Adversary or Ally: Industrial Strategic Energy Management and Demand Response – Can They be Integrated?

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ABSTRACT

Since 2010, Bonneville Power Administration's (BPA's) Energy Smart Industrial (ESI) program has helped approximately 100 industries implement Strategic Energy Management (SEM) and reduce energy costs through efficiency. More recently, BPA partnered with local utilities to offer a Demand Response (DR) pilot to industrial facilities. Though both SEM and DR are marketed as strategies for managing energy costs, SEM focuses on reducing consumption while DR programs increase awareness of and provide opportunities for managing demand costs.

An integrated approach to SEM and DR has clear benefits. Viewing energy management through both load and demand lenses can lead to new insights and better-prioritized efforts. Often a facility has a single energy champion to serve as the point of contact for both programs. Also, the same facility energy use and production data can be used for both short-term (DR) and long-term (SEM) energy models.

However, DR can potentially increase energy intensity. The optimal system set-points for efficiency are likely not optimal for demand response. As SEM and DR programs simultaneously expand, administrators of utility programs must identify situations where a DR product or control strategy increases energy intensity.

This paper examines four pilot participants, each with varying degrees of SEM maturity. The four participants included the following facility types: 1) municipal water, 2) cold storage, 3) frozen food processing and 4) chilled food processing. After performing site visits to assess opportunities and installing demand response end nodes, a series of increasingly challenging DR tests were performed to investigate the interactions between the two approaches. This paper will explore the resulting synergies and disconnects that can occur in certain types of operations and highlight lessons learned that should be taken into account for future program design.

Introduction

In the Pacific Northwest and nationally, both energy efficiency (EE) and DR programs are growing sources of reliable, clean, and low-cost power (NW Council 2016, Goldman 2010). Energy efficiency is the Pacific Northwest's second largest electricity resource, comprising 17% of the region's energy portfolio (Brooks and Martin 2016). As transmission capacity constraints have become a growing concern, BPA has launched DR pilots throughout the region to reduce summer and winter peaks, relieve congested transmission lines, and integrate renewable energy. All stakeholders—including industrial end users, utilities, and regional EE and DR program administrators and implementers—have a vested interest in maximizing the resources and benefits provided by each program.

Through seven years of implementation activity, the ESI program has developed deep relationships with utilities and end users throughout the region. In 2014, the ESI program leveraged these relationships to recruit four DR pilot participants in one month. The four participants included the following facility types: 1) municipal water, 2) cold storage, 3) frozen food processing and 4) chilled food processing. Control infrastructure at these facilities ranged from local microprocessors with humans in the loop to centralized control of the entire facility.

While the degree of energy management maturity varied amongst the participants, all had made significant investments in energy efficiency and had processes in place to make well-informed energy-related decisions. The participant diversity provided a rich pool of site-specific recommendations and allowed results to be compared against different system types. Energy use during DR curtailments was quantified and opportunities for continuous improvement, both EE and DR, were identified. In general, this pilot demonstrated how previous investments in EE, including SEM, can enable DR.

To facilitate testing, systems were prepared and hardware and software were installed for each participant. A total of thirteen tests were conducted among the four sites. For each test, the magnitude of the curtailment was quantified, the impact on energy efficiency was analyzed, and opportunities for improvements, both EE and DR, were evaluated. The timeline for this demonstration is shown in Table 1.

Table 1. ESI SEM/DR timeline of pilot

	Q3-2014			Q4-2014			Q1-2015			Q2-2015			Q3-2015		
	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9
Recruit participants			■												
Prepare systems				■	■	■									
Install hardware						■	■	■	■	■					
Perform testing								■	■	■	■	■	■		
Report findings														■	

Preparation

Energy maps and regression-based energy models had been created through previous SEM engagements. This provided an abundance of pertinent information at the start of the project, including historical energy use with sub-hourly recording frequencies. ESI staff, with an understanding of the intricacies of these systems, conducted site visits to identify opportunities for DR and to determine how DR hardware would be integrated with existing control systems.

ESI and utility staff reviewed the findings from the site visits and determined which opportunities would be tested, how the tests would be performed, and what hardware and software were needed for testing. An initial step in assessing the facility’s DR potential was to understand its energy use with respect to time. Advanced graphical techniques such as heat maps provided an understanding of both short-term (hourly) and long-term (seasonal) patterns in energy use. A heat map provides a three-dimensional view of energy use with day of year on the x-axis, hour of day on the y-axis, and color as the magnitude of energy use.

For many food processing facilities, processing is seasonal, resulting in much higher power draws in summer than winter. As an example, the patterns of bright yellow during June and July shown in Figure 1 indicate that energy use is high and the patterns of darker blue during the winter indicate that energy use is much less. However, the contrasts in colors, even during the summer, indicate high variability in energy use.

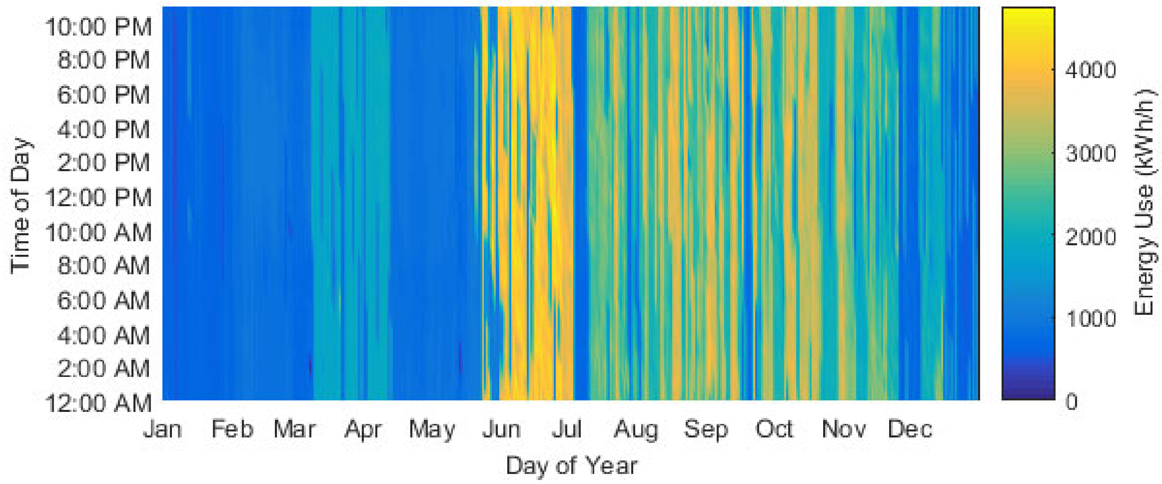

Figure 1. Energy use heat map of a cold storage facility

Hardware and Software

Energy use of industrial facilities is typically driven by production, and thus production data is necessary for understanding facility energy use. For example, the energy use of the municipal water facility exhibits a strong linear dependence. In addition, the three distinct operations also influence energy use, as shown in Figure 2.

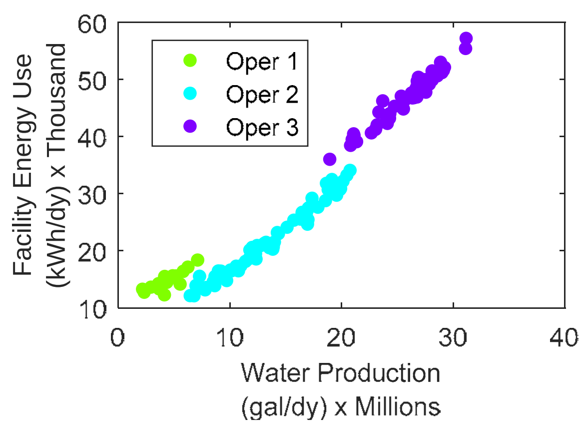

Figure 2. Facility energy use versus water production by operation (Oper) for municipal water facility

From participation in previous SEM engagements, each end user had already been equipped with an energy management and information system (EMIS) and data acquisition unit (DAU). The EMIS provides access to sub-hourly energy use, hourly weather temperatures, and daily production data. Each EMIS also incorporates a regression-based energy model to calculate energy savings based on weather and production. The DAU sends facility energy use to the EMIS.

To facilitate DR testing, existing investments in energy efficiency were leveraged and an end-node, human-machine interface (HMI), and pre-Demand Response Automation System (pre-

DRAS) were also installed. The pre-DRAS is a web-based software that provides the ability to schedule DR events and record facility energy use at one-minute intervals. In addition, the Pre-DRAS sends communication to program participants regarding the status of the test through email or text. The HMI provides an interface at the facility that allows operators to view the status of the test, view real-time energy use, and opt-out of the test if desired.

The end-node has a cellular gateway enabling it to receive communication from and send energy data to the Pre-DRAS. The end-node can communicate directly with the control system or signal the operator to take action; both approaches were tested during the pilot. Time and budgets did not allow the Pre-DRAS and EMIS to be integrated. A conceptual diagram of the hardware and software installed for both SEM and this DR pilot is provided in Figure 3.

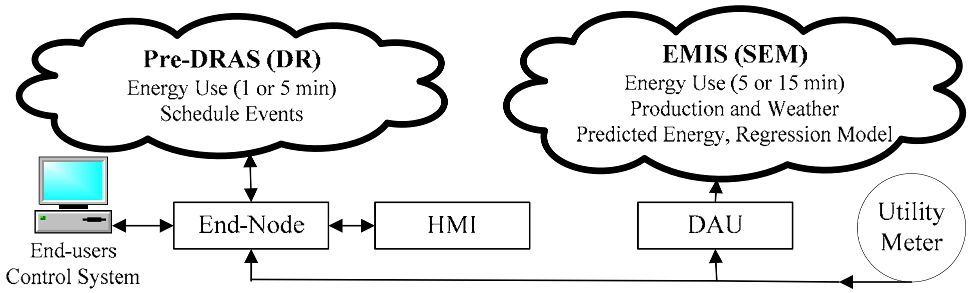

Figure 3. Conceptual diagram of the hardware and software used for DR testing

Testing of DR Opportunities

DR product types with short-(one hour) and long-(two to three hours) term responses were tested. While the curtailment strategies varied by site, the general approach involved a series of tests with increasing degrees of difficulty. This approach maximized curtailment while minimizing risk and permitted testing across multiple seasons. Additionally, stressing the system under different conditions allowed the pilot to identify control system optimization opportunities to improve both EE and DR performance. A summary of DR tests by facility type, season, and duration is provided in Table 2.

Table 2. Summary of demand response tests by facility type, season, and duration

Test	Municipal water		Cold storage		Chilled food		Frozen food	
#	Season	Duration	Season	Duration	Season	Duration	Season	Duration
1	Winter	Long	Spring	Short	Spring	Short	Spring	Short
2	Winter	Long	Spring	Short	Spring	Long	Spring	Long
3	Summer	Long	Summer	Short	Summer	Long	-	-
4	Summer	Short	Summer	Long	-		-	-

Upon completion of each test, energy and control system data were analyzed to quantify curtailment, assess system performance, and inform subsequent test design. During the initial test at the municipal water facility, sub-metered energy data showed that several pumps unexpectedly turned on during the test. While it was determined that testing did not influence this operation, these pumps were curtailed in later tests, thus increasing the magnitude and consistency of curtailment.

During the last test at the cold storage facility, condenser fans remained at 90% speed and the compressor continued to operate between zero and 50% capacity. Only when the compressor was near 50% capacity was there a call for cooling. Otherwise, all evaporator fans remained off. Energy use and selected system operations for these two aforementioned tests are shown in Figure 4 and Figure 5.

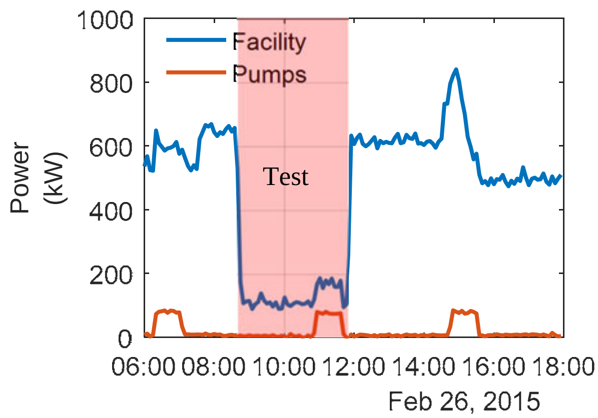

Figure 4. Municipal Water: Sub-metered electricity showing pumps on during testing

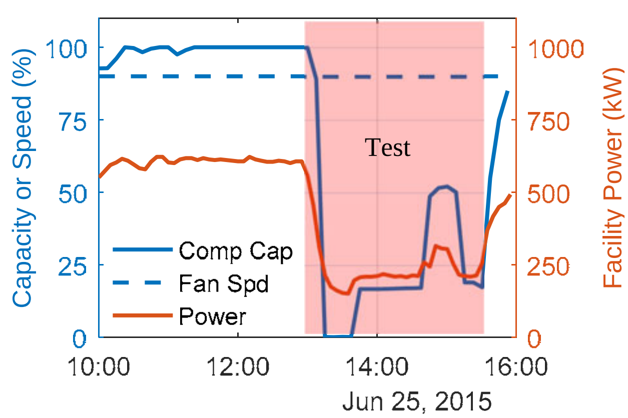

Figure 5. Cold Storage: Control system data showing condenser fans and compressor on during testing

Measuring Curtailment

Curtailment is the difference between baseline power and power measured during the event. Three different methodologies were used to measure curtailment: observed/measured, similar days, and regression. Because the power draw of the system could vary considerably based on hour of the day, production data and an understanding of the system operations were used when applying each method. In general, these methodologies provided similar results and allowed for discretion when reporting curtailment. A brief explanation of each of the three methodologies used to measure curtailment is provided in Table 3.

Table 3. Explanation of curtailment methodologies

Method	Baseline	Event
Observed/Measured (Used on BPA DR projects)	Minimum power measured within two hours prior to deployment	Minimum power during sustained response
Similar days (Southern California Edison)	Adapted from “10-Day Average Baseline and Day-Of Adjustment” (SCE 2013)	Average power for each hour during sustained response
Regression (Used on other BPA SEM projects)	Power estimated from regression model using temperature and/or production during test	Average power during sustained response

Measuring Energy Intensity

Energy models based on production data are essential for understanding energy performance in an industrial application. While the magnitude of a DR event can be estimated with high-frequency consumption data, regression-based energy models characterize energy intensity before and after curtailment. Comparing event days and non-event days provided insights into system preparation and recovery strategies, and analyzing event data revealed new EE opportunities by identifying unexpected baseload.

The use of control system data and follow-up conversations with end users provided further model refinement. This ensured that energy models were constructed with similar operating conditions as those experienced during the respective tests. Confining the models to similar operating conditions reduced the number of observations and thus statistical power. This was offset by increased model fitness, thus providing models with good predictive capability. An example of predicted energy use of the model and the actual energy use during the same time is shown in Figure 6.

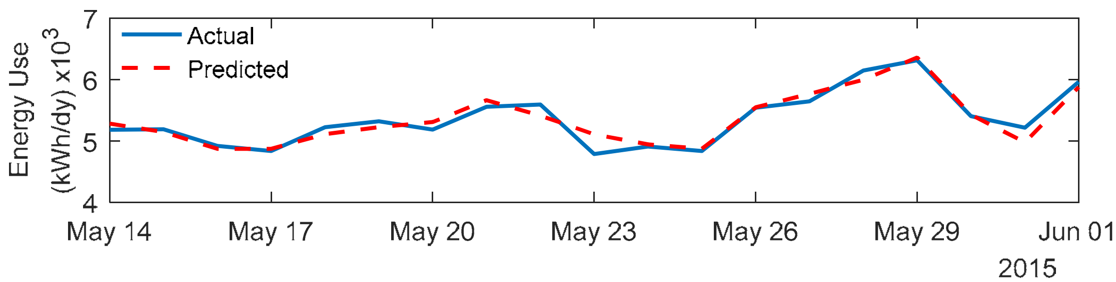

Figure 6. Actual energy use and energy use predicted from regression model

Case Study: Municipal Water

The municipal water facility provided a good example of a system that could be curtailed with minimal impact on energy efficiency. The facility utilizes 16 pumping stations to supply water to approximately 49,000 customers and has a centralized control system. Selected pumps were curtailed for each of the four tests. The first two tests were conducted in winter, when demand for water is low. Initiating testing when the system had a substantial buffer provided a level of comfort for the water manager and a good understanding of how the system would respond during peak conditions.

After seeing how the system responded during the first two tests, the water manager was confident that the system could provide curtailment for three hours without increasing water levels. This indicated that the facility could participate in future demand response programs requiring a day or less of notification. Generally, the duration increased with each test, but the water manager elected to perform the long (three-hour) test prior to the short (one-hour) test to better align with work schedules.

For all tests, including the two tests conducted during the summer (Tests #3 and #4), system power rapidly decreased within 15 minutes of curtailing selected pumps. The spikes in power that occurred during Test #3 (long) were a result of planned maintenance and would be mitigated in the future. After Test #3, reservoir levels were gradually increased, resulting in a gradual increase in power. For Test #4 (short), the system resumed normal operation immediately after the test, with power returning to approximately the same level as before the test. Profiles of system power for each day of the test are shown in Figure 7 and Figure 8.

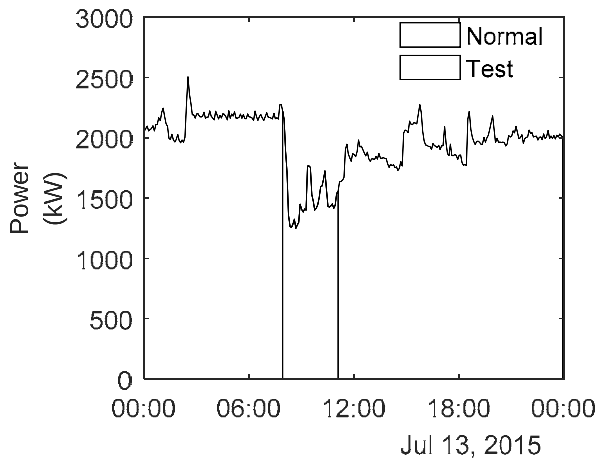

Figure 7. Municipal Water: Test #3 (Long)

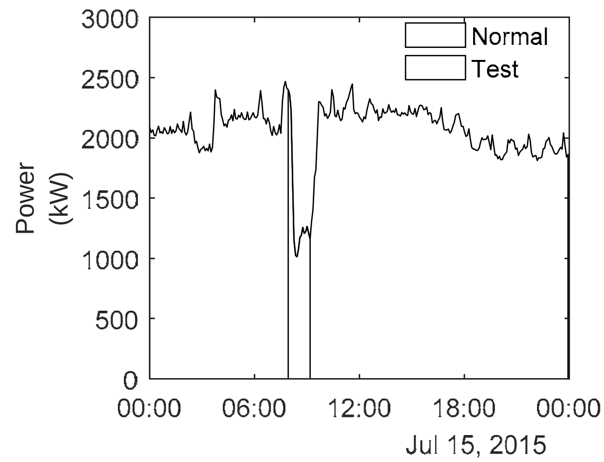

Figure 8. Municipal Water: Test #4 (Short)

The water system maintained normal operations before and after each test, resulting in a minimal impact to energy efficiency. A regression model representative of summer operations, with water production as the independent variable, was constructed to quantify the impact of these tests on energy efficiency. The model provides the expected energy use for a given amount of water production, as well as the confidence intervals of the prediction at 95% confidence. As shown in Figure 9, actual daily energy use on DR test days was within the prediction intervals of the regression model, indicating that testing did not change the energy intensity of the system.

The results of each test are provided in Figure 10. The difference between the curtailments of Tests #3 and Test #4 was a result of planned maintenance. Curtailment would have exceeded 600 kW if maintenance had not been scheduled during this time. For future curtailment requests, the water manager would target a set curtailment of approximately 500 kW, based on learnings from Tests #3 and #4.

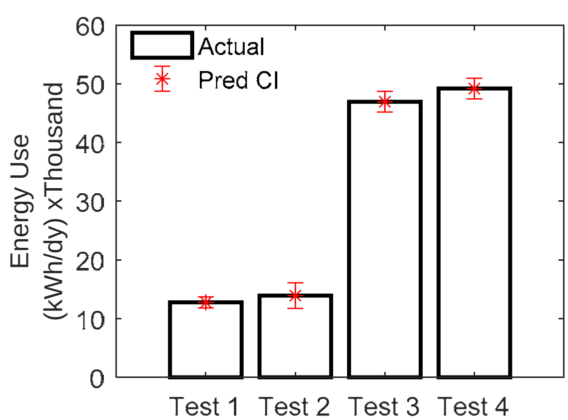

Figure 9. Actual energy use and 95% prediction confidence intervals of the regression model (Pred CI).

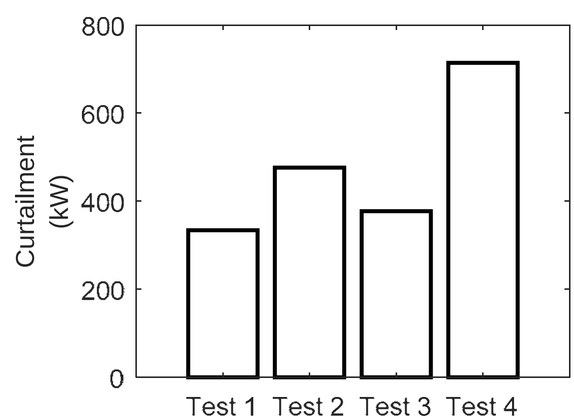

Figure 10. Curtailment for each test

Case Study: Cold Storage Warehouse

In contrast to the municipal water facility, the cold storage warehouse provided an example where energy use increased as a result of DR events. The cold storage warehouse is a 177,100 ft^2 public storage warehouse with six freezer rooms that must maintain a temperature of 0° F. Refrigeration is provided with a central ammonia refrigeration system, and the evaporator fans, compressors, and condenser fans are controlled by variable frequency drives (VFDs) with the use of a centralized control system. Twelve high frequency battery chargers used to charge forklift batteries have a total rated power draw of 127 kW and use local control.

ESI and the local utility provided incentives for this high efficiency equipment and controls prior to the pilot. Only a modest controls upgrade for a cost of about $4,000 was needed to enhance the system with auto DR capabilities. These capabilities were essential for curtailing load and obtaining system level data. Like the municipal water facility, four tests were conducted at the cold storage facility. Two early tests were conducted in spring. Two other tests were conducted in summer when outdoor air temperatures and refrigeration loads were higher.

Learnings from the first two tests helped inform the strategy for Test #3, which curtailed the refrigeration system until space temperatures were no longer maintained. Test #3 showed that the system could be curtailed within 15 minutes for a duration of one hour and 30 minutes. Upon resuming normal operations, a large “rebound” effect or significant increase in power was experienced as the evaporator fans operated at maximum speed to pull down space temperatures to set-point (**Error! Reference source not found.**11).

Test #4 employed a precooling strategy to extend the duration of curtailment. The strategy was to gradually reduce space temperatures by 3° F, beginning at 12:00 am on the day of the test. This strategy proved to be ineffective as half of the rooms’ temperatures were not reset until 8:00 am due to a control system glitch and suction pressure set-points were too high to achieve the desired room temperatures. This caused evaporator fans to operate at full speed in an effort to pull down room temperatures to a set-point that could not ultimately be achieved. Therefore, the attempt to precool consumed considerable power, as did the rebound effect after the test.

The system curtailed within ten minutes for a duration of two hours and 15 minutes, but refrigeration was required during the latter part of the curtailment to maintain space temperatures required by contractual obligations. This resulted in a spike in power during the curtailment though the need for cooling appeared to be localized. A profile of system power for the day of Test #4 is shown in Figure 12.

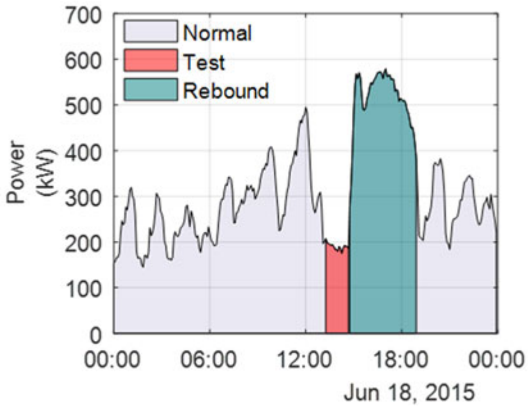

Figure 11. Cold Storage: Test #3 (Short)

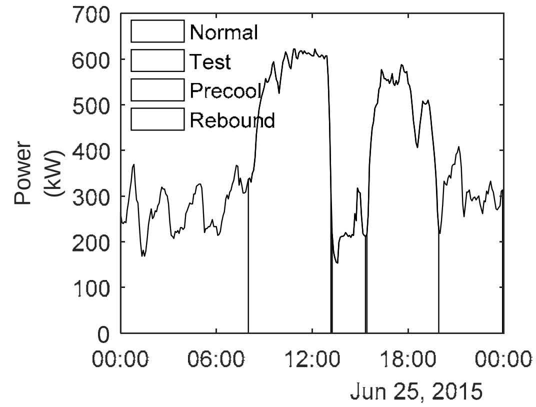

Figure 12. Cold Storage: Test #4 (Long)

A regression model was constructed to predict facility energy use for the day. The regression model correlated facility energy use to ambient temperature and product received and shipped, and was constructed using data from summertime operations. As shown in Figure 13, actual energy use was considerably higher than the predicted confidence intervals of the regression model, thus indicating an increase in energy intensity. This is primarily attributed to considerable increases in evaporator fan speeds during Tests #3 and #4 and underscores the influence of evaporator fan speed on facility-wide power.

Negligible curtailments were achieved during the first two tests as testing procedures were finalized. The battery chargers were curtailed for Test #4, providing modest additional curtailment as the power draw was small during this time. The measured curtailment for all four tests is provided in Figure 14.

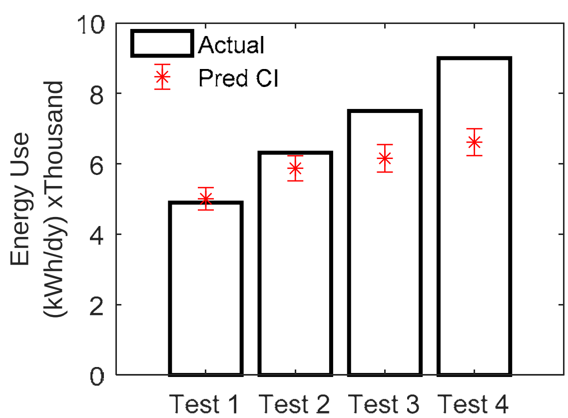

Figure 13. Actual energy use and 95% prediction confidence intervals of the regression model (Pred CI).

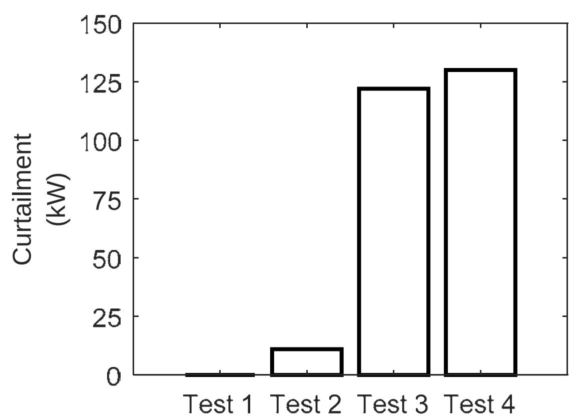

Figure 14. Curtailment for each test

Summary of Tests

Testing demonstrated that ample energy storage and automated controls are required to provide a reliable DR asset while minimizing the impact on energy intensity. The municipal water had ample energy storage capable of providing substantial curtailments in all seasons without the need to prepare the system prior to the DR event. The system could respond within 15 minutes of the deployment, and it proved reliable as the water manager and his team were able to respond to all four tests.

While the refrigeration system at the cold storage was curtailed using a centralized control system, pre-cooling would be required for curtailments exceeding one hour. The thermal storage characteristics and control strategy of the cold storage facility were different than the municipal water facility, resulting in an increase in energy intensity when curtailed. The battery chargers were curtailed manually and generally contributed a modest 20 kW or less.

Curtailments at the chilled and frozen food processors were performed manually due to control limitations. This resulted in difficult and unreliable curtailments. The refrigeration system at the frozen food processor was identified as desirable DR asset – capable of quick and sustained, if modest, curtailment potential – whose reliability would benefit greatly from an automated control system. The chilled food processor lacked thermal storage within the process and was therefore determined to be a poor candidate for DR. A summary of all 13 DR tests conducted during this pilot is provided in Table 4.

Table 4. Summary of all thirteen DR tests performed in pilot

End user	Test #	Season	Time required to curtail	Duration of curtailment	Measured curtailment (kW)	Impact on energy intensity
Municipal water	1	Winter	15 min	3 hr	334	None
	2	Winter	10 min	3 hr	476	None
	3	Summer	15 min	3 hr	377	None
	4	Summer	15 min	1 hr	714	None
Cold storage	1	Spring	15 min	1 hr 15 min	0	None
	2	Spring	15 min	1 hr 5 min	11	Increase
	3	Summer	15 min	1 hr 30 min	122	Increase
	4	Summer	10 min	2 hr 15 min	130	Increase
Chilled food	1	Spring	2 hr	15 min	0	None
	2	Spring	2 hr	3 hr	0	None
	3	Summer	2 hr	3 hr	0	None
Frozen food	1	Spring	20 min	55 min	238	None
	2	Spring	20 min	1 hr 55 min	235	None

Conclusions

As SEM and DR programs expand, program administrators must realize that EE and DR interaction is DR product- and system-dependent. The ability to store potential energy is unique in any complex industrial system. DR product criteria, including notification and duration times, affect the system preparation and recovery. The results of this pilot demonstrate the difficulty of generalizing the impact of DR on EE and the need for system-specific testing to understand the interactions. According to Vic Hubbard, the Commercial, Industrial, and Agricultural Sector Lead at Franklin County PUD, a utility participant of the pilot, “Franklin PUD has made significant investments in energy efficiency at many of our industrial end users. Understanding how these energy efficient systems respond during DR events was the most valuable part of this pilot." (Hubbard 2017)

SEM and DR share success factors that can be grouped into three categories: management, personnel, and technical. (1) Management recognizes the value of reducing energy intensity, and provides resources and support. SEM engagements are grounded in strong relationships between plant management and utility management that recognize the nuanced economic and technical considerations for both parties. (2) The energy team understands how energy is consumed and is empowered to test and implement improvements. (3) The plant has the capability to reduce load, and the data are available to monitor performance and communicate results.

This pilot also highlights the value of SEM and energy models that incorporate production data. These models help diagnose energy performance and provide a better estimate of curtailment. Although production data is typically limited to daily time resolutions and estimates of curtailment are made at a finer time resolution, understanding facility operation can be essential to accurately estimating curtailment. The system knowledge gained from SEM also enhances the ability to troubleshoot and optimize DR performance. For example, a thorough review of sub-metered energy data at the municipal water facility provided increased curtailment in later tests. Likewise, a review of control system data resulted in continuous improvement opportunities for both EE and DR. At the frozen food processor, findings from the DR pilot prompted the end user to work with ESI to evaluate a controls system upgrade.

Future Work

Significant efforts were made to develop a pre-cool strategy at the cold storage facility. The intent was to extend the duration of the curtailment without increasing energy use. Time was not available to refine these control strategies. Future work would seek to develop a pre-cooling strategy that provides the desired length of curtailment without impacting energy efficiency.

To better leverage program resources, hardware/software solutions that serve both EE and DR could be evaluated. Demand response concepts could also be incorporated into SEM cohort training as part of a comprehensive energy management curriculum. The capacity value of large energy efficiency projects, along with their DR potential, should also be assessed in the project development phase, and considered in project economics.

Acknowledgements

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