Massachusetts Department of Energy Resources
Peak Demand Management Grant Program
PON-ENE-2017-001

<u>Advanced Demand Management</u>

Final Report
Submitted by:

DemandQ, Inc.
Advanced Microgrid Solutions
Eversource

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Background

The Massachusetts Department of Energy Resources (DOER) awarded DemandQ, Inc. (formerly eCurv, Inc.), a leading provider of demand management software services, Advanced Microgrid Solutions (AMS) a pioneer in the use of advanced energy storage systems, and Eversource, the leading provider of energy in New England, a $179,500 grant to design and implement a highly scalable solution to decrease peak demand statewide as part of the Peak Demand Management Grant Program (PON-ENE-2017-001).

[https://ecurv.com/news/ecurv-179500-grant-doer]

DemandQ, AMS, and Eversource have partnered to demonstrate a combination of innovative software controls and advanced energy storage to permanently reduce peak load and provide a seasonal, dispatchable peak demand management resource for "big box" retail stores. The service has been designed to be extensible across a broad range of commercial and industrial properties.

[http://www.mass.gov/eea/pr-2017/4-6-million-grants-for-peak-demand-reduction-projects.html]

Electricity needs are met by generation in real time, leading to high prices and reliability issues during times of high peak demand. According to the Massachusetts DOER's State of Charge study, the top 1% of peak electricity demand hours account for 8% of electric energy costs, while the top 10% of hours accounts for 40% of overall electric energy costs. Because electricity transmission and distribution system investment is based on the single highest hour of use, reducing peak demand can defray the need for ratepayers to finance additions to system infrastructure.

[http://www.mass.gov/eea/docs/doer/state-of-charge-report.pdf]

This project is designed to reduce the operational and financial barriers to the widespread adoption of peak load management service programs in the big box retail segment. The demonstrated technology and business model, which we are calling "Active Demand Management" or "ADM," enables Utilities across Massachusetts to deliver a flexible and highly scalable solution to the problem of peak demand.

The ADM project was launched in Q1 of 2017 with deployment of DemandQ's innovative peak demand management solution to two national retailer locations in Burlington and Springfield Massachusetts. Both sites are in Eversource's service territory.

"Big box" retail stores that have solar installations tend to have "peakier" demand profiles, and there are few options available to property owners to manage the intermittency of solar output. Today, approximately 20% of big box stores in Massachusetts have PV solar installations. The selected Burlington site has a large solar array, while, for comparison purposes, the Springfield site does not. One of the principal objectives of this project is the demonstration of an economically viable integrated software enabled /solar / storage demand management solution.

DemandQ's Intelligent Demand Optimization service was first deployed in Massachusetts in the fourth quarter of 2015 as a demonstration project before being rolled-out commercially, and is now active in over 1,100 sites across the continental US. Data from the entire portfolio has been used to verify and validate the modelling activities of this program.

The second element of the ADM project pairs data collected during the DemandQ service period with a simulation of advanced energy storage in partnership with Advanced Microgrid Solutions. For the purposes of this program, AMS leveraged its proprietary ARMADA™ software platform to simulate the impact of its energy storage system when combined with DemandQ.

Milestones and Dates

Task	**Start**	**Finish**
DemandQ/AMS/Eversource MA DOER Project	2/3/17	1/25/18
Project Start	2/3/17	3/22/17
Award Letter From DOER	2/3/17	2/3/17
Notification to Program Team	2/6/17	2/6/17
NDAs submitted and approved	2/7/17	2/28/17
Counter-party Agreements Circulated and Approved	3/1/17	3/22/17
Task 1a - M&V plan development	2/3/17	4/7/17
Project Kickoff	2/3/17	2/3/17
Baseline Development for M&V	2/6/17	3/24/17
DemandQ/BAS server integration/configuration	2/6/17	3/10/17
DemandQ site data capture	3/27/17	4/7/17

ADM Performance Report

AMS simulation data development	2/6/17	3/17/17
Task 1b - Integration/configuration/implementation	3/20/17	5/12/17
DemandQ store deployments	4/10/17	5/5/17
AMS data prep and model configuration	3/20/17	5/12/17
First report to DOER submitted for approval	5/12/17	5/12/17
Task 2a - Mid-term analysis & report	5/15/17	10/13/17
AMD use cases and storage system design	5/15/17	6/9/17
AMS storage system simulation	6/12/17	7/7/17
Modeling AMD impact against DemandQ provided baseline	7/10/17	8/4/17
Integrated DemandQ/AMS system model	8/7/17	9/1/17
Run Integrated DemandQ/AMS simulation	9/4/17	9/15/17
M&V method submitted to Fraunhofer (via Eversource)	9/18/17	10/13/17
Quarterly report to DOER	10/13/17	10/13/17
Task 2b - Integrated & standalone systems analysis/report	5/8/17	12/28/17
Develop deck to Mass Save for EEAC presentation	10/16/17	11/10/17
Submit EEAC deck for posting	11/10/17	11/10/17
DemandQ performance monitoring	5/8/17	11/30/17
DemandQ Use Case Analysis (performance assessment)	12/1/17	12/14/17

Consumption and demand impact analysis and report	12/15/17	12/28/17
Report to DOER summing service impact through 10/30	12/28/17	12/28/17
Task 3 - Market opportunity assessment	11/12/18	1/12/19
Fraunhofer “On-Off” test – Design/Build/ Run	8/13/18	10/14/18
Fraunhofer Data Analysis/Report	10/14/18	1/12/19
Market approach	11/12/18	11/19/18
Market size and potential	11/19/18	12/7/18
Customer engagement plan	12/7/18	12/14/18
Program rollout model & impact	12/14/18	12/21/18
Program cost effectiveness	1/5/19	1/12/19
Platform Demonstration Project Completed		2/4/19

Technology

DemandQ Intelligent Demand Optimization Software

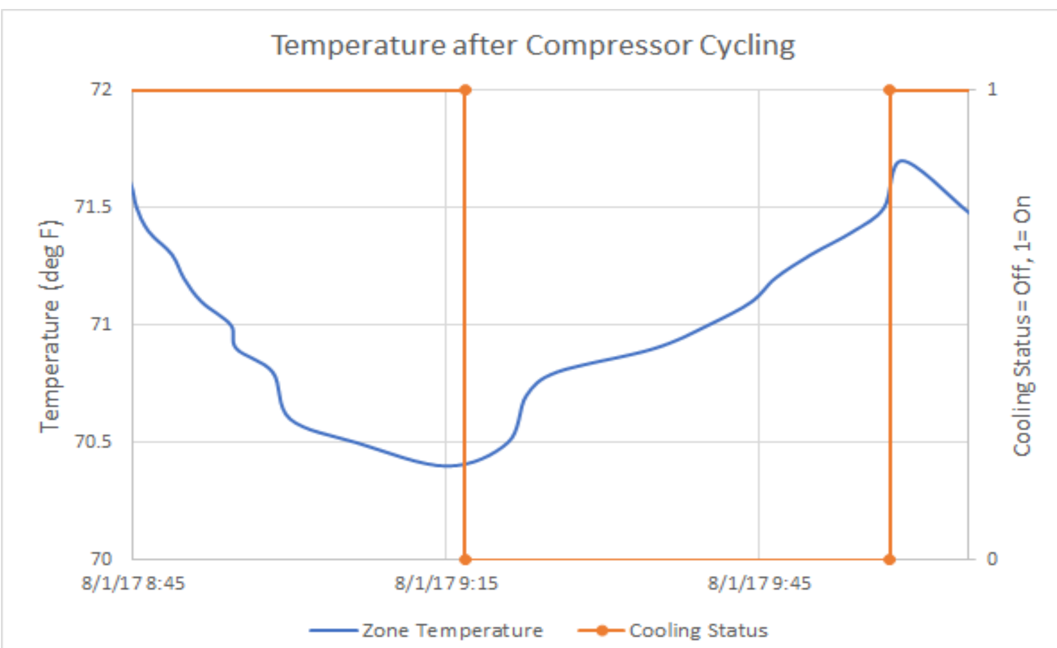
Electric loads, from lights to HVAC to electronics, have unrestricted access to power, limited only by a user operated switch or control circuit (as in a thermostat). The random and independent operation of multiple electrical loads within the confines of a building creates a high probability that the majority of these appliances will be drawing power simultaneously within any one of the 2880 15-minute intervals utilities use to meter commercial electricity and assess demand charges. These localized events in turn tend to “synchronize” with all the other endpoints/buildings in a utility operating region, driving grid level peaks. The impact of these coincident peak power events is increased operating costs for the Utility, which in turn get passed to consumers in the form of demand charges.

ADM Performance Report

DemandQ, Inc. developed Intelligent Demand Optimization as a software solution to mitigate the problem of coincident peak demand. Intelligent Demand Optimization is conceptually based on the algorithms that effectively manage the massive quantity of users/data transiting the mobile phone networks. Applying proven mathematical queuing/multiplexing models, DemandQ selectively grants access to targeted devices as they seek access to power, dynamically reducing instances of concurrent / coincident usage.

Existing building automation systems typically control individual HVAC units, such as packaged rooftop units (RTUs), in isolation. Under this management model, each RTU operates to maintain the temperature setpoint for its own zone. In contrast, DemandQ aggregates all the appliances/powered devices at a site into a single system view, micro-time shifting their operation to reduce coincident peaks while maintaining the target temperature.

When applied to appliances like commercial HVAC systems, DemandQ prioritizes (queues) each individual "load" in the context of all other loads/appliances that are in operation. For example, rather than allow two air conditioners to turn on and off together, DemandQ queues the units to operate sequentially. By leveraging the operational flexibility/inertia inherent in a building's thermodynamics, DemandQ can mitigate peak demand with no perceivable impact on occupant comfort. The data driven DemandQ platform leverages detailed HVAC manufacturer's information and Utility billing data to construct a model that is applied in prioritizing a broad range of cycling appliances, from HVAC units to battery charging systems, pumps and fans, all queued to reduce/manage peak demand.



While DemandQ is focused on mitigating peak demand, the service also delivers energy efficiency benefits. DemandQ collects operational data that is processed through an analytical engine, continuously evaluating the mechanical status of each connected device with the goal of optimizing its performance, while identifying anomalies and problems across the entire HVAC system. Examples of potential issues addressed by DemandQ include managing system operations around faulty compressors, economizer settings, HVAC schedules, and zonal/site overcooling.

AMS Energy Storage

ARMADA Load Optimization

Consumers of electricity have better tools than ever to control how they use energy, but are still exposed to swings in the price of energy. Exogenous factors—the need for lighting during the night, for space conditioning and services during business hours, etc.—force consumers to consume energy even if there are strong economic signals to do otherwise.

ARMADA, Advanced Microgrid Solutions' proprietary behind-the-meter energy storage optimization platform, manages energy usage and reduces energy costs. The lithium-ion energy storage systems used by AMS are integrated with ARMADA's software to dynamically respond to each consumer's demand load. When controlled by ARMADA, energy storage systems are charged and discharged to effectively manage and shape consumer load in a way that generates energy savings, with zero impact on customer operations.

Energy savings achieved by ARMADA are the result of energy arbitrage, either from load shifting (e.g., charging the battery when energy is cheaper and discharging when energy is more expensive), or demand rate arbitrage, where the service discharges the battery in a controlled fashion to reduce real-time demand during critical peak intervals (e.g., the Installed Capacity Tag in ISO-NE).

AMS managed energy storage capacity provides additional benefits at the utility or grid level, including but not limited to:

- Load Shed / Demand Response
- Ancillary Services
- Wholesale Market Participation

The ARMADA Optimization Engine

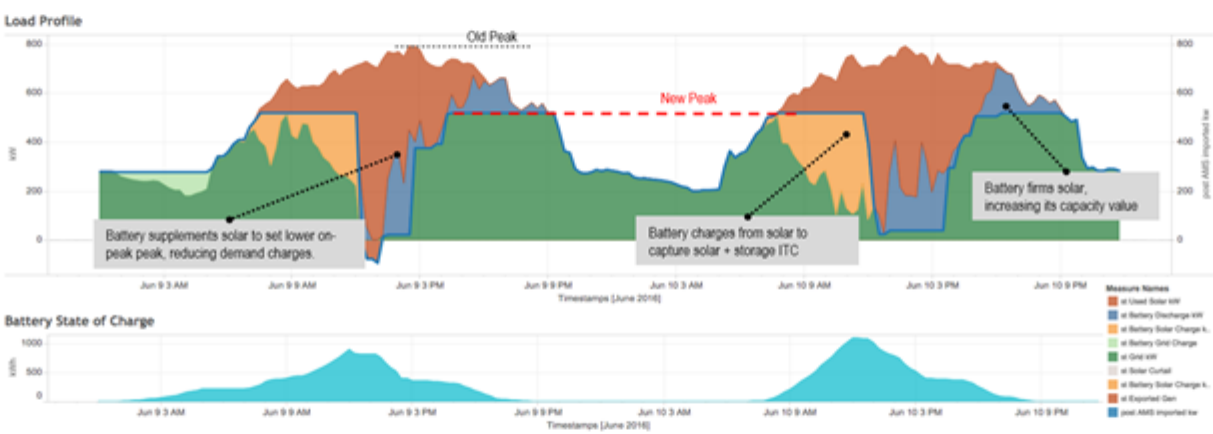
ARMADA is primarily an economic (rather than a rules-based) optimization platform. ARMADA constantly determines the most cost-effective distribution of battery capacity based on present and predicted economic opportunities like cost savings and revenue from grid services. The optimization occurs both at a site level—e.g., seeking the ideal economic distribution for the customer hosting the battery—and on a portfolio level, where batteries can be networked together to provide aggregated services to the grid.

ARMADA operates through the application of a range of data services, including but not limited to:

- **Tariff & Billing information,** utilizing Genability (a third-party tariff library)
- **Real-Time Customer Data,** collected remotely or from meters AMS installs on-site at utility, battery and on-site generation equipment.
- **Load Forecasting Engine,** created by AMS, which uses historical customer load data to forecast minute-to-minute energy usage.
- **LMP Data Collection,** using publicly available utility or RTO/ISO pricing information
- **TMY Weather Data,** using a variety of third-party APIs
- **Dispatch Forecasting Engine,** which uses historical dispatch activity to predict future demand response (or other) dispatches (if and when a battery will be enrolled in a utility or RTO/ISO demand response program or other types of grid services).
- **Contract Obligations:** Performance-based calculations and payout structures as defined by market programs and bilateral contracts.
- **Customer Requirements,** such as no-charging limits during certain hours or maximizing usage of specific energy blocks purchased directly from a supplier
- **Regulatory Parameters,** such as no-export conditions or charging from on-site renewables

ARMADA for the Peak Demand Management Grant Program

Since energy storage systems were not deployed as part of this program, AMS leveraged ARMADA's Solutions Design Suite to simulate how an energy storage system would have reduced/impacted the customer's energy costs.



Snapshot of AMS Solutions Design Suite energy storage + solar simulation output

Value Achieved Through A Combined Solution

This project has demonstrated the financial benefits and new operational insights that are achieved through the integration of Demand Management Software and Energy Storage Management. While a kilowatt of demand reduced by DemandQ is a kilowatt of demand that an ARMADA storage solution cannot reduce, DemandQ's services do not fully cannibalize the potential of storage savings. ARMADA and DemandQ technologies excel at reducing peak demand. The combination of energy storage and demand management software achieves additive benefits that are greater than either system can deliver individually to both customers and Utilities.

Behind-the-meter energy storage reduces peak demand, albeit at the expense of a net increase in energy consumption. This is because energy storage loses some energy as it charges and discharges. As modeled in this study, long duration/predicted demand response events are well served by ARMADA. As demonstrated by the test data, effective management of random short duration coincident peak events are delivered via DemandQs' software integration with a sites' existing building automation system. Taken together, the combined product of ARMADA and DemandQ delivers larger demand savings and net reductions in energy usage than either deliver as a standalone solution.

Deeper Reduction in Demand

DemandQ software is designed to minimize demand peaks that are driven by coincident operation of building environmental systems. AMS energy storage is designed to mitigate peaks by displacing energy from the grid with energy from batteries.

As developed for this program, DemandQ is utilized to focus on providing a real-time response to localized peak demand conditions. The ARMADA system can then be directed towards the remaining, more intransigent peaks. For example: a peak that is not driven by building system operations would be addressed by ARMADA, while the short duration peaks from the building systems would be mitigated by DemandQ, achieving the net result of deeper demand reductions. In addition, energy storage can help deal with the intermittency of other utility load-reduction technologies—especially solar—mitigating potential peaks that threaten to erase the peak reductions of DemandQ.

Active Demand Management

Another potential benefit to combining these systems is that AMS energy storage can provide redundancy for the DemandQ system. With visibility into their real-time energy usage, customers can quickly identify demand spikes that drive increases in their bill, and use that information to track down the cause and change it. However, at the moment of identification, the cost has been incurred (and the peak has affected the grid). The hypothesis behind active demand management is that the AMS energy storage system can mitigate the peak in real-time—both from a cost and an energy use perspective—but continue to provide the visibility that facility managers expect from monitoring-based commissioning. This is an added benefit to the combination of both systems.

Liberating Energy Storage Capacity for Grid Services

Energy storage, with its flexible and dynamic response capabilities, can be used for all types of grid services, including both active and dispatchable demand management. However, every kilowatt-hour of capacity that energy storage spends to lower a customer's peak is a kilowatt-hour that cannot be used for these types of utility and grid services.

Combining DemandQ with AMS energy storage relieves significant responsibility from the energy storage system, essentially making more storage capacity available for the grid, while still being able to backstop the peak reduction efforts of DemandQ. Given the relative cost of energy storage, it is far more cost-efficient to let DemandQ focus on reducing a customer's peak demand while letting an energy storage system focus on services that it is singularly capable of providing.

Technology Deployment

Site Information

The two locations involved in this study are referred to as the "West Springfield" site and "Burlington" site, located respectively in West Springfield, MA and Burlington, MA. The West Springfield store is 86,514 square feet (sf), and the Burlington store is 112,939 sf. Both are retail locations.

There are 6 RTUs at both sites. DemandQ service has been activated for the duration of the study.

The Burlington site currently has the following units:

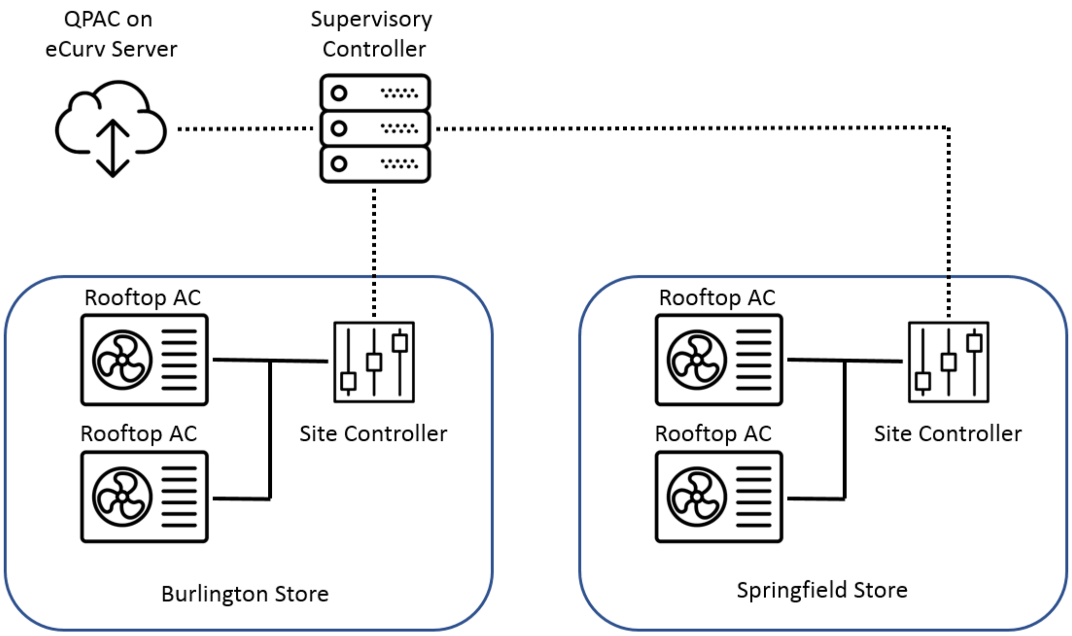
RTU	Area Served	Manufacturer	Model	Year	Tons
1	Sales or Stock	York	Z4	2017	40
2	Office	York	ZR240	2017	20
3	Sales or Stock	York	Z4	2017	40
4	Sales or Stock	York	ZJ120	2017	10
5	Sales or Stock	York	Z4	2017	40
6	Sales or Stock	York	Z4	2017	40

As of end-of-year 2017, the West Springfield site has slightly older units, as follows:

RTU	Area Served	Manufacturer	Model	Year	Tons
1	Sales or Stock	York	K14	2002	40
2	Sales or Stock	York	K14	2002	40
3	Sales or Stock	York	K14	2002	40
4	Sales or Stock	York	K14	2002	40
5	Office	York	DJ180	2012	15
6	Sales or Stock	York	DJ240	1998	20

DemandQ Integration Setup

The building automation system consists of site level controllers that directly interface with the site's HVACs, and supervisory controllers/servers that oversee multiple stores across the country. DemandQ software runs on DemandQ's cloud servers. A secure network connection is established between DemandQ's servers and the building automation server, which in turn allows DemandQ's servers to both read the site equipment status and send operational commands in real-time.



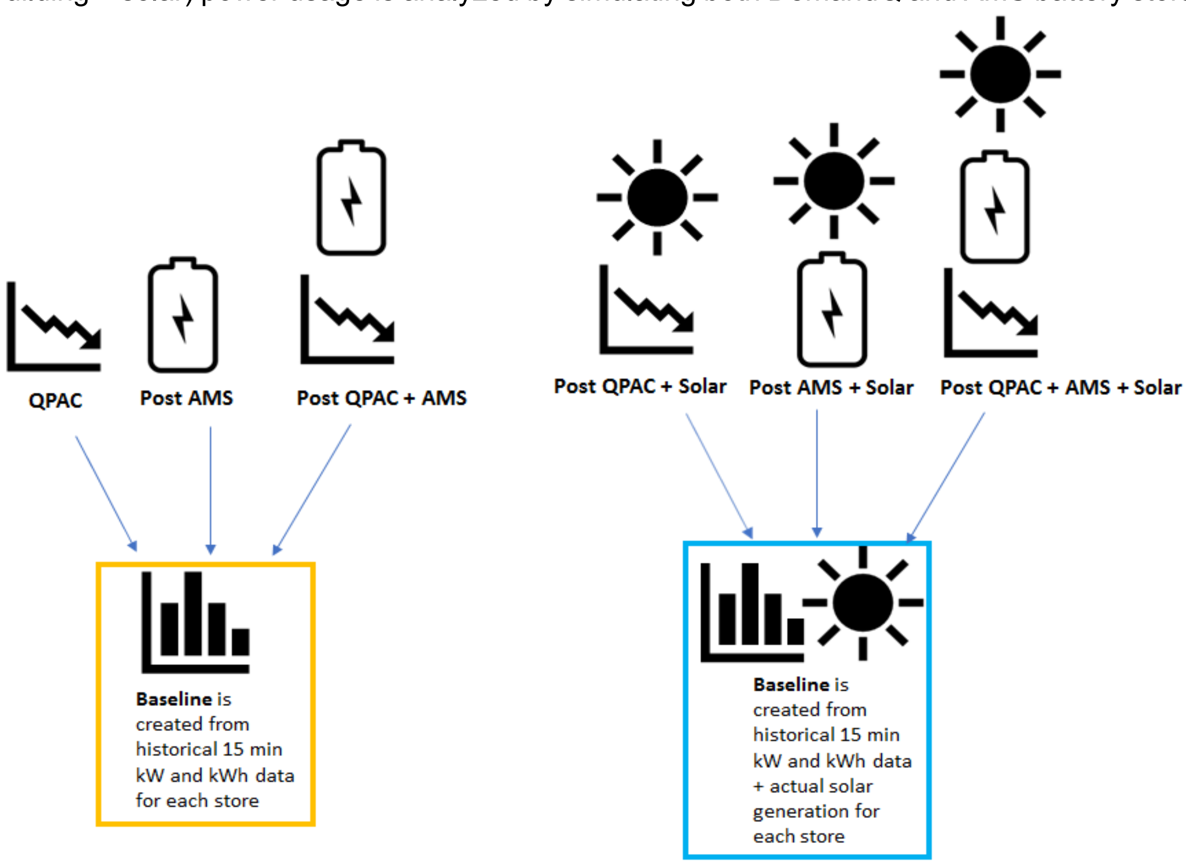
Assessment Methodology

The impact of DemandQ's service is assessed by first creating a baseline that reflects the expected power usage every 15 minutes in the absence of DemandQ. The baseline is then compared to actual 15 minute interval data collected by the utility.

The impact of AMS's battery storage on peak demand is assessed by running a simulation using the established baseline as its input. The output of the simulation estimates the power usage of the target site with battery storage, and is compared to the baseline to calculate storage system impact.

The net reductions in peak demand achieved by DemandQ and AMS battery storage have been assessed for this study by running the battery simulation based on actual 15 minute interval data collected from the utility, which already reflects the impact DemandQ on billings. The ARMADA simulation output estimates battery storage system cost reductions when integrated with DemandQ as compared to the baseline to calculate combined impact.

At the Burlington site, DemandQ was integrated with real-time data from a sub-meter that included building power usage but not solar generation. Hence, DemandQ optimized the building power separately from solar, and so the Burlington site is analyzed for the DemandQ, AMS, and DemandQ+AMS scenarios in the same way as Springfield. Additionally, the impact on the net (i.e. building + solar) power usage is analyzed by simulating both DemandQ and AMS battery storage.



Baseline Formulation

The baseline, as applied to the analysis of the project data, establishes the reference power usage of each site for the time period of the program. The baseline was modelled by applying a MATLAB implementation of a Gaussian Process Regression (GPR) using the predictor and response variables below. The West Springfield site utilized historical data for the two-year period from January 1, 2015 to January 1, 2017. The Burlington site utilized historical data for the one-year period from January 1, 2016 to January 1, 2017. Historical data for 2015 was not available for the Burlington location. The number of predictor variables was consequently reduced to avoid over-fitting the regression to the more limited dataset.

Variable	**Type**	**Description**	**Applicable Site(s)**
Apparent Temperature	Predictor	Temperature adjusted for humidity [reference]	• West Springfield • Burlington
Month	Predictor	Month of year	• West Springfield
Hour	Predictor	Hour of day	• West Springfield
Occupied	Predictor	Binary variable indicating whether or not store was occupied	• West Springfield
Cooling	Predictor	Binary variable indicating whether or not store was cooling	• West Springfield
kW, kWh	Response	kW / kWh data used as response (dependent variable) for training the regression models	• West Springfield • Burlington

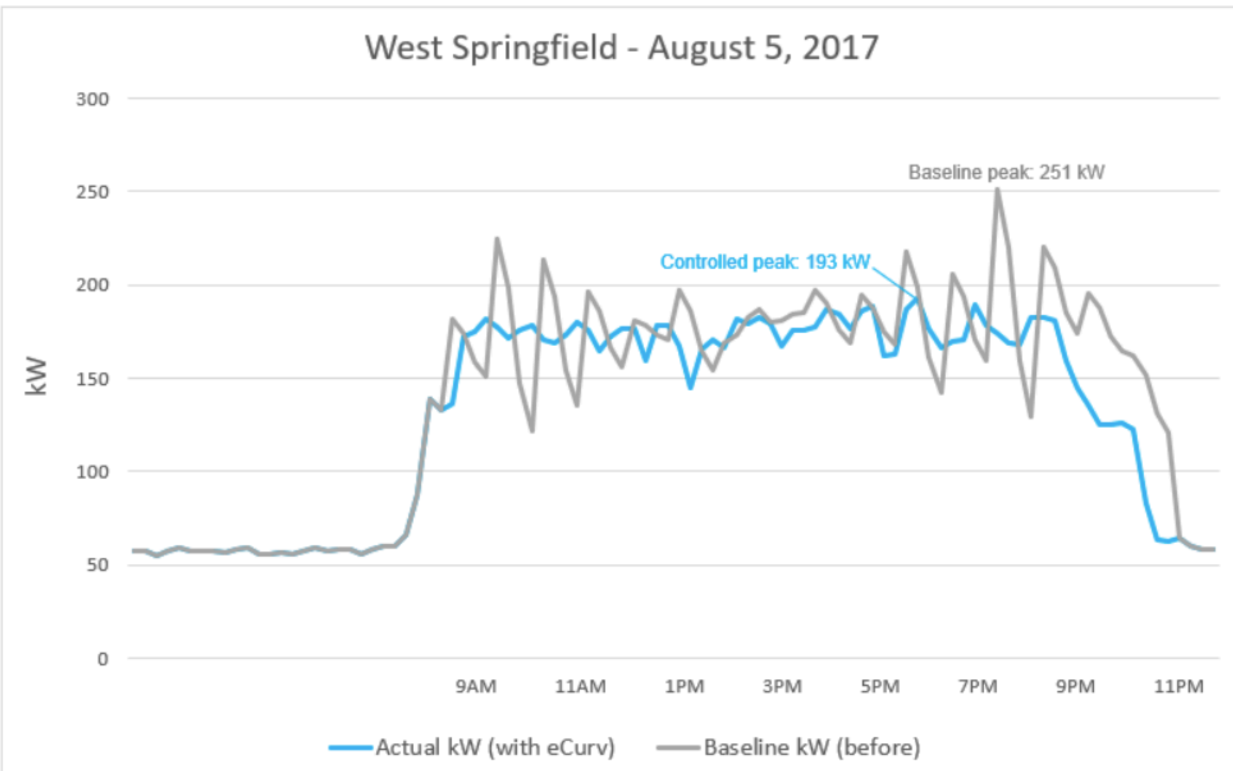
Predictor and response variables were sampled at 1 hour intervals, rather than 15 minutes, to improve the accuracy of the model. Note that historical power data was collected at 15 minute intervals, so resampling was necessary. The hourly kW values were taken as kW of the highest 15 minute interval within each hour. The hourly kWh values were taken as the average kW of all four 15 minute intervals within each hour.

The predictors and response variables were used to create a Gaussian Process model for kW and a second Gaussian Process model for kWh, both trained using the MATLAB Statistics and Machine Learning Toolbox. Gaussian Process is used because it is a probabilistic model that captures both the expected value and normally distributed noise associated with each prediction. For example, the model may predict kW demand of 170 +/- 10 kW at 10am, and 190 kW +/- 5 kW at 4pm.

[www.mathworks.com/help/stats/gaussian-process-regression-models.html]

Addressing modeling noise is crucial to creating a kW baseline. The upward and downward random fluctuations in demand kW result in a higher demand charge being assessed at the highest measured point, even if the fluctuations sum to zero. In contrast, zero sum fluctuations in predicted kWh cancel out when summed over the typical month-long billing period.

The kW and kWh GPR models are “trained” from historical data. The trained models are then used to create hourly baselines for the DemandQ active period from April 1, 2017 to November 30, 2017 using predictor data from the same DemandQ active period. The hourly kW and hourly kWh baselines are combined into a single 15 minute baseline that preserves both the peak kW and the average kWh in each hour. The 15 minute baseline is compared with actual recorded kW to assess service impact on demand, and is applied as input for the battery/energy storage simulation.



DemandQ baseline (gray) compared to actual demand profile (blue) illustrates peak load reduction

Adjustments to the Baseline

This section details additional adjustments made to the baseline as described in the Baseline Formulation.

Non-Cooling Periods

Periods of time when HVAC cooling is not necessary represent a different energy usage regime for both locations. Rather than HVAC driven variable demand, the power profile tends to be flat, predominantly reflecting lighting usage and equipment that operates on a fixed schedule.

Typically, cooling is not required when sites are unoccupied because the setpoint on the RTUs is raised to a higher temperature. Cooling is also generally not required when outside temperatures fall below 50 degF. When the sites are unoccupied or OAT falls below 50 degF, the baseline kW is set equal to the actual measured kW under the assumption that DemandQ does not impact power usage when mechanical cooling is inactive.

RTU Replacements (Burlington Site)

At the outset of the project, the Burlington store was unable to maintain relative humidity at or below its 48% target. New RTUs were installed in May 2017. While both the old and new units had the same total cooling capacity and similar efficiency, the new units were equipped to provide dehumidification, significantly impacting energy use. After the RTU upgrades were completed, year over year energy usage increased by 15% to 30%.

As reflected in the report, the baseline usage was adjusted to compensate for the energy impact of the equipment upgrade. Two models were constructed in eQUEST 3.65 and run on DOE2's simulation engine: one with dehumidification and one without. Both models were constructed by eQuest's default single story department store template (i.e. 65% Retail/Wholesale Showroom) with a square footage of 112,997 sf. The models were simulated using 2017 weather data. The increase in monthly energy usage was then applied to each month in the baseline. The increase was applied as a constant to all hours when cooling was active.

In addition to applying the dehumidification adjustment, the months of April and May are excluded for the Burlington store for this study due to the ongoing mechanical work associated with replacing RTUs.

Additionally, the Burlington location underwent upgrades to install LED lighting in October 2017. October results are excluded from this draft report but will be included in the final report, pending adjustments to compensate for lighting changes.

Battery Impact Assessment

Methodology

The AMS impact assessment models what each site's load profile—post-DemandQ—would look like if energy storage were deployed. The ADM simulation is based on actual data from the customer's utility meter, and, in the case of the Burlington site, includes on-site solar generation data. For the purposes of this study, the AMS simulation used a generic battery configuration; a 100-kW inverter with 400 kWh of storage capacity.

To demonstrate the added value of the grid services that a behind-the-meter energy storage system could provide, AMS included a dispatchable Grid/Utility demand response service in the simulation. The Grid/Utility service assumes that the battery is called on to discharge a fixed capacity to reduce customer load for a certain number of hours throughout the year, at a specified capacity value. This data was then applied as another input modelling how the energy storage system would choose to 'spend' capacity throughout the simulation period.

AMS ran two sets of simulations for each facility – one against the actual load (post-DemandQ), and one against the DemandQ baseline (pre-DemandQ). The simulation employs a pre-AMS energy storage dataset and a post-AMS energy storage dataset.

The result is 4 simulations that capture the peak kW and kWh, and a basic energy cost calculation for each facility:

1. Baseline Model (pre-DemandQ, pre-AMS)
2. Baseline Model + AMS (pre-DemandQ, post AMS)
3. Actual (post-DemandQ, pre-AMS)
4. Simulated (post-DemandQ, post-AMS)

In the case of the Burlington site, where native building load and solar data were accessed separately, AMS created two scenarios for pre- and post-solar, and two more for a DemandQ solar integration.

The savings are calculated as the delta between each of these scenarios.

ARMADA Model Inputs and Outputs

The following inputs were used for simulating the impact of energy storage:

- **15-minute interval energy usage data,** on which the customer was billed.
    - *This is post-DemandQ data, e.g., data reflecting the customer's energy usage after the deployment of DemandQ's proprietary system to optimize said customer's load.*
- **A 15-minute 'baseline' interval energy usage data for the same period,** which is in DemandQ's estimation the best representation of what the customer's energy usage *would have* looked like prior to DemandQ's optimization.
- **15-minute interval on-site generation output data for the same period.**

The following parameters were used for the simulation:

- **Assumed energy storage configuration:**
    - 100 kW maximum inverter capacity (nameplate; inverter blocks may need to be overbuilt in real life to compensate for round-trip efficiency)

    - 400 kWh maximum energy storage capacity
- **Assumed round trip efficiency:** ~82%
- **Assumed battery degradation cost:** $0.07, which is used to limit battery cycling and avoid unnecessary degradation of the battery over its lifetime
- **Assumed battery buffer margin:** 10% marginal capacity (40 kWh) to ensure 400 kWh can be discharged after round-trip efficiency losses
- **Pre/Post-optimization rate schedule:** Eversource G-3 (B3,G6) Time of Use
- **Pre/Post-optimization generation rate schedule:** $0.10 / kWh Flat
- **Grid/Utility Service parameters:**
    - **Commitment:** 100 kW
    - **Annual Rate:** $350 / kW-yr
    - **Dispatches Allowed/Year:** 150
    - **Dispatch Hours Allowed:** 0800 – 1800 Eastern Time, year-round, weekdays
    - **Dispatch Modeled:** Even distribution across 12 months
- **"No-charge" window:** 1300 – 1400 Eastern Time
- **Net Energy Metering allowance:** No
- **Onsite Generation?**: Yes, Burlington Site Only, 150 kW Solar system

Measurement & Verification

This report reflects the modeled optimal usage of a battery system unencumbered by the uncertainty inherent in actual operations. The predicted savings are reflective of the potential maximum economic value generated by the battery. This serves as a proxy—a snapshot based on modeled parameters. The financial benefits should be considered slightly aggressive rather than reflective of what is achievable in actual operation. However, this snapshot could also easily underestimate opportunities that future conditions (e.g., changing load profiles, tariffs, market products) may provide.

Since the ARMADA Platform is already tracking, analyzing and outputting data, it is a straightforward process to establish an objective account of energy savings for M&V by using a 'counter-factual' built upon the empirical data gathered over the course of this project. The ARMADA Platform feeds the pre-optimization data into the platform's tariff engine to calculate how much the customer energy use costs the customer, as well as other load statistics that are easily calibrated against actual utility bills.

Understanding the combined impact of both DemandQ's and AMS' ARMADA simulations is fairly academic; DemandQ addressed the central challenge by establishing a common baseline and developing a "pre-DemandQ" interval data set for AMS. AMS also analyzed energy storage simulations on these baselines to understand what the 'standalone' savings an AMS energy storage system could deliver and get an apples-to-apples comparison of cost-savings and load reduction.

Solar Impact Assessment

DemandQ utilizes a real-time feed of solar meter data to compensate for fluctuations in solar generation. However, during the April to November DemandQ service period, the solar meter at the Burlington location malfunctioned, and could not be used to provide a real-time feed. SunEdison, the owner and maintenance contractor for the solar installation and metering, was not able to repair the meter in a timely manner due to corporate restructuring. DemandQ was instead applied to reduce peak demand of the building, without consideration of the solar generation.

The solar baseline, with only the store and solar, is constructed by adding the actual solar generation during the April to November period to the non-solar baseline previously described. Actual solar generation data can be used as part of the baseline because neither DemandQ nor battery storage affects solar output. The battery simulation uses the same AMS procedure described previously. Post-DemandQ results were calculated using actual measured DemandQ performance.

Program Results

Summary

Individually, neither DemandQ or ARMADA were able to generate more than 30% peak demand savings. However, as a combined solution, reductions of up to 50% were achieved at the Burlington site. At the West Springfield site, where the baseline demand curve was flatter, the results were less clear cut – the combined systems did not lead to as large a net reduction in demand savings.

Adding PV solar to a property’s infrastructure creates significant demand peaks – typically at the junction between solar and non-solar operations. The energy profile generated during this transition is nicknamed “the duck curve” due to its inherent shape, peaking as solar generation diminishes and on-grid energy utilization becomes the primary resource.

As detailed below, the Burlington site’s load profile is more dynamic, which allows for greater incremental reductions, whereas the West Springfield facility’s flat load profile allowed for less incremental reduction. The baseline load profiles remain one of the best determinants in projecting potential energy savings.

West Springfield Site

	Apr ‘17		May ‘17		Jun ‘17		Jul ‘17	
	kWh	**kW**	**kWh**	**kW**	**kWh**	**kW**	**kWh**	**kW**
Baseline	**80,745**	**231**	**81,198**	**255**	**92,998**	**265**	**102,132**	**260**

AMS Battery Savings	81,831 (1,086) **-1.3%**	144 87 **37.6%**	82,040 (842) **-1.0%**	163 92 **36.0%**	94,218 (1,220) **-1.3%**	176 88 **33.4%**	103,485 (1,352) **-1.3%**	186 74 **28.4%**
DemandQ SaaS Savings	80,627 118 **0.1%**	229 3 **1.2%**	80,738 460 **0.6%**	232 23 **9.2%**	87,747 5,251 **5.6%**	247 17 **6.5%**	94,820 7,312 **7.2%**	224 36 **13.9%**
Combined Savings	81,686 (941) **-1.2%**	146 86 **37.0%**	81,447 (249) **-0.3%**	165 89 **35.1%**	88.859 4,139 **4.5%**	181 84 **31.7%**	95,734 6,398 **6.3%**	193 67 **25.9%**

West Springfield Site (continued)

	Aug ‘17		Sep ‘17		Oct ‘17	
	kWh	**kW**	**kWh**	**kW**	**kWh**	**kW**
Baseline	**101,601**	**270**	**90,863**	**259**	**84,609**	**236**
AMS Battery Savings	103,374 (1,774) **-1.7%**	184 86 **31.7%**	92,404 (1,541) **-1.7%**	174 84 **32.6%**	85,583 (974) **-1.2%**	167 69 **29.4%**
DemandQ SaaS Savings	94,994 6,607 **6.5%**	221 49 **18.0%**	87,259 3,605 **4.0%**	205 54 **20.8%**	82,612 1,997 **2.4%**	200 36 **15.4%**
Combined Savings	96,427 5,174 **5.1%**	183 87 **32.2%**	88,341 2,523 **2.8%**	176 83 **32.0%**	83,541 1,068 **1.3%**	166 70 **29.9%**

Burlington Site

	Jun ‘17		Jul ‘17		Aug ‘17		Sep ‘17	
	kWh	**kW**	**kWh**	**kW**	**kWh**	**kW**	**kWh**	**kW**
Baseline	**101,945**	**368**	**110,617**	**367**	**108,423**	**346**	**101,715**	**360**
AMS Battery Savings	102,970 (1,025) **-1.0%**	268 100 **27.2%**	111,476 (858) **-0.8%**	267 100 **27.3%**	109,731 (1,307) **-1.2%**	246 100 **28.9%**	102,672 (957) **-0.9%**	260 100 **27.8%**
DemandQ SaaS Savings	101,409 536 **0.5%**	300 68 **18.5%**	110,444 151 **0.1%**	298 68 **18.6%**	102,992 5,432 **5.0%**	272 74 **21.5%**	96,117 5,598 **5.5%**	283 77 **21.3%**
Combined Savings	102,553 (608) **-0.6%**	237 131 **35.5%**	111,203 (586) **-0.5%**	241 125 **34.2%**	104,365 4,058 **3.7%**	225 121 **35.0%**	96,994 4,721 **4.6%**	216 144 **40.1%**
Baseline (w/ PV)	**51,555**	**316**	**60,116**	**335**	**58,904**	**349**	**64,610**	**317**
AMS Battery Savings (w/ PV)	51,795 (240) **-0.5%**	216 100 **31.7%**	60,841 (725) **-1.2%**	235 100 **29.9%**	59,342 (439) **-0.7%**	249 100 **28.7%**	65,324 (714) **-1.1%**	217 100 **31.5%**

DemandQ SaaS Savings (w/ PV)	49,684 1,871 **3.6%**	274 41 **13.1%**	58,473 1,643 **2.7%**	276 59 **17.6%**	51,980 6,924 **11.8%**	252 97 **27.8%**	57,560 7,050 **10.9%**	265 52 **16.4%**
Combined Savings (w/ PV)	50,459 1,096 **2.1%**	174 141 **44.8%**	59,481 635 **1.1%**	176 159 **47.5%**	53,351 5,553 **9.4%**	175 174 **50.0%**	58,558 6,052 **9.4%**	189 129 **40.5%**

Impact On Peak Demand

DemandQ Intelligent Demand Optimization

As a standalone SaaS solution, DemandQ's demand management is nimble and quick – it can be rapidly deployed to many locations for a low up-front cost.

Average peak reduction, by facility (actual meter data, post-DemandQ):

- **Burlington (pre-solar):** 20.0%
- **Burlington (post-solar):** 19.0%
- **West Springfield:** 12.3%

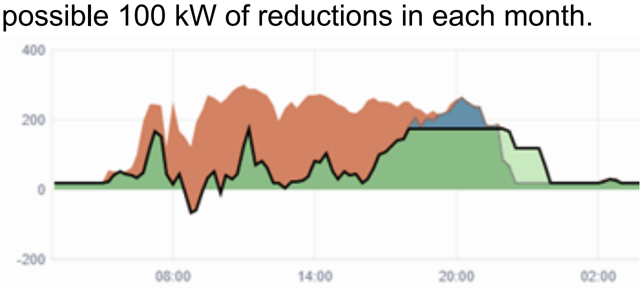
AMS Battery Storage

In general, AMS battery storage as a flexible standalone product reduced facility peaks significantly in both pre-DemandQ simulations.

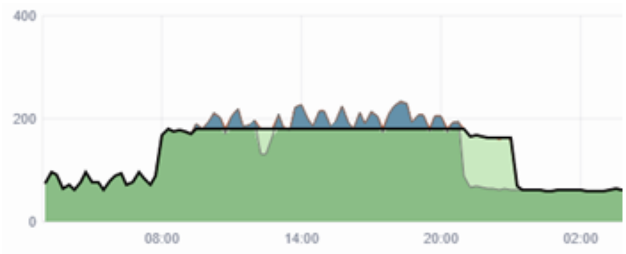
Average peak reduction, by facility (pre-DemandQ, post-AMS):

- **Burlington (pre-solar):** 27.8%
- **Burlington (post-solar):** 30.4%
- **West Springfield:** 33.3%

This is expected behavior. The modeled 100 kW-400 kWh battery achieved the maximum possible 100 kW of reductions in each month.



At the West Springfield site, the flat load profile makes incremental demand reduction difficult, but the battery managed to achieve 75% of that maximum possible reduction.

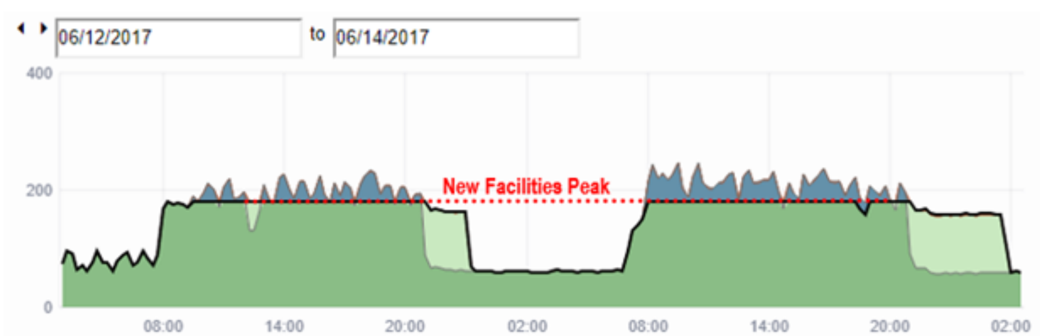


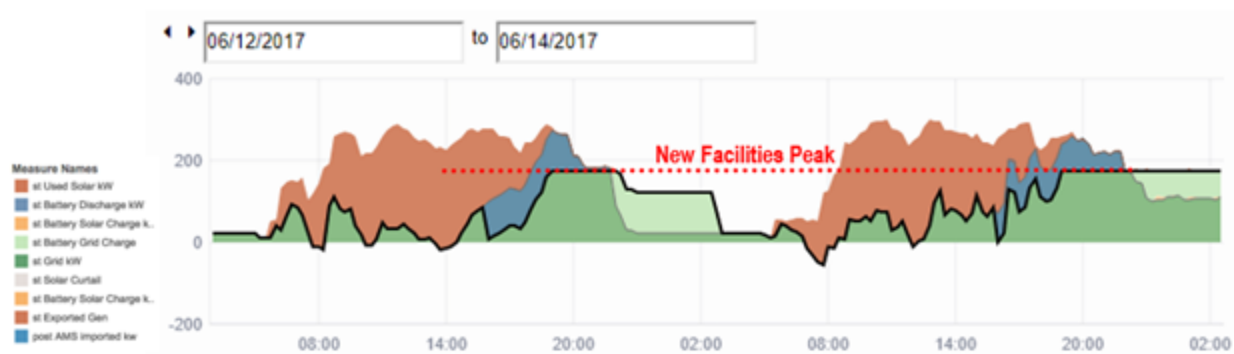
Combined Solution

Average peak reduction, by facility (post-DemandQ, post-AMS):

- **Burlington (pre-solar):** 36.2%
- **Burlington (post-solar):** 45.7%
- **West Springfield:** 32.0%

The simulated batteries at Burlington achieved 100% of the maximum reduction possible, whereas the West Springfield batteries achieved 75% of the maximum demand reduction.



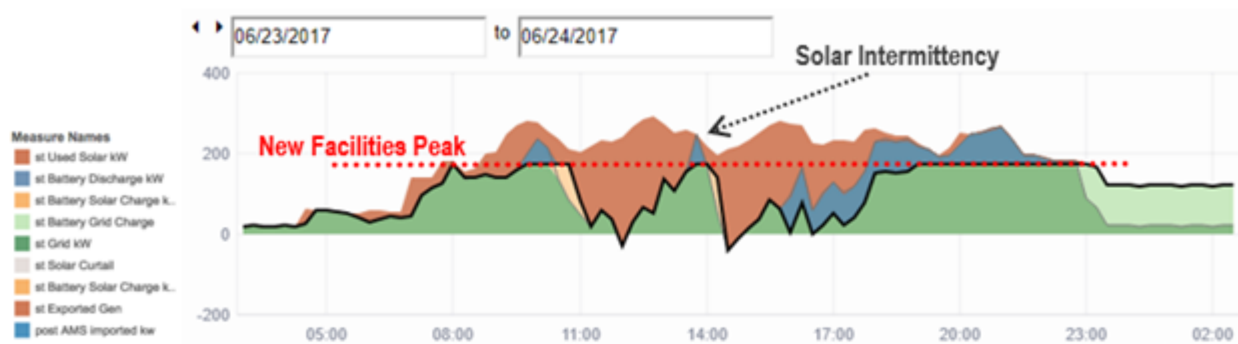


In the graphics above, the energy storage system at West Springfield would have to discharge 13 kWh to achieve the marginal kW of reduction, whereas the Burlington Storage system only needs 5 kWh for the marginal kW of reduction. When facility load plateaus like West Springfield, the battery capacity required to reduce peaks further is often cost-ineffective; the ARMADA *optimization decides to forgo further peak reduction in these cases to avoid unnecessary degradation.*

***AMS Analyst Note:** It's important to note that while the cumulative impact on demand reduction at West Springfield was not greater than either product's individual reductions, the modeled **cost savings** of the combined product was greater. The ARMADA optimization engine focuses on economic solutions – for the combined product, it modeled cost reductions up to 15% of the total electric bill.*

Active Demand Management

There were many examples of Active Demand Management – DemandQ mitigated the highest peaks by decreasing the standard deviation of the load profile, and the remaining peaks were prioritized and reduced with energy storage. At the Burlington location, intermittent solar production increased the volatility of the baseline load profile. On June 23rd, for example, a clear mid-morning spike was caught by the ARMADA system at the Burlington facility.



Energy Consumption Impact

DemandQ Intelligent Demand Optimization

In addition to mitigating demand peaks, DemandQ also optimizes kWh consumption. This is accomplished by continually assessing the cooling capacity of each HVAC appliance. This data is applied in managing the fleet of HVACs as a single system, and in prioritizing each zone for cooling. The most efficient HVAC in the queue at any given time is given priority, improving overall site kWh consumption.

Average kWh Reduction, by facility (actual meter data, post-DemandQ):

- **Burlington (pre-solar):** 2.8%
- **Burlington (post-solar):** 7.4%
- **West Springfield:** 4.0%

Compressor Runtime Analysis

One metric to determine the impact of DemandQ demand management is to compare the compressor runtimes from before and after DemandQ became active at stores. Compressor runtimes are the total amount of time compressors cycle on for the same time period (i.e. April - November, 11am - 5pm). Each RTU operates differently; the amount of time compressors run depends on internal loads (latent and sensible heat from people, lights, equipment, etc.), external loads (temperatures, humidity, amount of sunlight entering the space, building and envelope air leakage, etc.), unit logic and RTU specific logic and schedules. A suitable way to understand the impact of DemandQ is to compare RTU specific behavior is to compare an RTU's specific behavior before and after DemandQ.

Using historical data, compressor run times before DemandQ were calculated from April - November 2016, and compressor run times while DemandQ was live were calculated from April - November 2017. Observations with missing values (zone temperature or setpoint) were removed from this analysis.

For the West Springfield site, a compressor runtime analysis was done to understand the impact of DemandQ on each compressor as follows.

RTU #	**Run-time (hours, before DemandQ)**	**Run-time (hours, after DemandQ)**
1	1801	2493
2	2246	1641
3	1889	651
4	2136	1082
5	983	910
6	568	1182
Total	9623 gross run-time hours	7959 gross run-time hours

AMS Battery Storage

In general, AMS battery storage—like any storage system—is inefficient. As stated in our methodology, we model an 82% round-trip efficiency, so for every simulated discharged kWh, we have added 1.22 kWh to the total energy consumed by the facility. This inefficiency is reflected in an average 2% negative energy savings in our simulations.

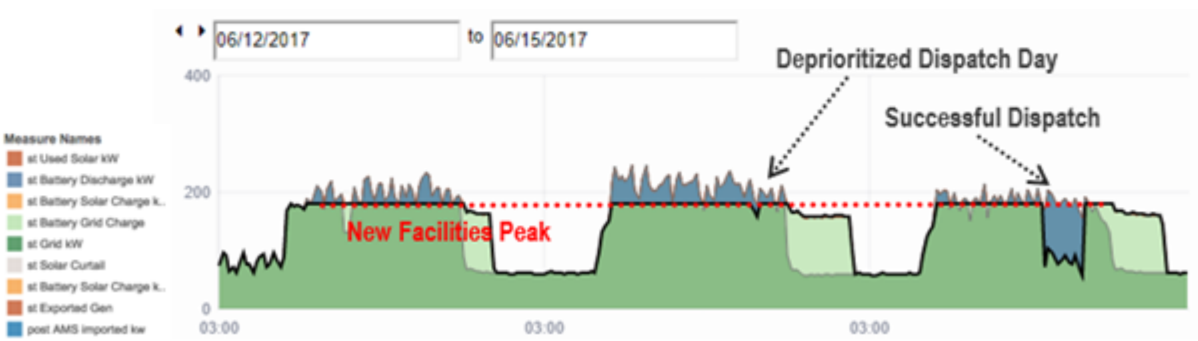
Integrating with DemandQ, however, helps to offset this well-known shortcoming. In every month simulated, DemandQ's energy savings significantly offset the increase in energy consumption modeled for the energy storage system.

Liberating Energy Storage Capacity for Grid Services

It should be noted that the simulated energy impact of AMS energy storage systems is higher than it could be because of the modeled performance in a utility dispatch product. The battery cycled considerably more than it would have otherwise, leading to greater energy costs to the customer.

However, those energy costs (~$0.05 / kWh, as modeled) pale in comparison to the simulated revenue opportunity ($350 / kW-yr, 150 dispatches allowed) the optimization engine was pursuing. Performance in our simulated utility demand response program was excellent when modeled against DemandQ's baseline *and* on actual data—delivering >97% load reduction against our theoretical obligation in all scenarios. In Burlington, where the solar output reduced available load below 100 kW, performance understandably was lower as the energy storage system was not allowed to export.

AMS Analysts Note: *AMS was surprised to see that in all 'post-DemandQ' scenarios, modeled performance in this utility demand response program dropped by 1-2 percentage points. The small reduction is due to the economic nature of the optimization and the way energy costs are billed to a customer – on certain days, a battery must devote almost all of its capacity to 'hold' customer load at a certain threshold to guarantee peak reductions.*



In the graphic above, a simulated utility dispatch falls on June 13th, and the ARMADA optimization prioritizes the demand reduction and sacrifices the utility dispatch. The DemandQ system created an opportunity for ARMADA to achieve greater savings, and ARMADA seized the opportunity.

Site Indoor Environment

Temperature Analysis

A temperature analysis can also be done to understand the impact of DemandQ on a store's temperature profile. Historical temperatures before DemandQ (April 1, 2016 - November 30, 2016) and after DemandQ (April 1, 2017 - November 30, 2017) were compared; the temperatures analyzed were between 56 F and 79 F to remove periods where mechanical failures or faulty temperature sensors were the cause for anomalous behavior. Temperatures were furthered filtered to include data between 11am - 5pm to remove any potential impact due to store opening and closing setpoint changes.

The metric used in this study to compare how well an RTU met its thermal load is to compare the difference between zone temperature (the temperature the zone is actually at) versus temperature setpoint (the temperature the zone should be at). A positive difference between zone temperature and setpoint indicates the zone is warmer than it is designed to be, and a negative difference indicates the zone is cooler than it is designed to be. The benchmark to compare differences in setpoint and temperature from before DemandQ (historical data) and after DemandQ is given as a percentile (25%, 50%, 75%, and 90%).

The results for the West Springfield store are shown in this study.

	Pre- DemandQ (4/2016 - 10/2016), °F				**Post- DemandQ (4/2017 - 10/2017),°F**			
RTU	**25%**	**50%**	**75%**	**90%**	**25%**	**50%**	**75%**	**90%**
1	0	0	0	0	-3	-1	0	0
2	0	0	0.8	1	0	0	1	2
3	0	0	0	1	0	0	0	0
4	0	0	3	3	0	0	0	1
5	-5	0	0	5	-4	0	1	1
6	-3	0	0	0	-1	0	1	2

Humidity Analysis

A store maintains humidity thresholds by means of specific RTUs with dehumidification capability. These units are configured in such a way that they can operate in two modes when their compressors are on: either in dehumidification mode (when they are removing moisture from the air), or cooling mode (when they are reducing the temperature of supply air entering a zone). The compressors specified to dehumidify also contribute to the peak demand the same way compressors specified to cool contribute to the peak demand.

In addition to temperature, relative indoor humidity is also an important factor when quantifying thermal comfort and the indoor site environment. The store indicated a target relative humidity (RH%) of 52%. With the same bounds in the temperature analysis (April - November, and 11am - 5pm), a humidity analysis was done to understand the impact of DemandQ on indoor relative humidity. The results for the West Springfield store are shown in this study. While the West Springfield store does not have specific dehumidification units, humidity levels should be analyzed to understand DemandQ's impact (if any) on a store's relative humidity. Pre and Post-DemandQ humidity level were only analyzed for the West Springfield site because the Burlington site installed new RTUs with improved dehumidification capability. The difference in Burlington's RTUs would invalidate any direct comparisons.

Month	**2016 Historical Indoor Relative Humidity Average**	**2017 DemandQ Period Relative Humidity Average**
4	25.8 %	33.7 %
5	39.5 %	41.5 %
6	50.7 %	50.0 %
7	57.6 %	50.6 %
8	58.9 %	55.6 %
9	54.1 %	53.1%
10	41.1 %	45.5%
11	29.3 %	29.7%

Fraunhofer - Independent Program Assessment

An independent data collection and impact assessment – in the form of a two-month experimental ON/OFF test – was commissioned by Eversouce and performed by Fraunhofer LLC to corroborate the results of the program. This assessment was motivated by significant mechanical and operational changes made to the Burlington site immediately after the baseline period. In May 2017, the site was re-decked with new RTUs that were equipped to provide dehumidification. Additionally, the Burlington location underwent upgrades to install LED lighting in October 2017. These changes to the site significantly impacted energy use. The experiment test procedure, as well as the measurement and verification of savings, are detailed in the Fraunhofer evaluation report in the attached appendix.

Eversource Demand Market Survey for Active Demand Management (ADM)

As the largest energy provider in New England, Eversource serves over 1.3 million customers in Massachusetts, 200,000 of which are commercial and industrial (C&I). From the C&I customers, only those segments whose energy consumption is predominantly comfort cooling and heating would see the greatest benefit from the DemandQ and AMS partnership. To that end Eversource identified Retail, Hotels, Government Agency, and Real-Estate Management as sectors where the Active Demand Management (ADM) package would be applicable. The Retail sector was chosen as it is the original target sector of this grant, and includes customers who are big box retailers, and whom explicitly cool and heat for comfort. Hotels often utilize packaged AC units for comfort and tend to have standardized equipment within a building and across multiple buildings (i.e. hotel chains). Government Agency was also chosen as a target sector because much like retail, they cool and heat for comfort and in most cases, are only open weekdays during peaking hours. Finally, Real-Estate Management was chosen in much the same vein that Government Agency was, it cools and heats for comfort, typically through rooftop units, and is open during peaking hours.

The tables below summarize the number of customers in the targeted sectors and bins them by their peak kW usage.

ADM Performance Report

Retail	
kW of Demand	# of Accounts
50	163
60	104
70	83
80	40
90	33
100	87
200	26
300	8
400	6
700	1
Retail Sub Total	551

Government Agency	
kW of Demand	# of Accounts
50	56
60	38
70	33
80	25
90	14
100	54
200	16
300	6
400	1
500	1
600	1
700	1
800	2
GA Sub Total	248

RE Management	
kW of Demand	# of Accounts
50	153
60	110
70	87
80	74
90	46
100	117
200	44
300	8
400	5
600	3
800	5
RE Sub Total	652

Hotels	
kW of Demand	# of Accounts
50	13
60	13
70	7
80	8
90	6
100	22
200	14
300	2
Hotels Sub Total	85

Grand Total	1536

The table breaks the sectors down by average monthly customer demand, whereby a customer who falls into the 200 kW bucket may have a demand as low as 150 kW or as high as 249 kW (the 100 kW bucket is from 90-149 kW). This stratification of customers allows for a better market understanding, as the ADM package could be scaled with the customer size, allowing for larger or smaller batteries depending on customer demand and load variability over the course of the day. At 1,536 customers, there is a significant potential market expansion, albeit many of these customers do not have solar installations but could otherwise still benefit from peak load mitigation.

An ideal customer who should implement the ADM package at their site is one whom has an Energy Management System (EMS) at their facility (which many of the retail, hotels, government agencies, and real-estate management firms have). This EMS should be controlling the heating and cooling functions of multiple RTUs with a total of 20-tons capacity. Each RTU should be at least 5-tons.

A 5-ton minimum RTU size and 20-ton minimum site size is required at least preliminarily to ensure the site has an EMS, and to ensure there is enough site demand to generate a profit stream for both customer and vendor. A secondary factor for a 20-ton minimum is that many customers under that cooling capacity typically do not have EMS onsite, instead relying on localized zone thermostats. Buildings that have an EMS on-site is preferable because the DemandQ software component of the ADM package can ride on the existing network. Buildings without EMS require installation of additional hardware. The associated costs may require external incentives to support. The battery component of the ADM package is suitable for sites with peak demand 100 kW and higher.

Site Peak Demand	**Cooling Capacity (approx.)**	**ADM Solution**
< 50 kW	< 20 tons	DemandQ software ADM only; EMS retrofit required

50 kW to 100 kW	20 tons to 50 tons	DemandQ software ADM only
> 100 kW	> 50 tons	Full ADM package (software + battery)

Finding new market participants would be a four-pronged approach. The first would be for DemandQ and AMS to operate "business as normal", searching out new customers within the Eversource service territories and soliciting them for business. A second prong would be a targeted direct mail campaign, based on the utility customer information. Through this process a discrete list of customers can be developed and have ADM program specific mailers sent to them through both electronic and physical mail. The third prong is to leverage Eversource's Energy Efficiency Account Executives knowledge of their customers to introduce the ADM package. This introduction can open many doors, as we are the trusted energy advisor to over 1,500 customers. The final prong is to leverage Eversource's National Accounts team to make introductions to qualified customers. Through this process, the sales are being made at an actionable level, not having to be pushed up through the organization for approvals.

Beyond the standard four-pronged approach there are a couple of other potential market pathways that the ADM package could generate a benefit. The first being through a comprehensive energy management retrofit package. This pathway is typically customized to each customer whom participates in it and would encompass large scale capital improvements like lighting upgrades, control systems, and mechanical systems. Combined with an ADM package the cost effectiveness of the overall package could be leveraged to bring greater incentives and drive greater deployment across the service territories. Another potential avenue to attract customers to install the ADM package at their facilities is to incorporate it as part of an early retirement of HVAC equipment initiative. This process would entail the customer updating their aging HVAC infrastructure to a qualifying Mass Save Tier 2 or 3 qualifying unit. In doing so, the customer would then not have concerns about the units failing and it would allow the DemandQ controls and AMS battery to be installed into a highly efficient system expediting the return on investment for the customer.

Eversource would propose that the customers be approached utilizing the retrofit energy efficiency program, as no major mechanical systems are being replaced due to end of useful life. In the retrofit program the project would likely be classified as a "Custom Application" and would incentivize based on the kWh and kW it is able to offset at the customers site. The incentive would be paid as per the program rules typically on a $/kWh and $/kW basis to offset up to 50% of the project implementation costs. As some customers do not have EMS at their facilities, this could be an opportunity for Eversource to capture two projects with one customer by having an EMS implemented along with the ADM (this avenue would still be considered a retrofit project). The additional kWh and kW savings from ADM could help justify an EMS retrofit for smaller buildings (e.g. smaller than 50 kW peak demand) that might not otherwise pursue the project.

Limitations of the market study: The data that Eversource utilized for the analysis was taken from consumption readings in 2017. As this data was extracted from a newly implemented system, demand readings were not necessarily available for all customers. Considering this, the numbers used represent a potential market in the Eversource service area, but do not show the complete picture.

Conclusions

DemandQ, AMS, and Eversource partnered to demonstrate a combination of innovative software controls and advanced energy storage to permanently reduce peak load and provide a seasonal, dispatchable peak demand management resource for “big box” retail stores. The findings substantiated that Active Demand Management (ADM) delivers substantial energy savings and peak demand reduction.

In conjunction with this project, Eversource conducted a market study to determine which market segments could realize the greatest benefit from the DemandQ and AMS partnership. Eversource identified Retail, Hotels, Government Agency, and Real-Estate Management as sectors where the Active Demand Management (ADM) package would be applicable. An ideal customer who should implement the ADM package at their site is one whom has an Energy Management System (EMS) at their facility.

Overall, this project validated the substantial financial benefits and new operational insights that are achieved through the integration of Demand Management Software and Energy Storage. While both AMS and DemandQ technologies excel at reducing peak demand, the combination of energy storage and demand management software achieves additive benefits that are greater than either system can deliver individually to both customers and Utilities.

Evaluating eCurv: A Coordinated Air Conditioning Controller for Reducing Energy Consumption and Peak Demand

Final Report to Eversource
January 2019

Prepared by
Bryan Urban and Kurt Roth
Fraunhofer USA Center for Sustainable Energy Systems

Kurt Roth, Ph.D. Director of Building Energy Systems
kroth@cse.fraunhofer.org +1 (617) 575-7256

Bryan Urban, Senior Technical Staff
burban@cse.fraunhofer.org +1 (617) 714-6514

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Table of Contents

List of Figures

List of Tables

ABBREVIATIONS

AIC	Akaike Information Criteria
BIC	Bayesian Information Criteria
BMS	Building Management System
CDD	Cooling Degree Day
CVRMSE	Coefficient of Variation of Root Mean Square Error
FA	Facility Average
IQR	Interquartile Range
MAD	Median Absolute Deviation
MAE	Mean Absolute Error
R^2_{adj}	Adjusted R^2 Coefficient
RMSE	Root Mean Square Error
RTU	Rooftop Unit Air Conditioner

EXECUTIVE SUMMARY

Packaged rooftop air conditioners (RTUs), a major component of retail facility peak electric demand, typically run independently to satisfy their respective target zone temperature setpoints. When unmanaged, multiple RTUs may run concurrently by chance, leading to increased monthly facility peaks and higher demand charges.

Intelligent software-based controls, responding to real-time feedback on facility power draw and zone temperature, could coordinate RTU runtimes to save energy and reduce peak facility loads. This report evaluates the eCurv RTU software control service using data from an on/off pilot test (August to October 2018) conducted in Massachusetts at two big-box retail facilities.

Using time-series facility and RTU electricity data, zone temperatures, and local weather, Fraunhofer modeled the energy savings and peak reductions associated with the eCurv software. Linear regressions were derived for the total daily RTU energy consumption and peak facility load based on cooling degree days and eCurv status. These models were then applied to typical Boston cooling season weather data to estimate the expected annual savings. Demand reductions were modeled using a Monte Carlo approach to account for natural load variability.

Results

Reductions in electricity consumption and peak demand were observed at both facilities (Table ES-1 and ES-2). Results for Site A were of limited value due to a major confounding HVAC controls fault that took place during the baseline periods, leading to an unbalanced test. Results for Site B were more reliable and were consequently used to project annual savings impacts.

Energy savings of about 6 percent of total RTU electricity consumption (or 2 percent of facility consumption) were observed at Site B. This equals about 5.2 kWh per cooling degree day (CDD_{55}, base 55°F) or 60 kWh per day during the test. Applied to typical Boston weather for the May to October cooling season, the linear regression models predicted RTU energy savings of about 10,400 kWh.

Peak load reduction estimates were about 18 kW (SD 5.7) and 15 kW (SD 5.4) for the two test months at Site B. This represents about 8 percent of total facility load or 10-15 percent of the highest observed RTU load. Applied to typical Boston weather for the May to October cooling season, these models predict monthly facility load reduction potentials of 13-20 kW.

The baseline controls faults encountered at both sites caused some RTUs to run more than expected, increasing energy use and potentially peak load. At Site A, several RTUs ran continuously overnight. At Site B, two RTUs cooled their zones significantly below their programmed setpoints. At both sites, these faults were corrected while eCurv was enabled. To the extent that other buildings have similar faults that would otherwise go unaddressed, eCurv may provide additional energy savings benefits.

Conclusions

Results from this test indicate that the coordinated control of packaged rooftop units could plausibly and significantly reduce both energy consumption and peak demand without detrimentally affecting zone temperatures. Secondary energy savings came from controls fault correction. Issues related to overcooling and incorrect scheduling were seemingly corrected or overridden by the eCurv software.

In practice, actual savings and impacts depend on site-specific characteristics. Demand reductions are highly sensitive to outlier load spike events. Unpredictable spikes in demand could undo a significant portion of the potential demand savings. Longer-term study of historic data from a larger number of sites would provide more reliable savings estimates and a better understanding of the frequency and impact of isolated load spikes.

Table ES-1. Summary of eCurv test results.

SITE DETAILS	SITE A Burlington, MA		SITE B W. Springfield, MA		NOTES
Floor Area (ft^2)	86,000		113,000		
Cooling Cap. (tons)	200		195		
No. RTUs	7		6		
Avg. EER	11		11		
Year Installed	2017		2017		
TEST CONDITIONS	**Baseline**	**eCurv**	**Baseline**	**eCurv**	
No. Days	48	15	36	27	
Outdoor (°F), Avg.	65	72	66	69	
CDD_{55} (°F), Avg.	10.6	15.8	10.9	12.8	
Facility Energy (MWh/d)	2.5	2.3	2.7	2.7	
RTU Energy (MWh/d)	1.1	0.9	1.0	1.0	
Peak Facility Power (kW)	222	191	215	193	On-peak 8AM-9PM
Peak RTU Power (kW)	145	114	130	104	On-peak 8AM-9PM
REGRESSIONS					Shown for SITE B ONLY. See notes below.
DAILY RTU ENERGY (kWh)					
Intercept (kWh)	-		564.4 (±34.6)		
+ CDD_{55} (kW/°F)	-		40.8 (±2.8)		
+ CDD_{55} · eCurv	-		-5.2 (±2.7)		eCurv (ON=1, OFF=0)
Model CVRMSE	-		6.2%		
DAILY PEAK FACILITY DEMAND (kW)					
Intercept (kW)	-		170.6 (±5.2)		
+ eCurv ON	-		-41.5 (±9.7)		eCurv (ON=1, OFF=0)
+ CDD_{55} (kW/°F)	-		1.3 (±0.3)		
+ CDD_{55} · eCurv ON	-		0.8 (±0.6)		eCurv (ON=1, OFF=0)
Model CVRMSE	-		14.2%		
NOTES	Unreliable Site A results due to baseline HVAC controls issues and unbalanced test periods.		No major Site B issues. Two RTUs overcooled during part of the baseline. This was accounted for in the analysis.		

Table ES-2. Summary of modeled annual eCurv savings.

		RTU Energy (MWh)					Facility Peak Demand ±SD (kW)			
Month	**CDD_{55} (°F)**	**Base**	**eCurv**	**Savings (e – B)**	**%**		**Base**	**eCurv**	**Savings (e – B)**	**%**
May	171	24	23	-0.9	-4%		197 ±4	183 ±4	-14 ±6	-7%
Jun	340	30	28	-1.8	-6%		213 ±5	195 ±4	-18 ±6	-8%
Jul	591	41	38	-3.1	-8%		226 ±5	205 ±4	-20 ±6	-9%
Aug	497	37	35	-2.6	-7%		213 ±4	195 ±4	-18 ±5	-8%
Sept.	294	28	27	-1.5	-5%		201 ±4	186 ±4	-15 ±6	-8%
Oct.	97	21	20	-0.5	-2%		196 ±6	182 ±4	-13 ±7	-7%
TOTAL	**1991**	**182**	**171**	**-10.4**	**-6%**	**AVG**	**207**	**194**	**-16**	**-8%**

Based on regression models for Site B applied to typical Boston, MA cooling season weather data.

1 INTRODUCTION

Packaged rooftop unit (RTU) air conditioners can strongly influence commercial facility energy use and peak electric demand. To reduce related costs, eCurv has developed an automated service for coordinating the runtime of multiple RTUs to lower the total facility electricity consumption (kWh) and demand (kW). To evaluate these potential impacts, we analyzed performance data collected during a two-month pilot (August to October 2018). The pilot was conducted at two big-box retail department stores (Site A: 86,000 and Site B: 113,000 ft^2) in Massachusetts using an on/off testing methodology.[1]

1.1 Opportunity

The compressors on RTUs are normally configured to run automatically when their respective zones call for cooling.[2] By chance, the compressors on many RTUs can occasionally run simultaneously, leading to higher facility demand charges. Intelligently managing RTUs, especially in response to real-time facility-level power draw, to reduce concurrent compressor runtime could significantly reduce total facility demand.

The RTUs at a single facility may also operate with different efficiency characteristics. This could happen for many reasons, including differences in hardware, neglected maintenance, mechanical faults, or other issues. When multiple RTUs serve a common zone, preferentially running the more efficient units could theoretically reduce the total cooling energy consumption.

1.2 Technology Description

To address these opportunities, eCurv has developed software service that automatically manages RTU compressors facility-wide (Figure 1). Using data from the Building Automation System (BAS), the platform models RTU performance and monitors facility loads to decide when to run the RTUs. Control algorithms are designed to maintain the existing zone setpoints while reducing both energy consumption and facility demand.

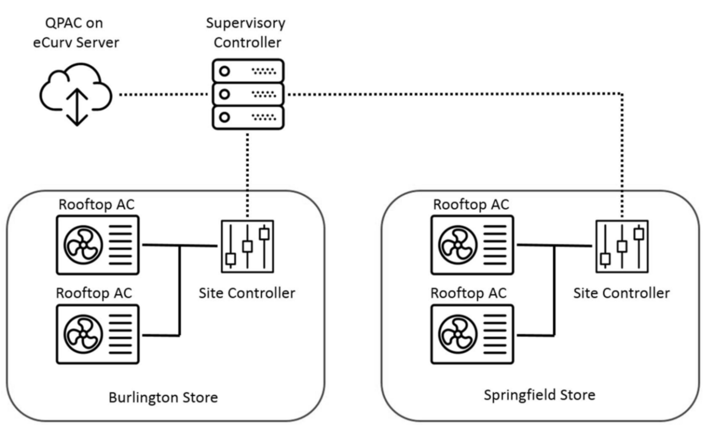
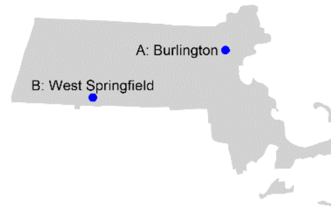


Figure 1. eCurv system diagram.

[1] A similar eCurv pilot, completed in 2017 (eCurv 2017), was found to be inconclusive (Fraunhofer 2018). This was primarily due to confounding differences between the baseline and eCurv periods (major HVAC equipment replacement, lighting upgrades, and schedule and control changes) and a lack of supporting data (RTU power draw, fan status, zone temperatures). This evaluation was pursued to overcome these limitations.
[2] For multi-stage RTUs, additional compressor stages come online as loads increase.

1.3 Site Description

Testing took place at two big-box retail stores in Massachusetts: Burlington (Site A)[3] and West Springfield (Site B). Each facility had three main zones – a large open-plan retail zone, a stockroom, and a smaller standalone office – cooled by six or seven standalone RTUs.[4] Cooling capacities ranged from 7.5-40 tons, with two or four compressor stages (Table 1, Figure 2).



The highest nominal RTU cooling electric load, $P_{max,nom}$ (kW), was estimated based on the nameplate RTU capacity and efficiency rating.[5] Summing over all RTUs yields a theoretical maximum facility cooling load of about 221-228 kW. During the test, however, the sum of maximum observed RTU loads, $P_{max,obs}$, was much lower, as the RTUs were sized to handle more extreme design loads. Nevertheless, the aggregate controllable load could exceed 100 kW per site, a portion of which could be shifted to reduce peak loads.

Table 1. Cooling equipment summary.

SITE	RTU	ZONE	MAKE	MODEL	YEAR	CAP (tons)	EER	STA-GES	Power (kW) F_{obs}	$P_{max,obs}$	$P_{max,nom}$
A	1	Sales or Stock	York	Z4	2017	40	10.7	4	0.4	17	45
	2	Office	York	ZR240	2017	20	12.1	2	0.4	21	20
	3	Sales or Stock	York	Z4	2017	40	10.7	4	0.3	27	45
	4	Sales or Stock	York	ZJ120	2017	10	12.0	2	0.4	10	10
	5	Sales or Stock	York	Z4	2017	40	10.7	4	0.4	29	45
	6	Sales or Stock	York	Z4	2017	40	10.7	4	0.3	17	45
	7	Office	York	ZJ090	2017	7.5	12.0	2	0.3	8	12
						200			**2.5**	**129**	**221**
B	1	Sales or Stock	York	Z4	2017	40	10.7	4	0.3	21	21
	2	Sales or Stock	York	Z4	2017	40	10.7	4	0.4	24	48
	3	Sales or Stock	York	Z4	2017	40	10.7	4	0.4	23	48
	4	Sales or Stock	York	Z4	2017	40	10.7	4	0.4	40	48
	5	Office	York	ZJ180	2017	15	12.2	4	0.3	43	48
	6	Sales or Stock	York	ZJ240	2017	20	11.0	2	0.3	15	15
						195			**2.2**	**165**	**228**

$P_{max.nom}$ = Maximum nominal RTU load = Nameplate capacity (tons) × 12 kBtu/ton ÷ EER (kW/kBtu).
$P_{max.obs}$ = Maximum observed RTU load F_{obs} = Observed fan power, typical

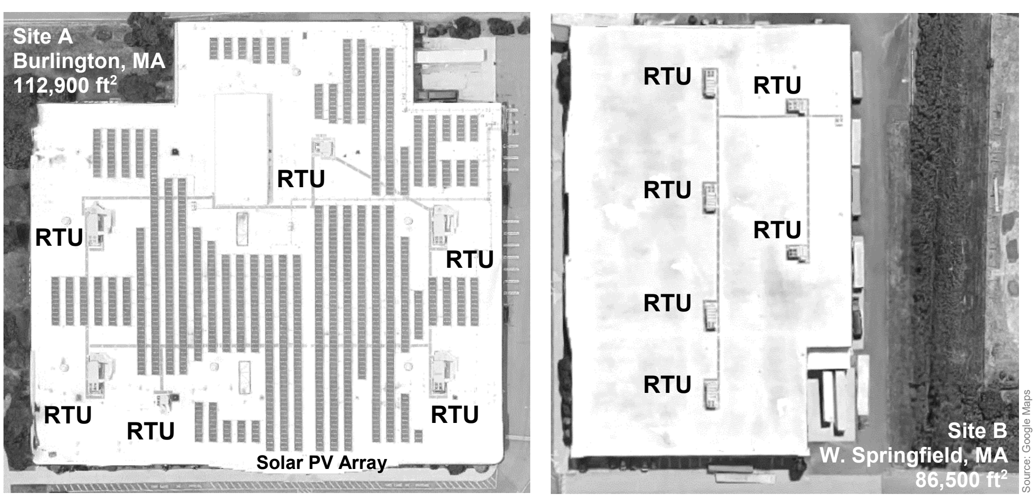


Figure 2. Big-box retail test sites and RTU locations.

[3] Although Site A had a large rooftop solar photovoltaic array, its generation was metered separately and did not influence facility meter or peak demand. Solar generation, therefore, was not considered in this analysis.
[4] Normalized cooling capacity was typical for MA: 600 ft²/ton (Site A) and 440 ft²/ton (Site B).
[5] Estimated as the nameplate capacity (tons) × 12 (kBtu per ton) and dividing by the EER (kW/kBtu).

2 TEST PLAN

2.1 Overview

An alternating on/off testing methodology was applied to measure eCurv impacts on energy and peak loads. For nine weeks (Aug. 13 to Oct. 14, 2018),[6] the eCurv controls were alternately enabled and disabled on a weekly schedule (Table 2). Switching took place late at night, normally on Sundays, while the building was unoccupied and cooling loads were lower. The on/off approach was chosen to reduce bias from changes in HVAC equipment performance or other site-specific changes.

The sites were initially kept on opposing test schedules to reduce bias related to weather and occupancy. After the first two weeks of testing, however, Fraunhofer detected a fault at Site A that caused several RTUs and fans to run continuously overnight while eCurv was disabled. For the remainder of the test, the facility managers decided to disable eCurv, greatly reducing the available data from Site A.

Table 2. Testing schedule: eCurv status by site and day.

	SITE A	B		A	B		A	B		A	B		A	B
Aug. 13	OFF	ON	27	ON	OFF	10	ON	OFF	24	OFF	OFF	8	OFF	OFF
14	OFF	ON	28	ON	OFF	11	OFF	ON	25	OFF	OFF	9	OFF	OFF
15	OFF	ON	29	ON	OFF	12	OFF	ON	26	OFF	OFF	10	OFF	OFF
16	OFF	ON	30	ON	OFF	13	OFF	ON	27	OFF	OFF	11	OFF	OFF
17	OFF	ON	31	ON	OFF	14	OFF	ON	28	OFF	OFF	12	OFF	OFF
18	OFF	ON	Sept. 1	ON	OFF	15	OFF	ON	29	OFF	OFF	13	OFF	OFF
19	OFF	ON	2	ON	OFF	16	OFF	ON	30	OFF	OFF	14	OFF	OFF
20	ON	OFF	3	OFF	ON	17	OFF	OFF	Oct. 1	OFF	ON			
21	ON	OFF	4	OFF	ON	18	OFF	OFF	2	OFF	ON			
22	ON	OFF	5	OFF	ON	19	OFF	OFF	3	OFF	ON			
23	ON	OFF	6	OFF	ON	20	OFF	OFF	4	OFF	ON			
24	ON	OFF	7	OFF	ON	21	OFF	OFF	5	OFF	ON			
25	ON	OFF	8	OFF	ON	22	OFF	OFF	6	OFF	ON			
26	ON	OFF	9	OFF	ON	23	OFF	OFF	7	OFF	ON			

No. Days	A	B
ON	15	27
OFF	48	36
TOTAL	**63**	**63**

SITE A: Burlington, MA
SITE B: W. Springfield, MA

Roles and responsibilities were as follows:

1. Fraunhofer designed the test plan and performed the evaluation
2. eCurv recruited the customer test sites and collected and submitted BMS data
3. Eversource reviewed and approved the test plan and hired a contractor to submeter the RTUs

In addition, eCurv was responsible for reporting any significant changes to the test sites, including any newly adopted energy conservation measures, changes to equipment, changes to schedules or setpoints, and RTU maintenance that could affect results.

[6] Fraunhofer recommended that testing span the entire summer to improve the likelihood of finding statistically significant results. Due to constraints related to the project start date and customer participation, testing was limited to two months. All parties acknowledged that this abbreviated test period would increase the potential for the kW and kWh analyses to have findings of limited or no statistical significance.

2.2 Variables

Primary dependent variables include:

1. HVAC electricity consumption: kWh reduction
2. Whole-facility monthly peak demand: kW peak reduction

Secondary dependent variables that were supposed to remain unchanged include:

1. Zone temperature: maintain setpoint schedules
2. Ventilation: maintain ventilation levels

The independent variables include:

1. eCurv status: on/off
2. Local weather: temperature, cooling degree days, relative humidity
3. Time of Day: peak/off-peak

2.3 Data Sources

Multiple data sources were used to evaluate system performance (Table 3). Facility and RTU data (electricity, temperature, humidity, compressor status, and occupancy) came from the building management system (BMS). RTU electricity submetering was installed by a third-party contractor.[7]

Table 3. Data field summary.

LOCATION	DATA	UNITS	RES.	FREQUENCY	SOURCE
Facility	Electricity	kW	0.01	15 min.	BMS
RTU	Electricity	kW	0.10	1 min.	Submeter
RTU	Zone Air Temperature	°F	0.10	change of value	BMS
RTU	Supply Air Temperature	°F	0.10	change of value	BMS
RTU	Zone Setpoint	°F	0.10	change of value	BMS
RTU	Compressor Stage Status	on/off	-	change of value	BMS
Facility	Relative Humidity	%	1.00	change of value	BMS
Facility	Occupancy	on/off	-	change of value	BMS
Weather	Outdoor Temperature	°F	0.01	60 min.	Third party
Weather	Outdoor Relative Humidity	%	1.00	60 min.	Third party

[7] Submeters included meters (AccuRev 2020 and Acuuvim II), with current transformers sized at 20, 30, or 60A (models SCT-075H, AcuCT-H040).

2.4 HVAC Service

Several HVAC service issues, summarized in Table 4, were encountered during the test. Most items were minor, though some issues affected exhaust fan operation, which could significantly affect ventilation loads and impact HVAC system performance. Unintended differences in cooling schedules and setpoints were observed and are discussed throughout this report.

Table 4. HVAC equipment service summary.

Site A: Burlington, MA

Date Called	Date Resolved	Equip.	Issue	Service Notes	Energy/ Demand Impact
-	Aug. 5	All	Preventative maintenance	Replace all air filters Visual inspection Clean condensate traps Check gas heat exchangers or electric heat operation	Low
Aug. 7	Aug. 9	RTU 3 RTU 5 RTU 7	(RTU 7) Bad zone pressure sensor, discharge fan running 24/7 (RTU 3,5,7) Exhaust fans do not run when commanded	No pressure sensor on RTU 7, reset unit; checked all units	High
Sept. 10	Sept. 11	RTU 1 RTU 2 RTU 6	RTUs not dehumidifying, only first stage was running	Changed RTU settings to allow higher stages to come on for dehumidification Observed dirty condenser coils (not cleaned)	Med
-	Oct. 6	All	Preventative maintenance	See above.	Low
Oct. 10	Oct. 10	All	Store is extremely hot/humid, customers are complaining	RTUs (1,2,6) were in dehumidification mode, cooling will resume once air is dried out No action needed	Low
Oct. 31	-	Misc.	Two failed exhaust motors, vibrating, failing bathroom exhaust motor	No repair yet	Low

Site B: West Springfield, MA

Date Called	Date Resolved	Equip.	Issue	Service Notes	Energy Impact
-	Aug. 1	All	Preventative maintenance	Replace all air filters Visual inspection Clean condensate traps Check gas heat exchangers or electric heat	Low
Aug. 21	Aug. 21	RTU 5	Blower bearings failed, damaged shaft	Replaced bearings and shaft	Low
-	Oct. 6	All	Preventative maintenance	See above	Low
Oct. 23	Oct. 30	RTU 1	Rainwater leaking into blower/roof	Repaired burner gasket, added weatherstripping	None
Oct. 26	-	Misc.	Failed exhaust fan in cash office Failed unit heater in sprinkler room Discharge louvers in front entrance very dirty	No repair yet	Low

2.5 Peak Hours and Time of Use Rates

Peak rate structures for demand charges vary regionally by utility and customer category. While it was beyond the project scope to evaluate energy and demand cost impacts, the current on-peak electric delivery rate structures and peak times were used to inform the analytical procedure. For the regions in this study, the peak hours were defined per Eversource (2018) as:

> **Eastern MA (Site A: Burlington)**
> On-peak hours from 9 A.M. to 6 P.M. weekdays (June to September) and 8 A.M. to 9 P.M. weekdays (October to May). All other hours and MA holidays off-peak.
>
> **Western MA (Site B: W. Springfield)**
> On-peak hours from noon to 8 P.M. weekdays, with all other hours off-peak.

Demand is calculated based on average power consumption calculated over specific time intervals. These, too, differed by region:

> **Eastern MA (Site A: Burlington)**
> "The billing demand will be the maximum fifteen-minute demand (either kilowatts or 90 percent of the kilovolt-amperes) as determined by meter during the monthly billing period, except any demand recorded during off-peak hours will be reduced by 55 percent."
>
> **Western MA (Site B: W. Springfield)**
> "The Demand shall be determined by meter, monthly, and shall be the highest 30-minute kilowatt registration during the month in the On-Peak hours determined to the nearest one-half kW."

In this analysis, we assumed a fixed fifteen-minute demand window and considered on-peak hours to be 8 A.M. to 9 P.M. We did not treat weekdays, weekends, and holidays differently since the stores were open on all days. When enabled, the eCurv controls were also active on all days.

2.6 Analytical Methods

Data analysis involved an initial data review to ensure quality and to understand pre-existing operational patterns and control strategies, and second a statistical analysis to model energy savings and demand reductions. All change-of-state data were converted to one-minute interval data for further processing and analysis.

The analyses compared and evaluated the statistical significance of eCurv terms using daily regressions for HVAC Electricity Consumption, E_{HVAC} (kWh), Peak HVAC Demand, P_{HVAC} (kW), and Peak Facility Demand $P_{FACILITY}$ (kW):

$$E_{HVAC} = A + B \cdot CDD_{55} + C \cdot CDD_{55F} \cdot eCurv \tag{1}$$

$$P_{FACILITY} = D + E \cdot CDD_{55} + F \cdot CDD_{55F} \cdot eCurv \tag{2}$$

where *eCurv* is 1 when enabled and 0 when disabled, and CDD_{55} represents the cooling degree days with a 55°F base temperature.

To account for deviations in facility temperature across testing periods, we also performed regressions using adjusted cooling degree days CDD_{adj}. These were calculated by shifting CDD_{55} by an amount equal to the deviation in daily average facility temperature from a base temperature of 72°F.

Though operating hours varied from about twelve to fifteen hours per day, occupancy was not considered as a factor in the model due to the risk of overfitting the relatively limited dataset.

Subsequently, the models were applied to observed weather data and to typical Boston, MA weather data to predict cooling season performance. To estimate peak demand reductions, Monte Carlo simulations were used to account for the stochastic variability in daily peak loads.

2.7 Claims and Assumptions

Several claims were evaluated in this analysis:

1. Packaged RTUs represent a significant fraction of the total facility electric load
2. RTU loads can be shifted in time and/or across units to reduce facility peak demand
3. RTU loads can be shifted to better-performing units to reduce cooling energy use
4. These shifts can be made without compromising zone temperature or humidity
5. These shifts can occur without significantly changing outdoor air ventilation rates

The analysis hinges on several assumptions. When these are violated, additional uncertainty is introduced that weakens any potential conclusions.

1. Test periods must experience a similar range of operating and weather conditions
2. Building characteristics and occupancy patterns are not substantially changed during the test
3. HVAC equipment is not substantially changed or reprogrammed during the test
4. Zone temperatures must remain consistent across testing periods
5. Zone temperature setpoint schedules must be consistent across testing periods
6. Ventilation fans must operate similarly across testing periods

In this study, assumptions (1), (2), and (6) generally held, while (3-5) were violated to some extent.

At both sites, the average daily zone temperatures for selected zones was slightly higher (by up to several degrees) when eCurv was enabled. At Site A, three RTUs initially ran overnight in the baseline and their higher stages were disabled. Night runtime stopped when eCurv was enabled. Halfway through the test, both faults were corrected; however, eCurv was disabled for the remainder of the test. This led to an unbalanced test at Site A with inconsistent results.

At Site B, RTUs 1 and 4 controlled their zones below their apparent setpoint in the baseline but not with eCurv. The consequences of these temperature variations differed, as did our treatment of the effects. Details are provided in the accompanying sections.

3 OPERATING DATA

3.1 Facility Power Draw

Facility power draw typically peaked around 180-200 kW, varying throughout the day according to a typical retail store occupancy profile: lowest at night, ramping up in the morning, and fairly stable during the daytime (Figure 3, shaded region indicates on-peak hours).

Daily peak loads, dependent on cooling degree days (Figure 4), were somewhat lower when eCurv was active. Detailed daily power profiles show how total facility loads and RTU component loads vary with time of day, weather, and eCurv status (Figure 5).

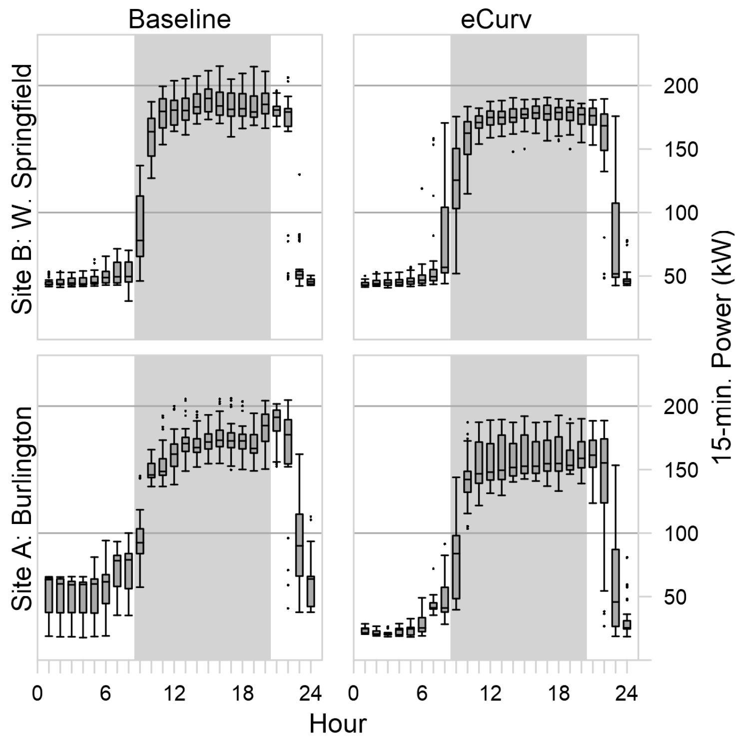


Figure 3. Daily facility load profiles. Days with CDD_{55}>15.
Marker = median. Box = IQR. Whisker = nearest point within 1.5 IQR from box.

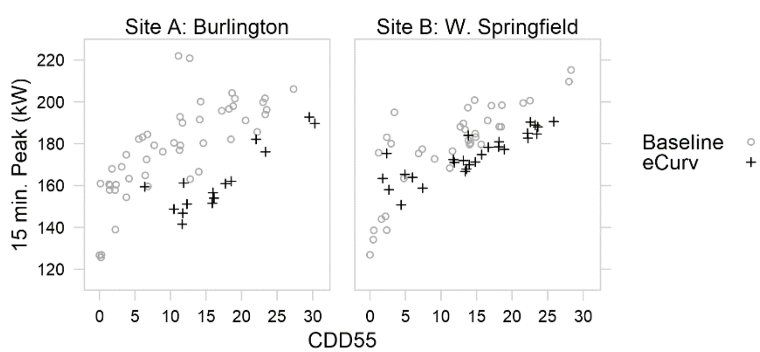
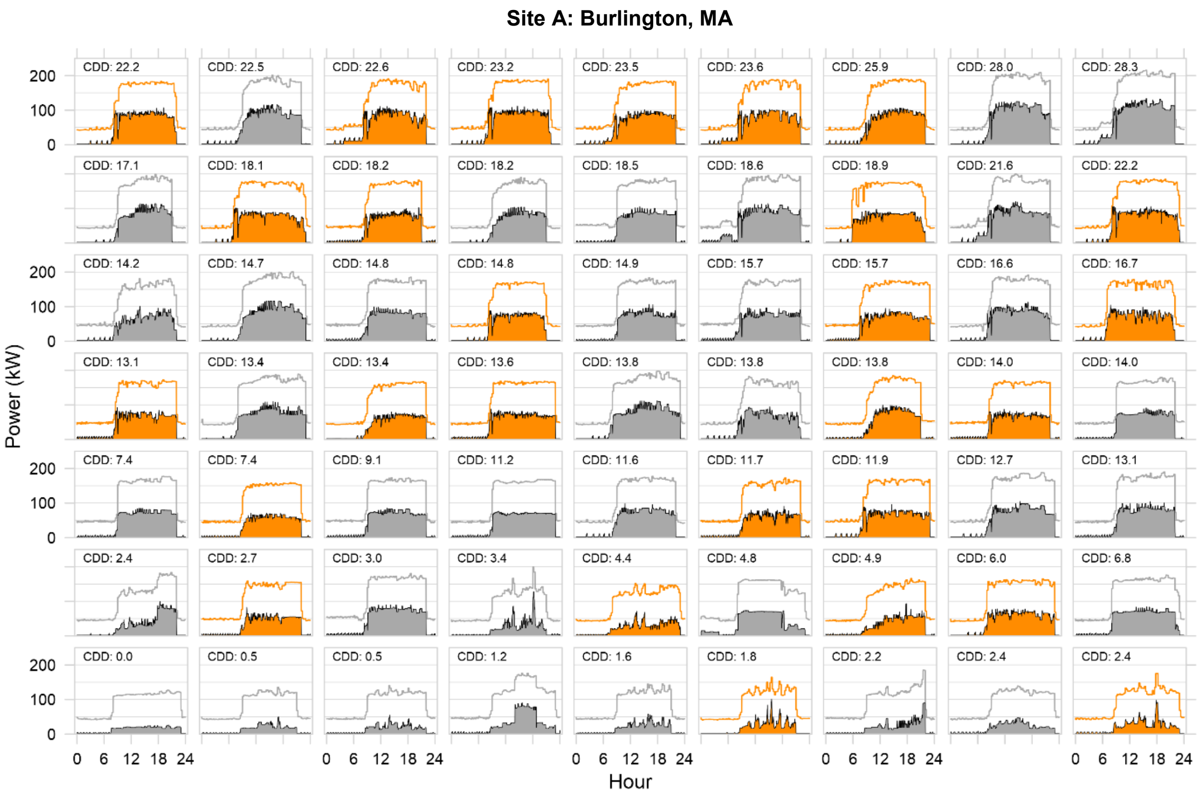


Figure 4. Daily facility peak loads during on-peak hours (8 A.M. to 9 P.M) by eCurv status.



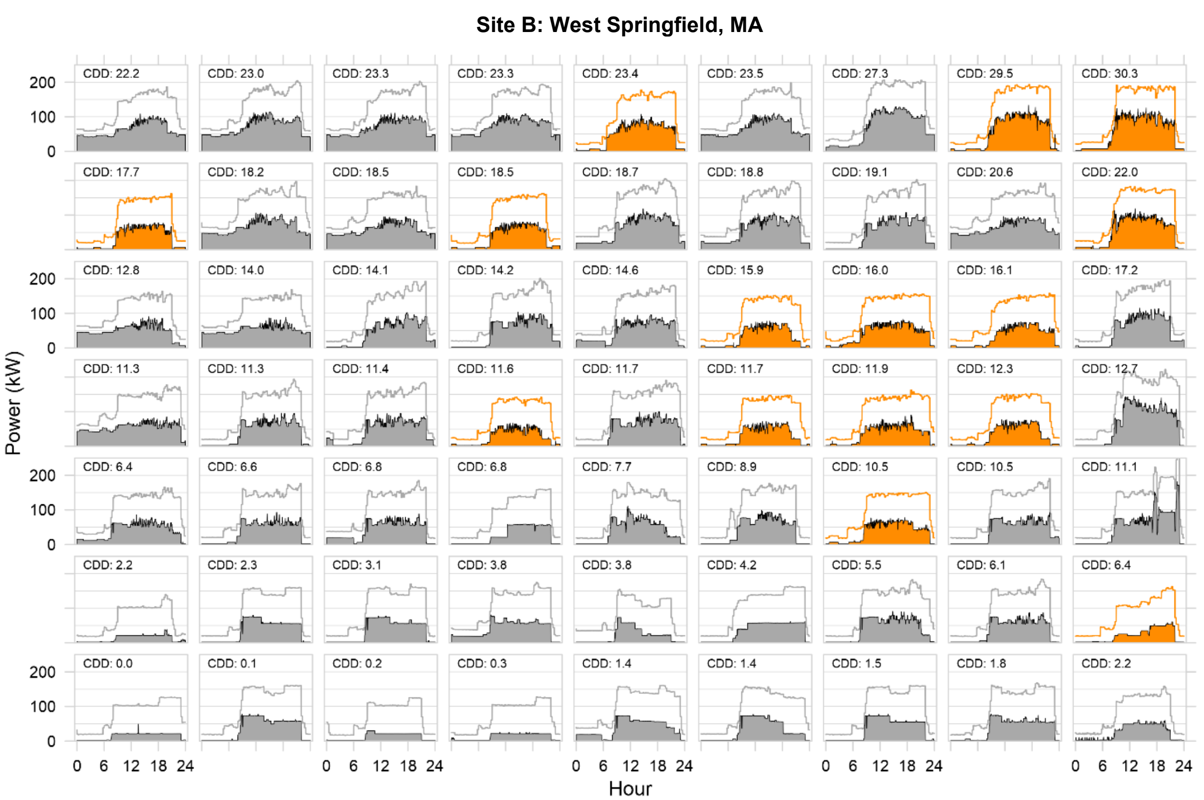


Figure 5. Daily power profiles sorted by cooling degree days (CDD_{55}).
Line = Total Facility Power. Filled Area = RTU Component.
Orange = eCurv. Gray = Baseline.

3.2 Non-RTU Power Draw

Non-RTU loads – driven by lighting, computers, plug loads, and other equipment – were rather stable, especially during on-peak hours, following regular operating schedules (Table 5, Figure 6). Daytime non-RTU loads of about 80-90 kW increased in the early evening to about 100 kW, likely due to outdoor lighting. These loads were consistent across testing periods and varied slightly with outdoor temperature at Site B. Since the non-RTU peak generally occurred in the evening towards the end of the on-peak window, this period could have significant bearing on results (Figure 6).

Table 5. Non-RTU load profiles, based on 15-min. average power.

	kW, Avg. (SD)				
Hour	**Site A**	**Site B**	**Hour**	**Site A**	**Site B**
0	18.4 (3.5)	42.0 (2.2)	**12**	80.9 (1.4)	90.7 (2.6)
1	17.9 (2.1)	42.1 (2.0)	**13**	81.0 (1.6)	90.5 (2.6)
2	17.8 (2.1)	42.0 (2.1)	**14**	80.8 (1.5)	90.1 (2.7)
3	17.8 (2.1)	41.7 (2.0)	**15**	80.6 (1.5)	90.1 (2.8)
4	18.5 (4.3)	42.0 (1.9)	**16**	80.3 (1.4)	90.1 (2.6)
5	25.8 (10.8)	42.5 (3.0)	**17**	79.9 (1.4)	90.1 (2.5)
6	38.5 (6.4)	43.5 (5.5)	**18**	85.5 (9.6)	91.6 (4.6)
7	35.3 (6.7)	43.1 (8.0)	**19**	98.5 (8.3)	96.3 (4.6)
8	40.8 (16.2)	48.8 (18.8)	**20**	102.9 (1.4)	98.1 (2.3)
9	81.1 (2.0)	90.9 (2.7)	**21**	94.9 (20.4)	91.8 (15.9)
10	81.3 (1.7)	91.1 (2.5)	**22**	57.5 (33.7)	65.6 (23.4)
11	81.2 (1.6)	91.0 (2.5)	**23**	26.5 (16.6)	45.8 (7.6)

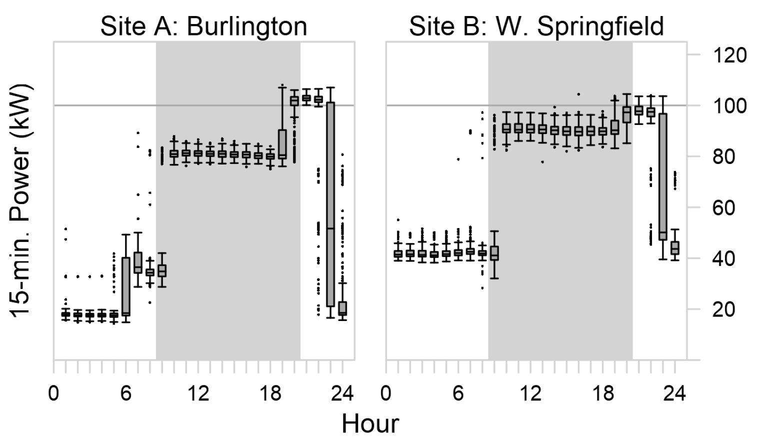


Figure 6. Daily non-RTU load profiles.
Marker = median. Box = IQR. Whisker = nearest point within 1.5 IQR from box.

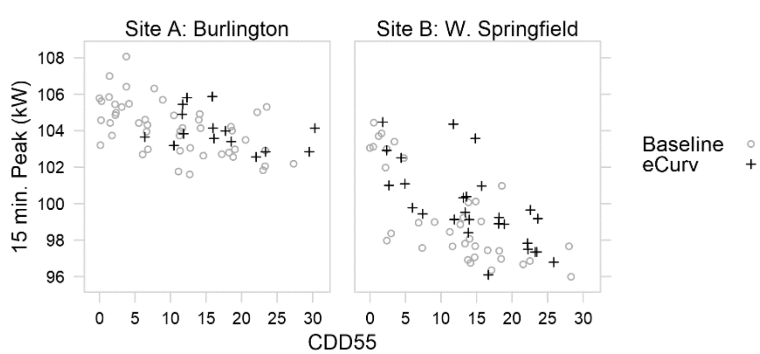


Figure 7. Daily peak facility non-RTU load during on-peak hours by CDD_{55} and eCurv status.

3.3 RTU Power Draw

Most RTUs consistently followed typical retail schedules (Figure 8), and on hot days, the total daily RTU loads typically peaked between 100-120 kW (Figure 9). RTU cycling patterns changed to some extent with eCurv enabled. Some RTUs cycled more frequently and some were used more or less often than in the baseline (Figure 10).

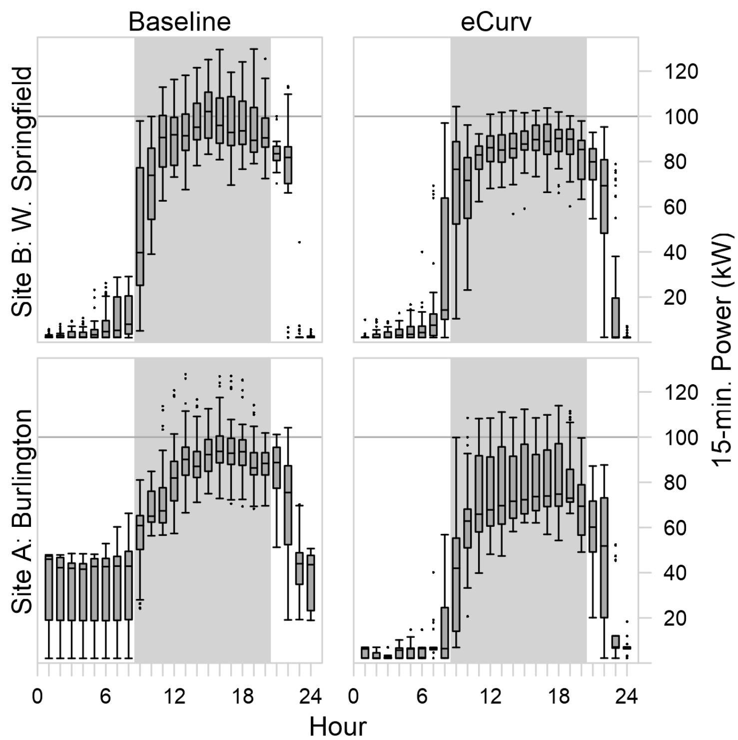


Figure 8. Daily RTU power draw profiles by eCurv status. Days with CDD_{55}>15. Marker = median. Box = IQR. Whisker = nearest point within 1.5 IQR from box.

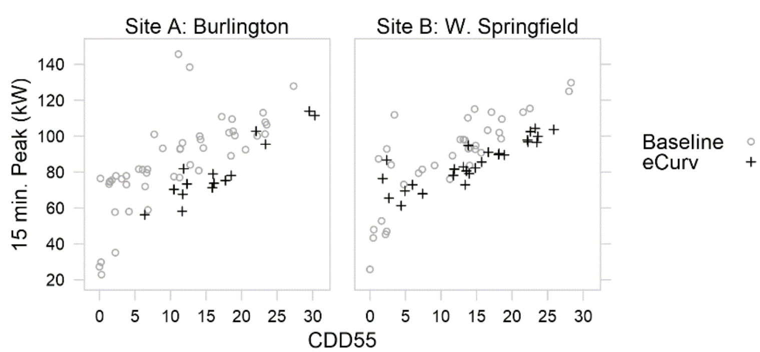


Figure 9. Daily peak RTU load from 8 A.M. to 9 P.M by eCurv status.

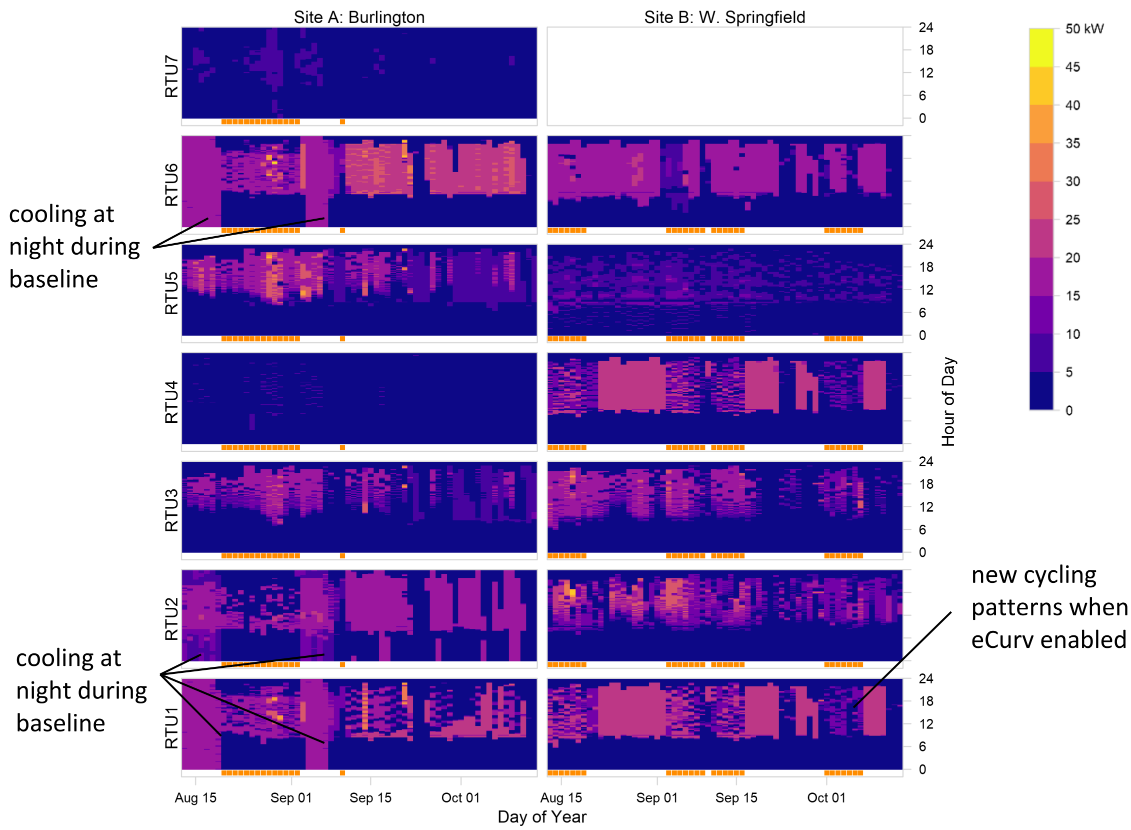


Figure 10. Daily RTU power draw, averaged to 15-min.
Orange = eCurv.

The first two compressors of RTUs 1, 2, and 6 at Site A unintentionally ran continuously in the baseline, contributing to significant overnight runtime. This overnight scheduling fault stopped when eCurv was enabled, but resumed afterwards, suggesting that eCurv has the potential to override and correct certain scheduling faults. Extra night runtime led to depressed morning zone temperatures that significantly inflated baseline energy consumption. Night cooling likely reduced morning peak loads by precooling the building, though these effects are not likely to have lasted into the afternoon or evening hours when the building peaks occur.

When we notified the team of the scheduling issue, the customer decided to disable eCurv for the remainder of the test. By early September, the issue appears to have been resolved. The service contractor also responded to a fault that RTUs 1, 2, and 6 were not dehumidifying and that their two upper cooling stages were disabled. This issue was resolved in mid-September, and subsequently, the daytime peak power draw of RTU 6 increased significantly.

As a consequence of these control challenges and schedule changes, the Site A analysis must be handled differently to focus on daytime energy performance. Since Site A had only fifteen days with eCurv enabled, the results derived from this test carry greater uncertainty.

Operating schedules for Site B were consistent across periods; however, the temperature control for certain zones did vary between test periods. This behavior is discussed in the next section.

Figure 11 and Figure 12 show the component and total RTU power draw for all days in the test. From these figures, the differences in baseline and eCurv cycling patterns are evident.

Site A: Burlington, MA

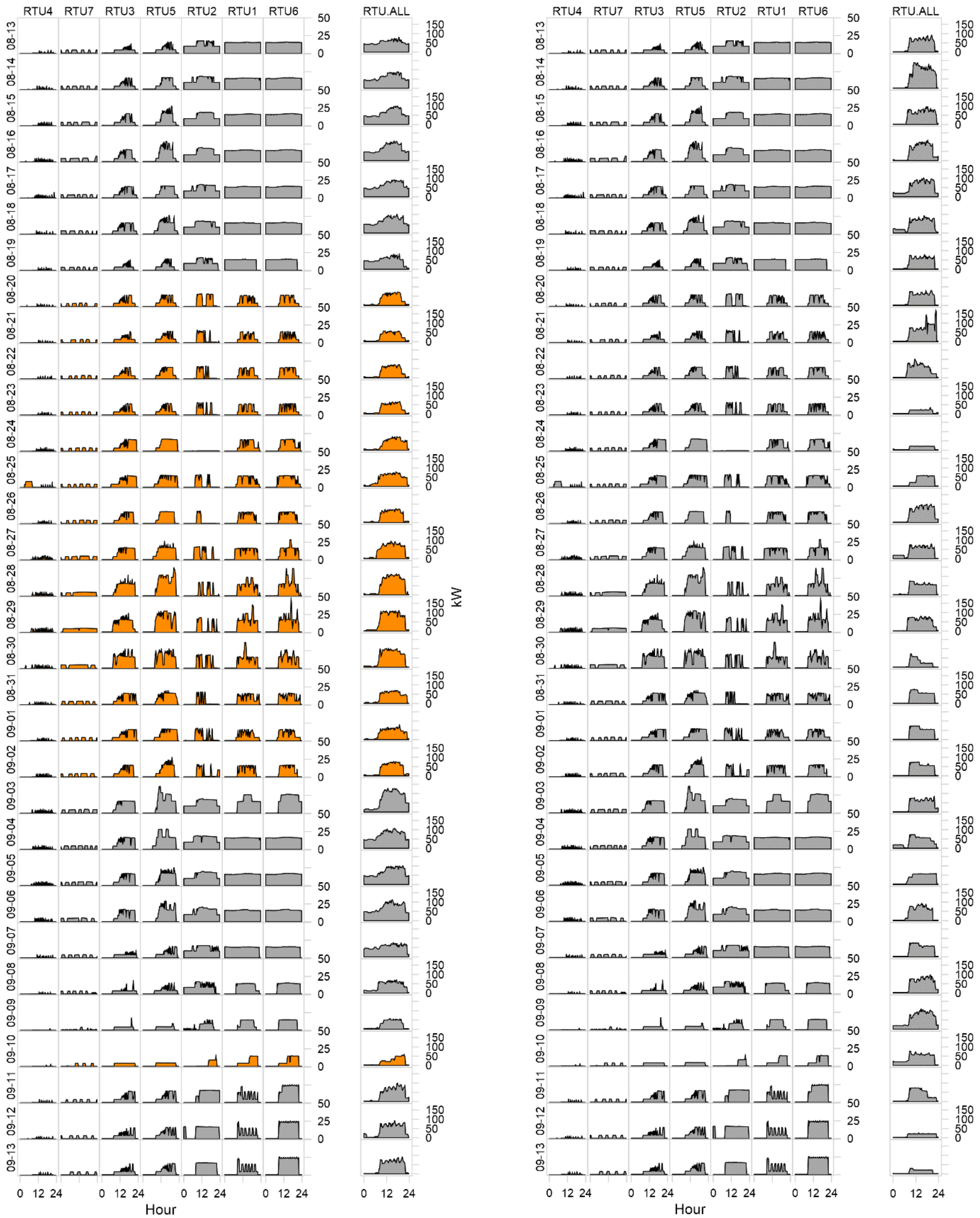


Figure 11. Daily RTU component power draw profiles, averaged to 15-min. Site A: Burlington, MA. Orange = eCurv. Gray = Baseline.

Site B: W. Springfield, MA.

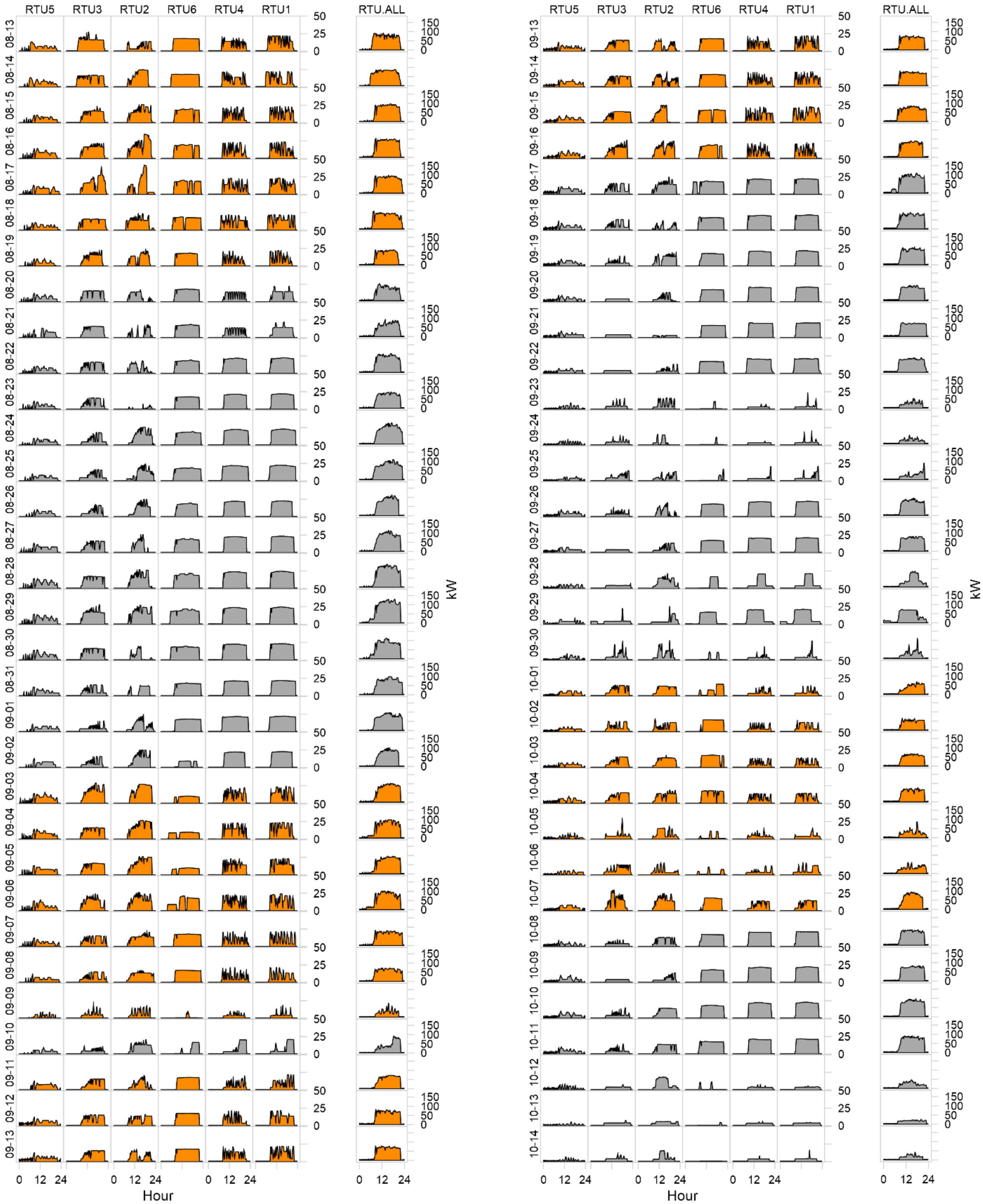


Figure 12. Daily RTU component power draw profiles, averaged to 15-min.
Orange = eCurv. Gray = Baseline.

3.4 Zone Temperature

By controlling the RTUs differently, eCurv could alter zone temperature and humidity in ways that affect comfort, energy, and power draw. Slight differences in zone temperature, for instance, can have outsize effects on cooling system energy consumption and power draw.

According to regressions derived later in this report, each additional degree-day tends to increase the total daily RTU energy consumption by 40-45 kWh and increase peak loads by 2 kW. Put another way, increasing average facility temperature by 1°F would tend to decrease average daily RTU consumption by about 5% and reduce peak loads by about 2 kW.

Observed daytime zone temperatures in this study were, in fact, higher when eCurv was enabled at both sites, by about +1°F on average and over +2°F for particular zones (Table 6). This was due to the aforementioned zone temperature decreases noted for the base case; average eCurv zone temperatures during store hours did not exceed temperature setpoints by more than 0.5ºF. Since zone floor areas were not available, facility average temperature was calculated by weighting zone temperatures by their RTU energy fraction. The RTU energy fraction was calculated based on the total fraction of RTU energy consumption observed during baseline operation.[8]

Table 6. Average zone and facility temperature.

Site A: Burlington, MA

ºF	Occ.	Daytime (8 A.M. to 9 P.M.)			All Day (24 Hours)			RTU Energy	Tonnage
RTU/Zone	Setpoint	Baseline	eCurv	e–B	Baseline	eCurv	e–B	Fraction	Fraction
1	73	72.2	73.0	0.8	72.0	73.1	1.1	21%	20%
2	73	71.2	73.3	2.0	71.4	73.4	1.9	23%	10%
3	73	72.4	73.3	1.0	72.1	73.2	1.1	10%	20%
4	75	74.5	75.0	0.5	74.5	75.1	0.7	1%	5%
5	73	72.4	73.4	0.9	72.2	73.3	1.1	13%	20%
6	73	72.2	73.1	0.9	71.9	73.2	1.2	29%	20%
7	73	70.1	70.0	-0.1	70.1	70.0	-0.1	3%	4%
Facility		**72.0**	**73.1**	**1.1**	**71.9**	**73.1**	**1.3**	**100%**	**100%**

Site B: W. Springfield, MA

ºF	Occ.	Daytime (8 A.M. to 9 P.M.)			All Day (24 Hours)			RTU Energy	Tonnage
RTU/Zone	Setpoint	Baseline	eCurv	e–B	Baseline	eCurv	e–B	Fraction	Fraction
1	73	71.0	72.9	1.8	71.3	73.0	1.7	24%	21%
2	73	73.3	73.4	0.1	73.1	73.4	0.4	13%	21%
3	73	73.1	73.3	0.2	72.8	73.2	0.4	11%	21%
4	73	70.2	72.8	2.6	70.7	73.0	2.3	23%	21%
5	72	71.2	71.2	0.0	71.9	72.1	0.2	9%	8%
6	75	74.7	75.0	0.3	74.8	75.2	0.3	20%	10%
Facility		**72.1**	**73.3**	**1.2**	**72.3**	**73.4**	**1.1**	**100%**	**100%**

Note: Facility temperature is an RTU Energy Fraction-weighted zone average.
RTU Energy Fraction is the portion of total RTU energy observed during baseline.
Tonnage Fraction is the rated RTU capacity divided by total facility RTU capacity.
Unoccupied setpoints were 78°F for all zones.

Zone temperatures differed for at least three reasons:

1. Zones 1, 2, and 6 (Site A) had RTUs that initially ran continuously at night (baseline only), leading to colder night and morning zone temperatures. While the issue was resolved mid-way through the test for RTUs 1 and 6, eCurv remained disabled for the remainder of the test, so the night schedules for these zones were ultimately not equivalent.

[8] Energy-weighted facility temperatures were used in favor of capacity-weighting (nominal tonnage) because the RTUs were well oversized for the loads encountered – some significantly more than others. Thus, energy weighting is likely to more accurately represent floor-area served. In practice, both approaches gave similar results for average daily facility temperature, with absolute differences averaging 0.1°F (0.4°F max).

2. Zone 2 (Site A) was about two degrees warmer on average with eCurv. This occurred because the higher stages of RTUs 1, 2, and 6 were initially disabled. A service call re-enabled their higher stages, but since eCurv was not enabled after this correction was made, the baseline data from the latter days of the test were not equivalent.
3. Zones 1 and 4 (Site B) were about two degrees warmer with eCurv. An unknown controls fault caused these RTUs to overcool during the daytime in the baseline.

For some zones, temperature also varied slightly with cooling degree days (Figure 13). Other than the RTUs listed above, daily zone temperature schedules were relatively consistent across periods, and no severe impacts on occupant comfort were observed (Figure 14).

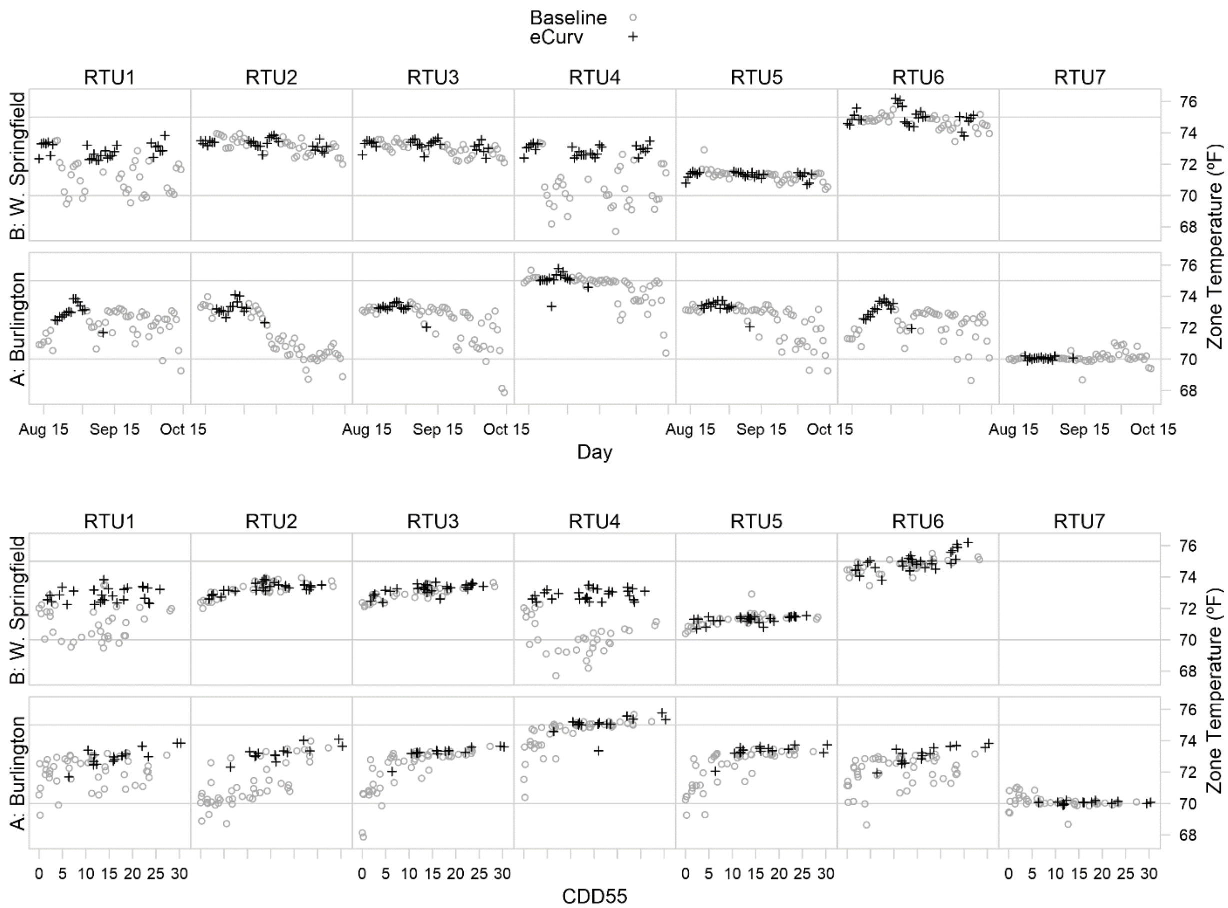


Figure 13. Average daily zone temperature vs. day and CDD_{55}.

To account for deviations in daily facility temperature, $T_{facility,day}$, relative to an arbitrary base temperature T_{base}, we define an adjusted cooling degree day variable:

$$CDD_{adj} = CDD_{55} + (T_{base} - T_{facility,day})$$

The average baseline temperature was about 72°F for both facilities, so we use this for T_{base}. Intuitively, when the facility temperature is higher than usual, there would be less cooling required – the same effect as having a lower degree day term.

For each day in the study, we computed CDD_{adj}. When fitting regressions, this term provides minor x-axis adjustments that compensate for temperature deviations. Full-day average facility temperatures were used to make these adjustments for the energy analysis, and on-peak hour average facility temperatures were used for the demand analysis; however, there was little difference between the two.

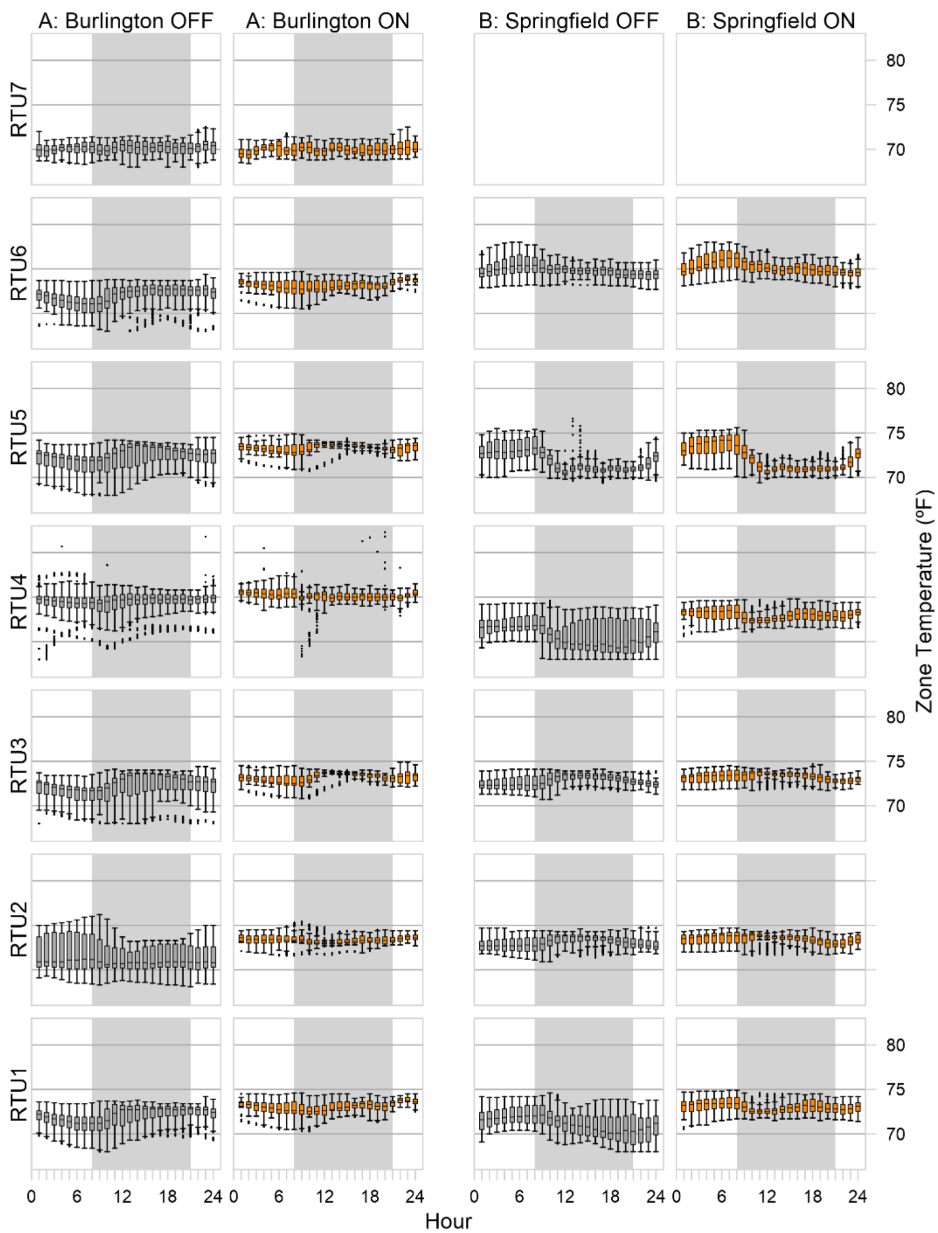


Figure 14. Zone temperature profiles by eCurv status. All days.
Marker = median. Box = IQR, Whisker = nearest point within 1.5 IQR from box.
Orange = eCurv enabled. Gray = baseline.

4 ANALYSIS

The combined RTU electricity consumption, as expected, increased approximately linearly with cooling degree days.

The relationship between daily electricity consumption by RTU and CDD is shown in Figure 15, using a normalized. common scale, by normalizing each RTU on a scale from 0 to 1 by dividing by its maximum observed kWh value. With eCurv enabled, certain RTUs were caused to run more, less, or about the same. At Site A, for instance, RTUs 2 and 6 ran less, while RTUs 3 and 7 ran more. At Site B, RTUs 1 and 4 ran less, while RTU 3 ran more.

Although the RTU and total facility consumption were clearly lower with eCurv enabled at Site A, this was due in part to a misconfigured schedule that forced several units to cool overnight in the baseline only. Energy consumption differences at consumption at Site B were smaller. Non-RTU consumption was relatively stable and not strongly influenced by outdoor temperatures.

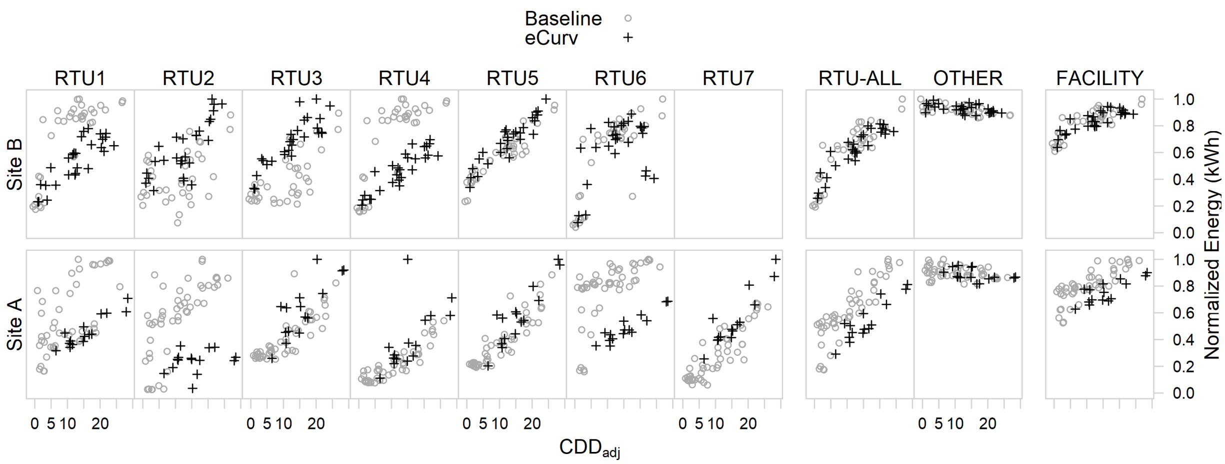


Figure 15. Daily electricity consumption (component-normalized by highest observed value) vs. *CDD_{adj}*.

FACILITY	= Sum of RTU-ALL and OTHER
RTU-ALL	= Sum of RTU Loads
OTHER	= Non-RTU Loads

Due to the severe nature of the confounding factors encountered at Site A, this analysis section includes results for Site B only. A separate Appendix includes the Site A results for reference only.

4.1 RTU Energy Consumption Regressions

We evaluated energy consumption as a function of CDD, implementing two-term linear regression models (intercept and CDD slope) with variable slopes and with common or variable intercepts as a function of eCurv status.

To account for the higher zone temperatures encountered when eCurv was enabled at both sites, we performed supplemental regressions using adjusted degree days CDD_{adj}. These adjustments reduced the energy savings estimates.

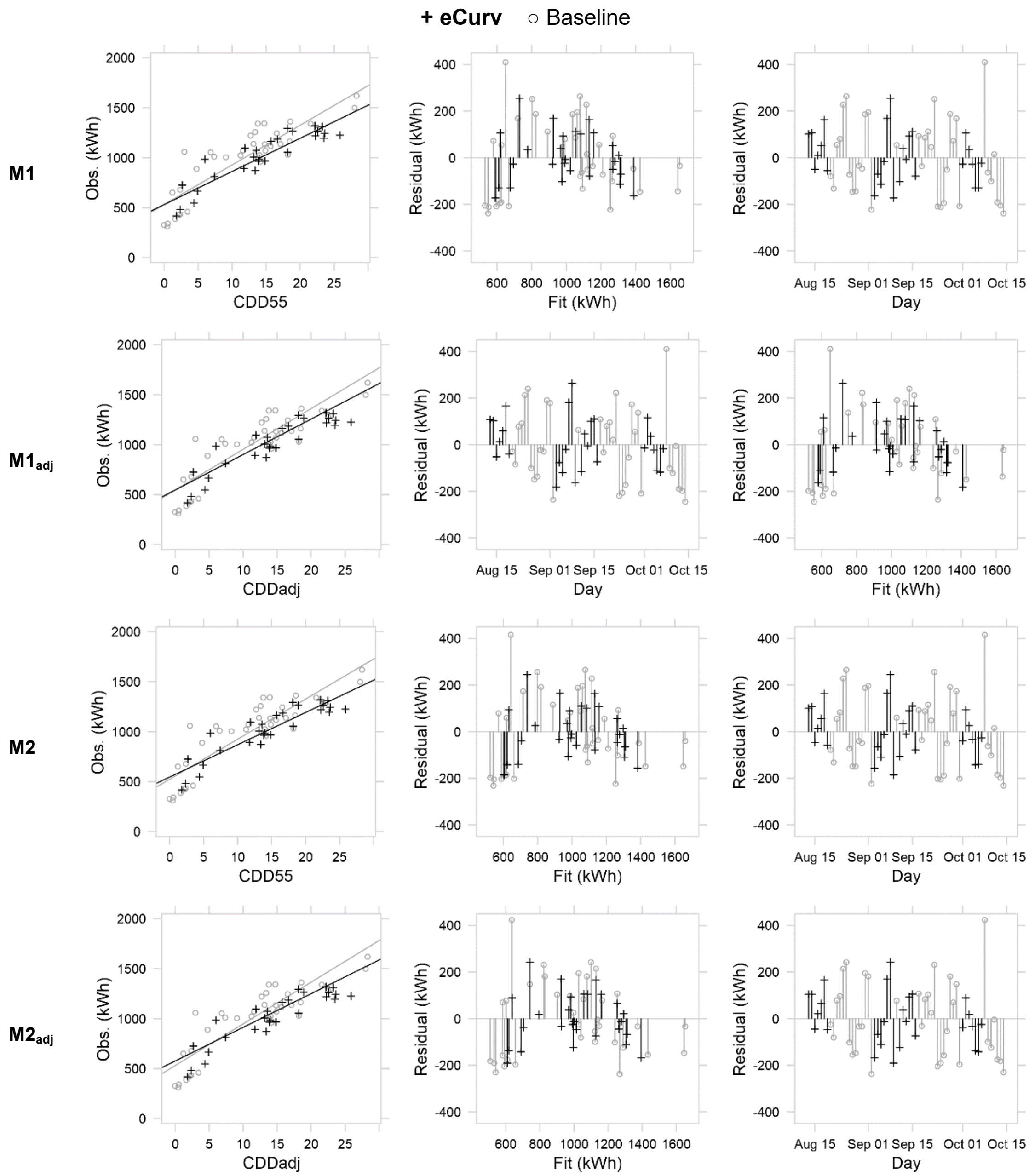
After accounting for zone temperature differences, the best performing regressions for Site B suggest up to six percent reduction in total RTU energy consumption or about 5 kWh per degree day (SE 2.7).

Table 7. Regressions of daily RTU electricity for Site B: W. Springfield, MA. Full day.

		Model \ Estimate (Std. Error)									
Terms	**Units**	**M0**		**M1**		**M2**		**M1$_{adj}$**		**M2$_{adj}$**	
Intercept	kWh	**536.9**	**(37.7)**	**530.9**	**(36.2)**	**523.7**	**(44.4)**	**546.4**	**(34.6)**	**530.9**	**(42.9)**
eCurv ON	kWh					**22.0**	**(77.7)**			45.4	(73.3)
CDD_{55}	kWh/°F	**36.1**	**(2.6)**	**39.7**	**(2.8)**	**40.1**	**(3.2)**				
CDD_{55}*eCurv ON	kWh/°F			**-6.5**	**(2.5)**	-7.8	(5.1)				
CDD_{adj}	kWh/°F							**40.8**	**(2.8)**	**41.8**	**(3.3)**
CDD_{adj}*eCurv ON	kWh/°F							-5.2	(2.7)	-8.0	(5.2)
R^2_{adj}	-	0.762		0.783		0.779		0.790		0.787	
AIC	-	817.3		812.6		814.5		810.6		812.2	
BIC	-	823.7		821.1		825.2		819.2		822.9	
MAD	kWh	109.3		102.6		101.7		108.0		105.0	
MAE	kWh	124.2		119.1		119.4		116.4		116.9	
RMSE	kWh	151.4		143.5		143.4		141.3		140.8	
CVRMSE	%	15.2%		14.4%		14.4%		14.2%		14.2%	
No. Obs.		63									
eCurv OFF	-			36		36		36		36	
eCurv ON	-			27		27		27		27	
RTU Energy	**Avg. (SD)**	994.7	(315.6)								
eCurv OFF	kWh			983.8	(354.4)	983.8	(354.4)	983.8	(354.4)	983.8	(354.4)
eCurv ON	kWh			1009.2	(260.6)	1009.2	(260.6)	1009.2	(260.6)	1009.2	(260.6)
$CDD_{55/adj}$	**Avg. (SD)**	12.7	(7.7)								
eCurv OFF	°F			11.5	(7.8)	11.5	(7.8)	11.5	(7.8)	11.5	(7.8)
eCurv ON	°F			14.3	(7.3)	14.3	(7.3)	14.3	(7.3)	14.3	(7.3)
Modeled Results	**Avg. (SD)**										
RTU Energy	kWh	994.7	(276.2)								
eCurv:OFF	kWh			1034.8	(304.0)	1033.1	(307.4)	1023.5	(298.5)	1019.4	(305.6)
eCurv:ON	kWh			951.8	(254.0)	956.2	(247.7)	962.1	(260.1)	970.8	(246.9)
Abs. Diff.	kWh			-83.0		-76.9		-61.4		-48.5	
Rel. Diff.	%			-8.0%		-7.4%		-6.0%		-4.8%	

Terms in bold are significant at the 0.95 level (p<0.05).

Figure 16. Energy model summary results, Site B: W. Springfield, MA.



4.2 Simulated RTU Energy Reductions on Typical Boston Weather

Applying the models to actual typical Boston weather during the cooling season provides an indication of annual energy savings. These results assume the models are correct and hold for the entire cooling season.

For Site B, modeled annual RTU energy savings was about 5-6 kWh per CDD_{55}, about 7-10 MWh per year or 4 to 7 percent of total RTU energy consumption. Results for this case were less sensitive to model selection. At this site, the temperature-adjusted models yield more accurate savings estimates.

Table 8. Modeled eCurv energy reductions. Site B: W. Springfield, MA.

Model $M1_{adj}$ (preferred model)	**(ºF) CDD_{55}**	**(kWh) eCurv**	**Baseline**	**eCurv – Baseline**	**%**
May	171	23,030	23,929	-899	-4%
Jun	340	28,471	30,254	-1,783	-6%
Jul	591	37,960	41,063	-3,103	-8%
Aug	497	34,602	37,209	-2,607	-7%
Sept.	294	26,843	28,386	-1,543	-5%
Oct.	97	20,386	20,895	-509	-2%
TOTAL	**1,991**	**171,292**	**181,736**	**-10,444**	**-6%**
Model M1					
May	171	22,143	23,262	-1,119	-5%
Jun	340	27,203	29,423	-2,219	-8%
Jul	591	36,083	39,945	-3,862	-10%
Aug	497	32,948	36,193	-3,245	-9%
Sept.	294	25,683	27,603	-1,920	-7%
Oct.	97	19,675	20,309	-633	-3%
TOTAL	**1,991**	**163,735**	**176,735**	**-13,000**	**-7%**

Model $M2_{adj}$	**CDD_{55}**	**eCurv**	**Baseline**	**Diff.**	**%**
May	171	23,645	23,614	31	0%
Jun	340	28,752	30,119	-1,367	-5%
Jul	591	37,815	41,158	-3,343	-8%
Aug	497	34,628	37,212	-2,584	-7%
Sept.	294	27,206	28,206	-999	-4%
Oct.	97	21,136	20,508	628	3%
TOTAL	**1,991**	**173,182**	**180,816**	**-7,634**	**-4%**
Model M2					
May	171	22,460	23,114	-653	-3%
Jun	340	27,366	29,354	-1,988	-7%
Jul	591	36,053	39,979	-3,925	-10%
Aug	497	32,996	36,186	-3,190	-9%
Sept.	294	25,884	27,515	-1,631	-6%
Oct.	97	20,054	20,128	-74	0%
TOTAL	**1,991**	**164,814**	**176,275**	**-11,461**	**-7%**

4.3 Peak Facility Power Regressions

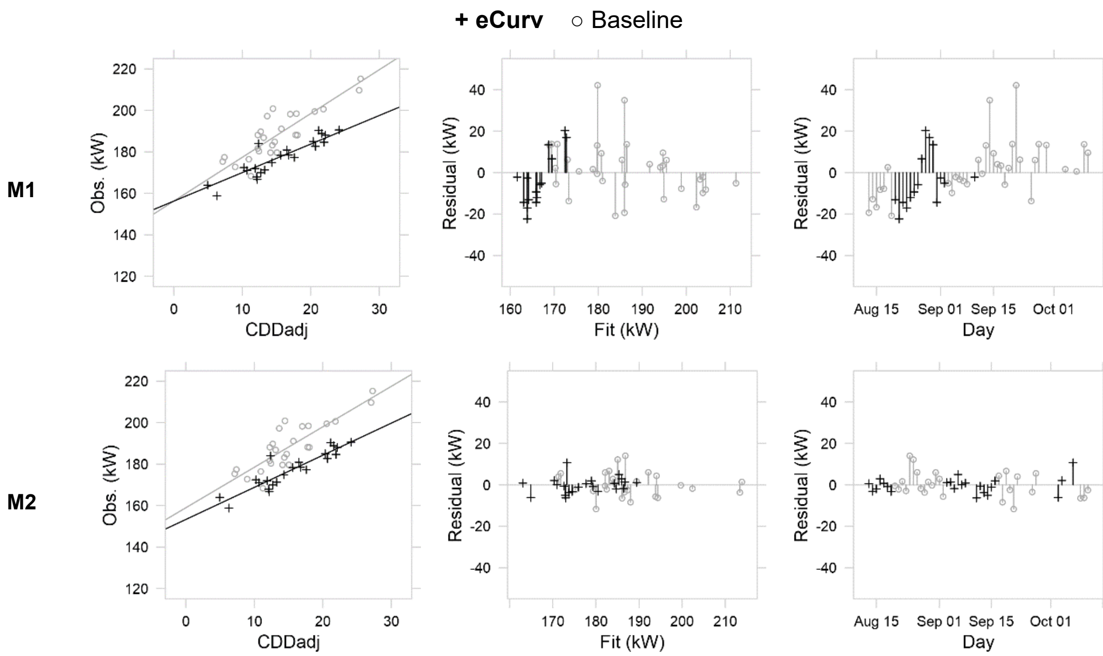
Power regressions were performed based on the daily maximum 15-minute peak facility power draw observed during on-peak hours (8 A.M. to 9 P.M). Since monthly peak demand is driven by the hotter days, we considered only those days with CDD_{55}>5. This provides a better linear fit in the region where peak loads occur. Less accurate peak load prediction at lower *CDD* does not materially affect the monthly peak demand calculations. As with the energy regressions, we considered models with eCurv terms for CDD and/or intercept, using CDD_{adj} to account for differences in daytime facility temperature.

For Site B, Model M2 gave the best statistical fit. Residuals for that model were relatively small and did not show the signs systematic bias present in Model M1.

Table 9. Regressions of 15-min. peak facility power for Site B: W. Springfield, MA. Based on on-peak hours: 8 A.M. to 9 P.M., days with CDD_{55}>5.

		Model \ Estimate (Std. Error)					
Terms	**Units**	**M0**		**M1**		**M2**	
Intercept	kW	**162.1**	**(6.7)**	**158.5**	**(5.2)**	**170.6**	**(5.2)**
eCurv ON	kW					**-41.5**	**(9.7)**
CDD_{adj}	kW/°F	**1.2**	**(0.4)**	**2.0**	**(0.4)**	**1.3**	**(0.3)**
CDD_{adj}*eCurv ON	kW/°F			**-1.5**	**(0.3)**	0.8	(0.6)
R^2_{adj}	-	0.140		0.491		0.632	
AIC	-	417.6		393.4		378.7	
BIC	-	423.2		400.8		388.0	
MAD	kW	12.9		9.3		5.3	
MAE	kW	14.3		10.6		8.2	
RMSE	kW	17.6		13.4		11.3	
CVRMSE	%	9.8%		7.4%		6.2%	
No. Obs.		47					
eCurv OFF	-			25		25	
eCurv ON	-			22		22	
Facility Power	**Avg. (SD)**	183.1	(11.9)				
eCurv OFF	kW			188.5	(11.7)	188.5	(11.7)
eCurv ON	kW			177.2	(9.0)	177.2	(9.0)
CDD_{adj}	**Avg. (SD)**	15.3	(5.1)				
eCurv OFF	°F			15.1	(5.1)	15.1	(5.1)
eCurv ON	°F			15.4	(5.3)	15.4	(5.3)

Figure 17. Peak power model summary results, Site B: W. Springfield, MA.



4.4 Monte Carlo Simulation of Peak Demand

Demand charges are assessed based on the highest peak incurred in a month during on-peak hours. Applying the daily peak power models derived earlier to actual or typical weather data gives the expected daily peaks for the baseline and eCurv cases. Comparing the highest monthly peaks yields the expected difference in peak demand ascribed to eCurv.

In reality, facility loads are stochastic, and random deviations from the linear models are expected. To account this natural variability, we form stochastic replicates by resampling the case-specific model residuals with replacement and add these back to the modeled results.

Taking the maximum monthly value of the modeled daily peak loads (one for each replication), yields a distribution of expected peak demand. The difference in expected values of the distributions for the eCurv and baseline cases gives the expected peak demand reduction. The approach is outlined as follows:

1. Derive models for daily peak facility power as a function of CDD and eCurv status
2. Compute model residuals
3. Calculate expected daily peak demand with and without eCurv for 10,000 replicates:
    a. Add resampled case-specific residuals (e.g., eCurv and baseline) to the modeled results
    b. Find the maximum daily peak demand with and without eCurv
    c. Calculate the difference in monthly peak demand
4. Summarize the distribution of the difference in monthly peak demand

4.4.1 Simulated Peak Reductions on Observed Data

Applying this method to Site B using the statistically preferred model M2 and observed weather data gives monthly peak reduction distributions centered on 18 kW (SD 5.7) and 15 kW (SD 5.4) (Figure 18).

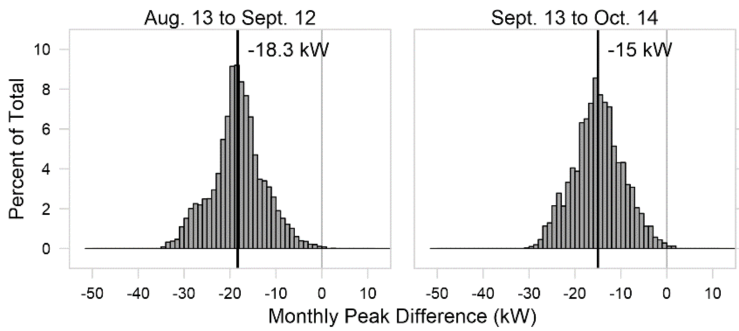


Figure 18. Modeled monthly peak difference distributions for Site B: W. Springfield, MA. Based on 10,000 replicates. Bin = 1 kW.

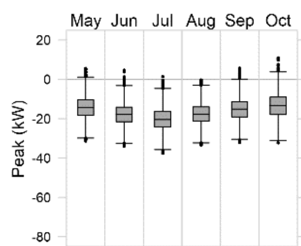
4.4.2 Simulated Peak Reductions on Typical Boston Weather

Applying the simulation approach to typical meteorological weather data for Boston, MA gives a distribution of monthly peak reductions. At Site B, this ranged from about 13 to 20 kW on average, or about 7-9 percent of the total facility peak.

Table 10. Simulated eCurv peak demand reductions.

Month	CDD_{55} (°F)	Facility Peak Demand ±SD (kW) Base	eCurv	Savings (e – B)	%
May	171	197 ±4	183 ±4	-14.3 ±5.9	-7%
Jun	340	213 ±5	195 ±4	-17.8 ±6.0	-8%
Jul	591	226 ±5	205 ±4	-20.3 ±6.0	-9%
Aug	497	213 ±4	195 ±4	-17.5 ±5.4	-8%
Sept.	294	201 ±4	186 ±4	-15.1 ±5.7	-8%
Oct.	97	196 ±6	182 ±4	-13.3 ±6.8	-7%
TOTAL	**1991**	**207**	**194**	**-16**	**-8%**

Typical Boston Weather. Based on 10,000 replicates.



5 CONCLUSIONS

Software for managing RTU cooling loads was evaluated at two big-box retail stores in Massachusetts during a two month-period for its ability to reduce RTU electricity consumption and monthly facility peak electric demand. Overall, the coordinated control of packaged rooftop units could plausibly and significantly reduce both energy consumption and peak demand.

Due to confounding equipment controls factors and a limited test duration, the conclusions from this study are limited in scope to buildings with similar load profiles, cooling equipment, operational behavior, and weather conditions. Nevertheless, statistically significant energy and demand savings were observed, and the technology functioned as intended.

Through this demonstration, we observed and modeled the following:

1. Energy savings of about 60 kWh per day – 6% of total RTU energy consumption or 2.2% of total facility energy consumption.
2. Peak demand reductions of about 15-18 kW – 10-15% of the highest observed RTU load or 8% of total facility load.
3. Zone temperatures typically remained within 0.5°F of the target setpoint.
4. Basic temperature control faults related to overcooling and incorrect scheduling were seemingly corrected or overridden by the eCurv software.
5. Modeling the May-October cooling season with typical Boston, MA weather predicts potential seasonal energy savings of about 10,400 kWh and monthly demand reductions of 13-20 kW.

In practice, actual savings and impacts depend on site-specific characteristics.

Control issues were encountered at both test sites that led to overcooling and increased baseline energy consumption. eCurv was able to overcome these faults, and save energy, by overriding the faulty controls.

Demand reductions, in particular, were highly sensitive to outlier load spike events. Unpredictable spikes in demand could undo a significant portion of the potential demand savings. Longer-term study of historic data from a larger portion of sites would provide more reliable savings estimates and a better understanding of the frequency and impact of isolated load spikes.

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APPENDIX A: Site A Analysis Results

Due to severe confounding test factors with three RTUs, the Site A results were unreliable. The analysis and results provided in this appendix are for illustration only and are of limited quantitative value.

A.1 RTU Energy Consumption Regressions

At Site A, a fault caused several RTUs to run continuously overnight in the baseline. To account for this issue, we considered energy models focused on daytime hours only (9 A.M. to 9 P.M.). Daytime hours accounted for about 80% of the total daily RTU energy consumption. Residual effects of night pre-cooling could carry into the daytime hours, which would tend to reduce the eCurv savings estimates.

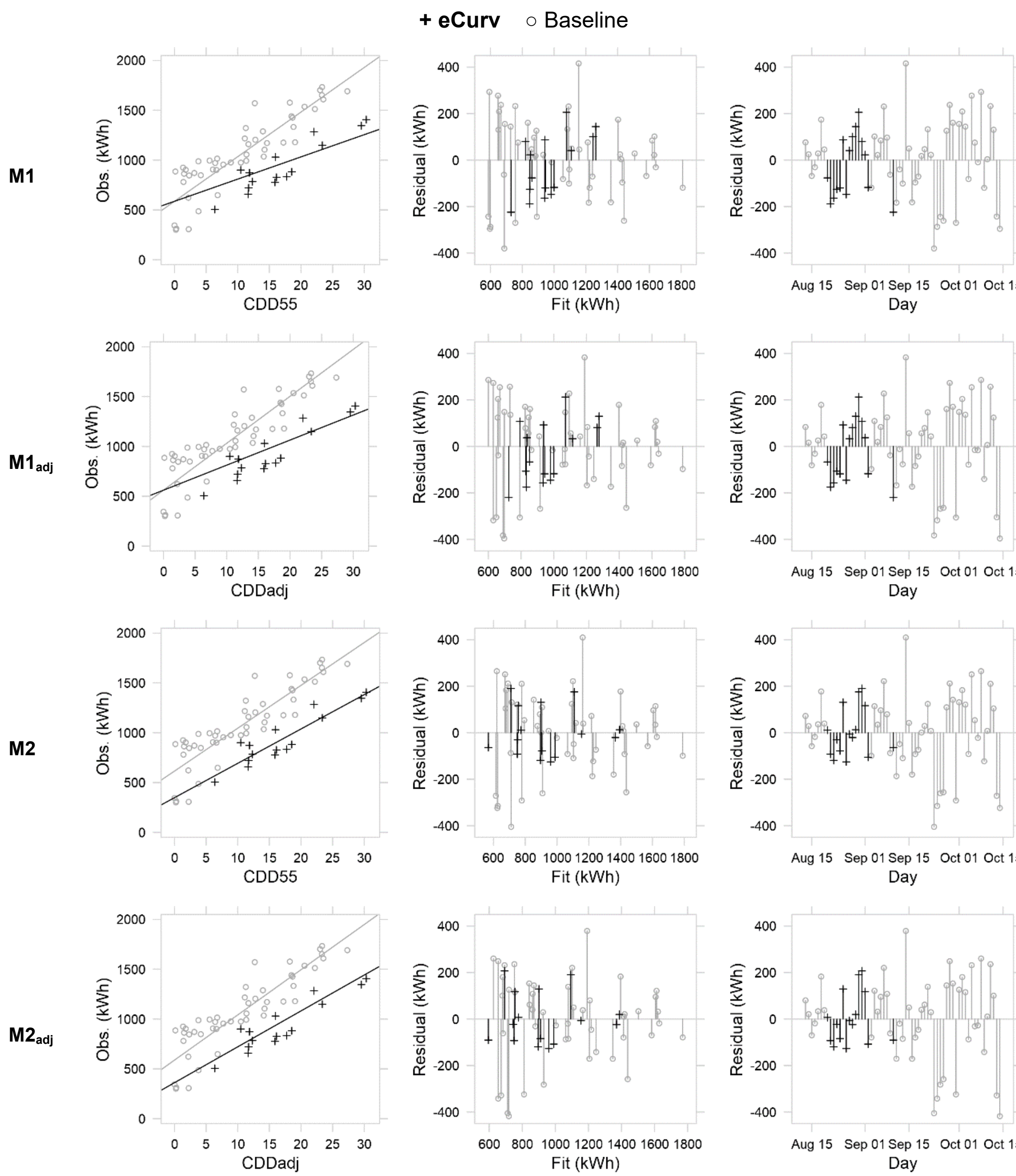
Energy performance results for Site A were highly sensitive to the model selection. The preferred Model, M1$_{adj}$, suggests at least 11 percent reduction in RTU energy consumption or about 8 kWh per degree day (SE 2.7).

Table 11. Regressions of daily RTU electricity for Site A: Burlington, MA. Daytime-only (9 A.M. to 9 P.M).

		Model \ Estimate (Std. Error)									
Terms	**Units**	**M0**		**M1**		**M2**		**M1$_{adj}$**		**M2$_{adj}$**	
Intercept	kWh	**537.1**	**(34.3)**	**522.9**	**(32.1)**	**550.8**	**(32.4)**	**514.2**	**(34.2)**	**542.3**	**(35.1)**
eCurv:ON	kWh					**-260.3**	**(99.1)**			**-239.4**	**(102.4)**
CDD$_{55}$	kWh/°F	**21.9**	**(2.4)**	**25.9**	**(2.5)**	**24.2**	**(2.5)**				
CDD$_{55}$*eCurv:ON	kWh/°F			**-8.4**	**(2.5)**	5.2	(5.7)				
CDD$_{adj}$	kWh/°F							**27.1**	**(2.8)**	**25.3**	**(2.8)**
CDD$_{adj}$*eCurv:ON	kWh/°F							**-8.0**	**(2.7)**	5.3	(6.3)
R^2_{adj}	-	0.576		0.636		0.669		0.613		0.640	
AIC	-	814.3		805.7		800.7		809.6		806.0	
BIC	-	820.8		814.2		811.4		818.2		816.7	
MAD	kWh	102.2		89.5		66.5		96.3		79.6	
MAE	kWh	116.1		104.9		92.5		108.5		97.7	
RMSE	kWh	147.9		135.9		128.6		140.2		134.1	
CVRMSE	%	18.4%		16.9%		16.0%		17.5%		16.7%	
No. Obs.		63									
eCurv:OFF	-			48		48		48		48	
eCurv:ON	-			15		15		15		15	
RTU Energy	**Avg. (SD)**	801.8	(230.9)								
eCurv:OFF	kWh			806.1	(238.1)	806.1	(238.1)	806.1	(238.1)	806.1	(238.1)
eCurv:ON	kWh			788.1	(213.3)	788.1	(213.3)	788.1	(213.3)	788.1	(213.3)
CDD$_{55/adj}$	**Avg. (SD)**	12.1	(8.0)								
eCurv:OFF	°F			10.6	(7.8)	10.6	(7.8)	10.6	(7.8)	10.6	(7.8)
eCurv:ON	°F			16.9	(6.9)	16.9	(6.9)	16.9	(6.9)	16.9	(6.9)
Modeled Results	**Avg. (SD)**										
RTU Energy	kWh	801.8	(230.9)								
eCurv:OFF	kWh			835.7	(208.3)	842.8	(194.5)	831.9	(202.1)	838.7	(188.5)
eCurv:ON	kWh			734.3	(140.8)	645.4	(236.4)	738.4	(142.6)	661.8	(228.2)
Abs. Diff.	kWh			-101.3		-197.4		-93.5		-176.9	
Rel. Diff.	%			-12.1%		-23.4%		-11.2%		-21.1%	

Terms in bold are significant at the 0.95 level (p<0.05).

Figure 19. Energy model summary results, Site A: Burlington, MA.



A.2 Simulated RTU Energy Reductions on Typical Boston Weather

For Site A, Model $M1_{adj}$ was statistically preferred and predicts savings of 8 kWh per CDD_{55}, about 11% reduction in total RTU energy or about 15.9 to 16.7 MWh per year, when applied to Boston weather data. Results for Site A were also highly sensitive to model selection, with Model M2 predicting about twice the savings of M1. We reiterate that the experiment for Site A was unbalanced, so actual savings were likely at least partly due to the confounding factors discussed throughout this report.

Table 12. Modeled eCurv energy reductions. Site A: Burlington, MA. Daytime only (9 A.M. to 9 P.M.)

Model $M1_{adj}$ (preferred model)

	(ºF) CDD_{55}	(kWh) eCurv	Baseline	eCurv – Baseline	%
May	171	19,218	20,584	-1,367	-7%
Jun	340	21,927	24,638	-2,711	-11%
Jul	591	27,255	31,973	-4,717	-15%
Aug	497	25,448	29,411	-3,964	-13%
Sept.	294	21,051	23,396	-2,345	-10%
Oct.	97	17,795	18,568	-774	-4%
TOTAL	**1,991**	**132,694**	**148,571**	**-15,877**	**-11%**

Model M1

May	171	19,211	20,649	-1,439	-7%
Jun	340	21,638	24,491	-2,853	-12%
Jul	591	26,567	31,532	-4,965	-16%
Aug	497	24,912	29,084	-4,172	-14%
Sept.	294	20,836	23,304	-2,468	-11%
Oct.	97	17,908	18,723	-814	-4%
TOTAL	**1,991**	**131,072**	**147,783**	**-16,711**	**-11%**

Model $M2_{adj}$

	CDD_{55}	eCurv	Baseline	Diff.	%
May	171	14,637	21,145	-6,508	-31%
Jun	340	19,494	24,863	-5,369	-22%
Jul	591	27,501	31,766	-4,266	-13%
Aug	497	24,608	29,378	-4,770	-16%
Sept.	294	18,091	23,704	-5,614	-24%
Oct.	97	12,360	19,265	-6,905	-36%
TOTAL	**1,991**	**116,690**	**150,121**	**-33,431**	**-22%**

Model M2

May	171	14,042	21,219	-7,177	-34%
Jun	340	18,705	24,744	-6,039	-24%
Jul	591	26,392	31,380	-4,989	-16%
Aug	497	23,614	29,095	-5,481	-19%
Sept.	294	17,358	23,636	-6,278	-27%
Oct.	97	11,856	19,420	-7,565	-39%
TOTAL	**1,991**	**111,966**	**149,494**	**-37,528**	**-25%**

A.3 Peak Facility Power Regressions

At Site A, two days had outlier-peaks during the baseline period on September 14 and 21. These days were relatively cool (CDD_{55} 13 and 11, respectively), yet the RTU loads spiked uncharacteristically, driving up facility peak loads. The regressions and predicted peak loads were highly sensitive to these two points.

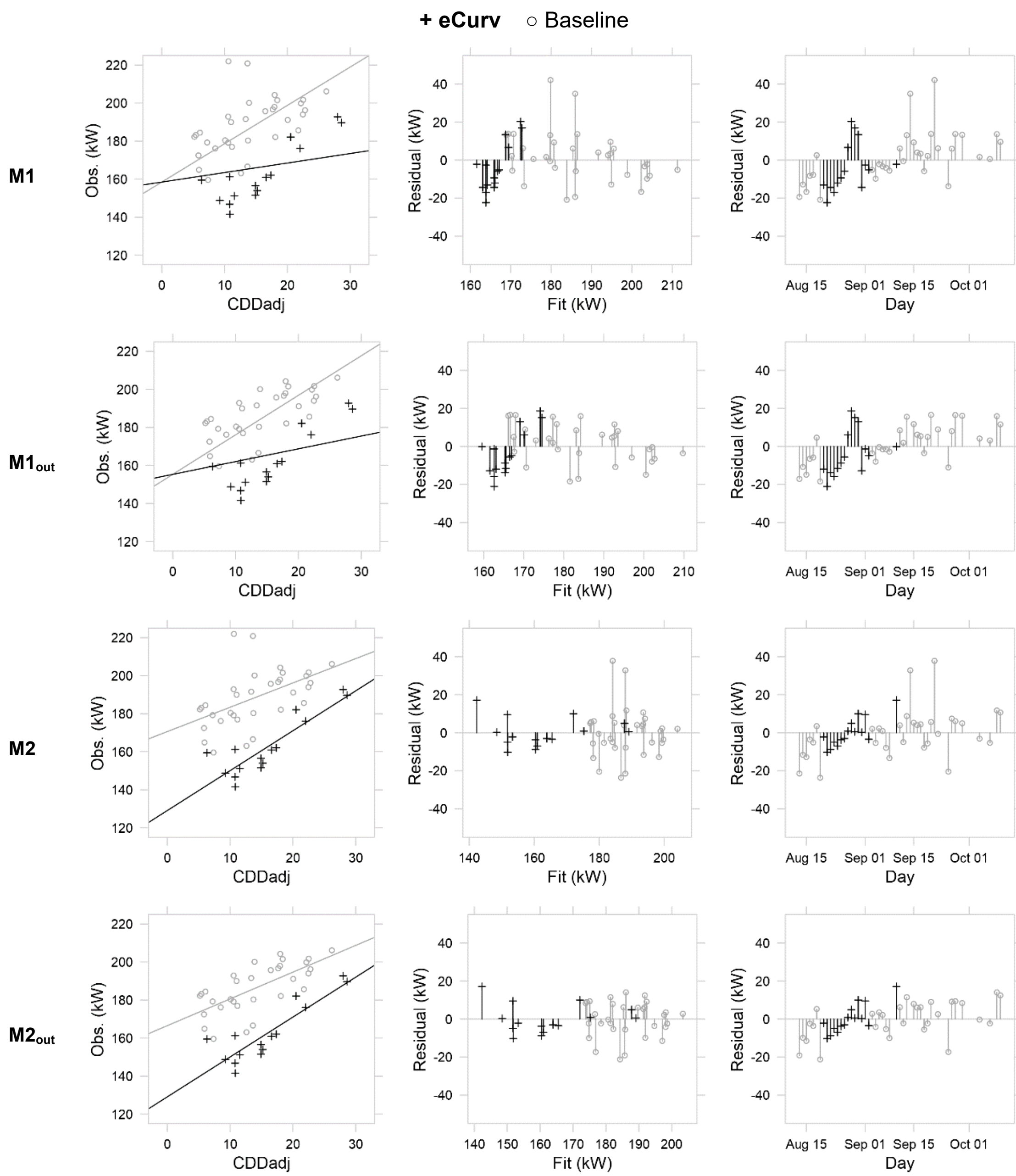
Without more context, it is difficult know the cause. If the cause were a manual or mechanical event, such as equipment malfunction or unplanned maintenance, then eCurv might not have been able to prevent those peaks from occurring. Conversely, if the cause were controls-related, then eCurv might have prevented such a peak. Since we had relatively little data to work with, we modeled these cases separately and simply note the potential consequences on results.

Model M2 provided the best statistical fit; however, the residual plots indicate systematic bias likely related to the RTU controls adjustments performed halfway through the test (Figure 20, “Day” plots). Specifically, residuals tend to be negative in the first half of the test (before the RTUs were adjusted) and positive in the second half of the test (after the higher stages were enabled). Consequently, results for this test are substantially less reliable.

Table 13. Regressions of 15-min. peak facility power for Site A: Burlington, MA.
Based on on-peak hours: 8 A.M. to 9 P.M., days with CDD_{55}>5.

		Model \ Estimate (Std. Error)											
		All Days						**Excluding Two Outliers**					
Terms	**Units**	**M0**		**M1**		**M2**		**$M0_{out}$**		**$M1_{out}$**		**$M2_{out}$**	
Intercept	kW	**162.1**	**(6.7)**	**158.5**	**(5.2)**	**170.6**	**(5.2)**	**158.3**	**(5.9)**	**155.3**	**(4.3)**	**166.5**	**(4.1)**
eCurv ON	kW					**-41.5**	**(9.7)**					**-37.4**	**(7.5)**
CDD_{adj}	kW/°F	**1.2**	**(0.4)**	**2.0**	**(0.4)**	**1.3**	**(0.3)**	**1.4**	**(0.4)**	**2.1**	**(0.3)**	**1.4**	**(0.3)**
CDD_{adj}*eCurv ON	kW/°F			**-1.5**	**(0.3)**	0.8	(0.6)			**-1.4**	**(0.2)**	0.7	(0.5)
R^2_{adj}	-	0.140		0.491		0.632		0.221		0.598		0.743	
AIC	-	417.6		393.4		378.7		387.6		358.1		338.5	
BIC	-	423.2		400.8		388.0		393.1		365.4		347.6	
MAD	kW	12.9		9.3		5.3		12.5		8.6		5.8	
MAE	kW	14.3		10.6		8.2		13.2		9.3		7.0	
RMSE	kW	17.6		13.4		11.3		15.3		10.9		8.6	
CVRMSE	%	9.8%		7.4%		6.2%		8.6%		6.1%		4.8%	
No. Obs.		48						46					
eCurv OFF	-			33		33				31			31
eCurv ON	-			15		15				15			15
Facility Power	**Avg. (SD)**	180.3	19.4					178.5	(17.7)				
eCurv OFF	kW			188.5	(15.0)	188.5	(15.0)			186.3	(12.7)	186.3	(12.7)
eCurv ON	kW			162.3	(15.7)	162.3	(15.7)			162.3	(15.7)	162.3	(15.7)
CDD_{adj}	**Avg. (SD)**	14.6	(6.2)					14.7	(6.3)				
eCurv OFF	°F			14.0	(6.0)	14.0	(6.0)			14.1	(6.2)	14.1	(6.2)
eCurv ON	°F			15.8	(6.6)	15.8	(6.6)			15.8	(6.6)	15.8	(6.6)

Figure 20. Peak power model summary results, Site A: Burlington, MA.



A.4 Simulated Peak Demand

A.4.1 Observed Data

To illustrate sensitivity to outliers, at Site A we estimated peak load reductions using both Models M2 and $M2_{out}$. During the observed months, we estimate a reduction of 34-43 kW (SD 11) using all points, or 19-25 kW (SD 7) excluding the outliers. Again, due to confounding factors, results for Site A are provided for illustration only.

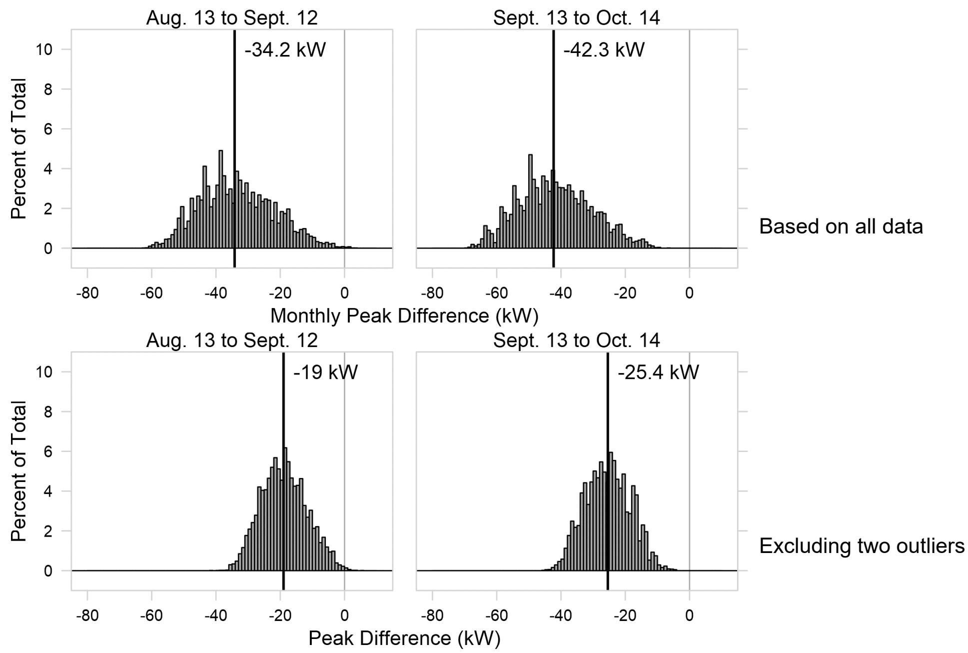


Figure 21. Modeled monthly peak difference distributions for Site A: Burlington, MA. Based on 10,000 replicates. Bin = 1 kW.

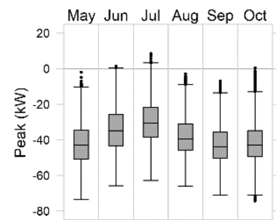
A.4.2 Typical Boston Weather

Results for Site A are shown for illustration only, mainly to emphasize how two baseline outliers could change the expected peak load reductions by a factor of two.

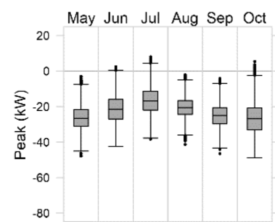
Table 14. Simulated eCurv peak reductions, Boston Weather. Based on 10,000 replicates.

Difference in Monthly Facility Peak (kW): eCurv – Baseline

Site A (M2, all data)	May	Jun	Jul	Aug	Sept.	Oct.	Avg.
Mean	**-42.5**	**-34.5**	**-30.0**	**-37.7**	**-42.4**	**-41.7**	**-38.1**
SD	11.3	12.4	11.8	10.9	11.1	11.5	**11.5**
Quantiles							
0.000 (min)	-73.5	-65.9	-62.8	-65.9	-71.0	-74.3	**-68.9**
0.025	-68.2	-62.3	-56.7	-60.1	-65.7	-72.8	**-64.3**
0.250 Q1	-50.7	-43.3	-38.5	-45.7	-50.4	-49.4	**-46.3**
0.500 (median)	**-42.9**	**-34.9**	**-30.6**	**-39.5**	**-43.9**	**-42.9**	**-39.1**
0.750 Q3	-34.5	-25.8	-21.7	-31.0	-35.6	-34.8	**-30.6**
0.975	-19.5	-9.9	-6.2	-13.8	-18.0	-18.0	**-14.2**
1.000 (max)	-1.9	1.5	8.5	-2.8	-7.0	0.5	**-0.2**



Site A (M2, no outliers)	May	Jun	Jul	Aug	Sept.	Oct.	Avg.
Mean	**-26.4**	**-21.1**	**-16.5**	**-20.5**	**-25.1**	**-26.5**	**-22.7**
SD	6.8	7.5	7.5	5.7	6.4	9.4	**7.2**
Quantiles							
0.000 (min)	-47.9	-42.5	-38.5	-41.3	-46.6	-48.8	**-44.3**
0.025	-43.0	-38.1	-33.9	-35.8	-41.4	-47.4	**-39.9**
0.250 Q1	-31.1	-26.9	-22.0	-24.4	-29.7	-33.1	**-27.9**
0.500 (median)	**-26.5**	**-21.5**	**-16.8**	**-20.6**	**-25.0**	**-26.8**	**-22.9**
0.750 Q3	-21.7	-16.0	-11.4	-16.6	-20.6	-20.8	**-17.8**
0.975	-12.8	-5.7	-1.6	-9.5	-12.2	-5.2	**-7.8**
1.000 (max)	-2.9	2.5	8.0	-2.0	-4.2	5.4	**1.1**



APPENDIX B: DATA TABLES

The following data tables summarize the underlying cooling system performance.

Fields include:

1. eCurv status (ON/OFF)
2. Heating and Cooling Degree Days (base 55°F)
3. Electricity Consumption (kWh)
    a. Individual RTU consumption
    b. RTU = total of all RTUs
    c. OTHER = total non-RTU site electricity
    d. TOTAL = RTU + OTHER
    e. RTU % = RTU/TOTAL x 100%
4. Peak Demand (kW) based on maximum 15 min. from 8 A.M. to 9 P.M.
    a. Entire Facility
    b. RTUs Only
5. Temperature & Humidity
    a. Outdoor Air Temperature
    b. Average Daily Zone Temperature
        i. By Zone
        ii. Facility Average (FA), RTU energy-weighted
    c. Minimum Supply Air Temperature

Table 15. Daily energy consumption.

Site A: Burlington, MA

2018-	eCurv	CDD$_{55}$		RTU # (kWh)							SITE (kWh)			RTU
MM-DD	**Status**	**(°F)**	**Adj.**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**RTU**	**OTHER**	**TOTAL**	**(%)**
08-13	OFF	14.0	13.7	365	305	83	11	108	368	49	1289	1414	2703	48%
08-14	OFF	18.5	18.3	377	334	116	15	159	381	58	1440	1398	2838	51%
08-15	OFF	22.2	21.9	384	337	129	19	186	388	70	1513	1360	2872	53%
08-16	OFF	23.5	22.9	389	344	154	23	227	393	80	1610	1359	2968	54%
08-17	OFF	20.6	20.2	380	343	152	24	186	385	67	1536	1499	3035	51%
08-18	OFF	18.2	17.8	378	343	163	15	233	384	61	1577	1485	3063	51%
08-19	OFF	12.8	12.7	320	287	85	14	113	325	60	1204	1296	2501	48%
08-20	ON	12.3	11.6	143	150	124	13	144	161	51	785	1373	2157	36%
08-21	ON	11.6	10.8	134	105	100	12	120	139	48	658	1380	2038	32%
08-22	ON	15.9	14.9	152	111	120	13	156	176	50	777	1376	2153	36%
08-23	ON	11.7	10.7	146	107	121	14	130	156	47	722	1385	2107	34%
08-24	ON	16.1	15.2	167	15	173	20	209	187	56	826	1505	2331	35%
08-25	ON	16.0	15.0	195	107	191	53	215	213	57	1030	1497	2527	41%
08-26	ON	17.7	16.7	172	60	152	15	188	187	61	834	1297	2132	39%
08-27	ON	23.4	22.0	235	146	199	30	244	214	79	1149	1419	2568	45%
08-28	ON	29.5	28.0	239	103	245	30	353	270	105	1346	1369	2715	50%
08-29	ON	30.3	28.5	279	114	246	37	338	272	120	1407	1379	2786	50%
08-30	ON	22.0	20.3	233	144	268	29	282	231	97	1284	1358	2643	49%
08-31	ON	10.5	9.2	177	81	173	18	206	178	67	900	1503	2404	37%
09-01	ON	11.9	10.9	153	114	171	15	198	173	50	873	1517	2390	37%
09-02	ON	18.5	17.5	173	104	150	19	192	180	64	882	1299	2182	40%
09-03	OFF	27.3	26.1	313	366	221	28	312	373	77	1691	1447	3139	54%
09-04	OFF	23.3	22.6	390	369	191	25	288	396	75	1733	1361	3095	56%
09-05	OFF	23.3	22.8	389	365	176	28	223	395	77	1652	1364	3016	55%
09-06	OFF	23.0	22.5	389	367	187	24	260	395	81	1702	1379	3082	55%
09-07	OFF	11.3	11.3	353	326	85	15	127	358	58	1322	1523	2845	46%
09-08	OFF	6.4	6.1	208	259	93	11	119	236	45	971	1529	2500	39%
09-09	OFF	2.2	2.1	154	112	71	5	71	187	22	622	1317	1939	32%
09-10	ON	6.4	6.5	125	62	70	6	72	140	31	505	1484	1989	25%
09-11	OFF	14.1	13.6	152	257	129	12	142	306	37	1035	1401	2437	42%
09-12	OFF	11.4	10.8	137	295	108	13	140	322	41	1056	1426	2482	43%
09-13	OFF	11.3	10.8	143	243	102	11	132	327	36	994	1395	2388	42%
09-14	OFF	12.7	13.3	394	261	239	9	256	364	49	1571	1488	3060	51%
09-15	OFF	11.7	11.5	181	279	127	13	155	375	31	1160	1522	2682	43%
09-16	OFF	17.2	16.7	187	288	143	16	190	315	37	1176	1299	2475	48%
09-17	OFF	18.8	18.2	190	420	147	17	182	332	44	1333	1459	2792	48%
09-18	OFF	14.6	13.9	154	366	120	16	149	322	43	1171	1397	2568	46%
09-19	OFF	6.6	6.0	130	247	84	9	85	321	25	901	1432	2333	39%
09-20	OFF	6.1	5.6	135	236	80	9	104	324	18	906	1390	2296	39%
09-21	OFF	11.1	10.8	293	230	135	11	140	383	25	1217	1461	2678	45%
09-22	OFF	7.7	7.4	246	133	88	8	126	331	23	955	1504	2459	39%
09-23	OFF	2.2	2.7	65	11	70	9	71	69	13	307	1315	1622	19%
09-24	OFF	0.3	1.5	70	12	70	9	74	67	12	313	1463	1776	18%
09-25	OFF	6.8	7.5	176	68	68	5	72	252	7	648	1396	2044	32%
09-26	OFF	19.1	18.7	177	286	147	12	193	334	30	1179	1414	2593	45%
09-27	OFF	6.8	6.2	139	341	86	9	97	321	22	1015	1400	2415	42%
09-28	OFF	1.8	1.5	140	247	74	7	77	344	14	903	1507	2410	37%
09-29	OFF	5.5	5.6	191	220	94	6	144	328	12	995	1534	2530	39%
09-30	OFF	3.8	4.9	135	23	68	4	70	173	13	487	1446	1933	25%
10-01	OFF	2.3	2.9	150	218	73	5	75	313	11	846	1470	2316	37%
10-02	OFF	1.5	2.1	166	222	73	4	75	311	12	863	1429	2292	38%
10-03	OFF	3.1	3.7	169	226	72	4	75	312	12	871	1468	2339	37%
10-04	OFF	10.5	10.5	170	269	78	8	100	327	23	975	1427	2402	41%
10-05	OFF	1.4	2.3	269	168	79	5	80	308	15	925	1549	2473	37%
10-06	OFF	4.2	6.4	301	13	81	5	88	350	9	848	1590	2438	35%
10-07	OFF	8.9	9.2	173	230	102	7	133	310	22	976	1398	2374	41%
10-08	OFF	0.1	0.8	302	102	75	6	76	313	13	886	1518	2405	37%
10-09	OFF	14.2	14.5	182	274	126	9	142	343	29	1105	1403	2508	44%
10-10	OFF	18.7	18.2	204	426	162	15	213	362	44	1426	1454	2880	50%
10-11	OFF	3.8	3.6	106	377	74	4	74	323	31	988	1442	2430	41%
10-12	OFF	1.4	2.0	235	126	78	4	76	246	15	781	1521	2301	34%
10-13	OFF	0.0	1.9	78	13	82	5	80	75	11	344	1582	1926	18%
10-14	OFF	0.2	2.9	65	11	83	4	68	63	7	301	1337	1638	18%
	Max.	30.3	28.5	394	426	268	53	353	396	120	1733	1590	3139	56%
	Avg.	**12.1**	**11.9**	**215**	**208**	**124**	**14**	**153**	**281**	**42**	**1037**	**1430**	**2467**	**41%**
	Min.	0.0	0.8	65	11	68	4	68	63	7	301	1296	1622	18%
Avg.	OFF	10.6	10.6	225	242	111	11	137	309	35	1069	1437	2506	41%
	ON	16.9	15.8	182	102	167	21	203	192	66	932	1410	2342	39%
	Diff.	6.4	5.2	-43	-140	56	10	66	-117	31	-137	-27	-165	

Site B: W. Springfield, MA

2018-	eCurv	CDD_{55}		RTU # (kWh)						SITE (kWh)			RTU
MM-DD	Status	(°F)	Adj.	1	2	3	4	5	6	RTU	OTHER	TOTAL	(%)
08-13	ON	16.7	15.0	250	106	265	181	114	271	1186	1775	2961	40%
08-14	ON	18.9	17.3	217	224	233	179	119	293	1265	1768	3033	42%
08-15	ON	22.2	20.4	210	245	212	181	111	260	1219	1637	2856	43%
08-16	ON	23.2	21.2	201	295	231	187	136	262	1313	1653	2966	44%
08-17	ON	22.2	20.1	244	204	271	208	130	263	1319	1697	3016	44%
08-18	ON	18.1	16.4	257	214	228	215	105	275	1295	1753	3048	42%
08-19	ON	14.8	13.0	160	167	189	133	84	234	968	1605	2573	38%
08-20	OFF	13.8	11.9	187	116	191	146	107	254	1002	1668	2670	38%
08-21	OFF	14.2	12.2	190	88	193	145	96	249	960	1671	2632	36%
08-22	OFF	16.6	15.2	295	118	179	289	106	256	1244	1621	2865	43%
08-23	OFF	11.6	10.7	286	22	148	280	90	247	1073	1649	2722	39%
08-24	OFF	14.7	14.3	315	223	131	309	98	267	1344	1665	3009	45%
08-25	OFF	13.8	13.6	330	180	130	323	98	281	1342	1735	3077	44%
08-26	OFF	17.1	17.0	271	173	111	266	88	230	1138	1573	2711	42%
08-27	OFF	22.5	21.6	303	124	168	296	123	265	1279	1692	2971	43%
08-28	OFF	28.0	26.7	321	228	209	314	139	289	1499	1605	3105	48%
08-29	OFF	28.3	26.9	326	260	242	319	144	331	1620	1612	3232	50%
08-30	OFF	21.6	20.2	314	80	205	308	127	306	1340	1647	2987	45%
08-31	OFF	12.7	11.9	305	107	134	299	108	269	1222	1722	2944	42%
09-01	OFF	13.4	13.1	329	147	93	323	97	267	1258	1756	3014	42%
09-02	OFF	18.2	17.7	273	200	104	267	98	90	1031	1582	2612	39%
09-03	ON	25.9	24.2	215	284	257	186	151	134	1226	1698	2924	42%
09-04	ON	23.6	21.8	245	283	201	225	137	153	1245	1649	2894	43%
09-05	ON	23.5	21.7	236	269	203	215	133	140	1196	1671	2867	42%
09-06	ON	22.6	20.8	231	250	202	210	126	246	1264	1645	2909	43%
09-07	ON	11.9	10.3	184	211	164	162	101	273	1095	1736	2831	39%
09-08	ON	6.0	4.9	160	190	138	148	91	258	985	1768	2753	36%
09-09	ON	1.8	1.0	76	109	90	67	51	25	418	1643	2061	20%
09-10	OFF	2.4	1.7	137	171	80	132	69	92	679	1748	2427	28%
09-11	ON	13.4	12.5	146	120	155	113	108	230	873	1692	2565	34%
09-12	ON	13.1	11.6	193	152	167	140	114	241	1007	1684	2690	37%
09-13	ON	14.0	12.5	196	115	177	152	104	243	987	1700	2687	37%
09-14	ON	13.6	12.0	197	159	184	157	116	262	1074	1729	2803	38%
09-15	ON	15.7	14.3	237	154	207	190	111	265	1164	1781	2945	40%
09-16	ON	18.2	16.4	158	215	194	152	113	224	1055	1605	2660	40%
09-17	OFF	18.6	17.3	305	201	135	299	126	295	1362	1716	3078	44%
09-18	OFF	15.7	14.8	288	62	116	283	106	261	1116	1694	2810	40%
09-19	OFF	13.1	12.6	281	163	81	276	99	239	1139	1667	2806	41%
09-20	OFF	9.1	8.9	275	77	61	271	90	230	1005	1690	2695	37%
09-21	OFF	11.2	11.2	296	40	64	292	87	245	1023	1727	2750	37%
09-22	OFF	6.8	7.0	301	68	68	295	81	241	1055	1775	2830	37%
09-23	OFF	1.6	1.5	66	109	78	53	56	25	387	1660	2047	19%
09-24	OFF	0.5	0.0	70	60	78	53	57	23	341	1758	2099	16%
09-25	OFF	2.2	1.2	89	83	97	63	57	34	423	1731	2154	20%
09-26	OFF	14.9	14.2	286	99	76	280	95	235	1071	1664	2735	39%
09-27	OFF	7.4	7.1	277	94	60	272	81	227	1011	1676	2687	38%
09-28	OFF	1.2	1.2	139	159	66	135	63	90	651	1772	2423	27%
09-29	OFF	4.8	5.0	240	93	93	221	69	173	889	1794	2684	33%
09-30	OFF	3.4	3.0	74	123	101	62	60	38	460	1650	2110	22%
10-01	ON	4.9	3.8	80	157	146	81	83	119	667	1765	2432	27%
10-02	ON	2.7	1.8	119	120	116	90	72	209	726	1743	2469	29%
10-03	ON	7.4	6.5	117	160	145	102	78	211	812	1692	2504	32%
10-04	ON	11.7	10.4	143	165	158	122	91	214	892	1684	2576	35%
10-05	ON	2.4	1.2	77	132	89	79	62	42	480	1769	2249	21%
10-06	ON	4.4	3.4	117	93	150	81	63	44	548	1815	2363	23%
10-07	ON	13.8	12.3	143	207	199	127	95	196	967	1626	2593	37%
10-08	OFF	3.0	2.5	279	136	71	271	71	231	1059	1770	2830	37%
10-09	OFF	14.0	14.2	288	80	58	281	85	233	1025	1687	2712	38%
10-10	OFF	18.5	18.1	296	163	82	290	92	240	1163	1703	2866	41%
10-11	OFF	14.8	14.5	281	161	80	274	89	250	1134	1661	2795	41%
10-12	OFF	2.4	1.9	62	156	64	60	59	32	434	1765	2199	20%
10-13	OFF	0.0	-0.5	65	79	68	60	35	19	326	1831	2158	15%
10-14	OFF	0.5	0.2	58	89	64	50	36	13	311	1657	1968	16%
	Max.	28.3	26.9	330	295	271	323	151	331	1620	1831	3232	50%
	Avg.	**12.7**	**11.7**	**211**	**151**	**142**	**194**	**95**	**201**	**995**	**1698**	**2693**	**36%**
	Min.	0.0	-0.5	58	22	58	50	35	13	311	1573	1968	15%
Avg.	OFF	11.5	10.9	236	126	111	227	88	196	984	1694	2678	36%
	ON	14.3	12.8	178	185	184	151	104	207	1009	1703	2712	37%
	Diff.	2.9	2.0	-58	59	74	-75	15	11	25	9	34	

Table 16. Daytime energy consumption (9 A.M. to 9 P.M.)

Site A: Burlington, MA

2018-	eCurv	CDD_{55}		RTU # (kWh)							SITE (kWh)			RTU
MM-DD	**Status**	**(°F)**	**Adj.**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**RTU**	**OTHER**	**TOTAL**	**(%)**
08-13	OFF	14.0	13.7	183	181	71	10	96	186	24	751	993	1745	43%
08-14	OFF	18.5	18.3	192	204	103	14	148	196	30	887	1000	1887	47%
08-15	OFF	22.2	21.9	196	213	118	18	175	199	39	957	990	1947	49%
08-16	OFF	23.5	22.9	199	219	141	21	216	202	38	1036	991	2028	51%
08-17	OFF	20.6	20.2	194	212	134	19	170	198	34	961	1004	1965	49%
08-18	OFF	18.2	17.8	191	211	143	13	212	196	25	990	990	1980	50%
08-19	OFF	12.8	12.7	183	177	77	13	106	187	22	765	995	1760	43%
08-20	ON	12.3	11.6	131	139	109	11	132	150	26	699	999	1698	41%
08-21	ON	11.6	10.8	123	93	86	10	109	129	26	576	1007	1583	36%
08-22	ON	15.9	14.9	140	99	106	12	145	166	32	700	999	1700	41%
08-23	ON	11.7	10.7	135	96	107	13	119	145	27	642	1001	1643	39%
08-24	ON	16.1	15.2	149	10	132	17	170	167	36	681	998	1679	41%
08-25	ON	16.0	15.0	169	79	142	10	174	181	31	785	990	1775	44%
08-26	ON	17.7	16.7	165	49	143	14	181	177	35	764	997	1761	43%
08-27	ON	23.4	22.0	182	102	171	27	212	192	44	930	997	1927	48%
08-28	ON	29.5	28.0	209	98	214	26	308	246	65	1166	987	2153	54%
08-29	ON	30.3	28.5	244	99	213	29	291	241	65	1182	993	2176	54%
08-30	ON	22.0	20.3	198	127	218	22	240	203	53	1061	990	2051	52%
08-31	ON	10.5	9.2	141	67	143	16	174	151	35	727	1007	1733	42%
09-01	ON	11.9	10.9	130	85	130	13	156	150	33	696	1002	1699	41%
09-02	ON	18.5	17.5	161	77	140	18	185	173	40	796	1007	1803	44%
09-03	OFF	27.3	26.1	250	231	192	24	287	303	33	1320	989	2309	57%
09-04	OFF	23.3	22.6	198	218	163	22	254	202	40	1096	989	2085	53%
09-05	OFF	23.3	22.8	199	226	149	24	200	203	47	1048	994	2042	51%
09-06	OFF	23.0	22.5	198	227	161	22	230	202	41	1081	1004	2086	52%
09-07	OFF	11.3	11.3	185	189	65	13	93	188	35	768	1022	1790	43%
09-08	OFF	6.4	6.1	173	157	69	9	98	184	21	713	1011	1724	41%
09-09	OFF	2.2	2.1	146	98	62	5	65	178	13	567	1013	1579	36%
09-10	ON	6.4	6.5	103	48	57	5	61	119	24	417	1034	1450	29%
09-11	OFF	14.1	13.6	133	195	106	10	119	272	24	860	1014	1875	46%
09-12	OFF	11.4	10.8	115	205	83	11	120	286	23	842	1020	1861	45%
09-13	OFF	11.3	10.8	122	206	88	10	115	290	18	850	1004	1855	46%
09-14	OFF	12.7	13.3	330	208	209	8	226	303	35	1319	992	2312	57%
09-15	OFF	11.7	11.5	136	208	90	11	123	292	20	879	1015	1894	46%
09-16	OFF	17.2	16.7	171	217	134	16	184	302	23	1046	1006	2052	51%
09-17	OFF	18.8	18.2	164	214	121	15	160	296	30	999	1010	2009	50%
09-18	OFF	14.6	13.9	124	208	105	14	127	286	18	883	1013	1895	47%
09-19	OFF	6.6	6.0	105	205	67	9	73	285	14	758	1023	1781	43%
09-20	OFF	6.1	5.6	115	200	67	8	93	287	8	777	1019	1796	43%
09-21	OFF	11.1	10.8	215	187	94	9	100	306	13	924	1007	1931	48%
09-22	OFF	7.7	7.4	199	97	64	7	105	286	13	770	1008	1779	43%
09-23	OFF	2.2	2.7	58	8	61	4	64	62	7	265	1022	1287	21%
09-24	OFF	0.3	1.5	59	8	58	5	63	56	7	257	1039	1296	20%
09-25	OFF	6.8	7.5	165	48	57	4	61	222	4	560	1020	1580	35%
09-26	OFF	19.1	18.7	152	215	124	11	170	296	18	986	1008	1994	49%
09-27	OFF	6.8	6.2	119	204	70	8	86	285	11	784	1017	1801	44%
09-28	OFF	1.8	1.5	115	199	56	5	62	286	5	729	1028	1757	41%
09-29	OFF	5.5	5.6	146	196	71	4	123	283	6	829	1014	1842	45%
09-30	OFF	3.8	4.9	126	21	61	4	64	161	8	444	1040	1484	30%
10-01	OFF	2.3	2.9	130	199	61	4	64	279	7	743	1037	1780	42%
10-02	OFF	1.5	2.1	146	196	60	4	64	276	8	753	1043	1796	42%
10-03	OFF	3.1	3.7	150	198	60	4	64	277	7	760	1059	1819	42%
10-04	OFF	10.5	10.5	144	205	63	6	83	290	14	807	1038	1845	44%
10-05	OFF	1.4	2.3	245	54	60	4	64	273	10	710	1046	1757	40%
10-06	OFF	4.2	6.4	244	8	61	4	64	277	5	661	1039	1701	39%
10-07	OFF	8.9	9.2	138	209	95	6	115	297	16	876	1047	1923	46%
10-08	OFF	0.1	0.8	264	83	61	5	65	278	8	764	1036	1800	42%
10-09	OFF	14.2	14.5	155	212	111	8	126	299	22	933	1028	1962	48%
10-10	OFF	18.7	18.2	167	218	144	14	185	306	32	1067	1035	2102	51%
10-11	OFF	3.8	3.6	86	205	59	4	62	288	19	722	1041	1764	41%
10-12	OFF	1.4	2.0	211	107	60	4	61	226	8	675	1038	1712	39%
10-13	OFF	0.0	1.9	58	8	61	4	60	56	6	253	1045	1298	20%
10-14	OFF	0.2	2.9	58	8	76	4	61	57	4	267	1043	1310	20%
	Max.	30.3	28.5	330	231	218	29	308	306	65	1320	1059	2312	57%
	Avg.	**12.1**	**11.9**	**161**	**146**	**104**	**11**	**133**	**223**	**24**	**802**	**1014**	**1816**	**43%**
	Min.	0.0	0.8	58	8	56	4	60	56	4	253	987	1287	20%
Avg.	OFF	10.6	10.6	161	165	93	10	119	238	19	806	1018	1824	43%
	ON	16.9	15.8	159	84	141	16	177	173	38	788	1001	1789	43%
	Diff.	6.4	5.2	-3	-81	48	6	58	-66	19	-18	-18	-36	

Site B: W. Springfield, MA

2018-	eCurv	CDD_{55}		RTU # (kWh)						SITE (kWh)			RTU
MM-DD	Status	(°F)	Adj.	1	2	3	4	5	6	RTU	OTHER	TOTAL	(%)
08-13	ON	16.7	15.0	201	81	211	149	72	214	928	1067	1995	47%
08-14	ON	18.9	17.3	153	210	177	144	82	216	982	1083	2065	48%
08-15	ON	22.2	20.4	176	220	191	159	85	216	1047	1068	2115	49%
08-16	ON	23.2	21.2	171	265	206	156	105	211	1113	1070	2184	51%
08-17	ON	22.2	20.1	191	183	224	162	94	195	1050	1078	2128	49%
08-18	ON	18.1	16.4	190	187	182	165	75	199	996	1086	2083	48%
08-19	ON	14.8	13.0	140	157	180	117	66	214	873	1098	1971	44%
08-20	OFF	13.8	11.9	170	101	172	130	79	213	865	1094	1959	44%
08-21	OFF	14.2	12.2	174	76	176	131	73	213	844	1092	1936	44%
08-22	OFF	16.6	15.2	259	107	159	253	82	215	1076	1066	2142	50%
08-23	OFF	11.6	10.7	259	14	134	253	67	210	937	1082	2018	46%
08-24	OFF	14.7	14.3	267	197	115	262	74	217	1133	1053	2186	52%
08-25	OFF	13.8	13.6	264	150	111	258	74	217	1073	1069	2143	50%
08-26	OFF	17.1	17.0	264	168	104	258	74	219	1087	1063	2150	51%
08-27	OFF	22.5	21.6	275	120	146	268	90	226	1123	1065	2188	51%
08-28	OFF	28.0	26.7	284	217	186	276	107	238	1309	1049	2359	56%
08-29	OFF	28.3	26.9	284	226	216	277	107	241	1352	1057	2408	56%
08-30	OFF	21.6	20.2	274	74	182	266	93	222	1111	1072	2183	51%
08-31	OFF	12.7	11.9	257	100	119	251	75	211	1013	1085	2097	48%
09-01	OFF	13.4	13.1	261	125	68	255	71	213	993	1087	2081	48%
09-02	OFF	18.2	17.7	266	195	97	259	79	86	982	1076	2059	48%
09-03	ON	25.9	24.2	195	256	226	165	112	110	1064	1079	2143	50%
09-04	ON	23.6	21.8	218	249	175	189	104	101	1036	1084	2120	49%
09-05	ON	23.5	21.7	209	235	179	182	96	106	1007	1090	2096	48%
09-06	ON	22.6	20.8	193	220	181	175	91	179	1038	1077	2115	49%
09-07	ON	11.9	10.3	148	174	133	127	69	210	860	1099	1960	44%
09-08	ON	6.0	4.9	122	159	112	114	65	205	778	1102	1880	41%
09-09	ON	1.8	1.0	70	104	83	60	45	21	384	1138	1522	25%
09-10	OFF	2.4	1.7	110	154	70	106	54	71	565	1122	1687	34%
09-11	ON	13.4	12.5	125	110	134	99	85	209	762	1116	1878	41%
09-12	ON	13.1	11.6	164	129	145	124	72	208	841	1108	1949	43%
09-13	ON	14.0	12.5	161	104	155	134	65	210	830	1112	1942	43%
09-14	ON	13.6	12.0	158	130	149	125	80	211	853	1108	1962	43%
09-15	ON	15.7	14.3	172	145	165	143	75	201	901	1106	2007	45%
09-16	ON	18.2	16.4	143	208	187	135	81	205	958	1093	2051	47%
09-17	OFF	18.6	17.3	262	179	118	256	89	218	1122	1091	2213	51%
09-18	OFF	15.7	14.8	254	48	103	248	67	212	931	1105	2036	46%
09-19	OFF	13.1	12.6	255	143	70	249	68	211	996	1095	2091	48%
09-20	OFF	9.1	8.9	248	71	50	245	58	206	879	1100	1979	44%
09-21	OFF	11.2	11.2	248	31	50	245	56	207	837	1104	1941	43%
09-22	OFF	6.8	7.0	251	53	50	246	52	204	856	1103	1959	44%
09-23	OFF	1.6	1.5	59	104	72	46	43	21	344	1150	1494	23%
09-24	OFF	0.5	0.0	60	55	67	43	41	19	285	1155	1439	20%
09-25	OFF	2.2	1.2	66	65	77	44	42	20	313	1155	1468	21%
09-26	OFF	14.9	14.2	259	90	65	253	67	214	948	1099	2047	46%
09-27	OFF	7.4	7.1	250	87	50	246	56	206	894	1098	1992	45%
09-28	OFF	1.2	1.2	126	147	51	122	42	84	572	1129	1701	34%
09-29	OFF	4.8	5.0	196	70	60	192	50	153	721	1118	1839	39%
09-30	OFF	3.4	3.0	68	118	95	55	47	34	418	1144	1562	27%
10-01	ON	4.9	3.8	70	140	129	66	62	91	558	1150	1708	33%
10-02	ON	2.7	1.8	105	102	105	76	52	186	626	1141	1767	35%
10-03	ON	7.4	6.5	105	144	130	88	55	190	712	1114	1825	39%
10-04	ON	11.7	10.4	132	144	137	106	62	193	774	1103	1877	41%
10-05	ON	2.4	1.2	59	116	71	65	41	34	386	1144	1530	25%
10-06	ON	4.4	3.4	91	75	116	58	42	25	406	1142	1549	26%
10-07	ON	13.8	12.3	136	201	192	120	71	190	911	1098	2008	45%
10-08	OFF	3.0	2.5	251	126	60	244	40	204	925	1095	2020	46%
10-09	OFF	14.0	14.2	260	67	48	254	63	212	904	1098	2001	45%
10-10	OFF	18.5	18.1	267	143	70	261	66	217	1023	1079	2102	49%
10-11	OFF	14.8	14.5	254	142	70	247	59	208	982	1091	2073	47%
10-12	OFF	2.4	1.9	48	143	50	48	37	19	345	1145	1490	23%
10-13	OFF	0.0	-0.5	48	62	51	44	22	14	240	1157	1396	17%
10-14	OFF	0.5	0.2	51	84	58	44	26	10	272	1152	1424	19%
	Max.	28.3	26.9	284	265	226	277	112	241	1352	1157	2408	56%
	Avg.	**12.7**	**11.7**	**182**	**135**	**122**	**167**	**68**	**166**	**840**	**1101**	**1941**	**42%**
	Min.	0.0	-0.5	48	14	48	43	22	10	240	1049	1396	17%
Avg.	OFF	11.5	10.9	162	135	118	147	64	155	781	1109	1889	40%
	ON	14.3	12.8	244	135	137	234	80	201	1031	1075	2106	49%
	Diff.	2.9	2.0	82	0	19	87	16	46	250	-33	217	

Table 17. Daily peak power draw (8 A.M. to 9 P.M.)

Site A: Burlington, MA

2018-	eCurv	CDD55		RTU # (kW)							SITE (kW)			RTU
MM-DD	**Status**	**(°F)**	**Adj.**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**RTU**	**OTHER**	**TOTAL**	**(%)**
08-13	OFF	14.0	13.7	16	18	14	4	16	16	5	81	105	167	49%
08-14	OFF	18.5	18.3	16	19	17	5	17	17	5	89	104	182	49%
08-15	OFF	22.2	21.9	17	19	17	5	28	17	5	100	105	186	54%
08-16	OFF	23.5	22.9	17	20	17	6	29	17	5	106	105	196	54%
08-17	OFF	20.6	20.2	17	19	16	5	17	17	5	92	104	191	48%
08-18	OFF	18.2	17.8	17	19	16	5	27	17	5	102	106	197	52%
08-19	OFF	12.8	12.7	16	18	15	5	16	16	5	84	103	163	52%
08-20	ON	12.3	11.6	16	18	16	4	17	16	5	73	106	151	49%
08-21	ON	11.6	10.8	16	18	16	4	16	16	5	58	105	142	41%
08-22	ON	15.9	14.9	16	18	16	5	17	17	5	71	106	152	47%
08-23	ON	11.7	10.7	16	18	16	5	17	16	5	68	105	147	46%
08-24	ON	16.1	15.2	17	1	17	5	17	17	5	74	104	154	48%
08-25	ON	16.0	15.0	16	18	17	4	17	17	5	79	104	157	50%
08-26	ON	17.7	16.7	16	18	17	5	17	17	5	75	104	161	47%
08-27	ON	23.4	22.0	17	19	18	7	26	28	5	95	103	176	54%
08-28	ON	29.5	28.0	27	20	30	6	40	39	6	114	103	193	59%
08-29	ON	30.3	28.5	39	21	27	7	30	49	6	111	104	190	59%
08-30	ON	22.0	20.3	37	20	28	6	28	26	5	103	103	182	56%
08-31	ON	10.5	9.2	16	18	16	4	20	16	5	70	103	149	47%
09-01	ON	11.9	10.9	16	18	16	4	17	16	5	82	104	161	51%
09-02	ON	18.5	17.5	17	18	17	5	28	17	5	78	103	162	48%
09-03	OFF	27.3	26.1	26	21	17	6	38	27	6	128	102	206	62%
09-04	OFF	23.3	22.6	17	20	17	6	29	17	5	108	103	194	56%
09-05	OFF	23.3	22.8	17	20	17	6	25	17	5	101	102	202	50%
09-06	OFF	23.0	22.5	17	21	18	6	30	18	6	113	102	204	55%
09-07	OFF	11.3	11.3	16	17	10	5	16	16	5	77	104	177	43%
09-08	OFF	6.4	6.1	15	17	19	3	16	16	5	72	106	165	44%
09-09	OFF	2.2	2.1	15	15	18	3	10	15	4	58	105	158	37%
09-10	ON	6.4	6.5	15	9	5	3	5	15	5	56	104	159	35%
09-11	OFF	14.1	13.6	23	18	16	5	17	25	5	100	105	192	52%
09-12	OFF	11.4	10.8	25	17	16	4	16	25	5	93	104	182	51%
09-13	OFF	11.3	10.8	23	17	16	5	16	26	5	93	103	193	48%
09-14	OFF	12.7	13.3	35	18	27	4	30	34	5	138	102	221	63%
09-15	OFF	11.7	11.5	23	18	16	5	17	26	5	96	104	190	51%
09-16	OFF	17.2	16.7	23	19	17	5	27	26	5	111	103	196	57%
09-17	OFF	18.8	18.2	23	18	17	5	18	25	5	103	103	198	52%
09-18	OFF	14.6	13.9	24	18	16	5	16	25	5	93	103	180	52%
09-19	OFF	6.6	6.0	23	17	11	4	15	25	4	80	104	172	46%
09-20	OFF	6.1	5.6	23	17	11	4	16	25	4	81	103	183	44%
09-21	OFF	11.1	10.8	38	18	36	3	34	41	5	146	102	222	66%
09-22	OFF	7.7	7.4	30	17	15	3	27	34	5	101	106	179	56%
09-23	OFF	2.2	2.7	5	1	5	0	5	18	4	35	105	139	25%
09-24	OFF	0.3	1.5	5	1	5	0	5	5	2	23	106	127	18%
09-25	OFF	6.8	7.5	23	17	5	0	5	25	0	59	103	160	37%
09-26	OFF	19.1	18.7	23	18	16	4	21	26	5	100	103	202	50%
09-27	OFF	6.8	6.2	23	17	11	3	16	25	5	82	104	184	44%
09-28	OFF	1.8	1.5	23	17	5	3	8	25	3	76	104	168	45%
09-29	OFF	5.5	5.6	24	18	19	3	16	25	3	82	106	182	45%
09-30	OFF	3.8	4.9	23	17	5	0	5	24	5	73	106	154	47%
10-01	OFF	2.3	2.9	23	17	5	0	5	25	3	78	105	160	49%
10-02	OFF	1.5	2.1	23	16	5	0	5	23	3	75	104	160	47%
10-03	OFF	3.1	3.7	23	17	5	0	5	24	4	76	105	169	45%
10-04	OFF	10.5	10.5	23	17	10	4	12	26	5	77	105	180	43%
10-05	OFF	1.4	2.3	23	17	5	0	5	23	4	73	106	161	46%
10-06	OFF	4.2	6.4	22	1	5	0	5	23	1	58	105	163	35%
10-07	OFF	8.9	9.2	23	18	17	3	17	26	5	93	106	176	53%
10-08	OFF	0.1	0.8	23	16	5	0	5	23	4	76	103	161	47%
10-09	OFF	14.2	14.5	23	18	17	4	17	26	5	98	104	200	49%
10-10	OFF	18.7	18.2	25	19	18	5	22	26	5	109	104	204	54%
10-11	OFF	3.8	3.6	23	17	5	0	5	25	4	78	108	175	45%
10-12	OFF	1.4	2.0	23	17	5	0	5	25	3	75	107	158	47%
10-13	OFF	0.0	1.9	7	1	5	0	5	7	1	27	106	127	22%
10-14	OFF	0.2	2.9	5	1	14	0	5	5	0	30	105	126	24%
	Max.	30.3	28.5	39	21	36	7	40	49	6	146	108	222	66%
	Avg.	**12.1**	**11.9**	**20**	**16**	**14**	**4**	**17**	**22**	**4**	**84**	**104**	**174**	**48%**
	Min.	0.0	0.8	5	1	5	0	5	5	0	23	102	126	18%
Avg.	OFF	10.6	10.6	21	16	13	3	16	22	4	85	104	178	47%
	ON	16.9	15.8	20	17	18	5	21	22	5	81	104	162	49%
	Diff.	6.4	5.2	-0.8	0.8	5.0	1.7	4.9	-0.5	0.8	-4.8	-0.3	-15.4	

Site B: W. Springfield, MA

2018-	eCurv	CDD_{55}		RTU # (kW)						SITE (kW)			RTU
MM-DD	Status	(°F)	Adj.	1	2	3	4	5	6	RTU	OTHER	TOTAL	(%)
08-13	ON	16.7	15.0	22	14	27	20	10	18	91	96	178	51%
08-14	ON	18.9	17.3	22	25	17	22	11	18	90	99	177	50%
08-15	ON	22.2	20.4	24	26	24	23	11	20	97	97	183	53%
08-16	ON	23.2	21.2	24	35	22	23	15	20	104	97	189	55%
08-17	ON	22.2	20.1	23	42	40	23	13	20	98	98	185	53%
08-18	ON	18.1	16.4	22	24	16	22	11	19	90	101	178	50%
08-19	ON	14.8	13.0	22	24	23	22	11	19	82	104	171	48%
08-20	OFF	13.8	11.9	22	17	16	14	13	19	93	100	182	51%
08-21	OFF	14.2	12.2	23	18	16	14	14	19	94	100	180	52%
08-22	OFF	16.6	15.2	23	18	16	22	11	19	103	97	191	54%
08-23	OFF	11.6	10.7	22	7	16	22	12	18	89	98	176	50%
08-24	OFF	14.7	14.3	23	26	18	23	11	19	115	97	201	57%
08-25	OFF	13.8	13.6	23	24	16	22	8	19	110	97	197	56%
08-26	OFF	17.1	17.0	23	25	18	22	11	20	113	96	198	57%
08-27	OFF	22.5	21.6	24	26	17	23	13	20	115	97	201	58%
08-28	OFF	28.0	26.7	25	27	17	24	14	22	125	98	210	60%
08-29	OFF	28.3	26.9	25	27	28	24	14	22	130	96	215	60%
08-30	OFF	21.6	20.2	23	20	17	23	15	20	113	97	199	57%
08-31	OFF	12.7	11.9	22	15	16	22	12	18	98	99	188	52%
09-01	OFF	13.4	13.1	22	25	15	22	8	18	98	99	187	52%
09-02	OFF	18.2	17.7	23	25	16	22	13	9	102	97	188	54%
09-03	ON	25.9	24.2	24	27	29	23	16	10	104	97	191	54%
09-04	ON	23.6	21.8	24	27	17	23	14	10	100	99	188	53%
09-05	ON	23.5	21.7	24	26	17	23	13	10	97	98	185	52%
09-06	ON	22.6	20.8	24	27	24	23	16	21	103	100	190	54%
09-07	ON	11.9	10.3	22	23	15	21	12	18	82	99	171	48%
09-08	ON	6.0	4.9	21	17	15	21	7	17	73	100	164	44%
09-09	ON	1.8	1.0	19	18	23	11	9	10	76	104	163	47%
09-10	OFF	2.4	1.7	21	21	12	20	10	17	93	98	183	51%
09-11	ON	13.4	12.5	22	21	16	20	13	18	73	100	167	44%
09-12	ON	13.1	11.6	22	16	15	21	12	18	83	100	172	48%
09-13	ON	14.0	12.5	22	18	15	21	13	18	79	99	170	47%
09-14	ON	13.6	12.0	22	22	16	21	11	18	81	100	168	48%
09-15	ON	15.7	14.3	23	25	16	22	11	19	86	101	175	49%
09-16	ON	18.2	16.4	23	25	26	23	12	20	90	99	181	50%
09-17	OFF	18.6	17.3	22	24	16	22	11	19	110	101	198	55%
09-18	OFF	15.7	14.8	22	14	15	21	14	19	91	99	180	51%
09-19	OFF	13.1	12.6	22	19	15	21	10	18	98	99	190	52%
09-20	OFF	9.1	8.9	21	14	4	21	10	18	84	99	173	48%
09-21	OFF	11.2	11.2	21	3	4	21	10	17	76	98	168	45%
09-22	OFF	6.8	7.0	21	13	4	21	7	17	79	99	175	45%
09-23	OFF	1.6	1.5	24	17	16	8	9	11	53	104	144	37%
09-24	OFF	0.5	0.0	21	15	14	6	8	12	48	104	139	35%
09-25	OFF	2.2	1.2	16	13	13	7	7	8	45	102	145	31%
09-26	OFF	14.9	14.2	22	20	14	22	10	18	95	100	183	52%
09-27	OFF	7.4	7.1	21	14	4	21	8	17	81	98	177	46%
09-28	OFF	1.2	1.2	21	21	4	21	7	17	87	104	176	50%
09-29	OFF	4.8	5.0	21	26	23	21	9	17	73	103	163	45%
09-30	OFF	3.4	3.0	27	28	27	19	9	12	112	103	195	57%
10-01	ON	4.9	3.8	15	14	15	14	7	17	70	101	165	42%
10-02	ON	2.7	1.8	16	19	15	13	7	17	66	101	158	41%
10-03	ON	7.4	6.5	14	18	15	13	7	18	68	99	159	43%
10-04	ON	11.7	10.4	14	19	15	14	11	18	78	104	172	45%
10-05	ON	2.4	1.2	16	19	30	16	9	12	87	103	175	49%
10-06	ON	4.4	3.4	18	18	16	13	7	11	61	103	151	41%
10-07	ON	13.8	12.3	15	25	30	14	8	19	95	98	184	52%
10-08	OFF	3.0	2.5	21	13	10	21	9	17	84	98	180	47%
10-09	OFF	14.0	14.2	22	14	4	22	10	18	84	98	180	47%
10-10	OFF	18.5	18.1	23	14	15	22	11	19	99	97	188	52%
10-11	OFF	14.8	14.5	22	14	15	21	10	18	93	98	185	50%
10-12	OFF	2.4	1.9	6	19	7	8	9	11	47	103	139	34%
10-13	OFF	0.0	-0.5	5	6	8	7	5	5	26	103	127	20%
10-14	OFF	0.5	0.2	16	15	12	8	7	1	43	103	134	32%
	Max.	28.3	26.9	27	42	40	24	16	22	130	104	215	60%
	Avg.	**12.7**	**11.7**	**21**	**20**	**17**	**19**	**11**	**17**	**87**	**100**	**177**	**49%**
	Min.	0.0	-0.5	5	3	4	6	5	1	26	96	127	20%
Avg.	OFF	11.5	10.9	21	18	14	19	10	16	89	99	179	49%
	ON	14.3	12.8	21	23	20	20	11	17	85	100	174	49%
	Diff.	2.9	2.0	-0.4	4.4	6.5	0.6	0.8	0.4	-3.7	0.5	-4.3	

Table 18. Daily temperatures.

Site A: Burlington, MA

2018-	eCurv	CDD_{55}		HDD_{55}	Outdoor (°F)			RH	RTU # Avg. Zone Air (°F)								RTU # Min. Supply Air (°F)						
MM-DD	**Status**	**(°F)**	**Adj.**	**(°F)**	**Min**	**Avg**	**Max**	**(%)**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**FA**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
08-13	OFF	14.0	13.7	0.0	67	69	71	69	71	74	73	75	73	72	70	72.3	64	48	65	55	65	64	48
08-14	OFF	18.5	18.3	0.0	69	74	80	74	71	73	73	75	73	71	70	72.2	55	49	58	54	57	53	38
08-15	OFF	22.2	21.9	0.0	69	77	86	77	71	74	73	75	73	72	70	72.3	64	49	67	60	61	64	49
08-16	OFF	23.5	22.9	0.0	68	79	88	79	72	74	73	75	73	72	70	72.6	65	50	67	58	61	65	46
08-17	OFF	20.6	20.2	0.0	67	76	83	76	71	74	73	75	73	72	70	72.4	64	48	65	58	66	64	47
08-18	OFF	18.2	17.8	0.0	66	73	83	73	72	74	73	75	73	72	70	72.5	65	49	65	58	60	65	48
08-19	OFF	12.8	12.7	0.0	65	68	72	68	71	74	73	75	73	71	70	72.0	64	48	65	57	64	64	47
08-20	ON	12.3	11.6	0.0	61	67	74	67	72	73	73	75	73	72	70	72.8	63	63	63	57	63	62	48
08-21	ON	11.6	10.8	0.0	61	67	71	67	73	73	73	75	73	73	70	72.8	61	63	60	58	60	59	48
08-22	ON	15.9	14.9	0.0	64	71	80	71	73	73	73	75	73	73	70	73.0	22	56	33	45	44	22	33
08-23	ON	11.7	10.7	0.0	57	67	77	67	73	73	73	75	74	73	70	73.1	63	62	63	56	63	61	47
08-24	ON	16.1	15.2	0.0	57	71	84	71	73	73	73	75	73	73	70	72.9	59	67	58	57	58	57	46
08-25	ON	16.0	15.0	0.0	59	71	82	71	73	73	73	81	73	73	70	73.0	64	64	63	51	62	62	48
08-26	ON	17.7	16.7	0.0	58	73	83	73	73	73	73	75	73	73	70	73.1	61	64	58	59	58	58	48
08-27	ON	23.4	22.0	0.0	68	78	87	78	73	73	73	75	74	74	70	73.3	66	65	64	58	61	63	50
08-28	ON	29.5	28.0	0.0	71	85	94	85	74	73	74	75	73	74	70	73.5	65	66	62	61	58	61	45
08-29	ON	30.3	28.5	0.0	75	85	95	85	74	74	74	76	74	74	70	73.8	62	53	64	60	63	60	54
08-30	ON	22.0	20.3	0.0	66	77	86	77	74	74	74	76	74	74	70	73.7	61	50	60	57	60	61	50
08-31	ON	10.5	9.2	0.0	57	65	73	65	73	74	73	75	73	73	70	73.3	60	64	62	56	59	59	48
09-01	ON	11.9	10.9	0.0	58	67	75	67	73	73	73	75	73	73	70	72.9	59	64	59	56	59	58	48
09-02	ON	18.5	17.5	0.0	60	74	84	74	73	73	73	75	73	73	70	73.1	63	64	61	58	60	61	48
09-03	OFF	27.3	26.1	0.0	71	82	92	82	73	74	73	76	73	73	70	73.3	64	51	67	60	59	62	51
09-04	OFF	23.3	22.6	0.0	68	78	88	78	72	74	73	75	72	72	70	72.8	53	50	46	36	51	53	34
09-05	OFF	23.3	22.8	0.0	68	78	89	78	72	74	73	76	73	72	70	72.6	64	50	67	58	61	64	50
09-06	OFF	23.0	22.5	0.0	68	78	93	78	72	74	73	75	73	72	70	72.6	66	49	66	59	60	65	48
09-07	OFF	11.3	11.3	0.0	62	66	71	66	71	74	73	75	73	71	70	72.0	61	67	64	56	63	60	46
09-08	OFF	6.4	6.1	0.1	54	61	68	61	72	73	73	75	73	72	70	72.4	60	50	52	54	52	58	45
09-09	OFF	2.2	2.1	0.1	54	57	62	57	72	73	72	75	72	72	70	72.1	53	56	51	52	53	51	45
09-10	ON	6.4	6.5	0.0	55	61	65	61	72	72	72	74	72	72	70	71.9	52	64	52	54	51	50	46
09-11	OFF	14.1	13.6	0.0	63	69	76	69	72	72	73	75	73	72	70	72.5	23	41	22	35	45	35	36
09-12	OFF	11.4	10.8	0.0	65	66	69	66	73	71	73	75	73	73	70	72.6	62	61	63	56	63	57	45
09-13	OFF	11.3	10.8	0.0	61	66	71	66	73	71	73	75	73	73	70	72.5	61	61	63	57	63	57	46
09-14	OFF	12.7	13.3	0.0	61	68	76	68	72	71	71	75	71	72	69	71.4	54	59	56	54	54	53	43
09-15	OFF	11.7	11.5	0.0	61	67	76	67	72	71	72	75	72	72	70	72.2	59	60	60	56	60	57	46
09-16	OFF	17.2	16.7	0.0	60	72	85	72	73	71	73	75	73	73	70	72.5	60	62	58	57	58	57	46
09-17	OFF	18.8	18.2	0.0	66	74	82	74	73	71	73	75	73	73	70	72.6	62	67	65	57	63	59	46
09-18	OFF	14.6	13.9	0.0	66	70	73	70	73	71	73	75	73	73	70	72.8	63	61	64	57	64	59	46
09-19	OFF	6.6	6.0	0.0	59	62	66	62	73	71	73	75	73	73	70	72.6	60	59	61	55	61	56	45
09-20	OFF	6.1	5.6	0.0	58	61	65	61	73	70	73	75	73	73	71	72.4	58	59	58	54	58	55	45
09-21	OFF	11.1	10.8	0.0	58	66	71	66	73	70	73	75	73	73	70	72.3	57	58	52	53	49	51	45
09-22	OFF	7.7	7.4	1.5	46	61	69	61	73	71	72	75	72	73	70	72.3	56	59	53	51	52	53	43
09-23	OFF	2.2	2.7	2.9	46	54	62	54	72	71	71	75	71	72	70	71.5	50	63	47	44	50	47	45
09-24	OFF	0.3	1.5	2.7	47	53	57	53	71	71	71	74	70	71	70	70.8	53	62	47	45	51	47	45
09-25	OFF	6.8	7.5	1.0	47	61	68	61	71	69	71	72	71	72	69	71.3	24	32	16	26	16	16	33
09-26	OFF	19.1	18.7	0.0	65	74	81	74	73	71	73	75	73	73	70	72.3	61	68	64	58	61	59	47
09-27	OFF	6.8	6.2	0.0	57	62	69	62	73	70	73	75	73	73	70	72.5	59	58	59	54	58	55	45
09-28	OFF	1.8	1.5	1.0	51	56	60	56	73	70	73	75	73	73	71	72.3	58	57	58	53	57	55	45
09-29	OFF	5.5	5.6	1.9	47	59	71	59	72	69	72	74	72	72	71	71.9	52	56	51	53	53	50	45
09-30	OFF	3.8	4.9	1.6	46	57	67	57	71	70	71	74	71	70	70	70.9	50	57	46	56	49	46	45
10-01	OFF	2.3	2.9	0.1	54	57	62	57	72	70	71	74	71	72	71	71.4	57	58	53	60	55	52	45
10-02	OFF	1.5	2.1	0.2	54	56	58	56	72	69	70	73	71	72	70	71.4	55	59	30	61	55	53	45
10-03	OFF	3.1	3.7	0.4	53	58	61	58	72	70	71	74	71	72	71	71.4	54	60	53	59	53	53	45
10-04	OFF	10.5	10.5	0.0	58	65	72	65	72	70	72	74	72	72	70	72.0	59	65	59	57	59	57	45
10-05	OFF	1.4	2.3	3.2	45	53	61	53	72	70	71	74	71	71	70	71.0	55	57	50	54	51	46	45
10-06	OFF	4.2	6.4	1.3	47	58	63	58	70	70	70	73	69	69	70	69.7	52	62	47	56	49	46	45
10-07	OFF	8.9	9.2	0.0	57	64	76	64	72	70	72	74	72	72	70	71.7	59	61	60	57	60	56	45
10-08	OFF	0.1	0.8	0.8	53	54	57	54	72	71	71	74	71	71	71	71.3	56	57	55	60	55	54	45
10-09	OFF	14.2	14.5	0.0	56	69	77	69	72	70	71	74	71	71	70	71.7	57	51	35	53	34	54	45
10-10	OFF	18.7	18.2	0.0	66	74	84	74	73	71	73	75	73	73	70	72.4	61	66	66	59	62	62	46
10-11	OFF	3.8	3.6	0.0	56	59	66	59	73	70	72	75	72	73	70	72.2	60	60	58	61	58	54	46
10-12	OFF	1.4	2.0	2.8	45	54	61	54	72	71	71	74	71	72	71	71.4	57	57	50	56	55	55	45
10-13	OFF	0.0	1.9	9.2	40	46	51	46	71	70	68	72	70	71	70	70.1	50	62	46	50	50	47	54
10-14	OFF	0.2	2.9	8.6	38	47	57	47	69	69	68	71	70	70	69	69.3	45	58	41	45	44	40	55
	Max.	30.3	28.5	9.2	75	85	95	85	74	74	74	81	74	74	71	73.8	66	68	67	61	66	65	55
	Avg.	**12.1**	**11.9**	**0.6**	**59**	**66**	**74**	**66**	**72**	**72**	**72**	**75**	**72**	**72**	**70**	**72.2**	**57**	**58**	**56**	**54**	**56**	**55**	**46**
	Min.	0.0	0.8	0.0	38	46	51	46	69	69	68	71	69	69	69	69.3	22	32	16	26	16	16	33
Avg.	OFF	10.6	10.6	0.8	58	65	72	65	72	71	72	74	72	72	70	71.9	57	56	55	54	55	54	45
	ON	16.9	15.8	0.0	62	72	81	72	73	73	73	76	73	73	70	73.1	59	62	59	56	59	57	47
	Diff.	6.4	5.2	-0.8	4.3	7.2	8.8	7.2	1.1	1.9	1.1	1.1	1.1	1.2	-0.1	1.1	2.1	5.5	3.9	2.2	3.3	2.8	1.8

Site B: W. Springfield, MA

2018-	eCurv	CDD_{55}		HDD_{55}	Outdoor (°F)			RH	RTU # Avg. Zone Air (°F)							RTU # Min. Supply Air					
MM-DD	Status	(°F)	Adj.	(°F)	Min	Avg	Max	(%)	1	2	3	4	5	6	FA	1	2	3	4	5	6
08-13	ON	16.7	15.0	0.0	70	72	74	72	73	74	73	73	72	75	73.7	59	63	59	60	49	50
08-14	ON	18.9	17.3	0.0	70	74	80	74	73	73	73	73	72	75	73.6	49	58	55	49	47	45
08-15	ON	22.2	20.4	0.0	69	77	88	77	73	74	74	73	73	75	73.9	60	58	61	60	52	50
08-16	ON	23.2	21.2	0.0	70	78	88	78	74	74	74	74	73	76	74.0	61	54	61	61	51	50
08-17	ON	22.2	20.1	0.0	69	77	87	77	74	74	74	74	73	76	74.1	61	52	58	60	51	49
08-18	ON	18.1	16.4	0.0	66	73	82	73	73	74	74	73	72	75	73.7	59	57	65	60	53	48
08-19	ON	14.8	13.0	0.0	64	70	78	70	74	74	74	74	73	75	73.8	59	56	59	59	51	48
08-20	OFF	13.8	11.9	0.0	59	69	77	69	74	74	74	74	73	75	74.0	58	60	65	63	48	48
08-21	OFF	14.2	12.2	0.0	58	69	78	69	73	74	74	73	73	75	73.9	59	58	65	63	48	48
08-22	OFF	16.6	15.2	0.0	66	72	81	72	72	74	73	71	72	75	73.4	48	59	18	18	33	35
08-23	OFF	11.6	10.7	0.0	56	67	76	67	72	74	73	70	73	75	73.0	55	65	63	53	47	49
08-24	OFF	14.7	14.3	0.0	55	70	83	70	71	73	73	70	72	75	72.4	54	55	64	54	49	48
08-25	OFF	13.8	13.6	0.0	58	69	80	69	70	73	73	69	72	75	72.1	53	55	62	53	52	48
08-26	OFF	17.1	17.0	0.0	58	72	82	72	70	73	72	70	72	75	72.1	56	56	64	55	50	49
08-27	OFF	22.5	21.6	0.0	67	78	87	78	71	73	73	71	72	76	72.9	58	57	64	57	49	49
08-28	OFF	28.0	26.7	0.0	71	83	93	83	72	73	73	71	72	76	73.3	54	58	59	58	50	51
08-29	OFF	28.3	26.9	0.0	74	83	94	83	72	72	73	72	72	76	73.4	59	57	61	59	51	50
08-30	OFF	21.6	20.2	0.0	64	77	85	77	72	74	73	71	73	76	73.4	58	60	64	56	50	48
08-31	OFF	12.7	11.9	0.0	60	68	75	68	71	74	73	70	72	75	72.8	55	59	63	53	47	48
09-01	OFF	13.4	13.1	0.0	59	68	77	68	70	73	73	70	72	75	72.3	55	56	63	54	46	60
09-02	OFF	18.2	17.7	0.0	61	73	82	73	71	73	73	70	72	75	72.5	57	56	63	56	47	54
09-03	ON	25.9	24.2	0.0	71	81	92	81	73	73	73	73	72	76	73.6	61	58	61	61	50	55
09-04	ON	23.6	21.8	0.0	67	79	89	79	73	73	74	73	72	76	73.8	49	34	52	52	51	46
09-05	ON	23.5	21.7	0.0	67	78	90	78	73	74	74	73	72	76	73.8	60	59	66	60	50	55
09-06	ON	22.6	20.8	0.0	70	78	93	78	73	74	74	73	73	76	73.8	59	57	59	60	51	50
09-07	ON	11.9	10.3	0.0	63	67	72	67	73	73	73	73	72	76	73.6	57	56	64	58	48	49
09-08	ON	6.0	4.9	0.3	53	61	67	61	72	73	73	73	72	75	73.1	57	57	63	57	47	59
09-09	ON	1.8	1.0	0.9	52	56	61	56	72	73	73	73	72	74	72.8	52	51	51	57	51	50
09-10	OFF	2.4	1.7	0.3	53	57	60	57	72	73	73	72	72	74	72.7	54	51	53	53	49	52
09-11	ON	13.4	12.5	0.0	60	68	75	68	72	73	73	72	72	74	72.9	50	58	35	54	46	35
09-12	ON	13.1	11.6	0.0	65	68	71	68	73	74	73	73	72	75	73.5	58	61	64	54	48	51
09-13	ON	14.0	12.5	0.0	65	69	73	69	73	74	73	73	72	75	73.4	59	60	65	59	48	49
09-14	ON	13.6	12.0	0.0	64	69	75	69	73	74	73	73	72	75	73.6	59	58	64	60	51	51
09-15	ON	15.7	14.3	0.0	64	71	82	71	73	74	73	73	72	75	73.4	58	59	65	60	50	48
09-16	ON	18.2	16.4	0.0	63	73	87	73	73	74	73	73	72	76	73.8	59	59	61	58	53	50
09-17	OFF	18.6	17.3	0.0	66	74	80	74	72	74	73	71	72	76	73.2	56	55	64	57	51	50
09-18	OFF	15.7	14.8	0.0	66	71	77	71	71	74	73	71	72	76	72.9	56	63	64	56	50	48
09-19	OFF	13.1	12.6	0.0	61	68	76	68	71	73	73	70	72	75	72.6	53	54	64	53	51	49
09-20	OFF	9.1	8.9	0.0	60	64	70	64	70	73	73	69	72	75	72.2	54	61	67	53	48	53
09-21	OFF	11.2	11.2	0.0	61	66	70	66	70	73	73	69	72	75	72.1	55	68	68	54	48	61
09-22	OFF	6.8	7.0	0.9	49	61	69	61	70	73	73	69	72	74	71.8	53	51	67	51	52	58
09-23	OFF	1.6	1.5	2.9	48	54	61	54	71	72	72	71	71	74	72.2	52	51	52	55	50	50
09-24	OFF	0.5	0.0	2.3	48	53	58	53	72	72	72	72	71	74	72.5	49	51	51	58	50	49
09-25	OFF	2.2	1.2	1.4	49	56	59	56	72	72	72	72	71	74	73.0	38	33	16	16	53	32
09-26	OFF	14.9	14.2	0.0	59	70	79	70	71	74	73	71	72	74	72.7	56	59	65	56	50	60
09-27	OFF	7.4	7.1	0.0	55	62	71	62	71	73	73	70	72	74	72.2	53	60	66	51	52	59
09-28	OFF	1.2	1.2	0.5	53	56	60	56	71	72	72	70	71	74	72.0	53	51	56	53	52	58
09-29	OFF	4.8	5.0	2.4	46	57	70	57	70	73	72	70	71	74	71.7	54	51	51	52	51	58
09-30	OFF	3.4	3.0	1.9	44	57	67	57	72	72	72	72	71	74	72.4	50	51	51	54	51	51
10-01	ON	4.9	3.8	0.2	52	60	69	60	73	73	73	73	71	75	73.1	60	61	63	58	52	51
10-02	ON	2.7	1.8	0.0	56	58	59	58	72	73	72	72	71	73	72.9	32	41	53	51	44	32
10-03	ON	7.4	6.5	0.0	58	62	71	62	73	73	73	73	72	74	73.0	64	60	63	63	52	58
10-04	ON	11.7	10.4	0.0	59	67	74	67	73	73	73	73	72	75	73.4	64	57	64	63	51	60
10-05	ON	2.4	1.2	1.7	51	56	64	56	73	73	73	73	71	75	73.1	53	51	50	55	48	51
10-06	ON	4.4	3.4	0.6	51	59	63	59	73	73	73	73	71	75	73.0	53	51	51	58	52	50
10-07	ON	13.8	12.3	0.0	61	69	80	69	74	73	73	73	72	75	73.5	64	57	56	64	54	48
10-08	OFF	3.0	2.5	0.0	57	58	61	58	71	73	73	69	72	75	72.5	53	59	63	52	51	51
10-09	OFF	14.0	14.2	0.0	59	69	78	69	70	73	72	69	71	73	71.8	48	47	56	52	45	34
10-10	OFF	18.5	18.1	0.0	67	73	83	73	70	73	73	70	72	75	72.3	56	60	63	56	51	60
10-11	OFF	14.8	14.5	0.0	62	70	75	70	70	73	73	70	72	75	72.3	55	60	62	55	50	50
10-12	OFF	2.4	1.9	2.8	46	55	62	55	71	72	72	72	71	75	72.5	62	51	55	57	50	50
10-13	OFF	0.0	-0.5	8.7	39	46	53	46	72	72	72	72	71	75	72.5	61	51	53	57	51	54
10-14	OFF	0.5	0.2	9.0	38	46	58	46	72	72	72	72	71	74	72.2	54	50	50	55	51	63
	Max.	28.3	26.9	9.0	74	83	94	83	74	74	74	74	73	76	74.1	64	68	68	64	54	63
	Avg.	**12.7**	**11.7**	**0.6**	**59**	**67**	**75**	**67**	**72**	**73**	**73**	**72**	**72**	**75**	**73.0**	**55**	**56**	**58**	**55**	**49**	**50**
	Min.	0.0	-0.5	0.0	38	46	53	46	70	72	72	69	71	73	71.7	32	33	16	16	33	32
Avg.	OFF	11.5	10.9	0.9	57	66	74	66	71	73	73	71	72	75	72.6	54	55	58	53	49	51
	ON	14.3	12.8	0.1	62	69	77	69	73	73	73	73	72	75	73.5	57	56	59	58	50	49
	Diff.	2.9	2.0	-0.8	5.5	3.7	3.6	3.7	1.7	0.4	0.4	2.3	0.2	0.3	0.9	2.6	0.2	0.5	5.3	0.8	-1.6