Work Paper PGECOREF130
ULT Freezers
Revision #0

Pacific Gas & Electric Company

Customer Energy Solutions

High Efficiency Ultra-Low Temperature Freezers

Measure Codes RF006, RF007

August 7, 2017

AT-A-GLANCE SUMMARY

Measure Codes	RF006, RF007
Measure Description	Installation of high efficiency ultra-low temperature (ULT) freezers RF006 : ULTRA-LOW TEMPERATURE FREEZER, 15 TO < 24 CUBIC FEET RF007 : ULTRA-LOW TEMPERATURE FREEZER, 24 TO 29 CUBIC FEET
Base Case Description	Industry Standard Practice (ISP): standard efficiency ULT freezers with dual cascade refrigeration system
Units	Each
Energy Savings	Refer to Table 17 for summary and work paper savings summary document PGECOREF130 R0.xlsx[1] for comprehensive list.
Full Measure Cost ($/unit)	N/A
Incremental Measure Cost ($/unit)	RF006: ULT 15 TO < 24 CUBIC FEET - $2,135 RF007: ULT 24 TO 29 CUBIC FEET - $1,790
Effective Useful Life	12 years (GrocDisp-FixtDoors)
Measure Installation Type	Replace on Burnout or New Construction (ROBNC)
Net-to-Gross Ratio	0.85 (DEER NTGR ID: ET-Default)
Important Comments	

REVISION HISTORY

Rev	Date	Author (Company)	Summary of Changes
0	8/7/17	Yin Yin Wu, PE (BASE Energy, Inc) Danielle Dragon, PE, CEM, CDSM (PG&E) Zyg Kunczynski (PG&E)	This is an original work paper.

COMMISSION STAFF AND CAL TF COMMENTS

Rev	Party	Submittal Date	Comment Date	Comments	WP Developer Response

Cal TF website: http://www.caltf.org/

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SECTION 1. GENERAL MEASURE & BASELINE DATA

1.1 BACKGROUND AND MEASURE DESCRIPTION

Ultra-low temperature (ULT) freezers are primarily used in labs at universities, biotech companies, biopharmaceutical companies, hospitals and medical testing centers to store samples at temperatures between -70 °C and -80 °C (-94 °F and -112 °F).

On August 31, 2016, My Green Lab, Fisher-Nickel, Inc., and kW Engineering published a report on ULT freezers entitled *Ultra-Low Temperature Freezers: Opening the Door to Energy Savings in Laboratories*.[2] This report was managed by Pacific Gas and Electric Company, Southern California Edison and San Diego Gas and Electric Company under ET project numbers ET14PGE1721, ET16SCE1060 and ET15SDG1092. It will be referred to in this work paper as the "ET Study".

According to the ET Study, there are an estimated 58,000 ULT freezers in California alone, consuming 400 million kWh/year. For perspective, replacing 10% of the existing installed base with more efficient models could save 49 million kWh annually (ET Study p. 153). In May 2017, EPA ENERGY STAR® established standards for ULT freezers to help move the market. Incentives from California utilities will further drive adoption.

This work paper details current conditions and proposed energy efficiency measures as shown in Table 1 and Table 2.

Table 1 Base, Standard, and Measure Cases

Case	Description of Typical Scenario
Measure	High Efficiency Ultra-Low Temperature (ULT, -80 °C) Freezers (includes blend of ENERGY STAR® certified units)
Base Industry Standard Practice (ISP)	Standard Efficiency Ultra-Low Temperature (ULT, -80 °C) Freezers (includes standard efficiency dual cascade refrigeration system)
Existing Condition	Existing Ultra-Low Temperature (ULT, -80 °C) Freezers (includes surveyed blend of less efficient aged ISP units)
Code/Standard	N/A

Table 2 Measures and Codes

Measure Codes				Measure Name
SCG	SDG&E	SCE	PG&E	
			RF006	High Efficiency Ultra-Low Temperature (ULT, -80 °C) Freezers, 15 to <24 ft^3
			RF007	High Efficiency Ultra-Low Temperature (ULT, -80 °C) Freezers, 24 to 29 ft^3

1.2 REQUIREMENTS

The measure type is Replace on Burnout or New Construction (ROBNC). A qualifying product must have the following:

- Upright ULT freezer designed for laboratory application that is capable of maintaining set point storage temperatures between -70 °C and -80 °C (-94 °F and -112 °F)
- ENERGY STAR® certification
- 15 ft^3 < Volume ≤ 29 ft^3

1.3 Technical Description

As documented in the ET Study, ULT freezers with temperature set points generally ranging from -56°C to -86°C entered the marketplace in the 1970s. In the past two decades, temperature set points of ULT freezers have generally fallen close to -80°C with an average temperature of -77.5°C (Section 1.8.3). These freezers are commonly called "minus eighties" and are used in a wide range of life science research laboratories to maintain the integrity of samples and reagents for long periods of time. As recommended in the ET study, to be conservative the temperature set point for energy savings calculations is -75°C.

1.3.1 Base Case: Industry Standard Practice (ISP)

Traditionally ULT freezers use a cascade system for achieving such low temperatures. The cascade system utilizes two individual compressor-refrigerant circuits in which one operates in high stage and the other in a low stage. The low-stage circuit removes heat from the freezer cabinet and transfers the absorbed heat to the high-stage via an interstage heat exchanger that acts as the condenser of the low-stage circuit and the evaporator of the high-stage circuit. The absorbed heat is then rejected to the room through the condenser coils of the high-stage circuit. The compressors cycle on and off based on inputs from the temperature control sensor inside the freezer cabinet. The dual-compressor cascade system continues to be the most widely used technology for ULT freezers.

1.3.2 Measure Case: ENERGY STAR® Certified ULT Freezers

This work paper adopts the eligibility requirements from EPA ENERGY STAR®, which were published in May 2017.[3]

The first major recent development in ULT freezer technology appeared in 2010, when Stirling Ultracold built its ULT freezers around a Stirling cooling engine instead of a dual-cascade compressor system.[4] The Stirling freezer uses an electrically driven free-piston engine to provide cooling and a thermosiphon to transport heat from the freezer cabinet to the Stirling engine. The Stirling engine uses helium as the working medium fluid and is a beta configuration that contains a piston and a displacer in the same cylinder. The piston is driven at a fixed frequency by an integral permanent magnet linear motor. Cooling capacity is modulated by changing the piston amplitude based on inputs from the temperature control sensor inside the freezer cabinet. The Stirling engine cold head is connected to a thermosiphon, which is a sealed copper tube that wraps around the cabinet interior. The thermosiphon uses ethane (R-170) as the working medium. Liquid ethane flows via gravity down the length of the tube, where it absorbs heat from the interior of the freezer. As it warms, the ethane transitions from a liquid to a vapor and rises up the tube. At the cold head of the engine, the ethane is condensed back into a liquid.

In 2016, Thermo Fisher Scientific released a new ULT freezer technology – the V-drive, which allows the compressors and condenser fans to run at variable speeds in response to the varying cooling load. For example, the V-drive is likely to operate in 'high speed' when the freezer door is opened, and operate in 'low speed' at night when the freezer is unlikely to be actively used. The compressor construction is similar to standard compressors with the inverter drive (converting A/C input to simulated 3 phase variable frequency output) and the motor being the unique difference.

Besides Stirling freezers and the V-drive technology, other energy efficiency practices of ULT freezers include optimizing the fans, compressors, and condensers, in combination with the recent adoption of natural hydrocarbon refrigerants, and applications of vacuum-insulated panels and high performance polyurethane insulation. These technologies are employed by several ULT freezer manufacturers, including Eppendorf and Panasonic.

1.4 Installation Types and Delivery Mechanisms

As shown in Table 3, this work paper addresses the installation type of Replace on Burnout or New Construction (ROB/NC). The delivery mechanism is down-stream rebate, where the customer installs the qualifying energy efficient equipment and submits an incentive application to the utility program. Upon application approval, the utility program pays a rebate to the customer (or vendor if indicated on the application).

PG&E will research the size of the secondary market for ULT freezers to determine if an "Appliance Turn-in and Recycling" delivery method is warranted.

Table 3 Installation Type Description

Installation Type	Savings		Life	
	1st Baseline (BL)	2nd BL	1st BL	2nd BL
Replace on Burnout or New Construction (ROBNC)	Above Code or ISP	N/A	EUL	N/A

1.5 Measure Parameters

1.5.1 DEER Data

As shown in Table 4, the measures in this work paper are not from the Database of Energy Efficient Resources (DEER) since no laboratory building prototype has previously been developed by DEER, and DEER does not include measures evaluating ULT freezers.

Table 4 DEER Difference Summary

DEER Item	Used for Work Paper?
Modified DEER methodology	No
Scaled DEER measure	No
DEER Base Case	No
DEER Measure Case	No
DEER Building Types	No
DEER Operating Hours	No
DEER eQUEST Prototypes	No
DEER Version	N/A
Reason for Deviation from DEER	DEER does not contain this type of measure.
DEER Measure IDs Used	N/A

1.5.2 Net-to-Gross Ratio

The NTG values were obtained using the DEER READI tool. Table 5 includes the relevant ET-Default NTG value of 0.85 for the measure in this work paper.

Table 5 Net-to-Gross Ratio

NTGR ID	Description	Sector	BldgType	Measure Delivery	NTGR
ET-Default	Emerging Technologies. Approved by Energy Division through work paper review.	Any	Any	All	0.85

1.5.3 Installation Rate

The installation rate (IR) values were obtained using the DEER READI tool. The relevant IR values for the measures in this work paper are in Table 6.

Table 6 Installation Rate

GSIA ID	Description	Sector	BldgType	ProgDelivID	GSIAValue
Def-GSIA	Default GSIA values	Any	Any	Any	1

1.5.4 Effective and Remaining Useful Life

The effective useful life (EUL) and remaining useful life (RUL) values were obtained using the DEER READI tool. DEER defines the RUL as 1/3 of the EUL value. The RUL value is only applicable to the first baseline period for an RET measure with an applicable code baseline. The relevant EUL and RUL values for the measures in this work paper are in Table 7.

Table 7 Effective and Remaining Useful Life

EUL ID*	Description	Sector	UseCategory	EUL (Years)	RUL (Years)
GrocDisp-FixtDoors	New case with Doors	Com	ComRefrig	12	4

*Note: This is the closest EUL ID from DEER READI tool to the measures in this work paper. Laboratory audits and analysis of procurement patterns indicate the average lifetime of a ULT freezer is approximately 10 years (ET Study, p. 127).

1.6 Codes and Standards Analysis

The measures in this work paper are not impacted by code standards. Discussion on the standards as they relate to the measures is summarized in Table 8 and presented here for information purposes only.

1.6.1 Title 24

Chapter 10.5 of the California's Title 24 2016 Non-Residential Compliance Manual addresses commercial refrigeration systems in retail food stores. *The Energy Standards apply to retail food stores that have 8,000 square feet or more of conditioned area, and utilize either refrigerated display cases or walk-in coolers or freezers, which are connected to remote compressor units or condensing units.*

Chapter 10.6 addresses the refrigeration systems serving refrigerated warehouses. *The Energy Standards address the energy efficiency of refrigerated spaces within buildings, including coolers and freezers, as well as the refrigeration equipment that serves those spaces. Coolers are defined as refrigerated spaces designed to operate at or above 28°F (-2°C) and at or below 55°F (13°C). Freezers are defined as refrigerated spaces designed to operate below 28°F (-2°C).*

1.6.2 Title 20

Title 20 covers the standards for commercial refrigerators, commercial refrigerator-freezers and commercial freezers in retail food stores. Measures for ULT freezers do not fall under Title 20 of the California Energy Regulations.

1.6.3 Federal Standards

Federal regulations cover the standards for commercial refrigerators, commercial refrigerator-freezers and commercial freezers in retail food stores. Measures for ULT freezers do not fall under Federal DOE or EPA Energy Regulations.

Table 8 Code Summary

Code	Reference	Effective Dates
Title 24 (2016)	These measures do not fall under Title 24	N/A
Title 20 (2013)	These measures do not fall under Title 20	N/A
Federal Codes (DOE / EPA)	These measures do not fall under Federal DOE or EPA Energy Regulations.	N/A

1.7 Market Study

In March 2015, My Green Lab published a report on the energy efficiency potential of various laboratory equipment. The report, *Market Assessment of Energy Efficiency Opportunities in Laboratories,* was managed by Pacific Gas and Electric Company, Southern California Edison and San Diego Gas and Electric Company under Emerging Technology (ET) project numbers ET14PGE7591, ET15SCE1070, and ET14SDG1111.[5] It will be referred to in this work paper as the “Market Study”.

The Market Study found that laboratories consume more energy per square foot of any sector other than data centers, and that California has the highest density of laboratories in the country (p. 1) and that in addition the number of refrigeration units per lab was 20% higher in California than in the rest of the country (p. 41).

1.8 Emerging Technologies (ET) Study

The ET Study is used as the basis for the high-efficiency ULT freezers analysis in this work paper and covers ULT freezer applications in the academic, life science research, and hospital market sectors in California and the rest of the US. The ULT freezer evaluation techniques include equipment monitoring, modeling and surveys. The main objectives of the ET Study were to:

- Use the EPA ENERGY STAR test method[3] to evaluate upright ULT freezers from a variety of manufacturers under controlled environment and field conditions.
- Evaluate ULT freezer temperature and energy performance under simulated working laboratory conditions at a research facility.
- Model the effects of ULT freezers on HVAC energy use.
- Characterize and evaluate the ULT freezer market in surveys.

The ET study sought to quantify the potential direct and indirect energy savings associated with energy-efficient ULT freezer technology. It evaluated the energy performance for the following three groups of ULT freezers: high efficiency, standard (ISP) efficiency and installed existing. Refer to Section 1.3 Technical Description of this work paper for technical descriptions of high efficiency and standard efficiency ULT freezers.

1.8.1 Direct Savings Measurements

Eight different ULT freezer brands from five manufacturers, accounting for over 80% of the total ULT freezer market, were selected for the ET study. Fifteen new ULT freezers, ranging in size from 16-29 ft^3, were evaluated according to the EPA ENERGY STAR test method, and of those, seven were further tested in a controlled field study that measured energy consumption and temperature performance. Of the ULT freezers tested, ten utilized traditional, standard dual-compressor technology while five were marketed as using new, high efficiency technology. Additional energy data were gathered for 101 existing ULT freezers in the field.

The ENERGY STAR test method monitors the energy consumption of an ULT freezer under controlled environment at -80°C and -70°C, respectively. The ENERGY STAR Maximum Daily Energy Consumption

(MDEC) requirement of 0.55 kWh/day/ft^3 considers the normalized and interpolated monitored energy consumption of a ULT freezer operating with a set point of -75°C.

Description of the fifteen ULT freezers and their energy performance under the controlled environment ENERGY STAR test are summarized in the following table.

Table 9 ULT Freezers Energy Performance under Controlled Environment ENERGY STAR Test

Freezer	Volume (ft^3)	Refrigerant Type*	Energy Consumption					
			At -80 °C Set Point		At -70 °C Set Point		At -75 °C Set Point (interpolated)	
			(kWh/day)	(kWh/ft^3/day)	(kWh/day)	(kWh/ft^3/day)	(kWh/day)	(kWh/ft^3/day)
High Energy Efficiency Units								
A	20.1	HFC	12.64	0.629	8.68	0.4318	10.97	0.546
F	27.5	Natural	9.68	0.352	7.89	0.2869	8.83	0.321
G	28.8	Natural	12.12	0.421	8.05	0.2795	10.49	0.364
H	19.4	Natural	10.44	0.538	7.06	0.3639	9.08	0.468
I	27.5	Natural	8.72	0.317	6.96	0.2531	7.86	0.286
Average of High Energy Efficiency Units				**0.45**		**0.32**		**0.40**
Standard (ISP) Efficiency Units								
B	23	HFC/Natural Blend	14.89	0.647	11.78	0.5122	13.5	0.587
C	24.7	HFC	22.52	0.912	15.11	0.6117	19.03	0.770
D	24	HFC	20.46	0.853	14.04	0.5850	17.88	0.745
E	25.7	HFC	26.71	1.039	19.85	0.7724	23.76	0.925
J	28.8	HFC/Natural Blend	19.96	0.693	13.76	0.4778	16.91	0.587
K	16	HFC	14.66	0.916	11.06	0.6913	12.94	0.809
L	25.7	HFC	18.89	0.735	14.11	0.5490	16.74	0.651
M	18	HFC	14.84	0.824	11.72	0.6511	13.22	0.734
N	18.9	HFC	20.43	1.081	14.99	0.7931	17.82	0.943
O	26	HFC	17.72	0.682	12.64	0.4862	15.17	0.583
Average of Standard Efficiency Units				**0.84**		**0.61**		**0.73**

* Natural refrigerants are substances that can be found in the nature, such as R290 and R170. HFC is synthetic hydrofluorocarbons based refrigerants, such as R-508, R-407D, R134 and R404-A.
Source: ET Study 2016, Tables 6, 10 and 11.

Seven ULT freezers were further tested in a controlled field study. Comparison between ENERGY STAR test method and field test method are summarized in the following table.

Table 10 Comparison between ENERGY STAR Test Method and Field Test Method

Parameter	ENERGY STAR Test Method	Field Test Method
Freezers Tested	15	7
Temperature Settings	-80 °C, -70 °C	-80 °C, -70 °C
Door Openings	6 openings, 1x/hour for 15 seconds	Various. See Appendix E of the ET Study
Number of Thermocouples	3 per shelf, diagonally placed	5 on top and bottom shelves, 3 per middle shelf
Full/Empty Freezer	Empty	Full
Duration of Test	30 hours at each temperature setting	7 days at each temperature setting

Source: ET Study 2016, Table 4.

Description of the seven ULT freezers and their energy performance under the field test are summarized in the following table.

Table 11 ULT Freezer Energy Performance under Field Test

Freezer	Volume (ft^3)	Refrigerant Type*	Energy Consumption					
			At -80 °C Set Point		At -70 °C Set Point		At -75 °C Set Point (interpolated)	
			(kWh/day)	(kWh/ ft^3/day)	(kWh/day)	(kWh/ ft^3/day)	(kWh/day)	(kWh/ ft^3/day)
High Energy Efficiency Units								
A	20.1	HFC	10	0.50	7.2	0.36	9.44	0.47
F	27.5	Natural	9.6	0.35	7.6	0.28	8.61	0.31
G	28.8	Natural	9.5	0.33	7.5	0.26	10.22	0.35
Average of High Energy Efficiency Units				**0.39**		**0.30**		**0.38**
Standard (ISP) Efficiency Units								
B	23	HFC/Natural Blend	14.5	0.63	12	0.52	13.01	0.57
C	24.7	HFC	18.1	0.73	10.5	0.43	14.74	0.60
D	24	HFC	16.9	0.70	13.4	0.56	16.11	0.67
E	25.7	HFC	23.3	0.91	17.9	0.70	21.77	0.85
Average of Standard Efficiency Units				**0.74**		**0.55**		**0.67**

Source: ET Study 2016, Tables 18 and 19.

Installed base energy data from 101 existing ULT freezers were also analyzed. The data was collected from academic institutions and biotech/pharmaceutical companies, and were analyzed based on freezer brand and age. The data were obtained through solicitations by the Green Labs Planning Group and through existing relationships with many of the participating organizations. As a result, normalizing the energy consumption as a function of freezer capacity reveals that the average energy consumption of the ULT freezers set to -80°C in the study is 1.1 kWh/ft^3/day, and the average energy consumption of ULT freezers set to -70°C is 0.8 kWh/ft^3/day.

1.8.2 Indirect Savings Measurements

An eQuest simulation model (v3.65) was used to determine the effects of improved ULT freezer efficiency on HVAC energy consumption. Since no laboratory building prototype has previously been developed by the California Database for Energy Efficient Resources (CA DEER), a new California Lab Prototype model was created and designed to be analogous to the CA DEER prototype models for other building types.

The following collected data was used to establish inputs for the model that represent typical design and operating parameters of lab buildings in California:

- Data obtained from the facility manager and previous energy audit surveys
- Lab building data from the Labs21 Benchmarking Tool database
- CEEL Laboratory Market Assessment (Market Study)
- And selected other references

The eQuest model was constructed to contain a weighted average of the thermal zones representing all four space types identified as common ULT freezer locations: 42% Equipment Room, 26% Lab, 20% Freezer Farm, and 12% Lab Hallway. The HVAC systems serving the building were selected to match typical properties from the facility manager survey.

To model the effect of improved ULT freezer efficiency on HVAC energy consumption, each of the four spaces was assigned an incremental equipment load (in addition to the base equipment loads) representing one ULT freezer. Using eQuest's parametric run function, the ULT freezer power for each space type was reduced in turn. The resulting overall building savings were then disaggregated into direct ULT freezer kWh savings, electric HVAC energy savings, and natural gas HVAC energy penalties. Source energy impacts were calculated using the standard ENERGY STAR Portfolio Manager value for electricity (site to source ratio of 3.14). The HVAC energy impacts were then prorated by the direct energy savings.

Critical modeling parameters used in eQuest model are shown in Table 12 and Table 13 (refer to Appendix G of the ET Study for additional inputs to the eQuest model). Table 14 includes the indirect energy savings by three representative California climate zones: CZ3 (Oakland), CZ9 (Burbank-Glendale), and CZ15 (Palm Springs).

Note: As described in 2.2 Indirect Energy Savings and Peak Demand Reduction, imperative updates (e.g. considering 2016 Title 24 HVAC system, all CA CZ, etc.) to the eQuest model were implemented in order to estimate compliant energy savings.

Table 12 Critical Parameters used in eQuest Model

Parameter	Value	Justification
Building area	90,000 sf	Median from audit back catalog* is 85,000 sf
Lab area fraction	40%	Median from Labs21 dataset is 43%
Lab ceiling height	10 ft	Typical; note plenums not modeled.
HVAC system serving labs	100% OA VAV with hot water reheat	Facility manager HVAC survey
SAT set point	60°F (constant)	Facility manager HVAC survey
Supply fan total static pressure	6” w.c.	Typical
Supply fan control	VFD	Typical
Exhaust fan total static pressure	5” w.c.	Typical
Exhaust fan control	Constant volume	Represents typical OA bypass used in lab buildings to maintain stack velocity
HVAC system serving freezer farm	Recirculating CHW fan coil units	Facility manager HVAC survey
HVAC system operation	24/7	Typical
CHW system	2 water-cooled non- VFD centrifugal chillers	Typical
Chiller full-load coefficient of performance	5.5	CA Title 24 2013 (and typical) for 166-ton chillers
HW system	2 forced-draft natural gas-fired boilers	Typical
Boiler efficiency	80%	CA Title 24 2013 (and typical)

* Audit back catalog: lab building energy audit reports, which include typical lab building sizes, configurations, lab area fractions, HVAC system types, and HVAC control parameters. Source: ET Study 2016, Table 28.

Table 13 Parameters used for Spaces with Freezers in eQuest Model

<table>
<tr><th>Space Type</th><th>Served by System</th><th>Cooling SAT (°F)</th><th>Min Vent ACH</th><th>Heating Set Point (°F)</th><th>Cooling Set Point (°F)</th><th>Equip Load (W/SF)</th><th>Resulting HVAC Mode</th></tr>
<tr><td>Main Lab</td><td rowspan="3">Lab VAV</td><td rowspan="3">60</td><td rowspan="2">8 const</td><td rowspan="3">72</td><td>75</td><td>1.5</td><td>Zone in reheat</td></tr>
<tr><td>Equipment Room</td><td>78</td><td>10</td><td>Zone in cooling</td></tr>
<tr><td>Lab Hallways</td><td>4 const</td><td>75</td><td>4*</td><td>Zone in cooling (overwhelmed)</td></tr>
<tr><td>Freezer Farm</td><td>FCUs</td><td>N/A</td><td>N/A</td><td>N/A</td><td>78</td><td>10</td><td>Zone in cooling</td></tr>
</table>

*only in core space used to represent overloading with plug loads. Source: ET Study 2016, Table 29.

Table 14 Weighted HVAC Energy Savings by Space Type

Electric (kWh/Direct kWh)			Natural Gas (therms/Direct kWh)			Source Energy (% of Direct Savings)		
CZ3	CZ9	CZ15	CZ3	CZ9	CZ15	CZ3	CZ9	CZ15
0.154	0.186	0.215	-0.010	-0.009	-0.009	6%	10%	13%
0.185 (average)			-0.009 (average)			10% (average)		

Source: ET Study 2016, Table 31.

1.8.3 Market Assessment

The market assessment of ULT freezers in the ET Study consisted of three approaches. In the first, scientists were surveyed at an international conference, the American Society for Cell Biology, about the brands, sizes, ages, and locations of their ULT freezers.

In the second approach, an online survey was developed to assess more detailed information about the ULT freezer market. This survey was distributed to scientists through a variety of channels, including through My Green Lab's newsletter and website, the Green Labs Planning Group listserv, Stirling Ultracold's marketing group, the International Society for Biological and Environmental Repositories (ISBER)'s newsletter, VWR's marketing channels, the International Institute for Sustainable Laboratories (I2SL)'s newsletter and website, and through personal connections with scientists across the United States.

On-site data were also collected from ten sources across California, half of which were from academic institutions and the other half were from biotech/pharmaceutical companies. No on-site data were collected from hospitals or other institutions. Brand, age, size, and location information were collected either in person by My Green Lab or by a staff member from a participating institution. A total of 3,425 freezers were analyzed from this data set.

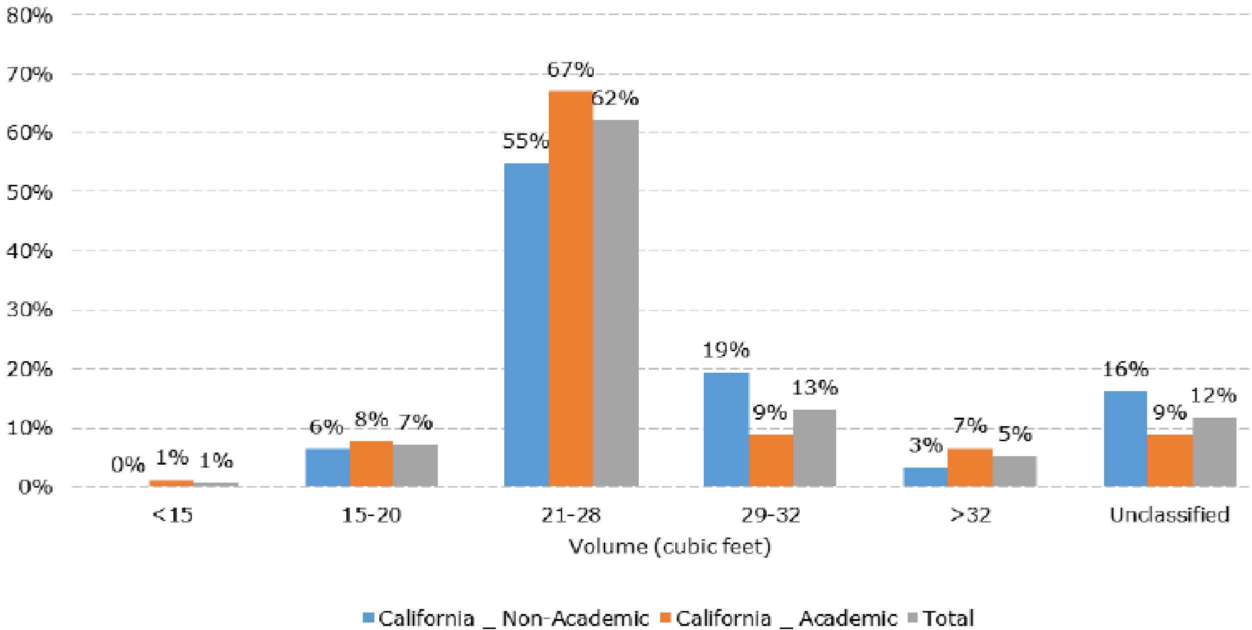
Data were acquired through a SurveyMonkey survey that respondents from 48 California laboratories completed online. Of these laboratories, 33 were at universities and 15 resided in non-academic sectors such as biopharmaceutical companies from the life science research market, hospitals, and medical testing centers. From outside of California, representatives from 185 laboratories provided responses. Of these, 123 were at universities and 62 were in other market sectors.

Survey results relevant to this work paper are shown in the figures below:

- Figure 1 includes survey data that shows about 70% of the ULT freezer distribution is made up of freezer units with volumes between 15 and 29 ft^3.
- Figure 2 shows that 52% of new ULT freezers are purchased to replace an existing freezer and 40% are purchased to increase capacity.
- Figure 3 shows that ULT freezers are set to operate at an average temperature of -77.5^{o}C.
- Both the Market Study and the ET Study found significant price sensitivity in the market, and that it is more pronounced in California than nationwide. These data demonstrate that standard efficiency ULT freezers remain the Industry Standard Practice (ISP):
    - Figure 4 shows that only a small amount of customers are willing to pay a premium for energy efficiency
    - Figure 5 shows that price was found to be the most important purchase factor, far ahead of energy efficiency.

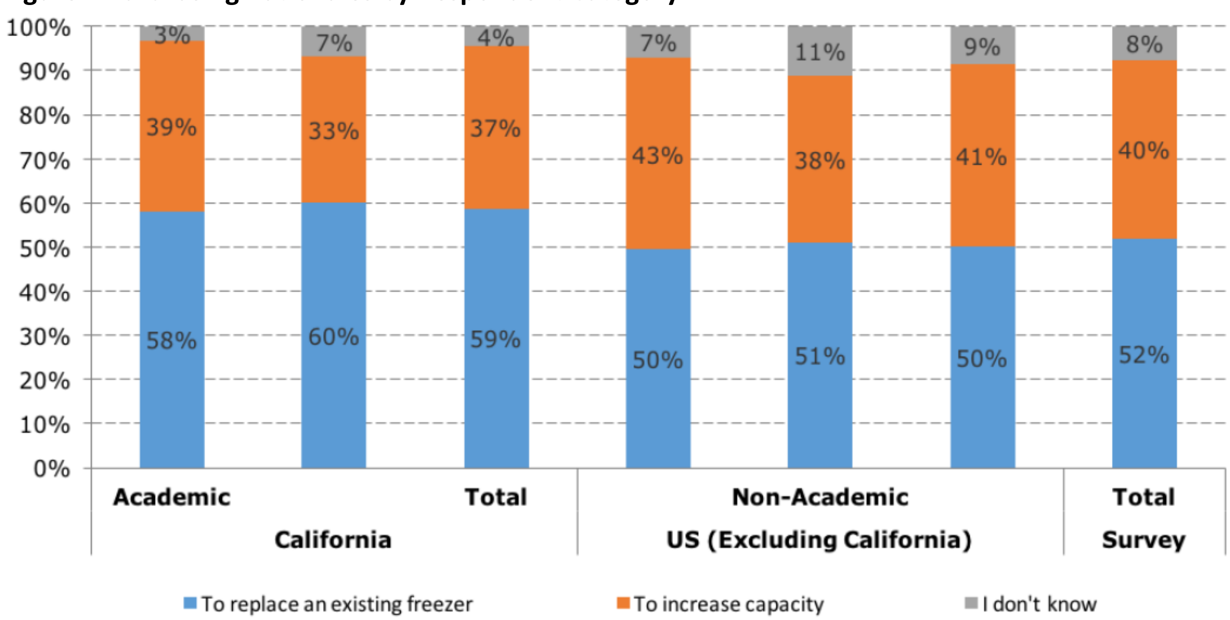
- The ET Study also includes survey data that supports a general ULT freezer lifetime under 15 years (ET Study, page 127).

Figure 1 Distribution of Upright ULT Freezer by Size – California, Online Survey Results



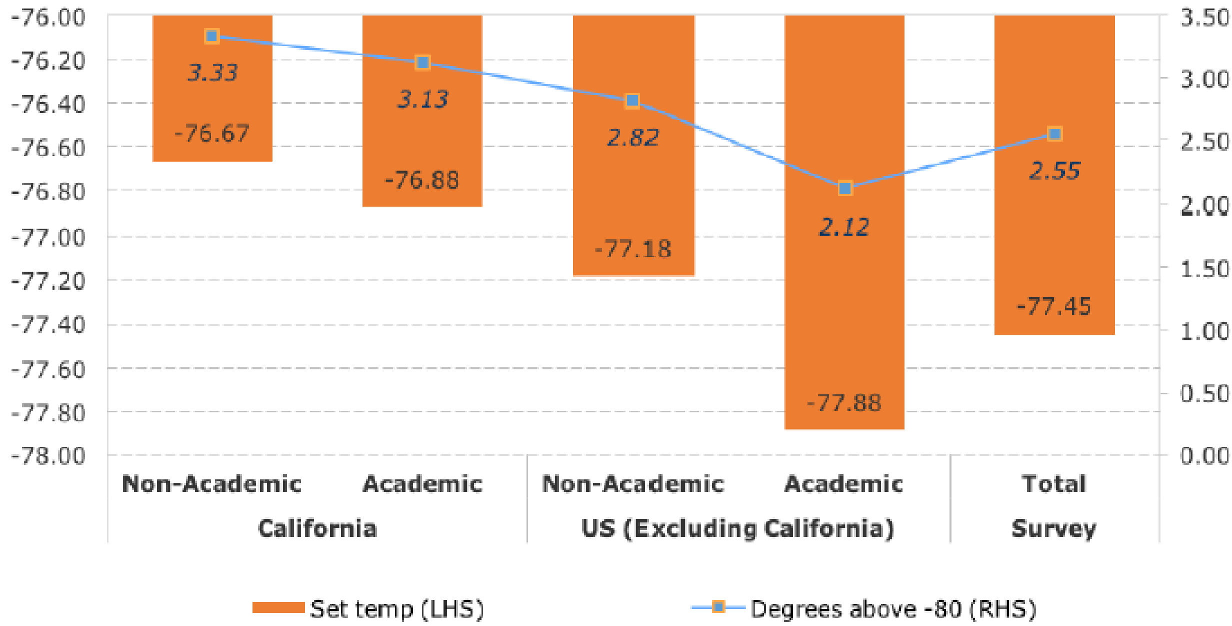
Source: ET Study 2016, Figure 74.

Figure 2 Purchasing Rationales by Respondent Category



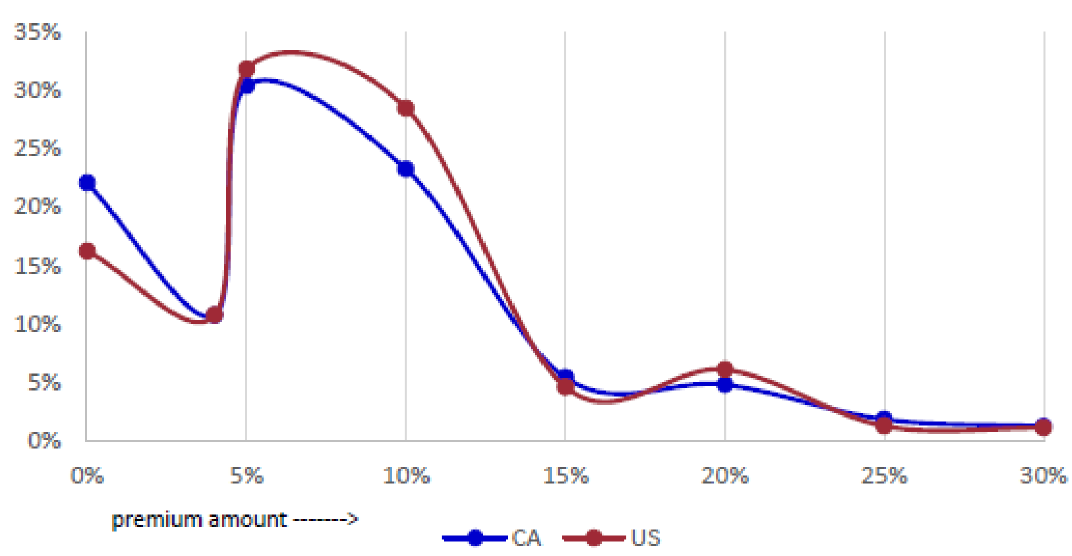
Source: ET Study 2016, Figure 97.

Figure 3 Operating Temperature by Respondent Category



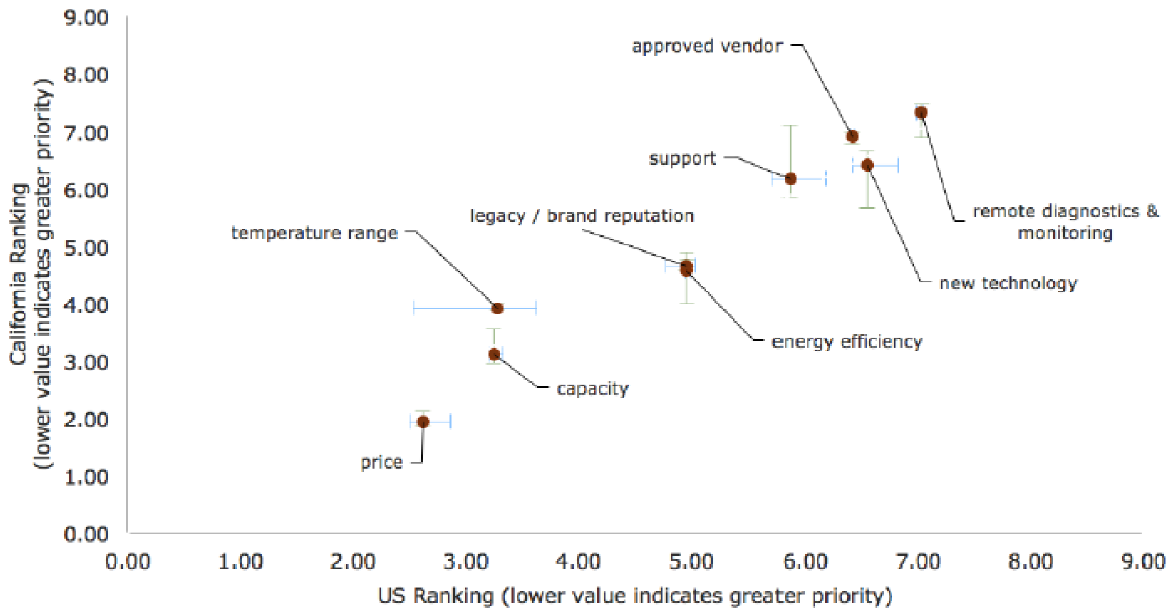
Source: ET Study 2016, Figure 105.

Figure 4: Premium willing to be paid for improved energy efficiency



Source: Market Study, page 107.

Figure 5: Relative importance of Purchase Factors by Survey Region and Respondent Category



Source: ET Study, Figure 98.

1.9 ENERGY STAR®

ENERGY STAR® *Program Requirements, Product Specification for Laboratory Grade Refrigerators and Freezers Eligibility Criteria Version 1.1* (published on May 18, 2017)[3] is based on the same data presented in the ET Study. The ENERGY STAR® document includes the following:

- Definition of ultra-low-temperature laboratory grade freezer: A freezer designed for laboratory application that is capable of maintaining set point storage temperatures between -70 °C and -80 °C (-94 °F and -112 °F);
- ENERGY STAR® test method for ultra-low temperature freezers;
- ULT energy consumption calculation method for the cabinet temperature of -75 °C, which is calculated and reported as the weighted average of the test results at -70 °C and -80 °C.
- The value established for maximum daily energy consumption (MDEC) for ENERGY STAR® certified ULT freezers at -75 °C (-103°F) is **0.55 kWh/day/ft^3 .** This is the criteria being used to qualify products eligible for incentives in this work paper.

SECTION 2. CALCULATION METHODOLOGY

The energy savings for this work paper are based on the direct and indirect effects of installing high efficiency ultra-low temperature (ULT, -80 °C) freezers in laboratory spaces. The savings calculations and eQuest outputs are located in the Savings Calculation eQuest Outputs.xlsx[6] spreadsheet.

The measures are divided into two volume ranges. Deemed savings are calculated as the average volume multiplied by the average savings per cubic foot for each range. The range for the first measure, for smaller volumes, is 15 ft^3 up to but not including 24 ft^3. The energy savings for the smaller range is based on data for freezers sized 16 to 23 ft^3. The average volume for the first measure category and for the data set is 19.5 ft^3. The range for the second measure, for larger volumes, is 24 ft^3 up to and including 29 ft^3. The energy savings is based on data for freezers sized 24 to 28.8 ft^3. The average volume for the second measure category is 26.5 ft^3.

2.1 Direct Energy Savings and Peak Demand Reduction

Direct energy savings from installing high efficiency ULT temperature freezers is calculated by taking the difference of the measure and base case's measured energy consumption with an operating temperature of -75 °C. Although the average temperature of ULT freezers found in laboratories is -77.5 °C (Section 1.3), the direct energy savings calculation considers a conservative ULT freezer operating temperature of -75 °C. Using a conservative operating temperature of -75 °C to calculate energy savings is recommended in the ET Study (page 147) and is also in line with the ENERGY STAR® test method (1.8.1 Direct Savings Measurements).

The direct electrical energy saving (EES_D) of installing high efficiency ULT freezers is calculated by the follow equation:

$$EES_D = V \times (ADEC_{SE} - ADEC_{HE}) \times C$$

Where,

V = average volume capacity of ULT freezer, ft^3 (19.5 ft^3 for sizes 15 to <24 ft^3 and 26.5 ft^3 for sizes 24 to 29 ft^3)

$ADEC_{SE}$ = average daily energy consumption of standard efficiency ULT freezers operating with a set point temperature of -75 °C, kWh/ft^3-day

$ADEC_{HE}$ = average daily energy consumption of high efficiency ULT freezers operating with a set point temperature of -75 °C, kWh/ft^3-day

C = constant, 365 days/yr

The energy consumption of ULT freezers is relatively constant and does not vary throughout the day or year. Therefore, the direct electrical peak demand savings (DS_D) of installing high efficiency ULT freezers is calculated by dividing the average energy savings by the annual freezer operating hours:

$$DS_D = EES_D / H$$

Where,

H = annual ULT freezer operating hours, 8,760 hr/yr

A summary of direct electric energy savings and peak demand reduction is included in Table 15. The average peak demand reduction and energy savings for ULT freezers with an average volume of 19.5 ft^3 is 0.21 kW and 1,859 kWh/yr, respectively. The average peak demand reduction and energy savings for ULT freezers with an average volume of 26.5 ft^3 is 0.43 kW and 3,740 kWh/yr, respectively.

Table 15 Direct Electric Energy Savings and Peak Demand Reduction Summary

Freezer	Volume Capacity (ft^3)	Energy Consumption (-75 °C Set Point) ($kWh/Ft^3/day$)
ULT Freezer Range: 15 to <24 ft^3		
High Energy Efficiency Units		
H	19.4	0.468
A	20.1	0.546
Average of High Energy Efficiency Units		0.507
Standard (ISP) Efficiency Units		
K	16	0.809
M	18	0.734
N	18.9	0.943
B	23	0.587
Average of Standard Efficiency Units ($ADEC_{SE}$)		0.768
Average Peak Demand Reduction (consider 19.5 ft^3)		**0.21 kW**
Average Electric Energy Savings (consider 19.5 ft^3)		**1,859 kWh/year**
ULT Freezer Range: 24 to 29 ft^3		
High Energy Efficiency Units		
F	27.5	0.321
I	27.5	0.286
G	28.8	0.364
Average of High Energy Efficiency Units		0.324
Standard (ISP) Efficiency Units		
D	24	0.745
C	24.7	0.770
E	25.7	0.925
L	25.7	0.651
O	26	0.584
J	28.8	0.587
Average of Standard Efficiency Units ($ADEC_{HE}$)		0.710
Average Peak Demand Reduction (consider 26.5 ft^3)		**0.43 kW**
Average Electric Energy Savings (consider 26.5 ft^3)		**3,740 kWh/year**

Source: ET Study 2016, Table 6

2.2 Indirect Energy Savings and Peak Demand Reduction

The heat generated by ULT freezers is rejected to the indoor space. High efficiency ULT freezers produce less heat than standard or code ULT freezers. As a result, the HVAC systems will produce less cooled conditioned air and increase the amount of heated air in order to maintain space set point temperatures. Indirect peak demand reduction and electric energy savings are realized from the reduced amount of needed cooling load and indirect natural gas penalties are realized from the increased amount of needed heating load.

As described in 1.8.2 Indirect Savings Measurements, this work paper uses the pre-developed eQuest lab prototype by the ET Study as the model basis, and modifies some eQuest inputs. The modifications are summarized below. HVAC chiller and boiler efficiencies as well as roof, wall, and window properties are updated or checked per 2016 Title 24.

- The modeled ULT freezer power is updated to represent both freezer sizes operating with a temperature set point of -75 °C.
- The modeled ULT freezer power is updated to represent both freezer sizes operating with a temperature set point of -75 °C and does not vary based on space type.
- Simulation is performed for 16 climate zones in California.

Table 16 includes the updated indirect peak demand reductions, electric energy savings, and natural gas penalties from HVAC systems. The average indirect peak demand reduction, electric energy savings, and natural gas penalties for ULT freezers with an average volume of 19.5 ft^3 is 0.08 kW and 256 kWh/yr, and -14.58 therms/yr, respectively. The average indirect peak demand reduction, electric energy savings, and natural gas penalties for ULT freezers with an average volume of 26.5 ft^3 is 0.08 kW, 623 kWh/yr, and -34.93 therms/yr respectively.

Table 16 Indirect HVAC System Impact Savings Summary

Climate Zone	Indirect HVAC System Impacts		
	DEER Peak Demand Reduction (kW)	**Electric Energy Savings (kWh/yr)**	**Natural Gas Penalty (therms/year)**
ULT Freezer Range: 15 to <24 ft^3			
CZ01	0.03	223	-14.81
CZ02	0.01	264	-13.75
CZ03	0.03	226	-15.49
CZ04	0.05	246	-15.34
CZ05	0.04	240	-14.88
CZ06	0.04	244	-16.05
CZ07	0.01	230	-16.61
CZ08	0.02	213	-16.44
CZ09	0.05	277	-15.40
CZ10	0.02	276	-15.06
CZ11	0.05	269	-14.11
CZ12	0.05	242	-14.75
CZ13	0.05	267	-14.58
CZ14	0.02	286	-11.48
CZ15	0.01	336	-16.57
CZ16	0.02	255	-7.98
Average	**0.03**	**256**	**-14.58**
ULT Freezer Range: 24 – 29 ft^3			
CZ01	0.07	543	-34.89
CZ02	0.10	607	-32.52
CZ03	0.08	566	-37.06
CZ04	0.12	598	-36.63
CZ05	0.10	575	-36.07
CZ06	0.10	685	-38.54
CZ07	0.03	556	-40.29
CZ08	0.04	583	-38.93
CZ09	0.13	698	-36.71
CZ10	0.04	649	-35.91
CZ11	0.11	651	-34.03
CZ12	0.12	582	-35.50
CZ13	0.11	646	-35.11
CZ14	0.05	651	-28.56
CZ15	0.01	740	-39.45
CZ16	0.04	630	-18.66
Average	**0.08**	**623**	**-34.93**

2.3 Total Energy Savings and Peak Demand Reduction

The total energy savings and peak demand reductions are the sum of the direct and indirect savings. As shown in Table 17, the average DEER peak demand reduction, electric energy savings, and natural gas penalties for ULT freezers with an average volume of 19.5 ft^3 is 0.24 kW and 2,116 kWh/yr, and -14.58 therms/yr, respectively. The average DEER peak demand reduction, electric energy savings, and natural gas penalties for ULT freezers with an average volume of 26.5 ft^3 is 0.51 kW, 4,362 kWh/yr, and -34.93 therms/yr respectively.

Table 17 Total Energy Savings and Peak Demand Reduction

Climate Zone	Total Energy Savings and Demand Reduction		
	DEER Peak Demand Reduction (kW)	Electric Energy Savings (kWh/yr)	Natural Gas Penalty (therms/year)
ULT Freezer Range: 15 to <24 ft^3			
CZ01	0.24	2,083	-14.81
CZ02	0.22	2,124	-13.75
CZ03	0.25	2,086	-15.49
CZ04	0.26	2,106	-15.34
CZ05	0.26	2,100	-14.88
CZ06	0.26	2,104	-16.05
CZ07	0.22	2,090	-16.61
CZ08	0.23	2,073	-16.44
CZ09	0.26	2,137	-15.40
CZ10	0.23	2,136	-15.06
CZ11	0.26	2,129	-14.11
CZ12	0.26	2,102	-14.75
CZ13	0.26	2,127	-14.58
CZ14	0.23	2,146	-11.48
CZ15	0.22	2,197	-16.57
CZ16	0.23	2,115	-7.98
Average	**0.24**	**2,116**	**-14.58**
ULT Freezer Range: 24 – 29 ft^3			
CZ01	0.50	4,282	-34.89
CZ02	0.53	4,346	-32.52
CZ03	0.51	4,305	-37.06
CZ04	0.55	4,337	-36.63
CZ05	0.53	4,315	-36.07
CZ06	0.53	4,425	-38.54
CZ07	0.45	4,296	-40.29
CZ08	0.47	4,323	-38.93
CZ09	0.55	4,438	-36.71
CZ10	0.46	4,389	-35.91
CZ11	0.54	4,390	-34.03
CZ12	0.54	4,322	-35.50
CZ13	0.54	4,385	-35.11
CZ14	0.48	4,390	-28.56
CZ15	0.44	4,480	-39.45
CZ16	0.47	4,369	-18.66
Average	**0.51**	**4,362**	**-34.93**

SECTION 3. LOAD SHAPES

The ideal load shape for net benefits estimates would represent the difference between the base case and measure case. The closest load shapes that are applicable to the measures in this work paper are listed in Table 18.

Table 18 Building Types and Load Shapes

Building Type	Load Shape	E3 Alternate Building Type
Education - University	Commercial Refrigeration	COMMERCIAL
Health/Medical - Hospital	Commercial Refrigeration	COMMERCIAL
Manufacturing Biotech	Industrial Refrigeration	INDUSTRIAL
Manufacturing Pharmaceutical	Industrial Refrigeration	INDUSTRIAL

SECTION 4. COSTS

ULT freezer pricing varies by purchaser, with larger buyers receiving greater discounts, and by manufacturer. Manufacturers do not disclose pricing details for competitive reasons. ULT freezer cost data was acquired from eleven universities and four large biotech companies with multiple sites across California. The cost data was divided into two volume categories: 15 to <24 ft^3 and 24-29 ft^3. It included three energy-efficient models with volumes under 24 ft^3 and four energy-efficient freezer models with volumes over 24 ft^3. The following methodology was applied (refer to Academic Biotech Pricing.xlsx[7] for cost analysis):

1. All price data for the same make and model freezer were averaged for academia and for the biotech industry.
2. Baseline freezer costs at least one standard deviation above the mean were excluded because average pricing for standard-efficiency units is likely to reduce over time.
3. Energy-efficient freezer costs at least one standard deviation below the mean were excluded because these were often introductory pricing that will be less common going forward.
4. The average ULT freezer volume for each size category was set to (19.5 ft^3 for the smaller size category and 26.5 ft^3 for the larger).
5. The average price per unit was divided by the average ULT freezer volume in step 3 in order to determine the price per cubic foot.
6. The final price was normalized by multiplying the average price per cubic foot in step 4 by the average ULT freezer volume.

4.1 BASE CASE COST

Base case costs for the 15 to <24 ft^3 and the 24-29 ft^3 size ranges is $8,849 and $10,670, respectively (see Table 19). These are the respective averages of 34 and 40 ULT freezer makes and models.

Table 19 ULT Freezer Baseline Cost Data

ULT Freezer Size	Average Retail Price
15 to <24 ft^3	$8,849
24-29 ft^3	$10,670

4.2 Measure Case Cost

Measure case costs for the 15 to <24 ft^3 and the 24-29 ft^3 size ranges is \$10,984 and \$12,460, respectively (see Table 20). These are the respective averages of 5 and 17 ULT freezer makes and models.

Table 20 ULT Freezer Measure Cost Data

ULT Freezer Size	Average Retail Price
15 to <24 ft^3	\$10,984
24-29 ft^3	\$12,460

4.3 Full and Incremental Measure Cost

The average price of a baseline 19.5 ft^3 ULT freezer is \$8,849 based on 34 pricing datasets, the average price of an energy efficient 19.5 ft^3 ULT freezer is \$10,984 based on 5 pricing datasets. The average incremental measure cost of a ULT freezer in the 15-23 ft^3 range is \$2,135. The average price of a baseline 26.5 ft^3 ULT freezer is \$10,670 based on 40 pricing datasets, the average price of an energy efficient 26.5 ft^3 ULT freezer is \$12,460 based on 17 pricing datasets. The average incremental measure cost of a ULT freezer in the 24-29 ft^3 range is \$1,790. Table 21 includes a summary of the ULT freezer cost difference data. As shown in Table 22, Table 23, and Table 24, installation, removal, and labor costs for ULT freezers is the same for baseline and energy efficient models.

Table 21 ULT Freezer Cost Difference Data

ULT Freezer Type	Average Retail Price	Cost Difference
Baseline, 15 to <24 ft^3	\$8,849	-
Energy efficient, 15 to <24 ft^3	\$10,984	\$2,135
Baseline, 24-29 ft^3	\$10,670	-
Energy Efficient, 24-29 ft^3	\$12,460	\$1,790

Table 22 Full and Incremental Measure Cost Equations

Installation Type	Incremental Measure Cost	Full Measure Cost	
		1st Baseline	2nd Baseline
ROBNC	(MEC + MLC) – (BEC + BLC)	(MEC + MLC) – (BEC + BLC)	N/A

MEC = Measure Equipment Cost; MLC = Measure Labor Cost
BEC = Base Case Equipment Cost; BLC = Base Case Labor Cost

Table 23 Full and Incremental Costs (15 to <24 ft^3)

Installation Type	Incremental Measure Cost	Full Measure Cost	
		1st Baseline	2nd Baseline
ROBNC	\$2,135	N/A	N/A

Table 24 Full and Incremental Costs (24-29 ft^3)

Installation Type	Incremental Measure Cost	Full Measure Cost	
		1st Baseline	2nd Baseline
ROBNC	\$1,790	N/A	N/A

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[5] The Center for Energy Efficient Laboratories (CEEL), et al. (2015, March 12). Market Assessment of Energy Efficiency Opportunities in Laboratories (ET Project Numbers: ET14PGE7591, ET15SCE1070, ET14SDG1111).

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