Project Report

Daily Energy Consumption of Self-Contained Commercial Refrigeration Equipment

CR24PGE115

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Credits

We are grateful to Mary Anderson and Mark Alatorre of PG&E's Codes and Standards project management and technical advisory team for their support of this work. We appreciate the work of Fernando Recino, Taras Budnik, and Rachel Schwanekamp at Intertek's Columbus lab for their testing support. Thanks to Holly White for her technical review of this report.

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INTRODUCTION

OVERVIEW

On October 10, 2023, the U.S. Department of Energy (DOE) published a Notice of Proposed Rulemaking (NOPR) and Technical Support Document (TSD) for Energy Conservation Standards for Commercial Refrigerators, Freezers, and Refrigerator-Freezers (CRE).[1,2] DOE proposed CRE standards at Trial Standard Level (TSL) 5. The NOPR also proposed establishing standards for chef bases for the first time. DOE based its proposed chef base standards on an ambient test temperature of 86.0 ± 2.0°F (86°F) instead of 75.2 ± 2.0°F (75°F) as established by EPCA during the initial test procedure for CRE, effective January 1, 2005.[3]

DOE did not provide test data in its NOPR or TSD. In its comments to the NOPR, the CA IOUs stated their intention to conduct laboratory testing and selective teardowns on chef bases and vertical self-contained equipment to support DOE's CRE standards rulemaking.

The CA IOUs conducted testing at Intertek's Columbus, Ohio, location to evaluate the energy use of vertical closed solid self-contained CRE (vertical CREs) and chef bases. Vertical CREs were tested to evaluate energy use relative to DOE's proposed standards for this equipment class and to assess food safety concerns raised by several stakeholders. For example, some stakeholders suggested that higher-efficiency vertical CREs could move the industry towards smaller compressors and that smaller compressors may not be able to maintain cabinet temperatures that meet food safety requirements at higher ambient temperatures or with more frequent door openings.[4,5] Chef bases were tested at 75°F and 86°F to evaluate the impact of increased ambient test temperatures on the equipment's energy consumption.

This project was developed and implemented by the team members shown in Table 1.

[1] Energy Efficiency and Renewable Energy Office. "2023-10-10 Energy Conservation Program: Energy Conservation Standards for Commercial Refrigerators, Freezers, and Refrigerator-Freezers; Notice of Proposed Rulemaking and Announcement of Public Meeting." Regulations.gov, October 9, 2023, https://www.regulations.gov/document/EERE-2017-BT-STD-0007-0056.

[2] Energy Efficiency and Renewable Energy Office, "2023-09 Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Commercial Refrigeration Equipment, September 2023 (NOPR)," Regulations.gov, September 28, 2023, https://www.regulations.gov/document/EERE-2017-BT-STD-0007-0051

[3] Cornell Law School, "42 U.S. Code § 6314 - Test Procedures," Legal Information Institute, n.d., https://www.law.cornell.edu/uscode/text/42/6314.

[4] Energy Efficiency and Renewable Energy Office. "2023-12-11 Comment response to the published Notice of proposed rulemaking and announcement of public meeting." Regulations.gov, December 11, 2023, https://www.regulations.gov/comment/EERE-2017-BT-STD-0007-0083.

[5] Energy Efficiency and Renewable Energy Office. "2023-12-11 Comment response to the published Notice of proposed rulemaking and announcement of public meeting." Regulations.gov, December 11, 2023, https://www.regulations.gov/comment/EERE-2017-BT-STD-0007-0082.

Table 1: Research Team	
Company	**Role**
Pacific Gas & Electric (PG&E)	Project Sponsor, Program Administrator
2050 Partners	Project Manager
Energy Solutions	Project Administrator
Intertek	Test Lab
Carl Cochran Consulting	Subject Matter Expert

Purpose

The purpose of this project is to assess the performance and design options of the most efficient vertical CRE on the market and popular chef bases. This report summarizes laboratory test results to support ongoing DOE regulatory processes and future efforts undertaken by the California Energy Commission (CEC), DOE, or other rulemaking bodies.

Objectives

The objectives of this testing include the following:

- **Evaluate Vertical CRE Energy Use**: Assess energy use of the most efficient vertical CRE available in the U.S. market and address food safety concerns documented by several stakeholders during DOE's rulemaking process for energy conservation standards.

- **Evaluate Chef Base Energy Use**: Analyze the energy use of popular chef base models, which are not currently required to meet an energy consumption standard.

- **Quantify Ambient Temperature Impacts**: Measure the increase in chef base energy use when ambient test temperature is increased from 75°F to 86°F.

KEY FINDINGS

VERTICAL FREEZERS

1. All six tested units met DOE's current daily energy consumption (DEC) standard and the current ENERGY STAR® specification for vertical freezers.
2. Tested energy consumption was not a function of price. Less expensive units (under $5,000) performed as well as more expensive units ($5,000-$8,500).
3. Three vertical freezers were tested under a modified NSF 7 test designed to more closely simulate temperature and door openings in hot kitchens (100°F).[6] Two of the three freezers met the modified NSF 7 temperature criteria, maintaining an integrated average of all test simulator temperatures between -2°F and +2°F over the 24-hour test.
4. Daily energy use under the modified NSF 7 test was approximately two times greater than that obtained under DOE test procedure conditions.

VERTICAL COOLERS

1. All nine tested units met DOE's current DEC standard for vertical coolers, and seven units met the current ENERGY STAR specification.
2. Tested energy consumption performance was not a function of price. Less expensive units (under $3,000) performed as well as more expensive units ($3,000-$5,500).
3. Four vertical coolers were tested using the modified NSF 7 test. All four units met the modified NSF 7 temperature criteria with average temperatures less than 41°F across all sensors over the 24-hour test and with no test simulator temperatures greater than 43°F.
4. Daily energy use under the modified NSF 7 test was approximately two times greater than that obtained under DOE test procedure conditions.

CHEF BASES

1. Two of the five tested chef bases (one cooler and one freezer) did not perform as expected and their energy use results have been removed from this report.
2. Energy use for the remaining chef base freezer increased by 32% when the ambient temperature was increased from 75°F to 86°F.
3. Energy consumption for the two remaining chef base coolers rose by 33% and 50%, respectively, when the ambient temperature was increased from 75°F to 86°F.

[6] The NSF 7 test for solid door equipment specifies an unloaded unit, a four-hour duration, and no door openings. The study's modified NSF 7 test retains the ASHRAE 72 test load, door opening procedure, and 24-hour duration specified in the DOE test procedure. This modified test increases the ambient temperature to 100°F, as defined in NSF 7. For additional details on the modified NSF 7 test, refer to the Vertical CREs Methods section.

METHODS

VERTICAL CREs

The CA IOUs tested vertical CRE to determine available and usable volume, evaluate performance according to the current DOE test procedure, and assess whether internal cabinet temperatures could meet stringent criteria under repeated door openings at a high ambient temperature.

The CA IOUs tested 15 self-contained units using the September 2023 DOE test procedure. The units included nine medium-temperature vertical closed solid self-contained units or vertical coolers (defined as VCS.SC.M by DOE) and six low-temperature vertical closed solid self-contained freezer units or vertical freezers (defined as VCS.SC.L by DOE).[7] Intertek's Columbus, Ohio, facility tested all units between November 2023 and August 2024. We selected these equipment classes because they are two of the most popular CRE categories based on DOE's shipment analysis.[8]

As of November 9, 2023, the selected vertical CRE units had among the lowest energy consumption listed in the DOE Compliance Certification Database (CCD) for the most common sizes: 18-22 ft^3 for one-door units and 40-45 ft^3 for two-door units.[9] We selected vertical CREs from nine manufacturers, including U.S. and international companies. Vertical CRE units from overseas manufacturers are often rebranded and sold in the U.S. by different retailers. All units use R-290 as the refrigerant, except Unit 11, which uses R-600A.

We also subjected seven vertical CREs (four coolers and three freezers) to a modified NSF 7 test, selecting units with compressors less than or equal to one-quarter horsepower (hp) for coolers and less than or equal to one hp for freezers.[10]

The NSF 7 storage refrigerator and freezer test takes place with the unit unloaded, lasts for four hours, and includes no door openings. To fully stress the vertical CRE compressors and to better simulate conditions in especially hot commercial kitchens, we included a test load (60-80% available volume), door opening procedure, test simulator locations, and a test duration of 24 hours, all as specified in the DOE test procedure. We raised the ambient temperature to 100°F, as required by the NSF 7 test for storage refrigerators and freezers. We also developed modified internal temperature criteria for coolers and freezers consistent with the NSF 7 temperature criteria. Vertical coolers would meet the modified NSF 7 test criteria if all test simulator temperatures average less than 41°F for the test duration and if no sensors record readings greater than 43°F. Vertical freezers would meet the modified

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[7] Appendix B to Subpart C of Part 431, Title 10

[8] Energy Efficiency and Renewable Energy Office, "2023-09 Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Commercial Refrigeration Equipment, September 2023 (NOPR)," pg. 9-12, Regulations.gov, September 28, 2023, https://www.regulations.gov/document/EERE-2017-BT-STD-0007-0051

[9] Energy Efficiency and Renewable Energy Office. "U. S. Department of Energy's Compliance Certification Database." Regulations.doe.gov, Accessed November 9, 2023, https://www.regulations.doe.gov/certification-data.

[10] NSF/ANSI 7-2023 outlines cold food safety requirements, including testing units at the extreme ends of the ambient temperature range.

NSF 7 test criteria if the integrated average of all test simulator temperatures remains between -2°F and +2°F throughout the test.

We also assessed the design options in nine units (seven coolers and two freezers) through non-destructive teardowns and manufacturer discussions to understand the design path different manufacturers used to reduce vertical CRE energy consumption.

Table 2 summarizes selected vertical coolers and freezers and their associated characteristics. Values were rounded to maintain unit anonymity. For freezers, "low" cost is less than $5,000 and "mid" cost is between $5,000 and $8,500. For coolers, "low" cost is less than $3,000 and "mid" cost is between $3,000 and $5,500.

Table 2: Selected Vertical Units

Unit #	Temp	Doors	Price	Dimensions (in) (W x D x H)	Rated Volume Range (ft^3)	Rated DEC (kWh/day) (rounded)
1	Freezer	2	Mid	57 x 29 x 82	40 – 45	7
2	Freezer	2	Low	54 x 33 x 82	40 – 45	5
3	Freezer	2	Mid	54 x 30 x 83	40 – 45	5
4	Freezer	2	Mid	52 x 33 x 83	40 - 45	7
5	Freezer	2	Low	54 x 81 x 82	40 – 45	7
6	Freezer	2	Mid	52 x 34 x 85	40 - 45	7
7	Cooler	1	Mid	27 x 30 x 78	15 – 25	1
8	Cooler	1	Low	27 x 32 x 82	15 – 25	1
9	Cooler	1	Low	27 x 33 x 82	15 – 25	1
10	Cooler	1	Low	29 x 26 x 83	15 - 25	1
11	Cooler	1	Mid	27 x 30 x 78	15 – 25	1
12	Cooler	1	Mid	27 x 33 x 83	15 – 25	2
13	Cooler	2	Mid	54 x 30 x 78	40 – 45	1
14	Cooler	2	Mid	52 x 35 x 83	40 – 45	2
15	Cooler	2	Low	54 x 32 x 83	40 – 45	1

Chef Bases

The CA IOUs evaluated five chef bases: two freezers and three coolers. We determined the DEC at 86°F ambient temperature utilizing the current DOE test procedure and then repeated the same test procedure at an ambient temperature of 75°F. All tested equipment is commercially available in the United States, uses R-290 (propane) or R-454A refrigerant, and has two drawers.

We selected the five representative chef base units based on the following factors:

- **Unit width of 48 inches:** the most popular size
- **Unit popularity**: based on expert feedback and the number of reviews on retail sites
- **Differences in design features impacting efficiency:**
    - Compressor capacity and type
    - Refrigerant
    - Coil efficiency
    - Defrost technology
- **Various manufacturers**
- **Price range**

Table 3 summarizes the chef bases selected for testing and their associated characteristics.

Table 3: Selected Chef Bases

Unit #	Temp	Doors	Refrigerant	Price	Dimensions (in.) (W x D x H)
16	Freezer	2	R-290	Mid	48 x 35 x 24
17	Freezer	2	R-454A	Mid	48 x 33 x 26
18	Cooler	2	R-290	Low	48 x 32 x 27
19	Cooler	2	R-290	Mid	48 x 34 x 27
20	Cooler	2	R-290	Mid	48 x 33 x 25

RESULTS

VERTICAL FREEZERS

COMPONENTS AND DESIGN OPTIONS

During testing, we collected design option information for each unit to understand the strategies manufacturers used to minimize vertical freezer energy consumption.

Table 4 presents the additional information collected for each vertical freezer, and Table 5 provides further design details for two vertical freezers.

TABLE 4: ADDITIONAL INFORMATION FOR TESTED VERTICAL FREEZERS

Unit #	Temp	Condenser Location	Compressor Horsepower	Defrost Type	Has Evaporator Fan Control?	Selected for Modified NSF Test?
1	Freezer	Top	0.5	Adaptive	No	Yes
2	Freezer	Bottom	1.0	Timed	No	No
3	Freezer	Bottom	0.67	Timed	No	No
4	Freezer	Top	0.67	Timed	Yes	Yes
5	Freezer	Top	1.29	Timed	No	Yes
6	Freezer	Top	0.75	Adaptive	Yes	No

Table 5: Design Options For Select Vertical Freezers		
Unit #	**3**	**4**
Compressor Type	Single speed	Single speed
Evaporator Fan Motor Type[11]	ECM	ECM
Evaporator Fan Blade Geometry	5 blade, 7 in. dia.	5 blade, 7 in. dia.
Evaporator Fan Airflow Direction	Straight down	Angled toward front
Condenser Fan Motor Type	ECM	ECM
Condenser Fan Blade Geometry	4 blade, 9 in. dia.	4 blade, 9 in. dia.
Insulation Thickness (in.)	2	2
R-290 charge (g)	130	139

Test Results

Table 6 presents the tested volume, the tested DEC, and whether the vertical freezers met the modified NSF 7 internal temperature criteria. We used tested volumes to calculate each unit's current DEC standard and ENERGY STAR specification.[12] Test simulator loading ranged from 67% to 76% of net usable volume, meeting the 60-80% loading requirement specified in the DOE test procedure. Additionally, some operation manuals permit product loading on the floor, while others do not, affecting the unit's net usable volume.

Table 6: Test Results for Vertical Freezers

Unit #	Tested Volume (ft^3)	Tested DEC (kWh/day)	Current DEC Standard (kWh/day)	ENERGY STAR Specification	Meets Modified NSF 7 Temperature Criteria?
1	41.95	7.24	10.61	8.93	No
2	41.80	6.05	10.58	8.89	N/A
3	44.04	6.07	11.07	9.47	Yes
4	41.50	5.93	10.51	8.81	Yes
5	42.52	7.09	10.73	9.08	N/A
6	46.44	9.71	11.60	10.09	N/A

[11] ECM = Electronically Commutated Motor, PSC = Permanent Split Capacitor Motor
[12] 10 CFR 431.66; ENERGY STAR, "Commercial Refrigerators and Freezers Specification V.5.0," https://www.energystar.gov/products/spec/commercial_refrigerators_and_freezers_specification_version_5_0_pdf.

All six vertical freezers tested met this equipment class's current DOE standard and ENERGY STAR specification. Energy consumption and unit price were not correlated. Unit 6 met the test procedure specifications and tolerances but had potential issues with its adaptive defrost controls. This unit defrosted more than 10 times during the 24-hour test period, while the other unit with adaptive defrost (Unit 1) defrosted four times during the same period.

Figure 1 shows tested DEC as a function of tested freezer volume. The data presented are relative to the current DOE standard and ENERGY STAR specification.

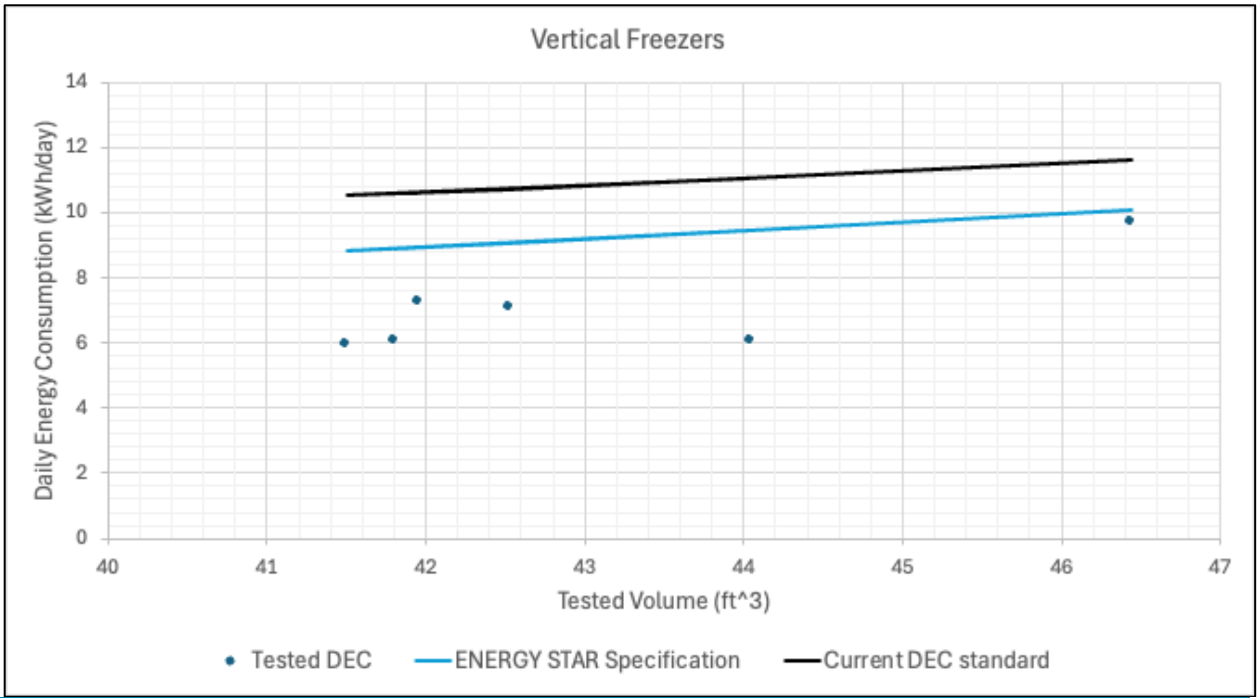

FIGURE 1: TESTED DEC VS. TESTED VOLUME FOR VERTICAL FREEZERS

We also tested three vertical freezers under the modified NSF 7 test conditions. Unit 1 had an average internal temperature of 4.9°F, higher than the maximum of + 2°F allowed by the modified NSF 7 interior temperature criteria.[13] A vertical freezer met the modified NSF 7 test criteria if the integrated average of all test simulator temperatures remained between -2°F and +2°F throughout the test. Daily energy use under the modified NSF test was approximately double that of the DEC under the DOE test procedure conditions.

Figure 2 shows the integrated average internal test simulator temperature versus compressor horsepower for vertical freezers tested under the modified NSF 7 test conditions.

[13] We would like to stress that, due to the stringent nature of the modified NSF 7 compared to the standard NSF 7 test for storage freezers, a unit's failure to meet modified NSF 7 internal temperature criteria should not by itself be considered a food safety concern.

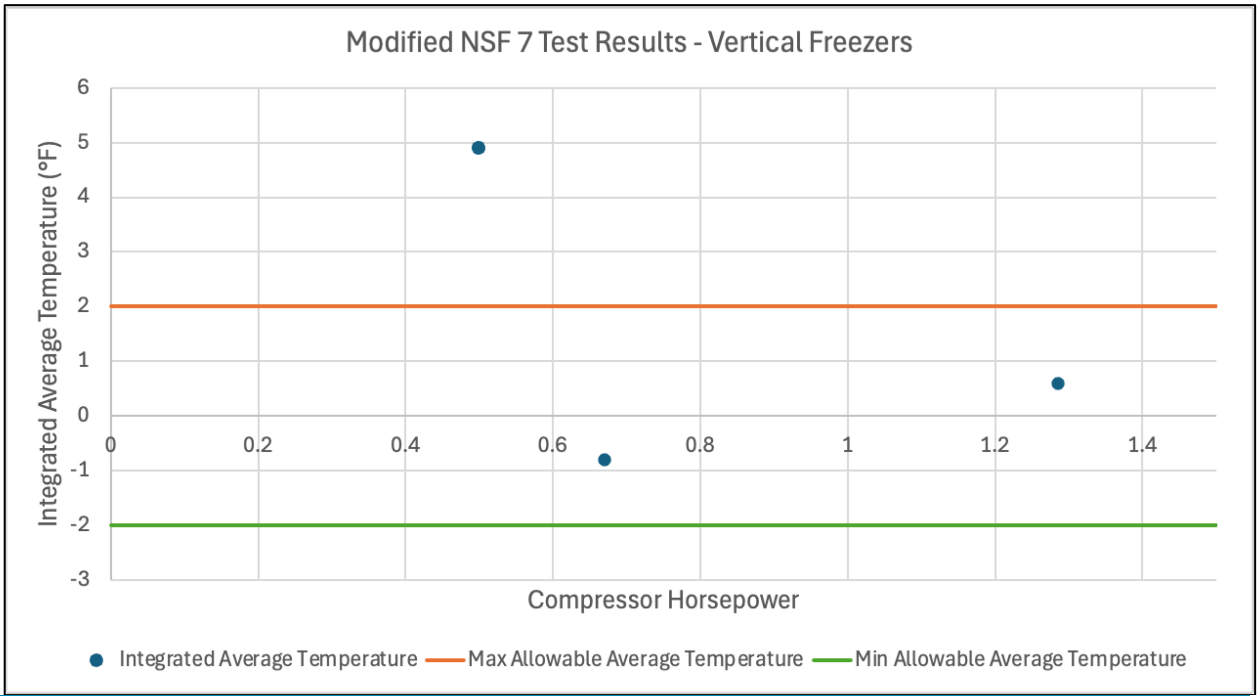

Figure 2: Integrated Average Internal Temperature vs. Compressor Horsepower for Vertical Freezers That Were Subjected to a Modified NSF 7 Test

Vertical Coolers

Components and Design Options

During testing, we collected design option information for each unit to understand the strategies manufacturers used to minimize vertical cooler energy consumption.

Table 7 presents additional information collected for each vertical cooler, and Table 8 shows further details for six vertical coolers. We suspect that differences in energy use among the six units in Table 8 are primarily due to the rated compressor coefficient of performance (COP). However, variations in evaporator and condenser fan motors may also contribute to energy use differences. All evaporators and condensers had axial fans, and all condensers were tube and fin style.

TABLE 7: ADDITIONAL INFORMATION FOR TESTED VERTICAL COOLERS

Unit #	Temp	Condenser Location	Compressor Horsepower	Defrost Type	Has Evaporator Fan Control?	Selected for Modified NSF Test?
7	Cooler	Bottom	0.25	Off-cycle	Yes	Yes
8	Cooler	Bottom	0.25	Timed	Yes	No
9	Cooler	Bottom	0.167	Adaptive	No	Yes
10	Cooler	Bottom	0.2	Timed	Yes	No
11	Cooler	Bottom	0.125	Timed	Yes	Yes
12	Cooler	Top	0.25	Timed	Yes	No
13	Cooler	Bottom	0.2	Timed	Yes	Yes
14	Cooler	Top	0.33	Timed	Yes	No
15	Cooler	Bottom	0.5	Timed	No	No

Table 8: Design Options for Select Vertical Coolers

Unit #	7	8	9	10	11	12	13
Compressor Type	Single speed	Single speed	Single speed	Single speed	Single speed	Single speed	Single speed
Compressor COP (ASHRAE)[14]	2.25	1.99	2.25	1.68	*Not reported*	*Not reported*	*Not reported*
Compressor HP	0.25	0.25	0.167	0.2	0.125	0.25	0.2
Evaporator Fan Motor Type[15]	ECM	PSC	ECM	PSC	ECM	ECM	ECM
Evaporator Fan Blade Geometry	5 blade, 9 in. dia.	5 blade, 7.75 in. dia.	5 blade, 9 in. dia.	5 blade, 7 in. dia.	5 blade, 7 in. dia.	5 blade, 7 in. dia.	5 blade, 7 in. dia.
Evaporator Fan Airflow Direction	Straight down	Straight down	Angled toward front	Angled toward front	Angled toward front	Angled toward front	Angled toward front
Condenser Fan Motor Type	ECM	PSC	PSC	PSC	ECM	ECM	ECM
Condenser Fan Blade Geometry	5 blade, 8 in. dia.	5 blade, 9 in. dia.	4 blade, 7 in. dia.	4 blade, 9 in. dia.	4 blade, 9 in. dia.	4 blade, 9 in. dia.	4 blade, 9 in. dia.
Capillary Tube Outer Diameter (in.)	0.1895	0.125	0.113	0.0975	*Not reported*	*Not reported*	*Not reported*
Insulation Thickness (in.)	2	2	2	2.5	2	2	2
R-290 charge (g)	94	72	85	75	75	79	100

[14] COP reported by compressor manufacturer according to ANSI/ASHRAE 23 test standard.
[15] ECM = Electronically Commutated Motor, PSC = Permanent Split Capacitor Motor

Test Results

Table 9 presents the tested volume, the tested DEC, and whether the vertical cooler met the modified NSF 7 internal temperature criteria. We used tested volumes to calculate each unit's current DEC standard and ENERGY STAR specification. Test simulator loading ranged from 61% to 80% of net usable volume, meeting the 60-80% loading requirement specified in the DOE test procedure. Additionally, some operation manuals permit product loading on the floor, while others do not, affecting the unit's net usable volume.

Table 9: Test Results for Vertical Coolers

Unit #	Tested Volume (ft^3)	Tested DEC (kWh/day)	Current DEC Standard (kWh/day)	ENERGY STAR Specification	Meets Modified NSF 7 Temperature Criteria?
7	18.74	0.84	2.30	1.39	Yes
8	18.51	1.22	2.29	1.38	N/A
9	19.04	0.93	2.31	1.40	Yes
10	21.29	1.72	2.42	1.51	N/A
11	18.75	0.93	2.30	1.39	Yes
12	21.59	1.10	2.44	1.53	N/A
13	42.83	1.83	3.50	2.59	Yes
14	44.34	2.54	3.58	2.67	N/A
15	43.68	2.72	3.54	2.63	N/A

All nine vertical coolers met the current DOE standard for this equipment class, but units 10 and 15 did not meet the current ENERGY STAR specification. Less expensive units performed as well as more expensive units.

Figure 3 shows tested DEC as a function of tested volume for vertical coolers. The test data presented are relative to the current DOE standard and ENERGY STAR specification.

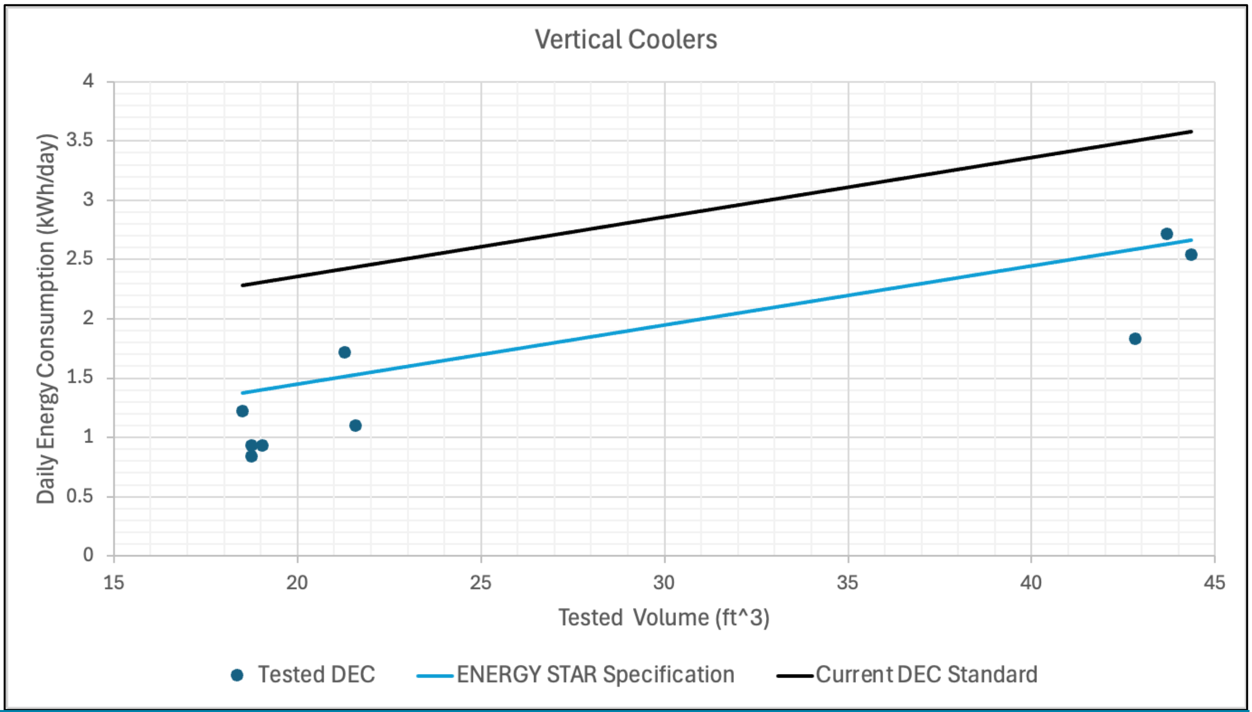

Figure 3: Tested DEC vs. Tested Volume for Vertical Coolers

Four of these vertical coolers were also tested under the modified NSF 7 test. All four units met the modified NSF 7 temperature criteria, with integrated average internal temperatures below 41°F and no individual test simulator temperatures exceeding 43°F. Daily energy use under the modified NSF test was approximately double that of the DEC under the DOE test procedure conditions.

Figure 4 shows the warmest average internal test simulator temperature versus compressor horsepower for vertical coolers tested under the modified NSF 7 test conditions. Rated compressor horsepower did not correlate with maximum internal temperatures during the modified NSF 7 test.

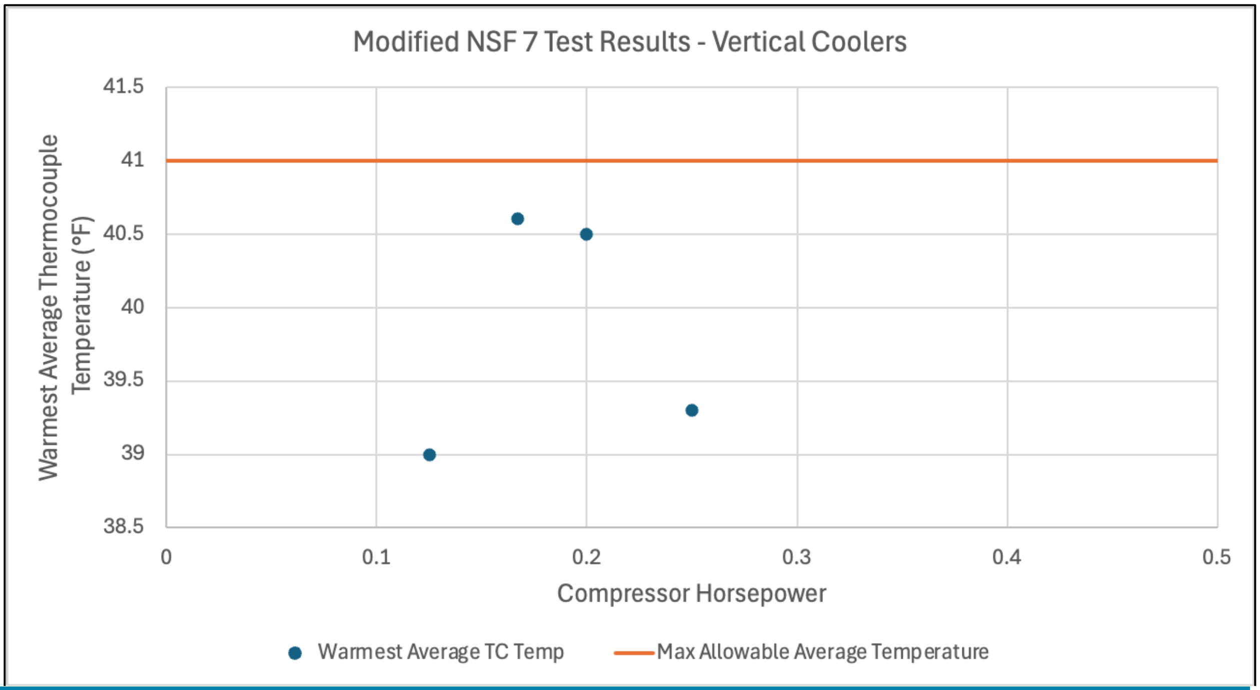

Figure 4: Warmest Average Internal Test Simulator Temperature vs. Compressor Horsepower for Vertical Coolers That Were Subjected to a Modified NSF 7 Test

Chef Bases

Table 10 presents test results at 75°F and 86°F for selected chef bases and the percentage increase in DEC from 75°F to 86°F.

Table 10: Test Results for Chef Bases

Unit #	Temp	Compressor Horsepower	Defrost Type	Tested Volume (ft^3)	DEC @ 75 °F	DEC @ 86 °F	% Increase in DEC @ 86 °F
16	Freezer	0.5	Adaptive	8.84	3.34	4.40	31.7%
17	Freezer	*Not reported*	Timed (Hot Gas)	5.54	-	-	-
18	Cooler	0.14	Timed	8.28	0.92	1.38	50.0%
19	Cooler	0.25	Timed	7.87	0.86	1.14	32.6%
20	Cooler	0.25	Timed	7.24	-	-	-

Unit 17's compressor operated at 100% runtime during the 86°F test (excluding defrost periods) and could not maintain the required internal temperatures.[16] Although the unit

[16] DOE's test procedure requires integrated average internal temperatures between −2°F and +2°F, while Unit 17's integrated average internal temperature was 2.8°F.

maintained internal temperatures during the 75°F test, we are still investigating its performance and have not presented its DEC results.

Unit 20’s condenser was replaced under warranty before testing because it could not maintain the required temperature. We are evaluating whether this unit may have additional technical issues and have not presented its DEC results.

For the remaining chef base freezer, the tested increase in energy use from 75°F to 86°F was 32%, while the tested increase for chef base coolers ranged from 33% to 50%.

Future Opportunities

To expand on this dataset and make more data publicly available for future rulemakings, the CA IOUs may conduct additional testing on the same or additional CRE units. Some test plans under consideration include the following:

1. **Test existing vertical coolers and freezers** under the formal NSF 7 test for storage refrigerators and freezers (units with solid doors) and compare results to those obtained using the modified NSF 7 test discussed here.
2. **Assess the impact of loading on energy consumption**. DOE's current test procedure specifies loading between 60% and 80% of a unit's usable volume.
3. **Evaluate the energy consumption of preparation tables**. DOE finalized a test procedure for preparation tables in October 2023 but has not proposed a standard for this equipment.