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Low-Temperature Freezer Monitoring in Scientific and Pharmaceutical Applications

Final Report

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Disclaimer

Executive Summary

This study investigates the energy savings capability and potential of ultra-low temperature freezer monitoring systems when used as an energy consumption diagnostic tool. Ultra-low temperature (ULT) freezers are common in university labs and facilities involved in research and development requiring the storage of sensitive materials such as pharmaceuticals and cultures. These ULT freezers often maintain temperatures as low as -80°C, thus consuming large amounts of energy. Reports estimate that the average ULT freezer uses about 6,400-9,300 kWh per year. Identifying energy savings opportunities in the ULT freezer market could prove highly beneficial to utilities, consumers, and the public.

A ULT freezer monitoring system designed to allow convenient access to freezer temperature, energy consumption, and other variables has been developed for application to freezer populations of various size. Whereas previous technology and standard practice relied solely on local, temperature-based alarming at the freezer, the system under study has enhanced, remote data monitoring, storage, and analytic features. It has been suggested that by using certain metrics, the monitoring system can identify poorly performing, over-consuming freezers. The technology assigns color grades to each freezer based on compressor behavior. Poorly functioning freezers can then be targeted for pre-emptive repair or maintenance in order to extend the lifetime, enhance reliability, and reduce energy consumption.

This study observed the long-term use of the monitoring system with respect to energy consumption and freezer repairs. The goal was to determine the effectiveness at engendering proactive freezer repair and to examine the quantity and persistence of any resultant energy savings. Since the technology is solely a monitoring application, any derived energy savings will be a result of user behavior. For instance, the technology will only cause energy savings if the user chooses to pre-emptively repair a freezer and if the repair addresses the root cause of high consumption. Additionally, pre-emptive repairs may face resistance from established service contractors. The vendor recommends the contracting of trained "Smart Service Providers" who provide continuous consultation and repair warranties that incorporate the technology. This recommended practice was not used in this study, but is discussed in detail. This strategy may help to ensure operational changes and sustained energy savings over time. Rather, the technology was used as a stand-alone product for facilities to utilize at their discretion.

Fifty-three freezers at three sites in the San Diego area were chosen for monitoring in this study. Based upon an instantaneous view, about eleven percent of installed freezers scored red and required repair or maintenance according to the grading system. This is in line with previous vendor findings. Additionally, thirty-two percent scored yellow. Of these freezers, facility management selected nine freezers as candidates for repair based upon the monitoring technology or standard operating procedure. The type of needed repair was determined by the contractor used by the host sites. Using the energy monitoring features of the technology, snapshots before and after each repair were used to determine energy savings and their persistence over time. The following table and plot show the repairs and energy savings persistence. Payback times and returns on investment were not calculated due to

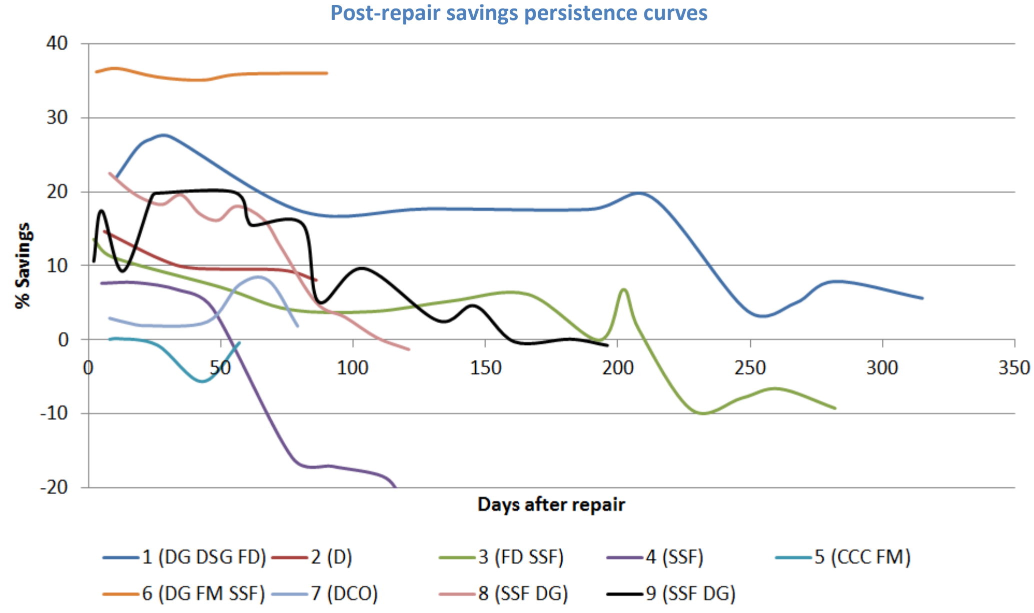
various factors including savings persistence unpredictability and the unknown values of non-energy benefits such as extended useful life and increased contents safety.

Freezer repair initial and end-of-measurement savings. Colors indicate technology grades of each freezer.

Freezer	Repair Cost [$]	Measurement Period Savings [$]	Consumption Before [kWh/year]	Initial % Savings	Final % Savings	Measurement Period [days]
1	$746	$133.7	11,925.0	21.9	5.6	315
2	$110	$25.7	12,133.9	14.7	8.1	86
3	$343	$10.4	10,561.9	13.6	-9.2	282
4	$672	None	10,173.8	7.6	-21.0	118
5	$137	None	8,475.4	0.1	-0.4	57
6	$1,132	$77.2	9,713.4	36.2	36.0	90
7	$3,997	$6.4	8,455.3	2.9	1.9	79
8	$970	$38.2	11,091.4	22.5	-1.3	121
9	$1,856	$56.6	13,438.1	10.6	-0.8	196

Continued monitoring of each freezer showed that the energy savings achieved by repairs did not typically persist long-term. This indicates that additional investment or procedures were warranted but not completed due to the lack of standard operating procedures that included use of the technology or unapproved expenses.

Post-repair savings persistence curves



The technology's approach to energy savings is highly dependent upon user behavior, repair diagnostics, and other variables. The system accurately measures energy consumption and identifies poorly performing freezers, but additional services or procedures to the ones used in the study are required for sustained savings. Determining the cost-benefit of such added measures requires additional study. If the energy savings could be sustained, utility programs could potentially offer an incentive application process that rewards proven, empirical energy savings up to the date of submission.

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Introduction

Ultra-low temperature freezers (ULT) can consume a large portion of a commercial building's energy since maintaining freezers at temperatures as low as -80°C is very costly, with each freezer consuming about 6,400 to 9,300 kWh per year [2, 13]. The contents of ULTs are often very sensitive and valuable materials such as biological or chemical samples stemming from multi-million dollar research projects. They need to be consistently maintained at an ultra-low temperature for proper, safe storage. Since ULT contents are sensitive and typically of vast importance to the user, extra monitoring and failure prevention precautions appear sensible.

It has been suggested that a large percentage of these freezers are not working at optimal performance. Despite this concern, there is no standardized method for the monitoring and pre-emptive repairing of ULT freezers other than spot checks, temperature alarms, and preventative maintenance protocols which generally address the entire population of freezers rather than only those with problems.

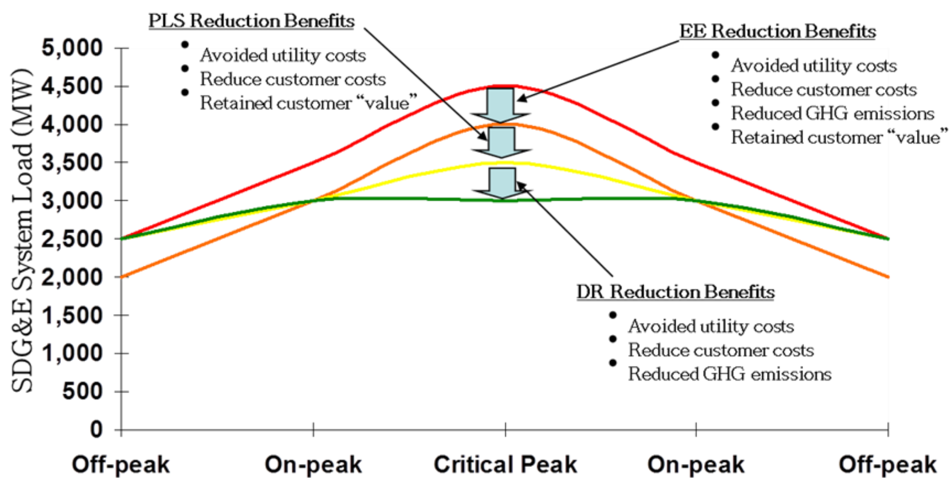
The goal of the technology evaluated here is to provide extensive ULT freezer monitoring and alarming capabilities to facility managers. Within this framework, freezer temperature, energy effectiveness, and energy consumption are assessed using dedicated sensors. With this data, failures and underperformance can be predicted and caught early. The technology scores freezers by color grades that represent their performance. This grade is then used to inform intelligent freezer management decisions which can include pre-emptive, non-regular maintenance or repair. Pre-emptive maintenance and repairs may improve ULT efficiency and energy consumption by ensuring that they operate at a more optimal state. Aside from possible energy savings, facility managers benefit from improved safety of the freezer contents and from extended freezer lifespan. A monitoring technology can allow for more intelligent allocation of time and resources; funds that would be used on preventative maintenance for the entire population of freezers can be better used by targeting the freezers which would provide the most benefit from repairs and investment. Energy savings and returns could potentially be maximized by empowering the customer to make more informed decisions for the allocation of funds.

This report is specifically about the monitoring of ULT freezer energy consumption as an entire freezer unit (not at the component level). Hereafter, the energy monitoring and performance evaluation aspects under study will be called the "technology" for brevity. This technology is part of a larger, customizable monitoring and ULT management system with additional non-energy features that are beyond the scope of this study.

The energy consumption before and after maintenance or repairs will be assessed. The technology's recommended practices include the contracting of a service provider that is dedicated and committed to the technology and maintaining resulting energy savings. This service provider will be henceforth called a Smart Service Provider (SSP) to indicate the level knowledge and ability to use the technology in an effective and continuous manner. This recommended practice is further discussed in the Technology Overview section. A SSP was not included in the study; thus, the technology is evaluated as a standalone product for use by the facility only. This stand-alone use is analyzed with respect to monitoring, maintaining, and reducing energy consumption of ULT freezers (as opposed to contents safekeeping, reliability, or other aspects). Demand or demand response considerations do not apply to this technology and therefore will not be considered.

As shown in Figure 1, energy efficiency (EE) measures help both the utilities and customers. EE measures will lower production requirements for the utility, thus reducing customer cost and environmental concerns. For this reason, technologies that purport increases in energy efficiency are of great interest to utilities and the general public.

Figure 1 - Utility and Customer advantages to energy efficiency (EE), demand response (DR), and peak-load shift (PLS).



No alterations to freezer performance or contents were made for the purpose of this study other than repairs or maintenance enacted due to the technology or standard facility procedures. The use and repair decisions were left to the discretion and judgment of the facility managers and the technology support team. This was in place of the vendor SSP recommended practice. The freezers operated within California regulations and this technology should be applicable to a wide range of similar freezers in California and elsewhere. However, it is important to note that various other regulations may apply, based on the contents of the freezer. Therefore, this report does not offer recommendations of the applicability of this technology to all potential uses. All uses and applications of this technology should be carefully considered in each individual context.

The study took place in San Diego Gas & Electric Company territory. However, the results should be applicable throughout most of California due to consistent legislation and tariffs throughout the state. As stated earlier, the applicability of codes and legislation may change depending on the contents of the freezers.

Project Objective

The main objective of this field evaluation is to study the effectiveness of this technology from an energy savings standpoint through a study of sample installations at three difference host sites: research laboratories at a university, a company specializing in food safety testing with molecular assays, and a research institute studying biological processes and associated therapeutics. For further site information, please see Detailed Host System Description.

Objectives include assessing the efficacy of the technology (does the product function as intended) as a standalone product and quantifying its use within the context of energy and cost savings. Additionally, the technology approach, benefits, validity, and potential are discussed without regard to particular vendor or product. We also briefly describe the marketplace as well as applicable codes and standards.

The review will also include a discussion of how the users and test sites used the technology. Since this is an *enabling* technology, energy and cost savings will be directly dependent on user action or lack thereof. The technology allows users to monitor energy and temperature and make informed decisions with these results. Energy savings can only result from improved freezer efficiencies if repairs are performed. The technology itself does not provide energy savings directly. The vendor typically recommends the use of a SSP as described in the Technology Overview section. This evaluation forwent this recommendation for the purposes of evaluating the technology as a standalone product without added service contracting. Thus, the energy savings are entirely dependent upon customer use of the technology and their repair decisions and protocols.

During the early stages of the study, NegaWatt Consulting and SDG&E studied the algorithms for determining freezer grade in detail. Early results were presented as suggestions to the vendor for developing a more rigorous and effective method of freezer grading. Several suggestions were incorporated into the technology for more consistent and reliable monitoring.

The project results sections include system setup and operation, roles and responsibilities, cost and cost-influencing factors, system functionality, software & algorithms, customer feedback, energy and cost reduction, and applicability of existing SDG&E programs.

Project Methodology

Full Project Plan and M&V Plan can be found in Appendix A and B, respectively.

The Project Plan (Appendix A) contains detailed information on the following:

- Description of the technology under investigation
- Description of the incumbent technology that is being replaced
- Goals of the assessment project
- Application and/or Generalization of project results to similar facilities in other locations
- Generic customer or laboratory information
- Project Milestones (initial tentative timeline)

The Measurement & Verification Plan (Appendix B) contains detailed information on the following:

- Host site
- Data collection procedures
    - Data points
    - Data sampling, recording, and collection intervals
    - Instrumentation
- Data analysis procedures
    - Data manipulation
    - Calculation of potential energy savings
    - Calculation of potential cost savings

Technology Overview

The deployed technology is composed a current transformer (CT) sensor and a temperature sensor at each ULT freezer. These sensors relay information to a central communication station which relays data to the vendor servers via the facility's wireless network. By monitoring the energy consumption (via the CT sensor and voltage from spot measurements), a performance grade can be calculated on the back-end. The grade is assigned for both compressor on-time and the number of cycles per day, based on expected optimal values. The algorithm provides each freezer with a color grade (green, yellow, red) based on optimal ranges as determined by the technology engineers. The grade ranges for both compressor on-time and number of cycles per day are proprietary and are based on extensive industry experience and testing. The grading algorithm will continue to develop as more data is collected over time. The grades and the values of these metrics can enable users to make informed decisions on maintenance or repairs.

The monitoring technology and its recommended energy savings strategy are based upon data collection, energy consumption grading, and a SSP program. The SSP support is optional and its use is at the customer's discretion, if more than a stand-alone product is desired. This SSP program includes consulting services to drive adoption and changes to standard operating procedures and contracting with select freezer maintenance companies. This strategy is used to develop preventative maintenance and repair decision protocols which incorporate the data collected by the technology. Additionally, the contracted maintenance company will be trained in the technology and may help to ensure that any energy savings derived from repairs are sustained over time. If savings realized from any given repair does not persist over time, the SSP program features could help stop or delay this degradation and restore optimal performance via further repair or diagnostics. If a repair did not produce sustainable energy savings as predicted by the technology, this service agreement warranty would guarantee additional repairs at no or adjusted itemized cost to the customer, in order to better address the root causes of poor performance. Thus, the technology can be used as a business intelligence tool via an iterative repair and maintenance decision making process, if necessary or desired.

The SSP program was not included this field evaluation. Thus, the full capabilities of the vendor's consulting services and sustained energy savings may or may not be represented by this study. Instead, the technology is evaluated as a standalone product that may or may not engender effective savings strategies in the customer facility. The implications of choosing not to use the vendor recommended SSP strategy are discussed in the Results and Discussion sections. Appendix E shows results from a separate, unrelated study that used the SSP strategy.

Alternatively, a customer could potentially develop his own intelligent use of the technology's monitoring capabilities by establishing best practices and procedures after becoming accustomed to the technology and its use. This approach would take considerable time and attention by the customer and was not in the scope of this study.

Host Site Overview

Three host sites were selected for the field evaluation as described in the Project Objective section. Hereafter, these three sites will be called University Labs, Food Safety Labs, and Biology Labs. These three sites had 30, 6 and 33 freezers, respectively, that were selected for the review. The freezers were of common models and the majority of them were between 2 and 10 years old. Food Safety Labs freezers were mostly 20 ft^3 while University and Biology Labs freezers were generally about 25 ft^3.

During the evaluation period the freezers were used normally and no new interactions with the freezers were introduced with the exception of repairs that may have been advised by the technology. Observations of the repair results were part of the field test and technology assessment and performed remotely.

These sites were chosen because they all had common ULT freezers and were located in California. This will be useful in market analysis for elaboration of market applicability to California, specifically. These sites were also chosen because the freezers did not contain anything under the regulation of the FDA;

FDA requires a much more complicated process of maintenance and monitoring which the scope of this project and technology do not encompass.

There are differences between each test site that will allow us to determine the effectiveness of the technology into a wider market. University freezers are used by various departments, so the upkeep and monitoring is the responsibility of the research group or professor. At other two sites, collections of freezers are the responsibility of facility managers who monitor and respond to freezer alarms. Since it is up to the user to determine how to use the data, it will be of importance to analyze the survey results to see if these differences matter to the implementation of the technology. This is important to SDG&E and the vendor because energy savings will only be results of the repairs or replacements enacted by the lab manager or research group.

There are no well-developed incumbent standard practices for monitoring freezer performance using remote access and data collection. Instead, freezers are typically equipped with on-board temperature alarms. These alarms sound when the temperature is out of setpoint range for an extended time in order to prevent losses. However, due to the audible nature of the alarms, personnel need to be within earshot to notice. Thus, audible alarms could sometimes be ineffective. Another problem with incumbent monitoring methods is that freezers can be accidentally unplugged or circuit breakers getting shut off; this effectively turns off the power to both the freezer and alarm. The technology evaluated here has battery power to negate such problems.

Measurement and Verification Plan Overview

This plan establishes methods for evaluating system setup and operation, roles and responsibilities, cost and cost influencing factors, system functionality, impact to host site staff, customer feedback, energy reduction, repair effect persistence over time, and applicability of existing SDG&E programs for the technology when used as a standalone product.

Emphasis is placed on the following aspects:

Verification of system operation and design

- Does the system monitor the current input of the freezer accurately and continuously?
- Is the system's 'ranking' algorithm robust to many different types of freezers?
- Does performing maintenance on poor-ranking freezers improve their performance?
- Do the energy benefits seen from repairs last over time?
- Does the alert system function proficiently to warn of poorly performing freezers?

Potential energy savings

Energy savings are calculated. Energy savings will be dependent on pre- and post-repair energy consumption of a low performing freezer. Energy savings will be based on the actual improvement (kWh/year), which will result in an estimated total kWh saved per repair. These estimations will be based on freezer history within the web utility. Any energy savings are the result of repairs or maintenance without inclusion of the vendor recommended SSP program.

Software and algorithms

This system is highly computerized and required a thorough review of the application, user interface, reporting capabilities, and algorithms. Specifically, how the software analyzes temperature and energy and relates this data to an alarm status was studied.

Customer feedback

Various questions were provided via an online survey to the lab managers in order to understand their use of the technology and its capabilities and features. Questions included the following examples:

Does the customer like the system? What improvements would make the system more attractive? Did the system require increased input/attention from staff? How does a lab manager respond to poor freezer grades?

Applicability of SDG&E incentive and rebate programs

This report reviews all relevant SDG&E programs with respect to this technology and provides recommendations on where program support may apply.

Finally, discussions conclude the study

- Benefits of a low-temperature freezer monitoring system
- Improvement opportunities for the tested product
- Applicability of this study to other load types and sectors
- Considerations for large-scale market implementation
- Potential future study

Applicable codes and standards

Title 16 Section 1751.3 of the California Code of Regulations pertaining to record keeping mandates that for sterile products compounded from one or more sterile or non-sterile ingredients, refrigerator/freezer temperatures must be kept for at least 3 years. This regulation wouldn't necessarily require the monitoring technology to log data, but it would be very advantageous for the monitoring system to keep a log so that accurate records would be able to be maintained and accessed as needed [1].

It is worth mentioning that California Title 20 and Title 24, which concern the energy efficiency of different types of refrigeration units, do not pertain to these types of freezers. Under these regulations a freezer has been defined as a cabinet designed as a unit for the freezing and storage of food, beverages, or ice at temperature of 0°F or below and that has a source of refrigeration requiring energy input. Based on the proposed contents of these ULT freezers these two sets of regulations are not applicable.

Subsequent codes and standards may be applicable to these freezers during or after a catastrophic event (freezer failure). If the freezer that is being monitored with this technology uses a hazardous coolant, then standard MSDS procedures should be taken to avoid further hazards and handling of the materials. The monitoring technology does not alert to the necessity of further precautions outside of those derived from a freezer's temperature or extreme energy consumption.

Most relevant codes and standards apply to the freezer unit and its functionality. Due to this technology mainly being a monitoring application, direct applicability of regulations is minimal unless the contents of the freezer require strict observation.

The FDA has various requirements and codes for freezers that house cultures and samples of products that are to be used in consumer goods. These codes are put in place to prevent contamination and spoiling, but are not ubiquitous across all ULT freezer applications.

The DOE and Energy Star program are in the process of developing standards for ULT freezers with respect to their energy consumption. The standard is still in development and specifics are not publicly available, yet.

Market Overview

Opportunity

It is estimated that 10,000 ULT freezers are sold in the United States each year [2]. Also, correspondence with an ULT industry engineer provided an estimated United States freezer count of about 400,000. Since each freezer uses about 6,400 to 9,300 kWh per year [2, 13], the potential for savings is large if freezers are over-consuming. By this estimate, total U.S. ULT freezer electricity consumption is about 3,140 GWh per year. In our study, 11% of the freezers received the worst color grade (red) and 32% received the middle grade (yellow).

Products and Systems

A list of vendors and products competing in this market sector is provided below in alphabetical order. [1]

Vendor	Product
• Amega Scientific [8]	CMS
• Hampshire Controls Corp [4]	CA5000
• Hydra-Numatic [5]	Sensaphone
• Klatu Networks [10]	Traxx
• Labcold [6]	RMAX9004
• Modularm [3]	75LC
• Networked Robotics [12]	Tempurity
• New Brunswick Scientific [7]	A2
• Two Dimensional Instruments [9]	ThermaViewer
• Veriteq [11]	viewLinc

[1] The list is in alphabetical order, provided as is, not exhaustive, and the selection is arbitrary. The authors of this report do not endorse or guarantee, and disclaim any responsibility for: the content, products or services offered, their performance or suitability, and any consequences or damages, incidental or otherwise, that may result from their consideration or use.

Project Results and Discussion

Detailed Host System description

The system being evaluated consists of wireless sensors, a web-based user interface, and back-end programs for collecting and analyzing data. Each of these components will be explained.

Sensors

The sensors at each freezer transmit to a central communication device that connects directly to the site's wireless network to transmit data to vendor servers. Each freezer being monitored has an internal temperature sensor and a CT clamp. These measure and relay the temperature and amperage of the freezer. The sensors and communication device have internal batteries, making them completely independent of the monitored freezer.

The sensors collect data instantaneously once every minute and then every five minutes transmit the collected data along with a respective time stamp. In the case of a freezer, wireless network, or power failure, the sensors will still function and will continue to record to internal memory until any failures have been resolved. The central communication device has back-up storage for up to 24 hours of lost internet connectivity.

Back-end Programs

After the sensors transmit data, the back-end processes the data and makes it available to the user via a web interface. The program provides ample amounts of data to the user such as freezer details (temperature, current, voltage, location, name, make/model), kWh consumption, annual cost based on instantaneous power, annual cost/ft^3, 'grades' of freezer performance, and more.

The areas focused on in our field evaluations are related to energy consumption. Along with spot measured voltages, the amperage data points were used to calculate instantaneous or average annual kWh, annual kwh/ft^3, annual costs, and other savings related values. The temperature is monitored to make sure that valuable contents of freezers are maintained at appropriate set-points; when freezer temperatures are too high for too long, alarms go off to allow facility managers to rescue these contents.

The back-end programs execute a grading algorithm for the monitored freezers based on compressor behavior in order to anticipate failure and identify potential energy savings targets.

Figure 2 - System diagram: Wireless sensors are installed at each freezer. Data is sent over the host sites' Wi-Fi network and internet gateway. From there it is sent to the vendor's server where data is processed and made available to the user via a web utility.

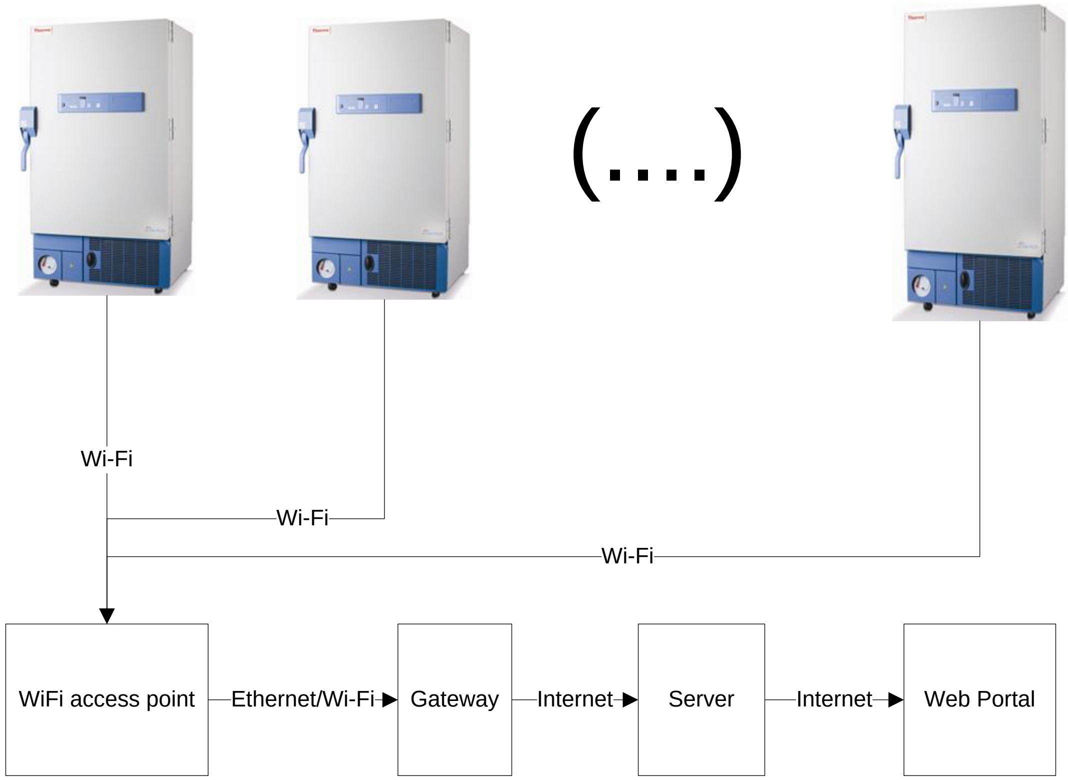


Figure 2 shows the communication architecture.

Web Utility

The user can access all monitored points and historical data through the web utility connected to vendor servers. Temperature, energy consumption, alarming, freezer database, freezer characteristics, and other variables for single or multiple freezers can be observed. A "study group" feature allows for the comparison of averaged energy consumption during snapshots of selectable date ranges for a selected group of freezers. One use of this feature includes comparing the energy consumption before and after a repair. This allows for the monitoring of energy savings results over time, allowing customers or service providers to make iterative maintenance decisions to ensure savings persistence, should they be warranted. Many other features intended for freezer management, maintenance, and monitoring are available. These include maintenance logs, alarm history, energy history, freezer reports, sensor list, and others. A comprehensive list and descriptions was excluded from the report due the complexity of the web portal; in general, it is a user interface that allows for observation and management of many monitored freezers and data points through a variety of features.

System deployment and operations-related roles and responsibilities

Once the system (Wi-Fi modules, sensors, and software) has been purchased from the vendor, the end user is responsible for the cost of installation. Each freezer may take up to 45 min per installation. The vendor can provide training for the software and a 1-year hosting and license fee is included in the cost. The 1-year includes hosting, technical support, features, and upgrades within current release. Various levels of service are available.

Without the SSP program, the host site is responsible for monitoring freezers via the system and responding to alarms and any information provided by the system after commissioning. The technology vendor is also not responsible for repair or maintenance protocols set up by the host site without the SSP program. The customer would want to actively monitor any alarming freezers, setpoint degradation, or energy consumption patterns in order to make informed maintenance and repair decisions. Savings could be maximized by allocating a maintenance budget more intelligently across the freezer population. By dedicating resources to the most problematic or over-consuming freezers, resultant energy savings and performance increases can be maximized.

However, providing pre-emptive repairs may not always appear to be in the best interest of the service providers at a customer's facility, especially if a conventional fail-and-fix contract with warranties exists. The vendor is currently working to develop relations with service providers and certify such companies after training, consulting, and other agreements.

List of controlled points

This technology is a monitoring-only application; there are no actively *controlled* points. In particular, the technology does not allow remote changes of the freezer setpoints or other settings.

Sequence of operations

Once the system has been installed and fully commissioned it will continuously deliver measurement values. See Figure 2 for the device connection diagram. As stated earlier, the sensors relay temperature and current data to a Wi-Fi communicating module at one minute time intervals. After 5 minutes the data is sent to the technology's server where it is processed and stored for access via a web-based user interface.

A user can add freezers easily through the web portal if they wish to expand the system. Also, users are able to place various freezers into 'study groups' to closely monitor units before and after repairs.

During normal use of the monitoring system, the users can be alerted 24/7 via email.

System cost and cost-influencing factors

Table 1 shows list pricing for host sites with 25 and 500 freezers. If host sites wish to expand their monitoring population in the future it will generally be at a linear cost increase. The displayed cost does not include the installation of freezer temperature sensors, which is typically done by the host site or a service provider.

Table 1 - Estimated total system cost for 25 and 500 freezer facilities; cost will depend on site and number of freezers.

	Project Cost @ 25		Project Cost @ 500	
Item	**Per Unit**	**Total 25**	**Per Unit**	**Total 500**
Software	$535.50	$13,387.50	$154.70	$77,350.00
1-yr Subscription Fee (yr 2 and on)	$141.31	$3,532.75	$44.63	$22,315.00
Gateway (optional)	$499.00	$499.00	$499.00	$499.00
Wi-Fi Module	$272.09	$6,802.25	$200.33	$100,165.00
Temperature Sensor	$158.40	$3,960.00	$100.80	$50,400.00
Split Core CT	$34.65	$866.25	$25.55	$2,555.00
Installation & Training	$67.20	$1,680.00	$13.98	$6,990.00
Installation Labor ($90/hr)	$65.20	$1,630.00	$12.08	$6,040.00
Total System Cost	**$1,133.04**	**$28,326.00**	**$507.44**	**$243,500.00**

The hosting fee is recurring after the first year. Beyond the first year, the facility will need to renew their agreement with the technology company, because all data is processed and stored on the vendor servers and the user interface is hosted there as well.

Repairs to freezers are not included as cost towards this technology but will be discussed later.

Verification of system operation and design

Does the system monitor the freezer current and energy consumption accurately?

Nine freezers (4 from Biology Labs and 5 from Food Safety Labs) were measured to check the validity of the data on the technology's web portal. The measurements were taken and then plotted against the logged data from a calibrated Fluke instrument. As can be seen in Figure 3, the Fluke data was denser because it was set to record at an interval of 2 seconds while the monitoring technology used minute intervals. A smaller interval was used to map out the freezer functionality more accurately and observe a more continuous pattern of energy consumption. The monitoring device performs instantaneous measurements as opposed to averaged aggregates, so this would help to verify frequency of anomalous data.

Below in Figure 3, a 20 minute amperage data sample for a single freezer with the compressor on is plotted. It can be seen that when there are no compressor cycles, the data is very similar between both sensing methods. This instance had a 0.4% total discrepancy, confirming accurate technology measurements.

Figure 3 - 20-minute sample of data comparison while freezer compressor on

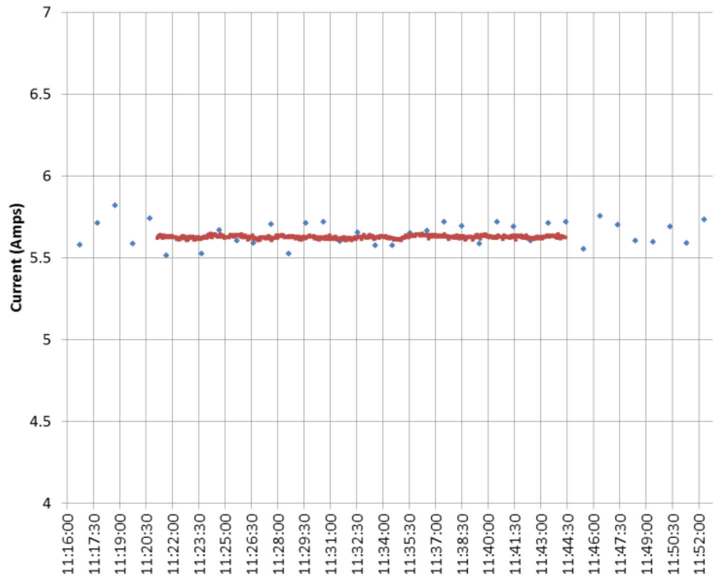
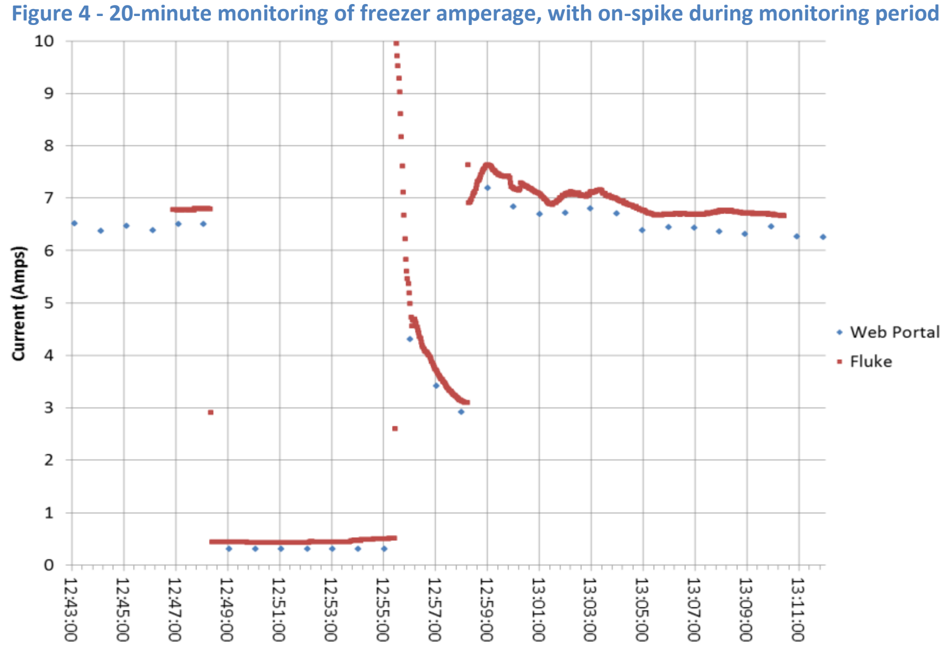


Figure 4 shows the technology amperage sensor and independent measurements taken during a sample compressor cycling. The two curves are sufficiently similar.

Figure 4 - 20-minute monitoring of freezer amperage, with on-spike during monitoring period



Over the 9 freezers monitored, the Fluke measurements were on average 4.6% higher. This is plausible and acceptable because the technology's sensor and the Fluke both have a ±2.5% error margin; therefore, a deviation of up to 5.0% can be expected. Also, an important note is that since the error of both devices is based on the percentage from the recorded data, higher values will result in a higher absolute error. This can be observed as the lines appear much closer between 12:49 and 12:55. Also, since the Fluke data was at a much higher interval it captured a spike at 12:56 that the technology's monitoring device did not. This may have actually skewed this specific test error upward. Because of the large time observation period overall, such short spikes (and any corresponding dips) will average away.

Since the amperage data is accurate, the energy consumption for each freezer should also be accurate. Therefore, the technology can accurately identify freezers which are over-consuming energy with respect to their specifications, history, or peers.

Is the system's grading algorithm robust?

After several grading algorithm design iterations, the present algorithm based upon compressor behavior was developed. By choosing ranges of compressor on-time and number of cycles for each color grade, the algorithm can easily be extended across all freezer models and sizes. The grade metrics were developed by extensive testing and experience. Since compressors generally size up or down with freezer capacity, the algorithm should be robust across all freezer sizes. Additionally, since compressor efficiency does not vary too much across models, a given range of on-time can capture the health of any compressor relatively well. It was seen that the grading correlated well with high energy consumption. The vendor hopes to continue to refine the algorithm as data becomes more available with increased product rollout.

Does performing repairs on an alarming freezer improve performance?

Freezers that were coded yellow or red were considered candidates for non-regular maintenance or repair. Typically, a repair company specializing in ULT freezers would first perform diagnostics on the freezer to determine the repair need. Repairs varied across the freezers, as did the energy savings with respect to the pre-repair energy consumption. The energy savings unfortunately did not persist in most cases, and occasionally even showed higher energy consumption over time. It is apparent that simply asking a repair contractor to perform one-time maintenance or repairs does not always address the root cause of poor performance. The inclusion of a SSP strategy may prevent against energy savings ineffectiveness.

Does the system warn for poor functioning freezers?

Freezers that are consuming larger than average amounts of energy are consistently marked red or yellow, depending on the severity of the concern. Note that the system is not able to predict and pre-empt *all* possible catastrophic failures; it does however allow for a significant reduction of such, as long as the provided alarms are diligently addressed by facility management.

Does the system accurately calculate cost and savings of each freezer?

The technology does not provide predicted cost and energy savings for repairs to poorly performing freezers. Rather, the technology has a feature which calculates yearly energy consumption based upon empirical data. The yearly consumption is calculated based upon an average value for a selectable snapshot range of dates. In other words, the technology calculates the average consumption for the snapshot and extrapolates this average across an entire year to obtain kWh/year without regards to energy trends over time. The yearly energy consumption for pre- and post-repair snapshots is then used to calculate realized energy savings (rather than predict). For this reason, any reliable energy savings calculated by the technology are historical in nature. The technology cannot accurately predict future energy consumption but can accurately calculate the savings realized to date. Thus, any presented energy savings may not necessarily be representative of future energy savings, due to unpredictability of performance degradation or long-term repair effectiveness.

A contracted service provider can use these snapshot results to determine whether energy savings have persisted. If they do not, then further action can be taken. In this manner, the technology and its web utility allow for decisions based upon actual results, both instantaneous and over time. However, as is, the technology does not allow for the prediction of energy savings for any given repair, freezer model, or pre-repair state. Perhaps as data and results accumulate, the technology could incorporate energy savings prediction in the future using a statistically representative population of results.

Energy Savings Evaluation

Energy savings were calculated using the web utility's energy consumption snapshot features. As shown earlier, the discrepancy between the logged data and calibrated instrument data was less than 5%. This was deemed acceptable so that the extensive web-accessible database could be used.

The instantaneous status of the monitored freezer pool grades can give insight into how many freezers may be operating poorly at any given time. Table 2 shows the instantaneous percentages of freezers that were operating within each of the technology's classification grades.

Table 2 - Instantaneous freezer grade distribution

Total Freezer Count	Green Status [%]	Yellow Status [%]	Red Status [%]
53	57%	32%	11%

This implies that at any given time, about 11% of a given freezer population is operating at very elevated energy consumption levels based upon compressor monitoring. Thirty-two percent are also operating out of optimal and could possibly benefit from extra monitoring, attention, or maintenance.

Energy savings were determined by comparing energy consumption during intervals before and after a repair. The energy consumption was recorded from the web utility for manually inputted time intervals of 2 to 8 days. The intervals were chosen based on amperage curves and sections, therein, that did not show measurement omissions or abnormalities that would skew results, such as extensive door opening, set point changes, or other uncontrollable load swings.

Immediate Post-Repair Energy Savings

There are two ways to approach the energy savings calculations: using energy consumption immediately following a repair or multiple samples extending over time after the repair. By tracking the energy consumption long-term after the repair, persistence of savings can be studied.

Table 3 lists the freezers graded red or yellow and were repaired, along with their properties, repair type, repair cost, and energy consumption before and *immediately after* repair. The age of each freezer and their repair histories are unknown. Table 4 lists the repair and maintenance acronyms.

Table 3 - Freezers, repairs, and immediate savings. Colors indicate freezer grades.

Freezer	Repair	Freezer Size [ft^3]	Repair Cost [$]	E Consumption Before [kWh/year]	E Consumption After [kWh/year]	Initial % Savings
1	DG, DSF, FD	20.2	$746	11,925.0	9,307.9	21.9
2	D	24.4	$110	12,133.9	10,355.1	14.7
3	FD, SSF	24.4	$343	10,561.9	9,126.8	13.6
4	SSF	24.4	$672	10,173.8	9,396.8	7.6
5	CCC, FM	17.2	$137	8,475.4	8,469.5	0.1
6	DG, FM, SSF	17.2	$1,132	9,713.4	6,194.9	36.2
7	DCO	20.2	$3,997	8,455.3	8,209.1	2.9
8	SSF, DG	24.4	$970	11,091.4	8,594.8	22.5
9	SSF, DG	24.4	$1,856	13,438.1	12,011.6	10.6
		Repair Cost [$]		kWh/year savings		% Savings
Average		$1,107		1,589.0		14.5

These values most nearly represent the maximum achievable savings for each particular instance that could potentially be sustained over time. With this before and immediately after method, the average savings were 1,589 kWh/year or 14.5% of the baseline consumption. There was such a wide variation in savings, repair type, and cost for a relatively low number of freezers that no correlations could be made between the results and variables. Even within equivalent repairs, results showed no clear patterns.

Table 4 - Repair and maintenance acronyms

CCC	Clean Condenser Coil	DSF	Dual System Flush
D	Defrost	FD	New Filter Drier
DCO	Dual Compressor Overhaul	SSF	Single System Flush
DG	Replace Inner Door Gasket	FM	New Filter Media

Cost savings and payback were not calculated with this method because doing so would require assuming that the immediate post-repair savings and energy consumption levels would persist over time. Furthermore, repairs and upkeep are not well-suited to a simple payback calculation. Rather, the situation demands a more complicated return on investment method that is further discussed at the end of this section.

Persistence of Repair Energy Savings

For studying energy savings persistence, energy consumption snapshots for normal, non-anomalous intervals of 2-8 days were recorded for as long as possible post-repair. In general, longer intervals were preferred in order to average out freezer opening and compressor cycling frequency. Additionally, the temperature points over the same span were recorded. Unfortunately, in many cases the temperature curves were not constant and varied over the measurement period. Since the setpoints were not controlled or recorded as part of this study, it is technically unclear whether the temperature changes were due to set point adjustments, other factors, or both[2]. At such low temperatures, even small changes to the setpoint can cause large shifts in energy consumption. Four freezers had internal temperatures that varied by as much as 3.4, 3.6, 5, and 10 degrees Celsius, respectively. All the other freezers varied less than 2 degrees Celsius.

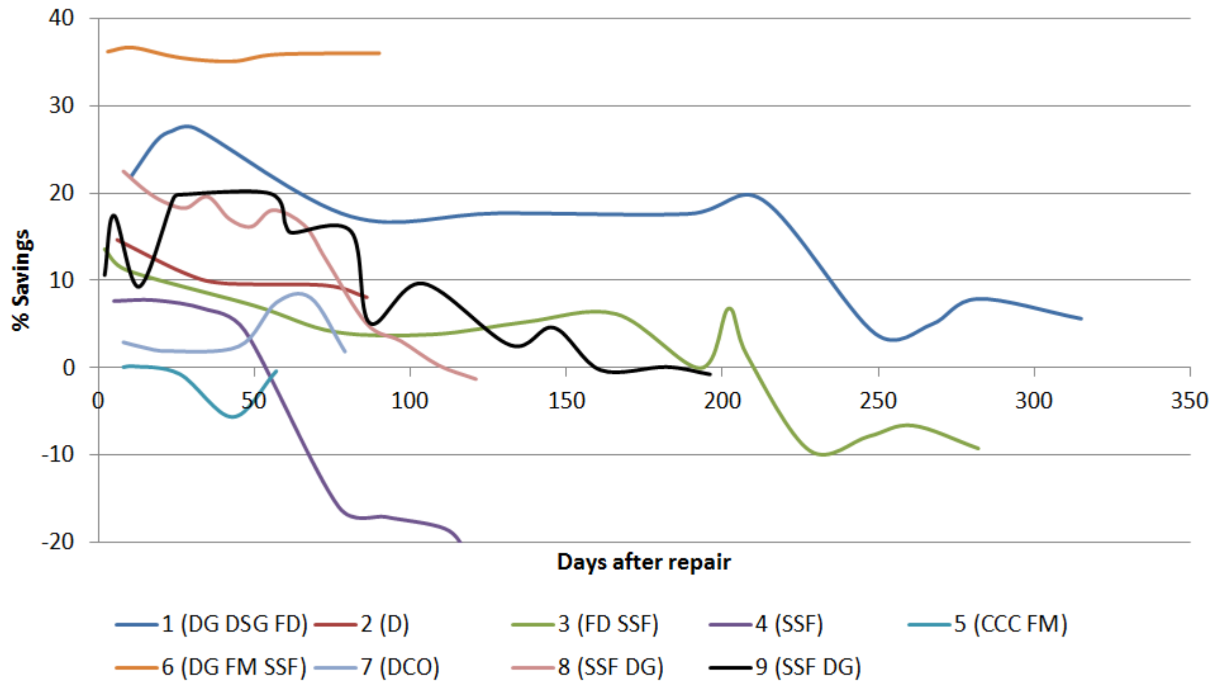
However, the customer survey indicated that setpoints were fixed for each freezer and not adjusted by the users. Thus, while we cannot be entirely certain, for purposes of the discussion we will assume that any overall temperature fluctuation was due to internal freezer operation rather than user influence, other than door openings. Also, the intervals for data collection were selected, in part, to maintain as constant an internal temperature as possible. For these reasons, we assume that these results are representative of normal freezer operation under setpoint controlled conditions.

In some instances the temperature drops correlate with increased energy consumption and decreased performance efficiency. However, this correlation was neither pervasive nor consistent; no clear correlation between internal freezer temperature and energy consumption variations could be determined. For freezer-specific savings and temperature plots see Appendix C.

[2] We would have liked to record setpoints over time, but retrofitting freezer control panels with data logging capabilities would have been prohibitively expensive, not feasible, not practical, or a combination of the above. The only alternative, asking facility managers and researchers to log setpoint changes manually, would not have been sufficiently reliable and consistent for purposes of this study.

The post-repair monitoring produced the savings persistence curves as shown in Figure 5.

Figure 5 - Post-repair savings persistence curves



All percent savings are relative to the freezer state prior to repair and therefore assume that no other degradation or failure would have occurred had repairs not been done. Across all points, savings range from less than zero (energy *increase*) to 36.7%. There is little indication that most savings will persist long enough for the repairs to pay for themselves without additional procedures. The savings vary widely across repairs, costs, and time. Only two freezers exhibited savings persistence over time (freezers 2 and 6). However, note these two freezers were monitored post-repair for less than 100 days.

It seems as though there are often systemic problems with the freezers that go beyond the repaired components, where continuous decrease in performance occurs despite the one-time investment in repairs, maintenance, and rebuilds. This was observed for the majority of the freezers. The specific reasons for each case were not investigated. This finding shows that without continued monitoring and attention, most repairs would not result in sustained energy savings. As such, in order to ensure sustained savings and performance, a facility manager or service provider would have to monitor a freezer post-repair. If savings do not persist, then additional repairs or operational changes could be performed, such as re-calibration. This continued monitoring and iterative decision making is the core of the SSP program that is recommended by the vendor. Without such an iterative decision making process, savings cannot be guaranteed or expected in the majority of cases.

Table 5 lists the repair costs and savings over the measured period. Payback times or returns on investment were not calculated for several reasons. The energy consumption and energy savings trends could not be extrapolated since the variation of energy consumption was too great and could not be normalized. Additionally, it is not reasonable to assume that the final level of energy savings would persist without continued monitoring and iterative repair decision making. For the sake of discussion, if the final level of savings did persist, 2 of the 9 freezers would pay back the repair costs in energy cost savings in less than 4 years. The costs of repairs for the remainder of the freezers would not be recouped in energy cost savings with the strategy used in this study.

Table 5 - Freezer repair initial and end-of-measurement savings. Colors indicate grades.

Freezer	Repair Cost [$]	Measurement Period Savings [$]	Initial % Savings	Final % Savings	Measurement Period [days]
1	$746	$133.7	21.9	5.6	315
2	$110	$25.7	14.7	8.1	86
3	$343	$10.4	13.6	-9.2	282
4	$672	None	7.6	-21.0	118
5	$137	None	0.1	-0.4	57
6	$1,132	$77.2	36.2	36.0	90
7	$3,997	$6.4	2.9	1.9	79
8	$970	$38.2	22.5	-1.3	121
9	$1,856	$56.6	10.6	-0.8	196

It is important to note that savings and payback times will vary with the following:

- Repair costs
- Utility rates
- Repair type
- Diagnostics quality and repair effectiveness
- Use patterns

Furthermore, the payback times were not calculated because some repairs to ULT freezers are investments that provide multiple benefits other than energy savings. Some repairs, especially rebuilds or compressor replacements, are investments that provide added contents security, freezer reliability, useful freezer lifetime, energy savings, and reduction of future repair costs. Furthermore, some of the repair codes correspond to routine maintenance that would normally occur, anyway. From the customer perspective, all of these returns factor into maintenance and repair cost-benefit analysis. As such, a simple payback calculation for repair energy savings would misleading and perhaps undervalue the benefits. Rather, a return on investment analysis for repairs such as compressor replacement is dependent on the rules of capital expenditures, amortization, and depreciation as prescribed by federal guidelines and would need to assign value to non-energy benefits.

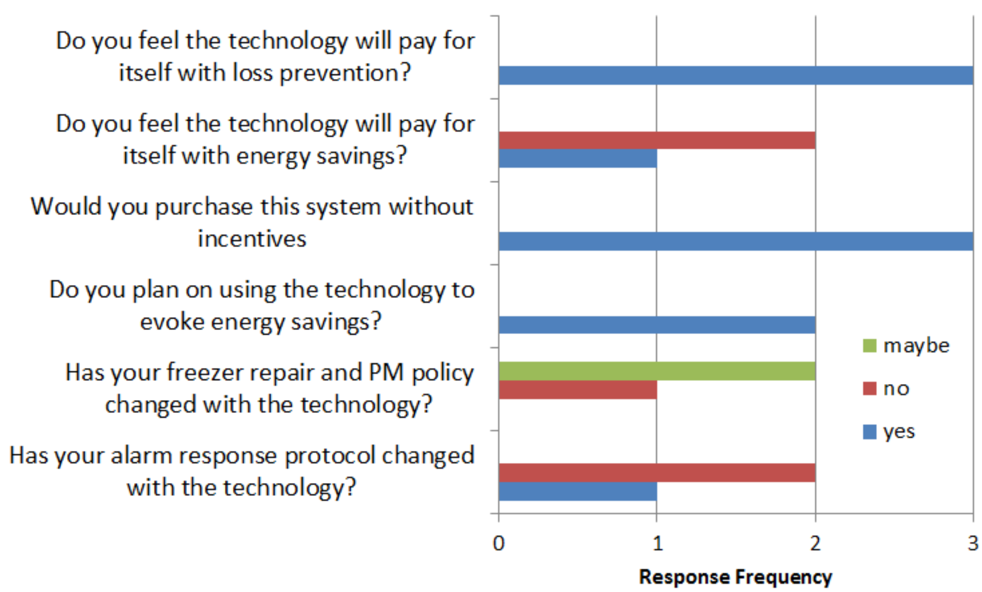
Despite the lack of obviously apparent repair cost payback from energy savings for most of the repairs in this study, there is promise in the approach and definite potential for enacting energy savings and conservation measures using the technology. The energy savings could potentially be sustained by using methods not evaluated in this study, as described in the Conclusions section.

Customer feedback

Three facility managers that oversee the maintenance, upkeep, quality, and protocols of their respective freezer populations were given a survey regarding the freezer monitoring technology. This survey gave insight into how the technology is used and what purposes it serves when used as a stand-alone product. These customers were also questioned on their perception of the technology when used as an energy saving tool. The full survey results and questions are tabulated in Appendix D.

All three users appreciated the monitoring technology for its temperature sensing, alerts, and detailed information. Each one would recommend purchasing the system on the loss prevention and temperature tracking capabilities, alone. However, they remained dubious of any real energy savings benefits of the system. They were interested in developing new preventative maintenance and repair protocols that incorporated the technology but none had been enacted, as of this report date. Without preventative maintenance and repair protocols that incorporate the technology, energy savings are unlikely to be achieved efficiently. It could be that with the development of such protocols, the expectations of energy savings could improve. As of now, the freezer managers use the technology for quality and reliability assurance and not energy savings. They do hope to do so in the future, if procedure becomes clearer and results more evident. The vendor-recommended SSP methods could potentially provide these procedures.

Figure 6 - Selected customer survey responses



Normal preventative maintenance was typically performed once or twice each year on every freezer, setpoints were constant and were not often changed by the lab members or users, and no pre-emptive action or anticipation of freezer failure was traditionally employed before the technology was installed. The constant setpoint response indicated that any changes in freezer temperature over the measurement span of this study were caused by internal freezer operation, rather than external control. This implies that any decreases in energy savings over the measurement period can probably be attributed to declining freezer component performance rather than increased user demand or settings adjustments.

Table 6 - Technology feature importance ratings from customer survey

Importance	Customer 1	Customer 2	Customer 3
1 – Most Important	Temperature monitoring	Temperature Monitoring	Temperature Monitoring
2	Alarm system	Alarm System	Alarm System
3	Freezer energy cost calculations	Historical Performance Data	Freezer Energy Cost Calculations
4	Energy monitoring	Energy Monitoring	Energy Monitoring
5	Historical performance data	Freezer Energy Cost Calculations	Historical Performance Data
6 – Least Important	Freezer grading system	Freezer Grading System	Freezer Grading System

Note that customer 1 responded to the survey in June of 2012 while customers 2 and 3 responded in June of 2013, after changes to the grading algorithm were completed. Still, the results were not measurably different.

Applicability of IOU programs

Energy Efficiency Business Incentive Program

San Diego Gas & Electric provides businesses with the ability to apply for incentives via the Energy Efficiency Business Incentive Program [14]. This program provides non-residential customers with the opportunity to receive incentives based on savings derived from the installation of energy-saving technology. The program requires a detailed application that includes establishment of baseline energy consumption via a measurement and verification test plan prior to installation of the technology. Following approval and installation, measurements and analysis are performed in order to calculate actual savings. The savings measures must have a life of at least five years. If the application is approved, the incentives rate for non-lighting electrical savings is $0.08/kWh or $0.15/kWh, for basic or advanced technologies, respectively. It is likely that this ULT monitoring technology would be considered an advanced technology but resulting equipment replacements could be considered basic. The program also has an incentive cap of 50% of the total project costs or $1,193,962 for a commercial site, whichever is smaller.

The program rules include eligible and ineligible energy savings measures. The eligible measures include condenser replacement, energy management systems for refrigeration equipment, refrigerated case doors, compressor replacement, and emerging technologies on a case-by-case basis. Ineligible measures include measures that save energy because of operational changes, technologies where there is no modification to existing equipment as determined by the administrator, and repair or maintenance projects.

The ULT monitoring technology and its energy savings measures as tested here are not eligible for current programs since they did not show persistent energy savings; however, it could potentially enable energy savings if further actions per vendor standard operating procedures are followed. Additionally, the technology and the various repairs it causes may or may not be eligible under the current incentive rules. The technology itself could be considered an eligible emerging technology but may be ineligible as it may also be a measure that saves energy because of operational changes and does not modify existing equipment. Alternatively, the component repairs and replacements made due to the monitoring technology could potentially be eligible for incentives under the various listed measures, such as refrigerator door or compressor replacement. However, some of the measures enacted by the technology may fall into the ineligible repair or maintenance projects, such as filter cleaning, freezer calibration, or door baseplate straightening. Due to the varied nature of the energy savings measures engendered by the technology, the most suitable category may be emerging technologies, until more results are available.

If the technology is approved for an incentive, savings would have to be demonstrated over an extended period in order to provide calculated, sustained savings. Since the technology cannot predict or ensure future savings, incentives must be based on realized, historical savings as calculated up to the date of submission. The measurement and verification for such an incentive application would require similar methods used in this study. An application would demonstrate energy consumption before repair and energy savings over a period of time following. After this extended period of time, the application could be completed by reporting final, sustained energy savings. If the technology itself is determined to be ineligible, some of the component replacements could be used as a different basis for incentive application.

Project Error

Project Plan Deviation

The primary deviation is that a sensitivity analysis of the factors influencing energy usage was not performed. Initially, it was anticipated that the testing conditions and data collected would allow such an analysis but this was not the case. Factors that could influence the energy usage and energy savings of repairs and maintenance include freezer age, make, model, repair type, repair history, service company, frequency of use, setpoint history, and others. Unfortunately, these factors varied uncontrollably across the sample population or the information was not available. No correlations were seen between energy usage/energy savings and the listed factors. Therefore, a sensitivity analysis was not possible as would be with a well-controlled experimental design.

Anomalous Data Treatment

The freezer data and usage was not controlled by NegaWatt Consulting. Rather, freezer operation continued as normal and was thus subject to uncontrolled variation in setpoint and freezer opening. Freezer openings were sometimes long or frequent and the internal temperature jumped occasionally. In order to control for these variables, data was taken for constant internal temperature timespans as much as possible, and anomalous freezer door openings or data omissions were not used in the measurement intervals.

Conclusions

Benefits of ULT Freezer Monitoring

The ULT freezer monitoring technology has benefits to the user regarding both energy and non-energy aspects. In general, it is a powerful tool for the development of intelligent ULT freezer management strategies.

With respect to non-energy benefits, the technology allows for advanced monitoring of temperatures and operation in order to anticipate freezer failure and detrimental setpoint trends. This can help the facility avoid losses of valuable biological, medical, or pharmaceutical samples (the typical use case), make future freezer purchase decisions, develop better maintenance protocols, and possibly extend the useful life of ULT freezers.

With respect to energy consumption and savings benefits, results are highly dependent upon customer use of the technology. The study results have shown that using the technology to target freezer repair and maintenance candidates based on overconsumption of energy is a possible use of the technology, but requires well-developed and diligent methods. This study evaluated a simple use of the technology: using the technology energy grading system to target over consuming freezers for a single repair by a service contractor while assuming that the diagnostics and repairs would sufficiently address the root causes of poor performance. This strategy did effectively identify freezers that warranted repairs and energy savings were usually observed post-repair. However, without continuous monitoring and further procedures after repairs and maintenance, sustained savings cannot be guaranteed or expected. Continuous monitoring can inform additional decisions and resources can be further allocated to freezers that do not have persistent savings after a repair. This strategy was not evaluated in this report but has been shown to be more effective in other studies.

The technology can be used to intelligently allocate a maintenance budget to freezers that most need attention. In this way, a given amount of funds can be applied to the units that will supply the greatest return, rather than performing broad maintenance for an entire freezer population and waiting until a unit fails to perform more intensive repairs. Such a strategy can maximize returns, both energy savings and otherwise.

Ancillary energy savings could be realized by the manufacturer warranty replacement of defective units that would not have otherwise been identified (this happened twice but were not considered in the energy savings calculations) and with the extension of freezer lifespan. Extending freezer lifespan due to more informed and pre-emptive protocols will delay the energy-intensive production and purchase of new freezers, an indirect benefit.

System Improvement Opportunities and Possible Future Study

As can be seen by the low success rate of repairs with respect to realized energy savings, continued monitoring and additional investments are required after most repairs. It is likely that repairs are indeed warranted in cases of red or yellow grades, but that diagnostics or repair contractors did not correctly identify the root cause of poor performance or all of the needed repairs. This is exemplified by the initial increase in performance followed by rapid post-repair degradation. Increased diligence and iterative maintenance decisions could perhaps help in this regard. Iterative, continuous post-repair monitoring is a key facet of the vendor recommended practices, but was not evaluated in this study.

It should be noted that continued monitoring and the contracting of a SSP who guarantees a solution to under-performing freezers would likely increase contract costs. SSP contracts that ensure sustained savings achieved by repairs would increase overhead. Still, without a more effective approach than the one studied here, sustained energy savings cannot be expected in most cases. It remains to be seen whether added costs incurred due to vendor recommended practices would pass a return-on-investment analysis with respect to the costs necessary for sustained energy savings. Further study of ULT freezer facilities that utilize SSP contracting, continuous monitoring, and iterative repair and maintenance decisions would provide insight into the full effectiveness of the technology and its energy savings measures.

For the sake of comparison, a separate industry study on a facility which utilized the vendor recommended best practices and use of a SSP to ensure sustained energy savings contrasts with the findings of this report which eschewed such methods. In this separate study two red freezers were repaired and initial savings of 38.9% decreased to 37.4% after 7 months. A third red freezer incurred multiple repairs before it was replaced entirely by a new model at high cost to the customer. Five yellow freezers were repaired and initial savings of 7.5% increased to 8.7% after 7 months. This study demonstrated sustained savings under the recommended SSP procedures. However, the data sampling methods and test conditions are unknown to the authors, as are the added costs. Future study of a facility which uses continuous consulting and SSP contracting to ensure sustained savings would provide insight into the effectiveness of the complete vendor strategy.

It has also been suggested that the technology is well-suited for further study of other energy saving strategies in ULT freezer facilities. For example, the information-rich database can serve as a platform for studying freezer arrangement strategies, ambient condition modification (HVAC controls), forced external air circulation, setpoint adjustments, or other measures. Any of these could prove to be effective and could be part of a future study.

Applicability of case study findings to other load types and sectors

This study only considered ULT freezers that were used in non-FDA regulated environments. It is conceivable that with approval, the technology could be extended to freezers under FDA restrictions.

The remote sensing, monitoring, graphing, and database for temperature and electrical current could potentially be useful for any facility that uses numerous, accessible machines that use electricity and where temperature plays a role. Service providers and vendors could consider such other sectors when developing future applications.

Considerations for large-scale and persistent market implementation

The technology's ability to monitor energy consumption and temperature is effective and useful for the supervision of ULT freezers. It is also able to identify over-consuming freezers. However, the energy savings benefits require more iterative maintenance decisions and investment than what was studied in this evaluation. It may be that the straightforward approach of "have problem, find repairman" is too simple and does not address the root cause of poor performance. It is unknown whether these added investments would pass a cost-benefit analysis.

The vendor is currently in the process of developing improved grading metrics and early anomaly detection of poor compressor behavior, along with other energy savings strategies. In the meantime, claims that long-term energy savings will be realized as the result of repairs to poorly graded freezers must include discussion of the added services and investment necessary for sustained results. Further independent, controlled study of the technology when used in conjunction with the vendors suggested strategies would be useful for determining the full effectiveness and viability of the energy savings measures.

Acronyms

CEC	California Energy Commission
CT	Current Transformer
MSDS	Material Safety Data Sheet
PM	Preventative Maintenance
SDG&E	San Diego Gas & Electric Company
SSP	Smart Service Provider
ULT	Ultra Low Temperature Freezer

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Appendix A: Project Plan

Description of the technology under investigation

It has been suggested that a significant percentage of commercial freezers used for ultra low temperatures (ULT) for scientific and pharmaceutical research samples are not operating at optimum efficiency. The per-unit energy usage is especially high for these applications due to the low temperature requirement of -80^{o}C. Consequently, the energy savings opportunities are also deemed significant. The scope of this study and of the technology under investigation is limited to ULT freezing where freezer maintenance is dependent on the site's standard operating procedures (SOP), and where groups of identical freezers are used in parallel. Therefore, variations in freezer performance as well as the impact of introducing new technology can be analyzed.

The technology investigated here is a combined application of monitoring hardware and software that allows the determination of whether an asset is running at optimum efficiency. The application provides operator alerts, as well as quality assurance for repairs and maintenance by comparing before and after performance. The alleged net effects are long-term energy savings – as long as alerts are appropriately resolved by repairing poorly performing freezers. In addition, it has been stated that a reduction in catastrophic freezer failure can be accomplished with this technology. The technology vendor states this is accomplished by employing analytics to identify changes in freezer performance behavior which are associated with reliability problems.

Description of incumbent technology that is being replaced (or existing standard practice, etc.)

Standard practice may include performing regular, preventative maintenance of all freezers based on a prescribed schedule. In addition, repairs on freezers that are no longer able to hold their temperature are performed whenever needed. Some sites do not conduct maintenance at all and are only notified when equipment fails. Energy efficiency is not considered, and freezers are generally not monitored for energy usage.

Sites where maintenance is regulated by FDA methods and procedures (M&Ps) such as drug manufacturing facilities are not considered in scope for this study. The technology may still apply at such sites. However, the benefits provided by the technology in such situations may be different. This will be discussed further in the final report.

Goals of the assessment project

The goals of this assessment project are to:

1) Describe system setup, operations, and functionality, and assess whether the system performs as designed.
2) Assess whether the *system*'s design is appropriate for the purpose and how well this system represents the technology as a whole
3) Quantify energy, demand and cost savings potential of the *technology*. This includes:
    a. Calculation of annual energy, demand and cost savings for our test sites
    b. Assessing accuracy of vendor- and system-provided reports
    c. Investigating to which extent freezer repairs can be expected as the direct result of the reports provided by the system
    d. Extrapolating our findings and test sites to other situations
    e. Review utility programs with respect to their present applicability to this technology, under particular consideration that this technology is an *enabling* technology.
    f. Provide recommendations as to how utilities could further support this technology
    g. Analyze factors that may cause variations in energy savings, cost and payback times under different circumstances
4) Determine readiness for large-scale, persistent implementation (e.g. study incremental cost, reliability, quality, scalability, risks, existing vs. new building deployment, maintainability, etc.)
5) Obtain and present customer feedback
6) Discuss possible risks of the technology, for example, that catastrophic failures cannot be predicted for all occurrences.

The monitoring application reviewed here is an *enabling* technology in that its installation does not directly result in energy savings. Users are now *able* to implement energy-savings measures by following the provided recommendations for freezer repairs. Actual savings resulting from repairs are shown using "baseline accounting" where snapshots of energy use are taken over time. The technology's proposition is that the potential energy savings plus further reduction of catastrophic failure risk is motivation enough for users to perform the suggested repairs. However, the energy savings are not *guaranteed* as the technologies by itself uses less energy than the incumbent. We will therefore need to carefully consider under which circumstances energy savings actually take place, whether incentives can be justified, and how incentive amounts can be determined and administered.

Application and/or Generalization of project results to similar facilities in other locations, other types of facilities, etc

Although the market for this technology is very narrow, there are a ***large number of variables*** that influence *achievable* energy savings and *actual* energy savings for any given cryogenic freezer farm. We believe they can be grouped into two major categories:

1. *Occurrence* of inefficiencies:
    a. Freezer make/model, age, degree of maintenance applied or withheld, environment/location, and quality of repairs
    b. Definition of "inefficient", i.e. what process drives the decision to flag a freezer as "inefficient"
2. *Remediation* of inefficiencies
    a. Possibility that not all repairs are successful from an energy perspective, and that multiple repairs will be performed now that repair success can be monitored/quantified.
    b. Organizational policy that drives what to do about necessary repair recommendations, and when.
    c. Some repairs will not provide a reasonable amortization period and may therefore not be performed.

We will approach this study by analyzing and quantifying these variables. This is best done with statistical methods and, where possible, with root cause analysis. The outcome will be a good approximation of average energy savings, that can be used to calculate a flat fee or "deemed" technology incentive. For reasonable accuracy and to understand the sensitivity of these variables, this approach requires the consideration of multiple test sites, freezer models, contractors, and so on.

Measurement Plan

Please see Appendix B.

Generic customer or laboratory information (e.g., the type and geographic location of the facility(ies) at which the research was conducted, etc).

With the given approach, we would like to suggest the evaluation take place at 3-5 different facilities with as many different freezer models as possible. Each site will contain enough assets to create groups, in which one of the groups will act as a control. All of the assets will be monitored and then energy savings will be compared between the groups. In order to control the number of variables and cause/effect, we further recommend the following:

- All freezers will use the same configuration / algorithm to control definition of alarming. If not all freezers on any given site have been added into the technology, the selection process must be documented (i.e. "all freezers ranked "C" or worse, older than 5 years", "all on the 5th floor", etc).
- The technology software must be fully commissioned and all freezers in database must have energy use data for at least two weeks
- A complete repair history and in-service date must be provided for all freezers that are to be included in the study. This should include notes as to *why* a freezer was repaired, i.e. the technology alarm or other.

- Each site must have a client-side technology champion, i.e. a fully trained and independent operator
- The system configuration will be locked down for the duration of the test such that performance ranking and energy data or readings, historical information about repair history, and the freezer population commissioned for monitoring does not change during the study.
- The technology vendor cannot be involved in any operational decisions e.g. when freezers should be repaired, after an initial discussion with the client of the new opportunities the system represents.

Etcetera

For a detailed statement of work and estimate please see [2].

This assessment follows the scientific rigor protocol described in [3].

The final report for this project will be made available as [4] on www.etcc-ca.org. Additional references will be contained therein.

This project will be tracked in NegaWatt's online project management tool once the project plan has been approved. The document repository for this project is NegaWatt's secure file server. Please contact the authors of this project plan if you need access to these systems or to any of the referenced documents.

References

[1] Freezer Monitoring Measurement Plan.docx

[2] Freezer Monitoring SOW and estimate v1.1.docx

[3] Draft ETP assessment protocol 061610.docx

[4] Freezer Monitoring Final Evaluation Report.docx

Appendix B: Measurement Plan

Introduction

This measurement plan is an integral part of the project described in "Freezer Monitoring Project Plan" [Appendix A]. If you are not familiar with this project, please read the project plan first for a number of necessary explanations and background information.

It follows the guidelines established in [2].

It has been designed to accurately assess both the baseline performance of the incumbent technology (or standard practice in the absence of an incumbent) and the performance of the technology under study.

It has been designed in compliance with the evaluation methods identified in the International Performance Measurement and Verification Protocol (IPVMP) Option A except where site- or technology-specific circumstances dictated a deviation from one of these protocols.

All instrumentation under the control of evaluation staff shall be calibrated in accordance with guidelines established in the IPMVP as described in [2].

For field evaluations, all reasonable efforts shall be made to calibrate or replace any customer-owned instrumentation or where this is not possible, to document the calibration status of such instrumentation.

Measurement uncertainty for each monitoring device will be documented. Note that an error analysis evaluating the uncertainty associated with energy and demand savings estimates will be required for the Final Report.

All instrumentation will be commissioned prior to initiating data collection to ensure that measurement and logging systems are functioning properly, to minimize risk of unusable data sets.

Any anomalous data will be investigated and explained. Following investigation, careful consideration will be given to whether such data should be incorporated in the analysis or replaced by additional data collection.

Any events that occur at customer premises during the data collection period that are likely to compromise the validity of the assessment project and that are beyond the control of evaluation staff will be communicated to program management without delay.

Test site description

The test sites for this project are academic and commercial environments with *cryogenic freezers* kept at approximately -80°C. Such freezers are also known as ultra-low temperature ("ULT") freezers. They are used for storage of perishable medical or scientific samples. We will monitor approximately 50-60 freezers in the scope of this project with the most recent generation of the product that has temperature and current monitoring capability.

Note that none of the freezers that we monitor in this project fall under FDA regulations for standard freezer maintenance and operation procedures as can be customary in *pharmaceutical* environments. Customers with such environments are extremely sensitive to disturbances and it was therefore decided not to pursue this category for purposes of the evaluation. We will however discuss in our report to what degree our findings would apply in environments with standardized maintenance practices, as there is a priori no reason why this technology should not penetrate into that market just the same.

The selection process of the sites in the project considered the following:

- Types of freezer makes/models. It is not practical to have a broad cross-section of make/model so we have instead attempted to focus on identical make/model to make for a good statistical distribution of variables. The emphasis will be on the most popular freezer make/models on the market
- Finding groups of identical freezers used in parallel, allowing for control groups (preferred but not must have)
- A fully trained and vendor-independent operator must be available, and the technology must be fully commissioned and in production
- Repair histories of monitored freezers should be available, as there can be variations in energy efficiency as freezers get older
- At least 10 freezers per site, i.e. with identical repair policies in place

All the freezers monitored in the scope of this project have energy and temperature sensors installed. The resulting data is stored and processed in a central software system that is an integral part of the technology. Among other things, the software system provides repair recommendations where repairs appear to result in an energy savings. We do not consider freezer content, however, we will normalize energy data for setpoint variations, where applicable.

We may exclude some monitored freezers from our evaluation if we determine that they are very atypical *and* rare, and as such would unnecessarily skew or complicate our calculations. An example of a freezer that we turned down during prescreening is a cryogenic test chamber that was converted for sample storage, and that was very different from standard ULT freezers in terms of cooling system buildup, insulation, size, and so on.

Thus far, three locations were chosen to participate in this project. It will be best for the analysis to have as many different makes, models and ages so that normalization for these variables becomes possible. The following table provides a detailed description of the sites and the ULT freezers monitored.

Site Name	Number of ULT Freezers selected	Make/Models	Age of Freezers	Volume and Size of Freezers
University Labs	7	Revco ULT2586-6-A46 2 - Revco ULT2186-6-A47 Revco ULT2586-10-A42 Revco ULT2586-10HD-A41 Revco ULT2586-10-D42 Revco ULT2186-6-A44	2-10 years	25 ft^3 21 ft^3 25 ft^3 25 ft^3 25 ft^3 21 ft^3
Food Safety Labs	6	Sanyo MDF-U72VC Revco ULT2090-9-D33 Revco ULT2090-9-A31 VWR 5721 VWR 5749 Revco 2090-9-D31	2-10 years	26 ft^3 20 ft^3 20 ft^3 20 ft^3 Unknown 20 ft^3
Biology Labs	17	Revco ULT2586-5-D35 Revco ULT2586-9-A35 Revco ULT2586-9-D31 Revco ULT2586-9-D34 3 - Revco ULT2586-9-D35 Revco ULT2586-9-D36 2- Revco ULT2586-9-D38 7 - Revco ULT2586-9-D40	0-10 years	25 ft^3 25 ft^3 25 ft^3 25 ft^3 25 ft^3 25 ft^3 25 ft^3 25 ft^3 25 ft^3

Data collection procedures

The main objective of this project, as specified in [1], is to assess whether the technology functionally performs as designed, to calculate energy and cost savings, to determine the readiness for a persistent market-wide implementation, and to advise our client on the possible administration of incentives. The data to be measured in this project will be various variables from sensors, monitoring of system software, and personnel feedback. The monitoring technology will be installed and commissioned by the vendor prior to data collection or tests. We will perform spot checks of the data collected by the system vendor, and utilize their data directly if we find it to be sufficiently accurate.

At the sites, where possible and where there are enough freezers to begin with, we will use control groups. Freezers will be grouped by similar make, model, age and repair history, then one group will be left alone, while the other will have repairs performed as recommended by the system.

Any non-energy related scalability evaluation will be truncated from testing in this project, except if there are obvious concerns with stability, reliability, maintenance/support, etc.

Data points

Initial data is necessary from each site in order to capture the operating conditions of the freezers before any changes to operating schedules or maintenance. This data includes:

1) Utility $/kWh cost for the site
2) General observation of vendor software program
    a. Regular alarms
    b. Visual interface of software
    c. Software configuration
3) Observation of the technology hardware
    a. Tool used to measure temperature
    b. Tool used to measure current and voltage
4) The standard operating procedure (SOP) of the site
    a. Maintenance schedule
    b. Repair decision making
5) Graded Rank of freezers for each make/model
    a. Number of freezers with acceptable performance (grades A or B)
    b. Number of freezers with poor performance, “C” graded rank (N_C)
    c. Number of freezers with poor performance, “F” graded rank (N_F)
    d. Ranking algorithm (should be identical across the entire project)

The software technology classifies each freezer into a grade rank (A, B, C, or F) which is symbolic to the state of health (SOH) of the freezer. Benchmark ranking begins with estimated quartile grades until there is enough data to calculate actual quartile grade. From there, each grade rank is identified by comparing the actual performance of each freezer against a pre-calculated standard. These standards are known achievable levels of energy efficiency based on statistical analysis of its peers (same make/model) in the population of all freezers in the database. Generally, the grade is classified after approximately three days of 1-minute interval data collection during the hours of 10pm-6am in order to avoid anomalies due to freezer doors openings. Freezers that are classified as an “A” or “B” are considered properly working freezers. In turn, those classified as “C” or “F” are underperforming and repair recommendations will be suggested until the freezer is working properly (to an “A” or “B” standard).

Based off this initial data, the total number of freezers to include in the analysis and the control group(s) will be determined. The focus of improvements will be on freezers with a grade rank of “C” and “F”, as they are the ones that are essential in determining achievement of pre-set goals, payback time, and energy savings. However, for each make/model, one freezer ranked at “A” (or “B”) will be measured in order to calculate the cost difference and compare energy usage and temperature plots. We will also record the *number* of freezers ranked A or B to help with determining the overall energy savings potential of the technology when deployed anew for a number of previously unmonitored freezers at once.

From there, data that is necessary for the remainder of the project are:

1) Electrical monitoring including current, voltage, and energy
2) Ambient conditions of the room the ULT freezers are located
3) Inside temperature and set points of the freezers
4) Repair recommendations and time for a repair to take place

Items 1) through 3) can also be measured during the initial data collection phase. Data for groups N_C and $N_{F,}$ of each make/model will be collected for both the control freezers and repaired freezers in order to compare the results. For the single "A" (or "B") freezer of each make/model, only items 1) through 3) will be necessary data to compare. The freezers will be located in the same area as ULT freezers are sensitive to room temperature and freezer efficiency. Although using data from the same area may not be possible, we will discuss the impact of different ambient conditions, and compare freezer data from different areas only where possible. In addition, item 1) will be spot measurements in order to confirm the sensors the vendor uses. Data may also be normalized for setpoint variations (but not for deviations of setpoint vs. actual, because that may stem from defects that result in excess energy usage, which we need to capture and analyze).

After repairs are finished with the underperforming freezers, the repair diagnosis, total cost, and the time for the repair completion will be documented. In some of the cases, the SOP will indicate that a rebuild will be needed rather than repairing the freezer. The data will also include freezers with multiple diagnoses and/or that required several fixes.

The Vendor software re-ranks the freezers to a new grade a) every month and b) when a repair is complete. At the end of the project, the final grades of each of the freezers will be documented as these represent the new state of health after the technology installation. This data will be in addition to the data listed earlier.

Data sampling, recording and collection intervals

Based on a review of curves from the vendor software we feel every 15 minutes should suffice to capture peaks and valleys in temperature, relative humidity and current changes. This interval would be verified by performing one test that monitors every 1 minute for a continuous 24-hour period. The results of the data will show if there is any significant data in between the 15-minute data points.

The total amount of monitoring M&V will depend on the repair standard operating policy (SOP) of the site. To achieve and sustain the energy savings potential of the technology, it is recommended that a detailed SOP be followed by the site and their service provider. In order to test the technology thoroughly, we would prefer to test until there is a need to repair the freezers. The table below indicates how long each of the data collection phases actually took.

Data collection	Total Observation/Data Collection Period	Measurement Interval
Baseline Data	1-2 months in most cases[1]	3-7 days[2]
Repair Downtime	1 week to 2 months[3]	N/A
After Repairs	Multiple months[4]	3-7 days

[1] Baseline energy usage was observed from the monitored pre-repair data for as long as possible in order to establish a representative usage value. This representative usage value was used as the baseline energy consumption and the data are listed in Table 3. Three of the nine freezers had baseline data spanning less than 2 weeks due to data availability. These three freezers (freezers 6, 8, and 9) had baseline anomalies, data omission, or other issues that prevented longer baseline collection.

[2] Each data point was the average consumption over 3-7 days. Multiple days were selected to average out freezer door openings and natural HVAC and usage variation.

[3] No data was collected during the repair downtime. The variation is due to lead time.

[4] Data was collected for as long as possible post repair until the setpoint was changed drastically and permanently or until the completion of the evaluation.

Instrumentation

Instruments that will be used in the project to measure the previous stated data points are:

- Energy Consumption:
  - A Fluke 1735 Three Phase Power Logger device for energy consumption. The 1735 conducts energy consumption testing by logging most electrical power parameters and captures voltage events. Calibration of the Fluke 1735 was done on 9/2012. Measuring range and accuracy for the main variables of the power logger are:
    - Voltage (V-RMS Wye measurement)

    Range (V-RMS Wye): 57 / 66 / 110 / 120 / 127 / 220 / 230/ 240 / 260 / 277 / 347 / 380 / 400 / 417 / 480 V AC
    Range (V-RMS Delta): 100 / 115 / 190 /208 / 220 / 380 / 400 / 415 / 450 / 480 / 600 / 660 / 690 / 720 / 830 V AC
    Resolution: 0.1 V
    Intrinsic error: ± (0.2% of measured value + 5 digits)
    Operating error: ± (0.5% of measured value + 10 digits)
    - Current (A-RMS)

    Range: 15 A / 150 A / 3000 A RMS (non-distorted sine wave)
    Resolution: 0.01 A
    For ranges 150 A/3000 A
    Intrinsic error: ± (0.5 % of m. v. + 10 digit)
    Operating error: ± (1 % of m. v. + 10 digit)
    For range 15 A
    Intrinsic error: ± (0.5 % of m. v. + 20 digit)

Operating error: ± (1 % of m. v. + 20 digit)

- Energy Measurement (kWh, KVAh, kVARh)

Intrinsic error: ± (0.7 % of measured value + F variation error* +15 digit)
Resolution: 1 W to 10 W
Operating error: ± (1.5 % of measured value + F variation error* + 20 digit)
* Frequency variation error: ±2 % measured value + 2* (% maximum frequency deviation)

- DENT instruments Elitepro Recording Poly Phase Power Meter. Last calibration data was September 2011:
  - ELOG 2009 Windows based software package for programming, set-up, communicating, data retrieval and analysis (can export to excel or access)
  - Voltage: 3 channels

Range: 0-600 V (AC or DC)
Accuracy: < 1% of reading, exclusive of sensor (0.2% typical)
Resolution: Better than 0.1% FS – 12 bit A/D

- Current: 4 channels

0-6,000 A (with current sensor having 333mVac output, ordered separately)

Range: 0-600 V (AC or DC)
Accuracy: < 1% of reading, exclusive of sensor (0.2% typical)
Resolution: Better than 0.1% FS – 12 bit A/D

- Ambient Room Conditions (Temperature and Relative Humidity)
  - Track-It Temperature and Humidity Data Loggers. The Track-it loggers do not have a settings for calibration, but factory accuracy for this device is stated below.
    - Temperature

Range: -20°C to 85°C (-4°F to 185°F)
Accuracy (0°C to 50°C): ±1.0°C
Accuracy (20°C to 85°C): ±2.0°C
Resolution: 0.4°C (1.0°F)
Repeatability: ±0.1°C (±0.2°F)

- Humidity

Range: 0 to 100% RH
Accuracy (Typical): ±3% (20% to 80% RH)
Accuracy (Max): ±5% (0 to 100% RH)
Resolution: 0.5% RH
Repeatability: 0.1% RH

Data analysis procedures

As stated in the Introduction, all data will be reviewed before analysis and any anomaly will be investigated and explained. Anomalous data will later be determined as to whether it shall be incorporated in the analysis, corrected, or replaced by additional data collection.

Due to the somewhat limited number of freezers that are part of the study (with respect the total population of available makes and models, and their repair history), we don't expect to have statistically representative results in all respects. We will therefore also perform a *sensitivity analysis* of the various factors influencing energy usage. This will help determine which factors to pay particular attention to when estimating energy savings for new installations of this technology, how accurate estimations can be, and where M&V of certain key factors may be advisable. (See Project Plan Deviation section in main report body for further details)

Data manipulation (aggregation, statistical analysis, etc)

A general analysis of the vendor software and interface will be conducted. This will involve the feedback of the trained operator of the site and screen shots. In addition, for the "A" freezers (or "B"), simple monitoring of vendor software alarms will be observed. The "A" or "B" freezer is part of this test scope because we want to observe the alarm system for a typical, properly working freezer. An example of when the alarms could be triggered is a freezer door opening. The frequency and method of the alarm will be noted.

The ambient climate measurements will be downloaded from the Track-it software on a 2 minute average and then stored and charted with Microsoft Excel 2007 as a comma separated value file. The temperature and the relative humidity measurements by the data logger during the whole testing period will be plotted versus time in order to observe the variations during the whole time period. An average and standard deviation will be calculated for both the temperature and relative humidity.

If there is a variation of greater than ±5% of temperature or ±10% of relative humidity within the data from day to day, the ambient condition measurements will then be plotted versus energy usage to observe the correlation of the room climate to the freezer system. The energy usage will then be normalized with the relative humidity and temperature by taking the ratio of energy usage over both factors.

The temperature measurements from the Track-it datalogger will also be normalized with the temperature measurements of the other freezers (as the freezers may be in different locations) in order to compare similar ambient condition data.

The temperature and relative humidity discrepancies from the Track-it data logger will be part of the error analysis.

The initial grade ranking data will be used to compare the percent of each grade at all the sites before the technology is installed. The grades would be placed in a bar chart format according to the site and any similarities or percent differences between sites would be noted. In particular, it would be documented as to how many of the freezers were underperforming as this represents the potential the Vendor software system had to improve energy usage. At the conclusion of the project, the data of the after grade ranks will also be collected. The post-repair grade ranks will show the delivered improvements the Vendor software system brought to the sites. In addition, any of the freezers that are in failure mode and how the customer dealt with them will be discussed in terms of energy and cost.

Calculation of energy and demand savings

During the beginning of the test period, the Elitepro and Fluke will collect spot measurements on a random 10% percent of the freezers. They will measure voltage and current usage measurements for these freezers involved in the testing (A or B, N_C, and N_F). The Elitepro and Fluke devices will be installed on the building circuit breaker as to measure the entire freezer consumption. They will calculate and log the energy and power from these factors while including the affects of errors. Actual energy consumption (kWh) would be calculated for each freezer using the formula:

kWh= Power factor x V x I/1000

The measurements will be downloaded in the relative instrument's based software. The data will then be transferred to a spreadsheet as a Microsoft Excel comma separated value file where calculations will be presented and charts created. In particular, the calculated energy (kWh) and power (kW) will be plotted versus time for all the freezers. For the freezers of varying volume, the energy and power will be normalized so that size does not create a discrepancy.

Error analysis of these calculations will be based off the inaccuracies of the power logger as provided in the Instrumentation section. In addition, the freezer farms will confirm that their schedule during the whole testing time period is similar in terms of events and energy habits.

The Vendor software data for energy usage will also be downloaded and formatted into Microsoft Excel 2007. The vendor data measures KVA as a proxy for kWh. This data will be compared to the data from the Elitepro or Fluke, using the power factor as needed, during the initial test time period by taking the percent difference of the same time stamped measurements. Hence, it will be essential that the time stamp of the energy logging devices be accurate to the actual time (and the technology's system). Plots of the Vendor software measurements and device measurements will be created. The average and a standard deviation will be calculated for the percent difference. If the power measurements are within a ±5 kW or 2% margin (whichever is smaller), it will be deemed that the vendor's data is accurate and the software's measurements will then be used for the rest of the test. In addition to testing if the vendor sensors are collecting proper data, this could also test if the extrapolation of the vendor software is correct.

From the Microsoft Excel plots, energy and power measurements of a set of two freezers will be compared based off the table below. Essentially, these comparison plots will provide information of the energy wasted. Of these plots, the energy differences will be calculated on a daily basis to get a total energy difference per day (kWh/day).

Freezer Energy/ Power Comparisons	Time period
A versus N_F	Before repair of $\mathbf{N_F}$
A versus N_C	Before repair of $\mathbf{N_C}$
A versus N_C	After repair of $\mathbf{N_C}$
N_C versus $N_{C\ (control)}$	After repair of $\mathbf{N_C}$
A versus N_F	After repair of $\mathbf{N_F}$
N_F versus $N_{F\ (control)}$	After repair of $\mathbf{N_F}$

Note that demand will not be considered.

Calculation of cost savings

A payback chart will be created in Microsoft Excel which will take all of the measurements and calculations into account. It will return the amount of time the repair cost will be recovered in cost savings from the reduction in energy from an underperforming freezer. In addition, a chart will be created of each freezer's diagnosis and how much the repairs were worth. The table below explains a typical cost analysis that will be conducted on a freezer. All cost figures are for sake of example only, and may turn out different in reality.

Item	Cost (+/-)	Comments
Excess energy cost while waiting for repair	-$50 total	Based off kWh of energy wasted. Assuming 10 days @ -$5/day, between alert and repair completed, for example
Parts cost	-$500	Broken thermostat, for example
Labor cost	-$225	3 hours @ $75/hour, for example
Energy cost of repaired freezer	$100/month	Based off kWh before repair and after
Total first year savings after repair	($5 x 365d) – $775 = $1050	Total excess energy cost per year without performing repair, minus repair cost
Payback time of repair	$775/$5 days = 5.2 months	

The decision making process (SOP) for repairs will have an impact on cost savings. This will depend on the amount on the time and energy used between having knowledge of a needed repair and when the repair actually takes place. From the first item of the table, repairs that take more than seven days, the energy usage during this time will be converted to a utility cost based off the assumed rate. In the event where a new freezer is purchased, the cost to rebuild a new freezer over repairing an underperforming will also be briefly discussed, but will not be included further in the analysis.

The energy usage of a repaired freezer will be measured and the total annual kWh cost estimated by the vendor software. This cost will then be compared to the cost of the calculated energy usage from the same freezer prior to repair, when it was underperforming (item 4). This will generate an annual cost savings estimate, which will then be related to the total cost of repairs for that freezer.

Again, the cost will be calculated with the same energy cost per kWh used throughout the project. We will use each customer's specific average cost of $/kWh under consideration of their current tariff. Demand charges will not be considered.

Ultimately, these cost savings could generate a cost of how much a site could save by having a freezer repaired. This will be presented in a tabular format.

References

[1] Freezer Monitoring Project Plan v.1.2.docx

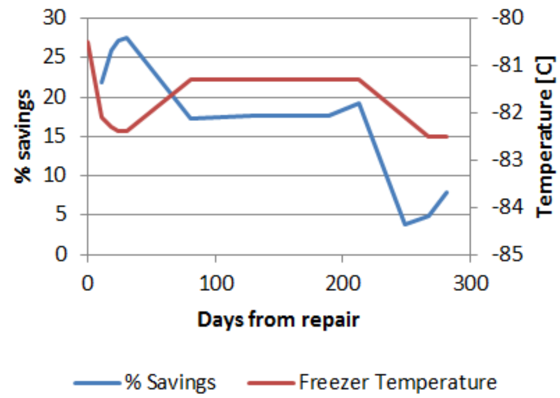
[2] Draft ETP assessment protocol 061610.docx

Appendix C: Individual Freezer Repair Results and Temperatures

Freezer 1

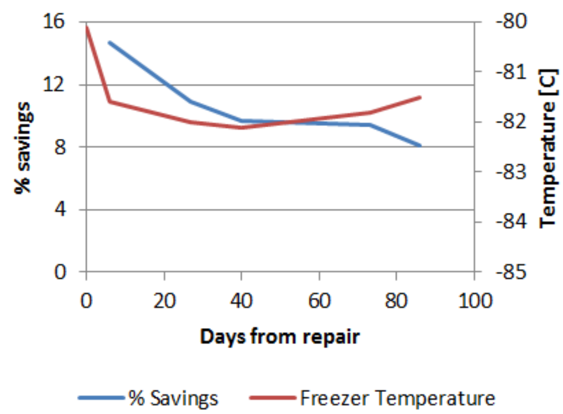
This freezer had relatively constant savings of 17.5% until the temperature dropped 2 degrees. This may be setpoint related or not.

Repair Cost [$]	Repair	$ Savings in Timespan	Payback [years]
746	DG, DSF, FD	128.3	8.1



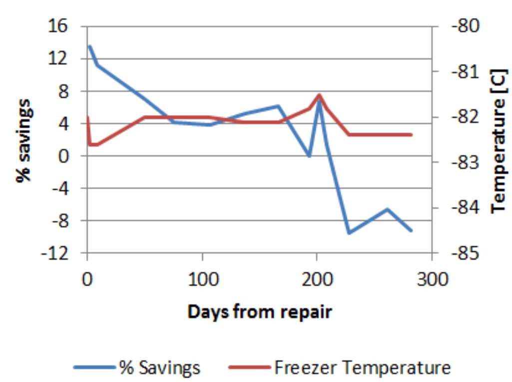
Freezer 2

Repair Cost [$]	Repair	$ Savings in Timespan	Payback [years]
110	D	25.7	1.2



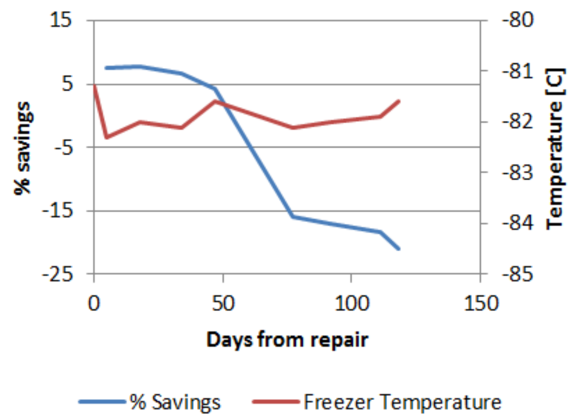
Freezer 3

Repair Cost [$]	Repair	$ Savings in Timespan	Payback [years]
343	FD, SSF	10.4	∞



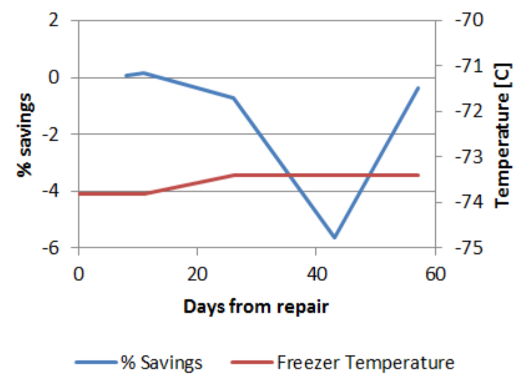
Freezer 4

Repair Cost [$]	Repair	$ Savings in Timespan	Payback [years]
672	SSF	0	∞



Freezer 5

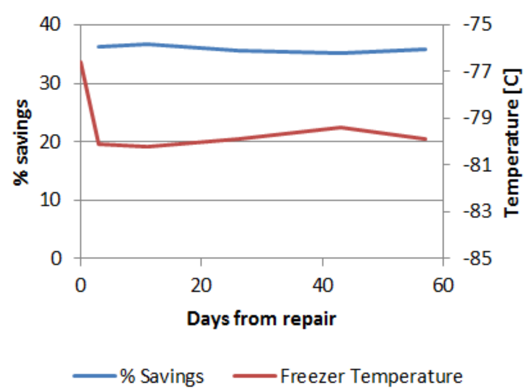
Repair Cost [$]	Repair	$ Savings in Timespan	Payback [years]
137	CCC, FM	0	∞



Freezer 6

Savings appear more constant than all other instances.

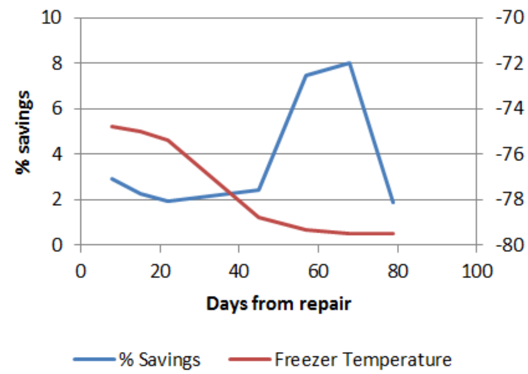
Repair Cost [$]	Repair	$ Savings in Timespan	Payback [years]
1132	DG, FM, SSF	48.7	3.6



Freezer 7

Vendor believes savings here are underreported and is investigating possible explanations. Freezer catastrophically failed at end of measurement period.

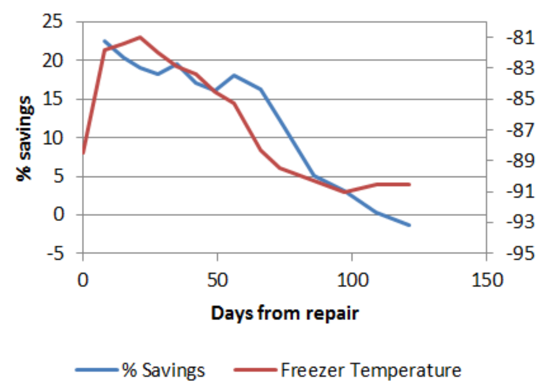
Repair Cost [$]	Repair	$ Savings in Timespan	Payback [years]
3997	DCO	6.4	∞



Freezer 8

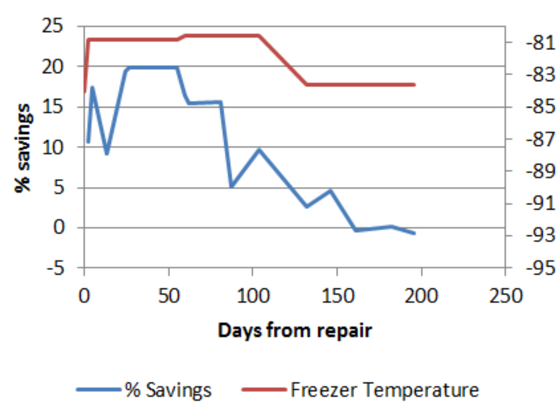
Note that the temperature drops from -82 to -91, taking the savings with it. However, the next freezer had the same repairs and saw a similar degradation in savings despite not having the same decreasing temperature trend.

Repair Cost [$]	Repair	$ Savings in Timespan	Payback [years]
970	SSF, DG	38.2	∞



Freezer 9

Repair Cost [$]	Repair	$ Savings in Timespan	Payback [years]
1856	SSF, DG	56.6	∞



Appendix D: Customer Survey

Question	Facility Manager 1	Facitlity Manager 2	Facility Manager 3
Are the users/owners of the freezers aware of the monitoring system?	Yes (please describe any feedback you have received below) - For the most part, scientists are aware that they're freezers are monitored.	Yes (please describe any feedback you have received below) - Most scientist know that we use a system, but not sure if they actually know the name.	Yes (please describe any feedback you have received below) - Haven't gotten any yet.
Are the lab managers aware of the system?	Yes (please describe any feedback you have received below) - The system is under constant upkeep by the lab managers on campus and off.	es (please describe any feedback you have received below) - All lab managers (coordinators) are aware of the system	Yes (please describe any feedback you have received below) - Haven't gotten any yet.
Please describe any alarm response protocols you had PRIOR TO the introduction of the technology	If there was an alarm during work hours, the owner of the freezer would notify us of any issues. During off hours, security would walk campus and notify the lab coordinators of any alarms.	Security would go around and check on freezers	Alarms were investigate when they were noticed.
Has your alarm response protocol changed as the result of the introduction of the technology? An example might be that you now ignore the freezer panel alarms in favor of the system alarms.	Yes (please describe below how your response protocol has changed) When an alarm is triggered, each lab manager can look at the system and reply appropriately to each freezer issue.	No (please describe below why you don't consider alarms in your response protocol) No, but this is an added advantage to have at our fingertips.	Yes (please describe below how your response protocol has changed) Now we look at the alarm before we go investigate. It's a faster alarm response adn easier to verify.
Have you changed the freezer temperature setpoints as the results of the introduction of the system? This would result in significant energy savings for most freezers.	Yes (please specify before and after setpoints below) Freezer Temp setpoints are specific for each type of freezer/samples.	No	No
Please explain your freezer repair and maintenance policy PRIOR TO the introduction of the technology.	Freezers would be repaired by a third party (Sharpe Refrigerations) when any issues occured. There are 2 PM sessions a year to check on freezer diagnostics.	When the freezer failed, it failed. But now, we have a record of how the freezer has been doing for the past months. We can see trend lines and clear signs of a freezer failing.	Users notified facilities that a unit wasn't functiong as required.
Has your freezer repair and maintenance policy changed as the result of the introduction of the technology?	Yes (please describe your new policy below) - Not completely as of yet. Ultimately, we would like to use the energy monitoring capabilities to predict failure before it happens.	Yes (please describe your new policy below) - Not really. We still have PM's and repair freezers as needed. It's nice to have a record of the freezer's activity.	No
How is the freezer Voltage determined that must be entered upon adding freezers to the system?	It is physically confirmed by checking the circuit type and/or measuring it	I am not sure	It is physically confirmed by checking the circuit type and /or measuring it AND it is derived from the freezer spec sheet
Please indicate your confidence level that the Voltage is determined and entered correctly. The system uses the Voltage to calculate the energy use of each freezer.	I think 90-100% of the Voltages are correct.	I think 70-90% of the Voltages are correct.	I think 90-100% of the Voltages are correct.

Have you used or looked at the "Freezer Report" and its energy features? Please answer "No" if you have only worked with Study Groups.	Yes	No (please describe why not) - We have worked closely with vendors to see which freezer is more energy efficient by looking at the Energy Freezer Report.	Yes
Did you or are you planning to act on the freezer report's energy features with the intention to evoke energy savings (for example, perform repairs to reduce energy consumption)?	Yes (please describe in detail what you did or are planning to do, and, if applicable, whether the desired result was accomplished)- This is the ultimate goal.		Yes (please describe in detail what you did or are planning to do, and, if applicable, whether the desired result was accomplished)- Once we have enough information we'll create a procedure.
How do you think the freezer report could be improved?	More user friendly system would be great. Vendor is already working on a mobile app and simplifying the system.		
Have you used the 'Study Group' feature?	Yes	Yes	No (please describe why not) - Don't know what it is.
Who adds new freezers to freezer report study groups for your organization?	We do it ourselves	We do it ourselves	
Did you or are you planning to act on the study group findings with the intention to evoke energy savings (for example, perform repairs to reduce energy consumption)?	Yes (please describe in detail what you did or are planning to do, and, if applicable, whether the desired result was accomplished) - In an attempt to standardize on a specific vendor and model for our campus, we used the study group findings to weight out pros and cons and determine this particular model.	Yes (please describe in detail what you did or are planning to do, and, if applicable, whether the desired result was accomplished)- We are in the starting stage of planning.	
How do you think study groups could be improved?	User friendly interface.	Not sure just yet.	
How satisfied are you with the system in general?,(very satisfied, satisfied, it falls short in some ways, it falls short in many ways, is doesn't meet my expectations at all)	2 - Satisfied	1 - Very Satisfied	2 - Satisfied
How easy to use is the system in your opinion? (very satisfied, satisfied, it falls short in some ways, it falls short in many ways, is doesn't meet my expectations at all)	3 - Takes some time to get used to	2 - Easy after a little training	2 - Easy after a little training
How would you recommend improving the system?	Making the program more user friendly would improve the system.	Make it phone friendly; however, that has been recently done	na
Would you purchase (or recommend purchasing) this system without incentives?	Yes	Yes	Yes

Do you feel the system will pay for itself based on resulting energy savings (please ignore SDG&E Emerging Technology incentives for the purpose of this answer)?	Yes	No	No
Do you feel the system will pay for itself as the result of reduced or avoided losses of freezer content (please ignore SDG&E Emerging Technology incentives for the purpose of this answer)?	Yes	Yes	Yes
Do you feel the system will pay for itself by a reduction in maintenance or repair cost (please ignore SDG&E Emerging Technology incentives for the purpose of this answer)?	Yes	No	Doubtful
Do you have a "success story" to share?	Yes (please share your success story) - The study on standardizing a freezer was very helpful into deciding what models we purchase.	No	No
Do you have a failure to share?	Yes (please describe the failure) - If upkeep is poor (failure to update when freezers are moved), there can be many problems. This is a constant struggle but can be worked on	No	No
Please rank the following features in terms of their importance to you. Each rank can only be selected once.			
most important	Temperature monitoring	Temperature Monitoring	Temperature Monitoring
	Alarm system	Alarm System	Alarm System
	Freezer energy cost calculations	Historical Performance Data	Freezer Energy Cost Calculations
	Energy monitoring	Energy Monitoring	Energy Monitoring
	Historical performance data	Freezer Energy Cost Calculations	Historical Performance Data
Least important	Freezer grading system	Freezer Grading System	Freezer Grading System
Is there anything about the technology or the vendor you'd like to add?		No	No
If you feel there is anything NegaWatt Consulting could have done differently in this evaluation, please let us know!			no
How frequent is PM performed?		semi-annual	Annually
Have you noticed any energy savings after PM?		I haven't looked for that	I haven't looked for that
Does your facility have standard, fixed setpoints for each freezer (or all		We have several set points. They are not frequently adjusted.	mostly fixed setpoints

freezers) or are they frequently adjusted?			
When a freezer is repaired, is it likely that the setpoint is different before and after the repair or is there a standard, fixed setpoint for each freezer?		No	mostly fixed setpoints
Do you use the system to examine freezers that are operating normally, without alarms, to anticipate failure? If yes, how often		Yes, 24/7	No, I only use it for alarming or malfunctioning freezers
Do you use the data to make purchase decision?		No	No
Do you use the system in your PM strategy?		No	No
Are setpoints altered by the users as needed for changing sample and use conditions		very few. I would say 2% of all units in the monitoring system	No
When a freezer is alarming for high energy use, what steps do you take to address the concern?		try to repair it for improvement however, most of the time due to budget constraints, this may not happen	none at the moment
What would cause you to schedule a repair for an alarming freezer? (check all that apply)		Inability to maintain or reach setpoints	Inability to maintain or reach setpoints
How do you think repair costs (not purchase/installation/dues) associated with energy alarming will be paid back? (check all that apply)		The repair costs will not be paid back	Loss prevention of freezer contents

Appendix E: Separate, External Study Results

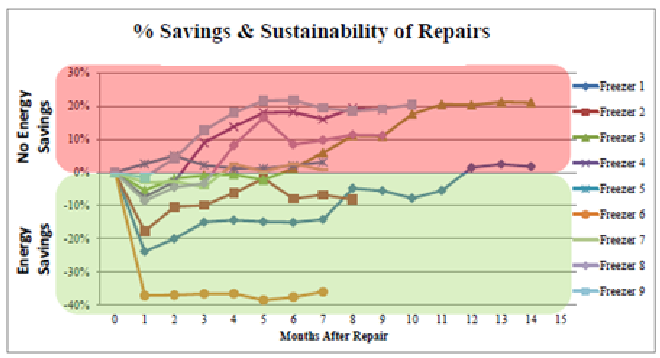
Separate studies and field testing using the vendor's recommended behavioral and management modification procedures have been carried out by other agencies. These studies included the use of "Smart Service Providers" trained in the operation of the technology and with contracts that guarantee repair effectiveness. While the tests done in this report placed the burden of repair management and sustained effectiveness on the user, these external studies placed the burden of repair guarantee on the service provider. The financial implications of this are not clear and the specific testing methodologies, impartiality, and conditions of the external study are unknown.

This external field testing found that energy savings could be sustained over many months if the use of the technology includes service agreements on the effectiveness and sustainability of repairs and iterative repairs as needed.

In the following "effective" refers to initially restored performance immediately post-repair while "sustainable" is defined as continued performance increase for 6 months or more.

Customer managed repairs

- 8 of 9 repairs deemed *effective*. 13% initial performance improvement compared to baseline.
- 7 of 8 effective repairs deemed not sustainable after 7 months. 4% sustained energy savings compared to baseline.
- 1 of 8 repairs sustainable after 7 months. This freezer had 36% energy savings compared to baseline.



Smart Service Provider managed, guaranteed repair effectiveness

- 8 of 8 repairs effective Average 23% initial energy savings compared to baseline.
- 8 of 8 repairs sustainable after 8 months. Average 25% energy performance savings compared to baseline.

Appendix F: Peer Review Certificate

Alternative Energy Systems Consulting, Inc.

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(760) 931-2641

Carlsbad, 11/22/2013

This report file, named

"UTL Freezer Monitoring Final Report 11-13-2013.pdf"

And titled

"Low-Temperature Freezer Monitoring in Scientific and Pharmaceutical Applications"

Has been peer reviewed by us, and our suggestions for improvement have been incorporated. Based on the information available, we believe that the research was conducted in a sound and rigorous manner and that the results are accurate and complete as presented.

Antonio Corradini, PE

Principal Engineer, Alternative Energy Systems Consulting Inc.

(end of document)