Maximizing Efficiency and Quality: Leveraging Automated Testing for Laboratory Commissioning

I2SL Annual Conference

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Anaheim, CA

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Learning Objectives

1. Understand traditional approaches to commissioning functional acceptance testing, including using sampling rates to perform hands-on testing of select equipment when large quantities of equipment are present.

2. Understand how fault detection and diagnostic software can be leveraged to automatically execute functional acceptance tests on all equipment controlled by the Building Automation System.

3. Identify the key stakeholders that need to be involved in planning conversations early in construction and commissioning to allow for successful automated functional testing.

4. Describe important advantages to utilizing automated functional testing over traditional approaches, primarily the elimination of sampling rates, availability of data-backed results, and ease of repeatability for long-term building performance and maintenance.

Case Study Project

Research and Innovation Laboratory (RAIL)

- Wet chemistry laboratory
  - Planned research: microbiology, battery chemistry, perovskites
  - Designed for maximum flexibility
- Approx. 15,000 GSF
  - 5400 SF laboratory space
  - 6600 SF support / office / meeting areas
  - 3000 SF mechanical penthouse
- Performance / efficiency features:
  - 100% outside air (makeup air unit, manifolded exhaust)
  - Full variable air volume laboratory air system
  - Runaround-loop heat recovery
  - Indirect evaporative cooling
  - Temperature and pressure reset sequences
- Construction, initial Cx completed spring 2023

Top: *RAIL Design Rendering / provided by NREL Site Operations;* ***Bottom:*** *Photograph by Werner Slocum / NREL (81556)*

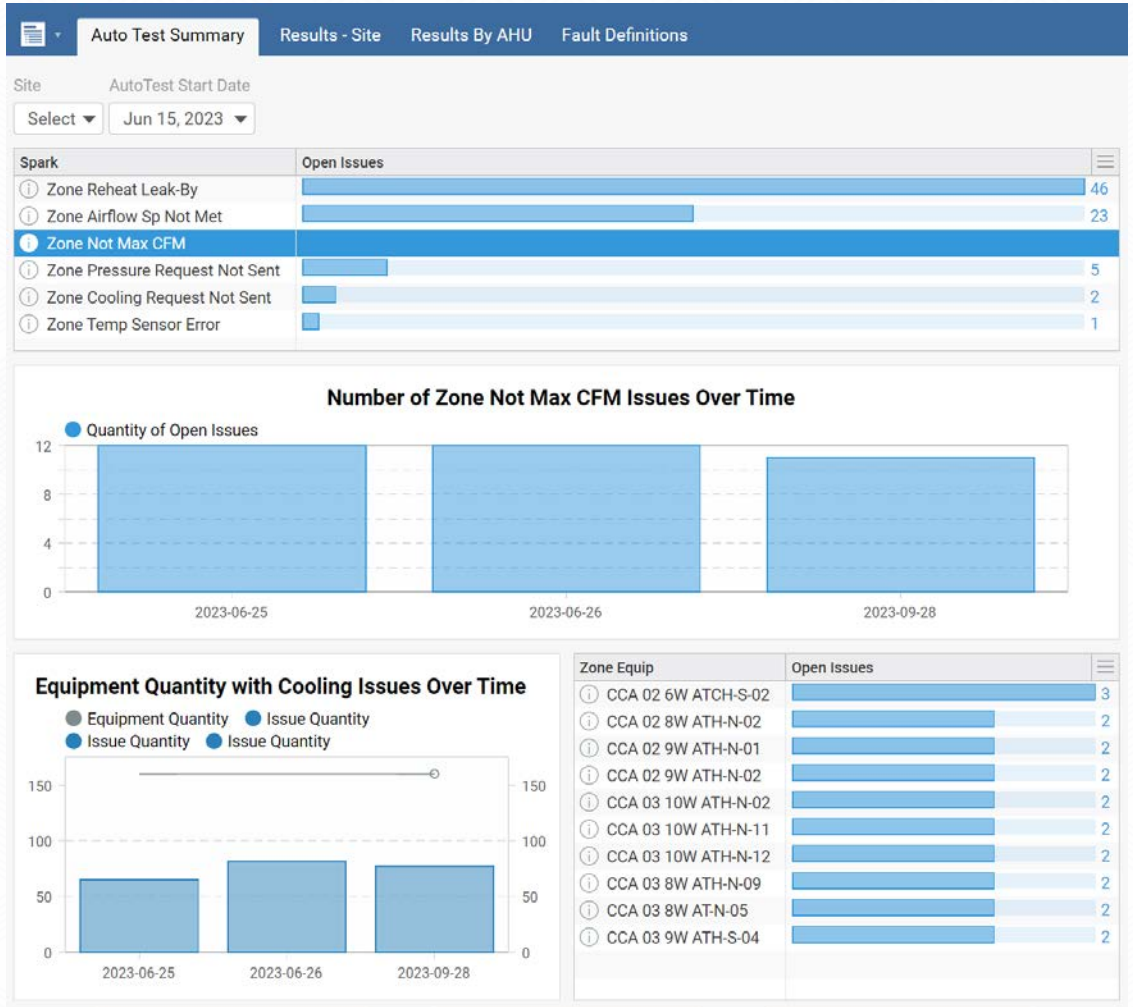
Case Study Project – Photographs

Clockwise from Top Left: *Joshua Bauer and Bryan Bechtold / NREL (80993), Werner Slocum / NREL (75710, 75761, 75714, 75740, 75709)*

Case Study Project (non-lab)

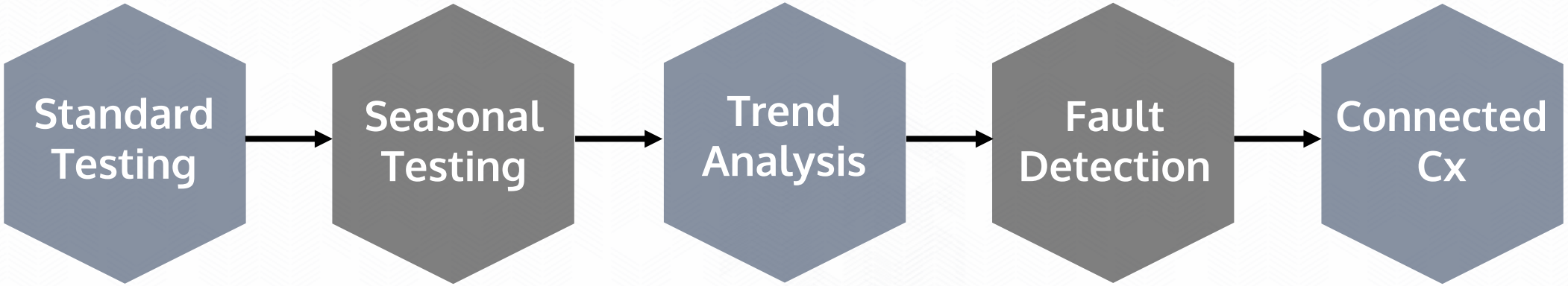
Airport Project

- Concourse Expansion
  - 530,000 square feet of new space
  - 12 new gates
  - 10,000 square feet of new concessions space
- Mechanical Systems
  - VAV AHUs and ERVs
  - Terminal equipment with hot water heating (160 units)
  - Passenger Loading Bridge ventilation systems
  - Temperature and pressure reset sequences
- Fault Detection for Commissioning
- ...with Automated Testing for Terminal Units



Developments in Commissioning

Process



- Manual manipulation
- 10-20% sampling rates
- Single snapshot in time

- Manual manipulation
- 10-20% sampling rates
- Testing in both heating and cooling seasons

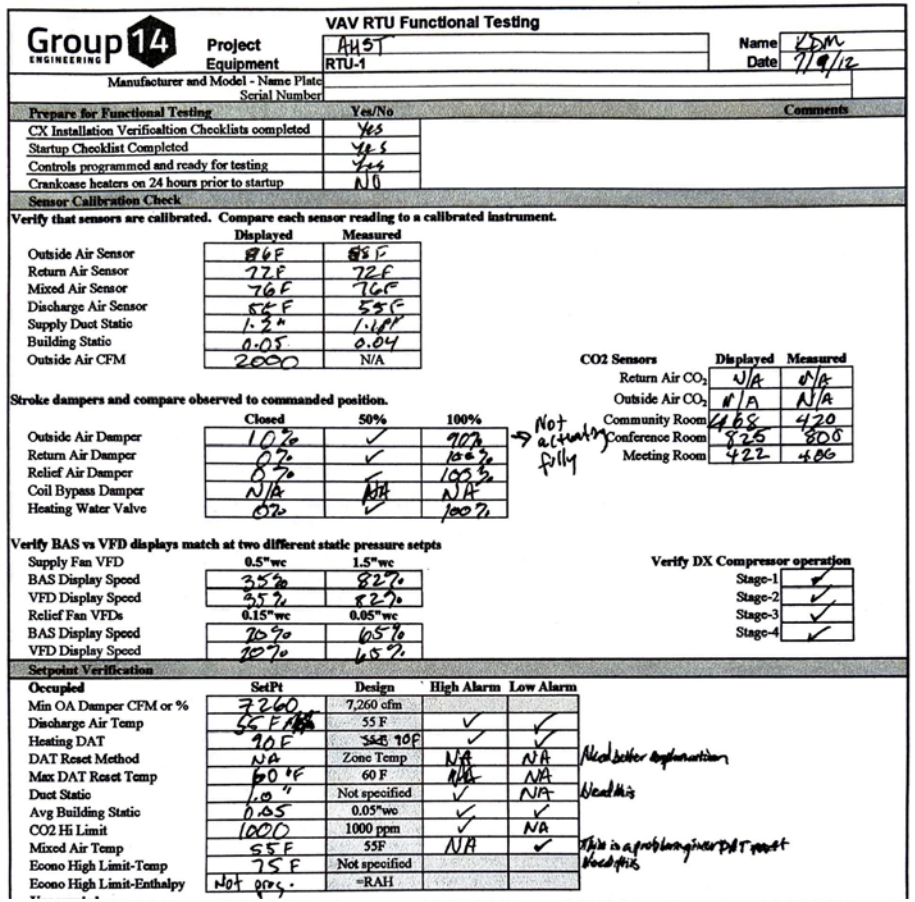
- Manual process
- *Potentially* 100% sampling rate
- Performance over time

- "Automated" trend analysis
- *More Time-efficient* 100% sampling rate
- Performance over time
- Relies on chance

- Utilizes the advantages of Fault Detection
- Trends and faults while manipulating setpoints
- 100% sampling rate
- **Allows for automated testing & reporting**

Developments in Commissioning

Documentation



Group 14 ENGINEERING

VAV RTU Functional Testing

Project: AH5T — Name: KDM
Equipment: RTU-1 — Date: 7/9/12
Manufacturer and Model - Name Plate:
Serial Number:

Prepare for Functional Testing	Yes/No	Comments
CX Installation Verificaltion Checklists completed	Yes	
Startup Checklist Completed	Yes	
Controls programmed and ready for testing	Yes	
Crankcase heaters on 24 hours prior to startup	NO	

Sensor Calibration Check

Verify that sensors are calibrated. Compare each sensor reading to a calibrated instrument.

	Displayed	Measured
Outside Air Sensor	86F	85F
Return Air Sensor	77F	72F
Mixed Air Sensor	76F	76F
Discharge Air Sensor	56F	55F
Supply Duct Static	1.2"	1.18"
Building Static	0.05	0.04
Outside Air CFM	2000	N/A

CO2 Sensors	Displayed	Measured
Return Air CO_2	N/A	N/A
Outside Air CO_2	N/A	N/A
Community Room	468	420
Conference Room	825	805
Meeting Room	422	486

Stroke dampers and compare observed to commanded position.

	Closed	50%	100%
Outside Air Damper	10%	✓	90%
Return Air Damper	8%	✓	100%
Relief Air Damper	8%	✓	100%
Coil Bypass Damper	N/A	N/A	N/A
Heating Water Valve	0%	✓	100%

→ Not actually fully

Verify BAS vs VFD displays match at two different static pressure setpts

	0.5"wc	1.5"wc
Supply Fan VFD		
BAS Display Speed	35%	82%
VFD Display Speed	35%	82%
Relief Fan VFDs	0.15"wc	0.05"wc
BAS Display Speed	70%	65%
VFD Display Speed	70%	65%

Verify DX Compressor operation

Stage-1	✓
Stage-2	✓
Stage-3	✓
Stage-4	✓

Setpoint Verification

Occupied	SetPt	Design	High Alarm	Low Alarm	
Min OA Damper CFM or %	7260	7,260 cfm			
Discharge Air Temp	55 F	55 F	✓	✓	
Heating DAT	90 F	85 to 90F	✓	✓	
DAT Reset Method	NA	Zone Temp	NA	NA	Need better implementation
Max DAT Reset Temp	60 °F	60 F	NA	NA	
Duct Static	1.0 "	Not specified	✓	NA	Need M/S
Avg Building Static	0.05	0.05"wc	✓	✓	
CO2 Hi Limit	1000	1000 ppm	✓	NA	
Mixed Air Temp	55 F	55F	NA	✓	This is a problem given DAT reset Need M/S
Econo High Limit-Temp	75 F	Not specified			
Econo High Limit-Enthalpy	Not prog.	=RAH			

Developments in Commissioning

Documentation

VAV Terminal Unit Functional Testing

Group 14 ENGINEERING

Project: | Name:
Equipment: VAV Boxes | Date:

VAV Box	Default	VAV-0-1	VAV-0-2	VAV-1-1	VAV-1-2	VAV-1-3	FTU-0-8	FTU-0-9	FTU-1-11
Verify Programming StPts									
Serves		Office 102	Office 103	Office 104	Corridor 101	Office 105	Conference 106	Break Room 108	Lobby 100
Max CFM	Verify	300	450	120	120	200	500	400	600
Min CFM	Verify	220	220	120	120	120	200	175	200
Heating CFM	Verify	120	180	48	48	80	375	250	525
Cool SetPt	74	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Heat SetPt	70	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Cool SetPt - Unocc		80	80	80	80	80	80	80	80
Heat SetPt - Unocc		65	65	65	65	65	65	65	65
Occupied/Auto Mode									
Space Temp		71	72	71	70	72	69	67	70
Heating Valve %		Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
CFM Displayed		Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
DAT Displayed	N/A	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Raise Stpt to Enable Full Heating									
CFM Displayed		120	180	48	48	80	375	250	525
Heating Valve %		Yes	Yes	Yes	Yes	Yes	No	Yes	No
DAT Displayed	N/A	90	92	91	89	90	91	58	90
DAT Measured	N/A	89	90	90	90	89	89	57	91
Lower Stpt to Deadband Range									
CFM Displayed		220	220	120	120	120	200	175	200
Lower Stpt to Enable Full Cooling									
CFM Displayed		300	450	120	120	200	500	400	600
Full CFM Achieved?		Yes	Yes	Yes	Yes	Yes	No	Yes	No
Typ Diffuser CFM-Design									
Typ Diffuser CFM-Hood									
Enable Unoccupied Mode									
Damper Position %		0%	0%	0%	0%	0%	0%	0%	0%
Verify RTU is Off		Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Override Zone Temps to just below Night Heat SetPt									
Verify FTUs Turn On		N/A	N/A	N/A	N/A	N/A	Pass	Pass	Pass
Verify RTU turns On		Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Verify Heating Valve Zero		Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Verify RTU DAT = 90F		Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
DAT - Displayed		90	92	91	89	90	91	90	90
CFM Displayed		300	450	120	120	200	500	400	600
VAV=0 whenTset achieved		Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Notes	N/A						Need to increase DSP setpoint/reset?	Valve backwards/broken?	Check TAB report

Restore original control settings

Developments in Commissioning

Documentation

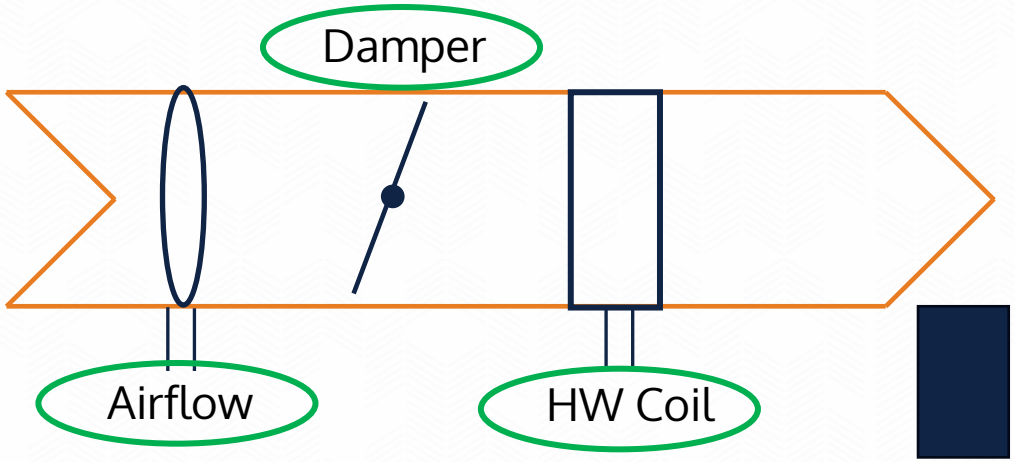
QUESTIONNAIRE

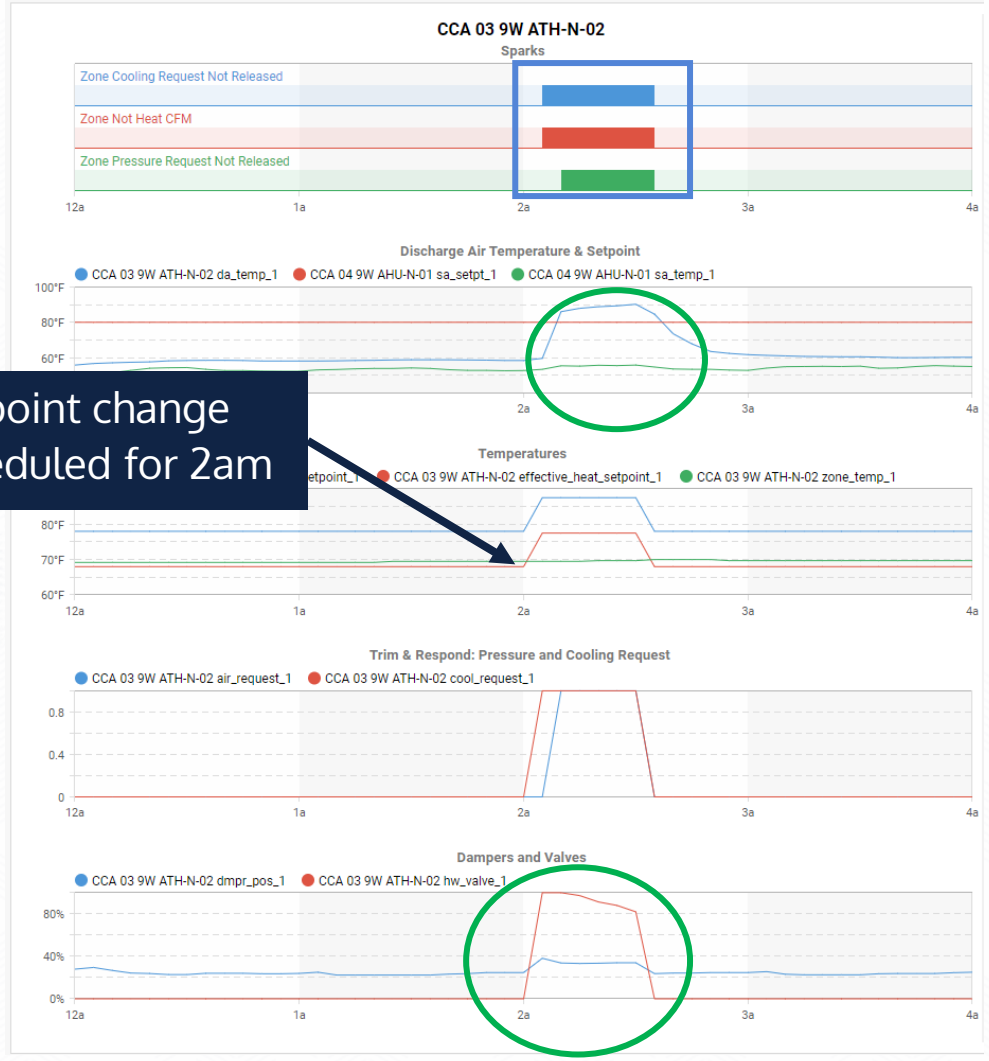
#	Question	All	FCU-118 (non-ducted, formerly 109)	FCU-102 (non-ducted, formerly 125B)	FCU-104 (non-ducted, formerly 120)	FCU-106 (ducted, formerly 119)	FCU-108 (ducted, formerly 125A)	FCU-110 (ducted, formerly 118)	FCU-114 (ducted, cooling only, formerly 111)	FCU-116 (non-ducted, cooling only, formerly 110)	FCU-201 (non-ducted, formerly R01)
	INSTALLATION REVIEW										
1	Unit is free from damage	None	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
2	Unit is clearly labeled	None	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
3	All components are installed (including line set insulation, condensate pump, and vibration isolation)	None	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
4	All components are accessible for maintenance	None	Pass	Pass	Fail	Fail	Fail	Fail	Fail	Pass	Pass
5	Installation is per project requirements	None	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
	Schedule										
1	Monday-Friday: [Not defined, record schedule]	None	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
2	Weekend: [Not defined, record schedule]	None	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass

Automated Testing

What is it?

- Direct manipulation of BAS setpoints / modes by the FDD software
- Tests scheduled to run automatically
- FDD software utilizes programmed rules to detect faults





Automated Reporting

Select Test Run

- Dashboards easily summarize test results
- Results from test iterations are displayed to track progress

View Test Results by Equipment

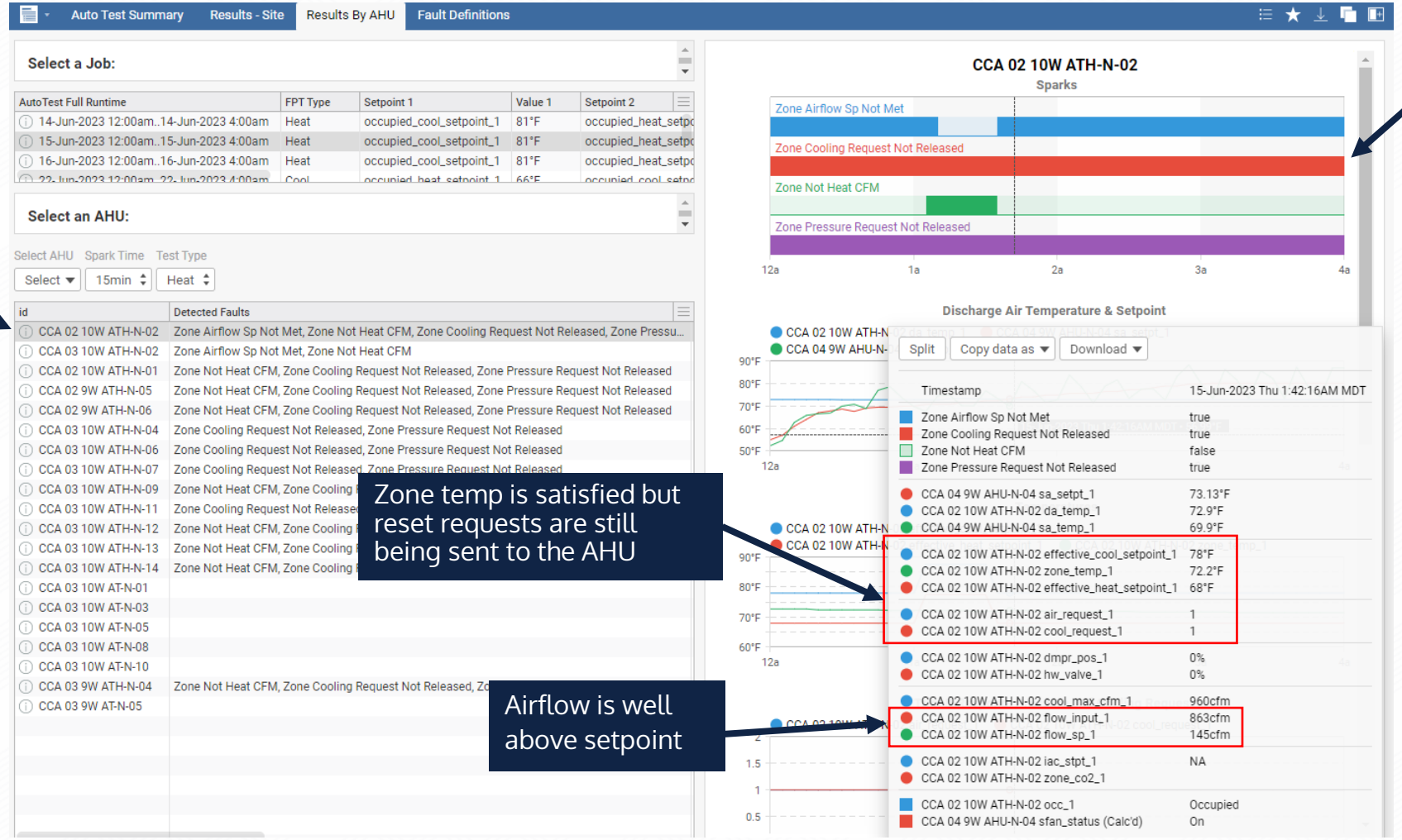
Auto Test Summary | Results - Site | Results By AHU | Fault Definitions

AutoTest Full Runtime	FPT Type	Setpoint 1	Value 1	Setpoint 2	Value 2	Runtime 1	Runtime 2
14-Jun-2023 12:00am..14-Jun-2023 4:00am	Heat	occupied_cool_setpoint_1	81°F	occupied_heat_setpoint_1	80°F	14-Jun-2023 12:00am..14-Jun-2023 12:30am	14-Jun-2
15-Jun-2023 12:00am..15-Jun-2023 4:00am	Heat	occupied_cool_setpoint_1	81°F	occupied_heat_setpoint_1	80°F	15-Jun-2023 12:00am..15-Jun-2023 12:30am	15-Jun-2
16-Jun-2023 12:00am..16-Jun-2023 4:00am	Heat	occupied_cool_setpoint_1	81°F	occupied_heat_setpoint_1	80°F	16-Jun-2023 12:00am..16-Jun-2023 12:30am	16-Jun-2
22-Jun-2023 12:00am..22-Jun-2023 4:00am	Cool	occupied_heat_setpoint_1	66°F	occupied_cool_setpoint_1	65°F	22-Jun-2023 12:00am..22-Jun-2023 12:30am	22-Jun-2

Spark Time: 15min Test Type: Heat

id	Detected Faults	Airflow Meets Setpoint	Zone Meets Min CFM	Cooling Request Rele
CCA 01 10W ATC-N-02	Zone Not Min CFM	Pass	Fail	Pass
CCA 01 10W ATH-S-04		Pass		Pass
CCA 01 5W ATC-S-01	Zone Cooling Request Not Released, Zone Pressure Request Not Released	Pass	Pass	Fail
CCA 01 6W ATCH-N-03	Zone Not Heat CFM, Zone Cooling Request Not Released, Zone Pressure Request Not Released	Pass		Fail
CCA 01 6W ATC-N-01	Zone Cooling Request Not Released, Zone Pressure Request Not Released	Pass	Pass	Fail
CCA 01 6W ATC-N-04		Pass	Pass	Pass
CCA 01 8W ATC-N-01	Zone Not Min CFM, Zone Cooling Request Not Released, Zone Pressure Request Not Released	Pass	Fail	Fail
CCA 01 9W ATCH-S-01	Zone Cooling Request Not Released, Zone Pressure Request Not Released	Pass		Fail
CCA 01 9W ATC-N-01	Zone Airflow Sp Not Met	Fail	Pass	Pass
CCA 01 9W ATC-N-02	Zone Not Min CFM, Zone Cooling Request Not Released, Zone Pressure Request Not Released	Pass	Fail	Fail
CCA 01 9W ATC-S-01	Zone Cooling Request Not Released, Zone Pressure Request Not Released	Pass	Pass	Fail
CCA 02 10W ATH-N-01	Zone Not Heat CFM, Zone Cooling Request Not Released, Zone Pressure Request Not Released	Pass		Fail
CCA 02 10W ATH-N-02	Zone Airflow Sp Not Met, Zone Not Heat CFM, Zone Cooling Request Not Released, Zone Pressure Re...	Fail		Fail
CCA 02 5W ATH-N-01	Zone Not Heat CFM, Coil Capacity Not Met, Zone Pressure Request Not Released	Pass		Pass
CCA 02 5W ATH-N-02	Zone Not Heat CFM, Coil Capacity Not Met, Zone Cooling Request Not Released, Zone Pressure Requ...	Pass		Fail
CCA 02 5W ATH-N-03	Zone Not Heat CFM, Coil Capacity Not Met, Zone Cooling Request Not Released, Zone Pressure Requ...	Pass		Fail
CCA 02 6W ATCH-N-03	Coil Capacity Not Met, Zone Cooling Request Not Released	Pass		Fail
CCA 02 6W ATCH-N-04		Pass		Pass
CCA 02 6W ATCH-N-06		Pass		Pass
CCA 02 6W ATCH-N-07	Coil Capacity Not Met, Zone Cooling Request Not Released, Zone Pressure Request Not Released	Pass		Fail
CCA 02 6W ATCH-S-02	Zone Airflow Sp Not Met, Coil Capacity Not Met	Fail		Pass
CCA 02 6W ATH-N-01	Coil Capacity Not Met, Zone Cooling Request Not Released	Pass		Fail

Automated Test Results



Select equipment

View FDD rule results and supporting trend data

Zone temp is satisfied but reset requests are still being sent to the AHU

Airflow is well above setpoint

Opportunities and Advantages

CxP's Perspective

- 100% review, no sampling rates
- Repeatability of retesting / ease of verifying resolution of issues
- Less on-site testing time between CxP and controls contractor
- Trend data to back up test results
- Allows for ease and consistency of ongoing commissioning

Owner's Perspective

- More rigorous commissioning process
- Reduced owner troubleshooting and warranty claims after building turnover
- Smoother handoff to ongoing commissioning
- Especially powerful for owners with large buildings, campuses, or large building portfolios

Set your project up for success

Key Stakeholders & Responsibilities

Owner

- OPR - Basis of Design Requirements
- BAS Standards
- Naming & Tagging Standards

Engineer

- Include Auto-Testing in Specs
- Incorporate all BAS, naming and tagging standards
- Specify necessary devices
- Control point matrices

CxP

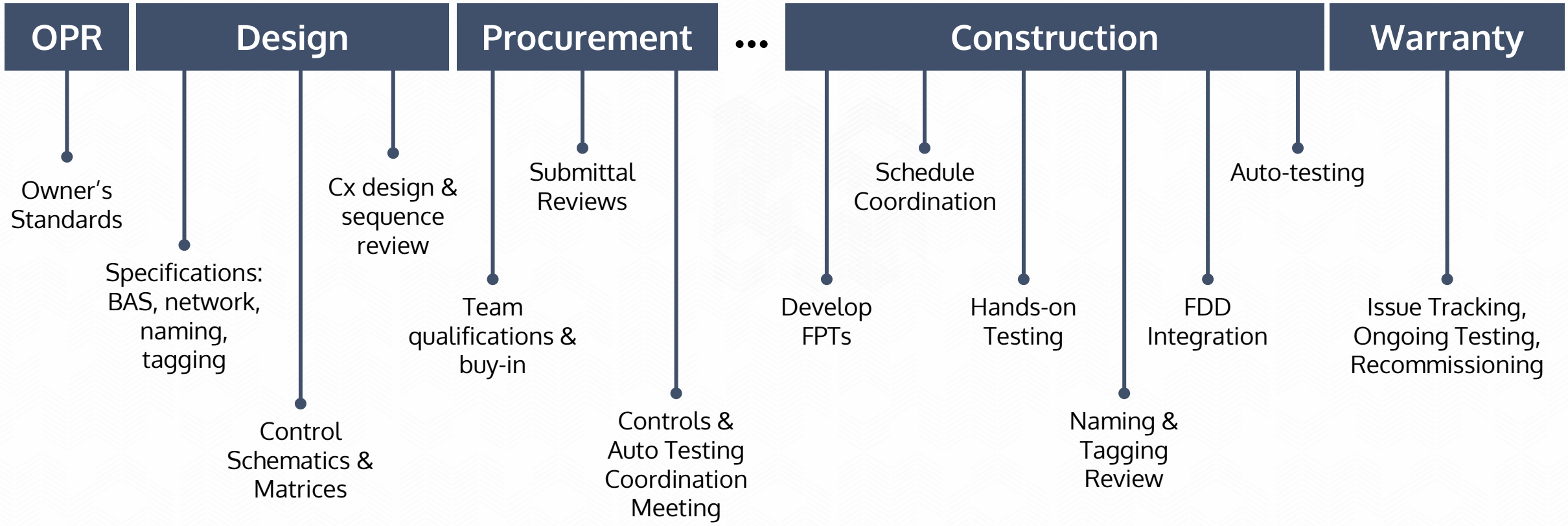
- Include in Cx Specs
- Auto-testing coordination
- Develop test scripts
- Implement programming

Contractors

- Submittal Accuracy
- Follow Naming & Tagging Standards
- Third party device coordination

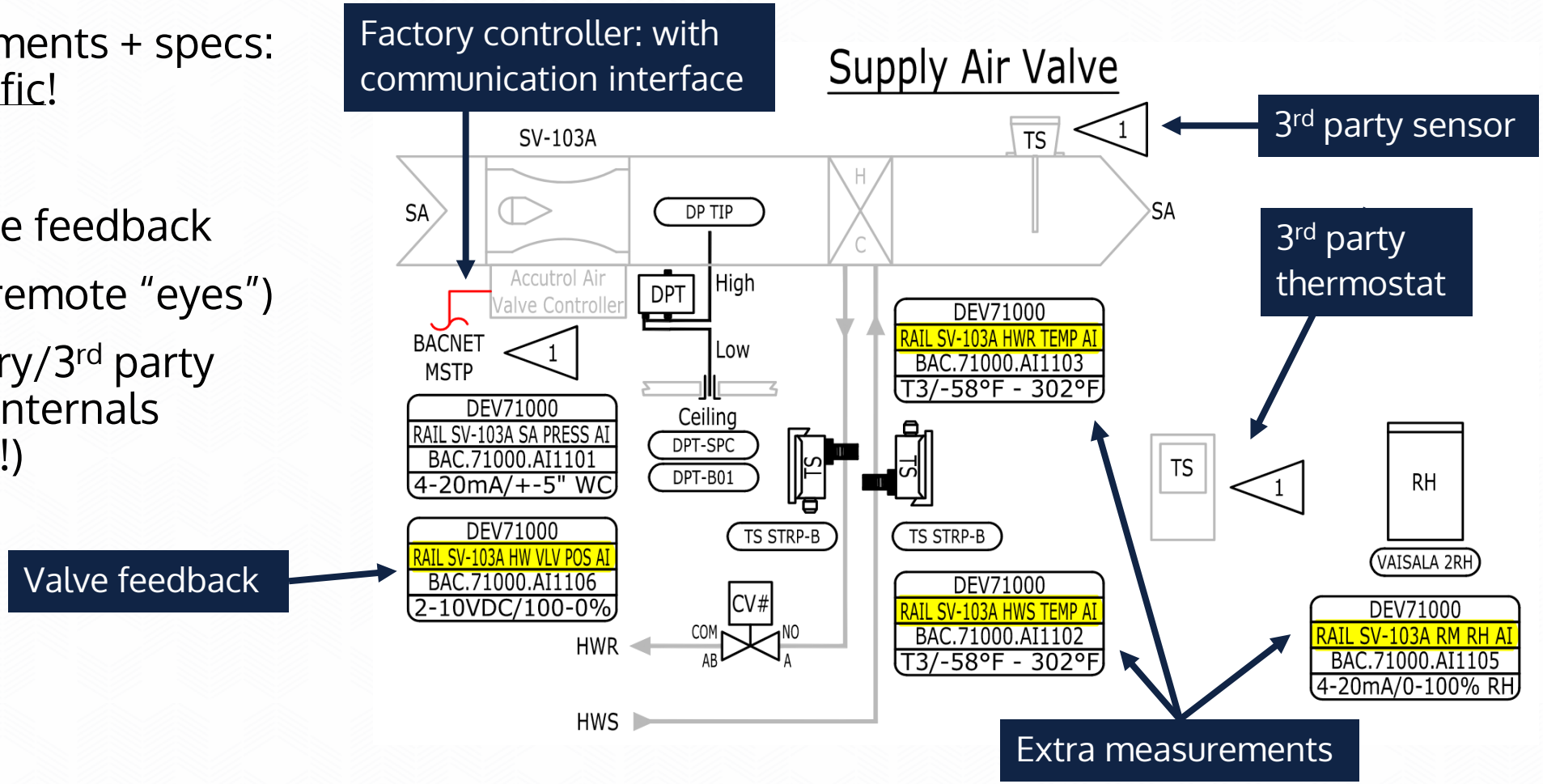
Set your project up for success

Timeline & Implementation



Designing for Automated Testing

- Design requirements + specs: Clear and specific!
- Standardize
- Actuator & valve feedback
- Extra sensors (remote "eyes")
- Access to factory/3rd party control device internals (read and write!)



Schematic by Setpoint Systems Corporation; NREL record drawing; used with permission

Sequences of Operation: Do & Don't

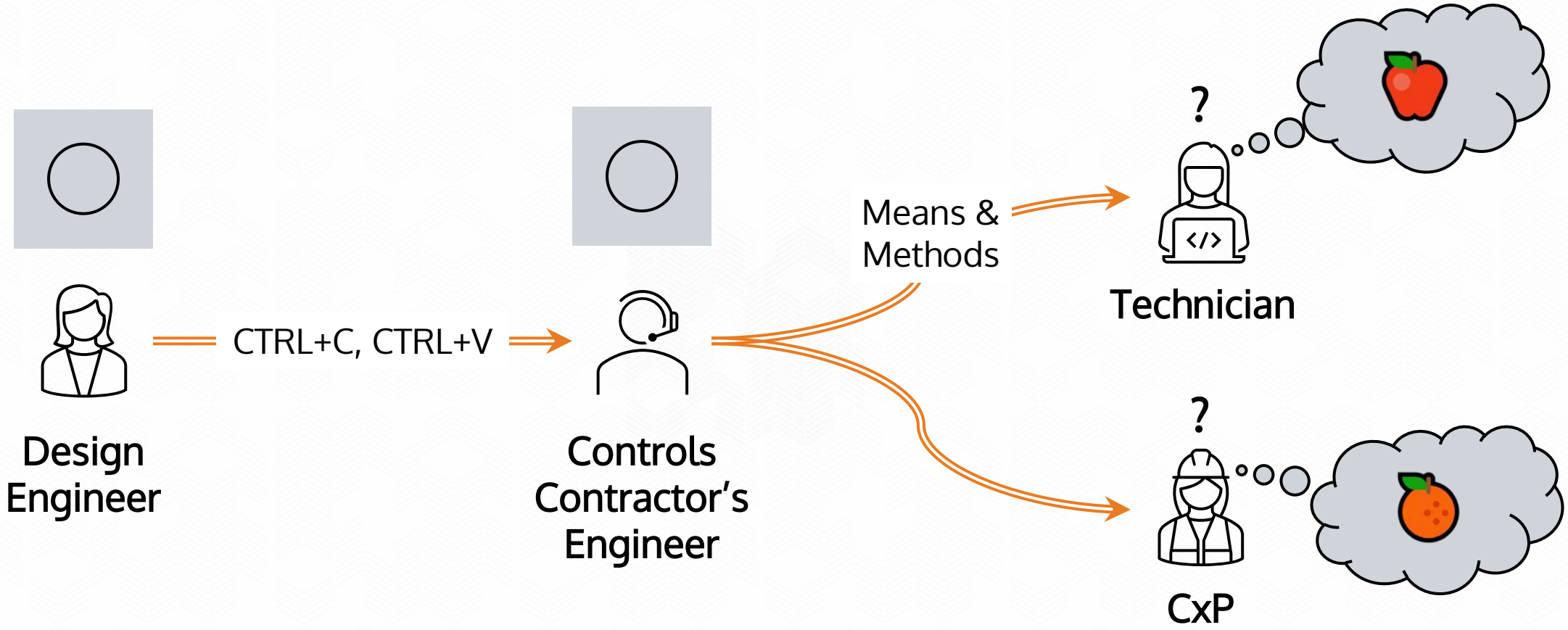
DON'T

- Force the technician (or CxP!) to make assumptions
- Defer key details to the controls contractor
- Rely on "means & methods"

DO

- Be clear
- Be precise
- Be complete
- Define all operating modes and mode transitions
- Describe all needed sensors, setpoints, and parameters

Don’t Rely on Means & Methods



Standardizing: Semantic Tagging

Semantic tagging standards…

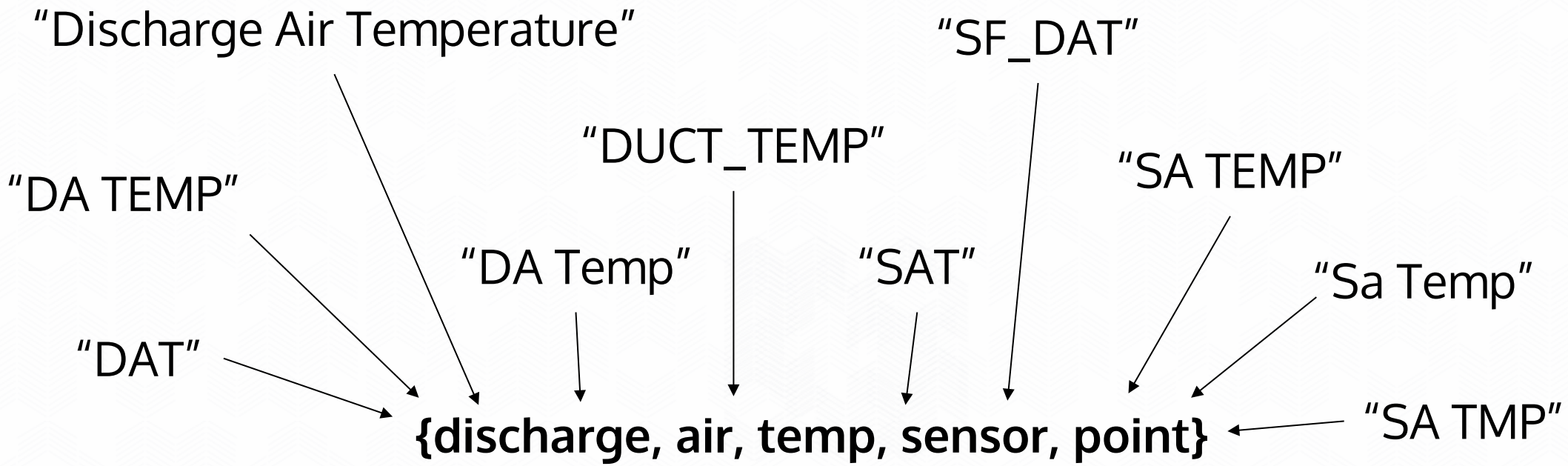
1. Use metadata to organize and attach meaning to raw data
2. Normalize that metadata to enable automated analytics at scale

https://project-haystack.org/

Brick Schema

https://brickschema.org/

Semantic Tagging Example



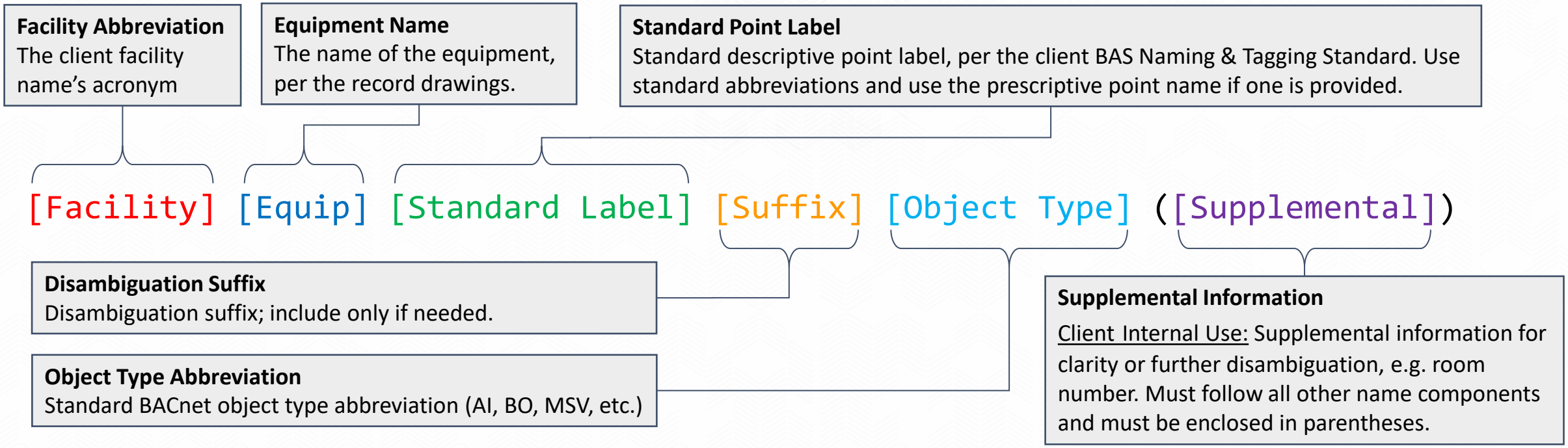
Project Haystack

*These are all actual names from NREL's building automation system controllers

Standardizing: Naming Conventions

Why use a naming standard?

1. Human readability
2. It makes semantic tagging *much* easier (maybe even automated!)



Standardizing: Equipment Profiles

Fan Coil Unit (Constant Speed, Cooling Only)

					HARDWARE POINTS				SOFTWARE POINTS							
POINT DESCRIPTION	BAS LABEL	UNITS		ENUM	AI	BI	AO	BO	AV	BV	MSV	SCHED	ALARM	TREND	SHOW ON GRAPHIC	NOTES
Zone Temperature	RM TEMP	°F			X									5 min	X	
Zone Relative Humidity	RM RH	%RH			X									5 min	X	
Occupancy Override Command	OCC OVRD	Binary		0 = Unoccupied, 1 = Occupied		X								COV	X	
Zone Temperature Cooling Effective Setpoint	RM TEMP CLG STPT	°F							X					COV	X	
Zone Temperature Heating Effective Setpoint	RM TEMP HTG STPT	°F							X					COV	X	
Zone Temperature Cooling Occupied Setpoint	RM TEMP CLG OCC STPT	°F										X		COV		
Zone Temperature Heating Occupied Setpoint	RM TEMP HTG OCC S															
Zone Temperature Cooling Unoccupied Setpoint	RM TEMP CLG UNOC															
Zone Temperature Heating Unoccupied Setpoint	RM TEMP HTG UNOC															
Zone Equipment Operating State	OPERATING MODE															
Occupancy Mode Indicator (Binary)	OCCUPIED															
Discharge Air Temperature	DA TEMP															
Discharge Air Temperature Setpoint	DA TEMP STPT															
Zone Equipment Fan Start/Stop (Command)	FAN SS															
Zone Equipment Fan Status	FAN STATUS															
Chilled Water Valve Command	CHW VLV CMD															
Chilled Water Valve Feedback	CHW VLV POS															
Heating Water Valve Command	HW VLV CMD															
Heating Water Valve Feedback	HW VLV POS															
Condensate Overflow Sensor	CONDENSATE OVFLW															
TOTALS																

POINT DESCRIPTION	BAS LABEL	UNITS
Zone Temperature	RM TEMP	°F
Zone Relative Humidity	RM RH	%RH
Occupancy Override Command	OCC OVRD	Binary
Zone Temperature Cooling Effective Setpoint	RM TEMP CLG STPT	°F
Zone Temperature Heating Effective Setpoint	RM TEMP HTG STPT	°F
Zone Temperature Cooling Occupied Setpoint	RM TEMP CLG OCC STPT	°F
Zone Temperature Heating Occupied Setpoint	RM TEMP HTG OCC STPT	°F
Zone Temperature Cooling Unoccupied Setpoint	RM TEMP CLG UNOCC STPT	°F
Zone Temperature Heating Unoccupied Setpoint	RM TEMP HTG UNOCC STPT	°F
Zone Equipment Operating State	OPERATING MODE	MSV
Occupancy Mode Indicator (Binary)	OCCUPIED	Binary
Discharge Air Temperature	DA TEMP	°F

Example: Lab Air Valve Auto-Testing

Group 14 ENGINEERING

National Renewable Energy Laboratory
NREL RAIL

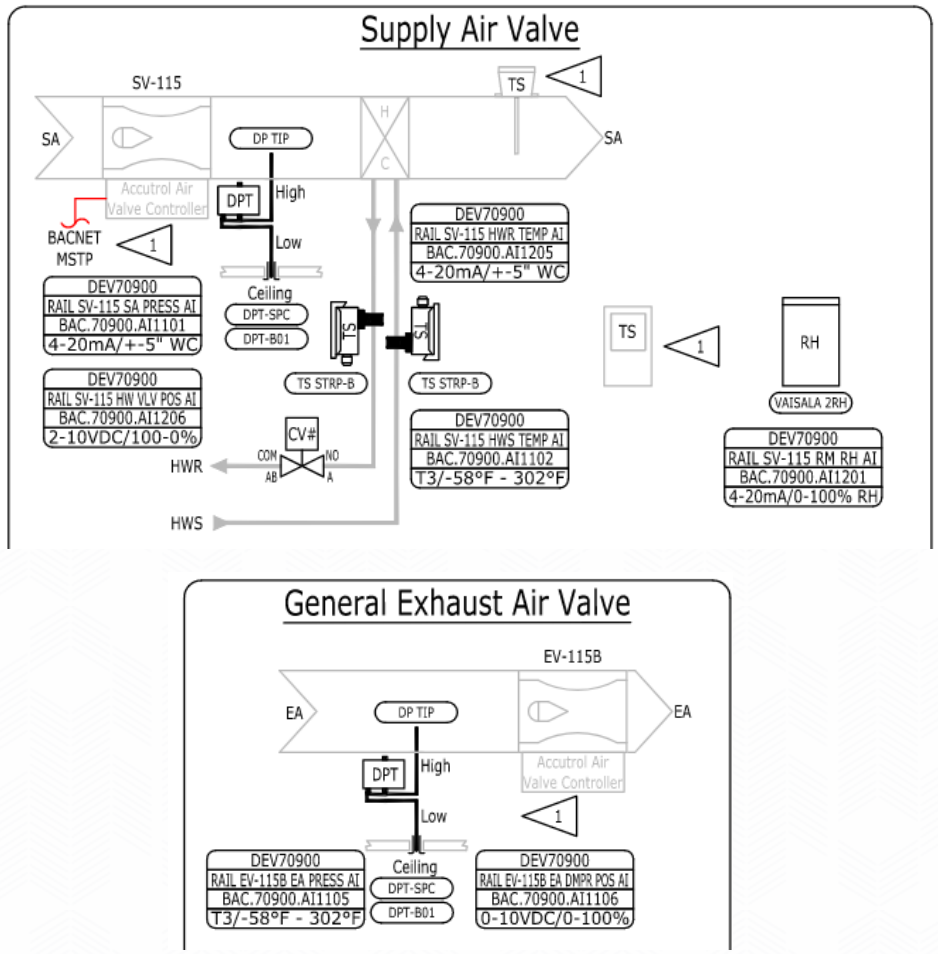
LACS - 103 Service Core (LACS)
FPT-47

#	Question	Answer	Details
2	Fume Hood exhaust air valve maintains face velocity	Pass Fail N/A	
3	Check door pressures	Pass Fail N/A	
	Unoccupied-- Simulate occ sensor unoccupied:		
1	Confirm supply and exhaust setpoints are adjusted to unoccupied values	Pass Fail N/A	
2	Confirm supply and exhaust airflows are met	Pass Fail N/A	
3	Fume Hood exhaust air valve maintains face velocity	Pass Fail N/A	
4	Check door pressures	Pass Fail N/A	
5	Heating is allowed to operate to meet space temperature setpoint if eneded	Pass Fail N/A	
	Fume Hood-- Raise and lower sash heigh:		
1	Fume hood face velocity is maintained	Pass Fail N/A	
2	Supply and exhaust air valves compensate as needed	Pass Fail N/A	
3	Check door pressures	Pass Fail N/A	
	Cooling SAT Reset Requests-- Simulate the various cooling scenarios, and confirm requests are sent to the MAU to reset SAT setpoint:		
1	Zone Temp is more than 5°F above setpoint for 2 minutes = 3 requests	Pass Fail N/A	
2	Zone Temp is 3°F above setpoint for 2 minutes = 2 requests	Pass Fail N/A	

Write to occ/unocc sensor point.

Write to space temp setpoints

Write to space temp setpoints



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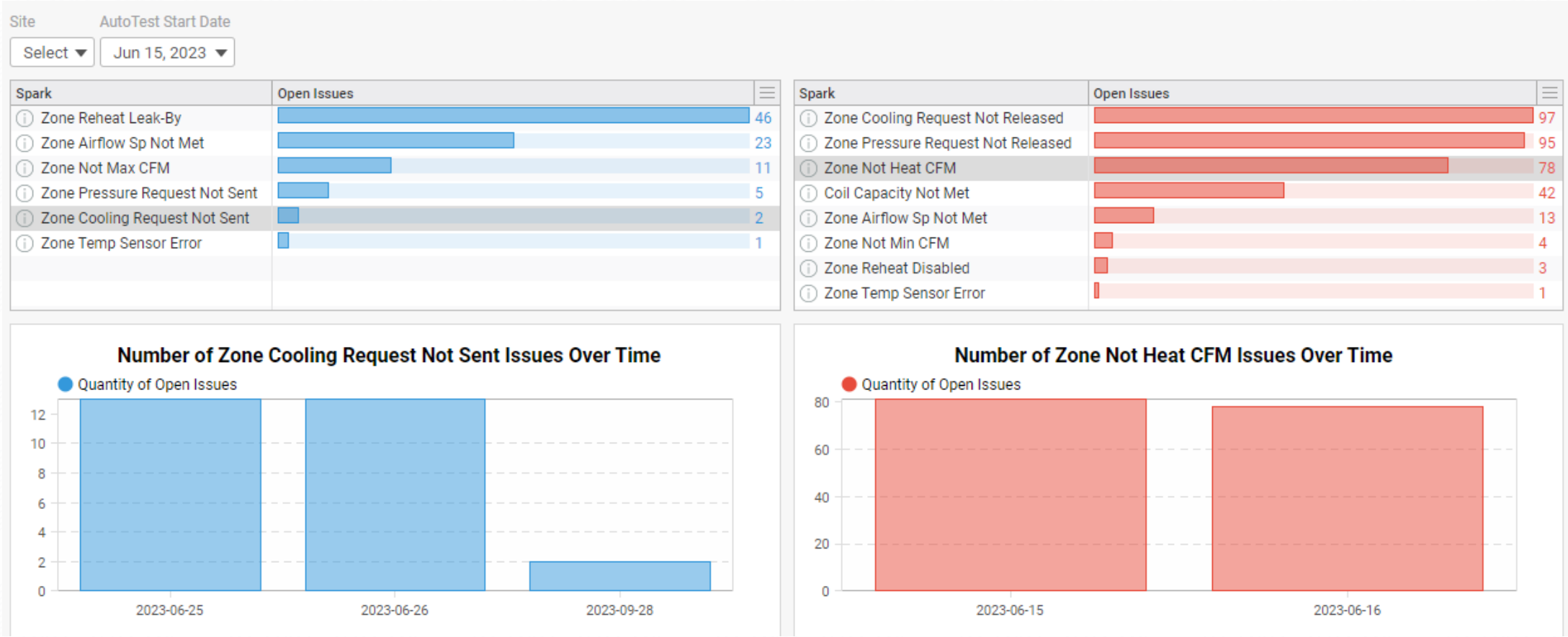
Outcomes: RAIL

- Issues identified through auto-testing:
  - FCU failed cooling
  - FCU fans short-cycling
  - FCU fans operating continuously
  - TBs maintaining higher DAT than specified
  - Flow setpoints not matching design
- Barriers encountered testing lab air valves:
  - Writing and releasing third party device points
  - Unresolved upstream issues (MAU/EAU) prevented reliable test results
  - Schedule compression and overlap

Outcomes: Airport

Auto-tested 160 pieces of terminal equipment



Summary

1. Auto-testing can be a powerful tool for building owners and CxP's, but requires an auto-testing-specific project approach throughout all phases to be successful.

2. Auto-testing offers a more thorough testing effort without sampling rates, ease of repeatability of tests, and more efficient and effective turnover to the building owner for ongoing commissioning.

3. The owner is pivotal in driving the project requirements around auto-testing, and assembling a team that understands and executes all requirements is key to success of the project.

4. A successful auto-testing effort will continue to bring value to the owner for the life of the building if executed correctly at the end of a construction project.

Questions?

I2SL Annual Conference

October 23, 2023

Anaheim, CA

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NREL/PR-3500-86668