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Optimizing Chiller Plant Efficiency: Factors to Consider

With the current and future phase-outs of ozone-depleting refrigerants, chiller replacement is on the minds of many building owners and managers. When considering any change in your chilled water system, you have a golden opportunity to examine the system as a whole. Many chiller plants are oversized or not configured to operate efficiently at part load conditions. New technologies and equipment can make significant improvements. When you look at total cost of ownership, these improvements can save you considerable money, as well as increase the reliability of your system. But to make the best choices, you must understand how a variety of factors influence chiller plant efficiency.

Managing a chilled water plant is a complex task. There are many factors besides the chiller itself to consider when looking at efficiency. Auxiliary equipment, such as pumps and cooling towers, affect and are affected by chiller operation. Together these components comprise your building's cooling system. When evaluating or replacing any part of the system, it is critical to consider its interaction with the other components. Like instruments in an orchestra, individual capability is only a starting point – the key factor is how the instrument combines with all the others to produce a symphony.

In addition to combined equipment capacity, many other factors influence the system's ability to meet your building's cooling load efficiently. Such things as weather patterns, number and type of operating hours, electric rates and building use should all be considered when selecting or retrofitting a chilled water system.

Basing chiller selection on single-machine performance is a mistake that often leads to misapplication, which can be costly in both the short and the long term.

And since more than 80% of all chilled water installations are multiple chiller systems, it is particularly important to understand the interaction between the chillers themselves. Basing chiller selection on single-machine performance is a mistake that often leads to misapplication, which can be costly in both the short and the long term.

Since the components of a chilled water system do not operate by themselves, it does not make sense to evaluate them this way. Yet, that is exactly what is typically done. Each component is specified as if it were operating in a vacuum. Not only that, but when specifying chillers, designers usually use a formula built on standardized conditions that do not reflect the actual operation of the building.

Condenser Water Hours Below 70°F (24-hr. Operation)

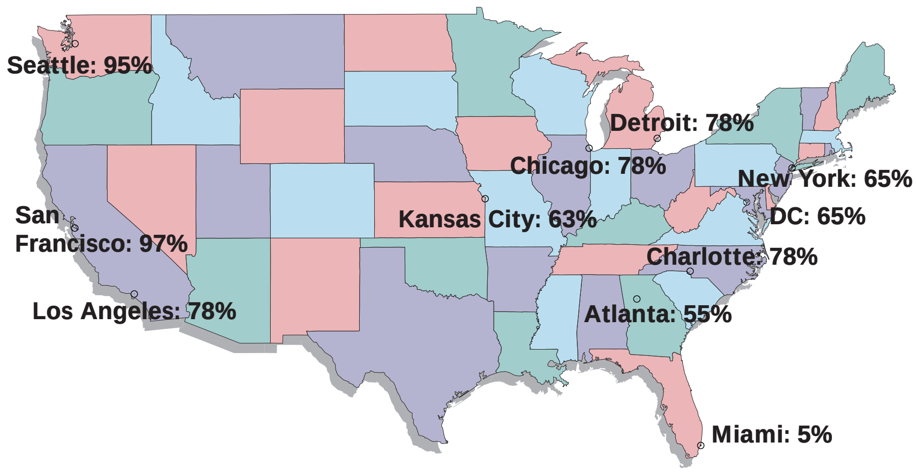

FIGURE 1

The IPLV Formula

In December of 1998, the American Refrigeration Institute (ARI) released a revised standard for water cooled chillers – ARI 550/590-1998. One of the major changes in the standard was made to the Integrated Part Load Value formula, or IPLV. The IPLV is a calculation of predicted chiller efficiency at the ARI Standard Rating Point – an estimate of how efficiently a chiller will operate at part load conditions, based on average criteria dictated by the standard.

The revisions to the IPLV equation were designed to make it a more accurate representation of actual operating conditions, such as geographic locations and building types. However, because the many assumptions in the formula cannot exactly match any one particular chiller installation, using it will not create a realistic picture of your building. Using the same formula for chiller systems in Alaska and Miami – and every place in between – cannot produce a very specific result.

The IPLV rating was meant to be a relative guide to single component efficiency, not *system* efficiency. ARI itself recognizes this and recommends performing a comprehensive analysis that reflects:

- actual weather data;
- building load characteristics;
- number of chillers;
- operational hours;
- economizer capabilities; and
- energy drawn from auxiliaries such as pumps and cooling towers

when calculating the overall chiller plant efficiency. This becomes increasingly important with multiple chiller systems because individual chillers operating within multiple chiller systems are more heavily loaded than single chillers within single chiller systems.

Given that many factors affect the efficiency of a chilled water system, let's take a look at the part each of these factors plays.

Weather

The IPLV formula assumes weather data for an "average" U.S. city. Since climate varies considerably in the U.S. and even more around the globe, any formula attempting to gather these into an average is bound to be inaccurate. Yet accuracy is important, because weather affects several aspects of a chilled water system. It is important to remember, however, that there is not a direct correlation between outside dry bulb temperature and building load. Specifying equipment based solely on temperature bin data is common, but will not provide a complete picture of your building's operating environment.

Run Hours

In colder climates, such as New York, Chicago or Beijing, there is less need for cooling, and many hours are spent with the building running at part load operation. The chillers may even be shut off for four or five months out of a year due to the lack of load, or the system may use economizers. In multiple chiller systems, if there is a load, the operator will probably turn all but one of the machines off, and run that one fully loaded.

In contrast, weather in warmer cities, such as Miami, Houston or Singapore, may create year-round system load. Cooling is always required, and the use of economizers may be impractical. So the number of run hours would be much higher.

Number of Machines Running

In any multiple chiller system, chillers spend most of the time running in the loaded position (70% to 100%). Weather affects how many machines need to be running to meet set point.

Cooling Tower Temperature

Weather will also greatly affect the temperature of the water coming from the cooling tower. Any Florida service technician will tell you that 65°F condenser water temperature does not happen very often in Miami. Yet, using the IPLV formula, this temperature is assumed to occur 57% of the time.
As the map in Figure 1 shows, the varying climate across the U.S. causes a wide variance in condenser water temperatures. This results in significant differences in the percentage of time condenser water temperatures are below 70°F – a mere 5% in Miami, but 97% in San Francisco.

Building Load Characteristics

The IPLV formula uses a building load profile that assumes the maximum building load (100%) occurs at the maximum outside temperature. This in itself is not a bad assumption. But from there, it assumes that building load will be at 20% at the minimum outside temperature and at 38% at 57.5°F. Few, if any

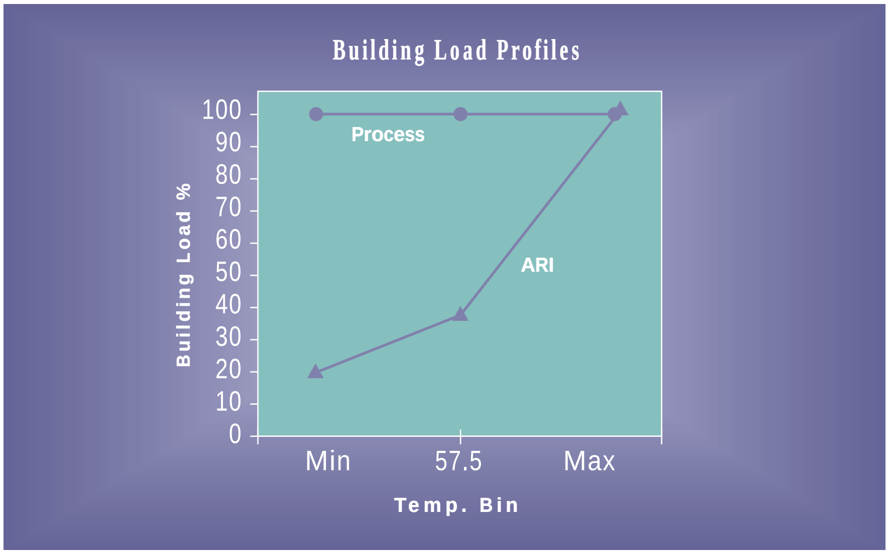

FIGURE 2

buildings will have this exact type of load profile.

Building load profiles vary according to how the building is used. For example, consider the following typical usage patterns:

- Office buildings: Operate 5.5 days per week, from 7:00 a.m. to 6:00 p.m.
- Retail: Operate 7 days per week, from 9:00 a.m. to 10:00 p.m.
- Hospitals: Operate 7 days per week, 24 hours per day
- Industrial Process facilities: Operate 7 days per week, 24 hours per day

Each building type has its own typical profile. But each also varies according to weather patterns and individual building usage. Chances are your building's load profile will not look anything like the ARI load profile. Figure 2 shows the ARI profile compared to a 24-hour process operation. Obviously these two are not very similiar.

Operational Hours

System performance is affected by the number of hours the chillers operate. Consider a school in the northern U.S. It may only use its chilling equipment a few hours a day for a few weeks out of the year. Total annual usage may be as low as 800 hours. In contrast, a 24-hour process application right next door could be running more than 8000 hours annually.

The difference in hours will greatly influence what type of system should be selected for a particular building. Just changing this one parameter – operating hours – will affect a host of others, such as entering condenser water temperature, electric rate structure, number of chillers running, chiller loading and, of course, equipment payback.

Number of Chillers and Economizer Capabilities

The IPLV calculation assumes single chiller operation, which is not normally the case. In fact, approximately 85% of the chillers sold are in some type of multiple machine system. For example, if a 1000-ton system is needed, two 500-ton machines will generally be purchased, as opposed to one 1000-ton machine. The number of chillers in the system and whether or not an economizer is used will affect at what percent of their capacity the chillers run – in other words, how efficient they are.

Figure 3 shows how a typical application using three equally-sized chillers might run without an economizer. The first machine turns on when cooling is first needed. It ramps up until it reaches its full capacity. If the building's cooling set point cannot be maintained, the second chiller is turned on. The first and second chillers then load up until they reach full capacity. If set point cannot be maintained, the third chiller is turned on. All three machines now ramp up until full building load is met.

If a building operates most of the time between 30% and 90% of total building load, the chillers will run between 70% and 95% capacity most of the time. An interesting thing

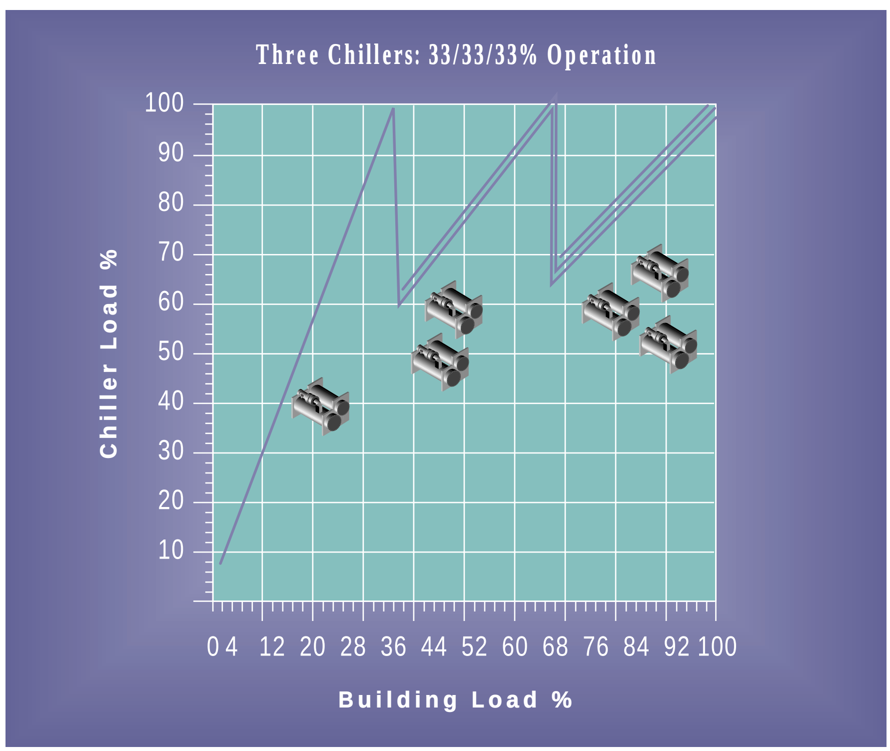

FIGURE 3

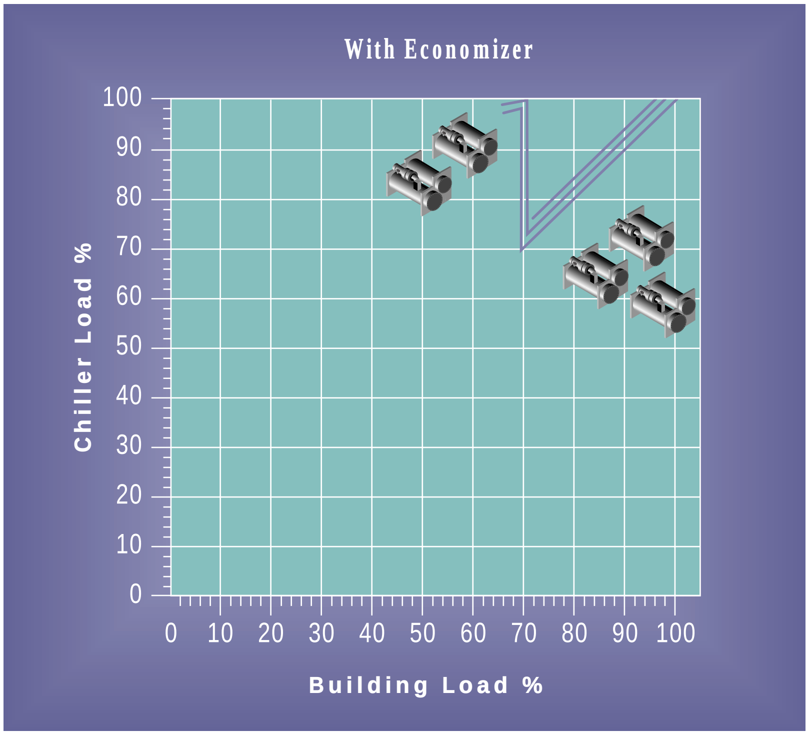

FIGURE 4

happens if an economizer is added to this same system.

Since the economizer takes over at operating hours below 55°F, for example, the chillers will operate with even less time at low loads. This scenario is depicted in Figure 4.

Condenser Water Temperature

Depending on the time of day a chiller is needed, the condenser water temperature can vary greatly. A system that runs around the clock will see much more time with colder condenser water than the same system running during typical office hours. This is due to the large number of night time hours, when the outside temperature tends to drop. But these machines also need to run at the design daytime condition, which may have 85°F condenser water temperature. In a case like this, the designer must select chillers that can do both duties (85°F and 60°F condenser water), but should optimize the selections where the most operational hours will be spent.

Referring back to Figure 1, we see that during 24-hour operation, a chiller in Chicago will see condenser water temperatures below 70°F approximately 78% of the time. It is important to understand this when selecting the proper chiller for the job.

Some chillers – for example, certain screw and negative pressure centrifugal chillers – cannot run below a certain condenser water temperature (70°F is typical). In areas like Chicago, these chillers may not be the best choice.

Other chillers – for example, certain positive pressure centrifugal chillers – are designed to operate effectively with colder condenser water. In Chicago, selecting a chiller that can operate effectively between 55°F (below which a typical economizer would turn on) and 70°F would be a critical decision.

Auxiliary Equipment

Cooling Towers

Any time a chiller can receive colder condenser water temperature from a cooling tower, it will operate more efficiently – it has less work to perform and therefore will use less energy. A general rule is that for every one degree drop in condenser water temperature, chiller efficiency will increase 2%.

It makes sense, then, to consider sizing your tower as large as possible to get the coldest condenser water temperature for the chiller. Towers can be rated in terms of approach temperature: the temperature difference between the outdoor wet bulb temperature and the water temperature leaving the tower. The smaller the approach, the more efficient the tower.

Figure 5 shows the exact same system with three different cooling towers. As expected, the chiller operates most efficiently with the largest tower. While this is not reflected in the chiller's IPLV rating, it does show up when evaluating the operating cost of the system as a whole. Although the largest cooling tower has the most expensive first cost, the savings in overall costs make for a quick payback.

Large Tower or Small Tower?

	Approach	IPLV	Op Cost
Small Tower	9 deg	.562	$114k
Medium Tower	7 deg	.562	$111k
Large Tower	5 deg	.562	$108k

FIGURE 5

continued on next page

continued from page 4

Pumping Requirements

When chillers are selected, their efficiency rating is expressed in kW/ton. There is also a pressure drop associated with its heat exchangers. The pressure drop indicates how much energy is lost in the water system as water flows through the cooler and condenser. This is the amount of pressure the pumps need to overcome to get water through the heat exchanger. The greater the pressure drop, the more pumping power needed.

If the flow is lowered on a system – for example with a variable speed drive on the pump motor – pressure drop will come down, and the pumping power requirement will be reduced. At the same time, the chiller efficiency will go down. It is important to understand the dynamics between pumping capacity and chiller capacity in order to strike the most cost-effective and efficient balance between them.

The Importance of Controls

Proper controls can be a key factor in meeting constantly changing building requirements in the most effective manner. Once equipment is selected for maximum efficiency, a chilled water control system will both supervise and optimize the operation of your chilled water plant. A good control system will consider all elements of the cooling operation, including cooling towers, pumps, variable frequency drives (VFDs), heat exchangers and the control valves used on the building's air handlers.

CONSIDER THESE IMPROVEMENTS TO GAIN EFFICIENCY

In addition to correct sizing of chillers, here are some other areas where efficiencies can be realized.

- **Multiple Chiller Configuration.** When selecting multiple chillers, be sure to analyze the difference in system performance between chillers that are equal and unequal in size. Splitting the load unevenly can result in more efficient operation at lower building loads.
- **Cooling Towers.** A larger cooling tower can boost chiller efficiency by lowering entering condenser water temperature. Factors such as size, height and fan configurations will affect the efficiency of the tower, and should be considered when making a replacement selection.
- **Controls.** A good energy management system will optimize the efficiency of individual pieces of equipment, as well as how they operate together. It will adjust the delivery of conditioned air to the specific and varying requirements of your building, maintaining comfort, while conserving energy.
- **Variable Frequency Drives (VFDs).** Adjust the speed of fan and/or pump motors to more precisely meet cooling load requirements and reduce power consumption. They are particularly helpful at part load conditions. If many chiller hours are spent in deep part load, these may be helpful.
- **Energy-Efficient Motors.** Today's improved motor designs can save energy and contribute to an overall system downsizing strategy. When properly matched with their anticipated load, motors can run at peak efficiency more of the time, improving their performance and saving money.
- **Variable Air Volume.** Replacing a constant volume air distribution system with a variable air volume system can increase energy efficiency. Variable systems use a combination of pressure controls and dampers to adjust air flow, rather than varying the air's temperature.

Conclusion

To thoroughly understand your application, a comprehensive review of the many factors contributing to chiller system efficiency should be conducted. As we have discussed these include geographic and climate conditions, building load characteristics, anticipated operational hours, economizer capabilities and predicted energy drawn from auxiliaries such as cooling towers and pumps. This kind of evaluation can help you assess your system-wide efficiency before you make purchasing decisions. It will show you which components, if replaced or retrofitted, will provide the most improvement overall.

The Integrated Part Load Value (IPLV) formula should not be relied on to accurately represent your chiller installation. Instead, take advantage of the new computer tools that can perform system evaluations not previously possible. They are comprehensive, time-efficient, and will allow your design engineer to truly optimize the chilled water system for your specific building.