Grocery Freezer: International Grocery Chain

70% Load Reduction and 38% Greater Temperature Stability using Thermal Energy Storage System

A large international grocery chain invited Viking Cold Solutions, Inc. to conduct a measurement and verification (M&V) study of its thermal energy storage (TES) technology. The purpose of the study was to determine the effectiveness of TES in a typical grocery storage freezer environment. Viking Cold's patented TES solution was installed in the 320 ft^2 main grocery walk-in freezer at a store in Fremont, CA. The freezer was equipped with a Hussmann Protocol rack refrigeration system, Emerson E2 controls, and Parasense monitoring.

Phase Change Material (PCM) for Thermal Energy Storage

PCM absorbs 300 times more heat per pound than the food product and remains at a near constant temperature. The PCM is environmentally safe and non-toxic. It is engineered to freeze/thaw inside its sealed containers at the specific temperature setpoint of the customer's freezer. Proprietary algorithms control the refrigeration units to minimize energy consumption, shift time of energy usage, and maintain more stable temperatures.

M&V Study Design: Grocery Freezer

This Grocery Freezer M&V study was designed to test the effectiveness of TES in three operational scenarios inside the main grocery walk-in freezer. Because Viking Cold has implemented these TES scenarios in larger facilities with significant, positive results, this study also aimed to understand the unique conditions and challenges of a typical small grocery freezer.

Table 1: M&V Study Experiments

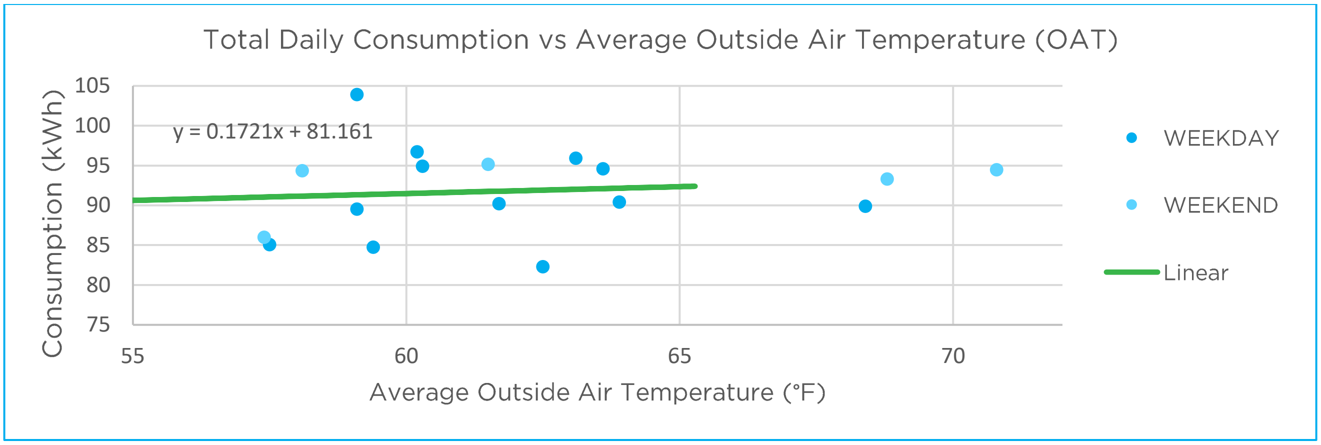
Experiment	Method	Output	Goal
0: Baseline	• Maintain original control method • No Viking Cold active control or TES	• Daily total kWh • Peak kW vs. time • Temperature vs. time	• Establish a benchmark for energy consumption and temperature profiles • Create energy baseline for weather normalization
1: Energy Reduction	• Use Viking Cold controls and TES to minimize energy consumption • Prioritize temperature limits over energy reduction	• Daily total kWh • Temperature vs. time	• Reduce net daily energy consumption by running compressors fully loaded at lower condensing temperatures • Improve temperature stability
2: Load Shift	• Reduce equipment runtime during peak hours • Prioritize temperature limits over energy reduction	• Peak-period kW • Peak-period kWh • Temperature vs. time	• Minimize energy consumption and/or peak demand between 8:30AM and 9:30PM • Improve temperature stability
3: Solar Shift	• Reduce equipment runtime during non-solar generation hours • Prioritize temperature limits over energy reduction	• Night time (non-solar) kW • Night time (non-solar) kWh • Temperature vs. time	• Minimize energy consumption between 7:00PM and 7:00AM • Target maximum benefit between 7:00PM and midnight (duck curve mitigation) • Improve temperature stability

M&V Study Baseline

Experiment 0: Baseline

To establish the baseline performance of the freezer, all related equipment ran under normal operating conditions without Viking Cold Systems intervention for two weeks. During this period, the Viking Cold system monitored energy consumption, temperatures, and refrigeration equipment status. The daily energy usage values were recorded and plotted against the daily average outside air temperature for the baseline period as shown below in Figure 1.

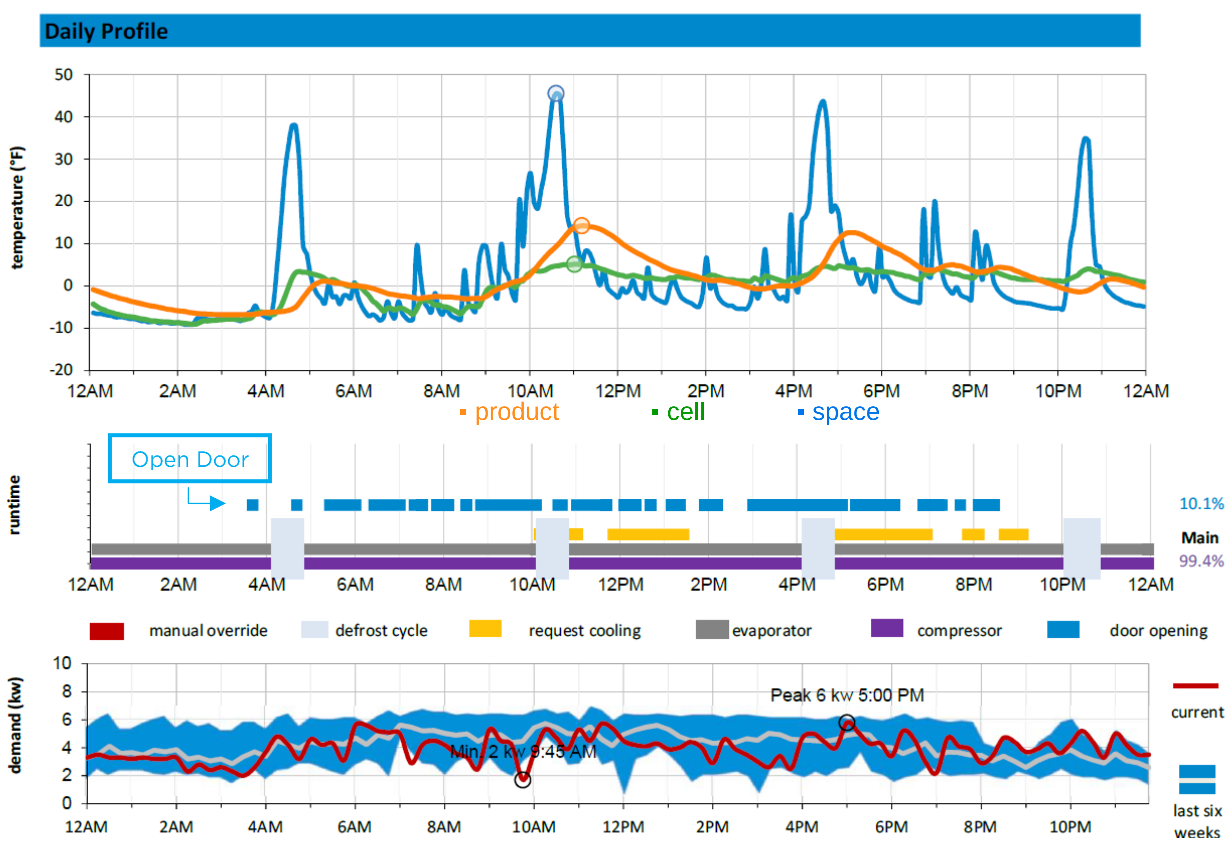
Figure 1: Baseline Daily Freezer Consumption



A best-fit linear equation was used to normalize the daily energy usage with outside ambient temperatures. This weather normalization formula was used to calculate energy savings during the tests by subtracting actual measured energy consumption from calculated baseline consumption.

In addition to energy consumption, room temperature, product temperature and equipment status were recorded throughout the duration of the test to quantify and analyze other system behaviors. Figure 2 below shows the Baseline equipment performance and freezer temperature profile.

Figure 2: Baseline Freezer Performance



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Experiment Results

Experiment 1: Energy Reduction

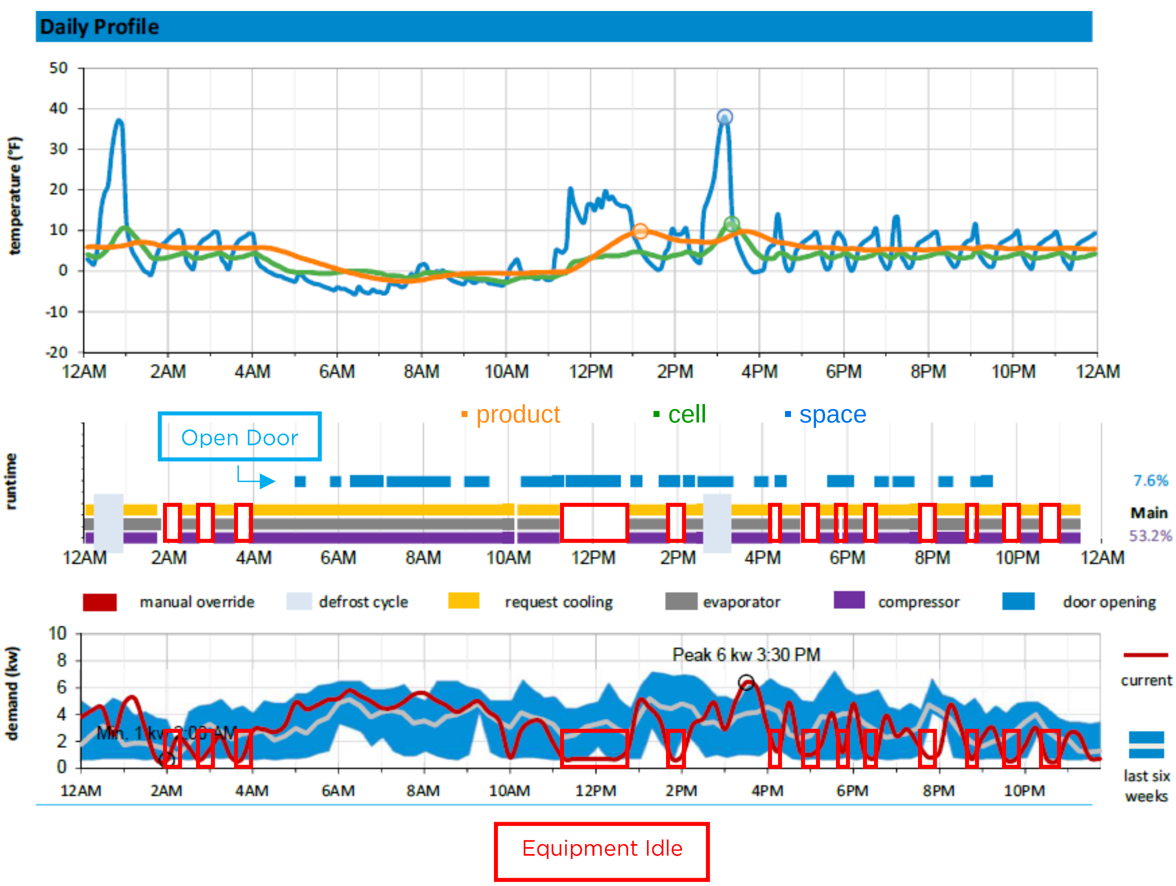
The goal of this experiment was to reduce the net daily energy consumption while maintaining temperature stability. The equipment control algorithms were configured to run the refrigeration equipment extensively at night to fully charge (freeze) the TES cells while ambient temperatures are lower, yielding maximum condensing efficiency. As ambient temperatures increase during the day and heat rejection of the condenser is less efficient, the control algorithms allow the TES to take over the duty of maintaining temperatures inside the freezer.

The energy reduction experiment was conducted over 10 days. The results of the test were favorable, reducing net consumption by 18% compared to the baseline. Similar consumption results were achieved by running intelligent controls only, however there was a significant improvement in temperature stability with TES. Further experiments showed challenges unique to this typical grocery freezer application. These observations are discussed later in the conclusions section.

Net Consumption Reduction (kWh)

↓ 18%

Figure 3: Energy Reduction Freezer Performance



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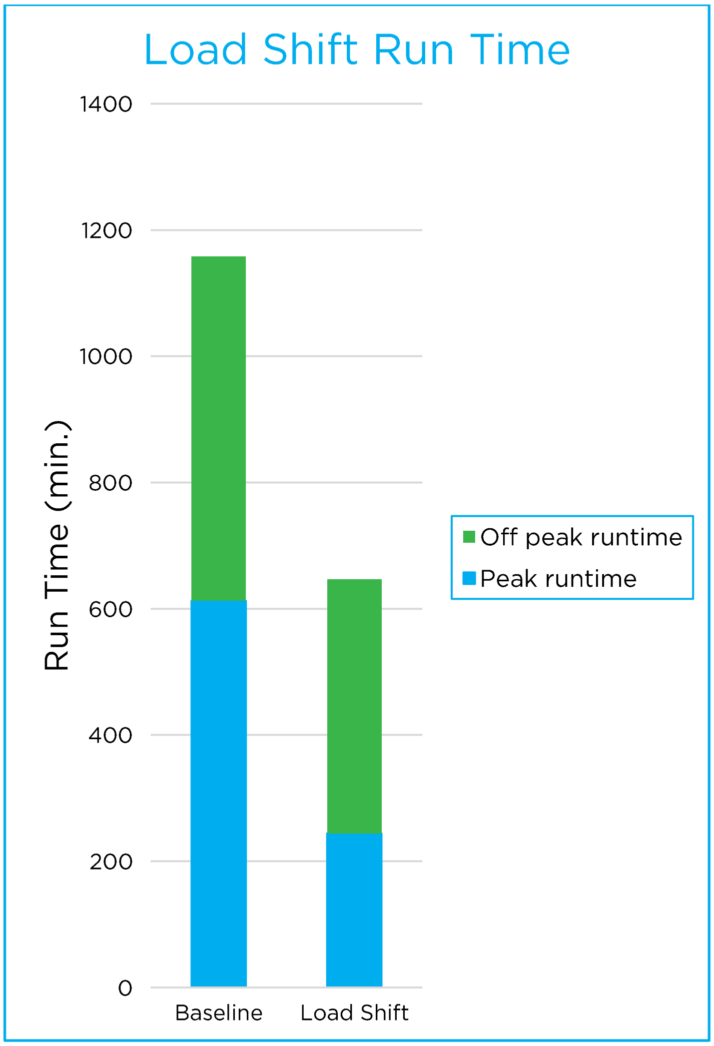
Experiment 2: Load Shift

The goal of this experiment was to minimize energy consumption during peak periods and/or minimize peak demand by running refrigeration equipment during *utility off-peak periods.* The benefit of this operating scenario is a reduction of energy costs from time-of-day kW demand charges associated with peak periods. For this test, the designated peak period was 8:30 AM to 9:30 PM.



Peak Period Run Time

↓ 60.2%

Peak Period
Equipment Idle

6.5 Hrs.

Load Reduction

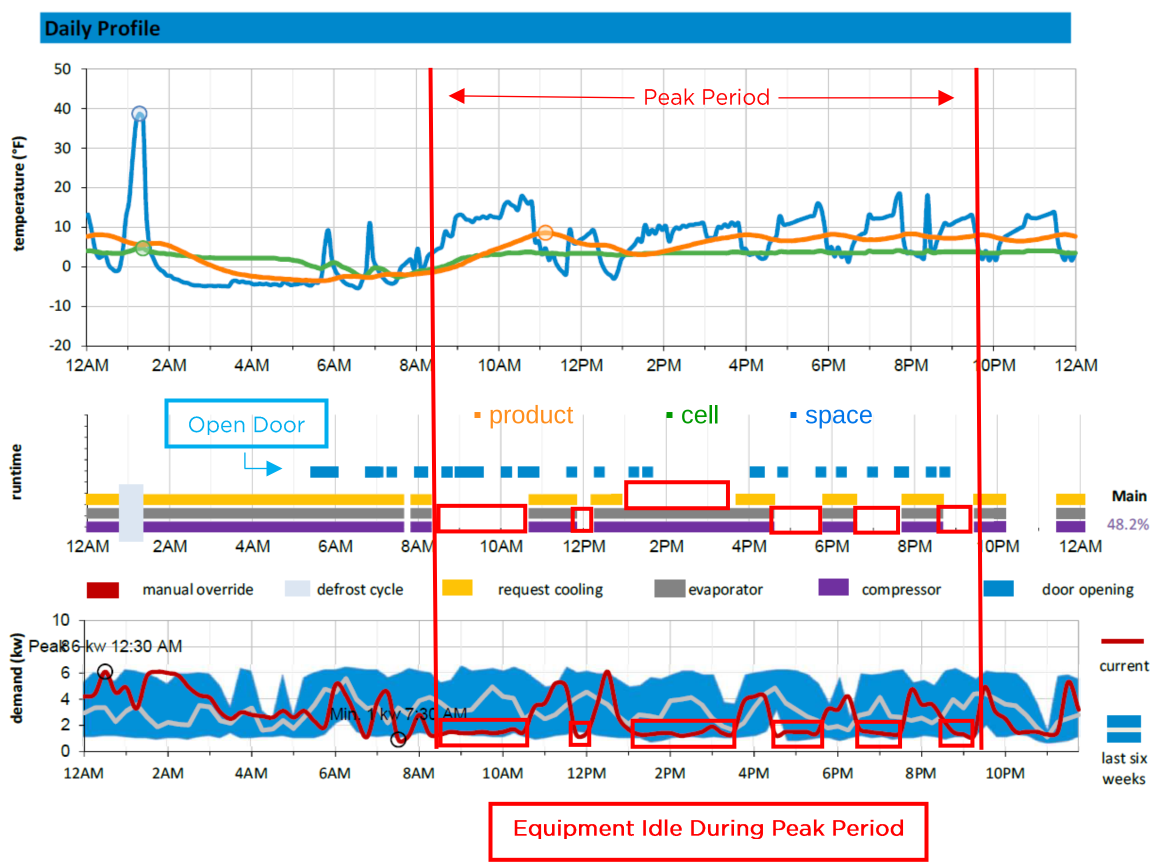
↓ 85%
(5 kW)

The load shift experiment was conducted over 10 days and significantly reduced peak consumption for long periods of time. Power consumption dropped from 6 kW to less than 1 kW, an 85% reduction. The TES could not maintain the temperature within control limits for the entire length of the peak period. On average, a total of 6.5 hours of energy consumption elimination was accomplished, with the longest single period of load shift lasting for 2+ hours before the upper temperature control limit was reached and refrigeration was initiated. Figure 4 below shows the temperature, equipment status, and energy consumption of a sample day during the load shift test.

Note: Figure 4 - there were extensive door openings during the first two hours of the planned load shift period. This large amount of heat infiltration into the freezer resulted in elevated temperatures, and therefore the load shift was interrupted to maintain temperatures within the control limits. Despite this, the energy stored in the TES was not completely exhausted, and significant additional periods of load shift were later available once temperatures were brought back into control.

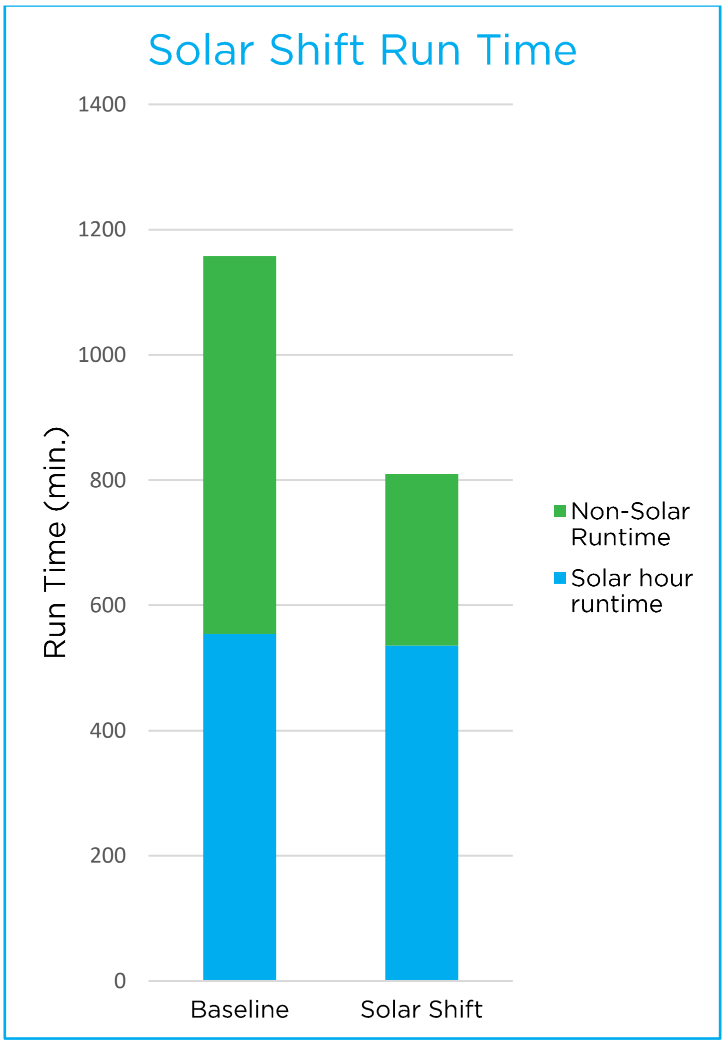
It should also be noted that the suction group for this freezer includes an icemaker elsewhere in the store, so the compressor still showed runtime even during periods when the liquid line solenoid was closed for the freezer.

Figure 4: Load Shift Freezer Performance



Experiment 3: Solar Shift

In this test, solar shift refers to leveraging photovoltaic (PV) generation by running refrigeration during PV generation times (7:00 AM to 7:00 PM) and reducing runtime when there is no PV generation. The goal of this experiment was to minimize on-grid energy consumption between 7:00 PM and 7:00 AM, with particular focus between 7:00 PM and 12:00 AM (duck curve avoidance). At this test site there is no PV generation, but the test was carried out as if peak PV generation was available during the peak sunlight hours of 7:00 AM to 7:00 PM.



Night Time (Non-Solar) Run Time

↓ 55%

Night Time (Non-Solar) Equipment Idle

6.5 Hrs.

Load Reduction

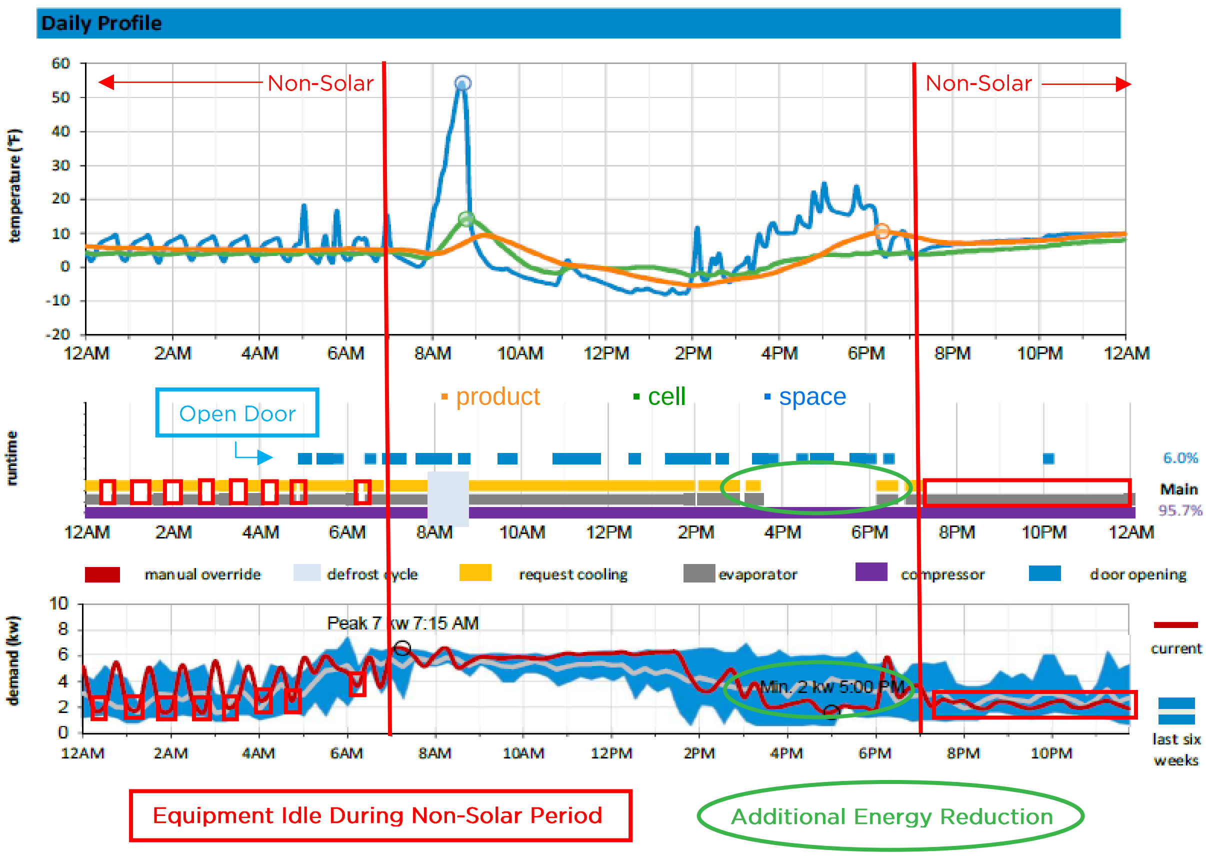
↓ 70%

(5 kW)

The solar shift experiment was conducted for 20 days and successfully demonstrated how TES can significantly shift demand to PV generation hours. Figure 5 below shows a sample day from the experiment and demonstrates how the TES system was able to turn off refrigeration for a total of 6.5 of the 12 non-solar-generation hours (7:00 PM to 7:00 AM) and maintain temperature control limits. During the first 5+ hours of night (duck curve period), the TES was able to reduce power consumption from 7 kW to 2 kW (70% reduction) and maintain temperatures within control limits.

Note: The continuous 5+ hours coincided with less door opening activity as normal daily grocery operations have concluded for the day. On-grid power was required intermittently for the balance of the night periods, but at a much lower amounts.

Figure 5: Solar Shift Freezer Performance



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Analysis: Temperature Stability

Throughout the duration of these experiments, product temperatures inside the freezer were measured and recorded to determine the benefits of TES on temperature stability. Two dependent variables were analyzed to quantify temperature stability; standard deviation of temperature amplitude and rate of temperature rise.

Rate of rise is a measure of how quickly the product temperature increased after the refrigeration equipment was shut off, and temperature amplitude is a measure of the standard deviation of the temperature range throughout the day.

The temperature stability analysis demonstrates the benefits of TES. Both dependent variable measures of temperature stability showed improvement with TES. The average standard deviation reduction across the three experiments was 23%, and the average rate of temperature rise was reduced by 38%. Figures 6 through 9 show the quantified temperature stability benefits.

Note: During Experiment 2 (Load Shift), the refrigeration equipment was off for long periods of time during the day which coincides with extensive door openings from normal daily activity.

Table 2: Temperature Stability

	Product Temperature Amplitude		Product Temperature Rate of Rise	
	Std. Deviation (°F)	% Reduction	°F/min.	% Reduction
Baseline (without TES)	4.6	-	.17	-
Experiment 1 (with TES)	2.8	38%	.11	35%
Experiment 2 (with TES)	4.1	9%	.10	40%
Experiment 3 (with TES)	3.5	23%	.10	40%

Temperature Amplitude
↓ 23%

Temperature Rate of Rise
↓ 38%

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Figure 6: Baseline Product Temperature Profile

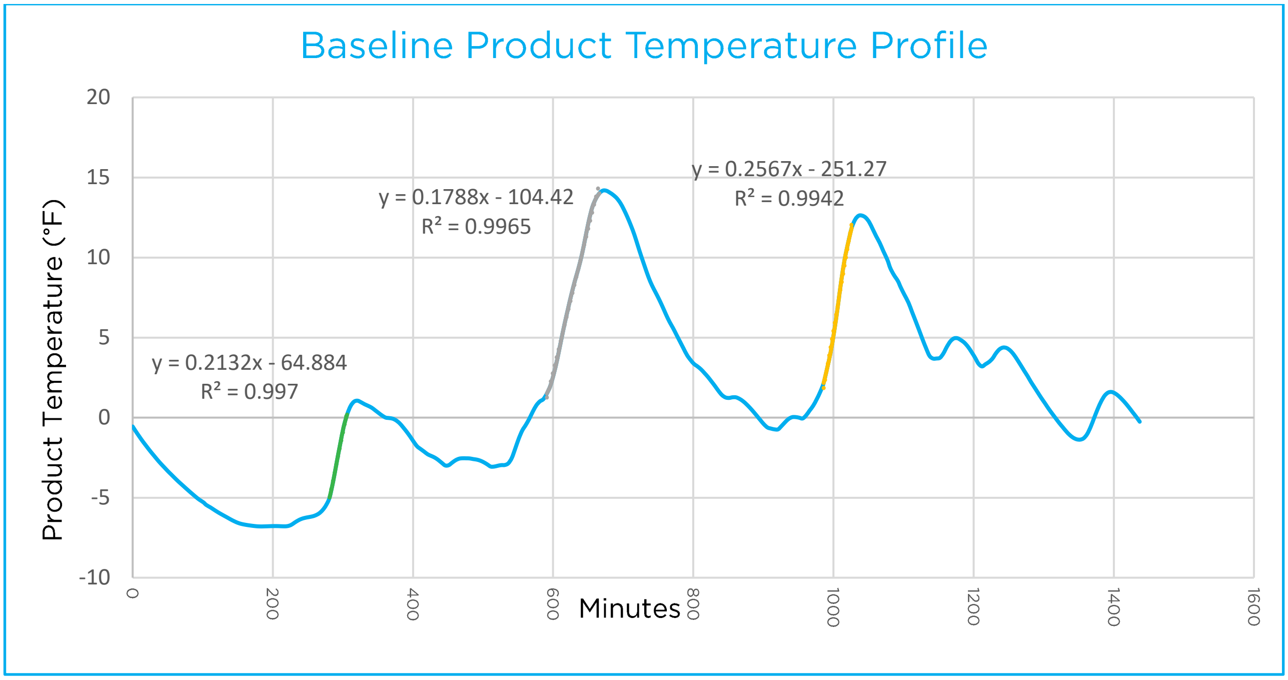

Figure 7: Product Temperature Profile with TES

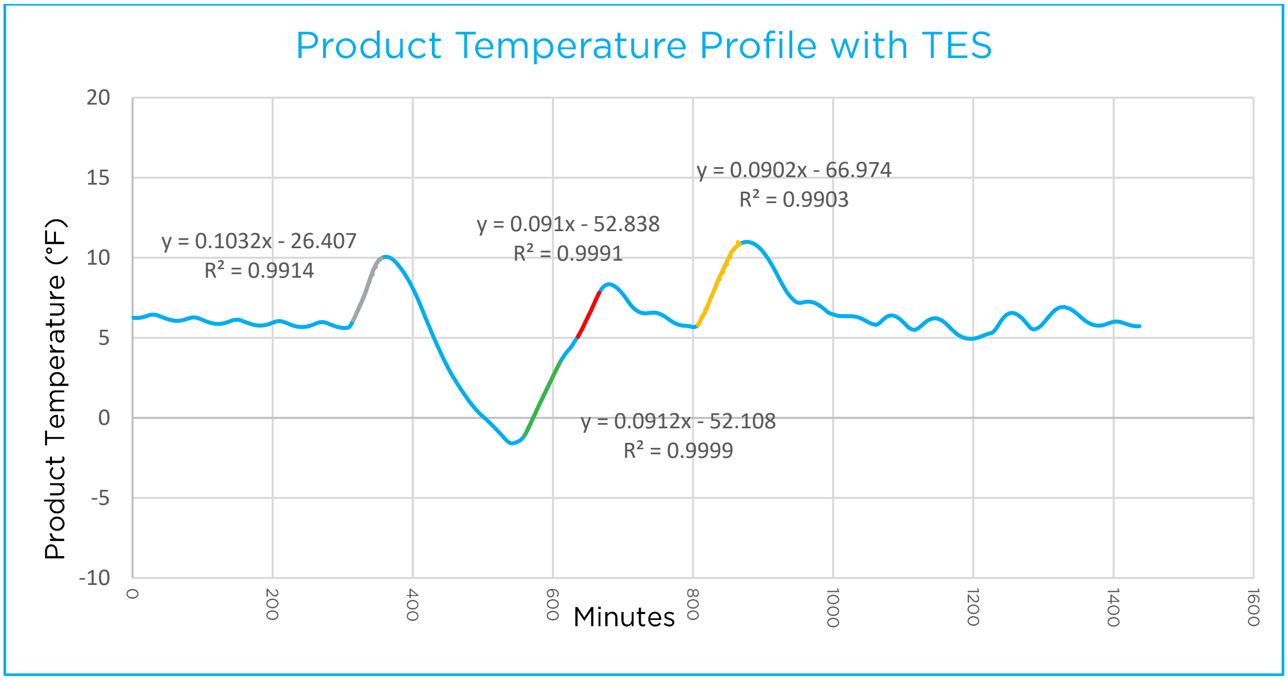

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Figure 8: Product Temperature Rate of Rise

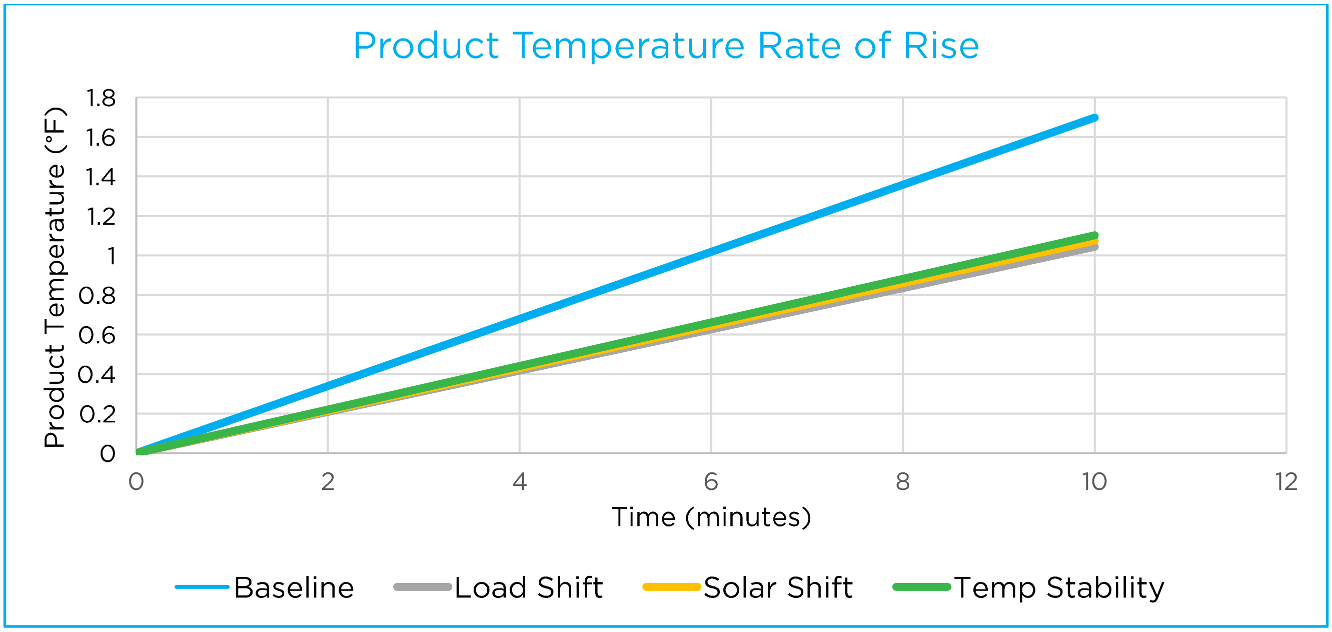
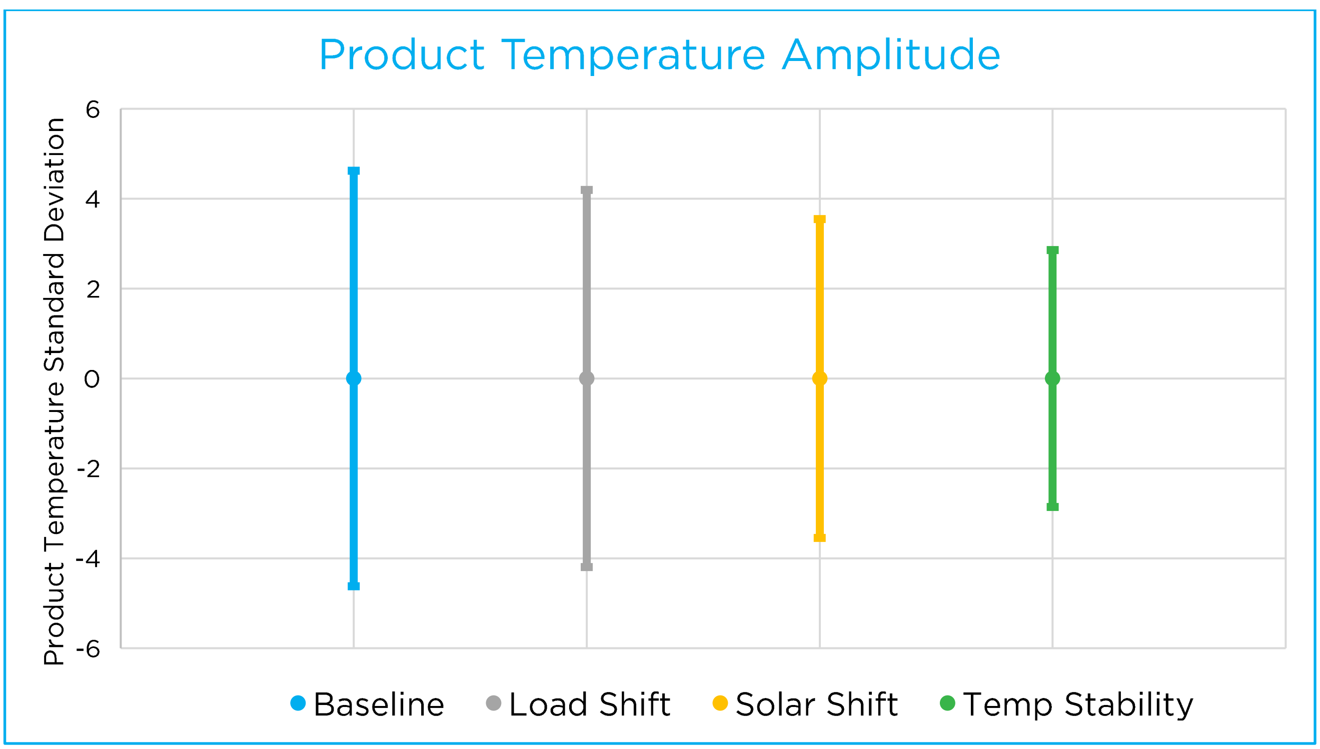


Figure 9: Product Temperature Amplitude



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Commentary

The original goal of this M&V study was to determine the effectiveness of TES in a typical grocery store freezer environment. However, much more was discovered about the refrigeration and energy challenges facing grocery operators.

In this M&V study we learned that integrating TES into a grocery freezer has significant energy and cost benefits across a variety of energy management applications.

In the first experiment where energy consumption reduction was the goal, we learned that small grocery walk-in freezers experience heat infiltration loads that are very severe during operating hours. The large door opening size relative to the internal volume of the freezer results in very quick air changeover. This condition is made even more severe when the freezer is in the backroom of the store very close to an open dock door, or when the strip curtains are tied back to facilitate hassle-free egress by the store associates performing their daily duties. Even with these challenging conditions, TES provided more stable temperatures while protecting the food product and reducing net energy consumption by 18%.

In the second experiment where the goal was extended load shed to avoid peak utility rates, we learned that prolonged periods of near-total electrical load shed were achievable while keeping the food product protected with temperature stability provided by the TES. For grocery operators facing steep energy penalties for demand peaks, utilizing the benefits of TES during known daily high demand periods (such as prepared meal cooking hours) can significantly reduce their peak demand charges for the month. For others who already have a microgrid management system or participate in ADR programs, the freezer load can now be shed for hours at a time for peak shaving and demand sequencing.

In the third experiment where PV generation was simulated to minimize on-grid consumption at night, we learned that the entire duck curve period after sunset can be avoided by utilizing the TES stored energy while keeping the food product protected and the temperature stable. Furthermore, the daily operating requirements of a grocery freezer are best aligned with this evening shed since the door openings are at a minimum and the TES can preserve temperature stability inside the freezer for longer periods of time.

Conclusion

Thermal Energy Storage achieved 38% greater temperature stability inside the grocery freezer under normal operating conditions. This additional stability enabled the refrigeration equipment to be turned off for extended periods of time, reducing the electricity load by 70% or more during those periods.

This study demonstrates that TES is effective and financially beneficial in grocery freezer applications under a variety of energy sourcing conditions.