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X1931-5 PSD Commercial Refrigeration Efficiency Update Study

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ABSTRACT

As part of the ongoing project X1931 CT Program Savings Document (PSD) Review and Update, the Connecticut Energy Efficiency Board (EEB) Evaluation Administrators commissioned DNV to update the average coefficient of performance (ACOP) efficiency values of commercial refrigeration equipment for use in the PSD. This report presents the methods and results of research to quantify ACOP efficiency values that represent commercial cooler and freezer refrigeration systems in Connecticut. The PSD uses the ACOP efficiency value to estimate annual energy impacts of measures that include refrigerator LED lighting, evaporator fan controls, evaporator fan motor replacement, and door heater controls. We recommend that the next versions of the PSD replace the preexisting average coefficient of performance efficiency values with the values presented in this study: 1.88 and 3.35 for commercial freezers and coolers, respectively. In parallel with the PSD update, we recommend updates to associated savings calculators and tracking systems to incorporate ACOP values based on this study.

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1 EXECUTIVE SUMMARY

This report presents the results of primary research to update the average coefficient of performance (ACOP) efficiency values for commercial refrigeration systems, in the Connecticut Program Savings Document (PSD). This research study was commissioned by the Connecticut Energy Efficiency Board (EEB) Evaluation Administrators (EA) as part of the project X1931 PSD Review and Update project. The 2021 PSD recommends two ACOP values, one for commercial freezer equipment and one for commercial cooler equipment for use in four measure calculations, refrigerator LED lighting, evaporator fan controls, evaporator fan motor replacement, and door heater controls. The values were developed based on communications with the Nicholas Group, P.C. The objective of this research study is to update the PSD's recommended commercial refrigeration efficiency values to represent the current commercial refrigeration equipment in the state.

1.1 Key Findings

The Connecticut PSD uses refrigeration ACOP efficiency values to estimate savings commercial refrigeration measures such as refrigerated case LED lighting, evaporator fan controls, evaporator fan motor replacement, and door heater controls. For these measures the savings is primarily due to increased efficiency of the upgraded products in refrigerated cases, but there is added savings from reduced load on the refrigeration systems. The ACOP is used to calculate the secondary effects for these measures. Use of site-specific ACOPs is required when available but the PSD provides default values when site-specific values are not known. The use of ACOPs and their default values were introduced in the 2011 PSD and their basis is noted as 2010 correspondence. Prior to 2011, "compressor factors" were used to account for interactive effects for some but not all such measures.

This study involved recalculation of commercial refrigeration ACOP efficiency values based on interviews with site owners and industry experts, refrigeration design documents, manufacturer databases, and compressor operating curves to accurately represent the efficiency of commercial refrigeration systems currently operating in CT. As shown in
Table 1-1, the updated ACOP value for commercial freezers is 8% lower and the updated ACOP value for commercial coolers is 24% higher than the ACOP values recommended in the 2021 version of the PSD. As shown below, using the new ACOP to calculate energy savings for an example measure using both current and updated values, but keeping all other parameters the same, the resulting savings difference is within ±5%.

Table 1-1. 2021 CT PSD ACOP values and updated ACOP values

Description	2021 CT PSD ACOP Values	Updated ACOP Values	% Difference (ACOP value)	% Difference (Example Measure Savings)
Freezer ACOP	2.03	1.88	-8%	3%
Cooler ACOP	2.69	3.35	24%	-5%

1.2 Recommendations

To best characterize the commercial refrigeration systems currently installed and operating in Connecticut, we recommend that future versions of the PSD adopt the average COP values presented in this study.

The commercial refrigeration efficiency ACOP values should be updated in the sections of the 2023 PSD listed in

Table 1-2.

Table 1-2. Recommended changes in the PSD

Description	PSD Reference	Action
Refrigerator LED, C&I Retrofit	Page 109, Table 3-E Page 110, bullet point 2	Update recommended ACOP value for freezers and coolers
Evaporator Fan Controls, C&I Retrofit	Page 153, Table 3-PP Page 154, bullet point 4	Update recommended ACOP value for freezers and coolers
Evaporator Fan Motor Replacement, C&I Retrofit	Page 156, Table 3-SS Page 158, Note [4]	Update recommended ACOP value for freezers and coolers
Door Heater Controls, C&I Retrofit	Page 159, Table 3-UU	Update recommended ACOP value for freezers and coolers

2 INTRODUCTION

The Connecticut PSD uses refrigeration ACOP efficiency values to estimate savings commercial refrigeration measures such as refrigerator LED lighting, evaporator fan controls, evaporator fan motor replacement, and door heater controls. For these measures, the savings is primarily due to increased efficiency of the upgraded products in refrigerated cases but there is added savings from reduced load on the refrigeration systems. The ACOP is used to calculate the secondary effects for these measures. The formulas in Table 2-1 illustrate their use.

Table 2-1. Measures in the PSD affected by the commercial refrigeration efficiency (ACOP) values

Measures Affected	Equation in the PSD
Refrigerator LED, C&I Retrofit	$AKWH = N \times \Delta kW \times h \times \left(1 + \frac{L}{ACOP}\right)$
Evaporator Fan Controls, C&I Retrofit	$AKWH = N \times V \times A \times Pf \times r \times (1 - DP) \times \frac{h}{1000 \, W/_{kW}} \times \left(1 + \frac{1}{ACOP}\right)$
Evaporator Fan Motor Replacement, C&I Retrofit	$AKWH = N \times V \times A \times Pf \times DP \times \frac{h}{1000} \times \left(1 + \frac{1}{ACOP}\right)$
Door Heater Controls, C&I Retrofit	$AKWH = \frac{N \times V \times A \times Pf \times h}{1000 \, W/_{kW}} \text{ x } [1 + 1/ACOP]$

The PSD currently recommends a single ACOP value for commercial freezer equipment and a corresponding value for commercial cooler equipment. Site-specific ACOPs are required when available but the PSD provides default values when site-specific values are not known, which is typical. The use of ACOPs and their default values were introduced in the 2011 PSD. Prior to 2011, "compressor factors" were used to account for interactive effects for some but not all such measures.

The calculations used to develop these values were not available, and the source for these values was ambiguous. The current PSD reads "*are based on communications* with the Nicholas Group, P.C.*". There is no reference associated with the asterisk. DNV was commissioned to calculate these values using actual site-level data that represents commercial refrigeration equipment currently installed in Connecticut.

2.1 Study Objectives

The primary objective of this project was to:

- Calculate refrigeration efficiency (COP) values from manufacturer data of actual, installed commercial refrigeration systems. The approach and calculations were to be refined by expert interviews.
- Aggregate the individual efficiency (COP) values for freezer and cooler systems, respectively, to obtain an average efficiency (ACOP) for each.

3 METHODOLOGY

This section describes the methodologies that DNV used to revise the refrigeration efficiency values. In summary, this study involved gathering and processing compressor data, aggregating it based on system temperature, and weighting COPs by temperature bins to calculate the ACOP. Additionally, DNV conducted interviews with industry experts on refrigeration to refine their approach at each step. Each task completed in this study is presented in following subsections.

3.1 Data Collection

The backbone of DNV's calculation approach was collecting nameplate data for refrigeration systems representative of the systems installed and operating in the state of Connecticut. Rack systems are predominantly found in large grocery stores which require different evaporator temperatures. Packaged refrigeration systems are often in smaller stores serving walk-in coolers/freezers, refrigerated cases, etc. The evaluators reviewed 2018/2019 tracking data for refrigeration system projects conducted under small business (SBEA) and commercial (C&I) programs to see the distribution of refrigeration systems in the state of Connecticut. The underlying assumption here was that the distribution of facilities, and their corresponding systems in the utility tracking data was representative of the distribution of systems in Connecticut. The evaluators found that approximately 90% of utility refrigeration savings come from installations of rack systems. The distribution of rack systems vs packaged systems and their tracked savings are shown in Table 3-1 below:

Table 3-1. Distribution of Rack and Packaged Systems in Utility Tracking Data

System Type	Count (CT)	Tracked Savings (kWh)	% Savings
Rack System	49	3,114,581	91%
Packaged System	30	284,703	9%
Total	79	3,399,284	100%

The final data collection involved recruitment of 27 sites (5 with packaged, and 22 with rack refrigeration systems), of which eight sites had data of sufficient quality to be used for the analysis. Compressor data for 66 compressors across all eight sites were used for this analysis. All compressors used in this study were part of rack systems and findings indicated that majority of the connected refrigeration load in the state of Connecticut comprises of rack systems (>90%, as corroborated in the expert interviews). DNV did not receive complete data for packaged systems to be included in the analysis, as such, packaged systems were not included in the analysis.

Through site-level interviews, DNV collected design drawings which detailed the refrigeration layout of the facility. The equipment specifications were obtained by looking up equipment nameplates on manufacturer databases online, to serve as an input to the analysis. DNV also conducted interviews with refrigeration experts in the industry and in-house, to refine the data collection and analysis process.

Data collection sources are explained in further detail below, while the analysis methodology is explained in section 3.2.

3.1.1 Site Interviews

DNV recruited 16 site contacts associated with 55 facilities across the states of Connecticut and Massachusetts. DNV supplemented site data with refrigeration design documents obtained from existing project files in both Connecticut and Massachusetts. DNV does not anticipate the inclusion of Massachusetts facilities will materially impact the savings since both states share similar facilities (such as grocery store chains) and climate patterns. This was further confirmed by industry experts who claimed that both facilities in both states share a common design process for refrigeration measures and often have the same inputs. Additionally, sites from Massachusetts were included in the analysis because the low response rate from Connecticut-based stores significantly limited the systems in our sample.

Between the site interviews and available project files, DNV gathered information from 27 sites that was complete enough for use in this study. The remaining 28 recruited sites were not included in the study due to unavailability of design documentation through either lack of response from the site contact, or policies preventing them from sharing refrigeration documents with us. After a detailed review of the available information, eight sites were chosen for inclusion in the ACOP analysis, based on amount of adequate data. Multiple follow up calls were made to sites with inadequate amount of data to be able to include them in the analysis. This proved to be difficult and additional information that we requested was not received. Table 3-1 summarizes the facility data collection and Appendix 2 contains the site interview template.

Table 3-2. Site-Specific Data Collection Summary

Site ID	System Type	System Temperature	Facility State	Used in Analysis?
ACOP01	Rack	Cooler and Freezer	CT	Yes
ACOP02	Rack	Cooler and Freezer	CT	Yes
ACOP03	Rack	Cooler and Freezer	CT	Yes
ACOP04	Rack	Cooler and Freezer	CT	No - compressor models unavailable
ACOP05	Rack	Cooler and Freezer	MA	No - design documents/nameplate data unavailable
ACOP06	Rack	Cooler	MA	No - design documents/nameplate data incomplete
ACOP07	Rack	Cooler and Freezer	MA	No - design documents/nameplate data incomplete
ACOP08	Rack	Cooler and Freezer	MA	No - design documents/nameplate data unavailable
ACOP09	Rack	Cooler and Freezer	MA	No - design documents/nameplate data unavailable
ACOP10	Rack	Cooler and Freezer	MA	No - nameplate data incomplete
ACOP11	Packaged	Cooler	MA	No - nameplate data incomplete
ACOP12	Packaged	Cooler and Freezer	MA	No - nameplate data incomplete
ACOP13	Packaged	Cooler	MA	No - nameplate data incomplete
ACOP14	Packaged	Cooler and Freezer	MA	No - nameplate data incomplete
ACOP15	Rack	Cooler and Freezer	MA	No - design documents/nameplate data unavailable
ACOP16	Rack	Cooler and Freezer	MA	Yes
ACOP17	Rack	Cooler and Freezer	MA	Yes
ACOP18	Rack	Cooler and Freezer	MA	No - capacity not available in nameplate data
ACOP19	Packaged	Cooler and Freezer	MA	No - design documents/nameplate data unavailable
ACOP20	Rack	Cooler and Freezer	MA	Yes
ACOP21	Rack	Cooler and Freezer	CT	No - design documents/nameplate data unavailable
ACOP22	Rack	Cooler and Freezer	CT	No - design documents/nameplate data unavailable
ACOP23	Rack	Cooler and Freezer	CT	No - design documents/nameplate data unavailable
ACOP24	Rack	Cooler and Freezer	CT	No - design documents/nameplate data unavailable
ACOP25	Rack	Cooler and Freezer	CT	No - design documents/nameplate data unavailable
ACOP26	Rack	Cooler and Freezer	MA	Yes
ACOP27	Rack	Cooler and Freezer	MA	Yes

3.1.2 Expert Interviews

DNV interviewed four experts in the refrigeration industry. These experts were identified through previous project refrigeration efforts and the connections through DNV staff. The experts helped understand the current distribution of refrigeration systems installed in CT. During the expert interviews, DNV gathered qualitative information on metrics such as typical equipment age and life, O&M of systems, common setups, and common controls. The expert interviews also included discussion of new technology, rate/readiness of adoption, and legislation-driven & energy-driven changes to refrigeration systems. Table 3-3 details the expert interview data collection approach and Appendix 2 contains the expert interview guide template.

Table 3-3. Expert Interview Data Collection Summary

Data Collection	Description
Population Description	List of refrigeration industry experts
Population Size/Sample Frame	4
Type of Sampling	None
Target Sample – Survey Completion	All
Instrument Type	Phone interview
Survey/Interview Length	Approximately 45 minutes
Description of Contact Sought	Refrigeration industry experts

3.1.3 Manufacturer Databases & Equipment Literature

Four predominant refrigeration system manufacturers in the Northeast include Bohn, Emerson Copeland, Hill Phoenix, and Larkin. Since the main driver for system efficiency (ACOP) is the compressor efficiency, and Emerson Copeland is the predominant compressor supplier to refrigeration system manufacturers, DNV used the Emerson Copeland Online Product Information database to gather performance coefficients for each facility’s compressors based on their model numbers and capacities. These performance coefficients along with the AHRI equation (discussed below), serve as the starting point for ACOP calculations.

3.2 Data Analysis and Results

DNV adopted an excel-based, temperature bin analysis model to calculate ACOP values for the refrigeration systems. Data obtained from facilities’ refrigeration system design were a key part of the analysis. The design documents specify compressor models, suction temperature groups, evaporator loads, and condenser capacities, among other variables. A typical site design document is as shown in Figure 3-1 below.

Figure 3-1. Typical Design Document for Rack System

Rev	Date	By	Comments

Design		Receiver		Electrical		Heat Reclaim		Orientation	
Elevation	180	Class	Horiz	Compressor/Motor	208/60/3	Air Heat Reclaim	Yes	Control Panel	Engineer pick
Summer Dry	92	Size	12x96	Control Circuit	208/60/1	Water Heat Reclaim	Yes	Circuits	See Notes
Summer Wet	76	90% Capacity	296			Tot Heat Rejection	261,898		
Winter Dry	30	Level Sensor	Mechanic			Reclaim Availability	130,949	Controller	
Nominal Tons	13.2	Rupture Disc	No			Rejection Factor	1.65	Manufacturer	Encore
Effective Tons	13.2							Model	SMPC

NOTE: Hill PHOENIX assumes no responsibility for the accuracy of the data presented herein. The user must verify all information prior to installation. Stub sizes may differ from field installed line sizes.

● = respective load is powered from the rack

DX Header Loads					Probes		Defrost					Fans			
ID	Load Description	Model	MBTU	Evap	Temp	Defr	Type	Voltage	Amps		KW	Voltage	Amps		KW
A1	15'x30', Grocery Freezer	(1)BML-250	23.0	-25			EL	208/3	23.2	●	8.3	208/1	5.4	●	1.1
A2	11'x12', Bakery Freezer	(1)LLE-102	10.5	-20			EL	208/3	8.6	●	3.1	208/1	3.3	●	.7
A3	16 Drs, Ice Cream	ONRZ	25.6	-23			EL	(1) 208		●	9.3	120/1	8.0		1
A4	15 Drs, Frozen Food	ONRZ	22.5	-13			EL	208/3	41.4	●	14.9	120/1	7.5		.9
A5	15 Drs, Frozen Food	ONRZ	22.5	-13			EL	208/3	41.4	●	14.9	120/1	7.5		.9
A6	12 Drs, Frozen Food	ONRZ	18.0	-13			EL	208/3	33.9	●	12.2	120/1	6.0		.7
A7	12'+2E, Dual Temp Island	OWEZ	12.6	-18			EL	(4) 208		●	7.2	120/1	4.6		.6
A8	Spare w/ Ball valves		0.0	-20			N/A								

	Lights - Sweats					Stub Sizes			Control Valves			Load Line Sizes			Riser	
ID	Amps	KW	Voltage	Amps	KW	Liq	Suct	HG	Liquid	Suction	Hot Gas	Run	Liq	Suct	Height	Size
A1						1/2"	1-5/8"		ME6S140	Ball Valve						
A2						1/2"	7/8"		ME6S140	Ball Valve						
A3	9.6	1.2	120/1	27.8	3.3	1/2"	1-5/8"		ME6S140	Ball Valve						
A4	8.7	1	120/1	25.8	3.1	1/2"	1-3/8"		ME6S140	Ball Valve						
A5	8.7	1	120/1	25.8	3.1	1/2"	1-3/8"		ME6S140	Ball Valve						
A6	7.2	.9	120/1	20.7	2.5	1/2"	1-1/8"		ME6S140	Ball Valve						
A7			120/1	11.2	1.3	1/2"	1-1/8"		Ball Valve	SPORT-B-79						
A8						5/8"	1-3/8"		Ball Valve	Ball Valve						

Summary -25 Suction Group MBTU 134.7 Defrost KW 70.0 Fan KW 5.8 Lt KW 4.1 Sweat KW 13.4
Compressor Capacity 158.9 Loading Ratio 118% 100% of Rack in 8 load(s)

Compressors															
SuctGrp	Design	Pos	Mfg/Model	Voltage	RLA	LRA	HP	RPM	Capacity	Rejection	Pct	UL	HF	CH	VFD Mfg/Model
-25 Suction	-25/105	1	2DF3-030L-TFC	208/3	16.8	102	3	1750	16.5	27.9	10%		●	●	
		2	3DB3A075L-TFC	208/3	31.5	161	7.5	1750	33.2	54.8	21%		●	●	
		3	3DS3A100L-TFC	208/3	42.0	215	10	1750	45.8	75.1	29%		●	●	
		4	4DL3-150L-TSK	208/3	52.6	278	15	1750	63.4	104.1	40%		●	●	

Condenser											
Mfg	Qty	Model	Cap	TD	Fans	Voltage	Amps	FPI	Split	Wt.	LWH
Bohn	1	BRH-066	306	8.6	4	208/3	28.0	10	50/50	1652	125x85x48

Notes: (1) - A3 16 Drs, Ice Cream Multiple electric defrost loads - 1@13.8 208/3, 1@13.8 208/3, 1@8.6 208/3, 1@8.6 208/3 (2) - A7 12'+2E, Dual Temp Island - Use E3S140 solenoid valve for dual temp operation (3) - A7 12'+2E, Dual Temp Island is a dual temp circuit. (4) - A7 12'+2E, Dual Temp Island Multiple electric defrost loads - 1@11.5 208/1, 1@11.5 208/1, 1@5.8 208/1, 1@5.8 208/1

DNV obtained sufficiently complete design documents for eight supermarket facilities across Connecticut and Massachusetts which had rack systems operating at different temperatures. Based on the design documents from the facilities, DNV were able to compile the list of compressors at every facility, and what temperature requirements they served on the evaporator side. Table 3-4 shows the compressor breakdown from the design documents.

Table 3-4. Compressor Counts from Facilities in Analysis

Internal Site ID	Freezer/Cooler	Number of Compressors
ACOP01	Cooler	10
	Freezer	6
ACOP02	Cooler	6
	Freezer	5
ACOP03	Freezer	4
ACOP16	Cooler	3
ACOP17	Cooler	6
ACOP20	Cooler	2
	Freezer	2
ACOP26	Cooler	5
	Freezer	2
ACOP27	Cooler	8
	Freezer	7

DNV included a total of 66 compressors across all eight sites in the calculations of ACOP which accounted for compressors serving both freezer and cooler suction temperatures.

The compressor ratings equation prescribed in the AHRI standard 540, was utilized for each compressor in the sample to calculate its coefficient of performance based on the suction and discharge temperatures[1]. The equation as seen in Figure 3-2 below, uses 10 coefficients to calculate an output at a specified suction and discharge temperature. Each set of coefficients is based on laboratory testing and provided by the manufacturer.

1 Air-Conditioning, Heating, & Refrigeration Institute. Standard for Performance of Positive Displacement Refrigerant Compressors. 2020. AHRI Standard 540.

Figure 3-2. AHRI Compressor Ratings Equation

AHRI STANDARD 540-2020

5.4 *Polynomial Equation*. The polynomial equation that shall be used to present the Individual Published Ratings is a third-degree equation of ten coefficients in the form of:

$$X = C_1 + C_2 \cdot t_S + C_3 \cdot t_D + C_4 \cdot t_S^2 + C_5 \cdot (t_S \cdot t_D) + C_6 \cdot t_D^2 + C_7 \cdot t_S^3 + C_8 \cdot (\cdot\, t_S^2 \cdot t_D) + C_9 \cdot (t_S \cdot t_D^2) + C_{10} \cdot t_D^3 \qquad 1$$

Where:

X = Refrigerating Capacity, Power Input, or Refrigerant Mass Flow Rate
t_D = Discharge dew point temperature, °F, °C, Discharge pressure, psi, bar
t_S = Suction dew point temperature, °F, °C
C_1 through C_{10} = Regression coefficients provided by the manufacturer

DNV obtained compressor coefficients for input power and capacity for each compressor from the Copeland/Emerson manufacturer database[2]. The suction temperature (T_s) and refrigerant for each compressor were identified on the design drawings. Using the coefficients for input power and refrigeration capacity, along with the suction temperature for each compressor, DNV calculated the coefficient of performance (COP) of the compressor. Furthermore, DNV developed an operating COP curve by varying the discharge temperature (t_D) 5°F increments. In addition to the t_s, and refrigerant, the TD (temperature difference) parameter was provided on the refrigeration drawings. The TD factor relates the discharge temperature and outside air temperature (OAT) according to the following equation:

$$t_D = OAT + TD$$

where,

OAT = Outside air temperature (°F)

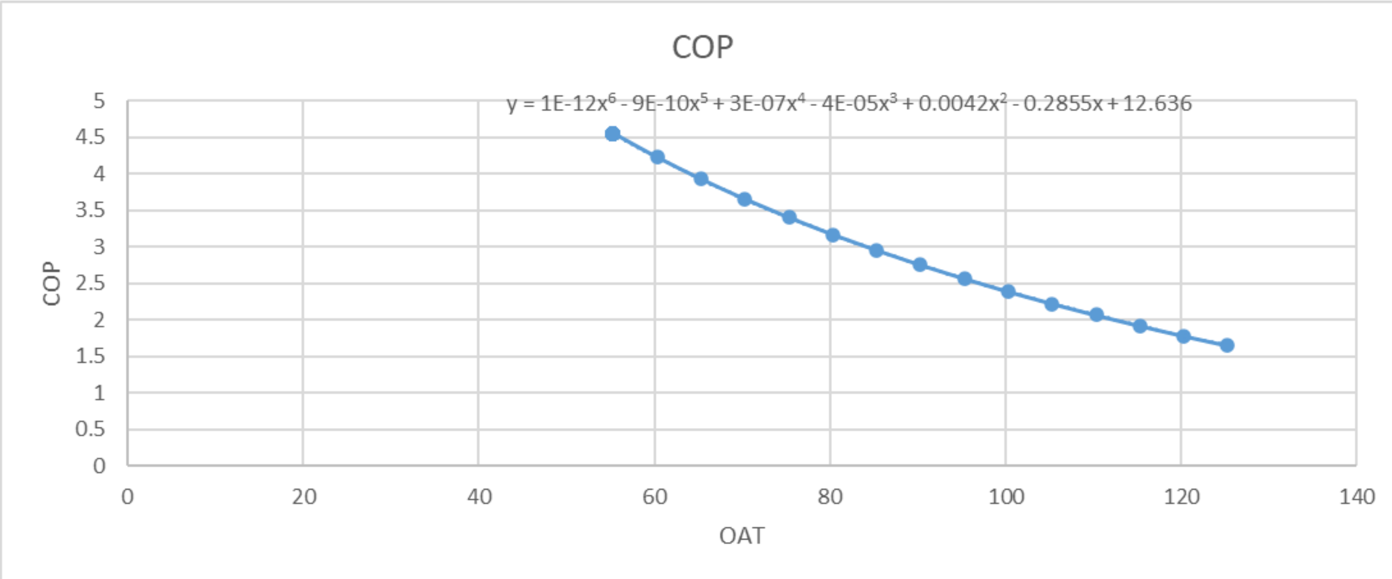
t_D = Discharge temperature (°F)

TD = Temperature difference parameter

With these data and relationships, DNV developed an OAT vs COP curve for each compressor model. An example of one such curve is seen in Figure 3-3 below. Compressor operation was limited to being between the minimum and maximum condensing temperatures provided in the manufacturer literature.

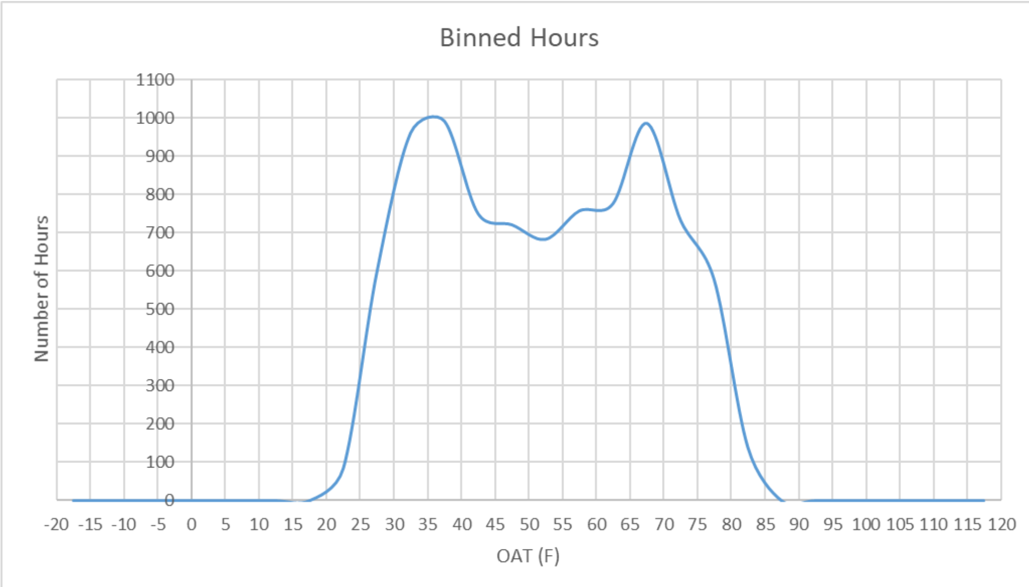
2 Emerson. Copeland Online Product Information. Emerson. [Online] 2020. https://webapps.emerson.com/online-product-information/.

Figure 3-3. Example of a Compressor COP vs OAT Curve



The next step in this process was to calculate an operating efficiency value which accounted for the variation in OAT in the state of Connecticut over a typical year. This was required because the refrigeration system operates at different efficiencies based on the OAT. Lower OAT decreases the discharge temperature (t_D), leading to a higher COP value. DNV used a binned aggregation approach. Average temperature values across all 10 weather stations in the state of Connecticut were obtained from NOAA weather data spanning 2006 - 2020. Each hour of the year was placed in a bin, which spanned 5°F, based on the dry bulb temperature of the hour averaged across all CT weather stations. The hourly distribution can be seen in
Figure 3-4 below.

Figure 3-4. Distribution of Hours based on OAT



The binned weather aggregation of compressor COP values were averaged to get the Compressor ACOP values for freezer and coolers. This is shown in Table 3-5 below.

Table 3-5. Compressor-Only Average COP Values for CT Weather Bins

Description	2021 CT PSD ACOP Values	Weather-Binned Compressor-Only ACOP Values	% Difference (ACOP value)	% Difference (Measure Savings)
Freezer ACOP	2.03	2.77	37%	-9%
Cooler ACOP	2.69	5.46	103%	-14%

The results so far show the averaged, compressor-only efficiencies for compressors at peak operating conditions, typically when they are new. According to interviewed experts and grocery store site contacts, rack systems operating in Northeastern U.S. grocery stores are an average of 15 years old. Mechanical systems' operating efficiency degrade as they age.

In addition to providing an estimate of the average equipment age of refrigeration systems in Northeastern U.S., the experts also shed light on how the performance of these systems would degrade with age. According to experts' interview responses, a 15-year-old typical rack system should be operating at 90% to 70% of its original design efficiency, i.e., at a degradation of 10% - 30%. The variation in degradation of system efficiency is influenced by several factors such as maintenance, climate, quality of installation, to name a few. Based on the expert's responses, DNV applied a 20% reduction factor to the ACOPs to account for efficiency degradation with age.

DNV also conducted literature research on age degradation of efficiencies of mechanical HVAC systems to corroborate the 20% factor. Reviews did not uncover and relevant, recent studies. CADMAC (California Demand-Side Management Measurement Advisory Committee) sponsored a series of persistence and degradation studies in the late 1990s that included HVAC refrigeration systems and components and for which DNV could not find superseding research[3]. This report also estimated a 20% reduction in HVAC operating efficiency for 10- to 20-year-old systems due age of operation via mechanical wear and tear, coil fouling and other failure routes. In Figure 3-5 the highlighted

[3] CADMAC. Summary Report of Persistance Studies: Assessment of Technical Degradation Factors, Final Report. 1999. Report #2030

M03 column shows the technical degradation factors across the lifetime of the measure, as supplied in the CADMAC report.

Figure 3-5. Technical Degradation Factors across Measure Life

M# YEAR	M01 Resid DX AC	M02 Comm DX AC	M03 Oversized Evap Condens
1*	1.00	1.00	1.00
2	1.00	1.00	0.98
3	1.01	1.00	0.96
4	1.01	1.01	0.93
5	1.02	1.01	0.91
6	1.02	1.01	0.89
7	1.03	1.01	0.87
8	1.03	1.01	0.84
9	1.04	1.01	0.82
10	1.04	1.02	0.80
11	1.05	1.02	0.80
12	1.05	1.02	0.80
13	1.06	1.02	0.80
14	1.07	1.02	0.80
15	1.07	1.02	0.80
16	1.08	1.02	0.80
17	1.09	1.02	0.80
18	1.09	1.02	0.80
19	1.10	1.06	0.80
20	1.10	1.08	0.80

This research corroborated the interviewed experts value of reduction in operating efficiency of 20% due to system age.Table 3-66 shows the age-degraded, weather aggregated, averaged, compressor-only efficiency numbers.

Table 3-6. Age-degraded, Weather-Aggregated, Compressor-only ACOP Values

Description	2021 CT PSD ACOP Values	Weather-Binned, Age-Degraded, Compressor-Only ACOP Values	% Difference (ACOP value)	% Difference (Measure Savings)
Freezer ACOP (Compressor Only)	2.03	2.22	9%	-3%
Cooler ACOP (Compressor Only)	2.69	4.37	62%	-10%

The final step to calculate the refrigeration system efficiencies was to account for the condenser fans. No evaporator fan adjustment was made because these fans typically do not change operation as a function of case heat gain and have minor impact on overall system efficiency when compared to compressors and condenser fans. DNV referenced the 2022 CA Title 24 “CASE Report Refrigeration System Opportunities” for the base case specific efficiency of 60

Btuh/W for air-cooled condenser in a supermarket refrigeration system.[4] Based on this specific efficiency, along with compressor efficiency from compressor curves, and the hear rejection, the team calculated the contribution of condenser to the overall system efficiency. The calculations established ratios of condenser to compressor energy, resulting in the following:

- Low Temp (Freezers) = 18.3%
- Med Temp (Coolers) = 30.5%

These condenser fan factors add to the refrigeration system power requirements and reduce its overall ACOP compared to that based on the compressor alone. These are the final ACOP values and are summarized in Table 3-7.

Table 3-7. Age-degraded, Weather-Aggregated, Refrigeration System ACOP Values

Description	2021 CT PSD ACOP Values	Weather-Binned, Age-Degraded, System (Compressor + Condenser) ACOP Values	% Difference (ACOP value)	% Difference (Measure Savings)
Freezer ACOP	2.03	1.88	-8%	3%
Cooler ACOP	2.69	3.35	24%	-5%

The updated ACOP value for commercial freezers is 8% lower than the current PSD value, while the updated ACOP value for commercial coolers is 24% greater than the current PSD value. While these differences in ACOP appear to be significant, the impact on calculated kWh savings for every measure affected by this update is within ±5%.

4 Bellon, T. and D. Scott. “Refrigeration System Opportunities,” Submitted to Energy Solutions under the Codes and Standards Enhancement (CASE) Initiative 2022 California Energy Code, September 2020.

4 CONCLUSIONS AND RECOMMENDATIONS

The PSD currently reports a single set of refrigeration system efficiency ACOP values (2.03 for freezer and 2.69 for cooler). They were calculated using undocumented methods, are at least 10 years old and it is not clear that the values are based on Connecticut systems. This study updates values based on operating refrigeration systems in Connecticut. Age degradation, system-efficiency, and operating conditions have been built into the analysis and documented.

Recommendation: For PSD measures that reduce the heat gain in existing commercial refrigeration equipment such as refrigerated case LED lighting, evaporator fan controls, evaporator fan motor replacement, and door heater controls, update the PSD default ACOP values to be 1.88 for freezers and 3.35 for coolers.

APPENDIX 1: SITE INTERVIEW TEMPLATE

Purpose

The objective of the facility interview survey is to gather refrigeration system information to be used in calculation an average coefficient of performance (ACOP). Interviews will take place over the phone, with email or video call follow-ups as necessary. The primary goal of each interview will be to obtain the site-specific refrigeration design document. The information to be collected from the design document is represented in the data collection form, including parameters such as system type (rack vs. packaged), application (freezer vs. cooler), compressor and condenser quantities, and nameplate performance specifications. Research team will also collect system vintage, location, and facility operation information.

Table 1: Research Objectives Mapped to Questions in This Instrument

Research Objectives	Survey Questions Address the Objectives
Collect system ACOP via photo of design doc	Q1
Categorize system and site	Q2
Gather general industry information	Q3

Instrument and Data Collection Information

Table 2: Overview of Data Collection Approach

Data Collection	Description
Population Description	Eversource Early Retirement Study refrigeration projects (tracking dataset) grouped by site and contact name
Population Size/Sample Frame	60 unique sites; 56 with contact information available
Type of Sampling	Stratified by system type (rack, 92% of savings; or packaged, 8%) Purposeful selection of largest participants in rack group. Random selection of smaller rack and of packaged system participants. Post-selection review will ensure varied representation by facility type and geography. Some convenience sampling is expected.
Target Sample – Survey Completion	10 facilities total; 7 facilities with rack systems (at least three different chains) and 3 facilities with packaged systems
Instrument Type	Phone interview
Survey/Interview Length	Approximately 20 minutes
Description of Contact Sought	Person familiar with refrigeration equipment at the facility. Likely facility/operations personnel, or regional refrigeration managers for larger grocery chains.

Facility Interview Contacts

Facilities will be selected from Eversource Early Retirement Study refrigeration projects tracking dataset. The research team will ensure that sites represent different geographical locations, facility types, and facility sizes. Rack systems, which are almost exclusive to grocery stores, account for 92% of kWh savings from Eversource x1939 refrigeration projects, while the remaining 8% of savings come from packaged refrigeration systems. The research team plans to include at least 3 different grocery store chains to make up the 7 facilities in the "Rack Systems" sample group, for better representation. Similarly, due to the wide variety of packaged systems available, the research team plans to include restaurant, convenience store, and small-services facility types in the interview sample. Facilities will be selected from the dataset below (REDACTED).

Interview Script

Interviewee		**Interviewer**	
Interviewee Company		**Interview Date**	
Interviewee Phone #		**Interviewee email**	

Introduction

Hello, my name is ___ and I am calling from DNV on behalf of the Connecticut Energy Efficiency Board. My company is conducting research on refrigeration systems in Connecticut. This is not a sales call. I see that your facility received refrigeration upgrades through an Eversource energy efficiency program last year, and you are the primary contact. Are you familiar with the refrigeration equipment at your facility?

> **If no:** ok, is there anyone available who is familiar? *We are looking for a facilities/operations manager, general manager, or refrigeration contractor if larger chain. Continue probing until reaching correct person, getting contact of correct person, or dead end.*
>
> **If yes:** great! I'd like to ask a few questions about your refrigeration equipment. Like I said, this is not a sales call and will not affect any prior or future utility incentives. All answers will be kept anonymous. Do you have about 20 minutes now? Are you on-site?
>
> > **If yes to both:** *continue to survey*
> >
> > **If yes to time but not on site and instead in office:** *Ask if design docs are on-site or in office. If in office, continue to survey*
> >
> > **If no:** no problem, when would be a good time to call back? Is this the best number to reach you?

1. Design Document/Screening

1.1 The Connecticut utilities want to update their savings estimates with current real-world data, so we are hoping to better understand the typical efficiency of refrigeration systems in Connecticut. We would like to learn about your refrigeration system's cooling capacity and power. This information will feed into new savings estimates for refrigeration measures. The main information we need will be contained in the refrigeration design document or site-specific refrigeration plans. The design document is typically located in the compressor room (attached to the compressor panels/racks) and will have technical data about each component of the refrigeration system. Are you able to walk there now and take a picture?

If yes: great! Are you to send me the picture via email right now?

If no: could you send me that photo after this call, or ask another employee to do so? Or, if you prefer, we can talk through the information over the phone so that you don't need to send a photo.

If contact able to locate design document but needs to ask permission to send photo, ask for a good contact and time to follow up.

If able to locate design document, but prefers to give information verbally, use DCF to collect system data from the design document.

If unable to locate design document, but familiar with refrigeration equipment, use DCF to collect system data from condenser/compressor nameplates.

If it becomes clear that collecting design document information is not feasible, say thank you and end call.

2. General Facility Information

2.1 What type of system is it, rack or packaged?

2.2 Is this a freezer or cooler system? Do you know what temperature cases the system serves? *Note for interviewer: Low (5F or below), Medium (6-32F), High/cooler (33F or above), choose all that apply.*

2.3 How old is your refrigeration system? *If parts have been replaced at different times, collect as detailed information as possible and use engineering judgement to assign an average vintage after call.*

2.4 Where are your refrigeration components located? *Conditioned vs unconditioned*

If heated: what heating equipment is used in these spaces? What is the heating fuel?

If cooled: what cooling equipment is used in these spaces?

2.5 Do your coolers/freezers operate 24/7 year-round? Are there any times of day or weeks of the year when the refrigeration system is completely shut down?

2.6 Can you explain the refrigeration controls you have in place?

2.7 Is there a desuperheater attached to the refrigeration system for water heating?

2.8 What's the square footage of your facility?

2.9 How old is the building?

3. Industry/Expert Information

Ask the following questions if applicable, especially if the contact is in charge or maintaining and upgrading the refrigeration equipment

3.1 We are gathering information regarding trends in the commercial refrigeration equipment? Have you been involved in the selection/design of your facilities' refrigeration system? If yes, can you please explain what were the main criteria for your selection? Also, can you share the services and resources you would use to size, spec, design and compare the equipment?

3.1.1 Now consider that, you are in the market to replace your current refrigeration (that we just discussed), what type of system would you look for?

Some useful questions to ask during this conversation:

Cost vs EE? Which is higher priority? Are you aware of EE programs and incentives offered by the utilities?

Is there a new refrigerant that you'd like?

Have you seen/heard of the popularity of one type of system over another?

If you have colleagues in the industry, do you know if they are opting for a specific manufacturer and system type over another?

3.2 Are you seeing an increase in energy efficient refrigeration products in the marketplace?

If yes: what do you think is the driving force? *Note: The objective of the question is to identify what is causing the move to EE equipment. Are the manufacturers/distributors pushing EE measures OR are the customers are demanding them OR a combination.*

3.3 (Ask if facility has this rack system) For rack-type refrigeration system what typical COP values are you seeing? Also, can you provide some insight into how typical COP values differ between the freezer vs cooler racks?

System COP is defined as full-load efficiency (including compressors and condenser fans) under design outdoor temperature.

3.4 (Ask if facility has this rack system) For packaged-type refrigeration system what typical COP values are you seeing? Also, can you provide some insight into how typical COP values differ between the freezer vs cooler packaged systems?

Closing

Thank you for taking the time to talk with me today.

If applicable: as a reminder, please send me the photos we discussed. Would you like me to send a follow up email so that you have my contact? *Clarify communication channel, thank, end call.*

APPENDIX 2: EXPERT INTERVIEW TEMPLATE

Objective

The primary objective of these interviews is to hear an insiders' view on the refrigeration industry and understand market trends. This is essential to identify how the market snapshot of refrigeration systems may change in the next several years. Additionally, the research team aims to understand some of the design calculations and operating profiles used by refrigeration manufacturers to model these systems.

Table 1: Research Objectives Mapped to Questions in This Instrument

Research Objectives	Survey Questions Address the Objectives
Gain insight on market trends, typical system parameters, and insider's view of the refrigeration industry.	Q1 through Q10

Instrument and Data Collection information

The research team have set a data collection approach which comprises of interviewing industry experts to understand typical system setups and characteristics. During these interviews, the research team will collect data based on responses to the questions given in section 3 and use it to fine tune the analysis of the facility data.

Table 2: Overview of Data Collection Approach

Data Collection	Description
Population Description	List of Industry experts on refrigeration
Population Size/Sample Frame	4
Type of Sampling	None
Target Sample – Survey Completion	All
Instrument Type	Phone Interview
Survey/Interview Length	Approximately 45 minutes
Description of Contact Sought	Refrigeration industry experts

The expert interviews will take place over the phone, after facility interviews are complete. The research team has identified the following experts to interview (REDACTED).

Instrument: Interview Script

Interviewee		**Interviewer**	
Interviewee Company		**Interview Date**	
Interviewee Phone #		**Interviewee email**	

Introduction

Hello, my name is ___ and I am calling from DNV on behalf of the Connecticut Energy Efficiency Board. My company is conducting research on refrigeration systems in Connecticut. We are interested in hearing insights from industry experts such as yourself.

Would you be open to us recording this interview session? We would like to do so, because some of the questions designed to for an open-ended response which may require some additional review to capture all of your feedback. Also, we would like to include paraphrased versions of some of your responses in the report appendix. They will be anonymized, and your name/contact information will not be included anywhere.

We'll begin with a little more background on our study: we are conducting research to estimate typical efficiencies of commercial refrigeration systems, as measured by their average Coefficient of Performance (COP). We're most interested in systems installed in grocery stores, convenience stores, and restaurants in the state of CT, over the last five years. Warehouses, medical cold storage, and other industrial refrigeration systems are not of interest. Our other research activities have included a literature review and collection of system data from a sample of facilities.

COP can vary by system type, temperature, size, controls, maintenance or other factors. We'd like to keep it simple and develop a COP value based on typical design, so the first step is to understand how to best group the systems. Our preliminary plan is to group them first by coolers vs freezers and then also by packaged (condenser and compressor contained in one package) vs rack systems. Other options considered were larger vs smaller, building type, location in CT, user level of sophistication, and so on.

Questions

1. Do you have any reactions to our grouping approach? How would you group commercial refrigeration systems in CT?

2. Are you seeing any trends in the CT commercial refrigeration sector on a high level? If yes, can you please explain in a few sentences?

   OR

   In your opinion, what would commercial refrigeration systems in Connecticut look like, 5 years from today?

   Some useful prompts to start the conversation:

   Is there a faster shift to a different refrigerant system?

   Are customers going for one type of system over another?

   Are customers opting for a specific manufacturer over another?

   Are some refrigerant types being phased out due to regulations/legislature?

   How are the technologies/approaches evolving to better match the equipment capacity to the load?

3. Are you seeing any trends in the sale/implementation of **rack-type refrigeration systems** at supermarkets?

   If yes: Can you please explain in a few sentences?

4. Are you seeing any trends in the sale/implementation of **packaged refrigeration systems** at restaurants, small businesses, convenience stores?

   If yes: Can you please explain in a few sentences?

5. Can you provide insight into how you've seen these systems typically set up and operated? (Ask for both rack and packaged systems).

   Some useful questions to ask during the conversation:

   Are they fully loaded or partially loaded? How is typical load modulation (if, any) achieved?

   Typical design conditions and control parameters? E.g. Variable condensing temperature controls as a function of outdoor conditions.Staged/split/VFD condenser control, staged/VFD compressor control, floating head pressure control

Design documents?

6. Do you have a database/catalogue/computer program of performance data for the typical systems you install? Do you know of a commonly available resource we can refer to for typical system designs (eg. Full line catalogue for Hussmann, Tyler, etc) in commercial settings? If yes, can you share with us?

   If yes: great! (provide your email address or sharepoint link for them to share)

   If no: No worries!

Do you perform refrigeration contracting/liaising with certain grocery store chains? Can you share typical design documents full-load EER (including compressors and condenser fans) under design outdoor temperature.

6.1. For packaged-type refrigeration system what typical COP values are you seeing for freezer and cooler suction ranges? Please feel free to break them down by typical facility types.

   If No: Could you point us to a resource or catalogue/dataset where we can find this information?

6.2. Are you noticing an increase in overall COP values for C&I refrigeration systems?

   If yes: In your opinion, what are the main reasons for the improvement of system COP values that we are seeing and will see in the future? And are you seeing a trend?

   Some useful questions to ask during the conversation:

   Ask how full load/part load COP values are trending overall, and for different systems

   Ask how COP values are trending in rack vs packaged systems.

   Ask how COP values are trending in Freezer vs Cooler applications within each of the rack/packaged systems.

   Ask about new refrigerants (like CO2) and how they are improving COPs. Are we expecting new refrigerants to come out in the next couple of years?

   Game-changer technology of the industry currently being installed/implemented?

   Try to get an information that can be interpreted like this: "Since the CO2 refrigeration systems have gained a lot of popularity in the last 5 years, we have seen them improve much more than say, R-22 systems from COP 1.5 to COP 4.5 in 5 years."

Closing

Thank you very much for your time today.

If applicable: I look forward to receiving the resources we spoke about. Would you like me to send a follow up email so that you have my contact? *Clarify communication channel, thank, end call.*

About DNV

DNV is a global quality assurance and risk management company. Driven by our purpose of safeguarding life, property and the environment, we enable our customers to advance the safety and sustainability of their business. We provide classification, technical assurance, software and independent expert advisory services to the maritime, oil & gas, power and renewables industries. We also provide certification, supply chain and data management services to customers across a wide range of industries. Operating in more than 100 countries, our experts are dedicated to helping customers make the world safer, smarter, and greener.