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

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CxEnergy 2022

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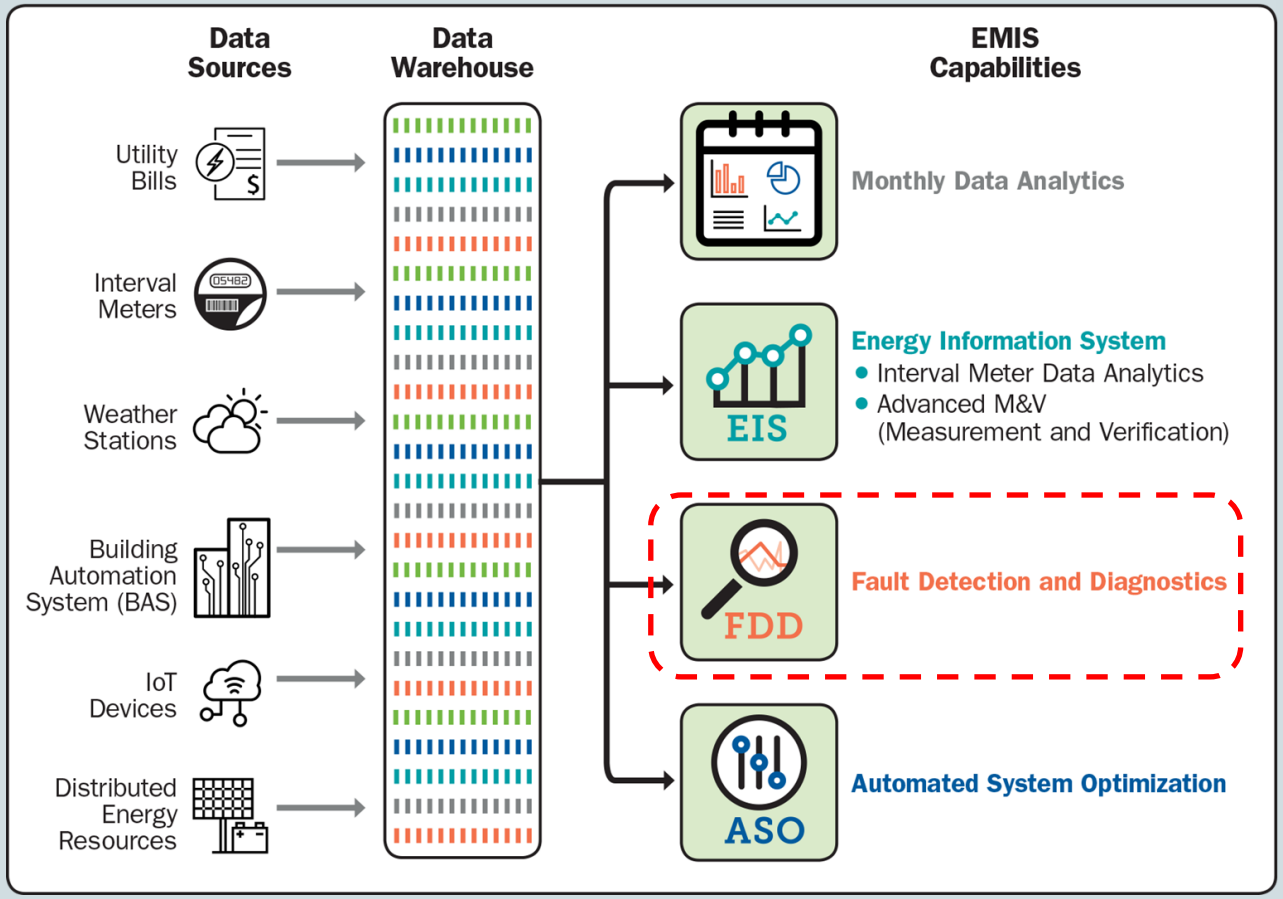
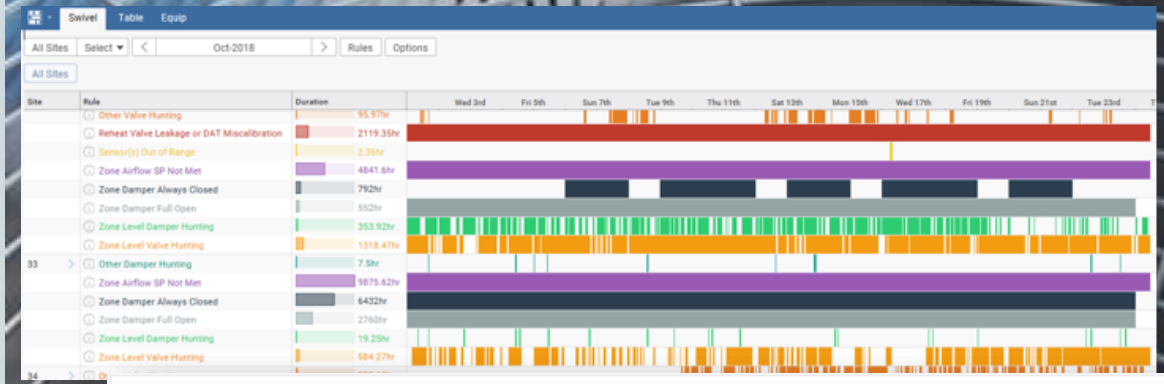
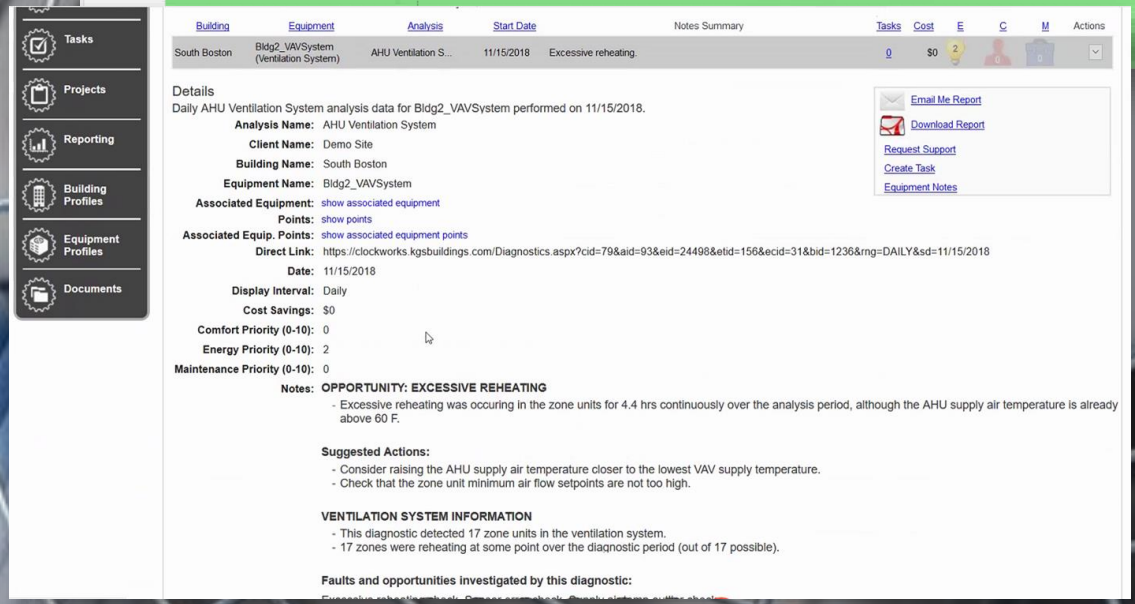
Energy Management & Information Systems (EMIS)







EMIS Costs and Benefits

EMIS Capability	Key Uses	Costs	Whole-Building Energy Savings
EIS	▪ 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	▪ System-level performance tracking (KPIs) ▪ Automated fault detection & notification ▪ Fault causes identification ▪ Issues tracking	$$$ Base: $0.06/sq ft Annual: $0.02/sq ft	9% median, portfolio-level $0.24/sq ft
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ASO	▪ Optimal HVAC settings prediction	$$$$ Higher than FDD	Limited Data

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EIS	· Benchmarking & energy dashb · Building load analysis · Energy anomalies alert · Peak demand reduction · Automated M&V	3% median, portfolio-level $0.03/sq ft
FDD	· System-level performance tr · Automated fault detection & · Fault causes identification · Issues tracking	9% median, portfolio-level $0.24/sq ft
ASO	· Optimal HVAC settings pre	Limited Data

Link

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?

BERKELEY LAB

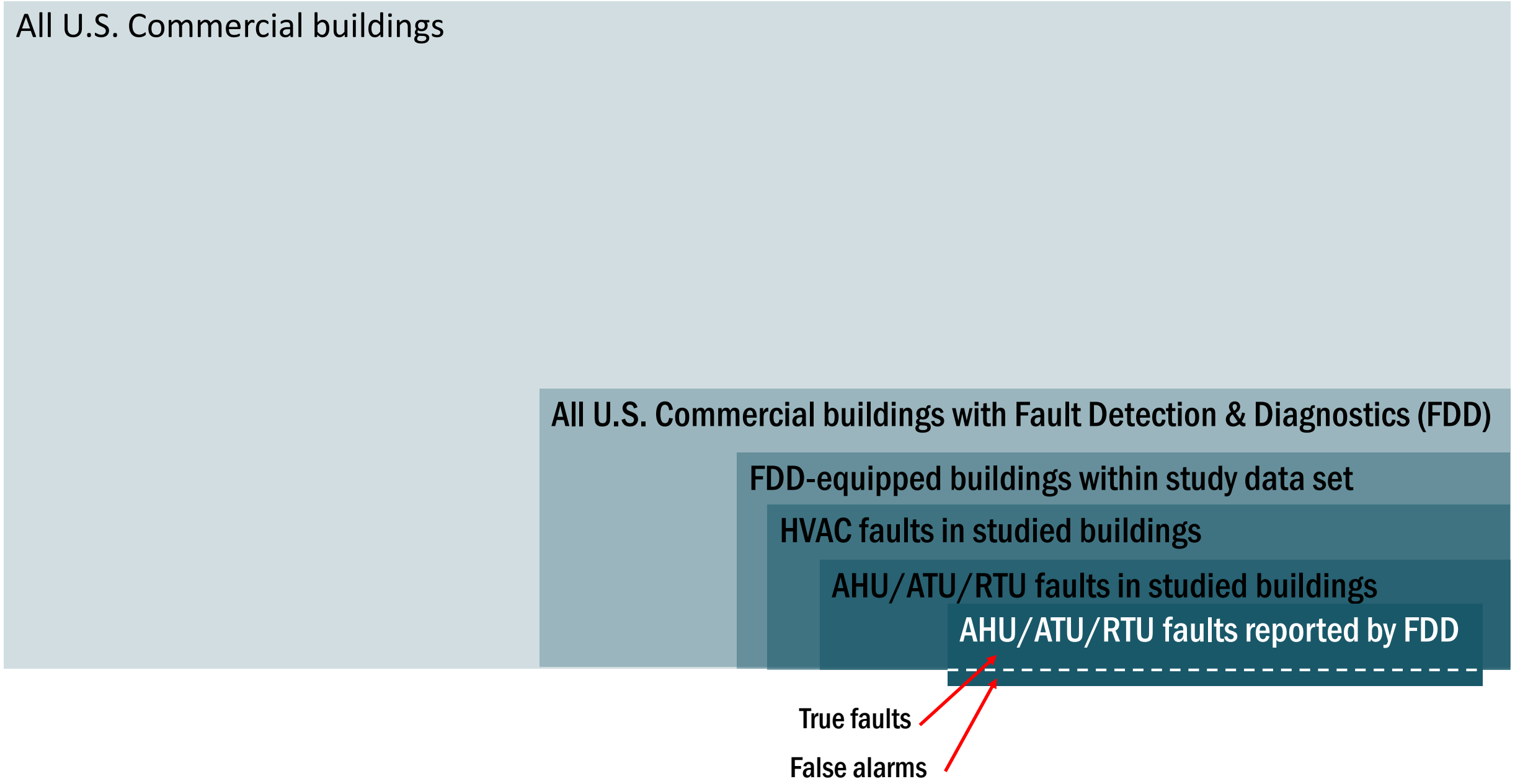
Pacific Northwest NATIONAL LABORATORY

UNIVERSITY of NEBRASKA LINCOLN

- 3,660 AHUs
- 53,865 ATUs

- 7,974 RTUs

What does our study population represent?



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

1. Raw data received from partners

- Reported faults
- Building/equipment metadata
- Fault definitions

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

2. Mapping

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

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

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

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

28 Components/Parameters

- 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

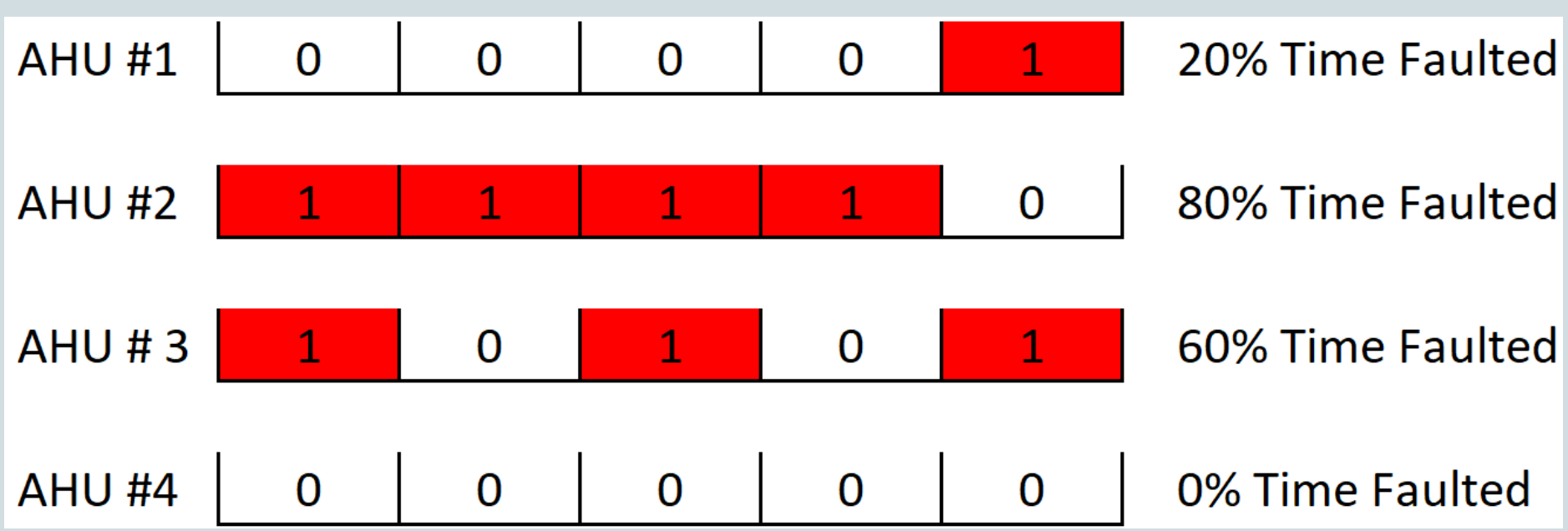
3.0

Faults per AHU per Month

1.2

Faults per ATU per Month

How common is AHU fault ‘x’?



75%

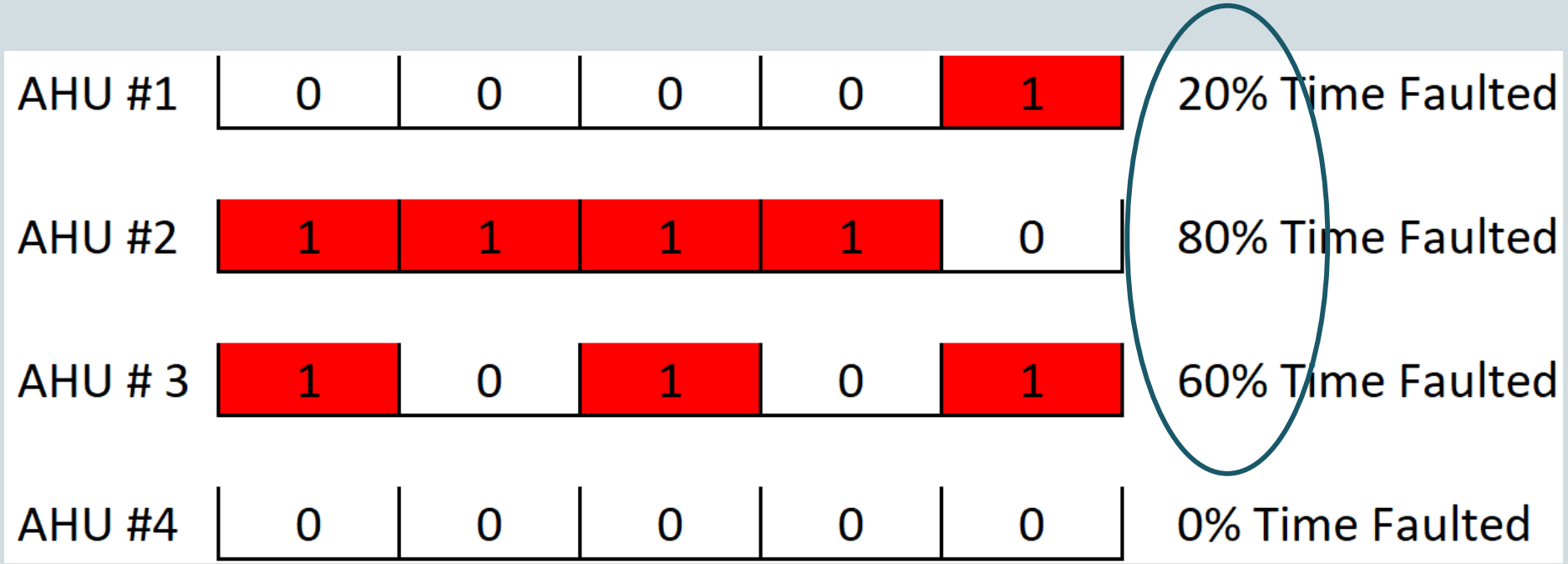
Of AHUs see this fault (Pct_Affected)

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’?



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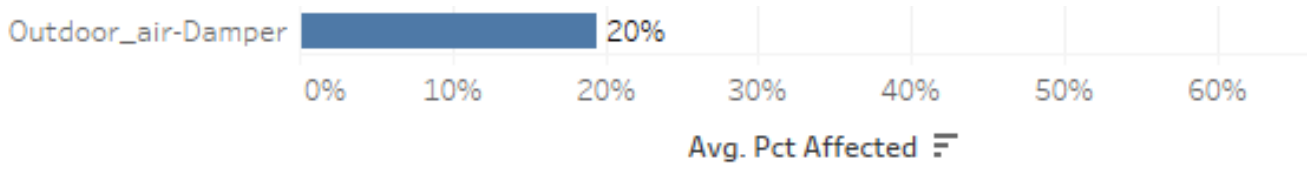
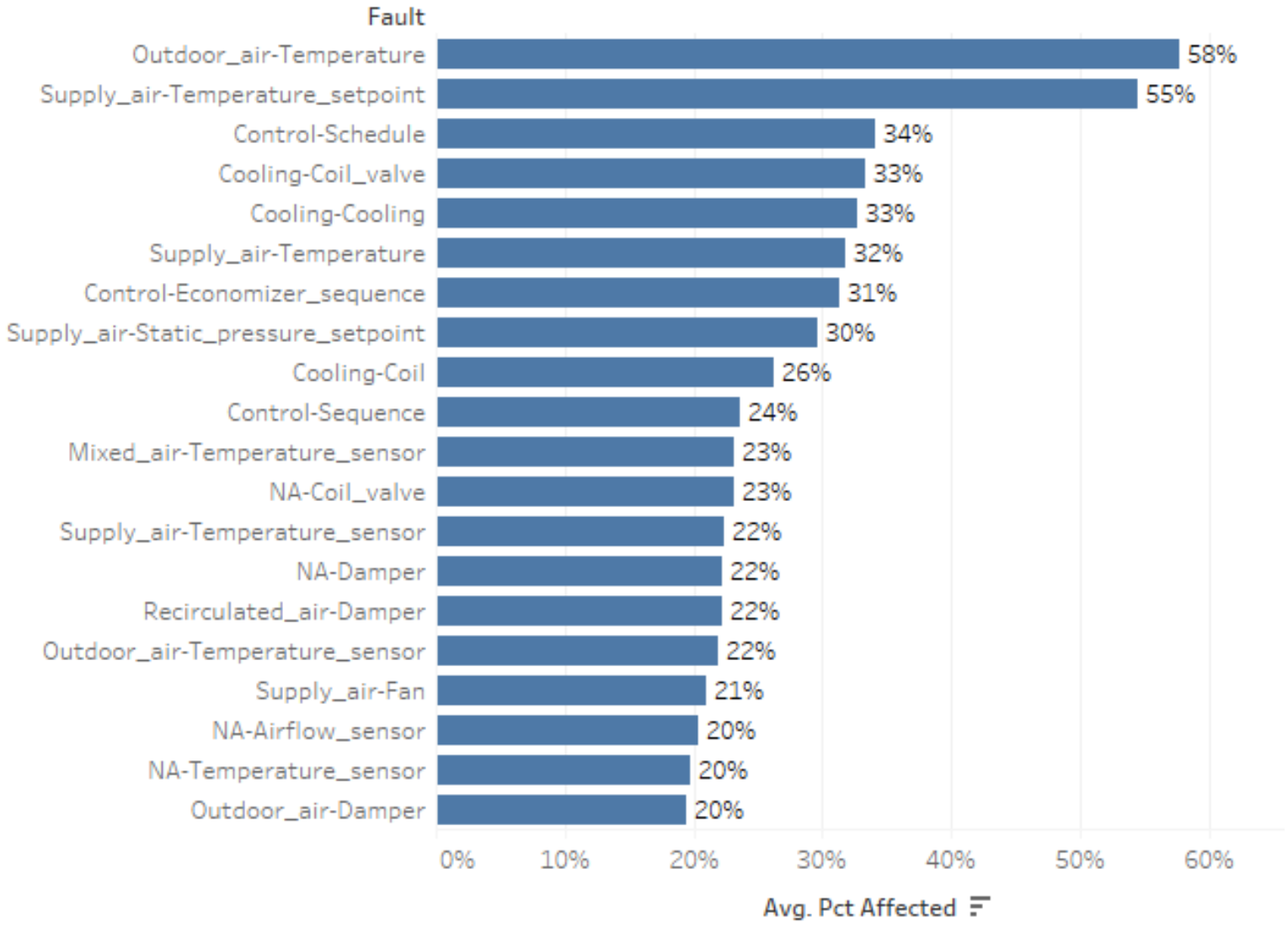
AHUs

Percent of AHUs Affected



Percent of AHUs Affected



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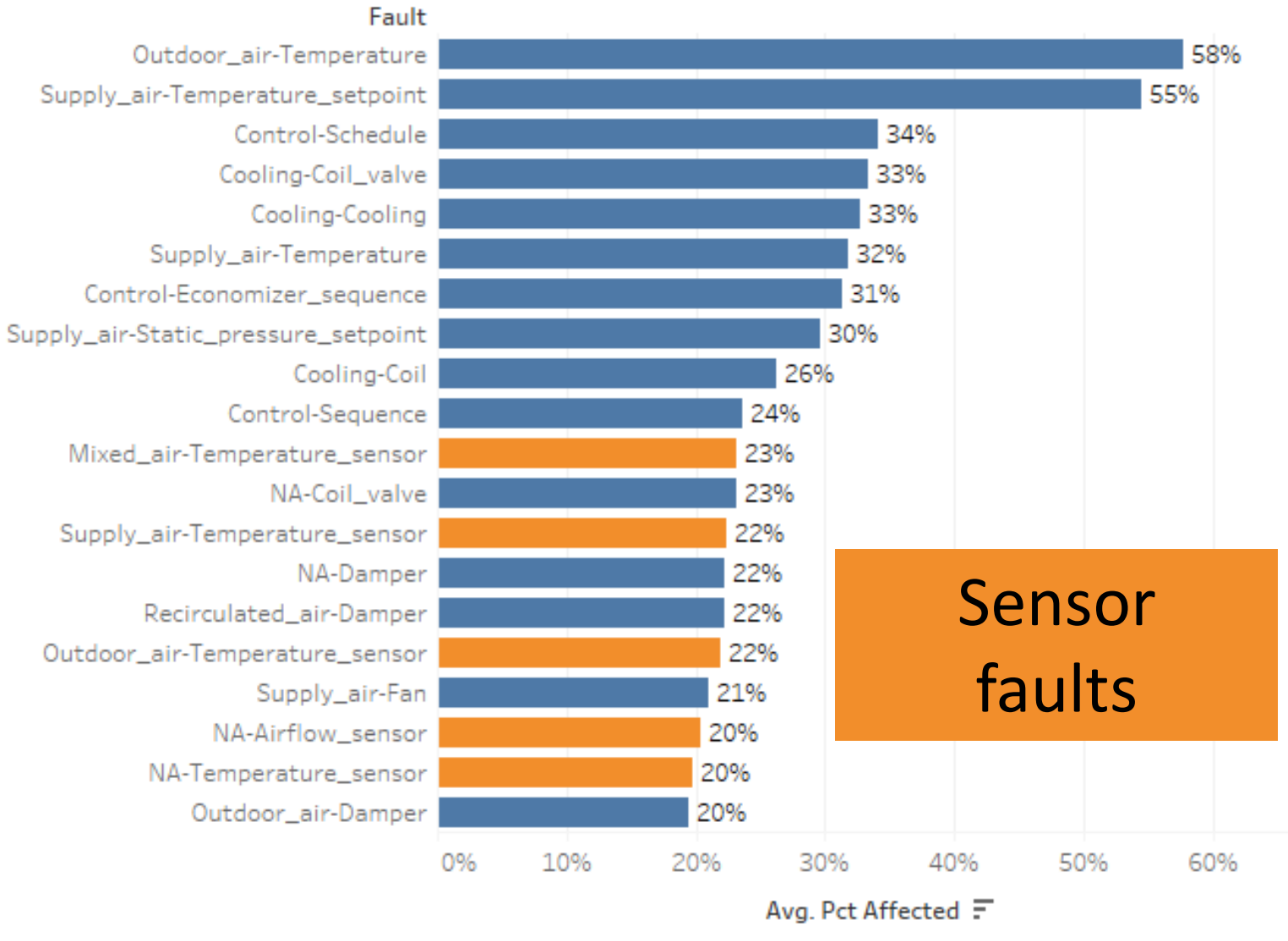
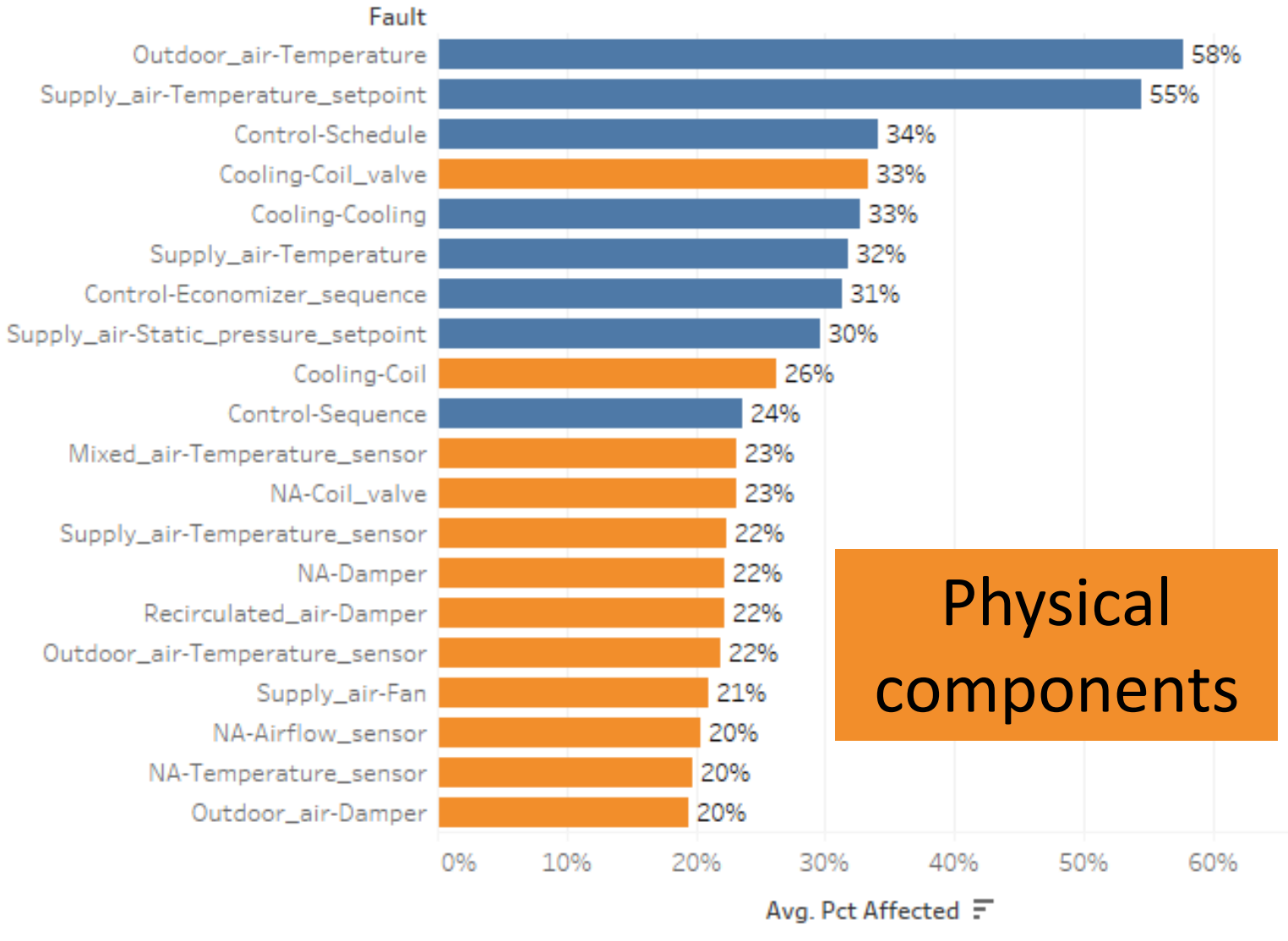


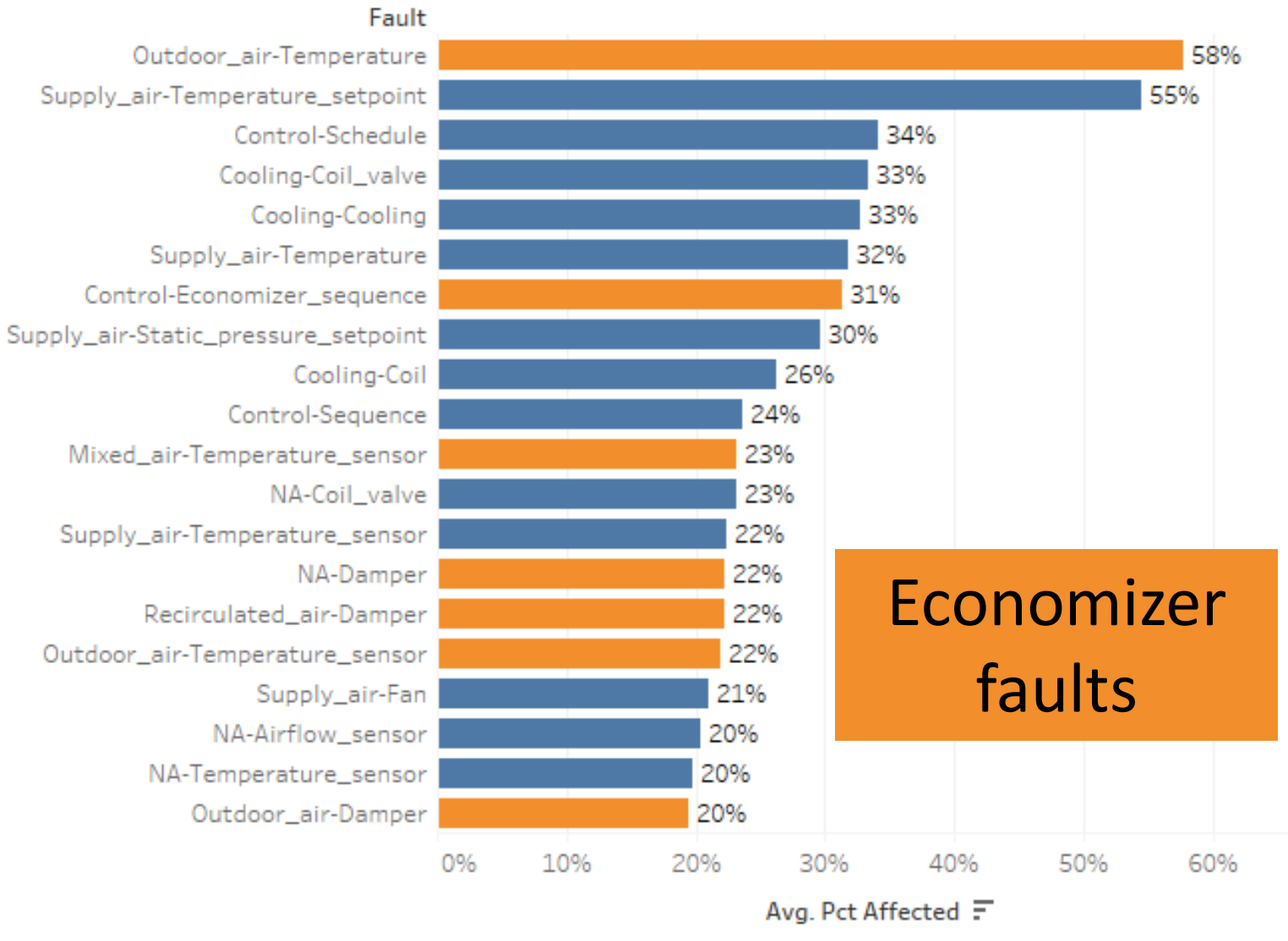
Sensor faults

Percent of AHUs Affected



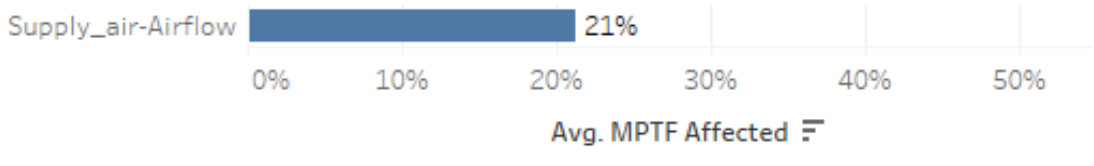
Physical components

Percent of AHUs Affected

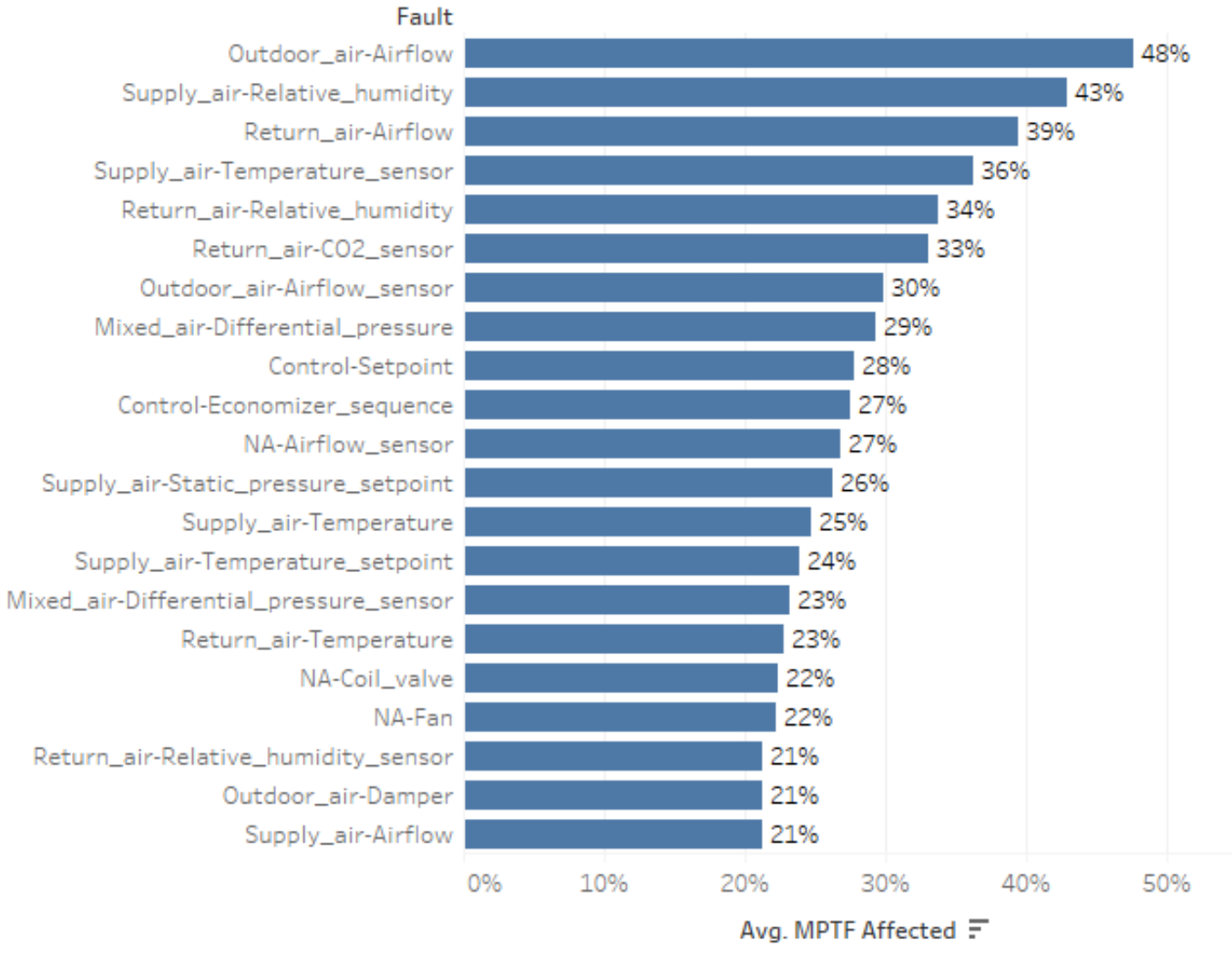


Economizer faults

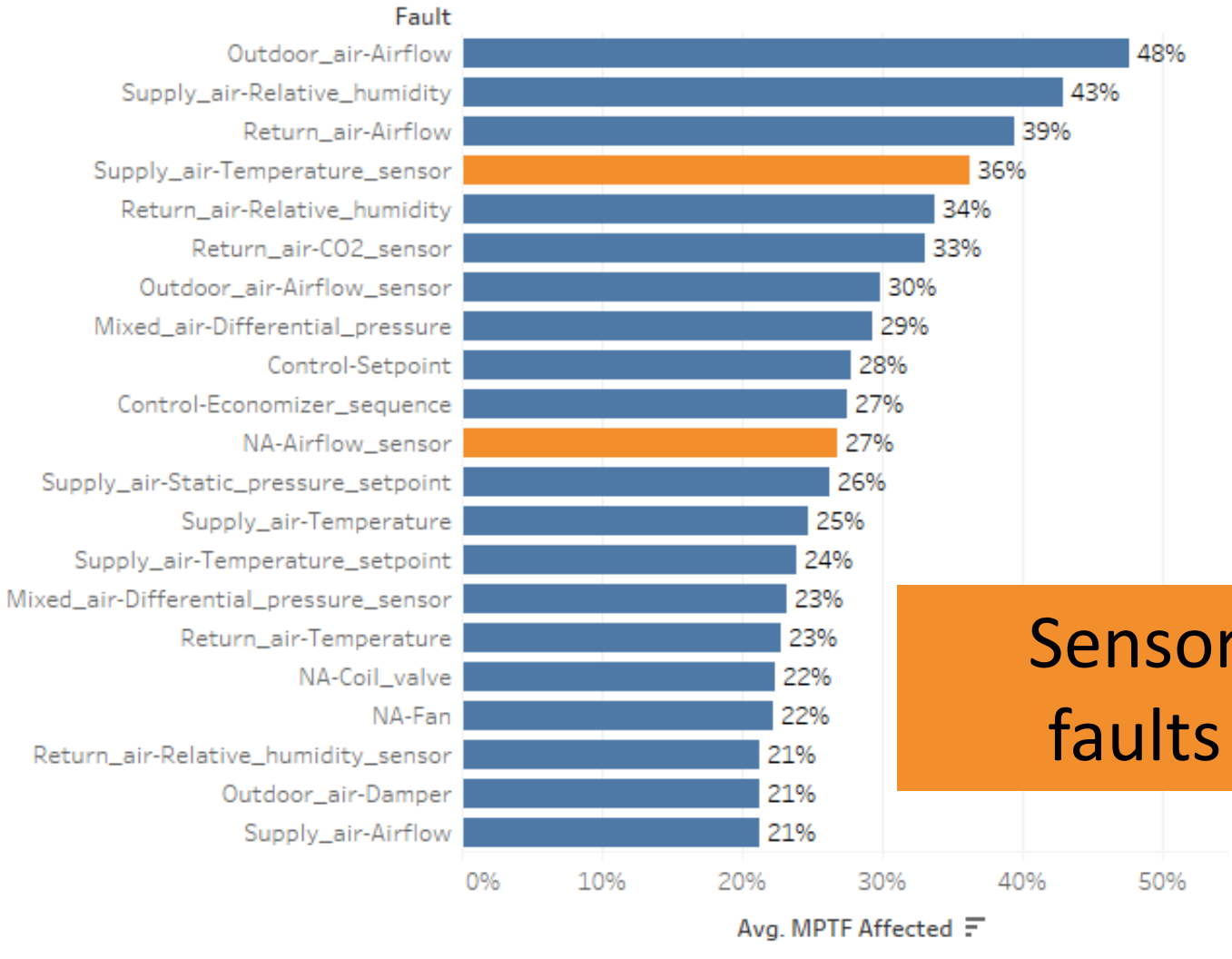
Mean Percent Time Faulted



Mean Percent Time Faulted

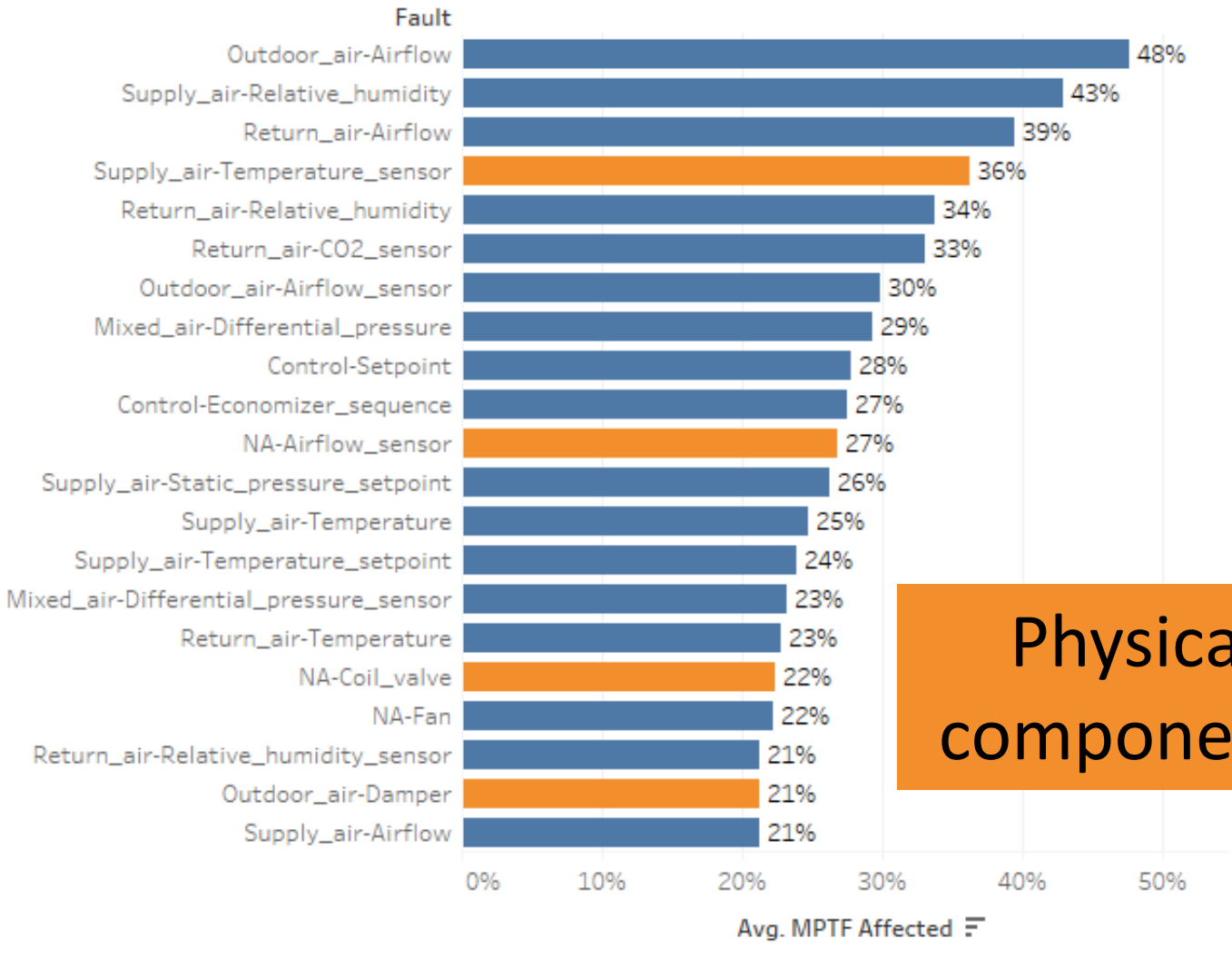


Mean Percent Time Faulted



Sensor faults

Mean Percent Time Faulted



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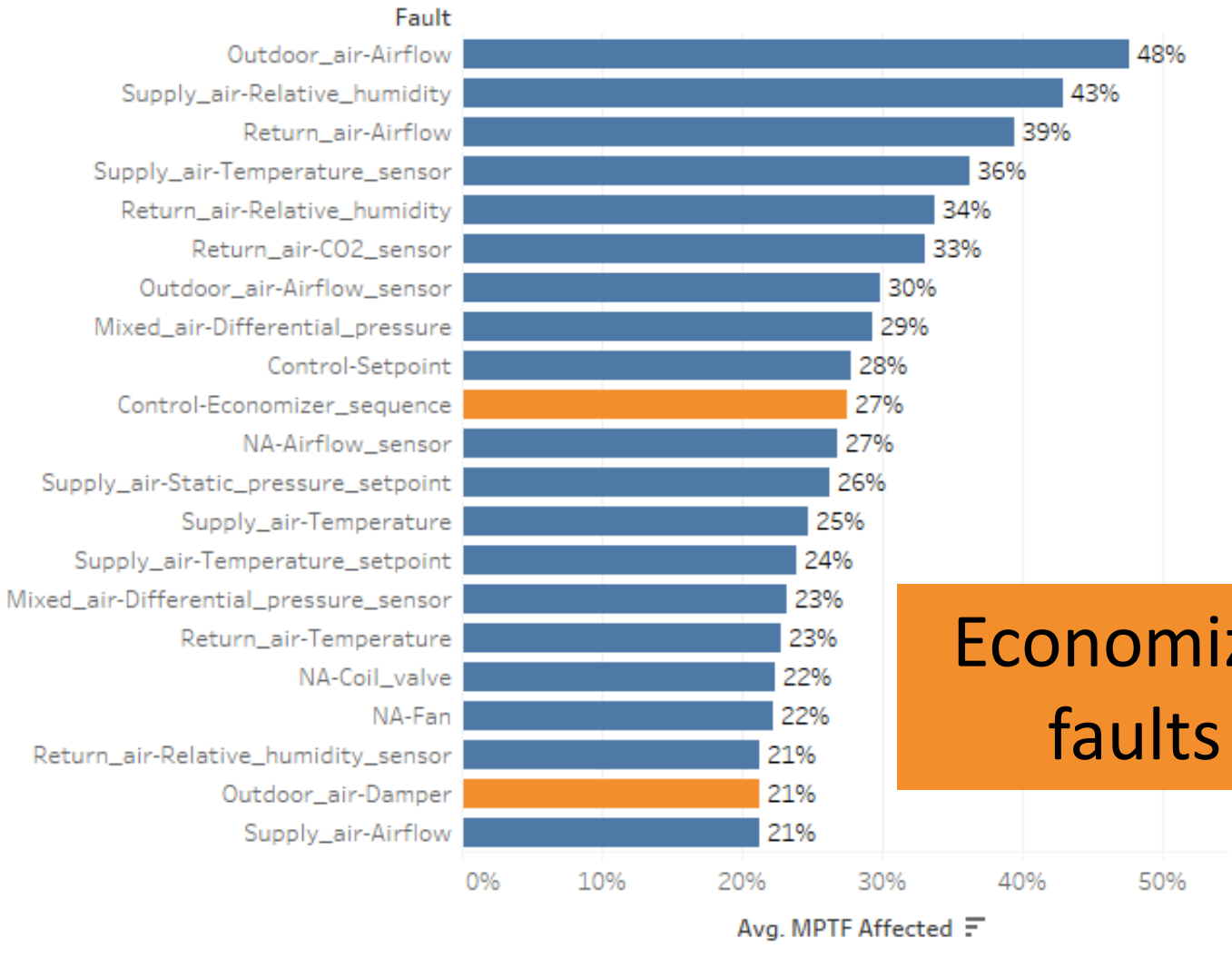
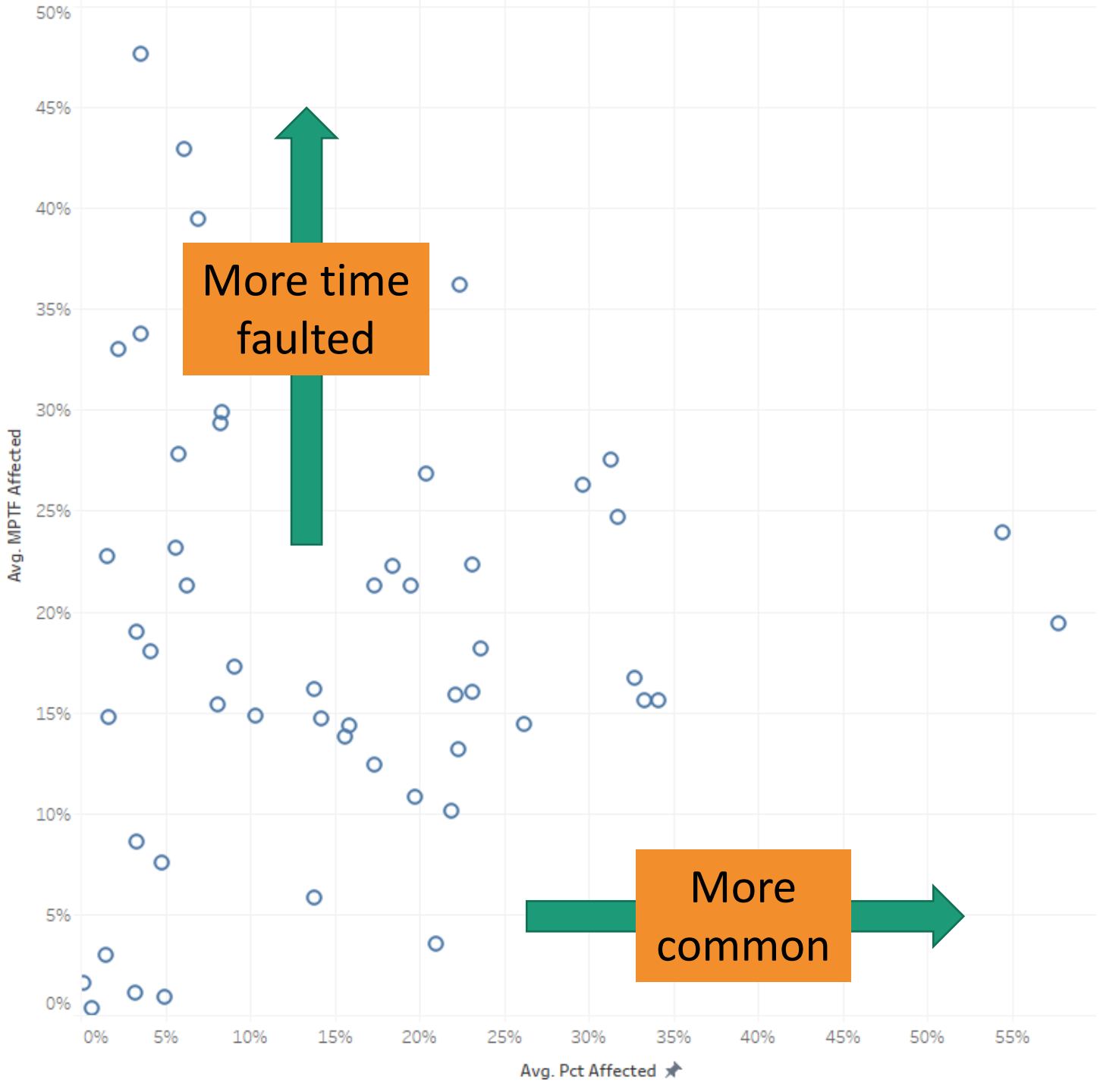
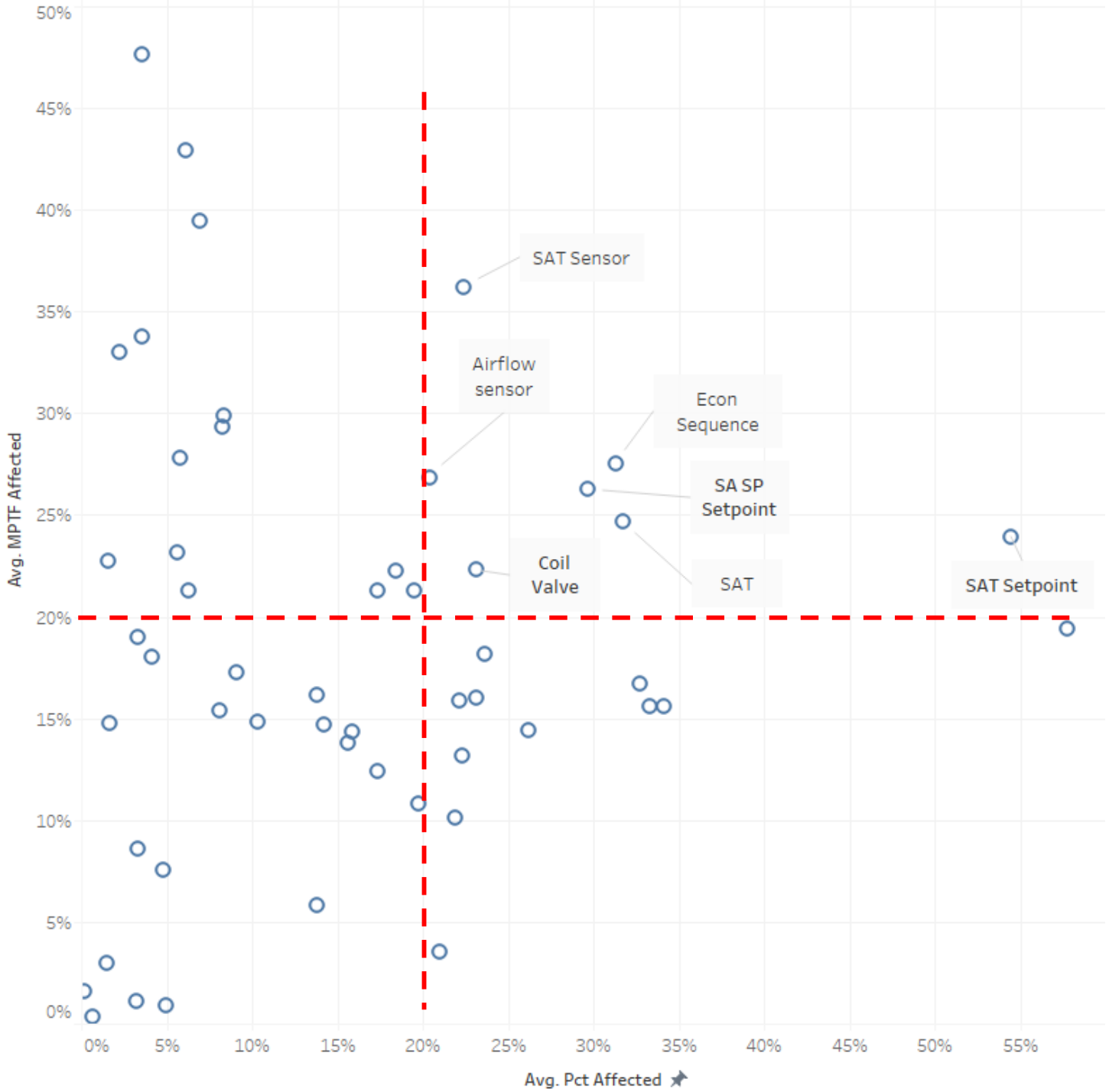


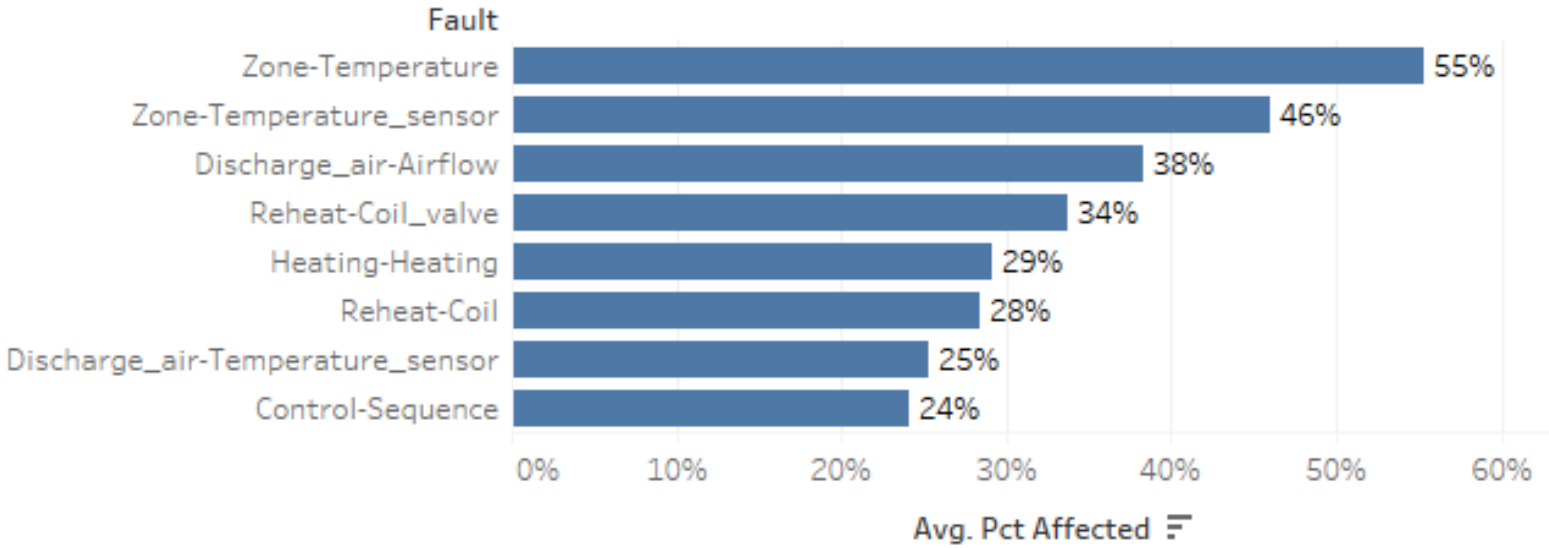
Economizer faults


50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
Avg. MPTF Affected
More time faulted
More common
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
Avg. Pct Affected

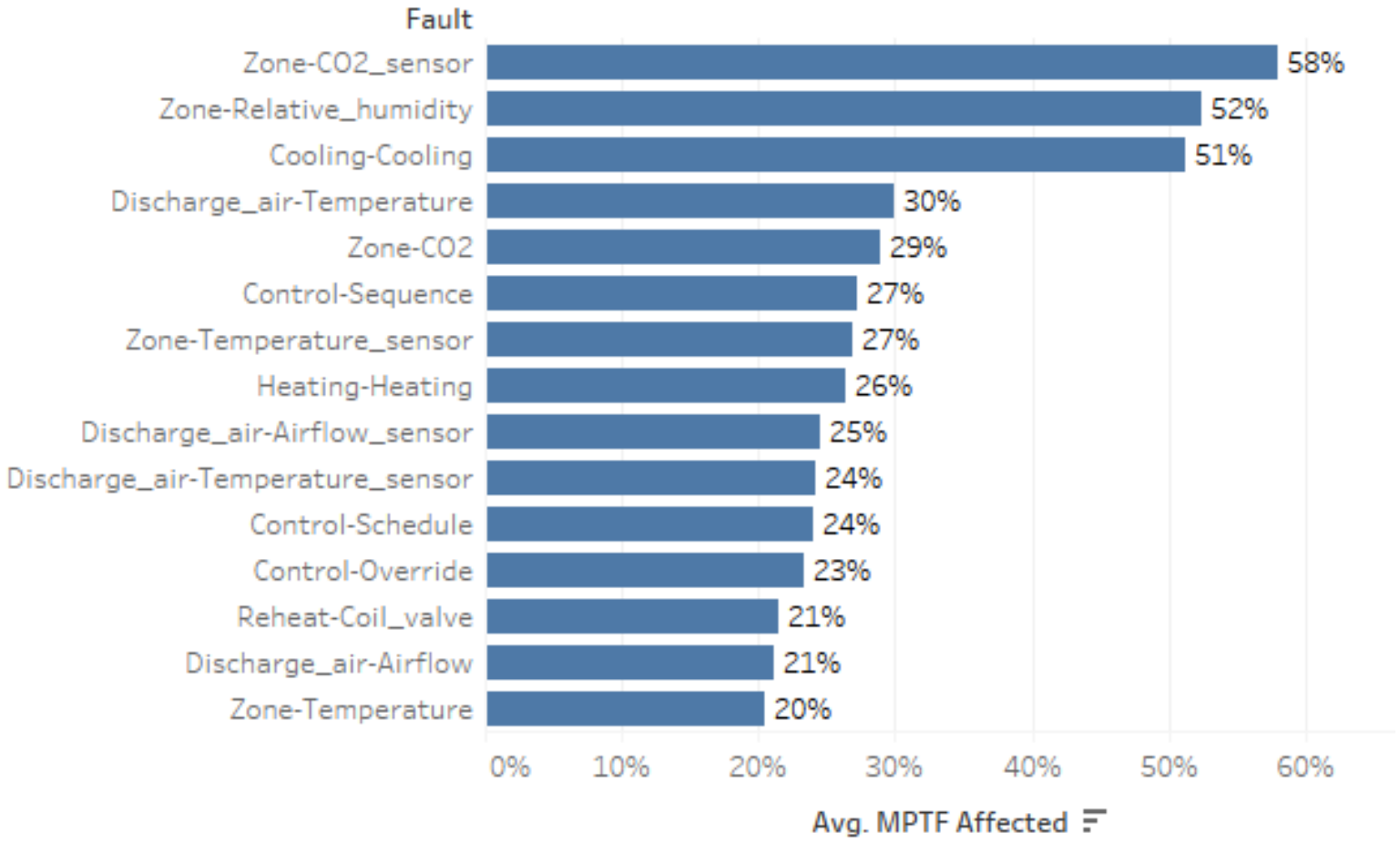

SAT Sensor
Airflow sensor
Econ Sequence
SA SP Setpoint
Coil Valve
SAT
SAT Setpoint
Avg. MPTF Affected
Avg. Pct Affected
50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%

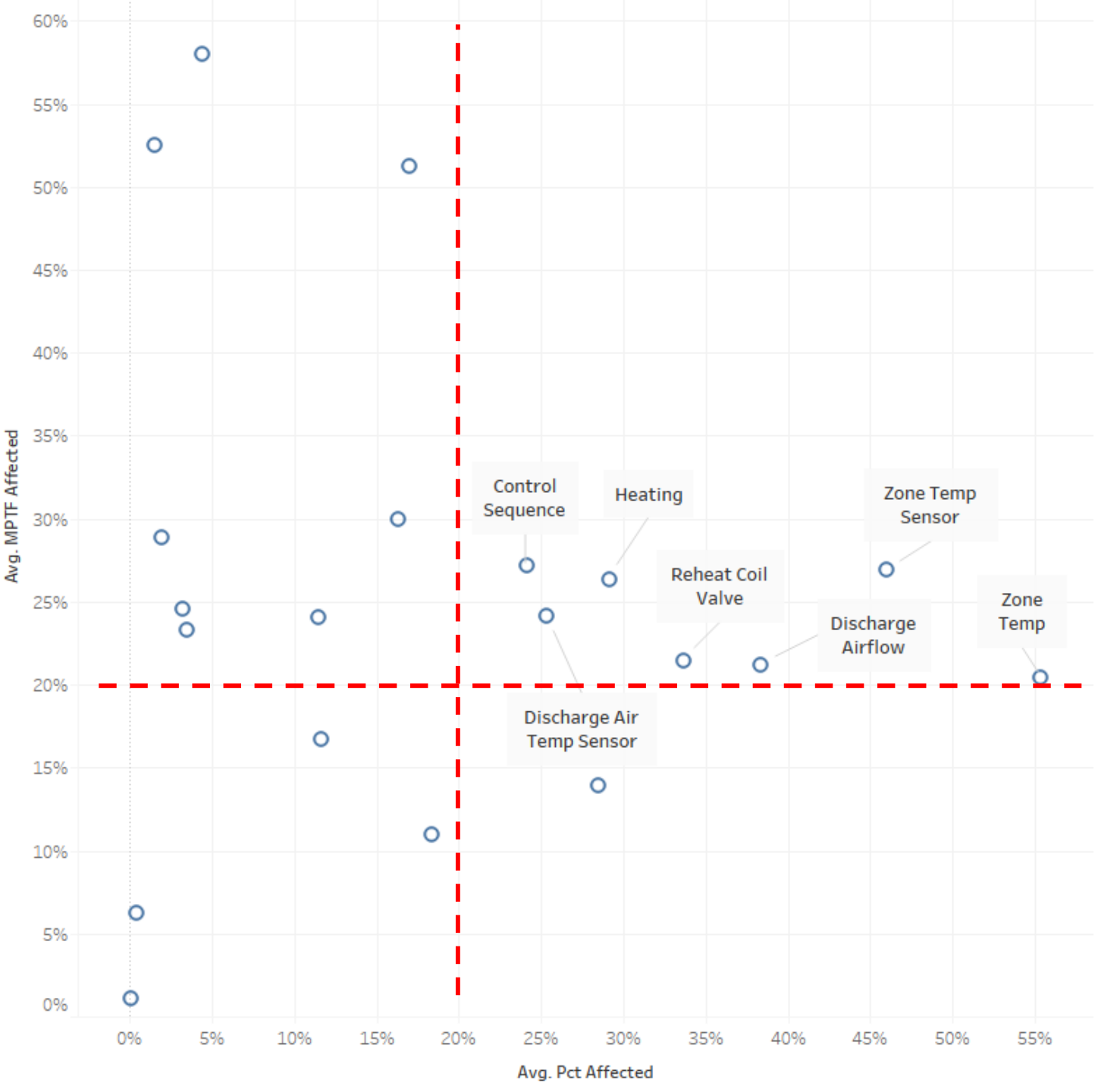
ATUs

Percent of ATUs Affected



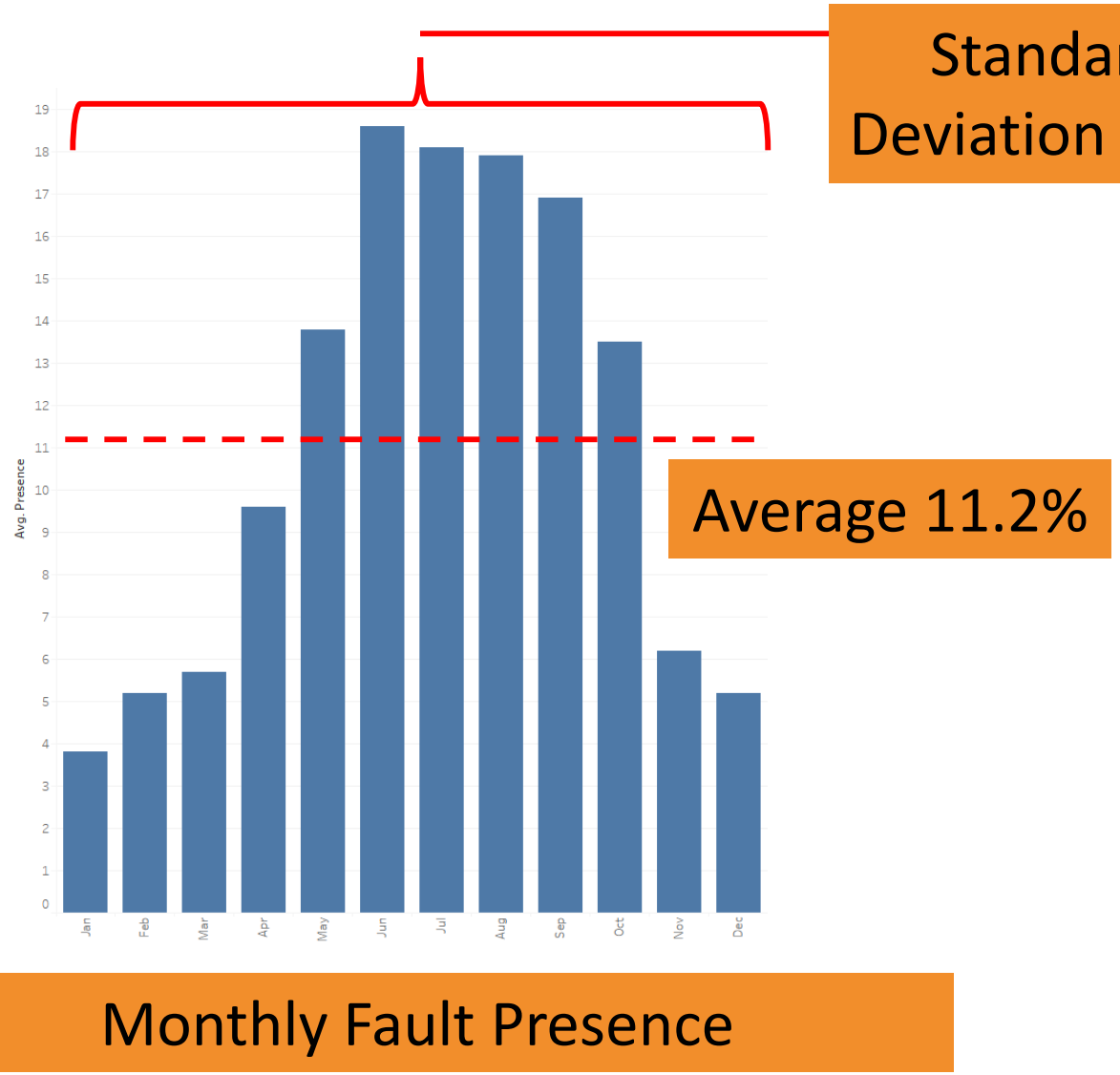
Mean Percent Time Faulted




Avg. MPTF Affected
60%
55%
50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%
55%
Avg. Pct Affected
Control Sequence
Heating
Zone Temp Sensor
Reheat Coil Valve
Discharge Airflow
Zone Temp
Discharge Air Temp Sensor

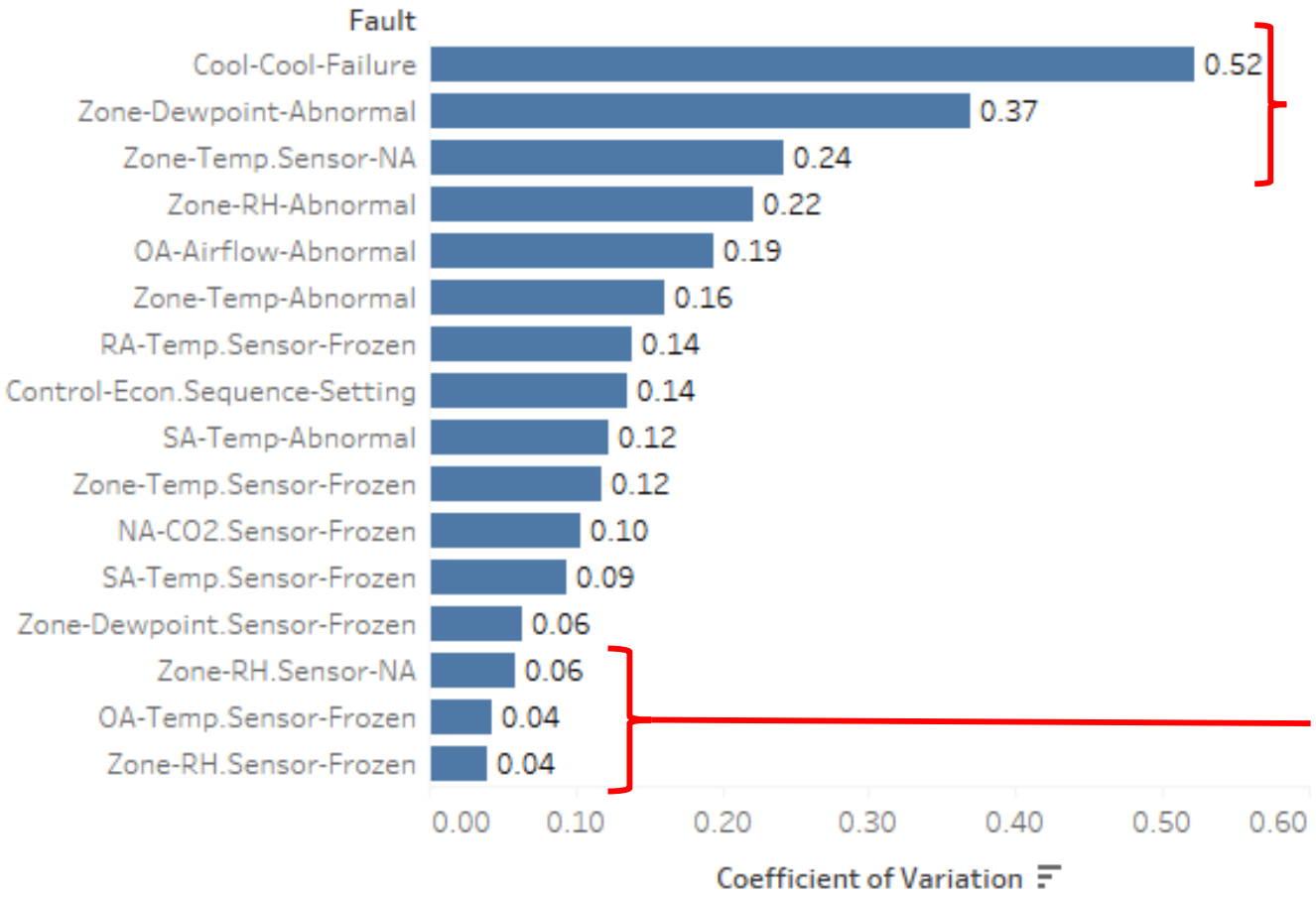
Drivers

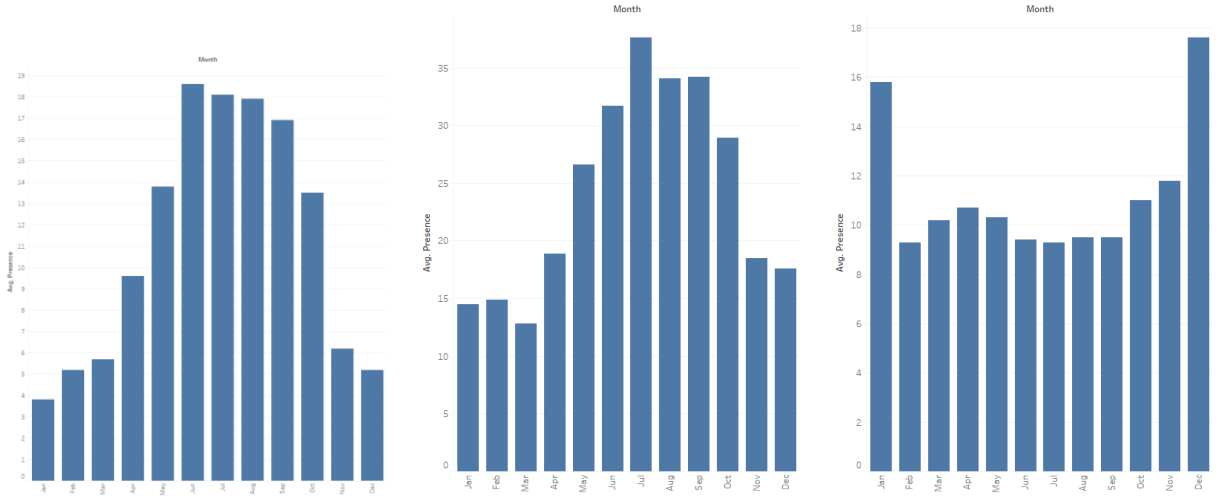
Seasonal Variation (Example: Cooling Failure)



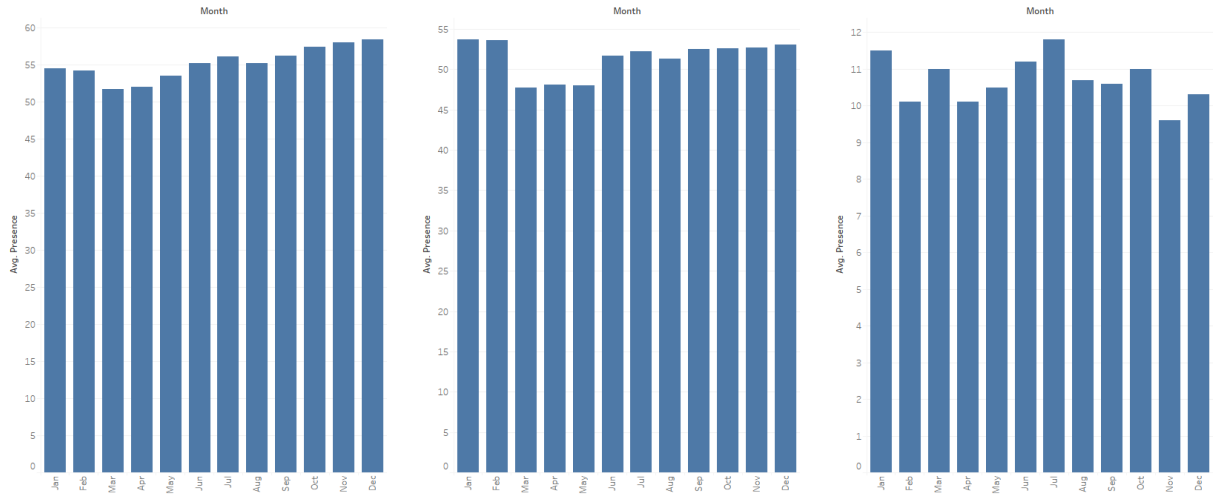
- Coefficient of Variation
  5.9% ÷ 11.2% = 0.52
- Higher COV means more seasonal variation

Seasonal Variation



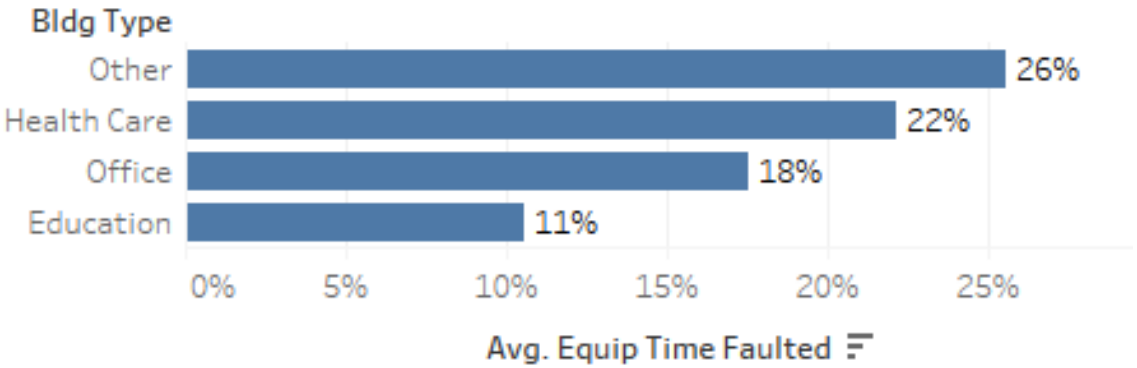


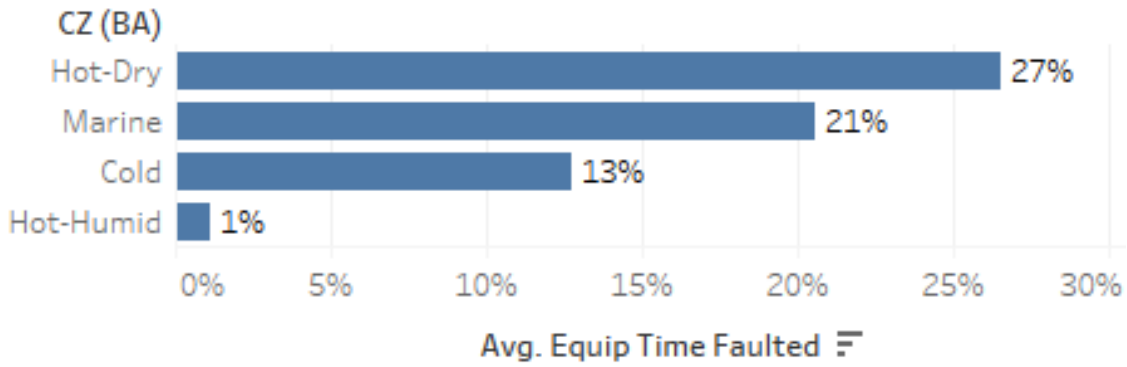
Top 3 faults for seasonal variation



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!