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Turnkey Heating, Ventilating, and Air Conditioning and Lighting Retrofit Solution Combining Energy Efficiency and Demand Response Benefits

Ian Doebber, Michael Deru, and Kim Trenbath

Produced under direction of Bonneville Power Administration by the National Renewable Energy Laboratory (NREL) under Interagency Agreement IAG-14-1922 and Task No WFGB.1000.

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Strategic Partnership Project Report
NREL/TP-5500-65064
April 2016

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List of Acronyms

AC	air conditioning
ASHP	air-source heat pump
BMS	building management system
BPA	Bonneville Power Administration
CBL	customer baseline load
CBSA	Commercial Building Stock Assessment
CI	confidence interval
CO_2	carbon dioxide
DR	demand response
DRAS	demand response automated server
EE	energy efficiency
EWH	electric water heater
ft^2	square foot
HVAC	heating, ventilating, and air conditioning
JACE	Java Application Control Engine
kW	kilowatt
LED	light-emitting diode
LPD	lighting power density
NREL	National Renewable Energy Laboratory
OA	outside air
OAT	outdoor air temperature
PNW	Pacific Northwest
ppm	parts per million
PUD	Public Utilities Department
ROI	return on investment
RTU	rooftop unit
VFD	variable frequency drive
W/ft^2	watts per square foot

Executive Summary

The National Renewable Energy Laboratory (NREL) worked with the Bonneville Power Administration (BPA) Technology Innovation Office to demonstrate a turnkey, retrofit technology that combines demand response (DR) and energy efficiency (EE) benefits for heating, ventilating, and air conditioning (HVAC) as well as lighting in retail buildings. As a secondary benefit, the team controlled various plug loads and electric water heaters (EWHs).

The technology demonstrated was Transformative Wave's eIQ building management system (BMS), which automatically responds to DR signals. The BMS controlled the HVAC rooftop units (RTUs) using the CATALYST retrofit solution from Transformative Wave. The non-HVAC loads were controlled using hardwired and ZigBee wireless communication. The wireless controllers, manufactured by Autani, were used when the electrical layout was too disorganized to leverage the less-expensive hardwired control.

Table ES-1 summarizes the average curtailments measured at each demonstration location. The team projected load sheds are highlighted in red. Beyond the average curtailment during the 4-hr summer events, Table ES-1 provides the summer sheds prior to saturation. Only one summer DR event was conducted at Casino #2 because the building manager opted out of the remaining summer events. Also no winter events took place at Casino # 2 because the building interval meter was not installed in time for the winter events.

Table ES-1. Demonstration locations and average curtailments measured during the two winter and seven summer DR events

(projected DR shed in red)	Building Area	Vintage[a]	*Winter DR Event Sheds (W/ft^2)*	*Summer DR Event Sheds (W/ft^2)*	*Summer Shed prior to Saturation[b] (W/ft^2)*	*Summer Saturation Time[b]*
Drug Store #1	16,210 ft^2	New	No Events (0.6)	0.2–0.3 (1.2)	0.3–0.4	2 h
Drug Store #2	15,400 ft^2	New	0.1–0.2 (0.6)	0.3–0.4 (1.3)	0.4–0.6	2–3 h
Furniture Store #1	27,823 ft^2	New	0.4 (1.1)	0.4–0.9 (1.8)	0.4–0.9	4 h
Furniture Store #2	21,717 ft^2	Old	0.1–0.2 (0.6)	0.5–1.0 (1.0)	0.9–1.5	1 – 2.25 h
Casino #1	11,173 ft^2	Old	0.3–0.5 (0.3)	0.1–0.6 (0.9)	0.2–0.8	0.75–1.5 h
Casino #2	16,653 ft^2	Old	No Events (0.5)	No Events (2.2)	No Events	No Events

[a] New buildings were constructed or retrofitted after 2004 while old buildings were prior to 2004.
[b] Saturation times show how long each building was able to last without compressor cooling.

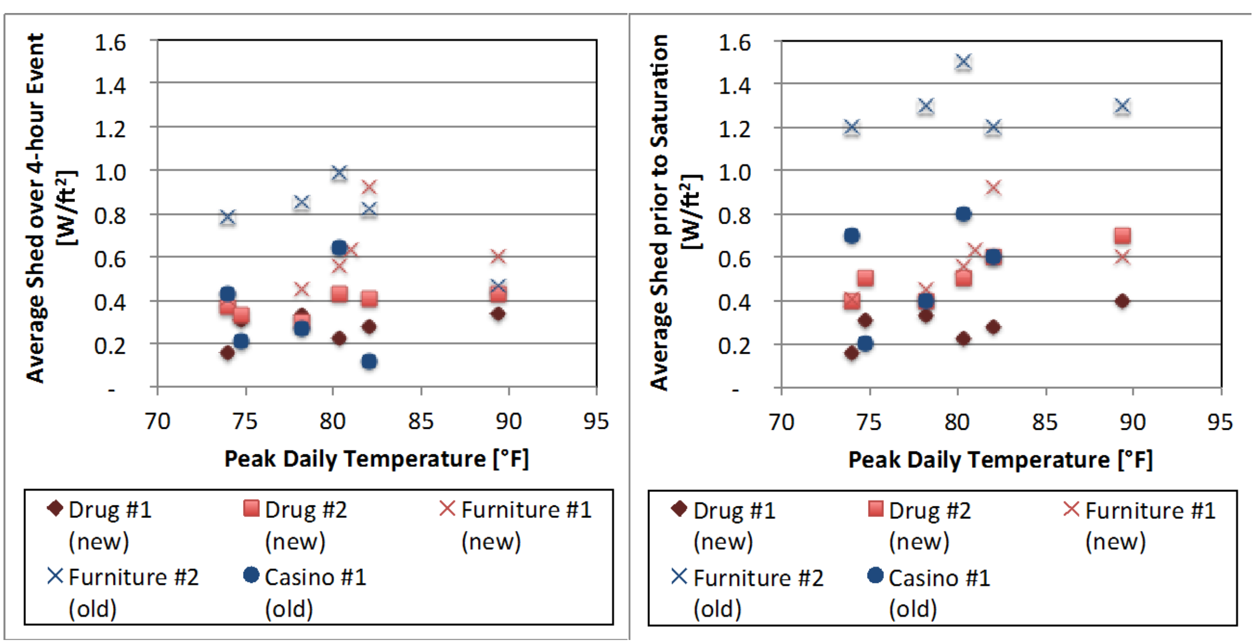
The team originally intended to include summer DR events given 10-minute notification. However, the team ran day-ahead events only because BPA was most interested in how DR could benefit distribution congestion in urban locations, and there was not time to complete the 10-minute DR events.

Two winter DR events were conducted in January while the peak daily temperature ranged from 46°–50°F. All the locations had natural gas heat, so the winter shed was almost entirely based on the lighting curtailment. This is common for most commercial buildings because only 10% of all Pacific Northwest retail and office buildings use electric heat (Navigant 2014). The team found that the supply fan power reduction during the winter DR events resulted in a 0.1–0.2 W/ft^2 reduction across all six locations. The plug loads and EWH added negligible shed.

The average shed across the 1-hour and 3-hour winter events was 0.2 W/ft^2 (ES-2a). Furniture Store #1 achieved the largest shed of 0.4 W/ft^2 because the team could leverage its organized electrical layout and its abnormally large lighting power density of 2.0 W/ft^2. Furniture Store #2 achieved the smallest shed of 0.1–0.2 W/ft^2 because it is an older store with less well organized lighting circuiting and wireless controllers were used to turn off 23 lamp fixtures throughout the store.

Seven day-ahead summer events were conducted from 2:30 to 6:30 p.m. The buildings were pre-cooled by 2°F below the normal set point starting at 12:30 p.m. (2 hours prior to the event) in preparation for the long DR event. The RTU cooling set point was changed to 4°F above the normal set point during the 4-hour DR event. The team calculated how long each building was able to float before the first compressor came back on to meet the warmer set point, which is defined as the *saturation time*.

Figure ES-1a shows the average shed maintained across the 4-hour events. Figure ES-1b shows the average shed prior to when the building saturated. The older buildings saturated much faster between 0.75 to 1.5 hours. The newer buildings saturated between 2 to 4 hours. Furniture Store #1 was able to last the entire 4-hours for all the summer events without needing compressors.



(a) **(b)**

Figure ES-1. Average DR curtailments across the seven summer events: (a) averaged across the 4-hour event; (b) averaged prior to saturation

The main lessons learned are summarized below.

- The newer stores (Table ES-1) showed a tighter distribution across the range of peak daily temperatures. The older stores showed mixed results (Figure ES-2b) with Furniture Store #2 achieving larger sheds than Casino #2.
- Furniture Store #2 achieved larger sheds because it had four compressor stages (two RTUs with two compressors each) serving an older building with lower-performing RTUs and envelopes (insulation and airtightness). Even though the newer buildings had greater lighting curtailments, they needed less compressor cooling. In all cases, the RTU curtailment was the dominant DR asset for the summer events.
- All of the buildings (except for Furniture Store #1 which did not need compressor cooling) exhibited load shed within the 0.4–0.6 W/ft^2 on the one summer event at a 90°F because they were all using compressor cooling at this high ambient temperature. When the peak temperature was lower than 85°F, these buildings required vastly different levels of compressor cooling.
- The older buildings saturated much faster (around 1 hour) than the newer buildings (2–4 hours). Prior to saturation, the other buildings maintained a significantly larger average shed of 0.92 W/ft^2, mainly due to Furniture Store #2's larger sheds. The newer buildings achieved an average shed of 0.46 W/ft^2 prior to saturation.
- Assuming 100% market penetration across all PNW commercial floor space served by RTUs, the team extrapolated that a winter DR event, up to 4-hours would be 425 MW based on 0.22 W/ft^2 for area served by AC RTUs and 0.60 W/ft^2 for area served by ASHP RTUs. A summer day-ahead DR event up to 4-hours would be 753 MW based on 0.41 W/ft^2 for new buildings and 0.56 W/ft^2 for older buildings. A summer day-ahead DR event up to 1-hour would be 1,101 MW based on 0.46 for newer buildings and 0.92 W/ft^2 for older buildings.

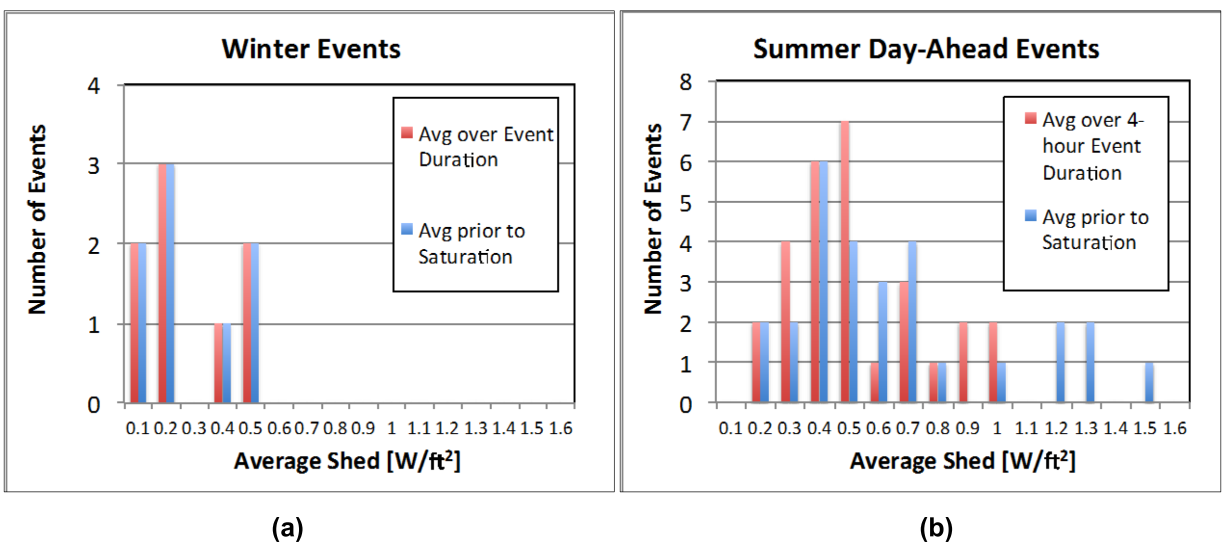


Figure ES-2. Histogram of curtailments: (a) winter events; (b) summer events

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1 Introduction

The National Renewable Energy Laboratory (NREL) worked with the Bonneville Power Administration's (BPA's) Technology Innovation Office[1] to demonstrate a turnkey, retrofit package that combines demand response (DR) and energy efficiency (EE) for heating, ventilating, and air conditioning (HVAC); lighting; plug loads; and electric water heaters (EWHs) in retail buildings. The technology demonstrated was Transformative Wave's eIQ[2] building management system (BMS), responding to DR signals. The eIQ controlled the HVAC rooftop units (RTUs) using the CATALYST retrofit solution[3] developed by Transformative Wave. The eIQ controlled the non-HVAC loads using both wired and wireless (ZigBee[4]) communication. Autani[5] wireless controllers managed the lighting, EWHs, and plug loads.

This field demonstration was conducted because BPA member utilities experience significant demand from commercial buildings smaller than 100,000 ft^2. These small to medium size buildings represent approximately 80% of the Pacific Northwest's total commercial area (Navigant 2014). BPA could provide—or incentive an aggregator to provide—energy and ancillary services by controlling these end uses through a DR signal sent to a BMS.

BPA and BPA member utilities currently provide incentives for EE technologies covering RTUs, lighting, and EWHs. EE incentives for wireless power strips to control plug loads are on the horizon. Yet few demonstrations have evaluated the ability to leverage these end uses for DR.

NREL and Transformative Wave conducted "proof-of-concept" field demonstrations in six retail locations throughout the Seattle metro area. The project goals were to:

- Target summer DR curtailments of 0.9 watts per square foot (W/ft^2) given 10-minute notice and 1.7 W/ft^2 given day-ahead (16 hours) notice.
- Target winter DR curtailments of 0.7 W/ft^2 for either 10-minute or day-ahead notices.
- Achieve a simple payback of 6 years based on the EE savings, excluding utility incentives.

By providing DR and EE benefits, this retrofit package would have a greater likelihood of receiving utility incentives. Ideally, these incentives would reduce the simple payback to less than 3 years. NREL has found a 3-year simple payback to be the typical return-on-investment (ROI) threshold desired by building owners when they pursue EE technologies.

This report begins by summarizing the hardware that makes up the retrofit package (Section 2), its sequence of operation during a DR event (Section 3), and the targeted DR asset at each demonstration location (Section 4). Section 5 details how the team calculated each DR event's curtailment (or "shed") using two estimates of the customer baseline load (CBL). Section 6 highlights lessons learned from the two winter and seven summer DR events. The team projects what the aggregated DR resource would be across the Pacific Northwest (PNW) region in Section 7. Section 8 summarizes the ROI of this EE and DR technology.

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[1] www.bpa.gov/Doing%20Business/TechnologyInnovation/Pages/default.aspx
[2] http://transformativewave.com/eIQ
[3] http://transformativewave.com/catalyst
[4] www.zigbee.org
[5] www.autani.com

2 Hardware and Control

During the DR events, the eIQ BMS curtailed RTUs, lighting, plug loads (e.g., drink coolers and vending machines), and EWHs. The following section summarizes the eIQ platform, the CATALYST advanced RTU controller, and the Autani wireless controllers. Finally, subsection 2.4 details the sequence of operation used to shed each asset during the winter and summer DR events.

2.1 eIQ Building Management System

Transformative Wave controlled the RTUs, lighting, plug loads, and EWHs using its eIQ BMS. This company typically packages the eIQ BMS with its CATALYST solution for clients who do not have a BMS and see the value in it. The eIQ platform provides building owners and managers on-line access to control and monitor their RTUs and other building equipment through a simple yet comprehensive interface shown in Figure 1.

Figure 1. eIQ BMS screenshot of real-time performance monitoring

Beyond establishing set points and schedules, building owners and managers are provided feedback about equipment fault detection and energy use. Automated alarming can be sent over email or text. The eIQ focuses on actionable alarms such that store staff or technicians are provided detailed instructions about what needs to be fixed.

eIQ users can quickly assess store operation across a large portfolio and then dive deeply as needed to investigate individual equipment operation. This functionality ranges from monitoring a lighting circuit's on/off operation to seeing the RTUs' real-time supply air temperatures or historical duty cycling of individual compressors.

2.1.1 Lighting, Plug Load, and Electric Water Heater Control

For this project, Transformative Wave customized an on-line dashboard for each demonstration location. Figure 2 shows how the dashboard summarizes the control of the various lighting circuits, plug loads, and RTUs. The "command" light indicates whether the asset is on or off. The "shed" light indicates whether the asset is currently being curtailed. The power draw of each asset is also displayed. The upper left table summarizes whether the building is in a DR event and if the building owner has decided to opt out of the event. The current weather is displayed in the lower left. The real-time building power is provided in a graphical format.

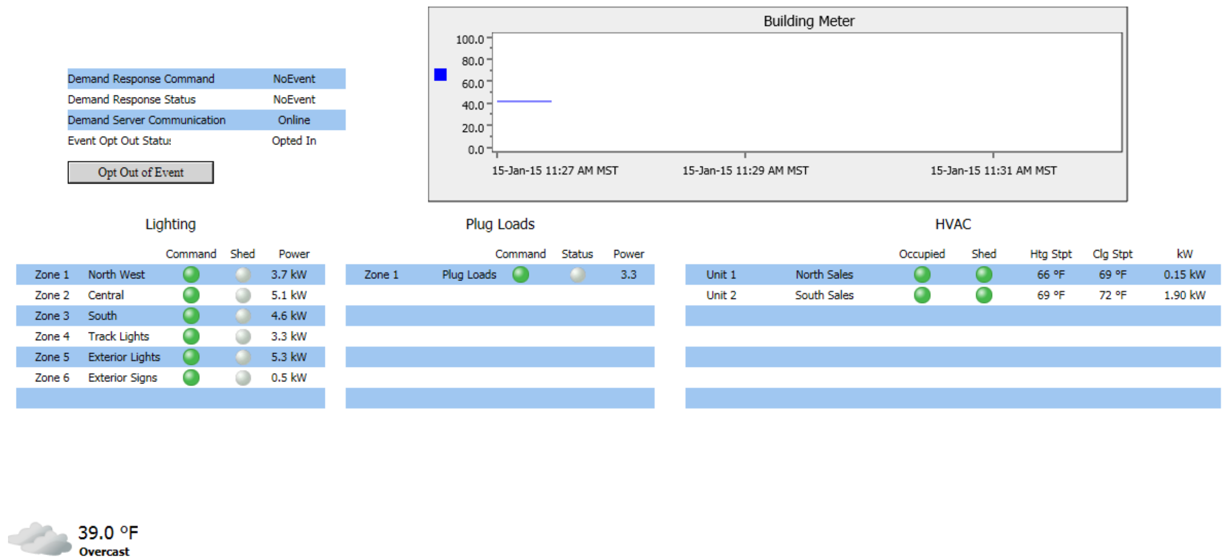


Figure 2. eIQ dashboard for Furniture Store #2

For the newer buildings (both drug stores and Furniture Store #1), which were built or retrofitted within the last 10 years, the non-HVAC assets were controlled by a hard-wired control panel located next to the circuit breakers in the electrical rooms. For the older buildings (both casinos and Furniture Store #2), the electrical layout was disorganized and not centralized. This is typical of older buildings as they expand or change function over time. Consequently, in lieu of a hard-wired control, the eIQ communicated with the ZigBee wireless controllers from Autani. Although more expensive than the hardwired approach, the Autani controllers provided the flexibility of a central communication router in the electrical room that wirelessly controls non-HVAC assets throughout the building.

The eIQ-enabled Web-based control and real-time monitoring of these non-HVAC loads is shown in Figure 2. The building owners and managers could schedule and monitor the operation of their HVAC and non-HVAC end uses. They could also opt out of a DR event by clicking the button on their eIQ dashboard page.

2.1.2 Demand Response Communication Topology

Figure 3 shows the communication topology. A separate segment of Transformative Wave's server acted as the demand response automated server (DRAS)—labeled "DR Supervisor" in Figure 3—by sending DR signals directly to each store's Java Application Control Engine (JACE) controller. For both drug stores, the DR signal was sent over their local area networks (LANs), saving the building owner money by eliminating the cellular modem and monthly cellular service. The furniture stores and casinos received the DR signal over the Verizon Code Division Multiple Access (CDMA) network.

Although the project did not implement OpenADR communication, the DR signal was configured according to this protocol. Per the OpenADR version 2.0,[6] the DR signals stated the start time of the event, the event duration, and the event type (10-minute or day-ahead). The event type was important because it initiated a different sequence of operations—the day-ahead event type used a precharge HVAC operation to prepare the conditioned space for a set point shift, for example.

Once it received the signal, each JACE made control decisions using its stored sequence of operation. Note that the sequence of operation on each JACE was updated at least hourly based on changes made on the eIQ website by a building owner or manager. Each JACE then communicated control to the hard-wired control panels that managed the non-HVAC loads and the CATALYST controllers using the Sedona protocol. For the two casinos and Furniture Store #2 with the Autani wireless equipment, the JACE communicated with the Autani Manager (see Section 1.3) over the BACnet protocol.

The JACE monitored building interval power from a hardwired connection to a pulse input box connected to each building's utility meter. Based on the pulse count, the energy use was calculated every minute. The JACE then calculated and stored the average power draw for each 15-minute interval.

Each lighting, plug load, and EWH communicated its operating status (on/off). The RTU operating information provided real-time to the JACE by the CATALYST controller was much more detailed, including compressor on/off operation, supply temperatures, and carbon dioxide (CO_2) concentrations. This information was cached in the JACE's onboard memory. At least once an hour, the data were sent back to the eIQ servers, where they were stored on an SQL server for data analytic purposes. The team leveraged these stored data to troubleshoot the DR sequences and calculate the curtailment achieved for each DR event. This data transfer between each JACE and the eIQ servers used the Niagara communication protocol.

Two separate eIQ servers controlled all six locations. One eIQ server controlled both drug and furniture stores. A second eIQ server controlled the casinos.

[6] www.openadr.org

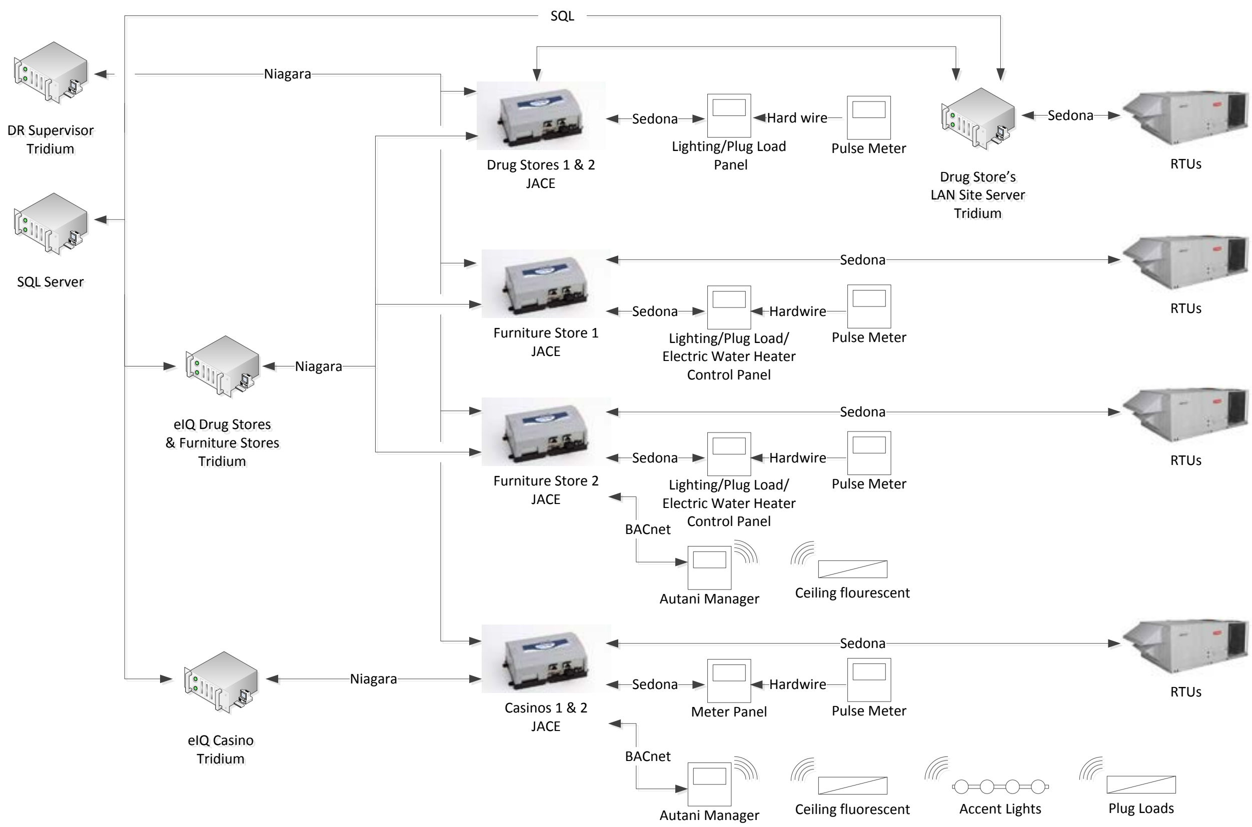


Figure 3. eIQ platform DR communication topology

2.2 CATALYST Advanced Rooftop Unit Controller

Transformative Wave's eIQ BMS communicated with its CATALYST technology controlling each of the 31 RTUs across the six demonstration sites. When not operating during a DR event, the CATALYST provides energy savings through multiple advanced control features.

- **Multispeed supply fan operation**—The CATALYST varies the speed of the supply fan using a variable frequency drive (VFD). As shown in Table 1, it maintains a different fan speed for each operational mode of the RTU. Fortunately, due to the fan affinity laws, the fan power reduces at a near cubic rate with respect to the fan speed. For instance, with the fan speed setting at 75%, the fan power is reduced by 50%.

Table 1. Fan Speed and Power at Different RTU Operational Modes

RTU Operation	Fan Speed Setting (% of Maximum VFD Speed)	Fan Power Reduction from Maximum Speed
Cooling Stage 2	90%	25%
Cooling Stage 1	75%	50%
Ventilation Mode (fan only)	40%	85%
Heating Stage 1	75%	50%
Heating Stage 2	90%	25%

- **Demand controlled ventilation**—A CO_2 sensor in the return air stream measures the CO_2 concentration, which represents the CO_2 concentration in the conditioned space. The CATALYST modulates the outdoor air (OA) damper to maintain the minimum ventilation rates according to ASHRAE 62.1, version 2010. If the CO_2 concentration exceeds 1,000 parts per million (ppm), the CATALYST opens the OA damper to bring in more fresh air.

  During the demonstration period, the six buildings' CO_2 concentration never exceeded 750 ppm. Therefore, none required additional ventilation air beyond the ASHRAE 62.1 minimum OA flow rate per square foot requirement (Ventilation Rate Procedure). Based on other HVAC field demonstrations, NREL has found this to be typical for retail buildings in which the number of occupants relative to the volume of conditioned space is small. As a result, for these six sites, the CATALYST reduced heating energy in the winter and cooling energy in the summer by not overventilating the buildings while still maintaining sufficient air quality according to ASHRAE Standard 62.1.

- **Integrated, differential dry-bulb economizing with predictive control**—The CATALYST uses differential dry-bulb control for integrated economizing. It also includes a 60°F ambient dew point lockout to prevent bringing in too much moisture. This was especially important for the drug stores, which had refrigerated cases. Note that for grocery store applications, Transformative Wave reduces the dew point lockout to 55°F or lower to minimize the latent load on the refrigeration system.

  The CATALYST also includes predictive economizing control. It calculates when the building has a "cooling disposition" and starts economizing before the thermostat calls for cooling. This control increases the number of economizing hours throughout the year, offsetting the number of hours that compressors are needed.

Compared to the control of the non-HVAC end uses, the CATALYST provides the lion's share of the energy savings of this turnkey, packaged retrofit solution combining EE and DR benefits.

The CATALYST energy savings have been extensively validated by many third-party studies. More specifically, U.S. Department of Energy, utility, and U.S. Department of Defense field demonstrations have shown significant HVAC energy savings. Based on these field demonstrations, BPA and BPA member utilities provide significant, streamlined rebates for CATALYST and eIQ installations. For example, some rebates provided by the BPA and

Snohomish County Public Utilities Department (PUD) exceed 70% of the installation cost of the CATALYST and eIQ. Three of these studies are summarized below.

- The field demonstration by the Pacific Northwest National Laboratory, sponsored by BPA and the U.S. Department of Energy, found that the CATALYST yielded annual HVAC energy savings of 22% to 90%, with an average of 57%. This was across 66 RTUs on eight buildings in four U.S. climates (Wang 2013).
- The field demonstration by BPA revealed that the CATALYST system reduced the annual HVAC energy by 45% for two 15-ton RTUs serving a retail store in the PNW (BPA 2013).
- NREL conducted another field demonstration for the Navy in Hawaii (Doebber et al. 2014). Beyond energy savings, NREL worked with Transformative Wave to quantify the CATALYST's DR potential during summertime cooling. The team found that the CATALYST provided a DR resource of 0.4 to 0.6 W/ft^2 on a large, 70,000 ft^2 dry-goods retail store solely controlling RTUs (no lighting, plug load, or EWH DR assets).

Figure 4 shows the CATALYST controller mounted to the side of the RTU. The blue control wire connects to the VFD controlling the supply fan. The pink wire shows the supply air temperature sensor, the yellow wire indicates the return air temperature sensor, and the remaining control wires control the operation of the compressors. Although not shown here, the CATALYST controls the outdoor air damper and has an ambient temperature and relative humidity sensor.

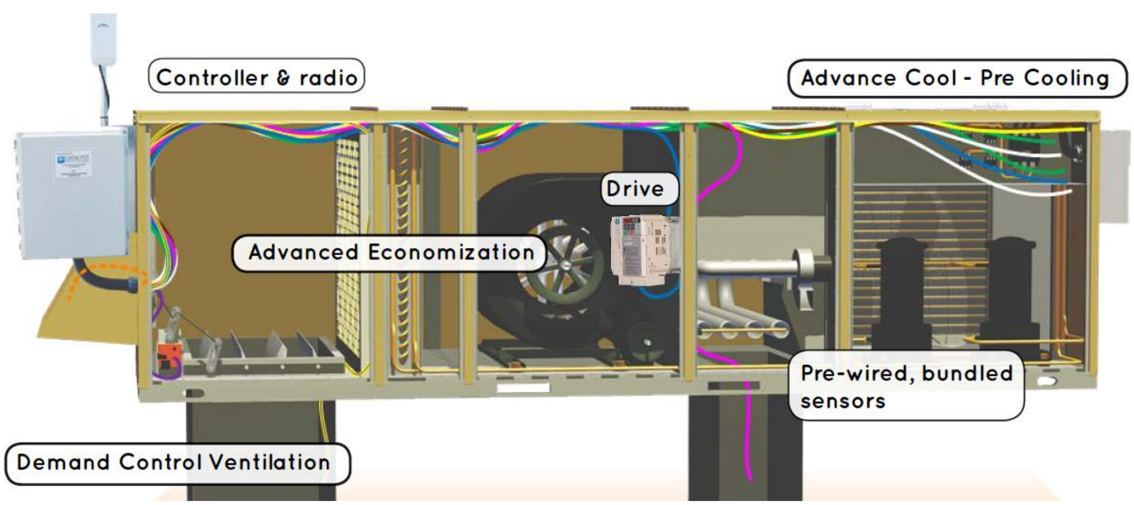


Figure 4. CATALYST RTU schematic

2.3 Autani Wireless Lighting, Electric Water Heater, and Plug Load Control

The team leveraged Autani hardware for lighting, plug load, and EWH control at both casinos and at Furniture Store #2. Autani is located in Columbia, Maryland, and provides wireless automation hardware for lighting, HVAC, plug load, networked personal computers, and overhead fan applications. Autani uses a 2.4-GHz mesh network based on the ZigBee protocol for its communication. Autani also provides wireless, revenue-grade power meters for measurement and verification applications.

Although Autani's software provides local and Web-based access to it hardware, Transformative Wave programmed the eIQ to enable the same scheduling and monitoring through their own Web-based user interface. For example, Figure 2 shows a screen shot of all the controlled equipment at Furniture Store #2, including the lighting, EWH, and plug loads using Autani wireless devices. One of the main reasons Transformative Wave chose Autani was because of its ability to connect to a third party's BMS using the BACnet IP, Tridium Niagrara, or ModBus communication protocols. For this project, Transformative Wave used the BACnet protocol to communicate with Autani. More information can be found at www.autani.com. Appendix E provides a summary of the Autani hardware and wireless controllers the team used.

3 Demand Response Sequence of Operation

This section details the sequence of operation for the summer and winter DR events for all six locations. Section 3.1 summarizes the results of testing various DR sequences with the CATALYST system during a field demonstration managed by NREL for the Navy used as cost share for this project. The lessons learned from the Navy project were leveraged to configure the DR sequence of operation for this field demonstration.

3.1 Test of CATALYST Demand Response Sequence with the Navy

From 2013 to 2014, NREL conducted a field demonstration of the CATALYST with eIQ technology on 11 RTUs across three buildings at Joint Base Pearl Harbor-Hickam in Hawaii for the Naval Facilities Engineering Command (Doebber et al. 2014). Beyond energy savings, NREL evaluated the DR capability of the CATALYST system at the largest of the three buildings, a 70,000-ft^2 big box retail building served by nine RTUs. Every Tuesday, Thursday, and Saturday throughout the demonstration period, from 3 p.m. to 5 p.m., the CATALYST system altered its sequence of operation in order to minimize RTU power use.

Table 2 and Figure 5 summarize the results, which resulted in two interesting findings:

- Precooling 1 hour prior to the DR event resulted in a new, larger peak demand, which might increase a building's demand charge each month. Then a rebound occurred at the end of the DR event.
- The team programmed July to start cooling to reach the occupancy set point at 1 a.m. instead of 5 a.m. Consequently, July had a significantly lower overall power demand profile along with a lower precool spike and rebound.

Table 2. NREL Demonstration of CATATLYST DR Sequence in Hawaii

	Daily Average Dry-Bulb	Normal Catalyst Operation 3–5 p.m. Peak	Day-Ahead DR Sequence 3–5 p.m. Peak	Peak Demand Reduction
July	79.2°F	118 kW	97 kW	21 kW (0.3 W/ft^2)
August	80.3°F	154 kW	112 kW	42 kW (0.6 W/ft^2)
September	79.7°F	152 kW	126 kW	26 kW (0.4 W/ft^2)

Based on these results, the team decided to extend the precooling from 1 to 2 hours for this project. The team conjectured that this extended precooling time would allow the HVAC to precondition the air and the surrounding interior surfaces. The cooler the interior surfaces, the longer thermal comfort will be maintained despite letting the space float up to warmer temperatures during the DR event. The long-wave radiative heat exchange between the building occupants and the surrounding surfaces can have just as significant an impact on thermal comfort as the surrounding air temperature.

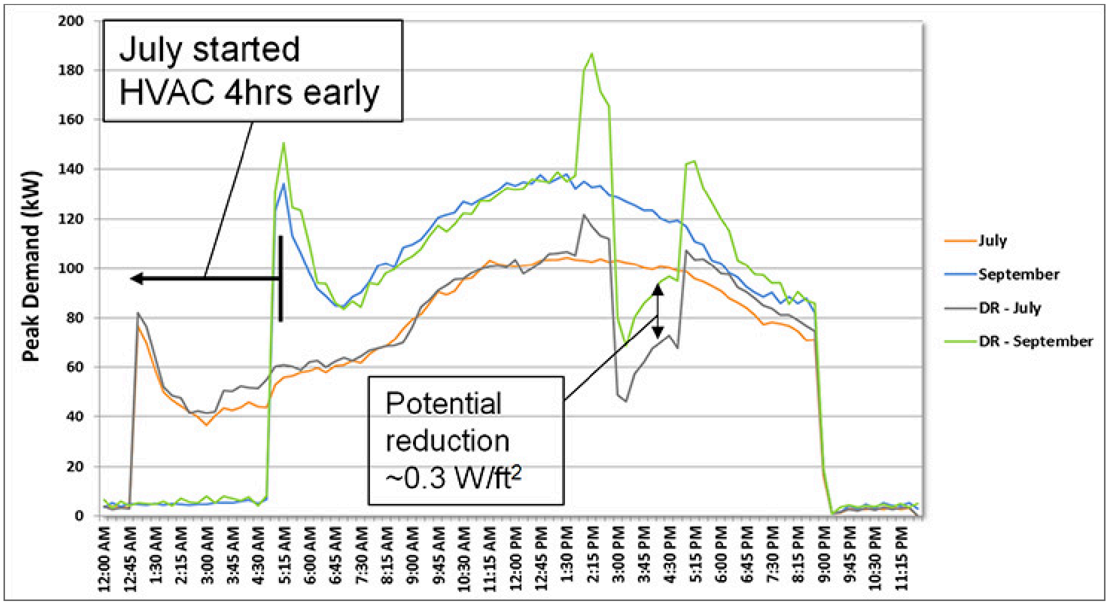


Figure 5. HVAC baseline and DR load profiles for a 70,000-ft^2 retail building during a Navy field demonstration in Hawaii

3.2 Demand Response Operation

The non-HVAC DR resources (lighting, plug loads, and EWHs) were either turned off or prevented from turning on during the DR events.

The eIQ BMS operated using a "capacity sharing sequence" for the duration of the DR event. It coordinated cooling/heating operation so the space with the highest load was allowed to operate its RTU to full cooling/heating capacity (second stage if a two-stage unit). As the load in the space changed, the shared capacity was shifted so the RTUs with the highest load (largest delta between space temperature and set point) would be allowed to operate. At the start of the DR event, priority was given to all the RTUs, such that they could operate using first-stage cooling before the capacity sharing enabled certain units to use both stages of cooling. Any change in operation was locked out for 5 minutes to protect the compressors.

3.3 Building Occupant Opt Out

For the non-HVAC assets (lighting, plug loads, and EWHs), building occupants were able to override each asset independently. They could opt out of an event using the local light switch on the lighting controller in the electrical room or through the Web-based eIQ user interface that the building managers could access through their own computers. There were room-based "opt-out" controllers. For example, occupants could use the wall switch in the break room to opt out.

The HVAC allowed both a manual and an automatic opt out. When the space temperature exceeded 78°F, each RTU automatically opted out of the DR event. The building managers could opt out each RTU separately through the eIQ Web-based interface on their own computers or the touch-screen display of the eIQ controller located in each building's electrical room.

3.4 Winter Sequence of Operation

For the day-ahead events (16 hour notice), during the DR event, the temperature set point was reduced 2°F lower than the normal operation set point. Once the DR event ended, the normal operating heating set point was reestablished. Pre-heating the space was not conducted.

All the RTUs for this demonstration were gas-pack units such that they did not use electricity for heating purposes (compared to heat pumps or electric resistance heating). The only HVAC power reduction during the winter DR events came from the supply fans operating at reduced speed. Table 1 showed that the fan power was reduced by 25% under second stage (heating or cooling), 50% under first-stage (heating or cooling), and 85% under ventilation mode operations. Appendix G quantifies the projected curtailments from the supply fans.

3.5 Summer Sequence of Operation

The day-ahead events (16 hours notification based on BPA's guidance) used 2-hour precooling during the summer events instead of a 1-hour precharge as was used for the Navy field demonstration (see Section 2.1 above). The purpose of the pre-event operation (defined as *pre-event*) was to provide the building with a coast period during the DR event. The cooling set point temperature was lowered by 2°F during the pre-event. During the DR event, the cooling set point temperature was increased 4°F higher than the pre-event set point (2°F higher than the normal set point). After the DR event, the set point returned to its normal operation.

4 Demonstration Sites

The field demonstration included six retail locations located within a 2-hour drive of downtown Seattle. Table 3 summarizes the area of each building and the DR projections at the beginning of the project based on a detailed audit of the HVAC, lighting, plug load, and EWH equipment. Appendix A summarizes the hardware and controls at each location.

Table 3. Demonstration Locations and DR Projections

	Building Area	Summer DR Day-Ahead Projection[a]	Summer DR 10-Minute Projection[a]	Winter DR Projections[1]
Drug Store #1	16,210 ft^2	1.2 W/ft^2 (19 kW)	0.9 W/ft^2 (14 kW)	0.6 W/ft^2 (9 kW)
Drug Store #2	15,400 ft^2	1.3 W/ft^2 (20 kW)	1.0 W/ft^2 (15 kW)	0.6 W/ft^2 (10 kW)
Furniture Store #1	27,823 ft^2	1.8 W/ft^2 (49 kW)	1.2 W/ft^2 (33 kW)	1.1 W/ft^2 (29 kW)
Furniture Store #2	21,717 ft^2	1.0 W/ft^2 (23 kW)	0.8 W/ft^2 (18 kW)	0.6 W/ft^2 (13 kW)
Casino #1	11,173 ft^2	0.9 W/ft^2 (10 kW)	0.6 W/ft^2 (7 kW)	0.3 W/ft^2 (4 kW)
Casino #2	16,653 ft^2	2.2 W/ft^2 (37 kW)	1.4 W/ft^2 (23 kW)	0.5 W/ft^2 (9 kW)
Total/Average	107,259 ft^2	1.5 W/ft^2 (158 kW)	1.0 W/ft^2 (109 kW)	0.7 W/ft^2 (73 kW)

[a] Projection based on the RTUs, lighting, plug loads, and EWHs curtailed by the eIQ platform

5 Calculating the Customer Baseline Load

A building's measured power profile during a DR event needs a baseline to compare against in order to calculate its shed response, which the team called the modeled shed. This baseline is typically defined as the CBL. It represents the behavior of the building had the DR event not occurred.

Unfortunately, the CBL cannot be measured—it must be estimated using historical interval data. The following section compares two methods for estimating the CBL, the 10-day rolling average method and the multilinear regression method. The team argues that the regression method is more robust because it explicitly accounts for daily rhythmic behaviors, weekly rhythmic behaviors, and weather. The rolling average method accounts for daily rhythmic behavior only. Finally, the team describes the methodology for quantifying the uncertainty in the model shed using the 95% confidence interval of the estimated CBL.

5.1 10-Day Rolling Average—Method 1

A common way to estimate the CBL is using the 10-day rolling average method (Goldberg 2013). This method calculates each 15-minute interval of the day according to the average power draw for the same 15-minute interval from the prior 10 business days (not including holidays or days when DR events occurred). Although this method captures daily rhythmic behavior, it ignores weekly rhythms such as that businesses may close earlier on Fridays. It also ignores the impacts of weather, such as when the day of the DR event is drastically hotter or colder than the prior days. In fact, DR events will typically occur on days with extreme weather. For each DR event, the team calculated the minimum, mean, and maximum shed response using this method and compared it to the calculated model shed using the regression approach to estimating the CBL.

5.2 Multilinear Regression—Method 2

The team also calculated the CBL using a modified approach to a multilinear regression method developed at the Lawrence Berkeley National Laboratory (Mathieu et al. 2011). This method explicitly accounts for three major influences on a building's power profile.

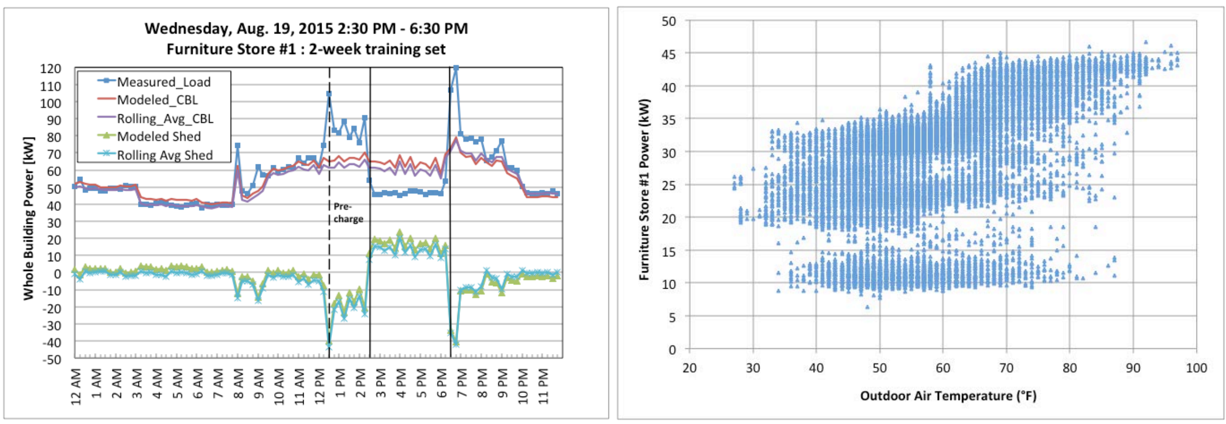
- **Daily rhythmic behavior**. Each 15-minute interval of the day received its own binary variable in the regression model, resulting in 96 binary variables (24 hours per day times four 15-minute intervals per hour). These binary variables enabled the regression to capture dramatic changes in power use as long as they consistently occurred in the days prior to the DR event.

  For example, the DR event in Figure 6a shows that Furniture Store #1 realized a significant increase in power at 8 a.m. when the HVAC system turned on as it transitioned from unoccupied to occupied operation. By accounting for each interval of the day with its own variable, the regression method can capture these consistent, yet drastic, changes in the power profile.

- **Weekly rhythmic behavior**. The team also included an independent variable that treated weekdays as a categorical variable equivalent to coding each weekday as a binary variable. This enabled the regression method to capture weekly rhythmic behavior. For example, both casinos were open 24 hours a day for all weekdays except Monday and Tuesday, when they were closed from 6 to 10 a.m. By comparison, the 10-day rolling average method would have smoothed over this and treated each weekday the same.

- **Outdoor air temperature**. The weather has a dramatic effect on a building's power profile. Outdoor air temperature (OAT) best captures weather impacts. OAT is a great variable to regress against because it is easy to measure (as long as the sensor is properly aspirated) and readily available from local weather stations around the country.

The regression model structure for this project was different than that developed by Mathieu et al. (2011). They assigned a unique variable for each interval of the week. Therefore, their regression model had 672 variables to capture daily and weekly rhythms. By comparison, this model had 103 variables. In addition, Mathieu used a binned approach to capture the OAT impacts. Instead, the team treated OAT as a continuous variable with polynomial terms. The team's regression model had significantly fewer variables, which resulted in greater degrees of freedom.



(a) **(b)**

Figure 6. Calculating the CBL for Furniture Store #1: (a) DR event on August 19, 2015; (b) interval power versus OAT

Figure 6b shows how the power draw by Furniture Store #1 had a curved correlation to OAT. Buildings typically experience a dogleg in their power versus OAT profile, which is called the *cooling balance point*—the OAT at which the building changes its behavior from cooling operation to ventilation-only operation (supply fans provide fresh air with no compressor-based cooling). Note that buildings with electric heating (heat pump or electric resistance) will have a heating balance point at the OAT when the building switches from ventilation-only to heating operation.

5.3 Quantifying Uncertainty

Because the team estimated the CBL using the methods above, the model shed—calculated using the CBL—has some uncertainty. Its uncertainty consists of two underlying factors: (1) how well the CBL represents the historical interval data used to train the regression model, and (2) the uncertainty in how well the building's behavior during the day of the DR event matches its behavior during the previous days. Did some uncharacteristic behavior occur that did not occur in the historical interval data used to estimate the CBL?

The following approach summarized in this section captures the first type of uncertainty. Capturing the second type of uncertainty is not possible because the regression method is based on the historical data. In other words, if the historical data do not experience the same behavior as those of the DR event day, the CBL will not capture that unique behavior. The only way to mitigate the second type of uncertainty is to integrate a BMS controlling the majority of the loads within the building. The more the building owners can shift control of the lighting, HVAC, and plug loads away from the occupants toward scheduled automation, the more accurate both the 10-day rolling average and regression model will be in estimating the CBL.

The team quantified the first type of uncertainty by calculating the 95% confidence interval (CI) about the mean model shed. A tight CI means that a utility (or aggregator) is more confident that the building met its contractual shed commitment. Conversely, if the CIs are large, they should reassess their contractual agreement, even if the mean model shed exceeded the agreed-upon shed commitment. Therefore, the CIs are just as important as the magnitude of the shed.

The team's method for calculating the CI is best explained using the DR event at Furniture Store #1 on August 19, 2015 (Figure 6). Table 4 shows that the mean model shed was 16.7 kilowatts (kW) (0.6 W/ft^2) for the 4-hour DR event (2:30 to 6:30 p.m.). The team used the following steps to calculate the 95% CI.

- **Step 1.** For each of the 20 days prior (July 22 through August 18), excluding weekends, holidays, and days with DR events, the team calculated the CBL using the regression method above. For example, July 22's unique CBL was based on a 2-week training set (10 days) from July 8 through July 21.
- **Step 2.** Based on the time of the DR event, the mean error (unmodeled load) between the CBL and the measured load was calculated for each day. On these days, because no DR event occurred, the team could calculate the mean error using the building's actual power profile.

  For example, on July 22, the mean error between the CBL and the measured load from 2:30-6:30 p.m. was 2.85 kW.
- **Step 3.** The team calculated the standard deviation (StDev) across the 20 mean errors from the previous step. For this DR event, Table 5 shows the StDev equaling 4.60 kW.
- **Step 4.** Finally, the team multiplied the T-Statistic (Tstat) based on 19 degrees of freedom (20 minus 1) and a 95% confidence level to the StDev from Step 3. Note that the Tstat is how the team scaled the CI. For example, if the team were interested in a 50% confidence level, the team would use the Tstat of 1.066, effectively half that of the 95% confidence level.

Table 4. Modeled Shed from 2:30 to 6:30 p.m.

	Total	Normalized
Min	11.2 kW	0.4 W/ft^2
Mean	16.7 kW	0.6 W/ft^2
Max	23.9 kW	0.9 W/ft^2

Table 5. Uncertainty Analysis Calculating 95% Confidence Intervals

	Total	Normalized
StdDev of mean shed over 20 prior days	4.60	-
Tstat based on 95% confidence level	2.09	-
95% confidence interval (StdDev * Tstat)	9.63 kW	0.26 W/ft^2
Mean shed with 95% confidence intervals	16.7 ±9.63 kW	0.6 ±0.3 W/ft^2

Utilities (and aggregators) have a better understanding of this DR event at Furniture Store #1 knowing that its mean model shed was 7.1–26.4 kW based on a 95% CI. Again, this CI captures the first type of uncertainty explained above. It is the team's best guess at quantifying the accuracy of the CBL in estimating the historical behavior of the building. It does not capture the second type of uncertainty in which Furniture Store #1 may display uncharacteristic behavior the day of the DR event. Typically this uncharacteristic behavior is due to the building staff overriding the BMS and altering the scheduled operation of the building.

For this demonstration, the team did experience BMS override issues with the employees at Furniture Store #1. During the first 2 months after the installation of the eIQ BMS, employees overrode the lighting controls at the panel, resulting in the lights being left on at night. They also turned certain circuits off during the day. The employees explained that they liked the store lighting better with some of the circuits off once they saw what the store looked like during the DR event.

6 Demand Response Event Summary and Lessons Learned

The team conducted day-ahead events only—no 10-minute events—over the summer. This decision was based on discussions with Frank Brown[7] with the BPA. He requested the team focus on day-ahead events with 16-hour notification because this would be the most applicable for the current transmission and distribution issues BPA member utilities are experiencing during summer heat waves in the Portland and Tri-Cities load centers. He also requested that the team run DR events on consecutive days for at least 3 hours and ideally up to 5 hours in duration.

He stated that the optimal times for the DR events were different depending on the load centers.

- On the east side of the Cascades (Tri-Cities), the need for the end of the DR event is fixed around 6:30 p.m., but the need for the event start is earlier with each successive year. Several years ago, the ideal DR start time was around 3:30 p.m. (3-hour duration). The current ideal DR start time is around 1:30 p.m. (5-hour duration).
- On the west side of the Cascades (namely Portland), the need for the DR event start time is fixed around 2:30 p.m. Yet, the need for the end of the DR event is later with each successive year. The current need is an event end time around 6:30 p.m. (4-hour duration).

To meet the need of both sides of the Cascades, the summer events were 4 hours, 2:30 to 6:30 p.m. Each event had 16-hours notification, so the team started the HVAC precool 2 hours prior, at 12:30 p.m. (see Section 3.5). And in response to Frank Brown's request for consecutive days, the team ran two sets of consecutive events, August 19–20 (2 days) and August 22–24 (3 days).

Table 6 summarizes the two winter and seven summer DR events. Although BPA was interested in weekday DR events only, to take advantage of the warmer weather at the end of the demonstration period, the team ran events on Saturday and Sunday (August 22 and 23). That weekend, peak dry-bulb temperatures were 79°F to 82°F and the skies were mostly clear. Based on each building's operating hours and daily power profiles, the team found the differences between weekday and weekend operation to be negligible. Therefore, the shed on Saturday and Sunday was the same as it had been during a weekday.[8]

Table 7 summarizes the mean curtailments – the average shed across the duration of the DR event. It also summarizes the mean curtailment prior to "saturation," which is the time from the start of the DR event to when at least one compressor comes on. The team labeled the curtailments in this table and the figures in Appendix B as 'Modeled Shed', because it is the difference between the measured load and the Modeled CBL (Section 5.2). The magnitude of the shed can vary significantly during an event. Therefore, Appendix B plots each DR event and highlights the minimum, mean, and maximum curtailment using both the 10-day Rolling Average and Multi-Linear Regression CBL methods (Section 5.1 and 5.2).

[7] Conversation with BPA's Frank Brown and Janice Peterson on April 7, 2015

[8] Both casinos had 24-hour operation for all days except Monday and Tuesday when they were closed from 6 to 10 a.m. Both furniture and drug stores had the same Saturday hours as during the week. For Sunday, Drug Store #2 had the same hours as during the week, Drug Store #1 closed 2 hours earlier (8 p.m. instead of 10 p.m.), and both furniture stores closed 1 hour earlier (8 p.m. instead of 9 p.m.).

Table 6. DR Event Summary

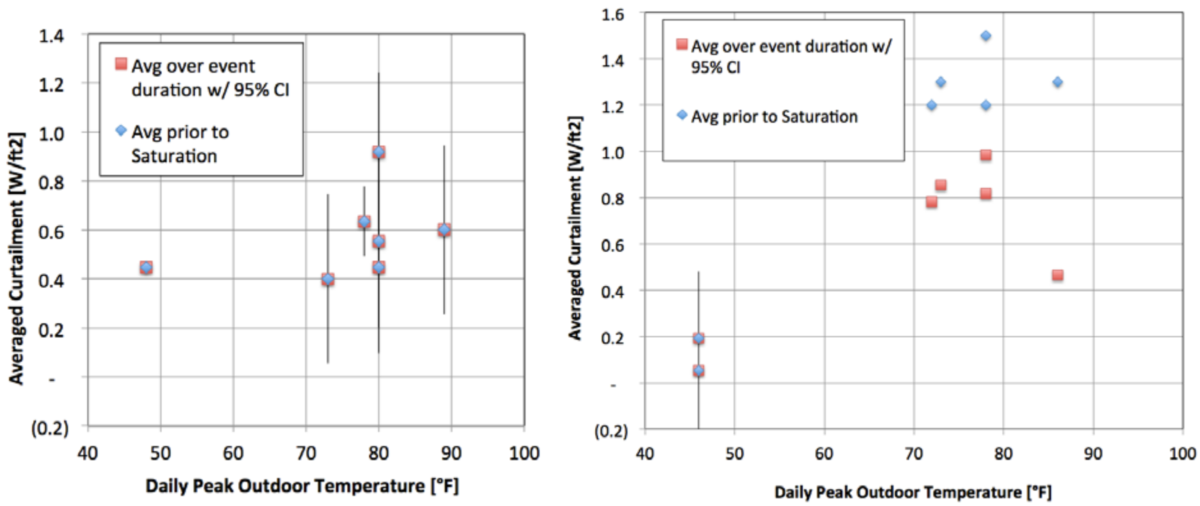
DR #	Date	DR Event Type	Event Time	Event Duration	RTU Precool
1	Jan 7 (Wed)	10-min	5:00 to 6:00 p.m.	1 hour	NA
2	Jan 21 (Wed)	10-min	5:00 to 8:00 p.m.	3 hour	NA
3 to 9	Aug 7 (Fri) Aug 13 (Thur) Aug 19 (Wed) Aug 20 (Thur) Aug 22 (Sat) Aug 23 (Sun) Aug 24 (Mon)	Day-Ahead (16 hour notice)	2:30 to 6:30 p.m.	4 hour	2 hours prior (start at 12:30)

Table 7. DR Event Ranges of the Average Curtailment

(projected DR shed in red)	*Winter DR Events[a] (W/ft²)*	*Summer DR Events[b] (W/ft²)*	*Summer Shed prior to Saturation[c] (W/ft²)*	*Summer Saturation Time[d]*	*Thermostat Set Point Shifts during event[e] (winter events)*	*Daily Peak Temperatures (winter events)*
Drug #1 (newer)	No Events[f] (0.6)	0.2–0.3 (1.2)	0.3–0.4	2 h	72°F to 76°F (68°F to 66°F)	77°–91°F (48–50°F)
Drug #2 (newer)	0.1–0.2 (0.6)	0.3–0.4 (1.3)	0.4–0.6	2–3 h	71°F to 75°F (68° to 66°F)	77°–90°F (46°F)
Furniture #1 (newer)	0.4[g] (1.1)	0.4–0.9 (1.8)	0.4–0.9[h]	4 h[h]	72°F to 76°F (68°F to 66°F)	73°–89°F (46–48°F)
Furniture #2 (older)	0.1–0.2 (0.6)	0.5–1.0 (1.0)	0.9–1.5	1 – 2.25 h	70°F to 74°F (68°F to 66°F)	72°–86°F (46°F)
Casino #1 (older)	0.3–0.5 (0.3)	0.1–0.6 (0.9)	0.2–0.8	0.75–1.5 h	71°F to 75°F (68°F to 66°F)	75°–91°F (48°–50°F)
Casino #2 (older)	No Events[i] (0.5)	No Events[j] (2.2)	No Events[j]	No Events[j]	72°F to 76°F (69° to 67°F)	

[a] Range of the *Modeled Shed* averaged across the duration of the two winter events
[b] Range of the *Modeled Shed* averaged across the duration of the seven summer events
[c] Range of the *Modeled Shed* averaged across the DR event prior to saturation. This represents the maximum shed when the RTUs are in ventilation-only mode with supply fans at 40% speed (no compressor cooling).
[d] Saturation times show how long each building was able to last without compressor cooling.
[e] During the summer pre-charge, the set point was adjusted to 2°F below the typical cooling set-point. During the summer DR event, the set point was adjusted to 4°F above the typical cooling set-point. During the winter DR event, the set-point was adjusted to 2°F below typical heating set-point.
[f] Store employees overrode the DR lighting circuit to be permanently on. No winter sheds occurred.
[g] The staff overrode the DR lighting circuit to be permanently off so no lighting shed on January 21.
[h] Furniture Store #1 used no compressor cooling for the entire 4 hours of all the summer DR events.
[i] Due to difficulties coordinating with the utility, the interval meter was installed after the winter events.
[j] Casino #2 only had one DR event on August 13 but the average *Modeled Shed* was negative, meaning that the control did not work properly. After this sole event, the building manager contacted Transformative Wave and opted out of all remaining DR events.

Figure 7 through Figure 9 plot the mean curtailments versus the daily peak dry-bulb temperature. The team then summarized the DR events at each location. The following subsections detail why the original projections were high and the lessons learned regarding the speed of response, the different DR assets (lighting, HVAC, and plug loads/EWHs), and the impact of human behavior.



(a) (b)

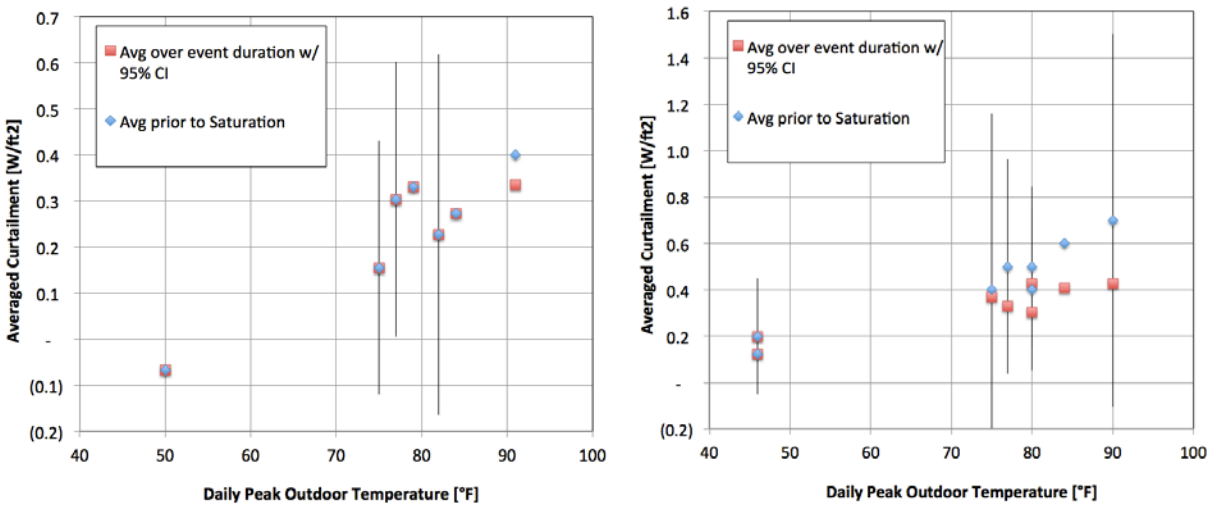
Figure 7. Furniture Store event summaries: (a) Furniture Store #1; (b) Furniture Store #2

Furniture Store #1 winter events. The only winter DR event on January 7, 2015, just exceeded 0.4 W/ft^2. Unfortunately, the team had insufficient historical data (needed 20 previous days) to calculate the uncertainty. Based on the nearly flat Model CBL in Figure B-1, though, the team would expect the uncertainty to be less than 0.1 W/ft^2. The team saw negligible DR curtailment during the January 21 event because, surprisingly, the staff had permanently turned off the DR lighting circuit (see Section 6.7).

Furniture Store #1 summer events. Furniture Store #1 realized the second-largest summer curtailment of all six locations, after Furniture Store #2. It was also the only store that used no compressor cooling during all the 4-hour events. As shown in Figure 7a, five of the summer events congregate in the 0.4–0.6 W/ft^2 range. The August 13 outlier hit 0.9 W/ft^2 because the building was able to sustain 6 kW less power during the DR event. The team compared this day's HVAC and lighting curtailment to the August 7 event and found no differences. The team hypothesized that the staff turned off some large plug load on August 13, creating this outlier.

Furniture Store #2 winter events. As expected, the winter DR was minimal because the team was curtailing a minimum amount of lighting. Due to the disorganized electrical layout in this older store, the team was leveraging the flexibility of Autani's wireless controllers to shed 20 three-lamp fluorescent fixtures totaling 1.9 kW (see Section 6.4). Unfortunately, the team was unable to calculate the event uncertainty because of insufficient historical data (needed 20 days).

Furniture Store #2 summer events. This store had the largest curtailment despite having one of the smallest lighting sheds. Four of the events had an average shed across the 4-hour duration in the 0.8–1.0 W/ft^2 range. Prior to saturation, which was relatively faster than the other stores at 1–2.25 hours, this store achieved 1.2–1.5 W/ft^2. These sheds were the closest to the team's 1.7 W/ft^2 target. The team concluded that the age of these RTUs and the fact only four compressors total served this store were the reasons for both the fast saturation time and larger, overall sheds. Figure F-2 shows that these RTUs operate in second-stage cooling nearly 100% of the time when the ambient temperature is above 80°F.



(a) (b)

Figure 8. Drug Store event summaries: (a) Drug Store #1; (b) Drug Store #2

Drug Store #1 winter events. On the day of the first winter DR event, the employees had overridden the DR lighting circuit control to be permanently on; therefore, no DR event occured. The same thing occurred on the January 21 event. After these two events, Transformative Wave worked with the building manager to ensure the employees would not override the lighting control for the remainder of the DR events.

Drug Store #1 summer events. The team was surprised how little shed the RTUs provided. The team was projecting a 1.2 W/ft^2 shed and only realized 0.2–0.3 W/ft^2. Figure F-4 and Figure F-5 show that the RTUs essentially never operated in second stage cooling, even up to 90°F ambient. In the mid-80°F ambient temperatures, the typical peak temperature during the summer events, the first-stage cooling operated less than 50% of the time. In short, the combination of being a newer store with a well-insulated envelope (namely roof insulation), newer RTUs, and the advanced control of the CATALYST technology permanently mitigates the power needed by the HVAC system to maintain thermal comfort. Section 6.5 covers this in more detail.

Drug Store #2 winter events. Both winter DR events realized a 0.1–0.2 W/ft^2, much less than the 0.6 W/ft^2 projection. This projection assumed the lighting shed contribution alone would be 0.4 W/ft^2. Unlike Drug Store #1, the employees did not override the lighting controls. The reason the measured sheds were essentially half of the lighting curtailment was due to the noise in the Model CBL. The impact of this noise is captured by the uncertainty in the Model Shed.

Drug Store #2 summer events. Averaged across the entire 4-hour duration, this store saw a shed of 0.3–0.4 W/ft^2. Again, this was much lower than the 1.3 W/ft^2 projection. The combination of overestimating the lighting and HVAC sheds was the reason this store was well below the target. Like Drug Store #1, the better insulation, newer RTUs, and advanced control of the CATALYST system permanently reduced the HVAC load. For these newer buildings, the lighting DR will need to be more aggressive, such as integrating dimming ballasts or dimming light-emitting diodes (LEDs), to hit the original targets.

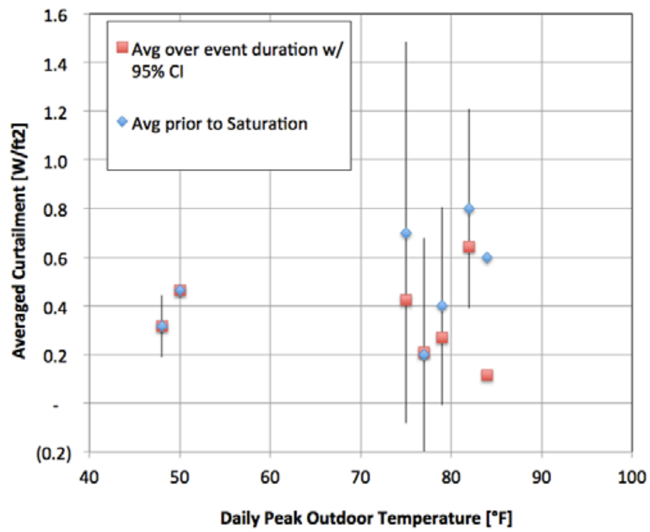


Figure 9. Casino #1 event summary

Casino #1 winter events. Both winter events met expectations with sheds of 0.3–0.5 W/ft^2. The team projected a 0.3 W/ft^2 shed. Compared to the winter events at the other demonstration locations, this store showed saturation (first stage heating) at 7:30 p.m., 30 minutes before the end of the DR event on January 21. When the first-stage heating came on, the supply fan speed changed from 40% in ventilation-only mode to 70%, reducing the supply fan shed.

Casino #1 summer events. Compared to the other locations, the shed was more variable, ranging from 0.1–0.6 W/ft^2. Looking at the scatter of data in Figure 9, there was no congregation of several DR events within a narrower range. The team believes this was due to the larger number of small-tonnage RTUs (six RTUs mostly at 3–4 tons). These smaller units serve smaller rooms, which results in less repeatable behavior than larger RTUs serving a single, large-volume sales floor. For the same reason, these RTUs tended to saturate quickly at 0.75–1.5 hours compared to the other buildings, which typically saturated after 2 hours or did not saturate at all in the case of Furniture Store #1.

Casino #2 winter events. No winter DR events took place at this location because the team had difficulty coordinating the installation of a utility meter at this casino. The interval meter was installed after both winter events took place.

Casino #2 summer events. Only one summer event took place at this location on August 13. Unfortunately, the HVAC controls did not operate correctly and no DR event occurred. After this event, the building manager opted out of the remaining DR events. Therefore, the team had no summer data for this casino.

6.1 Why the Winter Shed projections were High?

The projected lighting and supply fan curtailments at the beginning of the project were significantly larger than what was measured during the two winter DR events on January 7 and 20. As expected, the winter DR was primarily from the lighting curtailments. The supply fan shed did provide some DR resource but these were secondary to the lighting sheds. The plug load sheds were too small and EHW sheds were too intermittent to impact the overall magnitude of the curtailment. The team found the only benefit of curtailing the EWHs and plug loads was smoothing out the interval power draw during the DR event to improve confidence in the calculated shed.

For the newer drug stores and Furniture Store #1, which were built or retrofitted after 2004, the lighting curtailment ranged from 0.4–0.5 W/ft^2. This was 25%–30% of the total interior and exterior lighting load (Table H-1). The older casinos and Furniture Store #2 had a much smaller lighting curtailment of 0.1–0.2 W/ft^2 (6%–19% of the total connected lighting load). On a per-kilowatt lighting curtailment, the three older stores also had the most expensive hardware costs because the team had to use the Autani wireless equipment to access these lights. In the newer stores which had more organized electrical layouts, the light control was accomplished using much less expensive hard-wired relays located next to the electrical panels.

For typically-sized RTUs (350–450 ft^2 per ton), the team originally projected the supply fan shed would range from 0.1 to 0.2 W/ft^2 (Table G-1). Casino #2 was an outlier with a projected supply fan shed of 0.4 W/ft^2 because its RTUs were oversized at 191 ft^2/ton. These projections were based on the assumption that the supply fan would reduce in speed from stage 1 heating/cooling operation (70% fan speed) to ventilation mode (40% fan speed) based on the CATALYST sequence of operation (Table 1).

Combining the lighting and supply fan sheds, the total projected curtailment was 0.5 to 0.7 W/ft^2 for the newer stores. It was 0.2 to 0.4 W/ft^2 for the older stores. Except for the January 7 event at Furniture Store #2, which yielded a 0.4 W/ft^2 curtailment from 5 to 6 p.m., all the other demonstration locations yielded much lower curtailments ranging from 0.1 to 0.2 W/ft^2.

Looking at the submetered data further, the team understood the reason for the overprojected the supply fan shed. Appendix F shows the aggregated RTU operational mode runtime at each store location based on the ambient temperature. Both winter DR events were in the mid-40s, which is not that cold. At these mild temperatures, the RTUs serving these buildings will be in ventilation-only mode more than 70% of the time.

A basic approximation would be to derate the projected supply fan shed by 70% for temperatures in the mid-40s. Only at temperatures lower than 30°F does the RTUs' operation show first-stage heating operation more than 50% of the time. The casinos, with their extremely low lighting power densities (LPDs) below 1.0 W/ft^2, operated in a heating mode more than 80% of the time when the OAT is lower than 30°F. Unfortunately the scope only covered 2 winter DR events. The team would have preferred to run more winter DR events at colder temperatures to quantify the supply fan shed.

The team also looked further into the reason for lower curtailments on the lighting side. Both furniture store winter DR events showed curtailments that aligned with the projected lighting sheds. The Casino #1 lighting sheds occurred but were simply too small to see an impact on the whole-building interval meter. Note that no winter DR events occurred at Casino #2 because the interval meter was not yet installed due to delays coordinating with the local utility.

Finally, the team was unable to determine why a reasonable winter curtailment did not occur at both drug stores. Their lighting DR should have been around 6 to 7 kW (0.4 W/ft^2), but the team measured essentially no curtailment. The team confirmed that the hardwired relays shut power off to the DR lighting circuits during the event. The noise in the drug stores' power profile increased the uncertainty of the Model CBL which prevented the team from quantifying the lighting DR shed during both winter events. Essentially, the noise to whole building power signal was too large to distinguish the lighting curtailment of 6 to 7 kW.

6.2 Why the Summer Shed projections were high?

The summer DR projections were high for the same reasons as the winter events. The RTU curtailment provided most of the shed, and the team overestimated the amount of compressor cooling needed, particularly at the newer buildings.

Appendix F shows the duty cycles of the RTUs for each building based on the ambient temperature. The newer stores (both drug stores and Furniture Store #1) rarely needed second-stage cooling. At temperatures exceeding 85°F ambient, Drug Store #1 and Furniture Store #1 needed only first-stage cooling at a duty cycle of approximately 50%. Only when the temperature approached 90°F ambient did Drug Store #2 need first-stage cooling nearly 100% of the time.

Furniture Store #2 was the only location that aligned with the original projections. It needed first-stage cooling nearly all the time at temperatures higher than 75°F and second-stage cooling all the time at temperatures higher than 80°F. This behavior was due to a combination of a limited number of compressor stages (four stages from two RTUs with two compressors each) serving an older store with less efficient RTUs and a lower performance envelope. Therefore, the HVAC had fewer incremental stages to maintain the set point in a space that demanded more cooling per square foot relative to a newer building. The other older buildings, the casinos, had seven to thirteen stages of cooling, yielding a higher fidelity of control. Both drug stores only had five stages of cooling, but had new RTUs and a more efficiency, insulated building envelope.

The building's vintage and number of compressor stages also had an impact on the saturation time. Figure 10 shows that the older buildings maintained a saturation time around 1 hour, while the new buildings achieved a saturation time between two to four hours. In fact, Furniture Store #1 was able to maintain no compressor cooling throughout all seven DR events. Drug Store #1 was able to also maintain a 4-hour saturation until the daily peak temperature exceeded 80°F.

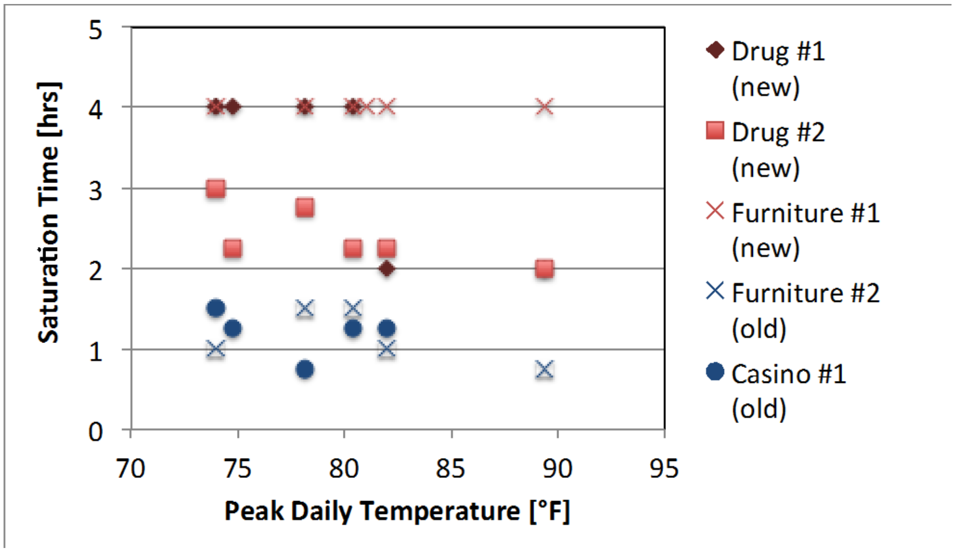


Figure 10. Summer DR event saturation time

6.3 Speed of Response

During the first DR event on January 7, all the demonstration sites experienced some communication latency such that the loads did not curtail until approximately 5 minutes past 5:00 p.m. when the DR event started. As shown in Figure 11a, Furniture Store #1 did not show its full curtailment until the second 15-minute interval during the DR event.

Transformative Wave was able to reduce the communication latency between the virtual DRAS, through each building's JACE controller, and finally to each curtailed device by the second winter event (see Subsection 2.1.2). The August 19 DR event at Furniture Store #2 shows how quickly the curtailed load responds within the first 15-minute power interval, from 2:30 to 2:45 p.m. Therefore Furniture Store #2 realized nearly the full shed down to 47 kW.

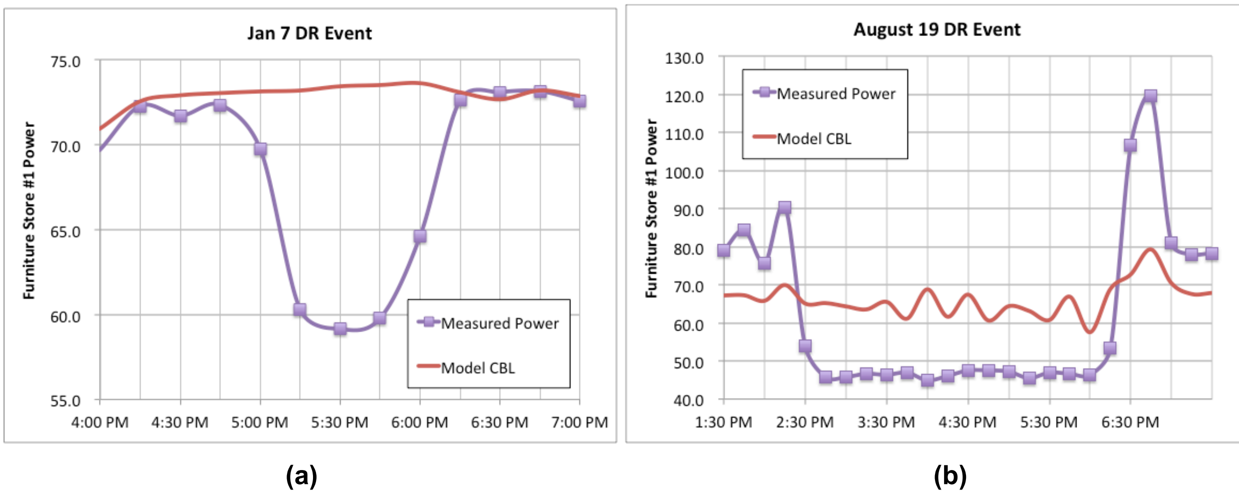


Figure 11. Speed of DR at Furniture Store #1: (a) January 7 DR event; event start at 5 p.m.; (b) August 19 DR event; event start at 2:30 p.m.

In order to achieve this response speed, Transformative Wave intentionally established the communication topology to have the DR signal from the DRAS direction to each building's JACE controller. Sending the DR signal from the DRAS to the eIQ server and then to each JACE would have slowed down the response.

6.4 Lighting Demand Response

Both drug stores and Furniture Store #1, which were constructed or renovated after 2004, provided the largest lighting DR resource at the lowest cost because their electrical panels and lighting circuits were well organized. Instead of using Autani's wireless devices to control individual room switches or fixtures, Transformative Wave was able to shed entire lighting circuits using inexpensive, hard-wired relays located next to the electrical panels.

The best example of the benefits of a new, organized electrical system was Furniture Store #1. Renovated in 2012, it had well-laid-out lighting circuits such that each circuit serving the main sales floor essentially controlled every third row. This allowed the eIQ BMS to shut off 240 two-lamp (T8) troffers yielding a 13.4 kW (0.5 W/ft^2) shed (see Appendix A). This lighting curtailment required only three hard-wired relays.

Table 8 shows how the lighting DR resource at the buildings constructed or renovated since 2004 ranged from 0.4 to 0.5 W/ft^2, or 25% to 30% of the total (interior and exterior) connected lighting power. The three older stores needed to leverage the flexibility of the Autani wireless controllers to achieve lighting DR. Due to the greater expense of the Autani hardware compared to hardwired relays, Transformative Wave installed fewer lighting DR assets at the older buildings. The lighting shed in both casinos and Furniture Store #2 ranged from 0.1 to 0.2 W/ft^2.

Table 8. Lighting DR Resource

	Lighting DR Resource	Store Renovated or Constructed Since 2004	Total Interior and Exterior Lighting (LPD)	Lighting Shed of Total Lighting
Furniture Store #1	13.4 kW (0.5 W/ft^2)	Yes	54.7 kW (2.0 W/ft^2)	25%
Drug Store #2	6.9 kW (0.4 W/ft^2)	Yes	23.2 kW (1.5 W/ft^2)	27%
Drug Store #1	6.2 kW (0.4 W/ft^2)	Yes	22.9 kW (1.4 W/ft^2)	30%
Casino #1	2.1 kW (0.2 W/ft^2)		< 11 kW [a] (< 1.0 W/ft^2)	19%
Furniture Store #2	1.9 kW (0.1 W/ft^2)		20.4 kW (0.9 W/ft^2)	9%
Casino #2	1.0 kW (0.1 W/ft^2)		< 17 kW [a] (< 1.0 W/ft^2)	6%

[a] The full lighting load at both casinos was not measured due to the disorganization of the electrical layout. Based on the lamp count throughout the buildings, the team estimated the LPD to be less than 1 W/ft^2.

6.5 Compressor Demand Response

The main HVAC DR lesson learned was over projecting the compressor cooling curtailment. Table 9 provides a summary of the RTUs and associated compressor loads at each location. Except for Casino #2 and Furniture Store #2, the cooling capacity relative to the conditioned floor area met the team's expected range of 350 to 450 ft^2/ton of cooling for the PNW region. This ratio resulted in a 2.3 to 2.8 W/ft^2 compressor power density.

The team incorrectly projected the cooling curtailment magnitude to be 25% of each store's compressors turning off during a summer day-ahead DR event. The team anticipated 12.5% of the compressors would turn off during a 10-minute DR event. At these projections, these typically sized HVAC systems would then realize a 0.5 to 0.7 W/ft^2 and 0.3 to 0.4 W/ft^2 compressor shed for the day-ahead and 10-minute events, respectively.

As an outlier, Casino #2 had an extremely oversized HVAC system with less than 200 ft^2/ton. This is essentially twice the capacity the team would expect. Its compressor power density reached a significant 6.9 W/ft^2. Conversely, Furniture Store #2 was slightly undersized with nearly 550 ft^2/ton and therefore, a lower compressor power density of 1.8 W/ft^2.

Table 9. HVAC DR Resource

	Total Compressor Power [a]	Compressor Number	Number of RTUs	Cooling Capacity per Area	Projected Summer Day-Ahead[b]	Projected Summer 10-min[c]
Casino #2	115 kW (6.9 W/ft^2)	13	9	191 ft^2/ton	29 kW (1.7 W/ft^2)	14 kW (0.9 W/ft^2)
Furniture Store #1	79 kW (2.8 W/ft^2)	13	7	352 ft^2/ton	20 kW (0.7 W/ft^2)	10 kW (0.4 W/ft^2)
Drug Store #1	40 kW (2.5 W/ft2)	5	3	405 ft^2/ton	10 kW (0.6 W/ft^2)	5 kW (0.3 W/ft^2)
Drug Store #2	40 kW (2.6 W/ft^2)	5	3	385 ft^2/ton	10 kW (0.6 W/ft^2)	5 kW (0.3 W/ft^2)
Furniture Store #2	40 kW (1.8 W/ft^2)	4	2	543 ft^2/ton	10 kW (0.5 W/ft^2)	5 kW (0.2 W/ft^2)
Casino #1	26 kW (2.3 W/ft^2)	7	6	430 ft^2/ton	7 kW (0.6 W/ft^2)	3 kW (0.3 W/ft^2)

[a] Compressor power based on estimate of 1.0 kW per ton of cooling; includes the condenser fan power. The compressor power was not measured at each RTU.
[b] The team projected that 25% of the building's compressors would curtail during a summer day-ahead DR event.
[c] During a summer 10-minute DR event, the team projected that 12.5% of the building's compressors would curtail.

During the field demonstration, the team found that the compressor operation was less than the original projections. For example, Figure 12 shows the percentage runtime of all the RTUs serving Furniture Store #1 at different ambient temperatures for a year. The second-stage compressors rarely ran, and the first stage compressors ran at only 45% to 50% duty cycle when the temperature was warmer than 80°F ambient.

By comparison, the two RTUs serving Furniture Store #2 operated nearly 100% of the time in first-stage cooling and 95% to 100% of the time in second-stage cooling when the ambient temperature exceeded 80°F.

Table 10 summarizes the typical percentage runtime of the first and second stages for ambient temperatures higher than 80°F. Appendix F shows the operational mode runtimes for all six locations. Except for Furniture Store #2, all the sites essentially never operated in second-stage cooling. Furniture Store #2 and Drug Store #2 were the only sites that had more than 50% runtime for first-stage cooling when the ambient temperature exceeded 80°F.

The lower duty cycling of the compressors resulted in a lower HVAC DR curtailment compared to the team's original projections. RTUs operating without the CATALYST advanced RTU controller would realize greater first and second stage operation. This is predominantly due to the CATALYST's ability to maintain a lower ventilation rate using demand controlled ventilation at warmer ambient temperatures.

Table 10. Typical RTU Operational Runtime Higher Than 80°F Ambient

	Ventilation-Only Mode (Supply Fan at 40% speed)	Stage 1 Compressors Percentage Runtime	Stage 2 Compressors Percentage Runtime
Casino #2	75%-70%	35%–40%	~0%
Furniture Store #1	50%-55%	45%–50%	~0%
Drug Store #1	50%-60%	40%–50%	~0%
Drug Store #2	10%-50%	50%–90%	~0%
Furniture Store #2	~0%	100%	95%–100%
Casino #1	90-95%	5%–10%	~0%

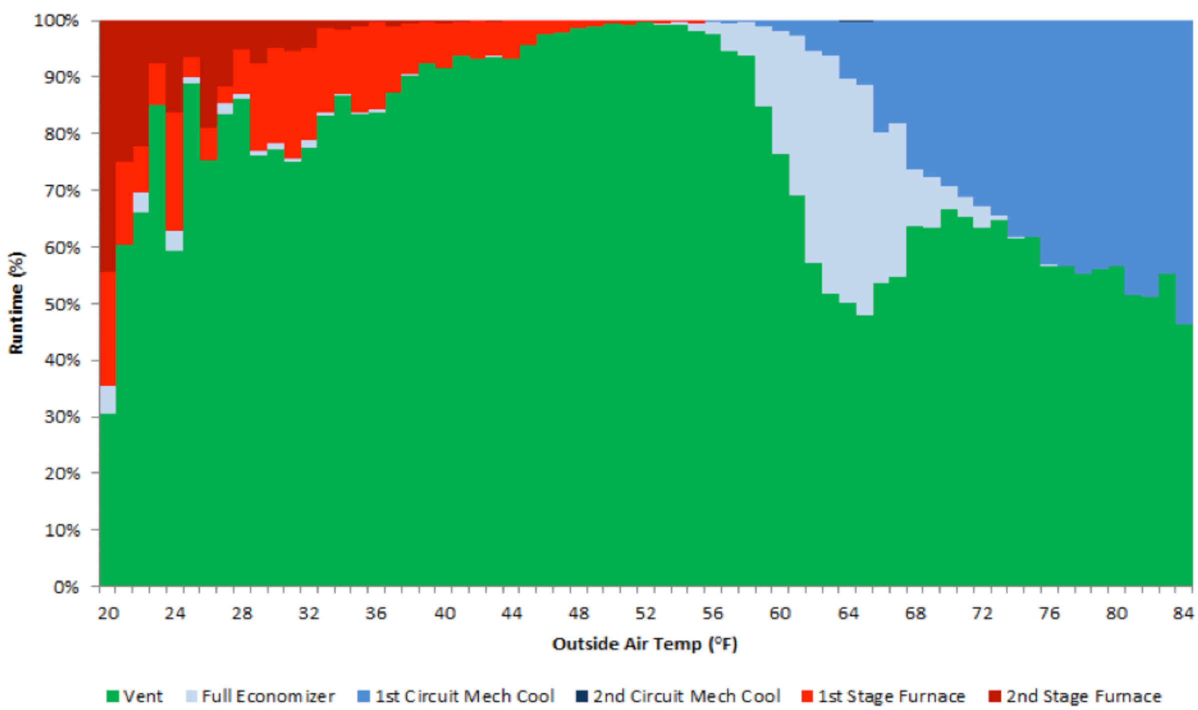


Figure 12. Annual percentage runtimes across the seven RTUs serving Furniture Store #1

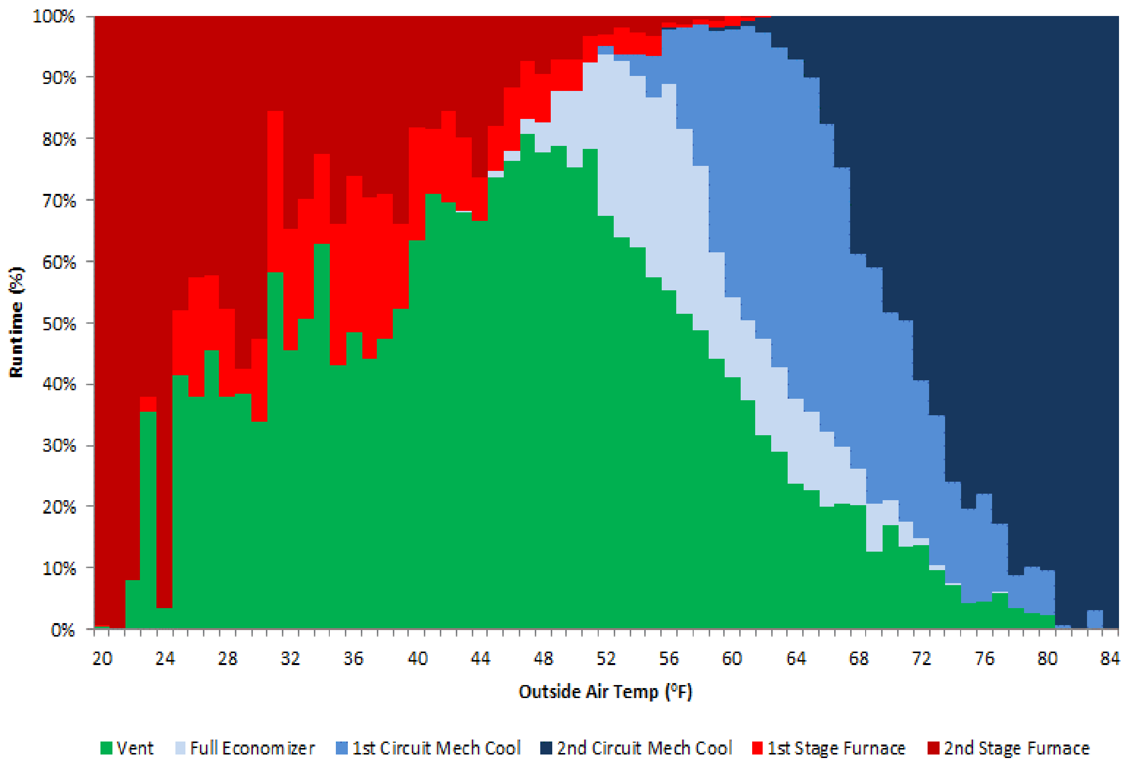


Figure 13. Annual percentage runtimes across the two RTUs serving Furniture Store #2

6.6 Plug Loads and Electric Water Heaters' Demand Response

In addition to overestimating the compressor curtailment, the team overestimated the shed from the plug loads and EWH. Just like compressors, most of the plug loads and the EWH are duty cycled such that they are turning on periodically throughout the day. For future projections, plug load and EWH curtailment should be derated based on anticipated duty cycling. The team determined that the curtailment from the plug loads and EWH was at most 25% of the original projections. Table 11 presents the estimate of the total connected plug loads and EWHs that were curtailed during each DR event.

The building owners and managers of the six demonstration sites saw the eIQ platform as a means to reduce both their HVAC and lighting energy usage. Beyond the RTU energy savings from the CATALYST system, they said they realized significant lighting energy savings simply by maintaining a consistent lighting schedule. Prior to the retrofit, they complained that they could not rely on their employees to routinely turn the lights off during non-business hours.

Yet, they were less interested in the plug load and EWH control. None of the EWHs served critical applications such as dishwashing, only restroom usage. The team was not able to control the EWHs at either drug store because the building manager wanted the water to be consistently hot for the pharmacy department. Office buildings, which have significantly more plug loads, may see more value in leveraging a BMS to control (or simply on-off schedule) these loads.

Table 11. Plug Load and EWH DR Resources

	Plug Load Projected DR	EWH Projected DR
Drug Store #1	0.4 kW (0.0 W/ft^2)	Not allowed[a]
Drug Store #2	0.4 kW (0.0 W/ft^2)	Not allowed[a]
Furniture Store #1	8.5 kW (0.3 W/ft^2)	3.6 kW (0.1 W/ft^2)
Furniture Store #2	5.5 kW (0.3 W/ft^2)	3.3 kW (0.2 W/ft^2)
Casino #1	0.3 kW (0.0 W/ft^2)	NA[b]
Casino #2	1.4 kW (0.1 W/ft^2)	NA[b]

[a] The drug store manager did not want the EWHs controlled because they wanted continuous hot water available for the pharmacy department.
[b] Both casinos had natural gas water heaters.

Building owner and manager interest in plug loads will depend on the building type. NREL has demonstrated that in a commercial office application, using wireless plug load controllers for scheduling can yield a 28% reduction in plug load energy resulting in an 8% whole-building energy reduction (Sheppy 2014). For these six retail demonstration locations, however, the plug load and EWH savings magnitude were much lower. The team was mainly controlling limited plug loads in the employee break room and some refrigerated drink coolers located at the registers.

Autani investigated a modification to one of its wireless controllers to turn televisions back on after the DR event. Scheduling of TVs in both furniture stores (>110 flat screens for each store) and both casinos (>40 flat screens for each casino) would have provided appreciable DR (15 kW across all six locations at ~100 W each). Unfortunately, Autani was unable to find a solution in time, so the team did not control the TVs. From this demonstration, the team concluded that controlling plug loads in retail environments beyond significant power consuming devices such as drink coolers or refrigerated vending machines was not cost effective from an EE or DR perspective.

The main benefit from curtailing some of the plug loads and EHWs was reducing the noise in the building power signal during a DR event. This provided a smoother building load which which to quantify the curtailment.

6.7 Human Behavior Impacts on Demand Response

On the day of the January 21 event at Furniture Store #1, the employees had permanently turned off the curtailment lighting circuit. Consequently, the average shed was effectively 0 W/ft^2

across the 5:00 to 8:00 p.m. event (Figure B-2). When asked, the employees stated that they preferred the lower lighting level during the first DR event.

This was one of the biggest surprises of the demonstration. The team never anticipated that the store staff would prefer the lower lighting level maintained during the events. Yet, this particular store's lighting design is an outlier. Its LPD is 2.0 W/ft^2 compared to the mean 1.33 W/ft^2 (±–0.06 at 90% confidence level) for retail buildings in the PNW region (Navigant 2014). Although this is a unique circumstance, it was a good lesson learned for certain stores with significant lighting levels—LPDs greater than 1.7 W/ft^2. They may not realize as significant a lighting DR asset if the employees prefer the DR event's lighting levels. For the remaining events, the Furniture Store #1 employees agreed to leave the DR lighting circuit on.

Conversely, the staff at Drug Store #1 over-rode the lighting control to keep the lighting DR circuit permanently on during both winter DR events. This was the response the team was anticipating. The team had to work with the building manager to ensure the staff did not touch the lighting control panel during the rest of the demonstration period. In hindsight, the team would have preferred to make it more difficult for unauthorized staff to have access to the lighting control panel. The override switches on the panel made it too accessible for anyone with access to the electrical room to override control. In the future, a better balance needs to be found between providing lighting control to the staff for emergency situations and preventing unintended operation.

7 Aggregated Demand Response Resource

Based on the Section 6 lessons learned, the team extrapolated the DR measured on the six locations to quantify the DR resource for the entire PNW region. The team used the detailed building demographics from the Commercial Building Stock Assessment (CBSA),[9] which the Northwest Energy Efficiency Alliance updated in 2014 (Navigant 2014).

The following section provides insight into the potential DR magnitude for a packaged EE and DR retrofit technology, targeting not just retail but any commercial building type served by air conditioning (AC) and air-source heat pump (ASHP) RTUs.[10] The team started with the entire commercial building population. From 2009 to 2014, the CBSA calculated the total commercial building area in the PNW increased by 27%, from 2,467 to 3,122 million ft^2.

Next, the team focused only on the floor space cooled by AC and ASHP RTUs. Figure 14 shows this being 1,510 million ft^2 or 48% of the total PNW commercial floor space. Within this total, the building types with the most square footage are office and retail, totaling 768 million ft^2 or 25% of the total PNW commercial floor space. Assembly (secular, religious, and cultural gathering places) is the third most common building type, representing 224 million ft^2 or 7% of the total PNW commercial floor space.

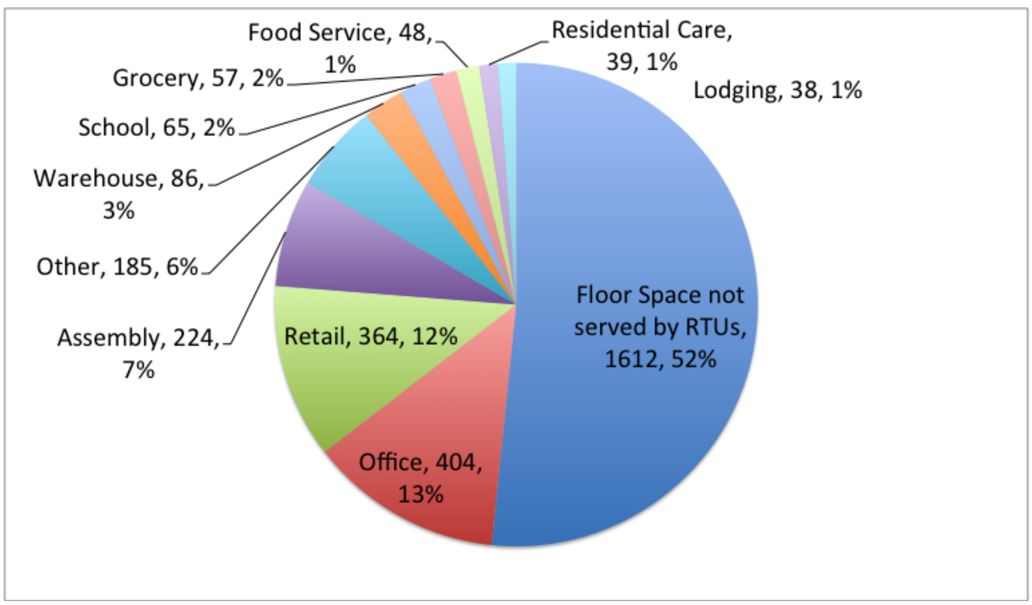


Figure 14. AC and ASHP RTUs serve 48% of the PNW commercial floor area

[9] Navigant stated that they designed their sampling to achieve an 80% confidence and 20% precision at the intersection of each categorization (type, vintage, size, urban/rural classification) and an average of 90% confidence and 10% precision by the building type.
[10] The CBSA categorized RTU equipment as either AC—electric cooling with non-electric heating—or ASHP—electric cooling with vapor-compression heating supplemented with electric resistance heating at extremely cold temperatures.

Figure 15 shows the floor space breakdown, separating AC RTUs (in blue) from ASHP RTUs (in red). AC RTUs condition 1,257 million ft^2 or 40% of the total PNW commercial floor space. ASHP RTUs condition significantly less, at 253 million ft^2 or 8% of the total PNW commercial floor space.

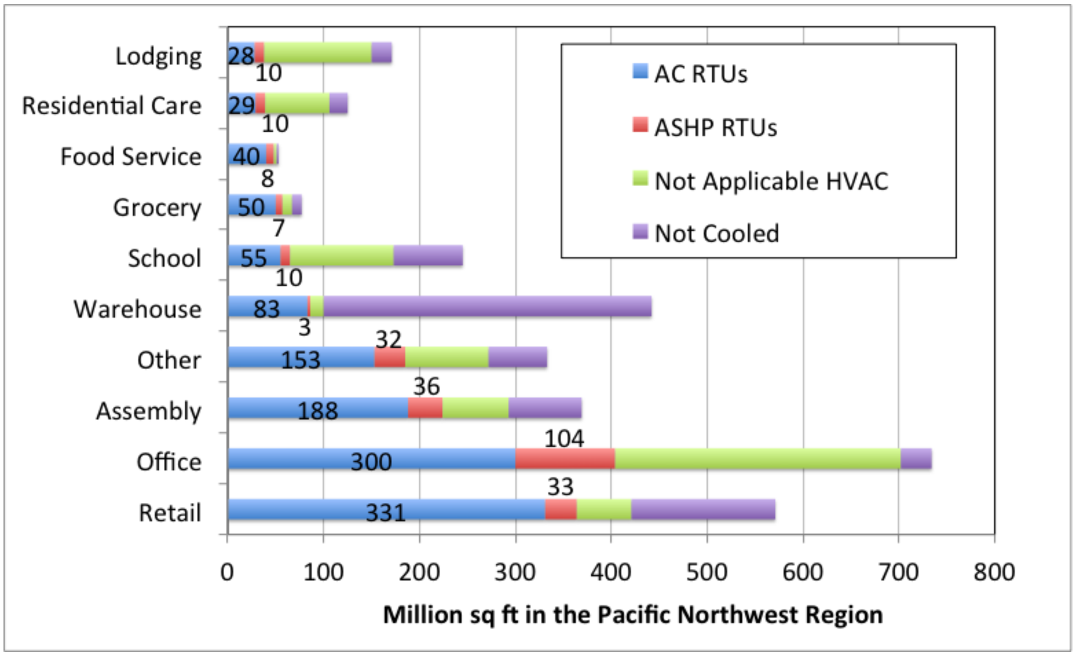


Figure 15. Area served by RTU-AC and RTU-ASHP by building type

7.1 Projected Summer Demand Response Resource

For the summer projection, the team combined the AC and ASHP RTUs. ASHP will have a slightly lower cooling efficiency than AC units due to the added pressure drop of the reversing valve. Yet, for this exercise, the team felt it was reasonable to assume they provided the same summer shed.

Table 12 summarizes the average shed across a 4-hour summer, day-ahead DR event in which the building has enough notification to pre-cool two hours prior to the event. The Newer Buildings shed is based on the average across both Drug Stores and Furniture Store #1 from the seven summer DR events demonstrations. The Older Buildings shed is the same calculation but includes Furniture Store #2 and Casino #1. As shown, the older buildings achieve a larger average shed because of their older, lower-performance RTU and envelope systems.

Table 12. Summer Shed Averages

	Newer Buildings[a]	Older Buildings[b]
More Than 4 Hours	0.41 W/ft^2	0.56 W/ft^2
Prior to Saturation	0.46 W/ft^2	0.92 W/ft^2
Saturation Time	2.0 to 4.0 h	0.75 to 1.5 h

[a] Average from both drug stores and Furniture #1
[b] Average from Furniture #2 and Casino #1

Table 12 also provides the average shed prior to saturation, which refers to the duration from the start of the DR event to when the first compressor comes back on. It is the time of the DR event when the RTUs are operating in ventilation-only mode with the CATALYST maintaining the supply fans at 40% speed.

Due to their higher-efficiency RTUs and envelopes, the newer buildings see only a small increase from the pre-saturation average to the 4-hour average. Yet their saturation time is much longer. In fact, all the Furniture Store #1 and most of the Drug Store #1 events lasted the entire 4 hours with no compressor operation. Conversely, the older store sheds doubled going from a 4-hour average to the average prior to saturation. Yet they could only last 45 minutes to 1.5 hours.

The team broke down the Figure 15 areas served by RTUs into newer buildings (built or retrofitted between 2004 and 2013) and older buildings (built or retrofitted prior to 2004) using the 2014 CBSA (Navigant 2014). The team multiplied these areas by the DR curtailments in Table 12. Figure 16 shows the summer DR resource for the PNW region across a 4-hour DR event assuming 100% market penetration. Figure 17 shows the DR resource for a 1-hour event, assuming the typical building saturation time was 1 hour and the building had sufficient notice to precharge.

The team separated the urban versus rural areas since BPA expressed interest in initially leveraging building DR to relieve distribution congestion in the PNW's metro areas. In particular, BPA stated they were realizing the greatest congestion in their Portland and Tri-Cities distribution areas. In total, the urban summer DR resource averaged across a 4-hour event is 453 MW. This assumes 100% market penetration across all buildings served by RTUs. The same resource increases to 662 MW for a 1-hour event.

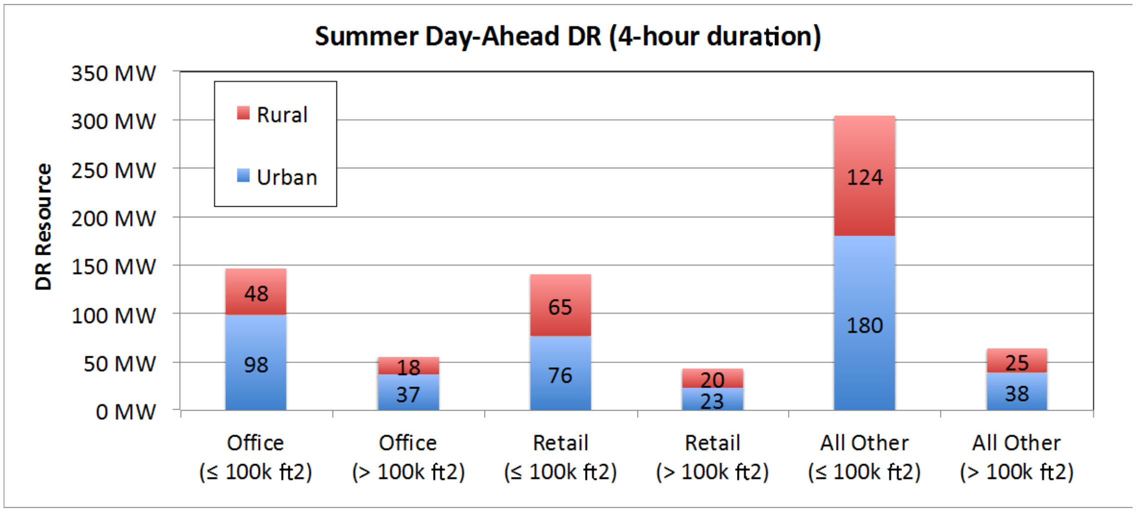


Figure 16. Summer shed averaged across 4-hour event

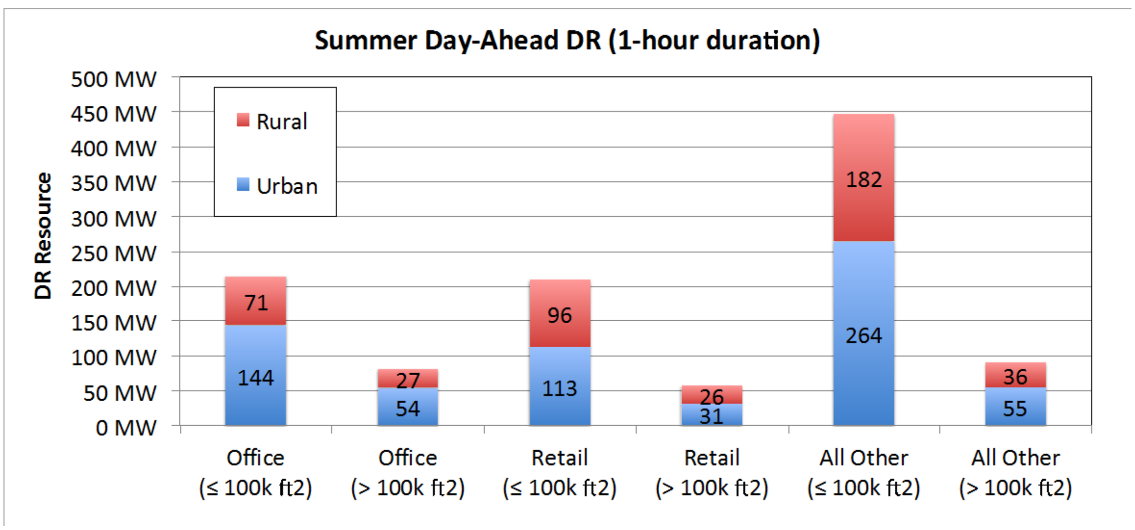


Figure 17. Summer shed averaged across 1-hour event

7.2 Projected Winter Demand Response Resource

Similar to the summer DR projection, the team calculated the winter DR projection. Yet the team did not split the buildings up by vintage. The field demonstration results did not show a significant difference in the shed between newer (0.18 W/ft^2) and older (0.26 W/ft^2) buildings. Instead, the team separated the buildings served by AC RTUs (non-electric heating) and by ASHP RTUs.

Table 13 shows the winter average shed measured across the demonstration locations based on the 1-hour and 3-hour winter events. The team then estimated the shed for ASHP RTUs based on a mix of electric resistance and heat pump operation. Typical ASHP RTUs switch over to electric resistance heating when the ambient temperature drops lower than approximately 35°F.

Table 13. Winter Shed Averages

	AC RTUs[a]	ASHP RTUs[b]
From a 1-hour to a 4-hour DR event	0.22 W/ft^2	0.6 W/ft^2

[a] Average from all demonstration sites
[b] Estimate assuming a mix of electric resistance and heat pump operation

Using the sheds in Table 13 and areas in Figure 14, the winter DR resource for the PNW region focusing on the commercial floor space served by AC RTUs is shown in Figure 18. Using the same steps, Figure 19 shows the ASHP resource across the PNW region. Since BPA is interested in pursuing DR within metro areas, the total urban resource is 165 MW assuming 100% market penetration across all buildings served by AC RTUs. The ASHP RTU resource is 93 MW for urban locations. The team found it interesting that for office buildings, even though ASHP RTU serve a much smaller area, their significantly larger shed magnitude results in roughly the same MW shed as AC RTUs serving office buildings.

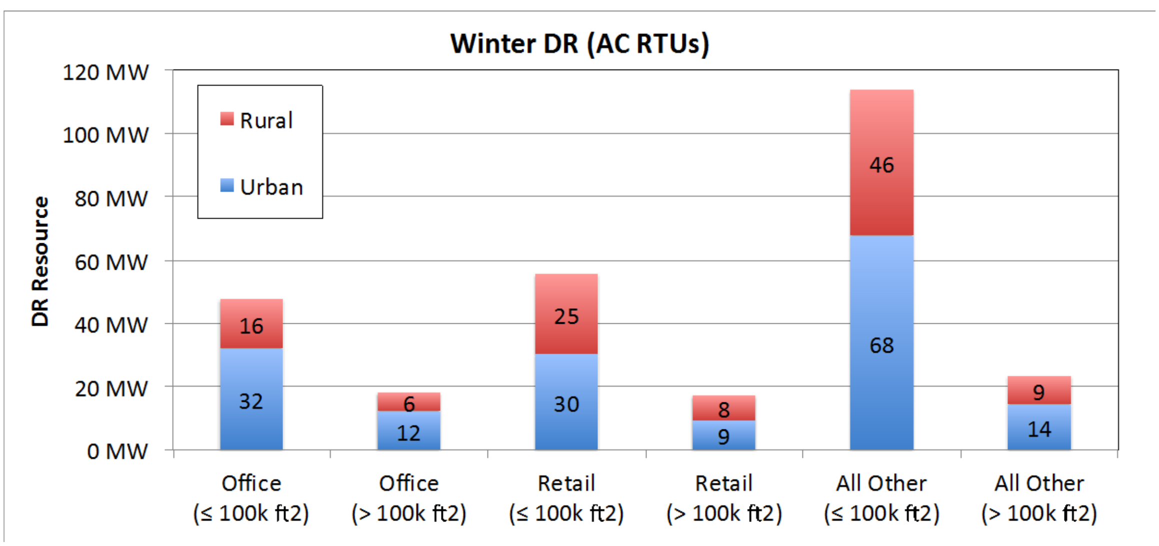


Figure 18. Winter shed for AC RTUs

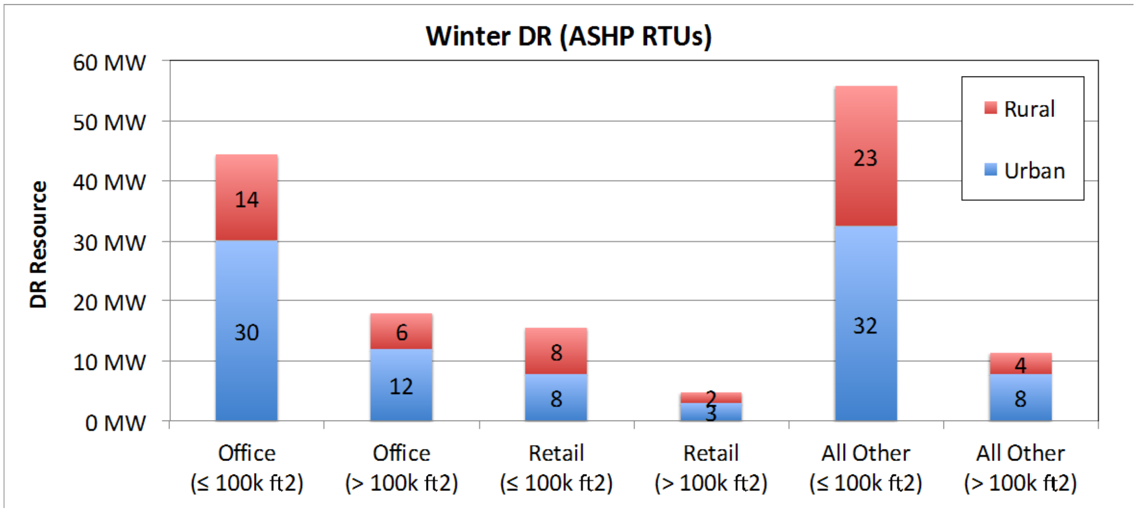


Figure 19. Winter shed for ASHP RTUs

7.3 Demand Response versus Pumped Storage

Figure 20 compares the aggregated summer and winter DR from PNW buildings against 14 proposed pumped storage facilities within the PNW region. The retail, office and all other building DR resource in this figure assumes 100% market penetration. It combines both urban and rural buildings, regardless of the building size. By assuming 100% market penetration, these projections estimate the upper bound of this technology applied to all commercial floor area heated and cooled by RTUs (AC or ASHP).

The winter DR, which can range from a 1 to 4 hour event, is the fourth largest in Figure 20, totaling 425 MW. With the additional compressor sheds during the summer, the 4-hour, day-ahead summer DR is the sixth largest at 753 MW. Finally, for a shorter event lasting 1-hour or less, the summer DR is the eight largest reaching 1,101 MW.

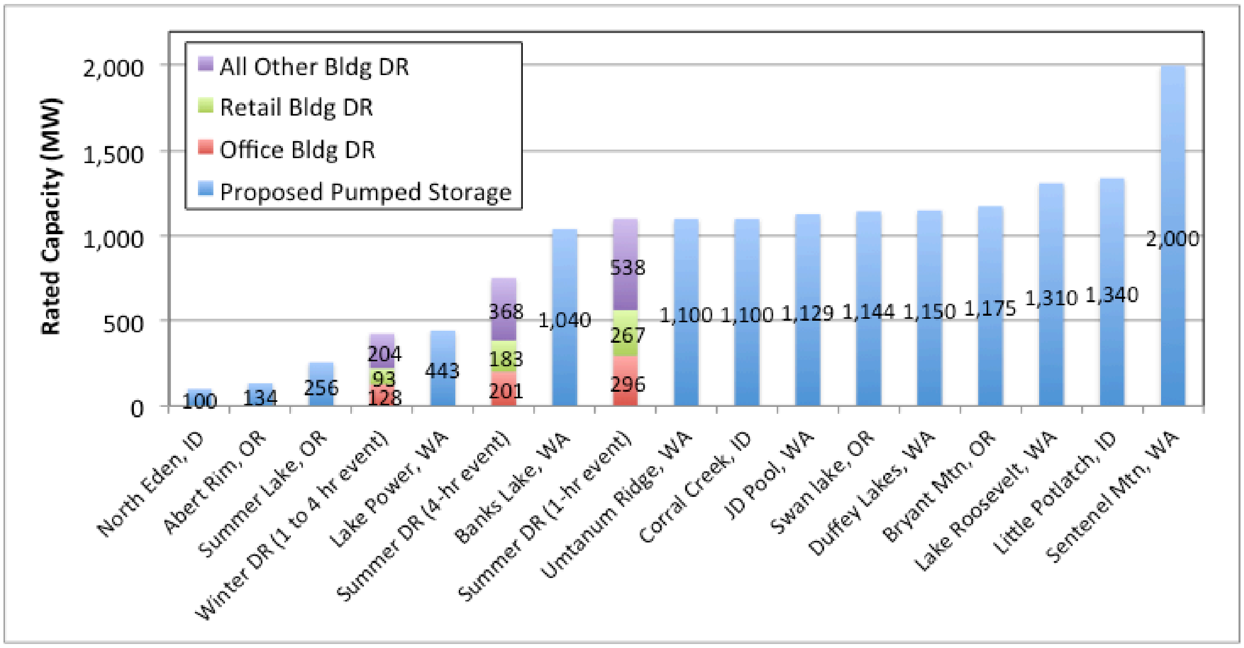


Figure 20. Rated capacity of proposed Pumped Storage Facilities compared to PNW Building DR

7.4 DR Resource Projection Assumptions

The DR projections in Section 7.3 above are extrapolations from the measured sheds averaged across the six demonstration locations. There are many inherent assumptions with this approach. The largest assumption being that the six locations in this field demonstration are a statistically significant sampling of all the commercial buildings in the PNW region. This is obviously not the case.

While the six demonstration sites provide a varied cross-section of the small retail building demographic, they do not statistically represent medium to large retail buildings, office buildings or other building types. Further evaluation should be done to quantify the magnitude of flexible loads at office and other non-retail buildings types, from small to large. This should also include medium to large retail buildings.

Since field demonstrations are expensive, NREL recommends leveraging building modeling along with field demonstrations. Currently, NREL is leveraging the EnergyPlus whole building modeling program to characterize the flexibility of building loads for different building types (i.e. office, retail, school) and DR technologies (i.e. lighting, HVAC).

Using high performance computing, NREL models several thousand simulations for one 'data point' – meaning one DR sequence of operation controlling one or multiple assets in one building type. By running many simulated DR events, the team can characterize how the resource changes across the day, the season and based on the weather. Figure 21 shows how a DR resource from an HVAC asset changes across the day by simulating DR events throughout the day. In other words, each annual simulation captures 365 DR events. Figure 22 shows the same HVAC DR resource by against the ambient temperature.

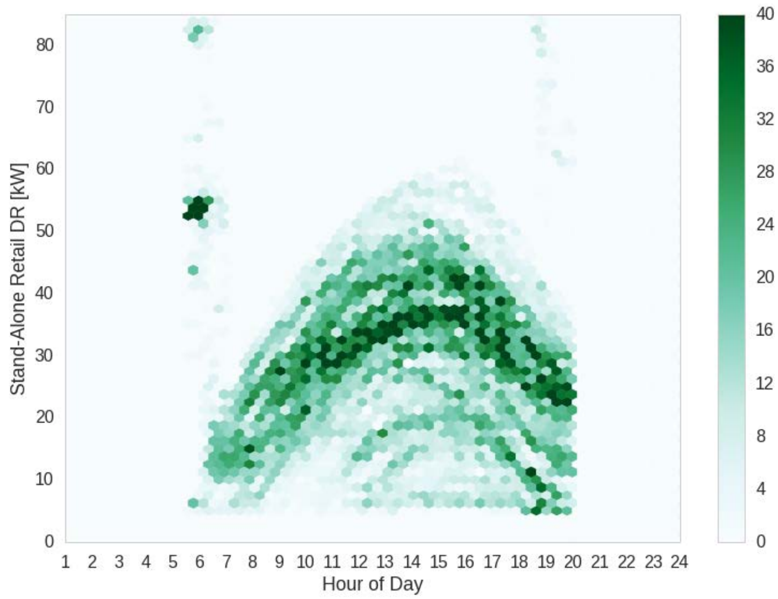


Figure 21. DR resource variability across the day

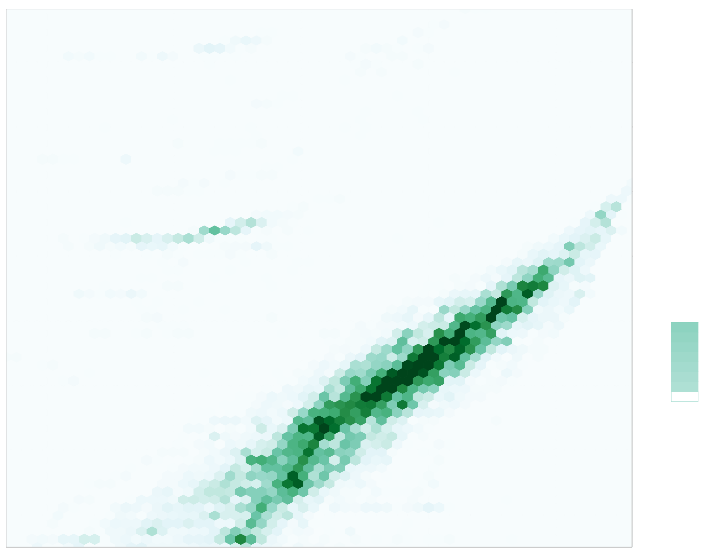


Figure 22. DR resource variability with the ambient temperature

Modeling can be used alongside a field demonstration to evaluate different sequence of operation as well as provide a more comprehensive map of the resource. Currently, modeling software can auto-calibrate by stochastically adjusting inputs in order to establish the correct set of inputs that is closest to the field measured data. Then, once a model is calibrated, it can be run quickly and inexpensively to capture the variability of the resource. Additionally, these calibrated models can be perturbed to better represent that building types resource across a region. Using building demographic data, like from the 2014 CBSA (Navigant 2014), important inputs such as the lighting power density or RTU efficiency can be altered to gain a statistically significant cross-section of a buildings based DR resource across a region.

8 Return on Investment

The ROI for each location is summarized in Table 14. In addition to calculating the total system simple payback, the team individually calculated the ROI of the HVAC and non-HVAC systems.

The utility savings and installed costs of the CATALYST and eIQ systems resulted in a simple payback ranging from 3.6 to 7.5 years. Casino #1 had a significantly longer payback because 5 of its 6 RTUs were under 5 tons. Therefore, its supply fan savings was mitigated because these units only had one stage of heating and cooling. The CATALYST realizes more energy savings when there are two stages of heating and cooling on RTUs.

The non-HVAC systems (lighting, plug loads and EHWs) realized a significantly longer payback ranging from 5.2 years to 25.1 years. Only Furniture Store #2 achieved a reasonable ROI because it had an abnormally large 2.0 watts per square foot lighting power density. The utility savings provided by these non-HVAC loads were based solely on the improved on-off control of each building's lighting circuits. Without the eIQ controlling the lights, the building owners and managers stated that they had difficulty ensuring the staff controlled the lights according to the building's operating hours. Yet the cost to utility savings ratio of the non-HVAC control, particularly when incorporating wireless controllers as done for the older buildings (both casinos and Furniture Store #2), is much larger than that of the CATALYST and eIQ systems.

Yet, when combined, the total system pay back mostly ranged between 3.4 to 6.8 years. Again, Casino #1 had a significantly longer payback at 12.2 years due to the lower energy savings from the CATALYST system because of its RTU configuration.

Table 14. Return on Investment

Location	HVAC Control (CATALYST & eIQ) Simple Payback[A]	Non-HVAC Control Simple Payback[B]	Total Installed Cost[C]	Total Utility Savings	Total System Simple Payback
Drug Store #1	3.6 years	14.2 years	$52,384	$7,826	6.7 years
Drug Store #2	4.0 years	8.5 years	$47,134	$9,188	5.1 years
Furniture Store #1	3.6 years	5.2 years	$71,039	$20,634	3.4 years
Furniture Store #2	5.1 years	12.5 years	$62,860	$9,252	6.8 years
Casino #1	7.5 years	25.1 years	$57,135	$4,688	12.2 years
Casino #2	4.8 years	21.9 years	$89,288	$15,598	5.7 years

A. Simple payback based on the utility savings versus installed cost of the CATALYST and eIQ systems.
B. Simple payback based on the utility savings versus installed cost of the lighting, plug load and EHW systems.
C. Total cost (labor, programming and hardware) for the entire (HVAC and non-HVAC) system.
D. Utility electric and gas savings across the year from the HVAC and non-HVAC systems

9 Conclusions

The team broke up the conclusions from this field demonstration to answer the following nine questions. These conclusions provide a solid foundation for the next step—conducting an in-depth market analysis to determine how best to deploy and incentivize (through coupled EE and DR rebates) this technology to promote significant market penetration.

Why were the original DR projections too high?

The summer (1.7 W/ft^2 for day-ahead and 0.9 W/ft^2 for 10-minute) and winter (0.7 W/ft^2) DR targets were established before the six demonstration sites were chosen. After the sites were agreed upon, the team found that the building vintage had a dramatic impact on how much DR could be provided cost-effectively.

On one side, the disorganized layout of the electrical rooms in the older buildings (both casinos and Furniture Store #2) made it cost prohibitive to obtain a significant lighting shed. The team had to use more expensive, wireless controllers to access some of the lighting. Then, despite the added expense, these older stores only provided 1.0 to 2.1 kW (0.1 to 0.2 W/ft^2) lighting DR per building. For the newer stores, the team was able to use inexpensive, hard-wired relays to curtail 25% to 30% of the total connected (interior and exterior) lighting load. These newer stores, built or retrofitted after 2004, yielded a healthier 6.2 to 13.4 kW (0.4 to 0.5 W/ft^2) lighting DR per building.

On the other side, the older stores provide a more significant compressor DR resource because their RTUs and building envelopes are less efficient. Unfortunately, for the same reasons, these older building realize a much shorter 'saturation time' – the time from the event start to when the first compressor comes on. The older locations (Casino #1 and Furniture Store #2) realized saturation times between 0.75 and 2.25 hours with curtailments reaching 1.5 W/ft2. The newer locations (both drug stores and Furniture Store #1) had saturation times over 2 hours but the largest curtailment only reached 0.9 W/ft^2. Except for Furniture Store #2, the annual RTU operation for all the demonstration locations showed nearly no second stage compressor operation. And the first stage compressor typically operated less than 50% of the time, even when the ambient temperature was approaching 90°F.

The plug loads and EWH provided minimal DR curtailment and were expensive to implement. In the newer vintage locations, the team was able to control these loads using inexpensive hardwired relays for dedicated circuits in the electrical rooms. For most locations—even some newer buildings—however, expensive wireless controllers will be needed to curtail these loads. Sometimes a building will have requirements that prevent curtailing the EWH, as demonstrated by the case of the drug store managers who did not want us shedding this load because the pharmacy department demanded continuous hot water. Compared to offices and other building types, retail building typically do not have significant plug loads. The team found that the only benefit of curtailing some plug loads and EHWs was reducing the signal noise during the DR event. Consequently, the smoother, flatter whole building power improved the confidence in the calculated shed.

How did the owners, managers and staff perceive this technology?

The building owners and managers stated that they were mostly impressed with the improved HVAC and lighting control. They expressed little interest in the plug load and EWH control. The proactive building managers were particularly happy with the ability to automate (namely schedule) the operation of the RTUs and lights. They conveyed their frustration with building staff over-riding set points and not properly operating the lights according to the building's schedule.

The staff did not comment on the HVAC control. Yet their behavior indicated frustration with the lighting DR. For Drug Store #1, the employees were switching the lights permanently on and leaving them on overnight, eliminating the lighting savings feature of this technology. Conversely, for Furniture Store #1, the employees preferred the lower lighting during the DR event and permanently shut off the lighting DR circuit, which eliminated the lighting DR component.

How can this technology achieve larger curtailments?

The BMS user interface needs to be well planned in order to balance ease of use for those with operational authority (building owners and managers), enabling the staff to have control during emergencies but prevent improper operation by unauthorized building staff. The lighting control panel installed in each building's electrical room had manual switches on the front. Therefore, anyone with access to the electrical room was able to permanently override the lights. For future implementation, permanent over rides should be eliminated from the front of the control panel while still allowing the staff to permanently turn the lights on during an emergency.

Larger lighting curtailments could have been realized by implementing more wireless controllers. Additionally, dimming florescent ballasts or dimming LED retrofits would enable larger sheds while still maintaining sufficient lighting levels in the space. Unfortunately the capital cost of these devices would significantly increase the simple payback on this technology. This turnkey, retrofit package will need to wait until wireless control, dimming ballasts and LED equipment prices drop to such an extent that the return on investment aligns with the expectations of building owners.

Much like lighting, other HVAC devices can assist with increasing the HVAC DR resource by allowing the BMS to achieve more aggressive set point shifts. One example would be high efficiency ceiling fans that use electronically commutated motors such as the Haiku ceiling fan that recently became commercially available from Big Ass Fans[11]. Ceiling fans can maintain air movement within the space and therefore allow warmer set points during summer DR events.

What makes a good building candidate for this technology?

Based on the DR curtailments over the demonstrated two winter and seven summer DR events (Table 7), the team summarize the attributes that make a building a good candidate for this packaged, retrofit technology.

[11] www.bigassfans.com/products/haiku/

Building vintage. The team found that the demonstration sites constructed or renovated since 2004 provided the greatest lighting DR curtailment for the lowest implementation cost (Table 8). Newly built or upgraded buildings will typically have an organized electrical layout. Often this means lighting circuits are controlling every other or every third row. Therefore, lighting DR can be realized through inexpensive hardwired relays connected to the BMS rather than having to resort to the flexible but expensive wireless controller approach. From an EE perspective, an existing organized electrical layout makes it easier to integrate the retrofit BMS controller in order to realize significant lighting savings through on/off scheduling.

BMS. It does not matter if the building has an existing BMS or not. The new BMS can supplant what was already there, and often an existing BMS makes the retrofit integration less expensive because the load controls have already been centralized and organized into the electrical room. Additionally, existing contactors and relays can be reused.

Communication latency. The BMS should be configured to minimize communication latency. As the team found during the demonstration, the time from when the DR signal is sent out to when the loads start shedding can be reduced by five minutes or more through software optimization.

Lighting/human behavior. The building engineer and building manager should be provided simple but comprehensive control through both the Web-based interface and at the physical controller located in the electrical room. The BMS, however, should be configured to prevent other building occupants without operational authority from overriding the set points. The lighting controller for this demonstration enabled anyone to override the schedule and permanently turn circuits on or off.

HVAC. Only ASHP RTUs will provide reasonable DR curtailment in the winter. The winter curtailment provided by AC RTUs (non-electric heating) will be minimal—0.1 W/ft^2 or less—from the reduced fan speeds during the DR event.

The team found the summer DR resource was less than anticipated. For typically sized RTUs of 350to 450 ft^2 per cooling ton, the original projections ranged from 0.5 to 0.7 W/ft^2 for day-ahead events to 0.3 to 0.4 W/ft^2 for 10-minute events (Table 9). The day-ahead events realize a larger and longer curtailment by precooling the space prior to the DR event (Section 0). This precharging of the space enables it to float longer before the DR thermostat set point is reached and compressors come back on.

Buildings with a minimal number of compressor stages relative to the conditioned area—more than 4,000 ft^2 per compressor—will saturate faster during a DR event. For example, Furniture Store #2 had only four compressors (in two RTUs) serving 21,717 ft^2 (5,429ft^2 per compressor). Compared to Furniture Store #1 (13 compressors yielding 2,140 ft^2 per compressor), Furniture Store #2 saturated within 1.5 to 2 hours of the DR event. Therefore, buildings with less than 4,000 ft^2 per compressor will yield larger and more sustained DR curtailment.

What was the return-on-investment of this technology?

The cost effectiveness of the CATALYST and eIQ systems was able to offset the long paybacks of the non-HVAC control. The utility savings from the improved RTU operation plus the reduced lighting energy use through improved on-off scheduling resulted in a total system simple payback that ranged for five of the locations between 3.4 to 6.7 years.

Yet Casino #1 achieved a much longer 12.2 year simple payback due to the reduced energy savings from the CATALYST system because five of its six RTU had only one stage of heating and cooling. The CATALYST realizes significantly larger supply fan energy savings with two stage RTUs. Casino #1 provides a great example how the economic feasibility of this technology is mostly based on the energy savings from the RTUs. Unless more expensive lighting control is integrated through dimming ballasts or LEDs, the lighting savings will be a secondary benefit.

What is the maximum potential of this DR resource?

RTU equipment is the most prevalent commercial HVAC system in the PNW region, so the aggregated size of potential buildings is significant. Based on the 2014 CBSA, AC and ASHP RTU equipment heat and cool 1,510 million ft^2, which is 48% of the total PNW commercial floor space.

To understand the total DR magnitude, assuming 100% market penetration of this technology (across all building types) and based on the curtailments measured from this demonstration, the team projected that a winter DR event, lasting up to 4-hours would be 425 MW based on 0.22 W/ft^2 for area served by AC RTUs and 0.60 W/ft^2 for area served by ASHP RTUs. A summer day-ahead DR event lasting up to 4-hours would be 753 MW based on 0.41 W/ft2 for new buildings and 0.56 W/ft2 for older buildings. Finally, a summer day-ahead DR event lasting up to 1-hour would be 1,101 MW based on 0.46 for newer buildings and 0.92 W/ft2 for older buildings.

BPA specified that the performance of this technology should be compared with pumped storage, currently the cheapest generation type to provide similar DR services. For perspective, the team compared the DR projections to the preliminary permits issued by the Federal Energy Regulatory Commission for future pumped storage projects in the PNW. Nine of the 14 planned pumped storage facilities range from 1,000 to 1,300 MW. The winter DR resource, assuming 100% market penetration, would be larger than three of these proposed pumped storage facilities. The summer day-ahead 4-hour event would be larger than four of these facilities. Finally, the summer day-ahead 1-hour would be roughly the same size as the 14 pumped storage facilities ranging from 1,040 to 1,340 MW.

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Appendix A. Demonstration Site Summary

This appendix summarizes the HVAC, lighting, plug load, and EWH equipment at each demonstration location. Based on this equipment audit, the team projected the DR magnitude for the winter and summer DR events. Although the team did not run 10-minute DR events during the demonstration, the team still included the projections for this event type.

Furniture Store #1

Furniture Store #1 represented a medium-sized, dry-goods retail building. Compared to Furniture Store #2, this furniture store is approximately 6,000 ft^2 larger and located in a new strip mall built in 2010. Consequently, the electrical layout was well organized and the team had drawings on site to identify what circuits controlled which lights on the sales floor—a luxury the team only found at the newer stores built within the past 10 years.

This store's 2013 utility bills showed monthly peak demands ranging from 89 to 98 kW (3.2 to 3.5 W/ft^2) in the winter and 108 to 131 kW (3.9 to 4.7 W/ ft^2) in the summer. At its SnoPUD Schedule 20 utility rate, the store paid $35,578 for electricity, consuming 464,840 kWh in 2013. The annual demand charges, which apply only in the summer months, were a small fraction of this at $415, approximately 1% of the annual utility bill. Like the other demonstration sites that had minimal or no demand charges, the building owner was incentivized by EE, not DR.

Heating, Ventilating, and Air Conditioning

CATALYSTs controlled six 12.5 tons (RTUs 1–6) and one 4-ton (RTU 7) Lennox RTUs. The small RTU served the break room and had a longer daily operation of 6 a.m. to 10 p.m. The 79 tons gave an area-to-cooling capacity of 350 ft^2 per ton. Assuming an AC cooling performance (compressor and condenser fans only) of 1 kW/ton, the peak HVAC draw (excluding the supply fans) was 79 kW (2.8 W/ft^2). The supply fans constituted another 13 kW (0.5 W/ft^2).

At the beginning of the project, the assumptions about HVAC curtailment were as follows:

- During a summer day-ahead DR event, assuming a quarter of the AC was curtailed (~19.8 kW) and the supply fan speeds would reduce from 90% to 70% (~3.9 kW), the total HVAC power draw reduction would be 23.7 kW (0.8 W/ft^2).
- During a summer 10-minute DR event, the team assumed an eighth of the AC would be curtailed (~9.9 kW) and the supply fan speeds would reduce from 90% to 70% (~3.9 kW). Therefore, the total HVAC power draw would be reduced by 13.8 kW (0.5 W/ft^2).
- During a winter DR event, the team assumed the supply fans would reduce from 90% to 70% providing 3.9 kW (0.1 W/ft^2).

Lighting

The store lighting was much higher than the other demonstration locations, including Furniture Store #2. The store was extremely bright and had a total LPD of 1.5 W/ft^2 (42 kW). The exterior signage and parking lot lights totaled 12.7 kW. The existing lighting was controlled by a Novar Savvy Energy Information System. The team replaced this lighting controller with Transformative Wave's control panel. During winter and summer DR events, the team turned off one circuit—the staff lighting circuit—over the sales floor; 240 two-lamp (T8's) troffers yielding 13.4 kW (0.5 W/ft^2).

Plug Loads and Electric Water Heater

One of the relays in Transformative Wave's control panel curtailed the electric water heater, which experienced a cyclic load measured at 3.6 kW. The control panel also curtailed a coffee pot, a cookie oven, a soda machine, two water fountain coolers, and a popcorn machine. The total plug load DR resource was 8.5 kW (0.3 W/ft^2).

The team decided not to control and curtail the 50 liquid crystal diode TVs on the sales floor with an estimated load of 5 kW. This store uses these TVs as visual and as its audio system to play music videos. While the TV load was sizable, the team felt that turning off these TVs would have been too noticeable. In addition, Autani was not able to configure one of its existing controllers to turn the TVs back on at the end of the DR event. The store manager would have had to turn on each TV with a remote, which would cause the staff frustration.

Estimated Demand Response

Based on the above estimates for HVAC, lighting, plug loads, and EWHs, the equations below estimate the summer and winter curtailment. These equations were rough estimates mainly due to the cyclic, unpredictable operation of the RTUs and plug loads.

Winter DR = 0 kW (RTU AC) + 3.9 kW (RTU supply fans) + 13.4 kW (lighting) + 12.0 kW (plug & EWH) = 29.3 kW (1.1 W/ft^2)

Summer day-ahead DR = 19.8 kW (RTU AC) + 3.9 kW (RTU supply fans) + 13.4 kW (lighting) + 12.0 kW (plug & EWH) = 49.1 kW (1.8 W/ft^2)

Summer 10-min DR = 9.9 kW (RTU AC) + 3.9 kW (RTU supply fans) + 13.4 kW (lighting) + 12.0 kW (plug) = 33.0 kW (1.2 W/ft^2)

Table A-1. Furniture Store #1 Site Details

Area	27,823 ft^2
Electric Utility	Snohomish PUD (SnoPUD)
Gas Utility	Puget Sound Energy (PSE)
Store Open	Mon–Fri 10–9 p.m.; Sat 10–9 p.m.; Sun 10–8 p.m. (3,952 annual h)
RTU Operational Hours	RTUs 1-6: All Days 8 a.m.–10 p.m. (5,110 annual h) RTU 7: All Days 6 a.m.–10 p.m. (5,840 annual h)
RTU Set Points	Occupied: 68°–72°F Unoccupied: 60°–80°F
Electricity Charge[a]	Summer (April–Sept): $0.077/$0.059/kWh[b] Winter (Oct–March): $0.086/$0.069/kWh[b]
Demand Charge[a]	$4.20/kW (all year)[c]
Gas Charge	$1.07/therm

[a] SnoPUD Schedule 20 (Med @ >100 kW or >30 MWh per month)
[b] (<20 MWh charge)/(>20 MWh charge)
[c] Demand charge applies to above 100 kW; applies to any day/time

Furniture Store #2

Furniture Store #2 represented a small, dry goods retail building. Compared to Furniture Store #1, this store is smaller and in a much older building with significantly lower lighting levels. The electrical layout, particularly the lighting circuits, was extremely difficult to navigate and the team had no electrical drawings to work from. During the initial site visit, the team spent 3 hours turning off each circuit and walking around the store to identify the lights associated with that circuit. The existing lighting was zoned such that each room mockup had its own lighting circuit.

Consequently, turning off an entire circuit eliminated all the lighting in a zone. This layout eliminated the ability to use circuit level control for DR the way the team did at both drug stores and Furniture Store #1—all stores built or retrofitted within the past 10 years. More specifically, Furniture Store #1 had a lighting layout more conducive to DR because it had multiple circuits serving the same zone (alternating rows of fluorescent lighting) and a higher ceiling, so turning off one circuit still left ample ambient lighting. Furniture Store #2 was also a DR challenge because even with all the circuits on, it had extremely low lighting levels.

In order to add lighting DR to this demonstration site, the team installed the Autani AFC-A wireless fixture controllers on 20 three-lamp troffers throughout the store. Even though the AFC-A controller had dimming capability, the team only turned these troffers off during a DR event. Although this limited DR resource provided only a 1.9-kW reduction, it provided us a detailed understanding of the cost-effectiveness of detailed, lamp-level lighting control using wireless technology. The team was then able to compare this approach to the less expensive circuit level control at the two drug stores and Furniture Store #1.

This store was under a SnoPUD rate schedule with no demand charges, so its utility bills did not provide monthly peak demand. During 2012 and 2013, the electricity charges ranged from $25,000 to $27,000, consuming 323,000 to 341,000 kWh annually.

Heating, Ventilating, and Air Conditioning

CATALYST systems controlled two 20-ton, two-stage York RTUs. The 40 tons provided an area-to-cooling capacity of more than 500 ft^2 per ton—significantly larger than the other stores, which ranged from 350 to 400 ft^2 per ton. With this smaller tonnage-to-area ratio and only four compressor stages, the team anticipated this furniture store would provide the least HVAC curtailment of all the stores. For example, Furniture Store #1 with 350 ft^2/ton and 13 stages of cooling has much greater potential as a DR resource due to its oversizing and greater capacity steps.

Assuming an AC cooling performance (compressor and condenser fans only) of 1 kW/ton, the peak HVAC draw, excluding the supply fans, was approximately 40 kW (1.8 W/ft^2). The supply fans constituted another 6.5 kW (0.3 W/ft^2).

At the beginning of the project, the assumptions about HVAC curtailment were as follows:

- During a summer day-ahead DR event, assuming a quarter of the AC was curtailed (~10.0 kW) and the supply fan speeds were reduced from 90% to 70% (~1.9 kW), the total HVAC power draw would reduce 11.9 kW (0.5 W/ft^2).

- During a summer 10-minute DR event, the team assumed one-eighth of the AC would be curtailed (~5 kW) and the supply fan speeds would reduce from 90% to 70% (~1.9 kW). Therefore, the total HVAC power draw would reduce 6.9 kW (0.3 W/ft²).
- During a winter DR event, the team assumed the supply fan speeds would reduce from 90% to 70% providing 1.9 kW (0.1 W/ft²).

Lighting

The store lighting layout was the most problematic of all the demonstration locations for implementing DR. The circuit layout was too coarse, such that shutting of a circuit would eliminate all the lighting in a zone. There were three main types of lights on the sales floor: 173 LED spotlights in the rear of the store, 158 three-lamp troffers for the remaining sales floor layout, and 89 table lamps that were a part of the furniture arrangements. The total LPD was 0.7 W/ft² (15.7 kW). The exterior signage and parking lot lights equaled 4.7 kW.

There were two existing Cooper Greengate Lighting control panels. The team replaced these with Transformative Wave's own control panel. Over BACnet communication, the eIQ communicated with an Autani manager located in the electrical room. The Autani manager then communicated wirelessly (over ZigBee) with AFC-A fixture controllers on 20 of the troffer lights, a water heater, and several plug loads. During winter and summer DR events, the team turned off these 20 troffers yielding 1.9 kW (0.1 W/ft²).

Plug Loads and Electric Water Heater

The team used an Autani ARC-L Switched Load Controller (wireless 120/277VAC relay) to curtail the EWH, which had a cyclic draw measured at 3.3 kW (0.2 W/ft²). Autani SmartLet Outlet Controllers curtailed two drinking fountain cooling systems totaling 1 kW, a coffee pot at 1.1 kW, a cookie oven and a soda machine at 2 kW, and a popcorn machine at 1.2 kW. The total potential plug load curtailment was 5.5 kW (0.3 W/ft²).

The team decided not to control and curtail the 60 liquid crystal diode TVs on the sales floor with an estimated load of 6 kW. This store used these TVs as visuals and as its audio system to play music videos. Although the connected load was sizable, the team felt that turning off these TVs would have been too noticeable. Plus Autani was not able to configure one of its existing products to turn the TVs back on at the end of the DR event. The store manager would have had to turn on each TV with a remote (the same as when opening and closing the store), which would have caused the staff frustration. Therefore, the total connected plug and EWH load that the team turned off or prevented from coming on during a DR event was 8.8 kW (0.4 W/ft²).

Estimated Demand Response

Based on the above estimates for HVAC, lighting, plug loads, and EWHs, the equations below estimate the summer and winter curtailment. These equations were rough estimates mainly due to the cyclic, unpredictable nature of the RTUs, EWH, and plug loads.

> Winter DR = 0 kW (RTU AC) + 1.9 kW (RTU supply fans) + 1.9 kW (lighting) + 8.8 kW (plug and water heater) = 12.7 kW (0.6 W/ft²)
>
> Summer day-ahead DR = 10.0 kW (RTU AC) + 1.9 kW (RTU supply fans) + 1.9 kW (lighting) + 8.8 kW (plug and water heater) = 22.7 kW (1.0 W/ft²)

Summer 10-min DR = 5.0 kW (RTU AC) + 1.9 kW (RTU supply fans) + 1.9 kW (lighting) + 8.8 kW (plug) = 17.7 kW (0.8 W/ft^2)

Table A-2. Furniture Store #2 Site Details

Area	21,717 ft^2
Electric Utility	Snohomish PUD (SnoPUD)
Gas Utility	Puget Sound Energy (PSE)
Store Open Hours	Mon–Fri 10–9 p.m.; Sat 10–9 p.m.; Sun 10–8 p.m. (3,952 annual h)
RTU Operational Hours	RTU 1: All Days 8:45 a.m.–10 p.m. (4,745 annual h) RTU 2: All Days 8 a.m.–10 p.m. (5,110 annual h)
RTU Set Points	RTUs 1: 66°–69°F/60°–80°F (occupied/unoccupied) RTU 2: 69°–72°F/60°–80°F (occupied/unoccupied)
Electricity Charge[a]	Summer (April–Sept): $0.086/kWh Winter (Oct–March): $0.077/kWh
Demand Charge[a]	none
Gas Charge	$1.07/therm

[a] SnoPUD Schedule 25 (Small General Service)

Drug Store #1

This drug store represents a small, dry-goods retail except that one entire wall was an open medium-temperature refrigerated case with four doored low-temperature cases. With a nearly identical layout, this drug store is only 800 ft^2 larger than Drug Store #2. Transformative Wave has an on-going relationship with this drug store chain and currently has its eIQ/CATALYST technology deployed at 42 of its locations.

This store was recently retrofitted in 2013. Consequently, it had a very organized electrical layout with a neatly circuited lighting system. This enabled us to achieve an appreciable lighting curtail with minimal hardware using a hardwired control panel located in the electrical room. This drug stores generally experienced a peak power draw of 70 to 80 kW (4.5 to 5.2 W/ft^2) during the summer months and 50 to 60 kW in the winter months (3.2 to 3.9 W/ft^2).

Heating, Ventilating, and Air Conditioning

CATALYST systems controlled the two 17.5-ton and one 5-ton Lennox RTUs serving the store. The 40-ton total capacity yields an area-to-cooling-capacity of 405 ft^2/ton. Assuming an AC cooling performance (compressor and condenser fans only) of 1.0 kW/ton, the peak HVAC draw (excluding the supply fans) was approximately 40 kW (2.5 W/ft^2). The supply fans constituted another 8 kW (0.5W/ft^2).

At the beginning of the project, the assumptions about HVAC curtailment were as follows:

- During a summer day-ahead DR event, assuming a quarter of the AC was curtailed (~10.0 kW) and the supply fan speeds were reduced from 90% to 70% (~2.5 kW), the total HVAC power draw was reduced 12.5 kW (0.8 W/ft^2).
- During a summer 10-minute DR event, the team assumed one-eighth of the AC would be curtailed (~5 kW) and the supply fan speeds would reduce from 90% to 70% (~2.5 kW). Therefore, the total HVAC power draw would reduce 7.5 kW (0.5 W/ft^2).
- During a winter DR event, the team only assumed the supply fan speed was reduced from 90% to 70% providing 2.5 kW (0.2 W/ft^2).

Lighting

The store's total LPD was measured at 1.2 W/ft^2 (19.5 kW). The exterior signage and parking lot lights totaled 2.3 kW. Transformative Wave used its control panel to control all five lighting zones in the electrical panel room—two zones included the exterior signage and parking lot lights. Most of the sales floor lighting was 32-W T8 fluorescents. Canned lighting was over the cosmetic/skin care area and entrance vestibule.

During the winter and summer DR events, the team curtailed two of these zones—several rows of lights over the sales floor and all the storage lighting—which corresponded to 6.2 kW (0.4 W/ft^2). The building manager was consulted about the lighting zones that remained on during the DR events to ensure sufficient illuminance on the products on the sales floor and in the pharmacy.

Plug Loads and Electric Water Heater

One of the relays in Transformative Wave's control panel curtailed the single beverage display cooler located at the checkout, which experienced a cyclic 0.4-kW load. Although this store had an EWH, the building manager did not want it curtailed to maintain consistent hot water for the pharmacy department. This load was cyclical and would draw power for brief periods of time only, such as 5 minutes on, 15 minutes off. The team kept this load off throughout the DR event using Autani's SmartLet Outlet Controller.

Estimated Demand Response

Based on the above estimates for HVAC, lighting, and plug loads (no water heater), the equations below estimate the summer and winter curtailment. These equations were rough estimates mainly due to the cyclic, unpredictable nature of the RTUs and drink cooler plug load.

Winter DR = 0 kW (RTU AC) + 2.5 kW (RTU supply fans) + 6.2 kW (lighting) + 0.4 kW (plug) = 9.1 kW (0.6 W/ft^2)

Summer Day-Ahead DR = 10.0 kW (RTU AC) + 2.5 kW (RTU supply fans) + 6.2 kW (lighting) + 0.4 kW (plug) = 19.1 kW (1.2 W/ft^2)

Summer 10-min DR = 5.0 kW (RTU AC) + 2.5 kW (RTU supply fans) + 6.2 kW (lighting) + 0.4 kW (plug) = 14.1 kW (0.9 W/ft^2)

Table A-3. Drug Store #1 Site Details

Area	16,210 ft^2
Electric Utility	*Seattle City Light (SCL)*
Gas Utility	*Puget Sound Energy (PSE)*
Store Open Hours	*Mon–Fri 9 a.m.–9 p.m.; Sat 9–6 p.m.; Sun 10–6 p.m. (4,004 annual h)*
RTU Operational Hours	*Mon–Fri 6 a.m.–10 p.m.; Sat and Sun 7 a.m.–9 p.m. (5,616 annual h)*
RTU Set Points	*Occupied: 68°–71°F* *Unoccupied: 60°–80°F*
Electricity Charge[a]	*$0.065/kWh*
Demand Charge[a]	*$2.24/kW (above 0 kW; applies anytime)*
Gas Charge	*$1.07/therm*

[a] SCL Sch MDC (≥50 kW; <1,000 kW)

Drug Store #2

This drug store represents a small, dry goods retail except that one entire wall was an open medium-temperature refrigerated case with four doored low-temperature cases. With a nearly identical layout, this drug store is only 800 ft^2 smaller than Drug Store #1. Transformative Wave has a strong relationship with this drug store chain and currently has its eIQ/CATALYST technology deployed at 42 locations.

This store was recently built in 2013. Consequently, it had a very organized electrical layout with a neatly circuited lighting system. This enabled us to achieve a reasonable lighting curtail with minimal hardware using a hardwired control panel located in the electrical room. This drug store generally experienced a peak power draw of 70 to 80 kW (4.5 to 5.2 W/ft^2) during the summer months and 50 to 60 kW in the winter months (3.2 to 3.9 W/ft^2).

Heating, Ventilating, and Air Conditioning

CATALYST systems controlled the two 17.5-ton and one 5-ton Lennox RTUs serving the store. The 40-ton total capacity yields an area-to-cooling capacity of 385 ft^2/ton. Assuming an AC cooling performance (compressor and condenser fans only) of 1 kW/ton, the peak HVAC draw, excluding the supply fans, was approximately 40 kW (2.6 W/ft^2). The supply fans constituted another 8 kW (0.5W/ft^2).

At the beginning of the project, the assumptions about HVAC curtailment were as follows:

- During a summer day-ahead DR event, assuming a quarter of the AC was curtailed (~10.0 kW) and the supply fan speeds were reduced from 90% to 70% (~2.4 kW), the total HVAC power draw was reduced 12.4 kW (0.8 W/ft^2).
- During a summer 10-minute DR event, the team assumed an eighth of the AC would be curtailed (~5.0 kW) and the supply fan speeds would reduce from 90% to 70% (~2.4 kW). Therefore, the total HVAC power draw would reduce 7.4 kW (0.5 W/ft^2).
- During a winter DR event, the team only assumed the supply fan speeds would reduce from 90% to 70% providing 2.4 kW (0.2 W/ft^2).

Lighting

The store's total LPD was 1.2 W/ft^2 (18 kW). The exterior signage and parking lot lights totaled 4.3 kW. Transformative Wave used its control panel to control all five lighting zones in the electrical panel room—two zones included the exterior signage and parking lot lights. Most of the sales floor lighting was 32-W T8 fluorescents. Canned lighting was over the cosmetic/skin care area and entrance vestibule.

During the winter and summer DR events, the team curtailed two of these zones, which corresponded to 6.9 kW (0.4 W/ft^2). The building manager was consulted about the single fluorescent lighting zones that remained on during the DR events to ensure sufficient illuminance on the products on the sales floor and in the pharmacy.

Plug Loads and Electric Water Heater

One of the relays in Transformative Wave's control panel curtailed the single beverage display cooler located at the checkout, just as in Drug Store #1. It experienced a cyclic 0.4 kW load. Although this store had an electric water heater, the building manager did not want it curtailed to maintain consistent hot water for the pharmacy department. This load was cyclical and would only draw power for brief periods of time such as 5 minutes on, 15 minutes off. The team kept this load off throughout the DR event using Autani's SmartLet Outlet Controller.

Estimated Demand Response

Based on the above estimates for HVAC, lighting, and plug loads (no water heater), the equations below estimate the summer and winter curtailment. These equations were rough estimates mainly due to the cyclic, unpredictable nature of the RTUs and drink cooler plug load.

Winter DR = 0 kW (RTU AC) + 2.4 kW (RTU supply fans) + 6.9 kW (lighting) + 0.4 kW (plug) = 10.2 kW (0.7 W/ft^2)

Summer day-ahead DR = 10.0 kW (RTU AC) + 2.4 kW (RTU supply fans) + 6.9 kW (lighting) + 0.4 kW (plug) = 20.2 kW (1.3 W/ft^2)

Summer 10-min DR = 5.0 kW (RTU AC) + 2.4 kW (RTU supply fans) + 6.9 kW (lighting) + 0.4 kW (plug) = 14.7 kW (1.0 W/ft^2)

Table A-4. Drug Store #2 Site Details

Area	15,400 ft^2
Electric Utility	Puget Sound Energy (PSE)
Gas Utility	Puget Sound Energy (PSE)
Store Open Hours	Mon–Fri 9 a.m.–9 p.m.; Sat 9–6 p.m.; Sun 10–6 p.m. (4,004 annual h)
RTU Operational Hours	All days 8 a.m.–10 p.m. (5,096 annual h)
RTU Set Points	Occupied: 68°–72°F Unoccupied: 60°–80°F
Electricity Charge[a]	Summer (April–Sept): \$0.085/\$0.068/kWh[b] Winter (Oct–March): \$0.094/\$0.068/kWh[b]
Demand Charge[a]	\$9.01 winter/\$6.01 summer/kW[c]
Gas Charge	\$1.07/therm

[a] PSE Schedule 25 (>50 kW; ≤350 kW)
[b] (≤ 20 MWh per month rate)/(> 20 MWh per month rate)
[c] demand charge applies to above 50 kW; anytime

Casino #1

Approximately 75% of Casino #1's floor area is the gambling pit, consisting of nine game tables. The next-largest area was a bar, which included a dining area. A small banquet room, approximately 400 ft^2, was adjacent to the bar. The back of house comprised the kitchen, break room, electrical room, and security office.

Much like Furniture Store #2 and Casino #2, this casino was an older building with a disorganized electrical layout. The electrical room showed significant panel- and circuit-level changes over the years. The most recent was the 2013 retrofit of 54 mini-flood lights throughout the gambling pit and bar from 40 W metal halides to 7 W LEDs.

The lighting levels were significantly lower compared to typical casinos, which can exceed 3 W/ft^2 LPDs. The team estimated this casino's LPD after the LED retrofit to be less than 1 W/ft^2.

The team curtailed lighting in the banquet room, server room, and electrical room as well as the gambling floor accent lighting and display lighting. The team could not do circuit-level control at the electrical room, so the team had to take a more surgical approach, leveraging the Autani wireless controllers. Due to the low lighting levels and the expense of using wireless devices, the total curtailed lighting was only 2.1 kW (0.2 W/ft^2).

The team curtailed the refrigerated vending machine located in the break room at 1.1 kW (0.1 W/ft^2). The majority of the DR load reduction was provided by the six RTUs. Across the six demonstration sites, the team anticipated this casino and Furniture Store #2 would provide the smallest DR curtailment. This was mainly due to the age of the building, which correlated to a disorganized electrical layout as the building had been expanded or changed over time.

Heating, Ventilating, and Air Conditioning

CATALYST systems controlled six RTUs—four 3-ton, one 4-ton, and one 10-ton. The 26 tons gave an area-to-cooling capacity of 430 ft^2/ton. Assuming an AC cooling performance (compressor and condenser fans only) of 1.0 kW/ton, the peak HVAC draw (excluding the supply fans) would be approximately 26 kW (2.3 W/ft^2). The supply fans constituted another 4.3 kW (0.4 W/ft^2).

At the beginning of the project, the assumptions regarding HVAC curtailment were:

- During a summer day-ahead DR event, the team assumed a quarter of the AC would be curtailed (~6.5 kW) and the supply fan speeds would reduce from 90% to 70% (~1.3 kW). Therefore the total HVAC power draw would reduce 7.8 kW (0.7 W/ft^2).
- During a summer 10-minute DR event, the team assumed an eighth of the AC would be curtailed (~3.3 kW) and the supply fan speeds would reduce from 90% to 70% (~1.3 kW). Therefore, the total HVAC power draw would reduce 4.6 kW (0.4 W/ft^2).
- During a winter DR event, the team assumed the supply fan speed would reduce from 90% to 70% providing 1.3 kW (0.1 W/ft^2).

Lighting

In general, the lighting throughout this casino was much lower than the team expected for a typical casino. The majority of the lighting in the gambling pit was 54 mini-flood lamps that had been retrofitted to 7 W LEDs. Based on information from the casino manager, the LEDs were intended to improve the light uniformity across the gaming tables, not to improve energy efficiency. This significant reduction from the original 40-W metal-halide lamps significantly reduced the DR potential of the building. As buildings incorporate energy efficiency measures such as LED technology, the DR potential reduces, and this was a great example of that. The bar had similar lighting levels using the same mini-flood LEDs. The banquet room and back of house were lit by standard T8 fluorescent lamps.

The electrical layout was too disorganized, so Transformative Wave did not build a control panel for this casino the way it did for both drug stores and Furniture Store #1. Instead, it leveraged the flexibility of the Autani wireless controllers to surgically control specific lighting resources throughout the building. The eIQ communicated with the Autani manager, which in turn communicated wirelessly with nine Autani lighting controllers (ARC-R). Some of the lighting in the banquet room, card room, server room, storage room, electrical room, gambling floor (sconces, display cases, LEDs), and break room were curtailed during a DR event.

The lighting level was already low throughout this casino, and installing the Autani wireless equipment was more expensive than doing circuit level control back at the electrical room, so the total curtailment was only 2.1 kW (0.2 W/ft^2). Because some of these lights were installed with occupancy sensors for certain rooms with infrequent use (banquet room, card room), the team anticipated the lighting curtailment to be less than 2.1 kW because there was a good chance the lights were already off prior to the DR event.

Plug Loads and Electric Water Heater

There were no EWHs. The kitchen was served by two natural gas tankless heaters. There were negligible plug loads in the gaming area and bar because these casinos were nontribal and could not have slot machines. The team used the Autani SmartLet Outlet Controller to curtail only the dry goods vending machine (0.3 kW) located in the break room. The building manager did not want the coffee pot or the microwave curtailed.

Due to increased liability, the team did not curtail the ice machine, walk-in cooler or walk-in freezer located in the kitchen. Also, the team did not curtail the 10 flat-screen TVs located in the gambling pit or the 14 flat-screen TVs located in the bar. Autani could not provide a product that would ensure the TVs would turn back on after the DR event. Additionally, with this casino's focus on sporting events, the casino manager stated that the TV would be off limits except for winter mornings when no games were on.

Estimated Demand Response

Based on the above estimates for HVAC, lighting, and plug loads, the equations below estimate the summer and winter curtailment. These equations were rough estimates mainly due to the cyclic, unpredictable nature of the RTUs.

> Winter DR = 0 kW (RTU AC) + 1.3 kW (RTU supply fans) + 2.1 kW (lighting) + 0.3 kW (plug) = 3.7 kW (0.3 W/ft^2)

Summer Day-Ahead DR = 6.5 kW (RTU AC) + 1.3 kW (RTU supply fans) + 2.1 kW (lighting) + 0.3 kW (plug) = 10.2 kW (0.9 W/ft^2)

Summer 10-min DR = 3.3 kW (RTU AC) + 1.3 kW (RTU supply fans) + 2.1 kW (lighting) + 0.3 kW (plug) = 6.9 kW (0.6 W/ft^2)

Table A-5. Casino #1 Site Details

Area	*11,173 ft^2*
Electric Utility	Snohomish PUD (SnoPUD)
Gas Utility	Puget Sound Energy (PSE)
Store Open Hours	Open 24-7 except for Mon 6–10 a.m. and Tues 6–10 a.m. (8,320 annual h)
RTU Operational Hours	24-7 (8,760 annual h)
RTU Set Points	Occupied: 67°–71°F
Electricity Charge[a]	Summer (April–Sept): $0.086/kWh Winter (Oct–March): $0.077/kWh
Demand Charge[a]	none
Gas Charge	$1.07/therm

[a] SnoPUD Schedule 25 (Small General Service)

Casino #2

This casino at 16,653 ft^2 is much larger than Casino #1. Like Casino #1, this location had a gaming room with card tables, a bar with a dining area, and back of house consisting of a kitchen, break room, security office, and electrical room. Casino #2 also had a nightclub/event room, lounge area, and pool room.

Much like Furniture Store #2 and Casino #1, this was an older building with a disorganized electrical layout. The lighting control was very similar to Casino #1. Transformative Wave did not install its control panels that provided circuit level control within the electrical room. Instead, it used Autani's wireless controllers to surgically control different lighting circuits throughout the building. Autani wireless controllers were also used to curtail the microwave and TV in the breakroom. Due to the complexity and expense of controlling individual light troffers and plug loads, the total curtailment provided by the lighting and plug loads was minimal. The lion's share of this casino's DR came from the RTUs.

Heating, Ventilating, and Air Conditioning

CATALYST systems control 11 RTUs (one 3-ton, two 6.5-ton; four 7.5-ton; one 8.5-ton; three 20-ton). The 115 tons gave an area-to-cooling capacity of 145 ft^2/ton. The excessive oversizing of this location was due to the cooling demand of the nightclub, although this level of oversizing was extreme. Assuming an AC cooling performance (compressor and condenser fans only) of 1 kW/ton, the peak HVAC draw (excluding the supply fans) was approximately 115 kW. The supply fans constituted another 21.3 kW.

At the beginning of the project, the assumptions regarding HVAC curtailment were:

- During a summer day-ahead DR event, the team assumed a quarter of the AC would be curtailed (~28.6 kW) and the supply fan speeds would reduce from 90% to 70% (~6.4 kW). Therefore, the total HVAC power draw would reduce 35 kW (2.1 W/ft^2).
- During a summer 10-minute DR event, the team assumed one-eighth of the AC would be curtailed (~14.3 kW) and the supply fan speeds would reduce from 90% to 70% (~6.4 kW). Therefore, the total HVAC power draw would reduce 20.7 kW (1.2 W/ft^2).
- During a winter DR event, the team only assumed the supply fan speed would reduce from 90% to 70% providing 6.4 kW (0.4 W/ft^2).

Lighting

In general, the LPD throughout this casino was much lower than would be expected for a typical casino, which can reach 3.0 W/ft^2. The team estimated that the whole building's LPD was less than 1.0 W/ft^2. Transformative Wave used Autani's ARC-R wireless controllers to control the lighting in the balcony, green room, boiler room, main bar display, banquet room, and balcony hallway. Because the wireless controllers cost more to implement and this casino did not have much lighting available to curtail due to its already dim interior, the total lighting reduction during a DR event was only 1 kW (0.1 W/ft^2). This was the smallest lighting curtailment of all six demonstration locations. The next-smallest was Furniture Store #2.

Plug Loads and Electric Water Heater

There were no EWHs because the kitchen was served by natural gas water heaters. There were negligible plug loads in the gaming area and bar because this casino was nontribal and could not have slot machines. The team used Autani SmartLet Outlet Controllers to curtail the microwave (1.1 kW) and breakroom TV (0.3 kW).

Due to increased liability, the team did not curtail the ice machine, walk-in cooler, or walk-in freezer located in the kitchen. The team also did not curtail the 12 flat-screen TVs located in the gambling pit or the six flat-screen TVs located in the bar. Autani could not provide a product that could ensure the TVs would turn back on after the DR event. Plus, with this casino's focus on sporting events, the casino manager stated that the TV would be off limits except for winter mornings when no games were on. The total connected plug load that the team turned off or prevented from coming on during a DR event was 1.4 kW (0.1 W/ft^2).

Estimated Demand Response

Based on the above estimates for HVAC, lighting, and plug loads, the equations below estimate the summer and winter curtailment. These equations were rough estimates mainly due to the cyclic, unpredictable nature of the RTUs.

Winter DR = 0 kW (RTU AC) + 6.4 kW (RTU supply fans) + 1.0 kW (lighting) + 1.4 kW (plug) = 8.8 kW (0.5 W/ft^2)

Summer day-ahead DR = 28.6 kW (RTU AC) + 6.4 kW (RTU supply fans) + 1 kW (lighting) + 1.4 kW (plug) = 37.4 kW (2.2 W/ft^2)

Summer 10-min DR = 14.3 kW (RTU AC) + 6.4 kW (RTU supply fans) + 1 kW (lighting) + 1.4 kW (plug) = 23.1 kW (1.4 W/ft^2)

Table A-6. Casino #2 Site Details

Area	*16,653 ft^2*
Electric Utility	Lakeview Power and Light
Gas Utility	Puget Sound Energy (PSE)
Store Open Hours	Open 24-7 except for Mon 6–10 a.m. and Tues 6–10 a.m. (8,320 annual h)
RTU Operational Hours	24-7 (8,760 annual h)
RTU Set Points	Occupied: 68°–71°F
Electricity Charge[a]	$0.082/kWh
Demand Charge[a]	No demand charge
Gas Charge	$1.07/therm

a Lakeview Power and Light

Appendix B. Demand Response Event Results

This appendix provides a detailed summary of each DR event during the demonstration period.

Furniture Store #1

Table B-1. Furniture Store #1 DR Event Summary[a]

Date	Event Time	HVAC Precharge	Peak Temp	Avg Temp	Conditions	Avg (kW)	95% Conf Interval[b] (kW)	Norm. Avg (W/ft^2)	Notes[c]
Jan 7 (Wed)	5–6 p.m.	NA	48	41	Partly cloudy	12.5	Insufficient data	0.4	Saturation time entire 1 h
Jan 21 (Wed)	5–8 p.m.	NA	46	45	Partly cloudy	-	-	-	No DR shed occurred; staff had overridden the lighting circuits.
Aug 7 (Fri)	2:30–6:30 p.m.	2 h prior (start at 12:30)	78	75	Clear	17.6	±4.0[a]	0.6	Saturation time entire 4 h
Aug 13 (Thur)	2:30–6:30 p.m.	2 h prior (start at 12:30)	80	73	Clear	25.6	±9.0[a]	0.9	Saturation time entire 4 h
Aug 19 (Wed)	2:30–6:30 p.m.	2 h prior (start at 12:30)	89	70	Clear	16.7	±9.6[a]	0.6	Saturation time entire 4 h
Aug 20 (Thur)	2:30–6:30 p.m.	2 h prior (start at 12:30)	73	61	Partly cloudy	11.2	±9.6[a]	0.4	Saturation time entire 4 h
Aug 22 (Sat)	2:30–6:30 p.m.	2 h prior (start at 12:30)	80	74	Scattered clouds	12.5	±9.8[a]	0.4	Saturation time entire 4 h
Aug 23 (Sun)	2:30–6:30 p.m.	2 h prior (start at 12:30)	80	63	Scattered clouds	15.4	±9.8[a]	0.6	Saturation time entire 4 h
Aug 24 (Mon)	2:30–6:30 p.m.	2 h prior (start at 12:30)	73	68	Clear	-	-	-	No DR event occurred; communication lost to controller during DR event.

[a] Target curtailments for Winter was 0.7 W/ft^2 (19 kW) and Summer Day-Ahead was 1.7 W/ft^2 (47 kW)
[b] 95% confidence interval based on uncertainty analysis
[c] Saturation is the time from the start of the event to the time when one of the compressors came back on

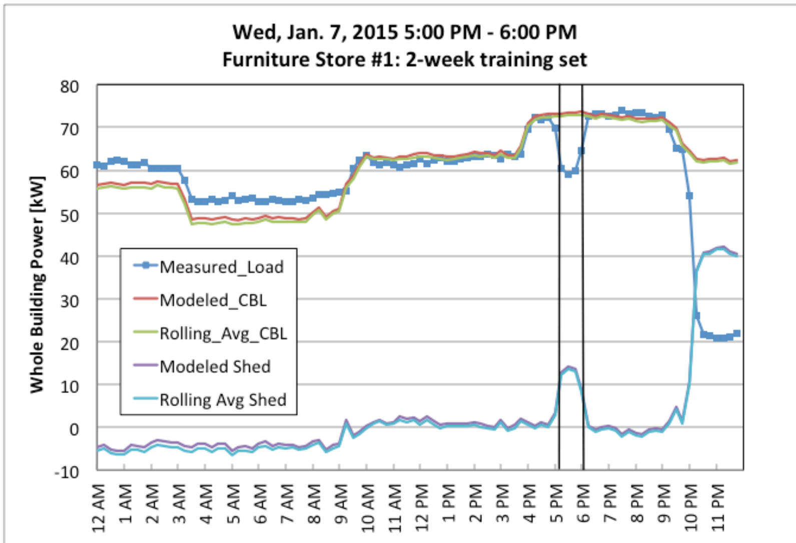


Figure B-1. January 7 event summary; Furniture Store #1

Table B-2. January 7 Event Summary; Furniture Store #1

	Modeled Shed			*10-Day Rolling Avg Shed*	
Min	9.0 kW	0.3 W/ft^2	NA	8.4 kW	0.3 W/ft^2
Mean	12.5 kW	0.4 W/ft^2	Insufficient data[a]	11.8 kW	0.4 W/ft^2
Max	14.3 kW	0.5 W/ft^2	NA	13.6 kW	0.5 W/ft^2

[a] 95% confidence interval based on uncertainty analysis (see Subsection 0)

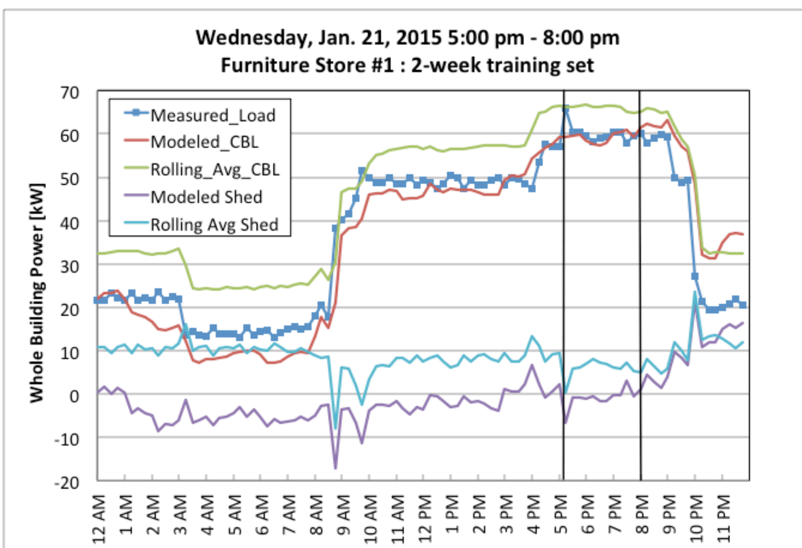


Figure B-2. January 21 event summary; Furniture Store #1

Table B-3. January 21 Event Summary; Furniture Store #1

	Modeled Shed	10-Day Rolling Avg Shed
Min Mean Max	No shed occurred; Building staff had overridden the lighting DR circuit to be off throughout the day. When asked about this, the staff stated that they preferred the lighting of the store when this circuit was off.	

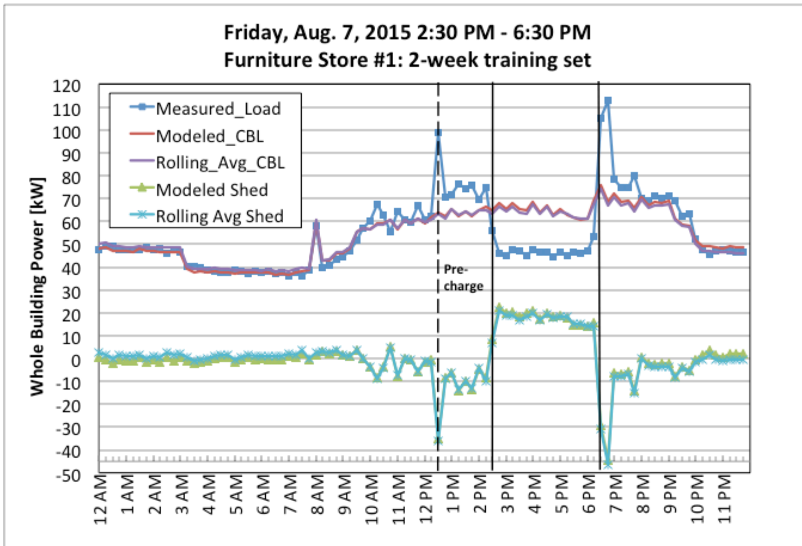


Figure B-3. August 7 event summary; Furniture Store #1

Table B-4. August 7 event summary; Furniture Store #1

	Modeled Shed			10-Day Rolling Avg Shed	
Min	8.6 kW	0.3 W/ft^2	NA	6.9 kW	0.2 W/ft^2
Mean	17.6 kW	0.6 W/ft^2	±4.0 kW[a]	16.9 kW	0.6 W/ft^2
Max	22.4 kW	0.8 W/ft^2	NA	20.8 kW	0.7 W/ft^2

[a] 95% confidence interval based on uncertainty analysis (see Subsection 0)

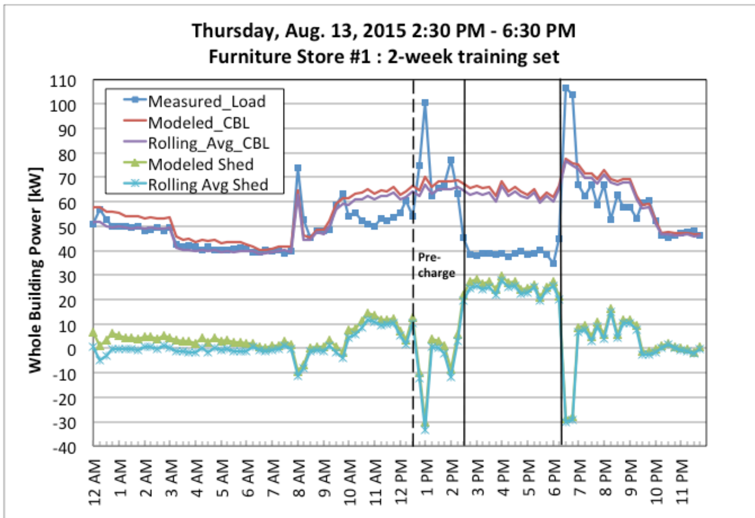


Figure B-4. August 13 event summary; Furniture Store #1

Table B-5. August 13 Event Summary; Furniture Store #1

	Modeled Shed			10-Day Rolling Avg Shed	
Min	20.8 kW	0.7 W/ft^2	NA	19.3 kW	0.7 W/ft^2
Mean	25.6 kW	0.9 W/ft^2	±9.0 kW[a]	23.6 kW	0.8 W/ft^2
Max	29.7 kW	1.1 W/ft^2	NA	27.7 kW	1.0 W/ft^2

[a] 95% confidence interval based on uncertainty analysis (see Subsection 0)

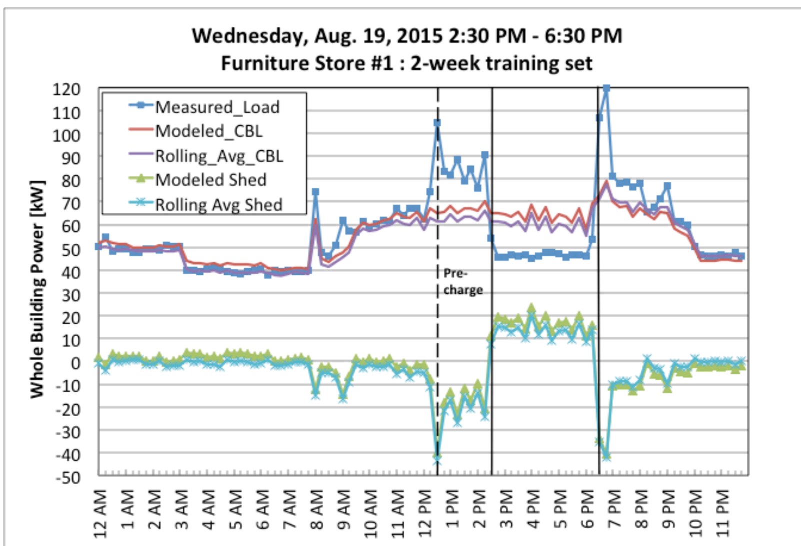


Figure B-5. August 19 event summary; Furniture Store #1

Table B-6. August 19 Event Summary; Furniture Store #1

	Modeled Shed			10-Day Rolling Avg Shed	
Min	11.2 kW	0.4 W/ft^2	NA	7.4 kW	0.3 W/ft^2
Mean	16.7 kW	0.6 W/ft^2	±9.6 kW[a]	13.0 kW	0.5 W/ft^2
Max	23.9 kW	0.9 W/ft^2	NA	19.8 kW	0.7 W/ft^2

[a] 95% confidence interval based on uncertainty analysis (see Subsection 0)

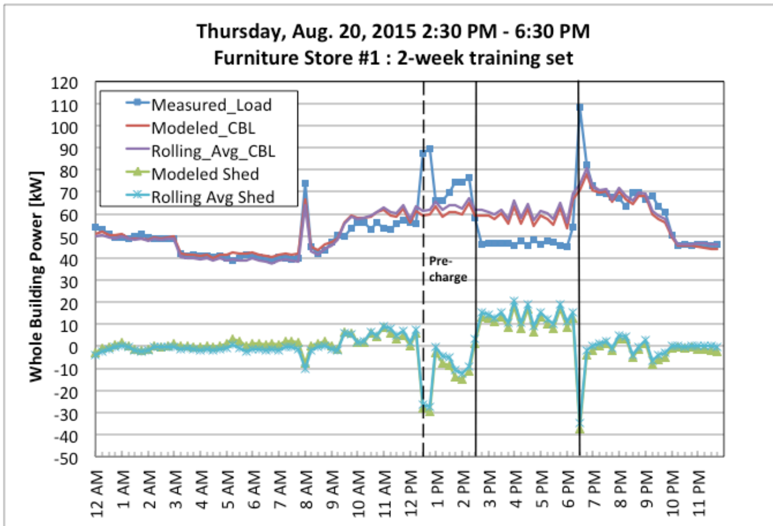


Figure B-6. August 20 event summary; Furniture Store #1

Table B-7. August 20 Event Summary; Furniture Store #1

	Modeled Shed			10-Day Rolling Avg Shed	
Min	1.1 kW	0.0 W/ft^2	NA	3.6 kW	0.1 W/ft^2
Mean	11.2 kW	0.4 W/ft^2	±9.6 kW[a]	13.4 kW	0.5 W/ft^2
Max	17.9 kW	0.6 W/ft^2	NA	20.4 kW	0.7 W/ft^2

[a] 95% confidence interval based on uncertainty analysis (see Subsection 0)

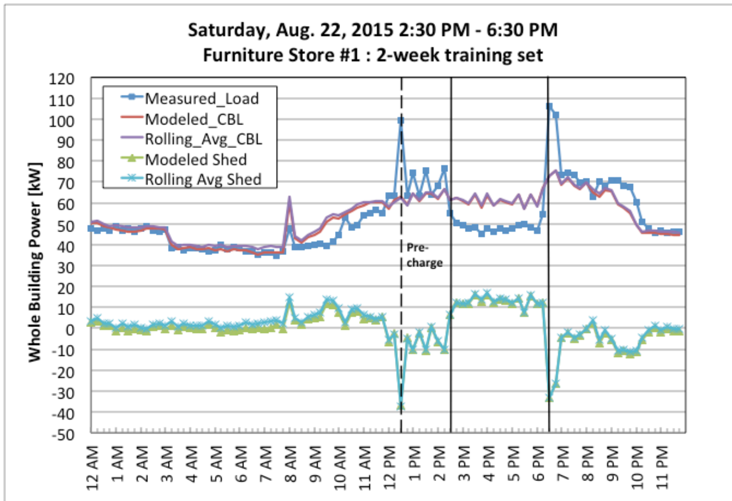


Figure B-7. August 22 event summary; Furniture Store #1

Table B-8. August 22 Event Summary; Furniture Store #1

	Modeled Shed			10-Day Rolling Avg Shed	
Min	6.5 kW	0.2 W/ft^2	NA	6.5 kW	0.2 W/ft^2
Mean	12.5 kW	0.4 W/ft^2	±9.8 kW[a]	12.8 kW	0.5 W/ft^2
Max	15.8 kW	0.6 W/ft^2	NA	17.0 kW	0.6 W/ft^2

[a] 95% confidence interval based on uncertainty analysis (see Subsection 0)

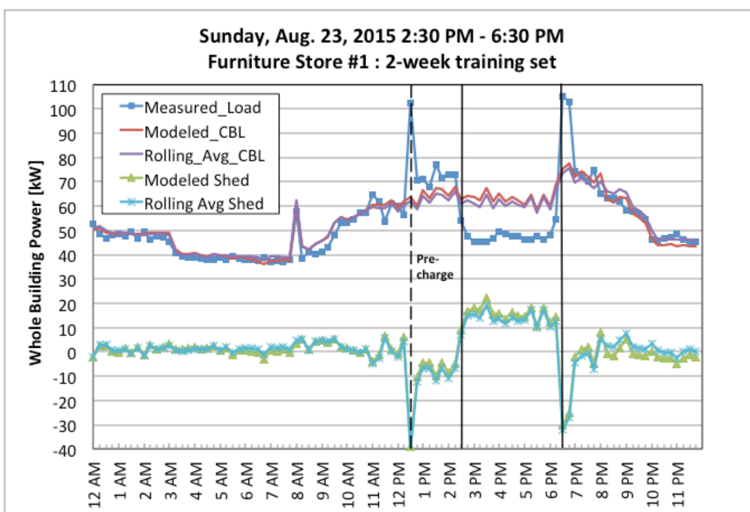


Figure B-8. August 23 event summary; Furniture Store #1

Table B-9. August 23 Event Summary; Furniture Store #1

	Modeled Shed			10-Day Rolling Avg Shed	
Min	8.8 kW	0.3 W/ft^2	NA	7.2 kW	0.3 W/ft^2
Mean	15.4 kW	0.6 W/ft^2	±9.8 kW[a]	13.5 kW	0.5 W/ft^2
Max	22.3 kW	0.8 W/ft^2	NA	19.2 kW	0.7 W/ft^2

[a] 95% confidence interval based on uncertainty analysis (see Subsection 0)

Furniture Store #2

Table B-10. Furniture Store #2 DR Event Summarya

Date	Event Time	HVAC Precharge	Peak Temp	Avg Temp	Conditions	Avg (kW)	95% Conf Interval[b] (kW)	Norm. Avg (W/ft^2)	Notes[c]
Jan 7 (Wed)	5–6 p.m.	NA	46	42	Partly cloudy	4.2	Insufficient data	0.2	Saturation time entire 1 h
Jan 21 (Wed)	5–8 p.m.	NA	46	46	Partly cloudy	1.1	±6.9	0.1	Avg 2.7 kW (0.1 W/ft^2) until 7 p.m. (2-h saturation)
Aug 7 (Fri)	2:30–6:30 p.m.	2 h prior (start at 12:30)	77	74	Clear	-	-	-	Data missing; Lost comm. with controller.
Aug 13 (Thur)	2:30–6:30 p.m.	2 h prior (start at 12:30)	78	74	Scattered clouds	16.4	Insufficient data	0.8	Avg 26.1 kW (1.2 W/ft^2) until 3:30 p.m. (1-h saturation). Data based on rolling avg.
Aug 19 (Wed)	2:30–6:30 p.m.	2 h prior (start at 12:30)	86	73	Clear	10.1	Insufficient data	0.5	Avg 27.4 kW (1.3 W/ft^2) until 3:15 p.m. (0.75-h saturation)
Aug 20 (Thur)	2:30–6:30 p.m.	2 h prior (start at 12:30)	72	71	Partly cloudy	17.0	Insufficient data	0.8	Avg 26.0 kW (1.2 W/ft^2) until 3:45 p.m. (1-h saturation). Data based on Rolling Avg CBL since insufficient data to calculate the Model_CBL.
Aug 22 (Sat)	2:30–6:30 p.m.	2 h prior (start at 12:30)	73	73	Scattered clouds	18.6	Insufficient data	0.9	Avg 27.8 kW (1.3 W/ft^2) until 4:00 p.m. (1.5-h saturation).
Aug 23 (Sun)	2:30–6:30 p.m.	2 h prior (start at 12:30)	78	72	Partly cloudy	21.4	Insufficient data	1.0	Avg 31.6 kW (1.5 W/ft^2) until 4:00 p.m. (1.5-h saturation).
Aug 24 (Mon)	2:30–6:30 p.m.	2 hours prior (start at 12:30)	70	72	Clear	-	-	-	No DR event occurred; Communication lost to controller during DR event.

[a] Target curtailments for Winter was 0.7 W/ft^2 (15 kW) and Summer Day-Ahead was 1.7 W/ft^2 (37 kW)
[b] 95% confidence interval based on uncertainty analysis
[c] Saturation is the time from the start of the event to the time when one of the compressors came back on

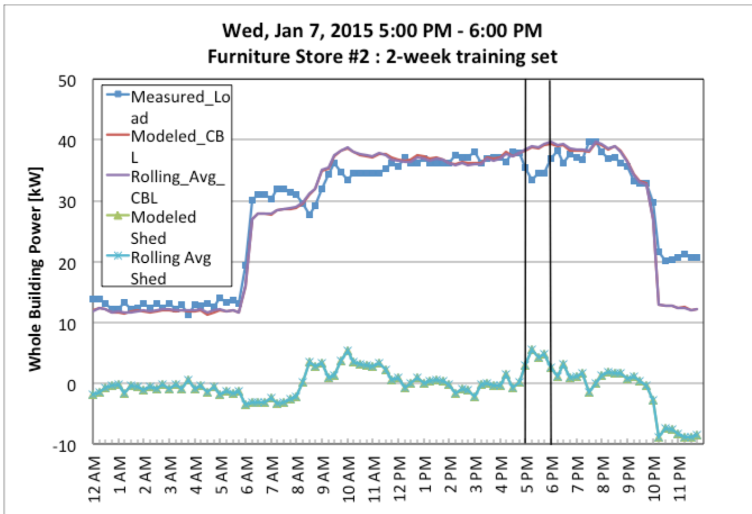


Figure B-9. January 7 event summary; Furniture Store #2

Table B-11. January 7 Event Summary; Furniture Store #2

	Modeled Shed			10-Day Rolling Avg Shed	
Min	2.8 kW	0.1 W/ft^2	NA	2.9 kW	0.1 W/ft^2
Mean	4.2 kW	0.2 W/ft^2	Insufficient data[a]	4.4 kW	0.2 W/ft^2
Max	5.3 kW	0.2 W/ft^2	NA	5.5 kW	0.3 W/ft^2

[a] 95% confidence interval based on uncertainty analysis (see Subsection 0)

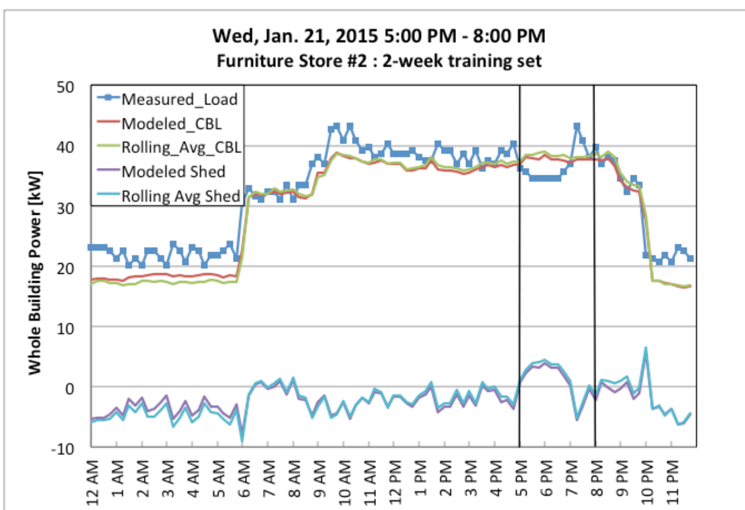


Figure B-10. January 21 event summary; Furniture Store #2

Table B-12. January 21 Event Summary; Furniture Store #2

	Modeled Shed			10-Day Rolling Avg Shed	
Min	–5.6 kW	–0.3 W/ft^2	NA	–5.1 kW	–0.3 W/ft^2
Mean	1.1 kW	0.1 W/ft^2	±6.9 kW[a]	1.6 kW	0.1 W/ft^2
Max	3.9 kW	0.2 W/ft^2	NA	4.4 kW	0.2 W/ft^2

[a] 95% confidence interval based on uncertainty analysis (see Subsection 0)

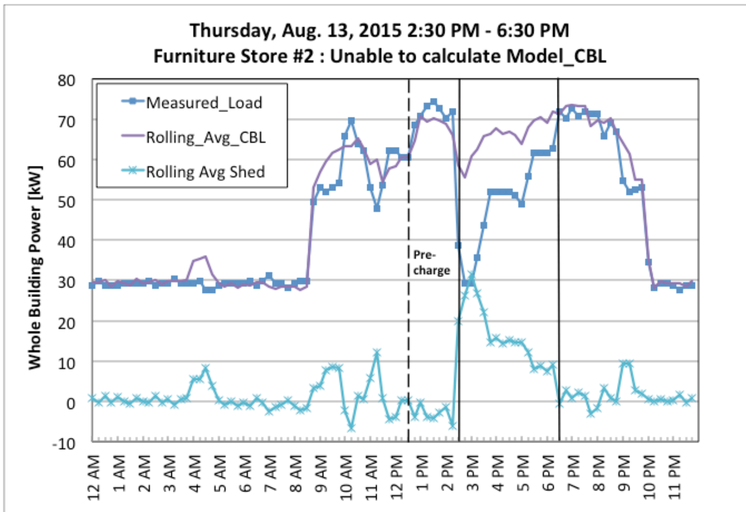


Figure B-11. August 13 event summary; Furniture Store #2

Table B-13. August 13 Event Summary; Furniture Store #2

	Modeled Shed	10-Day Rolling Avg Shed	
Min		7.5 kW	0.4 W/ft^2
Mean	Insufficient data to calculate Model_CBL	16.4 kW	0.8 W/ft^2
Max		31.5 kW	1.6 W/ft^2

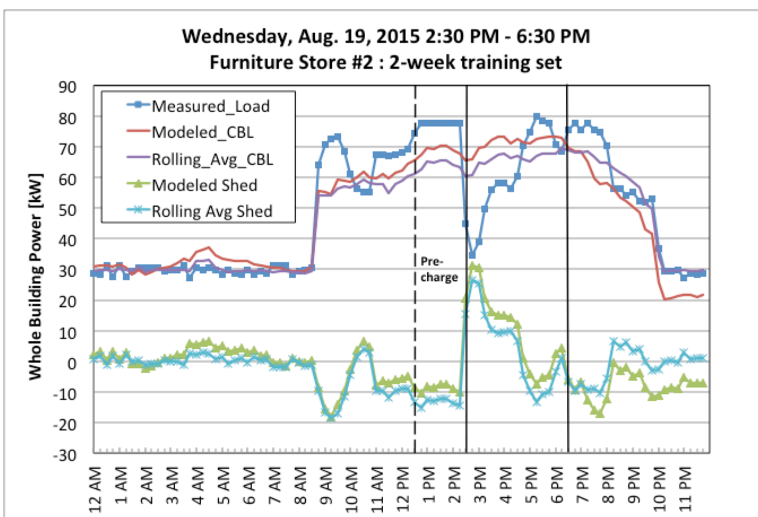


Figure B-12. August 19 event summary; Furniture Store #2

Table B-14. August 19 Event Summary; Furniture Store #2

	Modeled Shed			10-Day Rolling Avg Shed	
Min	–7.6 kW	-0.3 W/ft^2	NA	-13.2 kW	-0.6 W/ft^2
Mean	10.1 kW	0.5 W/ft^2	Not enough data[a]	4.8 kW	0.2 W/ft^2
Max	31.2 kW	1.4 W/ft^2	NA	26.3 kW	1.2 W/ft^2

[a] 95% confidence interval based on uncertainty analysis (see Subsection 0)

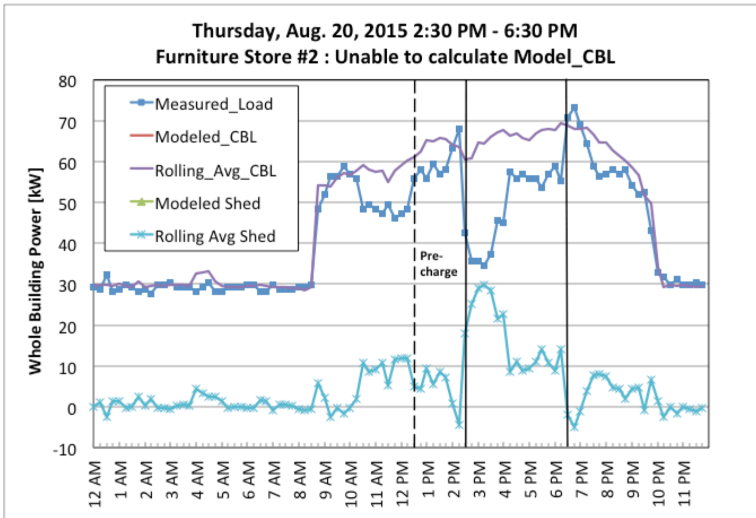


Figure B-13. August 20 event summary; Furniture Store #2

Table B-15. August 20 Event Summary; Furniture Store #2

	Modeled Shed	10-Day Rolling Avg Shed	
Min		8.6 kW	0.4 W/ft^2
Mean	Insufficient data to calculate Model_CBL	17.0 kW	0.8 W/ft^2
Max		29.9 kW	1.4 W/ft^2

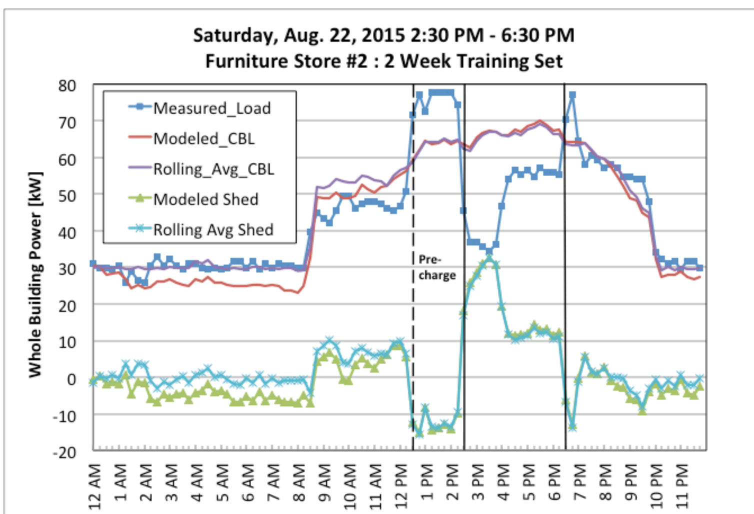


Figure B-14. August 22 event summary; Furniture Store #2

Table B-16. August 22 event summary; Furniture Store #2

	Modeled Shed			10-Day Rolling Avg Shed	
Min	11.2 kW	0.5 W/ft^2	NA	10.3 kW	0.5 W/ft^2
Mean	18.6 kW	0.9 W/ft^2	Insufficient data[a]	17.9 kW	0.8 W/ft^2
Max	32.6 kW	1.5 W/ft^2	NA	32.5 kW	1.5 W/ft^2

[a] 95% confidence interval based on uncertainty analysis (see Subsection 0)

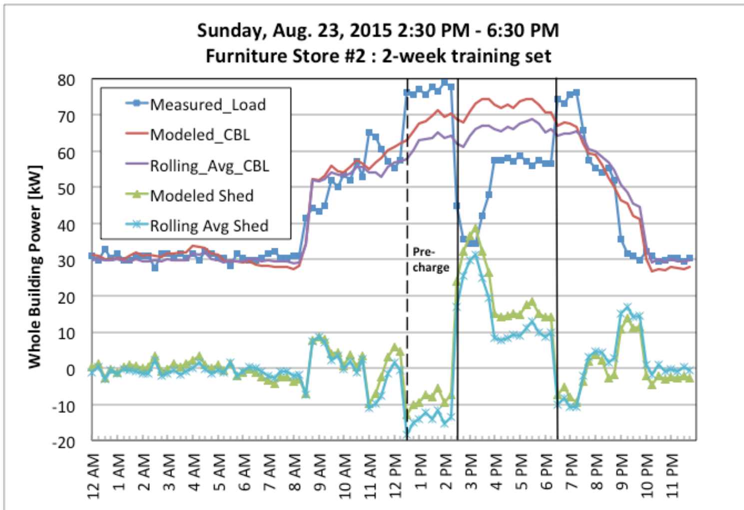


Figure B-15. August 23 event summary; Furniture Store #2

Table B-17. August 23 event summary; Furniture Store #2

	Modeled Shed			10-Day Rolling Avg Shed	
Min	14.1 kW	0.6 W/ft^2	NA	7.8 kW	0.4 W/ft^2
Mean	21.4 kW	1.0 W/ft^2	Insufficient data[a]	15.2 kW	0.7 W/ft^2
Max	38.6 kW	1.8 W/ft^2	NA	31.4 kW	1.4 W/ft^2

[a] 95% confidence interval based on uncertainty analysis (see Subsection 0)

Drug Store #1

Table B-18. Drug Store #1 DR Event Summary[a]

Date	Event Time	HVAC Precharge	Peak Temp	Avg Temp	Conditions	Avg (kW)	95% Conf Interval[b] (kW)	Norm. Avg (W/ft^2)	Notes[c]
Jan 7 (Wed)	5–6 p.m.	NA	50	44	Mostly cloudy	-	-	-	Store employees overrode the DR lighting circuit to be permanently on. No shed.
Jan 21 (Wed)	5–8 p.m.	NA	48	46	Foggy	-	-	-	Store employees overrode the DR lighting circuit to be permanently on. No shed.
Aug 7 (Fri)	2:30–6:30 p.m.	2 h prior (start at 12:30)	84	78	Clear	-	-	-	No DR event occurred at both drug stores due to DR scheduling issue
Aug 13 (Thur)	2:30–6:30 p.m.	2 h prior (start at 12:30)	84	75	Partly cloudy	4.4	NA	0.3	Data shown here based on the Rolling_Average baseline. Avg 4.9 kW (0.3 W/ft^2) until 4:30 p.m. (2-h saturation).
Aug 19 (Wed)	2:30–6:30 p.m.	2 h prior (start at 12:30)	91	73	Clear	5.4	Not enough data	0.3	Avg 6 kW (0.4 W/ft^2) until 5 p.m. (2-h saturation)
Aug 20 (Thur)	2:30–6:30 p.m.	2 h prior (start at 12:30)	75	74	Partly cloudy	2.5	±4.5	0.2	Saturation time entire 4 h
Aug 22 (Sat)	2:30–6:30 p.m.	2 h prior (start at 12:30)	79	74	Scattered clouds	5.3	NA	0.3	Data shown here based on the Rolling_Average baseline. Saturation time entire 4 h.
Aug 23 (Sun)	2:30–6:30 p.m.	2 h prior (start at 12:30)	82	73	Clear	3.7	±6.3	0.2	Saturation time entire 4 h.
Aug 24 (Mon)	2:30–6:30 p.m.	2 h prior (start at 12:30)	77	73	Partly cloudy	4.9	±4.8	0.3	Saturation time entire 4 h.

[a] Target curtailments for Winter was 0.7 W/ft^2 (11 kW) and Summer Day-Ahead was 1.7 W/ft^2 (28 kW)
[b] 95% confidence interval based on uncertainty analysis
[c] Saturation is the time from the start of the event to the time when one of the compressors came back on

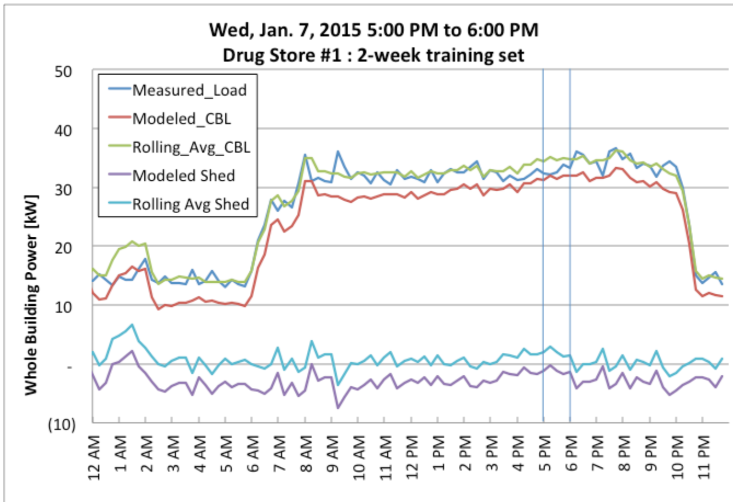


Figure B-16. January 7 event summary; Drug Store #1

Table B-19. January 7 Event Summary; Drug Store #1

	Modeled Shed	10-Day Rolling Avg Shed
Min Mean Max	No shed occurred; building staff had overridden the lighting DR circuit to be on throughout the day. After these two winter DR events, the team worked with the building manager of the drug stores to tell employees not to override the lighting controls in the electrical room.	

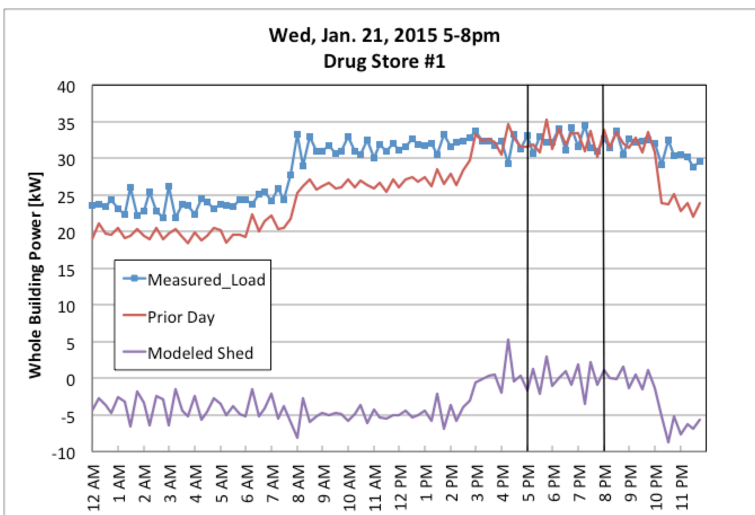


Figure B-17. January 21 event summary; Drug Store #1

Table B-20. January 21 Event Summary; Drug Store #1

	Modeled Shed	10-Day Rolling Avg Shed
Min Mean Max	No shed occurred; building staff had overridden the lighting DR circuit to be on throughout the day. After these two winter DR events, the team worked with the building manager of the drug stores to tell employees not to override the lighting controls in the electrical room.	

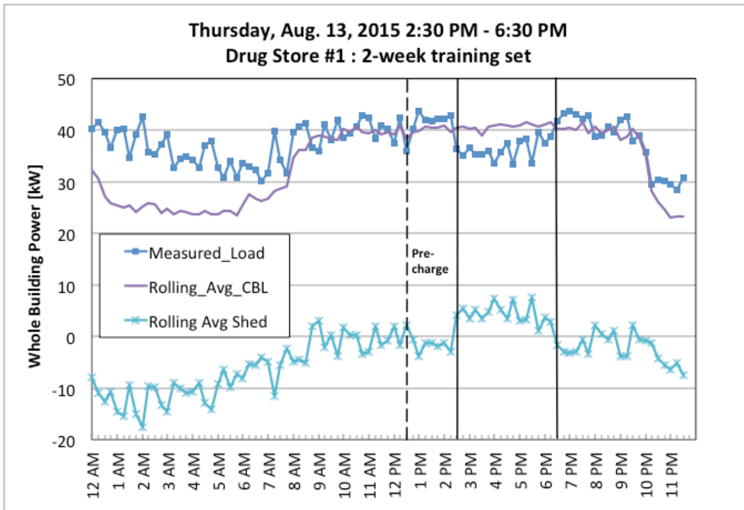


Figure B-18. August 13 event summary; Drug Store #1

Table B-21. August 13 Event Summary; Drug Store #1

	Modeled Shed	10-Day Rolling Avg Shed	
Min	The Model_CBL could not be calculated due to an incomplete historic data set.	1.2 kW	0.1 W/ft^2
Mean		4.4 kW	0.3 W/ft^2
Max		5.0 kW	0.3 W/ft^2

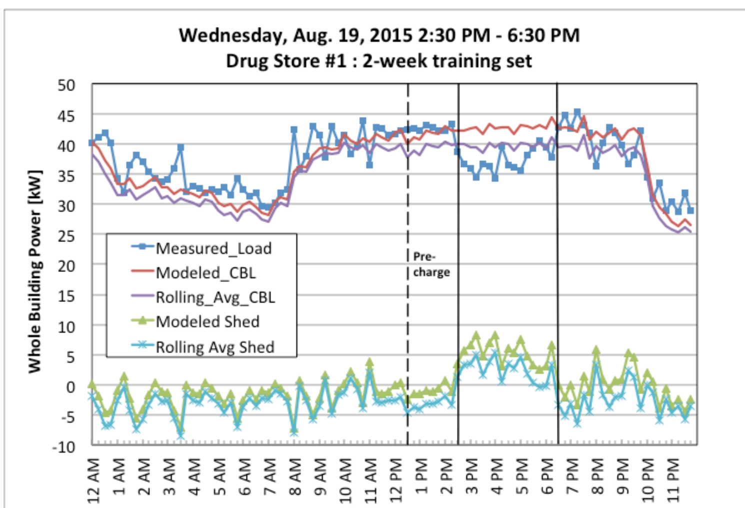


Figure B-19. August 19 event summary; Drug Store #1

Table B-22. August 19 Event Summary; Drug Store #1

	Modeled Shed			10-Day Rolling Avg Shed	
Min	2.6 kW	0.2 W/ft^2	NA	-0.5 kW	0.0 W/ft^2
Mean	5.4 kW	0.3 W/ft^2	Insufficient data[a]	2.5 kW	0.2 W/ft^2
Max	8.3 kW	0.5 W/ft^2	NA	5.3 kW	0.3 W/ft^2

[a] 95% confidence interval based on uncertainty analysis (see Subsection 0)

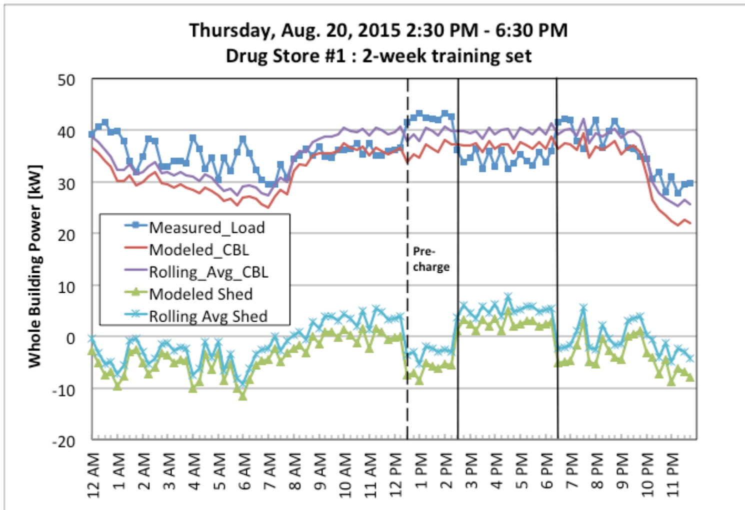


Figure B-20. August 20 event summary; Drug Store #1

Table B-23. August 20 Event Summary; Drug Store #1

	Modeled Shed			10-Day Rolling Avg Shed	
Min	1.0 kW	0.1 W/ft^2	NA	3.5 kW	0.2 W/ft^2
Mean	2.5 kW	0.2 W/ftv	±4.5 kW[a]	5.2 kW	0.3 W/ft^2
Max	4.9 kW	0.3 W/ft^2	NA	7.9 kW	0.5 W/ft^2

[a] 95% confidence interval based on uncertainty analysis (see Subsection 0)

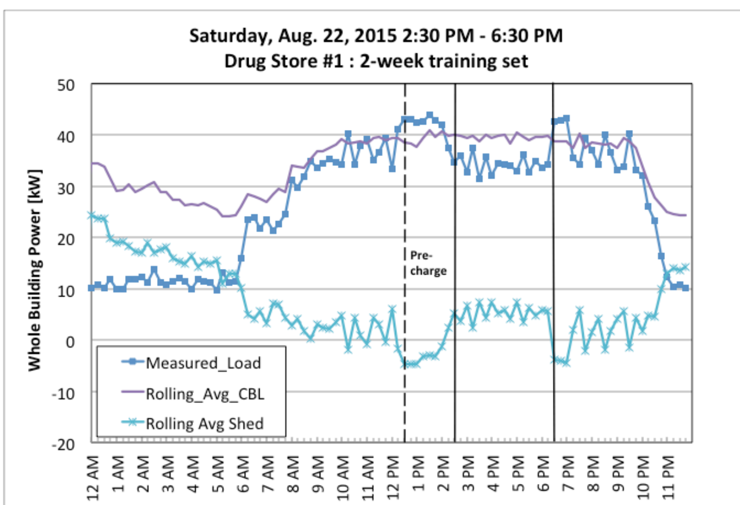


Figure B-21. August 22 event summary; Drug Store #1

Table B-24. August 22 Event Summary; Drug Store #1

	Modeled Shed	10-Day Rolling Avg Shed	
Min	The Model_CBL could not be calculated due to an incomplete historical data set.	3.5 kW	0.2 W/ft^2
Mean		5.2 kW	0.3 W/ft^2
Max		7.9 kW	0.5 W/ft^2

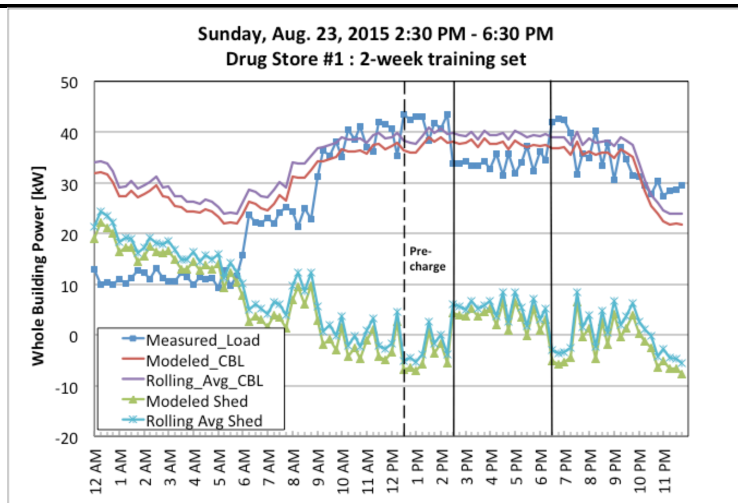


Figure B-22. August 23 event summary; Drug Store #1

Table B-25. August 23 Event Summary; Drug Store #1

	Modeled Shed			*10-Day Rolling Avg Shed*	
Min	-0.3 kW	0.0 W/ft^2	NA	1.7 kW	0.1 W/ft^2
Mean	3.7 kW	0.2 W/ft^2	±6.3 kW^{2}a	5.4 kW	0.3 W/ft^2
Max	6.5 kW	0.4 W/ft^2	NA	8.4 kW	0.5 W/ft^2

[a] 95% confidence interval based on uncertainty analysis (see Subsection 0)

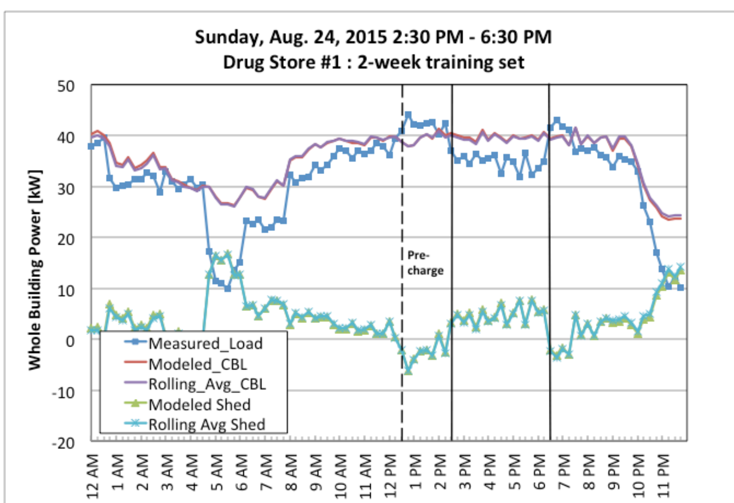


Figure B-23. August 24 event summary; Drug Store #1

Table B-26. August 24 Event Summary; Drug Store #1

	Modeled Shed			10-Day Rolling Avg Shed	
Min	2.5 kW	0.2 W/ft^2	NA	2.1 kW	0.1 W/ft^2
Mean	4.9 kW	0.3 W/ft^2	±4.8 kW[a]	4.6 kW	0.3 W/ft^2
Max	7.7 kW	0.5 W/ft^2	NA	7.5 kW	0.5 W/ft^2

[a] 95% confidence interval based on uncertainty analysis (see Subsection 0)

Drug Store #2

Table B-27. Drug Store #2 DR Event Summary[a]

Date	Event Time	HVAC Precharge	Peak Temp	Avg Temp	Conditions	Avg (kW)	95% Conf Interval[b] (kW)	Norm. Avg (W/ft^2)	Notes[c]
Jan 7 (Wed)	5–6 p.m.	NA	46	45	Fog	3.1	±3.9	0.2	Saturation time entire 1 h
Jan 21 (Wed)	5–8 p.m.	NA	46	46	Fog	1.9	Insufficient data	0.1	Saturation time entire 3 h
Aug 7 (Fri)	2:30–6:30 p.m.	2 h prior (start at 12:30)	82	77	Clear	-	-	-	No DR event occurred at both drug stores due to DR scheduling issue.
Aug 13 (Thur)	2:30–6:30 p.m.	2 h prior (start at 12:30)	84	76	Scattered Clouds	6.3	Insufficient data	0.4	Avg 9.0 kW (0.6 W/ft^2) until 4:45 p.m. (2.25-h saturation).
Aug 19 (Wed)	2:30–6:30 p.m.	2 h prior (start at 12:30)	90	75	Clear	6.6	±12.4	0.4	Avg 10.5 kW (0.7 W/ft^2) until 4:30 p.m. (2-h saturation).
Aug 20 (Thur)	2:30–6:30 p.m.	2 h prior (start at 12:30)	75	73	Partly Cloudy	5.7	±11.7	0.4	Avg 6.7 kW (0.4 W/ft^2) until 5:30 p.m. (3-h saturation).
Aug 22 (Sat)	2:30–6:30 p.m.	2 h prior (start at 12:30)	80	75	Scattered Clouds	4.6	±5.4	0.3	Avg 5.9 kW (0.4 W/ft^2) until 5:15 p.m. (2.75-h saturation).
Aug 23 (Sun)	2:30–6:30 p.m.	2 h prior (start at 12:30)	80	75	Clear	6.6	±5.3	0.4	Avg 8.4 kW (0.5 W/ft^2) until 4:45 p.m. (2.25-h saturation).
Aug 24 (Mon)	2:30–6:30 p.m.	2 h prior (start at 12:30)	77	75	Clear	5.1	±7.1	0.3	Avg 7.0 kW (0.5 W/ft^2) until 4:45 p.m. (2.25-h saturation).

[a] Target curtailments for winter was 0.7 W/ft^2 (11 kW) and summer day-ahead was 1.7 W/ft^2 (26 kW)
[b] 95% confidence interval based on uncertainty analysis
[c] Saturation is the time from the start of the event to the time when one of the compressors came back on

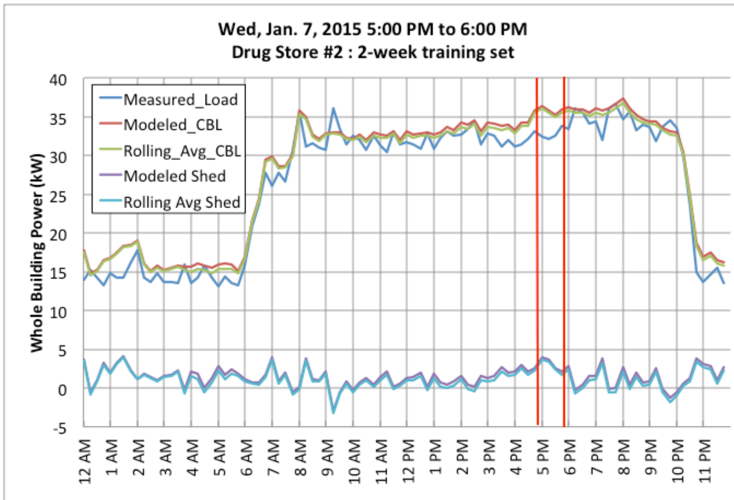


Figure B-24. January 7 event summary; Drug Store #2

Table B-28. January 7 Event Summary; Drug Store #2

	Modeled Shed			10-Day Rolling Avg Shed	
Min	2.1 kW	0.1 W/ft^2	NA	1.8 kW	0.1 W/ft^2
Mean	3.1 kW	0.2 W/ft^2	±3.9 kW[a]	2.8 kW	0.2 W/ft^2
Max	3.9 kW	0.3 W/ft^2	NA	3.7 kW	0.2 W/ft^2

[a] 95% confidence interval based on uncertainty analysis (see Subsection 0)

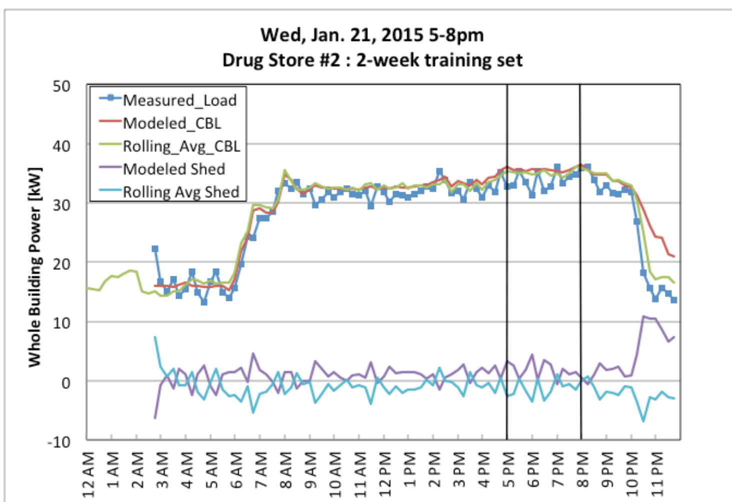


Figure B-25. January 21 event summary; Drug Store #2

Table B-29. January 21 Event Summary; Drug Store #2

	Modeled Shed			10-Day Rolling Avg Shed	
Min	-0.7 kW	0.0 W/ft^2	NA	-1.1 kW	-0.1 W/ft^2
Mean	1.9 kW	0.1 W/ft^2	Insufficient data[a]	1.4 kW	0.1 W/ft^2
Max	4.4 kW	0.3 W/ft^2	NA	3.5 kW	0.2 W/ft^2

[a] 95% confidence interval based on uncertainty analysis (see Subsection 0)

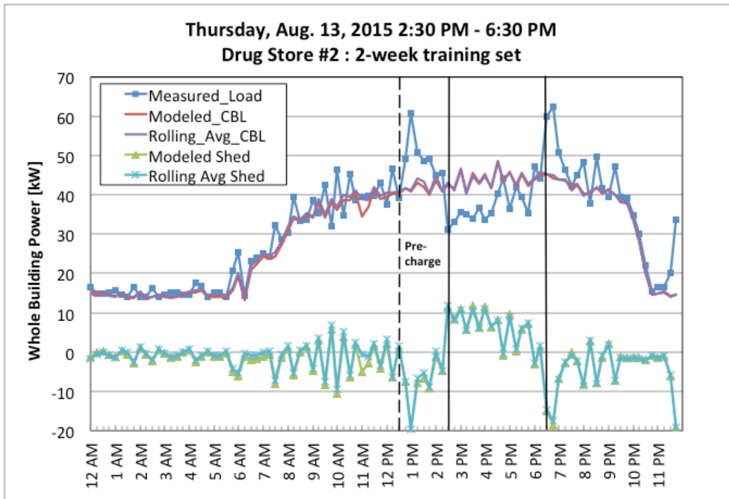


Figure B-26. August 13 event summary; Drug Store #2

Table B-30. August 13 Event Summary; Drug Store #2

	Modeled Shed			10-Day Rolling Avg Shed	
Min	-3.1 kW	-0.2 W/ft^2	NA	-2.9 kW	-0.2 W/ft^2
Mean	6.3 kW	0.4 W/ft^2	Insufficient data[a]	6.3 kW	0.4 W/ft^2
Max	11.8 kW	0.8 W/ft^2	NA	11.8 kW	0.8 W/ft^2

[a.] 95% confidence interval based on uncertainty analysis (see Subsection 0)

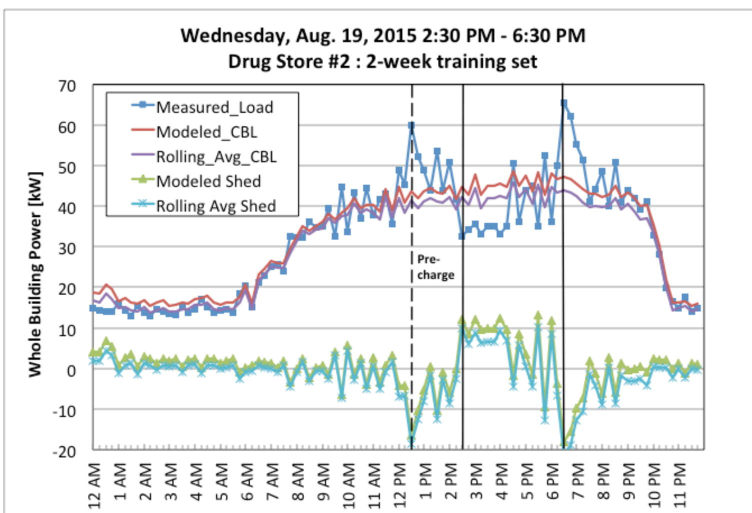


Figure B-27. August 19 event summary; Drug Store #2

Table B-31. August 19 Event Summary; Drug Store #2

	Modeled Shed			10-Day Rolling Avg Shed	
Min	–9.6 kW	–0.6 W/ft^2	NA	–12.7 kW	–0.8 W/ft^2
Mean	6.6 kW	0.4 W/ft^2	±12.4 kW[a]	3.6 kW	0.2 W/ft^2
Max	13.2 kW	0.9 W/ft^2	NA	10.0 kW	0.7 W/ft^2

[a] 95% confidence interval based on uncertainty analysis (see Subsection 0)

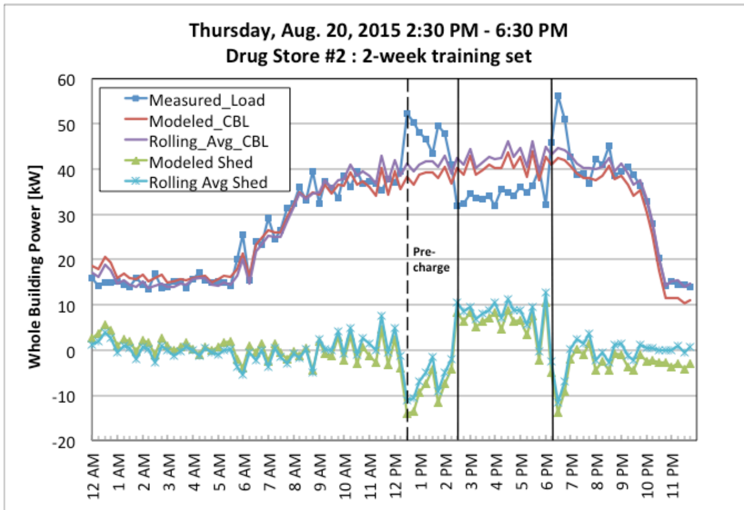


Figure B-28. August 20 event summary; Drug Store #2

Table B-32. August 20 Event Summary; Drug Store #2

	Modeled Shed			10-Day Rolling Avg Shed	
Min	–4.9 kW	–0.3 W/ft^2	NA	–2.6 kW	–0.2 W/ft^2
Mean	5.7 kW	0.4 W/ft^2	±11.7 kW[a]	7.7 kW	0.5 W/ft^2
Max	10.5 kW	0.7 W/ft^2	NA	12.7 kW	0.8 W/ft^2

[a] 95% confidence interval based on uncertainty analysis (see Subsection 0)

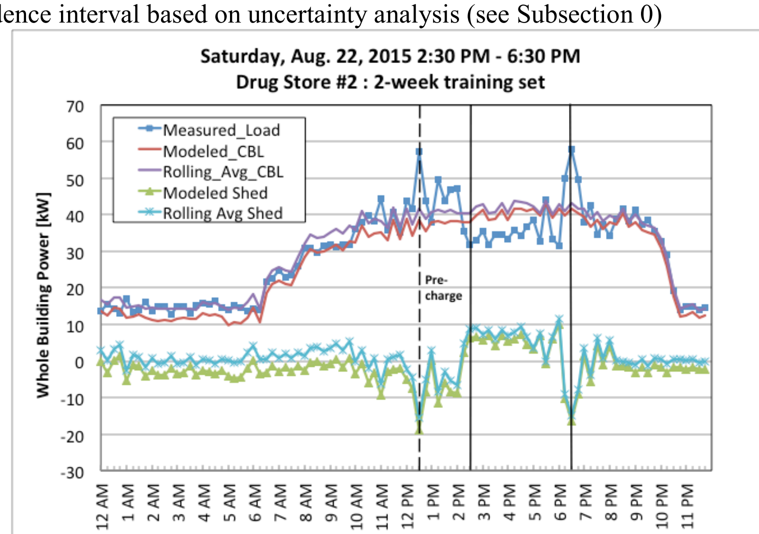


Figure B-29. August 22 event summary; Drug Store #2

Table B-33. August 22 Event Summary; Drug Store #2

	Modeled Shed			10-Day Rolling Avg Shed	
Min	–10.3 kW	–0.7 W/ft^2	NA	–9.0 kW	–0.6 W/ft^2
Mean	4.6 kW	0.3 W/ft^2	±5.4 kW[a]	6.2 kW	0.4 W/ft^2
Max	10.1 kW	0.7 W/ft^2	NA	11.5 kW	0.7 W/ft^2

[a] 95% confidence interval based on uncertainty analysis (see Subsection 0)

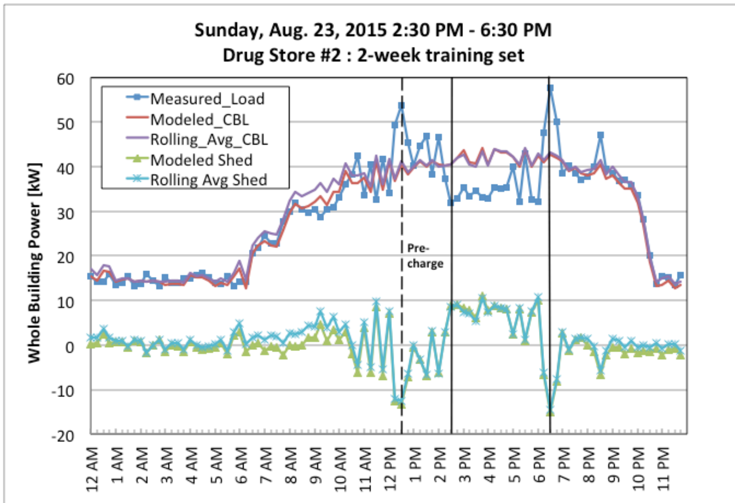


Figure B-30. August 23 event summary; Drug Store #2

Table B-34. August 23 Event Summary; Drug Store #2

	Modeled Shed			10-Day Rolling Avg Shed	
Min	–6.8 kW	–0.4 W/ft^2	NA	–6.2 kW	–0.4 W/ft^2
Mean	6.6 kW	0.4 W/ft^2	±5.3 kW[a]	6.5 kW	0.4 W/ft^2
Max	11.1 kW	0.7 W/ft^2	NA	10.7 kW	0.7 W/ft^2

[a] 95% confidence interval based on uncertainty analysis (see Subsection 0)

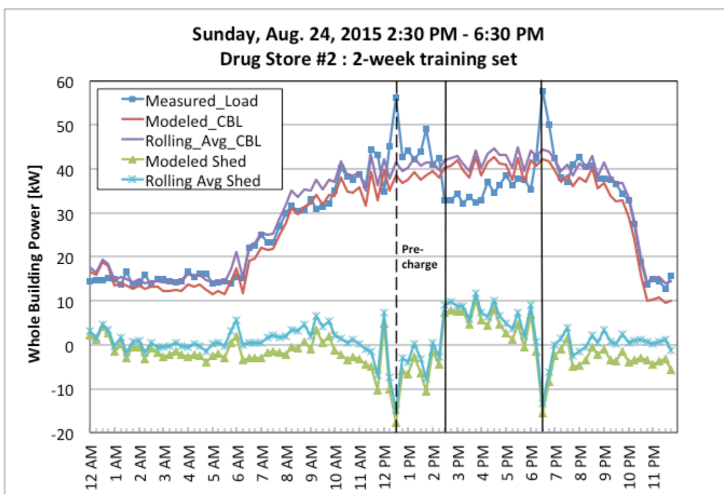


Figure B-31. August 24 event summary; Drug Store #2

Table B-35. August 24 Event Summary; Drug Store #2

	Modeled Shed			10-Day Rolling Avg Shed	
Min	–1.6 kW	–0.1 W/ft^2	NA	0.6 kW	0.0 W/ft^2
Mean	5.1 kW	0.3 W/ft^2	±7.1 kW[a]	7.0 kW	0.5 W/ft^2
Max	10.3 kW	0.7 W/ft^2	NA	11.7 kW	0.8 W/ft^2

[a] 95% confidence interval based on uncertainty analysis (see Subsection 0)

Casino #1

Table B- 36. Casino #1 DR Event Summary[a]

Date	Event Time	HVAC Precharge	Peak Temp	Avg Temp	Conditions	Avg (kW)	95% Conf Interval[b] (kW)	Norm. Avg (W/ft²)	Notes[c]
Jan 7 (Wed)	5–6 p.m.	NA	50	44	Mostly cloudy	5.2	Insufficient data	0.5	Based on the plot of the event, the team would expect that the uncertainty would exceed the average shed.
Jan 21 (Wed)	5–8 p.m.	NA	48	46	Foggy	3.5	±2.1	0.3	Supply fans ramped back from 40% to 70% speed when some of the RTUs went into first stage heating at 7:30 p.m., prior to the end of the DR event.
Aug 7 (Fri)	2:30–6:30 p.m.	2 h prior (start at 12:30)	84	78	Clear	-	-	-	No DR event occurred. Communication was lost with the on-site controller.
Aug 13 (Thur)	2:30–6:30 p.m.	2 h prior (start at 12:30)	84	75	Partly cloudy	1.3	Insufficient data	0.1	Avg 7.2 kW (0.6 W/ft²) until 3:45 p.m. (1.25-h saturation)
Aug 19 (Wed)	2:30–6:30 p.m.	2 h prior (start at 12:30)	91	73	Clear	-	-	-	No DR Event occurred. Communication was lost with the on-site controller.
Aug 20 (Thur)	2:30–6:30 p.m.	2 h prior (start at 12:30)	75	74	Partly cloudy	4.8	±12.7	0.4	Avg 7.4 kW (0.7 W/ft²) until 4 p.m. (1.5-h saturation)
Aug 22 (Sat)	2:30–6:30 p.m.	2 h prior (start at 12:30)	79	74	Scattered clouds	3.0	±6.6	0.3	Avg 4 kW (0.4 W/ft²) until 3:15 p.m. (0.75-h saturation)
Aug 23 (Sun)	2:30–6:30 p.m.	2 h prior (start at 12:30)	82	73	Clear	7.2	±6.7	0.6	Avg 9.2 kW (0.8 W/ft²) until 3:45 p.m. (1.25-h saturation)
Aug 24 (Mon)	2:30–6:30 p.m.	2 h prior (start at 12:30)	77	73	Partly Cloudy	2.4	±7.7	0.2	Avg 2.4 kW (0.2 W/ft²) until 3:45 p.m. (1.25-h saturation)

[a] Target curtailments for Winter was 0.7 W/ft² (8 kW) and Summer Day-Ahead was 1.7 W/ft² (19 kW)
[b] 95% confidence interval based on uncertainty analysis
[c] Saturation is the time from the start of the event to the time when one of the compressors came back on

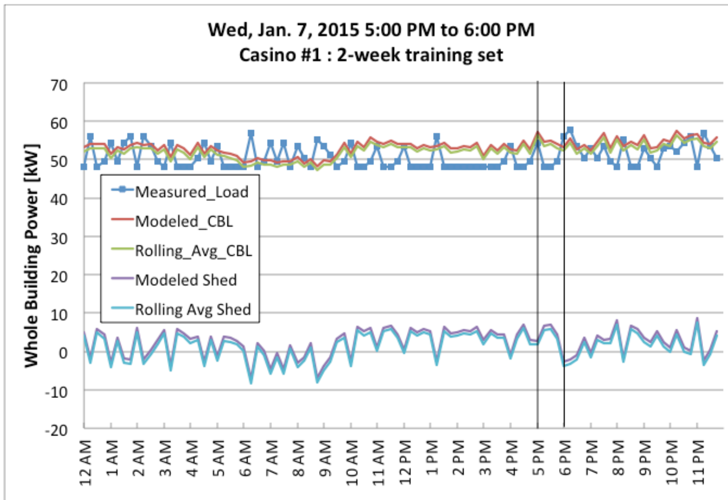


Figure B-32. January 7 event summary; Casino #1

Table B-37. January 7 Event Summary; Casino #1

	Modeled Shed			10-Day Rolling Avg Shed	
Min	2.8 kW	0.3 W/ft^2	NA	1.8 kW	0.2 W/ft^2
Mean	5.2 kW	0.5 W/ft^2	Insufficient data[a]	4.2 kW	0.4 W/ft^2
Max	7.0 kW	0.6 W/ft^2	NA	5.9 kW	0.5 W/ft^2

[a] 95% confidence interval based on uncertainty analysis (see Subsection 0)

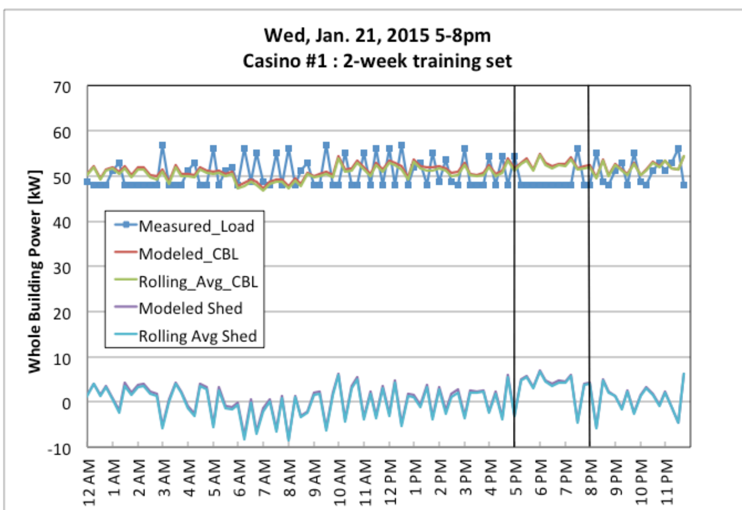


Figure B-33. January 21 event summary; Casino #1

Table B-38. January 21 Event Summary; Casino #1

	Modeled Shed			10-Day Rolling Avg Shed	
Min	–4.3 kW	–0.4 W/ft^2	NA	–4.6 kW	–0.4 W/ft^2
Mean	3.5 kW	0.3 W/ft^2	±2.1 kW[a]	3.2 kW	0.3 W/ft^2
Max	6.9 kW	0.6 W/ft^2	NA	6.7 kW	0.6 W/ft^2

[a] 95% confidence interval based on uncertainty analysis (see Subsection 0)

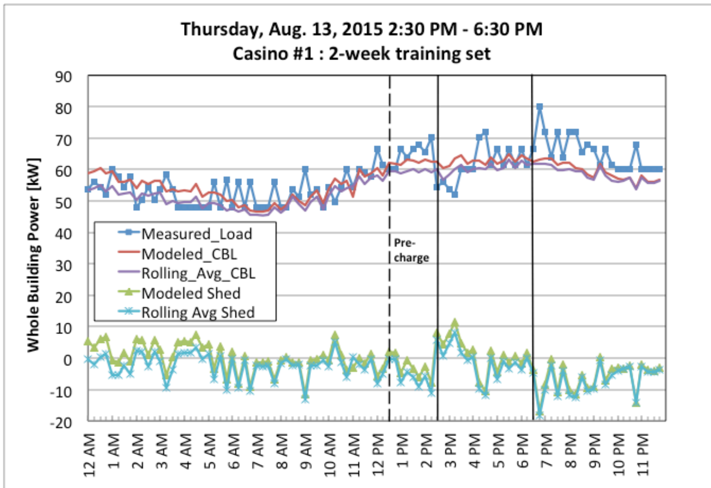


Figure B-34. August 13 event summary; Casino #1

Table B-39. August 13 Event Summary; Casino #1

	Modeled Shed			10-Day Rolling Avg Shed	
Min	–10.4 kW	–0.9 W/ft^2	NA	–11.8 kW	–1.1 W/ft^2
Mean	1.3 kW	0.1 W/ft^2	Insufficient data[a]	–1.1 kW	–0.1 W/ft^2
Max	11.4 kW	1.0 W/ft^2	NA	8.0 kW	0.7 W/ft^2

[a] 95% confidence interval based on uncertainty analysis (see Subsection 0)

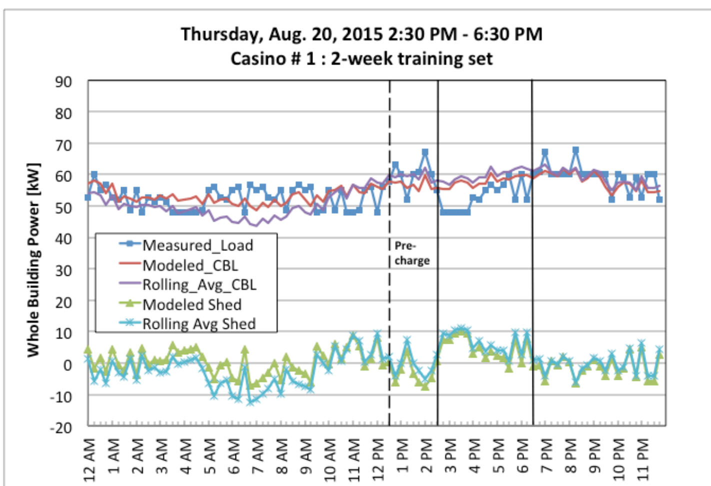


Figure B-35. August 20 event summary; Casino #1

Table B-40. August 20 Event Summary; Casino #1

	Modeled Shed			10-Day Rolling Avg Shed	
Min	–1.6 kW	-0.1 W/ft^2	NA	0.7 kW	0.1 W/ft^2
Mean	4.8 kW	0.4 W/ft^2	±12.7 kW[a]	6.6 kW	0.6 W/ft^2
Max	10.2 kW	0.9 W/ft^2	NA	11.3 kW	1.0 W/ft^2

[a] 95% confidence interval based on uncertainty analysis (see Subsection 0)

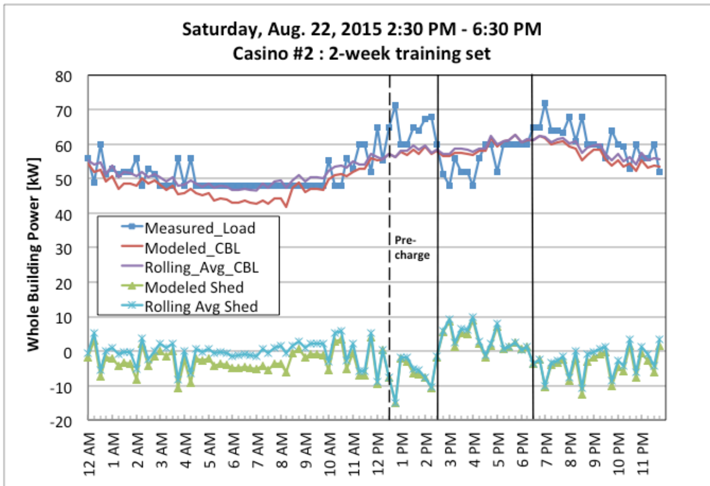


Figure B-36. August 22 event summary; Casino #1

Table B-41. August 22 Event Summary; Casino #1

	Modeled Shed			10-Day Rolling Avg Shed	
Min	–1.9 kW	–0.2 W/ft^2	NA	–1.5 kW	–0.1 W/ft^2
Mean	3.0 kW	0.3 W/ft^2	±6.6 kW[a]	3.5 kW	0.3 W/ft^2
Max	8.9 kW	0.8 W/ft^2	NA	9.8 kW	0.9 W/ft^2

[a] 95% confidence interval based on uncertainty analysis (see Subsection 0)

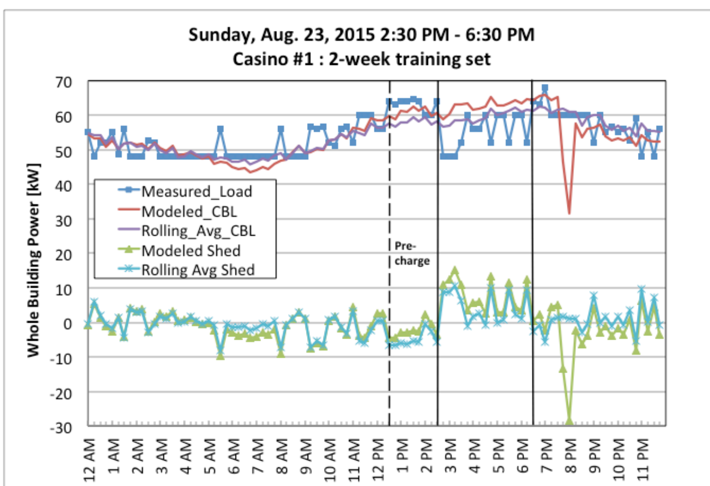


Figure B-37. August 23 event summary; Casino #1

Table B-42. August 23 Event Summary; Casino #1

	Modeled Shed			10-Day Rolling Avg Shed	
Min	–3.4 kW	–0.3 W/ft^2	NA	–5.7 kW	–0.5 W/ft^2
Mean	7.2 kW	0.6 W/ft^2	±6.7 kW[a]	4.0 kW	0.4 W/ft^2
Max	15.1 kW	1.3 W/ft^2	NA	10.5 kW	0.9 W/ft^2

[a] 95% confidence interval based on uncertainty analysis (see Subsection 0)

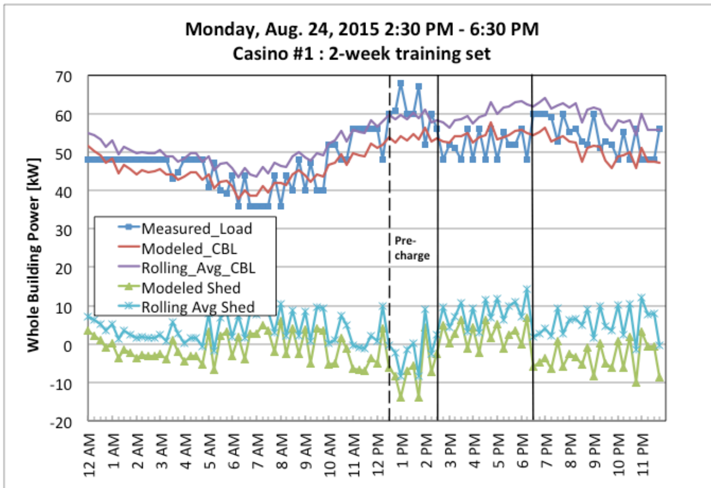


Figure B-38. August 24 event summary; Casino #1

Table B-43. August 24 Event Summary; Casino #1

	Modeled Shed			10-Day Rolling Avg Shed	
Min	–2.4 kW	–0.2 W/ft^2	NA	2.4 kW	0.2 W/ft^2
Mean	2.4 kW	0.2 W/ft^2	±7.7 kW[a]	8.1 kW	0.7 W/ft^2
Max	6.9 kW	0.6 W/ft^2	NA	14.4 kW	1.3 W/ft^2

[a] 95% confidence interval based on uncertainty analysis (see Subsection 0)

Casino #2

Table B-44. Casino #2 DR Event Summary[a]

Date	Event Time	HVAC Precharge	Peak Temp	Avg Temp	Conditions	Avg (kW)	95% Conf Interval[b] (kW)	Norm. Avg (W/ft^2)	Notes[c]
Jan 7 (Wed)	5–6 p.m.	NA	50	44	Mostly cloudy	-	-	-	No DR event since the interval power meter was not set up
Jan 21 (Wed)	5–8 p.m.	NA	48	46	Foggy	-	-	-	No DR event since the interval power meter was not set up
Aug 7 (Fri)	2:30–6:30 p.m.	2 h prior (start at 12:30)	84	78	Clear	-	-	-	No DR event took place. Communication was lost with the on-site controller.
Aug 13 (Thur)	2:30–6:30 p.m.	2 h prior (start at 12:30)	84	75	Partly cloudy	-3.9	NA	-0.2	For most of the event, the Casino #2 used more power than the rolling-average baseline. No Model_CBL was calculated since there was insufficient data.
Aug 19 (Wed)	2:30–6:30 p.m.	2 h prior (start at 12:30)	91	73	Clear	-	-	-	Casino #2 opted out of DR event
Aug 20 (Thur)	2:30–6:30 p.m.	2 h prior (start at 12:30)	75	74	Partly cloudy	-	-	-	Casino #2 opted out of DR event
Aug 22 (Sat)	2:30–6:30 p.m.	2 h prior (start at 12:30)	79	74	Scattered clouds	-	-	-	Casino #2 opted out of DR event
Aug 23 (Sun)	2:30–6:30 p.m.	2 h prior (start at 12:30)	82	73	Clear	-	-	-	Casino #2 opted out of DR event
Aug 24 (Mon)	2:30–6:30 p.m.	2 h prior (start at 12:30)	77	73	Partly cloudy	-	-	-	Casino #2 opted out of DR event

[a] Target curtailments for Winter was 0.7 W/ft^2 (12 kW) and Summer Day-Ahead was 1.7 W/ft^2 (28 kW)
[b] 95% confidence interval based on uncertainty analysis
[c] Saturation is the time from the start of the event to the time when one of the compressors came back on

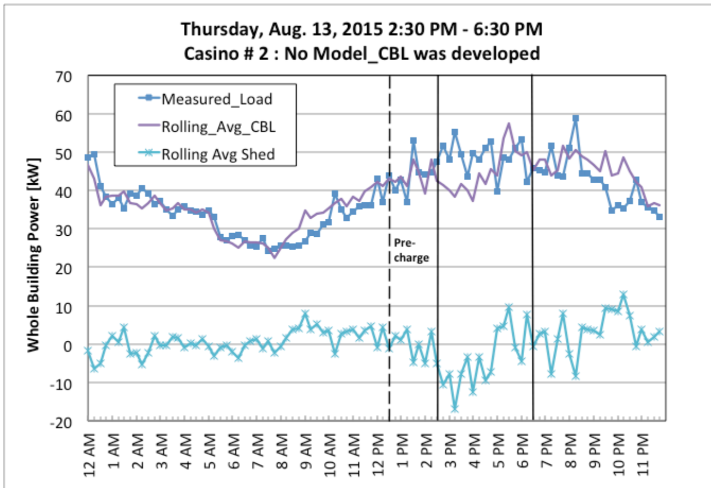


Figure B-39. August 13 event summary; Casino #2

Table B-45. August 13 Event Summary; Casino #2

	Modeled Shed	10-Day Rolling Avg Shed	
Min	Insufficient data to create the Modeled_CBL	-17.0 kW	-1.0 W/ft^2
Mean		-3.9 kW	-0.2 W/ft^2
Max		9.5 kW	0.6 W/ft^2

Appendix C. Pacific Northwest Pumped Storage

The following appendix provides information about proposed pumped storage facilities within the PNW. The team compared the DR magnitude of this technology to these potential facilities.

Table C-1. FERC preliminary permits issued by June 2009 (MWH 2009)

Project Name	Permittee	State	Capacity (MW)
RED MOUNTAIN BAR PUMPED STORAGE	MODESTO IRRIGATION DISTRICT (CA)	CA	880
SAN VICENTE PUMPED STORAGE	SAN DIEGO COUNTY WATER AUTH (CA)	CA	570
KINGS RIVER PUMPED STORAGE	PACIFIC GAS AND ELECTRIC CO (C	CA	380
MOKELUMNE PUMPED STORAGE	PACIFIC GAS AND ELECTRIC CO (C	CA	380
MULQUEENY RANCH PUMPED STORAGE	BPUS GENERATION DEVELOPMENT LLC	CA	280
LAKE ROOSEVELT PUMPED STORAGE	BPUS GENERATION DEVELOPMENT LLC	WA	1,310
DUFFEY LAKES PUMPED STORAGE	BPUS GENERATION DEVELOPMENT LLC	WA	1,150
JD POOL PUMPED STORAGE	PUD NO 1 OF KLICKITAT COUNTY, WA	WA	1,129
UMTANUM RIDGE PUMPED STORAGE	BPUS GENERATION DEVELOPMENT LLC	WA	1,100
BANKS LAKE PUMPED STORAGE	BPUS GENERATION DEVELOPMENT LLC	WA	1,040
LAKE POWELL PIPELINE	UTAH BOARD OF WATER RESOURCES	WA	443
SENTINEL MOUNTAIN	UNITED POWER CORPORATION	WA	2,000
PARKER KNOLL PUMPED STORAGE	PARKER KNOLL HYDRO, LLC	UT	1,330
LONG CANYON PUMPED STORAGE	UTAH INDEPENDENT POWER	UT	800
BULL CANYON PUMPED STORAGE	UTAH INDEPENDENT POWER	UT	800
CEDAR CREEK PUMPED STORAGE	CEDAR CREEK HYDRO, LLC.	TX	662
BRYANT MOUNTAIN PUMPED STORAGE	UNITED POWER CORPORATION	OR	1,175
SWAN LAKE NORTH PUMPED STORAGE	SWAN LAKE NORTH HYDRO, LLC	OR	1,144
SUMMER LAKE PUMPED STORAGE	NT HYDRO	OR	256
ABERT RIM PUMPED STORAGE	NT HYDRO	OR	134
MINEVILLE PUMPED STORAGE	MORIAH HYDRO CORP	NY	189
OGDENSBURG PUMPED STORAGE	RIVERBANK OGDENSBURG, LLC	NY	100
DIVISION CANYON PUMPED STORAGE	DIVISION CANYON HYDRO, LLC	NV	500
THOUSAND SPRINGS PUMPED STORAGE	THOUSAND SPRINGS HYDRO, LLC	NV	470
BLUE DIAMOND PUMPED STORAGE	NEVADA HYDRO COMPANY, INC.	NV	450
HOPPIE CANYON PUMPED STORAGE	HOPPIE CANYON HYDRO, LLC	NV	380
LOOMIS CREEK PUMPED STORAGE	LOOMIS CREEK HYDRO, LLC	NV	370
YEGUA MESA PUMPED STORAGE	YEGUA MESA HYDRO, LLC	NM	1,100
SPARTA PUMPED STORAGE	RIVERBANK SPARTA, LLC	NJ	1,000
RIVERBANK WISCASSET ENERGY PS	RIVERBANK WISCASSET ENERGY CENTER, LLC	ME	1,000
LITTLE POTLATCH CREEK PUMPED STORAGE	BPUS GENERATION DEVELOPMENT LLC	ID	1,340
CORRAL CREEK SOUTH PUMPED STORAGE	CORRAL CREEK SOUTH HYDRO, LLC	ID	1,100
PHANTOM CANON PUMPED STORAGE	H20 PROVIDERS, INC.	CO	220
NORTH EDEN PUMPED STORAGE	NORTH EDEN HYDRO, LLC	ID	100
34 Sites Total	Total MW Permitted		25,282

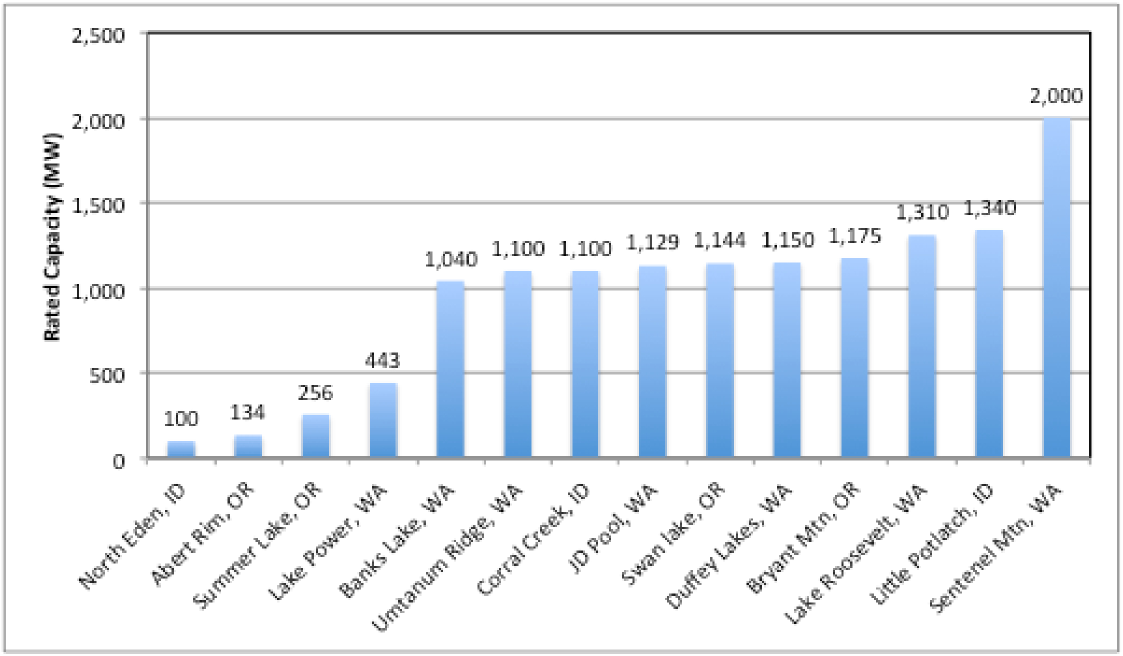


Figure C-1. FERC preliminary permits issues in 2009 within the PNW region (MWH 2009)

Appendix D. 2014 Pacific Northwest Commercial Building Stock Assessment Summary

The team summarized the 2014 CBSA information the team used to extrapolate the aggregated DR resource discussed in Section 0. The team focused only on the floor area cooled by RTUs. According to Table D-5, RTUs combine the "AC-Air" and "HP-Air" within Navigant's "DX-Air" designation. Navigant did not provided more detail beyond which are served by "DX-Air" systems, so the team focused on the retail, office, assembly, food service, grocery, residential care, school, and warehouse building types. To eliminate the majority of the area served by non-RTU "DX-Air" equipment types ("HP-Mini-split," "HP-Vrf," "Pthp," "Ptac," "Room-AC"), the team ignored the lodging building type typically served by these systems.

Scaling from Sample to Population

Navigant developed the PNW's building population frame using the data sources shown in Table D-1. Navigant then allocated each record in the population frame to a building type category (Table D-2). Finally, Navigant used "case weight" ratios (indicating the number of buildings in the population represented by each sample building) to extrapolate the data collected from each sample to the PNW regional level.

Table D-1. Population Frame Sources

Data Source	Description
Commercial Building Inventory™	A database representing buildings by parcel based on tax assessor records for commercial properties
CoStar™	A database reporting records by commercial building
McGraw Hill Construction Dodge	A database of permit applications for new construction and renovation projects
American Hospital Directory	A database of over 6,000 public and private hospitals nationwide
Integrated Postsecondary Education Data System	A compilation of survey data collected from all educational institutions that participate in federal student financial aid programs

Notes: CBI and CoStar™ information compiled by SBW Consulting, Inc. 2012. Other sources compiled by 2014 Navigant project team.

Table D-2. Number of records by Building Type in Population Frame (Navigant 2014)

Building Type	Number of Records
Assembly	23,057
Food Service	12,652
Grocery	5,136
Hospitals	288
Lodging	6,901
Office	42,113
Other	95,115
Residential Care	2,427
Retail	50,672
Schools	6,581
Universities	113
Unknown	768
Warehouse	24,171
Total	**269,994**

Notes: Data obtained from CBSA Study population frame

Sample Framework

Figure D-1 shows that the 859 samples (on-site surveys) used for the 2014 CBSA were chosen by Navigant within the building type, size, vintage, and urban-rural classification. Navigant designed this sampling to achieve an 80% confidence and 20% precision at the intersection of each categorization and an average of 90% confidence and 10% precision by the building type. Due to the comparatively small population in the 2004–2013 vintage, Navigant was not able to achieve statistically significant results by separately evaluating the rural and urban designations. Therefore, Navigant combined the rural and urban designations for the 2004–2013 vintage.

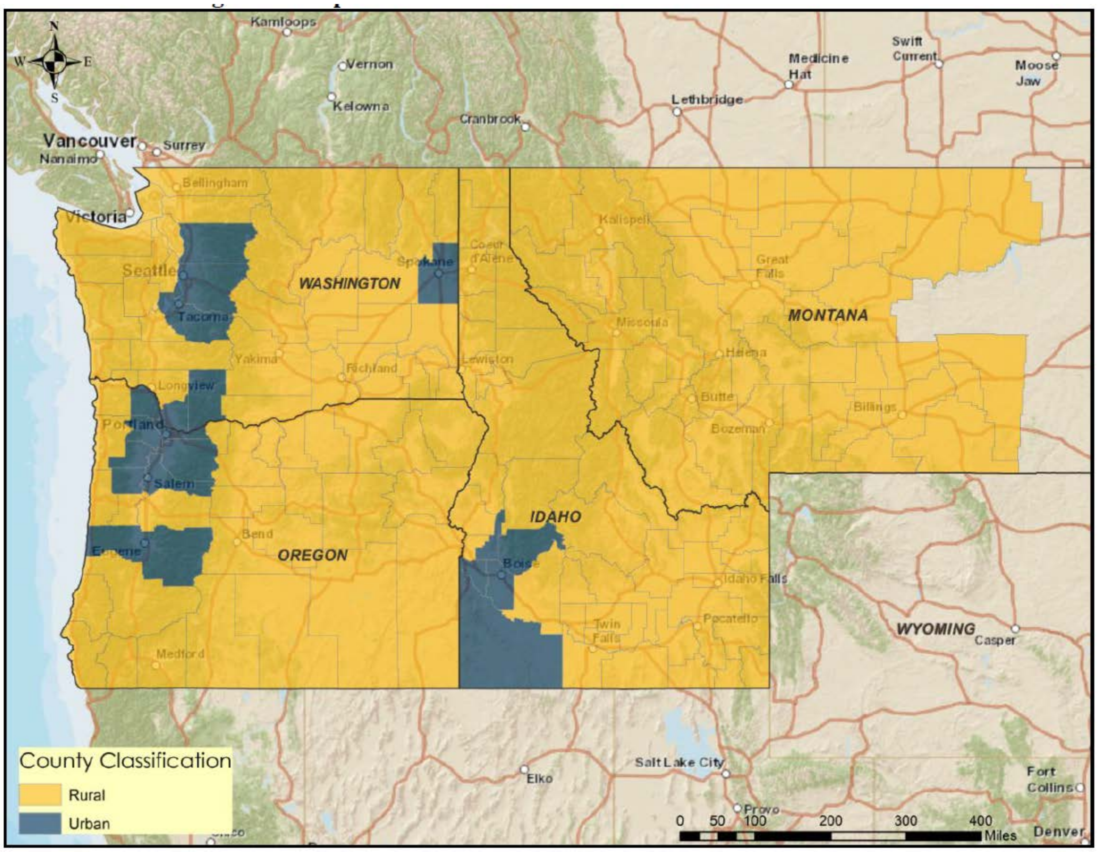
	Vintage	Size (SF)	Retail	Grocery	Office	Food Service	Warehouse	Hospital	Residential Care	Hotel-Motel	School	University	Assembly	Other
		5,000 or less	16	14	13								13	10
		5,001-20,000							12	14	14			
Urban	Pre-2004	20,001-50,000	12	12	14	12	12	12				12	12	9
		50,001-100,000							10		13			
		100,001 & Up	14		12					11			9	8
		5,000 or less	16	13	16								16	14
		5,001-20,000							14	14	12			
Rural	Pre-2004	20,001-50,000	13	14	12	12	12	12				11	15	7
		50,001-100,000							10		13			
		100,001 & Up	11		3					8			3	5
		5,000 or less	25	11	25								21	12
		5,001-20,000							12	18	11			
All	2004-2013	20,001-50,000	13	10	13	19	19						13	12
		50,001-100,000							12		12			
		100,001 & Up	12		9					7			3	4

Source: Navigant 2014

Figure D-1. Sample framework for the 2014 CBSA

Urban versus Rural Classification

Navigant categorized each building sample as urban or rural based on its Rural-Urban Continuum Code[12] (RUCC). They classified counties with a RUCC of two or lower as urban while those with a three or higher as rural. Figure D-2 shows the urban counties are within the Seattle, Portland, Spokane, Boise, and Eugene metro areas. Rural designations accounted for 40.4% of the commercial square footage but 48.5% of the sampled building square footage.



Source: Navigant 2014

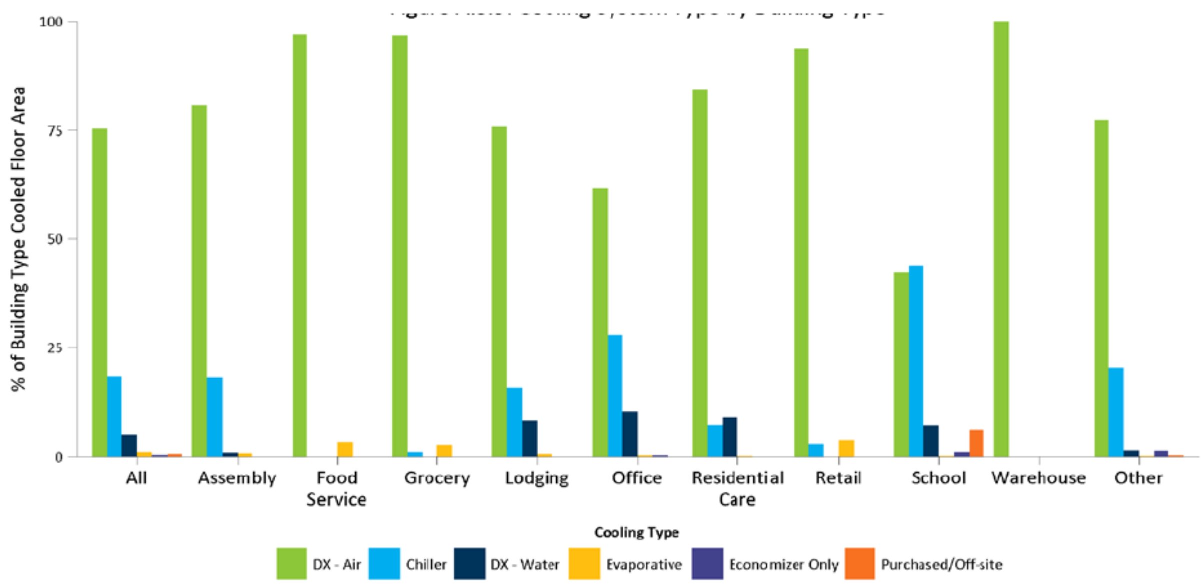
Figure D-2. Map of urban and rural classification for the 2014 CBSA

[12] Further information available at www.ers.usda.gov/data-products/rural-urban-continuum-codes.aspx.

Table D-3. Building Type Definitions

2014 CBSA Building Type		
Retail		
Auto Parts	Hardware	Beauty / Barber
Auto / Boat Dealer	Home Improvement	Car Wash
Clothing	Liquor Store	Dry Cleaner
Department Store	Pharmacy	Laundromat
Dept. Store with Grocery	Rental Center	Post Office
Electronics / Appliances	Studio / Gallery	Repair Shop
Florist / Nursery	Warehouse Club	Vehicle Repair
Grocery		
Convenience Store	Grocery	
Gas Station w/ Convenience		
Hospital		
Hospital		
Hotel / Motel		
Hotel	Dormitory	Shelter / Orphanage
Motel	Hotel - Resort	Convent or Monastery
Bed & Breakfast	Shelter / Orphanage	Fraternity or Sorority
Boarding House	Hotel - Resort	Halfway House
Office		
Professional Office	Financial / Govt. Office	Medical Office
Call Center	City Hall	Urgent Care Clinic
Retail Banking	Dental Office	Outpatient Rehab
Sales Office	Outpatient Medical	Veterinarian Office
Restaurant		
Cafeteria	Take-Out Restaurant	Catering Service
Fast Food Restaurant	Truck Stop	Coffee Shop
Sit-Down Restaurant	Bar, Pub, Lounge	Ice Cream Shop
School		
Elementary School	High School	Other K-12 School
Middle School	Pre-School	
University		
University / College		
Warehouse		
Mini-Storage	Warehouse, Storage	
Cold Storage	Warehouse, Distribution	
Not Characterized		
Assembly		
Arena	Convention Center	Performing Arts Theater
Auditorium	Gym, Exercise	Pool
Marina	Health Spa	Recreation Center
Bowling Alley	Ice Skating	Religious Assembly
Casino	Library	Roller Skating
Club, Lodges	Museum	Senior Center
Community Center	Movie Theater	
Residential Care		
Assisted Living	Nursing Home	
In-Patient Rehab	Retirement Home	
Other		
Airplane Hanger		
Asylum		
Courthouse		
Crematorium		
Data Center or Server Farm		
Fire Station		
Jail		
Police Station		
Police & Fire		
Prison		
Telephone Switching		
Adult / Career Education		
Vocational Training		

Table D-4. Cooling System Type by Building Type



Cooling Type	All (n=719)	Assembly (n=86)	Food Service (n=43)	Grocery (n=66)	Lodging (n=63)	Office (n=111)	Residential Care (n=66)	Retail (n=118)	School (n=62)	Warehouse (n=33)	Other (n=71)
DX - Air	1,724 75% ± 3%	234 81% ± 7%	49 97% ± 3%	64 97% ± 3%	113 76% ± 8%	422 62% ± 7%	87 84% ± 7%	382 94% ± 4%	73 42% ± 10%	90 100% ± 0%	210 77% ± 8%
Chiller	417 18% ± 2%	52 18% ± 7%	0 0% ± 0%	1 1% ± 2%	23 16% ± 7%	191 28% ± 7%	7 7% ± 4%	11 3% ± 3%	76 44% ± 10%	0 0% ± 0%	55 20% ± 7%
DX - Water	110 5% ± 1%	3 1% ± 1%	0 0% ± 0%	0 0% ± 0%	12 8% ± 5%	71 10% ± 5%	9 9% ± 5%	0 0% ± 0%	12 7% ± 5%	0 0% ± 0%	3 1% ± 2%
Evaporative	21 1% ± 1%	2 1% ± 1%	2 3% ± 3%	2 2% ± 2%	1 1% ± 0%	1 0% ± 1%	0 0% ± 0%	15 4% ± 3%	0 0% ± 0%	0 0% ± 0%	0 0% ± 0%
Economizer Only	6 0% ± 0%	0 0% ± 0%	0 0% ± 0%	0 0% ± 0%	0 0% ± 0%	1 0% ± 0%	0 0% ± 0%	0 0% ± 0%	2 1% ± 2%	0 0% ± 0%	3 1% ± 1%
Purchased/Off-site	11 0% ± 0%	0 0% ± 0%	0 0% ± 0%	0 0% ± 0%	0 0% ± 0%	0 0% ± 0%	0 0% ± 0%	0 0% ± 0%	10 6% ± 4%	0 0% ± 0%	0 0% ± 0%

Units: Regional Cooled Floor Area (Million Sq Ft), % of column total, error band shown at the 90% confidence level

Table D-5. DX-Air System Types

DX – Air	AC – Air	Cooling type = DX-Air & heat pump type = NF & Equipment type = RTU or MAU or AHU or Furnace or Cabinet heater
	HP – Air	Cooling type = DX-Air & heat pump type = Standard Air Source
	HP – Mini-split	Cooling type = DX-Air & heat pump type = Ductless minisplit
	HP – Vrf	Cooling type = DX-Air & heat pump type = VRF
	Pthp	Cooling type = DX-Air & heat pump type = PTHP
	Ptac	Cooling type = DX-Air & heat pump type = NF & Equipment type = PTAC
	Room AC	Cooling type = DX-Air & heat pump type = NF & Equipment type = Room AC

Projecting the Demand Response Resource

The team used the areas served by RTU-AC and RTU-ASHP equipment in Figure 15 to quantify the maximum DR magnitude assuming 100% market penetration of this EE and DR technology. The team established the winter and summer curtailments in watts per square foot based on the field demonstration results in Table 7. These curtailments are summarized in the following bullets.

- For the winter events (Table D-6), both 10-minute and day-ahead notice, the team used a curtailment of 0.22 W/ft^2 for spaces served by AC RTUs based on the average winter curtailment measured across all the demonstration locations for the two winter DR events. The team calculated that this curtailment would increase to 0.60 W/ft^2 for spaces served by ASHP RTUs based on a blended operated of vapor-compressor and electric resistance heating. These curtailments include both HVAC and non-HVAC shed assets.
- For the summer events lasting up to 4-hours (Table D-7), the team used a curtailment of 0.46 W/ft^2 for buildings served by either AC or ASHP RTUs. This was based on the average curtailment measured across the demonstration locations for the seven summer DR events.
- For the summer events lasting up to 1-hour (Table D-8), the team used 0.63 W/ft^2 for buildings served by either AC or ASHP RTUs. This was based on the average curtailment measured across all the demonstration locations from the seven summer DR events, prior to saturation.

Table D-6. Extrapolated PNW Aggregated Winter DR Resource

	RTU AC Equipment[a]		*RTU ASHP* Equipment[b]		*Total*	
	Area[c]	Winter DR	Area[c]	Winter DR	Area[c]	Winter DR
Office	300	66 MW	104	62 MW	404	128 MW
Retail	331	73 MW	33	20 MW	364	93 MW
Assembly	188	41 MW	36	22 MW	224	63 MW
Other	153	34 MW	32	19 MW	185	53 MW
Warehouse	83	18 MW	3	2 MW	86	20 MW
School	55	12 MW	10	6 MW	65	18 MW
Grocery	50	11 MW	7	4 MW	57	15 MW
Food Service	40	9 MW	8	5 MW	48	14 MW
Residential Care	29	6 MW	10	6 MW	39	12 MW
Lodging	28	6 MW	10	6 MW	38	12 MW
Total	1257	277 MW	253	152 MW	1510	425 MW

[a] Building with RTU AC equipment assumes an average shed of 0.22 W/ft^2 across the DR event
[b] Building with RTU ASHP equipment assumes an average shed of 0.60W/ft^2 across the DR event
[c] Million ft^2 within the PNW region (Navigant 2014)

Table D-7. Extrapolated PNW Aggregated Summer Day-Ahead DR Resource (4-hour duration)

	RTU AC Equipment[a]		*RTU ASHP Equipment*[a]		*Total*	
	Area[b]	Summer DR	Area[b]	Summer DR	Area[b]	Summer DR
Office	300	150 MW	104	52 MW	404	201 MW
Retail	331	167 MW	33	17 MW	364	183 MW
Assembly	188	93 MW	36	18 MW	224	111 MW
Other	153	76 MW	32	16 MW	185	92 MW
Warehouse	83	41 MW	3	1 MW	86	43 MW
School	55	27 MW	10	5 MW	65	32 MW
Grocery	50	25 MW	7	3 MW	57	28 MW
Food Service	40	20 MW	8	4 MW	48	24 MW
Residential Care	29	14 MW	10	5 MW	39	19 MW
Lodging	28	14 MW	10	5 MW	38	19 MW
Total	1,257	627 MW	253	126 MW	1,510	753 MW

[a] RTU AC and ASHP equipment assumes an average shed of 0.46 W/ft^2 across the DR event
[b] Million ft^2 within the PNW region (Navigant 2014)

Table D-8. Extrapolated PNW Aggregated Summer Day-Ahead DR Resource (1-hour duration)

	RTU AC Equipment[a]		RTU ASHP Equipment[a]		Total	
	Area[b]	Summer DR	Area[b]	Summer DR	Area[b]	Summer DR
Office	300	220 MW	104	76 MW	404	296 MW
Retail	331	242 MW	33	24 MW	364	267 MW
Assembly	188	136 MW	36	26 MW	224	163 MW
Other	153	111 MW	32	23 MW	185	134 MW
Warehouse	83	60 MW	3	2 MW	86	62 MW
School	55	40 MW	10	7 MW	65	47 MW
Grocery	50	36 MW	7	5 MW	57	41 MW
Food Service	40	29 MW	8	6 MW	48	35 MW
Residential Care	29	21 MW	10	7 MW	39	28 MW
Lodging	28	20 MW	10	7 MW	38	28 MW
Total	1,257	916 MW	253	185 MW	1,510	1,101 MW

[a] RTU AC and ASHP equipment assumes an average shed of 0.63 W/ft^2 across the DR event, prior to saturation
[b] Million ft^2 within the PNW region (Navigant 2014)

Appendix E. Autani Wireless Lighting, Electric Water Heater, and Plug Load Controllers

This appendix summarizes the Autani hardware used to control the lighting, plug loads, and EWH at Furniture Store #2 and both casinos.

Autani Manager

The Autani Manager is the control processor that communicated directly with the eIQ BMS over BACnet. The Autani Manager then communicated with the Autani hardware over its own ZigBee mesh network. More information can be found at www.autani.com/1022/autani-manager/.

Figure E-1. Autani Manager

Autani ARC-L Switched Load Controller

The ARC-L switched load controller provided local lighting override to the building occupants to opt out of a curtailment. Spanning 120/277VAC, the ARC-L Switched Load Controller was also used to curtail the electric water heater. More information can be found at www.autani.com/1847/arc-l-switched-load-controller/.

Figure E-2. Autani ARC-L Switched Load Controller

Autani SmartLet Outlet Controller

The SmartLet was used for all the 120VAC receptacle loads (15 amp or 20 amp) in the break room (i.e., coffee machine, vending machine) and on the sales floor. It was also set up to provide alerts and real-time energy monitoring. More information can be found at www.autani.com/700/smartlet-outlet-controller/.

Figure E-3. Autani SmartLet Outlet Controller

Autani AFC-A Dimming Fixture Controller

At Furniture Store #2, the team controlled 20, three-lamp troffers using the Autani AFC-A Dimming Fixture Controller. This device is a wirelessly managed 120/277/347VAC plenum rated lighting controller with integrated daylight harvesting. During a DR event, the team turned these lights off rather then dimming them. The team had to use this detailed level of lighting control because turning off entire lighting circuits as was done at both drug stores and Furniture Store #1 would have been too coarse a control—entire rooms in the building would have had no lighting. Furniture Store #2 served as an example to evaluate the cost-effectiveness of detailed control at the individual troffer level rather than circuit level control back at the electrical room. More information can be found atwww.autani.com/865/afc-a-dimming-fixture-controller/.

Figure E-4. Autani AFC-A Dimming Fixture Controller

Autani MINI Wireless Motion Sensor

In the break room of both casinos and the banquet room of Casino #1, the team installed the Autani MINI Wireless Motion Sensor. This device detects changes in infrared radiation that occurs when there is movement by a person (or object) that is different in temperature from the surroundings. The team provided this control not for DR purposes but rather energy savings to shut off lighting when no one was in these infrequently used spaces. This energy savings assists with the 6-year simple payback target based solely on energy savings (not including utility incentives). More information can be found at www.autani.com/883/mini-wireless-motion-sensor/.

Figure E-5. Autani MINI Wireless Motion Sensor

Appendix F. Rooftop Unit Operational Mode Runtimes

Figure F-1 through Figure F-6 plot the percentage runtime of each location's RTU operational modes at different ambient temperatures for a year.

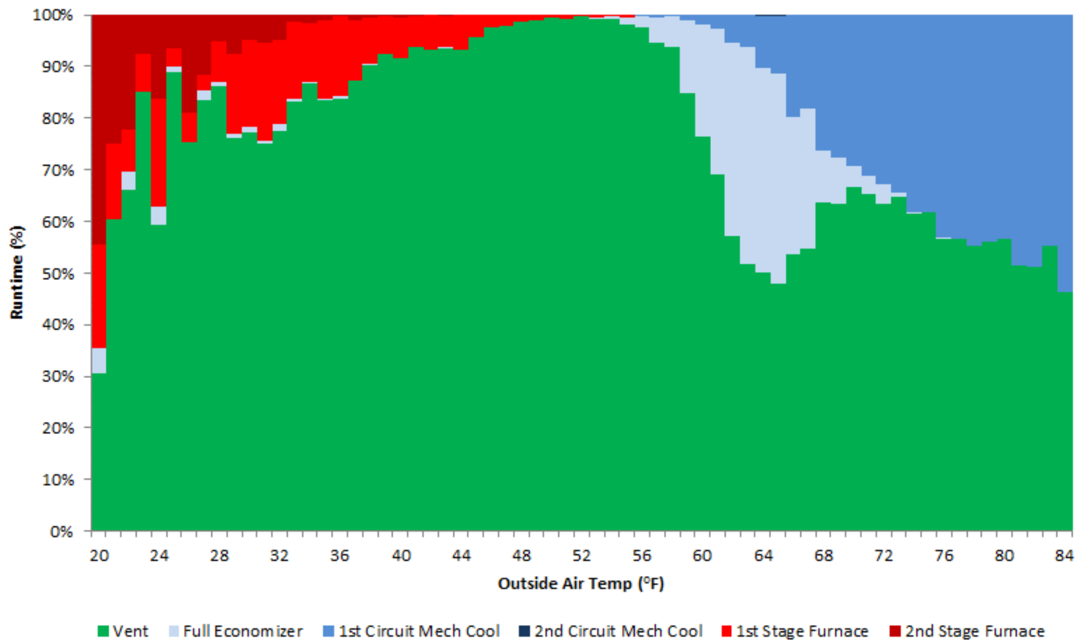


Figure F-1. Annual percentage runtimes across the 7 RTUs serving Furniture Store #1

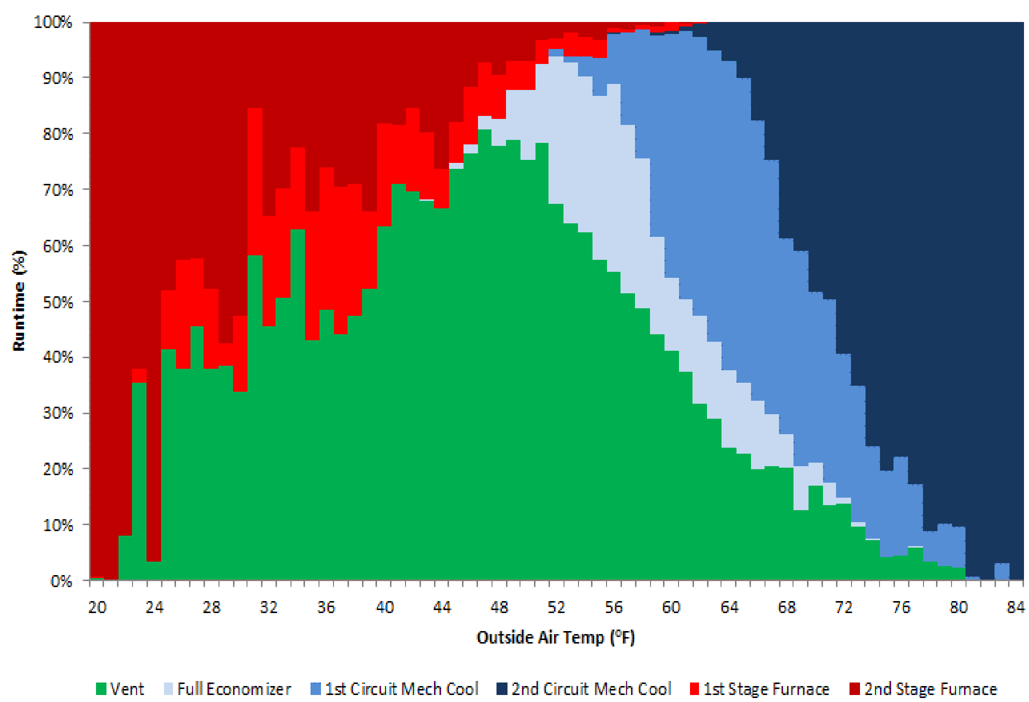


Figure F-2. Annual percentage runtimes across the 2 RTUs serving Furniture Store #2

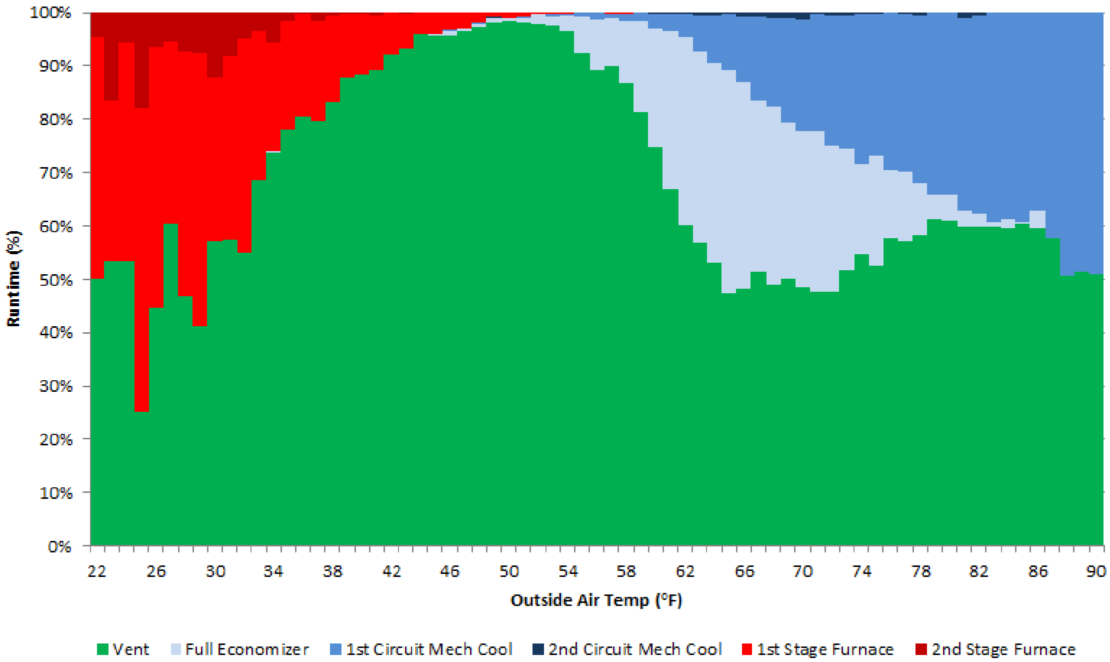


Figure F-3. Annual percentage runtimes across the 3 RTUs serving Drug Store #1

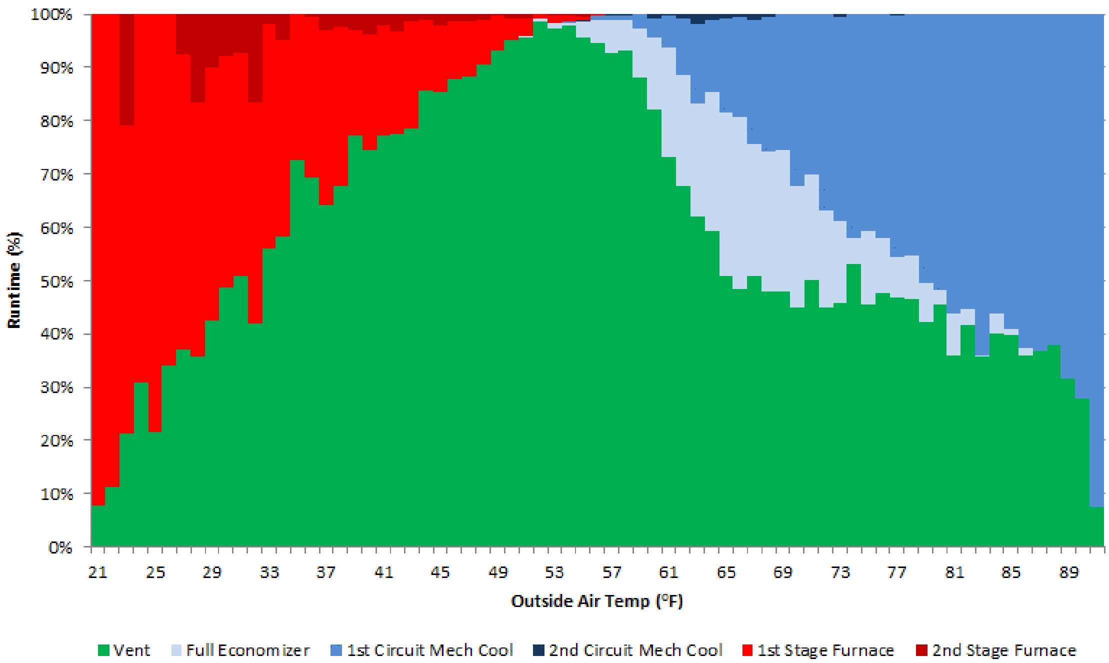


Figure F-4. Annual percentage runtimes across the 3 RTUs serving Drug Store #2

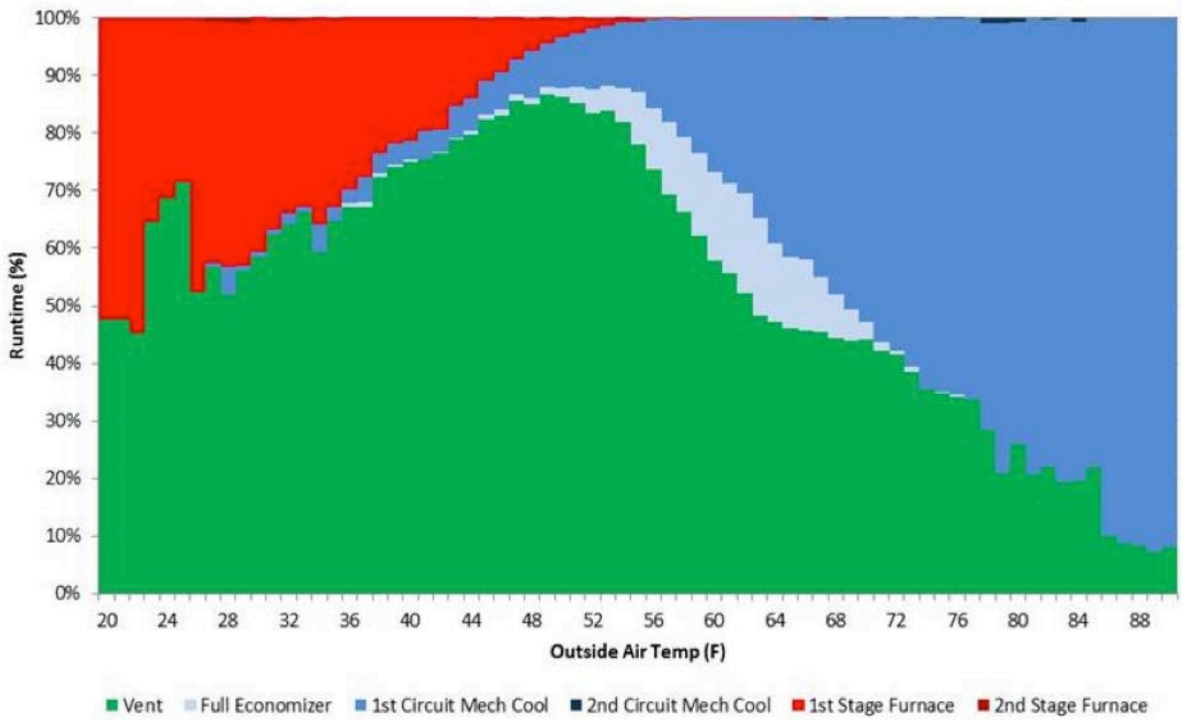


Figure F-5. Annual percentage runtimes across the 6 RTUs serving Casino #1

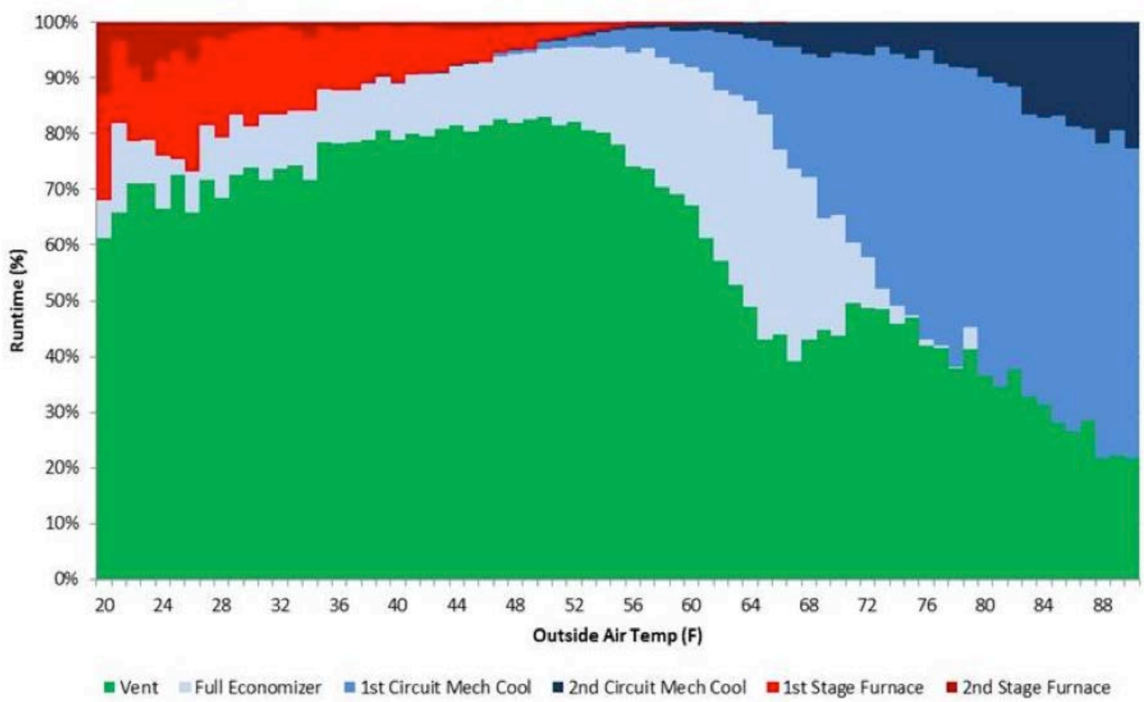


Figure F-6. Annual percentage runtimes across the 9 RTUs serving Casino #2

Appendix G. Projected Supply Fan Demand Response Asset

Table G-1 summarizes the total fan power at 100% speed measured for each location. During the initial curtailment projects at the beginning of the project, the team assumed the supply fan would reduce in speed from stage 1 heating/cooling operation (70% fan speed) to ventilation mode (40% fan speed) based on the CATALYST sequence of operation.

Table G-1. Supply Fan Total Power and Projected DR Curtailment at Each Demonstration Location

	Area	*Supply Fan Total Power*[a]		*NREL Projected DR assuming Fan Speed reduces from 70% to 40%*[b]	
Drug Store #1	16,210 ft^2	8.2 kW	0.5 W/ft^2	2.5 kW	0.2 W/ft^2
Drug Store #2	15,400 ft^2	8.0 kW	0.5 W/ft^2	2.4 kW	0.2 W/ft^2
Furniture Store #1	27,823 ft^2	13.0 kW	0.5 W/ft^2	3.9 kW	0.1 W/ft^2
Furniture Store #2	21,717 ft^2	6.5 kW	0.3 W/ft^2	1.9 kW	0.1 W/ft^2
Casino #1	11,173 ft^2	4.3 kW	0.4 W/ft^2	1.3 kW	0.1 W/ft^2
Casino #2	16,653 ft^2	21.3 kW	1.3 W/ft^2	6.4 kW	0.4 W/ft^2

[a] Based on the measured supply fan power at 100% speed (60 hz motor speed)
[b] Based on assuming the supply fan goes from 70% speed (stage 1 cooling or heating) prior to the DR event to 40% speed (ventilation only mode) during the DR event based on the CATALYST sequence of operation

Appendix H. Projected Lighting Demand Response Asset

Table H-1 summarizes the total connected lighting load and the lighting DR curtailment at each demonstration location. As shown, due to the building's age and disorganized electrical layout, Furniture Store #2 and both casinos had the smaller lighting DR. Suprisingly, the casinos had extremely low lighting levels, less than 1.0 W/ft^2. The team could not measure the lighting loads at these casinos since the electrical circuit layout was too embedded with other non-lighting loads.

Table H-1. Lighting Power and Projected DR Curtailment at Each Demonstration Location

	Area	*Total Interior and Exterior Lighting*[a]	*LPD*[b]	*Lighting DR*[c]		*DR % of Total Lighting*
Drug Store #1	16,210 ft^2	22.9 kW	1.4 W/ft^2	6.2 kW	0.4 W/ft^2	27%
Drug Store #2	15,400 ft^2	23.2 kW	1.5 W/ft^2	6.9 kW	0.4 W/ft^2	30%
Furniture Store #1	27,823 ft^2	54.7 kW	2.0 W/ft^2	13.4 kW	0.5 W/ft^2	25%
Furniture Store #2	21,717 ft^2	20.4 kW	0.9 W/ft^2	1.9 kW	0.1 W/ft^2	9%
Casino #1	11,173 ft^2	< 11 kW	< 1.0 W/ft^2	2.1 kW	0.2 W/ft^2	19%
Casino #2	16,653 ft^2	< 17 kW	< 1.0 W/ft^2	1.0 kW	0.1 W/ft^2	6%

[a] Based on measured power of each lighting circuit by Transformative Wave
[b] Lighting power density (LPD) includes interior and exterior lighting
[c] Lighting DR based on the lighting loads turned off during the DR events

Appendix I. Projected Compressor Cooling Demand Response Asset

Table I-1 summarizes the compressor load at a 95°F ambient temperature assuming a 1.0 kW of compressor and condenser fan power per ton of cooling. Then, based on NREL laboratory testing of RTU equipment, the team found that the compressor power reduces by approximately 12% when the ambient temperature is 85°F because a lower pressure differential is needed to properly condense the refrigerant.

Based on the compressor and condenser fan power at 85°F, the team assumed that a quarter of the compressors would turn off during a day-ahead DR event. The team then assumed that an eighth of the compressors would turn off during a 10-minute event.

Table I-1. Compressor Power and Projected DR Curtailment at Each Demonstration Location

	Compressor Total ft[a] (at 95° Ambient)		Compressor Total ft^2b (at 85°F ambient)		Day-Ahead DR ft[c] (assuming turning 1/4 comps off)		10-Minute DR ft[d] (assuming turning 1/8 comps off)	
Drug Store #1	40.0 kW	2.5 W/ft^2	35.2 kW	2.2 W/ft^2	8.8 kW	0.5 W/ft2	4.4 kW	0.3 W/ft^2
Drug Store #2	40.0 kW	2.6 W/ft^2	35.2 kW	2.3 W/ft^2	8.8 kW	0.6 W/ft2	4.4 kW	0.3 W/ft^2
Furniture Store #1	79.0 kW	2.8 W/ft^2	69.5 kW	2.5 W/ft^2	17.4 kW	0.6 W/ft2	8.7 kW	0.3 W/ft^2
Furniture Store #2	40.0 kW	1.8 W/ft^2	35.2 kW	1.6 W/ft^2	8.8 kW	0.4 W/ft2	4.4 kW	0.2 W/ft^2
Casino #1	26.0 kW	2.3 W/ft^2	22.9 kW	2.0 W/ft^2	5.7 kW	0.5 W/ft2	2.9 kW	0.3 W/ft^2
Casino #2	114.5 kW	6.9 W/ft^2	100.8 kW	6.1 W/ft^2	25.2 kW	1.5 W/ft2	12.6 kW	0.8 W/ft^2

[a] The team assumed the compressor and condenser fan power was 1.0 kW per ton of cooling, which equates to a 12.0 EER at 95°F not including the supply fan power

[b] Based on NREL testing of RTU equipment, the compressor power reduces by approximately 12% from 95°F to a cooler 85°F ambient

[c] The team assumed that a quarter of each store's compressors would turn off during a day-ahead DR event. The team used the compressor power at 85°F because this was the typical daily high temperature during the summer DR events.

[d] The team assumed that an eighth of each store's compressors would turn off during a 10-minute DR event. The team used the compressor power at 85°F because this was the typical daily high temperature during the summer DR events.

Appendix J. Projected Plug Load and Water Heater Demand Response Asset

Table J-1 quantifies the total plug and EWH assets that the team turned off or prevented from coming on during a DR event. Although the drug stores had EWHs, the building manager did not want the team curtailing them. He wanted to ensure hot water was always available at the set point temperature for the pharmacy departments. Only the furniture stores had their EWHs curtailed because the casinos had natural gas water heaters. More detail about which plug loads were controlled at each location is provided in Appendix A.

Table J-1. Plug Load and Electric Water Heater Power and Projected DR Curtailment at Each Demonstration Location

	Area	EWH DR		Plug Load DR	
Drug Store #1	16,210 ft^2	0.0 kW	0.0 W/ft^2	0.4 kW	0.02 W/ft^2
Drug Store #2	15,400 ft^2	0.0 kW	0.0 W/ft^2	0.4 kW	0.03 W/ft^2
Furniture Store #1	27,823 ft^2	3.6 kW	0.1 W/ft^2	8.5 kW	0.3 W/ft^2
Furniture Store #2	21,717 ft^2	3.3 kW	0.2 W/ft^2	5.5 kW	0.3 W/ft^2
Casino #1	11,173 ft^2	NA	NA	0.3 kW	0.0 W/ft^2
Casino #2	16,653 ft^2	NA	NA	1.4 kW	0.1 W/ft^2