Commercial Building Energy Alliance Technical Specification
Ultra-Low-Temperature Laboratory Freezers
Plug & Process Load Project Team
Version 1.1
April 19, 2012

Summary

This specification provides a description of performance characteristics for high-efficiency Ultra-Low-Temperature Laboratory Freezer (ULF) models. ULFs typically operate between -60 and -90 °C, but must be able to operate within the range of -70 to -80 °C. They are used to store medical or scientific samples in laboratories. ULFs are used by Commercial Building Energy Alliance (CBEA) sectors including hospitals and universities; and by other companies or organizations such as the National Institutes of Health (NIH) and pharmaceutical or biotechnology companies. The final specification will be developed with Commercial Building Energy Alliance (CBEA) member and manufacturer input and include minimum requirements that will be of interest to a critical number of CBEA members.

This specification is not intended to be a comprehensive purchase specification. It is intended to supplement a purchase specification by outlining energy-related product requirements.

1. Acronyms and Definitions

Air-cooled - using air to provide heat transfer from the condenser.

Chest - refers to a freezer accessed from a door positioned on the top of the freezer, parallel to the plane of the ground.

Self-contained - refers to a refrigeration system in which all components are integrated into one piece of equipment.

Ultra-Low-Temperature Laboratory Freezer (ULF) – a freezer designed for a laboratory application that is capable of maintaining storage temperatures between -70 and -80 °C, inclusive.

Upright - refers to a freezer accessed from one or more doors positioned on the side of the freezer, perpendicular to the ground.

Volume - means the interior volume of the ULF.

Water-cooled - using water to provide heat transfer from the condenser.

2. Specification Scope

2.1. Covered Equipment

This specification covers ultra-low-temperature laboratory-grade freezers with the following characteristics:

- Self–contained, electrically powered upright or chest freezers capable of maintaining storage temperatures of -70 to -80 °C.

2.2. Non-Covered Equipment

This specification does not cover ULFs with any of the following characteristics:

- Liquid-nitrogen cooling systems
- Water-cooled condensers.

2.3. Relevant Codes, Standards, or Specifications

The test method outlined in this specification references the method of test described in ANSI/ASHRAE Standard 72-2005, "Method of Testing Commercial Refrigerators and Freezers."

3. Energy Efficiency Requirements

3.1. Test Method

Products meeting this specification shall be tested in accordance with ANSI/ASHRAE Standard 72-2005, "Method of Testing Commercial Refrigerators and Freezers," with the exceptions listed in Table 1. Standard 72-2005 is available at: http://www.energystar.gov/ia/partners/prod_development/new_specs/downloads/freezers/ENERGY_STAR_Lab_Grade_Supplement.pdf?e916-0f77.

Table 1: Exceptions to ANSI/ASHRAE 72-2005 for ULFs

Topic/Section	**ANSI/ASHRAE 72-2005 Instructions**	**ULF Instructions**
Test simulators and filler packages	Contains specifications for test simulators and filler packages	No test simulators or filler packages shall be used. Chamber shall be empty during testing except for shelving that is packaged and shipped with the freezer by the manufacturer.
Thermocouple setup	Thermocouples are embedded in test simulators.	Bare, unweighted thermocouples shall be used.
Thermocouple placement	Contains specifications for thermocouple placement for units with and without shelves.	For upright freezers, thermocouples shall be placed as shown in Figure 1, on horizontal planes, one plane 3 inches from the bottom of the freezer, one plane 3 inches from the top of the freezer, and the remaining planes evenly spaced in the freezer such that the vertical distance between planes is no more than 18 inches. For chest freezers, thermocouples shall be placed as shown in Figure 2, on vertical planes, one plane 3 inches from the left side of the freezer, one plane 3 inches from the right side of the freezer, and remaining planes evenly spaced across the freezer such that the horizontal distance between planes is no more than 18 inches. 5 thermocouples shall be placed on each plane: 4 in the corners such that the distance from the thermocouple to each adjacent side is 3 inches, and one thermocouple in the center of the plane. Shelving that the manufacturer packages and ships with the ULF shall be in place during testing. Thermocouples must be a minimum of 3 inches from any shelf. If a thermocouple would be less than 3 inches from a shelf when in the above configuration, move the shelf to an adjacent position so that the thermocouple is a minimum of 3 inches from the shelf. If shelves cannot be adjusted, move the plane of thermocouples the minimum distance in order that the thermocouples are 3 inches from the shelf. All

		thermocouples in a plane should remain in that plane if moved.
Door-opening requirements	Contains specifications for door opening frequency, duration, and sequence	Doors shall not be opened during the test.

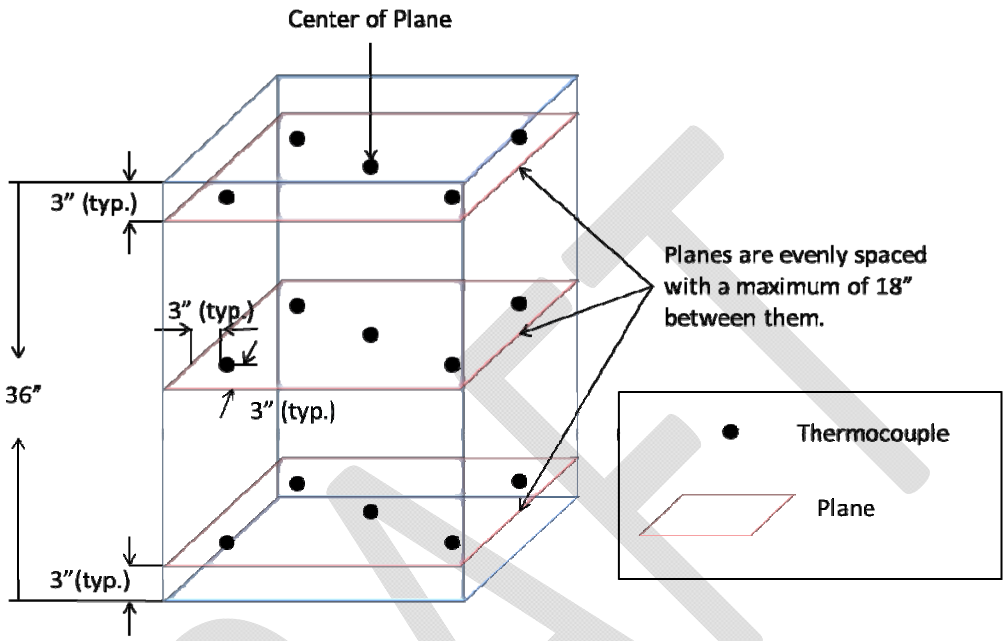


Figure 1: Example of Placement of Thermocouples in Upright Freezer

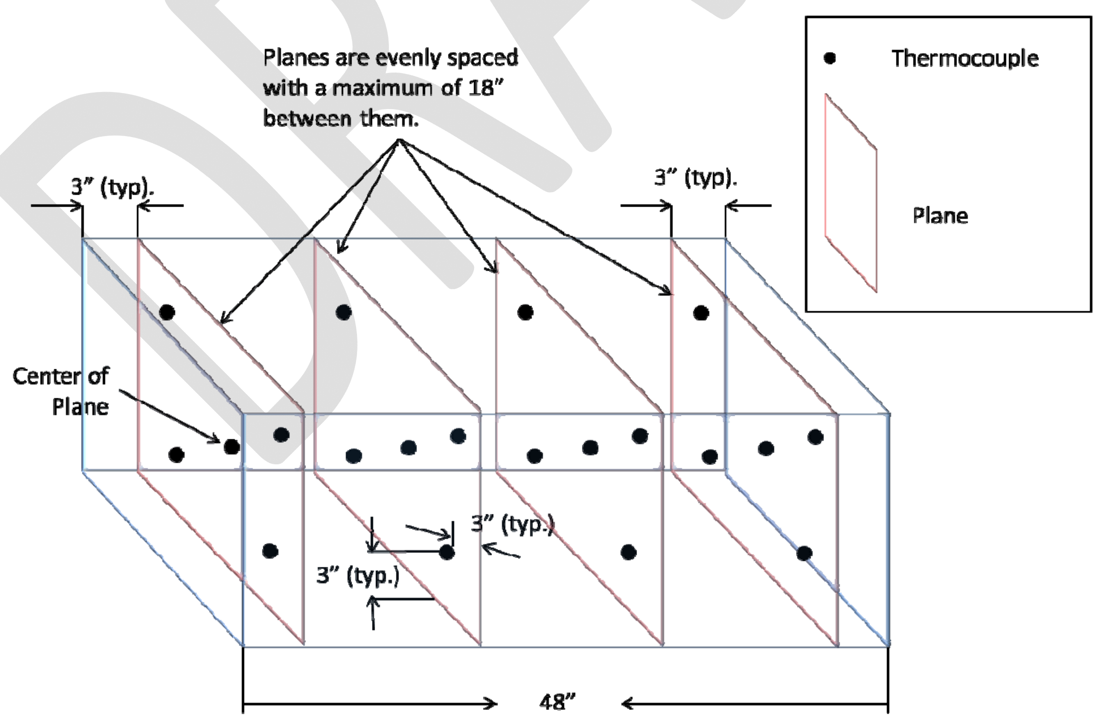


Figure 2: Example of Placement of Thermocouples in Chest Freezer

Question: *Should thermocouples be weighted, or should any test simulators or filler packages be used?*

Question: *Is the proposed thermocouple placement appropriate? If not, how should the thermocouples be placed to capture the temperature within the ULF?*

Question: *If the ULF is supplied without shelves, should manufacturers only be required to test and report results without shelves, or should they also be required to test with all options for manufacturer-supplied, field-installed shelving?*

3.2. Rating Conditions and Calculations

Two energy tests shall be performed at the rating conditions specified in Table 2. For each test, the refrigeration must achieve steady state before testing can begin, where steady state means that the refrigeration system has undergone at least 6 cycles after achieving the temperature rating condition and the average cabinet temperature is dropping by no more than 1.5 °C over a 1-hour period.

Table 2: Rating Conditions for Energy Measurements

Test	Duration	Rating Condition
Test 1	24 hours	Average thermocouple reading* of -70 °C ± 1.5 °C
Test 2	24 hours	Average thermocouple reading* of -80 °C ± 1.5 °C

*"Average thermocouple reading" means the average of all cabinet thermocouple measurements taken during the test.

Question: *Are the duration of each test and the requirements for steady state reasonable and adequate?*

Question: *Is a temperature uniformity condition necessary based on location within the ULF? (I.e., no thermocouple measurement may deviate more than a certain amount from the average thermocouple reading.)*

The calculated daily energy consumption (CDEC) used to determine compliance with the specification shall be calculated using the equation below, filling in the recorded values from the test measurements:

$$CDEC = E1 + (-75 - T1) \times \frac{(E2 - E1)}{(T2 - T1)}$$

Equation 1

Where:

T1 = Average temperature of all thermocouple temperatures recorded over the course of Test 1
E1 = Total energy consumption during Test 1
T2 = Average temperature of all thermocouple temperatures recorded over the course of Test 2
E2 = Total energy consumption during Test 2.

3.3. Efficiency Requirements

A product meets this specification if the CDEC, as calculated in Equation 1, is less than or equal to the maximum daily energy consumption given in Table 3 when tested in accordance with the above test method.

Table 3: Standards Equations

Product Type	Maximum Daily Energy Consumption (MDEC) (kWh/day)*
Chest Freezer	$MDEC = 0.38 \times V + (3\text{ to }5)$**
Upright Freezer	$MDEC = 0.38 \times V + (2\text{ to }4)$**

* *V* means the net usable volume in cubic feet, as defined in ANSI/ASHRAE 72-2005.

** The intercept for the line defining the MDEC is given as a range in this draft due to uncertainty about the performance of existing ULFs. Further testing is needed to specify the intercept. The final specification will include an exact value for the intercept of each MDEC curve. MDEC curves will be defined such that the standard can be met by a set of the most efficient products on the market.

Question*: Should the equations be based on net usable volume or a different metric? E.g., a different measurement of volume, number of sample boxes, etc.*

4. Other Requirements

Industry Compliance: Products that meet this specification shall comply with all applicable industry standards as set forth by ANSI, IEEE, UL, and others.

5. Warranty Requirements

The model will carry a warranty with minimum periods of:

- 1 year from date of purchase covering manufacturer defects on parts.
- 5 years from date of purchase covering manufacturer defects on the compressor.

Question: *Is this warranty appropriate for this type of equipment? What should be stipulated in the warranty for customers, for manufacturers?*

6. References

a. ANSI/ASHRAE Standard 72-2005, "Method of Testing Commercial Refrigerators and Freezers." Published August 2005. Available at: http://webstore.ansi.org/RecordDetail.aspx?sku=ANSI/ASHRAE+Standard+72-2005

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Source: *labs21wiki.lbl.gov*

Ultra-Low-Temperature Laboratory Freezers

Supplementary Information for Technical Specification

April 19, 2012

Index

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Technology Specification Overview

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

With assistance from CBEA members, DOE is pursuing technology specifications to help pull innovative, energy-saving technologies to market.

- This report supplements the technology specification for **Ultra-Low-Temperature Laboratory Freezers (ULFs).**
- ULFs are used to store medical or scientific samples in laboratories. ULFs are used by CBEA sectors including hospitals and universities; and by other companies or organizations including the National Institutes of Health (NIH) or private pharmaceutical or biotechnology companies.
- ULFs are major energy users in laboratories, with a single freezer using up to 15-20 kWh per day.
- ULFs are not covered by any existing U.S. energy standards or test procedures.

Laboratories use ULFs to store medical or scientific samples.

- Common characteristics for ULFs include:
  - Operate between -40 and -90 °C, most typically at -70 or -80 °C.
  - Typically between 18 and 24 cubic feet in interior volume, although “under-counter” type ULFs are smaller.
  - The vast majority are upright, but a small number are chest type.
  - Operate using a cascade refrigeration system that consists of two refrigeration cycles arranged in series. A competing technology is a Stirling freezer, which has only recently entered the ULF market.
  - Most are air-cooled, but some are water-cooled. However, water-cooled systems are limited to applications that have access to a cooling-water loop, which is not available at many labs. Therefore, we did not include water-cooled systems in the scope of the spec.

For ULFs, the metric for the spec is maximum allowable daily energy consumption (MDEC).

- The energy metric is calculated by the following equation:

$$MDEC = A \times V + B$$

Where:

- *MDEC* = maximum daily energy consumption
- *V* = interior volume
- A and B represent equation coefficients, which are different for upright and chest freezers.

Manufacturers currently test ULFs using differing test procedures.

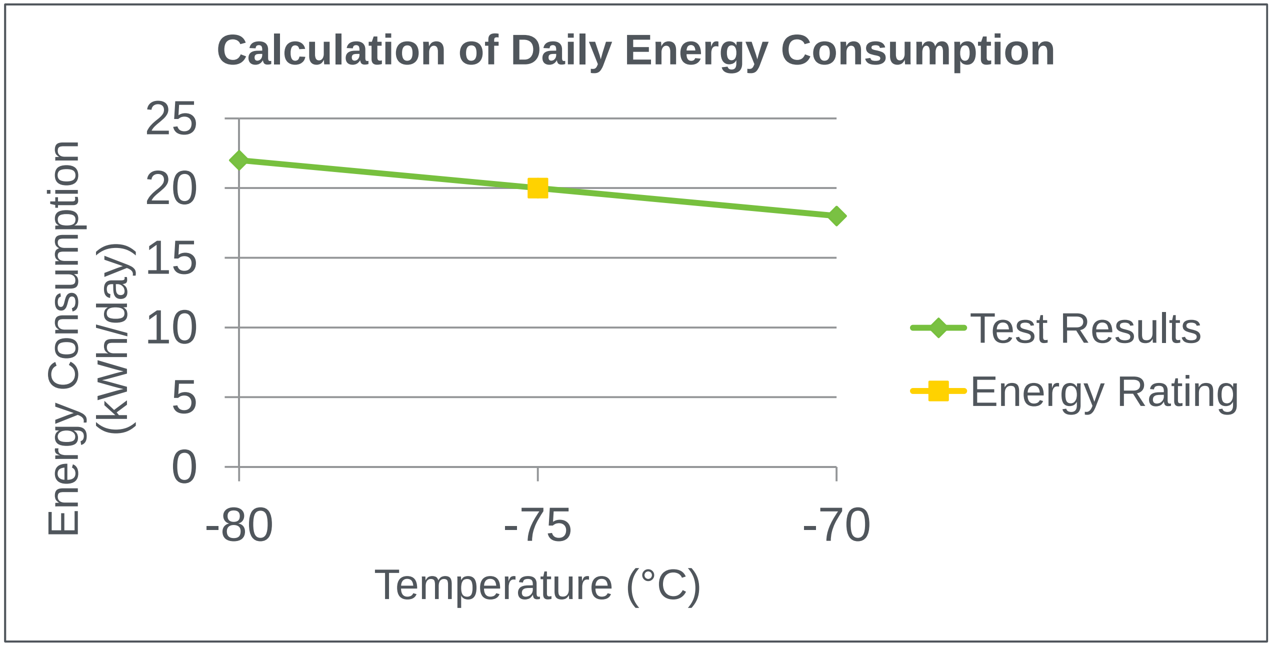
- Manufacturers and customers have identified the lack of a consistent test procedure as a major problem facing the ULF market.
- ULF manufacturers use their own internal methods to rate the energy use of their ULF models. There is no industry-accepted way to independently verify the ratings.
- For a ULF tech spec to be acceptable to stakeholders, there must be a reproducible, repeatable test method that applies to all ULF products so that efficiency ratings can be verified.

The tech spec must specify the test methodology because none is currently accepted uniformly by industry.

- The draft tech spec adapts ASHRAE 72-2005 for ULFs. ASHRAE 72-2005 is the test procedure for commercial refrigerators and freezers.
- The basic test method is as follows:
  - The unit is tested at both -70°C and -80°C cabinet temperatures (the two most common set-point temperatures, based on stakeholder inputs).
  - A thermocouple array placed inside the unit measures the cabinet temperature over each 24-hour test period.
  - The power draw of the unit over each test period is measured and recorded.

The final energy rating is a representative calculated daily energy consumption for the unit.

- The calculated daily energy consumption is an interpolation of the two test results to -75°C.
- The purpose of interpolating the results to a single temperature is to provide a basis of comparison in the market for ULFs.



A high-efficiency CBEA specification could have significant impact on the ULF market.

- Sales of ULFs in the U.S. market are estimated to be approximately10,000 ULFs per year.
- A typical freezer uses 15-20 kWh per day, nearly as much as a small house.

The industry is beginning to target ULFs for efficiency improvements, but there are barriers to implementation.

- The lack of consistent ratings makes it difficult to quantify efficiency improvements across manufacturers.
- Most purchasers – i.e., scientists – do not pay the utility bills, so have little to no incentive to purchase higher efficiency equipment.
- Brand recognition is a key factor in purchasing, which gives established manufacturers an advantage in the market and may hinder competition on an efficiency basis.
- Poor installation and maintenance by the customer can negatively impact efficiency in spite of ULF technology improvements.

We recommend a two-pronged approach to specifications for ULFs, targeting both manufacturers and customers.

- A technology specification sets minimum efficiency requirements for ULFs, where the rated efficiency is based on a standardized test procedure.
- An operational specification lists procedures that end-users pledge to follow to optimize the efficiency of their ULFs.

Manufacturers have multiple pathways to optimize efficiency for typical models of ULFs.

- High-efficiency compressors and fan motors can reduce energy use.
- Heat exchanger enhancements can improve the efficiency of the refrigeration system. One manufacturer reported significant progress in improving the refrigerant-to-refrigerant heat exchanger connecting the two cycles in the cascade system.
- Vacuum-insulated panels (VIPs) tend to have much higher insulating values than traditional foam-blown panels, although there is a risk of deterioration over time.

One manufacturer is promoting an entirely different refrigeration technology for ULFs.

- Global Cooling Inc. is developing and marketing a ULF that is refrigerated using a Stirling cycle cooler instead of a typical cascaded vapor-compression system.
- Stirling technology is not new, but has never before been applied to ULFs in this temperature range on a commercial scale.
- The manufacturer claims dramatic (50%+) savings over traditional systems, along with other benefits such as less heat rejection into the room, fewer moving parts and thus higher reliability, and reduced noise.

Several ULF customers identified operational flaws that cause ULFs to use excessive energy.

- Placement of ULFs in a manner that impedes air circulation to the second-stage condenser.
- Inadequate maintenance and repair programs.
- Lack of good sample management that causes users to use more ULFs than they need.

Frost buildup caused by inadequate maintenance.
Photo source: UC Davis

Stakeholders showed interest in a separate operational specification.

- Elements of an operational specification could include:
  - Implementation of a sample management system.
  - Placement of freezers with significant spacing so as not to obstruct airflow.
  - Maintenance activities to be performed.
- We will be working with stakeholders in the coming months to define an operational specification.

Although an operational specification does not include a specific efficiency level, the energy impact of operational improvements can be quantified indirectly.

- Adequate recording of operational activities can help link energy savings to improvements.
- DOE could partner with an organization to implement a "pilot program."
- The program could implement the operational specifications for some of a laboratory's freezers and, through metering, compare the energy use to areas without the operational specifications in place.

The draft performance requirements are based on limited test data from units on the market, but we need further test data to finalize these requirements.

- Data were gathered from a product database on labs21wiki.lbl.gov and manufacturer spec sheets.
- A trend line was drawn as the average of the trend lines through the test data at -70 °C and the test data at -80 °C.
- The draft specification equations for Maximum Daily Energy Consumption (MDEC) were specified to have the same slope as the trend line, but have ranges for intercepts as placeholders.
- More test data are needed to refine the MDEC curves. For the final specification, a single number will be chosen for the intercept in each of the specification equations.

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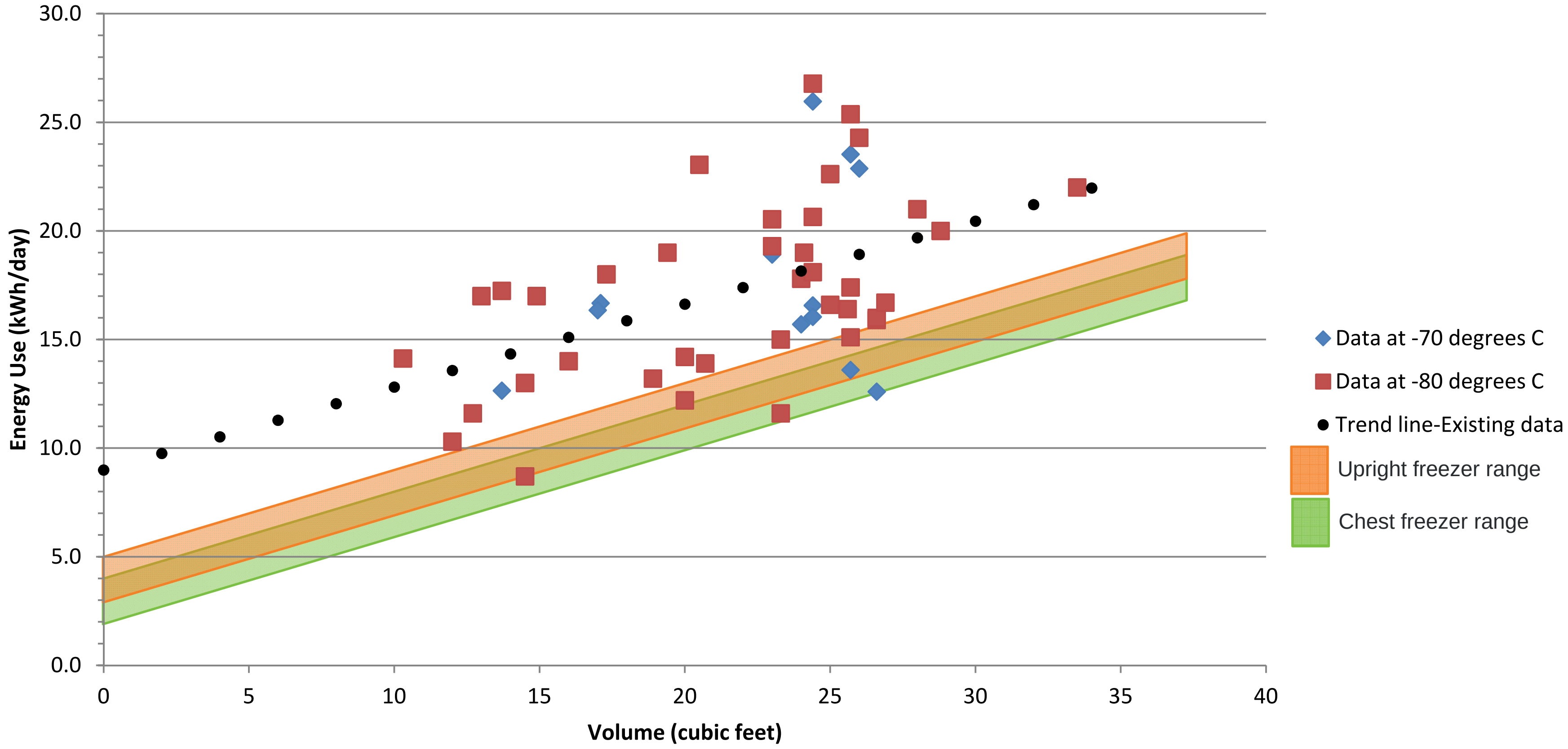
The chart below contains the data used to formulate the draft specification equations.



The specification sets a level of performance for ULFs that is more efficient than the standard product.

- The specification level is a maximum daily energy consumption for a ULF.
- ULFs meeting the spec must have a rated daily energy consumption less than or equal to the maximum value.
- The allowable energy consumption scales with the interior volume of the ULF.

Efficiency Levels for Proposed Specification

Product Type	Maximum Daily Energy Consumption (MDEC) (kWh/day)
Chest Freezers	*MDEC* = 0.87 × *Volume* + (3 to 5)*
Upright Freezers	*MDEC* = 0.25 × *Volume* + (2 to 4)

***** The intercept for the line defining the MDEC is given as a range due to uncertainty about the performance of existing ULFs. For the final specification, a single number will be chosen such that the standard can be met by a set of the most efficient products on the market.

Acceptable payback depends on the customer.

- Scientists who purchase equipment do not pay utility bills and are very first-cost sensitive, so they would be unwilling to pay more up front for a long-term energy benefit.
- However, managers of institutions that use ULFs are beginning to work with purchasers to incentivize the purchase of high-efficiency equipment that reduces the energy use of the institution as a whole.
- On an institutional basis, the acceptable payback depends on the nature of the institution.
  - A stakeholder from the National Institutes of Health (NIH) said that the maximum payback for governmental purchases would be 5 years.
  - A stakeholder from a university said that a 10-year payback would be acceptable, but noted their energy costs were only $0.05/kWh.