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Case Study: An Energy Review of Boston City Hall and Other Selected Facilities

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1 Executive Summary

Using open source utility bill and main meter interval data provided by the City of Boston, we examine the 5-minute electric utility interval data for selected buildings. With just interval data, we are able to identify peak demand reduction opportunities in buildings. The primary focus of our recommendations is active peak demand reduction and we also realize that some implementations will generate energy savings that will improve the cost-effectiveness for the building owner.

This case study is an extension of our previous work that delivered an Energy Map of the City of Boston. In that work, an online interactive visualization allows facility managers and city planners to review Boston's utility data for the past 5 years, compare facilities to each other by size and department, and to explore the ways that the City of Boston uses energy. That work sets the stage for a next level of review where main meter interval data for selected facilities with time-of-use (TOU) utility meters can be inspected in greater detail, and in specific ways such as the study of peak demands and their effects on the ISO New England grid.

The bulk of this report focuses on Boston City Hall where we parse the interval data to reveal demand profiles for the facility, examine the billing parameters in effect, and ultimately deliver an Opportunity Matrix where we assign dollar values to prescribed levels of demand reduction. These values inform the payback calculations associated with ECMs that might target specific portions of a facility's demand profile.

With the development of KPIs that specifically reference the profile data, we show a way that dozens or hundreds of buildings can be ranked and compared in a normalized way. When a specific key performance indicator (KPI) informs a specific energy conservation method (ECM) remedy, ranking the buildings by the KPI leads to the subset of buildings that might make the most of the ECM. KPIs can target load volatility during occupied hours, night and weekend setback, a building's initiative in responding to ISO New England demands, and a wide range of other metrics. AEI has developed its own KPIs, but we also leverage the work done by Lawrence Berkeley National Lab and their metrics for measuring demand response.

Finally, we look at a few specific cases of how we work with building automation data in those cases where the main meter interval data points to a need to dig deeper.

In short, the basic philosophy of our approach is to start with main meter interval data for the low-cost aggregate profile work which then points the way to a more discerned look via sub-metering and BAS inspection. When we start with the low-cost interval data for 100 buildings, normalized KPIs will usually reveal the subset of buildings with the best opportunities in very short order. For that next level, we will engage other streams of data including gas meter data, building automation system data and real-time portable logger and sub-meter data.

2 Contents

3 Methodology

Once the acquired utility interval data has been cleaned and normalized in the AEI platform, we apply additional metadata such as weather, ISO New England demand data, and certain intrinsic markers such as day of week, month, season, etc. Off to the side, we also have a basic understanding of the billing parameters in effect at the facility. This collection of data for a facility then supports a range of processes that we undertake:

- We deliver a number of profile and regression visualizations to deliver a basic visual understanding of how a facility uses electricity; by time of day, season of year, versus weather and ISO demand, etc. The visualizations are tuned to isolate and emphasize the way that energy is consumed in a building, along with its propensity to be different from other buildings, its relationship to the ISO New England demand at a given time, and the volatility of the energy use.
- We calculate certain quantitative performance metrics (key performance indicators or KPIs). These KPIs are not necessarily of particular interest for a single specific building, but in a population of hundreds of buildings they are an important and convenient way to rank and compare different buildings. AEI has developed several dozen KPIs for its own purposes, and we also use performance indicators developed by Lawrence Berkley National Lab (LBNL) for using utility interval data to understand how buildings are operated.
- In specific areas of interest, such as Peak Demands, we develop an Opportunity Matrix which uses the interval data in conjunction with billing parameters to develop the costs and savings associated with specific reductions in energy use and demand. By knowing what a facility pays for 1kW of demand, we are able to construct the Opportunity Matrix for each month or season in the year in a way that shows the value for each percentage of reduction in energy use or demand. The savings in the matrix can then be matched with the appropriate energy conservation measures (ECMs) to suggest the ways a facility might reduce its energy footprint with sufficient payback to make the ECMs worthwhile.

3.1 Additional Details - Visualizations

At a minimum, we deliver visualizations that show:

1. Time series; one for each year of available EPO data, showing hourly average values (Load versus calendar).
2. Load Profiles
    a. 7-day hourly average profile, one for each Summer, Winter and Shoulder season; repeated for each year of available EPO data
    b. 24-hour fifteen minute average profile, one for each Summer, Winter and Shoulder season; repeated for each year of available EPO data
    c. Monthly Facet: 24-hour profile for each month of each year
    d. S-Curve (ascending loads) to determine 95^{th} percentile load, median, and quick identification of large load duty cycles
    e. All of the above split into occupied and unoccupied equivalents
    f. Load volatility; the randomness of the interval-to-interval swings in load.

3. Regressions

    a. Load versus weather (outside air temperature and humidity). Correlations by season (season defined by calendar, and then by HDD/CDD).

    b. Two-dimensional Facet by Temperature and Humidity Bin (24 hour profiles arranged in a grid of temperature and humidity bins).

    c. Regression against ISO New England system load.

    d. Regression against ISO New England system load in the 95th percentile for facility and ISO NE. The data that is coincidentally in the 95th percentile for both the facility and ISO New England is a visual measure of demand response or lack thereof.

4. Weather normalization (multiple years of data required)

    a. Year/Year and Season/Season weather normalization to HDD, CDD, HDH and CDH. Isolated subsets for only occupied hours

At the completion of this phase, a set of comprehensive visual representations of the usage pattern at a facility is known. There is now a broad understanding of seasonal loads, night and weekend setback, correlation to the ISO grid and weather, and the percentile distribution of loads.

3.2 Additional Details – Key Performance Indicators

Consistent with work from Lawrence Berkeley National Lab (LBNL), it is recognized that many other metrics are relevant when profiling energy use in a particular building. We track the following metrics and use them to rank facilities and isolate specific characteristics that inform the application of relevant ECMs:

a. Near-Base Load (kW)
b. Near-Peak Load (kW)
c. High-Load Duration (hrs)
d. Morning Start-up (hrs)
e. Fall Time (hrs)
f. Max kW/sq ft per day comparison between buildings of similar types quickly identifies buildings with potential for improvement in peak kW management.
g. C_V (Coefficient of Variation) of average (1) occupied and (2) unoccupied kW per day identifies opportunities for improved control
h. Standard Deviation of average (1) occupied and (2) unoccupied kW per day (helps quantify opportunities for improved control).
i. Ratio of Max kW to Average kW/day (indicates the amount of kW that is possible of being reduced without any reduction in occupant comfort).
j. Delta kW (kW change between demand intervals to quantify kW values associated with improved control of specific equipment types).
k. Ratio of unoccupied to occupied kW indicates amount of building setback versus desired setback.
l. Building kW profile indicates how closely the actual building schedule follows the desired building schedule.

At the completion of this phase, we have a set of metrics that can be used to rank and compare facilities to each other. If, for example, a certain KPI measures the volatility of demand in the hours of 2pm to 8pm on summer weekdays, this KPI could then be used to rank all buildings in a portfolio in a way that would show the best candidates for ISO-coincident peak demand mitigation projects. In short, if a KPI maps to a specific savings opportunity that might be afforded by a particular ECM, ranking buildings by that KPI essentially leads to a list of project opportunities with the most favorable paybacks found at the top of the rankings.

3.3 Additional Details - An Opportunity Matrix

Once profiled, we have a distribution of loads in each billing period for the facility. Knowing the billing parameters in effect, we can assign a value to each percentage point of peak demand reduction in each month.

An ECM that targets a particular season with an estimated peak savings percentage then has a known value, and this value and the prescribed ECM cost yields a ROI calculation.

Furthermore, knowing the distribution of loads tells us how many hours are affected in each month by the prescribed percent reduction in peak demand.

From this, we calculate an Opportunity Matrix where incremental reductions in peak demand are assigned values in terms of dollars and hours. The billing parameters tell us the dollar amount, and the number of affected hours tells us the potential cost in terms of comfort.

4 Case Study: Boston City Hall

4.1 The Facility and Data Observations

AEI used open source data provided by the City of Boston to conduct a review of the City Hall electricity usage. We used their billing records to assess the impact of reduced usage on the utility bill, and then made estimates of the value associated with monthly reductions in peak demands.

The data consisted of two sets:

- EPO 5-minute interval data from Eversource for 2014
- Billing records from Eversource and Direct Energy, the commodity supplier to City Hall for 2015.

Our assessments in this document are made on 2014 interval data since that was the only data available from the City, but we use the utility and commodity rates from 2015 since they are more relevant. We do know that there has been a lighting and control system upgrade and more changes are planned for the central plant but until data is available that is reflective of current building operation, this discussion is a good example of our approach.

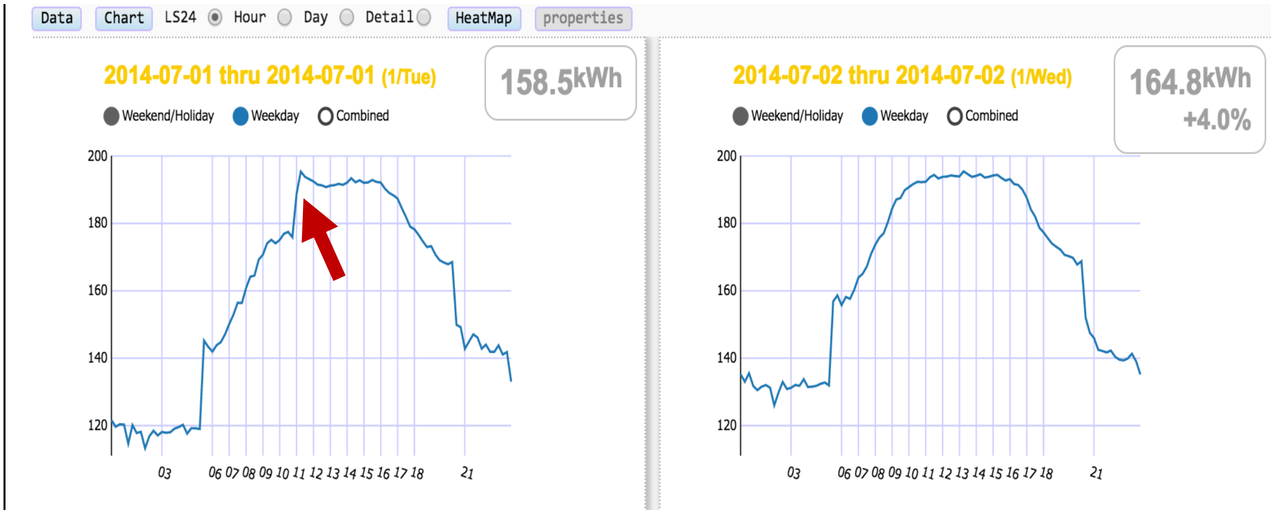
City Hall has a net square footage of approximately 511,000 and we are told that there is a significant level of occupancy on weekends in addition to the high weekday occupancy. We have no knowledge of any specific ECMs that have been deployed in the past few years.

The following Load Shape Parameters are observed during July and August 2014:

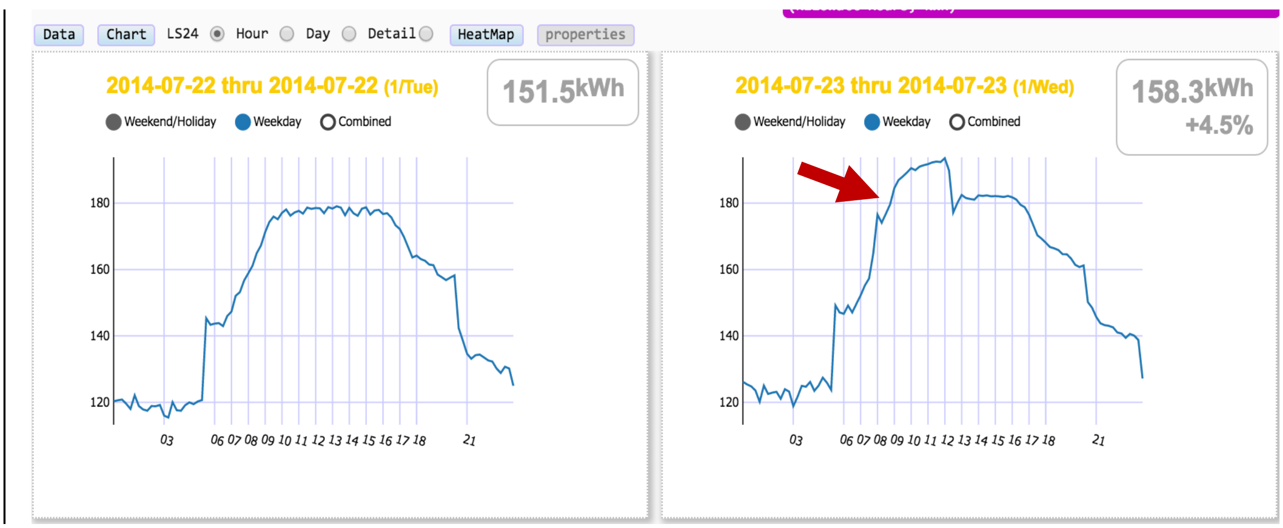
- Morning Start-Up 5:00 to 6:30 am
- Morning Rise-Time 6:30 to 9:00 am
- High Load Duration 9:00 to 4:00 pm
- Fall Time 4:00 to 8:00 pm

The peak summer demand level of 2,401 kW was recorded on July 1, 2014 when a 250 kW load came on during a 10-minute interval at approximately 11:00 am. During the High Load Duration of July 23, a 225 kW load was observed to shut off during a 10-minute interval at approximately 12:30 pm.
These days were reviewed based on high outside air temperatures, and on weekdays when the C_v (Coefficient of Variance) of the High Load Duration ranged from 0.03 to 0.04 vs. 0.01 to 0.02, similar load changes were observed. The C_v for days such as July 2 and July 22 were 0.02 and don't show the 200 kW change during the High Load Duration time period.

Raw kWh for July 1 and 2



Raw kWh for July 22 and 23



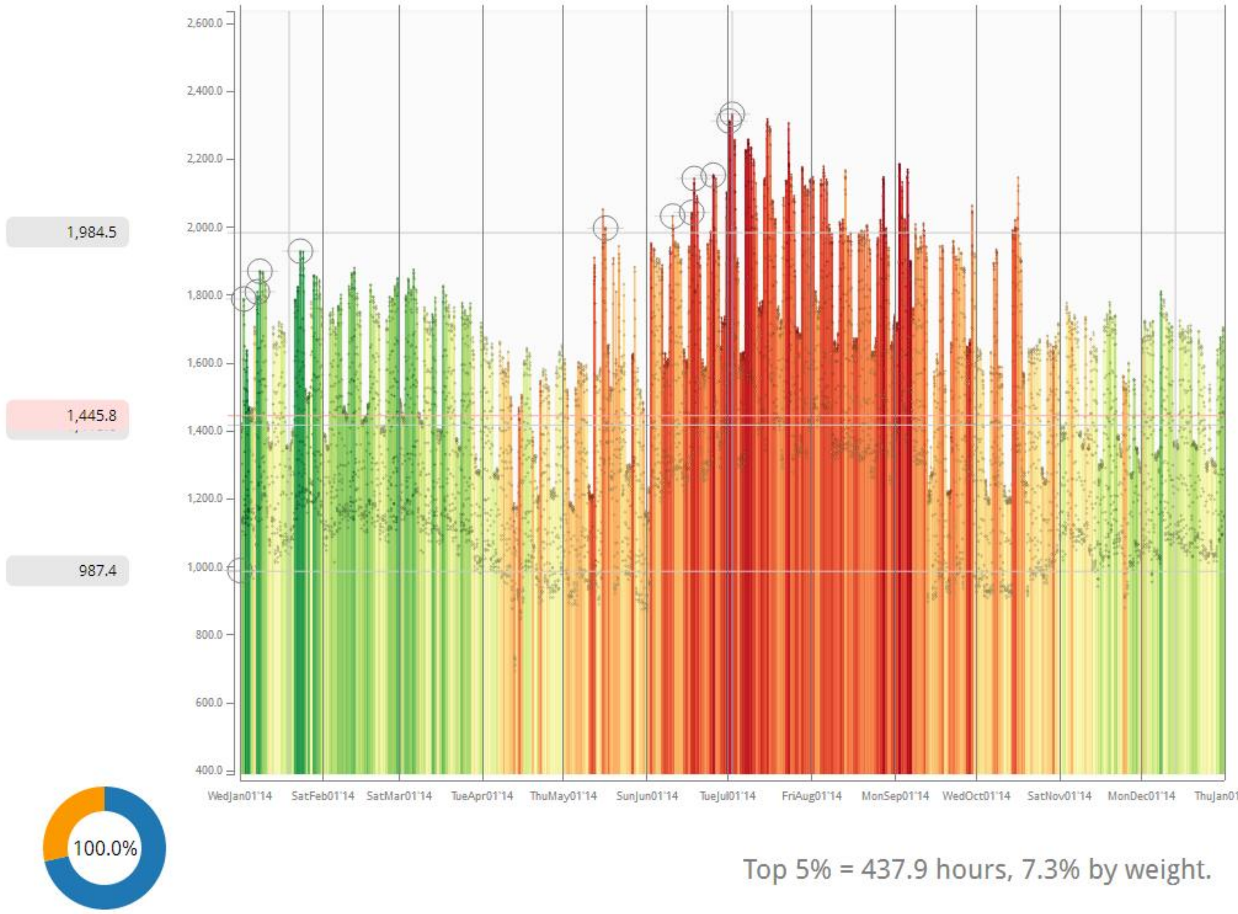
We believe that this load change of approximately 200 kW (5 minute kWh pulses x 12) is the result of turning on/off the final stage of cooling.

We don't have insight into the space temperatures throughout the day or the difference between the chilled water supply and return temperatures, but we do think it is worthwhile discussing the final stage of cooling when we see summer profiles like this. Is there a strategy that can be implemented to eliminate or shift the final stage of cooling to an hour that does not coincide with predicted ISO New England peak loads?

4.2 Several Profiles of Boston City Hall Electric Usage

4.2.1 A Standard Time Series Profile

This is a traditional view of time series data showing the load in kW (y-axis) versus the calendar year for 2014 on the x-axis. Each vertical line represents an hourly average value and there are 8,760 hours in the chart. Load peaks are highlighted with a gray circle.



4.2.2 Discussion

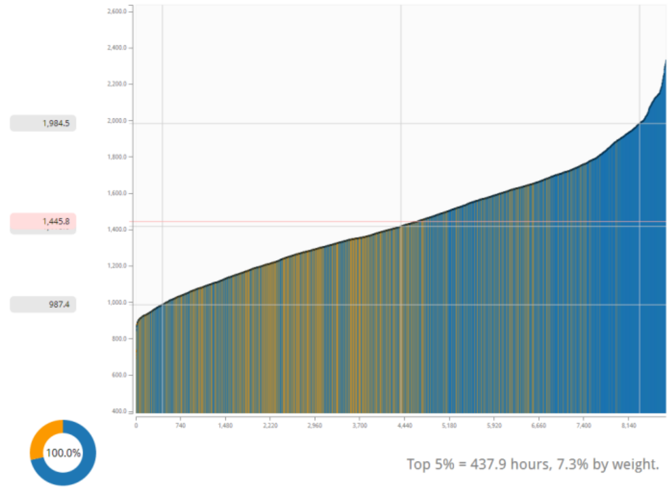
Everyone expects a standard time-series plot when talking about loads. It's helpful to get a basic understanding that the facility follows certain expected patterns. In the case of City Hall, we obviously see high cooling loads in June through August and electric heating loads on cold days in Jan and Feb. We can start to take a guess at the base load since in the shoulder months, the lowest hourly average values tend to be around the 1,000kW mark and the 5th percentile of all loads in the year is at 987kW.

The 95th percentile mark of 1,985kW starts to frame out the context for summer peak demand opportunities.

4.2.3 S-Curve, Whole Year (100%)

Loads in ascending order, 8760 hourly average values.

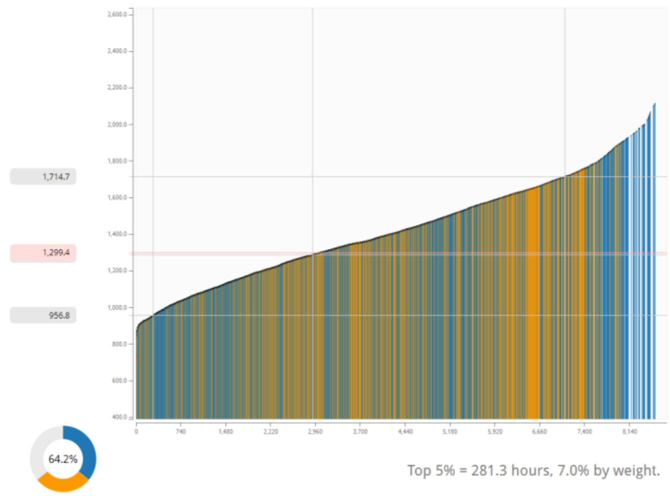
Average load (kW)	**1,445.8**
95th Percentile Load (kW)	1,984.5



4.2.4 S-Curve, Off Peak (64.2%)

Loads in ascending order, 5626 hourly average values. Off-peak is defined as Saturday, Sunday and weekday hours from 6pm to 6am.

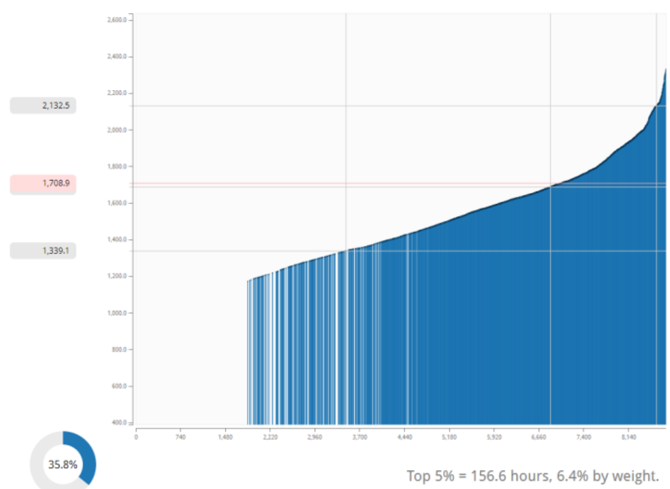
Average load (kW)	**1,229.4**
95th Percentile Load (kW)	1,714.7



4.2.5 S-Curve, Peak (35.8%)

Loads in ascending order, 3132 hourly average values.

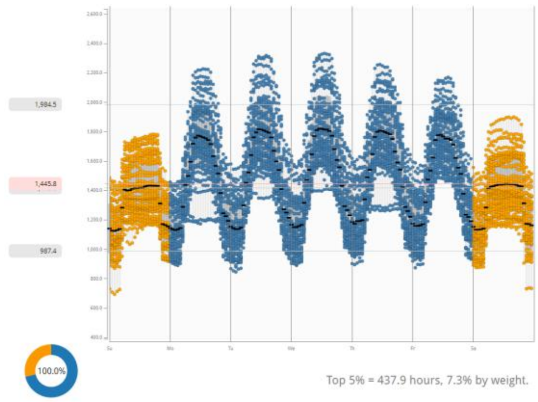
Average load (kW)	**1,708.9**
95th Percentile Load (kW)	2,132.5



4.2.6 7-day Profile

Average composite week for whole year.

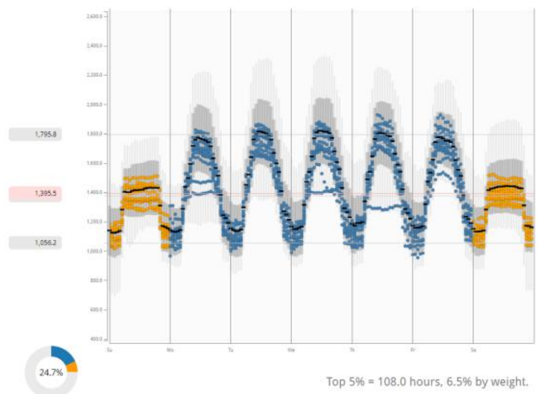
Average load (kW)	**1,445.8**
95th Percentile Load (kW)	1,984.5



4.2.7 7-day Profile, Winter

Average composite week for winter months.

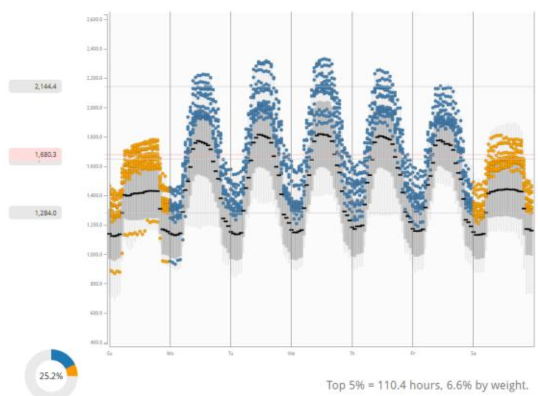
Average load (kW)	**1,395.5**
95th Percentile Load (kW)	1,795.8



4.2.8 7-day Profile, Summer

Average composite week for summer months.

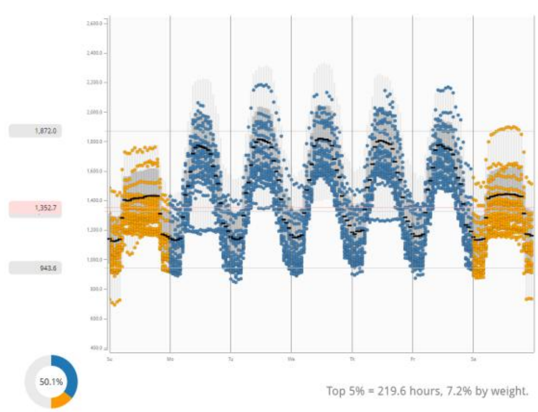
Average load (kW)	**1,680.3**
95th Percentile Load (kW)	2,144.4



4.2.9 7-day Profile, Shoulder

Average composite week for shoulder months.

Average load (kW)	**1,352.7**
95th Percentile Load (kW)	1,872.0



4.2.10 Discussion on Cumulative Load (S-Curve) and 7-Day Profile Visualizations

Cumulative Load charts display the hourly loads for a full year and are used to gauge the distribution of loads at the facility. The 5th and 95th percentile marks give an indication of the base load and peak demand opportunities.

When the S-Curve is smooth as shown in 4.2.3 , we can tell that the facility is composed of a large number of individual loads. When we separate the off-peak (4.2.4) and peak loads (4.2.5), we see a difference of nearly 500kW, a good indication that the building responds to occupancy in the expected way. We also note that even during off-peak hours 5% of the hours are above 1714kW, well above the average for all off-peak hours. This is likely because our definition of off-peak includes weekends, and we know that City Hall is partially operating and open to the public on weekends.

7-Day profiles provide another useful view of the electric energy use at City Hall. By presenting a composite 24-hour profile for each day of the week, we have a quick way to view an entire year of usage by day of week and for each season of the year. Other filtering combinations are available for more specific insight into hours of the day, versus outside air temperature and ISO grid ranges, etc. In charts 4.2.6 through 4.2.9 we can see how the profiles vary by season. By visually comparing winter versus summer, we can see a tighter range of loads in winter, suggestive of more centralized loads related to heating when compared to summer where a wider range of cooling assets distributed throughout the building results in a wider range of loads.

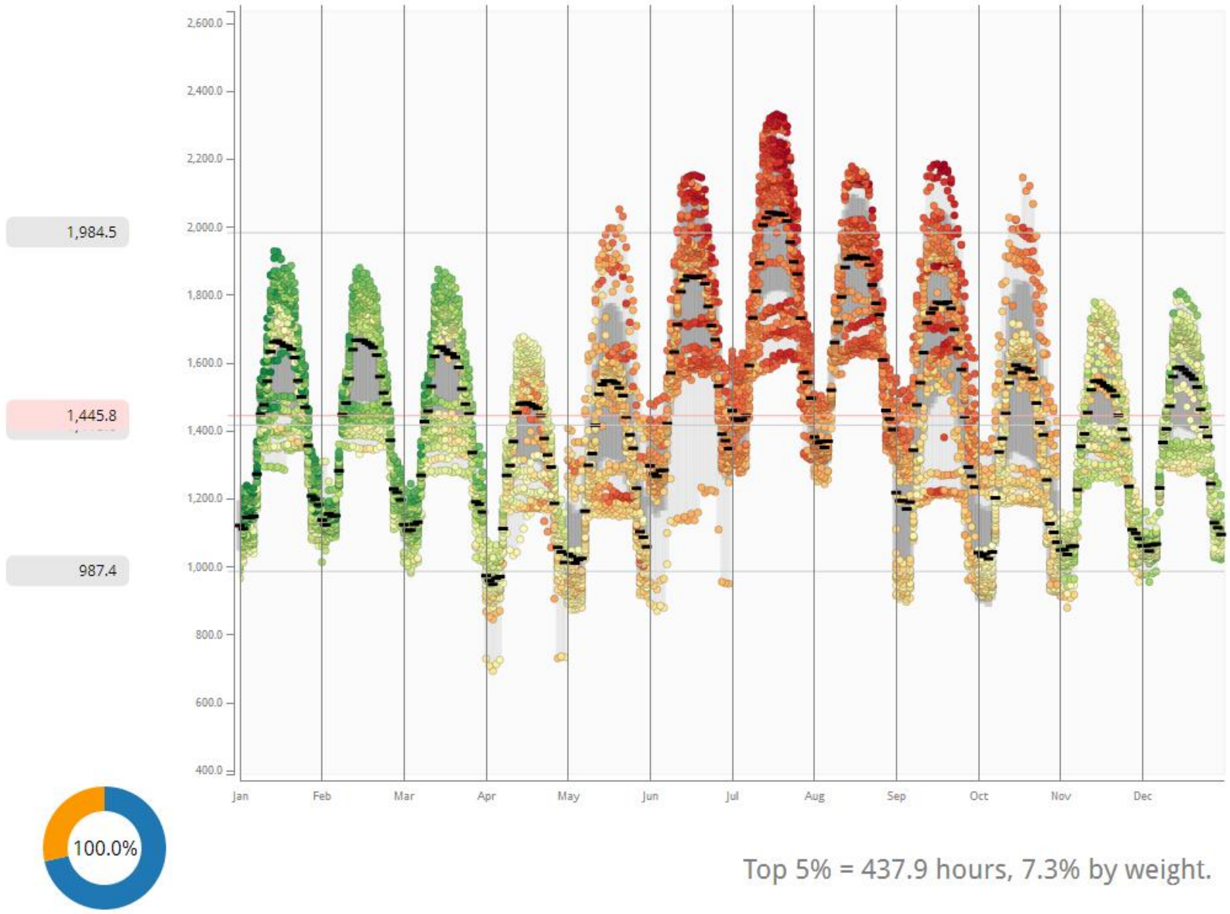
Not shown is a coefficient of variance (C_v) KPI that measures the variation in the loads versus the average. We can visually tell that the C_v for summer is larger than for winter, and if high variability is a precursor for volatility that leads to unexpected peaks during the cooling season, we would normally inspect this aspect at a deeper level to understand how the building is being controlled.

Finally, we note that the average and 95th percentile loads for summer are approximately 300kW higher than both the winter and shoulder seasons. All else being equal, it would make sense that this difference is due to chillers that are operating in the summer. If that is true, then it would make sense to develop a cost-to-operate model for those assets to better understand that the requirements of the building are being efficiently served. Then, to better control peak demands during the summer months, a review of the equipment schedule would be recommended to insure that scheduling alone is not the cause of unnecessary peak demands.

4.2.11 Daily Profile by Month for City Hall

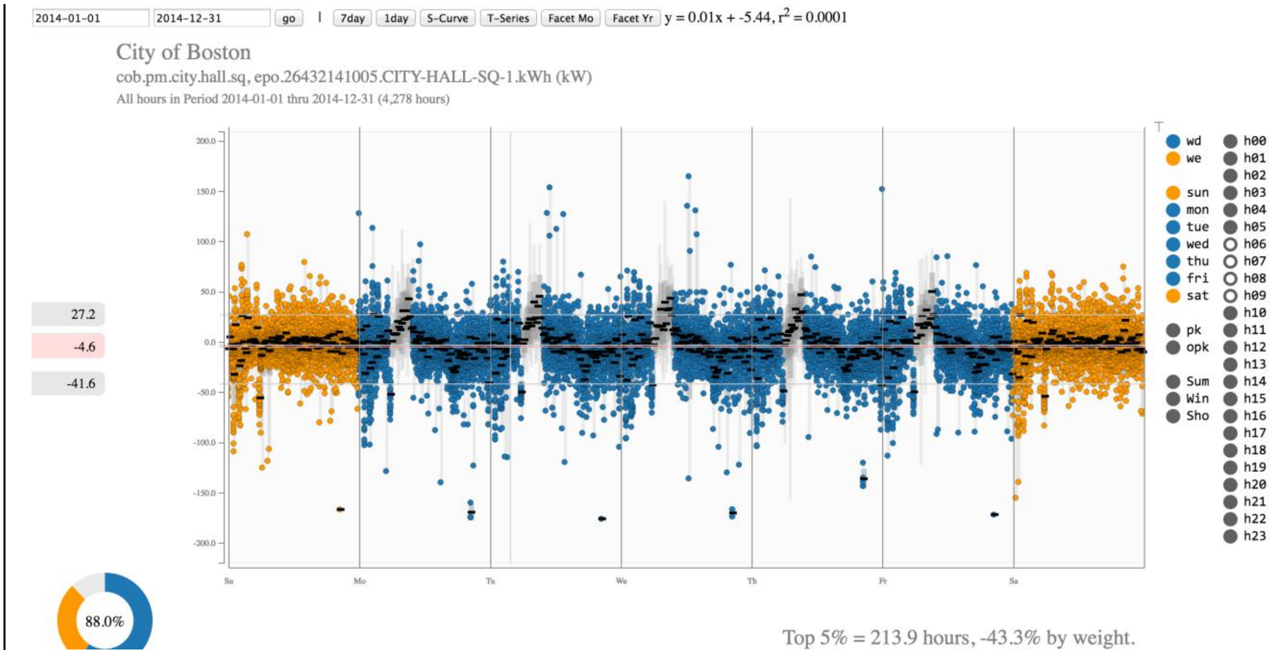
This view is similar to a standard time-series plot, but instead we show the average 24-hour profile for each month of the year. This makes it slightly easier to see that peak hours occur in the middle of the day as expected, and it's easier to compare the summer, winter and shoulder months.

We notice gaps in the June, July and August profiles which suggest that large isolated loads affect the daily profile in a step-wise manner.



4.2.12 7-Day Delta kW Profile for City Hall

The delta kW visualization below for the entire year shows the kW change from one 15-minute period to the next. The hours between 6:00 and 9:00 am are removed so that the Morning Rise-Time is not included. We see that there are many kW increases greater than 27.2 and some as high as 150 kW. Even though many of these kW changes take place during off peak hours, discussions with building personnel may lead to identifying them without having to install sub-meters. For example: the 125 kW loads that area seen coming on at midnight may be easily identified.



4.2.13 Discussion

Looking at the "Daily Profile by Month" for the summer months, there appears to be a step load in play where loads move to higher levels in roughly 50kW increments from one day to the next. The proportion of hours at each level gives us an idea of the duty cycle for those loads.

Sub-metering would obviously give us a more exact picture of the component loads that contribute to the overall demand, but with just the main meter we can start to get an idea of the magnitudes of those discrete loads and discussions with building personnel regarding the observed patterns may lead to identification of the loads.

We note that loads in January through March are considerably higher than during the shoulder months, suggestive of some electrical heating loads which might also be considered for a review in the same way we would look at the summer cooling loads.

4.2.14 A Cumulative Load "S-Curve" in the Extreme

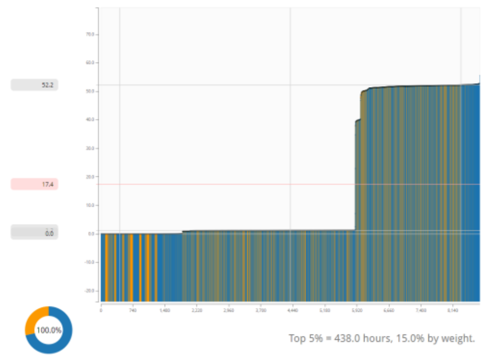
The Cumulative Load S-Curve gives us an idea of how discrete loads are combined to form the overall load profile at a facility. Caution should be applied when attempting to draw too many conclusions in the case where there may be dozens or hundreds of different loads that come on and off at different times as we see in City Hall where the S-Curve is very smooth.

A more extreme example (not relevant to City Hall) shows an individual discrete load where it's much easier to draw certain conclusions. Consider this case of a recirculation pump which would appear to have only two states. In the OFF condition, it draws a zero load. In the ON condition, it draws approximately 52kW.

4.2.15 A Discrete Load Example

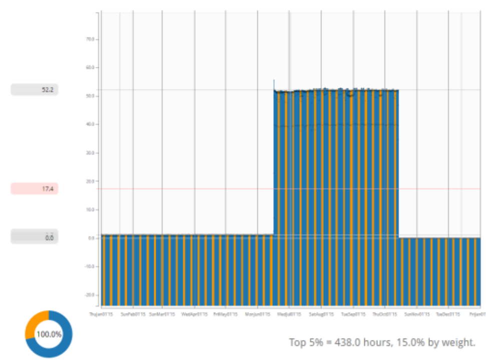
A year of hourly average loads for a single recirculation pump. When it's on, it draws 52kW, and when it's off it draws zero.

It's effectively at zero for approximately 6,000 hours in the year, and it's at 52kW for approximately 2760 hours. The duty cycle would therefore appear to be about 30%.



4.2.16 The Time Series view

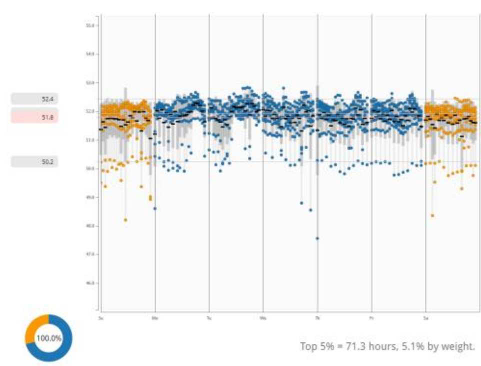
The time series view of the same data shows us that the pump is only used in the summer, and probably coincides with the cooling tower. So while the estimate of a 30% duty cycle is technically correct, the reality is that the pump is operating all the time but only during the summer.



4.2.17 The 7-day view

The same data plotted on a 7-day week tells us the pump is probably running all hours, on some sub-hour schedule. The low values are probably the snapshots where the pump was slightly more off than on during a given hour.

For all intents and purposes, this pump is on all the time during the summer – roughly the same 2760 hours as shown in the top chart.



A large building such as City Hall is a collection of many different loads that are on and off at varied and independent times of the day, week and year. Identifying the individual underlying loads is best done with sub-metering, but even with many independent loads we can sometimes identify a small set of dominant loads that shift the curve in some significant way. It would then seem to make sense to focus on those loads as the most significant opportunities for peak demand mitigation.

4.3 Pro Forma Billing Calculation

From the interval data profiles, we have a broad understanding of the facility's usage by season, average week, etc. We can start to see where the opportunities for peak demand mitigation might be located. In City Hall, it's obvious that the summer is a good place to focus, but we also see some peak effects in the winter heating season on cold days. Given the night and weekend setbacks, we could also make a case for ECMs that target those hours, or with a better understanding of the building's thermal mass we might look at overnight pre-cooling as a way to lower the summer loads during occupied hours. There are many options.

So the logical next step is to understand how an ECM might affect the utility bills at the site, and for that we do a couple of simple pro forma billing calculations based on what we know about the utility rates and the Direct Energy commodity contract in place at City Hall.

Boston City Hall		Square Feet:	511,000				
		Jan-15				**Jul-15**	
USAGE							
	Usage, kWh	Rate, $/kWh	Total Cost, $		Usage, kWh	Rate, $/kWh	Total Cost, $
Direct Energy	1,069,320	$ 0.0855	$ 91,443.16		1,210,720	$ 0.0426	$ 51,591.51
Eversource	1,069,320	$ 0.0103	$ 11,046.38		1,210,720	$ 0.0130	$ 15,774.92
DEMAND							
	Peak, kW		Total Cost, $		Peak, kW		Total Cost, $
Eversource	1,958.9	$ 18.9000	$ 37,023.21		2,409.1	$ 27.3500	$ 65,888.89
TOTAL			**$ 139,512.75**				**$ 133,255.32**
Demand/Total, %			26.5%				49.4%
Usage, kWh/SqFt			$ 2.09				$ 2.37
Usage, Average kW/h			1,437.26				1,627.31
Peak/Average Ratio, %			136.3%				148.0%
Combined $/kWh		$ 0.0958				$ 0.0556	

Notes:

1. We cannot explain how Direct Energy rates vary each month, let alone how their rate in July is significantly lower than January. We'd need to look at the contract.
2. DE bills for the cost of fuel, but Eversource bills for distribution and transmission in the form of demand charges on peak kW and a small kWh rate. In July, the demand charges are nearly 50% of the total bill and this is not unusual. And it's not unusual that the rate per kW for the demand charges is higher in summer.

The upshot here is that peak demand opportunities come in two flavors. First, and hidden from us, is the effect of reducing the ICAP tag for the building. A reasonable assumption is that Direct Energy accounted for the known capacity charges through FY19 when they quoted their contract to Boston sometime back in 2013, and those charges are reflected in the kWh rates in some way. Second, in each month the facility pays a demand charge based on the peak kW in the billing period, so a reduction in any given month has a direct effect on that month's bill. So while the rates may be fixed for the fiscal year, there's an opportunity for reduction each month – reducing a facility's ICAP tag is one important aspect of controlling for demand charges, but understanding and controlling the demands in each and every month are equally important.

4.4 Opportunity Matrix

Understanding how the utility bill is constructed now lets us close the loop on how to assign value to a peak demand reduction program. This is the intersection of what AEI can do for Guardian, and how Guardian might propose specific projects with an estimated ROI that is acceptable to DOER.

In the table on the next page, we show the peak demand in City Hall from the 2014 interval data along with a cost per kW inferred from the utility bill records for 2015, and as demonstrated with the pro forma bill calculations above.

Then, we show 10 rows, increasing from 1% to 10% to calculate the value of reducing the peak demand in each month by those percentages. We show each month separately because a 1% reduction is a higher kW value in summer than in winter, and the rates in summer and winter are different.

As an example, an ECM that could reduce the peak demand by 5% in January would affect 38 hours in that month. If the peak in January could be reduced such that it does not exceed 1,833.6kW, then that reduction of 5% would be worth $1,824. A similar 5% reduction in July would affect 55 hours and have a value of $3,191 because of the combined effect of a higher monthly peak and a higher rate compared to January.

By learning more about how the ICAP tag is incorporated into the rates quoted by Direct Energy, there is a potential for further cost reductions that we do not include in this table.

We show the "hours affected" because when talking about peaks, we are naturally talking about the very top portions of some near-normal distribution of load versus time of day, and with each percent of peak load reduction, a larger number of hours must be taken in to account and there could be an effect on building comfort. The obvious extreme would be to install an ECM that reduces peak demands down to the median, but in that case the building comfort would suffer in unacceptable ways because 50% of the hours – nearly all of which are during the occupied weekdays – are affected by the load reduction.

Period	2014-01	2014-02	2014-03	2014-04	2014-05	2014-06	2014-07	2014-08	2014-09	2014-10	2014-11	2014-12	Total Potential
Peak (kW)	1,930.1 Jan 23, 10:00	1,881.1 Feb 12, 11:00	1,875.9 Mar 06, 10:00	1,677.4 Apr 01, 11:00	2,053.1 May 15, 15:00	2,154.0 Jun 25, 13:00	2,333.5 Jul 02, 13:00	2,179.9 Aug 05, 11:00	2,186.7 Sep 02, 12:00	2,147.0 Oct 16, 13:00	1,779.8 Nov 19, 10:00	1,811.5 Dec 08, 11:00	
Rate ($/kW)	$18.90	$18.90	$18.90	$18.90	$18.90	$27.35	$27.35	$27.35	$18.90	$18.90	$18.90	$18.90	
1%	1,910.8 3 hrs $365	1,862.3 5 hrs $356	1,857.2 3 hrs $355	1,660.6 6 hrs $317	2,032.6 1 hrs $388	2,132.4 9 hrs $589	2,310.1 9 hrs $638	2,158.1 6 hrs $596	2,164.8 7 hrs $413	2,125.5 1 hrs $406	1,762.0 5 hrs $336	1,793.3 3 hrs $342	240.1 58 hrs $5,101
2%	1,891.5 6 hrs $730	1,843.5 10 hrs $711	1,838.4 9 hrs $709	1,643.9 21 hrs $634	2,012.1 2 hrs $776	2,110.9 16 hrs $1,178	2,286.8 23 hrs $1,276	2,136.3 20 hrs $1,192	2,142.9 13 hrs $827	2,104.0 3 hrs $812	1,744.2 12 hrs $673	1,775.2 8 hrs $685	480.2 143 hrs $10,203
3%	1,872.2 11 hrs $1,094	1,824.7 18 hrs $1,067	1,819.7 15 hrs $1,064	1,627.1 33 hrs $951	1,991.5 6 hrs $1,164	2,089.4 25 hrs $1,767	2,263.5 29 hrs $1,915	2,114.5 38 hrs $1,789	2,121.1 16 hrs $1,240	2,082.6 3 hrs $1,217	1,726.4 32 hrs $1,009	1,757.1 11 hrs $1,027	720.3 237 hrs $15,304
4%	1,852.9 26 hrs $1,459	1,805.9 34 hrs $1,422	1,800.9 25 hrs $1,418	1,610.3 46 hrs $1,268	1,971.0 8 hrs $1,552	2,067.8 34 hrs $2,356	2,240.1 43 hrs $2,553	2,092.7 46 hrs $2,385	2,099.2 19 hrs $1,653	2,061.1 4 hrs $1,623	1,708.6 44 hrs $1,346	1,739.0 16 hrs $1,369	960.4 345 hrs $20,405
5%	1,833.6 38 hrs $1,824	1,787.1 55 hrs $1,778	1,782.1 38 hrs $1,773	1,593.5 66 hrs $1,585	1,950.5 11 hrs $1,940	2,046.3 36 hrs $2,946	2,216.8 55 hrs $3,191	2,070.9 48 hrs $2,981	2,077.3 20 hrs $2,066	2,039.6 4 hrs $2,029	1,690.8 67 hrs $1,682	1,720.9 25 hrs $1,712	1,200.5 463 hrs $25,506
6%	1,814.3 48 hrs $2,189	1,768.3 70 hrs $2,133	1,763.4 54 hrs $2,127	1,576.8 86 hrs $1,902	1,930.0 15 hrs $2,328	2,024.7 46 hrs $3,535	2,193.5 68 hrs $3,829	2,049.1 49 hrs $3,577	2,055.5 22 hrs $2,480	2,018.2 7 hrs $2,435	1,673.0 76 hrs $2,018	1,702.8 40 hrs $2,054	1,440.6 581 hrs $30,608
7%	1,795.0 63 hrs $2,553	1,749.4 90 hrs $2,489	1,744.6 73 hrs $2,482	1,560.0 109 hrs $2,219	1,909.4 19 hrs $2,716	2,003.2 47 hrs $4,124	2,170.1 80 hrs $4,467	2,027.3 50 hrs $4,173	2,033.6 26 hrs $2,893	1,996.7 8 hrs $2,840	1,655.2 86 hrs $2,355	1,684.7 65 hrs $2,397	1,680.7 716 hrs $35,709
8%	1,775.7 81 hrs $2,918	1,730.6 108 hrs $2,844	1,725.9 99 hrs $2,836	1,543.2 116 hrs $2,536	1,888.9 26 hrs $3,104	1,981.7 60 hrs $4,713	2,146.8 90 hrs $5,106	2,005.5 66 hrs $4,770	2,011.7 34 hrs $3,306	1,975.2 17 hrs $3,246	1,637.4 92 hrs $2,691	1,666.5 99 hrs $2,739	1,920.8 888 hrs $40,810
9%	1,756.4 91 hrs $3,283	1,711.8 127 hrs $3,200	1,707.1 124 hrs $3,191	1,526.5 130 hrs $2,853	1,868.4 33 hrs $3,492	1,960.1 64 hrs $5,302	2,123.4 116 hrs $5,744	1,983.7 93 hrs $5,366	1,989.9 43 hrs $3,720	1,953.8 21 hrs $3,652	1,619.6 102 hrs $3,027	1,648.4 120 hrs $3,081	2,160.9 1064 hrs $45,911
10%	1,737.1 101 hrs $3,648	1,693.0 143 hrs $3,555	1,688.3 143 hrs $3,546	1,509.7 138 hrs $3,170	1,847.8 35 hrs $3,880	1,938.6 90 hrs $5,891	2,100.1 141 hrs $6,382	1,961.9 127 hrs $5,962	1,968.0 56 hrs $4,133	1,932.3 23 hrs $4,058	1,601.8 110 hrs $3,364	1,630.3 141 hrs $3,424	2,401.0 1248 hrs $51,013

Two examples are highlighted:

1. (Orange box) An ECM that could target peaks across the entire year such that peak demand is reduced by 3% in each month would have a total annual savings potential of $15,304. The candidate ECMs would clearly need to be able to target more than just cooling or heating if they are to be successful year-round. 237 hours are affected.
2. (Purple box) An ECM that targets just the four months where cooling loads are highest such that peak demand could be reduced by 5% would have a value of $11,184. Targeting specific cooling equipment has a larger per-kW value because of the higher rates during the summer combined with the higher peaks available to target, and these combine to lower the number of affected hours to 159.

The point of this Opportunity Matrix is to try and assign value to specific levels of peak demand mitigation, and to do so in ways that allow Guardian to target specific seasons where particular remedies have the greatest affect.

This is not to say that a percent-versus-month matrix is the only way to estimate values. We could just as easily develop opportunity valuation methods that target specific days, nights and weekends, or specific equipment if sub-metered data were made available.

Moreover, the larger point we wish to make is that all of the presentations of the data shown above are highly automated - or could be quickly made more automated – such that we are able to digest dozens and hundreds of buildings very rapidly. The result is that our deliverable to Guardian or DOER would be a systematic way to order and rank a large number of facilities so that opportunities at a wide range of facilities can be compared to each other on a normalized basis. It may turn out, for example, that the City Hall opportunities are less significant than some much smaller facility that has higher peak swings, or a cost structure that is not as favorable as City Hall. Or that a facility with a high electric heating load could see a far greater peak reduction value with some combination of ECMs that are favorable for Guardian to implement.

By assessing a large number of opportunities in this way, we expect to deliver the insight that at least gives you the best idea of where to look first in a given portfolio. Now imagine for a moment if DOER answers your questions favorably and that any buildings that Guardian might identify are eligible. In that case, we would be ready to move forward immediately on the 54 buildings in the City of Boston portfolio – 6.7 million square feet – where we already have the utility interval data and billing records.

4.5 Regressions

The utility main meter 5 minute interval data for a facility provides for one channel of data to work with. Knowing the date and time when each load occurred allows us to profile the data by several date and time aspects such as a time-series view, a composite wrap on a weekly or monthly x-axis and it permits time-based filtering so that we can focus on certain hours of the day or seasons of the year.

When we incorporate the coincident weather data and ISO New England load data, we now have two or three channels of coincident data to work with, and that allows for simple linear regressions where we can start to see how a building behaves when independent variables like weather and grid loads are taken into account.

The next few pages show X-Y plots where we show how a building's load correlates with those outside influences.

4.5.1 Regression versus Weather (Outside Air Temp), entire year 2014

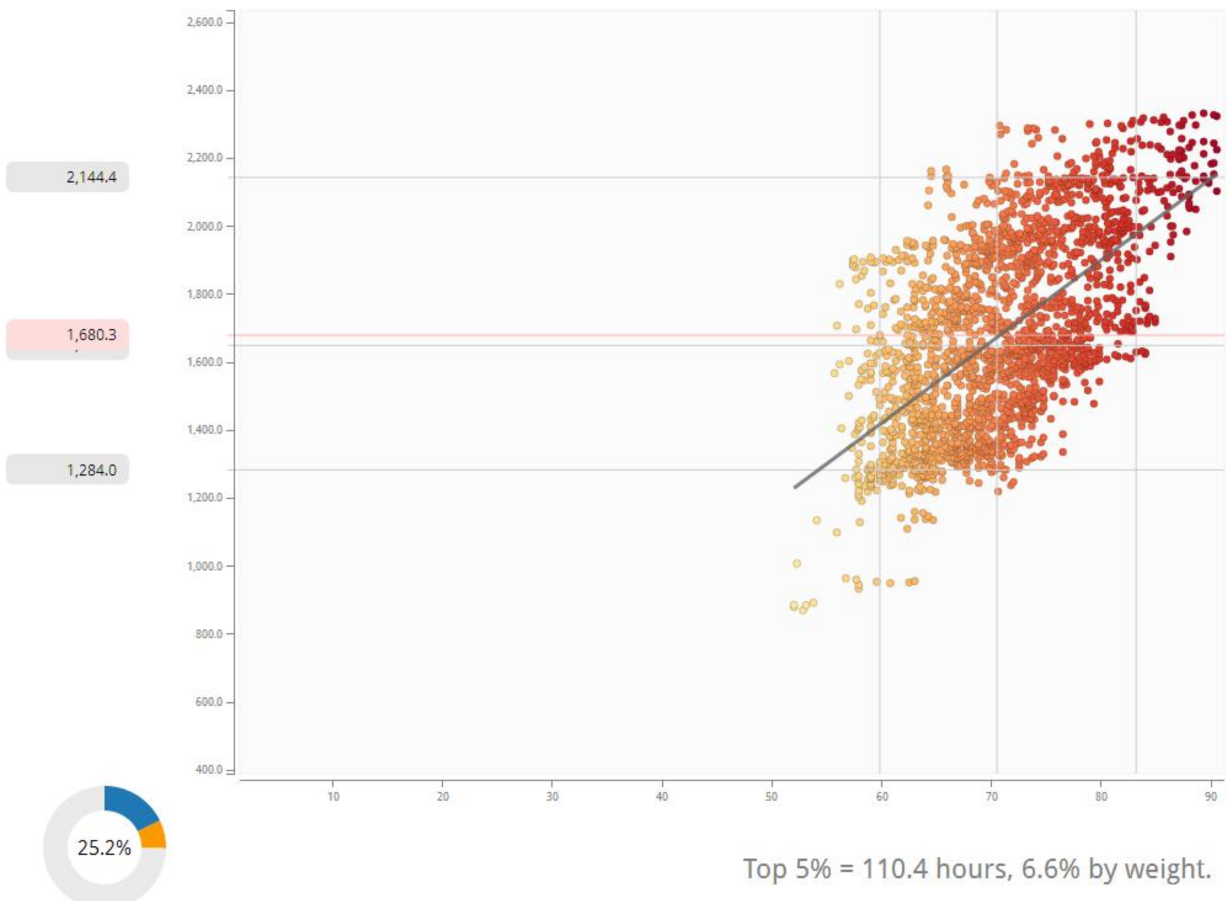
4.5.2 Discussion

In the figure above, we can see that City Hall exhibits a pretty strong response to weather, although the correlation isn't very good. Arguably, the building has such high thermal mass that it is slow to respond to outside air temperatures, or optimistically is it well insulated from those affects.   We decide this because of the high amount of scatter in the load data for temperatures above 70°F.

We also note a slight negative correlation at colder temperatures. The building seems to work harder during cold weather than during the shoulder seasons.

The linear regression line in the example is clearly not relevant for this data. There is a knee in the curve, so the better analysis should separate the data into two distinct populations and correlate them individually.

4.5.3 Regression versus Weather, Summer Only 2014



4.5.4 Discussion

By isolating just the summer data points, we see what appears to be a stronger relationship or the City Hall load versus OAT, but still the R^2 is just 0.36.   More interesting is the upper right corner of this data subset where the 95th percentile of OAT and building load coexist. The scatter of the data in this region of the chart tells us that City Hall does not implement any meaningful demand response in cases where it's very hot outside, or else we'd expect to see the loads above 2,144kW at much lower levels when the outside air is in the mid 80s or higher.

4.5.5 Regression versus ISO New England

4.5.6 Discussion

There are many services offered by MAPC and others (including AEI) that will alert a facility to a "high probability" of ISO New England peak load conditions. These alerts are intended to notify building operators of the possibility that ISO NE may hit its annual peak hour which, in turn, could be the hour at which a facility's ICAP tag is assigned for purposes of calculating their capacity charge rate next year. Buildings that are keen to this phenomenon typically show a strong demand response when ISO NE calls for a possible peak, and that condition is typically at a point where they expect to be north of 23,000MW in the region.

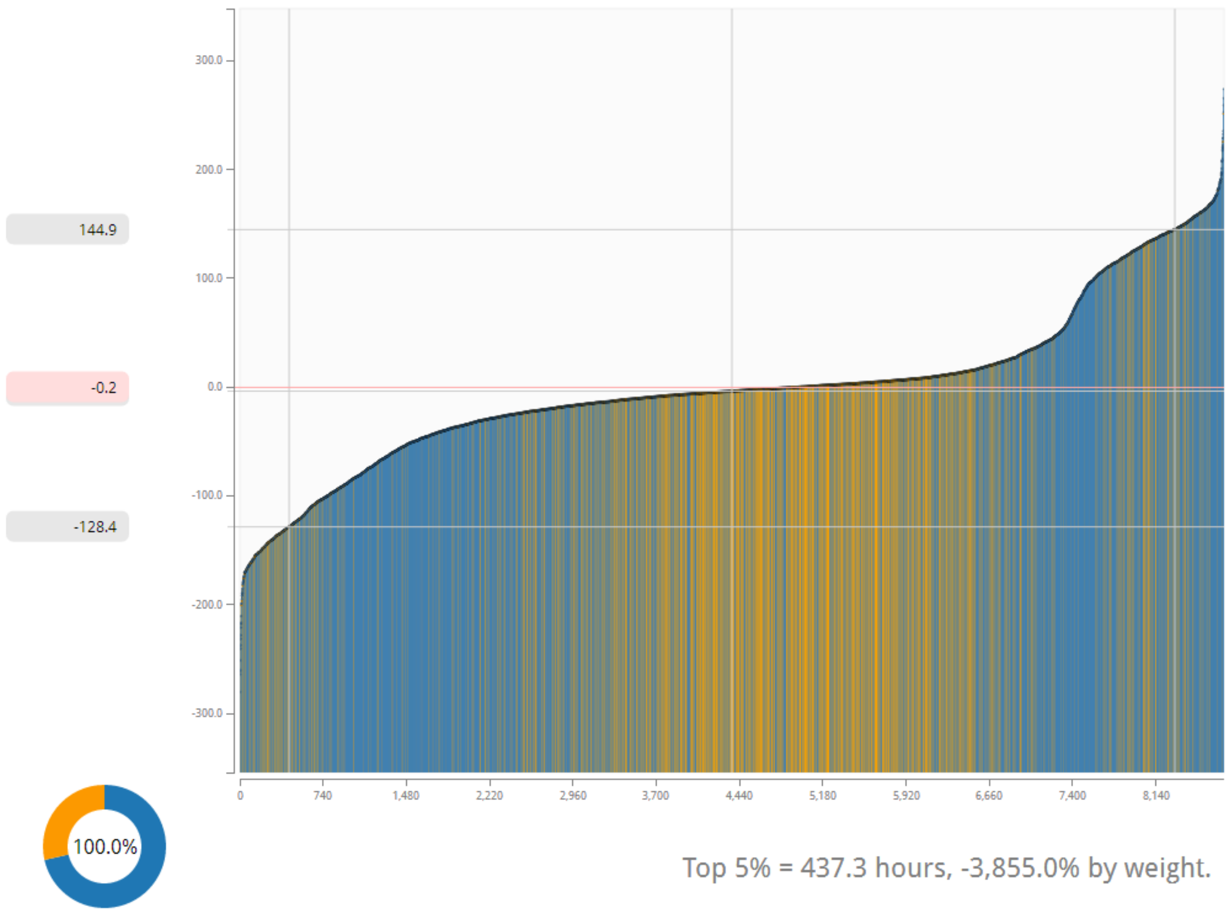
We see in the case of City Hall that if they had demand response protocols in place, we should expect their loads in the upper right area of the chart to be dramatically reduced in those cases where ISO load exceeded 22,000MW. But we do not see any response. Also, it seems that City Hall flat-lines around 2,300kW and perhaps they are unable to respond in any meaningful way because at full tilt they are unable to keep up with the required cooling load.

The R^2 versus ISO NE is 0.55 for the entire year but improves to 0.71 when looking at just summer. Clearly, there are other influences driving the load other than just ISO load and outside air temperatures. The large thermal mass of City Hall is a likely influence.

4.5.7 Swing Analysis

Similar to the generic S-Curve shown in previous discussions, we also plot the kW *swings* in consecutive periods found in the data. This presentation reveals systems that may be relatively hyperactive compared to others, and it would be logical to request additional BAS data to get to the underlying cause for this.

By measuring the delta change from one hour to the next, we are making a basis assessment of how well the building is controlled. If the swings between two consecutive hours are large compared to the average load – *relative to other similar buildings* – we can sometimes conclude that the building isn't controlled very well. When swings are large, the ability for a facility to predict its next hour load based on the current load starts to approach a random guess, and this means that hitting peaks are likely to come as a surprise. When we looked at Newton North HS on a different project, we found their large swings were a result of three large pieces of equipment that were operating on the same schedule when the better practice would have been to sequence them to avoid large swings and unexpected peaks.



At City Hall shown above, in 5% of the hours at either end of the chart, we see swings of about 120kW from one hour to the next. That leaves 90% of the cases where swings are less than this amount. As expected, swings are far less prevalent on weekends (orange).

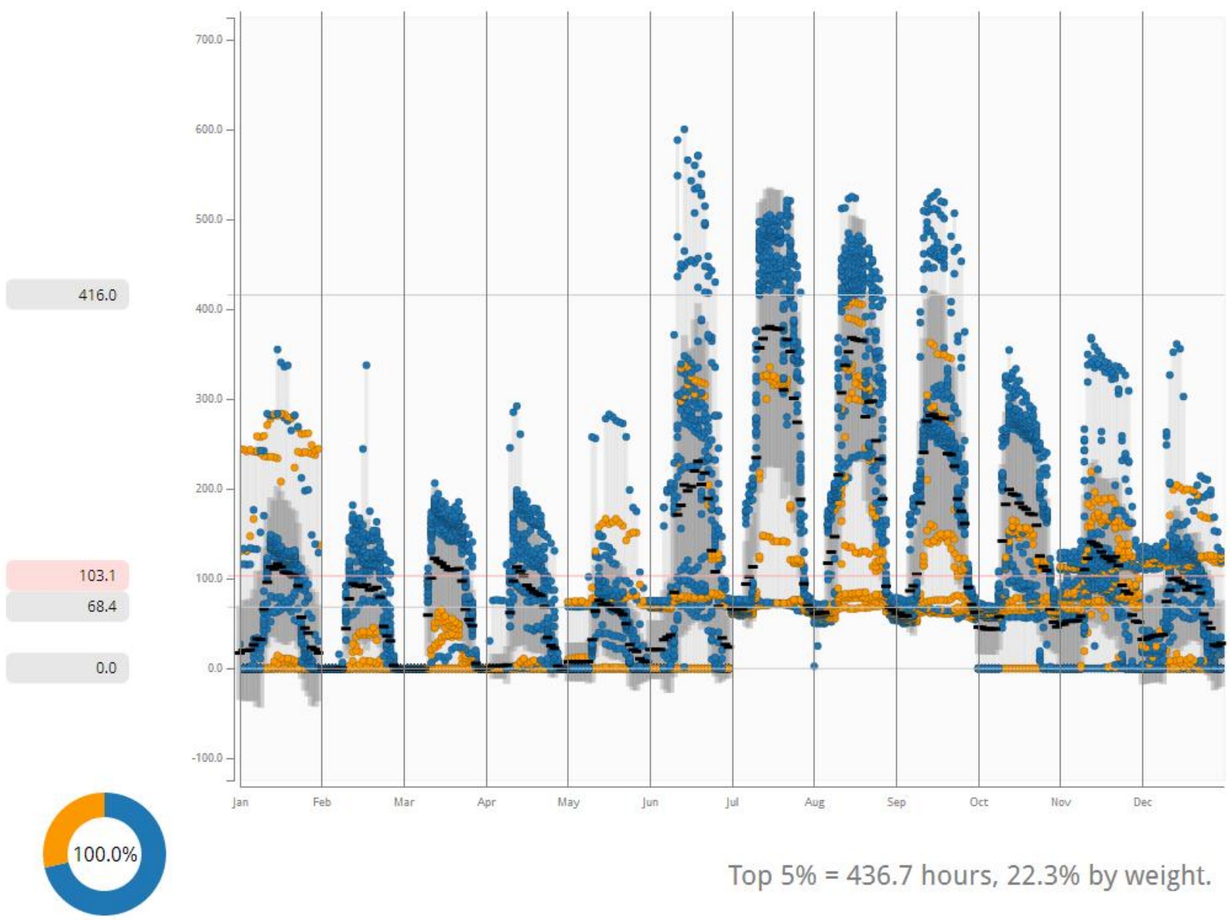
The bump in the curve around 7,400 suggests a significant collection of loads most likely associated with building start-up on occupied days. We do not see an accompanying down swing bump, so this is why we think it's a collection of independent loads that come on together but shut off at different times.

5 More on ICAP tags, other buildings

Putting City Hall aside one more time, we look here at a couple of other buildings in the City of Boston portfolio to illustrate how buildings are very different in ways that are easy to spot with just the main meter interval data.

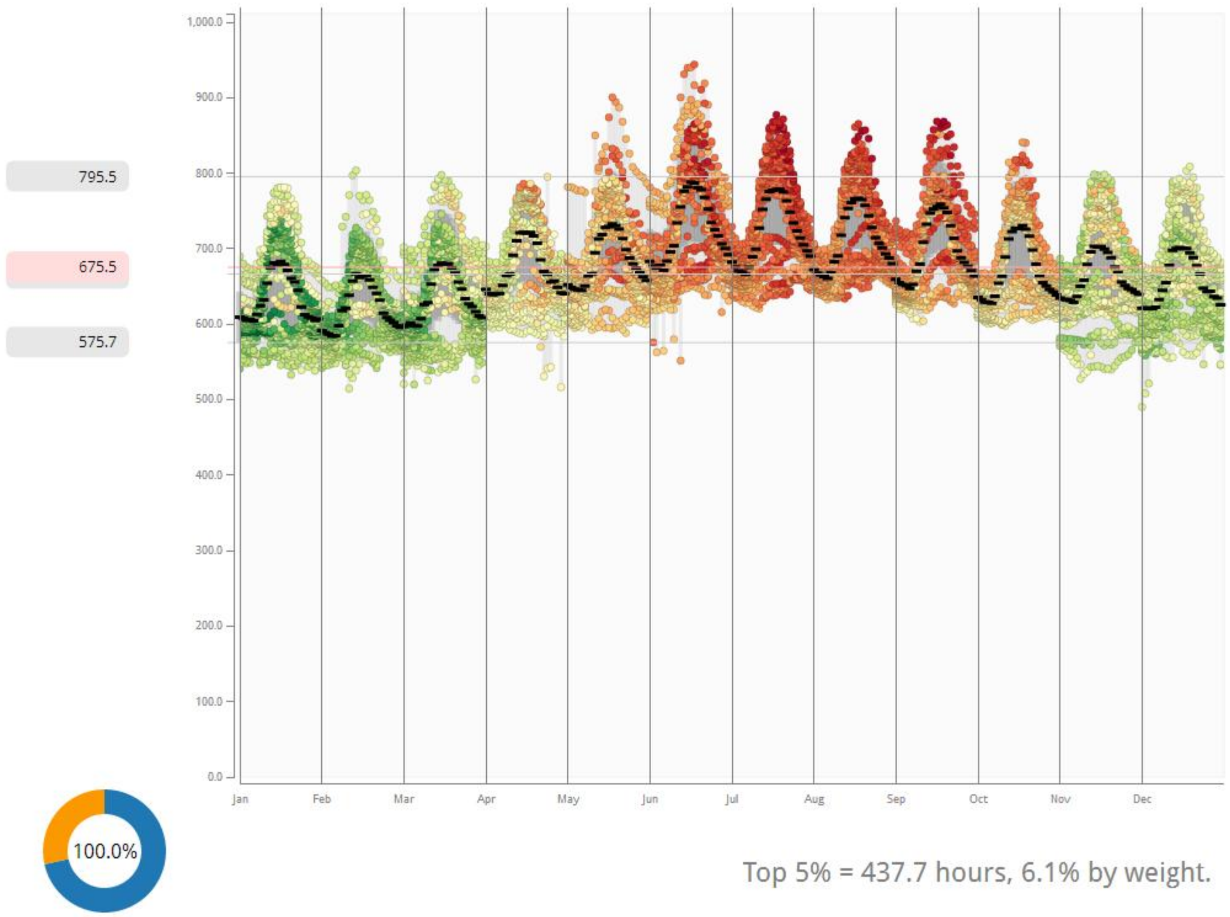
5.1 Blackstone School

There are many schools such as Blackstone that have a 75 kW Combined Heat and Power unit (CHP) but do not operate it in the summer. If these units were operated on days when ISO New England is experiencing high loads, each school could reduce the electric bill by approximately $13,000 per year. Given that we just recently saw the likeliest ISO candidate for annual peak hour on August 12th, if this 2014 profile were relevant here in 2016, there's a possibility that Blackstone's ICAP tag would read about 100kW but could have been as low as 25kW.



5.2 Boston Police Department Headquarters

BPD Headquarters is an example of a building that has a high base load. Night and weekend setbacks do not amount to much, and the operating band is very tight with a consistent average across the year of about 675kW and a 90 percent range of +/- 100kW.



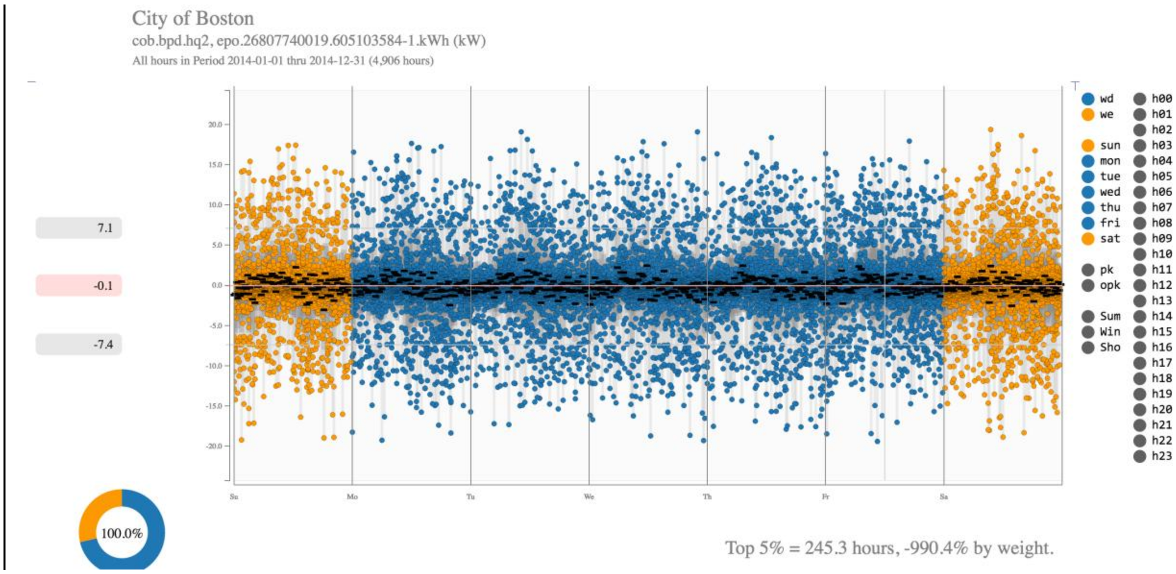
It would be logical to ask if this building is operating 3 shifts for all seven days of the week and, further, to make sure that it has had a lighting retrofit. The table below the graph shows that the BPD Headquarters has the highest kW/square foot in every month of the year when it is compared to 5 other buildings in the city. The high kW/sq. ft. does not appear to be related to the cooling load, but due to a high baseline load. The peak kW/sq. ft. loads occur in the spring and not the hotter summer months which is indicative of simultaneous heating/cooling.

Monthly Peak kW per 1000 sq ft - (based on 5 minute interval data) compared to other buildings

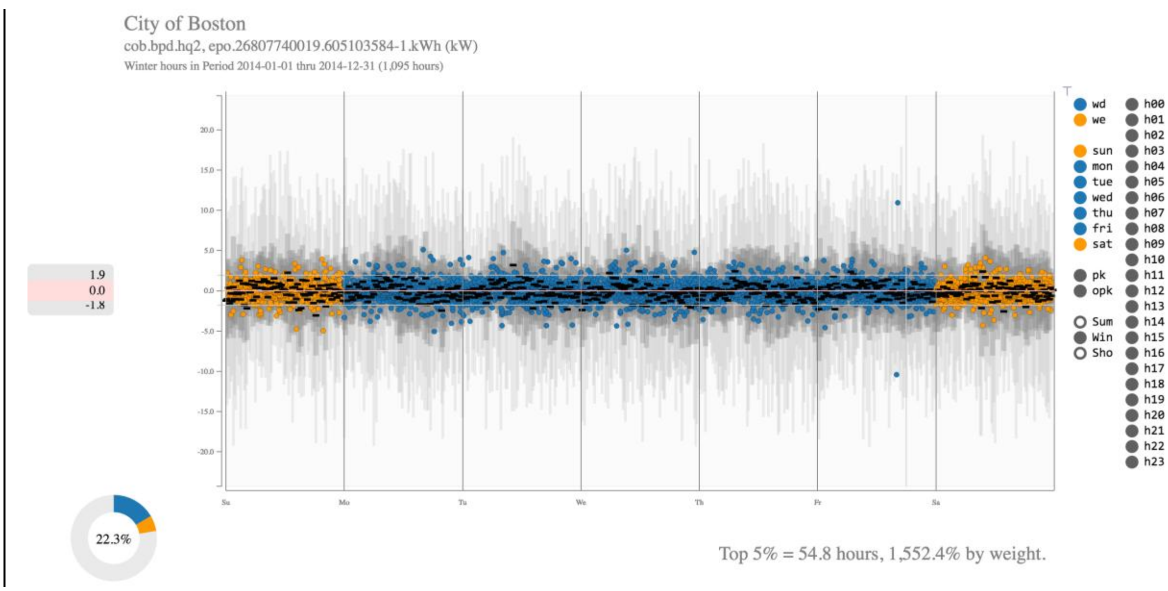
	Jan 2014	Feb 2014	March 2014	April 2014	May 2014	June 2014	July 2014	Aug 2014	Sept 2014	Oct 2014	Nov 2014	Dec 2014	Annual Summary Min	Max	Delta
City Hall	3.9	3.8	3.8	3.4	4.2	4.4	4.8	4.4	4.4	4.5	3.6	3.7	3.4	4.8	1.4
Fire Dept HQ	2.2	2.2	2.1	2.0	2.3	3.2	3.4	3.3	3.7	2.3	2.1	2.1	2.0	3.7	1.7
Copley Library	3.1	3.3	3.2	3.1	3.1	3.1	3.2	3.2	3.3	3.5	3.6	3.3	3.1	3.6	0.5
1481 Tremont	1.6	1.5	1.5	1.5	3.3	4.4	4.0	3.6	3.6	2.5	1.5	1.5	1.5	4.4	2.9
43 Hawkins	3.7	3.8	3.7	4.1	4.6	5.2	5.7	5.5	5.6	4.7	3.7	3.7	3.7	5.7	2.0
Police Dept HQ	4.9	4.9	5.1	6.4	6.6	6.5	6.1	6.2	6.0	6.7	4.9	5.2	4.9	6.7	1.8

The magnitude and the frequency distribution of the delta kW graphs below indicate the change in kW from one interval to the next is due to cycling compressors in summer/shoulder months. The roof of 1199 Tremont Street shows both a 2-cell cooling tower and air-cooled condensers.

Delta kW chart for entire year



Delta kW chart for winter months only.



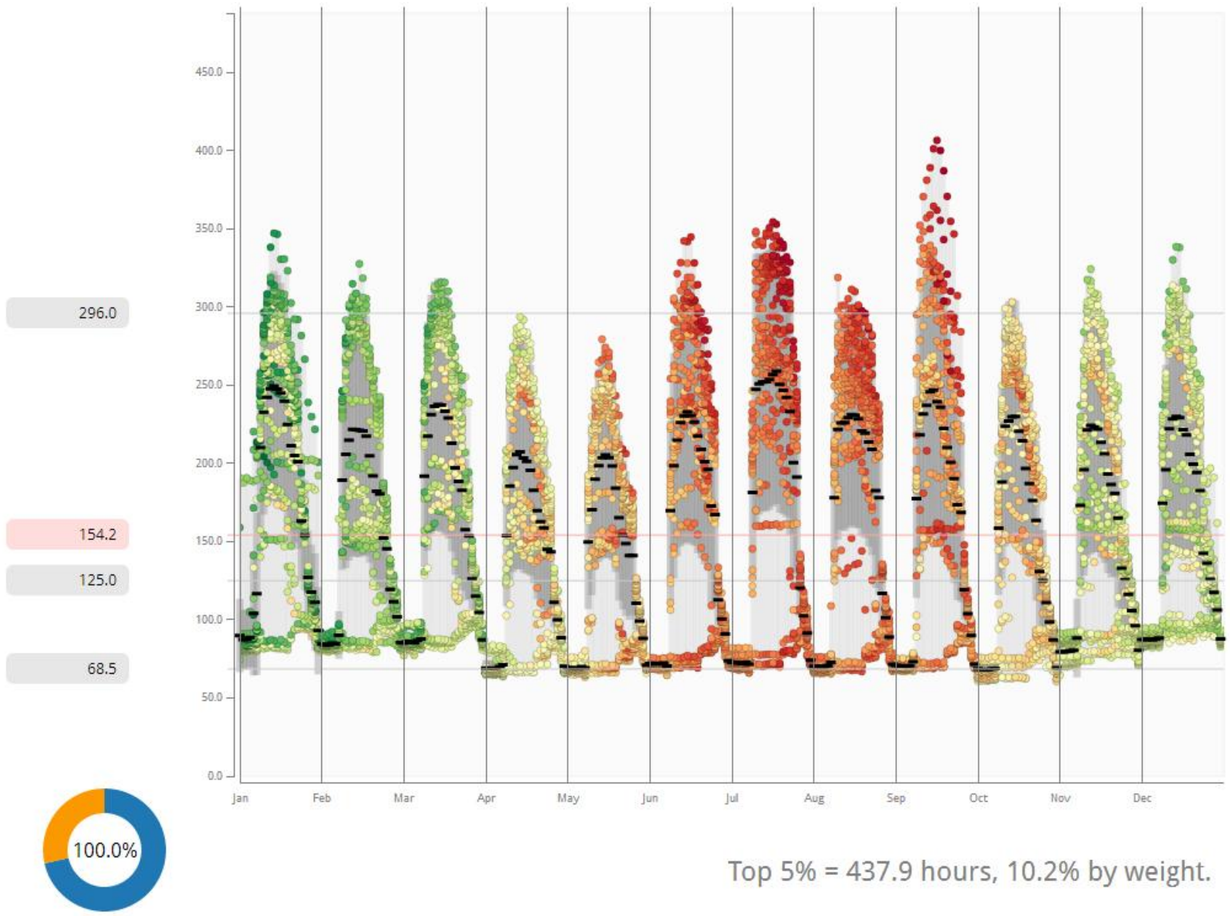
The volatility for all days isn't especially high compared to the average load, but it is significantly different than when we look at just the winter months. Volatility sometimes appears low because the facility has such a high baseline that there is relatively little room left for any large load swings; everything is already running and there's not much left to turn on.

5.3 Jeremiah Burke School

Jeremiah Burke School looks to be the opposite of BPD, in that the building has two states: It is either "off" at approximately 65kW, or else it is on and out of control, with wide load ranges during occupied hours and a year-wide 95th percentile around 300kW. A KPI which measures the weighted average kW above the 95th percentile relative to the average load in the building would surely put Burke near the top of a list that would make it a good candidate for ECMs that target summer cooling.

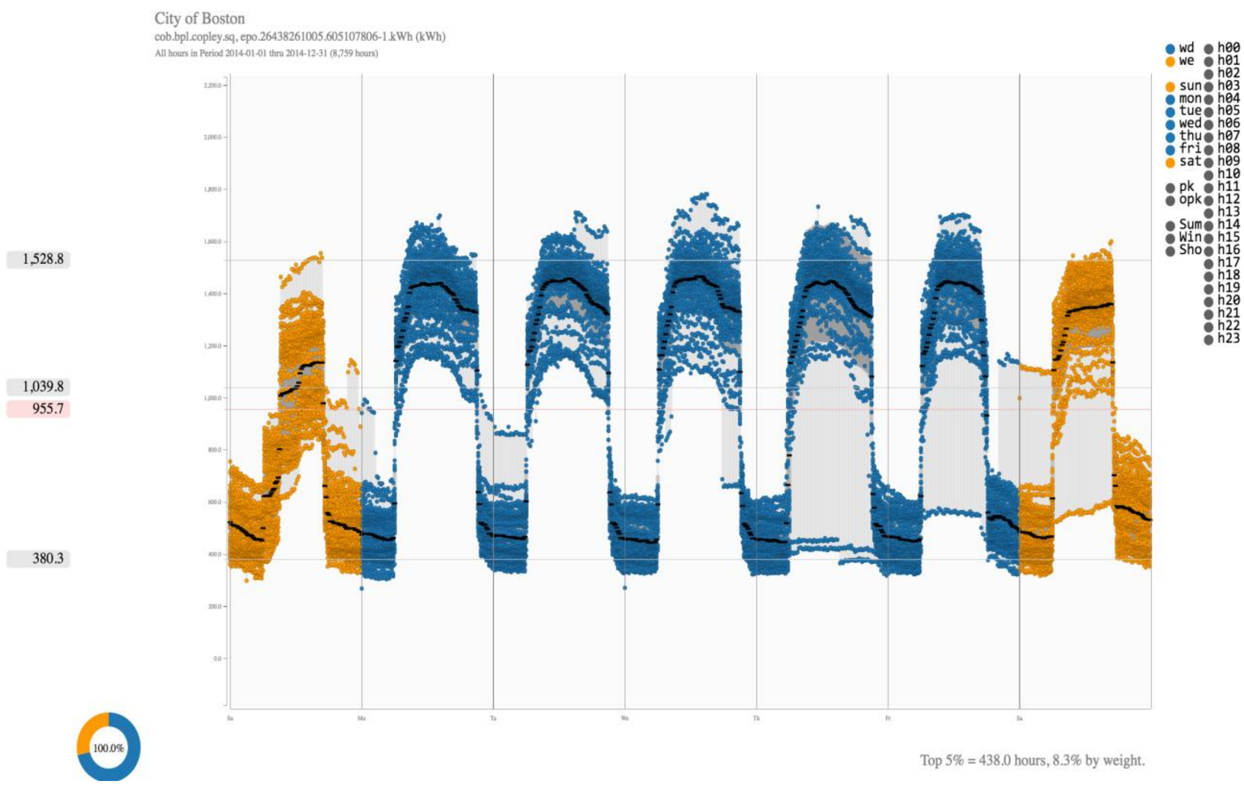
Noticeable in September is an effect that we see at many schools – the first day of school was September 2nd, and in 2014 this was an exceptionally warm day; the school is wide open as students and teachers try to locate their assigned rooms, so the building is at full tilt. A peak to average ratio of nearly 7 to 1 is not unexpected in these cases.

Also noteworthy is that schools are rarely shutdown during the summer and will sometimes show load profiles that equal or exceed the profiles of the standard school year. The question in our mind is whether or not the entire school needs to be conditioned in cases where only a portion of the school may be occupied.



5.4 Boston Public Library, Copley

The Copley library has interesting interval data. The graph below shows an average weekday for the entire year (Sunday – Saturday). The majority of all "high kW" outliers shown on the graph are Sunday Nov 9th, Tuesday Oct 15th, Wednesday Nov 12th, Thursday October 30th and Friday Oct 17th. A building with this pattern of outliers shows that equipment is ***not*** operating randomly, but there are differences on individual days. We don't see the typical scattered summer electrical peaks of New England because of the steam-fired absorption chiller.

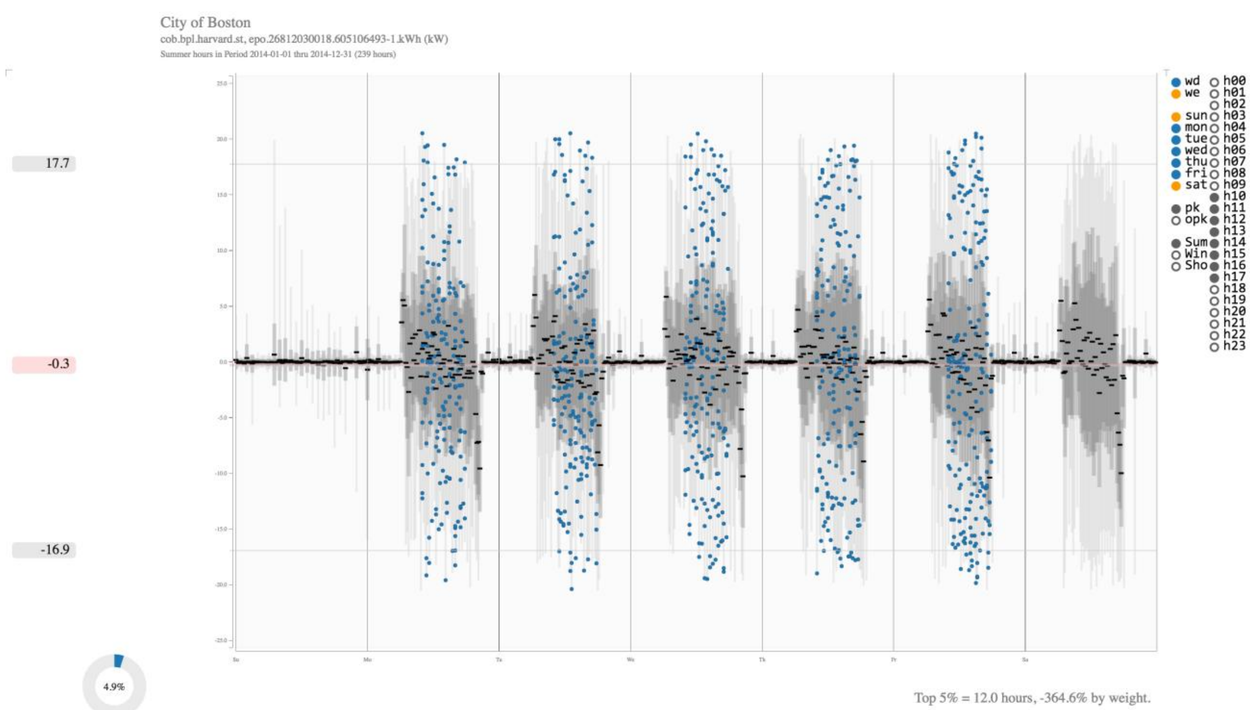


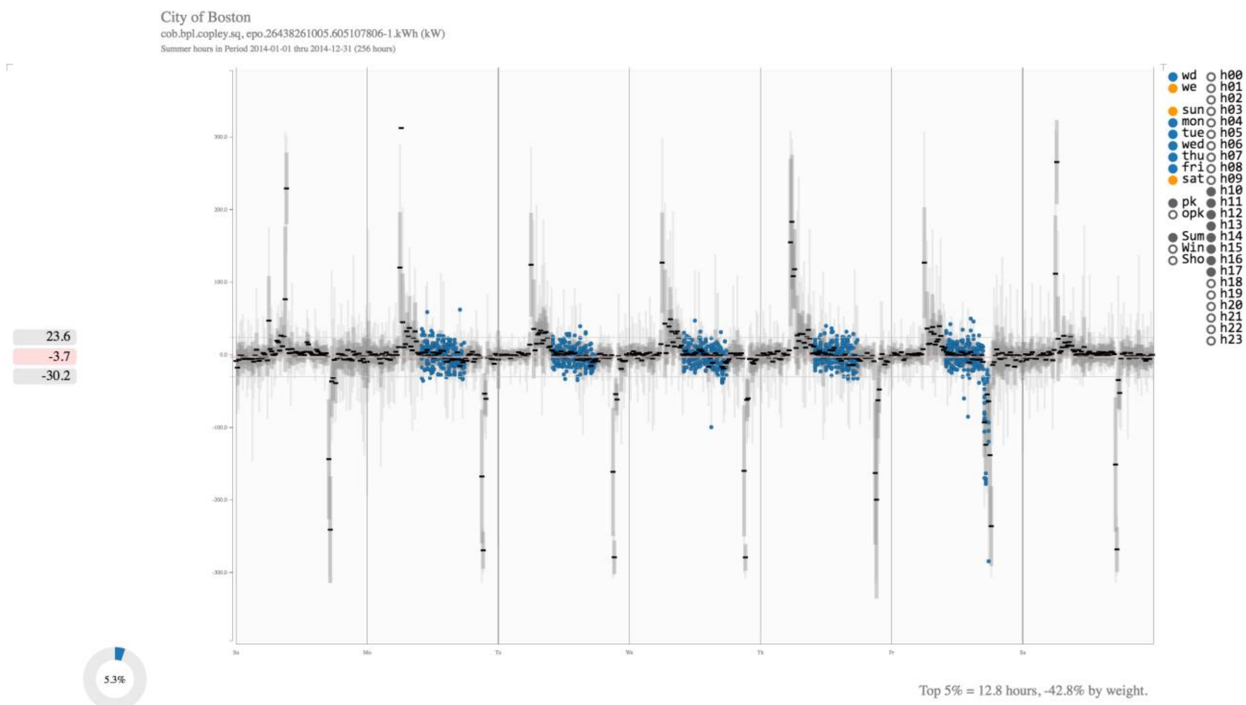
On the surface it looks like there is not much opportunity for improved control of the building when ISO New England experiences peak summer loads, but knowing that the building is open on Saturday and Sunday may lead to opportunities. If the building could be operated at the typical Saturday or Sunday level for a few hours on a peak summer day, then there is an opportunity for over 100 kW in savings. With a little flexibility from employees and patrons, this could probably be done without sacrificing comfort. The benefit of an opportunity like this is that it could be accomplished without any major programming changes to the building automation system.

5.5 Boston Public Library – Honan Alston vs. Copley (delta kW Load Profile)

The visualizations below show the delta kW from one 15-minute period to the next for summer months between 10:00 am and 6:00 pm for the 20,000 sq. ft. Honan-Alston vs. the 500,000 sq. ft. Copley branch. (Blue data points are the actual "filtered" data).

	Peak Summer kW	Delta kW
Copley	~1600 kW	~24 kW
Honan Allston	~100 kW	~18 kW





The similar delta kW values for buildings that are of such different sizes highlight the impact to ISO New England peak summer loads from different types of cooling equipment. Can the existing Honan Alston branch cooling equipment be economically retrofitted with Variable Speed Drives to improve both energy and demand savings each month? If VFDs are not immediately cost effective, can the cooling set point be maintained throughout the night prior to a predicted ISO New England peak day? This would utilize the thermal mass of the books in the library to maintain space temperatures while the air conditioning compressor is shut off for a few hours when the ISO New England grid is congested.

If the books in the library don't provide enough thermal mass to allow the compressors to be shut off for an extended period of time, is it economical to add thermal mass or simply utilize window shades/glazing to minimize solar gain from the large windows?

5.6 Monthly Billing Data used for Peak Demand Analysis at Boston Public Libraries

The table below demonstrates how we can use monthly billing data to screen buildings that don't have a time-of-use meter installed. Five years of monthly utility demand billing is presented in the tables for the 3 libraries. The South End Branch has a max kW/sq ft that is 142% higher than the West End and 218% higher than Codman Square.

Knowledge of the erratic daily load shapes from other libraries such as the Honan-Alston discussed in Section 5.5 lead us to believe that this high seasonal kW per square foot is due to a DX air conditioning system that is cycling on/off. If there is not an economical retrofit available at this time such as a variable speed drive for the cycling compressor motor and condenser fan, a specification is written to ensure the eventual replacement has the desired features that will reduce peak kW demand at the end of useful life.

Boston Public Libraries

Monthly Peak kW per 1000 sq ft - based on monthly billing data

West End 12,562 sq ft	Jan/Feb 1/24 2/24	Feb/March 2/24 3/24	March/Apr 3/24 4/24	Apr/May 4/24 5/24	May/June 5/24 6/24	June/July 6/24 7/24	July/Aug 7/24 8/24	Aug/Sept 8/24 9/24	Sept/Oct 9/24 10/24	Oct/Nov 10/24 11/24	Nov/Dec 11/24 12/24	Dec/Jan 12/24 1/24	Annual Summary Min	Max	Delta
2007	1.9	1.9	1.8	2.7	4.1	4.6	4.2	4.2	3.5	1.9	1.8	1.8	1.8	4.6	2.8
2008	1.8	1.8	1.8	3.4	3.9		4.2	4.1	2.6	1.7	1.7	1.6	1.6	4.2	2.6
2009	1.7	1.6	1.6	1.6	1.4	3.9	3.2	3.4	2.7	2.2	1.8	1.8	1.4	3.9	2.5
2010	1.7	1.7	1.7	2.7	2.9	3.4	3.0	3.0	2.5	1.5	1.6	1.6	1.5	3.4	1.8
2011	1.5	1.5	1.5	2.9	2.9	3.3	3.7	3.3	2.9	1.4	1.4	1.4	1.4	3.7	2.3

South End 11,342 sq ft	Jan/Feb 1/13 2/13	Feb/March 2/13 3/13	March/Apr 3/13 4/13	Apr/May 4/13 5/13	May/June 5/13 6/13	June/July 6/13 7/13	July/Aug 7/13 8/13	Aug/Sept 8/13 9/13	Sept/Oct 9/13 10/13	Oct/Nov 10/13 11/13	Nov/Dec 11/13 12/13	Dec/Jan 12/13 1/13	Annual Summary Min	Max	Delta
2007	2.1	2.0	2.0	2.3	5.1	5.1	5.4	4.9	4.9	3.0	2.1	2.1	2.0	5.4	3.3
2008	2.1	2.1	2.1	2.0	4.7		5.1	5.0	4.2	1.5	1.9	1.9	1.5	5.1	3.7
2009	2.0	2.1	2.0	4.7	4.1	4.2	5.2	5.2	3.6	1.9	2.1	2.0	1.9	5.2	3.3
2010	2.1	2.1	2.0	2.0	3.8	3.8	3.8	5.3	2.2	2.0	2.3	2.2	2.0	5.3	3.2
2011	2.0	1.9	2.0	4.4	4.6	4.7	4.9	4.9	4.6	1.8	1.8	1.8	1.8	4.9	3.2

Codman Sq. 20,000 sq ft	Jan/Feb 1/13 2/13	Feb/March 2/13 3/13	March/Apr 3/13 4/13	Apr/May 4/13 5/13	May/June 5/13 6/13	June/July 6/13 7/13	July/Aug 7/13 8/13	Aug/Sept 8/13 9/13	Sept/Oct 9/13 10/13	Oct/Nov 10/13 11/13	Nov/Dec 11/13 12/13	Dec/Jan 12/13 1/13	Annual Summary Min	Max	Delta
2007	2.5	2.5	2.5	2.5	3.5	3.7	3.8	3.5	3.3	2.6	2.6	2.5	2.5	3.8	1.3
2008		2.6	2.5	3.5	3.3	3.4	3.5	3.1	2.2	2.3	2.2		2.2	3.5	1.4
2009	2.5	2.5	2.5	2.5	3.6	3.7	3.7	3.8	3.2	2.9	2.5	2.6	2.5	3.8	1.3
2010	2.5	2.2	2.2	2.0	3.6	3.1	3.8	4.0	3.1	3.1	2.0	2.0	2.0	4.0	2.0
2011	2.1	2.1	2.0	3.4	3.6	3.1	4.0	3.9	3.2	3.1	2.0	2.0	2.0	4.0	2.0

This analysis is also applicable to compare similar buildings such as Fire Stations and Police Stations to each other, but is not limited to comparing similar building types. Even when we compare buildings of similar usage and in the absence of utility interval data, knowledge of building orientation, thermal mass, glass exposure, etc. will lead to cost-effective data-driven decision-making.

6 HDD and CDD Weather Normalization

When we have multiple years of data, of course we will do the traditional weather normalization that has very limited utility, but is nonetheless popular with facilities that like to use this measure as an indicator of progress. We rarely see cases where the quoted values don't show an improvement, so we submit that this inferior metric is only used when it paints a facility in a more favorable light. There are simply too many things at work in a large facility to use heating and cooling degree-days as the ultimate measure of progress, but it can be useful when occupancy and facility patterns don't change significantly year over year, and when the main meter data is the only dependent measurement.

In this example, we show the year/year normalized kWh for Newton North HS to determine if there were significant changes.

In the case of a geographically wide portfolio, we would use the HDD and CDD reported by the nearest Weather Underground weather station. We also have the means to make our own calculation of heating and cooling degree-hours which usually results in a tighter correlation of usage versus weather, with the additional benefit that we can eliminate the off-peak hours that tend to obfuscate any real trends.

	2013	2014	Delta, %
Cooling Season			
CDD	1,306	1,314	+0.6%
kWh	2,028,074	2,032,079	+0.2%
Heating Season			
HDD	2,563	2,923	+14.0%
kWh	1,797,209	1,863,789	+3.7%
Shoulder Season			
HDD + CDD	2,301	2,498	+8.6%
kWh	3,805,008	3,926,602	+3.2%
Combined			
HDD + CDD	6,190	6,745	+9.0%
kWh	7,630,292	7,822,469	+2.5%

In short, blind use of heating and cooling degree-days is a terrible way to adjust for weather because buildings never follow the circadian weather rhythm, so why should we expect that there is good correlation when all hours are included? The only appropriate use of HDD and CDD normalization is when monthly billing data is the only available data. A single value to represent an entire year-over-year trend simply masks too many details to be very useful.

7 User Defined KPI Metrics

As needed, we develop metrics and key performance indicators that are relevant to the data we have available. The best metrics are those that help to normalize a large number of buildings such that they can be fairly compared to each other.

As an example, two simple KPIs our City of Boston Energy Map visualization uses the EPO interval data for certain buildings to show, for each month:

- KPI 1: the ratio of Peak to Average Weekday Occupied Load … the magnitude of peak loads when compared to the average in the building, as a measure of how "wild" the peaks are when compared to the average
- KPI 2: the ratio of Average Weekday Occupied Load to Average Night Load … a measure of how well the building is set back in its unoccupied mode.

These are just two possible measures that, intrinsically, do not necessarily reveal great insight but in the context of a large population of buildings can be useful when comparing similar building types. For example, we earlier mentioned the interesting high apparent base load at Boston Police Headquarters:

Night/Weekend Setback Calculations

Month	Peak Demand (kW)	Avg Load (kW)	Avg Load Weekday Occ (kW)	KPI 1 Peak/WdOccAvg	Avg Load Nights (kW)	KPI 2 WdOccAvg/Nights	Avg Load Weekend (kW)	Avg Load Base (kW)
Jan	814.3	634.3	686.2	1.2	615.9	1.1	586.2	0.0
Feb	816.8	622.2	672.2	1.2	598.0	1.1	590.0	505.4
Mar	855.0	636.3	693.1	1.2	615.0	1.1	598.8	492.5
Apr	1,019.5	673.6	728.5	1.4	652.4	1.1	627.3	468.4
May	1,029.6	684.9	737.0	1.4	663.2	1.1	647.7	546.1
Jun	971.6	727.6	792.7	1.2	704.7	1.1	678.4	460.1
Jul	892.8	722.4	781.9	1.1	699.9	1.1	669.3	529.6
Aug	938.9	710.7	772.5	1.2	687.5	1.1	670.2	567.0
Sep	884.5	697.9	752.1	1.2	669.4	1.1	662.7	538.6
Oct	1,050.8	672.8	730.5	1.4	645.1	1.1	629.5	582.8
Nov	816.8	662.6	717.8	1.1	648.3	1.1	621.6	506.5
Dec	868.3	657.4	708.5	1.2	634.9	1.1	616.5	458.6

Compare the BPD monthly average values to those of the Boston Fire Department headquarters:

Night/Weekend Setback Calculations

Month	Peak Demand (kW)	Avg Load (kW)	Avg Load Weekday Occ (kW)	KPI 1 Peak/WdOccAvg	Avg Load Nights (kW)	KPI 2 WdOccAvg/Nights	Avg Load Weekend (kW)	Avg Load Base (kW)
Jan	138.5	85.6	99.7	1.4	78.4	1.3	75.6	0.0
Feb	139.3	82.9	96.0	1.5	75.5	1.3	75.9	0.0
Mar	132.8	81.5	99.5	1.3	73.0	1.4	71.5	0.0
Apr	126.4	78.0	93.8	1.3	69.9	1.3	67.3	0.0
May	145.0	75.2	92.8	1.6	66.3	1.4	64.7	0.0
Jun	198.7	93.4	122.6	1.6	78.8	1.6	76.3	0.0
Jul	211.7	111.5	146.7	1.4	95.0	1.5	84.7	0.0
Aug	209.0	101.8	135.3	1.5	86.7	1.6	82.5	60.8
Sep	230.6	91.7	115.7	2.0	78.2	1.5	77.4	0.0
Oct	145.5	76.5	97.6	1.5	66.4	1.5	60.5	0.0
Nov	129.9	76.2	92.7	1.4	67.6	1.4	68.3	0.0
Dec	131.8	78.7	93.2	1.4	70.6	1.3	69.5	0.0

Granted, the two facilities may very likely have different operating profiles, but if they should be considered equal in terms of energy footprint then it would be fair to conclude that the Fire Department does a better job of setting back during third shift. Given that both have EUI values over 300 kBtu/ft^2/year, we'd want to learn more before drawing any conclusions about how we might reduce their peak demands. But at least it's helpful to have a metric that helps to assign them each a relative score that starts to explain their usage.

A typical school without CHP (Boston Latin) shows a set of metrics that appear to follow an occupancy pattern with better night set back.

Night/Weekend Setback Calculations

Month	Peak Demand (kW)	Avg Load (kW)	Avg Load Weekday Occ (kW)	KPI 1 Peak/WdOccAvg	Avg Load Nights (kW)	KPI 2 WdOccAvg/Nights	Avg Load Weekend (kW)	Avg Load Base (kW)
Jan	138.5	85.6	99.7	1.4	78.4	1.3	75.6	0.0
Feb	139.3	82.9	96.0	1.5	75.5	1.3	75.9	0.0
Mar	132.8	81.5	99.5	1.3	73.0	1.4	71.5	0.0
Apr	126.4	78.0	93.8	1.3	69.9	1.3	67.3	0.0
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Oct	145.5	76.5	97.6	1.5	66.4	1.5	60.5	0.0
Nov	129.9	76.2	92.7	1.4	67.6	1.4	68.3	0.0
Dec	131.8	78.7	93.2	1.4	70.6	1.3	69.5	0.0

We continue to develop additional KPIs to that normalize facilities in ways that let us rank and compare them, and inform the development of ECMs that target demand in specific ways.

For additional ways that we currently rank facilities in terms of costs, MMBtu and EUI, visit our City of Boston Energy Map. Click on any facility to see its relevant values and how the facility ranks against others in its department and other buildings of similar size.

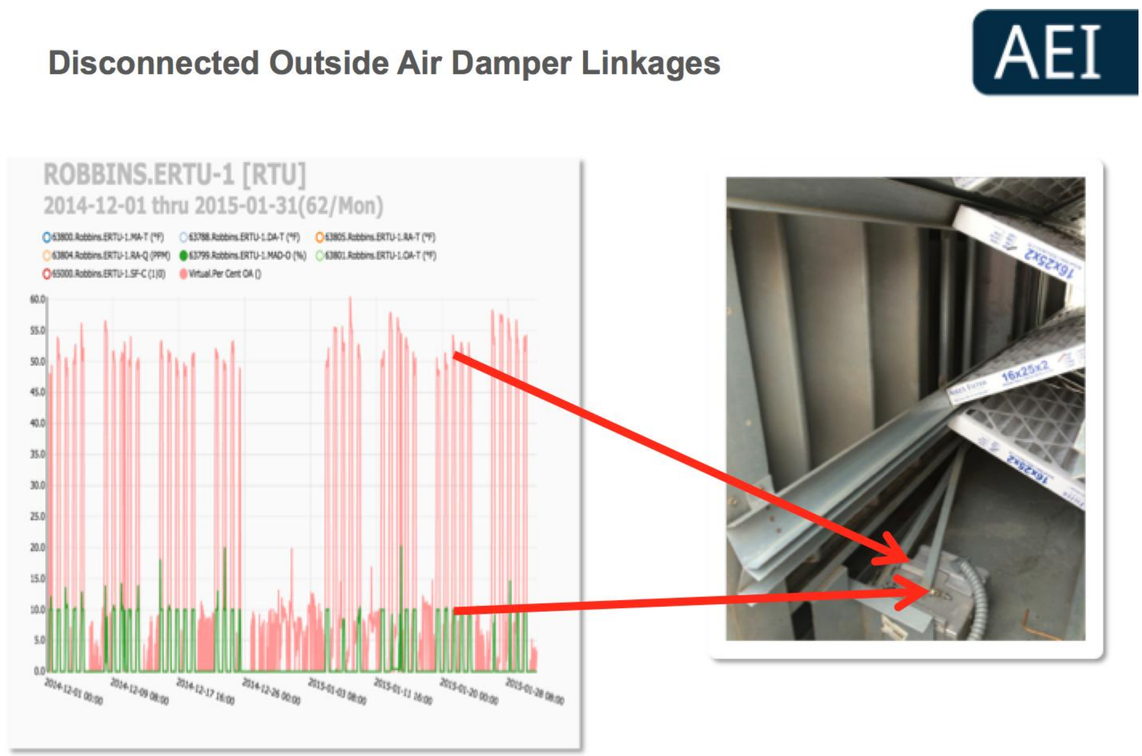
8 Building Automation System Data

When the path forward to reducing electric and gas demand is not obvious from the main utility meters, the option to drill down into the Building Automation System data is available through AEI software. In addition to basic analysis of items such as Variable Speed Drives and Demand Control Ventilation strategies working properly, analysis of temperature drops across boiler and chiller plants can add tremendous insight into gas and electric demand savings opportunities.

In this section we discuss various items we evaluate in a building that would affect peak gas and electric demand.

8.1 AHU Outside Air Dampers

In the chart below, the green lines are daily outside damper signals of 10% for a period of approximately 2 months. The red lines show the outside air is calculated to be 50% based on the following ratio of air temperatures: (MAT-RAT)/(OAT-RAT) where MAT is Mixed Air Temperature, RAT is Return Air Temperature, and OAT is Outside Air Temperature.



Fixing this outside air damper linkage was not difficult and resulted in both heating and cooling savings for this facility.

Our experience shows that when there is a temperature difference >10°F between RAT and MAT, the above equation yields reasonable results that can be used to identify outside air dampers that are not operating smoothly. The large temperature difference we have in the

New England heating season between RAT and MAT provide a good opportunity to verify dampers are operating smoothly.

Our experience has shown many outside air dampers do not shut tightly when the air handler is operating in the "early morning warm-up" mode with the outside air damper at 0%. Leakage rates of 7% are common. The time of day/season that the air handlers are operating in the "early morning warm-up" mode and leaking may correspond to times when the New England gas pipeline is experiencing imbalances. It may not be cost-effective to replace leaking dampers, but when new dampers are needed, it may be cost-effective for DOER to incentivize an upgrade to tighter-sealing dampers based on peak gas savings.

If the ratio of MAT/RAT/OAT is not precise enough to verify incentive payments, there are products made by companies such as Aircuity, Inc that would satisfy incentive payments M&V requirements.

8.2 Chilled/Hot Water Primary/Secondary Loops

The previous discussion of calculating the actual % of outside air is also applicable to calculating the % recirculation rate on central plant primary/secondary loops as loads change throughout the day. When these loops are not balanced, recirculation rates are too high and design temperature drops across the loops are not achieved. This can result in operating more boilers/chillers than is required to meet the load.

8.3 Heat Recovery Wheels/coils

Heat Recovery Wheels are notorious for not being maintained properly. Both wheels and coils are generating maximum savings when operating with outside air temperatures at their extremes. When data is available from the building automation system, the analysis of the desired temperature sensor differentials is straightforward.

9 Conclusions

With just the utility 5-minute interval data and a little knowledge of the billing parameters at a facility, we are able to visualize and quantify how energy is used in a building by time of day and day of week, month and year. Adding weather and ISO New England demand data offers insight into the way a building actively or passively responds to outside influences.

The range of loads in a facility – particularly those in the 95th percentile each month – offer opportunities for demand reduction. The higher the variability in the range, the larger the opportunity because controlling just a few hours in each month can have a significant impact on the kW reduction. For a given facility with known profiles, an Opportunity Matrix can be developed which quantifies those opportunities.

Lawrence Berkeley NL and others have developed key performance indicators that help to characterize the way a building is being operated just by using the main meter interval data. With these KPIs, buildings can be compared and ranked leading to suggested ECMs that better target a building based on its specific characteristics.

Since access and manipulation of utility interval data is easy and low-cost, the insight value of exploring this data is an excellent way to glean insight into the way buildings are being operated prior to engaging in more expensive methods. When evaluated properly, main meter interval data points the energy analyst in the right direction and is an essential tool for any large portfolio.

We hope that some of the examples we have presented here highlight the fact that peak demand reduction is not always limited to installing hardware.

We feel that we can exceed the desired goals by presenting data to a cross-section of people that are familiar with the buildings in a way that they can understand and put an action plan in place.

We have included examples of building automation system analysis because many people are evaluating cost-effective strategies such as solar, battery storage, fuel cells etc. and if the buildings are tuned up first, the installed options will be more cost-effective.

9.1 Selected Detail Conclusions

The main electric meter of the 20,000 sq ft Honan-Alston Library clearly shows an opportunity to minimize 18 kW swings from air conditioning equipment between 10:00 am and 6:00 pm.

The main electric meter from the 500,000 sq ft Boston City Hall indicates there may be an opportunity to improve control of a 200 kW load that is probably the final stage of air conditioning delivered from the central plant.

The main electric meter from the Copley Library indicates an opportunity to reproduce the Saturday/Sunday occupancy levels for a few hours on a weekday when ISO New England is interested in peak demand reduction.

10 About AEI

Advanced Energy Intelligence, LLC is a Massachusetts company that specializes in tuning buildings and improving the energy performance for facilities of all sizes.   We use the data from a facility's EMS/BAS, combined with the facility's utility data and publicly available weather data to understand how buildings use energy, from the main meter down to individual pumps and motors in any mechanical system.

We have expertise in large facilities such as university and school campuses, Federal, State and municipal properties, as well as commercial and industrial facilities.

Our services include:

- Low-cost, rapid deployment Soft Start^{SM} review of a facility's utility data,
- Whole-Portfolio Energy Maps for a comprehensive energy view of an entire city, town, campus or property portfolio of any size,
- EMS/BAS review and commissioning services and consulting,
- Full IPMVP-compatible consistent commissioning of a facility by continuous review of EMS/BAS data using our high-performance data processing, analytical tools and in-house Certified Energy Managers.

We deliver specific and plain-spoken ROI-prioritized analyses for boilers, chillers, roof top units, air handlers, steam heat systems, water and gas, for a single building or an entire campus.

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