Keep It Cool: Real-time Monitoring of Convenience Store Refrigeration Systems

EFFICIENCY VERMONT REPORT

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Introduction

Regulated energy efficiency service providers are in the business of responding to customer needs and delivering cost-effective clean-energy solutions while meeting regulatory performance targets.

Energy efficiency programs' commercial customers frequently follow a business model of responding to energy operational needs, as they arise. What happens when a commercial customer's business objectives shift from a reactive—energy operational service model, to a proactive one?

Efficiency Vermont's "Keep It Cool" project shows the benefits to customers when they adopt a proactive approach for energy systems operation management. By using a combination of targeted data analytics and with an objective of avoiding unexpected equipment failure in stores that rely on refrigerated cases and other spaces, Efficiency Vermont identified three cost and service advantages to its customers:

1. Pre-empting technology and service delivery failures saves money and reduces food spoilage.
2. Real-time data visualizations of refrigeration system power draw and sensor readings are of high-value for avoiding equipment failures and identifying energy efficiency opportunities. The data visualizations are also valuable to Efficiency Vermont for monitoring efficiency measures - determining how effective the measures are, and for how long the savings persist.
3. Creating a trusted relationship among the customer, energy efficiency program staff, and mechanical contractors provides businesses with a team that can identify and implement energy efficiency opportunities that will have the greatest bottom-line impact. This frees businesses to focus on operational improvements and running the business

What are the constraints of a transition from a reactive to a proactive energy operations model for a specific customer type? And what are the opportunities for applying these learnings across the rest of the commercial and industrial (C&I) market for an efficiency program?

These are the questions the "Keep It Cool" project explored in 2018 and 2019. The project sought to create an affordable preventive maintenance and monitoring system for the convenience store refrigeration market by monitoring refrigeration system health and preventing costly equipment failures.

Background and Significance

Convenience store refrigeration is a critical element of a demanding market environment. Heavy use and infrequent preventive maintenance can result in degradation of equipment effectiveness, and poor energy performance. When it comes to managing these costly assets, convenience store operators and maintenance contractors have multiple, competing challenges, including:

- Convenience store facility managers do not have real-time visibility into the performance of refrigeration systems. This lack of visibility makes it difficult to maintain consistent food quality and hinders cost-effective preemptive maintenance schedules at stores.
- Maintenance contractors tend to be short-staffed, so the greater the notice they have of an upcoming repair request, the easier it is for them to schedule and perform the task in a way that reduces customer impact. The surest way to prevent costly repairs and outages is to obtain early warning of failures before they happen.
- Most preventive maintenance work convenience stores perform is based on seasonality and proximity of the maintenance contractor to the store. For example, some stores schedule preventative maintenance in the spring when there is a lot of pollen build up. This clogs heat exchanger fins, and results in compressor failures. In addition, convenience store managers often call the closest contractor to the store location.

This reactive model leads to higher-than-necessary energy use, substantial maintenance costs, shortened equipment life—and, in cases where equipment fails to maintain adequate temperatures—food spoilage. All of this is preventable, and the surest way to prevent costly repairs and outages is to obtain early warning of failures before they happen.

The Efficiency Vermont "Keep It Cool" project had the following objectives:

- Understanding challenges the convenience store market routinely experiences related to refrigeration system operations and maintenance,
- Testing the extent to which installed sensors can enable remote modeling of compressor performance, and
- Instituting cost-effective clean-energy solutions for monitoring refrigeration system health and preventing premature, costly equipment failures.

The project objectives were chosen to increase Efficiency Vermont stakeholder satisfaction and enhance organizational impact by (1) helping the customer quantify the value of its potential losses and the value of avoided service disruptions; and (2) enabling Efficiency Vermont to estimate and capture savings resulting from refrigeration system energy conservation measures such as smart defrost systems and crank case heaters.

Research Questions

Building on the defined customer challenges and past program experience, Efficiency Vermont developed the following research questions:

1. Can the Efficiency Vermont project team build a model to reliably estimate power consumption from the compressor(s) so that energy and cost savings from compressor maintenance could be determined?
    a. Efficiency Vermont proceeded on the assumption that installing sensors at specific points in each refrigeration system would enable its project team to model compressor performance, using system temperature and pressure measurements. If successful, the team could then use the resulting model to estimate compressor power consumption and estimate cost savings resulting from compressor maintenance.

2. If the monitoring and modeling are successful, can the convenience store facility manager use prompts for non-emergency maintenance to avoid extra costs from deferred maintenance and subsequent equipment failure?
    a. The project team assumed adequate monitoring, modeling, and communication regarding convenience store refrigeration systems could give the facility manager advance notice on the need for compressor maintenance or repair.
    b. The project team also assumed that giving the facility manager an estimate of the energy and cost savings associated with coil cleaning would prompt action.
    c. An objective for both the project team and the facility manager was the prevention of costly equipment failures.

Methods

Customer Engagement

Delivering value to customers required knowing who the customers were and what the customers valued most.

Identifying Customers

The Efficiency Vermont project team identified possible customer-candidates for "Keep It Cool" through its contacts with partner organizations. For each convenience store chain or group, the project team asked:

- Which customers can be helped, and how can those customers be helped?
- Who among the customers is aware of and engaged in the energy problems associated with the refrigeration units?
- Which customers will value this service the most?

The list of possible candidates quickly led the project team to Jolley Associates' ("Jolley") and Dick Soule Refrigeration, its maintenance contractor. Both were good project partners because of their level of engagement, willingness to try new approaches, and their commitment to the efficient operation of a chain of convenience stores located throughout the state.

Understanding the Customers

The Efficiency Vermont project team explored the needs and pain points of the two customer types via interviews, charts, and data visualizations. Through conversations, the project team discovered the authentic needs of each customer, which went beyond the team's assumptions of what they would find valuable. The team used the customer value discovery process framework outlined in Value Proposition Design,[1] which elicited the following feedback:

- Knowledge of internal refrigeration system temperatures was a very important feature for Jolley Associates and Dick Soule Refrigeration, the maintenance contractor.
- The Jolley facilities manager did not want details of the refrigeration system state, but rather whether the system was functioning properly, or if there were any fault conditions.
- If there was a fault condition, the Jolley facilities manager wanted to know its severity.
- System temperatures, and especially system pressures, are valuable data for the maintenance contractor.
- Being able to view system data over different time horizons (e.g. 8 hours, 24 hours, weekly.) was helpful for determining the persistence of anomalies.

The project team confirmed that Jolley's concerns were:

1. Determining if there was the risk of food spoilage.
2. Early warning of when compressors required cleaning.
3. Estimates of how much dirty compressors were costing the business.
4. Benchmarking stores against one another in terms of energy consumption and refrigeration system performance.

The project team then confirmed that Dick Soule Refrigeration's concerns were:

1. Knowing when to deploy a truck to a customer location.
2. Knowledge of the equipment required for addressing the service call before arriving on site.

Project Design

Efficiency Vermont's project team undertook the following tasks:

- Assembling a sensor hardware package for capturing and transmitting power consumption, system temperatures, and pressures in real time.
- Collecting the data and transforming and combining the data into a format suitable for analysis and visualization.
- Verifying that the saturated temperatures and pressures of refrigerants correlated in the real world as they are presented to correlate in documented pressure temperature (PT) charts. This needed to happen on both the low and high sides of the systems.

[1] Osterwalder, Alexander P. 2014. *Value Proposition Design: How to Create Products and Services Customers Want*. Hoboken, N.J.: John Wiley & Sons.

The project team designed the tasks to result in the following deliverables:

- A user-facing proof of concept of a real-time refrigeration system health monitoring service,
- A list of minimal requirements (sensors, data infrastructure, and analytics) for monitoring refrigeration system health in real time.

Analysis

Market Characteristics

There are approximately 230 convenience stores in Vermont. Offering roadside gasoline services, packaged snack items, dessert novelties, over-the-counter health remedies, beverages, and other pick-up items, they provide goods and services that are considered significant to the economic infrastructure of many rural Vermont towns.

Taken together, this market sector represents approximately 575,000 square feet (average store size is 2,500 square feet) and annually uses an aggregated 42,000 MWh of electrical energy (126 MWh / store / year; and 3,775 MWh / year / per chain). Based on Efficiency Vermont's analysis of energy usage at a typical convenience store, it estimates that approximately 30 percent of that energy load comprises refrigeration. An efficient refrigeration system can further reduce that to 15 percent of total electric usage, offering industry-wide potential savings of 4,300 MWh per year, enough to power more than 600 homes[2].

The typical store has one walk-in freezer, a walk-in cooler (which is about three times the size of the walk-in freezer), and multiple self-contained refrigeration units for ice cream and beverages.

The Role of Energy Efficiency in the Market

Common energy efficiency retrofit measures for convenience stores are:[3]

- Retrofitting electronically commutated (ECM) fan motors
- Adding evaporator fan controls
- Adding floating head pressures

Non-retrofit energy efficiency measures typically involve high-efficiency condensing units or evaporators.

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[2] Based on average Vermont home electricity consumption of 7,200 kWh per year (https://www.vtenergydashboard.org/my-community/chittenden-county-regional-planning-commission/progress)

[3] E Source, 2009. "Managing Energy Costs in Convenience Stores." http://dsoelectric.coopwebbuilder2.com/sites/dsoelectricdsoelectric/files/images/Business/conveniencestores.pdf.

Common Maintenance Challenges

- It is time-consuming and difficult to replace compressors for self-contained units.
- On warm days, there are temperature issues across the entire refrigeration system, resulting in high energy use (and costs) to keep coolers and freezers cool enough for customer preference and food safety.
- Over time, dirt and debris builds up on the condenser heat-exchanger.
- Temperature management issues arise if mechanical thermostats are unreliable.

Warm box temperatures are the most noticeable indicator of a refrigeration system problem, but those can be caused by different combinations of component failures. The most common remedy convenience store staff use when they are aware of warm box temperatures is notifying the store manager, who then escalates the problem to the facility manager, who then calls a maintenance contractor. Unfortunately store staff may lack the knowledge of what abnormal box temperatures are. There have been multiple occasions when no action is taken because staff don't report temperature issues as they are either unaware of the issue, or don't understand the implication of the measured values. This demonstrates the need for automatic temperature logging and alerting systems for refrigeration systems.

Refrigeration System Analysis

The Basics

Refrigeration systems in convenience stores typically use the compression refrigeration cycle shown in Figure 1. The refrigerant boils at low temperatures (typically below the ambient temperature of the refrigerated space), and changes from a liquid to a vapor, absorbing heat from the refrigerated space. Refrigerants are chosen for their ability to meet the required temperatures and pressures for the system. For example, R404 is a refrigerant commonly used in convenience stores and has a boiling point of -54ºF (-47.8ºC).

The components of a refrigeration system are:

- Evaporator: Boils the refrigerant and passes it to the compressor,
- Compressor: Creates high-pressure gas from the low-pressure refrigerant vapor,
- Condenser: Transfers heat from the refrigerant to the surrounding air or water; because of the temperature differential, the refrigerant condenses to a mix of liquid and vapor, and
- Expansion valve: The high-pressure, low-temperature refrigerant gas flows into the expansion valve and is converted to a low-pressure, low-temperature liquid, passing into the evaporator to start the refrigeration cycle again.

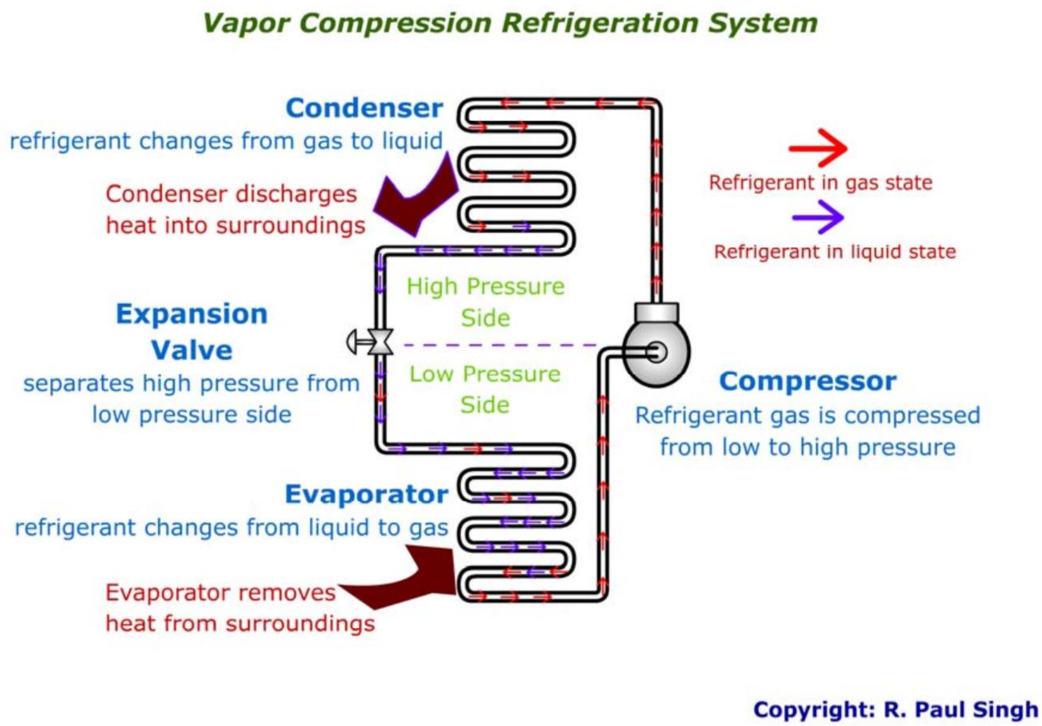

Figure 1: Vapor compression refrigeration cycle [4]

Metering the System

The hardware for this project needed to fit several specifications. These ranged from the ability to handle Vermont winter weather conditions (temperatures below -30°F, 2 to 3 feet of snow, and ice and rain) to a wireless communication capability to mitigate the need for adding roof, wall, or floor penetrations. Cost effectiveness, low power use, and long battery life were also key requirements.

With 8 pressure parameters, 21 temperature points, and power monitoring on 4 pieces of 3-phase equipment, as well as the supporting communications components, hardware costs could easily reach $20,000 for a typical site, excluding labor and installation costs. By taking advantage of newer Industrial Internet of Things (IIOT[5]) technology, the project team kept hardware costs to less than $10,000. With further refinement, the project team believes it will be possible to reduce equipment costs to below $5,000 per site.

The Efficiency Vermont project team chose eGauge for power monitoring hardware. eGauge meters offered reliable, true-power values across all four condensing units. The meters record data at 1-minute intervals and contain an onboard server that can be accessed over the internet in real time with an XML application programming interface. The meters are revenue grade, with an accuracy specification of ±0.5

[4] Walker, Rusty, 2010. "Refrigeration 101." Presentation for Energy & Store Development Conference, Food Marking Institute. https://www.epa.gov/sites/production/files/documents/Refrigeration_101.pdf.

[5] Ranger, Steve, March 1, 2019. ZDNET "What is the IIoT? Everything you need to know about the Industrial Internet of Things", https://www.zdnet.com/article/what-is-the-iiot-everything-you-need-to-know-about-the-industrial-internet-of-things/

percent. The meters come with many available channels, allowing the team to pick up several additional loads such as HVAC units and the building mains, at a negligible additional cost. This feature opened up other possible areas of data collection and analysis work in the future.

For the non-power parameters—refrigerant pressures and temperatures, as well as outdoor ambient air dry-bulb temperature—the project selected Monnit equipment in its first round of deployments. Monnit sensors speak wirelessly to over a thousand feet on a 900MHz frequency to a web-connected gateway. This capability allowed the project team to install sensors on the roof or across a facility, and to capture the data transmitted to the web, without running networking cable and conduit and without penetrating walls or rooftops. With a wide array of sensor types, and because the gateways can each handle up to a hundred sensors, the possibility for cost-effective, easy expansion of the monitoring system is high.

The feasibility of driving the system cost down to the minimum was explored in the 2019 cycle of the project. The eGuage power meters continued to offer very reliable results at very competitive prices. For non-power parameters, a parallel set of both Monnit and ControlByWeb sensors were tested at a new site. By deploying both, a direct apples-to-apples comparison was permissible. ControlByWeb sensors were selected as the sensors showed promise in two specific areas. First, ControlByWeb sensors came in at roughly half the price of the Monnit gear due to the ability at most points for the units to collect multiple parameters on a single device, rather than needing one device per parameter setup as Monnits are designed. Second, the data from the ControlByWeb devices can be funneled directly to the on-site eGauge via local Wi-Fi for collection, storage, and transmission to the cloud.

At the first project site, the Efficiency Vermont and Dick Soule Refrigeration partnership installed Monnit pressure transducers to capture suction pressure and head pressure for four condensing units on the roof, as shown in Figure 2. The partners also deployed temperature sensors on the roof for the condensed refrigerant gas piping off the compressor heat exchangers, as well as for the superheated refrigerant gas off the compressor discharge line. The partners then deployed temperature probes in each of the of the walk-in coolers and freezers, to monitor the condensed refrigerant liquid after the expansion valve, the cool refrigerant gas after the evaporator, and the ambient box air temperatures. Finally, the partners installed the final temperature sensor on the roof to capture the ambient outdoor air temperature.

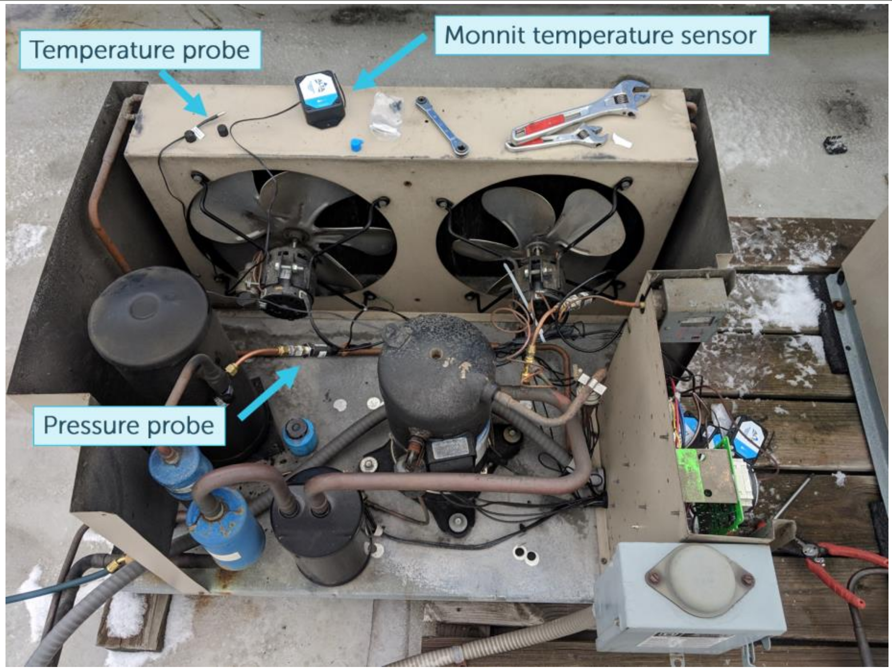

Figure 2: Installation-in-progress of Monnit sensor package for a rooftop unit.

All 29 Monnit sensors transmitted readings to the gateway that had been set up in the manager's office. This, in turn, was connected to a cellular modem via a network switch. A subcontracted electrician installed the eGauge in the basement of the facility, next to the primary-load electrical panel. That firm also connected the voltage leads and current transformers via conduit to this panel from the small eGauge electrical enclosure. An existing, extra ethernet cable strung from the manager's office to the basement provided a network connection back-up from the eGauge to the same network switch and cellular modem. Thus, all the site's data could be communicated out without impinging on the customer's network. It also could be piggy-backed onto the customer's single, secure, low-cost data plan.

Working with the maintenance contractor for the installation work had several advantages. The maintenance crew was already familiar with the sites and site idiosyncrasies. The crew had a desire to be helpful and responsive, because Jolley Associates was a long-term customer. The crew also recognized that this installation would both make jobs easier and less costly, and would deepen their business relationship with Jolley. By training the contractor's crew on how to install the sensors properly, the project team had begun lining up the option for future work to be done semi-independently, reducing Efficiency Vermont's future labor time and budget.

Although the Efficiency Vermont project team had significant experience with sensor deployments, every installation has its idiosyncrasies. First, Vermont's harsh winters are hard on small, wireless sensors. Minor defects and design flaws in the equipment led to moisture infiltration that either caused the batteries to drain more rapidly or simply shorted out the sensor circuits. Signal strength through a metal and concrete ceiling structure, plus a couple walls, combined with a noisy radio wave space, often led to a sensor being dropped from the network which led to battery drainage.

The Efficiency Vermont project team is moving away from cellular technology where possible and is making use of the customer's data network. The team is now exploring alternative sensor manufacturers, adhering almost exclusively to the latest generations of wireless communications and taking steps to make sure all sensors are line-powered. The project team is also planning to keep all vital rooftop sensor logging and communication components either inside the controls panel for the condensing units or within separate enclosures as shown in Figure 3. This enclosure was deployed on the roof of the third Jolley's store and comprises of Monnit and ControlByWeb temperature and pressure sensors, a Monnit gateway, a WiFi router, cellular modem and power supplies for all the equipment. All other sensors and meters, such as the eGuage, were deployed down inside the building and communicated via Wi-Fi back up to this router.

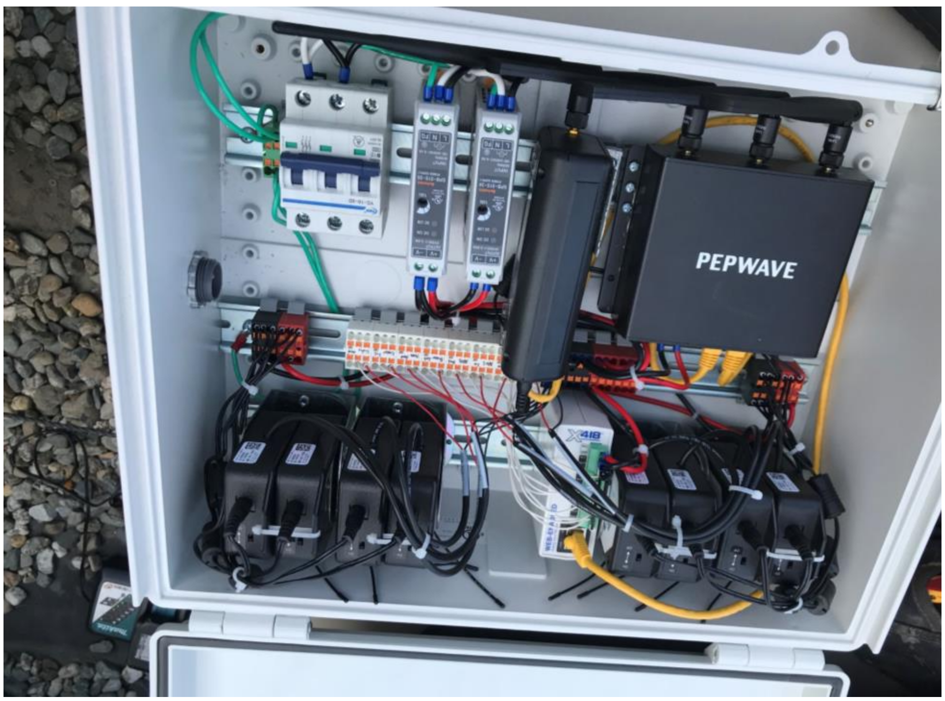

Figure 3: Sensor enclosure for third deployment: Temperature and pressure sensors, Sensor Gateways, WiFi Routers, power supplies

The team is also seeking and discovering other opportunities for cost savings to help increase the substantial value from this work. Examples include: reducing the number of points needed down to only what is valuable to all parties; and working with the maintenance contractor to make minor equipment changes that reduce the time needed for install.

Data Analysis

The project team cleaned and converted the sensors' data into a format that made it easy to combine and time-align temperature, pressure, and power information.

Data ingestion. The project team extracted data from eGauge and Monnit sensors, using each manufacturer's application programming interfaces (APIs). The team also used open-source Python libraries (for example, Requests[6] to retrieve the data over the internet, and the Pandas library[7] to parse the data, modify column names, and store the data.

Data cleaning. The project team then explored minimum and maximum values, and distributions and statistical properties; it also identified missing blocks of data. Knowing expected ranges of sensor data was important for detecting anomalies and sensor problems. Figure 4 presents a typical chart from the Python MissingNo package[8]; such charts were critical in identifying sensor or cellular modem outages.

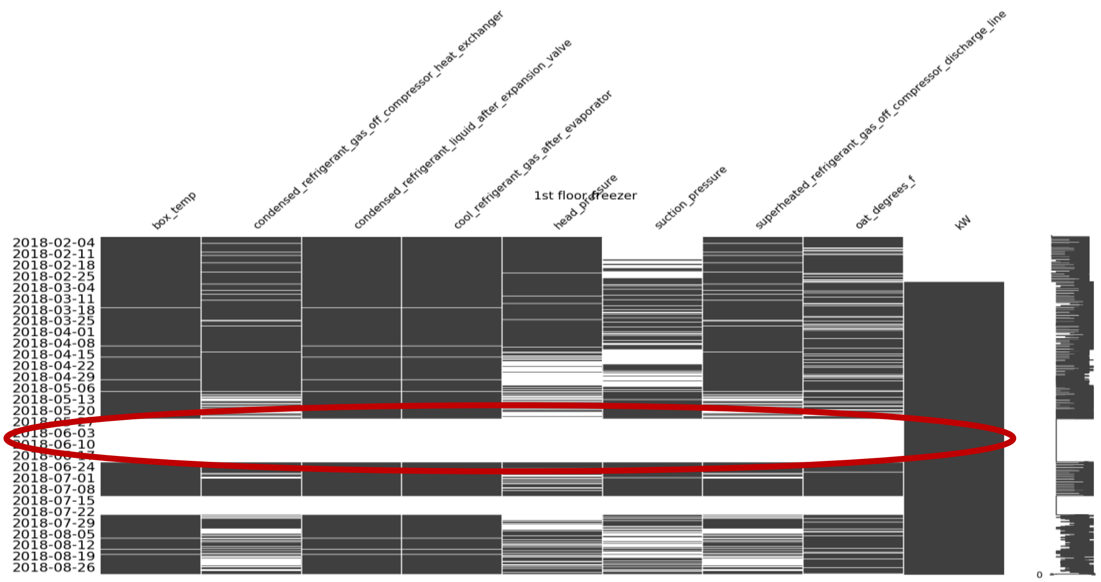

Figure 4. Data completeness diagram, showing and specifying missing data, via Python MissingNo package.

In some cases, a faulty sensor might intermittently generate an extremely low temperature reading, but by generating summary statistics, the project team could locate the issue, as shown in Figure 5.

[6] Reitz, Kenneth, n.d. *Requests*.. https://3.python-requests.org/.
[7] McKinney, Wes, 2010. "Data Structures for Statistical Computing in Python." *Proceedings of the 9th Python in Science Conference*, 51-56. https://pandas.pydata.org/.
[8] Bilogur, A., n.d. *MissingNo: Missing data visualization module for Python*. https://github.com/ResidentMario/missingno.

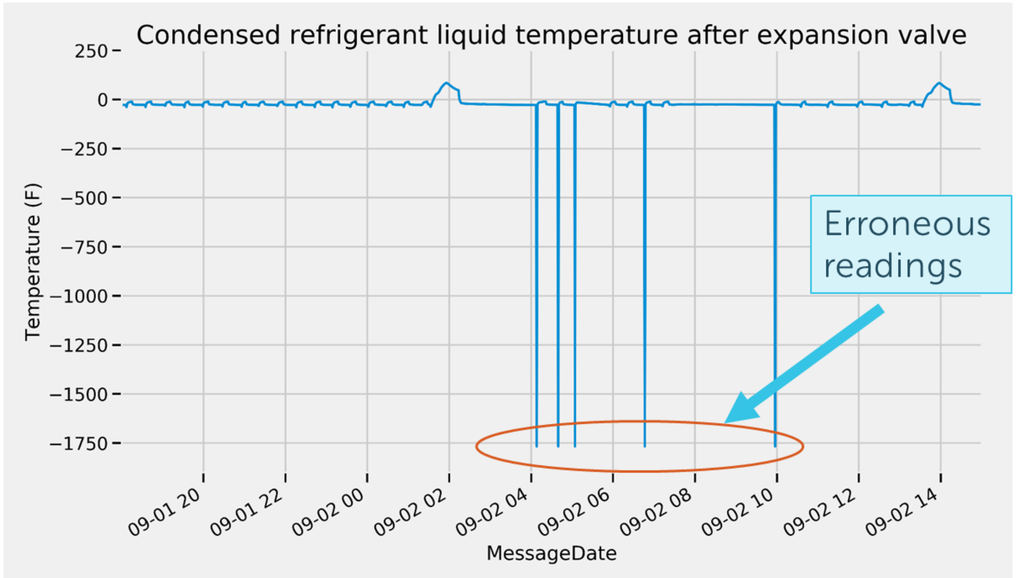

Figure 5. Indication of faulty sensor activity in the process following the refrigerant's passage through the expansion valve.

Fault detection. The project team combined its knowledge of the valid ranges for the temperature and pressure readings for each of the different system temperatures and pressures. Combining these two factors allowed the team to define fault conditions and create alerting criteria that it could then build into the refrigeration monitoring application to generate alerts and alarms for end users. Table 1 details the parameters defined for each sensor

Table 1. Sensor value ranges and criteria for alerts

Refrigeration system	Sensor type	System lower limit	System upper limit	Sensor lower limit
Cooler	Head pressure	110 PSI	250 PSI	0 PSI
	Suction pressure	None	None	0 PSI
	Box temperature	32 F	40 F	-40 F
	Condensed refrigerant liquid after expansion valve	None	None	-40 F

Data analysis and visualization. Once the project team cleaned and aligned all the data, it created algorithms that allowed for the calculation of system states such as defrost. These calculations allowed the team to demonstrate the effect of defrosts to Jolley stores, and to identify issues such as variations in box temperatures reached in their freezers during defrost events. The visualization is shown in Figure 6.

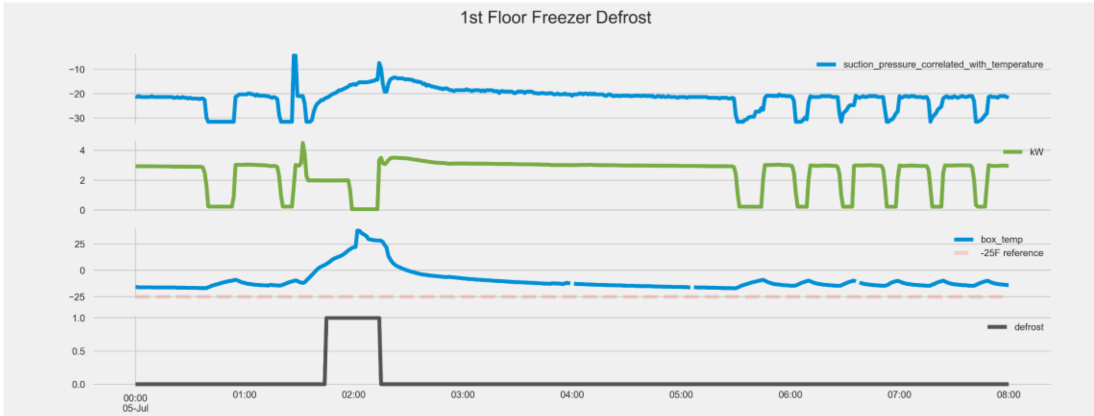

Figure 6: Box temperatures during defrost cycle.

During a defrost event, the freezer temperature rises to almost 40°F. It takes approximately 3.5 hours to return to its steady-state temperature of -8°F.

The temperature sensors within the walk-in units also allowed the team to demonstrate the superior performance of electronic thermostats, compared to Jolley's mechanical units. The team detected consistent temperature issues with one of the coolers, which led to a management decision to replace the mechanical thermostat with an electronic one. As shown in Figure 7, the cooler temperature dropped by approximately 5°F, and is now consistently below the critical 40°F threshold.

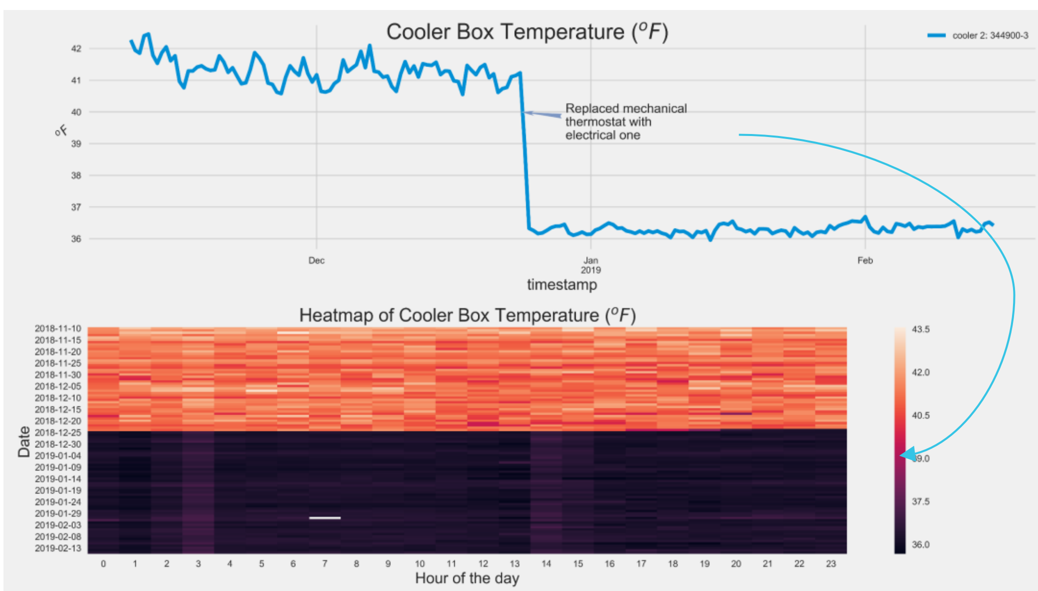

Figure 7. Change in box temperature due to replacement of mechanical thermostat with an electronic one, four-month view.

Predictive maintenance

The methods discussed to date have focused on real-time feedback, but real-time feedback only equips customers to react to situations. A greater value lies in being able to pre-empt failures and receive an early warning with sufficient notice to schedule maintenance before equipment failure or food spoilage occurs.

The field of prognostics and health management deals with the prediction of the expected remaining useful life (RUL) of a device or system based on prior usage history, its current state, and anticipated/future operating conditions [9] and it is illustrated using the DIPF curve in Figure 8.

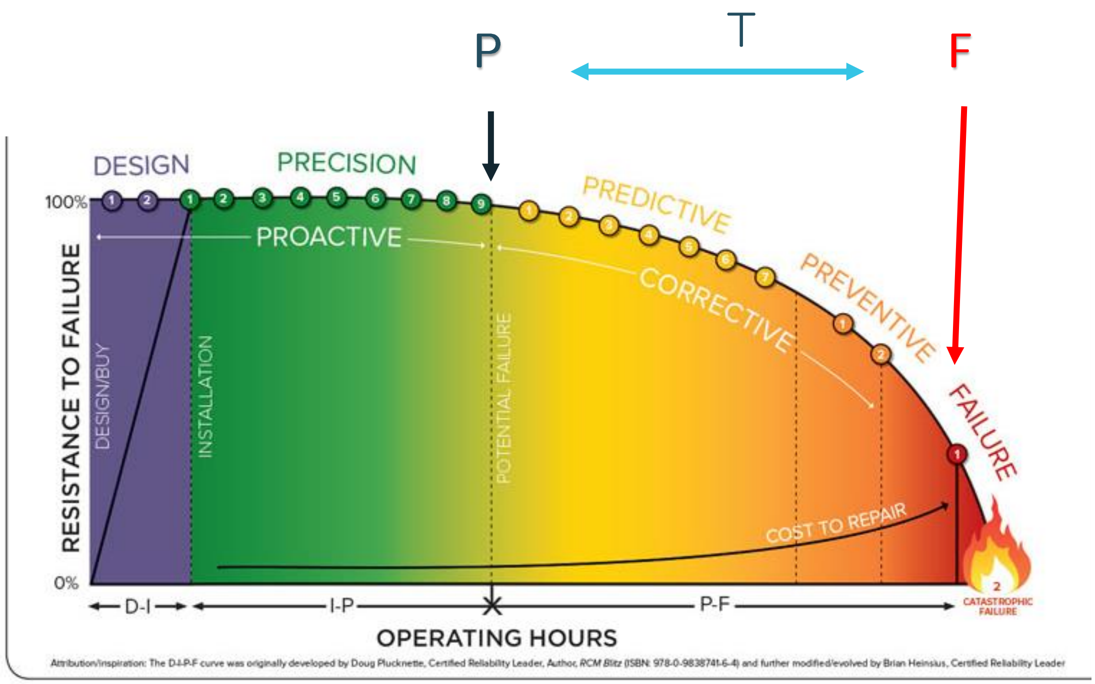

Figure 8. The DIPF curve[10], based on

Once a system is installed it begins to degrade and its likelihood of failure begins to increase. A potential failure occurs at point P and if left unaddressed, it will result in a functional failure at point F, and ultimately a catastrophic failure. The goal of a preventative maintenance program is to detect potential failures as early as possible and increase the time T between when a potential failure is detected, and when the equipment fails. The earlier a potential failure is detected and addressed, the lower the repair cost, the greater the flexibility in scheduling a maintenance contractor, and the lower the impact to the customer.

An effective prognostics and health management system requires the following:

1. Sensors: monitoring equipment that measures the performance and degradation of a system e.g. temperature, pressure, vibration etc.

[9] Pecht, M. G., Kang, M. (2019) Prognostics and Health Management of Electronics: Fundamentals, Machine Learning, and the Internet of Things, Wiley-IEEE Press.
[10] https://reliabilityweb.com/articles/entry/completing-the-curve

2. Anomaly detection: use of sensor outputs to detect anomalous system operation or deviations from normal operation e.g. abnormally high operating pressures, or a significantly different duty cycle.
3. Diagnostics: knowledge of the different failure modes of a system, and how that failure manifests in terms of sensor readings. This relies on failure mode, mechanisms and effects analysis (FMMEA)[11].
4. Prognostics: equipment history information, FMMEA, and sensor readings are combined to predict the remaining useful life (RUL) of a system and schedule maintenance or reply as soon as possible

An example of the first two steps is demonstrated in Figure 9 where the team encountered a walk-in cooler issue due to low refrigerant charge. It's clear from the condenser power, head and suction pressure duty cycle changes that there is a problem. The earliest time the team could infer a potential failure is point P at approximately noon on the 13th of June, but this fault wasn't detected by the customer until time F on the 15th when the box temperatures in the cooler had risen to noticeable levels.

An open issue for the team is building a fault event library large enough to be able to accurately predict and classify such failures. The project team is exploring partnerships with refrigeration system manufacturers to collect such data and combine it with FMMEA information to develop an accurate predictive maintenance system for this market segment.

[11] Pecht, M. G., Kang, M. (2019) Prognostics and Health Management of Electronics: Fundamentals, Machine Learning, and the Internet of Things, Wiley-IEEE Press.

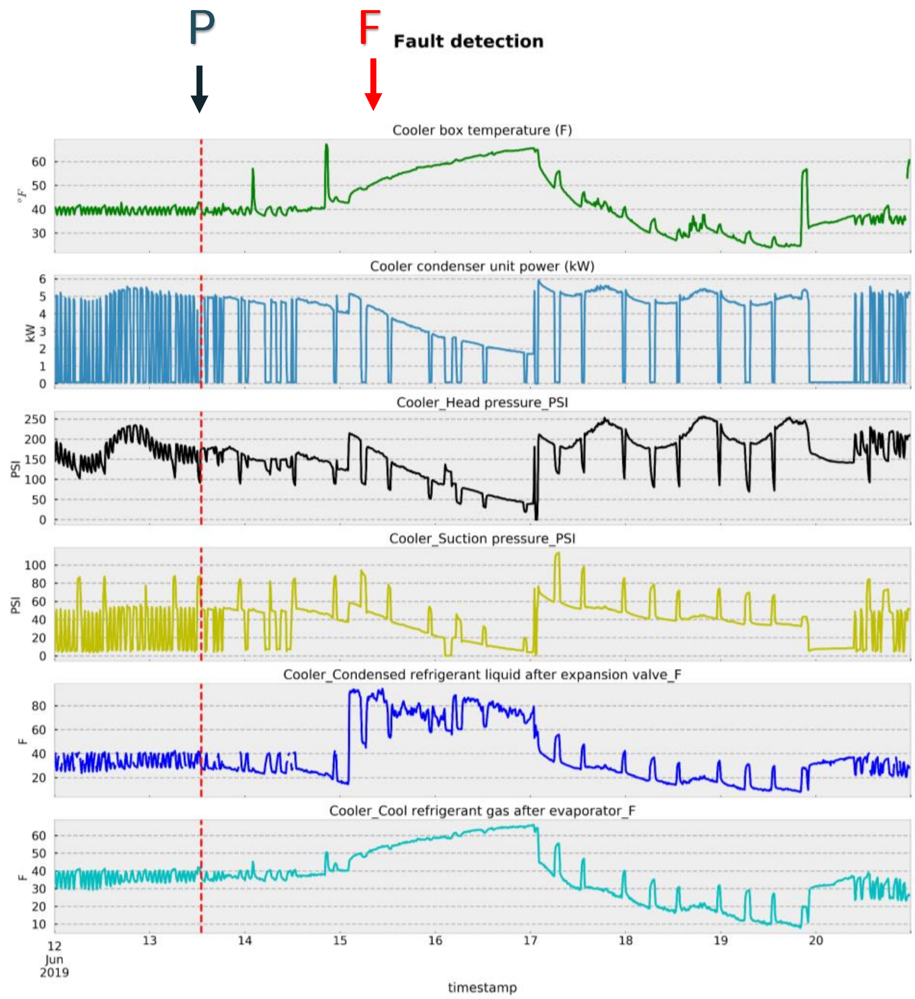

Figure 9. Low refrigerant charge problem

Discussion: The Role of IoT

Refrigeration System Monitoring Application Development

The Efficiency Vermont project team recognized that providing a mobile-friendly real-time refrigeration system monitoring was an important next step. To create an application Jolley's could use, the project team partnered with Leverege LLC, a Maryland startup that specializes in IoT service development. Leverege created role-specific dashboards that were optimized for desktop and mobile viewing. There were two primary objectives for the dashboards: (1) to provide a tool that maintenance contractors could use remotely to view detailed system information on smart phones; and (2) to offer the Jolley facilities managers insights into the high-level status of the refrigeration systems.

Using the customized Leverege dashboards, the project team demonstrated the value of submetering in detecting faults in the condenser. The sensors detected abnormally high box temperatures, as well as head pressure readings consistently at the maximum value of the pressure sensor. The team provided these observations to the maintenance contractor, who could remotely diagnose the problem. Before the maintenance contractor arrived on site, the maintenance crew already knew where the problem was, and its likely cause (a faulty starting capacitor for the compressor). When the maintenance crew arrived, the crew confirmed that it was indeed the starting capacitor and replaced it. Figure 10 shows the high head pressure readings that resulted in the alert. Figure 11 shows the compressor power draw before and after the problem was fixed. Had the problem continued, it would have resulted in compressor failure and a costlier replacement.

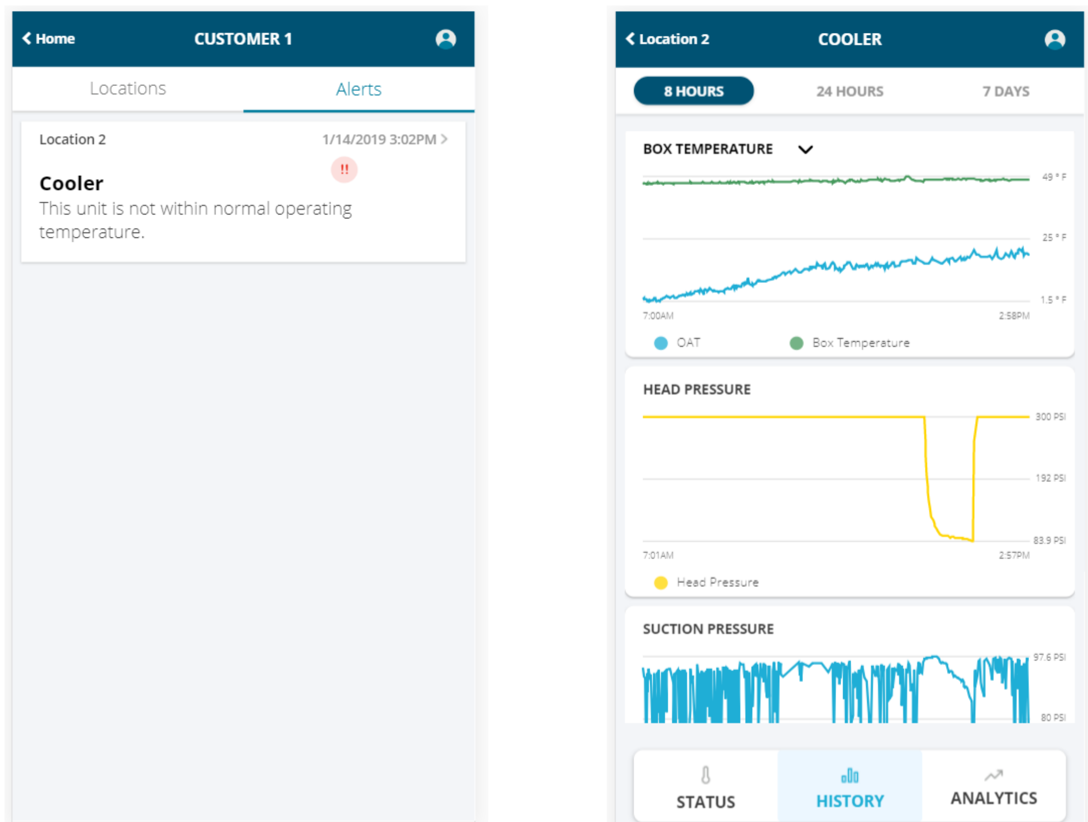

Figure 10. Two screenshots showing mobile alerts and abnormally high head pressure readings.

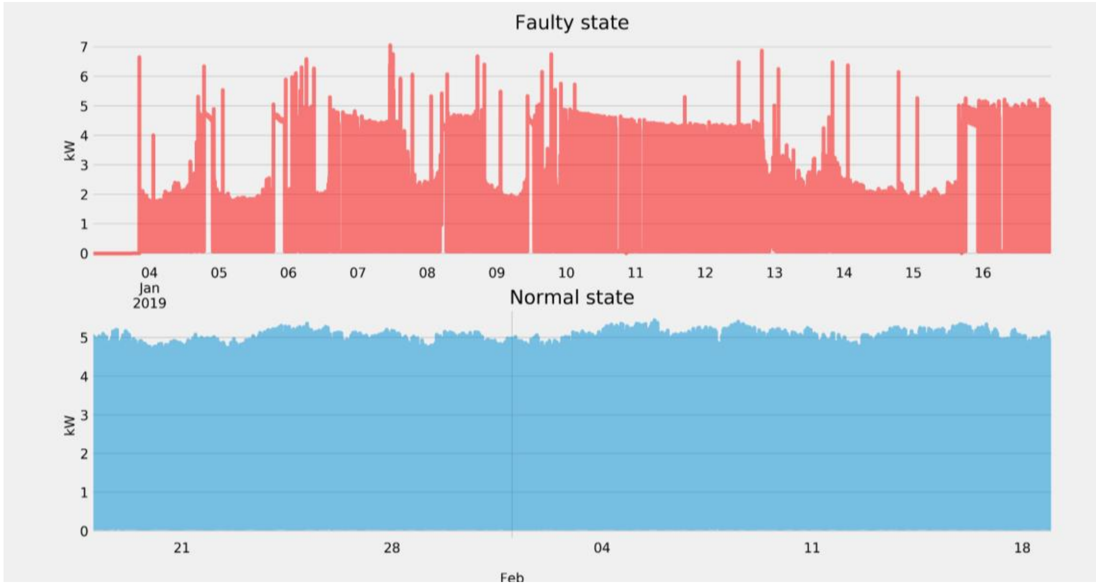

Figure 11. Compressor power draw before and after replacement of faulty condenser starting capacitor.

Results

The Efficiency Vermont project team has sensors deployed at three Jolley convenience stores. In two of the three stores, the project team accurately detected and alerted Jolley Associates to serious problems with store refrigeration systems, which were causing abnormally high temperatures in the coolers. The information the team provided told Jolley's and the maintenance contractor when and where the problems occurred, facilitating a more rapid fix than would have been possible if the company had to troubleshoot the system without the sensors and dashboard. Efficiency Vermont estimates the cost of a comprehensive refrigeration efficiency project for a typical store is $20,000 including metering equipment. Estimated savings are $6,500 a year, which means that customers would see a payback of approximately 3 years. Jolley Associates sees the value of this systemic approach, and requested Efficiency Vermont expand the monitoring to air-conditioning systems and the lighting system in the third deployment. The Efficiency Vermont project team is now monitoring refrigeration, HVAC and lighting systems in that store and will use the additional data to provide a wholistic picture of energy draw and performance in that location.

Conclusions and Next steps

This research and development project demonstrated the value of real-time insight into refrigeration system operation using temperature, pressure, and power sensors. The monitoring and visualization systems allow stakeholders to remotely diagnose system performance, identify faults, and optimize system performance.

This new approach allows for real-time monitoring of refrigeration systems, moving facilities managers away from being in a position of having to react to system failures after they occur, to being in a position of staying ahead of failures and proactively planning for cost-effective need-based systematic equipment replacement.

The approach, complemented by IoT applications, has analogies to other business practices—and to improvements in energy efficiency delivery generally.

Lessons from the Field

- There is a market for real-time monitoring solutions that address specific customer needs, and real-time feedback is a powerful motivator for engaged customers who care about the performance of equipment and/or want to mitigate product loss.
- Remote, accurate visibility into box temperatures at convenience and grocery store food cases is of high value—from the standpoint of a customer's bottom line and for an efficiency program's ability to obtain and maintain energy savings.
- Real-time monitoring enables the remote diagnosis of refrigeration system issues. Mechanical teams can optimize workflows when given reliable and visual information about refrigeration performance.
- The combination of existing customer relationships, Efficiency Vermont staff expertise and real-time monitoring will create opportunities for real-time energy efficiency detection and persistence tracking.

Next Steps

Efficiency Vermont is using lessons learned in developing this system and dashboard for Jolley's to create a larger platform that can provide similar dashboards for Vermont companies that have requested submetering services from Efficiency Vermont. This will provide customers with deeper insights into facilities, and allow Efficiency Vermont to collaborate with these customers to detect and monitor energy efficiency opportunities in real-time and obtain deeper savings than might otherwise be possible.

Outstanding tasks for this project are: (1) pursuing partnerships with refrigeration system vendors to collect the data required for building robust predictive maintenance models, and (2) identifying an affordable, robust, and reliable sensor package for capturing data. Completing these tasks will equip Efficiency Vermont to scale this solution to a larger number of Jolley locations.

Moreover, a larger number of multi-feature Efficiency Vermont projects like "Keep It Cool" will allow expansion to other industries in the Efficiency Vermont state-wide service territory—and demonstrate Vermont's ongoing leadership in a next-generation energy system.