Impact Evaluation of 2012 National Grid-Rhode Island Prescriptive Chiller Program

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1 EXECUTIVE SUMMARY

This document presents the results of DNV GL's Impact Evaluation of 2012 and 2013 Prescriptive High Efficiency Chiller (HE Chiller) Installations for National Grid Rhode Island.

1.1 Evaluation Objectives

The objective of this Impact Evaluation of 2012 Prescriptive HE Chiller Installations is to provide verification or re-estimation of gross energy and demand savings through site specific inspection, monitoring and analysis. The results of this study will be used prospectively to adjust energy and demand savings estimates in future program years. Results were determined by combining RI observations with those from National Grid in Massachusetts. In addition, the impact evaluation provides new deemed savings estimates, savings algorithms and/or savings factors (such as Effective Full Load Hours, or ELFH) to be used to inform future savings estimates. The evaluation sample for this study was designed in consideration of the 90% confidence level for energy (kWh) and 80% for coincident peak summer demand (kW).

1.2 Summary of Approach

DNV GL conducted the following steps in order to achieve the research objectives and ensure the Sponsors' satisfaction with this Prescriptive HE Chiller evaluation effort:

- Designed an efficient sampling plan for the selection of Prescriptive HE Chiller participants for on-site visits, optimized to the extent possible to result in energy savings estimates with ±10% precision at the 80% confidence interval for RI and MA National Grid combined;
- Developed a project work plan outlining the major approaches and foreseeable research issues of this impact evaluation effort;
- Reviewed the formulas, calculations, and factors used in the development of the tracking savings for each sampled participant to develop measure specific M&V plans;
- Perform comprehensive data collection at each sample site to support an independent analysis of adjusted gross energy and demand savings realization rates; and
- Produced comprehensive reporting of results, including analysis methods, findings and trends, final sample plans and data collection instruments used.

1.3 Chiller Results

Data collection, which included power monitoring of each incentivized chiller, occurred at 17 different sites, including 5 in RI and 12 in MA. The DNV GL team used a chiller analysis tool, which included curve fit coefficients for baseline and installed chiller efficiencies to feed into equations which represent chiller usage at various temperatures and part loads. Using this methodology for both the baseline and installed chillers, the DNV GL team was able to produce retrospective savings realization rates as well as providing additional data points for updated TRM savings assumptions (National Grid utilizes the TRM savings methodology) coupled with prospective savings adjusted realization rates which may be applied to future projects.

The retrospective chiller realization rates compare the modeled chiller savings estimates to the PA's program tracking database savings estimates. Second, in order to calculate prospective savings estimates the evaluators have produced updated key assumptions and parameters to be used in the TRM savings methodology, including updated EFLHs and the recommendation to only use rated IPLV. An adjusted realization rate, which accounts for the updated savings assumptions, is also included for prospective application.

Table 1-1 presents the retrospective realization rates for Gross kWh, Summer and Winter On-Peak kW savings. The "TRM Users" results in this table represent the realization rates as compared against tracking estimates, which used the TRM methodology.

Table 1-1: Retrospective Chiller Realization Rates

number of Sites, n	Statistic	Gross kWh Savings (90% Confidence)	Summer On-Peak kW (80% Confidence)	Winter On-Peak kW (80% Confidence)
n = 17	Realization Ratio (Evaluated to Tracking)	107.9%	35.6%	N/A
	Relative Precision	±30.9%	±14.6	N/A
	Error Ratio	1.14	0.75	N/A

These realization rates were the result of three primary factors: chiller loading, equivalent full load hours, and the delta efficiency between the baseline and the installed chiller.

Overall, the weighted average operating load was found to be 21% of rated capacity for the entire sample. This indicates that, on average, many of the installed chillers are operating below their minimum rated capacity. In addition, the weighted average maximum monitored load was approximately 52% of rated capacity. Both these findings suggest significant oversizing. There are both benefits and downsides to oversizing. Benefits include more-efficient heat transfer due to larger heat exchangers and reduced risk of the equipment not meeting the maximum load on a hot day. Downsides include equipment rapid-cycling and low part-load operation which can reduce equipment life and efficiency, as well as increased upfront capital expense. From an efficiency perspective, there is reason to believe that high-efficiency chillers operate much more efficiently at low part-load conditions than baseline chillers. This could mean that the real achieved savings are even higher than this study found because—while existing analysis tools aren't fully equipped to model usage under these conditions—the savings could be very large.

The evaluation calculated equivalent full load hours (EFLH) for each chiller by summing the total ton-hours across the 8,760 hour year and dividing by the rated capacity (tons) of the installed chiller. The weighted average EFLH for all chillers was estimated to be 1,328 hours. As a comparison, National Grid currently uses an estimate of 817 EFLH for the "Hours" variable in the TRM savings algorithm.

The evaluation estimated the average operating efficiency values for both the installed chiller and the baseline chiller for each site. While the TRM allows for the use of either full load (FL) efficiency or integrated part load value (IPLV), the evaluation estimate of average operating efficiency accounts for the actual operation of the chiller over its range of chiller loads. The evaluation calculates efficiency at each hour of the year based on outdoor air conditions. Using IPLV correlates more strongly with our evaluated savings estimates even though it represents an approximation over a hypothetical load. However, even using IPLV there could still be a small adjustment of the type shown Table 1-2.

What is most critical is the difference in efficiency between the baseline and installed conditions. As shown in Table 1-2, at actual operating conditions, the baseline and installed performance curves provide larger delta efficiency than at IPLV rated conditions, which results in higher savings.

Table 1-2: Rated IPLV vs. Average Operating Efficiency in kW/Ton

Chiller Performance (kW/ton)	Baseline	Installed	Delta Efficiency
Rated IPLV	0.894	0.720	0.174
Evaluation Average Operating Efficiency	0.899	0.697	0.203

This evaluation has also produced adjusted prospective TRM savings estimates using the updated savings assumptions listed below. These adjusted tracking estimates were then used to produce adjusted realization rates for energy savings and coincidence factors for summer and winter peak demands. These savings factors should only be applied to future chiller projects that use an updated TRM methodology. This methodology would change the existing algorithm by removing the load factor, and would use IPLV efficiency values. This new TRM methodology would use the following components in the savings estimates:

- Rated Tons
- Rated IPLV – Baseline and Proposed[1]
- EFLH – 1,328 hours from this study
- Adjusted kWh Realization Ratio – National Grid Value (See Table 1-3) – This is the ratio of evaluated kWh savings divided by the updated TRM kWh savings. The updated TRM kWh savings is calculated as the Rated Tons x ($IPLV_{baseline}$ – $IPLV_{proposed}$) x EFLH.

Peak Coincidence Factors – National Grid Values for Summer and Winter On-Peak (See

- Table 1-4) – This is ratio of evaluated peak kW savings (at the defined peak periods) divided by the updated TRM kW savings. The updated TRM kW savings is calculated as the Rated Tons x ($IPLV_{baseline}$ – $IPLV_{proposed}$).

Table 1-3: Prospective Chiller Energy Realization Rate vs. Adjusted Tracking Savings

number of Sites, n	Statistic (90% Confidence)	Gross kWh Savings
n=17	Adjusted kWh Realization Ratio (Evaluated to Adjusted Tracking)	107.2%
	Relative Precision	±31.4%

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[1] For projects that will use rated full load (FL) efficiency in their TRM savings estimates, updated realization rates and coincidence factors are provided in Appendix C.

Table 1-4: Prospective Chiller Peak kW Coincidence Factors

number of Sites, n	Statistic (80% Confidence)	Summer On-Peak CF	Winter On-Peak CF
n=17	Coincidence Factor	0.41	0.08
	Relative Precision	±16.9%	±58.5%

1.4 Conclusions and Recommendations

1.4.1 Prescriptive Chiller

This evaluation found that savings from new prescriptive chillers are being realized with a retrospective energy savings realization rate of 107.9%. The realization rates were driven by two factors, increased delta efficiency and an increase in EFLH. In addition, it appears that the TRM methodology underestimated savings.

1.4.1.1 Application of Results

These realization rates represent the difference between evaluated annual energy (kWh), evaluated peak demand (kW) savings, and the respective gross tracking estimates. This evaluation recommends that National Grid RI use the TRM retrospective realization rates.

This study also produced new savings factors and prospective realization rates for chillers using the new factors. These savings factors, which are calculated based on the average operating kW of the sample of chillers, may be used to update the values in the TRM. DNV GL recommends that the TRM be updated to include the prospective savings factors and prospective realization rates which would then be applied to future projects analyzed using the TRM methodology.

1.4.1.2 General Recommendations

Consider more research around the key finding that many chillers operate at very low part loads. Consider looking into the implications for reliability, cost and energy savings with relation to chillers operating at very low part loads. The key point is that the chillers are not cycling, which means they are operating below the manufacturer-recommended part load values. A number of DNV GL engineers have suggested that running at this low part load isn’t safe for chillers and may have significant efficiency implications. Based on the feedback evaluators have received from some engineers, baseline chillers may operate at extremely low efficiencies at these conditions, which (if it can be quantified) could result in very large actual savings. National Grid may also consider an educational initiative to help vendors and customers understand the sizing requirements of their facility better.

Consider a closer review of project applications. Our evaluation found some sites with multiple chillers and also one installation with primarily a process load. Based on the TRM definition, only the lead chiller in a multiple chiller plant may be rebated. Likewise, the prescriptive program is designed for comfort cooling applications, which wouldn’t include process loads. These types of projects may be more appropriate for the custom track.

Encourage vendors to look for additional chiller savings opportunities. In most cases the chillers were operating at the same conditions as prior to installation, according to facility personnel.

When making changes to the chiller plants, it is worthwhile to consider different controls set points, such as lower condenser water temperature, higher chilled water temperature and resetting chilled water temperatures based on outdoor conditions[2]. Revising chiller plant sequences of operation to incorporate more advanced control strategies will result in additional energy savings.

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[2] Only air-cooled chillers were observed in the sample; however, the consideration for assessing an appropriate condenser water temperature applies to potential water-cooled installations.

2 PRESCRIPTIVE HIGH EFFICIENCY CHILLERS

This section documents the results from the impact evaluation of Prescriptive High Efficiency Chiller installations in Rhode Island. This evaluation reviewed the projected savings for high efficiency chillers as defined in the Rhode Island Technical Reference Manual (TRM) dated October 2012. The current program covers only new construction or time-of-failure installations. The chiller types include:

- Air Cooled Chillers
- Water Cooled Rotary and Screw Chillers
- Water Cooled Centrifugal Chillers for Single Chiller Systems or for Lead Chiller Only in Multi-Chiller Systems.

Tracking system savings for the three measures are combined into two categories: air cooled and water cooled chillers.

This section presents the following items:

- Tracking Savings Review
- Sample Design
- Data Collection Methods
- Analysis Methodology
- The Results of our Evaluation

2.1 Tracking Savings Review

Energy (kWh) and demand (kW) savings were calculated using the algorithms and inputs specified in the Rhode Island TRM.

Notes on TRM Savings Methodology

From the TRM, prescriptive savings are based upon chiller size, efficiency, and hours of operation. Table 2-1 shows the minimum efficiency requirements for new chillers to be eligible for incentives. According to the TRM, compliance with this standard may be obtained by meeting the minimum requirements of Path A or B; however, both the full load and IPLV must be met to fulfill the requirements of Path A or B.

Table 2-1: Minimum Efficiency Requirements[3]

Equipment Type	Size Category (Tons)	Units	Path A		Path B	
			Full Load	IPLV	Full Load	IPLV
Air-cooled Chillers	< 150	EER	9.562	12.5	NA	NA
	≥ 150	EER	9.562	12.75	NA	NA
Water-cooled, electrically operated, positive displacement (rotary screw and scroll)	< 75	kW/ton	0.780	0.775	0.800	0.600
	≥ 75 and < 150	kW/ton	0.775	0.680	0.790	0.586
	≥ 150 and < 300	kW/ton	0.680	0.580	0.718	0.540
	≥ 300	kW/ton	0.620	0.540	0.639	0.490
Water cooled, electrically operated, centrifugal	< 150	kW/ton	0.634	0.596	0.639	0.450
	≥ 150 and < 300	kW/ton	0.634	0.596	0.639	0.450
	≥ 300 and < 600	kW/ton	0.576	0.549	0.600	0.400
	≥ 600	kW/ton	0.570	0.539	0.590	0.400

TRM Algorithms for Calculating Primary Energy Impacts

The TRM specifies the following equations to use for the determination of energy and demand savings. Consistent efficiency types (FL or IPLV) must be used between the baseline and high efficiency cases.

Air Cooled Chillers:

$$\Delta kWh = (Tons)\left(\frac{12}{EER_{BASE}} - \frac{12}{EER_{EE}}\right)(Hours)$$

$$\Delta kW = (Tons)\left(\frac{12}{EER_{BASE}} - \frac{12}{EER_{EE}}\right)(LF)$$

Water Cooled Chillers:

$$\Delta kWh = (Tons)(kW/ton_{BASE} - kW/ton_{EE})(Hours)$$

$$\Delta kW = (Tons)(kW/ton_{BASE} - kW/ton_{EE})(LF)$$

Where:

Tons = Rated capacity of the cooling equipment

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[3] Path A and B are alternate compliance paths that allow the programs to choose a chiller baseline depending on whether the chiller in question is optimized for Full Load or Part-Load Efficiency. The Path A option more closely approximates the IECC code minimum values.

EER_{BASE} = Energy efficiency ratio of the baseline equipment
EER_{EE} = Energy efficiency ratio of the efficient equipment
Hours = Equivalent full load hours of chiller operation
kW/ton_{BASE} = Energy efficiency rating of the baseline equipment
kW/ton_{EE} = Energy efficiency rating of the efficient equipment
LF = Load factor

Baseline Efficiency:
The baseline efficiency case assumes compliance with the efficiency requirements as mandated by the Rhode Island State Building Code. Minimum efficiency requirements are categorized by air cooled chillers, water cooled screw and scroll chillers, and water cooled centrifugal chillers. Each measure type is given a full load (FL) and integrated part-load value (IPLV) depending on the size of the equipment.

High Efficiency:
The high efficient case assumes that chillers will exceed the mandated Rhode Island State Building Code as well as meet the minimum efficiency requirements of the New Construction HVAC energy efficiency rebate forms.

Hours:
The annual hours of operation for water chilling packages are site-specific and are determined on a case-by-case basis. These are the equivalent full load run hours of the chiller and not the operating hours of the facility. If the site-specific annual hours are unknown, the default hours of 817 from the TRM are used.

2.2 Sample Design

The population frame for the sample design included all RI Prescriptive High Efficiency Chiller projects installed in the 2012/2013 program year. The primary variable of interest for the sample design was annual kWh savings. The sample design results for annual kWh savings were calculated at the 80% confidence level.

Since the number of sample points required to achieve a desired level of precision depends upon the expected variability of the observed realization rates, DNV GL looked at prior chiller measure evaluation studies to determine likely error ratios. There have not been any recent prescriptive studies on these measures, so evaluators referred to recent Custom evaluation results. Based on prior custom studies that have been done for the MA and RI, the error ratios for realization rates for annual energy savings have ranged from about 0.4 to 0.8. To be conservative and provide confidence that precision targets will be met, the final sample design used an error ratio of 0.6.

The final sample design presented in this section provides for the estimation of realization rates. The target precision on energy savings for the state as a whole is ±20% at the 80% confidence level. That is, an achieved precision of ±20% for an estimated realization rate of 100% means that we are 80% confident that the true realization rate is between 80% and 120%.

Table 2-2 shows the stratum cut points and distribution of sample sites for the final sample design.

Table 2-2: Sample Design based on Preliminary Scenario

Stratum	Maximum kWh Savings	Projects (N)	Total kWh Savings	Planned Sample (n)	Inclusion Probabilities
1	19,661	12	141,662	4	0.33
2	47,788	7	203,229	3	0.43
3	89,874	1	89,874	1	1.00
Total		20	434,765	8	

Table 2-3 lists the calculated precision estimates for this scenario. The anticipated precisions are shown by measure, by state and overall for National Grid. When the RI sample is stratified optimally, the statewide precision of ±20.45% is reasonable. When combined with the MA anticipated results, the National Grid total would be expected to achieve a precision of ±9.79% at 80% confidence.

Table 2-3: Estimated Precision for Energy for Preliminary Sample

State	Projects	Total kWh Savings	Error Ratio	Confidence Level	Planned Sample Size	Anticipated Relative Precision	Error Bound
MA	26	818,359	0.6	80%	15	±10.34%	84,623
RI	20	434,765	0.6	80%	8	±20.45%	88,892
Total	46	1,253,124	0.6	80%	23	±9.79%	122,731

Note that the final sample included five RI sites rather than the proposed eight projects. This was a decision that was made by the study manager as the summer metering period ended prior to recruiting all eight sites.

2.3 Field Data Collection

The DNV GL Team installed power meters on each evaluated chiller. For sites where multiple chillers received incentives all participant chillers were fully monitored to determine hours of operation for each chiller. We found one site with two rebated chillers in a lead/lag configuration. According to the TRM, only one chiller should be incentivized under lead/lag scenarios where only one chiller operates at any given time. Ancillary system equipment (pumps, towers, fans etc.) were inventoried in order to obtain a complete picture of the chilled water plant. Table 2-4 presents a summary of the evaluation metering equipment used for each rebated chiller.

Table 2-4: Summary of Evaluation Metering

Measurement Variables	Chiller (Volts, Amps, PF, kW)
Measurement Equipment	Dent Elite Pro SP Power Meter or Onset HOBO Microstation
Installation	Clamp-on CTs and Voltage
Frequency of Observations	5-minute
Duration of Metering	Minimum 12 Weeks[4] (Aug. 19-Nov. 21)
Metered by	DNV GL Team

Evaluators interviewed facility personnel to determine operating schedules and set points. The DNV GL Team collected information on when the chiller(s) were brought on-line for the season, and when they were shut down. They also inquired about occupied and unoccupied schedules where applicable. Evaluators collected chiller nameplate information to compare to the file documentation. Chilled water and condenser water set points were also collected through observation and discussion with site personnel.

After reviewing the meter data, evaluators adjusted the customer reported occupied and unoccupied schedules, as well as the time of year in which the chiller is shut down, to match the metered data.

2.4 Analysis Methodology

For years, chiller savings estimation confounded most simple analysis methodologies for one very good reason:

> *Every chiller operates under a unique set of circumstances.*

In other words the same chiller, installed in different buildings with different operators, can perform at dramatically different efficiency levels, loading and run hours.

Underpredicting by Default,[5] an article in the ASHRAE Journal, found that a remarkably high percentage of chillers operate at very low partial loads (less than 20%) a large percentage of the time. At these conditions, some chillers continue to operate efficiently while others become significantly less efficient. This trend becomes clear in Figure 2-1, taken from this article.

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[4] One site (ID # 3551798) had less than 12 weeks metering time because of a logger malfunction. There was still enough logger data to utilize this site in the evaluation.

[5] Hardman, Anthony. *Underpredicting by Default*. ASHRAE Journal, December 2013.

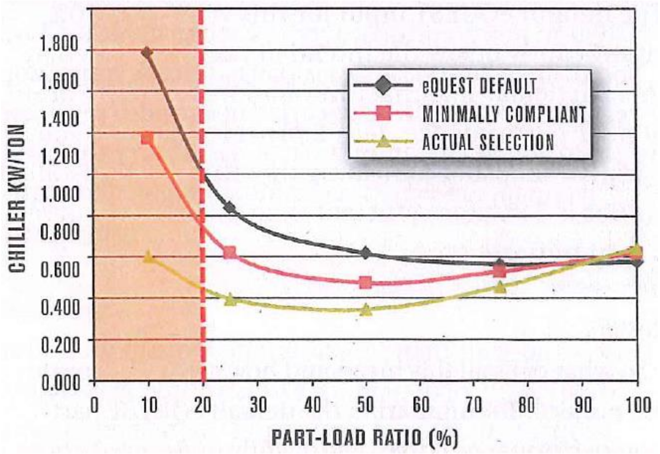

Figure 2-1: Three Chiller Curves Compared

To make matters worse, commonly available data reported by manufacturers—IPLV and full load kW/ton (or EER)—don't provide any guidance for operating conditions at these low partial loads. Some manufacturers provide partial loading data, but this data is inconsistent between manufacturers, often not readily available, and often doesn't provide any information about low partial load operation.

Our metering data suggested the same phenomenon at a number of chiller sites. Numerous chillers appear to be operating for significant portions of the time at less than 20% of their available cooling capacity.

Three primary analysis methods were considered as options for using the metered data to estimate energy savings for high efficiency chillers. The following three sections describe each of these methods, which include:

- Shifting by Ratios
- Part Load Shifting
- Curve Fit Coefficients

1.1.1.1 Shifting by Ratios

The simplest calculation methodology involves shifting the measured usage up and down by the ratio between IPLV or Full Load kW/Ton values. This is perhaps the most common approach used by impact evaluations, desirable for its simplicity and its use of readily-available data.

The method for accomplishing this involves developing a kW vs. temperature curve for the metered data, and using it to estimate kW usage for the installed (efficient) unit throughout the full 8,760 hour calendar year. Baseline usage then comes from multiplying the load at every point by the ratio between IPLV or full load kW/ton values for the baseline unit and the installed high efficiency unit. For example, an efficient chiller with an IPLV (kW/ton) of 0.400 and a baseline chiller IPLV of 0.600 would result in a ratio of 1.5. This results in energy savings estimates of the type shown in Table 2-5 and Figure 2-2.

Table 2-5: Shifting by Ratios – kW vs. Temperature

Temperature	Installed (kW)	Baseline (kW)	Savings (kW)
60°F	150	225	75
70°F	200	300	100
80°F	250	375	125

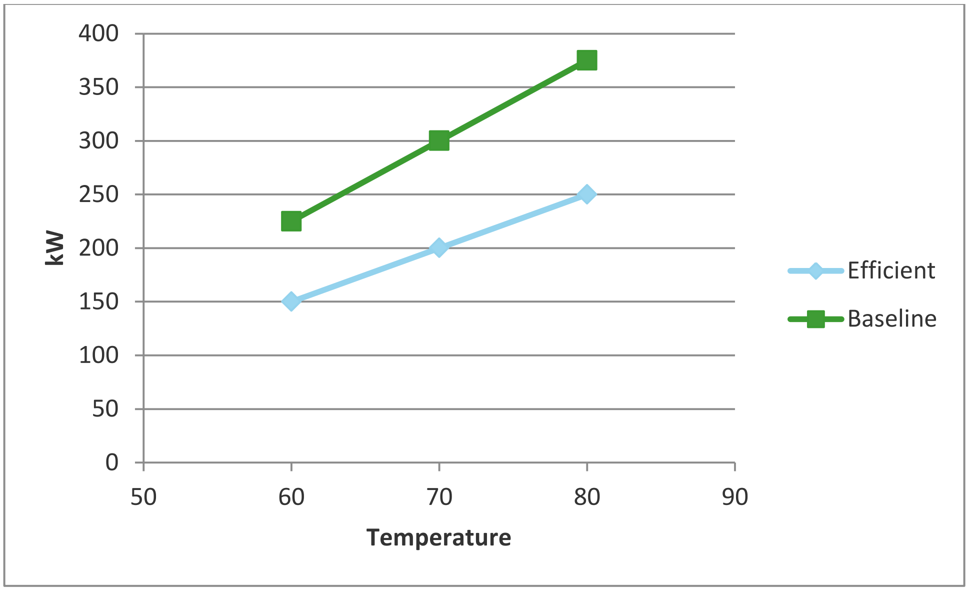

Figure 2-2: Shifting by Ratios Chart Example

This method provides accurate savings estimates when the load profile of the chiller matches the load profile assumed in the calculation of IPLV. However, this is not usually the case and these ratios can in fact vary dramatically as shown in Figure 2-1.

1.1.1.2 Part Load Shifting

An improvement upon the Shifting by Ratios method, Part Load Shifting, allows evaluators to apply different ratios at different loading conditions using manufacturer-reported part load data. If the installed chiller includes a set of part load values, this allows evaluators to convert the measured kW values into chiller loads. Manufacturer-reported part load data comes in various forms. One common form is show below in Table 2-6:

Table 2-6: Manufacturer Reported Part Load Ratios (EXAMPLE ONLY)

Part Load Ratio	Power (kW)
25%	50
50%	75
75%	150
100%	250

Comparing this data to an assumed set of baseline part load ratio values allows evaluators to account somewhat for the fact that chillers operate at different efficiencies at different loading conditions. This results in a set of curves like those shown below in Figure 2-3.

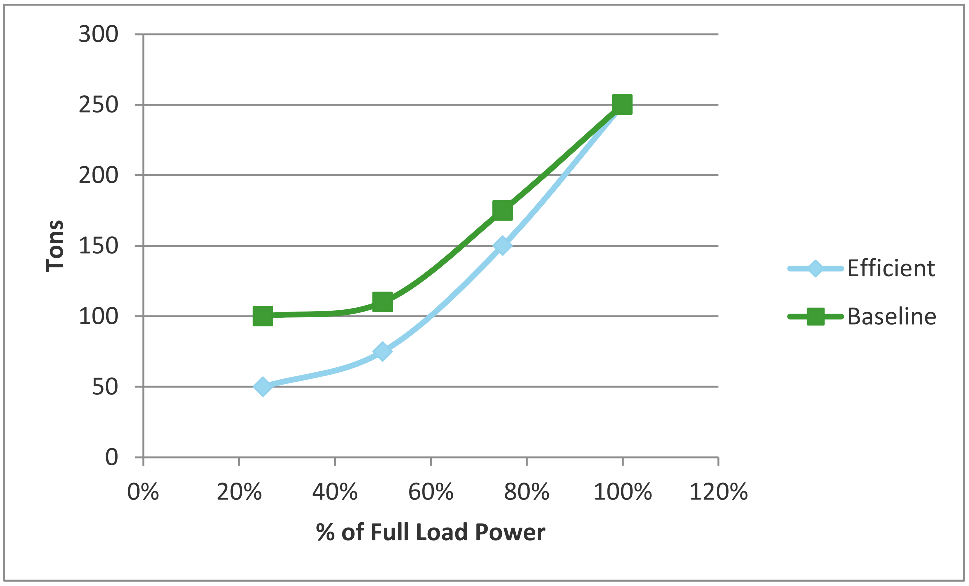

Figure 2-3: Shifting by Ratios Curve Example

As shown, this allows the baseline and installed curves to have different shapes from one-another.

The challenges associated with this method include the following:

- Manufactures often don't report this data or report it differently from one-another.
- No standard baseline (minimum code-compliant) set of part load kW values exists.
- Varying chilled and condenser water temperatures or outdoor air temperatures cannot be taken into account. These can make a very large difference in chiller power usage depending on whether the operator uses constant or variable set points.
- As discussed above, many chillers routinely operate below 25% load, where the energy usage between units diverges greatly.

1.1.1.3 Curve Fit Coefficients

In 2009, Energy Design Resources published a series of papers and tools called CoolTools for use with electric chillers. Underlying these tools was a methodology for estimating chiller usage known as the chiller curve fit coefficients. These feed into an equation which represents the chiller usage at various temperatures and part load ratios. The equations themselves are shown in 3Appendix B.

The result of these equations is a chiller performance curve which accounts for performance variation due to partial loading, varying chilled water temperatures, varying condenser water temperatures (for water-cooled chillers), and outdoor air temperatures.

Additionally, the CoolTools program included an effort to reach out to manufacturers to gather inputs to these equations representing a wide variety of actual manufactured chillers. These chiller curves were provided to the Energy Plus building simulation software design team and serve as the source for Energy Plus chiller power usage data. A similar method is used to calculate chiller usage in eQuest, but the curve fit coefficients for specific chillers are not included with the standard eQuest package.

The challenges associated with these chiller curve fit coefficients include the following:

- The curves are known to be less accurate at very low part load ratios. The ratio at which they become inaccurate varies by curve, but it typically ranges between 10-20%. More detail on the approach to dealing with the high number of lightly loaded chillers in the sample is addressed in the section on *Comparing and Annualizing* below.
- A number of the curves are only accurate for a small range of chilled and condenser water temperatures.
- ASHRAE and IECC do not publish a set of curve fit coefficients to represent code. ComNet[6] attempted to publish a series of code-compliant curves, but our experimentation and conversations with other engineers revealed that they do not accurately reflect code.

Despite these challenges, DNV GL chose to apply the curve fit coefficient method as it represents the best available option and provides the most accurate estimate of savings compared to the other two options considered. This option also included the chiller curves for a significant portion of the installed chillers in the sample, and curves which closely approximated the rest of the installed equipment.

Choosing a Baseline

The first step in using this methodology was to find a set of baseline chiller curves which represented code. After an extensive literature review, the evaluators found a document which contained a set of air cooled chiller curves[7] which exactly matched the efficiency values required by the Rhode Island Building Code in place in 2013 for air-cooled chillers between 75-150 tons, which covers most of the chillers in the evaluation.

Unfortunately, evaluators did not find similar curves for water-cooled chillers. However, this did not affect analysis for the sampled sites because only air-cooled chillers were observed.

Modifying the Curves

For each set of chiller curve fit coefficients, there are a set of outside air and condenser/chilled water temperatures for which the values resulting from the equations mentioned above equal 1. These are the "normalization temperatures." Curves normalized at the same temperatures are easy to compare, contrast, and troubleshoot, while those normalized at different temperatures are harder. All of the air cooled chillers were normalized at AHRI full load reference conditions[8].

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[6] *Commercial Buildings Energy Modeling Guidelines and Procedures*. Publication 2010-001. Resnet, 2010.

[7] *Technical Support Document: 50% Energy Savings Design Technology Packages for Medium Office Buildings*. Pacific Northwest National Laboratory, 2009.

[8] AHRI Standard 550/590

Each of the curves has bounds under which it is considered accurate. These bounds apply to part load ratio as well as chilled water and outside air temperatures. For some chillers the bounds excluded many commonly experienced temperature conditions, including in a number of cases at ARHI reference conditions. We eliminated these curves from our analysis.

Reversing the Curves

The original curves discussed above for the curve fit coefficient method were created to estimate kW energy use from assumed inputs in a building simulation model such as chilled water supply temperature and outside air temperature. However, the evaluation needed to use them in reverse to estimate chiller load from chiller energy use and operating conditions. To use the curves in this study, evaluators solved the combined equations for operating tons, which allowed us to estimate the tons on the chiller at each chilled water, condenser water, and outdoor air temperature. This equation is shown below[9]:

$$Tons_{Operating} = \frac{CAP_{FT} \times Q_{Rated} \times \left(-b_{EIR\_FPLR}\right) + \sqrt{{b_{EIR\_FPLR}}^{2} - 4 \times c_{EIR\_FPLR} \times \left(a_{EIR\_FPLR} - \frac{P_{operating\ (calculated)}}{P_{rated} \times CAP\_FT \times EIR\_FT}\right)}}{2 \times c_{EIR\_FPLR}}$$

Using self-report data provided by the site contacts for the chilled water set points and the building occupied hours, together with 2014 weather data from the nearest weather station, evaluators used the equation to calculate the chiller full load rated power at the given conditions.

Averaging the chiller loading across three-degree temperature bins, evaluators developed a chiller load vs. temperature curve for both the occupied and unoccupied periods using a second-order quadratic model. Other models were considered such as exponential, third-order, linear, etc. and found that the second-order quadratic curves offered a balance between best fit and ability to model values outside the metered range. Figure 2-4 shows an example of a load vs. temperature graph. R^2 values for other models are shown below in Table 2-7.

Table 2-7: Load vs. Temperature Curve R^2 Values

Model	R^2 Value
Linear	0.9583
Logarithmic	0.9785
Exponential	0.8271
Power	0.8791
2nd Order Polynomial	0.9872
3rd Order Polynomial	0.9888
4th Order Polynomial	0.9963

While the metering period began in late August of 2014 and, thus, contained a number of rather hot days, the hottest days of the year occurred earlier in the summer of 2014 and were not metered. Those non-metered hot days were often several degrees higher than any during the metered period. The second-order

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[9] See Appendix B for the original equations which are combined to produce this equation, as well as a legend.

quadratic equations often dropped off after the highest metered temperature and yield a lower load and power, though this effect was less extreme than with higher-order polynomials. To overcome this, the data was limited so that any point above our highest metered temperature would show at least as much kW usage as the highest metered value. This issue is not significant with regard to energy savings as the number of metered data points above the highest metered value is very small, representing a small fraction of the total number of data points.

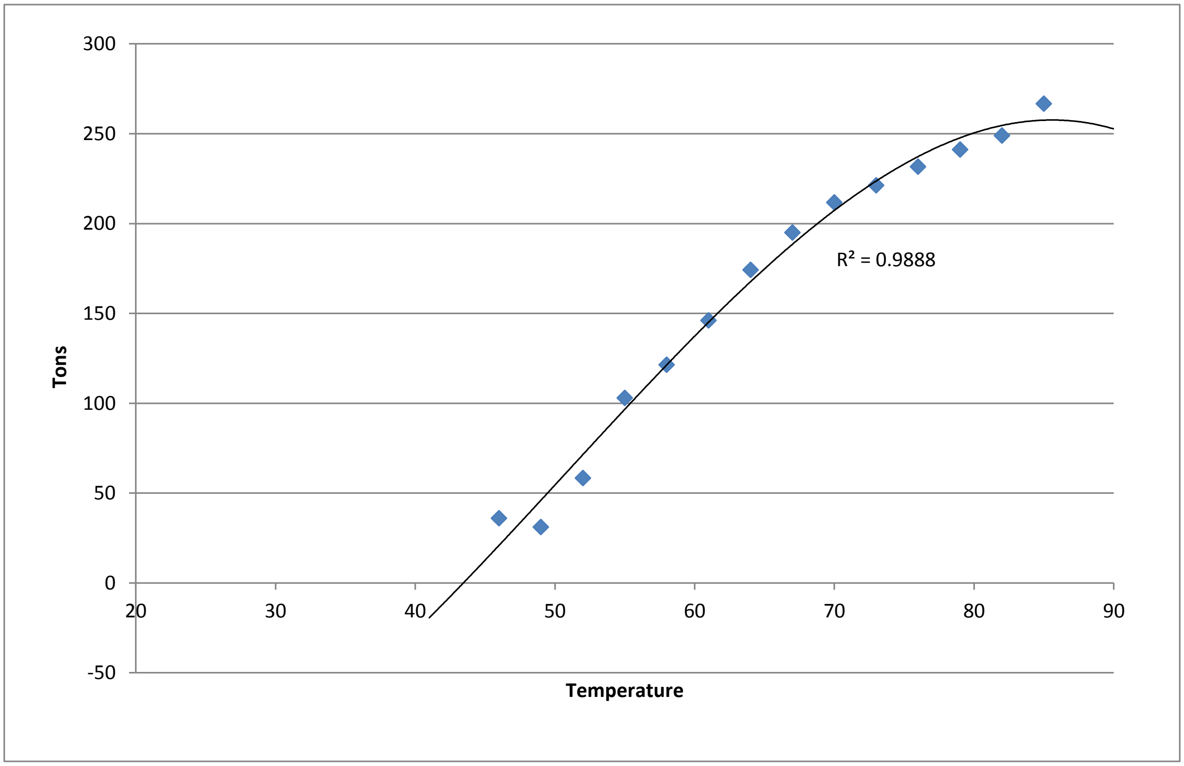

Figure 2-4: Load vs. Temperature Example

Comparing and Annualizing

Evaluators then took this hourly load profile from the installed chiller and used it to estimate the power usage at each temperature condition for the baseline chiller using the equation shown above under "Reversing the Curves." This developed curves like those shown below in Figure 2-5. R^2 values for other models are shown below in Table 2-8.

Table 2-8: Power vs. Temperature Curve R^2 Values

Model	R^2 Value	
	Baseline	Installed
Linear	0.9125	0.9781
Logarithmic	0.9645	0.9883
Exponential	0.7722	0.8536
Power	0.8287	0.9009
2nd Order Polynomial	0.9746	0.9897
3rd Order Polynomial	0.9757	0.9907
4th Order Polynomial	0.9839	0.9965

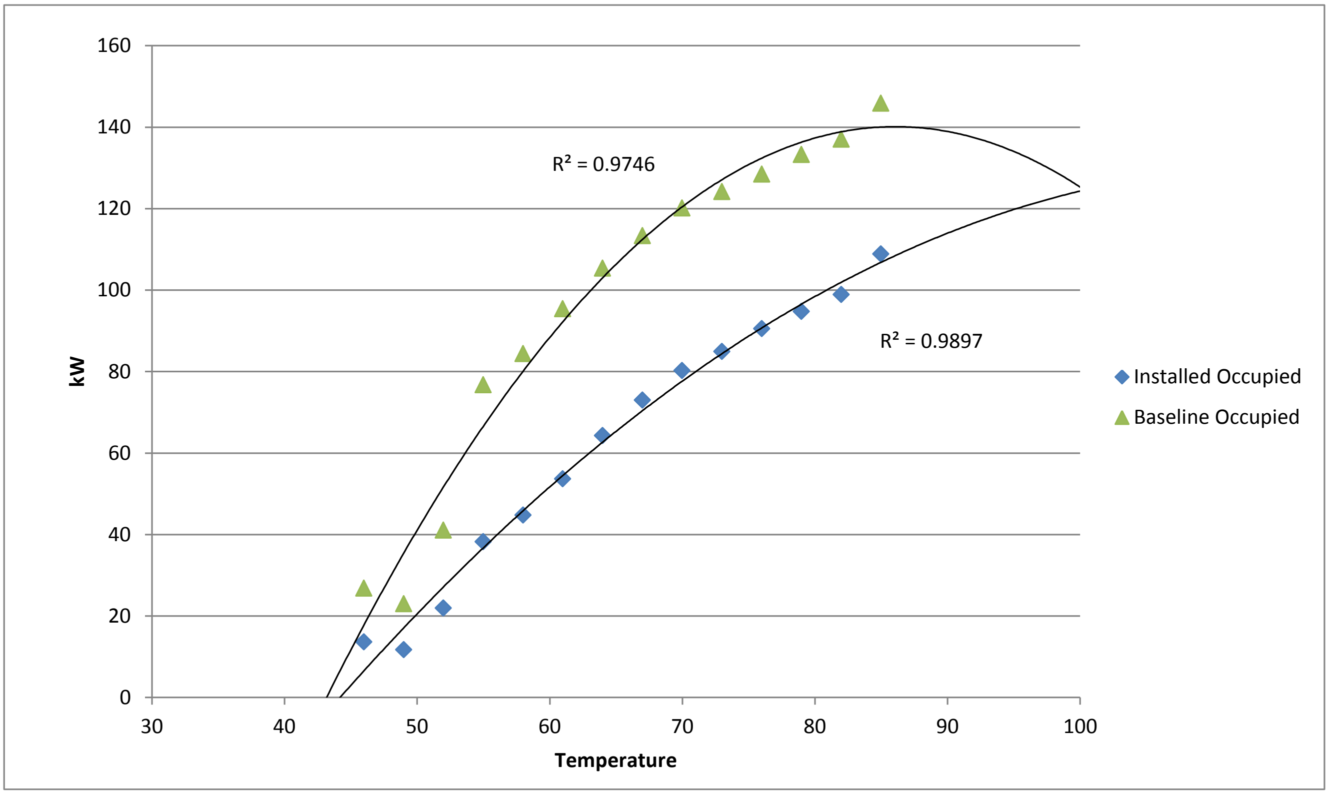

Figure 2-5: Power vs. Temperature Example

To model chiller usage throughout the year, evaluators calculated chiller usage from these occupied and unoccupied chiller curves over the 8,760 hour year using the typical meteorological year (TMY) dataset for the nearest weather station combined with the chiller startup / shutdown and occupied/unoccupied periods and chilled water set point temperatures provided by our site contact.

Using data on building occupied hours provided by the site contact where applicable, we broke the usage data into two curves—one for occupied periods and another for unoccupied periods, and modelled these separately. We combined the two data sets in our 8,760 analysis by applying the appropriate curve for the occupied/unoccupied period.

When the data itself for startup/shutdown and occupied/unoccupied disagreed with the answers provided by site contacts, we chose to rely on the measured data.

Having annualized chiller usage from both the installed and baseline chillers in hand, evaluators summed the hourly difference between them across the entire year to determine annual energy saving. Through this comparison, it was found that the chiller curve fit coefficients do not model chiller performance at extremely low part-load values very well. Others have wrestled with this issue in using building simulation models, and after some research it was concluded that no one had yet found an especially elegant solution. The evaluation ended up adopting the solution that seemed the most accurate, which is to assume that the chillers cycled off-and-on below a certain minimum part load value. This value varied by the nature of each curve, and was determined by the bounds set on it by the manufacturer (usually between 10-20%). Below this minimum value, we assumed a linear relationship down to zero power at zero load.

An example chiller site is provided in

Appendix A to walk through the calculation of tracking and evaluated savings.

Calculating Peak

Peak savings were calculated based on the equations provided in the TRM, using the on-peak periods as defined there, as follows:

- Summer On-Peak: average demand reduction from 1:00-5:00 PM on non-holiday weekdays in June July, and August
- Winter On-Peak: average demand reduction from 5:00-7:00 PM on non-holiday weekdays in December and January

While the peak periods represent the hottest hours of 2014, two issues remain in developing peak savings based on these metered results:

1. The summer of 2014 was on average several degrees cooler than the average year according to the TMY3 data
2. Our metering began mid-August, which did not include the hottest few days of 2014 which occurred earlier in the summer.

These issues mean that our metering period did not include a large quantity of very hot hours, and the flat approximation we made above our hottest metered hour, our seasonal peak savings may slightly underestimate actual seasonal peak savings for the program.

This issue is discussed in more detail in Section 2.5.1.3.

2.5 Results

2.5.1 Retrospective Realization Rates

2.5.1.1 Savings Results vs. Tracking

Figure 2-6 presents a scatter plot of evaluated annual kWh savings vs. tracking kWh savings for each sampled site, which resulted in a 108% realization rate. The RI sites are represented by the green squares and the MA sites are represented by the blue diamonds.

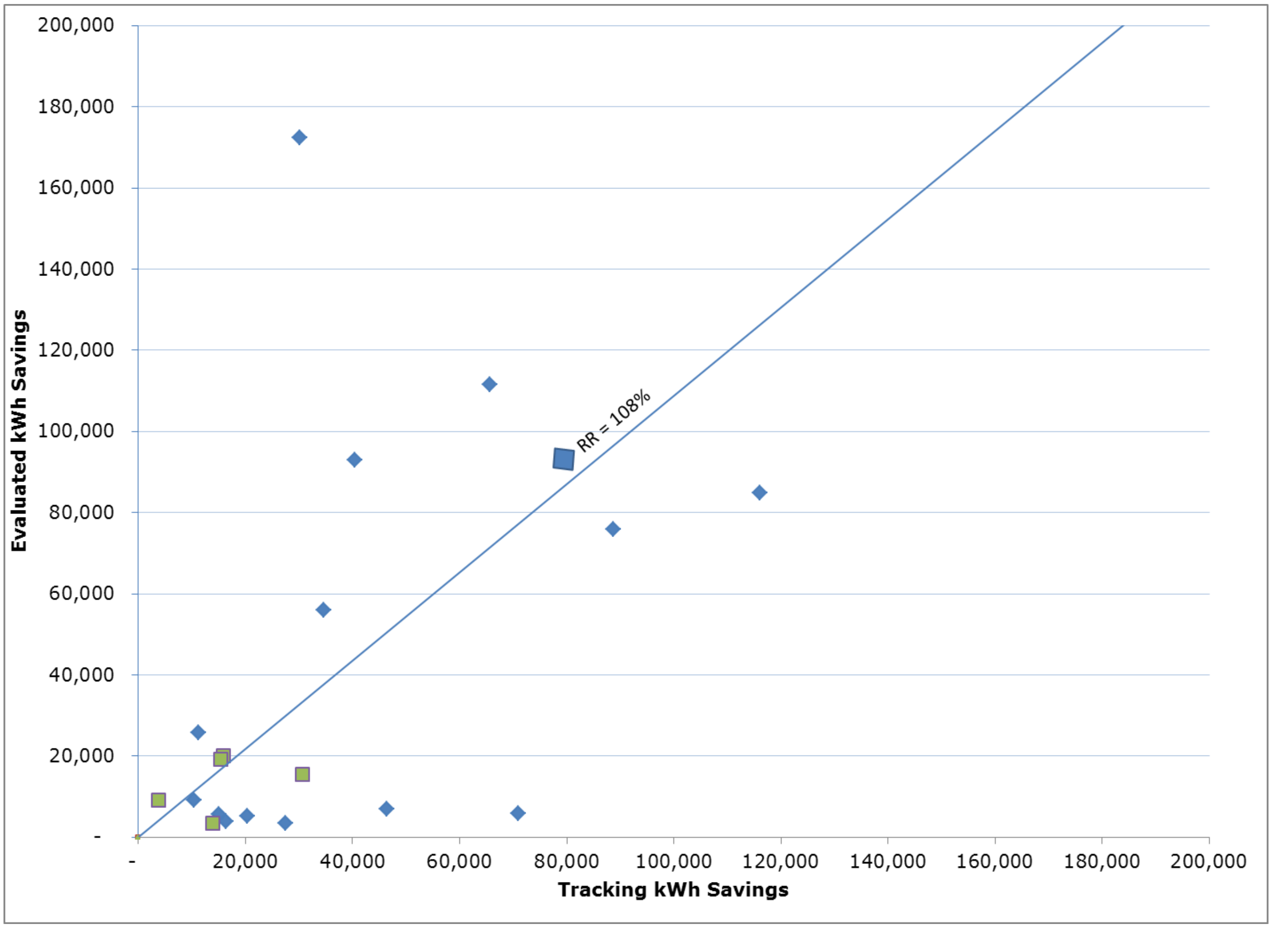

Figure 2-6: Evaluated vs. Tracking Annual kWh Savings

Table 2-9 provides realization rates for Gross kWh, Summer and Winter On-Peak and Seasonal kW savings. As discussed earlier National Grid utilizes the TRM savings estimation methodology. Here we see that, on average, the TRM underestimates savings.

Table 2-9: Prescriptive Chiller Retrospective Realization Rates

Sites	Statistic	Gross kWh Savings (80% Confidence)	Summer On-Peak kW (80% Confidence)	Winter On-Peak kW (80% Confidence)
n = 17	Realization Ratio (Evaluated to Tracking)	107.9%	35.6%	N/A
	Relative Precision	±30.9%	±14.6%	N/A
	Error Ratio	1.14	0.75	N/A

2.5.1.2 Site Results

Table 2-10 and Table 2-11 present the site level results for each RI sampled site, including the key parameters that impact the evaluated savings. These parameters include operating tons, operating baseline and installed efficiency and EFLH. Table 2-10 and Table 2-11 include all rebated chillers at each site.

Table 2-10: Site Level Chiller Results

Application ID	Number of Chillers	Rated Tons	Tracking kWh Savings	Evaluated kWh Savings	Average Operating Tons	Average Baseline Operating kW/Ton	Average Installed Operating kW/Ton	EFLH
1398801	2	20	3,726	20,688	7.3	1.07	0.72	3,003
1448251	1	80	30,577	21,511	11.9	0.98	0.70	978
1994110	1	120	15,801	35,085	16.3	1.00	0.73	1,168
2184027	1	90	15,429	49,284	38.5	1.22	0.81	1,455
3551798	1	100	13,893	4,210	8.3	1.05	0.89	263

Table 2-11: Site Level Chiller Summer Peak kW Results

Application ID	Max. Measured Tons	Summer Peak kW Savings	Summer Seasonal kW Savings
1398801	17.9	5.4	4.2
1448251	37.4	11.0	9.0
1994110	35.6	8.4	6.5
2184027	63.6	26.5	22.4
3551798	29.1	2.2	1.6

2.5.1.3 Chiller Load

Chiller load (tons) were estimated for each chiller using the methodology described above by converting monitored kW to load with the installed chiller efficiency coefficients. Overall, the weighted average operating load was found to be 21% of rated capacity for the entire sample. This indicates that, on average, many installed chillers are operating below their minimum rated capacity. In addition, the weighted average maximum monitored load was approximately 52% of rated capacity. Table 2-12 provides load bins with average operating load ranges and maximum measured load ranges for all chillers. It should be noted that one of the chillers with a greater than 75% max measured load serves a process load. In general, these findings suggest significant oversizing.

Table 2-12: Average and Maximum Chiller Loads by Load Bin

Chiller % Load	Number of Chillers	
	Average Operating Load	Max Measured Load
>75%	0	2
50% - 74%	0	0
25% - 49%	2	3
0% - 24%	3	0
Total	5	5

To consider the extent to which our metering period in 2014 included periods of very hot weather, we compared temperatures around greater New England. Table 2-13 shows the number of hours which exceeded various temperatures in a typical year in comparison to our metering period. It can be seen that, in most cases, while we did not capture data during the hottest periods of the year (>95°F), we did achieve a significant sample of hours from moderately hot periods (>85°F).

The fact that we did not see extremely hot temperatures suggests that our EFLH may slightly underestimate the actual EFLH of the chillers in our analysis and slightly mitigates our finding of significant oversizing.

Table 2-13: Comparison of 2014 to Typical Meteorological Year Summer Temperatures

Month	TMY	2014
5	93.0	81.0
6	91.0	87.1
7	95.0	90.0
8	91.9	88.0
9	87.1	89.1
Average	**91.6**	**87.0**

Table 2-13 shows that the fact that 2014 was a cool summer is more important than the fact that our metering did not start till mid-August. Our metering period (August-October 2014) included multiple occasions when temperatures approached 90°F. Neither effect is a major one, however, as these brief very hot periods are not significant when averaged across the on-peak periods of June, July, and August.

2.5.1.4 Chiller Hours

The evaluation calculated equivalent full load hours (EFLH) for each chiller by summing the total ton-hours across the 8,760 hour year and dividing by the rated capacity (tons) of the installed chiller. The weighted average EFLH for all chillers was estimated to be 1,328 hours.

EFLH does not represent the operating hours of the chillers. As noted above, the average operating load for the chillers in the sample was approximately 21% of full capacity. This means that the actual operating hours of the chillers, defined as any hours that the chillers run, are much higher than the EFLH.

Table 2-14, Table 2-15, and Table 2-16 show the loading of various chillers by the number of chillers per site, the type of chiller, and the building type. With the small sample size it is difficult to make conclusions about the operating characteristics. However, the site with the with two chillers (Application ID 1398801) had a primary process driven load therefore much higher ELFH and average percent load than the other sites. There was also significant variation by building type. The K-12 school (Application ID 3551798) had an EFLH of 263 hours. Across all of the sites, the average EFLH is close to the TRM value for National grid (1,373 average and 1,053 weighted versus 989 hours in TRM).

Table 2-14: Operating Characteristics by Number of Chillers

Number of Chillers	Number of Sites	EFLH	Max. % Load	Average % Load
1	4	966	46%	21%
2	1	3,003	91%	37%

Table 2-15: Operating Characteristics by Building Type

Building Type	Number of Sites	EFLH	Max. % Load	Average % Load
Other-Process Load	1	3,003	91%	37%
University	2	1,073	40%	15%
Other - Nursing Home	1	1,455	76%	46%
K-12 Schools	1	263	29%	8%

Table 2-16: Operating Characteristics by Chiller Size

Rated Tons	Number of Sites	EFLH	Max. % Load	Average % Load
0-75	1	3,003	91%	37%
75-125	4	966	46%	21%
125+	0	.	.	.

2.5.1.5 Chiller Efficiency

The evaluation estimated the average operating efficiency values for both the installed chiller and the baseline chiller for each site. While the TRM allows for the use of either full load (FL) efficiency or integrated part load value (IPLV), the evaluation estimate of average operating efficiency accounts for the actual operation of the chiller over its range of chiller loads. Using IPLV correlates more strongly with our evaluated savings estimates. However, even using IPLV there could still be a small adjustment of the type shown Table 2-17.

What is most critical is the difference in efficiency between the baseline and installed conditions. As shown in Table 2-17, at actual operating conditions, the baseline and installed performance curves provide a larger delta efficiency than at IPLV rated conditions.

Table 2-17: Rated IPLV vs. Average Operating Efficiency in kW/Ton

Chiller Performance (kW/ton)	Baseline	Installed	Delta Efficiency
Rated IPLV	0.894	0.720	0.174
Evaluation Average Operating Efficiency	0.899	0.697	0.203

2.5.2 Prospective Savings Factors

For prospective use, this evaluation has produced adjusted realization rates for energy savings and coincidence factors for summer and winter peak demands. These savings factors should only be applied to future chiller projects that use an updated TRM methodology. This methodology would change the existing algorithm by removing the load factor, and would use IPLV efficiency values. This new TRM methodology would use the following components in the savings estimates:

- Rated Tons
- Rated IPLV – Baseline and Proposed[10]
- EFLH – 1,328 hours from this study
- Adjusted kWh Realization Ratio – National Grid Value (See Table 2-18) – This is the ratio of evaluated kWh savings divided by the updated TRM kWh savings. The updated TRM kWh savings is calculated as the Rated Tons x ($IPLV_{baseline}$ – $IPLV_{proposed}$) x EFLH.
- Peak Coincidence Factors – National Grid Values for Summer and Winter On-Peak or Summer and Winter Seasonal (See Table 2-19) – This is ratio of evaluated peak kW savings (at the defined peak periods) divided by the updated TRM kW savings. The updated TRM kW savings is calculated as the Rated Tons x ($IPLV_{baseline}$ – $IPLV_{proposed}$).

Table 2-18: Chiller Energy Realization Rate vs. Adjusted Tracking Savings

Sites	Statistic (90% Confidence)	Gross kWh Savings
N=19	Adjusted kWh Realization Ratio (Evaluated to Adjusted Tracking)	107.2%
	Relative Precision	±31.4%

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[10] For projects that will use rated full load (FL) efficiency in their TRM savings estimates, updated realization rates and coincidence factors are provided in Appendix C.

Table 2-19: Chiller Peak kW Coincidence Factors

Sites	Statistic (80% Confidence)	Summer On-Peak CF	Winter On-Peak CF
N=19	Coincidence Factor	0.41	0.08
	Relative Precision	±16.9%	±58.5%

2.6 Conclusions

This evaluation found that savings from new prescriptive chillers are being realized with a retrospective energy savings realization rate of 107.9% at the program level. This realization rate was driven by two factors, increased delta efficiency and an increase in tracking EFLH. In addition, it appears as if the TRM methodology underestimated savings.

2.7 Recommendations

2.7.1.1 Application of Results

This evaluation recommends that National Grid RI use the TRM retrospective realization rates. These savings factors, which are calculated based on the operating kW of the sample of chillers, may be used to update the values in the TRM. DNV GL recommends that the TRM be updated to include the prospective savings factors and prospective realization rates, which would then be applied to future projects analyzed using the updated TRM methodology, as shown below. Note that load factor was removed from the existing TRM kW algorithm, and replaced with coincidence factor.

All Chillers:

$$\Delta kWh = (Tons)(kW/ton_{BASE} - kW/ton_{EE})(Hours)(RR_{adjkWh})$$

$$\Delta kW = (Tons)(kW/ton_{BASE} - kW/ton_{EE})(CF)$$

Where:

Tons = Rated capacity of the cooling equipment

Hours = Equivalent full load hours for chiller operation from evaluation (1,053 hours)

RR_{adjkWh} = Adjusted kWh Realization Ratio from evaluation (119.6%)

kW/ton_{BASE} = Energy efficiency IPLV rating of the baseline equipment

kW/ton_{EE} = Energy efficiency IPLV rating of the efficient equipment

CF = Coincidence factor from evaluation (0.49 Summer On-peak, 0.06 Winter On-Peak, 0.42 Summer Seasonal Peak, 0.04 Winter Seasonal Peak)

2.7.1.2 General Recommendations

Consider more research around the key finding that many chillers operate at very low part loads. Consider looking into the implications for reliability, cost and energy savings with relation to chillers operating at very low part loads. The key point is that the chillers are not cycling, which means they are operating below the manufacturer-recommended part load values. A number of DNV

GL engineers have suggested that running at this low part load isn’t safe for chillers and may have significant efficiency implications. Based on the feedback evaluators have received from some engineers, baseline chillers may operate at extremely low efficiencies at these conditions, which (if it could be quantified) could result in very large actual savings. This study was not able to quantify savings accurately at these part loads due to the issues discussed above in the “Analysis Methodology” section. National Grid may also consider an educational initiative to help vendors and customers understand the sizing requirements of their facility better.

Consider a closer review of project applications. Our evaluation found some sites with multiple chillers and one process chiller. Based on the TRM definition, only the lead chiller in a multiple chiller plant may be rebated. Likewise, the prescriptive program is designed for comfort cooling applications, which wouldn’t include process chillers. These types of projects may be more appropriate for the custom track.

Encourage vendors to look for additional chiller savings opportunities. In most cases the chillers were operating at the same conditions as prior to installation, according to facility personnel. When making changes to the chiller plants, it is worthwhile to consider different controls set points, such as lower condenser water temperature, higher chilled water temperature and resetting chilled water temperatures based on outdoor conditions. Revising chiller plant sequences of operation to incorporate more advanced control strategies will result in additional energy savings.

2.8 APPENDIX A - CHILLER EXAMPLE SITE

NGRID #1994110, 111.8 Ton Air Cooled Chiller

This chiller is a new replacement, which serves a University. The chiller operates 24/7.

Tracking Savings Review

Tracking kWh = 15,801
IPLV Based Tracking kWh[11] = 111.8 ton x (0.96 kW/ton – 0.795 kW/ton) x 427.5 hours = 15,801kWh
IPLV Based TRM kWh = 111.8 ton x (0.96 kW/ton – 0.795 kW/ton) x 817 hours = 30,197 kWh
Tracking Summer kW = 111.8 ton x (0.96 kW/ton – 0.795 kW/ton) x 0.715 = 13.19 kW

Where,

0.960 kW/ton = TRM 2012 Path A [12], Air Cooled, < 150 ton, IPLV
0.795 kW/ton = Proposed Chiller Rated IPLV
817 hours = Deemed EFLH
0.715 = TRM Load Factor

Evaluated Savings

Evaluated kWh = 111.8 ton x (0.882 kW/ton – 0.729 kW/ton) x 1,168 hours = 19,977 kWh

Where,

0.882 kW/ton = Average Evaluated Operating Baseline IPLV
0.729 kW/ton = Average Evaluated Operating Installed IPLV
1,168 hours = Evaluated EFLH

Evaluated Summer On-Peak kW = 111.8 ton x (0.882 kW/ton – 0.729 kW/ton) x 0.13 = 2.17 kW

Where,

0.882 kW/ton = TRM 2012 Path A [13], Air Cooled, < 150 ton, IPLV
0.729 kW/ton = Proposed Chiller Rated IPLV
0.13 = Evaluated Summer On-Peak Coincidence Factor

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[11] This chiller does not qualify as the full load kW/ton value does not meet the minimum required full load kW/ton

[12] Path A and B are alternate compliance paths that allow the programs to choose a chiller baseline depending on whether the chiller in question is optimized for Full Load or Part-Load Efficiency. The Path A option more closely approximates the IECC code minimum values.

[13] Path A and B are alternate compliance paths that allow the programs to choose a chiller baseline depending on whether the chiller in question is optimized for Full Load or Part-Load Efficiency. The Path A option more closely approximates the IECC code minimum values.

The Evaluated Summer Coincidence Factor represents the ratio of evaluated peak demand reduction using the operating load/performance and the rated IPLV performance rated reduction during the summer peak period.

Data Collection

One Dent ElitePro power logger was installed on the chiller. The monitoring period was 62 days from August 21, 2014 to November 18, 2014.

The following tables present the site information that was collected on-site and—in the case of operating hours—verified through metered data.

Operating Hours		
Day of Week	**Occupied Time**	**Unoccupied Time**
Sunday	0:00	23:59
Monday	0:00	23:59
Tuesday	0:00	23:59
Wednesday	0:00	23:59
Thursday	0:00	23:59
Friday	0:00	23:59
Saturday	0:00	23:59
Holiday	0:00	23:59

Chiller Info.	
Tons	111.8
AC Rated IPLV (kW/ton)	0.795
AC Full Load kW/Ton	1.263
Nominal kW	140.6
Cooling Type	Trane
Compressor Type	CGAM130
Start-up Date	Air-Cooled
Shutoff Date	Scroll
OAT Enable	01/01/14
OAT Disable	12/31/14

Site Conditions	
Chilled Water Adjustment (Deg F)	
CHW at High OAT	44.0
High OAT	80
CHW at Low OAT	44.0
Low OAT	60

Figure 2.8-1: Example Tons vs. Temperature Graph

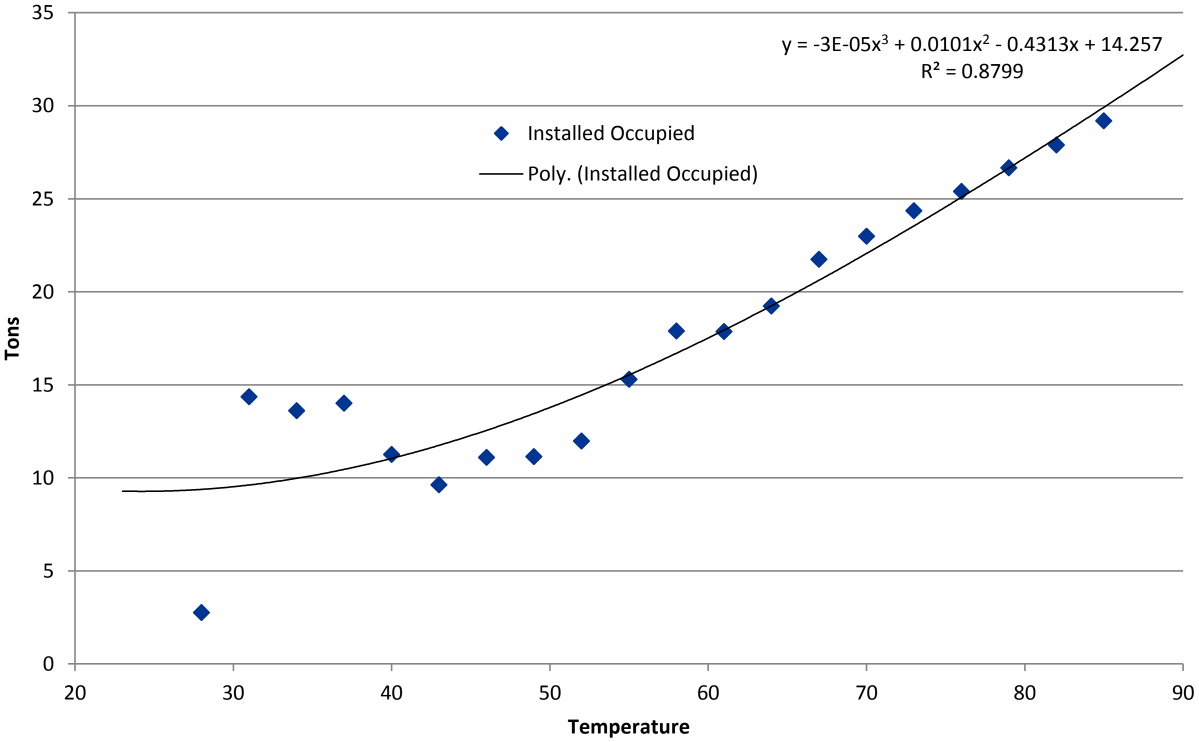
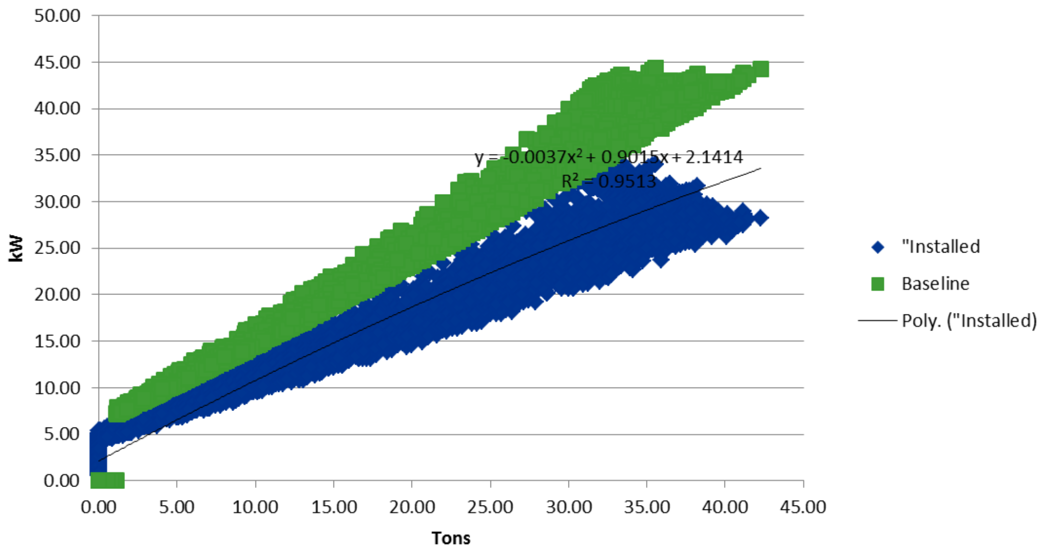


Figure 2.8-2: Example kW vs. Ton Graph



Savings Outputs

kWh Savings				
Baseline Usage	115,109			
Installed Usage	95,132			
Total ton-hour	130,541			
kWh Savings	19,977			
EFLH (TRM)	989			
EFLH (Calc)	1,168			
	Full Load kW/Ton			
	Baseline	Installed	Baseline	Installed
Efficiencies from Curve Fits:	1.255	1.263	0.960	0.795
Average operating efficiency			0.882	0.729

On-Peak Period Savings	**Summer**	**Winter**
Baseline Peak kW	32.03	10.26
Installed Peak kW	29.86	8.51
kWh Savings	2.17	1.75

Installed chiller load	**Ton**
Maximum measured tons	35.57
Average tons	16.27
Rated tons	111.80

3 APPENDIX B

The formulas used to calculate chiller operating power (kW) are shown below:

$$P_{operating} = P_{rated} \times EIR\_FPLR \times EIR\_FT \times CAP\_FT$$

$$PLR = \frac{Q_{operating}}{Q_{available}\left(t_{chws}, t_{cws/odb}\right)}$$

$$EIR\_FPLR = a + b \times PLR + c \times PLR^2$$

For Air-Cooled Chillers:

$$CAP\_FT = a + b \times t_{chws} + c \times t_{chws}{}^2 + d \times t_{odb} + e \times t_{odb}{}^2 + f \times t_{chws} \times t_{odb}$$

$$EIR\_FT = a + b \times t_{chws} + c \times t_{chws}{}^2 + d \times t_{odb} + e \times t_{odb}{}^2 + f \times t_{chws} \times t_{odb}$$

For Water-Cooled Chillers:

$$CAP\_FT = a + b \times t_{chws} + c \times t_{chws}{}^2 + d \times t_{cws} + e \times t_{cws}{}^2 + f \times t_{chws} \times t_{cws}$$

$$EIR\_FT = a + b \times t_{chws} + c \times t_{chws}{}^2 + d \times t_{cws} + e \times t_{cws}{}^2 + f \times t_{chws} \times t_{cws}$$

Where,

PLR	Part load ratio based on available capacity (not rated capacity)
$Q_{available}$	Available cooling capacity at present evaporator and condenser conditions (MBH)
Q_{rated}	Rated capacity at ARI conditions (MBH)
$Q_{operating}$	Present load on chiller (Btu/h)
t_{chws}	The chilled water supply temperature (°F)
t_{cws}	The condenser water supply temperature (°F)
t_{odb}	The outside air dry-bulb temperature (°F)
P_{rated}	Rated power draw at ARI conditions (kW)
$P_{operating}$	Power draw at specified operating conditions (kW)
a – e	Equation coefficients. Provided by EnergyPlus for each chiller.
CAP_FT	Factor expressing capacity as a function of temperature.
EIR_FT	Factor expressing efficiency in EIR (energy input ratio) as a function of temperature.
EIR_FPLR	Factor expressing efficiency in EIR as a function of PLR (part load ratio)

4 APPENDIX C

For projects that will use the rated full load (FL) efficiency values as opposed to IPLV with the TRM savings methodology going forward, this evaluation has also produced adjusted prospective TRM savings estimates. These adjusted tracking estimates were then used to produce adjusted realization rates for energy savings and coincidence factors for summer and winter peak demands. These savings factors should only be applied to future chiller projects that use an updated TRM methodology with rated FL efficiency values. This methodology would change the existing algorithm by removing the load factor, and would use FL efficiency instead of IPLV. This new TRM methodology would use the following components in the savings estimates:

- Rated Tons
- Rated FL – Baseline and Proposed
- EFLH – 1,328 hours from this study
- Adjusted kWh Realization Ratio – National Grid Value (See Table 4-1) – This is the ratio of evaluated kWh savings divided by the updated TRM kWh savings. The updated TRM kWh savings is calculated as the Rated Tons x ($FL_{baseline}$ – $FL_{proposed}$) x EFLH.
- Peak Coincidence Factors – National Grid Values for Summer and Winter On-Peak (See Table 4-2) – This is ratio of evaluated peak kW savings (at the defined peak periods) divided by the updated TRM kW savings. The updated TRM kW savings is calculated as the Rated Tons x ($FL_{baseline}$ – $FL_{proposed}$).

Table 4-1: Prospective Chiller Energy Realization Rate vs. Adjusted Tracking Savings (FL)

PA	Statistic (90% Confidence)	Gross kWh Savings
n=17	Adjusted kWh Realization Ratio (Evaluated to Adjusted Tracking)	250.9%
	Relative Precision	±28.3%

Table 4-2: Prospective Chiller Peak kW Coincidence Factors (FL)

Program Administrator	Statistic (80% Confidence)	Summer On-Peak CF	Winter On-Peak CF
n=17	Coincidence Factor	85.8%	N/A
	Relative Precision	±19.8%	N/A

Note that the 251% realization rate for FL estimates is significantly higher than the 108% realization rate for IPLV estimates. This is because the delta efficiency, i.e. baseline minus proposed, is greater at part load than at full load. Efficient chillers tend to operate most efficiently at about 75% part load. This is why the evaluated results are closer to the IPLV calculation than the FL calculation. When applying the FL efficiency savings calculation, there are no winter on-peak kW savings, which is why this field shows "N/A."

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