Pacific Northwest
NATIONAL LABORATORY

PNNL-33891

Energy Efficiency Analysis and Grid Service Results for Commercial Buildings using the VOLTRON IoT Platform

October 2024

Robert G. Lutes
Srinivas Katipamula

U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

Printed in the United States of America

Available to DOE and DOE contractors from
the Office of Scientific and Technical Information,
P.O. Box 62, Oak Ridge, TN 37831-0062
www.osti.gov
ph: (865) 576-8401
fox: (865) 576-5728
email: reports@osti.gov

Available to the public from the National Technical Information Service
5301 Shawnee Rd., Alexandria, VA 22312
ph: (800) 553-NTIS (6847)
or (703) 605-6000
email: info@ntis.gov
Online ordering: http://www.ntis.gov

Table of Contents

Figures

Tables

1. Introduction

Commercial buildings in the United States consume over 18 Quads of energy. Even buildings that have building automation systems (BASs) do not always or consistently use best practice control sequences and consume more energy than needed. Although commercial buildings are responsible for about 20% of the total U.S. energy consumption, they contribute almost 40% to the peak electricity consumption. Therefore, commercial buildings also represent a major opportunity for more effectively balancing electricity supply, demand, and costs.

In 2006, to address the inefficiencies in commercial building operations, Pacific Northwest National Laboratory (PNNL) developed the Re-tuning™ process to help building owners and portfolio managers improve energy efficiency (Brambley and Katipamula 2009). Inspired by the Re-tuning approach, in 2016, City of Seattle created a Building Tune-up mandate that requires all buildings greater than 50,000 square feet to be re-tuned every five years. In 2019, City of Philadelphia passed a mandate similar to that of Seattle's. To address the growing need for Re-tuning around the nation, PNNL developed the software tool Automated Identification of Re-tuning/Retro-Commissioning (AIRCx) measures and integrated it with the VOLTTRON™ [1] platform. Integration of AIRCx with VOLTTRON allows for continuous improvement energy efficiency of an individual building or collection of buildings via a Cloud deployment. This approach for Re-tuning buildings also meets Seattle and Philadelphia's mandates. Because it is a continuous process, it ensures persistence of building operations more than the periodic Tune-ups and it can be less expensive than the manual Tune-up approach.

Also, as part of a previous Building Technologies Office-Emerging Technologies (BTO-ET) funded project, PNNL developed Intelligent Load Control (ILC), which offers a solution to manage building peak consumption to support supply-demand imbalance. The ILC is an algorithm, or a set of actions, deployed using the VOLTTRON platform. The ILC technology can automatically adjust building energy use by coordinating heating and cooling, lights, and other building functions, while minimizing the negative effects to occupant comfort.

In fiscal year 2021 (FY21), the Commercial Buildings Integration Program (CBI) within the Building Technologies Office (BTO), funded PNNL to conduct a field evaluation of the AIRCx and ILC using an Internet-of-Things (IoT) platform, VOLTTRON. The primary goal of the project is to show that software solutions deployed and delivered through an IoT-platform can identify energy efficiency opportunities and manage peak load (beyond the traditional demand response) in commercial buildings. There are also two secondary goals: 1) show that the energy efficiency solutions will result in identification of significant savings opportunities (10% to 30%) as well as energy cost reductions (10% to 15%) by managing the peak load in commercial buildings, and 2) show that an IoT-based software solution is more cost-effective compared to a manual process in meeting the Re-tuning/retro commissioning[2] (RCx) mandates and there is a pathway for broader adoption of this approach.

This report provides AIRCx and ILC results for two building located in District of Columbia managed by the energy service provider Intellimation.

---

[1] VOLTTRON™ is sponsored by the Department of Energy and Pacific Northwest National Laboratory.

[2] Traditional RCx approach is mostly manual and measures that are implemented during that process may not persist for a long time.

2. Background and Motivation

VOLTTRON is an open-source distributed control and sensing platform that is designed for integrating buildings with the power grid. VOLTTRON connects devices, agents in the platform, agents in the Cloud, and signals from the power grid. The platform also supports use cases such as demand response and integration of distributed renewable energy sources. VOLTTRON provides an environment for agent execution and serves as a single point of contact for interfacing with devices (building HVAC systems, building electrical systems, power meters, etc.), external resources, and platform services such as data archival and retrieval. VOLTTRON applications are referred to as agents since VOLTTRON provides an agent-based programming paradigm to ease application development and minimize the lines of code that need to be written by domain experts such as buildings engineers. VOLTTRON provides a collection of utilities that simplifies agent development.

2.1. Overview of Automated Identification of Re-tuning Measures

Many operational problems that are identified during the retro-commissioning (RCx) process can be continuously and automatically detected. Immediately correcting operational problems will result in the building operating optimally on a continuous basis. Because it is a software-based solution, VOLTTRON-based RCx delivery lowers the cost and increases the persistence of efficient building operations. PNNL developed a set of algorithms to perform continuous Re-tuning or RCx. These continuously running software applications are integrated with BASs using VOLTTRON to monitor key building systems, including air handing units (AHUs), economizer systems, hot-water, and chilled-water central plants, and to provide actionable, real-time information to building operations staff[1]. Unlike automated fault detection and diagnostic processes, AIRCx processes identify opportunities rather than operational faults that, when implemented, will results in energy and cost savings. Therefore, the actionable information that is generated is not only a list of faults, but also includes best practice guidance. A generic AIRCx process is shown in Figure 2-1. The AIRCx process is done in three steps: (1) automated data acquisition, (2) identification of Re-tuning opportunities, and (3) evaluation of energy impact and reporting. This seamless integration of problem detection and correction allows building operations staff to focus on maintenance and up-keep of equipment along with occupant comfort issues. Both AIRCx and AFDD technologies can be deployed in commercial buildings that use variable-air-volume (VAV) AHUs with centrally distributed hot water for heating and centrally distributed chilled water for cooling.

[1] Katipamula S., R.M. Underhill, R.G. Lutes, and S. Huang. 2018. Automatic Identification of Retro-commissioning Measures. PNNL-27338. Richland, WA: Pacific Northwest National Laboratory.

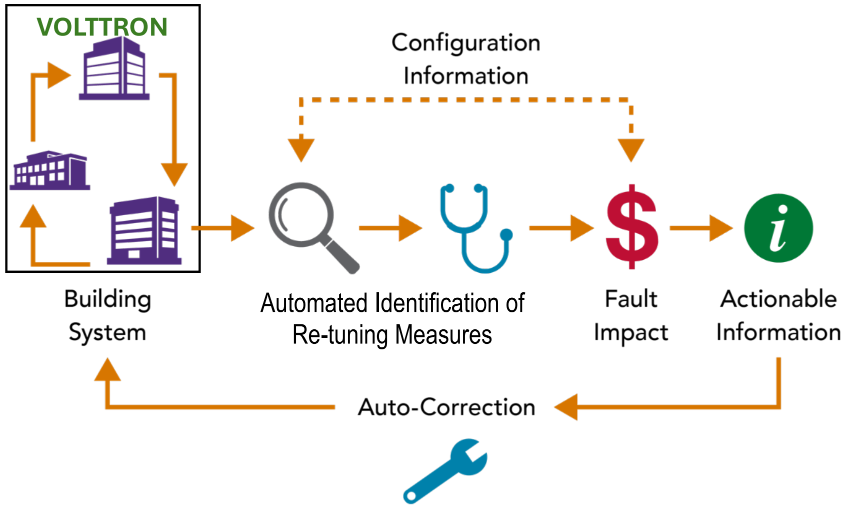

Figure 2-1: Schematic of the AIRCx process

2.2. Overview of ILC

The ILC application runs continuously and is also integrated with the BAS[1]. Because commercial buildings use over 30% of electricity generated in the United States and because several end-use loads are demand flexible, they can be managed to mitigate some of the supply-demand imbalance caused by variable distributed renewable generation. Control of building end-use loads has been shown to provide significant demand relief in response to grid needs. In addition, building end-use loads have been managed to limit electric demand when a demand charge is a significant percentage of the total energy cost or when a building must maintain a certain level of maximum demand in response to changes in the price of electricity over time. However, an accurate and reliable load control strategy is required to manage peak loads because even one excursion could cause a significant increase in utility bills. To address this need, PNNL developed ILC application to help manage distributed energy resources (DERs) inside buildings. ILC is integrated with the VOLTTRON platform and coordinates with external signals (including markets) to make local device control decisions.

[1] Kim W., S. Katipamula, R.G. Lutes, and R.M. Underhill. 2016. Behind the Meter Grid Services: Intelligent Load Control. PNNL-26034. Richland, WA: Pacific Northwest National Laboratory.

3. Selected Pilot Buildings

Energy efficiency and grid service application are deployed at Anacostia High School and One Judiciary Square; both buildings are owned by the District of Columbia (DC). The following section will briefly describe the two building and associated heating ventilation and air-conditioning (HVAC) systems.

3.1. Anacostia High School

Anacostia High School is a 200,000 sf facility located at 1601 16Th Street SE near the Anacostia River. The building was originally completed in 1935 with subsequent additions in the proceeding decades. In 2013, a large renovation effort estimated at $63 million dollars was completed. Figure 3-1 shows a street view image of Anacostia High School.

Figure 3-1. Anacostia High School

The building is served by two 250-ton McQuay magnetic bearing centrifugal chillers in a primary only loop. The primary loop has two 15 hp variable speed driven pumps that are controlled to maintain the loop differential pressure at a given set point. The condenser water loop has two 250-ton open cooling towers equipped with variable frequency drives (VFD) connected to the tower fans. The condenser water loop is served by two 20 hp constant speed pumps. The hot water system is served by three 1,400 MBtu natural gas-fired boilers. The hot water loop is a primary and secondary configuration where the secondary loop has two 10 hp VFD pumps controlled to maintain differential pressure at given set point.

The building air systems are served by four large AHUs that serve approximately 170 variable-air volume (VAV) boxes throughout the building and two large constant volume AHUs that serve the gymnasium and cafeteria (Table 3-1 and Table 3-2). Each AHU is equipped with a VFD for the supply fan, hot water coil, chilled water coil and heat recovery system in the form of an enthalpy wheel. The AHUs are equipped with modulating dampers that allow for airside economizing but the AHUs are not equipped with the typical mixed-air temperature sensor, making economizer diagnostics difficult to implement.

Table 3-1: AHU (Energy Recovery Units (ERUs)) Design Specifications

UNIT	Minimum Outdoor Air (cfm)	Supply Fan		Chilled Water Coil		
		Airflow (cfm)	Motor (hp)	Total (MBtu)	Sensible (MBtu)	Water flow (gpm)
B-1	20175	27500	(2) 30	1305	919	200
C-1	18472	27500	(2) 30	1300	920	200
C-2	18472	27500	(2) 30	1300	920	200
C-3	10765	13527	(2) 15	555	374	96
D-1	19101	33407	(2) 30	1473	1065	225
E-1	10770	20000	(2) 20	709	516	125

Table 3-2: AHU (Energy Recovery Units (ERUs)) Design Specifications

UNIT	Minimum Outdoor Air (cfm)	Supply Fan		Hot water coil			Energy Recovery		
		Airflow (cfm)	Motor (hp)	Entering Water Temperature (EWT °F)	Leaving Water Temperature (LWT °F)	Water flow (gpm)	Summer Total (MBtu)	Summer Sensible (MBtu)	Winter Sensible (MBtu)
B-1	20175	27500	(2) 30	180	160	135	713	277	813
C-1	18472	27500	(2) 30	180	160	145	614	237	695
C-2	18472	27500	(2) 30	180	160	145	614	237	695
C-3	10765	13527	(2) 15	180	160	35	419	162	477
D-1	19101	33407	(2) 30	180	160	165	567	219	642
E-1	10770	20000	(2) 20	180	160	70	419	163	478

3.2. One Judiciary Square

One Judiciary Square (OJS), located at 441 4th Street, NW in Washington D.C. is an 875,000 sf building that accommodates 20 DC government agencies. The building has 11 above grade floors and three sub-grade floors. The first sub-grade floor and all the above grade floors are primarily used for office space and the other below grade floors are used as an underground parking garage. Figure 3-2 shows a street view of the One Judiciary Square:

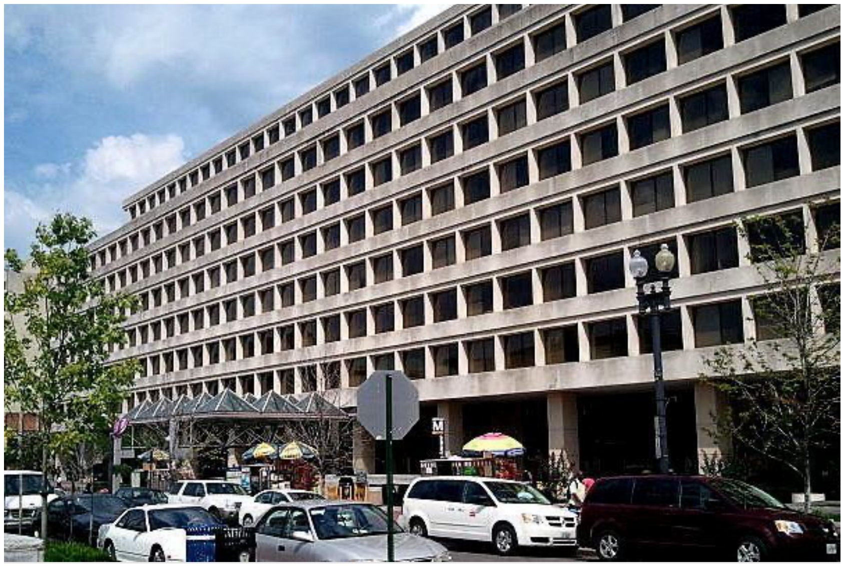

Figure 3-2. One Judiciary Square Building

Each floor of the building is served by four water-cooled direct expansion (DX) AHUs with waterside economizing coils. Figure 3-3 shows a building automation system (BAS) schematic of an AHU on the 9th floor.

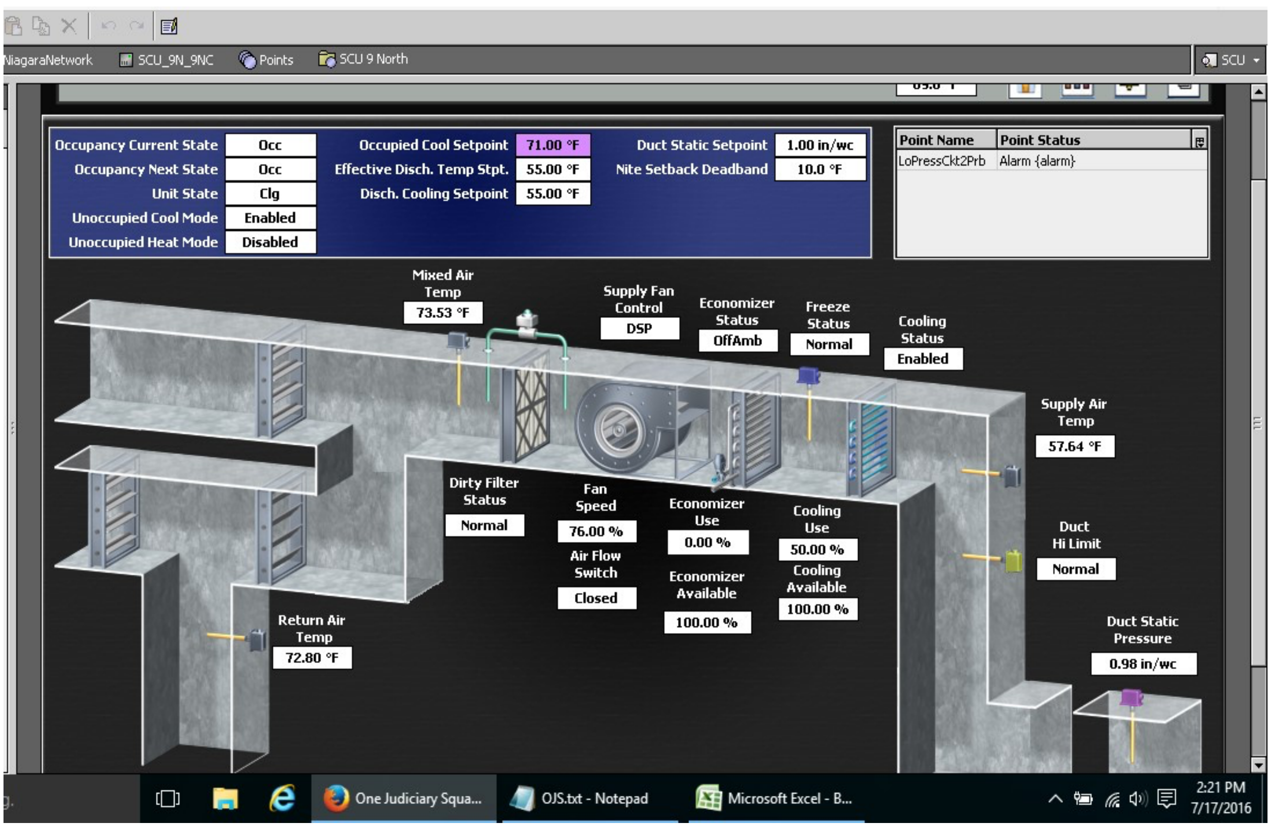

Figure 3-3. Building Automation System Schematic of AHU

All the AHUs are equipped with VFD drives on the supply fan. Based on review of the control drawings the AHUs do have modulating outside-air dampers and do not utilize airside economizing. They do utilize the waterside economizer.

The condenser water loop that provides cooling to the DX coils in each AHU is served by three large, three cell cooling towers on the roof of the building. Two of these towers serve the primary conditioning systems in the building while the third tower is used for critical and tenant conditioning equipment. The tower fans are VFD driven. The towers are also used to cool the condenser water for economizing when outside conditions are favorable for waterside economizing. The condenser water loop is served by eight 75 hp pumps. The differential pressure in the condenser water loop is controlled by modulating a pressure bypass valve. Figure 3-4 shows a schematic of the condenser water system on the roof of the building.

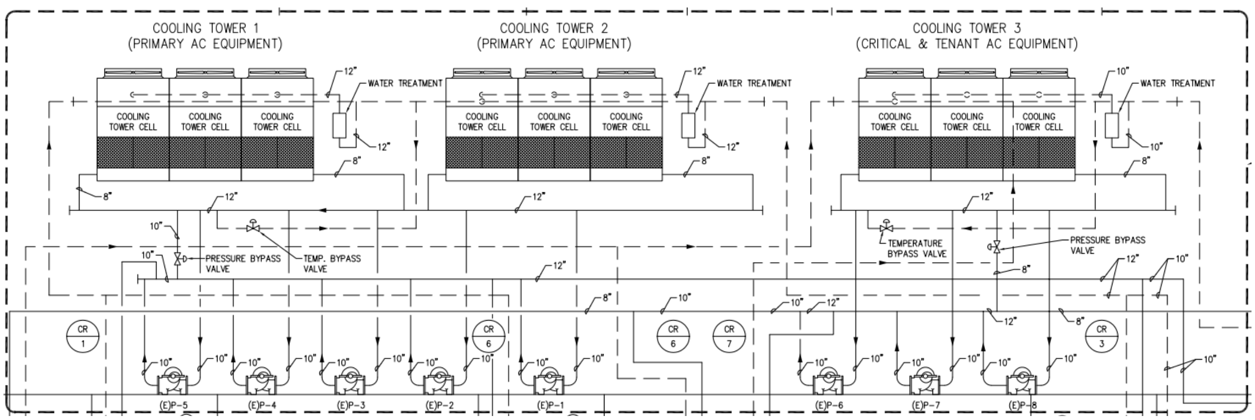

Figure 3-4. Schematic of Condenser Water System

The AHUs serve approximately 600 VAV boxes throughout the building. Each AHU serves between 20 and 30 VAV boxes. The VAVs utilize dual max airflow control and respond to thermostat readings in the zone the box serves to modulate the airflow set point between minimum and maximum to satisfy the heating and cooling needs of the space. When the zone temperature is close to setpoint (within the thermostat dead band), the airflow set point will go to the minimum airflow. Most VAVs are equipped with multi-stage electric reheat but some are cooling only boxes.

4. Results from Deployment of Automatic Identification of Retro-Commissioning Measures Application

The AIRCx process uses a decision-tree structure to detect, diagnose, and automatically provide corrective actions for the problems associated with an AHU's operation.

Detecting and diagnosing problems within an AHU is crucial because the unit can increase system energy expenditures and adversely affect the comfort of building occupants. The air-side re-tuning diagnostics are designed to monitor conditions within the AHU and the zones served by the AHU using sensors and control points that are typically associated with the AHU and zone controllers. When a problem is detected, the diagnostic identifies the problem and notifies the operator of the problem and its potential cause.

The diagnostic algorithms use rules derived from engineering principles of proper and improper AHU operations. Seven air-side diagnostics correspond to the seven operational problems; the air-side diagnostics include the following.

- Detect whether the supply air temperature (SAT) for an AHU is too low.
- Detect whether the SAT for an AHU is too high.
- Detect whether the SAT set point for an AHU is reset or fixed.
- Detect whether the fan is operational during unoccupied time periods.
- Detect whether the duct static pressure for an AHU is too low.
- Detect whether the duct static pressure for an AHU is too high.
- Detect whether the duct static pressure set point for an AHU is not reset.

The intent of these algorithms is to provide actionable information to building owners and operations staff while minimizing false alarms. In addition to providing actionable information, these algorithms can be configured to provide automated corrective actions. The remainder of this section provides a more detailed summary of the seven algorithms used to detect, diagnose, and provide automated corrective actions.

4.1. AIRCx Results for Anacostia High School

Preliminary results for AIRCx at Anacostia are presented in this section. These results were collected during the winter season. Future diagnostic result and analysis will include operations during the spring and cooling seasons and should give additional insight into improving the buildings operations using AIRCx.

Many of the AHUs at the Anacostia High School are operating nearly continuously. In Figure 4-1 and Figure 4-2 the **orange line** is the duct static pressure set point and the **red line** is the duct static pressure. The static pressure indicates that the supply fan for the AHU is operational continuously. The AIRCx algorithm detects this issue and reports that the AHU is operating outside of scheduled occupancy period. Operating the AHU outside of the occupancy period increases the buildings energy usage and adds additional run-time (wear and tear) on the AHU supply fan.

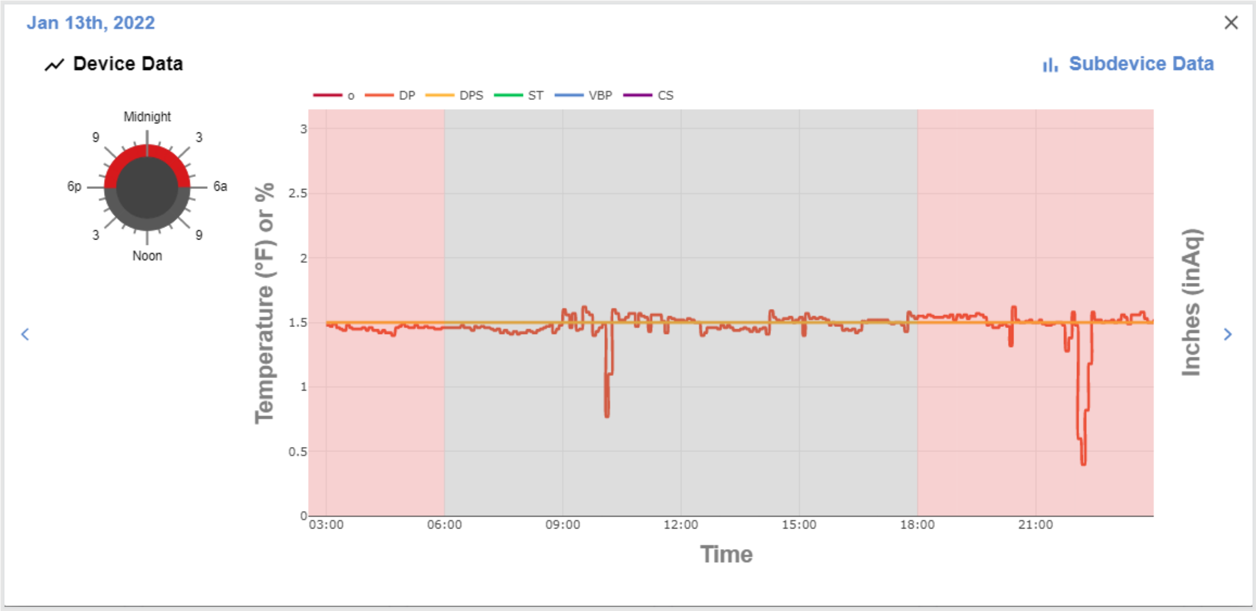

Figure 4-1. ERU-B1-NWING Operating Continuously During Unoccupied Hours

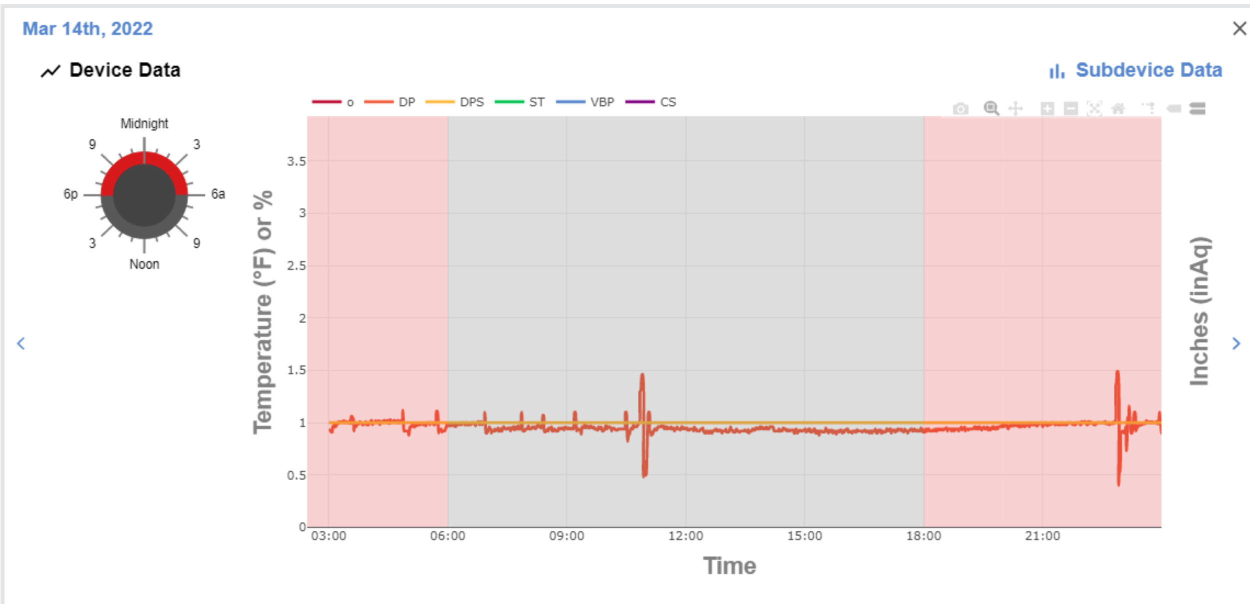

Figure 4-2. ERU-C1-MWING Operating Continuously During Unoccupied Hours

PNNL recommends that the AHUs be turned off during unoccupied hours. Night setbacks for the heating and cooling set points for VAV served zones should also be implemented if not currently in place. Allow the AHU to cycle on when four (adjustable) or more VAV boxes fall outside of the setback temperature set points. This will limit how far zones will drift from occupied set point during the unoccupied period but also limit the AHUs operation during these unoccupied periods. Most modern BAS's provide optimal start capabilities for the AHUs. PNNL would recommend that optimal start also be implemented if possible.

Another prevalent finding at the site was that the static pressure set point was not reset (remained constant) as seen in Figure 4-3. The airflow demand at zones varies throughout the day. Resetting the duct static pressure based on the overall airflow need of the spaces can save significant fan energy.

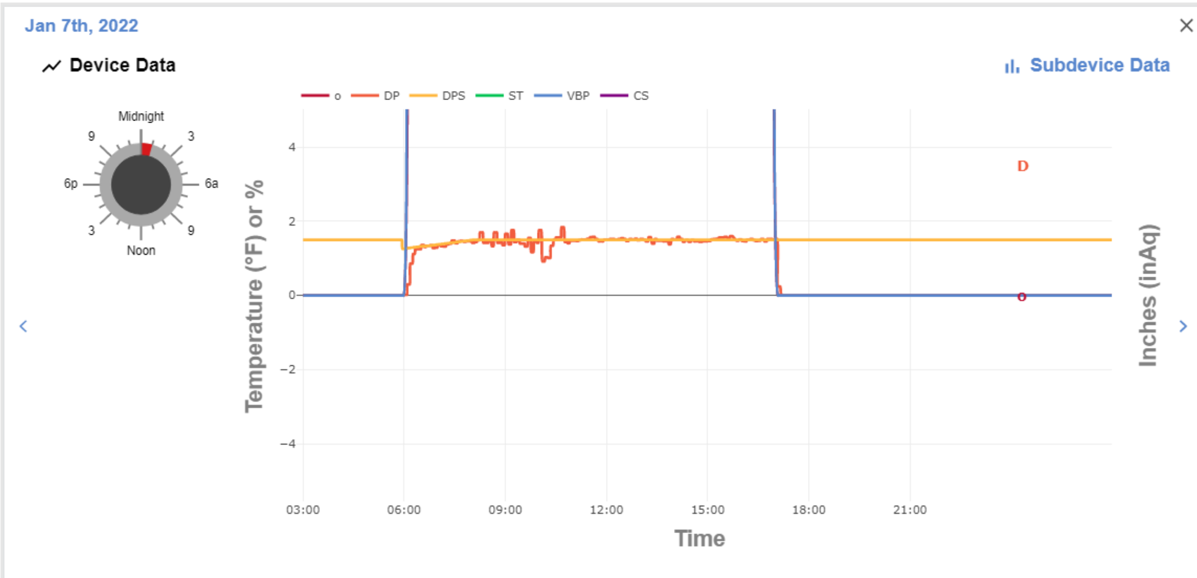

Figure 4-3. Static Pressure is Not Reset

Low duct static pressure was detected for several of the AHUs. In Figure 4-4 (ERU-C1-MWING) and Figure 4-5 (ERU-D1-SWING) one can see that the supply fan speed (**blue line**) is at 100%, so no additional airflow (static pressure) could be provided. In Figure 4-4 for ERU-C1-MWING the duct static pressure set point is 3.0 in water column and the achieved static pressure is less than 1.0 in. Similarly, in Figure 4-5 for ERU-D1-SWING the static pressure set point is 1.5 in and the achieved static pressure is never greater than 1.0 in. It is also possible that the static set point for these AHUs is set too high and the fan cannot achieve that set point.

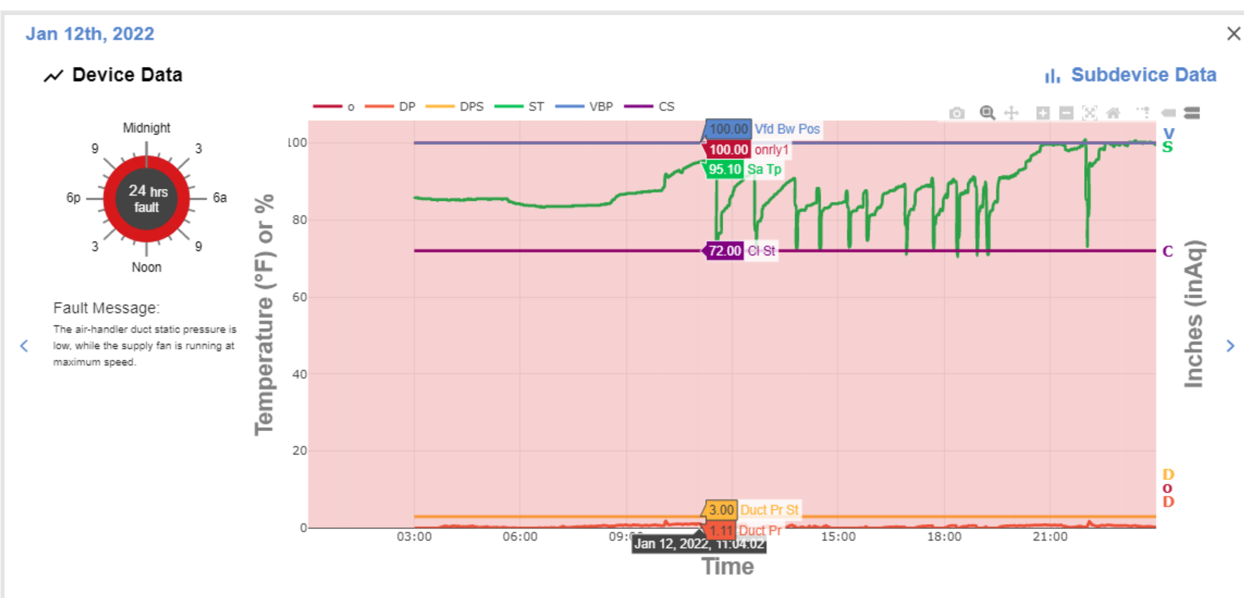

Figure 4-4. Static Pressure is Too Low for ERU-C1-MWING

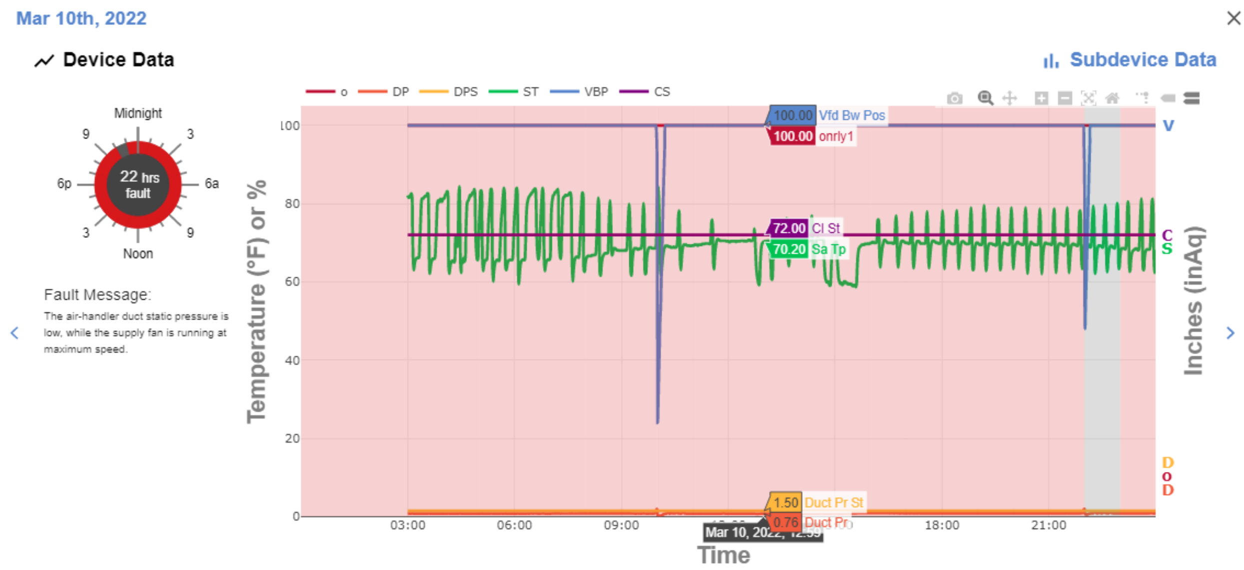

Figure 4-5. Static Pressure Is Too Low for ERU-D1-SWING

Figure 4-6 shows a box plot with VAV damper commands corresponding to the ERU-C1- MWING and Figure 4-7 shows the same box plot for ERU-D1-SWING. The plots show that the mean value for the VAV damper positions during the occupied period is close to 80% but there are some zones with damper positions of 100% (zones are starved for airflow). The AHUs inability to meet static set point and not provide sufficient airflow to these spaces should be investigated by site staff. There are a variety of possible causes for this type of issue including dirty filters, VFD failure or malfunction, VAV actuator failures, failed or improperly located static pressure sensors, warm discharge air temperatures, slipping belts, breached ductwork or there could be a design issue that cannot be easily corrected.

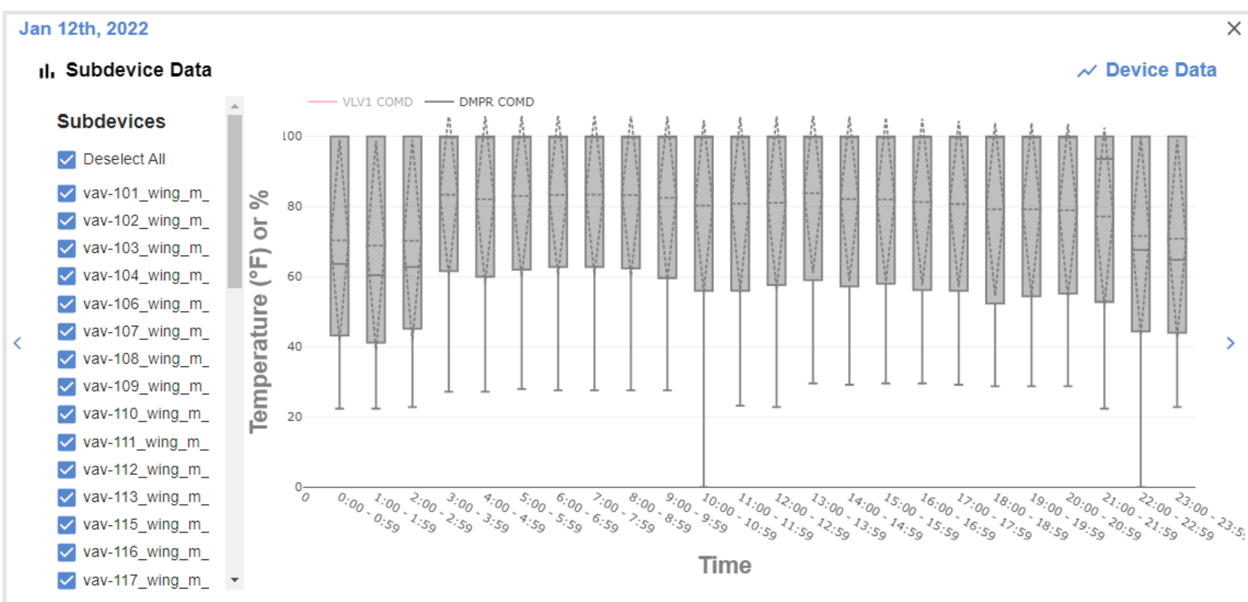

Figure 4-6. Box Plot for VAV Damper Positions for ERU-C1-MWING

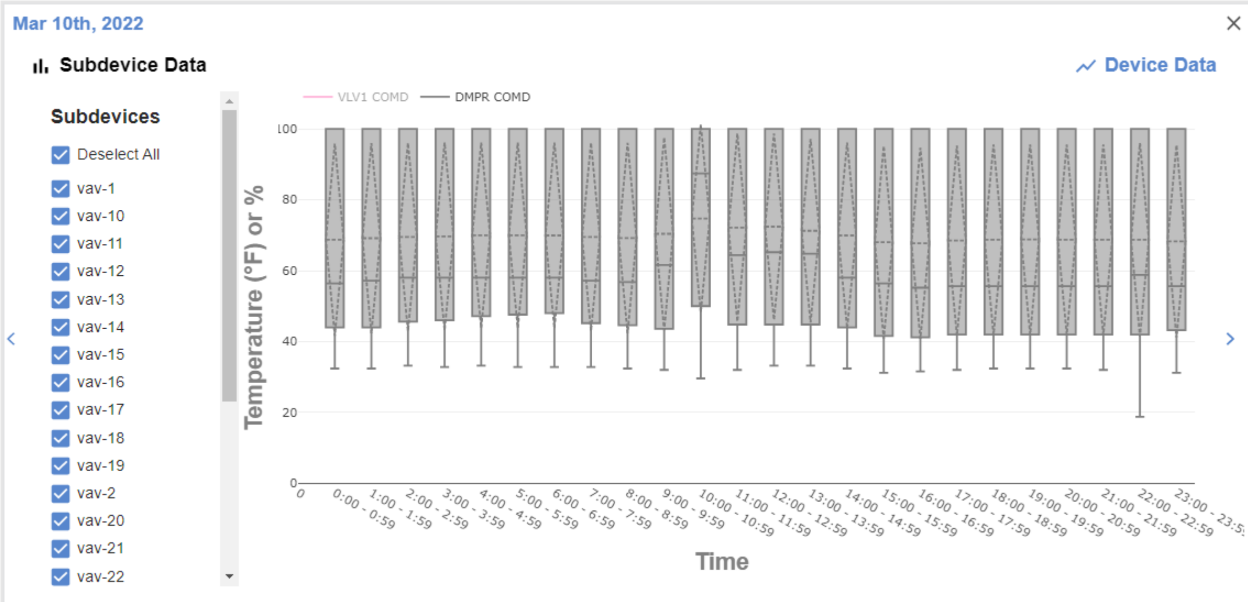

Figure 4-7. Box Plot for VAV Damper Positions for ERU-D1-SWING

The AIRCx detected low supply air temperature for ERU-D1-SWING. This issue was detected nearly continuously even into mid-March. In Figure 4-8 the green line is the supply air temperature, and the **purple line** is the supply-air temperature set point. There is significant deviation between the supply air temperature and set point that needs to be investigated. The figure also shows that the supply air temperature has significant fluctuations in the early morning and late evening. As shown in the figure this AHU is also operating continuously even during unoccupied periods.

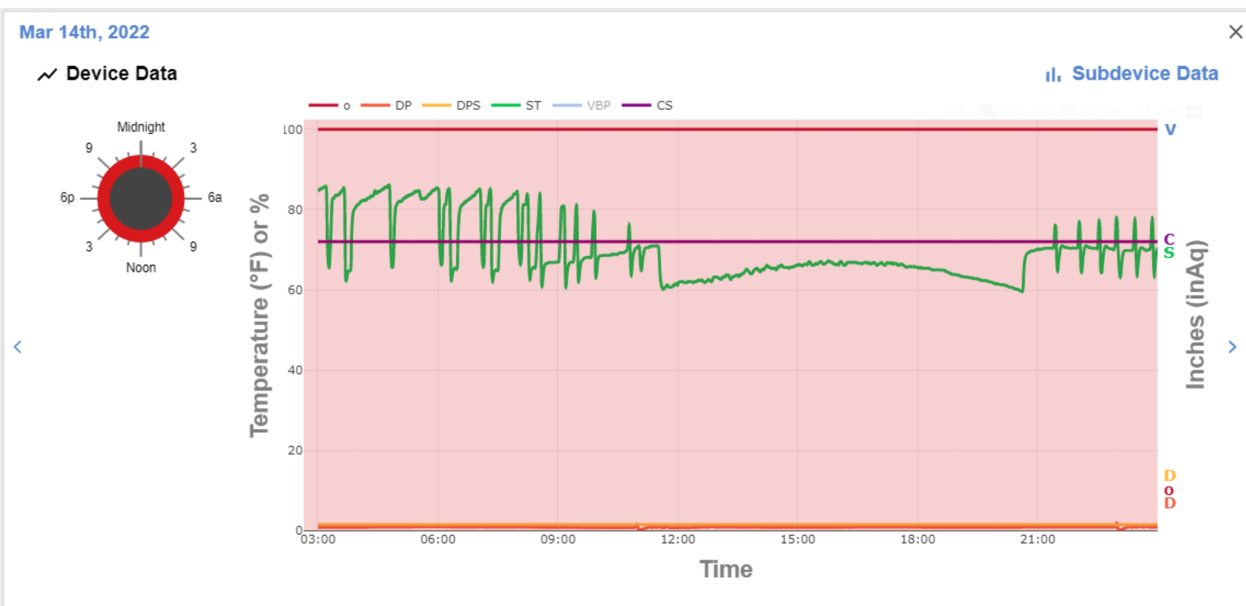

Figure 4-8. Low Supply-Air Temperature Detected for ERU-D1-SWING

The low supply-air temperature algorithm analyzes conditions at zone levels. When the algorithm detects many zones with excessive reheat the algorithm flags a potential low supply air temperature issue. Figure 4-9 shows a box plot for the zone reheat commands for ERU-D1-SWING. The reheat is active continuously for nearly all the zones and after 10 a.m. many of the zones are in full reheat. This problem can be caused by either low supply-air temperatures, high minimum VAV airflow settings or high zone temperature set points, all of which can lead to excess energy consumption.

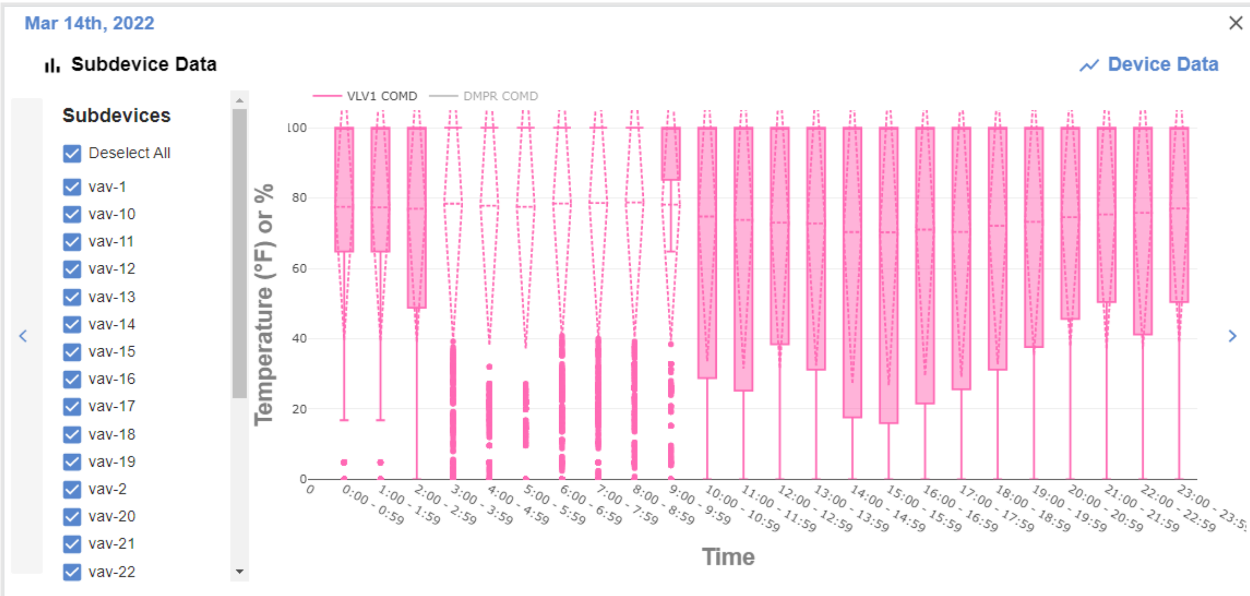

Figure 4-9. Box Plot for VAV Reheat for ERU-D1-SWING

AIRCx detects that the supply air temperature deviates significantly from set point for ERU-C1-MWING. The supply air temperature control is erratic at times (Figure 4-10 Boxed area). This is a consistently detected issue amongst the other AHUs as well. Also, the supply air temperature seems to be controlled to a point other than the one we are monitoring (early morning and late afternoon) as the difference is too large to be considered erratic control.

Figure 4-10. Supply-air Temperature is Deviating Significantly from Set Point

4.2. AIRCx Results for One Judiciary Square

The AIRCx results for OJS are limited. Shortly after the installation of VOLTTRON and AIRCx at OJS the hardware onsite hosting data collection and VOLTTRON experienced a failure. Replacement of the board and subsequent redeployment of VOLTTRON and AIRCx was required. Also, a memory leak in the BACnet software, Normal Framework (not a PNNL software), caused exhaustion of system RAM and required significant debugging and tuning to eliminate the issue. During this period AIRCx was not operational. More results are expected from spring and summer operations.

All AHUs under AIRCx analysis are operating continuously. In Figure 4-11 the **orange line** is the duct static pressure set point, the **red line** is the duct static pressure, and the green line is the supply fan speed. The static pressure and supply fan speed show that the supply fan for the AHU is operational continuously. The AIRCx algorithm detects this issue and reports that the AHU is operating outside of scheduled occupancy period. Operating the AHU outside of the occupancy period increases the buildings energy usage and adds additional run-time (wear and tear) on the AHU supply fan.

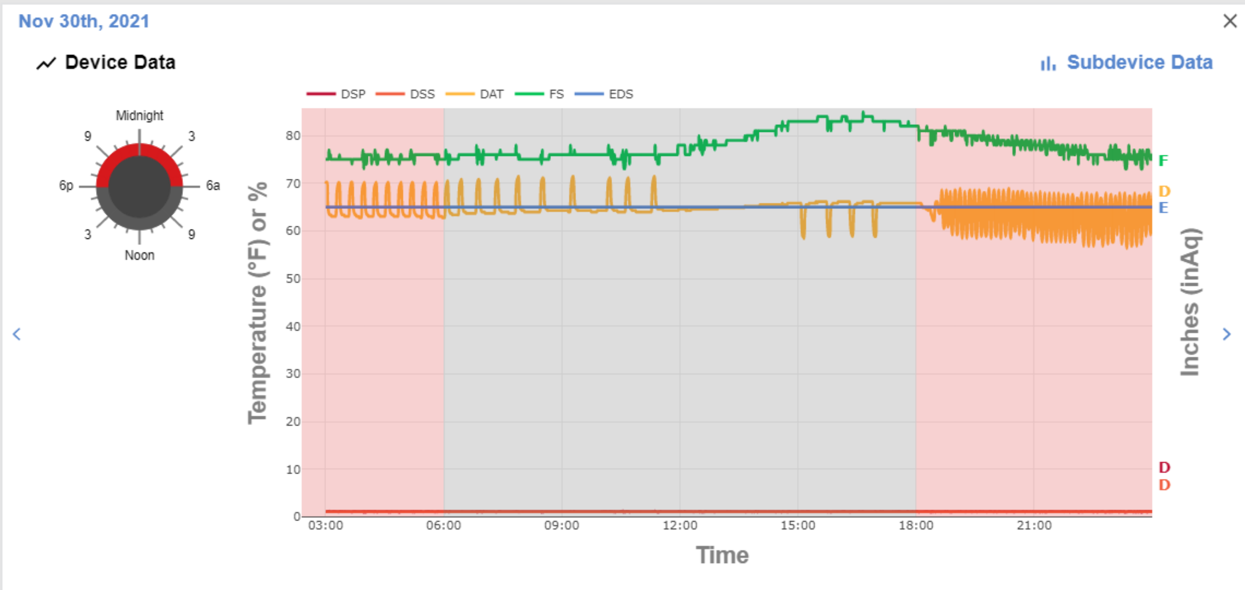

Figure 4-11. AHU-11-SOUTH Operating Continuously During Unoccupied Hours

PNNL recommends that the AHUs be turned off during unoccupied hours. Night setbacks for the heating and cooling set points for VAV served zones should also be implemented if not currently in place. Allow the AHU to cycle on when four (adjustable) or more VAV boxes fall outside of the setback temperature set points. This will limit how far zones will drift from occupied set point during the unoccupied period but also limit the AHUs operation during these unoccupied periods. Most modern BAS's provide optimal start capabilities for the AHUs. PNNL would recommend that optimal start also be implemented if possible.

The AIRCx detected that the static pressure set point is not reset. This was consistent for all the AHUs at the site. In Figure 4-12 the **orange line** is the duct static pressure set point and the **red line** is the duct static pressure. The static pressure set point is constant for the entire day (not reset).

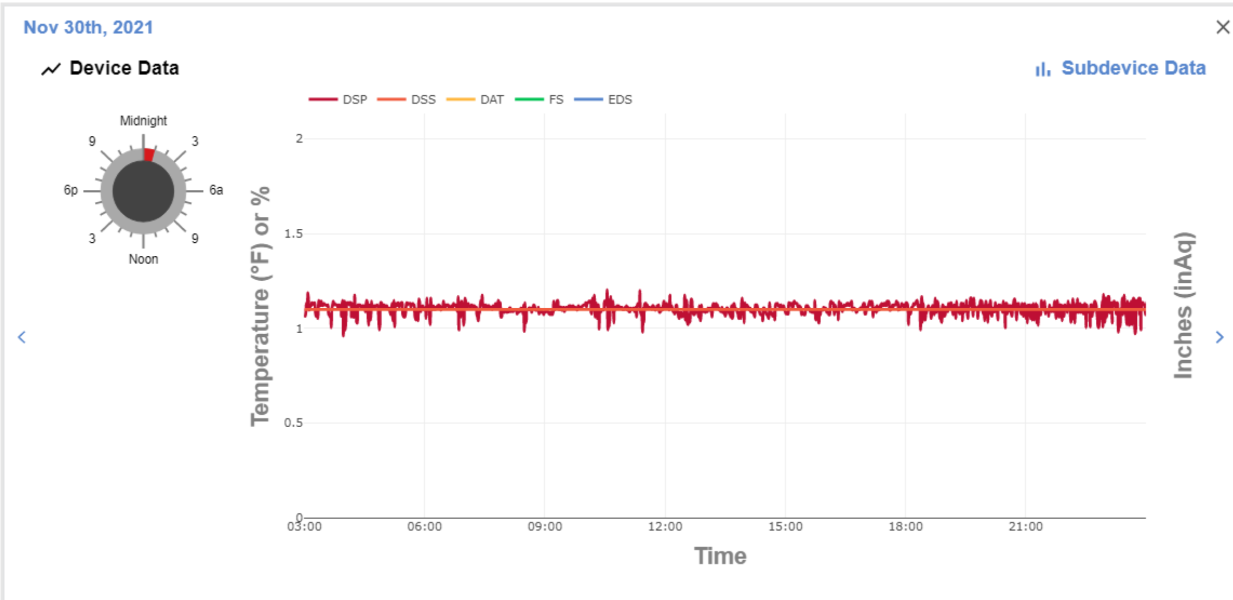

Figure 4-12. Static Pressure Set Point is Constant for AHU11-SOUTH-CENTER

Figure 4-13 shows a box plot for the VAV damper positions for AHU-11-SOUTH-CENTER. The figure shows that the average VAV damper position is about 40% for most of the day. Ideally, the static pressure should be reset to drive most of the VAV boxes to between 60% and 80% open. This plot shows that there is an opportunity to reset the static pressure set point (lower) for the AHU.

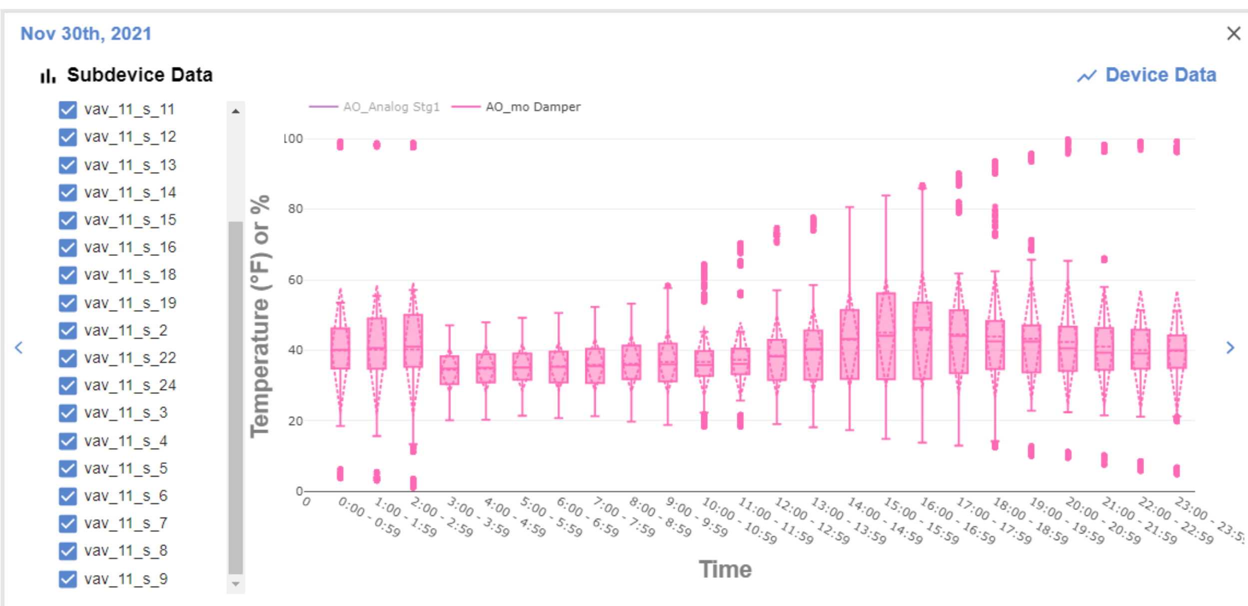

Figure 4-13. Box Plot for VAV Damper Positions for AHU-11-SOUTH-CENTER

The AIRCx detected that the supply air temperature was not reset for most of the AHUs. In Figure 4-14 the yellow line is the supply air temperature, the **blue line** is the supply air temperature set point, and the **green line** is the supply-fan speed. The plot shows the supply air temperature set point is constant at 65°F for the entire day. This result is not conclusive as a reset might be employed but the supply air temperature set point may be at the high end of the reset for the duration of the day due to cold winter outdoor temperatures. Further validation of the presence of a supply air temperature reset will have to occur during spring or summer.

Figure 4-14. Supply Temperature Set Point is Constant for AHU-11-NORTH

Figure 4-15 shows the VAV electric reheat commands for the VAVs for AHU-11-NORTH. This shows that most of the VAVs are heating during the day. This is further evidence that the constant supply air temperature set point of 65°F might be appropriate.

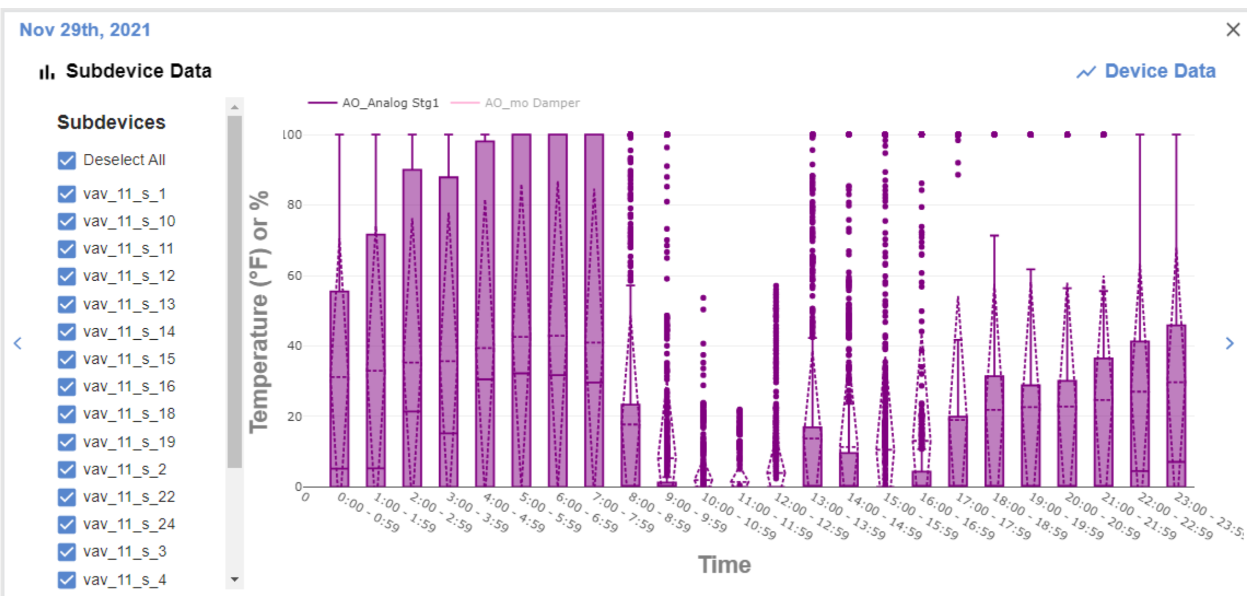

Figure 4-15. Box Plot for VAV Electric Reheat Command for AHU-11-NORTH

The supply air temperature control AIRCx measure detected that the AHU supply-air temperature deviated significantly from set point. Figure 4-16 shows that the supply air temperature is oscillating about the set point of 65°F from as low as 54°F to as high as 70°F for AHU-10-SOUTHCENTER. This issue was consistently detected for nearly all AHUs. This is likely a result of the AHUs using DX coils which stage on and off and where continuous control is more difficult to achieve.

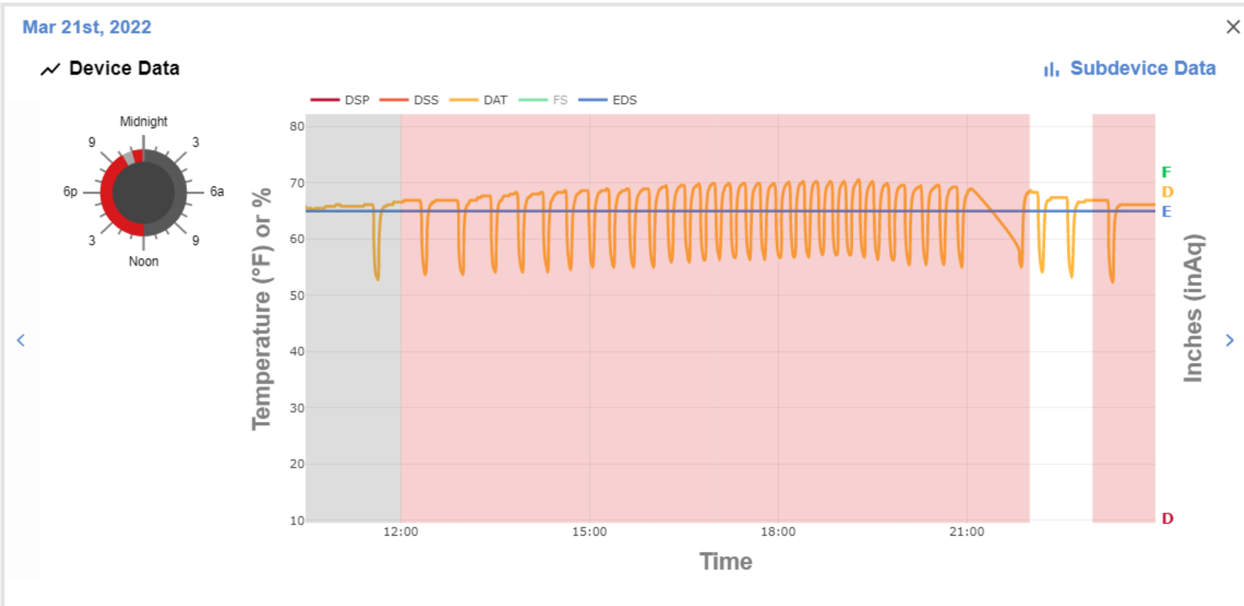

Figure 4-16. Supply-air Temperature Deviating from Setpoint for AHU-10-SOUTHCENTER

4.3. Energy Savings from RCx Measures

Best efforts were made to accurately model the two buildings using Building Re-tuning Simulator. Since the Building Re-tuning Simulator is a more simplified approach compared to full energy modeling (e.g. EnergyPlus), in addition to incomplete design and operational information and unknown operational constraints related to the two buildings, the **resulting savings estimates should be used qualitatively to gauge the potential impact of the Re-tuning measure at each building**.

The Building Re-tuning Simulator is an Excel based modelling tool using a Visual Basic engine that allows users to create a simplified model of a commercial building and implement control measures to obtain savings estimates. The simulator allows users to specify sizing and equipment configuration to create a representative floor, air handler, interconnected heating, and cooling system (hot water and chilled water) and allows for the creation of up to 8 zones. These zones have loads, internal and external, which determine the cooling and heating loads for the building. Schedules for lighting, occupancy, plug loads, and HVAC equipment are also input into the model. Control strategies for multiple components exist as well, including AHU properties such as supply air temperature and static pressure setpoints, chiller/boiler plant properties like chilled/hot water temperature setpoint, and zone equipment setpoints like VAV minimum/maximum airflow and thermostat setpoints.

The building model is "calibrated" based on utility data. After the calibration step, Re-tuning measures can be modeled to see how the estimated energy usage of the building changes. Setpoints can be controlled using linear resets, trim and respond strategy, and constant setpoints. These control strategies can be based on a variety of feedback variables, including outdoor air temperature, zone damper positions, zone cooling/heating demand, and fan speed.

5. Anacostia High School Energy Model and Savings

The following section lists the building configuration for the baseline model, the modelled retuning measures, and the energy savings estimates for Anacostia High School:

Building Model Parameters:

- 80,000 sf floor plate, 200,000 sf total (Figure 5-1)
- 11 ft ceiling
- 45% Window: Wall on all exterior walls
- Classroom zones: 1 and 5, Auditorium zone: 2, music room zone: 3, office zone: 4, cafeteria zone: 6, restroom zone: 7, corridor zone: 8

Lighting density between 0.6 and 0.95 W/sf
  - Plug load between 0 and 1 W/sf
  - Occupant density between 5 and 30 people/1000 sf
- Lighting, equipment, and occupancy schedules based on typical school hours, 7 a.m. – 3 p.m. and low Saturday usage
- Envelope characteristics: R-9 walls, R-1.5 windows, 0.4 SHGC, Infiltration rate of 0.4 cfm/sf wall area
- Heating and Cooling Equipment:
  - 3 - condensing 1.4 MMBtu boilers
    - 2 - 10 hp pumps
  - 2 - 250-ton chillers
    - 2 - 15 hp ChW pumps
    - 2 - 20 hp CW pumps
    - 2 - 250-ton cooling towers
- AHU Details:
  - Heat recovery present (60% effective)
  - 65% minimum outdoor-air fraction
  - No economizer modeled
  - Single deck, cooling coil, heating coil, and supply fan (no option to model multiple supply fans)
  - Return fan present

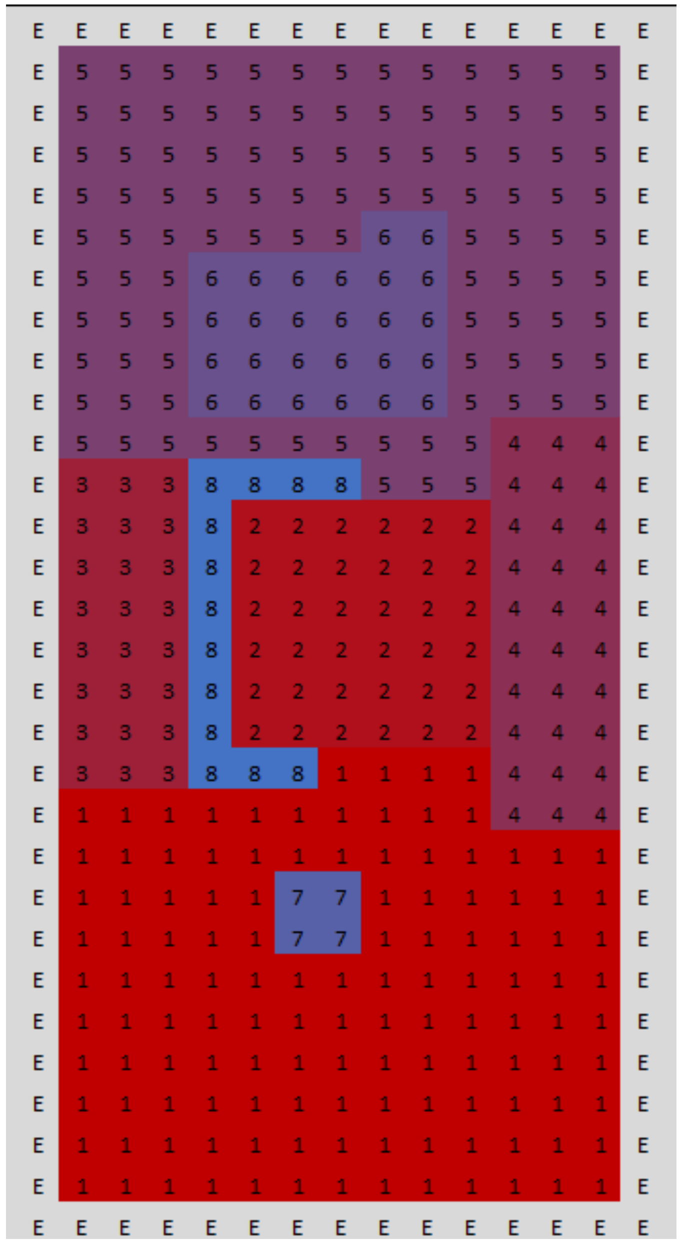

Figure 5-1: Anacostia building footprint, simplified

    - Constant supply-air temperature set point: 65°F
    - Constant static pressure set point: 1.5 in. w.c.
    - Scheduled to run constantly
- Thermostat setpoints:
    - Occupied heating: 71°F
    - Occupied cooling: 72°F
    - Unoccupied heating: 60°F
    - Unoccupied cooling 80°F

Re-tuning Measure Information

- **Reduce HVAC schedules**: changed from 24/7 to 6:30 a.m. to 7 p.m. on weekdays, the systems are off on weekends
- **Static Pressure Reset**: implemented a trim and respond based on maximum zone damper position; the pressure resets between 1.0 to 1.5 in. w.c. with a target maximum position of 95%.
- **Supply Air Temperature Reset**: implemented a trim and respond control using zone cooling demand between 55°F and 65°F, 0.5°F change per hour with a target demand of 30%.

Energy Savings Information

Energy saved by measure:

- Reduce HVAC schedules: 21%
- Static pressure reset: 8% savings AFTER reducing HVAC schedule
- Supply-air temperature reset: 7% savings AFTER reducing HVAC schedule

6. OJS Energy Model and Savings

The following section lists the building configuration for the baseline model, the modelled retuning measures, and the energy savings estimates for OJS:

Building Model Parameters:

- 61,104 sf floorplate, 875,000 sf total (see Figure 6-1)
- 10 ft ceilings
- 55% Window: wall on all exterior windows
- 4 office zones: NW, NE, SE, SW
  - Lighting density: 1.1 w/sf
  - Electric equipment density: 0.95 W/sf
  - Occupant density: 10 people/1000 sf
- Lighting, equipment, and occupancy schedules based on typical office hours, 8 a.m – 5 p.m. and low Saturday usage
- Envelope characteristics: R-9 walls, R-2 windows, 0.4 SHGC, 0.7 cfm/sf wall area
- Equipment:
  - Electric resistance heating
  - Direct expansion cooling coils
    - 4 - 150 HP CW pumps (instead of 8 75 HP pumps; max allowed is 4)
    - 3 - cooling towers
- AHU Details
  - 20% min OA
  - Single deck, cooling coil
  - Return fan present
  - Supply-air temperature setpoint 65°F when outdoor-air temperature is 47°F or lower, Supply-air temperature setpoint 55°F when outdoor-air temperature is 48°F or higher (mimics changing setpoints in heating and cooling seasons as observed in building data)
  - Constant static pressure set point: 1.5 in. w.c.
  - Scheduled to run constantly
- Thermostat setpoints:
  - Occupied heating: 65°F
  - Occupied cooling: 68°F
  - Unoccupied heating: 55°F
  - Unoccupied cooling 80°F
- Perimeter zone heating (electric resistance)

Figure 6-1: OJS building footprint, simplified

Re-tuning Measure Information

- **Reduce HVAC schedules**: changed HVAC schedules from 24x7 to 6:30 a.m. to 7 p.m. on weekdays; the systems are off on weekends.
- **Static Pressure Reset**: implemented a trim and respond based on maximum zone damper position from 0.5 to 1.5 in. w.c. with a target maximum position of 95%.
- **Supply Air Temperature Reset**: implemented a trim and respond control based on zone cooling demand: between 55°F and 65°F, 0.25°F change per hour with a target demand of 85%.

Energy Savings Information

- Reduce HVAC schedules: 22% savings
- Static Pressure Reset: 4% savings AFTER reducing HVAC schedule
- SAT Reset: 2% savings AFTER reducing HVAC schedule

7. Results from Deployment of Intelligent Load Control Application

The ILC application manages controllable loads in a building while also mitigating service-level excursions (e.g., occupant thermal and visual comfort, minimizing equipment ON/OFF cycling) by dynamically prioritizing available loads for curtailment using both quantitative (deviation of zone conditions from set point) and qualitative rules (type of zone). The ILC algorithm uses the analytical hierarchy process (AHP) to prioritize loads for curtailment.

The AHP is a structured technique for organizing and analyzing complex decisions based on mathematics and psychology. The process can generate a numerical score to prioritize each alternative being considered based on associated decision criteria. The AHP algorithm is ideal when it is difficult to formulate a goal using quantitative criteria alone for evaluation because it uses both qualitative and quantitative criteria to solve complex decision-making problems. The primary goal of the ILC process is to prioritize controllable loads for curtailment to keep the building's dynamic electric demand from exceeding the target demand, while simultaneously assuring service levels. Although the ILC process supports a number of grid service use cases, all of them result in a building-level peak demand target for ILC to manage. The ILC process prioritizes a set of criteria used to rank the alternatives of a decision and distinguish, in general, the more important factors from the less important factors. As shown in Figure 7-1, AHP has three major elements—the goal, the criteria, and the alternatives. In this section, the results from deploying ILC on a building a set of VAV AHUs is presented.

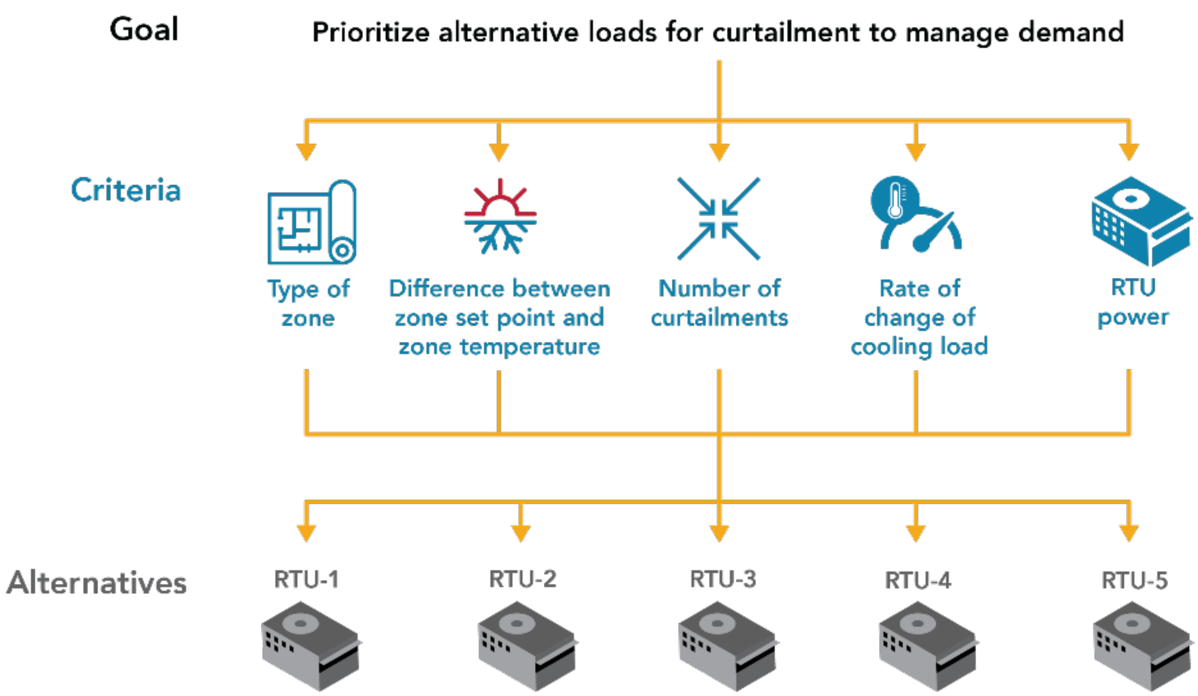

Figure 7-1: An example of the AHP process that uses RTU loads to manage building peak demand.

7.1. ILC Results for Anacostia High School

The ILC application was deployed and configured to control the cooling temperature set points for the VAVs served by AHUs at Anacostia High School. Typically, when thermostatic controls are employed for load reduction, ILC is configured to increase the cooling temperature set point by 1°F to 3°F. At Anacostia, the site staff were most comfortable with increasing the cooling temperature set points by 1°F so peak demand reductions would be modest. During the initial deployment it was discovered that the whole building power measurements for the building were incorrect. Meter constants configured by site staff were wrong and had to be corrected prior to deployment of ILC. This meant that there was no historical data associated with building demand. Best efforts were made to use recent demand measurements to pick an appropriate demand target, but several iterations occurred. Figure 7-2 shows the demand for Anacostia High School on August 27th, 2022.

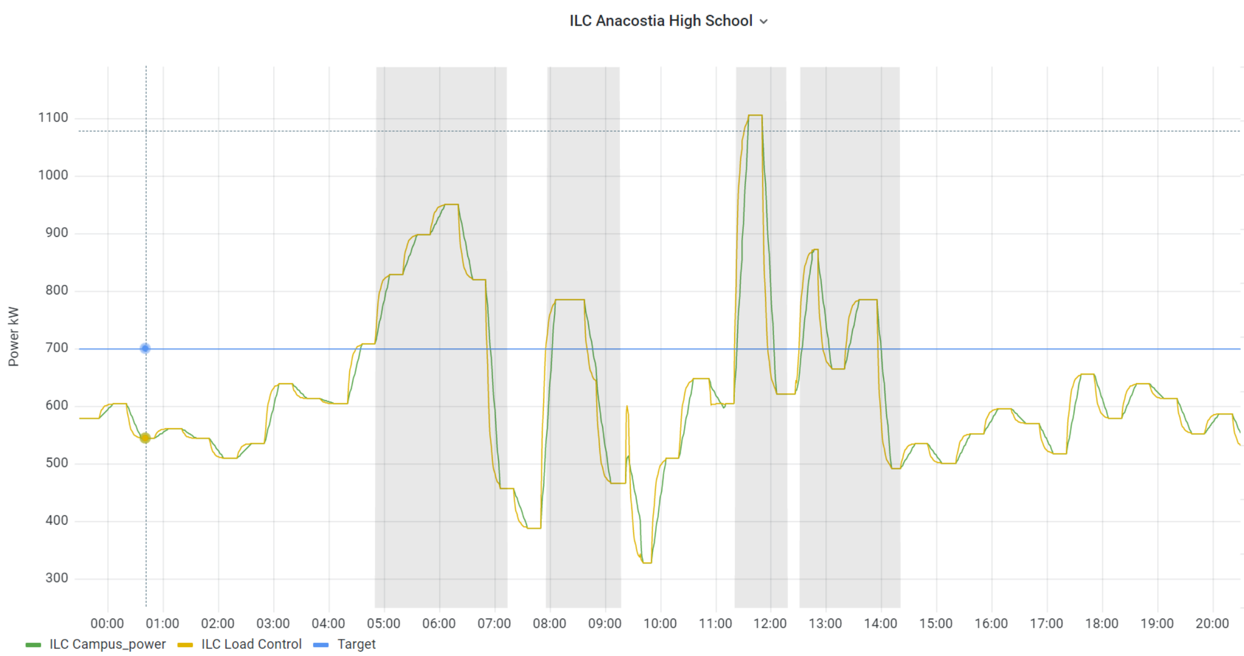

Figure 7-2: Anacostia Building Demand and ILC Target August 27th, 2022

The green curve is the 30-minute moving average building power, the yellow curve is the 30-minute exponential moving average power, and the blue line is the ILC target. One can see that ILC becomes active (shown as shaded area in the graph) each time the yellow curve exceeds the target of 700 kW. However, ILC is not able to meet the target. ILC is interacting with zone level cooling set points. By increasing the cooling set point the zone should require less cooling and the controller should reduce the airflow requirement to the zone as well. This would in-turn begin to close the zone damper and ideally reduce the supply-fan speed (and power) at the AHU serving the zone. To understand why ILC cannot meet the target let us look at the effect ILC is having at the AHU level. Figure 7-3 shows the supply-fan speed for AHU D-1. The green curve is the supply-fan speed, and the grey shading indicates when the ILC is actively trying to reduce the building demand.

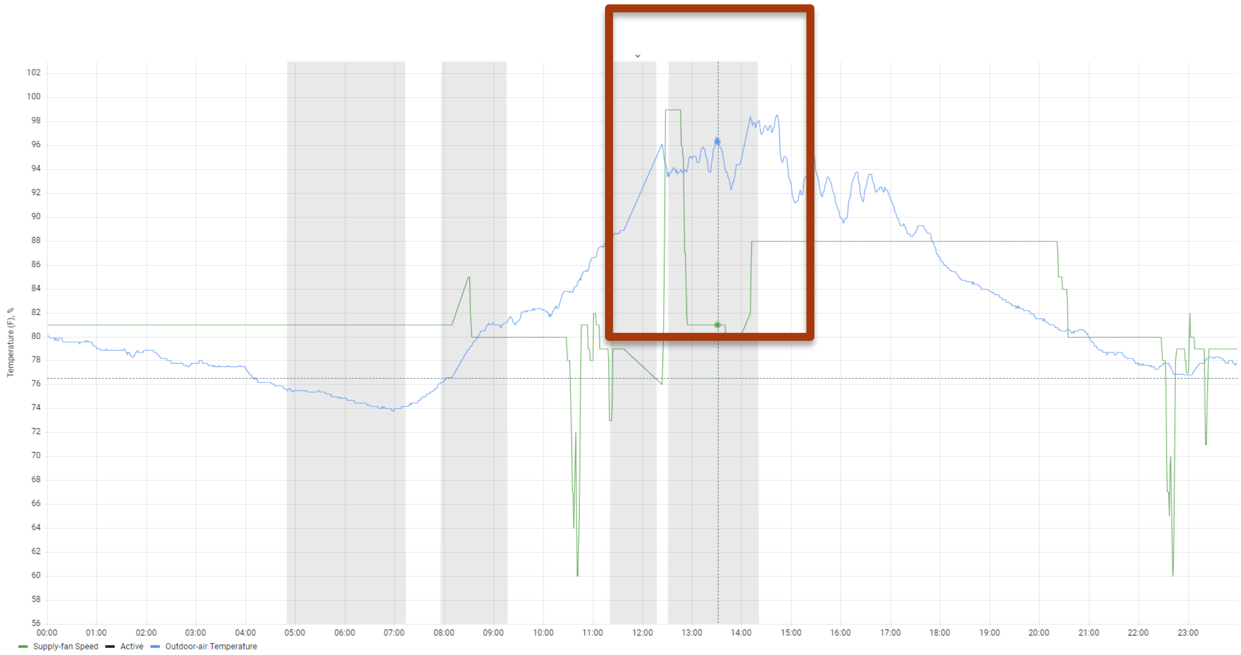

Figure 7-3: Anacostia High School AHU D-1 Supply-fan Speed August 27th, 2022

During the ILC interaction boxed in red in the figure, the supply-fan speed (green curve) reduces from 99% to 81%. It should also be noted that this is a warm August day where the outdoor-air temperature is greater than 90°F (blue curve). AHU D-1 is served by two 30 hp fans, so based on the fan affinity laws this should lead to a reduction of about 20 kW or about 40% reduction in fan power. This behavior is not consistent amongst the AHUs. Figure 7-4 shows the supply fan speed and ILC status for AHU C-2. We can see that during the ILC active period blocked in red there is no reduction in the supply-fan speed, therefore, no reduction in power for the AHU.

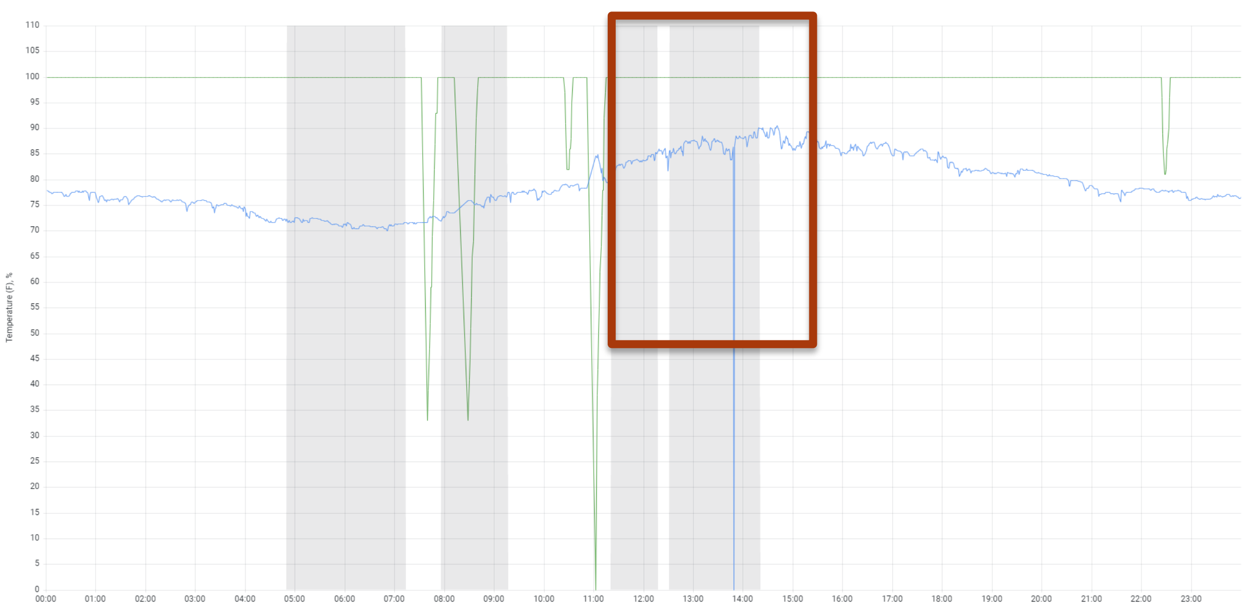

Figure 7-4: Anacostia High School AHU C-2 Supply-fan Speed, August 27th, 2022

Figure 7-5 shows the ILC interaction for August 27th, 2022, for VAV-16 served by AHU D-1

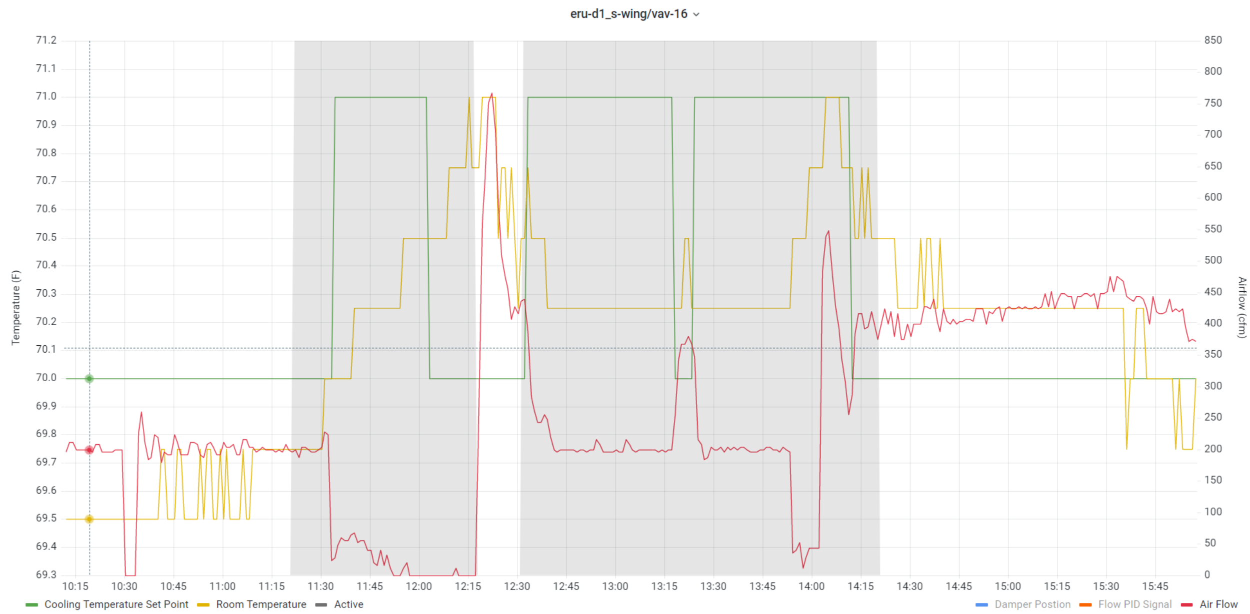

Figure 7-5 VAV-16 Served by AHU D-1 During ILC Control August 27th, 2022

The green curve is the zone cooling temperature set point, the yellow curve is the room temperature, the red curve is the zone airflow, and the shaded region indicates when ILC is actively controlling the building systems. In Figure 7-5 we can see that the ILC goes active at approximately 11:30 a.m. and increases the zone cooling temperature set point from 70°F to 71°F. When the cooling temperature setpoint is higher than the room temperature the controller sees that the zone is satisfied and reduces the airflow to the space by modulating the zone damper closed. Shortly after 12 p.m. ILC releases control of the set point back to 70°F, causing the room temperature to exceed the cooling set point and the controller to increase the airflow to the space. Subsequently, the ILC becomes active again at approximately 12:30 p.m. and the control the cooling temperature set point causing the airflow to again reduce. This is a substantial reduction in airflow but unfortunately, many of the other zones do not behave in this desirable manner.

7-6 shows the ILC interaction for August 27th, 2022, for VAV-1 served by AHU D-1. At approximately 11:20 a.m. the ILC goes active and increases the set point. The room temperature (yellow curve) is already significantly cooler than the cooling set point. The room temperature is close to 65°F, when the outdoor-air temperature is warm (between 85°F - 90°F). The ILC increasing the zone cooling temperature set point when the room temperature is already low will not affect reductions in the zone airflow. ILC uses the current airflow set point to determine if the zone is available for curtailment. For a device to be considered available the current air flow set point must be greater than the minimum airflow. This should ensure that only zones that are actively cooling are targeted for load reduction. The airflow for this zone is at the maximum airflow (1000 cfm), even though modifying the thermostatic set point will not and did not cause a reduction in airflow. This was a common issue with the zones.

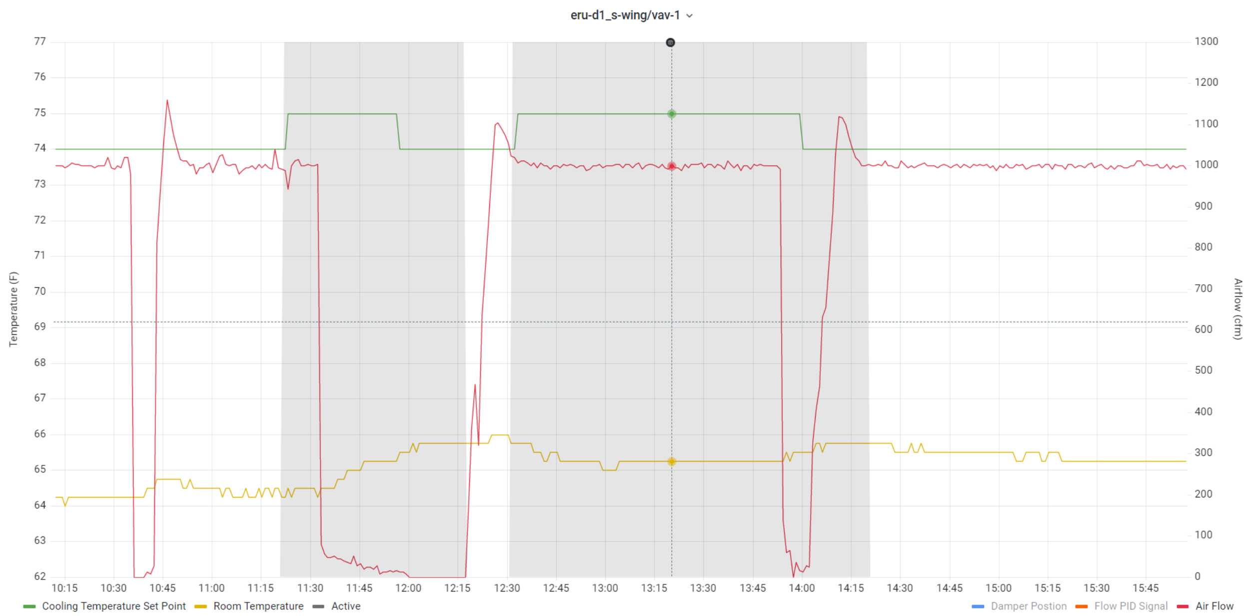

Figure 7-6: VAV-1 Served by AHU D-1 During ILC Control August 27th, 2022

To further evaluate ILC results we will examine Tuesday September 13th. Figure 7-7 shows the average building demand (yellow curve) and ILC demand target (blue curve) for Anacostia High School on September 13th, 2022. Figure 7-8, Figure 7-9, Figure 7-10, and Figure 7-11 show the supply-fan speed command (green) and outdoor-air temperature (blue) for AHU C-1, AHU D-1, AHU B-1, and AHU C-2 on September 5th, 2022. The shaded regions in these plots indicate when the ILC detects that the building load is above the target and is actively trying to reduce the load.

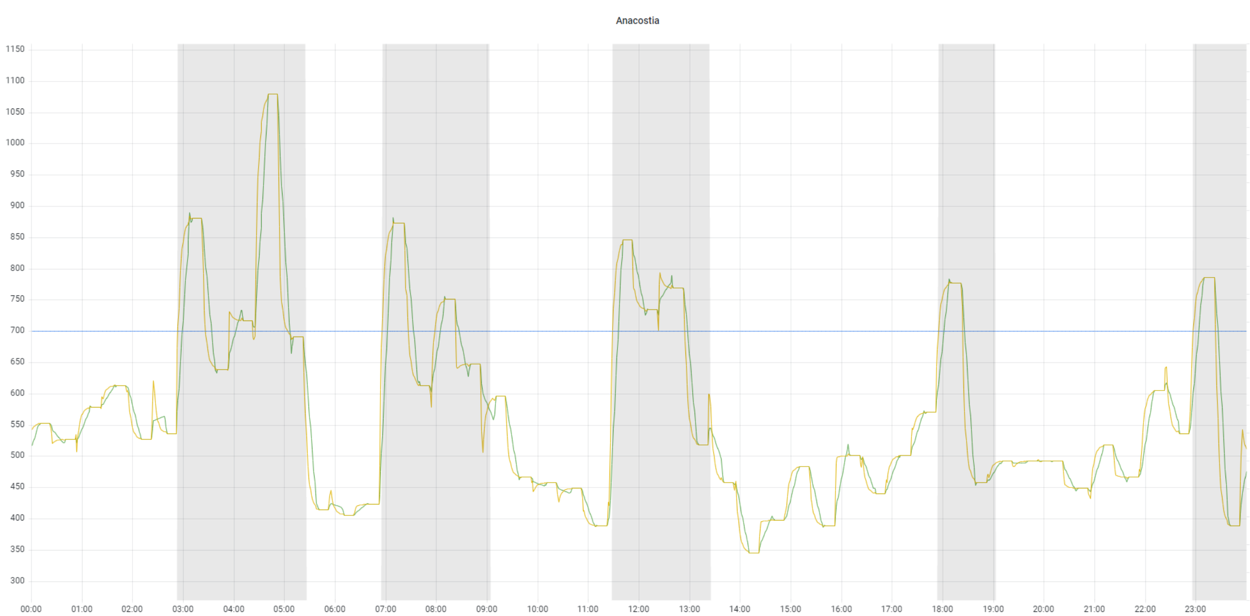

Figure 7-7: Anacostia Building Demand and ILC Target September 13th, 2022

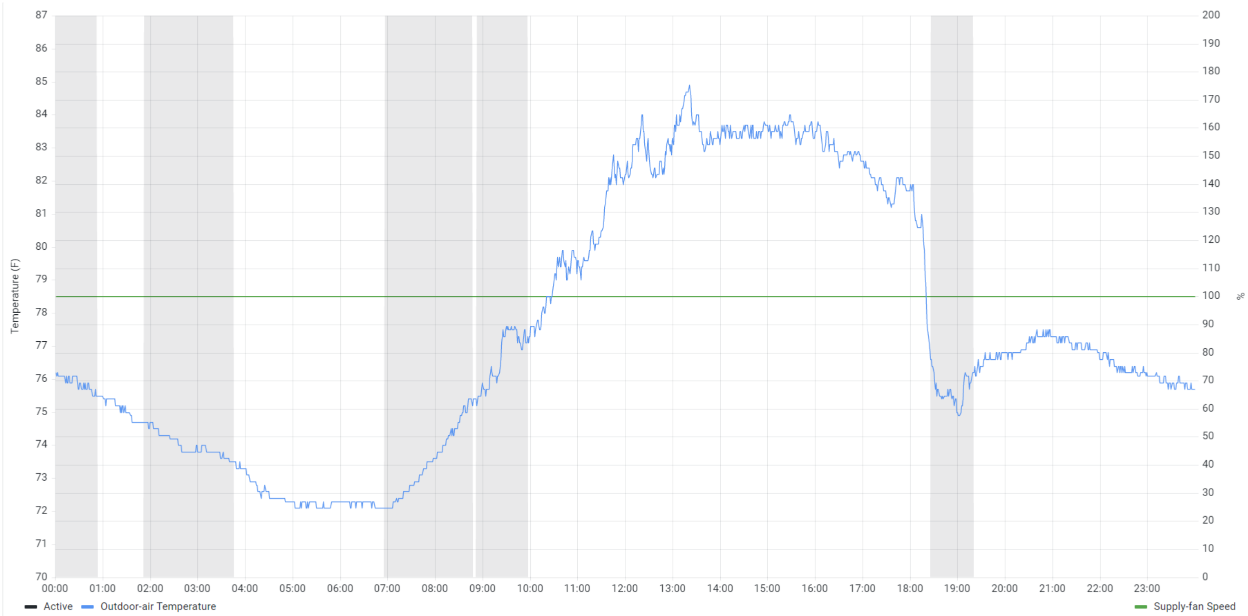

Figure 7-8: Anacostia High School AHU C-1 Supply-fan Speed, September 13th, 2022

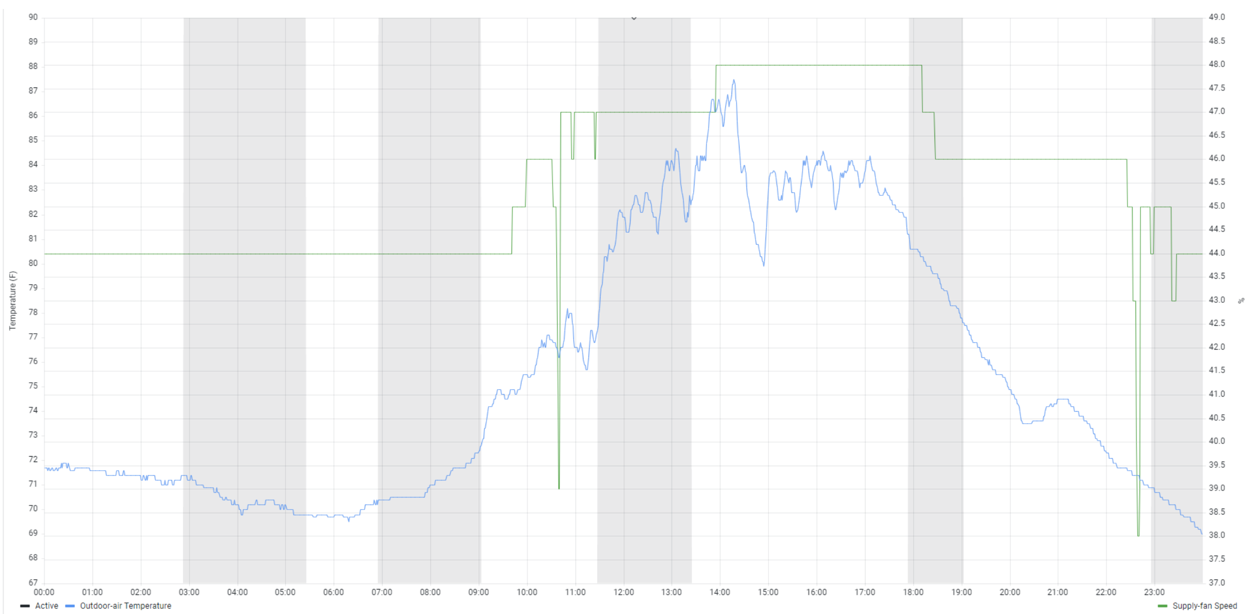

Figure 7-9: Anacostia High School AHU D-1 Supply-fan Speed, September 13th, 2022

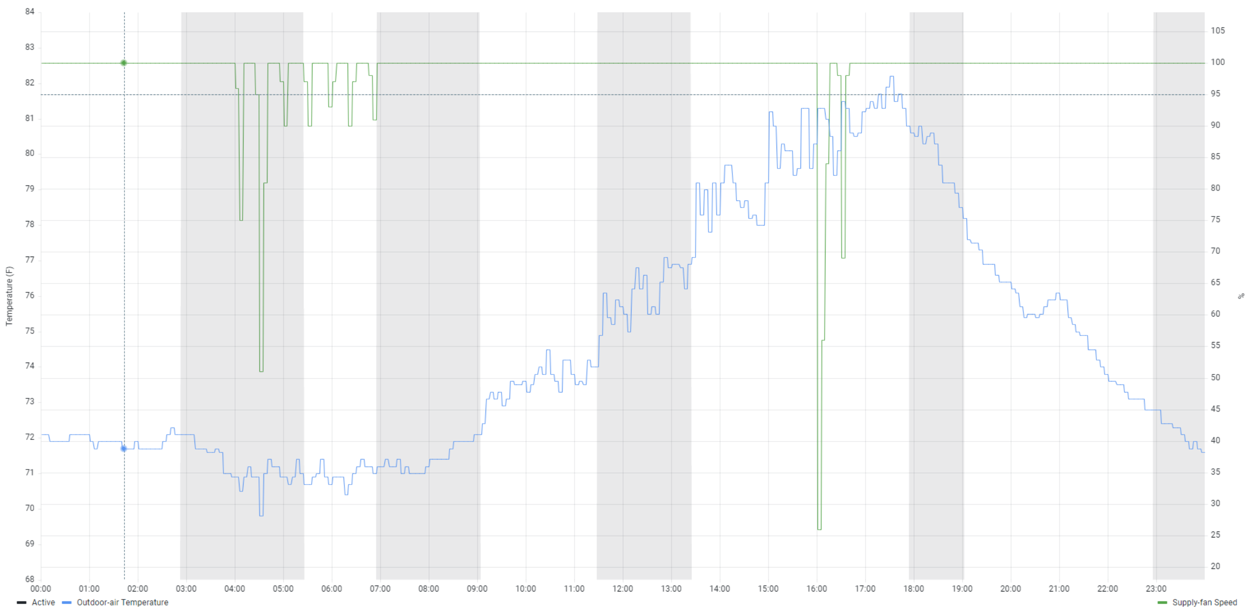

Figure 7-10: Anacostia High School AHU B-1 Supply-fan Speed, September 13th, 2022

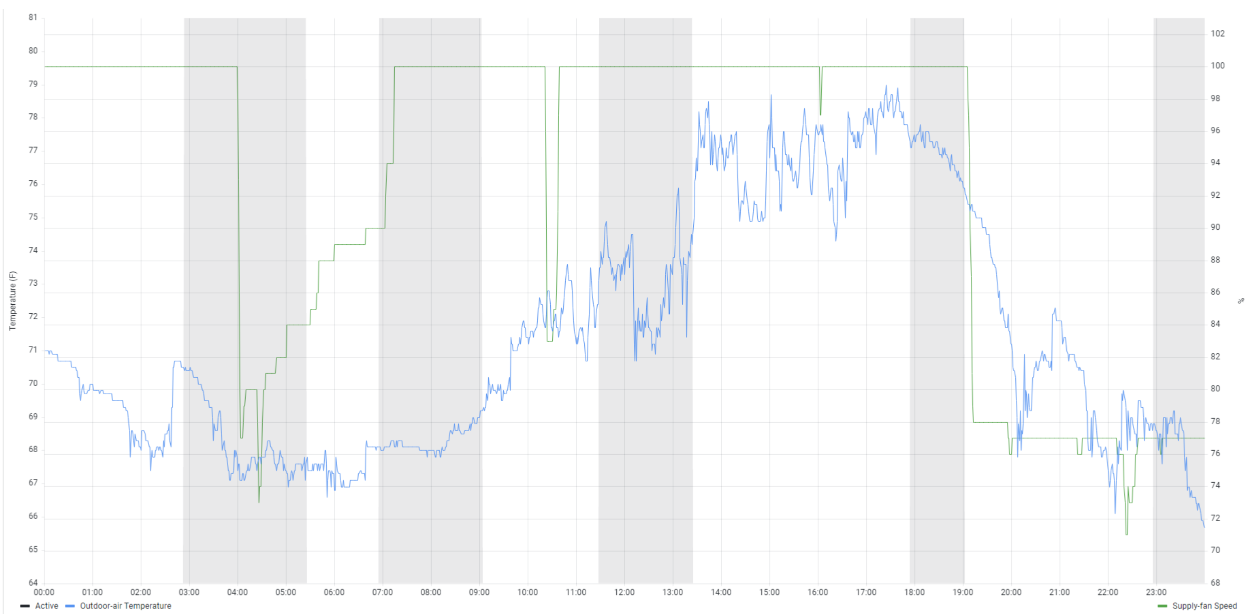

Figure 7-11: Anacostia High School AHU C-2 Supply-fan Speed, September 5th, 2022

A few noteworthy observations on the data: 1) the largest peaks in building demand occurs very early in the morning, between 3 a.m. and 5:30 a.m., and late in the evening, 6p.m. to 7 p.m. and 11 p.m. to midnight, 2) AHUs are operating continuously, even during periods that are typically unoccupied, 3) the building power consumption does not appear to be dependent on the outdoor-air temperature and 4) there is no (or little) reduction in the AHU's supply fan speed during ILC interactions with zone thermostat set points (shaded grey regions).

Figure 7-12 shows data for VAV-16 served by AHU D-1. The yellow curve is the room temperature, the green curve is the zone cooling temperature set point, the orange curve is the airflow, the purple curve is the zone maximum air flow, the blue curve is the zone minimum airflow, and the shaded region indicates time that the ILC is actively managing the building demand. This VAV was selected to show the expected behavior of a VAV under ILC control. In the early morning when the building power exceeds the demand target there is very little load in the space, and the airflow is already at the minimum, so the ILC does not command the cooling temperature set point. Later in the afternoon, the room temperature increases the zone responds by increasing the airflow to the space. During each of the three afternoon ILC interactions ILC increases the zone cooling temperature set point and the VAV responds by reducing the airflow to the space.

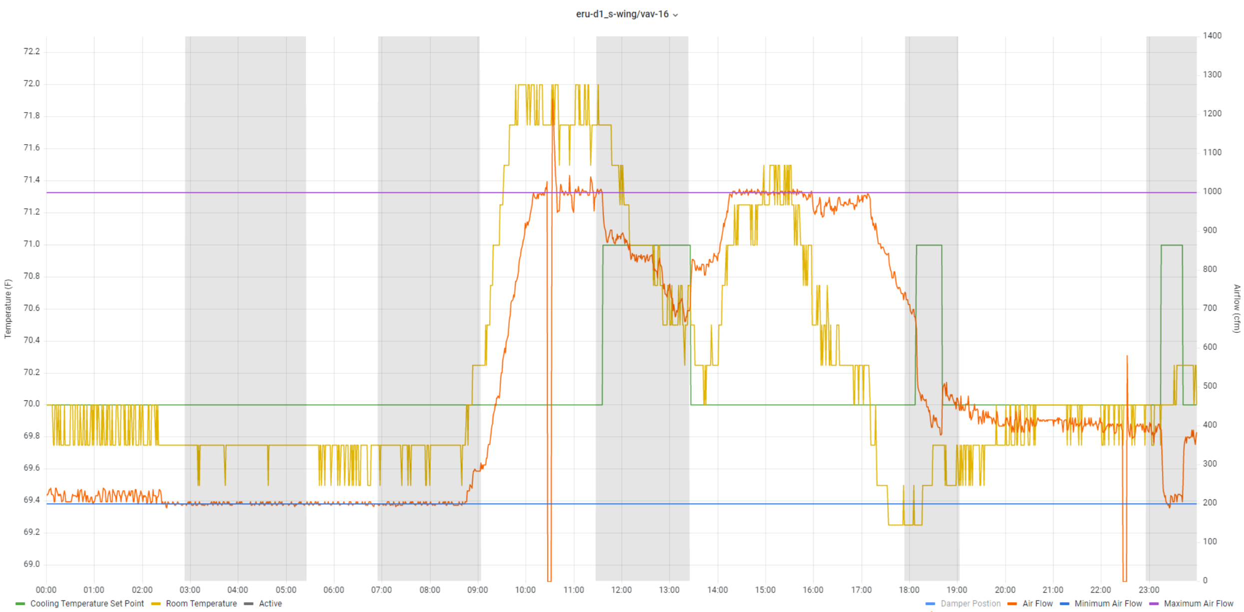

Figure 7-12: VAV-16 Served by AHU D-1 During ILC Control August 27th, 2022

Figure 7-13 shows data for VAV-18 served by AHU D-1. We can see that the zone is significantly overcooled. The nominal zone temperature set point is 74°F and the room temperature is close to 69°F. Further investigation of this zone showed that during this period the reheat valve was fully open, indicating the zone was calling for full heating. Also, review of the BAS and the Siemens thermostat documentation showed that the heating maximum airflow and cooling maximum airflow were both set to 1000 cfm. The heating controls are staged as follows: when the heating loop is between 0% and 50% modulate the reheat valve from 0% to fully open. When the heating loop is between 50% and 100% modulate the airflow between the heating minimum and heating maximum airflow. During this period both the reheat valve and the airflow are set to the maximum, but the boiler was turned off (Figure 7-14 shows the hot water supply (yellow curve) and hot water return temperature (green curve) for the boiler system at Anacostia during September of 2022). This caused excessive cool air from the AHU to overcool the space. Also, since the increased airflow was not beneficial to meeting the zone temperature set point it was effectively increasing the airflow of the space far more than what was needed; this is a large waste of energy. This behavior and overcooling was seen in a large percentage of the VAVs.

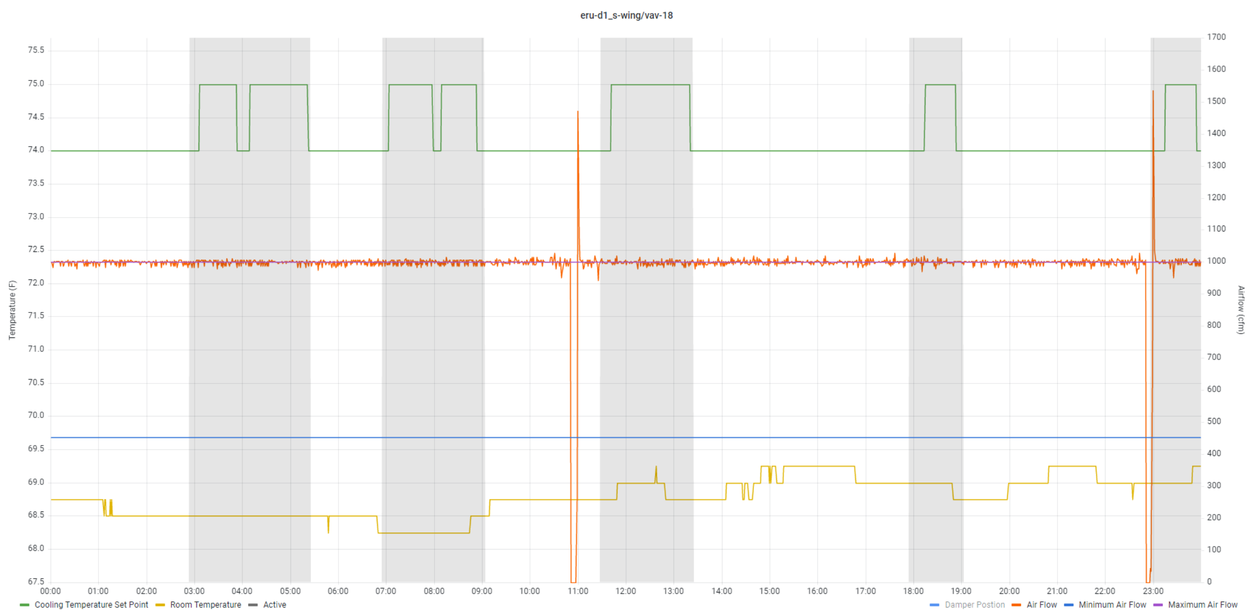

Figure 7-13: VAV-18 Served by AHU D-1 During ILC Control August 27th, 2022

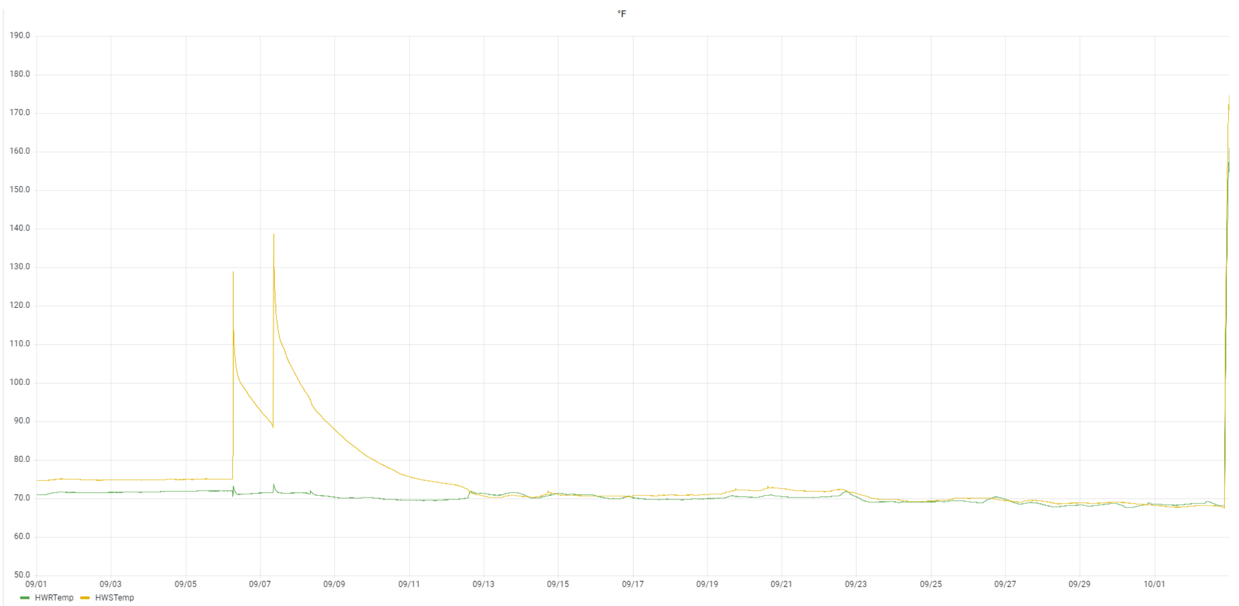

Figure 7-14: Hot Water Supply and Hot Return Temperature from Hot Water Distribution System for September 2022

Further evaluation of ILC at Anacostia will continue. Since the VAVs utilize a dual maximum airflow control there will be some flexibility at the AHU supply fan during the winter. When the heating season begins PNNL will continue to exercise ILC at Anacostia, but we will need to work with the project partner, Intellimation, to investigate/fix some operation issues:

1) Evaluate minimum cooling airflow settings for VAV boxes. PNNL recommends that the cooling airflow set points be as low as possible while maintaining acceptable ventilation standards. This will minimize zone overcooling and reduce fan energy consumption.

2) Evaluate heating airflow set points. Typically, when dual maximum airflow controls are utilized the heating maximum airflow should not exceed 50% of the maximum cooling airflow.
3) Also, care must be taken with these settings when the boiler system is disabled. If the boiler is disabled and the heating loop is calling for additional airflow, the zone will become overcooled (as was observed with many VAV at the Anacostia site). This is of no benefit to meeting the cooling load and on aggregate can waste significant fan and chiller energy.

7.2. ILC Results for One Judiciary Square

OJS is an 11-story 875,000 sf building with over 700 VAV boxes. Many of these are known to have sporadic and/or failed communication. It should be noted that difficulties at the OJS site delayed the device data collection, AIRCx, and the deployment of ILC. Hardware issues and device communications issues continue to be a problem, but discussions with Intellimation have led to the conclusion that a more powerful data collection computer is needed to host VOLTTRON and the Normal Framework (software doing the BACnet data collection and interfacing with VOLTTRON and Intellimation data collection database) for a site this large. This section will summarize the ILC results to date for the OJS site and give our plan to improve ILC performance by configuring ILC to target both cooling and heating operations.

To make the ILC deployment more manageable and to reduce the impact of failed devices 4 floors (of the 12 floors) were identified by Intellimation as having more reliable device communication than most. The floors that were targeted for ILC were floor 3, floor 8, floor 10, and floor 11. Each floor has approximately 80 VAV boxes that are served by 4 large AHUs. Each AHU has a VFD driven supply fan and four compressors for DX cooling. One instance of ILC was deployed per targeted floor. Since the AHUs are not sub-metered the power per AHU was estimated using real time data as shown in Table 7-1.

Table 7-1: Virtual Meter Power Calculation for AHU

Component	Rated Power (kW)	Value	Point	Calculation
Supply fan	28	0-100%	VfdBwPos	VfdBwPos cubed x 25
Compressor 1	5.5	25%	ClgCapacity	if 25%, then 5.5 kW
Compressor 2	10.2	50%	ClgCapacity	or if 50%, then 15.7 kW
Compressor 3	10.2	75%	ClgCapacity	or if 75%, then 25.9 kW
Compressor 4	10.2	100%	ClgCapacity	or if 100%, then 36 kW

Using the supply-fan speed (VfdBwPos) and the cooling signal (ClgCapacity) the total AHU power can be calculated. The total floor power is then calculated as the sum of the AHU power for the four AHUs serving that floor. ILC is then set to maintain the overall floor power below a configured target. Review of the data shows that during the ILC deployment period (September 2022 to current) there was not significant flexibility for cooling operations. Figure 7-15 shows the average building demand (yellow curve), the 15-minute exponential moving power (red curve - value ILC manages target to), and ILC demand target (blue curve) for Floor-3 of OJS on September 13th, 2022.

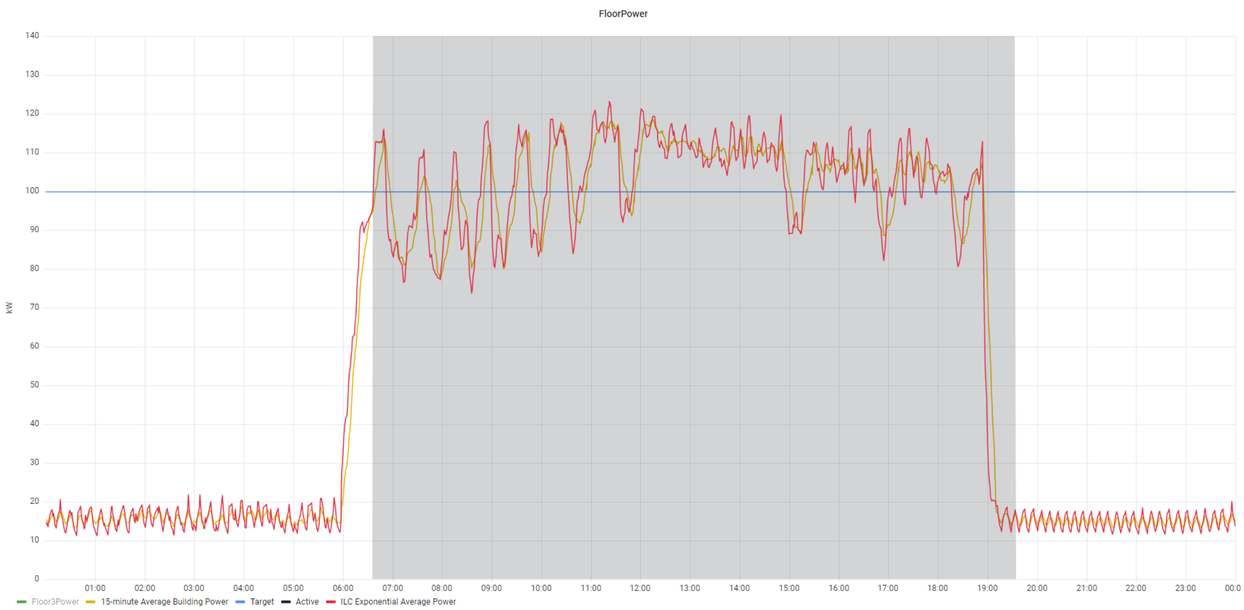

Figure 7-15: OJS Floor-3 Demand and ILC Target September 19th, 2022

Soon after occupancy begins at 6 a.m. the target is exceeded and ILC attempts to meet the demand limit of 100 kW. Figure 7-16 show VAV-17 for served by Floor-3 AHU North Center. The orange curve is the zone airflow, the red curve is the zone temperature set point, the yellow curve is the zone temperature, and the purple curve is the minimum cooling airflow.

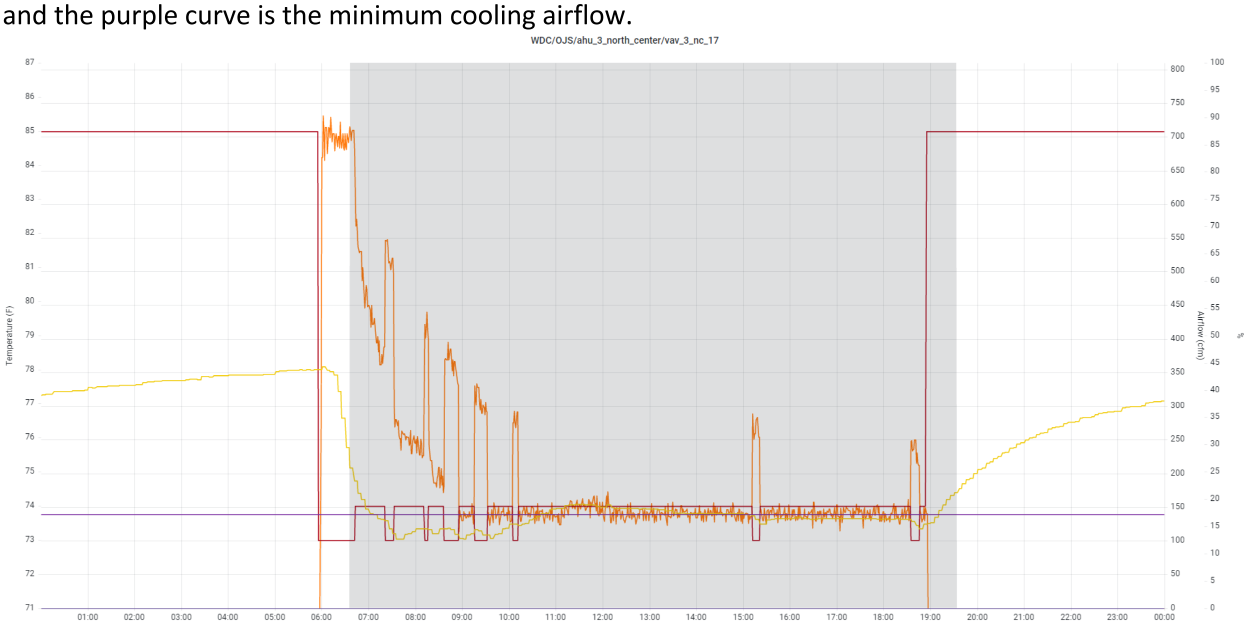

Figure 7-16: VAV-17 Served by Floor-3 AHU North Center During ILC Control September 19th, 2022

The ILC is active and attempting to manage the power for the floor for the nearly all the occupied periods. As ILC increases the set point (red curve) from 73°F to 74°F the airflow shows significant reduction. This VAV shows fairly good performance, and if the remainder of the zones had similar flexibility, then the ILC would easily meet the demand target. Unfortunately, that is not the case. Figure 7-16 shows the typical response of a VAV during the ILC test on September 19th, 2022. The zone temperature is significantly lower than the effective set point and the airflow is close the minimum airflow (purple curve). ILC is configured to only interact with zones when the measured VAV airflow is greater than the minimum. This demonstrates a configuration flaw. The ILC configuration should be changed to account for the measurement noise around the minimum airflow (i.e., the measured zone airflow should be 10% to 20% greater than the minimum zone airflow prior to determine a VAV available for control).

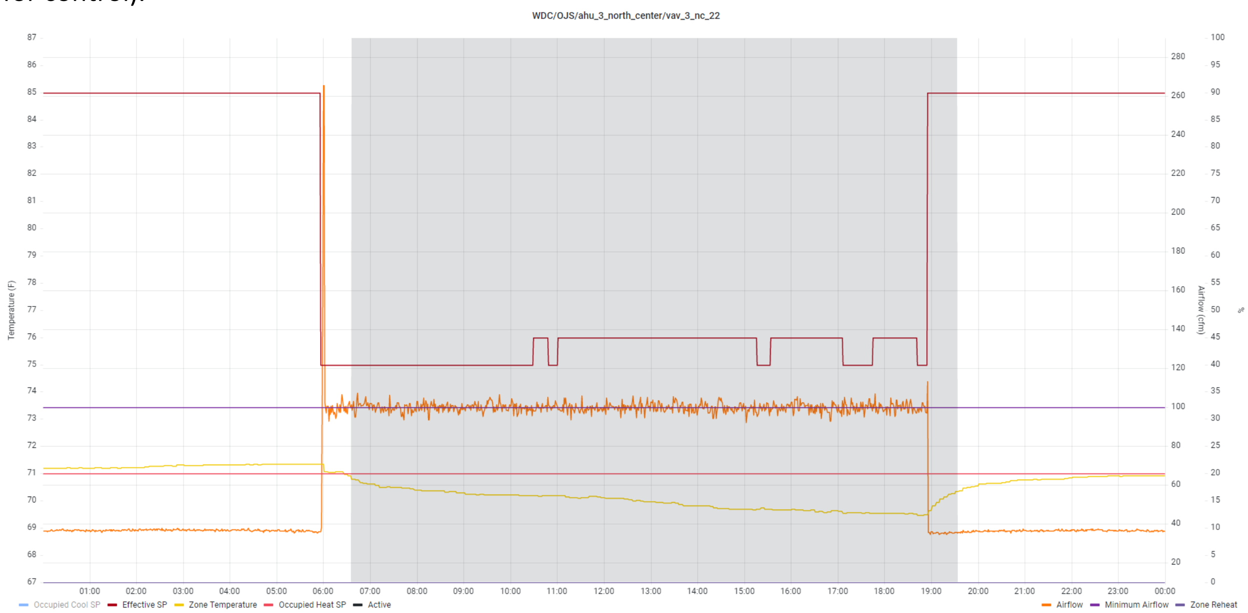

Figure 7-17: VAV-22 Served by Floor-3 AHU North Center During ILC Control September 19th, 2022

Figure 7-18 shows data for VAV-19 served by Floor-3 AHU North Center. This zone is in heating mode and the electric reheat is active (dark blue curve). When ILC reduces the zone temperature set point the electric heat turns off. This is close to a 4-kW reduction for this VAV alone, but this is currently not accounted for in our virtual meter (shown in Table 7-1). With the assistance of Intellimation we have sized the zone electric reheat coils and are adding them to the virtual meter calculation for floor power. This will allow us to do demonstrate that buildings with electric zone reheat have significant load flexibility during the heating season.

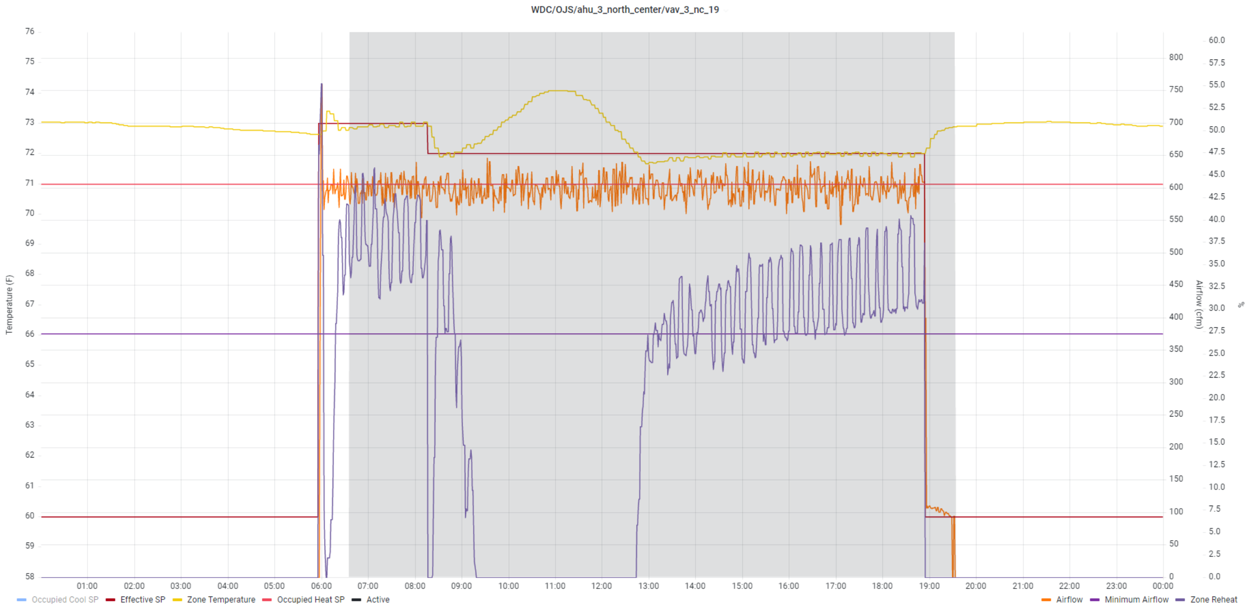

Figure 7-18: VAV-19 Served by Floor-3 AHU North Center During ILC Control September 19th, 2022

Figure 7-19 shows the average building demand (yellow curve), the 15-minute exponential moving power (red curve - value ILC manages target to), and ILC demand target (blue curve) for Floor-8 of OJS on September 20th, 2022. ILC is actively trying to limit the peak demand for Floor-8 to 100 kW after 9:30 a.m. Based on the load peak of 135 kW, the power target of 100 kW is too aggressive, especially since the zones are not showing significant cooling flexibility.

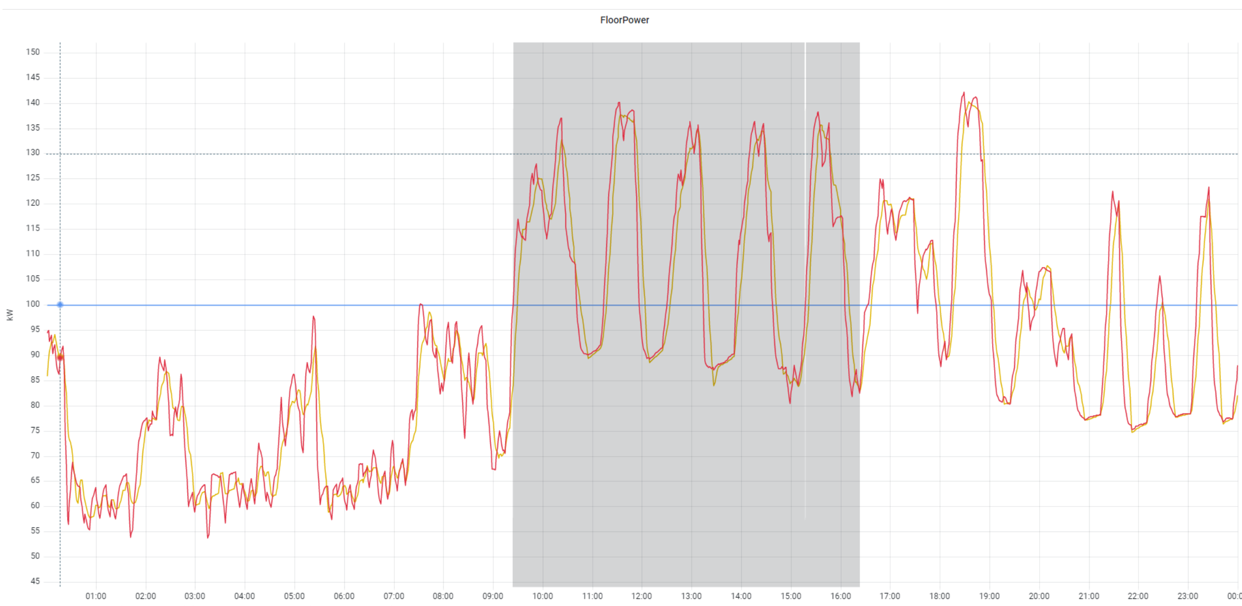

Figure 7-19: OJS Floor-8 Demand and ILC Target September 20th, 2022

Figure 7-20 shows data from VAV-16 served by Floor-8 AHU South. This zone shows some flexibility during the initial control when the zone set point is increased from 72°F to 73°F (approximately 10 a.m.). The airflow (orange curve) shows reduction but as the zone temperature increases above set point the airflow again begins to increase. Using a more aggressive set point increase (2°F - 3°F) increase the airflow reductions and only marginally reduce occupant comfort (set point would be 74°F - 75°F).

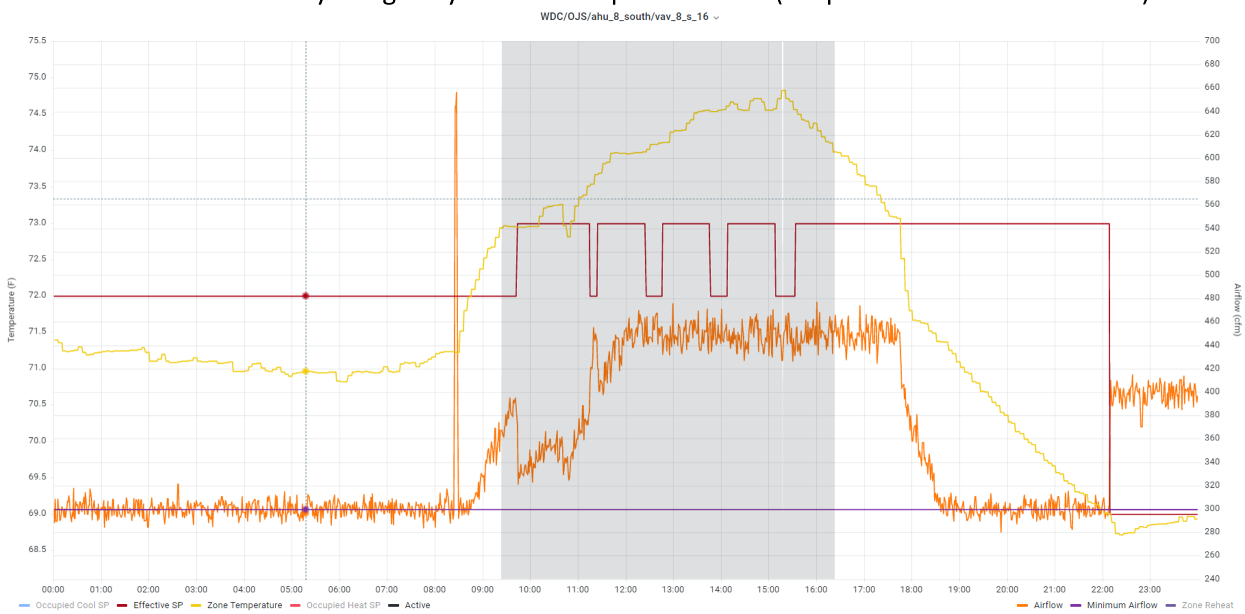

Figure 7-20: VAV-20 Served by Floor-8 AHU South During ILC Control September 20th, 2022

Figure 7-21 shows data from VAV-10 served by Floor-8 AHU South. This zone shows some flexibility during the initial control when the zone set point is increased from 72°F to 73°F (approximately 9:30 a.m.). The remainder of the ILC active period the zone temperature is significantly lower than the zone set point. This causes the airflow to be very close to the minimum. This is a typical response for the VAV during this period, low cooling flexibility. Many of the VAVs are heating.

Figure 7-21: VAV-10 Served by Floor-8 AHU South During ILC Control September 20th, 2022

Figure 7-22 shows data from VAV-21 served by Floor-8 AHU South. This zone is actively heating. The zone reheat signal (dark blue curve) peaks at 100%. During ILC active period ILC reduces the zone set significantly reducing the electric reheat. We can see four occurrences in the shaded active period where ILC reduces the setpoint and the electric heater response is nearly instantaneous. This is a modest reduction in set point. More aggressive or incremental changes in the set point would lead to increased reduction in zone electric reheat. Again, although this demonstrates the ILC will elicit load reduction during heating the electric reheat still needs to be added to the floor virtual meter calculation to capture this load reduction in the data.

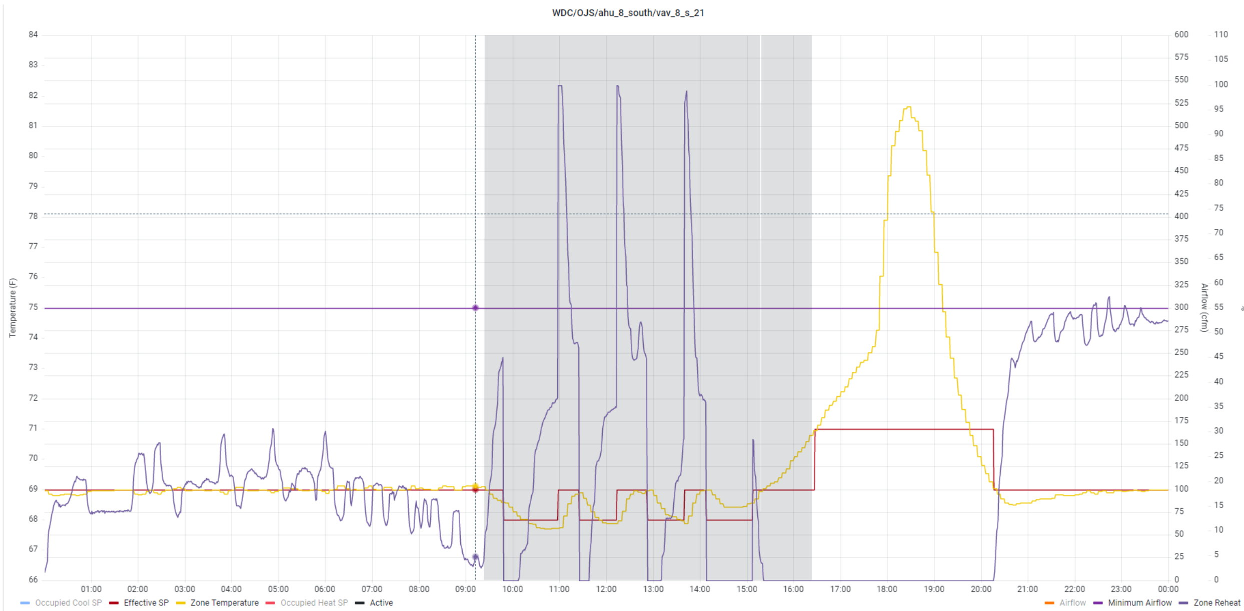

Figure 7-22 VAV-21 Served by Floor-8 AHU South During ILC Control September 20th, 2022

The results for Floor-10 and Floor-11 were similar, showing minimal cooling flexibility but opportunities to with respect to zone electric reheat. Also, there has been some issues on the VAVs and our ability to predictable control the set point. The adjustable points are the occupied cooling and occupied heating set points but the VAVs are using another point, called the effective set point to control the zone temperature. There is an offset applied to the occupied cooling and heating set point and depending on the VAV mode (cooling or heating) which then determines the effective set point. This offset is not uniform amongst the VAVs and sometimes causes the effective set point to be more than or less than both the cooling and heating occupied set point. This adds complexity to the set point adjustments that was not anticipated and often reduces or nullifies the impacts of an ILC control action. Understanding how the controller determines the effective set point is critical to successful deployment of ILC at OJS.

8. Conclusions

The installation of VOLTTRON, AIRCx, and the AIRCx Visualization UI was successfully completed for Anacostia High School and One Judiciary Square. This task was accomplished with significant partnership actions between the Intellimation team and the PNNL team.

The Appendix of the report describes all the steps necessary to install VOLTTRON, AIRCX and AFDD, and the AIRCx Visualization UI in a secure and succinct way. This step-by-step documentation can be used as a deployment recipe, so future use of VOLTTRON and/or the AIRCx and AFDD by Intellimation would require minimal effort compared to these sites. Further work to automate the deployment of these tools is being undertaken in a separate project between PNNL and Intellimation.

AIRCx was successful in identifying several operational opportunities in the buildings. This includes:
- reduction of HVAC schedules,
- implementation of AHU static pressure reset, and
- implementation of AHU supply-air temperature reset.

Energy savings were estimated using a PNNL developed Re-tuning emulator for both buildings.
- At Anacostia, the reduction of HVAC schedules had an estimated savings of 21%, static pressure reset had an estimated savings of 8%, and the supply-air temperature reset had 7% savings.
- At OJS reduction of HVAC schedules had an estimated savings of 22%, static pressure reset had an estimated savings of 4%, and the supply-air temperature reset had 2% savings.

Note that savings estimates for the static pressure reset and supply-air temperature are calculated using the AHU fan run time from the reduced HVAC schedules so as not to inflate the savings estimates. The estimated savings modelled is probably on the high end for the savings potential because models always assume a perfect control; therefore,
- the expected savings for Anacostia for all three measures is between 25% and 35%
- the expected savings for all three measures at OJS is between 18% and 28%.

The low end of the savings is more realistic estimate for what the expected savings will be if these measures were implemented in those buildings.

8.1. Grid Services Results, including Next Steps

The grid service application, ILC, has also been deployed at Anacostia and at OJS in summer of 2022 with preliminary results available in fall of 2022. ILC algorithm manages peak demand in a building while minimizing negative effects on occupant comfort. The ILC results at the two buildings have been marginal, but we have identified issues and opportunities at both sites to improve ILC performance.

- At Anacostia when the 2023 cooling season begins PNNL will continue to exercise ILC and work with Intellimation to investigate/fix some operational issues as noted in the results section.

- At OJS, Intellimation deployed a more robust computer (in summer of 2021) to host VOLTTRON and the Normal Framework BACnet data collection tool. The current deployment computer had experienced memory exhaustion (exceeding the overall RAM usage) that caused the computer and applications to crash or run out of hard drive space causing applications to become nonfunctional. Adding the zone electric reheat into our virtual meter calculations was completed in December 2022. This will demonstrate the benefit of ILC for VAVs with electric reheat. Finally, at OJS the effective zone set point does not seem to predictably coincide with the occupied cooling or heating set points which are the controllable points via VOLTTRON. Intellimation is reviewing the control specifications for the VAV controller to understand how the various set points in the controller are being utilized by the controller to modulate airflow and heating. Understanding how the controller is using these points will allow ILC issue control actions that are more impactful. In spring of 2023, PNNL will review the recommendations from Intellimation and decide if any updates to ILC controls are needed.

8.2. Lessons Learned

There were several lessons that were learned from the deployment of these technologies at the two field test sites. Those are summarized as follows:

1. Even though both buildings have BASs, we noted several issues:
    a. Lack of standard naming convention
    b. Lack of use of advanced control sequences
    c. Sometimes, each zone controller had several virtual set points; it was not clear which of the set points controlled the damper
2. Lack of whole building power measurement impedes peak load management. Both buildings had issues with whole building power. We had to create virtual power meters based on available information to deploy grid services. This is an acceptable practice but requires additional time and resources.
3. Lack of net meters when a building has solar also impedes peak load management. The high school had solar without a net meter.
4. AIRCx identified several measures for energy reductions. PNNL had several meetings with Intellimation to encourage them to discuss the findings with the building owners and implement the measures. Intellimation had discussions with the building owners; however, none of those measures were implemented yet.
5. The VOLTTRON platform has the capability to send email alarms when there are problems with data collection; however, an email sever is needed to enable this feature. Lack of an accessible email server limited the ability to set up alarms. Alarms are useful because email messages can be sent when there is a data collection failure or application failure. One of the buildings had numerous issues where data collection failed.
6. The deployments relied on hardware that Intellimation already had in the field. The OJS building is very large with hundreds of zones and thousands of data points. The hardware at OJS was not adequate to the deployment.
7. During the initial deployment of VOLTTRON, data from devices from the PNNL applications was stored locally on the edge device, eventually we moved the storage to PNNL AWS because of the volume of data being stored.

9. Appendix

VOLTTRON Platform Installation

The following section describes the steps necessary to install the VOLTTRON platform.

1. Install software dependencies:

```
$ sudo apt-get install build-essential libffi-dev python3-dev python3-venv openssl
libssl-dev libevent-dev git
```

```
$ sudo useradd -c ‘VOLTTRON admin’ -m -d /home/volttron -s /bin/bash volttron
$ usermod -aG dev volttron
$ sudo passwd volttron # set volttron account password
```

2. Clone the VOLTTRON repository and build VOLTTRON:

```
$ git clone -b main https://github.com/VOLTTRON/volttron
$ cd volttron
$ python3 bootstrap.py --driver --web
```

3. Install and configure Apache proxy (Optional hardening measure):

```
$ sudo apt install apache2
$ visudo sudo a2enmod ssl
$ sudo a2enmod rewrite
$ sudo a2enmod headers
$ sudo a2enmod proxy
$ sudo a2enmod proxy_http
$ sudo service apache2 restart
```

4. Edit /etc/apache2/mods-available/ssl.conf:

```
#
# ssl.conf

<IfModule mod_ssl.c>
    SSLPassPhraseDialog  exec:/usr/share/apache2/ask-for-passphrase
    SSLSessionCache         shmcb:${APACHE_RUN_DIR}/ssl_scache(512000)
    SSLSessionCacheTimeout  300
    SSLRandomSeed startup file:/dev/urandom  256
    SSLRandomSeed connect builtin
    SSLCryptoDevice builtin
```

```
    <VirtualHost _default_:443>
        ErrorLog logs/ssl_error_log
        TransferLog logs/ssl_access_log
        LogLevel warn
        SSLEngine on
        # Require TLS 1.2 only
        SSLProtocol -all +TLSv1.2
        # Require Strong Ciphers
        SSLCipherSuite "EECDH:!RC4:!3des:!SHA"
        # Require Cipher Order
        SSLHonorCipherOrder on

        # Using the included (Debian based systems) self-signed snakeoil certificate
and key.
        # These should be replaced with a key cert pair signed by your
        # institution's CA or a trusted 3rd party.

        #CHANGE PATH TO CERT ISSUED BY APPROVED CA
        SSLCertificateFile      /etc/ssl/certs/ssl-cert-snakeoil.pem

        #CHANGE PATH TO APPROVED KEY
        SSLCertificateKeyFile /etc/ssl/private/ssl-cert-snakeoil.key

        <Files ~ "\.(cgi|shtml|phtml|php3?)$">
            SSLOptions +StdEnvVars
        </Files>
        BrowserMatch "MSIE [2-5]" \
                 nokeepalive ssl-unclean-shutdown \
                 downgrade-1.0 force-response-1.0
        CustomLog logs/ssl_request_log \
                  "%t %h %{SSL_PROTOCOL}x %{SSL_CIPHER}x \"%r\" %b"

        #Setup proxy for volttron
        ProxyRequests Off
        ProxyPreserveHost Off
        ProxyVia Off
        # Set proxy path as appropriate.
        ProxyPass          /     http://localhost:8080/ timeout=60
        ProxyPassReverse   /     http://localhost:8080/ timeout=60

        #Setup websockets to proxy for volttron central
        RewriteEngine On
        RewriteCond %{HTTP:UPGRADE} ^WebSocket$ [NC]
        RewriteCond %{HTTP:CONNECTION} Upgrade$ [NC]
        # Set proxy path as appropriate
        # This is only needed if VC is installed.
        RewriteRule /vc/index.html#/dashboard(.*)
ws://localhost:8080/vc/index.html#/dashboard$1 [P]

        #Add HSTS header:
        Header always set Strict-Transport-Security "max-age=31536000"

    </VirtualHost>
</IfModule>
```

5. Edit /etc/apache2/apache2.conf:

```
##
# configuration directives that give the server its instructions.
```

```
# See <URL:http://httpd.apache.org/docs/2.4/> for detailed information.
# In particular, see
# <URL:http://httpd.apache.org/docs/2.4/mod/directives.html>
# for a discussion of each configuration directive.
# apache2.conf

ServerRoot "/etc/apache2"

# Set User, Group, and ServerAdmin based on your system and organization

# User will be a non-root unix user that the server will use to respond to requests.
# It is recommended to create a new user group specifically for the apache server.
# The user and group should not have the ability to access any files that are not
# intended to be available to the apache proxy, or have the ability to
# execute code beyond the anticipated scope.
User apache
Group apache

# ServerAdmin will be an email address.
ServerAdmin admin@localhost

<Directory />
    AllowOverride none
    Require all denied
</Directory>

<IfModule dir_module>
    DirectoryIndex index.html
</IfModule>

<Files ".ht*">
    Require all denied
</Files>

# Stored in /etc/apache2/ by default
ErrorLog "logs/error_log"
LogLevel warn

<IfModule log_config_module>
    LogFormat "%h %l %u %t \"%r\" %>s %b \"%{Referer}i\" \"%{User-Agent}i\"" combined
    LogFormat "%h %l %u %t \"%r\" %>s %b" common
    <IfModule logio_module>
      LogFormat "%h %l %u %t \"%r\" %>s %b \"%{Referer}i\" \"%{User-Agent}i\" %I %O"
combinedio
    </IfModule>
    CustomLog "logs/access_log" combined
</IfModule>

<IfModule mime_module>
    TypesConfig /etc/mime.types
    AddType application/x-compress .Z
    AddType application/x-gzip .gz .tgz
    AddType text/html .shtml
    AddOutputFilter INCLUDES .shtml
</IfModule>

AddDefaultCharset UTF-8

<IfModule mime_magic_module>
    MIMEMagicFile conf/magic
</IfModule>

EnableSendfile on
```

```
# Set Security headers
ServerTokens Prod
TraceEnable Off
Header always set X-Frame-Options "SAMEORIGIN"
Header always set X-Xss-Protection "1; mode=block"
Header always set X-Content-Type-Options "nosniff"
Header always set X-Permitted-Cross-Domain-Policies "none"
Header unset ETag
FileETag None
Header Unset X-Powered-By

# Force redirect of http to https
RewriteEngine On
RewriteCond %{HTTPS} off
RewriteRule ^/+(.*) https://%{HTTP_HOST}%{REQUEST_URI} [R=permanent,L]

# Include module configuration:
IncludeOptional mods-enabled/*.load
IncludeOptional mods-enabled/*.conf

# Include list of ports to listen on
Include ports.conf

# Include generic snippets of statements
IncludeOptional conf-enabled/*.conf

# Include the virtual host configurations:
IncludeOptional sites-enabled/*.conf
```

6. Copy 000-default.conf to apache directory

```
$ sudo cp /home/volttron/volttron/scripts/admin/apache-proxy/000-default.conf
/etc/apache2/sites-available/000-default.conf
```

7. Start the apache2 proxy service.

```
$ sudo systemctl start apache2
```

8. Configure the VOLTTRON Platform:

```
$ cd /data/volttron/volttron
$ source env/bin/activate
$ vcfg
## Enter when prompted, If field is blank will use selection in bracket
Your VOLTTRON_HOME currently set to: /data/volttron/.volttron

Is this the volttron you are attempting to setup? [Y]:
What type of message bus (rmq/zmq)? [zmq]:
What is the vip address? [tcp://127.0.0.1]: tcp://<IP ADDRESS OF SERVER>
What is the port for the vip address? [22916]:
What is the name of this instance? [p04tcm-plvtnap1]:
Is this instance web enabled? [N]: Y
What is the protocol for this instance? [https]: http
What is the port for this instance? [8080]:
Is this an instance of volttron central? [N]: Y
```

```
Configuring /data/volttron/volttron/services/core/VolttronCentral.
Installing volttron central.
['volttron', '-vv', '-l', '/data/volttron/.volttron/volttron.cfg.log']

Will this instance be controlled by volttron central? [Y]: N
Would you like to install a platform historian? [N]: N
Would you like to install a platform driver? [N]: Y

Configuring /data/volttron/volttron/services/core/PlatformDriverAgent.
['volttron', '-vv', '-l', '/data/volttron/.volttron/volttron.cfg.log']

Should the agent autostart? [N]: Y
Would you like to install a listener agent? [N]: Y

Configuring examples/ListenerAgent.
['volttron', '-vv', '-l', '/home/volttron/.volttron/volttron.cfg.log']

Should the agent autostart? [N]: N
```

9. Create an activate file. Each time one logs and wants to interact with the VOLTTRON platform this file should be executed:

```
$ vi activateenv
# copy contents

#!/bin/bash
export VOLTTRON_HOME=/home/volttron/.volttron
source /home/volttron/volttron/env/bin/activate
```

10. Create the log file directory and edit rotating_log.py:

```
$ mkdir /data/volttron/volttron-log
$ cp /data/volttron/volttron/examples/rotatinglog.py /data/volttron/volttron/
$ vi rotatinglog.py
## edit file to match
{
    'version': 1,
    'disable_existing_loggers': False,
    'formatters': {
        'agent': {
            '()': 'volttron.platform.agent.utils.AgentFormatter',
        },
    },
    'handlers': {
        'rotating': {
            'class': 'logging.handlers.TimedRotatingFileHandler',
            'level': DEBUG,
            'formatter': 'agent',
            'filename': '/home/volttron/logs/volttron.log',
            'encoding': 'utf-8',
            'when': 'midnight',
            'backupCount': 90,
        },
    },
    'root': {
        'handlers': ['rotating'],
        'level': DEBUG,
    },
```

```
}
```

11. Create volttron.service file to run VOLTTRON as a system service (ensures auto start on system reboot):

```
$ vi /etc/systemd/system/volttron.service

## edit file to match
# VOLTTRON SystemD unit
# Exec Start executes the volttron platform script built by bootstrap
# this does not have to activate the virtualenv as the script will do that
[Unit]
Description=VOLTTRON Platform Service
After=network.target

[Service]
Type=simple
User=volttron
Group=volttron
WorkingDirectory=/data/volttron/volttron
Environment="VOLTTRON_HOME=/data/volttron/.volttron"
ExecStart=/home/volttron/volttron/env/bin/volttron -L /home/volttron/volttron/rotatinglog.py
ExecStop=/home/volttron/volttron/env/bin/volttron-ctl shutdown –platform

[Install]
WantedBy=multi-user.target
```

12. Enable and run the volttron platform service:

```
$ mkdir ~/home/volttron/data
$ mkdir ~/home/volttron/logs
$ sudo systemctl enable volttron.service
$ sudo systemctl start volttron.service
```

13. Set the Admin password for VOLTTRON by visiting http://<VOLTTRON IP>/admin/login.html in a web browser.

14. Finally, install the local sqlite historian to populate data for the AIRCx Visualization. Create a file ~/volttron/upgrade-scripts/upgrade-historian with the following content:

```
#!/usr/bin/env bash

# Build a temp file string for use with the configuration
export CONFIG=$(mktemp /tmp/abc-script.XXXXXX)

cat > $CONFIG <<EOL
{
    "agentid": "sqlhistorian-sqlite",
    "connection": {
        "type": "sqlite",
        "params": {
            "database": "~/data/analysis.historian.sqlite"
        }
    },
    "capture_device_data": true,
```

```
    "capture_analysis_data": true,
    "capture_log_data": false,
    "capture_record_data": true,
    "custom_topics": {},

    },
    "history_limit_days": 90
}
EOL

python ./scripts/install-agent.py \
    -s services/core/SqlHistorian \
    -i analysis.historian \
    --tag historian \
    --start \
    --force \
    --config $CONFIG


rm $CONFIG.py
```

Run the following commands to install the agent:

```
$ mkdir ~/data
$ cd ~/volttron
$ bash upgrade-scripts/upgrade-historian
```

This configuration assumes that the points configured in the "device_data_filter" (mapped during the BACnet device integration) are using the GSA standard point naming convention.

9.1.1. AFDD and AIRCx Configuration and installation

The following section will describe the configuration and installation of the AFDD and AIRCx. AFDD and AIRCx code resides in a GitHub repository specific to PNNL developed applications.

1. Download the volttron-pnnl-application repository:

```
$ git clone https://github.com/VOLTTRON/volttron-pnnl-applications ~/volttron/
```

2. Manually edit or use the web configuration tools to create the configuration files for the AHUs that will be analyzed.

   There is a web user interface (UI) that can be used to generate the configuration file for AFDD (Economizer) or AIRCx (Airside):

   https://ahu-configuration-tool.web.app/

   There is also an online user guide on using the online configuration generator:

   https://ahu-userguide.readthedocs.io/en/latest/

The configuration tool requires the PlatformDriver config store located on the VOLTTRON server here:

~/.volttron/configuration_store/platform.driver.store

These tools can help to eliminate typographical errors when constructing the AFDD and AIRCx text configuration files. The tool reads the PlatformDriver configuration store (a repository for all device driver and registry files) and creates drop downs for the selection of devices (AHUs and VAVs) as well as drop downs for the points associated with each device. The following is the configuration file for the AIRCx for AHU1 (following steps will assume that the configs are stored at ~volttron/config/aircx/):

```
{
    "agentid": "airside_aircx",
    "application": "airside_aircx.Application",
    "device": {
        "campus": "Anacostia",
        "building": "HighSchool",
        "unit": {
            "eru-b1_n-wing": {
                "subdevices": ["vav-101_wing_n_room_n028",
                               "vav-102_wing_n_room_n013",
                               "vav-103_wing_n_room_n011",
                               "vav-104_wing_n_room_n015",
                               "vav-105_wing_n_room_n005",
                               "vav-106_wing_n_room_n106",
                               "vav-107_wing_n_room_n001",
                               "vav-108_wing_n_room_n108",
                               "vav-109_wing_n_room_n002",
                               "vav-110_wing_n_room_n010",
                               "vav-111_wing_n_room_n110",
                               "vav-112_wing_n_room_n109"
                            ]
            }
        }
    },
    "analysis_name": "AirsideAIRCx",
    "actuation_mode": "PASSIVE",
    "local_timezone": "US/Eastern",
    "arguments": {
        "point_mapping": {
            "fan_status": ["OnRly1"],
            "zone_reheat": ["VLV1 COMD"],
            "zone_damper": ["DMPR POS"],
            "duct_stcpr": ["DuctPr"],
            "duct_stcpr_stpt": ["DuctPrSt"],
            "sa_temp": ["SaTp"],
            "fan_speedcmd": ["VfdBwPos"],
            "sat_stpt": ["SaTpStM"]
        },
        "autocorrect_flag": false,
        "sat_retuning": 1,
        "stcpr_retuning": 0.15,
        "min_stcpr_stpt": 0.5,
        "max_stcpr_stpt": 2.5,
        "minimum_sat_stpt": 50,
        "maximum_sat_stpt": 75,
        "no_required_data": 10,
        "warm_up_time": 15,
        "sensitivity": "default",
        "sat_stpt_deviation_thr": 5,
```

```
        "stcpr_stpt_deviation_thr": 20,
        "low_sf_thr": 20,
        "high_sf_thr": 95,
        "zn_high_damper_thr": 90,
        "zn_low_damper_thr": 10,
        "hdzn_damper_thr": 30,
        "percent_reheat_thr": 25,
        "rht_on_thr": 10,
        "sat_high_damper_thr": 80,
        "percent_damper_thr": 60,
        "reheat_valve_thr": 50,
        "sat_reset_thr": 5,
        "stcpr_reset_thr": 0.25,
        "unocc_time_thr": 40,
        "unocc_stp_thr": 0.2,
        "monday_sch": ["05:30", "18:30"],
        "tuesday_sch": ["05:30", "18:30"],
        "wednesday_sch": ["05:30", "18:30"],
        "thursday_sch": ["05:30", "18:30"],
        "friday_sch": ["05:30", "18:30"],
        "saturday_sch": ["00:00", "00:00"],
        "sunday_sch": ["00:00", "00:00"]
    }
}
```

3. Update the configuration file for AIRCx and AFDD.

   If manually editing this file, the “device” dictionary should be updated to reflect the “campus”, “building”, “unit” (AHU), and a list of all “subdevices” (VAVs) as configured in the PlatformDriver file. The “point_mapping” dictionary should be updated to reflect the point name for the AHU or VAV for each indicated parameter (PlatformDriver configuration). It is not necessary to modify the configuration parameters. The exception is the “Schedule/Reset AIRCx Thresholds”. Each daily schedule should be updated to reflect the actual occupancy schedule for the AHU where `["0:00","0:00"]` indicates always unoccupied and `["0:00","23:59"]` indicates always occupied.

   Configuration of AFDD can be done using the same web UI as AIRCx or manually via a text editor. The AFDD configuration file for AHU1 at the Yakima Courthouse is as follows:

```
{
    "device": {
        "campus": "CAMPUS",
        "building": "BUILDING",
        "unit": {
            "AHU1": {
                "subdevices": []
             }
        }
    },
    "analysis_name": "EconomizerAIRCx",
    "actuation_mode": "PASSIVE",

    "arguments": {
        "point_mapping": {

            "supply_fan_status": "SFSts",
            "outdoor_air_temperature": "OATmp",
            "return_air_temperature": "RATmp",
            "mixed_air_temperature": "MATmp",
```

```
            "outdoor_damper_signal": "OADmpPos",
            "cool_call": "CCVlvPos",
            "supply_fan_speed": "SFSpd"
        },
        "data_window": 30,
        "no_required_data": 20,
        "economizer_type": "hl",
        "sensitivity": "custom",
        "temp_band": 2.0,
        "econ_hl_temp": 70.0,
        "open_damper_time": 15,
        "low_supply_fan_threshold": 20.0,
        "minimum_damper_setpoint": 10.0,
        "desired_oaf": 10.0,
        "rated_cfm": 27000.0
    }
}
```

There are several configuration parameters that should be edited to the best of the user's ability:

*economizer_typ*e: "hl" for outdoor-air temperature high limit and "db" for differential dry bult economizer

economizer_hl: the outdoor-air temperature high limit set point. Only used if *economizer_type* is set to "hl"

temp_band: temperature dead band around the switchover set point (for "hl" and "db" economizer types)

desired_oaf: the minimum desired outdoor-air fraction the AHU will provide when conditions are not favorable for economizing.

rated_cfm: the rated CFM for the AHU or observed CFM when the supply fan is at 100%.

The "device" dictionary and the "point_mapping" dictionary should be configured like the AIRCx with mapping information for the topic and points related to the AHU being analyzed.

4. Next construct upgrade-scripts for the AFDD and AIRCx (typically stored in ~/volttron/upgrade-scripts):

```
#!/bin/bash

python ./scripts/install-agent.py \
    -s <PATH TO SOURCE>
    -i <VIP> \clear
    --start \
    --force \
    --config <PATH TO CONFIG>
```

-s : path to source code

AIRCx: /home/volttron-pnnl-applications/EnergyEfficiency/AirsideRCxAgent

AFDD: /home/volttron-pnnl-applications/EnergyEfficiency/EconomizerRCxAgent

-i : unique platform identifier (e.g., aircx_ahu1).

--config : absolute file path to the AIRCx or AFDD configuration file.

5. Finally, run the upgrade-scripts to install AFDD and AIRCx. One can verify that the agents are running with:

9.1.2. AFDD and AIRCx Web Visualization Installation

The following section will describe the steps necessary to install the AFFD and AIRCx web visualization.

The code base for the visualization can be downloaded using the git command as follows:

```
$ git clone https://github.com/VOLTTRON/volttron-AIRCx-visualization ~/
```

Next, the prerequisite libraries must be installed:

```
$ cd ~
$ wget https://nodejs.org/dist/v12.19.0/node-v12.19.0-linux-x64.tar.gz
$ tar -xf node-v12.19.0-linux-x64.tar.gz
```

Add the node libraries to the user PATH. Edit ~/.bashrc and add the following text:

```
proxy="patchproxy11.gsa.gov:3128"
export NODEJS_PATH=/data/volttron/node-v12.19.0-linux-x64
export PATH=$NODE_JS_PATH/bin:$PATH
export PATH=/data/volttron/node_modules/yarn/bin:$PATH

######################
# npm Settings
######################
npm config set registry http://registry.npmjs.org/
npm config set proxy "http://$proxy"
npm config set https-proxy "http://$proxy"
npm config set strict-ssl false
echo "registry=http://registry.npmjs.org/" > ~/.npmrc
echo "proxy=http://$proxy" >> ~/.npmrc
echo "strict-ssl=false" >> ~/.npmrc
echo "http-proxy=http://$proxy" >> ~/.npmrc
echo "http_proxy=http://$proxy" >> ~/.npmrc
echo "https_proxy=http://$proxy" >> ~/.npmrc
echo "https-proxy=http://$proxy" >> ~/.npmrc
```

Install yarn dependency using NPM (from the Node library):

```
$ cd ~
$ source .bashrc
```

```
$ npm install -g yarn
$ source .bashrc
```

Configure and install the AIRCx Visualization. Build the client application:

```
$ cd ~/volttron-AIRCx-visualization/client
$ yarn build
$ yarn deploy
```

Build and install the server application:

```
$ cd ~/volttron-AIRCx-visualization/server
$ cp -r ~/volttron/config/aircx data/validation/
$ cd data/validation/
$ for f in *; do sed 's/#.*$//' $f; done
$ cd ../..
$ yarn build
$ yarn deploy
```

Edit the environment file for the server (.env). A sample file is shown below:

```
# server port and hostname to use
SERVER_PORT=7898
SERVER_ADDRESS=127.0.0.1
# enable https/ssl
HTTPS=false
# password hashing salt
PASSWORD_SALT=password.salt
# https ssl key and certificate
SERVER_KEY=server.key
SERVER_CERT=server.cert
# jwt public and private
PUBLIC_KEY=public.key
PRIVATE_KEY=private.key
# logging levels: info, warn, error
LOG_CONSOLE=debug
LOG_FILE=warn
# historian configuration
HISTORIAN_ADDRESS=http://127.0.0.1:8080
HISTORIAN_API=gs
HISTORIAN_USERNAME=admin
HISTORIAN_PASSWORD=<VOLTTRON ADMIN PASSWORD>
HISTORIAN_DATA_ID=historian.analysis
HISTORIAN_ANALYSIS_ID=historian.analysis
# other
NODE_TLS_REJECT_UNAUTHORIZED=0
# enable to parse invalid JSON
# enabling this setting is extremely inefficient
CLEAN_DATA=true
# enable to convert string to JSON
# this is already performed when enabling clean data
PARSE_DATA=true
# use either utc offset or timezone (with DST)
# DEFAULT_UTC_OFFSET=-08:00
DEFAULT_TIMEZONE=America/Los_Angeles
# regular expression used to identify point mapping key or value
# that should be converted for clarity within visualizations
```

```
POINT_MAPPING_CONVERSION_REGEX=.*fan_status
# require authentication
REQUIRE_AUTHENTICATION=true
```

Edit the file and change the HISTORIAN_PASSWORD to the VOLTTRON Admin password set in the web interface when installing VOLTTRON. Change the DEFAULT_TIMEZONE if desired.

Next, in order to use authentication at least one user must be created and the database needs to be setup. By default the server uses a file based SQLite database. Users can not be added directly because the password is hashed before storing. In order to create users add them to the server/config/users.js file. This file can either be deleted (so no passwords are stored as clear text) and then used to incrementally add users or retained (suggest clearing passwords at a minimum) and all users can be wiped and recreated as a batch.

The client configuration option REACT_APP_LOGIN must be set to true. The server configuration option REQUIRE_AUTHENTICATION must also be set to true. A sample user.js file is shown below.

```
$ ~/volttron-AIRCx-visualization/server/config/users.js
#######################################################
const Users = [
  {
    name: "guest",
    surname: "guest",
    email: "guest.demo@pnnl.gov",
    password: "guest",
    scope: "",
  },
  {
    name: "admin",
    surname: "",
    email: "admin.demo@pnnl.gov",
    password: "ubC8t@6h",
    scope: "admin",
  }
];

module.exports = Users;
```

To load users into the database run:

```
$ cd ~/volttron-AIRCx-visualization/server
$ yarn seed-all
```

To delete the database and all users:

```
$ cd ~/volttron-AIRCx-visualization/server
$ yarn reset
```

Set up the AIRCx visualization to run as a system service. Create file /etc/system/systemd/yarn.service with the following contents:

```
[Unit]
Description=AIRCx Web Server
After=network.target

[Service]
ExecStart=/data/volttron/node-v12.19.0-linux-x64/lib/node_modules/yarn/bin/yarn start

WorkingDirectory=/data/volttron/volttron-AIRCx-visualization/server
StandardOutput=syslog
StandardError=syslog
SyslogIdentifier=nodejs_www_AIRCx
User=volttron
Group=volttron
Environment=PATH=/data/volttron/node_modules/yarn/bin:/data/volttron/node-v12.19.0-
linux-x64/bin:/opt/rh/llvm-toolset-6.0/root/usr/bin:/opt/rh/llvm-toolset-
6.0/root/usr/sbin:/opt/rh/devtoolset-
8/root/usr/bin:/usr/local/bin:/bin:/usr/bin:/usr/local/sbin:/usr/sbin:/data/volttron/.
local/bin:/data/volttron/bin

[Install]
WantedBy=multi-user.target
```

Enable and run the visualization service:

```
$ sudo systemctl daemon-reload
$ sudo systemctl enable yarn.service
$ yarn start yarn.service
```

The visualization is now accessible at http://<VOLTTRON SERVER IP>:8443. The AIRCx by default creates hourly results and the AFDD will create a diagnostic result every 30 minutes

Pacific Northwest
National Laboratory

902 Battelle Boulevard
P.O. Box 999
Richland, WA 99354
1-888-375-PNNL (7665)

www.pnnl.gov