

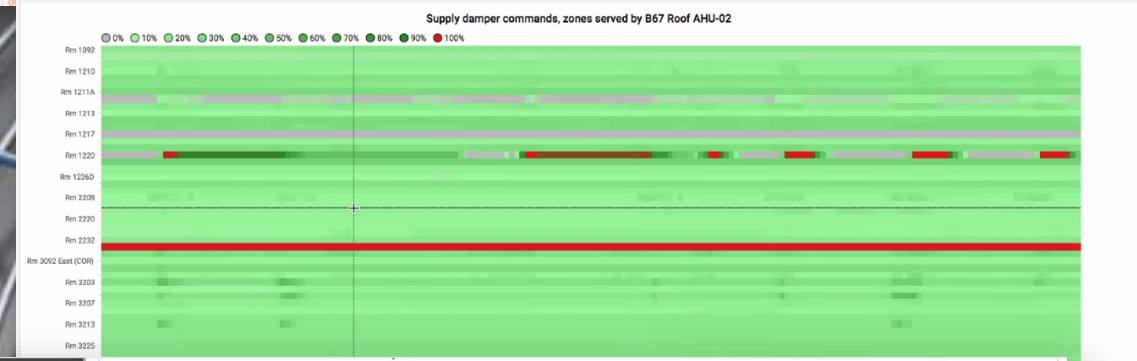
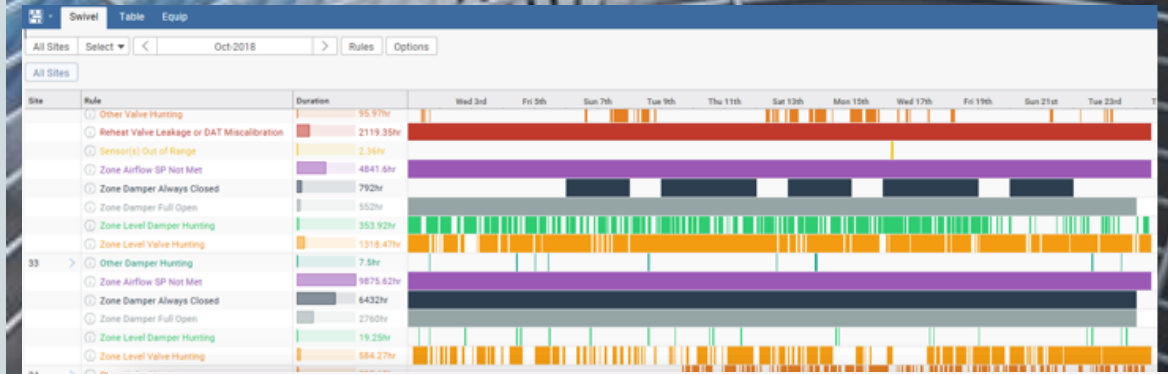
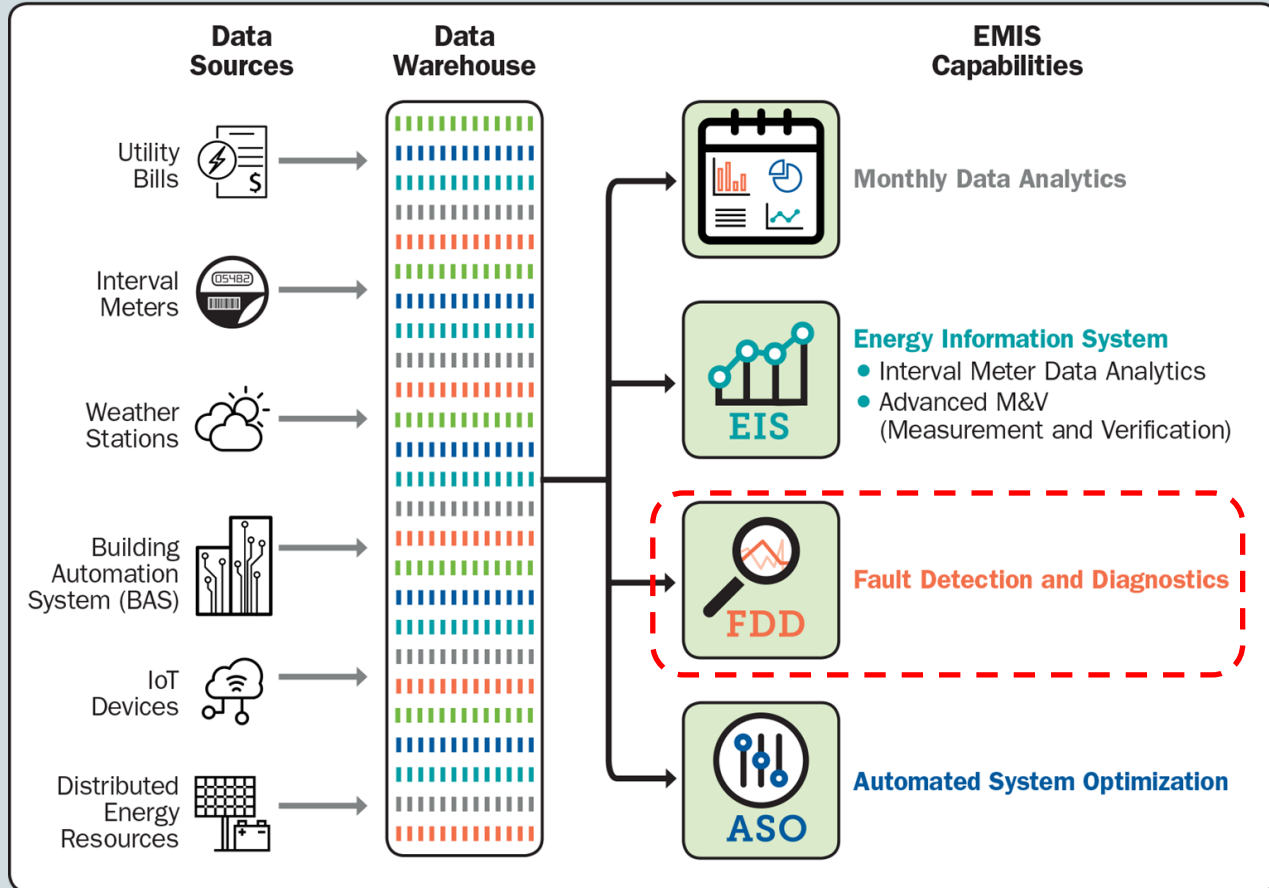
What to Expect When You're Expecting Fault Detection & Diagnostics (FDD)

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Energy Management & Information Systems (EMIS)



This screenshot shows a software interface displaying analysis details for an AHU Ventilation System. The interface includes a sidebar with navigation options: Tasks, Projects, Reporting, Building Profiles, Equipment Profiles, and Documents. The main content area shows:

- Building:** South Boston
- Equipment:** Bidg2_VAVSystem (Ventilation System)
- Analysis:** AHU Ventilation S...
- Start Date:** 11/15/2018
- Notes Summary:** Excessive reheating.

Details: Daily AHU Ventilation System analysis data for Bidg2_VAVSystem performed on 11/15/2018.

- Analysis Name:** AHU Ventilation System
- Client Name:** Demo Site
- Building Name:** South Boston
- Equipment Name:** Bidg2_VAVSystem
- Associated Equipment:** show associated equipment
- Points:** show points
- Associated Equip. Points:** show associated equipment points
- Direct Link:** <https://clockworks.kgsbuildings.com/Diagnostics.aspx?cid=79&aid=93&eid=24498&etid=1566&cid=31&bid=1236&rng=DAILY&sd=11/15/2018>
- Date:** 11/15/2018
- Display Interval:** Daily
- Cost Savings:** \$0
- Comfort Priority (0-10):** 0
- Energy Priority (0-10):** 2
- Maintenance Priority (0-10):** 0

Notes: **OPPORTUNITY: EXCESSIVE REHEATING**

- Excessive reheating was occurring in the zone units for 4.4 hrs continuously over the analysis period, although the AHU supply air temperature is already above 60 F.

Suggested Actions:

- Consider raising the AHU supply air temperature closer to the lowest VAV supply temperature.
- Check that the zone unit minimum air flow setpoints are not too high.

VENTILATION SYSTEM INFORMATION

- This diagnostic detected 17 zone units in the ventilation system.
- 17 zones were reheating at some point over the diagnostic period (out of 17 possible).

Faults and opportunities investigated by this diagnostic:

EMIS Costs and Benefits

EMIS Capability	Key Uses	Costs	Whole-Building Energy Savings
EIS	<ul style="list-style-type: none"> ▪ Benchmarking & energy dashboard ▪ Building load analysis ▪ Energy anomalies alert ▪ Peak demand reduction ▪ Automated M&V 	\$\$ Base: \$0.01/sq ft Annual: \$0.01/sq ft	3% median, portfolio-level \$0.03/sq ft
FDD			
ASO			

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FDD	<ul style="list-style-type: none"> · System-level performance tracking (KPIs) · Automated fault detection & notification · Fault causes identification · Issues tracking 	\$\$\$ Base: \$0.06/sq ft Annual: \$0.02/sq ft	9% median, portfolio-level \$0.24/sq ft
ASO			

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ASO	<ul style="list-style-type: none"> · Optimal HVAC settings prediction 	\$\$\$\$ Higher than FDD	Limited Data

EMIS Costs and Benefits

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ASO	<ul style="list-style-type: none"> ▪ Optimal HVAC settings pre 	Limited Data



DOE-sponsored Fault Prevalence Study

- Which HVAC faults are most often observed to be present?
- How many faults occur each month for a given building?





- 3,660 AHUs
- 53,865 ATUs



- 7,974 RTUs

What does our study population represent?

All U.S. Commercial buildings

All U.S. Commercial buildings with Fault Detection & Diagnostics (FDD)

FDD-equipped buildings within study data set

HVAC faults in studied buildings

AHU/ATU/RTU faults in studied buildings

AHU/ATU/RTU faults reported by FDD

True faults

False alarms



Data Unification Steps

DiagnosticID	Date	EID	AID	ResultID	CFP	ENP	MNP
1441052425	2019-12-31T00:00:00	139193	27	1	0	10	0
374317463	2019-12-31T00:00:00	139234	65	2	0	10	0
728521891	2019-12-31T00:00:00	139186	52	6	0	10	6
431177347	2019-12-31T00:00:00	135309	86	8	0	2	6
79265722	2019-12-31T00:00:00	139194	27	10	0	2	0
402670674	2019-12-30T00:00:00	139193	27	1	0	10	0
1453381484	2019-12-30T00:00:00	139186	52	6	0	10	6

Fault name raw	Number of record	Percentage of record	Fault name mapped	Fault type
Stuck Zone Air Relative Humidity Sensor	212015	16.7%	no	no
Stuck Outside Air Temperature Sensor	186060	14.6%	RTU-OAT-Frozen	CB
SAT Too High Condition	124078	9.8%	RTU-SAT-Abnormal	BB
Economizer is Disabled during Economizing Conditions	91223	7.2%	RTU-Eco-Set-Fault	CB
Free Cooling Setpoint Not Met - SAT Too Warm	80999	6.4%	RTU-Spt-Fault	CB
Zone Air Temperature Sensor C2 Failure: Reading less than 45	79564	6.3%	VAVUNIT-ZAT-Unspecified	CB
Zone Air Dew Point Reading Exceeds 53	49845	3.9%	VAVUNIT-ZAT-Unspecified	CB
Zone Air Relative Humidity Sensor Failure: Reading less than 5%	37090	2.9%	no	no
Outside Air Ratio Below Design at Minimum Position	33790	2.7%	no	no
Setpoint Not Met - ZAT - Over Cooling	33401	2.6%	VAVUNIT-ZAT-Abnormal	BB

bldg_id	equip_id	equip_type	date	fault
4	58	AHU	20190401	Control-Sequence-Setting
4	57	AHU	20190401	Heating-Heating-Abnormal
4	48	AHU	20190401	Cooling-Cooling-Abnormal
4	48	AHU	20190401	Cooling-Coil_valve-Leakage
4	58	AHU	20190401	Cooling-Coil_valve-Leakage
4	49	AHU	20190401	Heating-Coil_valve-Leakage
4	57	AHU	20190401	Heating-Coil_valve-Leakage
4	282	ATU	20190401	Reheat-Coil_valve-Leakage
4	254	ATU	20190401	Reheat-Coil_valve-Leakage
4	48	AHU	20190401	Heating-Coil_valve-NA
4	53	AHU	20190401	NA-Coil_valve-Hunting

1. Raw data received from partners

- Reported faults
- Building/equipment metadata
- Fault definitions



2. Mapping

- AHU/ATU/RTU faults renamed per taxonomy
- Anonymized metadata files



3. Binary Daily Fault (BDF) data

- Faults reported by date, by equipment ID, by building ID
- Base unit of analysis for study

Analysis Unit: Fault_Day

1 Fault_Day = presence of a specific fault on a specific piece of equipment on a specific date

Multiple faults may be observed on a given date

17,939,843

Fault_Days in the study dataset

Faults

28 Components/Parameters

3
Equipment
Types

- AHU
- ATU
- RTU

16 System
Locations

- Control
- Cooling
- Economizer
- Exhaust_air
- Heating
- Mixed_air
- Outside_air
- Preheat
- Return_air
- Supply_air
- Discharge_air
- Reheat
- Zone
- Compressor
- Condenser
- NA

- Schedule
- Sequence
- Setpoint
- Coil
- Coil_valve
- Coil_valve_control
- Airflow
- Temperature
- Temperature_sensor
- Airflow_sensor
- Damper
- Damper_control
- Relative_humidity
- Fan_control
- Differential_pressure
- Fan
- Filter
- Static_pressure_setpoint
- Temperature_setpoint
- Cooling_heating_control
- Pressure_sensor
- Sensor
- Relative_humidity_sensor
- CO2
- CO2_sensor
- Control_board
- Dewpoint_sensor
- NA

13 Fault
Modes

- Setting
- Fouling
- Leakage
- Stuck
- Hunting
- Abnormal
- Block
- Rule_abnormal
- Simultaneous
- Drift
- Frozen
- Malfunction
- NA



245

Faults per Building per Month
(AHUs and ATUs)

27 - 274

Interquartile Range



3.0

Faults per AHU per Month

1.2

Faults per ATU per Month

How common is AHU fault 'x'?

AHU #1	0	0	0	0	1	20% Time Faulted
AHU #2	1	1	1	1	0	80% Time Faulted
AHU #3	1	0	1	0	1	60% Time Faulted
AHU #4	0	0	0	0	0	0% Time Faulted

75%

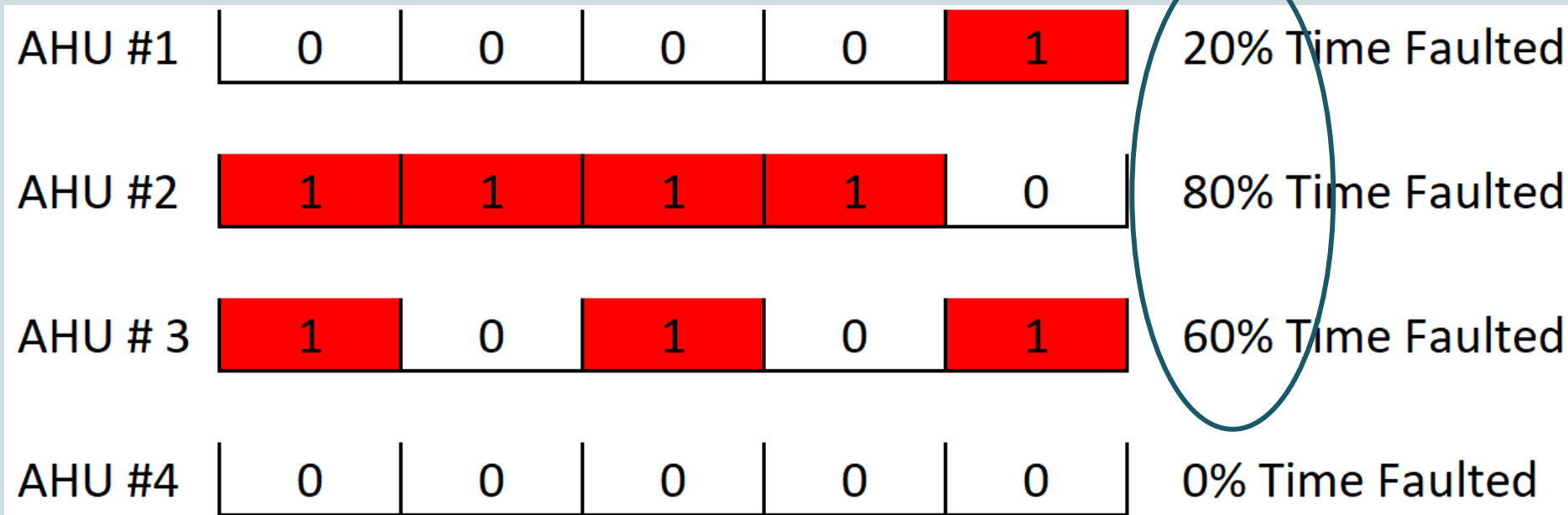
Of AHUs see this fault (Pct_Affected)

For equipment that sees the fault, what portion of their time is faulted?

53%

Mean Percent Time Faulted (MPTF_Affected)

How common is AHU fault 'x'?



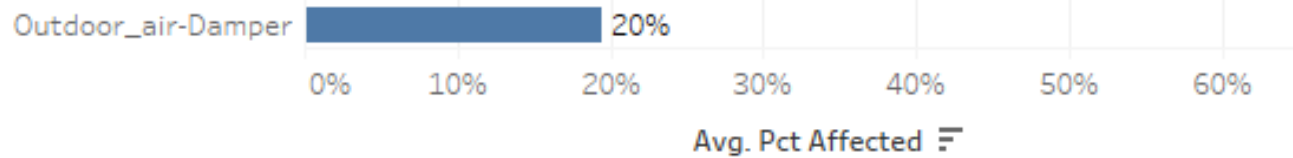
75%

Of AHUs see this fault (Pct_Affected)

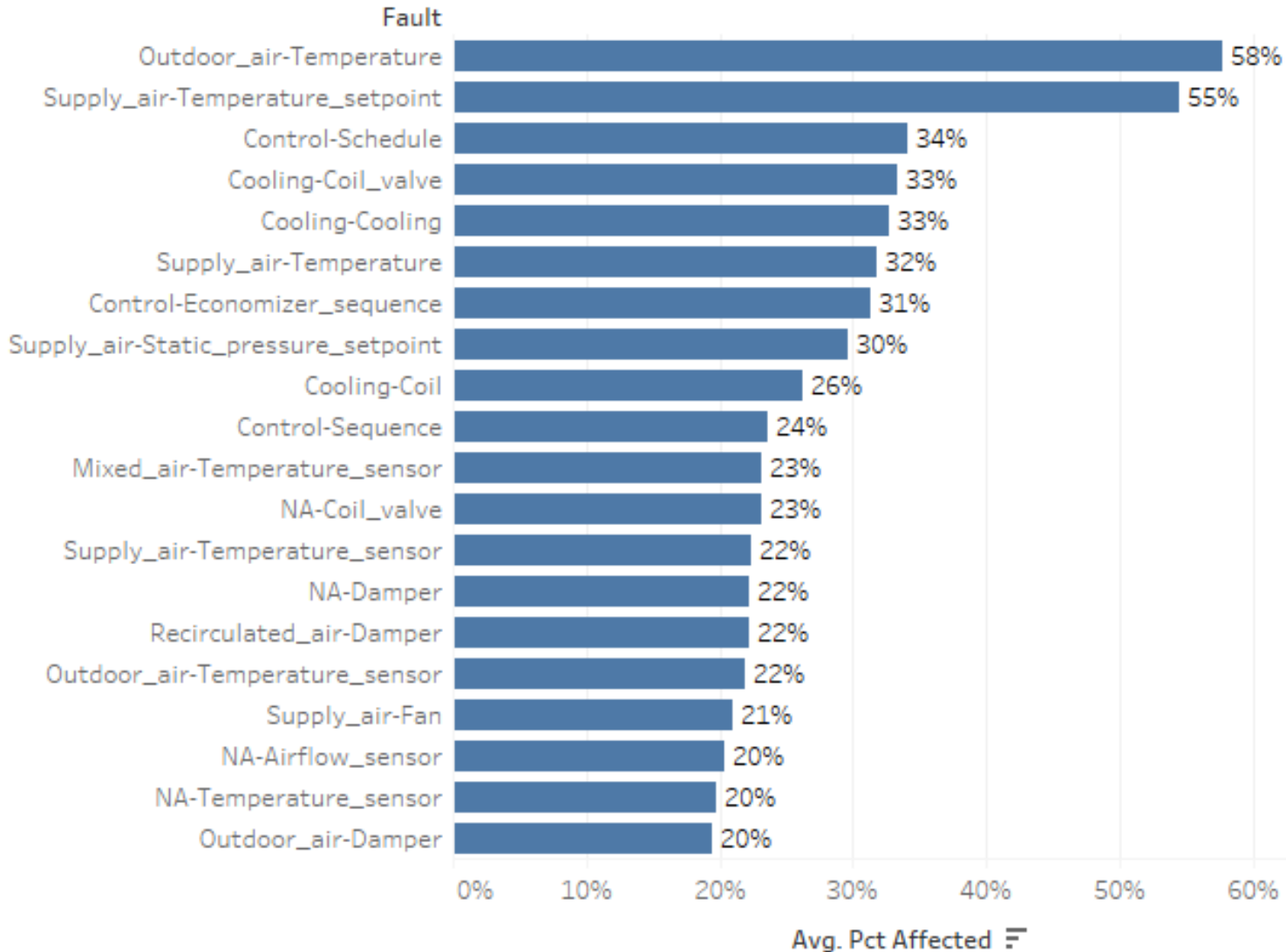
AHUs



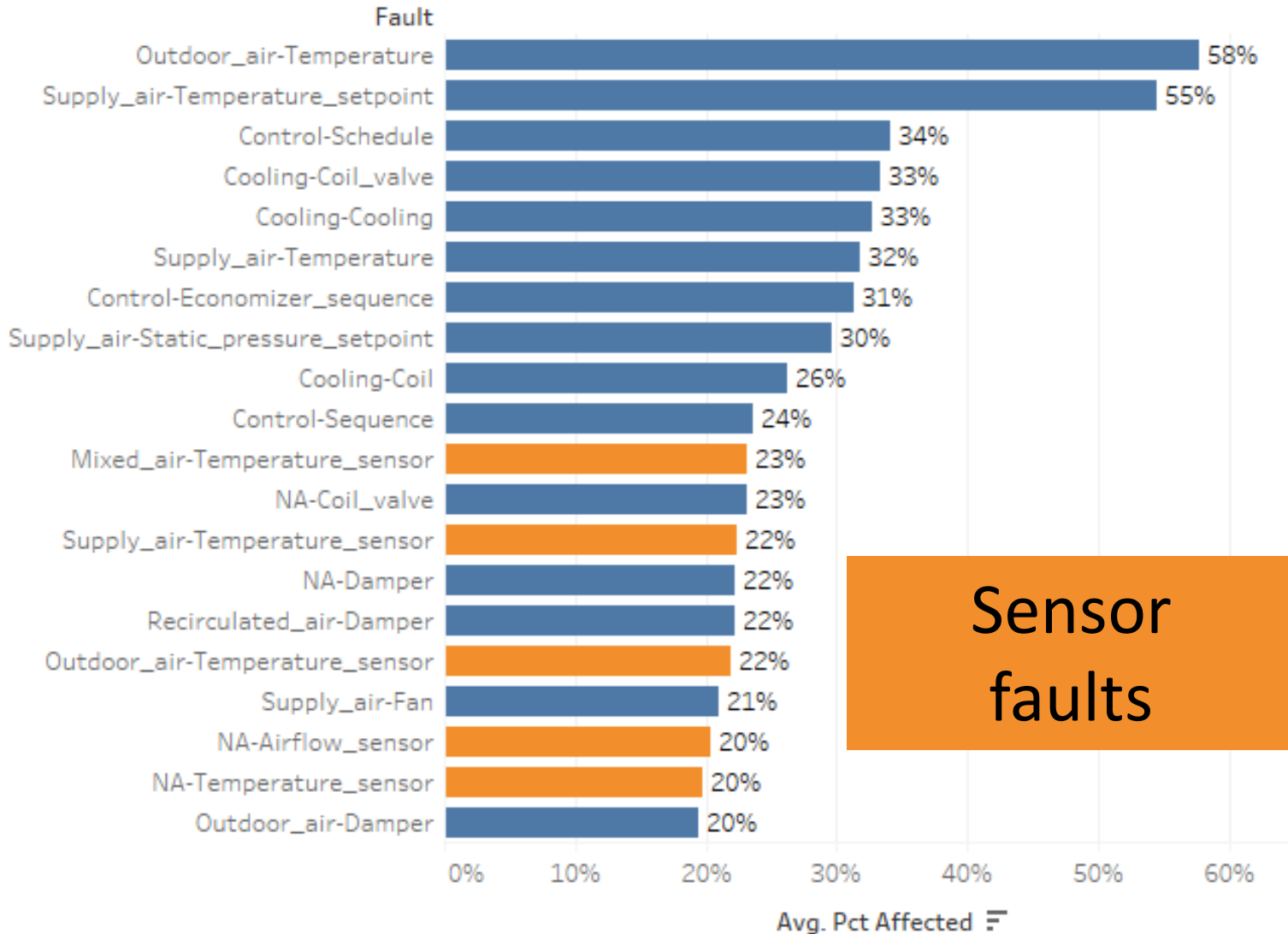
Percent of AHUs Affected



Percent of AHUs Affected



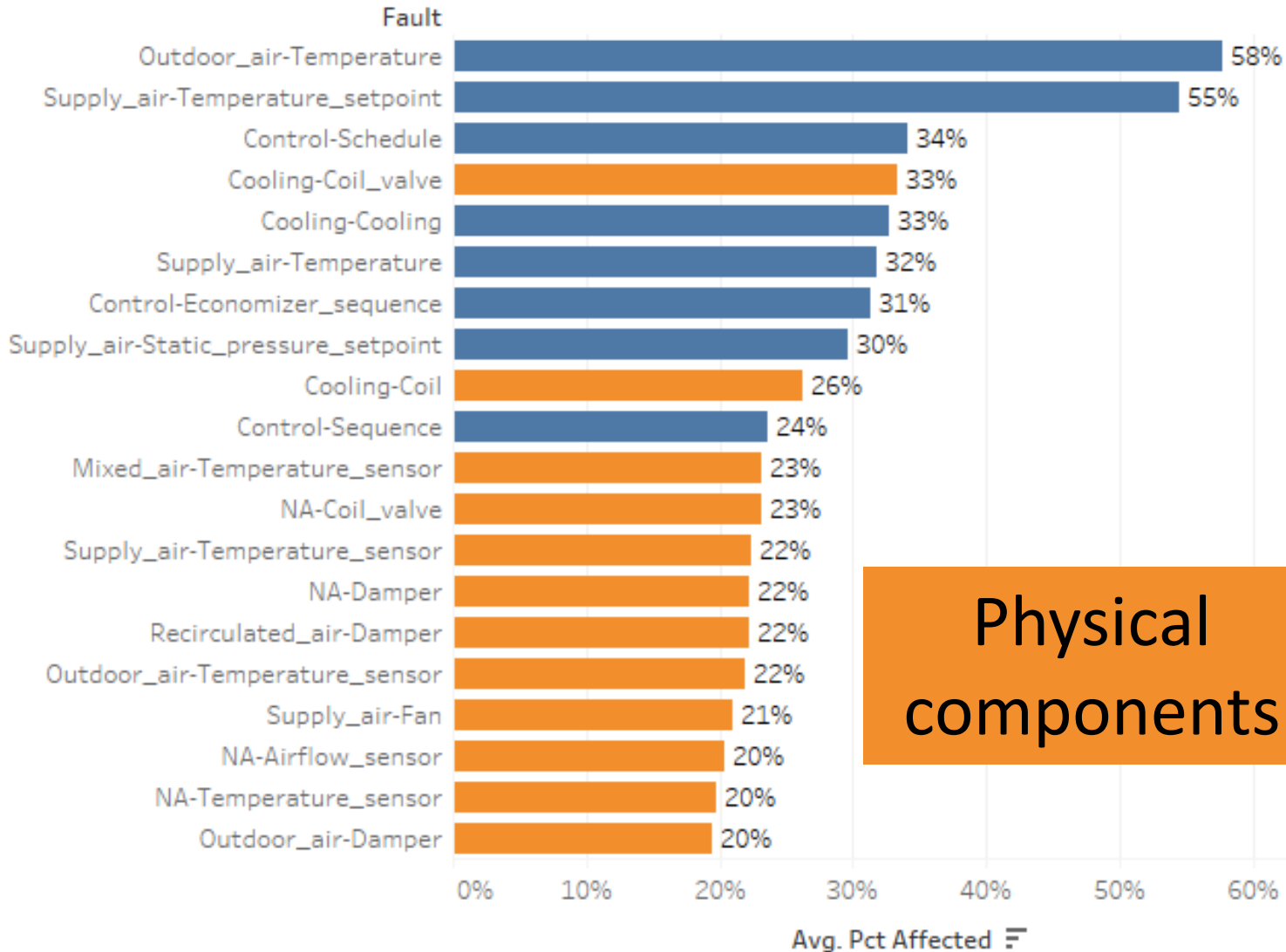
Percent of AHUs Affected



Sensor faults



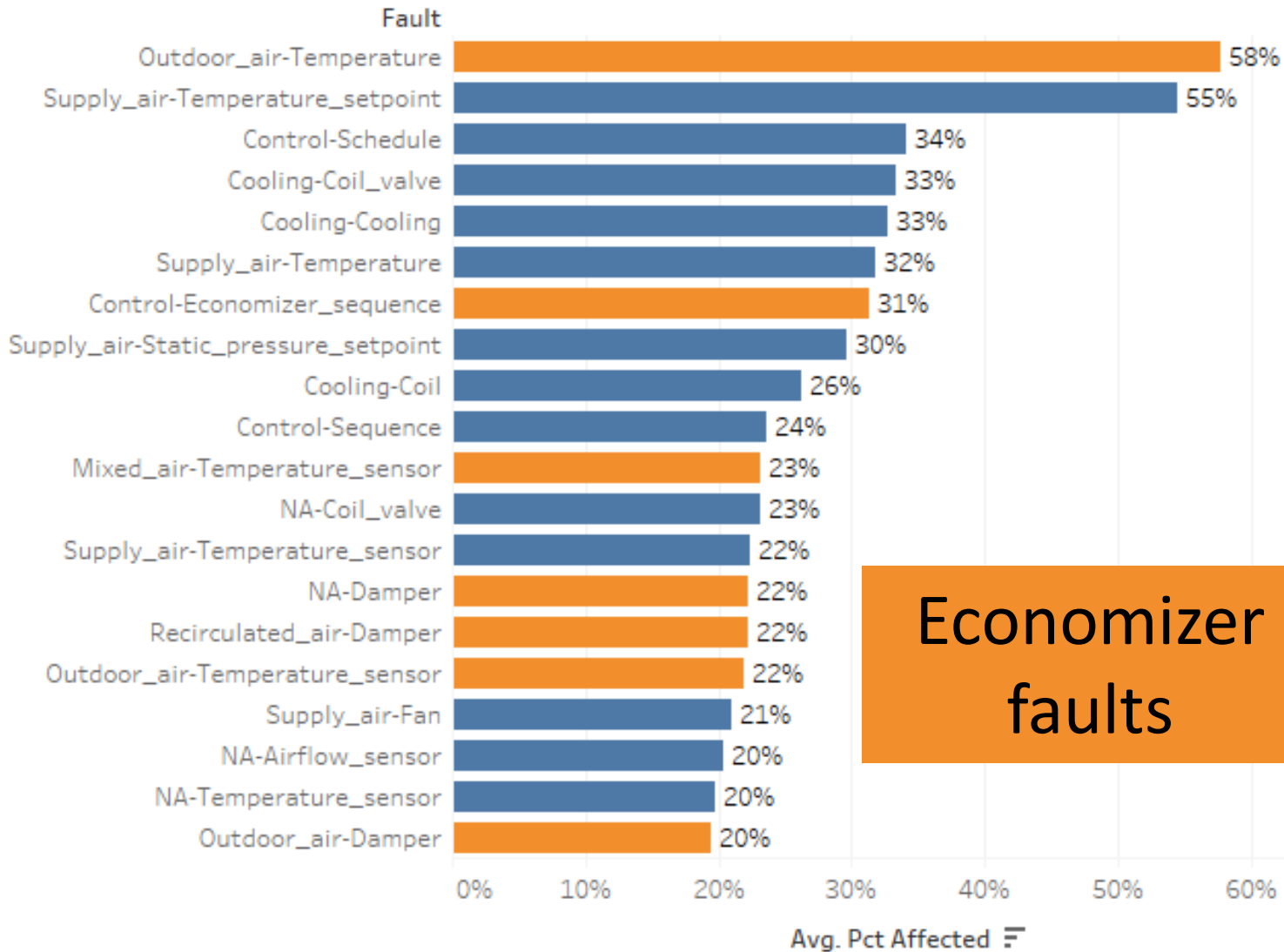
Percent of AHUs Affected



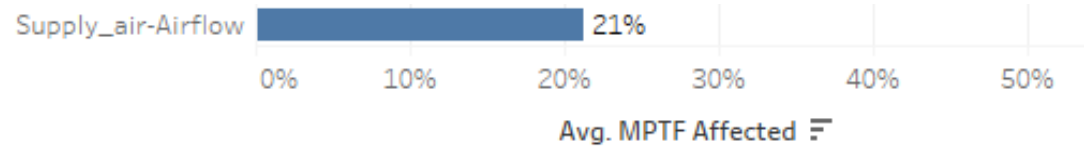
Physical
components



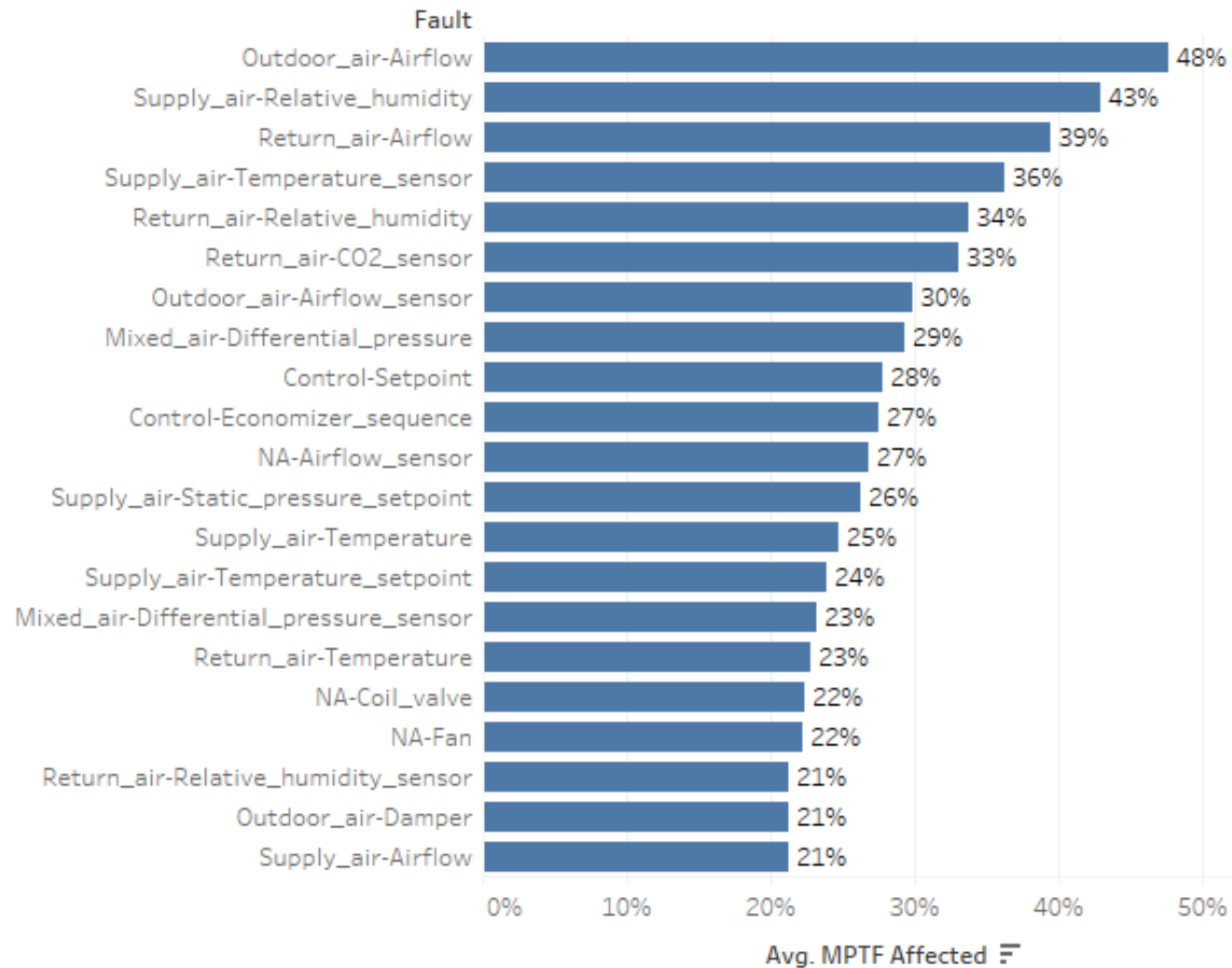
Percent of AHUs Affected



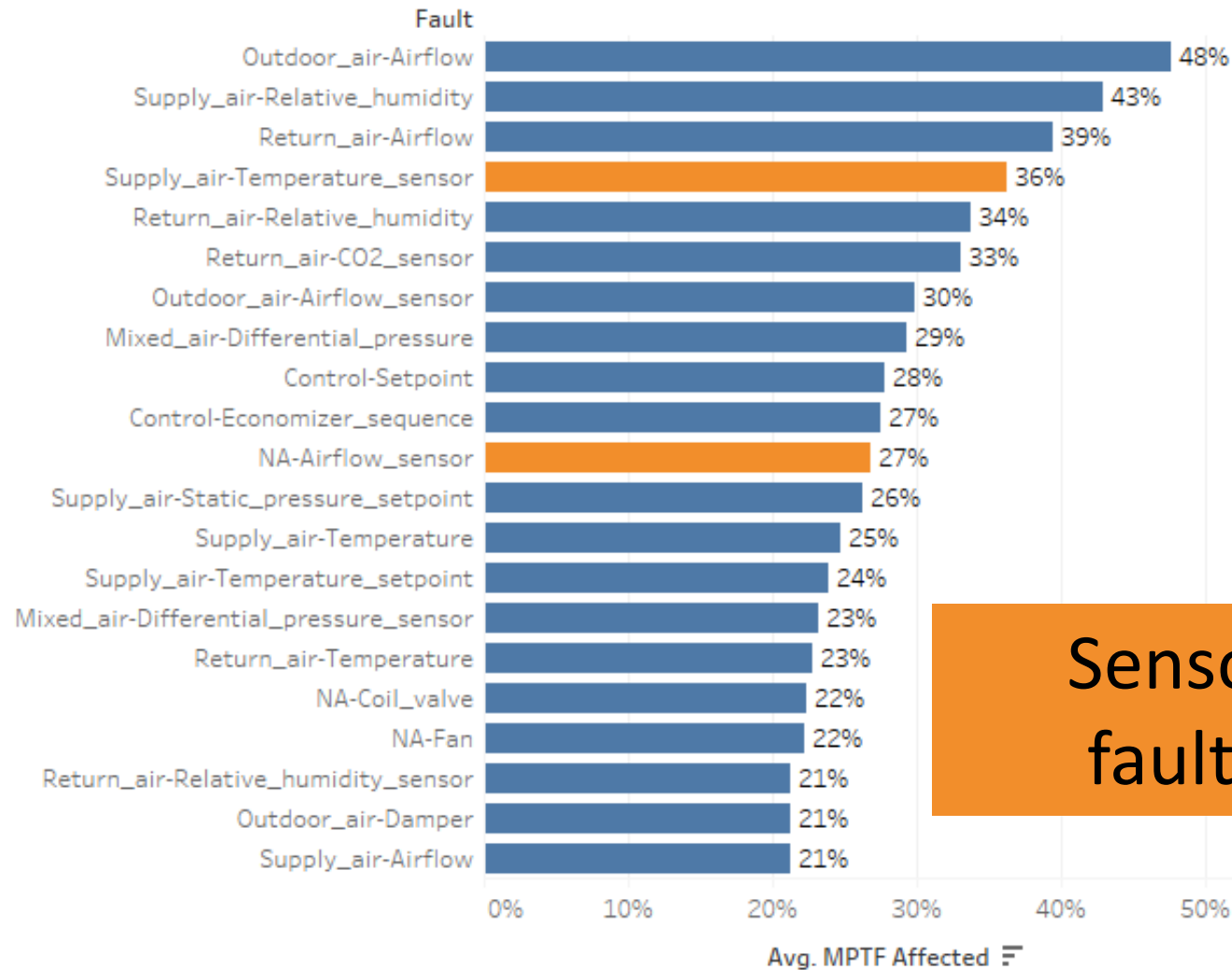
Mean Percent Time Faulted



Mean Percent Time Faulted



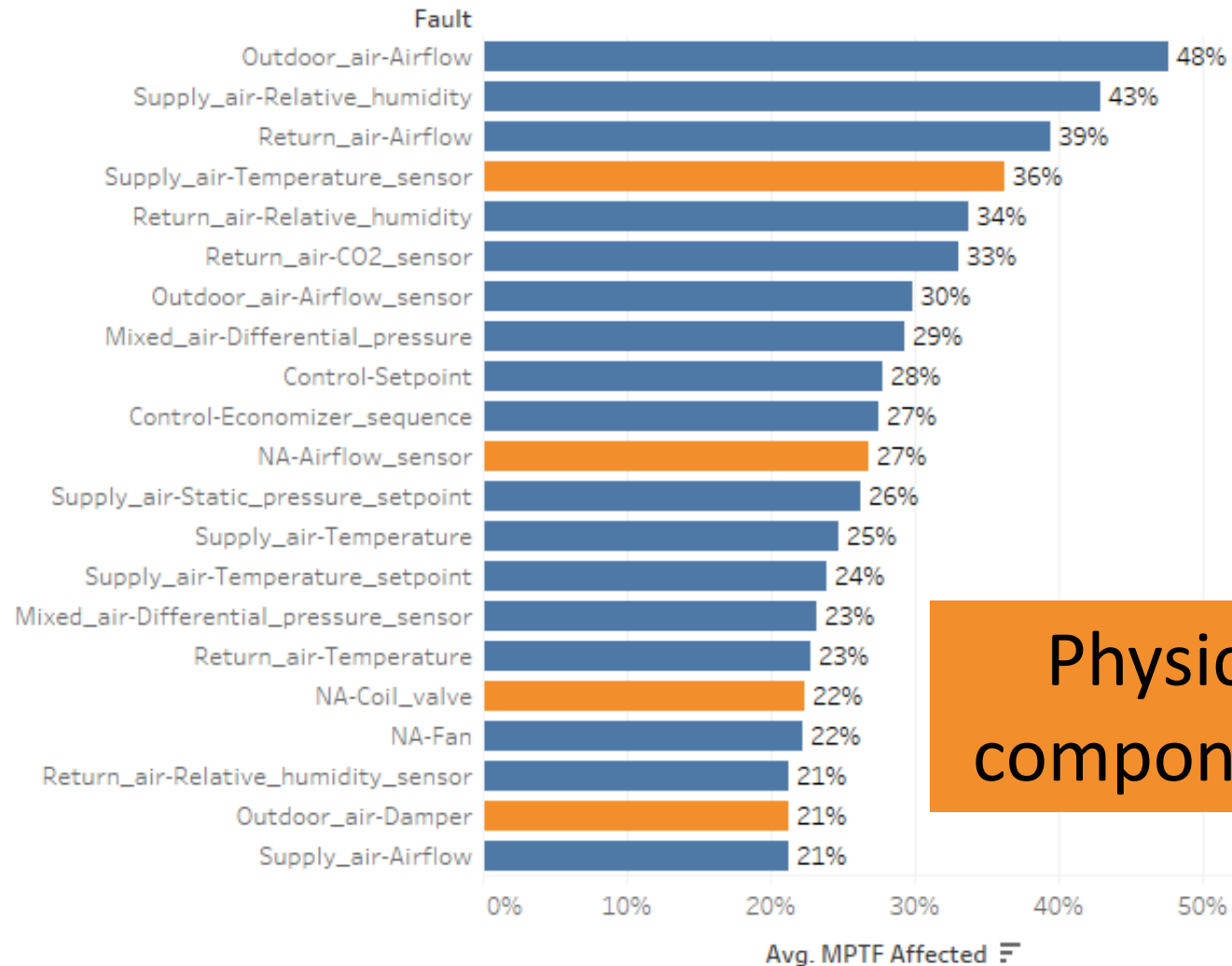
Mean Percent Time Faulted



Sensor
faults



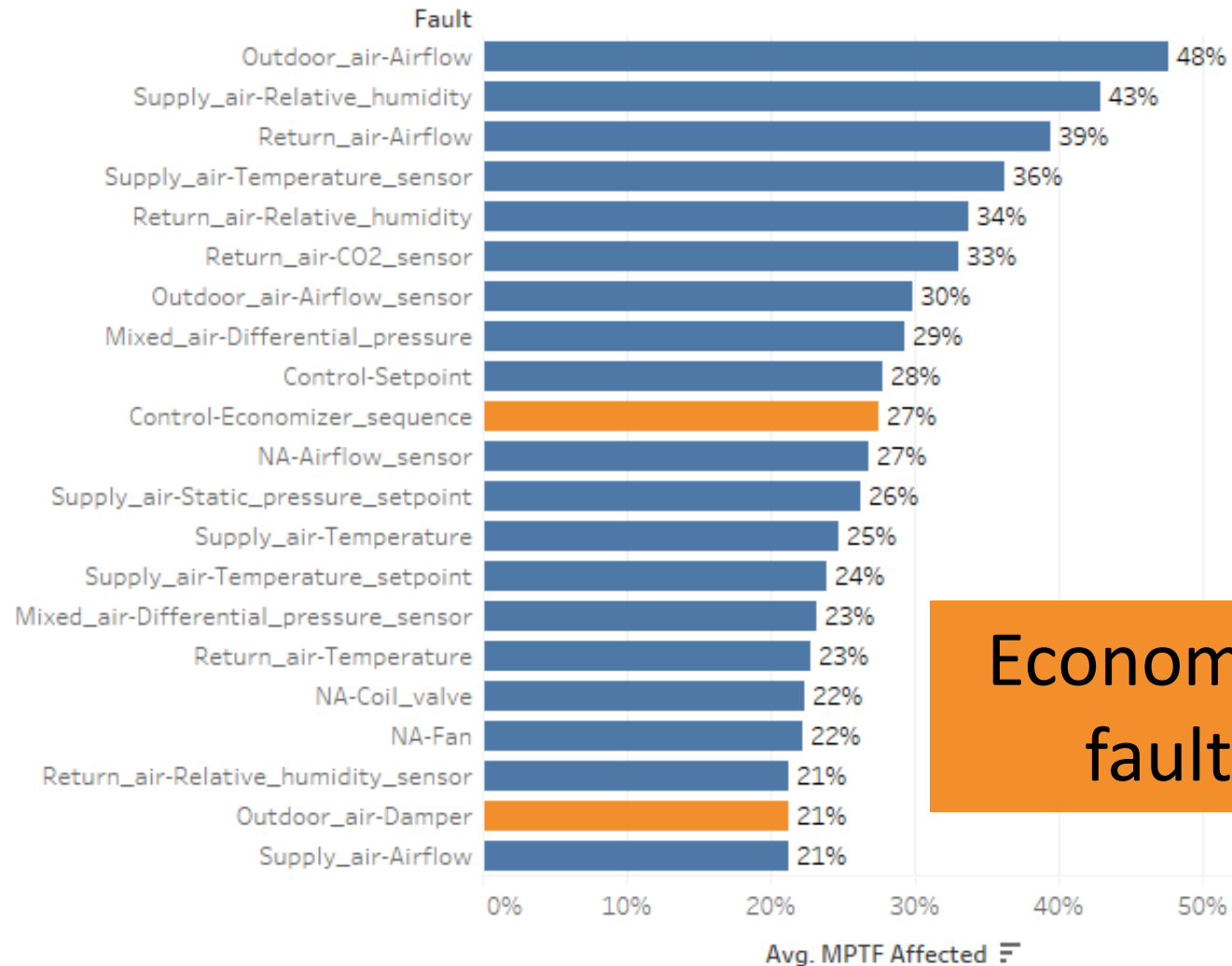
Mean Percent Time Faulted



Physical
components

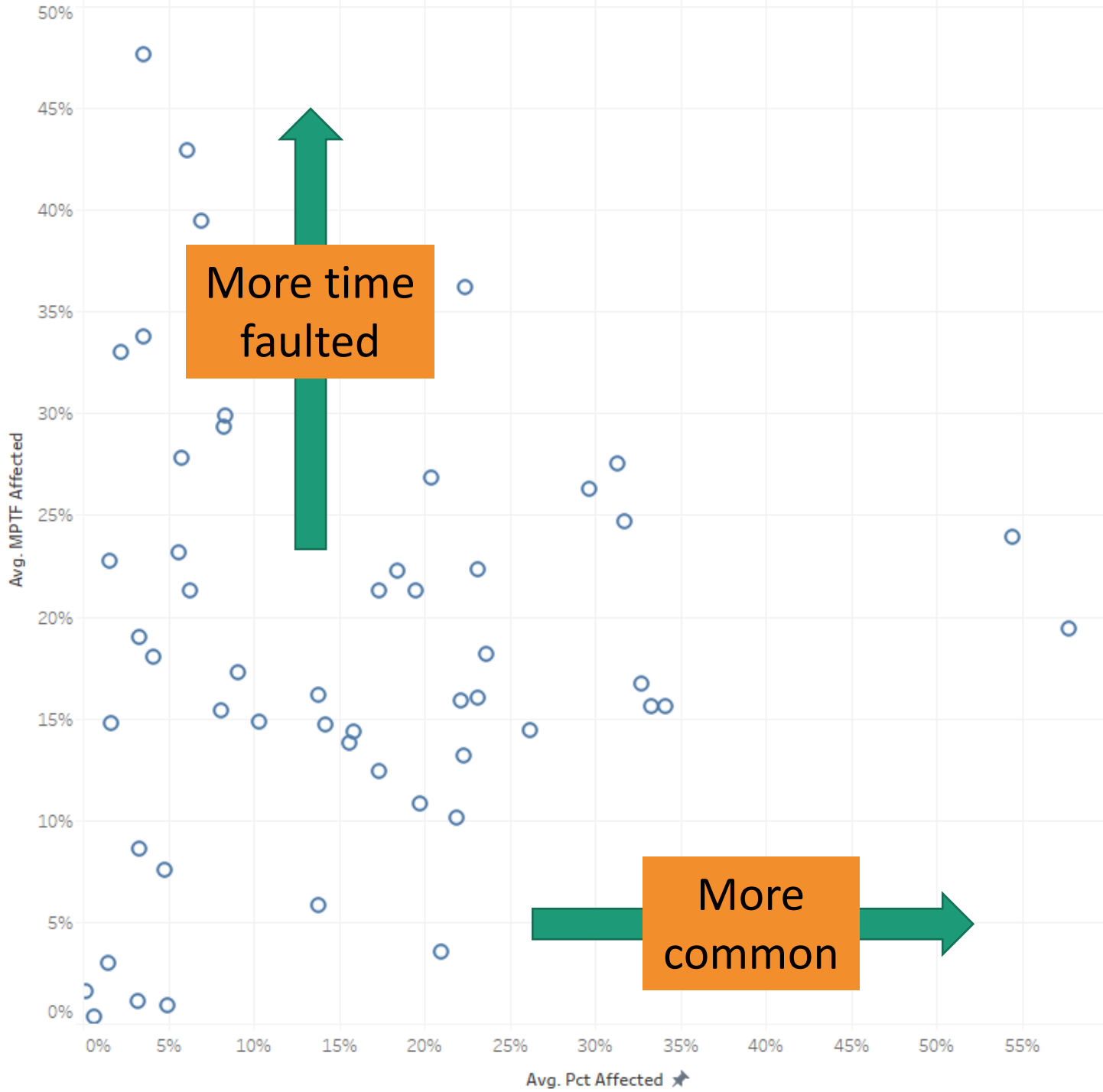


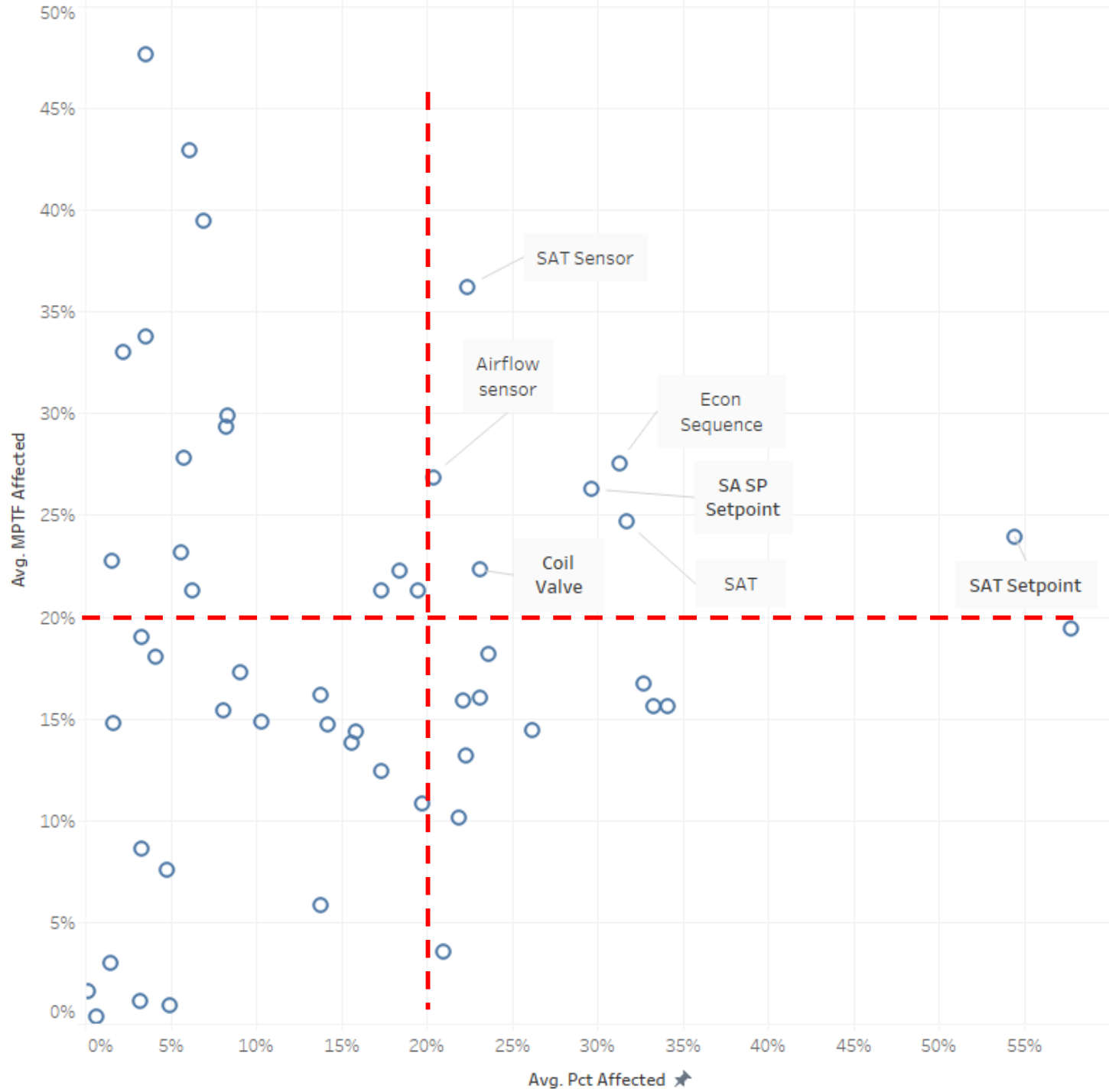
Mean Percent Time Faulted



Economizer
faults



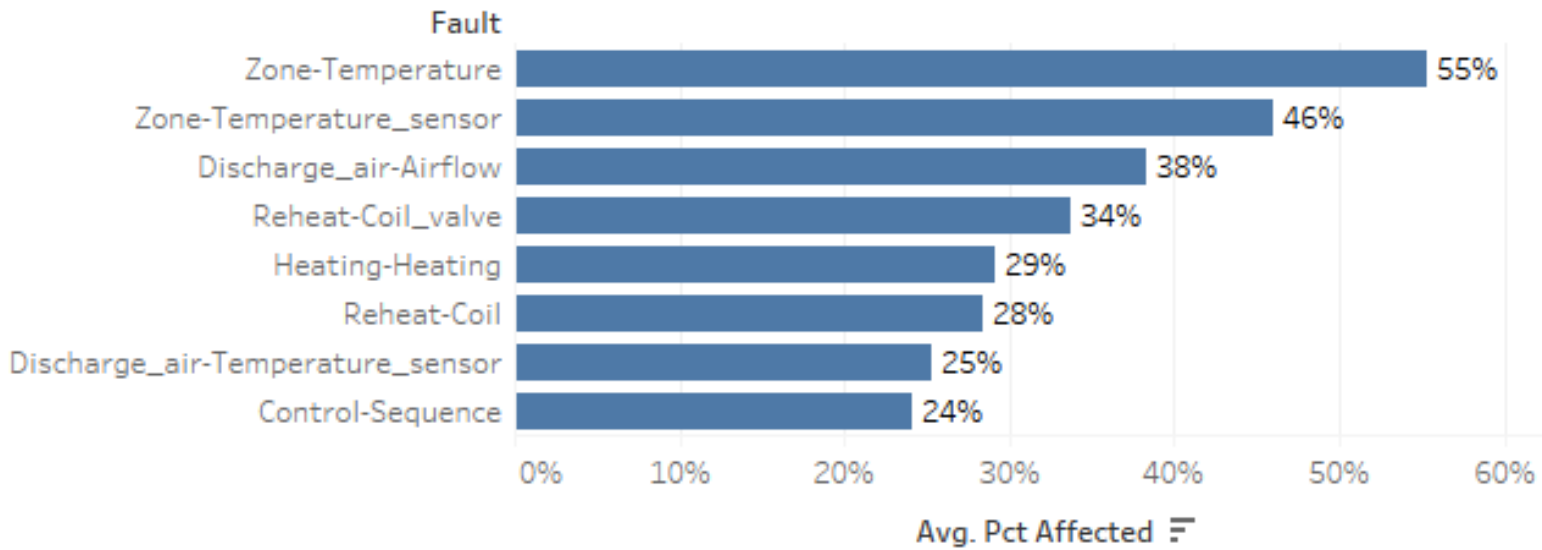




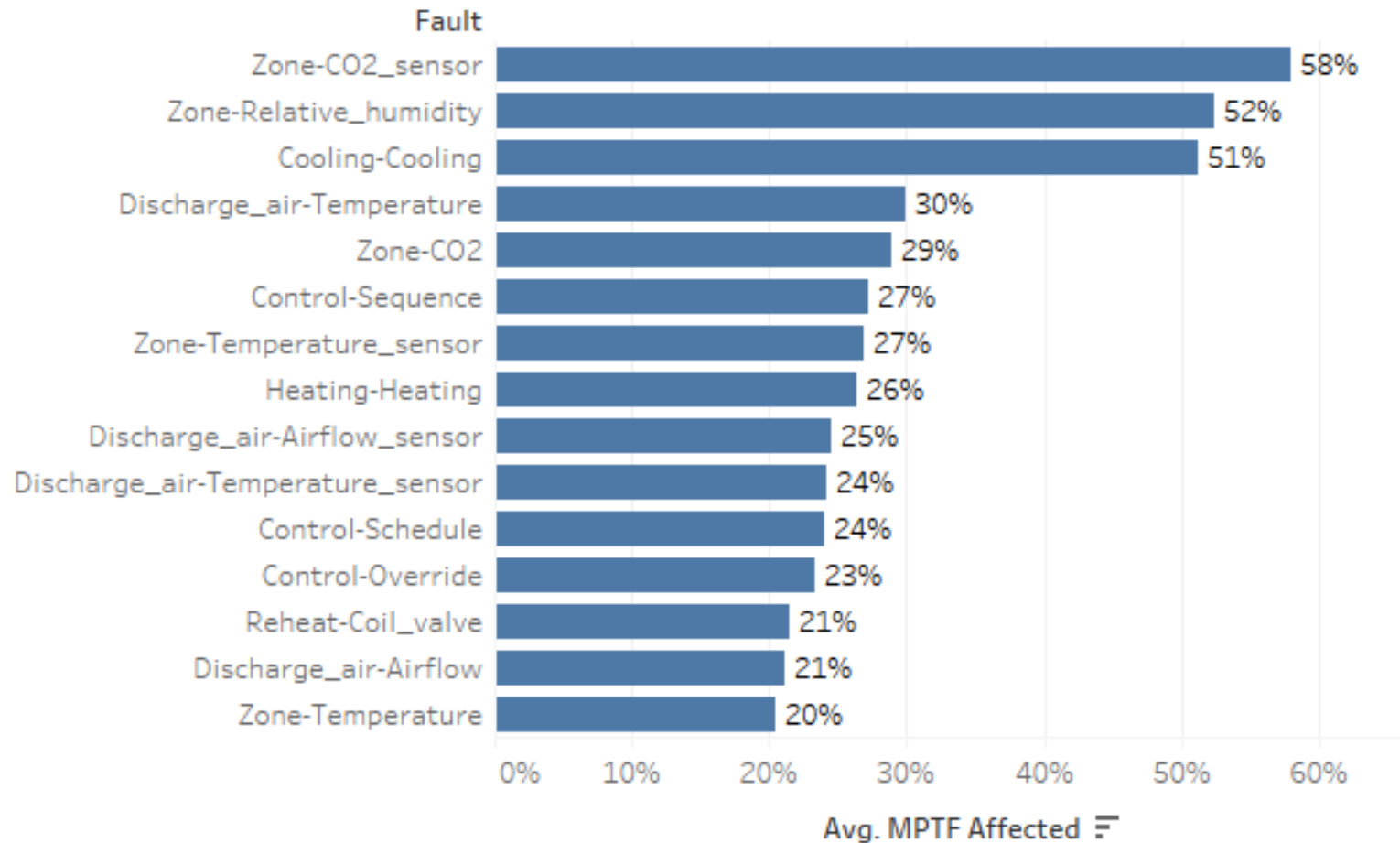
ATUs

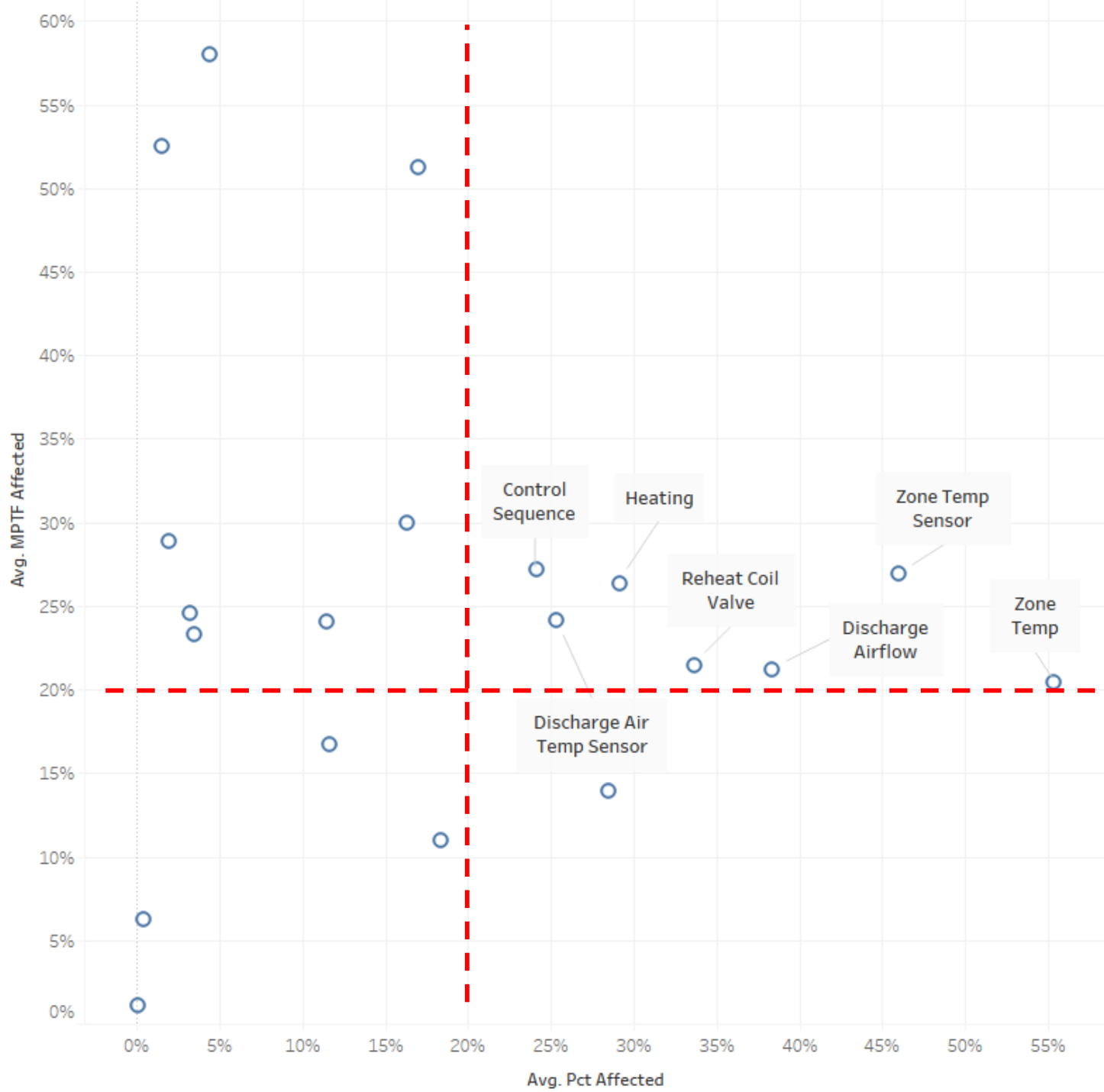


Percent of ATUs Affected



Mean Percent Time Faulted

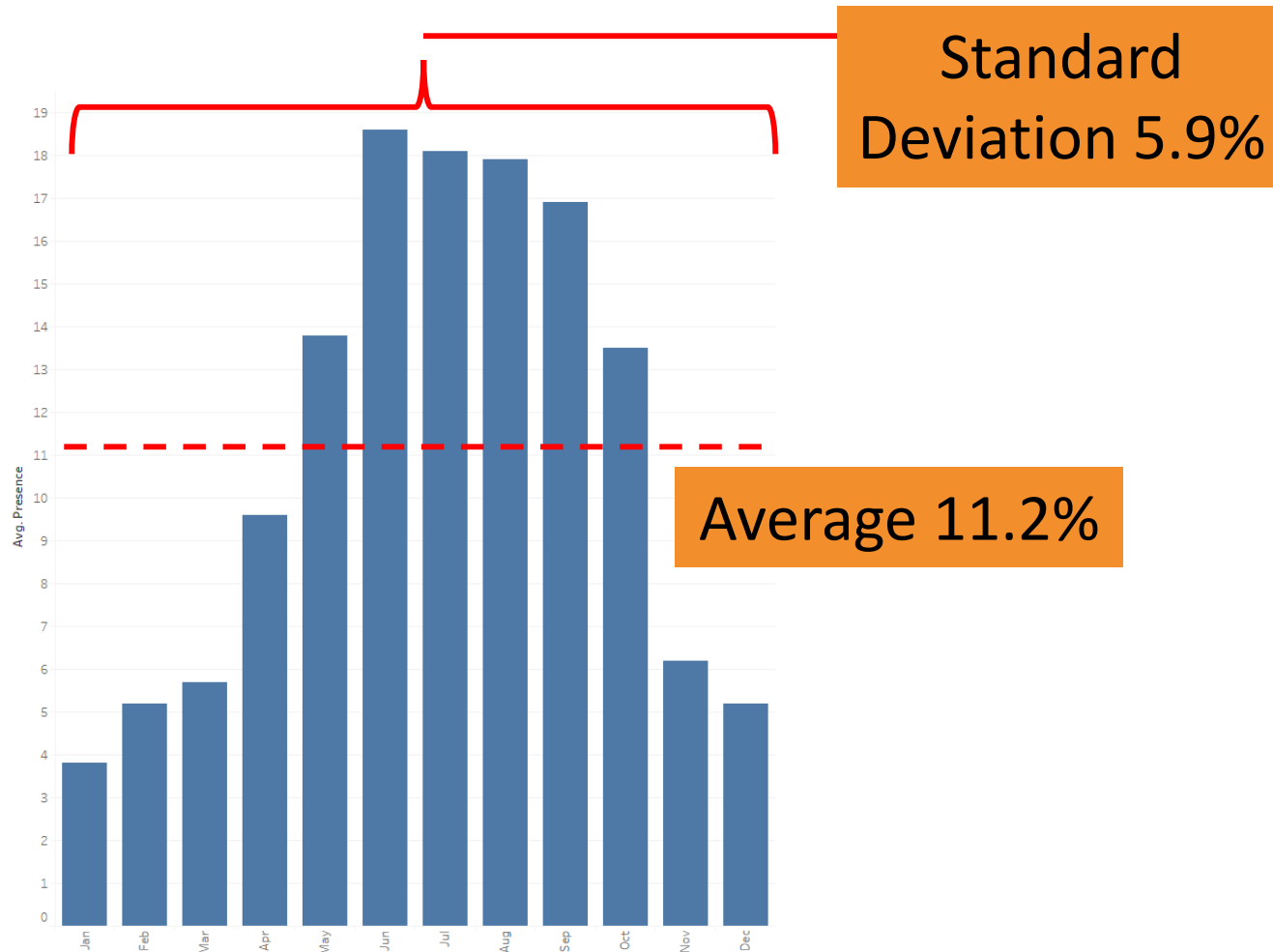




Drivers



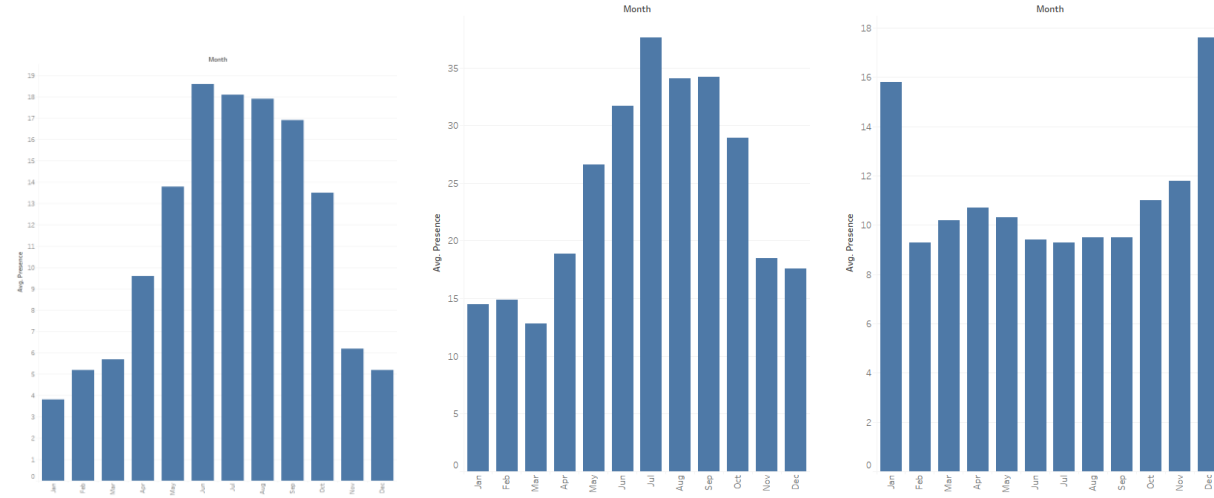
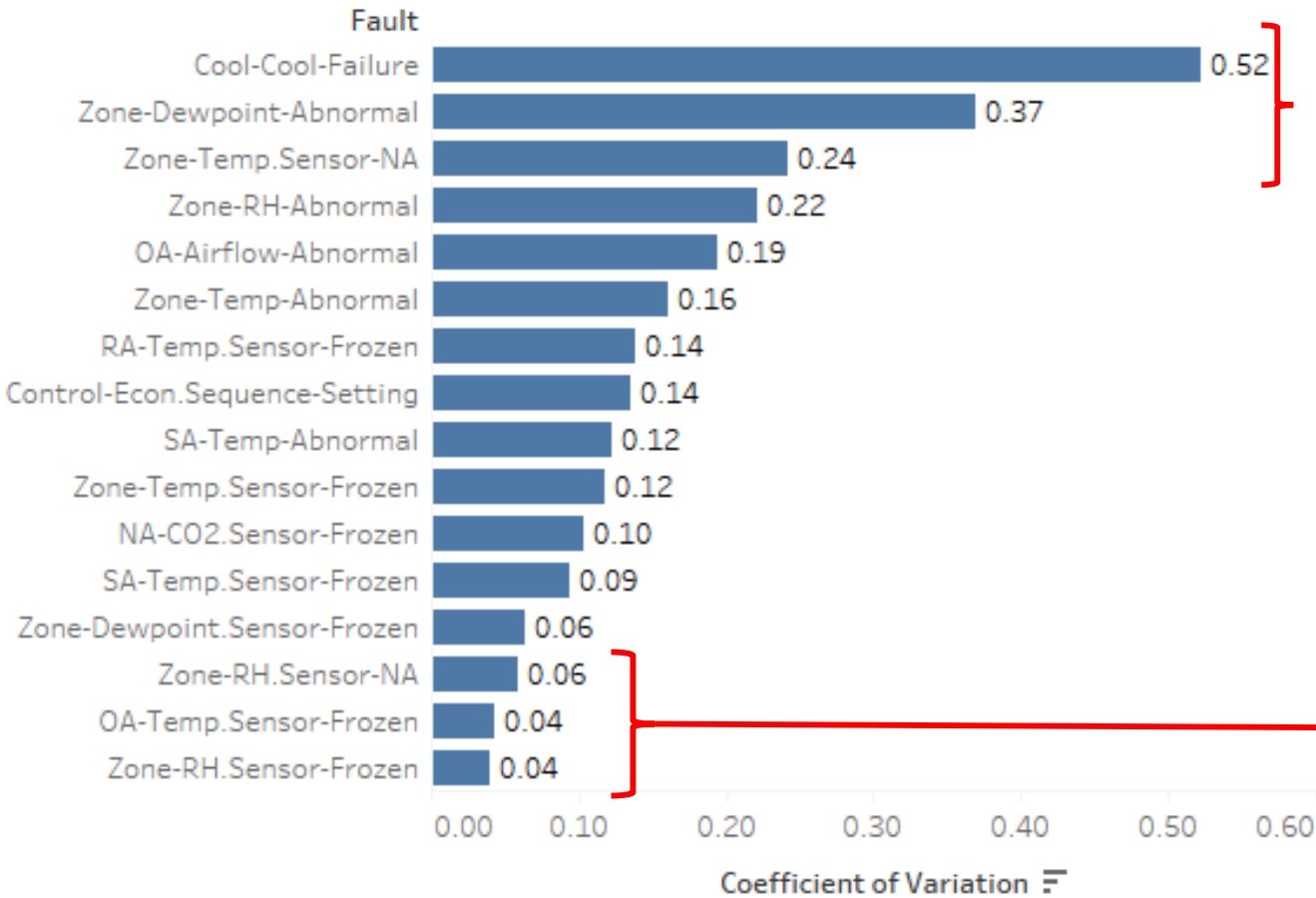
Seasonal Variation (Example: Cooling Failure)



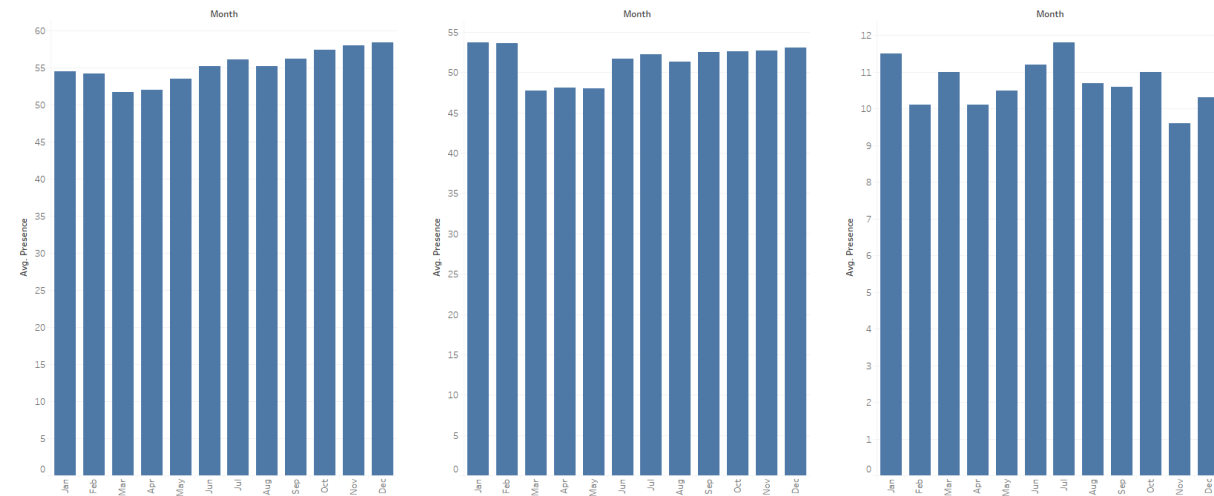
Monthly Fault Presence

- Coefficient of Variation
 $5.9\% \div 11.2\% = 0.52$
- Higher COV means more seasonal variation

Seasonal Variation

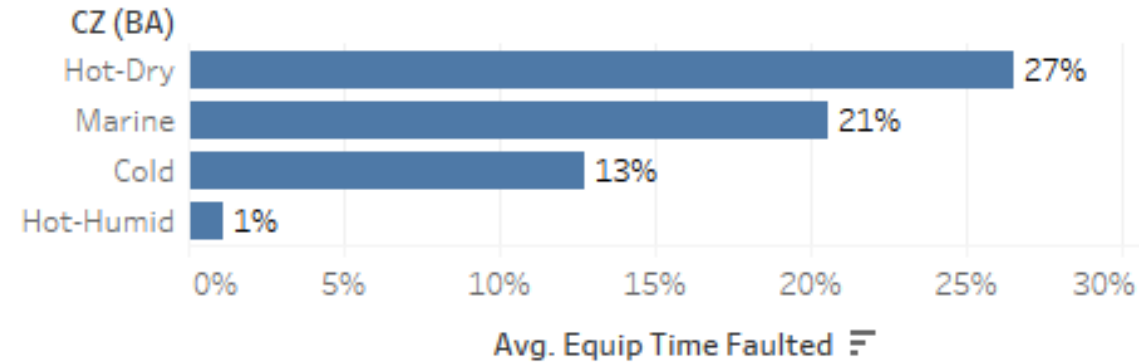
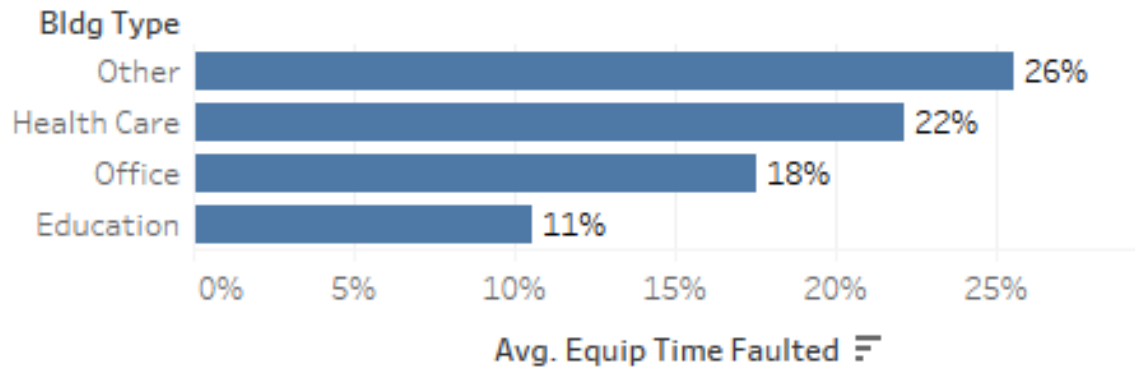


Top 3 faults for seasonal variation



Bottom 3 faults for seasonal variation

Building Type & Climate Zone



Critical Process / Design Needs

- Commissioning
- Improved sensing
- Methods to prioritize faults by impact type and impact magnitude
- Improved root cause diagnostics
- Automating the correction of faults where possible





Areas for Further Study

- Expansion to more equipment types
- Persistence study
- More data!

