JOHNSON CONTROLS

HVAC&R Engineering Update

NPLV Rating Is Valid "Weather" Your Plant Has Single or Multiple Chillers

The Non-standard Part Load Value (NPLV) rating has become the industry's standard measurement for water-chiller efficiency. This rating is now included in almost all chiller specifications. Developed by the Air-conditioning and Refrigeration Institute (ARI) in 1988, the NPLV rating has been revised several times to improve its accuracy and broaden its scope.

Research by Johnson Controls shows that the NPLV rating is applicable to both single-chiller and multiple-chiller plants.

As an industry leader, YORK International (acquired by Johnson Controls in 2005) was involved in the rating's development. Today, part of our ongoing commitment is to research the applicability of the rating, specifically for multiple-chiller plants. Originally, the rating was derived from analysis of single-chiller plants, even though the vast majority of plants contain multiple chillers. Research by Johnson Controls shows that the NPLV rating is applicable to both single-chiller and multiple-chiller plants. This Update will explain those findings.

Table 1 — NPLV Operating-Condition Scenarios

Load	Head[1]		Operating Hours
	Air-cooled chillers	Water-cooled chillers	
100%	95°F ECAT	85°F ECWT	1%
75%	80°F ECAT	75°F ECWT	42%
50%	65°F ECAT	65°F ECWT	45%
25%	55°F ECAT	65°F ECWT	12%
0%	55°F ECAT	65°F ECWT	0%

1. Table 1 example is for design heads of 85°F ECWT for water-cooled chillers and 95°F ECAT for air-cooled chillers. For other design conditions, rating points vary linearly with load from design head to minimum of 65°F ECWT at 50% load for water-cooled chillers and to minimum of 55°F ECAT at 33% load for air-cooled chillers.

Calculation of NPLV Rating

In order to analyze the applicability of the NPLV rating to multiple-chiller plants, it is important to first understand how the rating is calculated. The formula utilizes a set of five operating-condition scenarios. Each scenario consists of a "% Load" and a "Head." The head is represented by either an entering condenser-air temperature (ECAT) for air-cooled chillers, or an entering condenser-water temperature (ECWT) for water-cooled chillers. Temperatures factored into the formula are derived from 25 years of documented weather data in 29 U.S. cities which represent 80% of U.S. chiller purchases during that time period. These operating-condition scenarios are presented in Table 1.

Perhaps the most important finding to emerge from the weather-data studies was the distribution of operating hours, which is shown in the last column of Table 1. Only 1% of operating hours are spent at maximum load and maximum head. It is important to note that this scenario refers to the **simultaneous** occurrence of **both** conditions, which are collectively known as "design conditions." In multiple-chiller plants, as we will see shortly, there are other occurrences of 100% load, but at lower heads. These are "off-design conditions." It is a very important distinction.

Chiller efficiencies at these rating points are used to calculate the NPLV rating, a weighted chiller efficiency expressed in kW/TR.

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Multiple-Chiller-Plant Differences

ARI Standard 550/590-2003 states that the NPLV rating was derived from the study of single-chiller plants. What makes multiple-chiller plants different from single-chiller plants, as far as chiller efficiency is concerned?

In a single-chiller plant, the chiller sees its full range of cooling loads: from 100% design load down to minimum load, when the chiller cycles off. In most multiple-chiller plants, on the other hand, chillers cycle off as the building cooling load decreases, and the load on the remaining chillers increases to compensate. The result is that the individual chillers see higher loads, on average. In fact, the more chillers there are in the system, the higher the average chiller load. Table 2 illustrates this phenomenon.

However, the head (which is driven by weather) would be fundamentally unchanged. No matter how few or how many chillers it contains, the plant sees exactly the same weather.

With that said, which factor has the greater impact on chiller efficiency: load or head?

Table 2 — Average Chiller Loads in Multiple-Chiller Plants (parallel chillers)

Number of Chillers in the Plant	Size of Chillers (TR)	Building Total Load (TR)	Building Average Load (TR)	Building Average Load (%)	Chiller Average Load (%)
1	4000	4000	2000	50	**50**
2	2000	4000	2000	50	**67**
3	1333	4000	2000	50	**75**
4	1000	4000	2000	50	**83**

Multiple-Chiller-Plant Similarities

To answer that question, let's look at water-cooled centrifugal chillers, the most common type of chiller used in large plants. Figure 1 shows the energy performance of an "average" centrifugal chiller. These performance curves were created by averaging together performance curves published for YORK, Carrier and Trane chillers. (Note that because some chillers can operate with 55°F ECWT or lower, while others can do no better than 65°F ECWT, ARI includes all chillers by assuming an ECWT minimum of 65°F.)

If we hold the head constant (at 85°F ECWT, for example) and vary the load, what happens to chiller efficiency between 50 and 100% load — the range in which most chillers in multiple-chiller plants operate? We find that the kW/TR varies relatively little — 5% or less. This is illustrated in Figure 2, using the same curves as in Figure 1.

Alternatively, if we hold the load constant (at 100%, for example) and vary the head, we find the variation in chiller efficiency is 30%. Compared to the 5% impact of variable load, that is a 6:1 ratio! This is illustrated in Figure 3 using the same curves as in Figure 1.

So the answer to our question is this: head has a major impact on chiller efficiency, while load has a minor impact.

Multiple-Chiller-Plant Analysis

We noted earlier that the chiller-loading pattern in a multiple-chiller plant is different than a single-chiller plant. However, the weather stays the same, no matter how many chillers are in the plant. Because head (determined by the weather) will have the major impact on chiller efficiency, and load (determined by the number of chillers) will have a minor impact, it stands to reason that the NPLV rating will accurately predict chiller efficiency in multiple-chiller plants, when the chillers are viewed as a group (sum of all chiller kWs divided by sum of all chiller TR). Let's analyze a multiple-chiller plant to see if that is true.

Using the same ARI-accepted, energy-analysis software used to do the original NPLV analyses, six plants were evaluated. The plants addressed the same building-design parameters (Table 3), using from 1 to 6 chillers each, using average U.S. weather data, and run with 4 different operating schedules.

From this information, 24 analyses were done. These were created using the ASHRAE Temperature-Bin Method for calculating energy. The results are summarized in Table 4 (next page). They show that the Average Efficiency for single- and multiple-chiller systems are within 2% of each other. They also show that the NPLV rating of 0.478 kW/TR is within 1% of all of the Average Efficiency ratings, demonstrating that the NPLV rating can accurately predict the efficiency of multiple-chiller systems, as well as single-chiller systems.

The ARI recognizes that the NPLV rating can't predict exactly what the absolute chiller energy consumption would be in a particular single- or multiple-chiller installation. The rating does, however, provide a meaningful way of comparing the relative efficiency of different chiller models on the basis of annual energy consumption. The actual efficiency may vary from the NPLV rating by a few percent, but the rating is an excellent tool for efficiency comparisons and, therefore, specifications.

Table 3 — The Building-Design Parameters

Design Building Cooling Load = 4000 TR
Design Outdoor Temperatures = 100°F DB/78°F WB
Design Cooling-Tower Approach = 7°F
Design Efficiency for All Chillers = 0.576 kW/TR
NPLV for All Chillers = 0.478 kW/TR
Design Leaving Chilled-Water Temperature = 44°F
Minimum Entering Condenser-Water Temperature = 55°F
Average Internal Load = 40% of Peak

Figure 1 — Energy Performance of "Average" Water-cooled Centrifugal Chiller

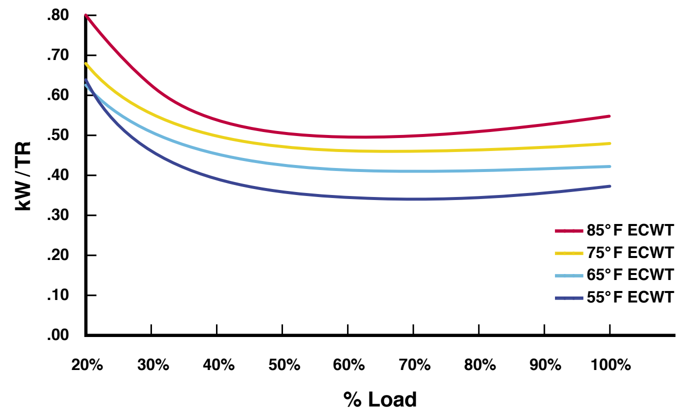

Figure 2 — Chiller-Efficiency Changes with Variable Load

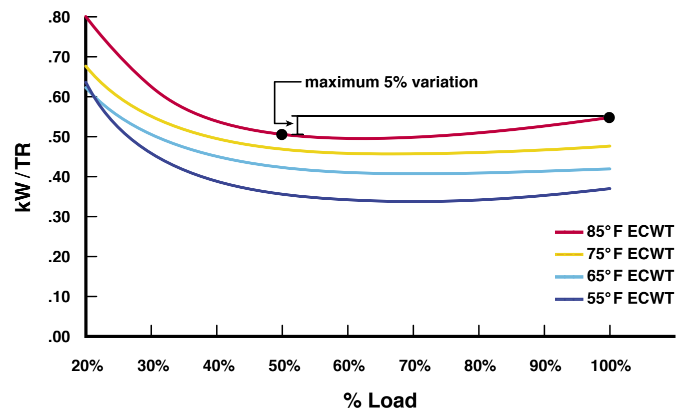

Figure 3 — Chiller-Efficiency Changes with Variable Head

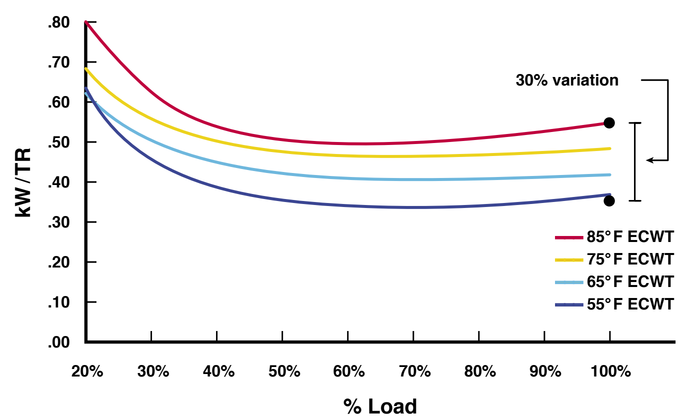

TABLE 4 — Average Efficiency of Six Chiller Systems (kW/TR)

Description of Operating Schedule	System 1 One 4000-TR chiller	System 2 Two 2000-TR chillers	System 3 Three 1333-TR chillers	System 4 Four 1000-TR chillers	System 5 Five 800-TR chillers	System 6 Six 667-TR chillers
24 hr/day, 7 days/wk, no economizer below 55°F	0.483	0.466	0.470	0.471	0.472	0.473
24 hr/day, 7 days/wk, with economizer below 55°F	0.477	0.476	0.479	0.482	0.483	0.486
12 hr/day, 5 days/wk, no economizer below 55°F	0.484	0.472	0.477	0.477	0.479	0.481
12 hr/day, 5 days/wk, with economizer below 55°F	0.481	0.480	0.484	0.486	0.488	0.490
Average Efficiency	**0.481**	**0.474**	**0.478**	**0.479**	**0.479**	**0.482**
NPLV	**0.478**	**0.478**	**0.478**	**0.478**	**0.478**	**0.478**
Variance	**1%**	**1%**	**0%**	**0%**	**0%**	**1%**

Research by Johnson Controls shows that the NPLV rating is applicable to both single-chiller and multiple-chiller plants.

Summary

Because the development of the NPLV rating was based on analysis of individual chillers, it has been unclear whether it is valid for multiple-chiller plants. That's because multiple-chiller plants see heavier average loads than is assumed in the rating formula. Nevertheless, research by Johnson Controls shows that the NPLV rating is applicable to both single-chiller and multiple-chiller plants, because variations in chiller load only marginally impact chiller efficiency. The major factor in chiller efficiency is head, which is determined by the weather. And the weather doesn't care how many chillers a plant contains.

References

- The NPLV standard can be downloaded at www.ari.org/standardscert/standards/550590-2003.
- A more comprehensive discussion of the NPLV formula can be found in HVAC&R Engineering Update 160.00-PM22, available from Johnson Controls.
- A more comprehensive discussion of multiple-chiller plants and the NPLV rating can be found in the International District Energy Association whitepaper "Application of ARI Standard 550/590-98 to Multiple-Chiller Systems." It can be found on the IDEA website: **www.districtenergy.org**.

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