Memo to:
ISP TWG Members

Copied to:

From: DNV
Date: 9/8/21
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ISP High Rigor Study Findings – HVAC Chillers

1 HVAC CHILLER INDUSTRY STANDARD PRACTICE SUMMARY

This memo details the findings of an industry standard practice (ISP) study undertaken as a part of the ongoing Massachusetts Baseline Repository maintenance and updates. This study characterizes the ISP in Massachusetts for HVAC chillers and their auxiliary equipment including controls, pumps, and cooling tower fans. The high-rigor study included background research, a roundtable with PA representatives, interviews of eight different market actors, and the integration of results from a recent non-residential new construction market characterization study[1] ("NRNC Study").

The recommended ISP baseline conditions for both prescriptive and custom new construction (NC) HVAC chillers are summarized in Table 1a and 1b. Table 1a summarizes the recommended ISP baseline NC chiller configurations and controls.

Table 1a. NC HVAC Chiller ISP Summary

Equipment	Parameter	Industry Standard Practice
Chiller	System Type	• Same equipment capacity, centrifugal vs. non-centrifugal and heat sink (air-cooled or water-cooled) as the installed equipment
	Efficiency	• 3% better than code as shown in Table 1b
	Controls	• Chilled water temperature reset unless the facility has dew-point limit. While CHW reset is considered ISP, incentives may still be provided for projects that incur an added expense and go beyond typical chilled water reset • Condensing water temperature reset (for water-cooled chillers) • Chiller efficiencies used in energy savings calculations should reference Table 1b and 1c whether equipped with a VFD or not. • Air-side economizing (free cooling via air-handlers) or water-side economizing (free cooling via cooling towers or dry coolers)
	Fuel	Electric chillers
Pump (chilled water and condenser water)	Control type	VFDs on chilled water and condenser water pumps are standard practice when required by code
Cooling tower fans (water-cooled only)	Control type	VFDs on cooling tower fans are standard practice when required by code

[1] **"Massachusetts NRNC Market Characterization Study - MA19C08-B-NRNCMKT" June 21, 2021**

Table 1b summarizes the recommended NC ISP efficiencies which should be substituted for the minimum rated efficiencies of Table C403.3.2(7) of the building code.

Table 1b. Recommended Baseline HVAC Chiller Efficiencies for New Construction

		Recommended Baselines			
Equipment Type	Size Category	Path A FL	Path A IPLV	Path B FL	Path B IPLV
		kW/ton	kW/ton	kW/ton	kW/ton
Water-cooled, Non-Centrifugal	< 75 tons	0.728	0.582	0.757	0.485
	>= 75 tons and < 150 tons	0.698	0.543	0.728	0.475
	>= 150 tons and < 300 tons	0.640	0.524	0.660	0.427
	>= 300 tons and < 600 tons	0.592	0.504	0.606	0.398
	>= 600 tons	0.543	0.485	0.567	0.369
Water-cooled, Centrifugal	< 150 tons	0.592	0.534	0.674	0.427
	>= 150 tons and < 300 tons	0.592	0.534	0.616	0.388
	>= 300 tons < 400 tons	0.543	0.504	0.577	0.378
	>= 400 tons and < 600 tons	0.543	0.485	0.567	0.369
	> 600 tons	0.543	0.485	0.567	0.369
		EER	EER	EER	EER
Air-cooled	< 150 tons	10.403	14.111	9.991	16.274
	>= 150 tons	10.403	14.420	9.991	16.583

Table 2a summarizes the recommended ISP baseline for replace on failure (ROF) chiller configurations and controls.

Table 2a. ROF Chiller ISP Summary

Equipment	Parameter	Industry Standard Practice
Chiller	System Type	Same as the existing system.
	Compressor type	Same as the existing system.
	Efficiency	Code compliant for the system type and capacity
	Controls	Same as the existing system
	Fuel	Same as the existing system
Pump (Chilled and condenser water)	Control type	Same as the existing system
Cooling tower fans (water-cooled only)	Control type	Same as the existing system

Table 2b summarizes the recommended ROF ISP efficiencies which are equivalent to the minimum rated efficiencies of Table C403.3.2(7) of the building code.

Table 2b. Recommended Baseline HVAC Chiller Efficiencies for Replace on Failure (Code Compliant - Table C403.3.2(7))

		Recommended Baselines			
Equipment Type	Size Category	Path A FL	Path A IPLV	Path B FL	Path B IPLV
		kW/ton	kW/ton	kW/ton	kW/ton
Water-cooled, Non-Centrifugal	< 75 tons	0.750	0.600	0.780	0.500
	>= 75 tons and < 150 tons	0.720	0.560	0.750	0.490
	>= 150 tons and < 300 tons	0.660	0.540	0.680	0.440
	>= 300 tons and < 600 tons	0.610	0.520	0.625	0.410
	>= 600 tons	0.560	0.500	0.585	0.380
Water-cooled, Centrifugal	< 150 tons	0.610	0.550	0.695	0.440
	>= 150 tons and < 300 tons	0.610	0.550	0.635	0.400
	>= 300 tons and < 400 tons	0.560	0.520	0.595	0.390
	>= 400 tons and < 600 tons	0.560	0.500	0.585	0.380
	> 600 tons	0.560	0.500	0.585	0.380
		EER	EER	EER	EER
Air-cooled	< 150 tons	10.100	13.700	9.700	15.800
	>= 150 tons	10.100	14.000	9.700	16.100

The NC and ROF findings have also been combined to form a baseline recommendation for prescriptive chiller offerings. Since prescriptive projects typically have a mix of ROF and NC projects, a blended average was used to calculate a % relative to code baseline for the prescriptive measure calculations. In this case, interviewees noted that about 80% of the chillers sold were for ROF and 20% were for true NC. These values were used to calculate a weighted average of 0.6% better than code for prescriptive chiller measures. The values are outlined in Table 3 below.

Table 3. Recommended Baseline HVAC Chiller Efficiencies for Prescriptive Offerings

		Recommended Baselines			
Equipment Type	Size Category	Path A FL	Path A IPLV	Path B FL	Path B IPLV
		kW/ton	kW/ton	kW/ton	kW/ton
Water-cooled, Non-Centrifugal	< 75 tons	0.746	0.596	0.775	0.497
	>= 75 tons and < 150 tons	0.716	0.557	0.746	0.487
	>= 150 tons and < 300 tons	0.656	0.537	0.676	0.437
	>= 300 tons and < 600 tons	0.606	0.517	0.621	0.408
	>= 600 tons	0.557	0.497	0.581	0.378
Water-cooled, Centrifugal	< 150 tons	0.606	0.547	0.691	0.437
	>= 150 tons and < 300 tons	0.606	0.547	0.631	0.398
	>= 300 tons and < 400 tons	0.557	0.517	0.591	0.388
	>= 400 tons and < 600 tons	0.557	0.497	0.581	0.378
	> 600 tons	0.557	0.497	0.581	0.378
		EER	EER	EER	EER
Air-cooled	< 150 tons	10.16	13.78	9.76	15.89
	>= 150 tons	10.16	14.08	9.76	16.20

These findings are based on research of current practices as reported by market actors in 2020 and on buildings permitted under IEEC 2015. Since there are no updates impacting chillers in IEEC 2018, the ISP findings apply to applications approved in 2022 and going forward until such time that the study is revised or there are subsequent revisions to building code impacting chillers. These findings will be published with the next Baseline Repository update January 1, 2022.

2 METHODOLOGY

The high-rigor study included background research, a roundtable with PA representatives, interviews eight different market actors, and the integration of results from a recent non-residential new construction market characterization study. The Baseline Framework defines industry standard practice as the "baseline condition that would have existed absent the installed measure". The determination of ISP was further refined during the NRNC study which confirmed that the intent of ISP is to reflect equipment choices if the program-eligible products were not available.

In preparation for the primary research, the DNV team conducted secondary research and conducted a roundtable discussion with five PA representatives:

- ❑ **DNV conducted secondary research** to gather information on chillers in preparation for the PA and market actor interviews. DNV reviewed documentation such as the MA Baseline Repository, 2020 MassSave program baseline document, IECC2015, DEER workpapers, and other publications to synthesize current chiller baselines. DNV (as legacy ERS) compiled the findings from the secondary research and submitted them in a memo on 10/21/2020, also found in Appendix A.
- ❑ **DNV conducted a roundtable with five PA representatives** via a conference call on 10/16/2020. The overall purpose of the PA interview process was to help the researchers develop an understanding about how the program currently handles projects involving HVAC chillers and what information the program implementers felt could be

clarified. The researchers provided the PA representatives with an overview of the evaluation ISP research process and solicited feedback. The findings from this interview are presented in Section 3.

Primary research included two components, in-depth interviews with market actors and the statistical sample

- **DNV (as legacy ERS) conducted a total of eight in-depth-interviews** with five manufacturer representatives, two designers from engineering firms, and an implementation contractor. The interviewees provided their assessments of the typical chiller configurations and controls sold in Massachusetts. The five manufacturers interviewed represent almost all the HVAC chillers sold in Massachusetts. The findings included estimates of average efficiencies of equipment sold in Massachusetts provided by three manufacturer representatives.
- **The NRNC study** was based on a review of a statistically representative sample of building construction documents to determine ISPs of a variety of equipment including chillers. These construction document specified efficiencies were compared to code requirements to calculate a state-wide average rating above (or below) code required efficiency.

The recommended ISP equipment configuration and controls reflect the majority opinion of the market actor as expressed in the in-depth interviews. The ISP efficiency values were calculated by combining the results of market actor reported efficiencies and the efficiency findings of the NRNC study. The ISP efficiencies were structured to represent customer equipment selection practices “absent the installed measure”. More specifically, the NRNC Study efficiencies exclude equipment eligible for program incentives and the market actor reported efficiencies gather in this study exclude the most efficient quartile of equipment sold in the market.

3 PREPARATORY RESEARCH

This section summarizes the preparatory phase of this study.

3.1 Secondary Research Summary

As part of the PA interview process, the researchers identified the established program baselines for chillers as provided in the 2020 Mass Save Baseline document. Chiller baselines are provided in Appendix B.

In addition, the research team also identified key factors that determine the selection of chiller systems. Those factors, which are summarized and explained below, were used as key discussion points during both the PA interviews and the market actor interviews:

- **Building load and partial load**: this step helps determine the quantity, size, and staging strategy of the chillers. Oversized chillers cannot run at their optimal performance level, and undersized chillers fail to meet the facility’s load.
- **Chiller type**: There are two type of electric chillers, water cooled and air cooled. Water-cooled chillers tend to be a better fit for larger applications and are generally more efficient than their air-cooled counterpart. However, water-cooled systems occupy more space because of the auxiliary equipment associated with them and therefore must be installed indoors. Air-cooled chillers are a better fit for smaller applications and are typically installed outdoors. Installing multiple smaller chillers in a modular array allows for easier scalability.
- **Capital cost**: Water-cooled chillers have a higher upfront cost associated with them due to the additional equipment required to operate the system such as cooling towers, condenser pumps, etc. Air-cooled chillers are standalone systems and therefore are generally cheaper. Finally, it’s important to note that there is a trade-off between scroll and screw air-cooled compressors. Scroll air-cooled chillers are cheaper but less efficient than screw air-cooled chillers.
- **O&M cost**: Water-cooled chillers are generally more energy efficient than their air-cooled counterpart; however, the cooling towers that are part of the water-cooled system utilize great amounts of water, which would factor into the operating cost. Water-cooled systems also tend to have a higher maintenance cost. Air-cooled chillers are cheaper to maintain and have a lower upfront cost.

As a result, the chiller selection is highly dependent on the overall load, available space, and cost associated with purchasing and running the equipment.

3.2 Program Administrator Roundtable Findings

The researchers conducted a roundtable discussion with PA representatives from National Grid and Eversource to better understand the chiller program, to identify trends in completed projects, and to solicit contact information for key market actors. The interview guide used as a basis for the discussion can be found in Appendix C.

Since this ISP study covers HVAC chillers only, the perspectives provided are focused on those systems. The following summarizes the PA views on the topics covered.

What do you currently consider baseline practice for new construction HVAC chiller installations?

The PAs agreed that customers are mostly driven by two factors, capital cost and customer preferences for a certain manufacturer to standardize on a single supplier. This makes their life easier when needing maintenance or replacement. In most cases, the project that is implemented is the one with the lowest upfront and maintenance cost. PAs expect new construction equipment will at least meet code.

High efficiency projects will typically encompass the entire plant, not just the chiller. The PAs engage with the vendors and engineers to not only focus on the kW/ton of the installed chiller, but the efficiency of the chiller plant as a whole including:

- Higher delta T and lower gpm/ton
- Chilled water and condenser water temperature reset, if possible
- Free cooling (airside)
- VFDs on chilled and condensing water pumps, as well as on cooling tower fans where applicable

More high-efficiency systems are seen in new construction projects due to an overall better operation of the chiller plant with better controls and VFDs and not necessarily higher-efficiency kW/ton chillers.

What do you currently consider baseline practice for retrofit or replace on failure HVAC chiller installations?

Most replacement projects occur at or beyond the EUL of the chiller; the PAs rarely see an energy efficiency-driven replacement. As a result, the customers tend to install new replacement chillers that are similar to the existing one, and if that's not available, they opt for the closest alternative (similar compressor type, chiller type, flow rate, tonnage, etc). The new chiller, at the very least. In the instance where the customer is provided with multiple makes and models, the cheapest option prevails.

One of the PAs who has a majority of replacement/retrofit projects in their portfolio mentioned that in many cases, customers tend to go for a one-to-one replacement, stating that the urgency of getting the chiller plant up and running supersedes any efficiency upgrades.

In other cases, however, customers tend to upkeep their chiller plants and optimize through controls and auxiliary equipment measures (VFDs on pumps, pressure controls, etc) since those are a cheaper alternative to a chiller replacement.

PAs also reported instances where a new high-efficiency chiller replaced an older one in an existing plant. In that scenario, the new chiller cannot run at its optimal performance since it's part of a system that in and of itself requires an efficiency overhaul.

Another PA stated that some facilities with existing water-cooled plants are moving to air-cooled systems since the latter have a lower maintenance cost.

Do chiller replacement/installation projects consider the systems as a whole? Do they include the auxiliary equipment such as pumps, cooling towers, valves, etc?

Replacement/retrofit projects typically look at improving the performance of the entire system, which includes the auxiliary equipment. This is achieved by retrofitting the chilled and condenser water pumps as well as the cooling tower fans with VFDs along with improved controls.

What are some of the factors that influence the type of chiller equipment that is selected?

As discussed, most replacement projects are highly dependent on the pre-existing chiller. However, according to the PAs, controls integration and facility load are also considered in the decision-making process. It is important that the chiller can communicate with the building's various systems, controls, and building management system (BMS). In addition, the chiller must be properly sized so that it operates at its optimum performance. In conclusion, the factors driving chiller selection includes compatibility, ease of integration, and proper sizing.

How are electric chillers treated differently than gas chillers?

The program does not support electric-to-gas chiller conversion projects. The PAs also stated that gas chillers are rarely encountered in HVAC applications. In most cases, gas chillers are used in facilities that benefit from co-generation, such as indoor agriculture facilities.

How does used equipment predicate chiller baselines?

The program does not support used equipment; all chillers that go through the utility programs must be new to be eligible for an incentive, therefore the PAs do not have direct knowledge of a secondary market.

Is there anything else you think we need to know about chillers in MA?

The PAs gave their perspectives on various other factors that contribute to chillers and chiller-plant efficiency that ought to be considered:

- ❑ New refrigerants coming out might lead to an efficiency or capacity decrease in some of the systems.
- ❑ There is still significant opportunity with chiller plant optimization controls packages.
- ❑ Some facilities, such as schools, have their own requirements to apply for an incentive and are typically better candidates for higher efficiency installations and may be responsive to incentives.
- ❑ Some customers have sustainability and carbon-reduction goals that drive their energy-efficiency installations – those projects may be more responsive to incentives.
- ❑ Downtown areas tend to be more adamant on efficiency to attract tenants with sustainability goals and be responsive to incentives.

4 PRIMARY DATA COLLECTION RESULTS

This section summarizes the data collection phase of this study.

4.1 Market Actor Interview Results

This section summarizes the market actor responses to interviewer questions. Appendix D is the interview script and Appendix E contains abridged individual answers to each question by each respondent with summary observations. All interviewees stated that they were familiar with the design, sale, and installation of chillers in Massachusetts, and all interviewees also had experience in other states. Table 4 summarizes the respondent market roles, service territories, and sales volumes.

Table 4. Market Actor Summary

ID	Market Role	Location of Work	Chillers Sold in MA	Estimated Participation Rates	Percent ROF
1	Design firm	Mostly in MA; focus on Boston and Cambridge	36	80%	10%
2	Manufacturer/distributor	100% Northeast	**100**	50%	95%
3	Vendor/implementation contractor	100% Northeast	12	100%	50%
4	Design firm	100% Northeast	2	ND	ND
5	Manufacturer/distributor	100% Northeast	**8**	ND	ND
6	Manufacturer/distributor	100% Northeast	**8**	100%	100%
7	Manufacturer/distributor	Northeast, NY, and NJ	**40**	<10%	90%
8	Manufacturer/distributor	100% Northeast	**100**	50%	70%
	Estimated total (includes manufacturer/distributor counts only)		**256**	~45%	~80%

Table 4 presents notable findings in aggregate as follows:

- **Size of the market**. In total, the manufacturer/distributors reported Massachusetts annual sales of about 250 units for the year ending in late 2020. The Estimated Total in Table 4 includes only the manufacturer/distributor market size estimates since they are likely to be mutually exclusive, while the design firms and contractor estimates are likely to overlap manufacturer/distributor estimates. The interviewees included represented sales estimates from the 'Big Three', therefore we conclude that the total is a good estimate of the total Massachusetts annual market size.
- **Dominated by ROF**. In aggregate, about 80% of the market is replace on failure. This is not surprising, when one considers that new construction contributes about 1% to floor space annually, while about 4-5% of existing chillers will reach end of life each year, assuming a 20 to 25-year measure life. This suggests that ratio of NC to ROF is 1:4 or 1:5 which aligns with market actor reports.
- **Exaggerated participation rate**. The interviewees estimated that almost half of the chiller projects went through the programs. This is not supported by tracking data which suggests that only about 15% of units sold participate in programs. The 2019 tracking data included only 15 prescriptive and 20 custom chillers, with potentially a few more chillers incentivized through CDA projects. The NRNC Study further support this finding since none of the chillers (eleven chillers at five sites) received incentives. This suggests that distributors and manufacturer representatives are not privy to the final customer participation decision or it is possible there is a bias towards over-reporting participation.

4.1.1 Chiller Efficiencies

Interviewees were asked to estimate the average efficiencies of chillers sold in the previous year. As a proxy for an ISP baseline, which ideally excludes eligible measures, the request specifically requested the interviewees to estimate the minimum efficiency of the bottom three-quartiles (75% to 80%) of units sold in Massachusetts. The interviewees were provided a template for recording results for each of the chiller system type and capacity combinations found in Table C403.3.2(7) of the building code.

Three manufacturer's representatives provided both full load and part load efficiencies for different equipment combinations. Table 5 presents a summary of the number of manufacturer responses provided for each combination. Individual manufacturer values are not included to maintain confidentiality of the source material.

Table 5. Minimum Efficiency for Majority (~75% to 80%) of Sales

Equipment Type	Size Category	Responses	Path
Water-cooled, Non-Centrifugal	< 75 tons	1	Path A
	>= 75 tons and < 150 tons	1	Path A
	>= 150 tons and < 300 tons	1	Path A
	>= 300 tons and < 600 tons	1	Path A
	>= 600 tons	0	NA
Water-cooled, Centrifugal	< 150 tons	0	NA
	>= 150 tons and < 300 tons	1	Path B
	>= 300 tons and < 400 tons	3	Path B
	>= 400 tons and < 600 tons	3	Path B
	> 600 tons	3	Path B
Air-cooled	< 150 tons	1	Path A
	>= 150 tons	1	Path A

As Table 5 demonstrates, the number of responses varied by combination. The values were averaged in each cell. In cases where only one value was received, that value was used. The average estimate for each combination was then compared to code to determine how much better (or worse) the average efficiency was to code. The code comparisons were made using IECC 2018 (which are equivalent to IECC 2015).

The chiller category within IECC has two separate compliance paths, Path A and Path B. Path A is intended to be used for chillers that will generally operate fully loaded, while Path B is intended to be used for chillers that are generally operating at part load (i.e., seasonal loads). This ensures that the values were not skewed too high or too low. For example, a water-cooled centrifugal chiller with an IPLV of 0.32 kW/ton would most appropriately follow Path B with respect to code compliance. If this value were compared to the Path A IPLV efficiency it would appear to be 30% better than code. However, using Path B, the chiller efficiency is only about 10% better than code which more accurately reflects what is happening in the market with respect to code. Table 5 notes the Path reference efficiencies used in calculating the percent better than code for each combination.

Once each value was assigned an appropriate code comparison path, evaluators averaged the total percentage better than code across all equipment configurations. On average, the market actor reported efficiencies were **4.9% better than the code required minimum efficiencies**.

4.1.2 Chiller plant configuration and controls

This section of the interview focused on establishing configuration and control ISP for chillers.

What is the standard practice for chiller type?

Most larger applications (those with a facility load greater than 500 tons) are water cooled (WC). (Hospitals are a prime candidate for WC). Larger facilities that have WC chillers need the staff and budget to maintain the type of plants, which is why they are exclusive to larger applications. Smaller applications (those with a facility load less than 350 tons) tend to utilize air-cooled chillers (offices, schools, etc). Facilities with a cooling load between 350-500 tons can have either chiller type. The selection depends on the budget, maintenance staff availability, and the space allocated for the equipment.

What is the standard practice for chiller fuel?

Almost all interviewees stated that they only deal with electric chillers. The research team had one interviewee who worked on a gas chiller project where the gas chillers were used as back-up to the electric chillers.

What is the standard practice for chiller compressor type?

Most air-cooled chiller compressors are screw. Scroll compressors are more cost effective; screws cost more but are more efficient since they come with variable frequency drives. Water-cooled chillers are centrifugal. Vendors always attempt to retrofit centrifugal chillers with VFDs when possible.

What is the standard practice for chiller controls?

The interviewees provided varying responses for control types:

- ❑ Air-side free cooling is ISP with all vendors and designers
- ❑ About half of the interviewees reported that they attempt to install VFDs when doing chiller plant retrofits on auxiliary equipment (cooling towers and pumps), screw, and centrifugal chillers.
- ❑ Industry is shifting to variable flow primary pump instead of primary/secondary pumps.
- ❑ CHW temperature resets are done when possible; however, this is sometimes limited by dewpoint limits. Actual CHW temperatures and resets are project and application specific.
- ❑ CW temperature reset is also implemented (specific to water cooled chillers).

Interviewees also mentioned that controls are specified by the engineering firm/designer of the chiller plant. Major chiller manufacturers have sophisticated control packages that can usually tie into a BMS. These practices lead to variation between sites with respect to plant controls, for example chiller staging.

How do the installed chillers compare to what is required by code?

Recent chiller sales are about 4.9% better than code on average, as reported by the distributors.

Does the system design vary depending on whether it is replacing a failed unit (ROF), or adding capacity to a new or existing system (NC)? If so, how? If yes, probe for whether there is a particular baseline type (retrofit, ROF, NC) that is more common for a given system design.

ROF is typically restricted to what is already installed. The interviewees mentioned that with ROF projects, the customer expects a one-for-one replacement. As a result, in most scenarios the vendors install a code-compliant chiller that is the same size and type (both chiller and compressor type) as the replaced equipment. The customers also require that the new chiller be compatible with their existing controls and control system. Vendors typically suggest some improvements (VFDs, controls, etc) but there is usually not a lot of room for improvement or interest from the customer.

NC offers more opportunity for more efficient installations, but high efficiency is hindered by the project's budget caps.

4.1.3 Auxiliary Equipment

What is the typical standard practice for cooling towers (constant speed, variable speed)?

Variable speed cooling towers for NC are ISP. Variable speed drive retrofits on CT fans are not standard practice for ROF, rather the existing system tends to dictate what is installed.

What is the typical standard practice for CHW pumps (constant speed, variable speed)?

Variable speed CHW pumps are ISP for NC, however the interviewees gave a mixed response when it comes to ROF of the chiller plant.

What is the typical standard practice for valves (two-way vs. three-way valve)?

It depends on the installed system. As one interviewee stated, the project is never designed around the valve. In most cases, constant-speed systems have a three-way valve to maintain minimum flow, while variable-speed systems have a two-way valve.

How does the installed equipment compare to what is required by code? (That is, above code, enough to satisfy code, etc.)?

All auxiliary equipment, whenever possible, is installed with or retrofitted with VFDs in NC projects, however the interviewees gave a mixed response when it comes to ROF of the chiller plant.

4.1.4 Program Influence

This section of the interview describes the interviewee's assessment of the impact of the incentive programs.

What percent of the chiller projects you worked on received financial incentives or technical assistance from the Massachusetts PAs (e.g., National Grid, Eversource, Cape Light, etc.)?

Engineering firms and manufacturers reported that they work with their NC customers to apply for incentives when they can. ROF projects are typically tight on timeline due to the urgency of getting the facility up and running again. As a result, vendors and implementers are more inclined to skip the incentive for time constraint reasons.

In total, the interviewees suggest that about 45% of the chillers sold in Massachusetts receive incentives. As noted earlier in this section, that percentage is likely overstated by a factor of three.

What percent of the projects that you've worked on in Massachusetts were not eligible for incentives because they took place in municipal utility territories?

The market actors had no recollection of projects in municipal utility territories.

Are there any consistent differences in the chiller efficiencies for those you sell/install for projects that do or do not receive incentives/assistance?

Engineering firms on new construction projects often present the customers with both code compliant and high efficiency options - the level of efficiency highly depends on the budget cap of the project. If the difference in cost between the high efficiency chiller and the cap is marginal, an incentive may enable a higher-efficient plant while keeping the project on budget. In most instances, the high efficiency chiller exceeds the budget cap by a large margin which leads to a cut down on costs by resorting to lower efficiency options. Vendors/implementors will select the chiller model to bid based on the estimation of what their competitors will offer.

Some vendors stated that the competition with others drives them to offer cheaper options, which are typically less efficient. To meet the client's budget, the first thing the vendors exclude from their proposals are equipment or add-ons that increase the plant's efficiency; the vendor's goal is to win the project, and it's up to the client to decide. Neither increased efficiency nor the potential-incentive drive the design: The overall project cost and competitive positioning do.

4.2 NRNC Results

DNV carried out the NRNC Study for the Massachusetts Program Administrators (PAs) and Energy Efficiency Advisory Council (EEAC) Consultants from May 2019 to February 2021. The NRNC Study recruited 38 municipal building departments to provide data on a sample of recently constructed NRNC buildings. The team gathered new construction practice via a review of construction documents from a random sample of 55 NRNC buildings acquired from municipal building departments. The plans were reviewed to determine specifications of three building systems: mechanical systems (HVAC), lighting systems (lighting), and building envelope. This study took exceptional care to represent the new construction market as it is without non-response bias.

Chillers were determined to serve about 4% of newly constructed space. Table 6 summarizes the chiller specifications for the chillers observed in the study. The rated efficiency verified in the construction documents and the building code minimum required efficiency was calculated using the same methodology described in Section 4.1.

Table 6. NRNC Chiller Findings

SITE ID	Equipment Count	Eligible	System Type	EF% Better or worse than code	Assessed Eff	Code Efficiency Units #2 (IPLV for chillers)	Capacity tons/unit
S0020	2	N	Air-cooled	8.9%	15.24	EER	275
S0014	1	N	Air-cooled	1.5%	13.9	EER	20
S0039	4	N	Air-cooled	8.9%	15.1	EER	309
S0055	1	N	Air-cooled	1.0%	9.8	EER	216
S0021	3	N	Water -cooled	-0.9%	0.589	kW/ton	650

Out of the 5 sites observed, 4 installed air-cooled chillers and 1 installed water-cooled chillers. The air-cooled chillers observed were rated at above code performance while the water-cooled chiller was slightly below code. Eleven chillers were installed in total, none met the program's current eligible requirements for chillers and two sites had participated in another HVAC category, although not for chillers. The overall % better than code was calculated by taking the median weighted % to code of the observed chillers based on facility square footage and extrapolated to the population using a case weight. In this case, about 50% of weighted square footage had chiller efficiency less than or equal to 1% better than code, and 50% had chiller efficiency greater than 1% better than code. Expanding the site chillers results to the population resulted in a 1% better than code observed in the NRNC study.

The MA C&I Baseline Study 2019 update examined equipment installed in the existing building stock in MA. The chillers that were most relevant to this ISP research from that study include those that were installed within the last 5 years. The chillers observed in this category are summarized in Table 7.

Table 7. MA C&I Baseline Study

Number	Type	Size (tons)	Efficiency EFL
Water Condenser			
1 **(part)**	Screw/Scroll	160	0.60 kW/ton
2 **(part)**	Centrifugal	400	0.59 kW/ton
3 **(part)**	Centrifugal	107	0.48 kW/ton
Air Condenser			
4 **(part)**	Screw/Scroll	460	9.6 EER
5 **(part)**	Screw/Scroll	460	9.6 EER
6 **(non-part)**	Screw/Scroll (3)	450	11 EER
7**(part)**	Unknown	55	10.1 EER

Out of the 7 sites with chillers installed in the last five years, only one was a non-participant site. This customer installed an air-cooled chiller that is 8.9% better than the code required efficiency. Since it was only one machine, this was not used directly in our calculation but further supports above code practices.

4.3 Combined Primary ISP Research and NRNC Results

The percent better than code findings of the NRNC Study (1% better than code) and the primary data collection findings from this study (4.9% better than code) were combined as an average of the two values. This average, which is positive, indicates that on average new construction chillers have rated efficiencies 3% better than the coder required minimum. This percentage can be directly applied to IEEC Table C403.3.2(7) referenced by the building code to compute ISP minimum efficiencies to be used as the baseline efficiencies in savings estimates. The results of the application are presented in Table 8 (which is identical to Table 1b).

Table 8. Recommended Baseline Chiller ISP Efficiencies

		Recommended Baselines			
Equipment Type	**Size Category**	**Path A FL**	**Path A IPLV**	**Path B FL**	**Path B IPLV**
		kW/ton	kW/ton	kW/ton	kW/ton
Water-cooled, Non-Centrifugal	< 75 tons	0.728	0.582	0.757	0.485
	>= 75 tons and < 150 tons	0.698	0.543	0.728	0.475
	>= 150 tons and < 300 tons	0.640	0.524	0.660	0.427
	>= 300 tons and < 600 tons	0.592	0.504	0.606	0.398
	>= 600 tons	0.543	0.485	0.567	0.369
Water-cooled, Centrifugal	< 150 tons	0.592	0.534	0.674	0.427
	>= 150 tons and < 300 tons	0.592	0.534	0.616	0.388
	>= 300 tons and < 400 tons	0.543	0.504	0.577	0.378
	>= 400 tons and < 600 tons	0.543	0.485	0.567	0.369
	> 600 tons	0.543	0.485	0.567	0.369
		EER	EER	EER	EER
Air-cooled	< 150 tons	10.403	14.111	9.991	16.274
	>= 150 tons	10.403	14.420	9.991	16.583

Like code specification for ratings standards, the ISP efficiencies are rated following the provisions of C403.3.2 which follow AHRI protocols. The selection of the Path and full or part load ratings should follow the provisions noted in the footnotes of Table C403.3.2(7). In building simulations, the default full and part load baseline efficiencies should be replaced with the corresponding ISP efficiencies, which will adjust the underlying baseline performance curve in the models. We have confirmed that this will work for eQUEST.

We note that C403.3.2(7) is the same for both IEEC 2015 and 2018.

5 CONCLUSIONS AND RECOMMENDATIONS

All the market actors interviewed for this research project were credible and able to provide good insights into the chiller market in Massachusetts. They had extensive industry experience both in and outside of the state, and the approximately 250 chiller installations that they completed in the last year across the state represent a wide variety of different facilities. Additionally, for many of the different parameters that were being studied, a high degree of consistency was present across the interviewee responses, with the NRNC study findings, and with the secondary research.

5.1 Conclusions

A key finding of the primary research is that the installed chiller is dependent on whether a project is ROF or a true new construction project.

Replace on failure. Based on the interviews, about 80% of the chillers sold each year are at end of life or have failed. In this scenario, it is usually easier, quicker, and more cost effective to replace failed equipment with similar equipment, using existing accessories when possible. This means that the replacement is more likely to be from the same manufacturer, be the same general chiller type, have the same type of compressor, however, the installed unit is expected to meet or slightly exceed code. With ROF, there is not as much time and latitude as in NC to specify and install higher efficiency equipment. While half of the interviewees reported that they ‘try’ to upgrade pumps and fans with VFDs as part of a chiller replacement, half did not note this practice and VFDs in ROF are not considered standard practice. Additionally, controls relating to economizing are typically dictated based on the existing system, which can serve as the baseline for that component of ROF scenarios.

New construction. For NC projects, market actors reported that the industry standard practice, is to install chillers that are slightly better than code but are less efficient than a program eligible chiller. This is further supported by findings in the NRNC Study. Combining the results of the two studies results in an NC chiller ISP efficiency that is 3% better than the code required minimum efficiency, which is also lower than the program eligibility threshold of about 5% above code.

Common to new construction and replace on failure. There are chiller characteristics that are consistent for both scenarios:

- ❑ Interviewees identified the typical system types were selected by capacity ranges as follows:
  - ➢ HVAC chillers above 500 tons are mostly water cooled, while those below 350 tons are air cooled. Chiller between 350 to 500 tons can be either water or air cooled, depending on the facility.
  - ➢ Most air-cooled chillers are screw due to increased efficiency opportunities. Scroll compressors are more cost effective.

  However, it was also noted that exogenous factors are important in the selection of a system type, therefore system capacity does not dictate the ISP system type. For example, the ISP of a 200-ton water-cooled chiller should reference the water-cooled chiller efficiency, not that of an air-cooled chiller - although it is a more typical choice in this capacity range. This does not preclude a program administrator that has influenced a customer to install a more efficiency system type (water-cooled vs. air-cooled) to reference an air-cooled chiller baseline, however, it will require a site-specific baseline with appropriate supporting documentation.

- Other findings supported by most of the interviewees includes:
  - Most HVAC chillers are electric chillers.
  - Variable flow systems are equipped with two-way valves, while constant flow are equipped with three-way valves.
  - Air-side economizer or free cooling is ISP for both ROF and NC; chilled water temperature reset, and condenser water temperature reset is ISP for NC.
  - ISP NC projects is pumps and fans with VFDs, for ROF the responses were mixed, and it is not considered ISP.

Role of the Program. Some of the findings regarding program influence appeared to be contradictory. Interviewees claimed that half of the projects went through the program while also claiming that first cost drives equipment selection precluding more efficient options. Some of the interviewees reported that the program had little influence on equipment selection. To make sense of these findings we considered the following:

- Most of the chillers do not go through the programs, this is clear comparing the reported number of units sold in Massachusetts versus the number of incentivized chillers recorded in program tracking (about 15% of units sold). None of the NRNC Study chillers were eligible for program incentives.
- Installed chillers slightly exceed code minimum efficiency requirements, but also do not meet program eligibility requirements on average. Since chillers are legally required to meet code, it is not surprising that the average is slightly better than code, providing a margin of safety to ensure the threshold is met.
- Interviewees report that most customers will select the lowest cost option and that the incentives do not cover the gap. As one interviewee stated: "The rebates are not that great. After meeting efficiency thresholds, we can't get more than $60/ton so there is no incentive to put in a really efficient chiller." Exceptions are those customers with other motivation like corporate sustainability goals, potentially combined with an incentive, will lead to selection of higher efficiency equipment.

The DNV Team concludes that high efficiency chillers are not standard practice because they cost significantly more, and the program incentives do not overcome that cost gap. This is consistent with the relatively low penetration of the program in the market and the perception of vendors that the incentives have little impact. Vendor do not see a big impact of the program on the market because incentivized projects are relatively rare, and the incentives are usually not sufficient to influence the chiller selection in bids to clients. We conclude that the vendor perception that half of the chillers go through the program is not supported by the data and maybe due to a desire to appear aligned with program goals.

We also conclude that if the PAs wanted a larger share of the market (that may or may not be the case), the program may need to offer higher incentives and develop a more stream-lined process for ROF applications.

5.2 Program implementation findings

While program design is not the study's primary objective, PAs and market experts shared information with the research team that can benefit program evolution. The following are the ancillary findings:

- Program influence was not a primary focus of this study, however some of the interviewees reported that incentives are not sufficient to drive the selection of higher efficiency chillers. The program's relatively low penetration rate, and the market findings that chiller efficiencies slightly exceed code, but do not meet high efficiency thresholds, suggest this might be true. The program should consider researching the incremental costs of a high efficiency chiller compared to an ISP chiller with an eye to modifying future incentives if there is a desire to increase participation rates.

- In addition, the majority of ROF installs do not apply for an incentive due to their quick turn-around time. This presents an opportunity for the program. The program should consider a streamlined and abridged application process for ROF efforts
- Program designers should look at their process to figure out how to engage customers in chiller plant controls improvements as part of a ROF. VFDs are a common and low-cost practice; however, not all the opportunities are captured in chiller replacement projects.
- The market experts anticipate a move to more waste heat recovery. Some also expect to see more geothermal systems used for HVAC. These findings should be considered in future program planning discussions.

5.3 Recommendation and Consideration

The DNV team has the following recommendation and consideration:

Recommendation #1

The evaluators recommend that the ISP standards presented in Tables 1a, 1b, 2, 2b and 3 be incorporated into the Baseline Repository roll-out upon finalization of these results. The ISP findings apply to applications approved in 2022 and going forward until such time that this study is revised or there are subsequent revisions to building code impacting chillers.

Consideration #1

Program designers should consider updating chiller cost research and consider higher incentive to increase the penetration of higher efficiency chillers by making the units more cost competitive. Program designers should also consider whether a streamlined application process might increase participation in the ROF market.