energy costs of the WCC condenser water pumps and cooling tower fans, as well as the makeup water and water treatment, must be considered.

Space and Sound

Another contributing factor to the growth in popularity of air-cooled chillers is the fact that they do not require as much interior building space when compared to WCC systems. This results in more usable and billable space for a building owner.

Footprint is an important consideration, especially for replacement projects.

The chillers of today are much larger than previously existing models. National energy efficiency code requirements for increased efficiency have increased the size of the chiller and also increased the amount of condenser airflow, resulting in larger condenser service areas. A small footprint for an ACC can be advantageous when replacing an existing unit. A new, larger replacement chiller could result in additional costs required to increase the concrete housekeeping pad or relocate the external barriers.

With the air-cooled chiller located outdoors, sound considerations become more critical. Also, more local building codes are now implementing sound requirements, so it is important to consider the best methods of noise reduction. The first step of sound abatement is to wrap the compressors with mass-loaded vinyl acoustical jackets. If this is insufficient in reducing the sound levels, external sound barriers usually designed by an acoustical consultant, may be installed.

The controls associated with variable speed technology are the newest resource for additional sound reductions. When acceptable for the application, the controls can work towards reducing frequencies on the compressors and fans resulting in further sound reduction. It is most likely that the chiller capacity will be affected and possibly the efficiency as well, but for critical applications such as hospitals, this is an alternative that can contribute to lower sound levels.

In addition to acoustic barriers, architectural barriers are often installed to match the style of the building. These barriers are available in many different designs and configurations, and although they are pleasing to the eye, there are potential consequences to the ACC. Depending on the type of barriers, a balancing act must be considered to allow efficient condenser airflow while preventing line of sight visualization.

Evaluating the Effect of Airflow Restrictions on Efficiency

The recent increase in the use of external barriers on ACC for architectural and visual purposes, as described previously, has created consequences for ACC operation. These barriers often impede the flow of condenser air that is required for the ACC. Further compounding the problem with the airflow, ACCs have been increasing in size and increasing the required amounts of condenser airflow in recent years. Sufficient condenser airflow is required so that the ACC can properly reject the energy from the building as well as the energy added by the compressor.

Chapter 24, “Airflow Around Buildings,” of the *2013 ASHRAE Handbook – Fundamentals,*[1] discusses how airflow around buildings affects HVAC systems. The explanation of how air flows over buildings is pertinent to how airflow travels over barriers surrounding ACCs. As wind strikes a solid barrier, the part of the airflow that is near the top is pushed upward over the barrier, mixing with the air that is above the barrier. On the downwind side of the barrier, the lower portion of this airflow exhibits a region of low average velocity and high turbulence. This airflow is not carried away from the barrier; rather, it is recirculated downward and back towards the barrier. If this recirculated air is too close to HVAC equipment, it can cause problems with the discharge and intake of the condenser airflow.

If the condenser airflow is restricted too much on an ACC installation, the refrigerant condensing temperature increases and the equipment will produce less cooling capacity. The reduction in cooling capacity is known as “de-rate.” A generic example of the effects of de-rate would be a nominal 200-ton chiller being able to produce only 180 tons. In addition, the condenser airflow restrictions could cause the chiller to operate less efficiently while consuming more energy. Furthermore, the chiller could have operational issues and see a reduction in its useful operating lifespan.

All air-cooled chiller manufacturers publish recommended clearances around the chiller to allow for proper condenser airflow operation. When rating the performance of their equipment according to AHRI (Air-Conditioning, Heating, and Refrigeration Institute) Standard 550/591, ACC manufacturers follow the guidelines that have been established by the independent third-party organization. AHRI instructs manufacturers on the acceptable procedures to follow for condenser airflow, testing temperatures, measuring procedures, etc.

One of the limitations with AHRI testing is that it is performed in a laboratory that simulates a free field condition without any obstructions, which does not replicate actual field-installed situations. AHRI does not have any testing procedures of ACCs to account for installations that include external obstructions and external barriers. Because of the infinite number of installation possibilities that could be found in the field, this testing is not feasible. In the past, ACC manufacturers could only provide performance tables that had been adjusted to take into account external obstructions. Such adjusted performance tables are limited in terms of precision. They typically do not take into consideration the effect of the ambient temperature and can only simulate limited scenarios. The designer cannot use the tables to model performance of a specific installation. Today, new software is being introduced that will allow this capacity/efficiency reduction resulting from airflow restrictions to be modeled more accurately.

[1] ASHRAE (American Society of Heating, Refrigeration, and Air-Conditioning Engineers), 2013, www.ashrae.org

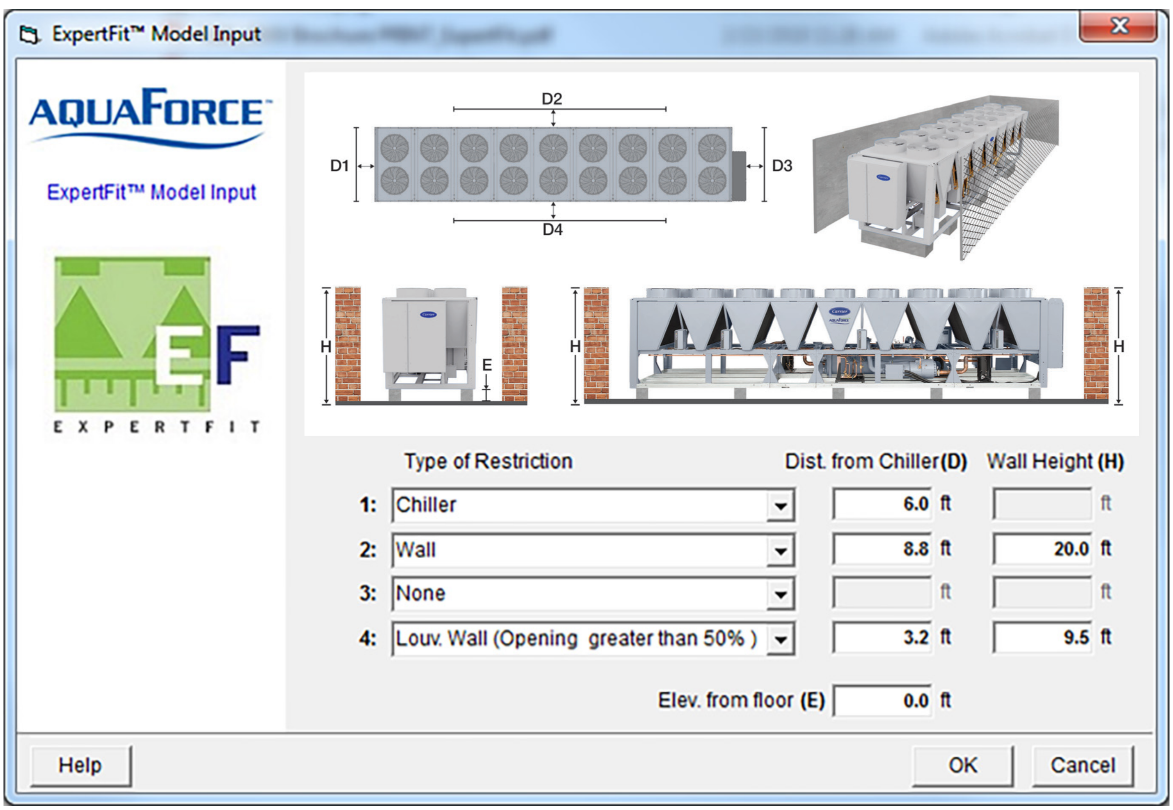
Innovative Software Programs Optimize the Air-Cooled Chiller

Some air-cooled chiller manufacturers have developed software that can accurately model condenser airflow by computational fluid dynamics (CFD). Designers will be able to input orientation, clearances, height and free open area of barriers and receive manufacturers estimated output data regarding the operation of their air-cooled chillers. With this software it will be possible to evaluate different chiller and barrier layouts to maximize capacity/efficiency using scenarios based on temperatures that will occur in real life situations.

As seen in Figure 2, using the Carrier ExpertFit™ Modeling Software, an engineer provides inputs regarding the planned installation, including the type of wall.

This information is combined with design criteria and chiller characteristics, including options and accessories, and is used to generate a summary performance report.

Figure 2 – Modeling a Chiller Installation Scenario using the Carrier ExpertFit™ Modeling Software



Customers will now be able to avoid costly modifications to alleviate an operational problem with their ACC after the chiller and its associated barrier have been installed and the chiller is operating. Using this new software, the designer will be able to explore installation options and estimate the effects of moving a wall or changing the wall material and can evaluate the return on investment for a suggested installation modification that might improve the capacity/efficiency of an air-cooled chiller.

This new software may prove to be a useful tool for evaluating the effects of installation design decisions, but it is important to understand that a performance estimate provided by one manufacturer cannot be applied to another manufacturer's equipment. Each manufacturer has a unique design, and condenser airflow and condenser coil and fan system operation is different for each chiller design. Each individual manufacturer's combination of compressor/cooling capacity/condenser system is unique and cannot be applied to a different set of components. In addition, all of the possible combinations of external barriers affect different ACCs in different ways. A given chiller manufacturer generates a performance estimate based on the CFD analysis done on a particular chiller. Each chiller design has its own CFD characteristics which cannot be extended to competitive units.

Conclusion

Advancements in technology and customization options have made today's improved air-cooled chillers a popular choice for process and HVAC applications. Previously existing only as packaged products, these chillers now may be fully modified to meet the specific needs of the client and installation. With the ability to optimize the sound, efficiency, and even footprint of the air-cooled chiller comes the recognition that it is important to understand the implications of the available options before beginning to customize a selection. The introduction of innovative software programs for further optimization will make it easier to evaluate the first cost and life cycle cost of the air-cooled chiller system and optimize the improvements in air-cooled chiller technology.