SAN DIEGO GAS AND ELECTRIC COMPANY

EMERGING TECHNOLOGIES PROGRAM

ASSESSMENT REPORT

PROJECT ID ET11SDGE0013

ADAPTIVE REFRIGERATOR AND FREEZER CONTROLS FOR COMMERCIAL APPLICATIONS

FINAL REPORT

PREPARED FOR

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Project Team

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Disclaimer

Executive Summary

This review investigates the energy savings potential of an advanced refrigeration controller. The technology continuously monitors conditions of a refrigeration unit and controls the system components in real time using an adaptive strategy. Traditionally, refrigeration controllers monitor space temperature with a thermostat, and only control the compressor. This new technology monitors inlet temperature, evaporator temperature, space temperature, evaporator fan use, defrost element use, and compressor use. This allows for a significantly improved control algorithm that results in:

- Running the fans only when needed instead of 24/7
- Decreasing compressor cycles
- Decreasing the defrost time
- More stable temperature and humidity

The goal of this project was to assess the validity of the efficacy of the new technology on energy consumption. Our study monitors the use of specific components, internal temperature, humidity, and total energy consumption of a walk-in freezer (sub 32°F) and a walk-in refrigerator (over 32°F), before and after the installation of the new controller. A San Diego McDonald's Restaurant was chosen as the test site. This is a good representation of the walk-in size refrigeration market.

The new controller is very effective at reducing the operation of the refrigeration components while maintaining appropriate temperatures. Defrost cycles were significantly reduced. The controller installed on the freezer resulted in an overall energy reduction of about 33.6%, while the controller installed on the refrigerator reduced energy consumption by about 15.5%.

Data analysis was performed to appropriately compare the before and after setup of the refrigeration units. Data was corrected for delivery schedules, temperature variations from an accidentally moved thermometer, and for changes in temperature set-point.

Although both controllers resulted in energy savings, our calculations only showed the freezer having a reasonable payback period. At an assumed $0.16 per kWh, the freezer's energy savings would offset the cost of the controller at 1.2 years, while it would take approximately 19.7 years for the refrigerator.

System	Energy use before [kWh/day]	Energy use after [kWh/day]	Energy savings [kWh/day]	Energy savings [kWh/year]	Energy savings [%]	Blended energy cost [$/kWh]	Total savings [$/year]	Controller Installed cost [$]	Simple payback [years]
Refrigerator (455cuft)									
Fan	2.4	1.5	0.9	340	38.9%	$0.16	$54		
Compressor	8.8	8.0	0.8	294	9.2%	$0.16	$47		
Total	11.2	9.5	1.7	634	15.5%	$0.16	$101	$2,000	**19.7**
Freezer (1070cuft)									
Total	83.7	55.5	28.2	10286	33.7%	$0.16	$1,646	$2,000	**1.2**

Figure 1 Simple payback of walk-in refrigerator and freezer before and after new adaptive controller

We believe that this technology is ready for persistent deployment. Both the reviewer's study of the technology and the vendor supplied materials showed a savings in energy consumption by retrofit of existing refrigeration units. To minimize payback periods, it is suggested that further study be performed on the influence of refrigeration volume, internal and external temperatures, door size/volume ratio, door opening frequency and refrigeration R-values.

Market potential was found to be significant for California. According to CEUC 2006 [1] even with a moderate 10% penetration of the refrigeration market for restaurant and warehouses, a total of 275.3 GWh/year can be impacted. Additional markets will likely apply. With this technology being capable of 20% or more energy savings, we estimate that this technology could save at least 55GWh annually considering the aforementioned assumption.

Customer response to the functionality of the controller was very positive. They said that it required no further training or attention from the users and they were very satisfied with its ease of use. They also appreciated the fact that they were able to monitor actual temperatures and that it was accurate. Another comment (that agreed with data) was that they noticed temperature fluctuations were much less with the new controller.

There are some auxiliary benefits to this system that may extend beyond energy savings. The controller was shown to reduce fluctuations in temperature and humidity, which may reduce food spoilage. There is also an alert capability which may help to hasten repairs and thereby reduce down.

It should also be noted that this technology may have possible drawbacks that were not investigated in detail in this review. Possible drawbacks include a reduced refrigeration system lifespan (due to increased cycling), as well as uneven temperature distribution (due to reduced fan use). The manufacturer of the particular system that we investigated states that these issues are prevented by their "algorithms including minimum run-times and off-times for the equipment to ensure that short-cycling or overrunning does not occur. Also, the controls cycle the evaporator fans every 12 minutes for 3 minutes when setpoint temperature has been maintained". The approach appears sensible; note however we have not verified their statement and the effect of this aspect of their control strategy.

As always, it behooves the reader to conduct your own research and to use your own judgment when assessing whether a new technology may benefit your site. Your results may vary.

Demand reduction and demand response capabilities do not apply to this technology.

Note Appendixes A and B, where we provide a sensitivity analysis of the various factors influencing energy consumption, and a tabular comparison of this technology with a similar one, respectively.

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Introduction

Refrigeration and freezing units can make up a substantial amount of a commercial building's energy use. Most units in place currently use controllers that minimally monitor the system and maintain certain components of the system at an always-on state, which continuously raises energy costs. The goal of the technology is to reduce overall energy usage of refrigerator and freezer units and reduce cost while still maintaining desired conditions within the units.

The technology and this report are specifically about energy efficiency and energy conservation in the refrigerator and freezer systems. We do not discuss demand or demand response. This technology proposes a continuous active monitoring of the refrigerator and freezer system for a continuous increase in energy efficiency.

Energy and demand cost can vary significantly with time of use as illustrated below, but as stated before, this technology focuses on curtailing energy consumption through efficiency.

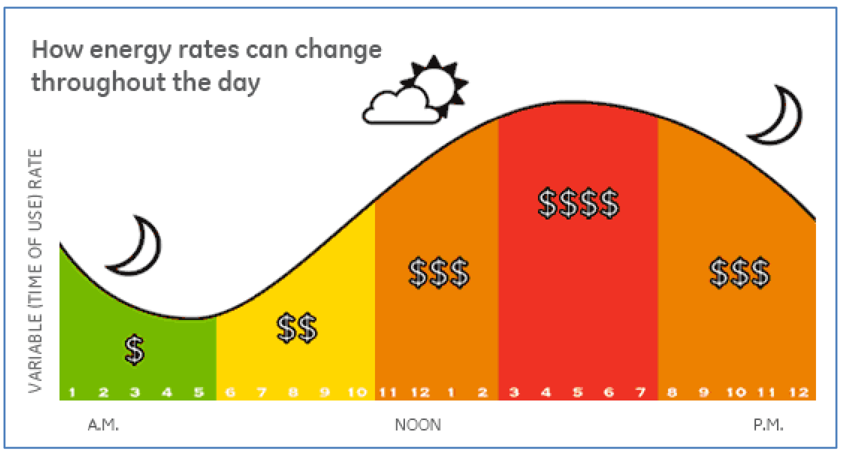

Figure 2: Electricity rate variance with time of use

This report presents a case study of the previously installed controller against the new technology. Both systems were used in a way that is compliant with the restaurant's regulations and the conditions observed in the study should be applicable to other similar environments in California due to similar regulations.

The technology and its advantages should also be applicable to other similar refrigerator and freezer systems in California as retrofit (as done in this study). The technology should also be beneficial as a new installation unit but the comparative benefit against a retrofit was not included in this study.

Project Objective

The main objective of this evaluation is to study effectiveness of this technology by reviewing a sample installation at a McDonalds Restaurant in El Cajon, CA. Please see Detailed Host System Description on page 17 for a more detailed description of the particular system used in this study.

Our evaluation is to determine the efficacy of the technology (does the product function as intended), and quantify its use within the context of energy and cost. We go beyond one particular vendor, and assess benefits, validity and potential of the technology as a whole. We also briefly describe the marketplace, as well as applicable codes and standards.

Our study has taken place in San Diego Gas & Electric territory; however, the results should be applicable throughout most of California due to consistent legislation and tariffs throughout the state. The results may also be most applicable to areas of the same or similar climate zone.

In our project result section, we describe system setup and operation, roles and responsibilities, cost and cost-influencing factors, system functionality, customer feedback, energy reduction, and last but not least, applicability of existing SDG&E programs.

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Project Methodology

[Full M&V and Project Plan can be found in Appendix C and D, respectively]

The Project Plan [pg 40] 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 M&V Plan [pg 47] contains detailed information on the following:

- Host site
- Data collection procedure
    - Data Points
    - Data sampling, recording, and collection intervals
    - Instrumentation
- Data analysis procedures
    - Data manipulation
    - Calculation of energy and demand savings
    - Calculation of cost savings

Technology Overview

The adaptive refrigerator and freezer controller is essentially a microprocessor with inputs and outputs that allows for the continuous monitoring and control of compressor and fan to meet desired space conditions (i.e. internal temperature) while optimizing energy use. Using the system's compressor and fan only when necessary reduces waste heat that is injected into the system and also eliminates unnecessary cooling to lower than the temperature set-point. These adaptations to the system will presumptuously lower the operating cost of the refrigerator and freezer.

Host Site Overview

The chosen host site for this case study was a McDonald's Restaurant in El, Cajon, CA. The freezer and refrigerator storage areas were 1078.00 ft^3 and 456.60 ft^3, respectively. The host site's freezer and refrigeration system were monitored continuously during the month of September (2011). During the study period the restaurant operated normal business which included business 24/7 hours, regulated delivery schedules, and use (door opening frequencies). Also, previous to the study, the current refrigeration and freezers were inspected and verified to be operating correctly. [3]

This site was chosen based on upon it being representative of commercial refrigeration market in California that would be appropriate for this technology. It consisted of large walk-in units that were in active use with regular schedules.

This site was also appropriate to review the efficacy of this new technology because the outside temperature was relatively stable in San Diego, CA. Figure 3 shows the temperature data for the month of September. The temperature spike in early September was not corrected for because the power outage that occurred eliminated the data in that range. Also, the data shown is for San Diego, CA not El Cajon, CA which may be slightly more unstable but since the refrigeration and freezer units were inside an air conditioned building, heat gain/loss from the units would not transfer directly outside. So this would not affect the results.

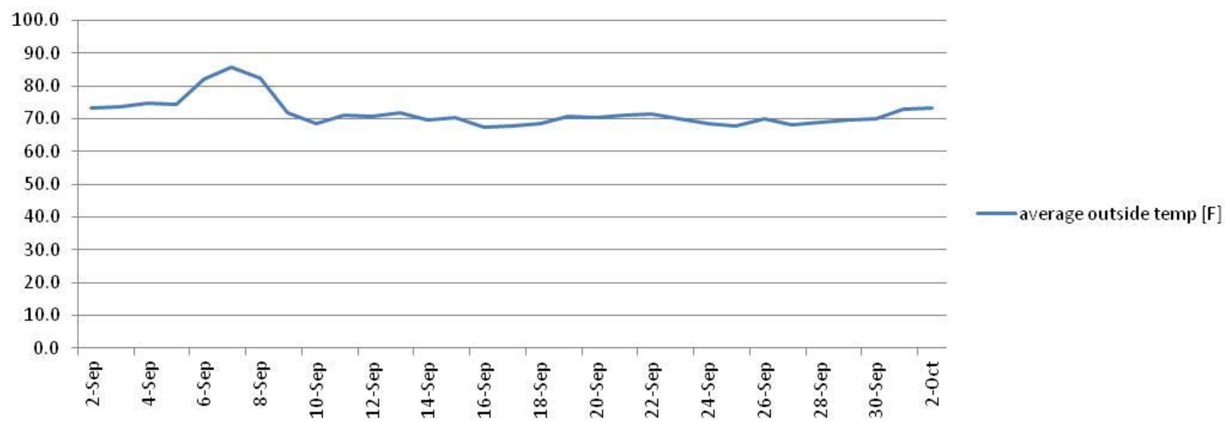

Figure 3 Temperature data in San Diego, CA during September 2011

Measurement & Verification Plan Overview

We evaluate system setup and operation, roles and responsibilities, cost and cost influencing factors, system functionality, impact to host site staff, customer feedback, energy reduction, and applicability of existing SDG&E programs.

Emphasis is placed on the following aspects:

Verification of system operation and design

- Does the controller reduce use of individual system components?
- Does the controller maintain temperature desired by operators and meet regulations for freezing and refrigeration?
- Does the controller require increased/decreased attention from operating staff?

Potential energy savings

We calculate energy savings and simple payback times without incentives or rebates. Energy savings will be calculated for the annual energy usage with the new system minus what an average annual cost of energy usage would have been with the old system.

Customer feedback

Does the customer like the system? What would he improve to make the system more attractive? Did the system require further training from host site staff?

Applicability of SDG&E incentive and rebate programs

We review relevant SDG&E programs with respect to this technology, and provide recommendations for where we believe program support may apply.

Finally, we conclude our study with a discussion of

- Benefits of adaptive refrigerator and freezer control
- 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

Market Overview

Opportunity

The California market for this technology is significant. Theoretically, this technology can be applicable to any commercial freezer or freezer/refrigeration system. (Although efficiency benefits will vary)

The following table shows the distribution of total California commercial energy pertaining to refrigeration. The data is taken from The California End-Use Survey of 2006. [7]

California Commercial Energy - Refrigeration (Annual)

Building Type	Refrigeration (GWh)
All Commercial	**9014**
Small Office	208
Large Office	268
Restaurant	1469
Retail	726
Food Store	3233
Refrigerated Warehouse	1284
Unrefrigerated Warehouse	154
School	225
College	95
Health	166
Lodging	244
Miscellaneous	942
All Office	**476**
All Warehouse	**1438**

Table 1: Annual Commercial Refrigeration Energy Use (CEUS 2006[1])

This technology is applicable to any of the above sectors assuming their refrigeration/freezing equipment is similar to our host site. The most directly applicable building type is the restaurant type due to the host site being included within. Since there is no data relating the energy consumption to refrigerator/freezer type/size, this opportunity is only an assumption.

To calculate energy savings in California, we assumed a simple 10% market penetration of this technology. Also, we will only consider restaurants and refrigerated warehouses because they have larger refrigeration needs that would be similar to the host site. This results in a refrigeration market penetration of 275.3 GWh. These two building types alone would have an annual energy savings potential of 55 GWh (assuming a conservative 20% energy reduction with the new technology).

Products and Systems

A list of vendors and products competing in this market sector is provided below in alphabetical order. Some of these controls may be more technologically advanced and a better representation of the technology in this study than others.[1]

- Carel IR33 smart [12]
- Danfoss EKC 102 [11]
- Emerson XR75 [10]
- Johnson Controls Inc. MR4 [9]
- JUMOP eTRON M100 [13]
- NECI Cool Expert MIC QKL mini e3 [8]
- NOVUS N323R [14]
- NRM CoolTrol [27]
- WEISS Instruments XR06CX [15]

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[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.

Applicable codes and standards

Codes and standards that apply to an adaptive refrigerator and freezer controller are the same as those that apply to standard refrigeration controllers and their installations.

The California Code of Regulations Title 20 (Public Utilities and Energy) has an effective code concerning refrigeration systems, although the code does not hold regulations to the control systems or energy consumption levels for refrigeration units larger than 39 sq-ft.[16]

Manufacturer specifications have stated that a refrigeration control technology with dual sensor control, combined with the optional network module and a recorder is compliant with hygiene regulation for quality assurance of chilled goods according to HACCP. HACCP requires active monitoring with alert capabilities. [24]

Currently, there is a proposed addition to Section 6 of California's Title 24 building code which is specific to energy-efficiency in supermarket refrigeration systems. The proposed code would require fan speed control on walk-in cooler and freezer evaporators as the primary means on space temperature control. The code is proposed as a Reach measure due to not enough industry experience with this type of refrigeration control by the CASE study stakeholders. The code addition is proposed to be included by 2013 [17]. This code change would be directly applicable to the evaluated technology. However, refrigeration fans may be designed to provide the necessary throw distance for even temperature distribution only at 100% speed, in which case varying their speed may be less sensible than on/off cycling. Further research is needed in this area.

Additional investigation into Title 24's Reach measure wording for 'variable fan speed control' is required. The technology reviewed only toggles (on/off) fan speed appropriately to maintain desired conditions. If the measure's goal is to have specific motor control for various speeds within a fan's range, then this specific control would not suffice as is.

Furthermore, the reviewed controller is not limited to a specific heat transfer media and is applicable to be used with direct expansion, CO_2, pump operation, NH_3 and dual circuit refrigeration. This may result in further codes and standards for leak detection when using different coolants.

Project Results and Discussion

Detailed Host System Description

Overview

An adaptive refrigerator and freezer controller is a device that continuously monitors components of the refrigeration system (compressor, fan, temperature, etc.) and is able to appropriately control the system (compressor and fan) to optimally meet preset conditions. The controllers at the host site were connected to refrigerator and freezer systems and were fully operational and actively used.

Energy consumption reduction of the refrigeration systems stems from the new controllers' ability to eliminate the fan's previous always-on state, dynamically controlling the compressor, and reducing defrost cycles and cycle times.

Figure 4 Example controller unit, most controllers on market have similar dimensions and UI

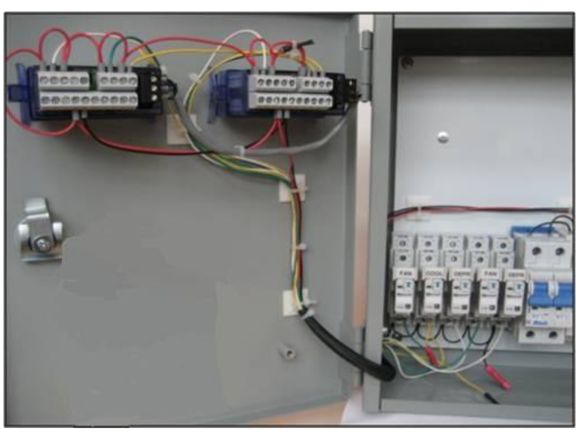

Figure 5 Example installation of a refrigeration controller

Once the system has been properly installed, the user can determine the set point for the refrigerator or freezer's temperature. From there an algorithm determines how to appropriately control the fan, compressor, and defrost cycles. The general process to which the controllers follows:

- Use evaporator fan and compressor if internal temperature needs to be raised
- Once an adequate temperature is reached the compressor may be turned off but the evaporator fans can stay on as long as there is residual cool air that can be circulated
- Turn off the fan when appropriate to save additional energy costs

System Deployment and Operations-Related Roles and Responsibilities

List of Controlled Points

The data that is necessary in order to accomplish the specified objectives [1] are divided into two time periods. The control to this project for the energy usage comparison is the data from the refrigerator and freezers prior to installation of the technology. The table below provides a description of the data collected for each tested freezer and refrigerator per time period:

Time Period	Data Measurements			
Pre-Installation	Energy usage over time	System Air temperature	System Humidity	
Post-Installation	Energy usage over time	Vendor's assumption	System Air temperature	System Humidity

Table 2 Controlled points in data measurement

The system air temperature and humidity are significant variables to measure as they may be affected when the doors are opened, and therefore changing the amount energy usage. Relative humidity is important because moist air has higher heat capacity and therefore would require more energy to be cooled. These measurements will also confirm if the factors change drastically after the new technology is installed.

Sequence of Operations

The controller technology states that it has an improved algorithm with increased control of the refrigeration system. It monitors the refrigeration temperature at the evaporator and also takes the temperature of the cooled space. The controller has the ability to control the compressor as does all standard controllers, but also controls the operation of the cooling fans and defrost circuits.

As the controller monitors the system, it is comparing the temperature at the fan vs. the temperature of the room. If it sees the ability to turn the compressor off and still cool the room only using the fan (due to lower temperature being at the cooling coils), it activates the fan. When the temperature of the room is at the set-point again, then the fan is allowed to turn off. Only when the temperature at the fan reduces enough to not be able to cool the rooms appropriately will the compressor become active.

This reduced function of the system components allows the system to reduce energy consumption while still maintaining the desired set-points.

The review controller also has other configurations to monitor the system but these were not reviewed in this study.

System Cost and Cost-Influencing Factors

The cost of the technology is $2000 per controller before rebates, regardless if its application is to a refrigerator or freezer. The system cost may vary with an inclusion of an optional network module for two way data transmission.

Total cost will also include the cost of installation but will vary based on installer. There is no recurring maintenance contract, subscription cost, license renewal, etc.

Verification of System Operation and Design

Does the controller reduce the use of individual system components? YES
Does the adaptive controller save energy in the freezer/refrigerator? YES

The system was monitored before and after for two continuous weeks each. The compressor and fan energy consumption was monitored separately in the refrigerator, while in the freezer they were monitored jointly (limited by availability of data loggers). Being able to individually monitor the separate components in the refrigerator, it was able to be measured that each component was used significantly less. Also, when averages are stated it should be noted that they are the averages of the two week period (before or after the new controller installation) unless noted otherwise.

The fan use by the original controller was programmed to be at an always-on state while after incorporation of the new controller it was used noticeable less, reducing the energy consumption by 38.88%. The following image (Figure 6) shows the energy consumption of the evaporator fan on the day of installation, with the noticeable decrease in energy consumption with the new controller. The average energy consumption of the fan before the new controller was 2.39kWh/day and after it was 1.46kWh/day.

The refrigerator compressor also resulted in an energy consumption reduction after the new controller. It is not as apparent graphically (Figure 7) because the compressor was never at an always-on state so there isn't an obvious change as in the fan. The compressor used an average 8.8kWh/day before the controller and 8.0kWh/day after for an energy reduction of 9.2%.

Lastly, the freezer resulted in an overall reduction of energy consumption as well. The compressor and fan were measured together in this review due to the limitation of data loggers but data still shows an end result of energy reduction via the new controller. Before the new controller was installed on the freezer the average energy consumption was 83.7kWh/day and 55.5kWh/day, resulting in a 33.7% energy savings (Figure 8).

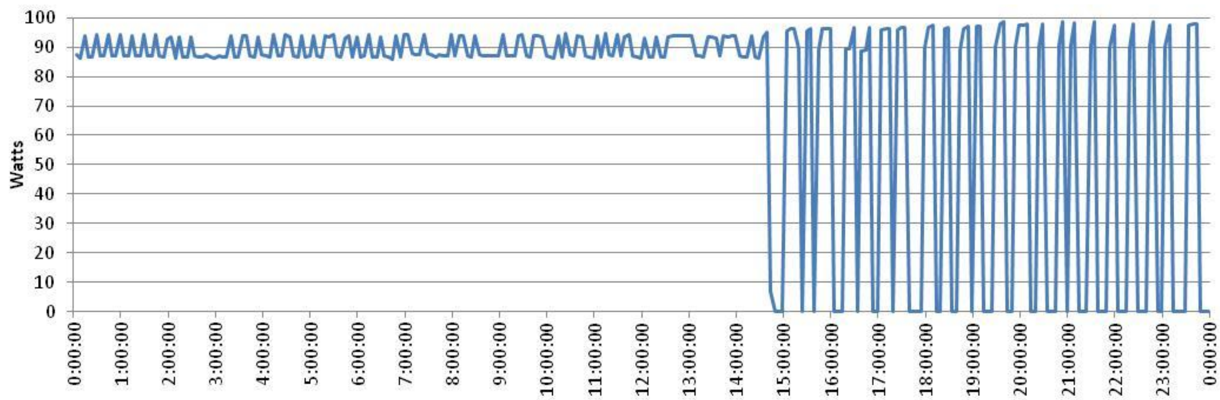

Figure 6 Refrigerator fan energy consumption in Watts over a 24h period on 9/15/2011, uncorrected data (installation day)

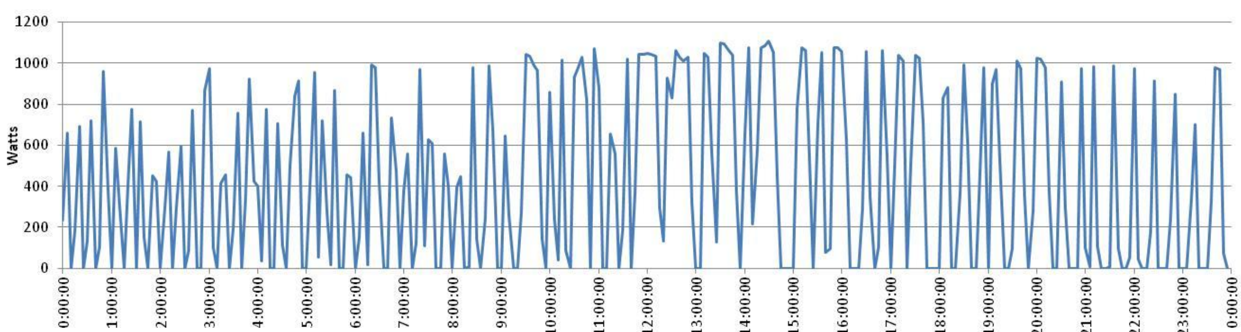

Figure 7 Refrigerator compressor energy consumption in Watts over a 24h period 9/15/2011, uncorrected (installation day)

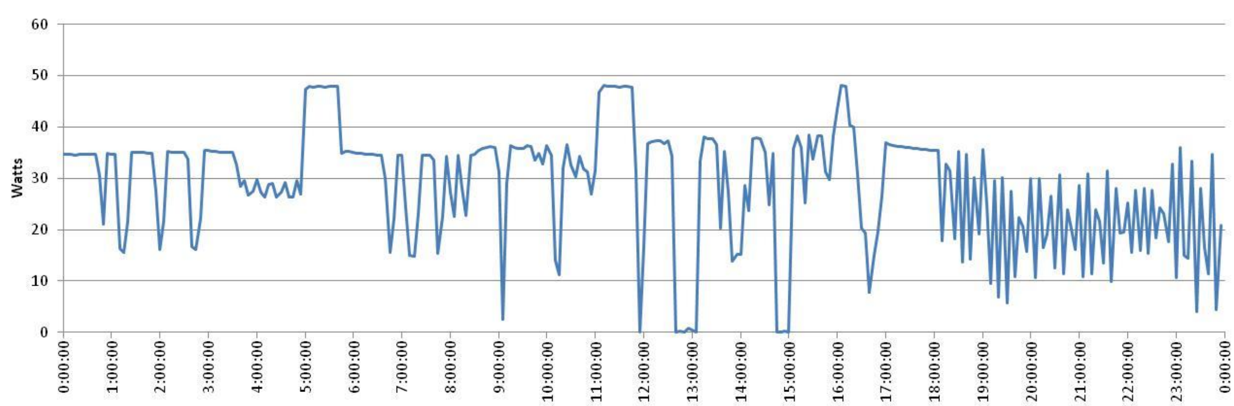

Figure 8 Freezer fan and compressor energy consumption in Watts over a 24h period on 9/15/2011, uncorrected data (installation day)

In order to show a more accurate representation of the energy savings obtained from installing a new adaptive controller the data needed to be corrected for various factors that were involved in the testing environment. Those factors included: (See Project Error Analysis on page 30)

- Scheduled deliveries at host site
  - Hours 8am-12pm on Tuesdays and Thursdays were replaced with 6am-8am and 12pm-2pm
- San Diego power outage (9/8/11)
  - Data was lost on 9/8-9/9 due to power outage
- Temperature set-point change and moved thermometer
  - Energy consumption was multiplied by the current set-point divided by the set-point average (before and after installation).
- Installation day (9/15/11)
  - Installation day was neglected from data analysis due to change in controller and allowing for system stabilization

The following graphs (Figure 9 and Figure 10) display the most accurate representation of energy consumption from the refrigerator and freezer. The data has been corrected for the delivery schedule and the difference in set-points before and after installation. As stated earlier the freezer averaged 83.7kWh/day before installation and 55.5kWh/day after, resulting in a 33.7%. As for the refrigerator, when the compressor and fan data were combined, the controller contributed to a 15.5% energy consumption savings. Before the controller, the refrigerator consumed an average of 11.19 kWh/day and 9.46kWh/day after.

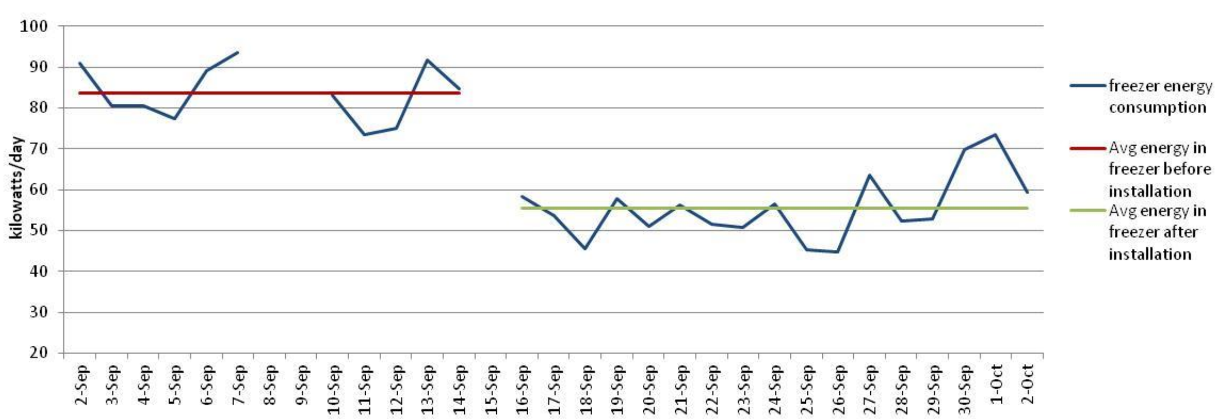

Figure 9 Energy consumption of the freezer (fan+compressor) before and after control installation (9/15/2011)
NOTE: data missing 9/8-9/9 due to power outage and data shown is correct for delivery schedule and temp setpoint

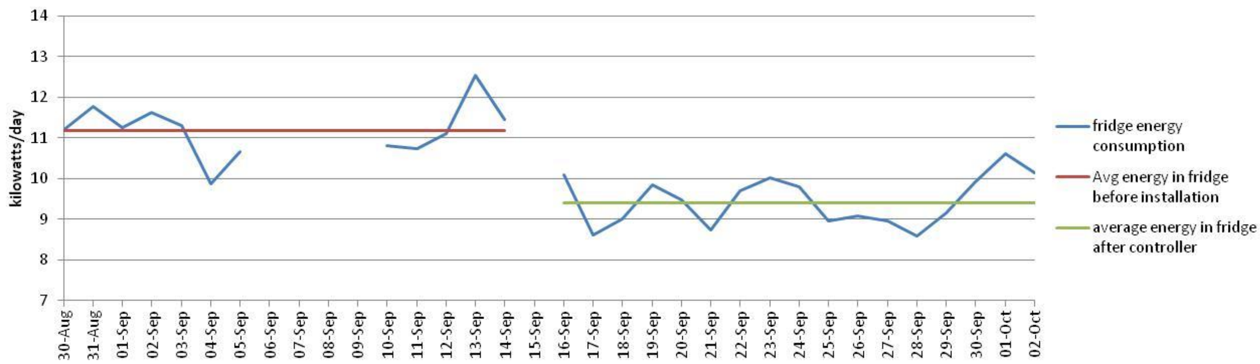

Figure 10 Energy consumption of the refrigerator (fan+compressor) before and after control installation (9/15/2011) NOTE: data missing 9/6-9/9 due to power outage (and battery issues) and data shown is correct for delivery schedule and temp setpoint

As stated earlier, the adaptive controller reduces the energy consumption by actively monitoring the components so they are only used when needed and not over cooling the refrigeration container. A side benefit to this, which also is a source of energy savings, is reduction of defrost cycles. This is specifically advantageous for the freezer due to the set-point being well below freezing temperature (32°F).

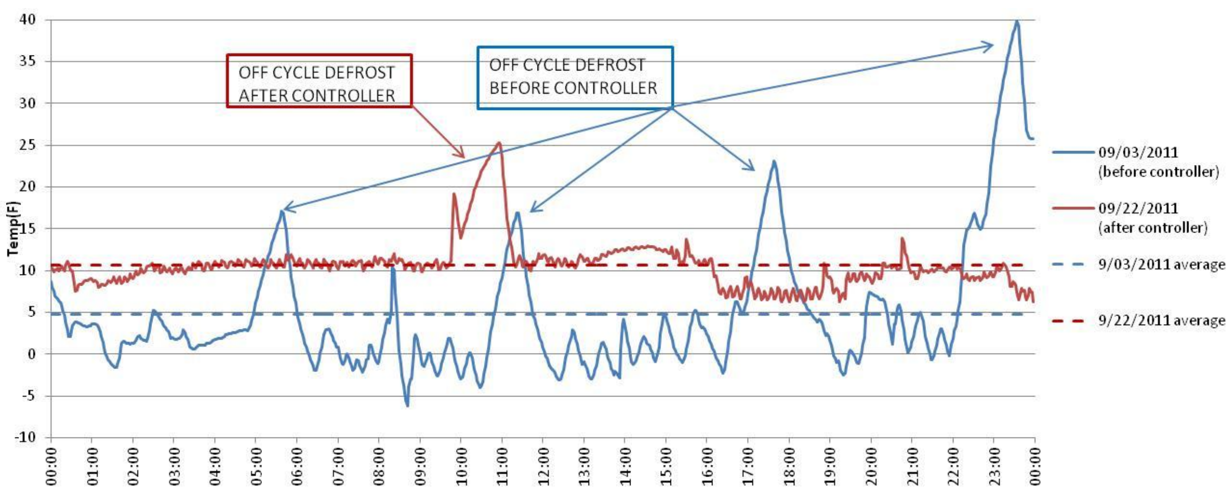

Figure 11 Freezer's defrost cycle frequency and average temperatures before and after controller installation

The comparative analysis of defrost was not performed for the refrigerator due to its average temperature being over freezing temperature, so large changes were not noticed.

Does the controller maintain temperature desired by operators and meet regulations for freezing and refrigeration? YES

The host site stated that they must maintain their refrigerator unit below 41°F. Before the installation the average internal temperature was 38.8°F, while after the installation the average temperature was 40.4°F.

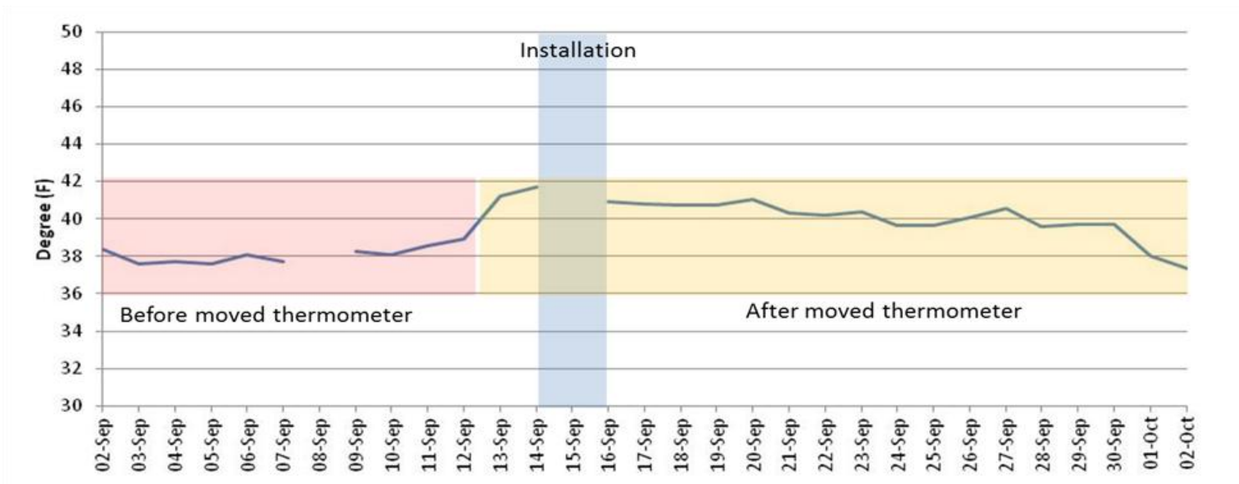

Figure 12 Refrigerator temperature data before and after installation (break in data at 9/8/11 due to power outage)

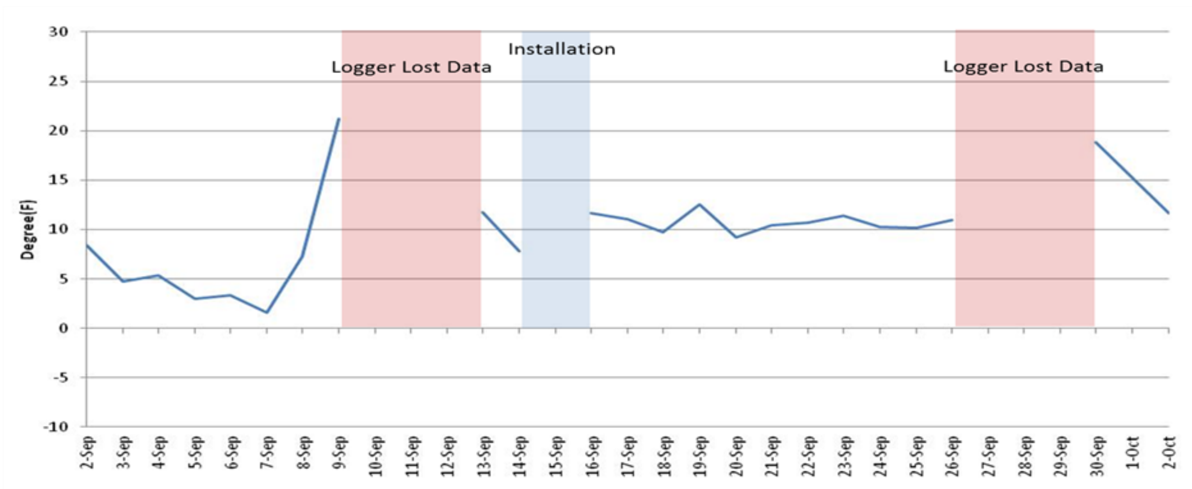

Figure 13 Freezer temperature data before and after installation (breaks due to power outage and lost data from logger)

The graph for the freezer's average temperatures can be seen in Figure 11.

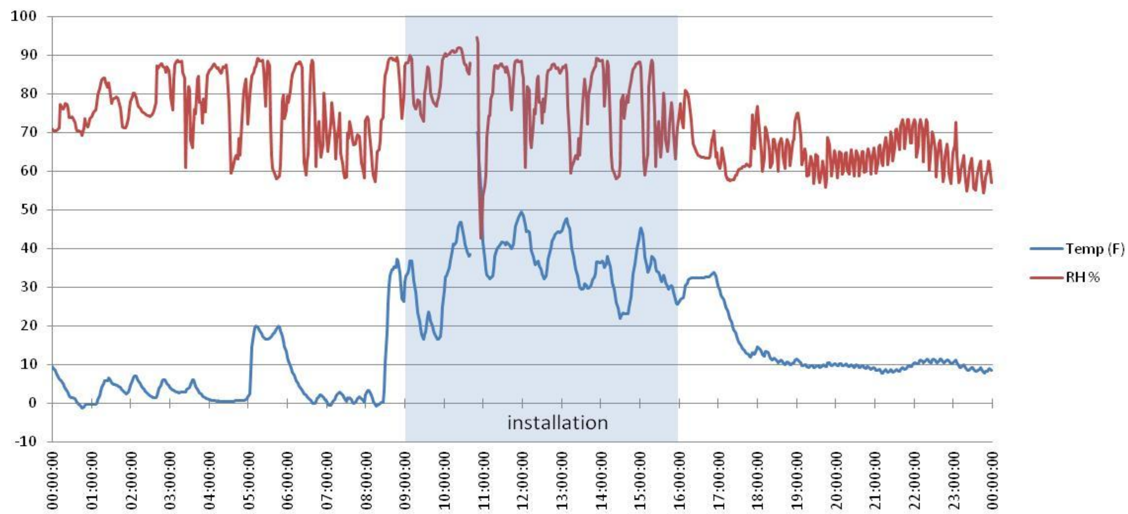

Figure 14 Freezer RH and Temperature before and after controller installation

After the controller was installed, it was also noticed that the temperature was much more stable. As can be seen in Figure 14, there is a lot less variation in the data. This may help a restaurant with food spoilage due to less frequency of temperatures dipping below a desired level.

Does improved efficiency from the control extend to delivery schedules? Possibly

Although not under the main objective of the review, the effect of the controller on delivery schedule was observed. The periods in which the reviewer assigned to delivery schedules were observed and it showed that the controller did help improve efficiency. This data is not to be taken quantitatively because of numerous variables that are included in the delivery event. Variables such as specific delivery length, quantity/temperature of items delivered, number of staff involved, etc. would influence the data and was not recorded.

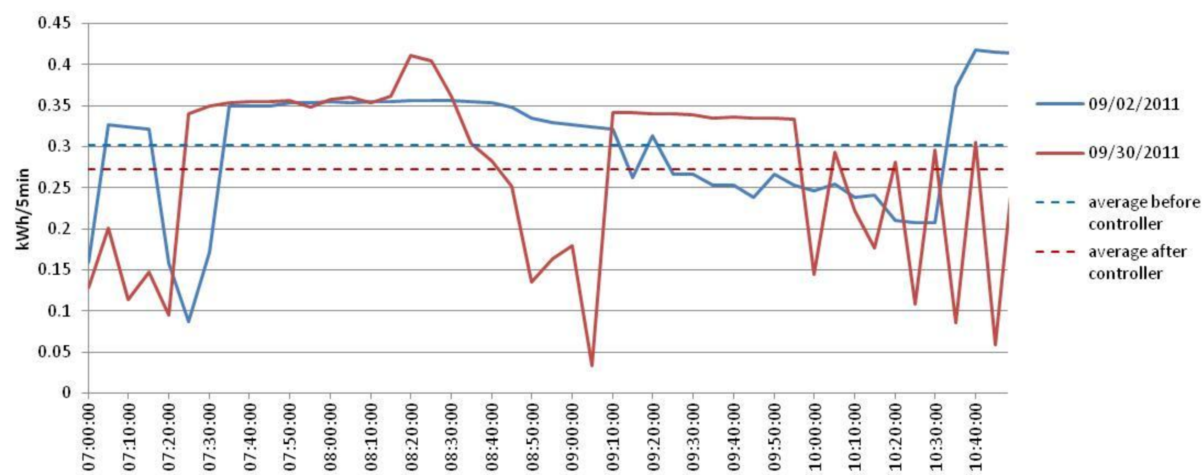

Figure 15 Energy consumption in freezer during a delivery day (Tuesday and Friday, 7-11am), averages are of all delivery days before and after controller installation

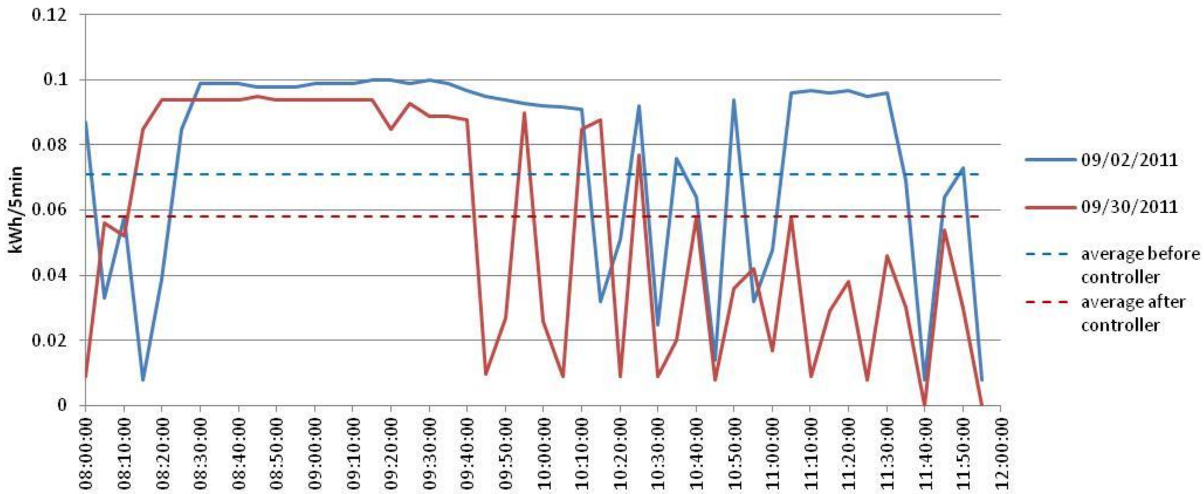

Figure 16 Energy consumption in refrigerator during a delivery day (Tuesday and Friday, 8-12am), averages are of all delivery days before and after controller installation

As seen in Figure 15 and Figure 16 energy consumption was decreased during delivery events.

Again it should be noted that this data is meant to show that the controller is not detrimental during delivery events, but more studies should be performed to make conclusions on the effect the controller has during these types of events.

Does the controller require increased/decreased attention from operating staff?

The new controller should require the same or a reduced amount of attention compared to the previous controller after installation and setup is complete.

The host site stated specifically that they (gladly) didn't require any personnel to be trained on the technology. After the initial installation further attention was not needed. The controller also requires no attention or interaction after a power outage, although in this case it may take a few days of (non-interactive) "relearning" the environment to achieve maximum energy savings.

Evaluation of Impact to Users (McDonald's staff)

Based on a customer survey, there was minimal impact to McDonald's staff. As predicted, once the controller was installed it required no further attention or training and performed its tasks appropriately.

Also, the host site stated that based on their observations it seemed as though the temperature range variances were less. This is agreeable to the data as was shown in Figure 14 Freezer RH and Temperature before and after controller installation. Another positive feedback statement was that the users liked the fact that they were able to see the actual temperature of the units at any given time and they found that the temperatures were accurate.

Additional Customer Feedback

The host site said that they were generally positive from the new controller. They were very satisfied with how the temperature was maintained and the ease of use of the new technology. Also, in general they were satisfied with the controller on an overall comparison to the old controller.

They weren't able to comment on the actual energy savings because they said they were sure of what it is. The customer also did say that they weren't positive about purchasing this controller without incentives without actual energy savings data.

Energy Savings

Calculated Savings

Table 3 shows the estimated savings for refrigerator and freezer using the new adaptive controller at the McDonald's test site. The results are broken down for the refrigerator's fan and compressor components with totals also. An average kWh cost of $0.16 is used in the simple payback calculation. The data shows that a payback of 19.7 years is found for the refrigerator and 1.2 years for the freezer.

System	Energy use before [kWh/day]	Energy use after [kWh/day]	Energy savings [kWh/day]	Energy savings [kWh/year]	Energy savings [%]	Blended energy cost [$/kWh]	Total savings [$/year]	Controller Installed cost [$]	Simple payback [years]
Refrigerator (455cuft)									
Fan	2.4	1.5	0.9	340	38.9%	$0.16	$54		
Compressor	8.8	8.0	0.8	294	9.2%	$0.16	$47		
Total	11.2	9.5	1.7	634	15.5%	$0.16	$101	$2,000	19.7
Freezer (1070cuft)									
Total	83.7	55.5	28.2	10286	33.7%	$0.16	$1,646	$2,000	1.2

Table 3 Refrigerator and Freezer energy savings and simple payback period at reviewer's host site

For informational purposes, the R-values of the test site refrigerator and freezer were also calculated. This value expresses the quality of insulation of the respective units. It is calculated as follows using the internal surface area (SA) of the refrigeration container, the temperature difference at equilibrium of the inside and outside of the container (delta T), and the energy (BTU converted from kWh) that it takes to maintain the temperature difference:

$$R - value = \frac{SA\ [sqft] x\ delta\ T}{energy\ [btu]}$$

System	SA(sqft)	deltaT(F)	time(hrs)	energy(btu)	R-value
Refrigerator	301	39.2	10	1457	8.1
Freezer	496	70.4	10	10634	3.3

Table 4 Host site refrigerator and freezer R-value approximations

The higher the R-value the better the insulation properties. Interestingly the freezer has a much worse R-value than the refrigerator. It is to be noted that therefore improvements to the freezer envelope may be a worthwhile measure to further save energy in the case of our test site.

Cost affecting factors

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

- Storage volume
  - The larger the amount of volume to be cooled will increase the cost of operation. More volume will represent larger amounts of heat that need to be removed from the system, this will require a greater amount of work from the system.

- Storage insulation (thermodynamic R-value)
  - If there is a low R-value, there will be more heat loss through the refrigeration container. If there is a larger amount of heat that will be entering the refrigeration container through the walls then heat will need to then be removed at a higher rate. This heat removal will require more work from the system as well, thus increasing operating costs.

- Initial cost
  - High installation cost or a different technology
  - Updating system components if they are below operational
  - Certifying the system to meet incentives
  - Cost of gaining heat in the refrigeration container during installation.
  - Cost of possible training required by staff

- Utility rates
  - Rates may differ based on utility and territory or if the existing refrigeration is already on some type of incentive

If there is a higher operating cost of the refrigeration, whether it is because of a high storage volume or small R-value, it may seem much more enticing to invest in this type of technology because the controller is a one-time payment. If a controller may result in 15% percent savings, this may be of a high dollar value and would quickly offset the cost of the controller. Also, vice-versa, if a unit has a low operating cost, a 15% energy savings could take as long at 19 years as in our refrigerator.

Please note, life cycle cost analysis is not in scope of this study, and would be very difficult to carry out accurately due to the large number of independent variables.

Applicability of energy saver programs

Energy Efficiency Business Incentive

SDG&E offers an Energy Efficiency Business Incentive (EEBI) to customers involved in the installation of new high-efficiency equipment or systems. The project may consist of the retrofit of existing equipment/systems or the installation of equipment associated with new/added load. Eligibility consists of any commercial, industrial or agricultural customer who pays the public goods charge regardless of size or project scope. [18]

Air Conditioning and Refrigeration II **Energy - $0.09 / kWh** **Peak Demand - $100 / kW**	▪ Controls and energy management systems for HVAC or refrigeration equipment ▪ Variable speed drives on fans (including supply fans, exhaust fans, and cooling tower fans) ▪ Variable speed drives on pump motors (including chilled water and cooling tower pumps) ▪ Fan, pump, and/or motor replacements ▪ Refrigeration evaporator fan controls ▪ Insulating chilled water, condenser water, or refrigerant pipes ▪ Insulating cool air ducts ▪ Insulating storage tanks ▪ Demand control ventilation installation (CO_2 sensors) ▪ Installation of high-speed cold storage doors ▪ Air Conditioner air-side or water-side economizer installations on units not already equipped with a 100% economizer ▪ Building shell improvements ▪ Cooling tower upgrades ▪ Refrigerated case doors

Figure 17 SDG&E EEBI program incentive
SOURCE: http://sdge.com/sites/default/files/documents/SPC%20Policy.pdf

The reviewed technology should be directly applicable to this incentive. The controller has been reviewed as a retrofit device that can reduce the energy consumption of an existing system. It should be noted that the applicability is limited to SDG&E, SCE, and PG&E territory. Other similar incentives may be available in other territories.

On-Bill Financing

In addition to the incentives allowed by the EEBI Program, SDG&E also offers an On-Bill Financing (OBF) program. This can be applicable alongside EEBI. The program offers to finance, at 0% interest, energy-efficient business improvements through their SDG&E bill. This allows a commercial customer to pay for energy efficient programs with the savings acquired from energy efficient technology. [19]

Figure 18 shows the rebates/incentives for the OBF program based on customer types

Maximum Loan Terms - Taxpayer-Funded Customers

Customer/Project Type	Rebate/Incentive	Payback Requirements
Taxpayer-Funded Customer (Institutional)	All projects that qualify receive 100% rebate and/or incentive	10 years or better or EUL[1], whichever is shorter

Maximum Loan Terms - Commercial Customers

Customer/Project Type	Rebate/Incentive	Payback Requirements
Commercial Customer	All projects receive 100% rebate and/or incentive	5 years or better or EUL, whichever is shorter
Commercial Customer Lighting-Only & Low-Cost Measures[2]	All projects receive 100% rebate and/or incentive	3 years or better or EUL, whichever is shorter

1. EUL - Equipment Useful Life as defined by the Database for Energy Efficiency Resources (DEER)
2. Lighting-only & Low-Cost measures include lighting, lighting-controls, pipe insulation, window film, plug load sensor, low flow showerhead, vending machine controller.

Figure 18 OBF maximum loan terms
SOURCE: http://sdge.com/sites/default/files/documents/237908273/On-Bill%20Financing%20Application%202012.pdf

As stated earlier, this technology does not influence demand control or demand response so it is not applicable to those types of incentives or rebates. This technology reduces the energy consumption of a refrigeration unit and increases its efficiency.

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Project Error Analysis

This section provides deviations from the original project plan and explanations of errors that occurred during the project

Project Plan Deviation

Use of optional fan heat barrier

The fan heat barrier(used during defrost cycle) was not considered or used within this study. To purpose of this study was to examine and measure the system improvements by solely replacing the original refrigeration controller. This heat barrier is provided by the vendor but is recommended for much larger systems.

How often is the cooling environment "disturbed" by opening doors

The frequency of the doors being opened/closed was not monitored. The objective of this study was to assess the efficiency improvement of the controller on a normal use refrigeration unit. This data would not provide useful feedback because recommending any change to door operation would alter the scope of the project, which was directed at the normal use refrigeration unit.

New setup vs. replacement of existing controls

Since the scope of the project focused on a retrofit of a McDonald's host site, a new installation project was not completed. Thus an overall comparison of new vs. replacement could not be completed.

Quantify demand savings potential

As stated earlier, demand savings is not a result of this technology's advantage. The benefit here is improved efficiency and reduction of energy consumption.

Anomalous Data and Treatment

San Diego power outage (9/8/2011)

As stated earlier, power was lost to San Diego for the second half of the day. This resulted in data being lost for loggers that were plugged in (DENT loggers for monitoring energy consumption) and also timestamp error in the fan data logger (WattsUP.net). The energy consumption was treated by replacing the lost data with the averages of a similar day and similar time period. Since it was clearly obvious of before and after installation for the fan (due to before installation having a 100% duty) the time periods were averaged for a day(24 hour period) of before installation and a day of after installation and energy consumption calculated.

Moved thermometer and set-point difference in walk-in refrigerator

Host site staff moved our temperature/humidity logger in walk in refrigerator. Originally it was placed inside the refrigerator near the door, which was to show influence from door activity. The logger was moved approximately 9/13/2011 to a box that contained limes to another shelf in the refrigerator. This was noticed in the data and the temperature showed an increase of about 3 degrees. Once this was physically noticed the logger was moved to the back of the evaporator to avoid further disturbances.

Also, there was a difference in temperatures from the freezer and refrigerator before and after the installation of the new controller. Both new controllers were configured to the same settings as the previous unit but the measured temperature was different. This needed to be corrected so that energy consumption was compared with similar temperature (because the lower the temperature would require more energy). Energy consumption before the installation was multiplied by the 1st measured temperature divided by the average of the two temperatures and the energy consumption after the installation was multiplied by the 2nd temperature and again divided by the average of the two temperatures.

Battery drain in freezer

Due to the low temperatures in the freezer, the battery in the HOBO logger was drained very rapidly. Some section of data was lost due to this. No data manipulation was done but the temperature averages were taken from just the collected data around these events.

Deliveries

Our host site had a standard schedule of two deliveries per week (Tuesday and Friday) for 4 hours each. This was corrected for by replacing the data of those hours with averages of data from hours outside of the delivery schedule (Figure 19). Correction was necessary because although deliveries would be expected in other comparable setups, the time allowance and frequency per week may change so it was more appropriate to find average energy consumption outside of these events. Deliveries were still of importance because, like just stated, it is assumed that other sites will have their own schedules. So, because the delivery schedules were standard at our host site we were able to extract the data and compare how the controller performed specifically during deliveries.

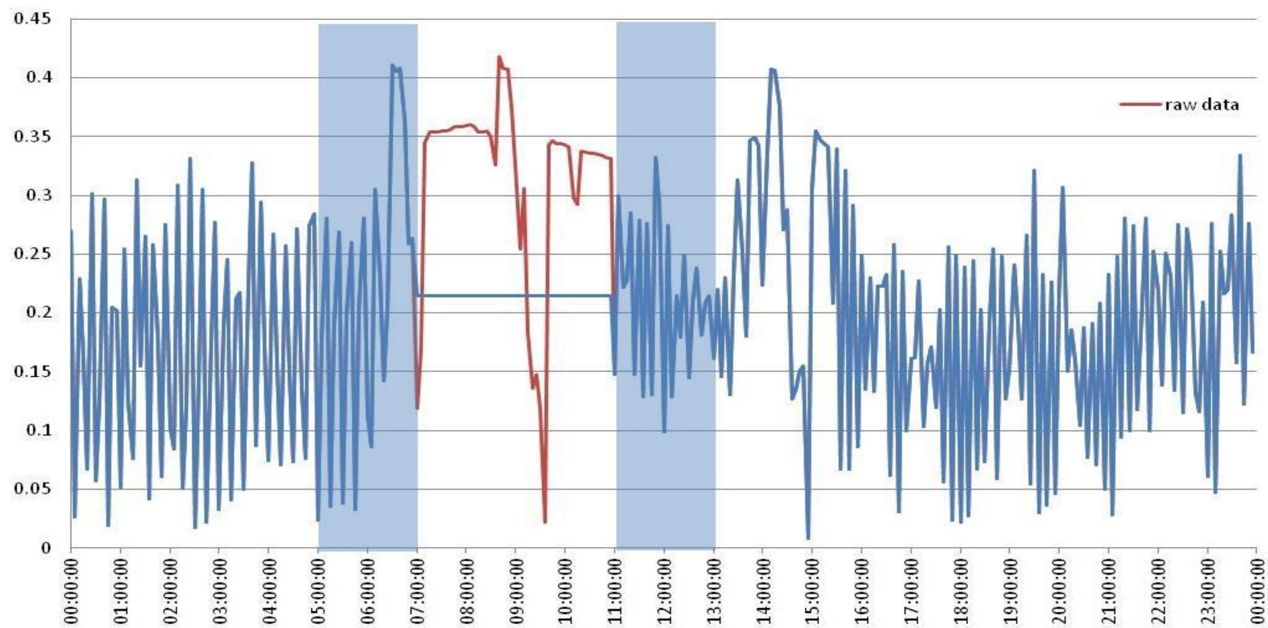

Figure 19 Single day example of corrections for delivery (9/16/11); the average of data from 2 hours before and after the event(shaded areas) was put in place of the data from the actual delivery time

Installation Day (9/15/11)

Data from the installation day of the new controller was excluded from the overall averages. This was because the system was disturbed excessively and after installation we wanted to allow the system adjusts to the new controller. Figures that were of the installation day were still used to graphically show the effect of the technology but he data was not used quantitatively.

Technical Statistical and Error Analysis

Controller effect on system

In the M&V plan, we stated that if the temperature after the controller is above the standard deviation of the temperature during of the baseline period, then the controller did affect the system. If it is shown then we would correct the data accordingly.

The refrigerator had a temperature average of 37.67°F before the controller with a standard deviation of 1.38°F. After the controller was installed, the average temperature was 40.0°F which was above the standard deviation. Due to this being outside of the standard deviation range, the data was corrected.

The correction need was also in the freezer. Before the controller the average was 6.17°F with a standard deviation of 3.11°F and the temperature after the install was 11.7°F.

Sensor uncertainty potential influence on cost and payback

The error in the DENT and WattsUP.net loggers would pose a small deviation in the payback period. The DENT logger is specified to have an uncertainty of 1% and the WattsUP.net logger has an uncertainty of about 1.5%. The following tables the uncertainty in the freezer and refrigerator and their influence on payback. The payback range is much larger (20.1 ± 2.6 years) for the refrigerator because two different logging devices were used so the uncertainty from each device had to be accounted for. The range for the freezer (1.2 ± 0.6 years) is much smaller due to only using one logger for both the compressor and fan; also the DENT logger had a smaller uncertainty than the WattsUP logger.

Freezer Uncertainty Analysis		Reading	Error (+/-)
DENT (+/- 1%) Compr. and Fan			
	Average Pre (kWh/day)	83.7	0.84
	Average Post (kWh/day)	55.5	0.56
	Difference (kWh/day)	28.2	1.39
Annualized Error			
	Annual savings (kWh)	10286	508
	Cost savings ($/year)	$1,646	$81
Simple payback range		**From**	**To**
	Simple payback (years)	1.16	1.28

Table 5: Sensor uncertainty potential influence on cost and payback for freezer

Refrigerator Uncertainty Analysis		Reading	Error (+/-)
DENT (+/- 1%) Compressor			
	Average Pre (kWh/day)	8.80	0.088
	Average Post (kWh/day)	7.99	0.080
WattsUP (+/- 1.5%) Fan			
	Average Pre (kWh/day)	2.40	0.036
	Average Post (kWh/day)	1.46	0.022
Total			
	Average Pre (kWh/day)	11.19	0.124
	Average Post (kWh/day)	9.46	0.102
Annualized Error			
	Annual savings (kWh)	634	82
	Cost savings ($/year)	$101	$13
Simple payback range		**From**	**To**
	Simple payback (years)	17.5	22.7

Table 6: Sensor uncertainty potential influence on cost and payback for refrigerator

Conclusions

Benefits of an Adaptive Refrigeration Controller

The adaptive refrigeration controller has shown cost benefits for a freezer and refrigerator unit at the McDonald's Restaurant host site. The refrigerator experienced a 15.5% reduction on energy consumption while the freezer was reducing by 33.6%. Since the both the freezer and refrigerator used the same model controller with different temperature set-points we will discuss their functionality jointly.

The controller was shown to very effectively reduce the use of individual system components. The fan was changed from being always on to only on when needed. This action was also able to help reduce the compressor run time because heat generated from the fan was curtailed.

The controller also helped to dramatically reduce ice build and defrost cycles in the freezer. This allowed for the average temperature to be better maintained due to not needing the defrost heat, which is a positive result on food preservation.

Customer response to the functionality of the controller was very positive. They said that it required no further training or attention from the users and they were very satisfied with its ease of use. They also appreciated the fact that they were able to monitor actual temperatures and that they were accurate. Another comment (that agreed with data) was that they noticed temperature fluctuations were much less with the new controller.

Also, by either retrofitting a refrigeration unit or installing as new, the customer is eligible for valuable incentives/rebates from the Utility. These help to offset the initial cost to the customer and influence future customers to increasing their energy efficiency.

By increasing adaptive controller's presence in the commercial applications, new additions to energy efficient building codes will be adopted. As stated earlier, Title 24 has a proposed addition to require variable fan control on commercial walk in refrigeration units. A benefit to adopting adaptive controller would be to conform to potential future regulations.

There are also some auxiliary benefits to the technology. The controller showed to stabilize temperatures more than the previous controller. This may be beneficial to food storage and reduce food spoilage by keeping temperatures lower for a higher percentage of time. The new controller also has alerts available which would help with early detection for errors. If problems are found earlier this may also help with a quicker response to help maintain food at adequate temperatures. Also, this would trickle down to being able to keep other operations functional that would rely on food storage.

Possible Drawbacks of an Adaptive Refrigeration Controller

There are possible drawbacks of an adaptive refrigeration controller that this study did not extend to but are still of importance to take note of.

One method of energy savings that this technology takes advantage of is being able to shut down the fan and only operate it when determined by an algorithm. Although the review showed immediate benefit in terms of energy savings, there could be future repercussions of toggling the fan on/off in terms of reduced life span, especially if cycling occurred very frequently.

Also, another fan related issue is that there may not be appropriate circulation of air when the fan is not at full duty at all times. For example, reviewers of the Title 24 reach method (P.16) stated that not having the fan at full may be detrimental to refrigeration: cooling may no longer be evenly distributed.

Finally, it is conceivable that compressors may be short cycled or overrun by an aggressive control strategy, reducing their efficiency and/or life span.

Vendors of adaptive refrigeration controllers therefore need to implement their control algorithms such as to minimize or avoid these concerns.

We understand that the particular vendor we evaluated here provides for compressor and fan short cycling prevention by using hard-coded minimum runtimes for the applicable system components. The particular runtime value for the compressor was derived from researching compressor specifications, then adding a safety margin. This appears to be a sensible approach. Note however that it was not in the scope of this study to formally evaluate its effectiveness.

System and Technology Improvement Opportunities

By performing this review of the technology, some system improvements can be suggested. It is noted that these suggestion by the reviewer are made via observation of the technology and its market and have not been tested for feasibility or functionality.

Backup/internal battery

Due to the unexpected occurrence of the San Diego power outage on 9/8/2011, a design improvement of internal/backup power source can be suggested. The manufacturer for this controller states in documentation that there is no internal/backup power source and that if power is lost data memory is lost. The system will “relearn” its environment, but energy savings will not be optimal during this period. Depending on the vitality of the data that is lost it, a method to keep the power on may be necessary.

Variable fan-speed control

The Title 24 part 6 reach measure states that the code addition is not immediately in the 2013 addendum due to inadequate industry research into the effects of varying the speed of an evaporator fan. The reasoning behind this is because CASE stakeholders state that there will not be enough circulation of the cooling and certain areas may not maintain needed temperatures. Due to this concern, the only system improvement that can be suggested is to have the control algorithm intelligently vary the speed between off, low and full in a manner that ensures enough circulation to the refrigerated volume. It is likely that this will save energy over the current on/off strategy.

Applicability of Case Study Findings to Other Load Types and Sectors

This case study shows applicability to other sectors that support walk-in sized refrigeration systems or larger. Since this was a retrofit of a controller with no modification to other refrigeration system components, it can confidently be suggested that other systems should respond similarly (with considerations to cost influencing factors as stated earlier). Payback times have been variable between our review and the vendor reports; nonetheless, all reports have shown a significant energy savings percentage.

Although our review focused on a restaurant type walk-in, the vendor has stated multiple target markets. They have suggested use in reach-in and large warehouse type refrigeration systems as well. Based on findings within this report in which the larger unit provided faster payback time, it seems viable to apply this technology to larger scale systems.

Smaller units cannot be directly supported. There is more regulation (Title 20) on units less than 39 ft^3 that are not considered in this report. Also, the door size to volume ratio is much larger, so heat transfer would be much higher for any door events.

Since this technology is specifically a refrigeration controller, it cannot be recommended for different load types without further study.

It should also be noted that the adaptive controller is targeted at improving efficiency and should not be used to extend beyond manufacturers specifications of a refrigeration system.

Considerations for Large-scale and Persistent Market Implementation

It is in the opinion of the authors that an adaptive refrigeration controller is ready for market implementation.

Customers can benefit from immediate energy savings on their existing refrigeration systems. The smaller volume refrigerator showed to benefit with approximately 15.5% energy savings and the larger freezer unit lowered energy consumption by approximately 33.6%. For comparative purposes, if our freezer unit only resulted in 15% savings, payback would still be approximately 2.5 years. So if faster payback is crucial for a customer, they need to take into consideration their initial operating costs.

This controller technology should have a positive outlook for long term implementation. This is due to the only cost being the initial investment and not having recurring costs.

Possible future Study

There are various areas of this technology that may be studied to be able to widen the scope of its applicability into the refrigeration market.

- Can the technology be further optimized when there are heat gains due to power outages, prolonged door openings, deliveries, etc.
- Efficiency and cost-effectiveness in relation to refrigeration size and/or set-point.
- Use on different types of refrigeration (reach-in, warehouse, ultra-low temperature, etc.)
- Are there other ways to reduce long-term energy consumption that have a good return on investment, such as conservation-oriented measures (e.g. improve insulation before upgrading controllers)
- Can variable speed fans bring additional benefits?

Glossary and Acronyms

(In alphabetical order)

CASE – Codes and Standards Enhancement Initiative

CEUS – California End-User Survey [7]

EEBI – Energy Efficiency Business Incentive [18]

HACCP – Hazard Analysis & Critical Control Points [23]

M&V – Measurement and Verification

OBF – On-bill financing [19]

PG&E – Pacific Gas & Electric[22]

SDG&E – San Diego Gas & Electric[21]

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Appendix A: Sensitivity analysis of conditions applicable to walk-in refrigerators and freezers – or, when does a $2,000 controller saving 20% really make sense?

Fourier's Law for heat conduction is

$$q = k\frac{(t_{s1} - t_{s2})A_c}{L}$$

where heat transfer rate *q* has units of Btu/h, thermal conductivity *k* has units of Btu/h·ft·°F, surface temperatures *t* have units of °F, wall area A_c has units of ft^2, and wall thickness *L* has units of ft. *q* is therefore directly proportional to delta t and also to the wall area.

For illustration, with all else equal, if refrigerator wall area doubled, then the heat transfer rate and hence total energy required to cool the enclosed volume would double as well. The payback time of a fixed-cost, fixed-savings-percentage product would then be cut in half.

As a second illustration, again with all else equal, and with assuming ambient temperature of 72°F, if the set point of a refrigerator were decreased from a refrigerator-like 40°F to a freezer-like 8°F, the energy required for cooling would double. In turn, the simple payback for said product would be half.

The conditions at real-world sites are more complex than these theoretical examples. Interior and ambient temperatures vary, doors open and close more or less often, the efficiency of refrigeration equipment varies with outside conditions and cycling patterns, humidity fluctuates with refrigerator content type and quantity, and some equipment may be subject to recurring defrost cycles. These variations will lead to heat loss rates and equipment energy consumption that deviate over time even as wall area and delta t remain constant. The energy savings potential of any technology operating under real-world conditions will therefore equally vary.

We believe this ECM technology is capable of savings of least 20% in most cases on refrigerators and freezers alike. We will therefore use this number as a baseline. Using first cost of $2,000 and maintenance cost of $0, Table 1 shows the required baseline annual energy use for this technology to have a payback time of less or equal than 5 years, broken down for different blended electricity rates.

Assumptions	Value
First cost of ECM technology	$2,000
Maintenance cost of ECM technology	$0
Maximum allowed payback period (yrs)	5
ECM technology savings rate (%/yr)	20%
Blended Electricity Rate ($/kWh)	**Minimum Annual Energy Use for <= 5 year payback (kWh/yr)**
0.10	20000
0.12	16667
0.14	14286
0.16	12500

Table 1: Minimum Baseline Annual Refrigerator Energy Use for technology payback to be less or equal to 5 years at 20% savings

The actual value of annual energy consumption of a particular refrigerator or freezer could be estimated with high accuracy by logging the energy on a typical day and then multiplying by the number of operating days per year. Alternatively, annual energy consumption can be estimated using mechanical engineering equations if the equipment owner or operator were to provide details about refrigerator make, model, age, tonnage, square footage and height of refrigerated space, defrost cycles, temperature set point, and ambient conditions.

For simplicity it may be considered to use the workflow below to estimate annual energy usage and whether payback time for this technology can be expected to be 5 years or less. Disclaimer: this is an approximation.

1. Is this equipment a walk-in refrigerator or freezer of "typical" construction and use (e.g. small or medium commercial food storage)? If yes, continue. If no, not applicable.
2. Is this equipment brand new, has benefitted from a utility incentive, or utilizes an electronic controller that dynamically cycles fan and compressor based on sensor data from various points in the system? If yes, not applicable. If no, continue.
3. Determine minimum annual energy consumption E_{min} [kWh/yr] required for <=5 year payback time for the site's blended electricity rate using Table 1. Prorate linearly as needed if the site's rate is not listed.
4. Determine the refrigerated space's total interior surface area A_{tot} in *square inches*. Do not confuse this with the *floor's* surface or square footage. Given width (W), length (L) and height (H) of the refrigerated space (assuming a rectangular shape), A_{tot} [in^2] = 2 × (W×H + W×L + H×L).
5. Determine specific annual energy consumption of the refrigeration unit using the unit's setpoint and the average temperature surrounding the refrigerated space (ambient temperature) as follows[2]:
   E_{spec} [kWh/yr·in^2] = 0.00755 × (ambient temperature – unit setpoint) – 0.164
6. Determine total annual energy consumption of the refrigeration unit
   E_{annual} [kWh/yr] = E_{spec} * A_{tot}
7. If E_{annual} >= E_{min} the unit in question should yield a payback time of less or equal to 5 years at its particular site and electricity rate when retrofitted with the controller studied here.

[2] This equation is derived from our field-verified values of 4,000 kWh for the refrigerator at 96 × 79 × 104 inches and (72 – 40)°F, and 30,000kWh for the freezer at 80 × 127 × 178 inches and (72 – 8)°F.

Appendix B: Comparison of Energy Savings Technologies for Refrigeration

This section compares the system we studied in depth for SDG&E with a similar system that was evaluated on behalf of Southern California Edison in 2010[3]. Both systems are compared in detail in Table 2 below. Both systems use a similar mechanism to save energy in refrigeration systems. *Without* such controls, the evaporator fan and compressor shut down simultaneously even though the cooling coil can still absorb heat. Both technologies compared here instead utilize a dynamic, conditions-based strategy that allows for the evaporator fans to run longer than the compressor, while the cooling coils can still absorb heat. Additionally, the fans will turn off when the space's setpoint temperature has been reached, as opposed to traditional systems where the fans run continuously. Both technologies also provide Smart Defrost, performing a precisely timed defrost cycle to melt ice only when there actually is any.

Both systems can be recommended for the California marketplace and apply equally across the market from small to large applications, both yielding significant (and comparable) savings. Technology 2 stands apart somewhat in that it also has EMS *control* capabilities (and not just monitoring), which would seem to allow for a better "system wide" approach when auxiliary opportunities beyond compressor and fan control exist in the scope of larger projects.

For further details please refer to the table below.

Energy Saving Refrigeration Technology Comparison

Technology Name	Control Strategy	Actual condition-based defrost	Web-based FDD and Reporting (based on system MONITORING)	Web-based EMS (adding sytem CONTROL including lighting, and other peripheral systems)	Evap Fan Motor upgrade to ECM	Stratification Fans for large spaces	Evap Fan Heat Barrier reducing defrost energy use	Minimum Unit Cost including installation without options	Target Market	California Utility Incentives Available	Avg kWh Savings	Should M&V be Required?
"Tech 1" as evaluated for SDG&E	Monitors setpoint at Evap Fan & Internal Space Temp. Turns compressor and fans on/off dynamically.	Yes	Optional	Integration with 3rd party systems possible	3rd party	3rd party	Optional	$2,000	Small, Medium and Large Commercial Refrigeration	Not yet	20% or more	Not for single controller installs, otherwise yes
"Tech 2" as evaluated for SCE	Same. Adds "System Approach" where related savings opportunities are identified and harvested when applicable.	Yes	Yes	Yes	Optional	Optional	No	?	Small, Medium and Large Commercial Refrigeration and Lighting	Yes (ESB and EEBI)	20% or more	Yes

Table 2 Technology 1 and 2 Comparison

[3] www.etcc-ca.com/images/stories/et_08.10_ibrmcs_final_report.pdf

Appendix C: Project Plan

Description of the technology under investigation

It has been suggested that commercial refrigerator and freezer control devices use preprogrammed evaporator fan and compressor cycling algorithms that are "unaware" of changing conditions. This is thought to result in unnecessarily long runtimes of both fans and compressors, resulting excessive use of energy. This study investigates an adaptive control device that promises significant energy savings by factoring current conditions into its control algorithm, and thereby reducing fan and compressor runtimes. Savings during normal operations are complemented by intelligent defrost control, where defrost cycles are adapted to begin and end at optimal conditions from an energy perspective, instead of on regular, predetermined schedules. We furthermore investigate an optional accessory, a heat barrier mounted onto the evaporator fan that helps speed up the defrost cycle by retaining defrost heat.

The technology investigated here also includes a software application for performance monitoring. The application provides operator alerts. This allows for early identification and rectification of mechanical or electrical issues, including issues that would cause increased energy use while otherwise remaining undetected for some time. An example of such an issue is excessive compressor runtime due to low refrigerant charge. It is therefore believed that monitoring & alarming further contributes to energy reduction in the long term.

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

The incumbent technology consists of preprogrammed, unmonitored evaporator fan and compressor algorithms as provided by refrigerator, freezer or component manufacturers. Maintenance is performed on a recurring schedule or as needed. Energy efficiency is generally only a factor during the initial system design and component selection. Monitoring, if performed at all, is limited to systems with low sophistication and to applications where HACCP compliance is required (HACCP is a management system in which food safety is addressed [24]).

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. 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 refrigerator and freezer repairs and resulting energy savings can be expected as the direct result of alarms provided by the monitoring system.
   d. Extrapolating our findings and test sites to other situations.
   e. Review utility programs with respect to their present applicability to this technology, and provide recommendations as to how utilities could further support this technology
   f. 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, could the use of an adaptive controller result in excessive compressor and fan cycling, and therefore premature failure?

If sufficient background information is available, NegaWatt shall also elaborate on

1. Potential market size and associated market barriers
2. Likely adoption rate
3. Discussion of codes and standard aspects
4. Discussion of improvements and alternative offerings, technologies or systems

The monitoring application portion of this study is an *enabling* technology in that its installation does not directly result in energy savings. However, users are now *able* to implement energy-savings measures (repairs) when they realize that their refrigerators or freezers no longer operate optimally. However, energy savings resulting from the monitoring application are not *guaranteed*.

We believe that the controller itself is more likely to generate "guaranteed" savings. However, it is possible that the controller may be extensively programmable, or may be disabled by an operator without affecting overall cooling. Under such circumstances, savings could no longer be considered "guaranteed".

We will therefore investigate monitoring application and controller very carefully from the perspective of when and if energy savings actually take place and ultimately, 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

The market for this technology is quite wide – any large walk-in or reach-in refrigerator or freezer can theoretically benefit. The focus is on food applications, because the monitoring application conveniently provides the necessary data for HACCP compliance, and because this appears to be the largest market for this technology. Scientific, medical and pharmaceutical applications may also benefit.

Upfront, we are able to identify the following relevant factors that can vary from site to site:

1) Refrigerator vs. freezer
2) Refrigeration applications that require defrosting vs. such that do not (defrosting is often not required when thermostat setpoints are above 34-38F).
3) New setup vs. replacement of existing controls (in the first case, energy savings cannot be verified by measurement)
4) The sophistication of existing controls that are being replaced may vary, and therefore energy savings due to adaptive control may vary
5) Use of the optional fan heat barrier
6) Payback times may vary significantly between small and large installations. Large installations will likely benefit from economy of scale: we expect the adaptive controller system cost does not increase proportionally with refrigerated sqft or volume, while energy use most likely does.
7) Consistent use of the monitoring application (very dependent on operator skill & "level of interest")
8) How often is the cooling environment "disturbed" by opening doors. We suspect that adaptive controls are particularly beneficial in situations where there is frequent influx of warm air or moisture that may cause traditional controls to "overreact".

Measurement Plan

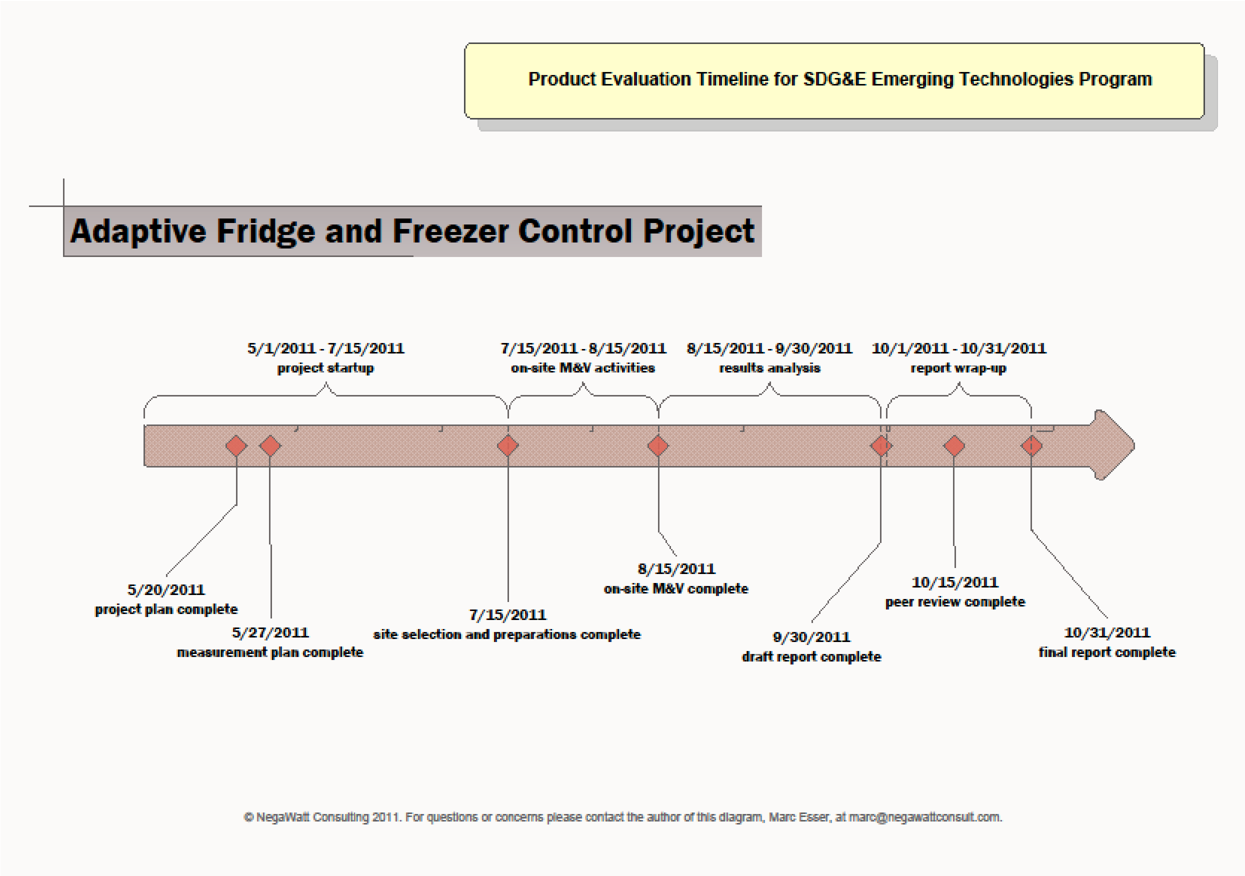
Please see pg. 47

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

We would like to suggest the evaluation take place for a minimum of two installations, **one with a refrigerator and one with a freezer**. Both installations should otherwise be as similar to each other as possible, so that we can compare the results of freezer vs. refrigerator. Therefore,

- both installations should not have adaptive controls at first
- installation of the new system should only take place after we have measured a baseline
- both installations should be similar in size and volume (ideally, also in energy loss per sqft, although we expect freezer sites may be designed to be more efficient due to higher delta-T
- both sites should have a similar frequency of opening and closing doors (and similar door-to-volume ratio), but should have "quiet periods" with doors closed of at least 8 hours per day. This will allow us to compare undisturbed vs. disturbed performance at each site.
- Both sites should be fairly large with high, steady operating cost so that the effect introduced will be easy to observe
- The freezer site should allow for the installation of the heat barrier hood midway through the project so that we can determine the barrier's effect on defrosting efficiency

Project Milestones



Milestones are subject to change.

Etcetera

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

This assessment follows the scientific rigor protocol described in [25].

The final report for this project will be made available 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.

Appendix D: Measurement and Verification Plan

Introduction

This measurement plan is an integral part of the project described in "Adaptive Refrigerator and Freezer Controls for Commercial Applications Project Plan" [pg. 40].

It follows the guidelines established in [25].

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 one of the evaluation methods identified in the International Performance Measurement and Verification Protocol (IPVMP) except where site- or technology-specific circumstances dictated a deviation from one of these protocols. The Measurement Plan identifies selected IPMVP method to be used or the justification for any deviations from IPMVP.

All instrumentation under the control of evaluation staff shall be calibrated in accordance with guidelines established in the IPMVP as described in [26].

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 site for this project is a commercial based company in San Diego. In particular, this site uses large walk in or reach in refrigerator and freezers for food applications, which is the biggest market for the technology. Other markets could include scientific, medical, and pharmaceutical applications. This project is a monitoring test to measure energy usage data for an assessment of energy savings.

From these criteria, a local McDonald's was chosen to participate in the project. The table below provides a detailed description of the site.

Factor	Specification
Location of technology installation	McDonald's back room
Exposure to outside environment	Freezer minimal exposure (not considered)
Frequency of usage (per 24 hour period)	24 hours/day
Total number of Refrigerator an Freezers being tested	Two
Size of Refrigerator	Approximately 455 ft^3(roof mounted compressor)
Size of Freezer	Approximately 1070 ft^3(roof mounted compressor)
Other factors	Food delivery every Tuesday and Friday mornings

For the site, the site-specific factors (e.g. anticipated changes in a production facility) that could obfuscate the impact of the technology under study on the functionality of the technology as well as energy and demand savings are (a) whether the system is a refrigerator or freezer and (b) if there will be a change in behavior of how often the doors are open during testing.

Data collection procedures

Below is a list of general assumptions and preliminary comment that the data points are based off of:

- The freezer or refrigerators are located in a room with no outside exposure (such as windows). If there is any outside exposure, the room conditions will be such that the exposure will not affect the system.
- The control thermostat set point will be identical before and after technology installation, or this will be normalized if it is a different value.
- We will normalize for exterior conditions e.g. door open/close, or control these parameters.
- There will be no change in user behavior of the refrigerators or freezers.

Data points

The data that is necessary in order to accomplish the specified objectives [pg. 40] are divided into two time periods. The control to this project for the energy usage comparison is the data from the refrigerator and freezers prior to installation of the technology. The table below provides a description of the data collected for each tested freezer and refrigerator per time period:

Time Period	Data Measurements			
Baseline (prior to installation)	Energy usage over time	System Air temperature	System Humidity	
Installation	Energy usage over time	Vendor's assumption	System Air temperature	System Humidity

The system air temperature and humidity are significant variables to measure as they may be affected when the doors are opened, and therefore changing the amount energy usage. Relative humidity is important because moist air has higher heat capacity and therefore would require more energy to be cooled. These measurements will also confirm if the factors change drastically after the new technology is installed.

Data sampling, recording and collection intervals

The technology involved has an added feature of a data logger that connects to an online IP address. This online browser would provide information for when a part of the system is operating (i.e. compressor or evaporator fan), monitors the trends of how the system is running, and alerts the user when a part of the system is not working. However, this project site will not quantify possible energy savings resulting from early fault detection nor user interface of web browser.

A main portion of this project is the energy monitoring for each refrigerator and freezer. Every refrigerator and freezer with a technology system installed will be monitored and measured. For both of the time periods stated above, the measurement sample will be long enough to cover multiple defrost cycles in both the refrigerator and freezer.

The climate (temperature and humidity) of the system will be directly measured to observe the impact to the whole system. This is especially important since the technology itself does not measure these factors. This measurement will be taken continuously for the baseline time period and for comparison it will then be measured for the rest of the project.

Instrumentation

All the instrumentation used in this project will be tested prior to official data collection in a refrigerator and freezer in order to avoid any erroneous data. Tools and instruments that will be used in the project are:

- Room humidity and temperature will be measured using an Onset HOBO data logger. The HOBO-U10-003 data logger has internal temperature and relative humidity sensors, while accepting a wide range of external sensors. The advantage of having the temperature and humidity measurements from the same sensor is that the time stamps on the temperature match the humidity measurements, which is essential. The ranges of the sensor include:

- This device was calibrated at purchase (by CCSE), high temperature accuracy not critical to project due to scope and objectives. Also, manufacturer does not recommend specific calibration periods.
- Drift
    - 0.2°F/year
- Temperature
    - Range: -4°F to +158°F (-20°C to +70°C)
    - Accuracy: ±0.72°F at 77°F
- Humidity
    - Range: 25% – 95% non-condensing over the range of 41°F to 131°F
    - Accuracy: 3.5% from 25% to 85% on the range of 59°F to 113°F
- Time accuracy: approximately ±1 minute per week
- 64.2= Refrigerator, 64.1= freezer

- DENT instruments Elitepro Recording Poly Phase Power Meter:
    - Last Calibrated on January 2011
    - ELOG 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

- Watts up? .Net to measure refrigerator fan energy usage:
    - Measures and records 18 parameters, including: Current Watts, Minimum Watts, Maximum Watts, Power Factor, Volt Amp (apparent PWR), Cumulative Watt Hours, Average Monthly Kwh, Elapsed Time, Duty Cycle, Frequency (Hz), Cumulative Cost, Average Monthly $, Line Voltage, Minimum Volts, Maximum Volts, Current Amps, Minimum Amps, Maximum Amps.
    - Calibrated at purchase in January 2011
    - Accuracy: +/- 1.5%, + 3 counts of the displayed value
    - Automatic mode with all parameters recorded the storage is approximately 4000 records.
    - UL listed to standard UL 610010-1, and CAN CAS/C22.2 61010-1
      UO version also CE marked
    - Temperature 5 C to 40 C
    - Maximum relative humidity 80% for temperatures up to 31 C decreasing linearly to 50% relative humidity at 40 C

Data analysis procedures

As stated in the Introduction, all data will be reviewed before analysis and any anomaly will be investigated and explained.

Data manipulation (aggregation, statistical analysis, etc)

The system's 2 minute instantaneous measurements climate data will be downloaded from the HOBO software onto a comma delimited text file, then stored and charted with Microsoft Excel 2007. These measurements by the data logger during the baseline time period will be graphed versus time in order to observe the variations during the whole time period. An average, and more importantly, the standard deviation will be observed. In addition, the temperature and humidity will still continue to be measured until the conclusion of the project. The temperature and relative humidity will again be graphed versus time for both the baseline and the installation times. From the calculations, if the standard deviation of the climate measurements during the baseline time period versus installation is greater than ±5%, it will be determined that the new technology installation did affect the system. The temperature measurements from the HOBO datalogger will also be normalized (as they may be in a different location). The temperature and humidity will be plotted to observe the trends in the refrigerator and freezer between the two time periods. The system climate measurements will then be plotted versus energy usage to observe trends. 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 and relative humidity discrepancies from the Onset HOBO data logger will be part of the error analysis.

Calculation of energy and demand savings

During the baseline and after installation time periods, the Elitepro will collect the energy usage measurements for both the walk-in refrigerator and freezer. The Elitepro device has two components: one that measures voltage and the other that measures current. The assumptions taken (if any) by the technology will also be accounted for in the baseline time period measurements for later comparisons. Tools to measure these factors will be installed on the commercial building's circuit breaker as to measure the entire refrigerator or freezer consumption. For the refrigerator, the evaporator fans are on a different circuit than the compressor. In addition to the Elitepro (which will only measure the refrigerator compressor), a Wattup .Net will be used to measure the energy usage of the refrigerator fan circuit. This will be combined with the Elitepro's measurements of the compressor to obtain a total energy usage. The Elitepro will calculate and log the energy from these factors while including the effects of errors. The energy will be logged at a 5 minute interval for the full time of the periods mentioned earlier. The measurements will then be downloaded in the Elitepro based Elog software. The data will then be transferred to a spreadsheet as an Excel comma separated value file where calculations will be presented and charts created. For comparison purposes, it is essential that the time stamp of the Elitepro device be accurate to the actual time (and the technology's system). Plots of the two measurements will be created. The average and a standard deviation will be calculated for the percent difference.

All of the energy usage measurements from the technology baseline and installation time periods will first be plotted versus time. These measurements will include any sort of aforementioned necessary normalization. The total energy usage from the two time periods (with the same interval of time and days of week) will then be calculated in order to compare the energy savings. If the energy measurements are greater than a 20% margin, it will be deemed that the vendor's technology was affective and the technology functioned as it was described. However, if the energy usage falls within the appropriate margin, then a discussion of the energy savings will be discussed as well as possible improvements.

Error analysis of these calculations will be based off the inaccuracies of the power logger as provided in the Instrumentation section. In addition, the customer will confirm that their schedule during the baseline time period observed and the installed time periods are similar in terms of events and energy habits.

Calculation of cost savings

From the results of the normalized energy savings calculations and power measurements, the cost savings calculations will be measured. The cost reductions will be based off SDG&E's specific average cost of $/kWh under consideration of the site's current tariff. Demand charges will not be considered.

A payback chart will be created in Microsoft Excel which will take all of the previous measurements and calculations into account. It will return the time the technology cost will be recovered from cost savings as a result of the energy reduction in the refrigerator and freezer prior to the technology installation. The table below explains a typical cost analysis that would be conducted on a refrigerator and freezer. All cost figures are for sake of example only, and may turn out different in reality.

Product	Cost of Product (Total)	Energy Difference (Before-After)	$ Savings/month (kWh x $)	Payback time (Cost/savings)	Comments
Freezer Technology	$2000	500 kWh/month	500 x $0.20 = $100	20 months	
Refrigerator Technology	$2000	240 kWh/month	240 x $0.20 = $48	42 months	