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Improving Facility Operations and Achieving Sustainability Goals through Machine Learning

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ABSTRACT

The facility management industry is experiencing an influx of smart technologies and a retiring workforce. There are not enough qualified replacements coming into the industry to offset the retiring engineers and maintenance staff. Facility owners are faced with adopting technology to augment their workforce shortages and are constantly being asked to do more with less. More facilities, more square footage, more complex systems, while being given fewer resources and tighter budgets. Technology, specifically advanced analytics and machine learning, must be adopted and operationalized to augment the current tools and staff. The primary business drivers are enhanced productivity through root cause analysis, energy reduction, and streamlined operations, while establishing and exceeding sustainability goals. This case study explains the journey from a local government perspective on how they added an initiative to the City's Strategic Plan, piloted the technology to prove the value, and created the business case to get approval from the City Manager for expansion.

INTRODUCTION

The City of Durham experienced a variety of challenges in managing and controlling their owned city buildings. These challenges led them to launch a formal request for proposal (RFP) process to acquire an advanced analytics solution for their building systems. The intent of this system was to collect and analyze data from the local building automation system to better understand how to control and maintain the building.

The City chose SAS® and Building Clarity in August of 2018 to provide the expertise and technology to address their issues. The team began by installing a patent-pending IoT gateway developed by Building Clarity to collect thousands of data points being generated from the building every second. After establishing a constant flow of data, the team then cleansed, provided context, and prepared the data for analytics. The data was then sent from Building Clarity's cloud service to SAS® Cloud where Event Stream Processing (ESP) began scoring the data in real-time. Statistical models are built through ESP and visualized within Visual Analytics (VA) for a team of experts to interpret and deliver results to the end client. This paper will highlight the process of data collection and preparation, creating models and visualizations, and the results that have been delivered to the City of Durham.

DATA COLLECTION AND PREPARATION

In order for ESP to be able to ingest the data without traditional extract, transform, and load (ETL) processes, the various disparate data sources must be integrated together into a normalized data structure in stream and in real time ahead of the ingestion process. In order to do this, the team began by installing an IoT Gateway: a commercial-off-the-shelf (COTS) hardware stack hosting a software stack comprised of both open source and patent-pending integration software developed by Building Clarity.

HARDWARE STACK

The hardware stack was selected and built to meet the network integration needs for continuous, robust communications with the device(s) operating on the building automation system (BAS) network. The primary edge device is a small form-factor computer that provides the processing power for the software stack. Additionally, the Gateway contains a communicating UPS that provides dedicated battery back-up to facilitate data capture during anomalous, transient events in the building, and to protect the computer in case of damaging power conditions.

SOFTWARE STACK

The integration software collects data points being generated from the building systems in real-time via connectors designed specifically for each of a set of industry standard communication protocols, such as BACnet and Modbus. The data is translated from its source communication protocol into MQTT and transformed into a schema designed to be easily read by ESP. The data is also anonymized through the assignment of a globally unique identifier (GUID) to each point. Additionally, the data is stripped of all its meta-data. This is done to reduce the overhead of each data packet with goal of minimizing the bandwidth required. All these processes are performed by the software in real time without the data ever being put to rest.

The final data packet contains only an MQTT topic that includes the GUID and an anonymous customer ID, a date-time stamp, and the corresponding value of the point. An example of the raw data that is broadcasted after preparation for ESP is shown in Figure 1.

sensor ID	date	time	value
c4656b62-adee-4df1-a464-d4497e3b8a30	21217	64009	9.00
6db92420-ded4-4a20-aa66-5b70ee37900e	21217	64009	62.93
5e9ba2b8-3a30-4d38-bfe8-971196145adc	21217	64009	0.00
587bfb53-d209-41fa-a08b-6d179e7ba2a9	21217	64009	66.76
843bf0ab-c797-4df6-a107-117f1967e0db	21217	64009	0.00
ae6dc9b5-1714-403f-a6d1-e8c7f470278a	21217	64009	75.01
a4e2e702-257c-4e5b-8ee8-815ee63a8c6f	21217	64009	0.00
00f7511b-b040-44eb-b48e-1eb7804fea07	21217	64009	12.08
6d816ab2-1465-4420-aa72-ea17b625bd40	21217	64009	0.00
af4908ff-114d-4d28-ba12-158e021c0138	21217	64009	120.00
39ca006c-42ce-4228-9e6d-4d6146d7e0f4	21217	64009	39.99
7f07dcfd-9138-4925-9f82-efb9a9891b13	21217	64009	0.00
3dabb244-b240-45fb-a2e2-4a29ef26b58c	21217	64009	0.00
c644e5ea-3f7c-4c4f-979b-f7c2d7a24233	21217	64009	74.00

Figure 1. Raw data points broadcasted by Gateway

DATA FLOW AND CYBERSECURITY

Once the MQTT data packet is constructed, it is then encrypted and broadcasted via HTTPS from the edge device to a cloud-based MQTT broker-cluster that republishes the data for ESP to subscribe to. The Gateway can only call home to the broker-cluster, and ESP can only subscribe to the broker-cluster's published data feeds, thus creating a layer of security for the Gateway. There are no in-bound ports from the internet to the Gateway, making it invisible to port scanning. The anonymization of the data itself also serves as a means of security beneath the encryption layer, as does the removal of the meta-data which eliminates all data context.

RE-APPLYING THE DATA CONTEXT FOR ESP

Once the integration to the building systems and devices are completed, a team member begins the process of building out a series of three configuration files for ESP. These files allow ESP, through a patent-pending process, to add back in the context to the data automatically as it is ingested from the MQTT feed. The process for creating these files is colloquially called “point-mapping”. Assuming nothing changes within the building, point-mapping is a one-time process during the implementation of the project. Point-mapping serves two primary goals: translation and normalization.

The first goal is to translate all the data from a BAS hierarchy (derived from the meta-data) to a “physical” hierarchy that represents the actual function of the building and its systems. It is counter-intuitive that the raw data doesn’t implicitly represent the actual function of a building. However, in most cases, raw sensor values and other system data are inherently tied to building automation/control or metering devices, not necessarily to the actual “thing” that the data is representing. For example, the meta-data for an electrical power point indicates that the point is associated with a certain meter type, or possibly an asset tag, but not what the actual point represents within the building’s specific context. The meta-data may say that the point is generated by Meter Type X with Asset Number Y, and has the units of kilowatts (or kW). However, that meta-data does not always designate if that is a measurement of the building-level electric demand, or if it represents a fan motor’s power. Moreover, it doesn’t describe how that power measurement relates to those devices and their sensors upstream and downstream within its specific building sub-system, and similarly within the system of sub-systems. Providing this context is foundational for accurate, meaningful data visualizations, as well as the alerting and root cause analysis (RCA) tools within the analytics software. Figure 2 shows an example of how one system of devices (and their points) are connected through a building’s hierarchy.

The second goal of point-mapping is to normalize the data’s nomenclature. For example, the supply air temperature of air handler one could be represented a large number of ways within the BAS depending on the technician who programmed the system. The example point could show up as “AHU1 Supply Air Temp”, “AHU-1 SAT”, “AH_1 SA-T”, etc. So for each air handler in the building, there could be many different designations and many different ways to annotate “supply air temperature” points associated with those air handlers. A nomenclature standard has been created to which all point names are normalized. This normalization allows each point to be automatically assigned to each of the models running in ESP that require them during the ingestion process.

A necessary by-product of the point-mapping process is that the data is cleansed. For example, there are not just multiple ways to designate a specific point or sensor, but there may also be two devices designated as unit “one” within a building. This duplication must be rectified as a part of this process. Other irregularities within the data are often identified very early during point-mapping, such as sensors that have drifted out of calibration or sensors that have incorrect scaling factors applied within the building automation controllers. Some of these may be immediately correctable within the BAS, while others may require intermediate steps to be implemented to ensure that the data entering the models is accurate and applicable. Furthermore, data points may be missing from the building systems that are crucial to a model’s accuracy. These are usually recognized as missing during the point-mapping process, and suitable proxies can then be identified and implemented.

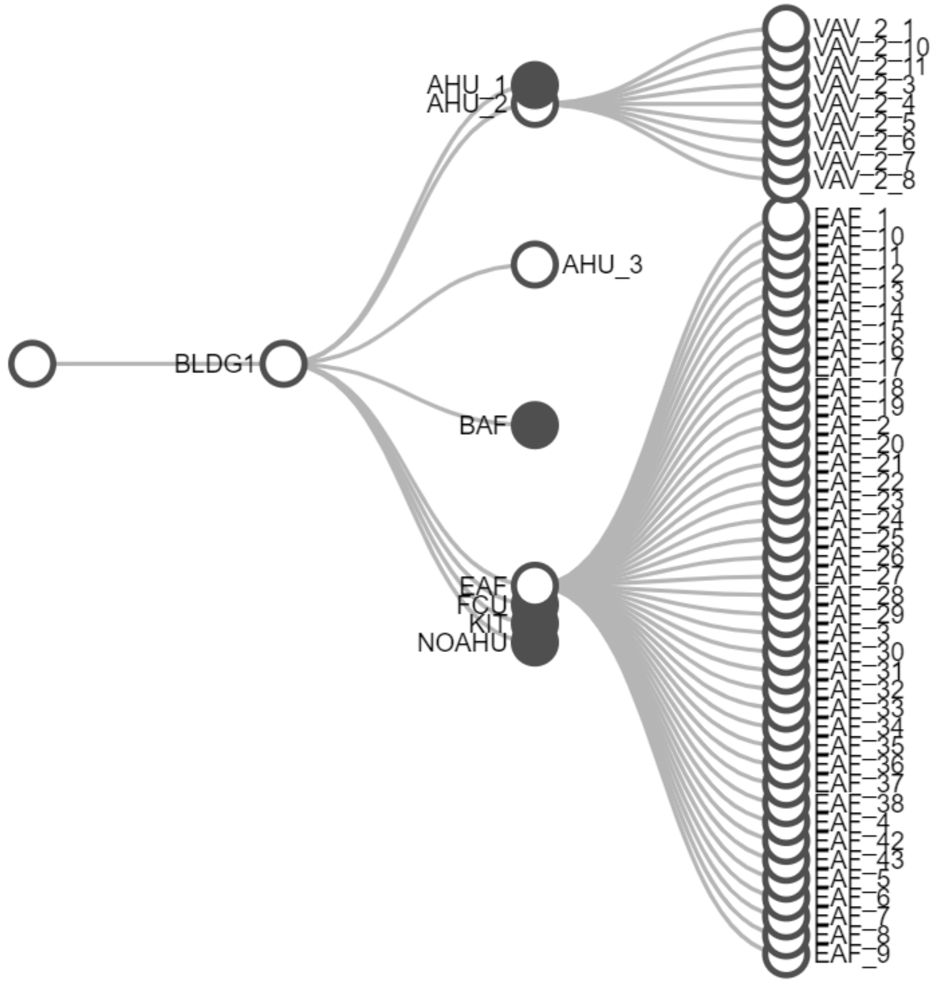

Figure 2. Example of an air-side system hierarchy

CREATING MODELS, ALERTS, AND DASHBOARDS

The traditional approach for monitoring system performance has been to write hundreds or thousands of business rules to try to highlight unexpected behavior. These are simple rules that look for unexpected changes based on an individual sensor – or at most based on a handful of sensors. However, from a practical perspective, building and maintaining these rules represents a significant challenge for facilities teams, many of which have seen their numbers decrease over the past 10 years.

Our approach has sought to use machine learning to modernize this antiquated process. For all of the various key metrics and settings, SAS® data scientists and Building Clarity subject matter experts have worked together to define an appropriate set of predictors, and then neural network models were fit using VIYA's new auto tune capabilities to arrive at the best fitting model. The predictions from these models allow a simplified deployment of business rules. Whereas before many rules were needed to address all of the various operating conditions, the deployment of a model that incorporates these conditions as predictors allows for simple questions to be asked like "Is the fan's speed and energy use currently higher than expected?" Or, "Is the chilled water temperature in an expected range based on current demands?" This is also much simpler to explain to clients and allows for soliciting input to design valuable alerts for clients. It is useful to note that the neural network models mentioned above can use as predictors measurements from throughout the connected system – models are not dependent on only a single sensor or on only sensors from a single device.

A main focus has been to ensure that decisions can be made based on a view of the entire connected system. There is nowhere that this is more relevant than in designing and delivering relevant alerts to customers. With facilities teams tending to operate with smaller staffs, it is important to try to surface alerts which help them operate more efficiently. Therefore, we develop and deliver root cause analysis alerts, which help to both surface important issues and guide technicians to potential causes. These are presented to clients in a mobile dashboard which can be viewed by a technician in the field on a tablet.

Finally, to support investigation of potential issues, there have been 90+ different dashboards developed using Visual Analytics that allow technicians to drill into the key information related to 12 unique device types. Some of these are focused on providing a high-level view of energy use or the various issues that have been detected over a period of time, while others drill all the way into the relevant measures to help diagnose an issue on an individual device.

CITY OF DURHAM GENERAL SERVICES USE CASES

The Building Clarity Smart Building Analytics Platform has uncovered a multitude of insights around building operation and performance at the City of Durham General Services building during the pilot project of this solution.

WEEKEND SETBACK

When data began streaming to the SAS® cloud the total building energy data was visualized in a public-facing kiosk dashboard built specifically for the City of Durham. Even from this high-level building perspective it quickly became apparent that something was going on with the energy use. Instead of the energy use dropping significantly on the weekend when the building was unoccupied and closed, it was consistent with energy use on normal weekdays. The issue was verified in the building automation system and it was identified that the equipment in the building was not scheduled to turn off on the weekends. This was a simple change that would result in estimated annual energy savings of $1,900 and reduced wear on equipment from shorter runtime. Assuming the equipment life can be increased by 50% through scheduling, this amounts to an estimated avoided cost of $3,750 per year in capital expenditure. The schedule change was made in the second week of April 2019.

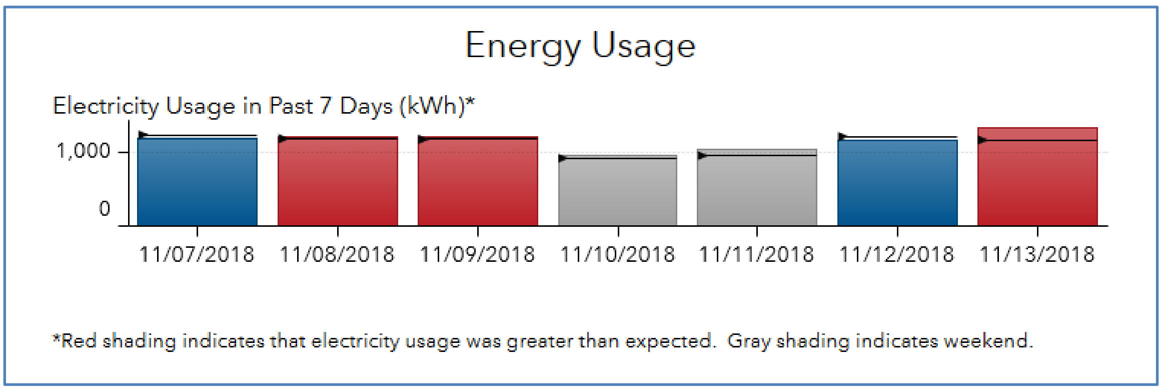

Figure 3. BEFORE. High energy use on the weekends.

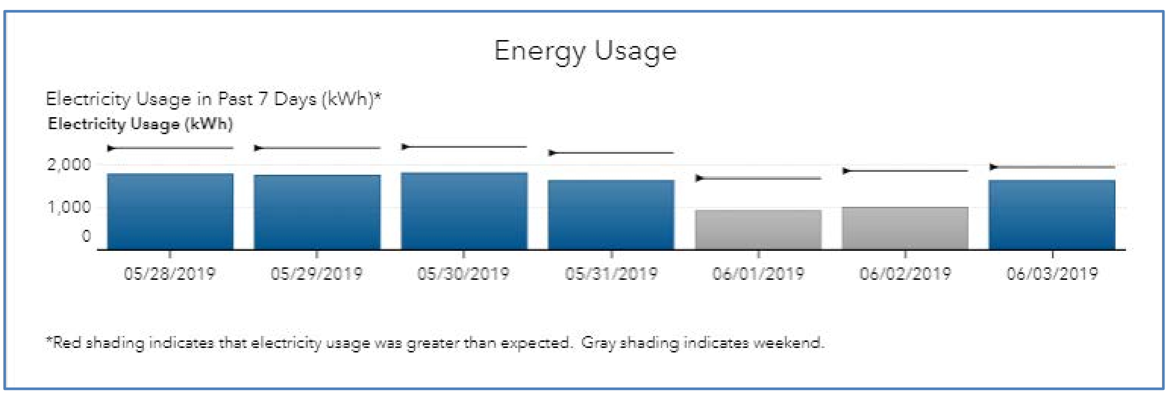

Figure 4. AFTER. Energy use on weekends is less than during the week.

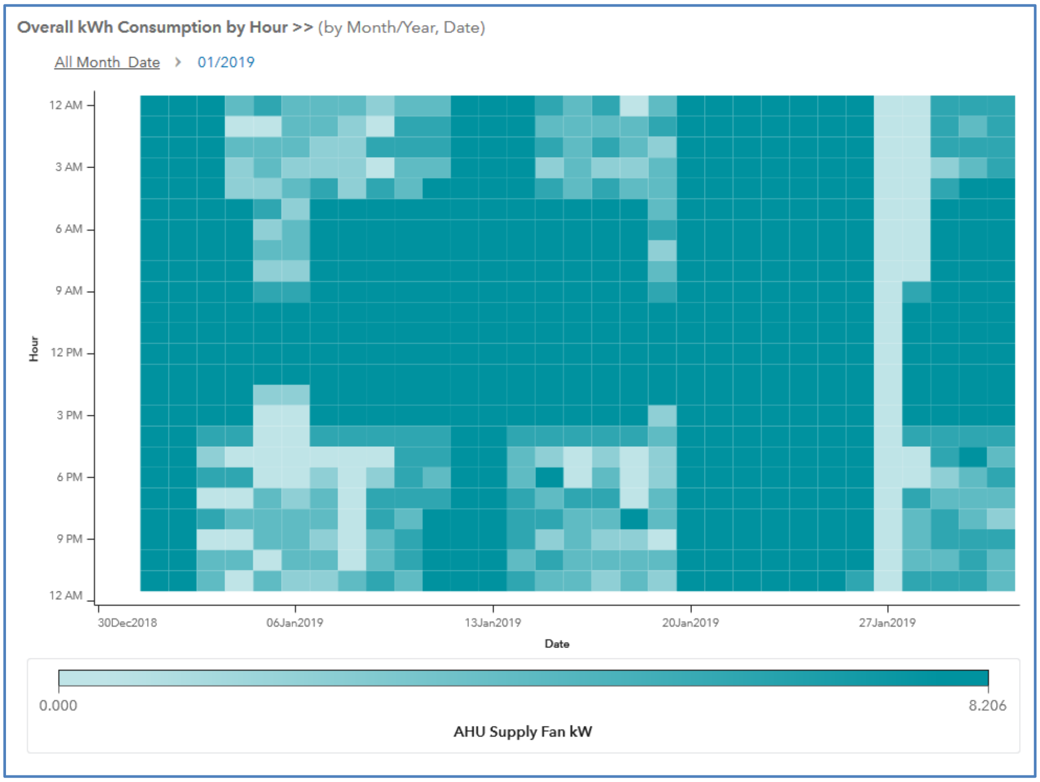

Figure 5. BEFORE. AHU runtime heat map showing AHU operating hours.

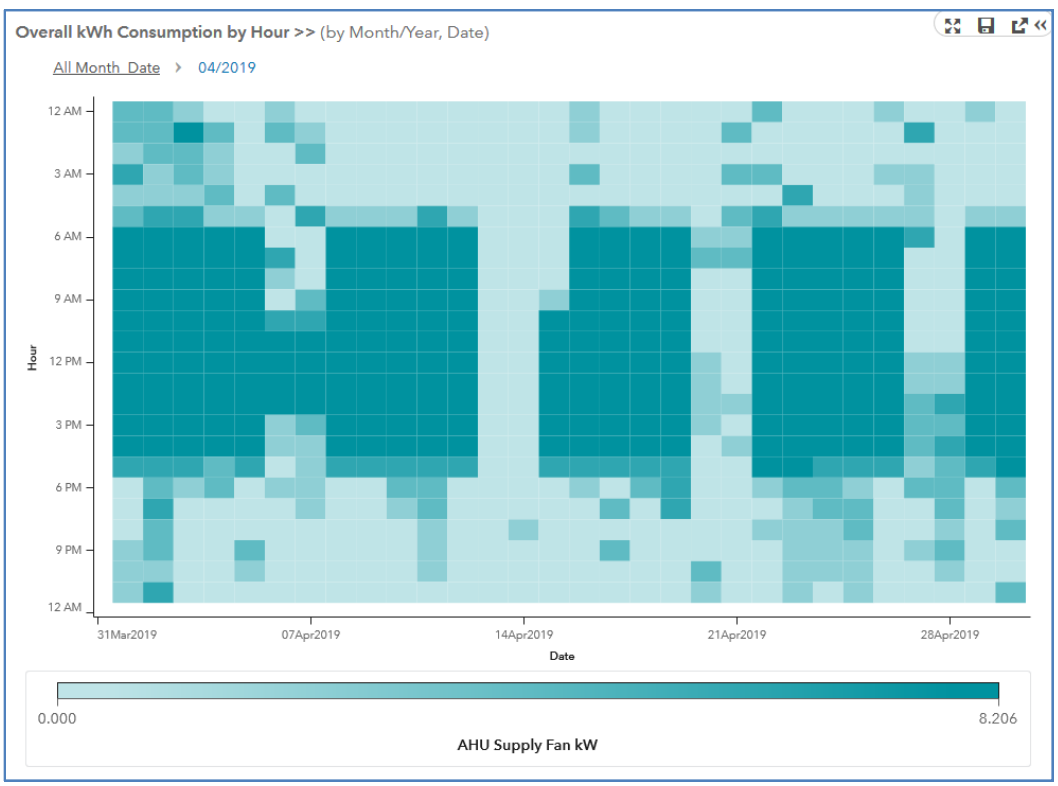

Figure 6. AFTER. AHU runtime heat map showing AHU operating hours.

UNIT HEATER OPERATION

In addition to identifying the scheduling issue, the portfolio-level kiosk dashboard also highlighted an issue with natural gas use in the building. Due to the availability of real-time data, it quickly became apparent that the amount of natural gas being used was much higher than expected. Typically, it would not be until receiving the natural gas bill as many as 6 weeks later that the customer may identify this issue. Building knowledge pointed to warehouse unit heaters as one of the few pieces of equipment using natural gas, and on-site investigation revealed that these heaters were set to a temperature that was leading them to run nearly 24/7. This issue was quickly brought to the attention of the Durham facilities staff so that it could be remediated before it turned into an even bigger issue as outdoor temperatures warmed up. It is estimated that this simple change is worth over $1,900 in energy savings annually, and with more aggressive control strategies this number could be increased significantly.

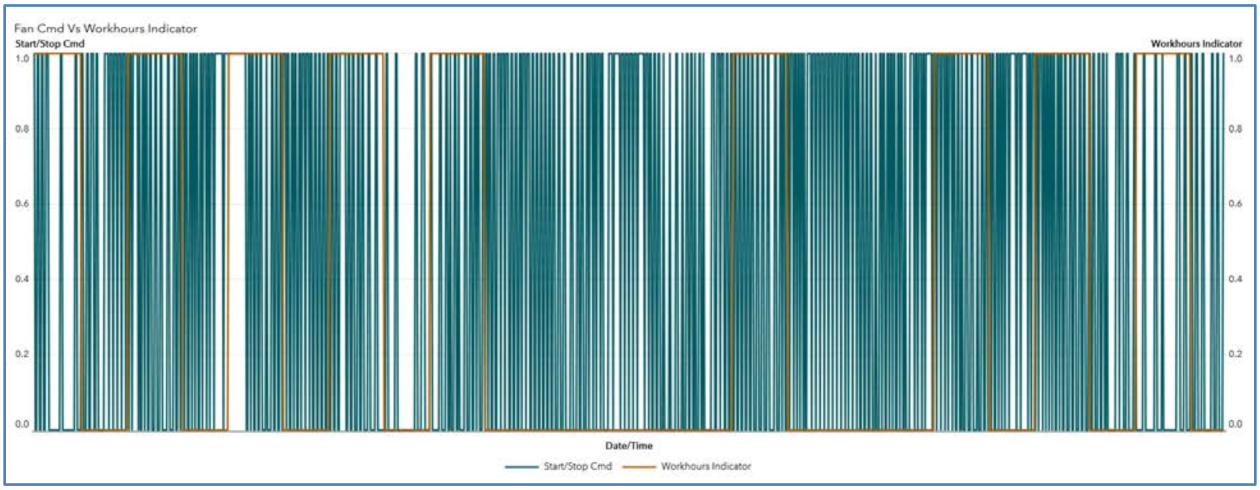

Figure 7. Unit heater run status (blue) vs. work hours (orange)

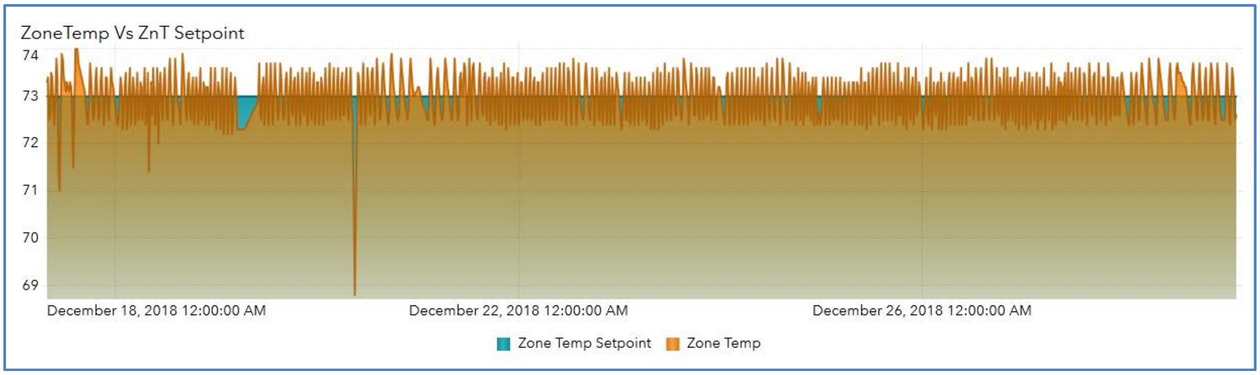

Figure 8. Unit heater control: Zone Temperature vs. Setpoint

VFD OPERATION

When looking specifically at the Air Handling Units (AHUs) it quickly became clear that the Variable Frequency Drives (VFDs) on AHU-2 and AHU-3 were not operating as intended during heating mode. Although the static pressure setpoint for these units was 1.5 inches, the fans were maintaining a static pressure of close to 3 inches; ideally, as soon as the static pressure exceeds the static pressure setpoint the fans would slow down to maintain this target value. It is suspected that this is an issue with the control sequence of operations, and should be able to be remediated with a small change to this sequence of operations. Initial estimates prior to an on-site investigation point to potential energy savings of about $700 per year from this change, realized by very little, if any, cost to make this change.

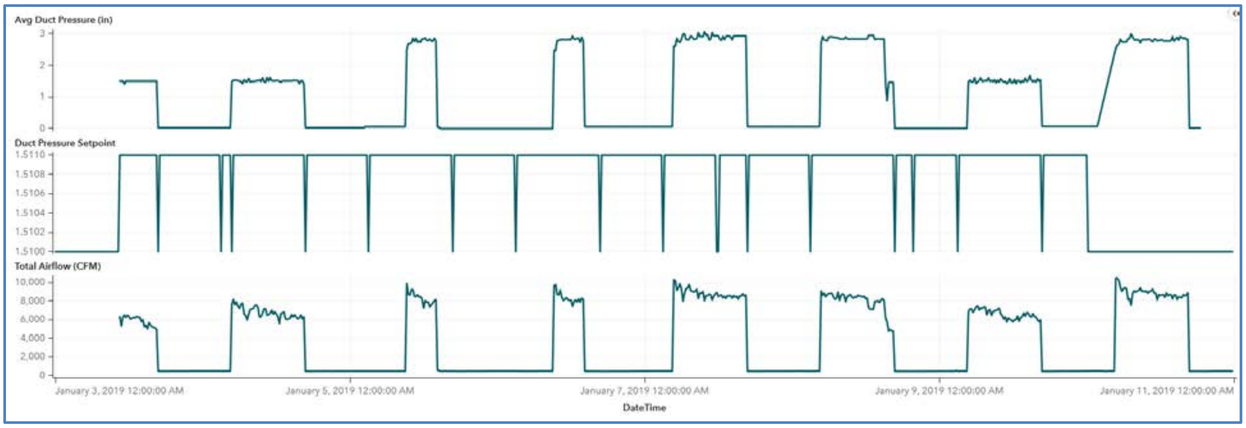

Figure 9. VFD Operation: Static Pressure vs. Setpoint

THERMOSTAT LOCATION

The smart building analytics Zone Temperature Check report highlights the zones in a portfolio that are most frequently operating outside the building's standards of comfort, helping facilities staff prioritize the least comfortable zones. This report highlighted one zone in particular that was consistently operating above its setpoint, with certain instances of the temperature climbing upward of 85°F. Upon consultation with the facilities staff, this particular space was formerly a utility closet that was then converted to a fitness room for the building's staff. When the space was investigated, the team discovered the thermostat was located next to electrical equipment that was periodically exhausting heat directly onto the thermostat. The thermostat was recommended to be relocated, allowing the zone to maintain the space setpoint and the air handling unit to turn off when satisfied.

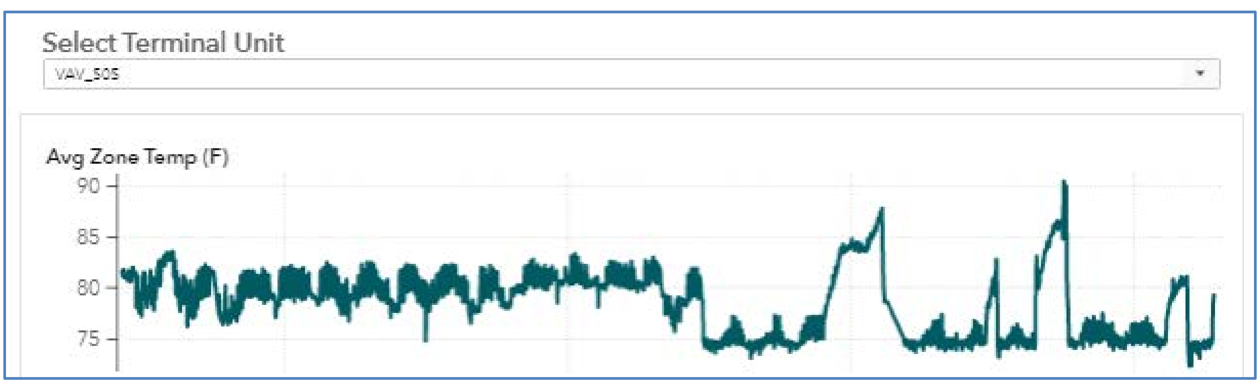

Figure 10. Average Zone Temp for VAV_505 by Thermostat

CONCLUSION

The City of Durham is experiencing many benefits from deploying machine learning models on their building data. These benefits include: energy reduction, prolonged asset lifecycles, emission reductions, and productivity enhancements through root cause analysis tools. The City has approved expansion of an initial pilot in one building into the two largest city owned buildings.

CONTACT INFORMATION

Your comments and questions are valued and encouraged. Contact the author at:

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