



PRESENTS:

HVAC Monitoring for Measurement & Verification and Ongoing Commissioning

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IDEA CampusEnergy 2019



Objectives

1

Review M&V of an HVAC system retrofit project

2

Review methodology and results of ongoing commissioning





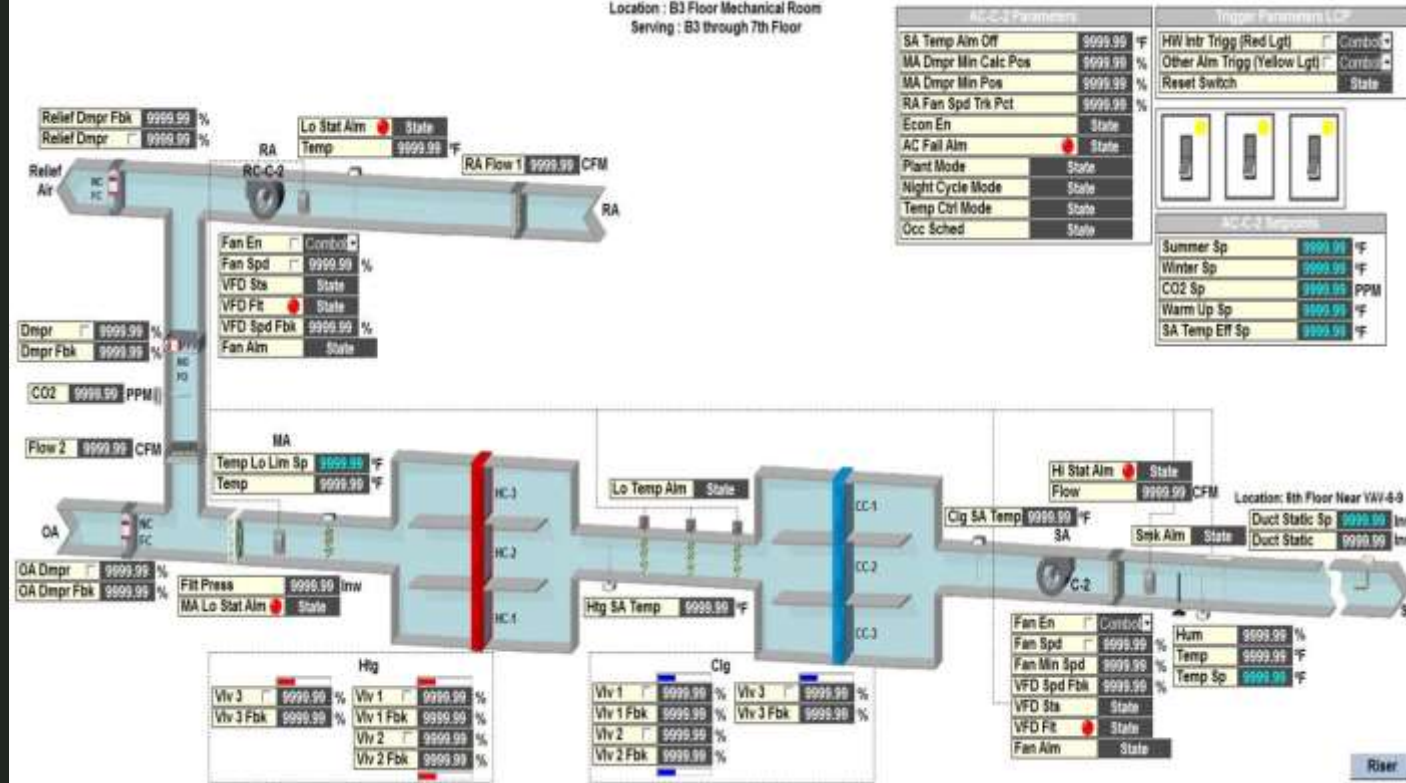
Hunter College HVAC Renovation Overview

- ✓ Replaced 3 AHUs, VAV boxes, PIUs & upgraded controls
- ✓ DASNY Energy savings guarantee project
- ✓ ASHRAE Guideline 14 M&V
- ✓ Hourly interval data from BMS
- ✓ Ongoing commissioning focused on thermal comfort

ACEC *New York*

American Council of Engineering Companies of New York

**Silver Award
Energy**



Baseline

- AC-1 & AC-2 serve core zones with (55 & 67) VAV boxes (no RHC)
- AC-4 serves (26) perimeter induction units (w/ heating coils)
- System failing; poor control; end of life (constant fan speeds!)

Renovation Scope

New VFD AHUs, VAV boxes, and PIUs to meet current loads and ventilation

Full DDC controls through Building Management System

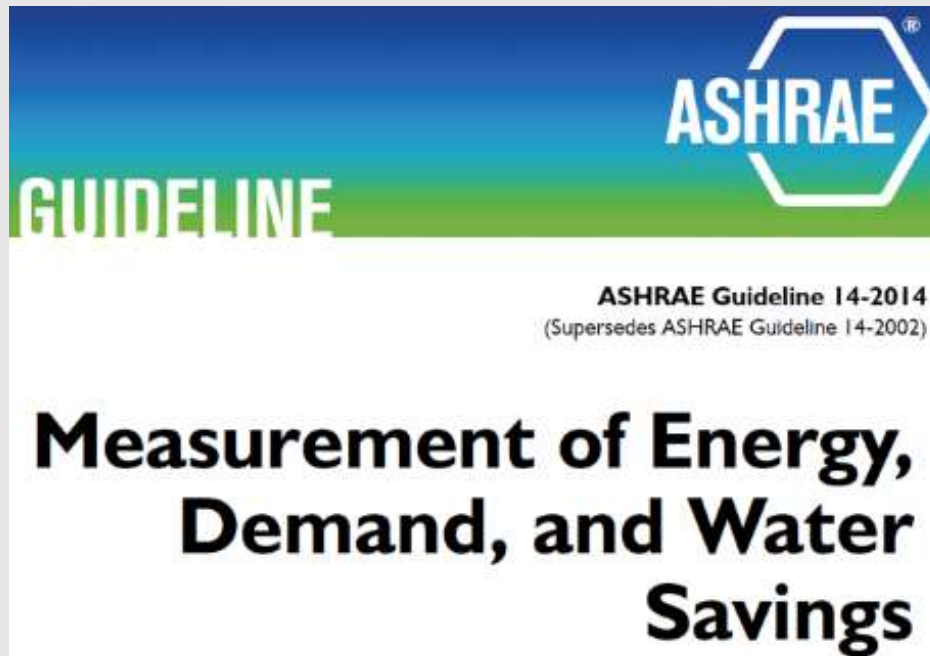


Measurement and Verification

✓ DASNY Energy Performance Guarantee

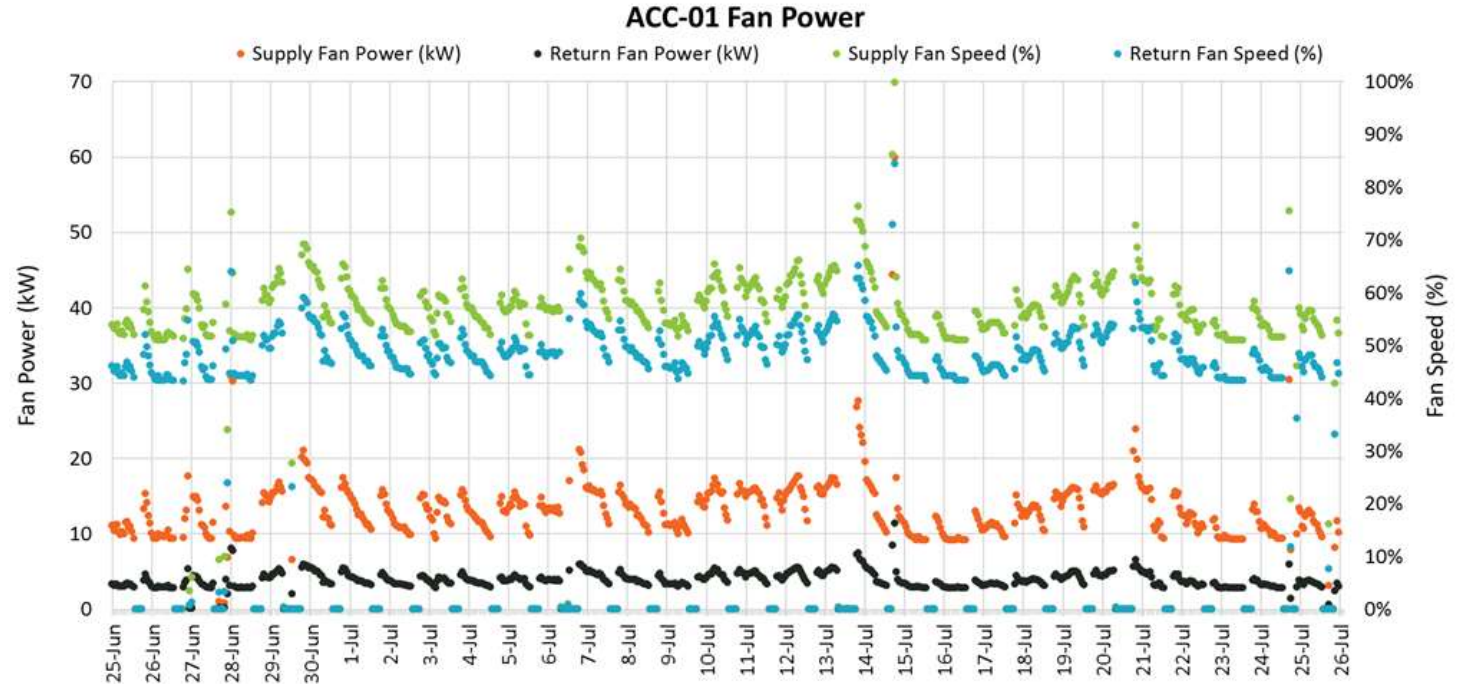
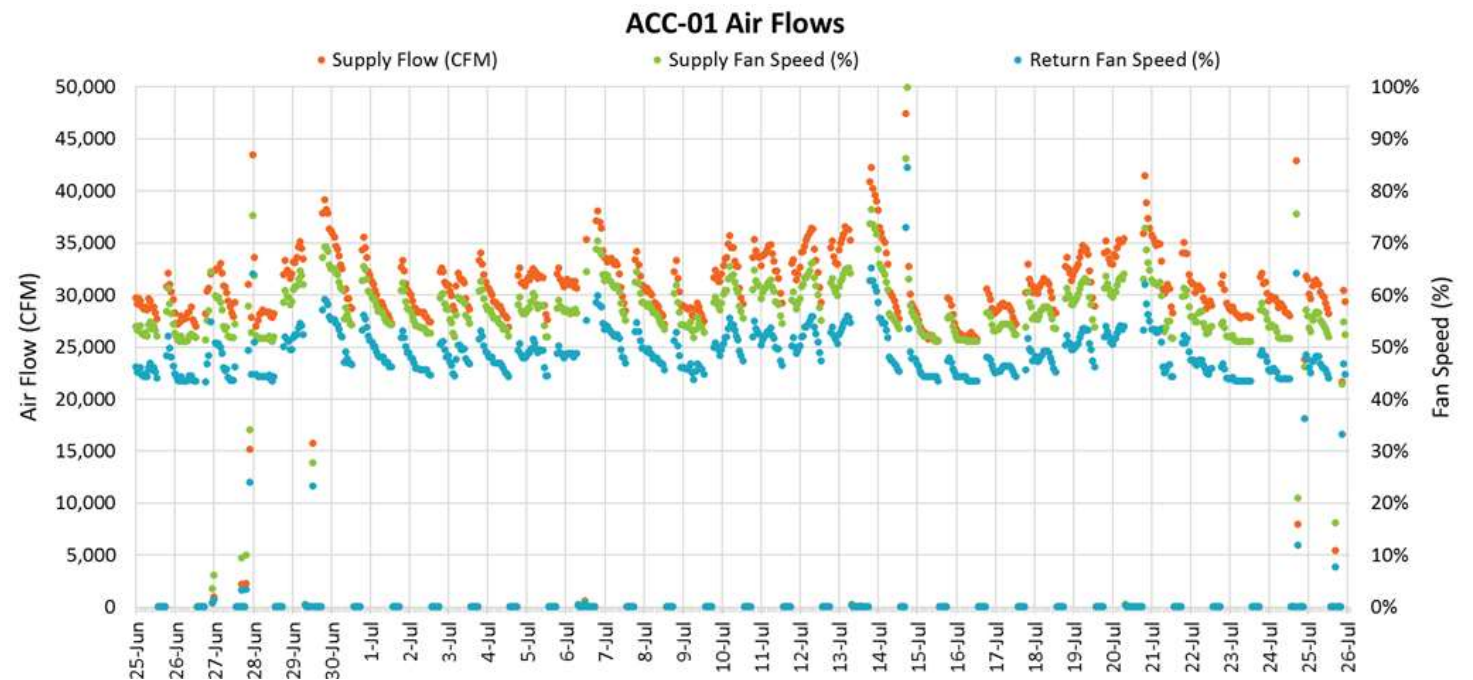
✓ ASHRAE Guideline 14 – Retrofit Isolation Approach

- Short term monitoring of power and flow
- Range of flow rates
- Additional points encouraged



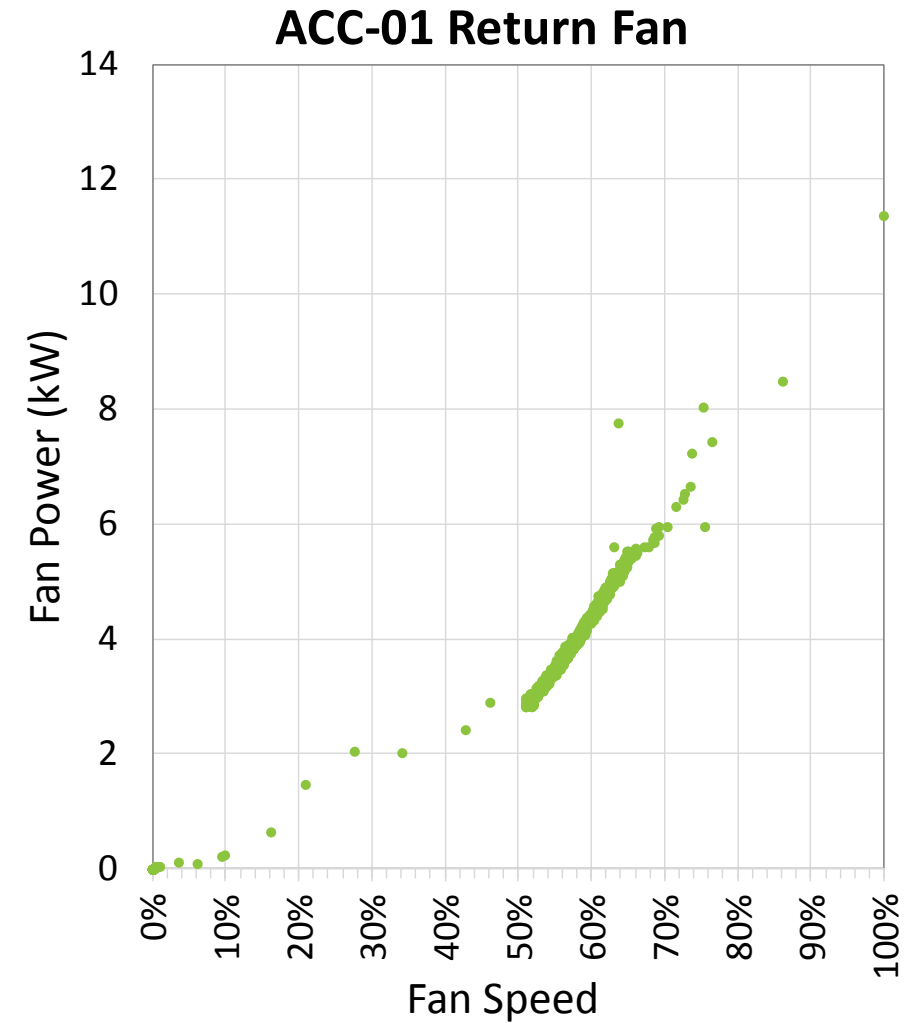
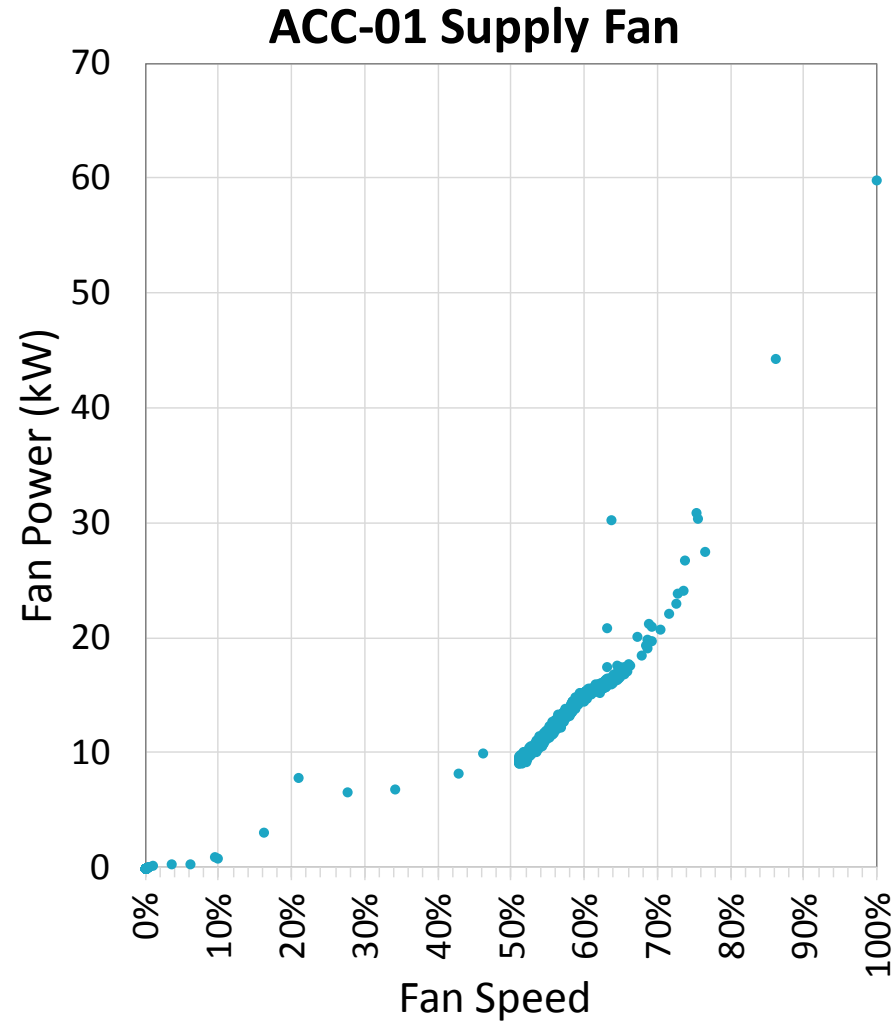
M&V Energy Analysis

*Flow, Speed,
Power*



M&V Energy Analysis

Power vs Speed



M&V Energy Results

Fan	Baseline Power (kW)	Post-Retrofit			Annual Run Hours	Baseline Energy (kWh)	Post-Retrofit Energy (kWh)	Energy Savings (kWh)
		Peak Power (kW)	Average Power (kW)	Average Speed (%)				
AC-C-1	39.0	54.8	13.2	53%	6,625	258,635	87,662	170,973
AC-C-2	34.0	43.4	11.3	55%	6,625	225,523	74,986	150,536
AC-C-4	35.1	56.1	16.0	56%	6,836	239,959	109,687	130,272
R-C-1	16.4	22.9	3.9	45%	6,624	108,634	25,979	82,656
R-C-2	12.3	21.0	3.9	50%	6,571	80,827	25,870	54,957
R-C-3	7.9	7.0	1.3	48%	6,836	54,001	9,065	44,935
Total	144.8	205.2	49.8			967,579	333,250	634,328

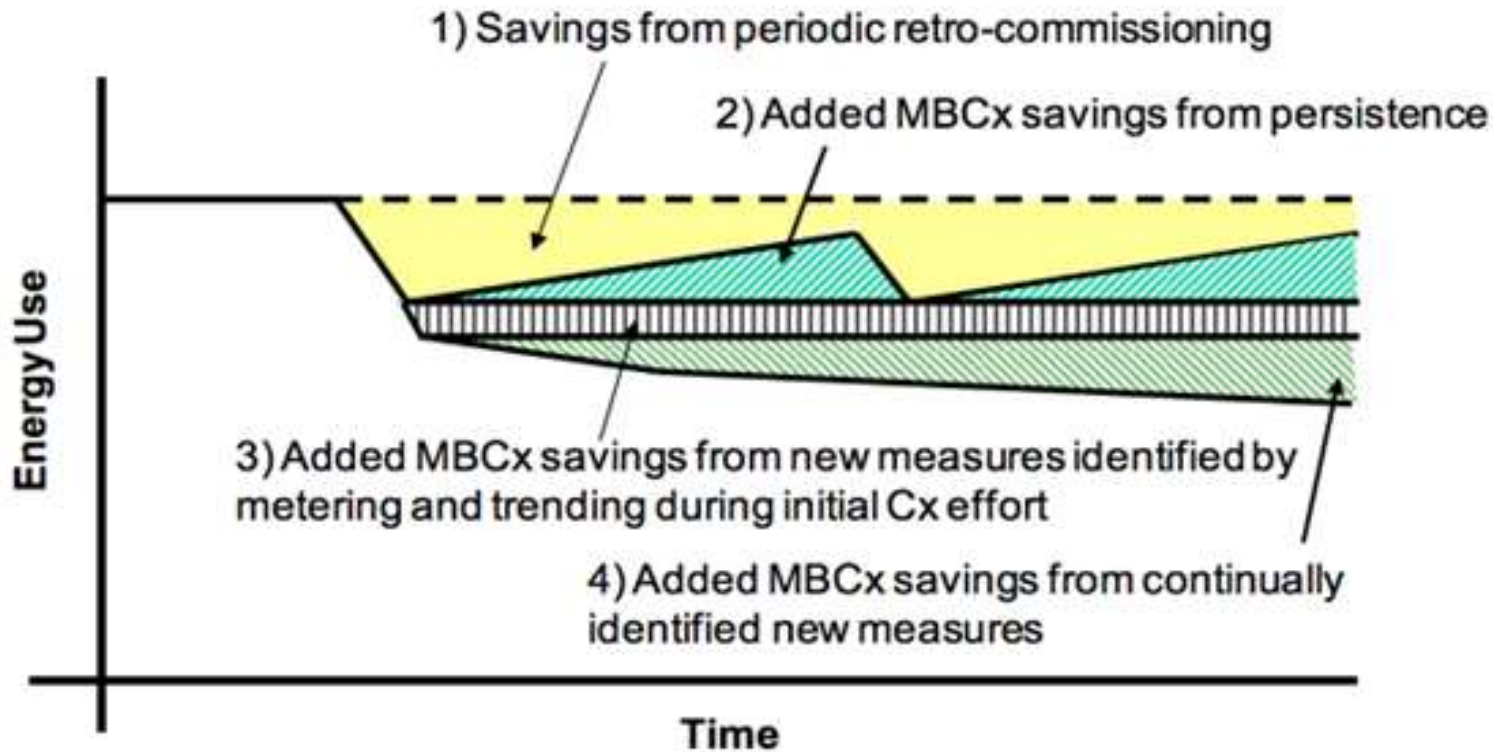
66% Fan Energy Savings

Ongoing Commissioning



A continuation of the Commissioning Process well into the Occupancy / Operations Phase to verify that a project continues to meet current and evolving Owner's Project Requirements. Ongoing Commissioning Process Activities occur throughout the life of the facility; some of these will be nearly continuous in implementation, and others will be either scheduled or unscheduled (as needed).

ASHRAE (Guideline 0-2013 The Commissioning Process)

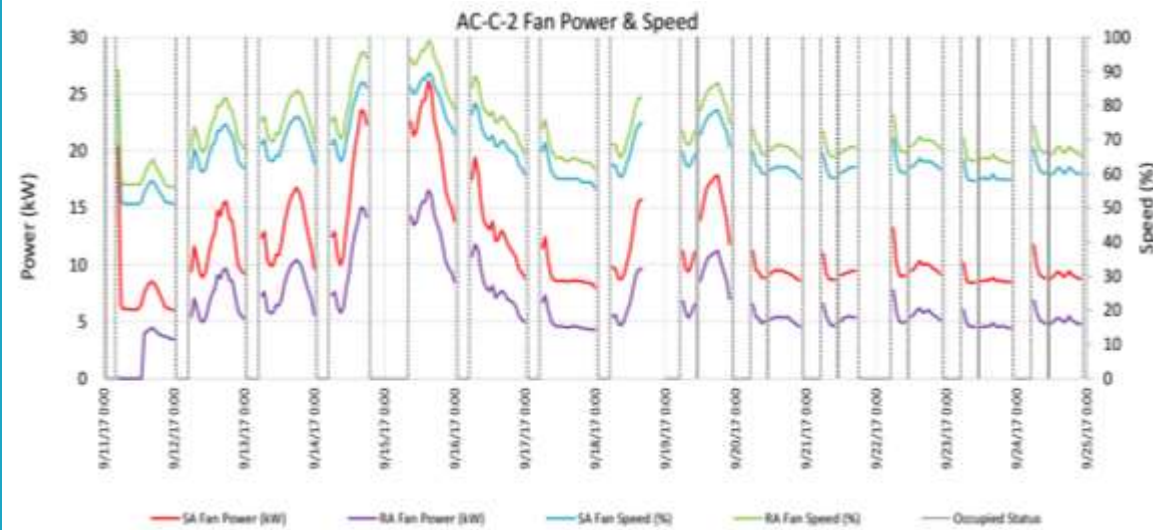


Source: LBNL, 2012, Evan Mills, "Monitoring-Based Commissioning: Benchmarking Analysis of 24 University Buildings in California"

Benefits of Ongoing Cx

Persistence of savings and opportunities for additional savings

Ongoing Commissioning



Building management system trend data

Data Point	Units
Outside Air Temperature	°F
Outside Air Relative Humidity	%RH
Space Temperature (typ. of 55)	°F
Space Temperature Setpoint (typ. of 55)	°F
VAV Box Supply Air Flow (typ. of 55)	CFM
VAV Box Supply Air Flow Setpoint (typ. of 55)	CFM
VAV Box Damper Position (typ. of 55)	% open
VAV Box Supply Air Temperature (typ. of 55)	°F
AC-C-1 Supply Air Flow	CFM
AC-C-1 Supply Air Temperature	°F
AC-C-1 Supply Air Temperature Setpoint	°F
AC-C-1 Return Air Temperature	°F
AC-C-1 Mixed Air Temperature 1	°F
AC-C-1 Mixed Air Temperature 2	°F
AC-C-1 Outside Air Damper Position	% open
AC-C-2 Supply Air Flow	CFM
AC-C-2 Supply Air Temperature	°F
AC-C-2 Supply Air Temperature Setpoint	°F
AC-C-2 Return Air Temperature	°F
AC-C-2 Mixed Air Temperature	°F
AC-C-2 Outside Air Damper Position	% open

Hourly interval data

108 zones / 2 AHUs

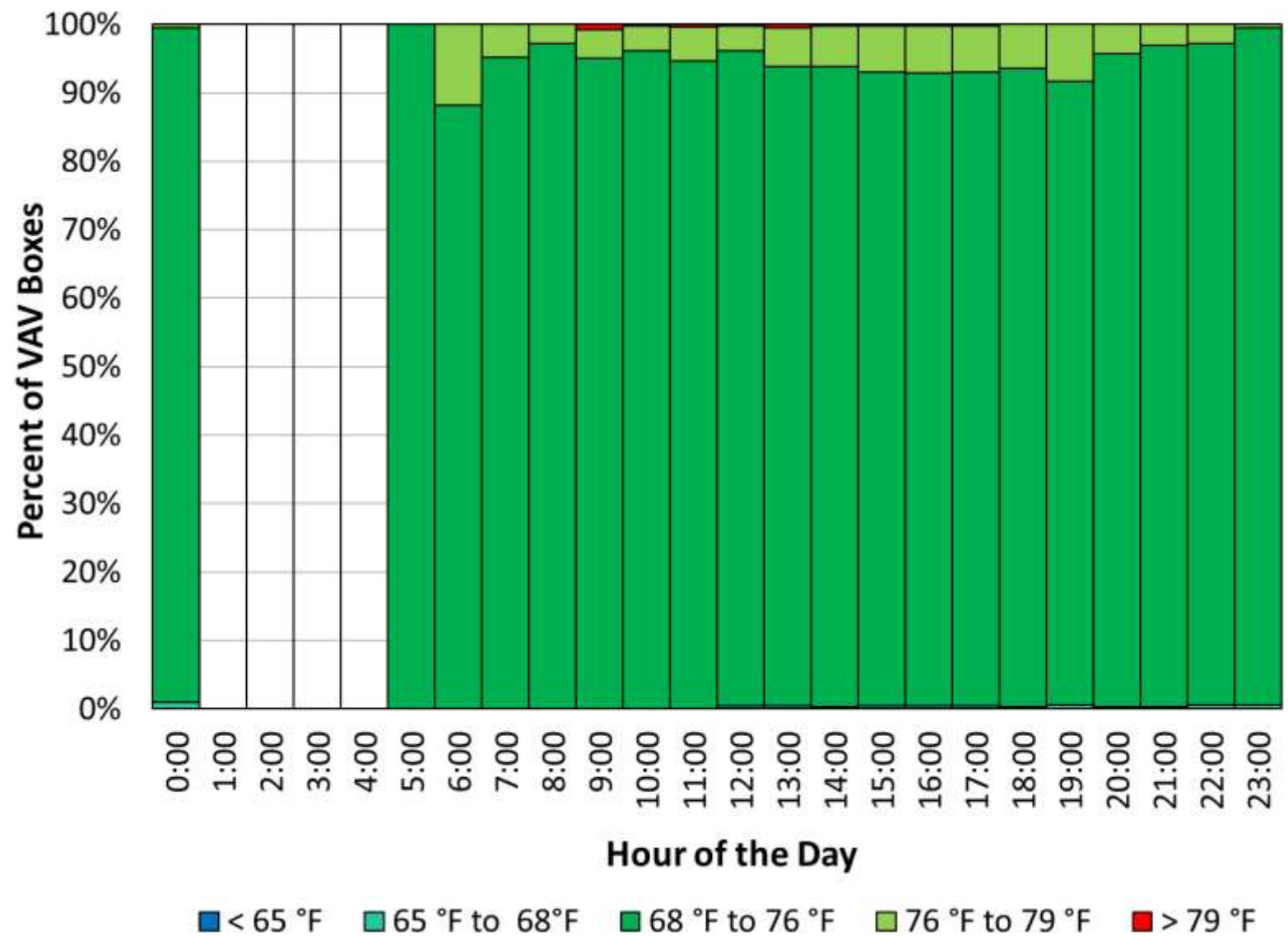
2-week reporting periods

Focus on thermal comfort

Identify issues and recommend actions

OCx Analysis

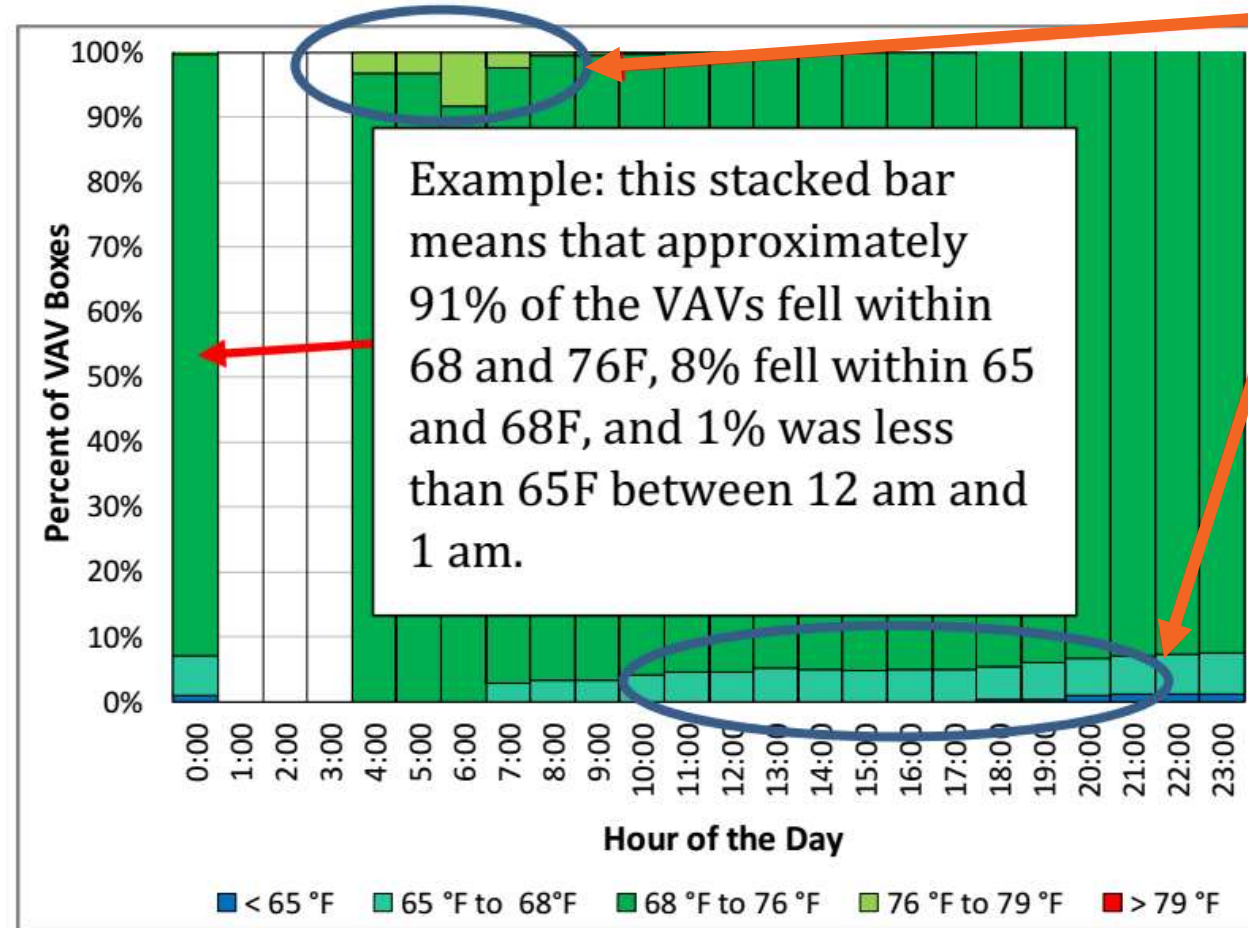
AHU Level Comfort Evaluation



Hourly Distribution of VAV Box Space Temperature for AC-C-1

OCx Analysis

AHU Level Comfort Evaluation

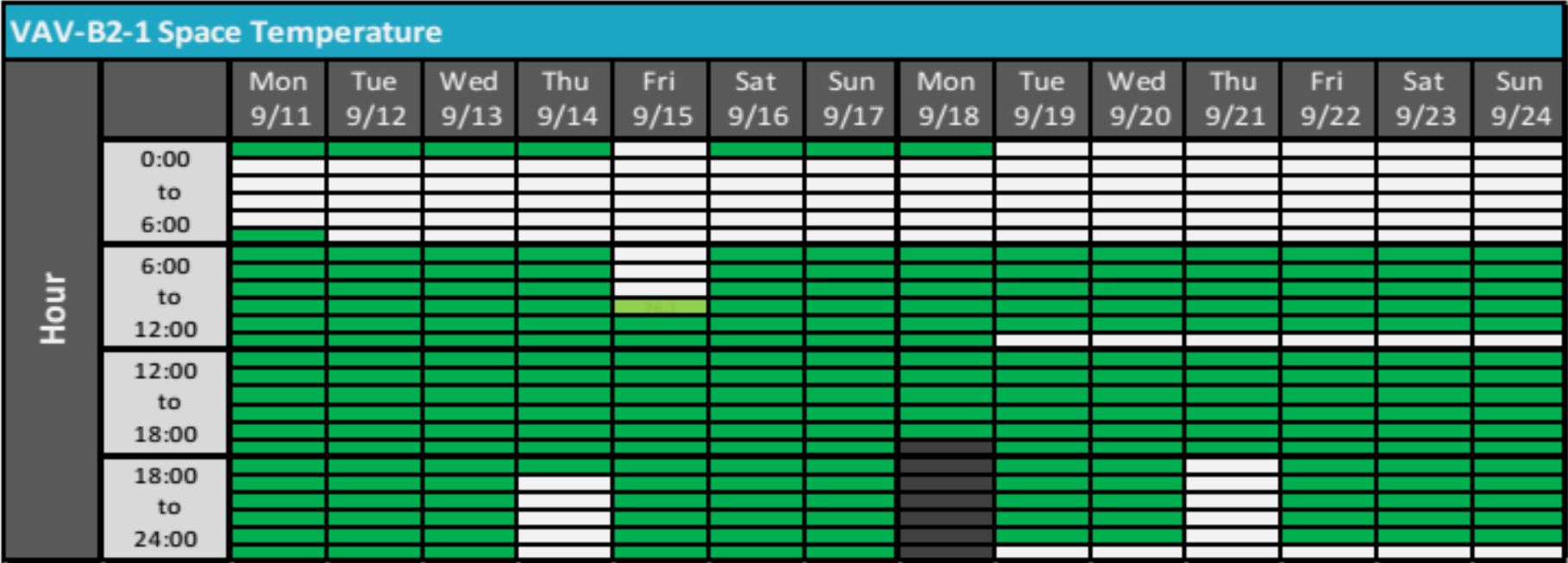


Colors quickly identify outlying data

Space
Temperature
Heat Map

OCx Analysis

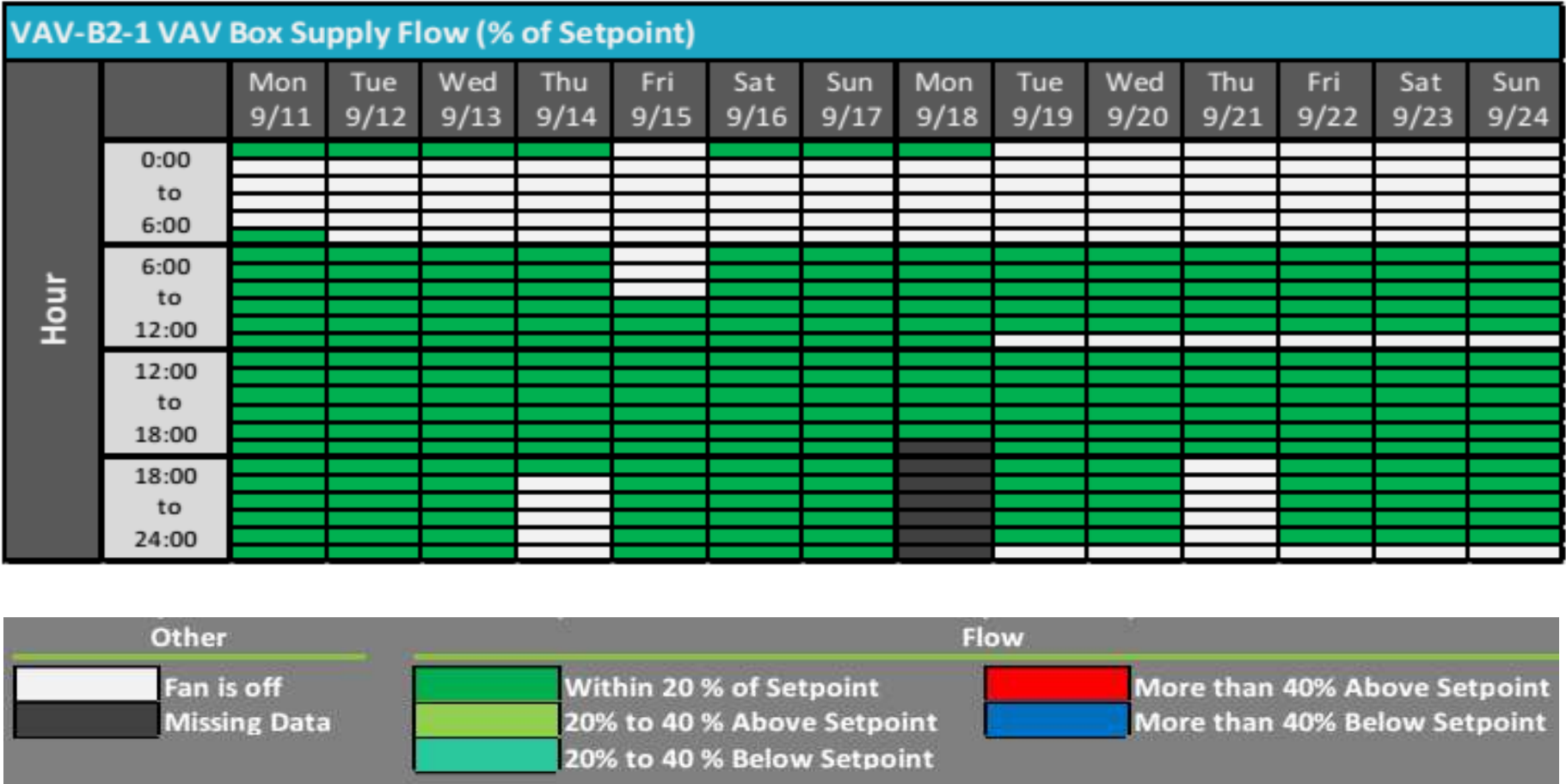
Zone Level
Comfort
Evaluation



VAV Box Flow Heat Map

OCx Analysis

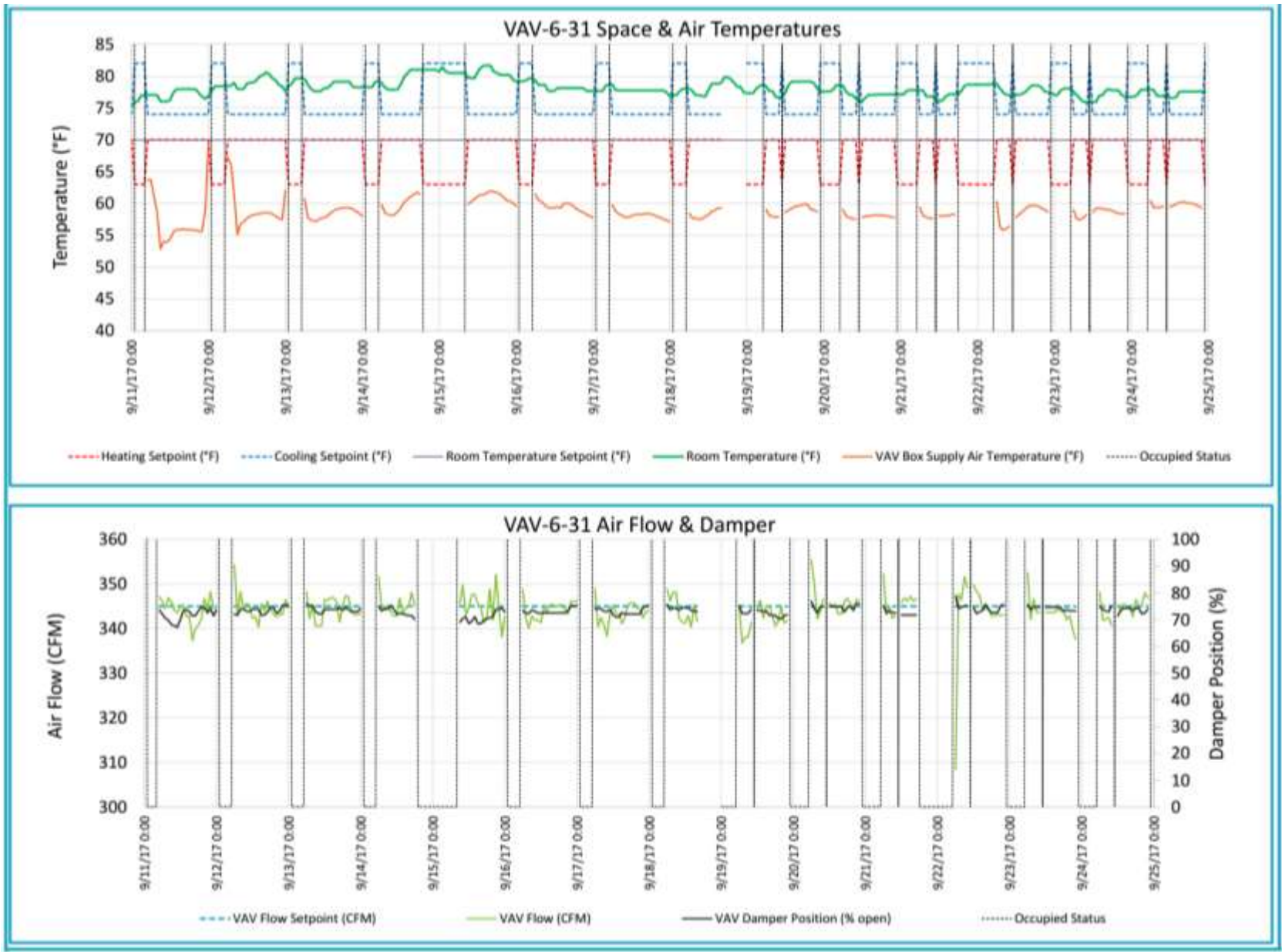
Zone Level
Comfort
Evaluation



Time Series Plots

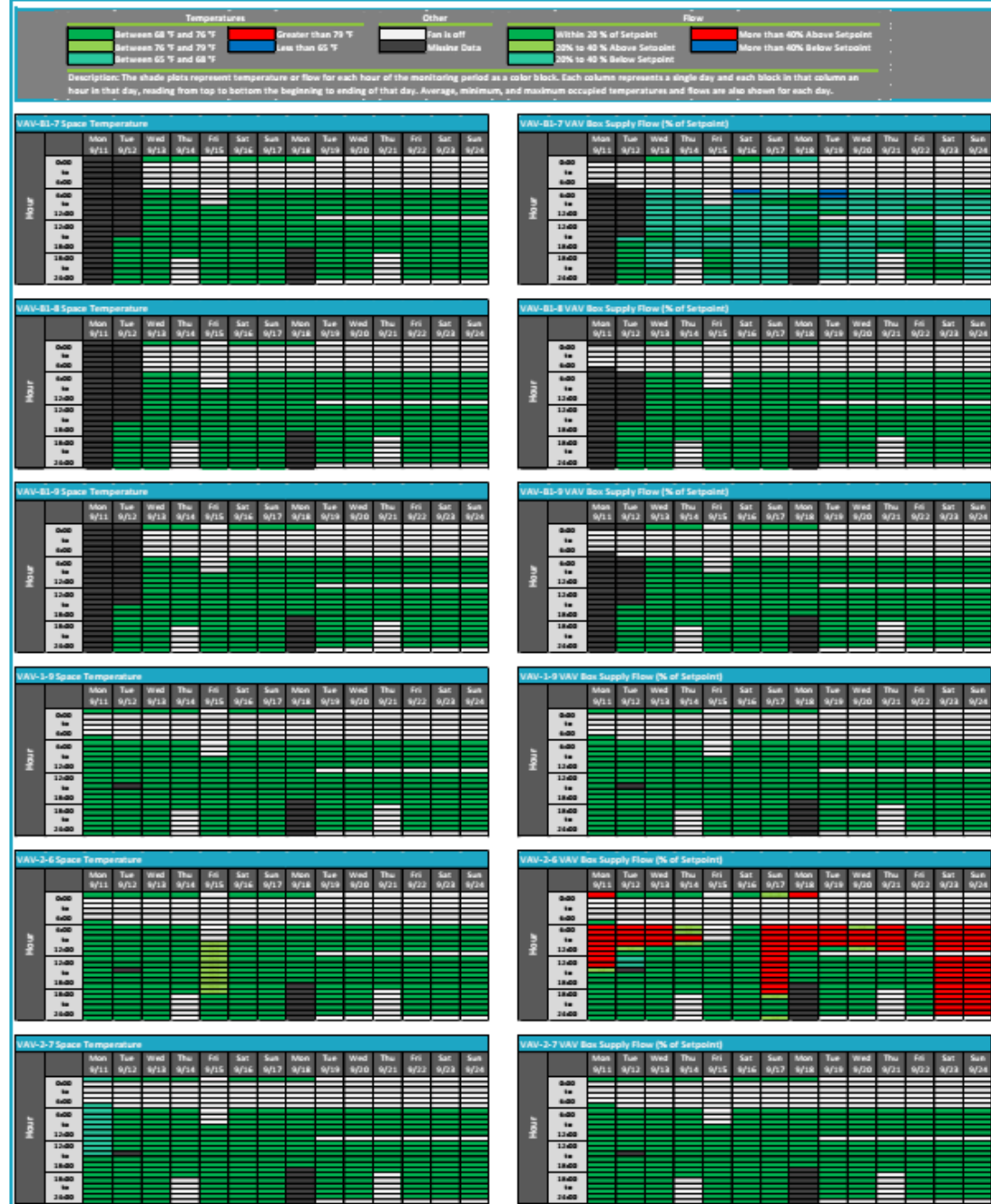
OCx Analysis

Zone Level Comfort Evaluation

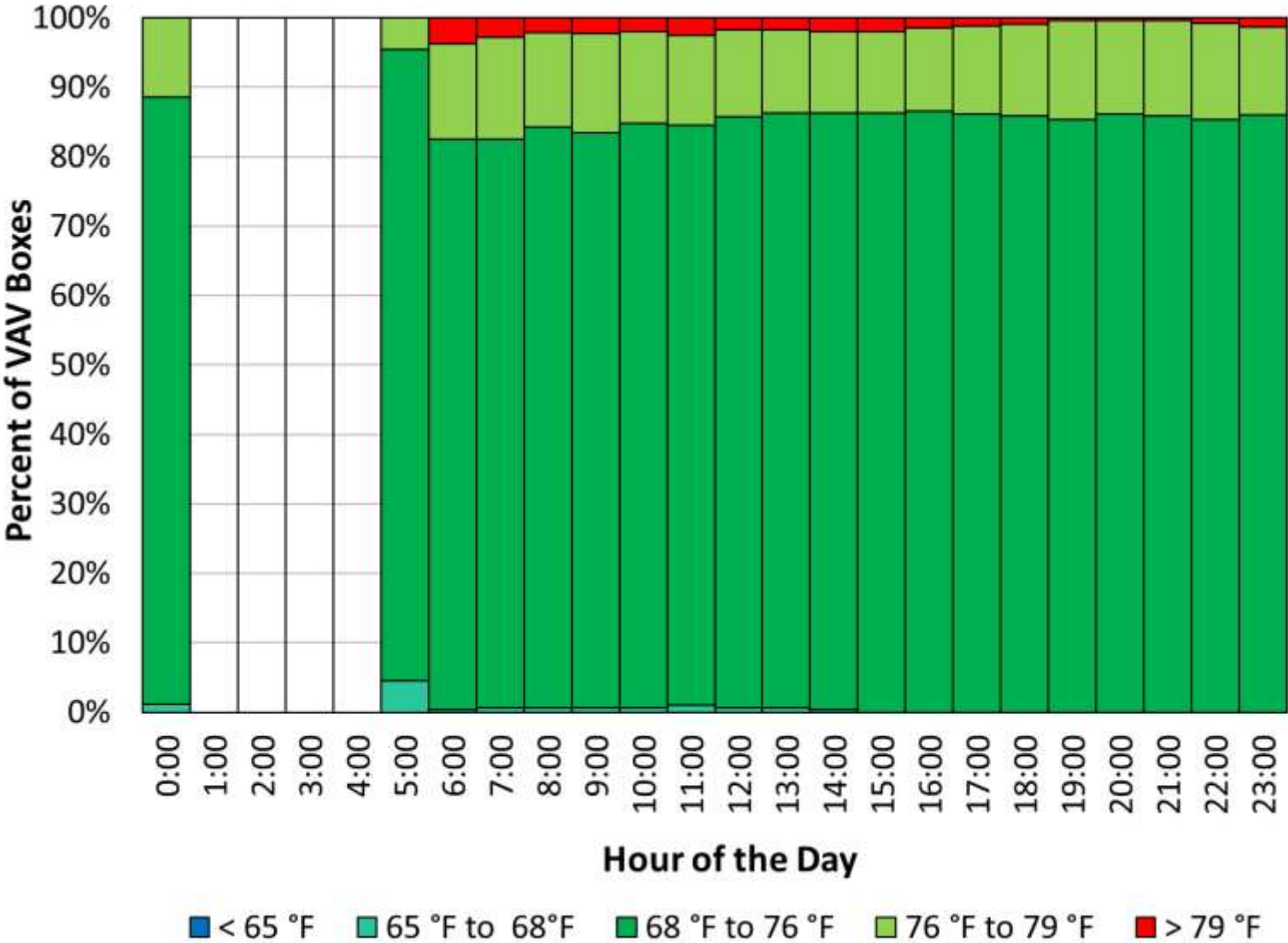


OCx Analysis

Efficient Evaluation of System Performance



Cooling Season Example



Hourly Distribution of VAV Box Space Temperature for AC-C-2

Cooling Season Example

Operational Summary for Hunter College - East Building
Reporting Period: 9/11/2017 through 9/24/2017

VAV-6-31

Summaries for VAV Boxes served by AC-C-2
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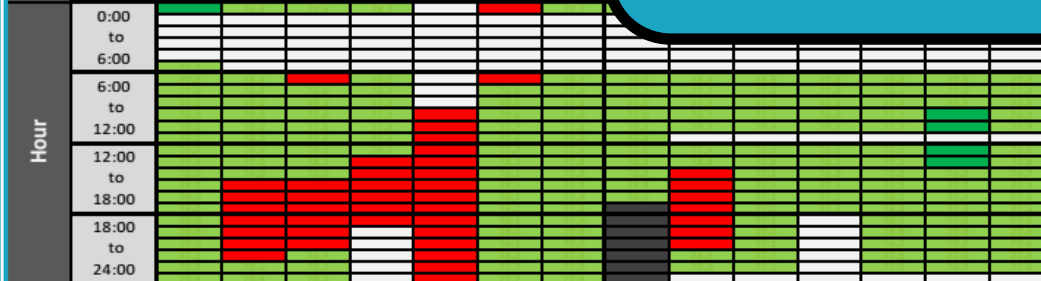
Data Summary Statistics

Variable	Average	Minimum	Maximum	Hours Above Setpoint		Hours Below Setpoint		Time Outside of Expected Range ¹
				> 2 °F	> 5 °F	> 2 °F	> 5 °F	
Occupied Space Temperature (°F)	78.0	75.1	81.7	223	44	0	0	19%
Unoccupied Space Temperature (°F)	78.3	76.0	81.4	0	0	0	0	0%
VAV Box Supply Air Temperature (°F)	58.8	52.9	69.4	Note 1. Percent of time space temperature was more than 5 °F away from setpoint.				
AC-C-2 Supply Air Temperature (°F)	60.7	53.8	71.9					
Variable	Average	Minimum	Maximum	Hours Above Setpoint		Hours Below Setpoint		Time Outside of Expected Range ²
				> 20 %	> 40 %	> 20 %	> 40 %	
Zone Supply Air Flow (CFM)	344	308	355	0	0	0	0	0%
Zone Damper Position (% open)	73			Note 2. Percent of time zone supply air flow was more than 40% away from setpoint and fan was on.				
AC-C-2 Supply Air Flow (CFM)	28,356							
AC-C-2 Supply Fan Speed (%)	66							
AC-C-2 Return Fan Speed (%)	72							

Flow Maintaining Setpoint
Inadequate Cooling

Space Temperature for VAV-6-31 (served by AC-C-2)

	9/11 - 9/24	Mon 9/11	Tue 9/12	Wed 9/13	Thu 9/14	Fri 9/15	Sat 9/16	Sun 9/17
Avg.	78.0	77.1	78.9	78.5	79.3	80.5	78.2	77.8
Min.	75.1	75.1	76.9	77.6	77.9	79.4	77.6	77.4
Max.	81.7	78.0	80.6	79.5	81.0	81.7	79.3	78.7



Temperatures

Between 68 °F and 76 °F	Greater than 79 °F
Between 76 °F and 79 °F	Less than 65 °F
Between 65 °F and 68 °F	

Other

Fan is off
Missing Data

Flow for VAV-6-31 (served by AC-C-2)

	Fri 9/15	Sat 9/16	Sun 9/17	Mon 9/18	Tue 9/19	Wed 9/20	Thu 9/21	Fri 9/22	Sat 9/23	Sun 9/24
Avg.	100%	100%	100%	100%	99%	100%	100%	100%	100%	100%
Min.	98%	99%	98%	99%	98%	99%	99%	89%	98%	99%
Max.	102%	101%	101%	101%	100%	103%	102%	102%	102%	101%

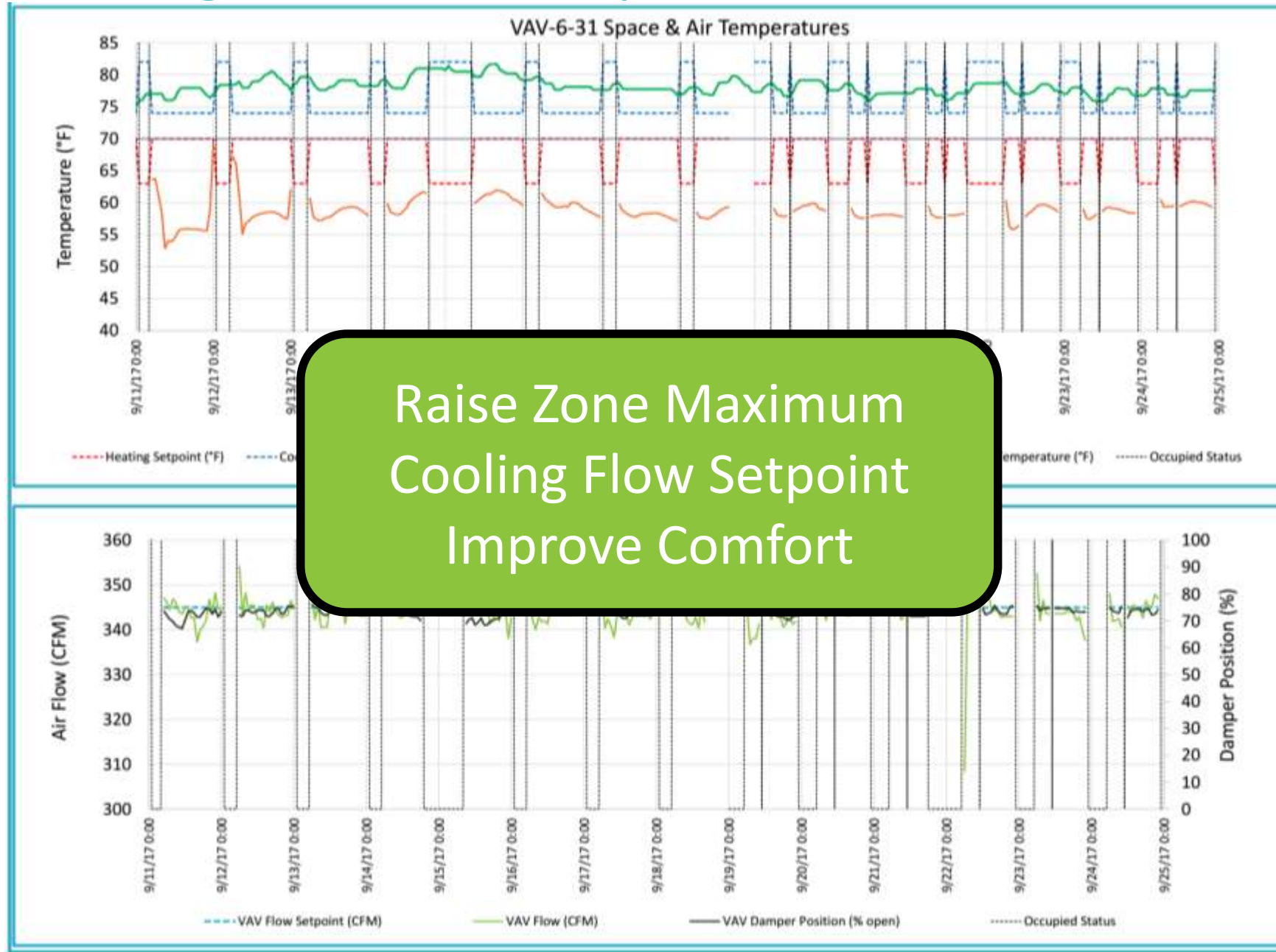


Flow

Within 20 % of Setpoint	More than 40% Above Setpoint
20% to 40 % Above Setpoint	More than 40% Below Setpoint
20% to 40 % Below Setpoint	

Description: The shade plots represent temperature or flow for each hour of the monitoring period as a color block. Each column represents a single day and each block in that column an hour in that day, reading from top to bottom the beginning to ending of that day. Average, minimum, and maximum occupied temperatures and flows are also shown for each day.

Cooling Season Example



Cooling Season Example

Operational Summary for Hunter College - East Building
Reporting Period: 9/11/2017 through 9/24/2017

VAV-B1-7

Summaries for VAV Boxes served by AC-C-2
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Data Summary Statistics

Variable	Average	Minimum	Maximum	Hours Above Setpoint		Hours Below Setpoint		Time Outside of Expected Range ¹
				> 2 °F	> 5 °F	> 2 °F	> 5 °F	
Occupied Space Temperature (°F)	72.8	71.6	76.0	0	0	0	0	0%
Unoccupied Space Temperature (°F)	73.1	71.2	76.7	0	0	0	0	0%
VAV Box Supply Air Temperature (°F)	57.5	57.0	65.5	Note 1. Percent of time space temperature was more than 5 °F away from setpoint.				
AC-C-2 Supply Air Temperature (°F)	60.7	53.8	71.9					

Variable	Average	Minimum	Maximum	Hours Above Setpoint		Hours Below Setpoint		Time Outside of Expected Range ²
				> 20 %	> 40 %	> 20 %	> 40 %	
Zone Supply Air Flow (CFM)	679	437	852	0	0	146	3	2%
Zone Damper Position (% open)	99							
AC-C-2 Supply Air Flow (CFM)	28,356							
AC-C-2 Supply Fan Speed (%)	66							
AC-C-2 Return Fan Speed (%)	72							

Flow below Setpoint

Adequate Cooling

Space Temperature for VAV-B1-7 (served by AC-C-2)

	9/11 - 9/24	Mon 9/11	Tue 9/12	Wed 9/13	Thu 9/14	Fri 9/15	Sat 9/16	Sun 9/17
Avg.	72.8	N/A	72.6	72.7	72.9	74.4	73.0	72.3
Min.	71.6	N/A	71.7	71.7	72.2	72.6	72.4	71.6
Max.	76.0	N/A	72.8	74.2	74.1	76.0	74.6	74.3



Temperatures

Green	Between 68 °F and 76 °F	Red	Greater than 79 °F
Yellow	Between 76 °F and 79 °F	Blue	Less than 65 °F
Light Green	Between 65 °F and 68 °F		

Other

White	Fan is off
Grey	Missing Data

Flow for VAV-B1-7 (served by AC-C-2)

	Fri 9/15	Sat 9/16	Sun 9/17	Mon 9/18	Tue 9/19	Wed 9/20	Thu 9/21	Fri 9/22	Sat 9/23	Sun 9/24
Avg.	79%	71%	75%	83%	70%	72%	76%	82%	77%	71%
Min.	65%	59%	66%	73%	49%	62%	70%	70%	71%	65%
Max.	91%	80%	81%	90%	81%	78%	81%	88%	81%	80%

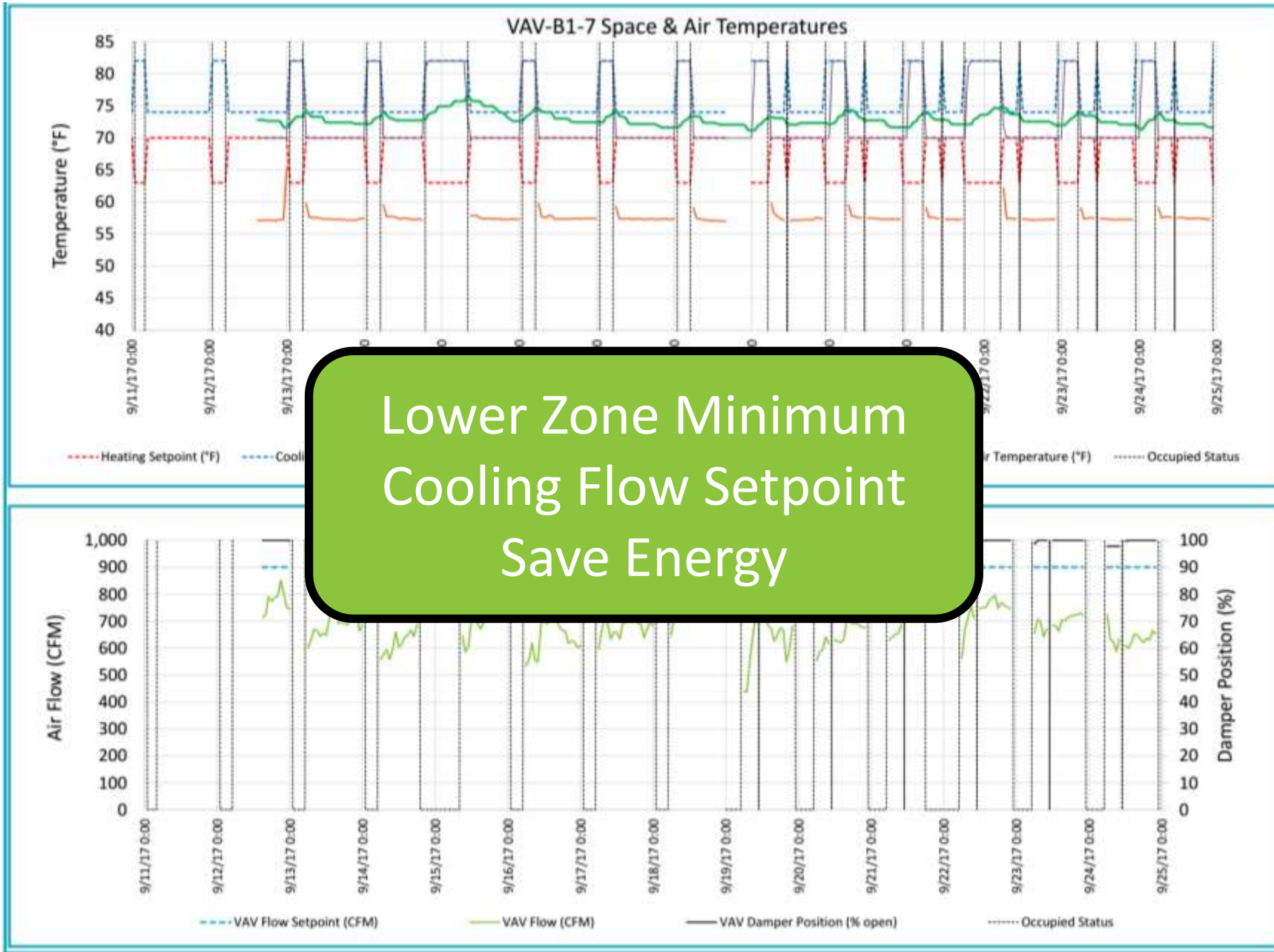


Flow

Green	Within 20 % of Setpoint	Red	More than 40% Above Setpoint
Yellow	20% to 40 % Above Setpoint	Blue	More than 40% Below Setpoint
Light Green	20% to 40 % Below Setpoint		

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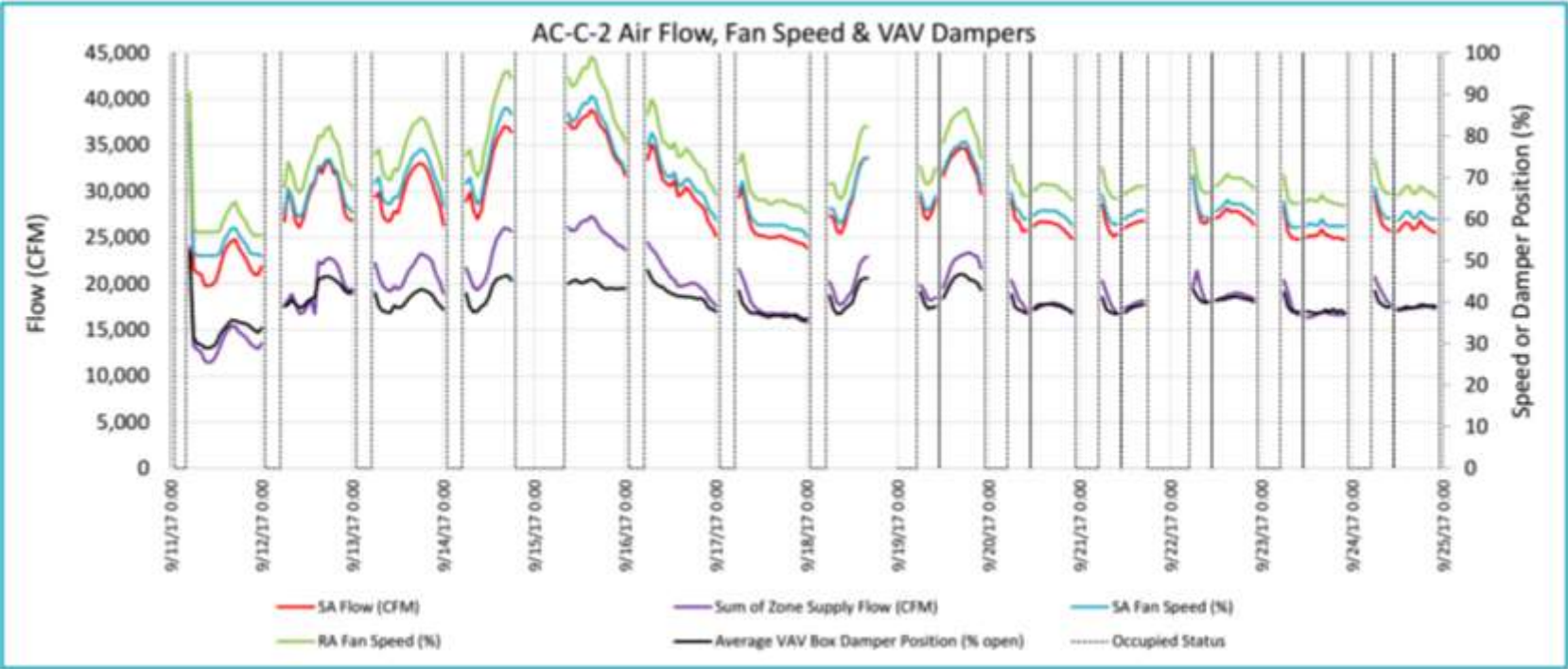
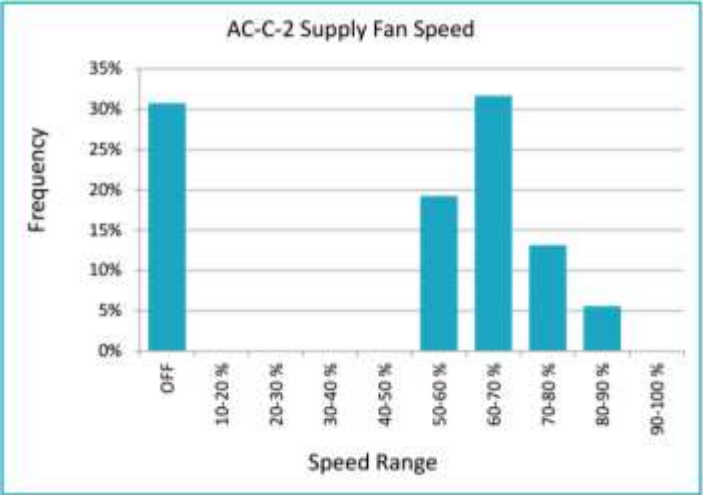
Cooling Season Example



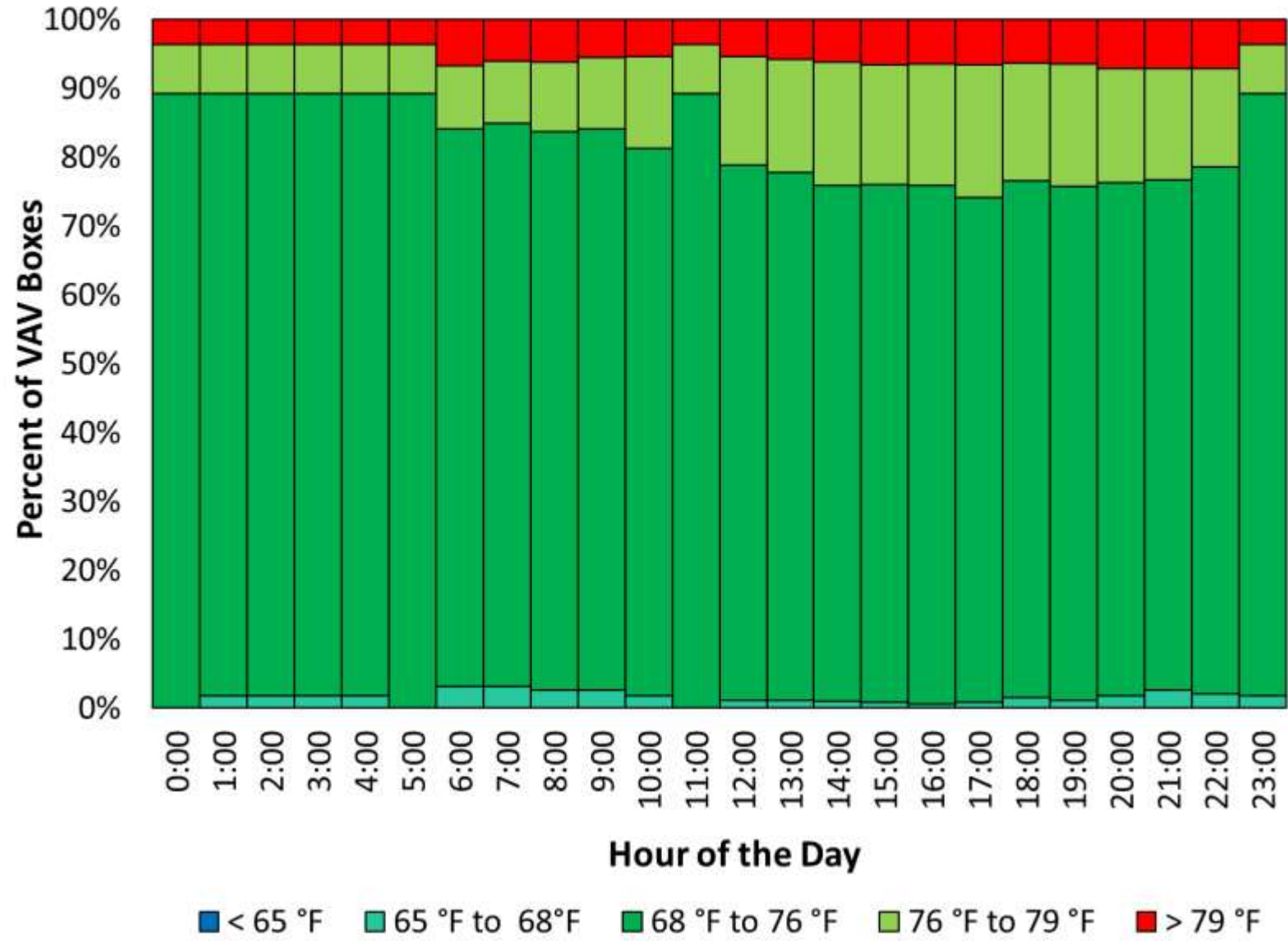
Cooling Season Example

OCx Analysis

System Level Data



Heating Season Example



Hourly Distribution of VAV Box Space Temperature for AC-C-1

Heating Season Example

Operational Summary for Hunter College - East Building
Reporting Period: 2/19/2018 through 3/04/2018

VAV-6-12

Summaries for VAV Boxes served by AC-C-1
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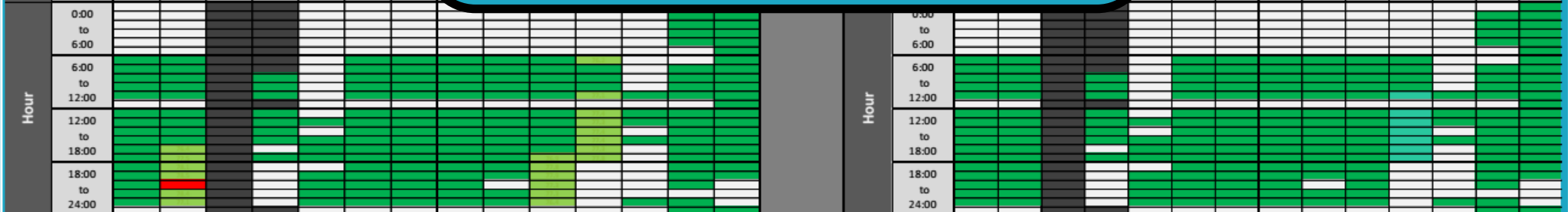
Data Summary Statistics

Variable	Average	Minimum	Maximum	Hours Above Setpoint		Hours Below Setpoint		Time Outside of Expected Range ¹
				> 2 °F	> 5 °F	> 2 °F	> 5 °F	
Occupied Space Temperature (°F)	73.4	70.3	79.1	21	1	0	0	1%
Unoccupied Space Temperature (°F)	74.9	71.3	80.7	0	0	0	0	0%
VAV Box Supply Air Temperature (°F)	67.3	56.8	76.9	Note 1. Percent of time space temperature was more than 5 °F away from setpoint.				
AC-C-1 Supply Air Temperature (°F)	68.3	56.1	78.8					

Variable	Average	Minimum	Maximum	Hours Above Setpoint		Hours Below Setpoint		Time Outside of Expected Range ²
				> 20 %	> 40 %	> 20 %	> 40 %	
Zone Supply Air Flow (CFM)	315	227	603	0	0	7	0	0%
Zone Damper Position (% open)	51			Note 2. Percent of time space temperature was more than 5 °F away from setpoint and fan was on.				
AC-C-1 Supply Air Flow (CFM)	41,741							
AC-C-1 Supply Fan Speed (%)	76							
AC-C-1 Return Fan Speed (%)	64							

Space Temperature for VAV-6-12 (served by AC-C-1)

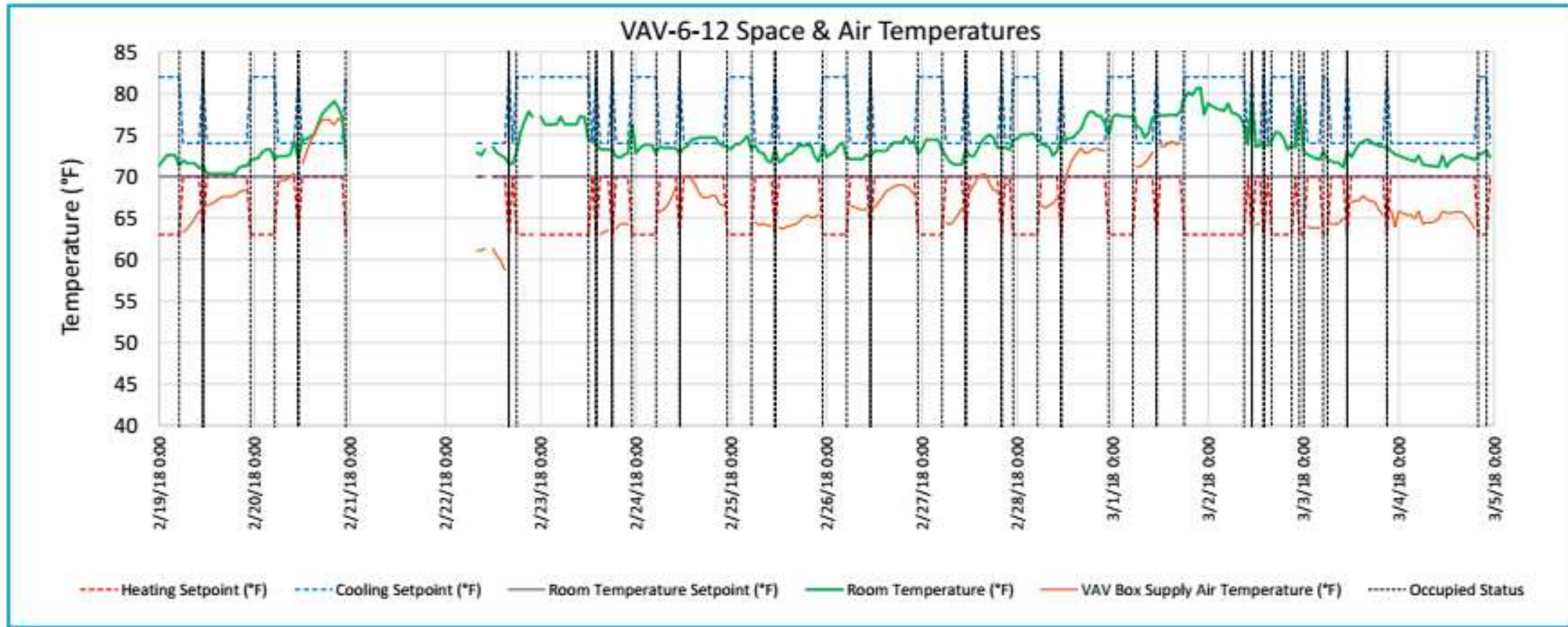
	2/19 - 3/4	Mon 2/19	Tue 2/20	Wed 2/21	Thu 2/22	Fri 2/23	Sat 2/24	Sun 2/25		Fri 2/23	Sat 2/24	Sun 2/25	Mon 2/26	Tue 2/27	Wed 2/28	Thu 3/1	Fri 3/2	Sat 3/3	Sun 3/4
Avg.	73.4	70.9	75.5	N/A	72.7	73.0	74.0	72.8		72.8	73.4	74.0	72.8	73.4	74.0	72.8	73.4	74.0	72.8
Min.	70.3	70.3	72.5	N/A	71.6	72.3	73.4	71.7		71.7	72.3	73.4	71.7	72.3	73.4	71.7	72.3	73.4	71.7
Max.	79.1	72.0	79.1	N/A	73.6	74.3	74.7	73.8		73.8	74.3	74.7	73.8	74.3	74.7	73.8	74.3	74.7	73.8



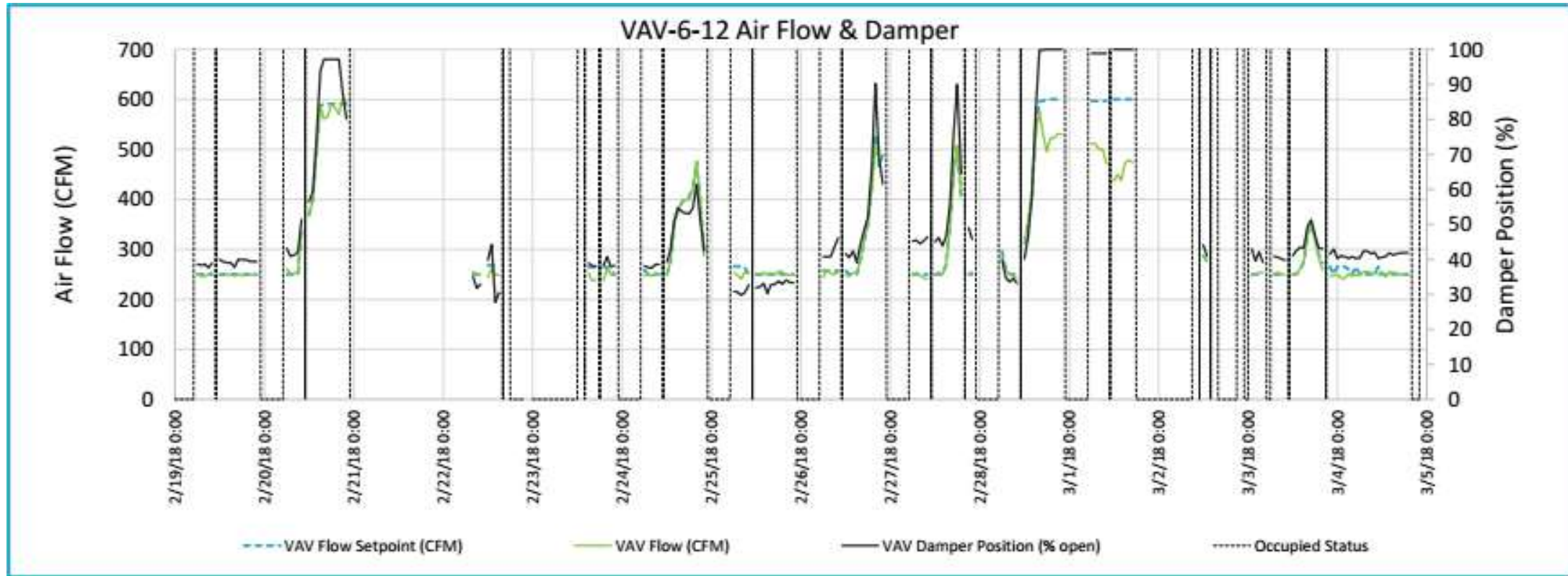
Temperatures			Other		Flow	
Between 68 °F and 76 °F	Between 76 °F and 79 °F	Between 65 °F and 68 °F	Greater than 79 °F	Less than 65 °F	Within 20 % of Setpoint	20% to 40 % Above Setpoint
			Fan is off	Missing Data	20% to 40 % Below Setpoint	More than 40% Above Setpoint
						More than 40% Below Setpoint

Description: The shade plots represent temperature or flow for each hour of the monitoring period as a color block. Each column represents a single day and each block in that column an hour in that day, reading from top to bottom the beginning to ending of that day. Average, minimum, and maximum occupied temperatures and flows are also shown for each day.

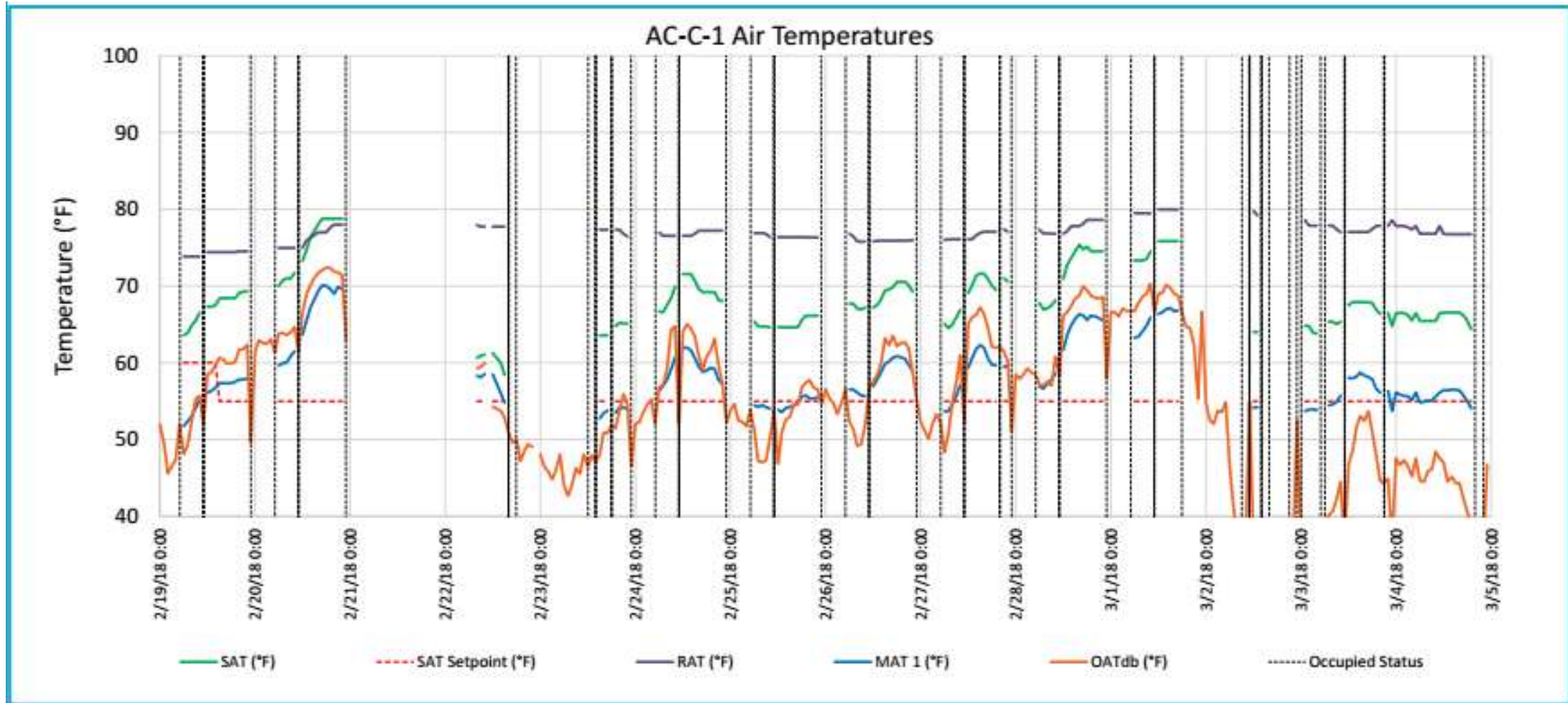
Heating Season Example



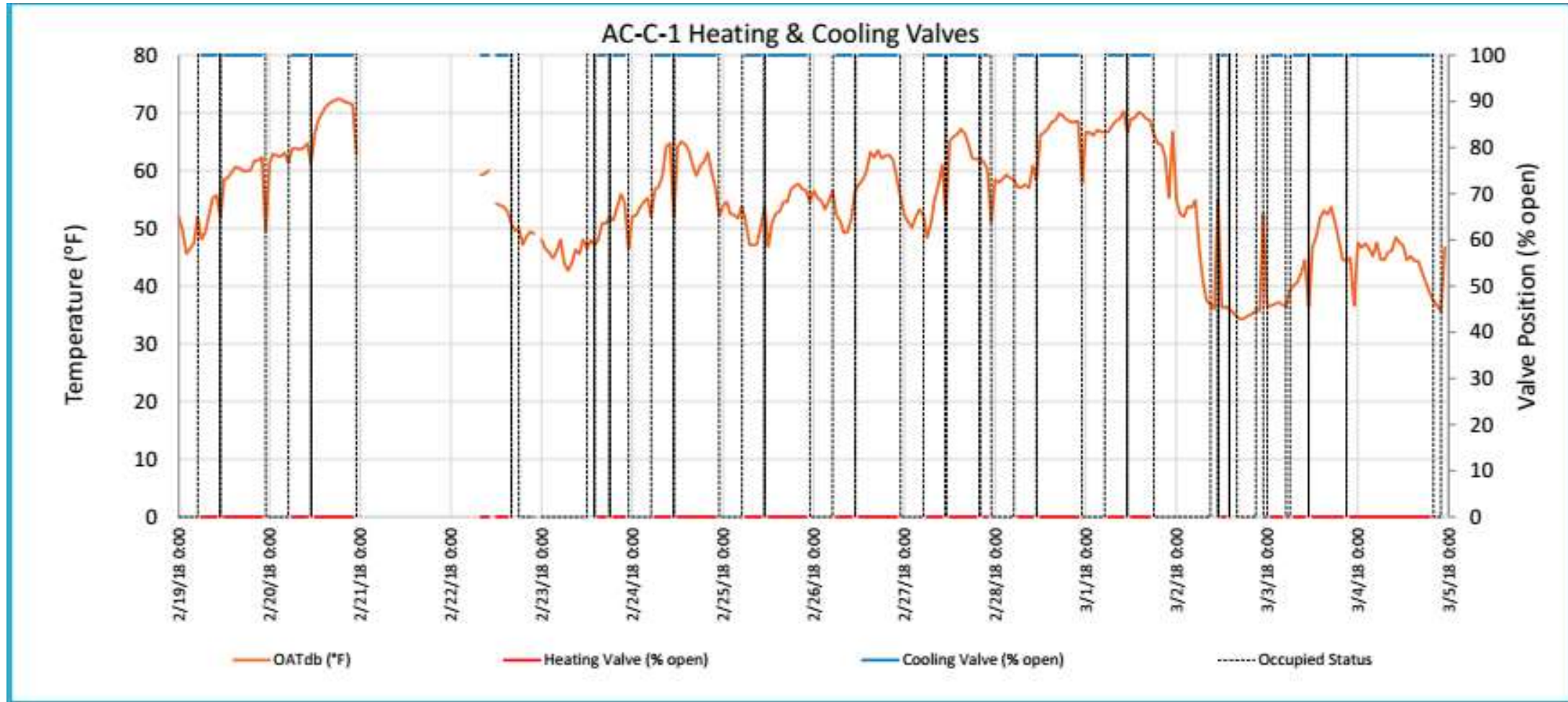
Heating Season Example



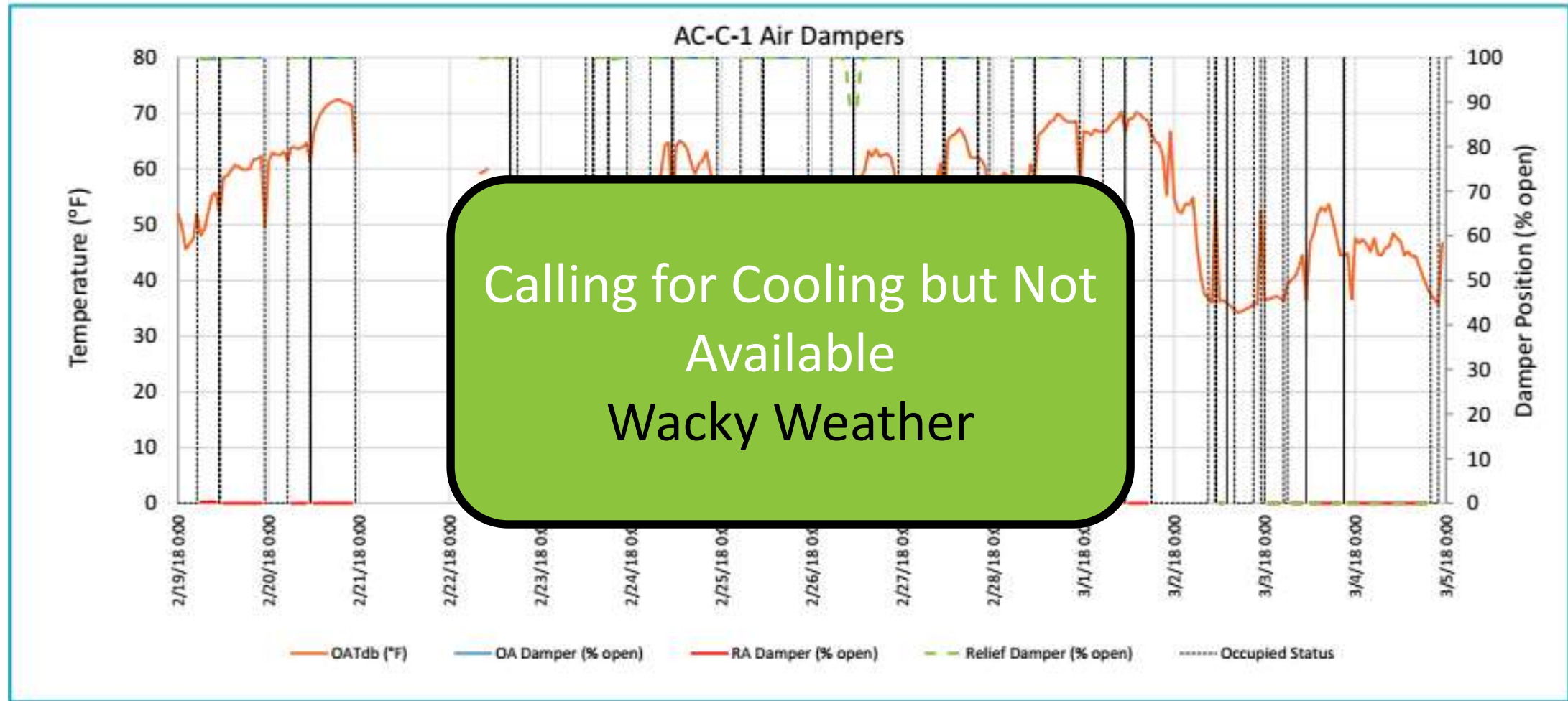
Heating Season Example



Heating Season Example



Heating Season Example





Ongoing Cx Value?

Collected lots of data

Analyzed and interpreted data

No value until...
Corrective Actions/Improvements

Issue #	System / Component	Date Identified	Issue Description	Date Resolved	Notes
3	VAV-1-8	7/3-8/13	VAV-1-8 deviated more than 5 °F from setpoint at times; this terminal box provided maximum flow all occupied mode periods (about 880 CFM) apparently overcooling the space.	9/13/2017	DMC/Honeywell reported the damper for this VAV box was set in manual to be 100% open and it was returned to auto mode.
5	AC-C-2	7/17-8/27	Supply air temperature ranged from 48.7 °F to 60.1 °F, with an average temperature of 53.3 °F when the supply fan was on. Unit supply air temperature was not tightly controlled; at times up to 6 °F away from setpoint. Over the monitoring period, the supply air temperature was more than 2 °F away from setpoint 48% of the occupied hours. Temperatures below setpoint were most prevalent.	9/13/2017	DMC/Honeywell tightened the PID control loop parameters.
6.1	AC-C-2	7/31-8/13	Supply air flow ranged from 18,992 CFM to 39,232 CFM, with an average of 23,480 CFM. Fan speed ranged from 51% to 99%, averaging 58% speed. Like AC-C-1, the maximum observed flow and speed occurred on August 1 between 10 a.m. and 12 p.m. when duct static pressure dropped to 0.04 in. w.g. (1.0 in. w.g. setpoint). A similar spike occurred on August 5 with a more gradual reduction in flow into the following day.	10/9/2017	Unit was manually turned off and on, On each Supply fan On signal, every VAV associated with the unit goes from 0% to 100% for damper synchronisation purpose and then returns back to its normal position. This explains the drop in static pressure and high air flow & fan speeds.
6.2	AC-C-2	8/14-8/27	Supply air flow ranged from 9,345 CFM to 40,040 CFM, with an average of 24,991 CFM. Fan speed ranged from 52% to 100%, averaging 61% speed. A minimum flow of about 21,000 CFM would be expected at the minimum fan speed observed over the period (52%), and in fact this was confirmed from the data; the 9,345 CFM minimum reported above is an outlier that occurred at unit startup on August 25. Like AC-C-1, the maximum observed flow and speed occurred on August 25 between 12 p.m. and 1 p.m. when duct static pressure dropped to 0.55 in. w.g. (1.0 in. w.g. setpoint).	10/9/2017	Unit was manually turned off and on, On each Supply fan On signal, every VAV associated with the unit goes from 0% to 100% for damper synchronisation purpose and then returns back to its normal position. This explains the drop in static pressure and high air flow & fan speeds.
7	AC-C-2	7/17-7/30	The minimum outside air damper position was reduced from 25% to 10% open on July 21 and remained at 10% through the end of the monitoring period. This event occurred the same hour as the July 21 supply air flow spike (Issue 6).	9/13/2017	DMC/Honeywell reported that the damper position was manually changed from 25% to 10%. OBG will compare this to design intent.
8	VAV-B1-2	7/17-9/10	VAV-B1-2 (AC-C-1) flow was significantly higher than setpoint; damper was commanded 100% open all hours.	9/13/2017	DMC/Honeywell reported the damper was overridden to manual and put it back into automatic operation.
9	VAV-B1-3	7/17-9/10	VAV-B1-3 (AC-C-1) flow was significantly higher than setpoint; however, its damper was commanded open manually over the monitoring period.	9/13/2017	DMC/Honeywell reported too much air coming to the VAV box and suggested adjusting the upstream balance damper.
10	VAV-2-3 VAV-4-2 VAV-4-12	7/17-8/27	VAV-1-3, VAV-1-6, VAV-2-3, VAV-2-4, VAV-4-2, VAV-4-12, and VAV-5-3 (AC-C-1) flow did not meet minimum CFM setpoint when damper was commanded to 100% open.	9/13/2017	VAV-2-3, VAV-4-2, and VAV-4-12 (AC-C-1), DMC/Honeywell confirmed it is due to air loss (duct leakage) and is not a controls issue.
14	AC-C-1	7/31-8/13	The minimum outside air damper position was reduced from 20% to 10% open on July 31 until it returned to 20% open on August 5.	10/9/2017	This is a Setpoint, overridden by operator
15	AC-C-2	7/31-8/13	The minimum outside air damper position was increased from 10% to 20% open on August 1 and remained at 20% through the end of the monitoring period. This event occurred the same hour as the August 1 supply air flow spike described above; it is also observed that the outside air damper opened to 90% before modulating back to 20% open.	10/9/2017	This is a Setpoint, overridden by operator
17	AC-C-1	8/14-8/27	Supply air temperature ranged from 52.5 °F to 61.4 °F, with an average temperature of 57.0 °F when the supply fan was on. Unit supply air temperature was tightly controlled to the 55 °F setpoint. However, when the setpoint increased to 61°F from Friday, August 18 to Thursday, August 24, supply air temperature remained below setpoint most of the time until the last two days of this period when it was maintained. The setpoint returned to 55 °F on Friday, August 25.	10/9/2017	PID tuned, Need to monitor for further events
18	AC-C-2	8/14-8/27	Supply air temperature ranged from 56.1 °F to 62.5 °F, with an average temperature of 58.5 °F when the supply fan was on. Unit supply air temperature was not tightly controlled and was always higher than the 55 °F setpoint; at times more than 5 °F higher than setpoint. Over the monitoring period, the supply air temperature was more than 2 °F away from setpoint 83% of the occupied hours.	10/9/2017	PID tuned, Need to monitor for further events
20	AC-C-2	8/14-8/27	The minimum outside air damper position remained at 20% open throughout the monitoring period, with some exceptions; the damper was fully closed for several hours after morning startup on August 25 before returning to 20% open.	10/9/2017	Unit was manually off for some part of the day in morning and afternoon time, due to this damper wasn't open.
38	VAV-7-29	8/28-9/10	VAV box VAV-7-29 (AC-C-2) flow was always higher than setpoint and was at least 40% higher 6% of the time. The terminal box damper was commanded to 0% open all hours as the control loop unsuccessfully attempted to reduce flow to setpoint. This occurred at the minimum CFM setpoint for the box (40 CFM), when about 55 CFM was typically supplied to the zone. Space temperature was controlled to an average of 68.3 °F, possibly indicating a minimum CFM setpoint that is too high for the zone resulting in overcooling of the space.	10/9/2017	Box is in manual control
39	VAV-7-31	8/28-9/10	Beginning Sunday, September 3, VAV box VAV-7-31 (AC-C-2) flow was always higher than setpoint. The terminal box damper was commanded to 0% open as the control loop unsuccessfully attempted to reduce flow to setpoint. This occurred at the minimum CFM setpoint for the box (40 CFM), when about 400 to 500 CFM was typically supplied to the zone. Space temperature was controlled within the expected range all hours (72.7 °F average).	10/9/2017	Box is in manual control

Ongoing Commissioning – Recommended Actions

Symptom	Issue/Resolution
Unable to maintain space temperature setpoint	Manual override of VAV box damper – Release to auto
Poor supply temperature control	Adjust PID loop
Mid-day spike in air flow/drop in duct pressure	Unit manually turned off/on (VAV dampers cycle)
Unable to modulate zone air flow low enough	Too much supply air pressure – adjust balance damper
Unable to modulate zone air flow high enough	Upstream duct leakage

A photograph of two men in business suits shaking hands in a modern office setting. They are standing in front of a large window that looks out onto a city skyline. The man on the left is younger with dark hair, and the man on the right is older with grey hair. They are both smiling. The background shows a bright, sunny day with a view of a city with tall buildings.

Project Outcomes

Happy Client

- System Performance
- Reports and Recommendations

Persistence of Savings and Comfort



Thank you!

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