TRANE

ENGINEERS NEWSLETTER

providing insights for today's HVAC system designer

ARI Standard 550/590–1998…

Implications For Chilled-Water Plant Design

In December 1998, the Air-Conditioning and Refrigeration Institute (ARI) published a new standard that affects the rating and testing of chillers used in comfort cooling applications. ARI Standard 550/590–1998, "Standard for Water Chilling Packages Using the Vapor Compression Cycle," replaces:

- ARI Standard 550–1992, "Centrifugal and Rotary Screw Water Chilling Packages," and…
- ARI Standard 590–1992, "Positive Displacement Compressor Water Chilling Packages."

ARI hopes that the combined standard will *"reduce confusion in equipment application and assure consistent treatment for rating and testing of two very similar and overlapping product lines,"* particularly with respect to chillers with screw compressors.

Of more immediate interest, ARI Standard 550/590–1998 redefines certain key terms and rating conditions that impact cataloged chiller efficiency and, therefore, chiller plant design, specification and application. This said, it's important to note that the revised Standard does not change the actual performance or cost of specific chillers. Nor does it change the real energy consumed by a chiller and its accessories in an actual application over its lifetime.

This newsletter reviews the principal changes enacted by the Standard as they pertain to chillers with water-cooled condensers and chilled-water plant design. It also relates the reasons for these changes and identifies the limitations of the Standard as ARI has identified them.

Evaporator Tube Fouling Factor

What Changed? Impurities in the chilled water system eventually deposit on evaporator tube surfaces, impeding heat transfer. Cataloged performance data includes a "fouling factor" that accounts for this effect to more closely predict actual chiller performance. Research conducted by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) reveals that the negative effect of fouling on the long-term performance of closed-loop chilled water systems is usually less than 0.00025 h·ft²·F/Btu. ARI Standard 550/590–1998 reduces the fouling-factor allowance from that value to the **0.00010** h·ft²·F/Btu suggested by the study results.

"…ARI Standard 550/590–1998 does not change the actual performance or cost of specific chillers, nor the real energy consumed…"

Its Effect… Assessing a smaller fouling factor lets specifying engineers, owners, and manufacturers alike take credit for seemingly better heat transfer. With cataloged performance that more closely matches actual operation, specifying engineers can select chillers with greater precision—and owners purchase no more cooling capacity than they actually need.

[The revised evaporator fouling factor has little effect on full-load efficiency, i.e. roughly 2 percent. As noted later, full-load efficiency remains an important criterion in many applications.—Editor]

Part-Load Efficiency Rating System

What Changed? ARI's part-load efficiency rating system establishes a single, "blended" estimate of stand-alone chiller performance. The standard defines two "figures of merit":

- **Integrated Part Load Value, IPLV**, predicts chiller efficiency at the ARI Standard Rating Point.
- **Non-Standard Part Load Value, NPLV**, predicts chiller efficiency at rating conditions other than the ARI Standard Rating Point but within prescribed limits.

Both ratings result from the same equation. ARI Standard 550/590–1998 changes the basis of that equation to *"more closely reflect actual operating experience found in the field for a single chiller."* The calculation now uses weighted averages representing a much broader range of geographic locations, building types, and operating-hour scenarios with and without airside economizer.

While the weighted averages place greater emphasis on the part-load operation of an **average, single-chiller installation**, as shown in Table 1, they will not—by definition—represent any particular installation.

Table 1
Weighting Of Part-Load Points

Part-Load Point, %	Weighting, %	
	1992 Standard	1998 Standard
100	17	1
75	39	42
50	33	45
25	11	12

The combined Standard also replaces the Application Part Load Value (APLV) with a Non-Standard Part Load Value (NPLV) for any chiller that cannot operate at ARI standard rating conditions for part load.

Table 2 summarizes ARI Standard 550/590–1998's IPLV and NPLV parameters for water-cooled chillers. Of course, a building-specific analysis remains the most accurate energy prediction tool.

Its Effect… When comparing equipment, remember that the IPLV rating is only valid for chillers expected to run at standard IPLV rating conditions… despite the fact that IPLVs and NPLVs are derived from the same equation using the same part-load weightings. More importantly, **IPLV/NPLV ratings describe average, stand-alone chiller performance.** Appendix D of ARI Standard 550/590–1998 explains this caveat:

> *…The [IPLV] equation was derived to provide a representation of the average part load efficiency for a single chiller only. However, it is best to use a comprehensive analysis that reflects the actual weather data, building load characteristics, operational hours, economizer capabilities and energy drawn by auxiliaries such as pumps and cooling towers, when calculating the chiller and system 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.*

Table 2
IPLV/NPLV Equation And Rating Conditions From ARI Standard 550/590–1998

Expression Of Chiller Efficiency	Equation
Coefficient Of Performance–COP, W/W, or Energy Efficiency Ratio–EER, Btu/h/W	IPLV or NPLV = 0.01A + 0.42B + 0.45C + 0.12D
Power Per Ton, kW/ton	$\text{IPLV or NPLV} = \dfrac{1}{\dfrac{0.01}{A}+\dfrac{0.42}{B}+\dfrac{0.45}{C}+\dfrac{0.12}{D}}$

	Chiller Energy Efficiency, Load				
	A at 100%	**B** at 75%	**C** at 50%	**D** at 25%	— at 0%
IPLV Rating Conditions					
Condenser, water-cooled only:[a]					
Entering water temperature, F [C]	85 [29.4][b]	75 [23.9]	65 [18.3]	65 [18.3]	65 [18.3]
Flow rate, gpm/ton [Lps per kW]	3.0 [0.054][c]				
Fouling factor, h·ft^2·F/Btu [m^2·C/W]	0.00025 [0.000044]				
Evaporator:					
Leaving water temperature, F [C]	44 [6.7][b]	—	—	—	44 [6.7]
Flow rate, gpm/ton [Lps per kW]	2.4 [0.043][c]	—	—	—	2.4 [0.043]
Fouling factor, h·ft^2·F/Btu [m^2·C/W]	0.0001[0.000018]				
NPLV Rating Conditions					
Condenser, water-cooled only:[a]					
Entering water temperature, F [C]	As selected[b]	—[d]	65 [18.3]	65 [18.3]	65 [18.3]
Flow rate, gpm/ton [Lps per kW]	As selected[c]				
Fouling factor, h·ft^2·F/Btu [m^2·C/W]	As specified				
Evaporator:					
Leaving water temperature, F [C]	As selected[b]	—	—	—	—
Flow rate, gpm/ton [Lps per kW]	As selected[c]	—	—	—	—
Fouling factor, h·ft^2·F/Btu [m^2·C/W]	As specified				

[a] If the chiller manufacturer's recommended minimum entering-condenser water temperature, ECWT, is greater than that specified above, then it may be used in lieu of the specified value.

[b] Corrected for fouling-factor allowance by using the calculation method described in C6.3 of ARI Standard 550/590–1998.

[c] Flow rates are to be held constant at full-load values for all part-load conditions.

[d] For part-load ECWTs, the temperature should vary linearly from the selected ECWT to 65F [18.3C] for loads ranging from 100% to 50%, and should be fixed at 65F [18.3C] for loads ranging from 50% to 0%.

Condenser Relief Schedule

What Changed? The IPLV/NPLV rating is a function of the condenser relief schedule. Under ARI Standard 550–1992, entering-condenser water temperatures (ECWT) declined in "straight-line" fashion from 85F at full load to 60F at 0-percent load. Said another way, the relief schedule reduced ECWT by 2.5F for every 10-percent drop in load.

ARI Standard 550/590–1998 changes the ECWT based in part on the interpretation of cataloged cooling-tower performance at part load given the average weather data of 29 cities. Now, ECWT only declines in a "straight line" from 85F at full load to 65F at 50-percent load…or 4F for every 10-percent drop in load. Between 50 and 0 percent, ECWT remains constant at 65F. Figure 1 compares the old and new condenser relief schedules.

Its Effect… The new, steeper ECWT drop at standard ARI rating conditions means that part-load efficiencies improve more quickly. **Expect to see cataloged IPLV/NPLV ratings that are lower than the IPLV/APLV ratings under ARI Standards 550–1992 and 590–1992.** The apparent improvement simply reflects the redefined part-load rating conditions—**actual performance of specific chillers has not changed.**

Most manufacturers offer units that can operate at or below 65F ECWT. To assure

Figure 1
Condenser Relief Comparison

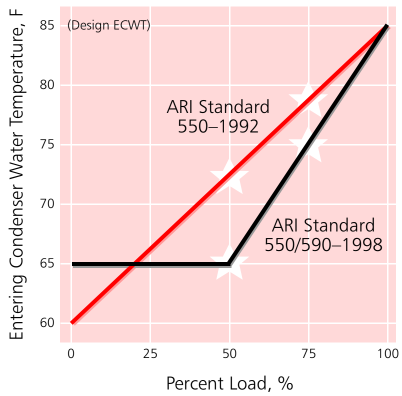


Figure 2
System Load Profile

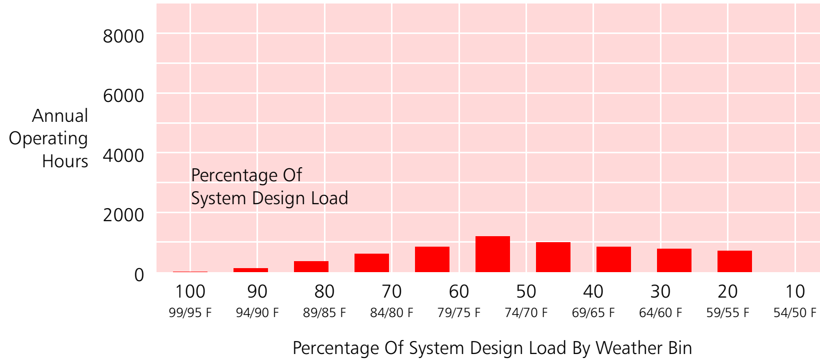
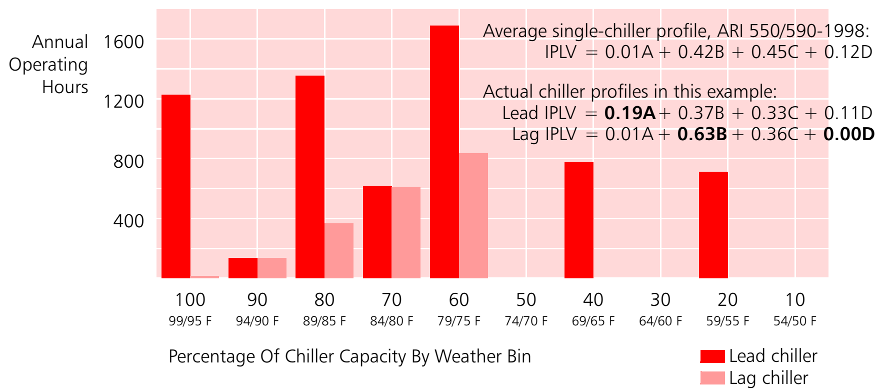


Figure 3
Individual Profiles Of Chillers Sized For Equal Capacity



the "apples-to-apples" comparison intended by the ARI part-load-efficiency rating system, **make sure that stated performance at loads of 50 percent or less is based on 65F ECWT.**

Once installed, the chilled water plant's energy consumption is determined by the tradeoff between chiller, tower and pump power. At many part-load conditions, the coldest water temperature possible does not result in optimal system operation. Load, ambient conditions and the part-load operating characteristics of the chiller and tower will ultimately determine the optimum ECWT for a given installation.

[Engineers Newsletter Vol. 24–No. 1 explored the effect of ECWT and optimized tower control on total system energy consumption.—Editor]

Plants With Multiple Chillers

ARI data shows that more than 80 percent of all chillers are installed in multiple-chiller plants. ARI Standard 550/590–1998 specifically advises that a comprehensive analysis be used to predict **system** performance. It also cautions that *"individual chillers operating within multiple chiller systems are more heavily loaded than single chillers within single chiller systems."*

The upshot is this: To successfully optimize the performance of a multiple-chiller plant and deliver the greatest possible energy cost savings, the designer must account for these facts:

- Variables other than outdoor air dry bulb—e.g. humidity, solar loads, operation schedules, use of integrated economizers—greatly affect cooling loads in commercial and industrial applications.
- System loads and individual chiller loads in multiple-chiller plants are distinctly different.
- Changing loads affect cooling-tower operation and entering-condenser water temperatures.

The December 1996 Engineers Newsletter, "'Off-Design' Chiller Performance," demonstrates that a weather-versus-time system load profile bears little resemblance to the load profiles of individual chillers in a multiple-chiller plant. That publication considered an 800-ton chilled water plant with a system profile defined in terms of weather bins, as summarized in Figure 2. In the first example, the load was evenly split between two chillers.

Like most plants, the chillers were piped in parallel so that both would "see" equal loads as long as they produced the same system-supply water temperature. In that scenario, any system load greater than 400 tons required the operation of both chillers. As long as the system load was 45 percent, the lead chiller operated alone and at 90 percent of its capacity. The lag chiller only ran when the system load exceeded 50 percent.

Figure 3 illustrates the individual load profiles of each chiller. Notice that the lead chiller runs at full capacity about 20 percent of its annual running time…a far cry from the less than 1 percent suggested by the actual system load profile depicted in Figure 2!

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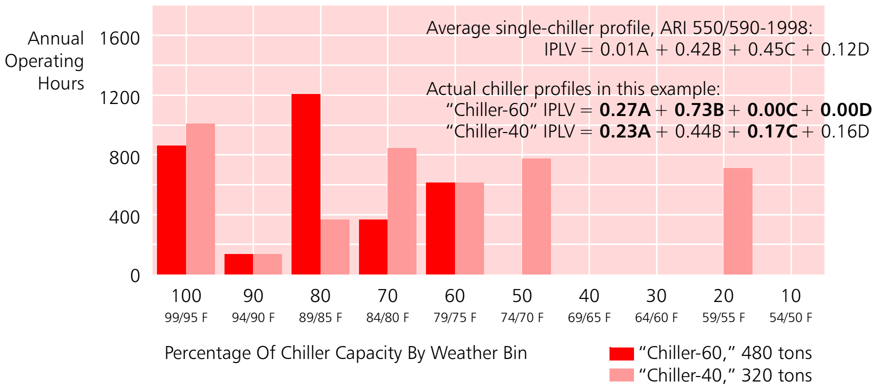
Figure 4
Individual Profiles Of Chillers Sized For Equal Operating Hours



The 1996 newsletter then examined the effect of redesigning the same system to equalize the annual operating hours with a 60/40 split in chiller capacity. This shift in design strategy not only lowered the first cost of the system, but also cut operating costs and total run time.

Don't Forget Full-Load Efficiency. Figure 4 suggests the relevance of that example to our current discussion of chiller performance. A quick comparison of profiles reveals that each chiller now runs at full capacity about 25 percent of its annual operating hours.

The disparity between the part-load weightings in Figures 3 and 4 clearly demonstrates why **the standard IPLV equation may poorly predict system operating costs**, especially in multiple-chiller plants. But there are other reasons to **specify full-load kilowatts per ton**:

- To comply with ASHRAE Standard 90.1–1989R, the chillers must satisfy minimum full-load and part-load efficiency ratings.
- Utility pricing is volatile. Though real-time pricing eliminates demand charges during peak utility periods, these prices still reflect demand and may escalate from 5¢ to 75¢/kWh. Under some programs, real-time charges have been as much as $1.86/kWh.

Recap

Like its predecessors, ARI Standard 550/590–1998 establishes requirements for rating and testing chillers, and thereby creates a method for representing chiller capacity and performance at a set of **standard conditions**. Changes implemented in the 1998 Standard attempt to improve that representation and promote consistent rating and testing methods for all chiller types and sizes. How do these changes affect rated performance? It varies from one chiller to the next, but on average, expect a 12-percent reduction in IPLV ratings. However, **this improvement does not extend to actual performance**.

Remember that the ARI rating is a **standardized representation**. Most chillers, i.e. about 75 percent, do not run at ARI standard rating conditions and less than 20 percent of large-tonnage chillers are applied in single-chiller installations. Given the distinct differences between system and chiller load profiles in multiple-chiller plants, expect significant differences between ARI-rated performance and the actual performance of a specific chiller in a specific application. ■

By Andy Poselenzny, marketing engineer, and Brenda Bradley, information designer, The Trane Company.

Checklist For Multiple-Chiller Plants

During design:

- Recognize that weather and loads are not proportional to each other, particularly in multiple-chiller installations.
- Develop a basic system load profile using a computerized analysis tool.
- Investigate the case for dividing the system load unevenly. Though popular, splitting the load equally seldom yields the most efficient or least expensive system operation.
- Perform a comprehensive energy analysis to estimate system operating costs. TRACE® 600 or DOE-2 software can help.

When writing specifications:

- Specify an evaporator fouling factor allowance of either 0.00010 h·ft²·F/Btu for standard ARI rating conditions **or** a value that better represents your application.
- Specify the condenser relief schedule per ARI Standard 550/590–1998 **or** a relief schedule that better represents the application.
- Specify full-load COP and part-load IPLV efficiencies that satisfy the minimum ratings ASHRAE Standard 90.1–1989R requires.

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