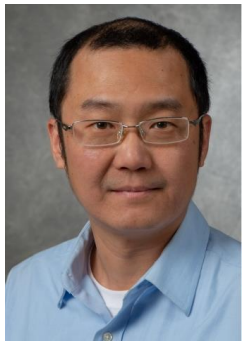
What We Learned From Analyzing 18 Million Rows of Commercial Buildings' HVAC Fault Data

Eliot Crowe, Yimin Chen, Jessica Granderson, Lawrence Berkeley National Laboratory
Hayden Reeve, Lucas Troup, Pacific Northwest National Laboratory
David Yuill, Yuxuan Chen, University of Nebraska - Lincoln

Presenter: Jessica Granderson
Deputy for Research
Building Technology & Urban Systems Division

Project Team







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Background

- Target: Reduce U.S. net GHG emissions 50% by 2030, reach net zero by 2050
- Achieving goal requires mix of efficiency, fuel switching, demand flexibility, and clean electricity
- DOE studies on operational savings potential:
  - 29% savings potential from equipment/controls faults, and common problems (pull)
  - Commissioning saves 6% (common problems in chart top right)
  - FDD savings 9% (common faults in chart bottom right)

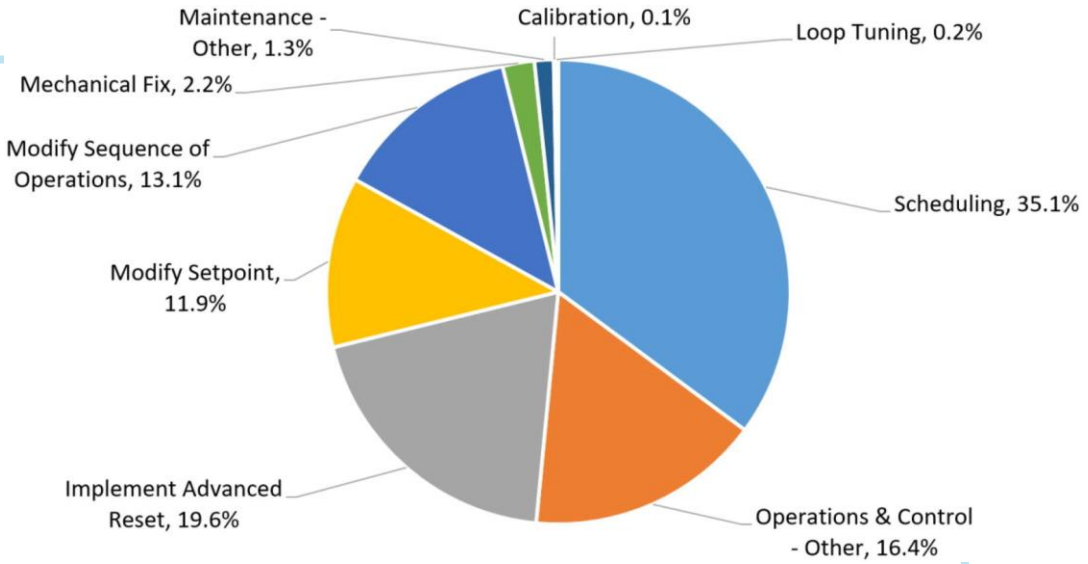
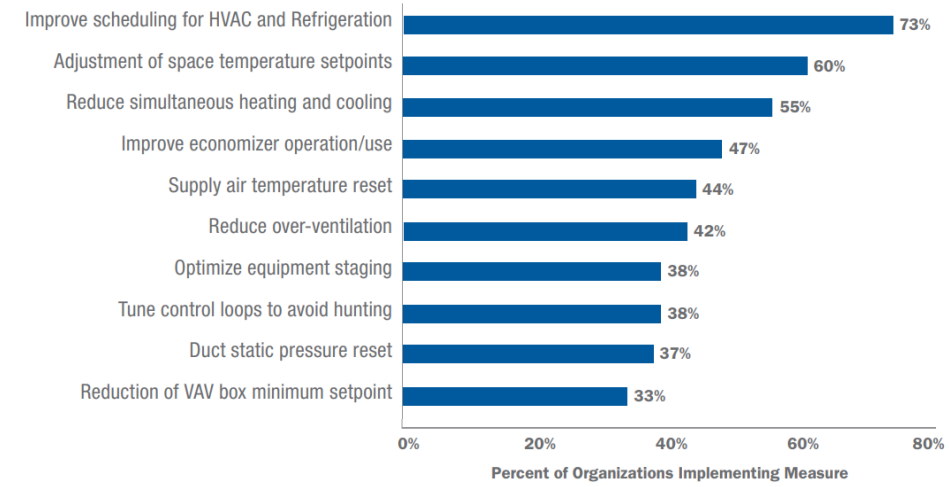


FIGURE 8: **Measures implemented with EMIS support by organizations in the Smart Energy Analytics Campaign**

(Respondents may indicate multiple measures; n = 78)



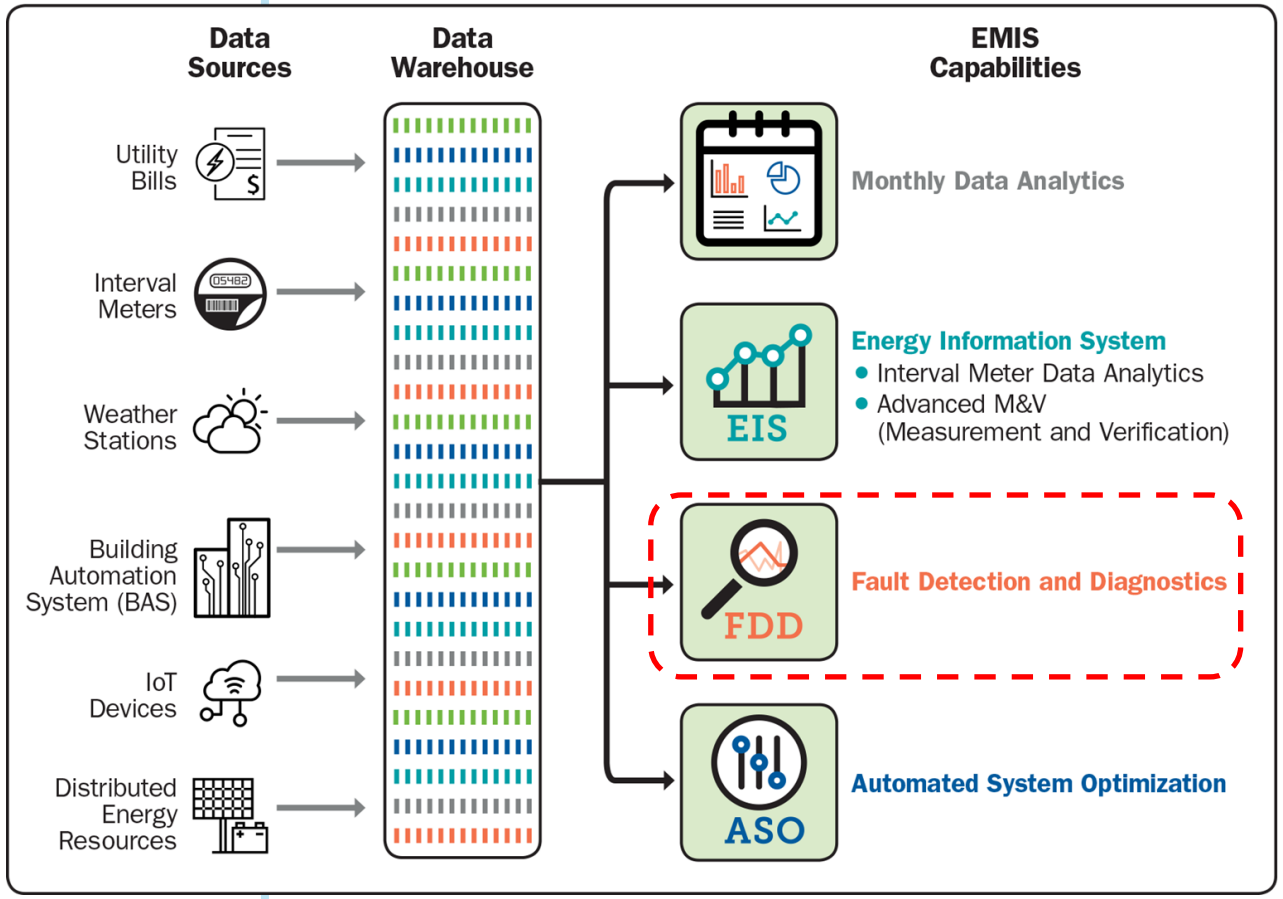
N. Fernandez, S. Katipamula, W. Wang, Y. Xie, M. Zhao, C. Corgin, "Impacts of Commercial Building Controls on Energy Savings and Peak Load Reduction."
Crowe, Eliot, Evan Mills, Tom Poeling, Claire Curtin, Diana Bjornskov, Liz Fischer, and Jessica Granderson."Building Commissioning Costs and Savings Across Three Decades and 1,500 North American Buildings."
Lin, Guanjing, Hannah Kramer, Valerie Nibler, Eliot Crowe, and Jessica Granderson."Building Analytics Tool Deployment at Scale: Benefits, Costs, and Deployment Practices."

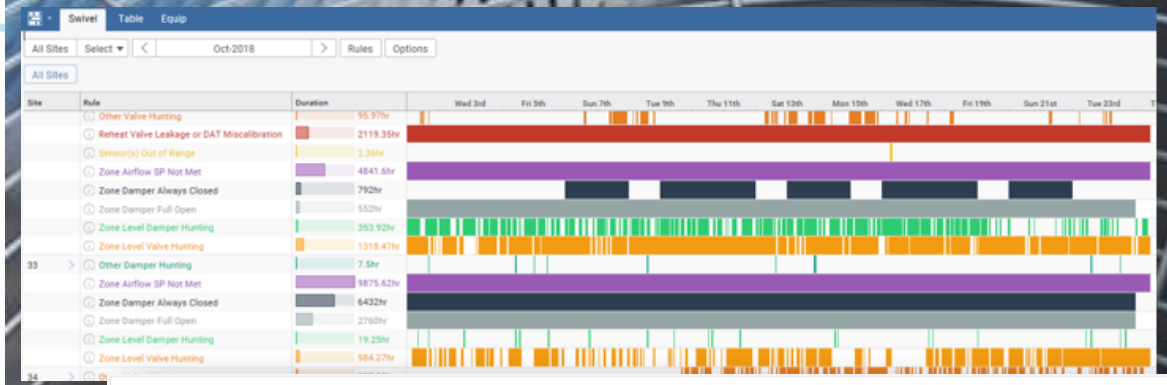
Background

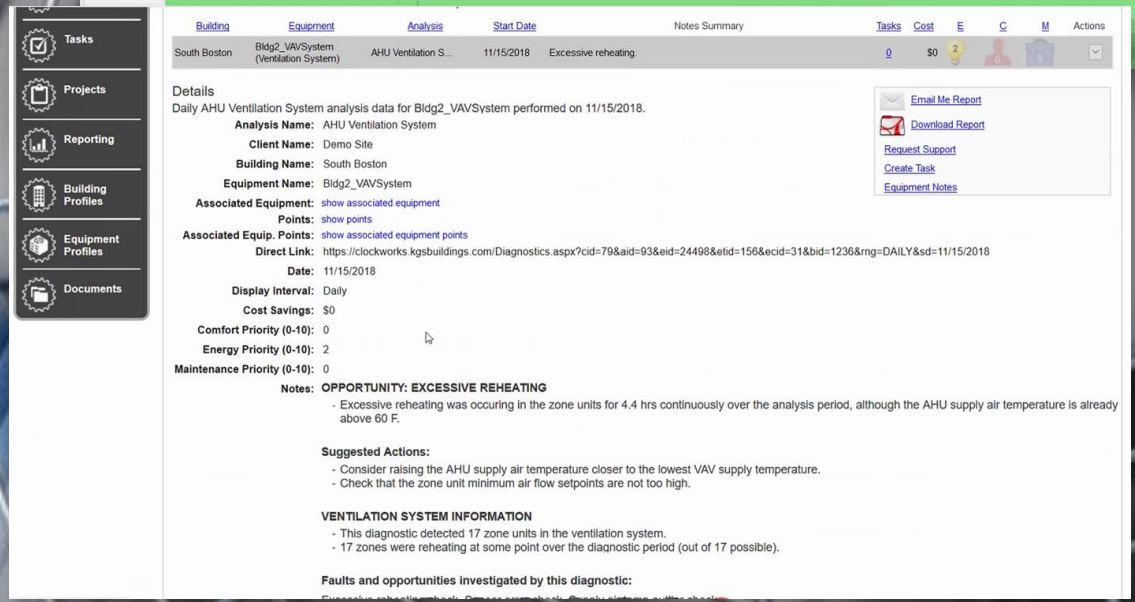
- FDD/MBCx approach proven to reap savings, and we have data on common measures – but:
  - Which faults are most often observed to be present? (just *how* common are they?)
  - How many faults occur each month for a given building?
  - What percentage of units are faulted at any given point in time?
- FDD fault historians enable us to answer those questions!
- Who cares?

FDD tool developers	Researchers	Building owners/operators
• Add or refine rules for highest priority fault types, and establish more consistent approach to fault naming/hierarchy to enable big data analysis	• Build from new base of empirical understanding for fault reporting prevalence	• Ensure adequate operations resources to address highest priority fault risk areas; further bolster business case for analytics investment

Energy Management & Information Systems (EMIS)



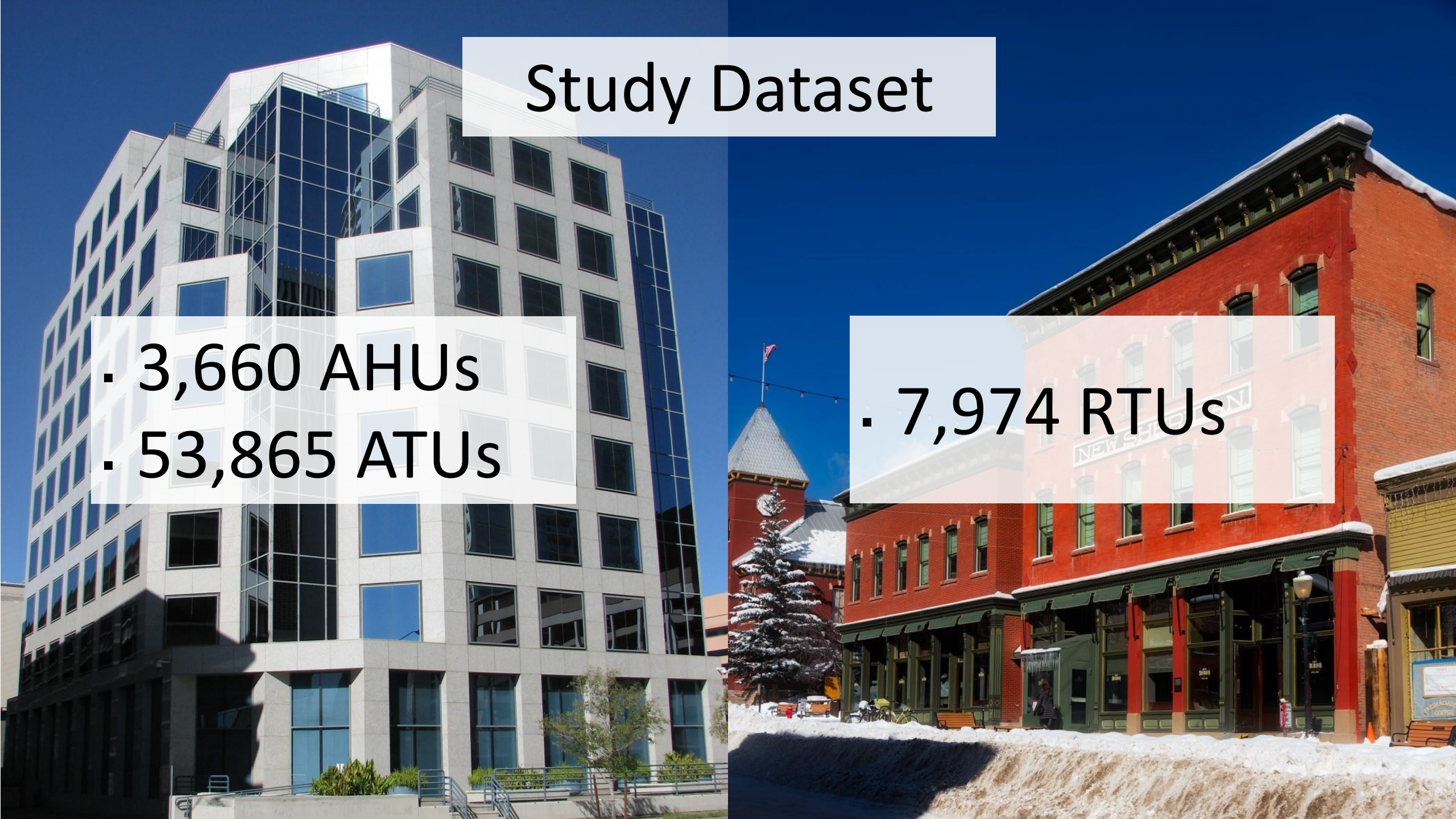




Study Dataset

- 3,660 AHUs
- 53,865 ATUs

- 7,974 RTUs



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

- Reported faults
- Building/equipment metadata

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

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

>2,000 raw fault names unified, then reduced/synthesized

13 Fault Modes

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

245

Faults per Building per Month
(Median, AHUs and ATUs)

27 - 274

Interquartile Range

3

Faults per AHU per Month

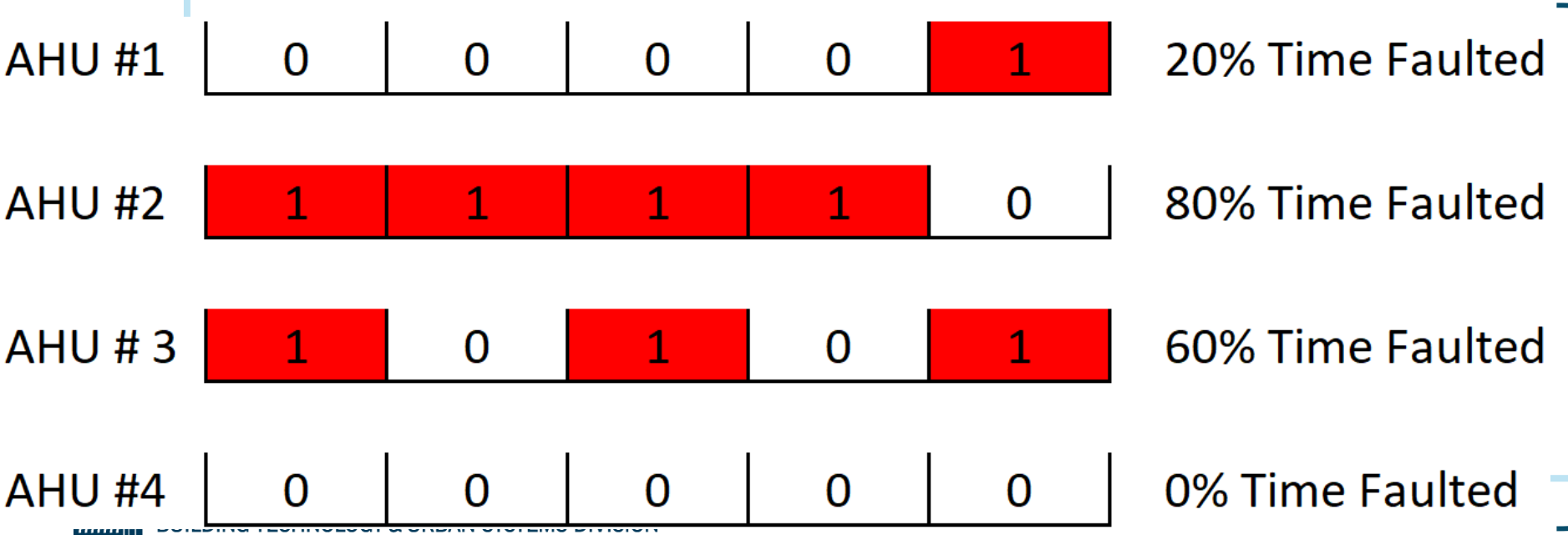
1

Fault per ATU per Month

AHUs

Metrics based on daily fault records

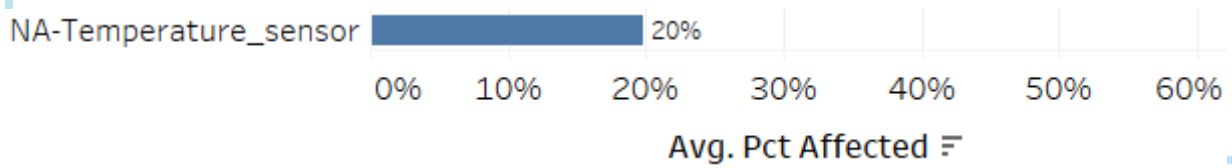
How common is AHU fault ‘x’?



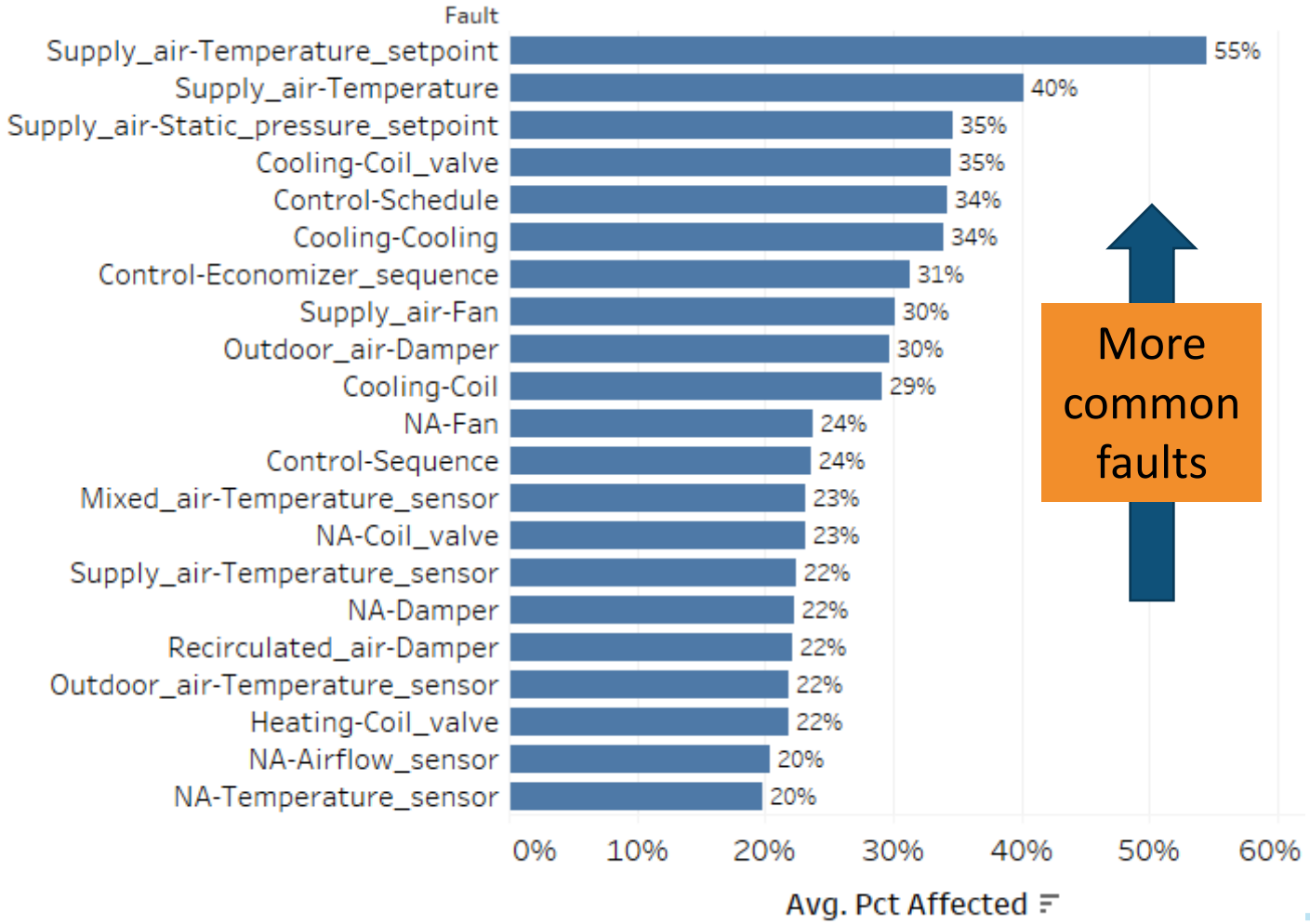
75%

Of AHUs see this fault (Pct_Affected)

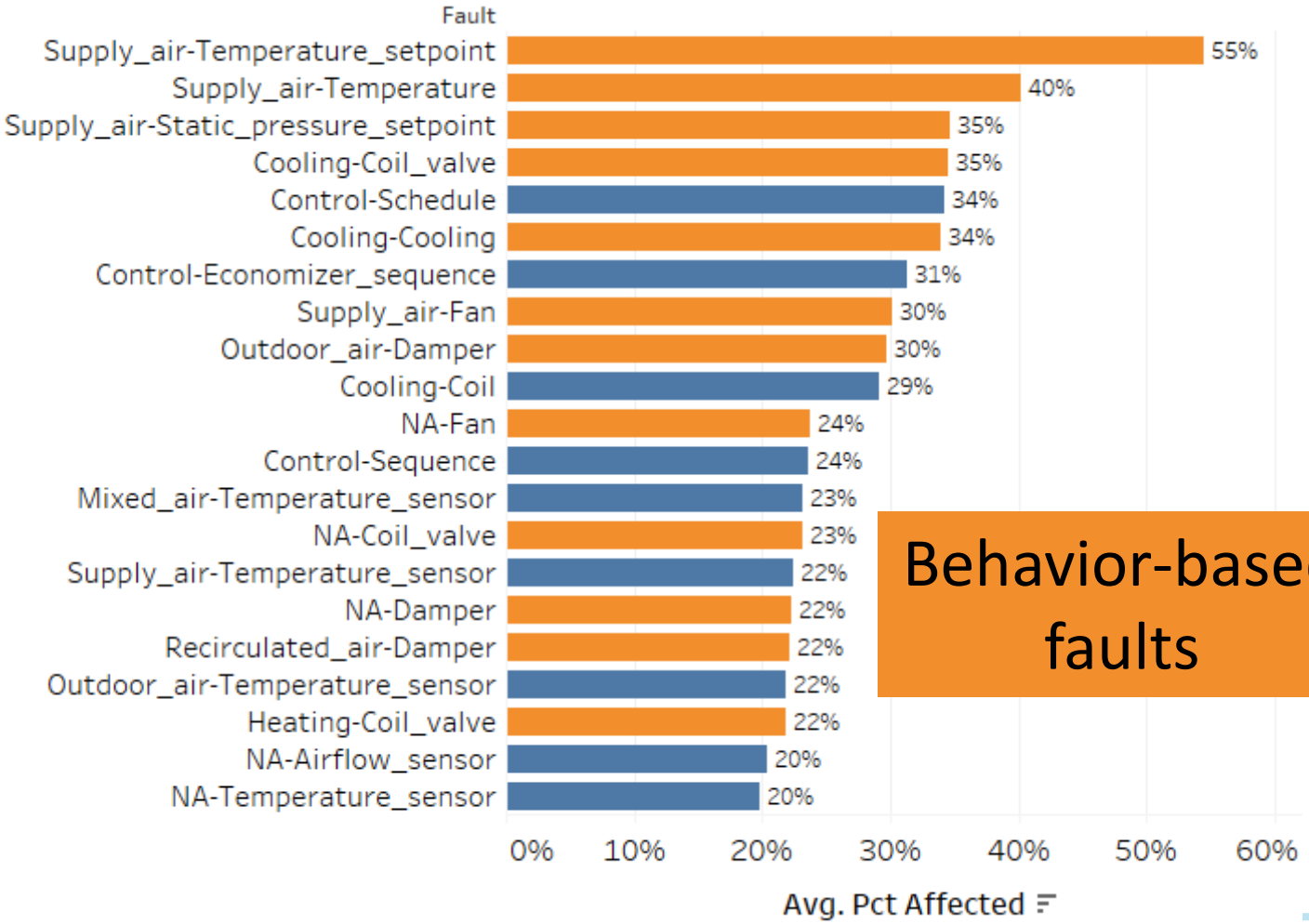
Percent of AHUs Affected



Percent of AHUs Affected

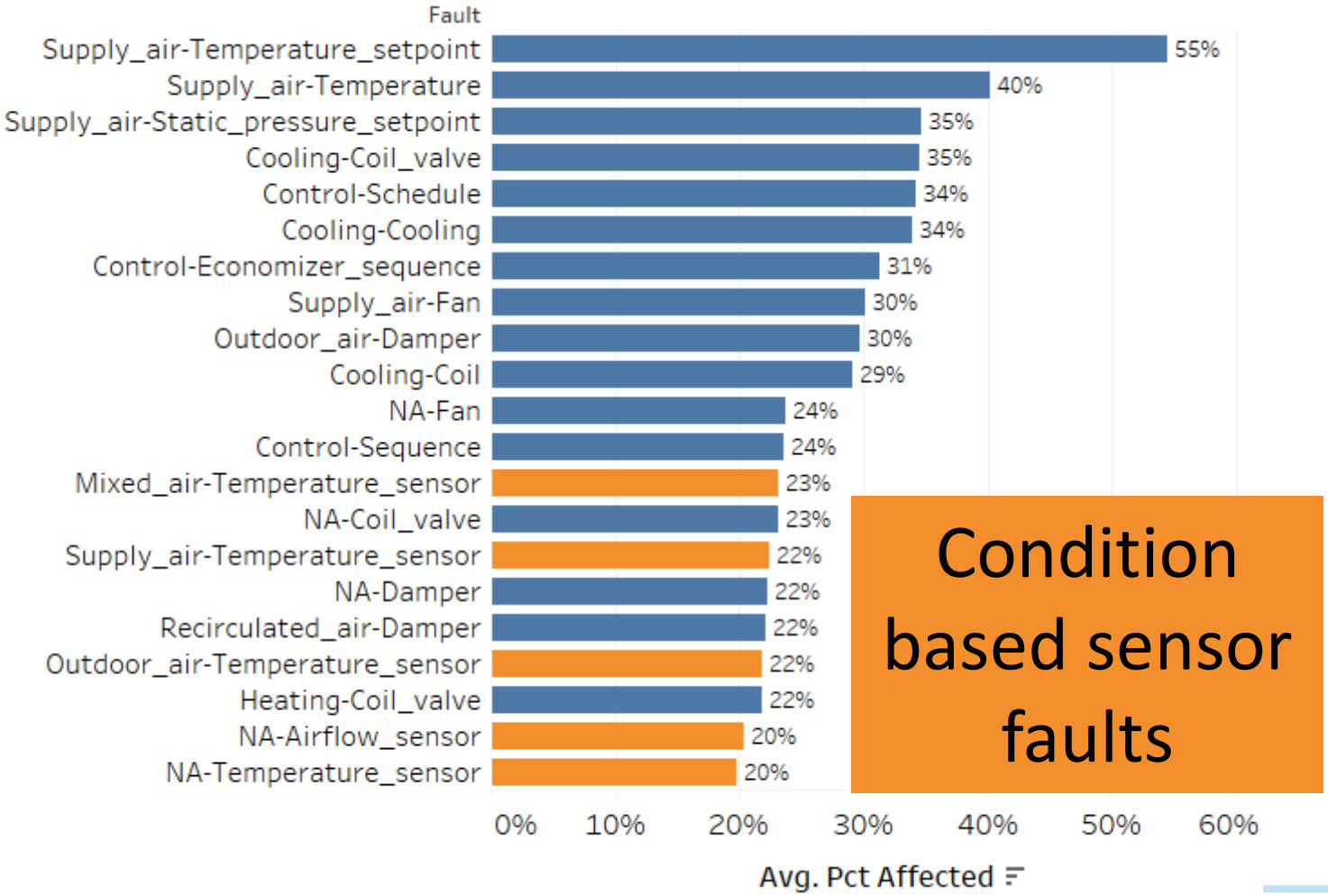


Percent of AHUs Affected



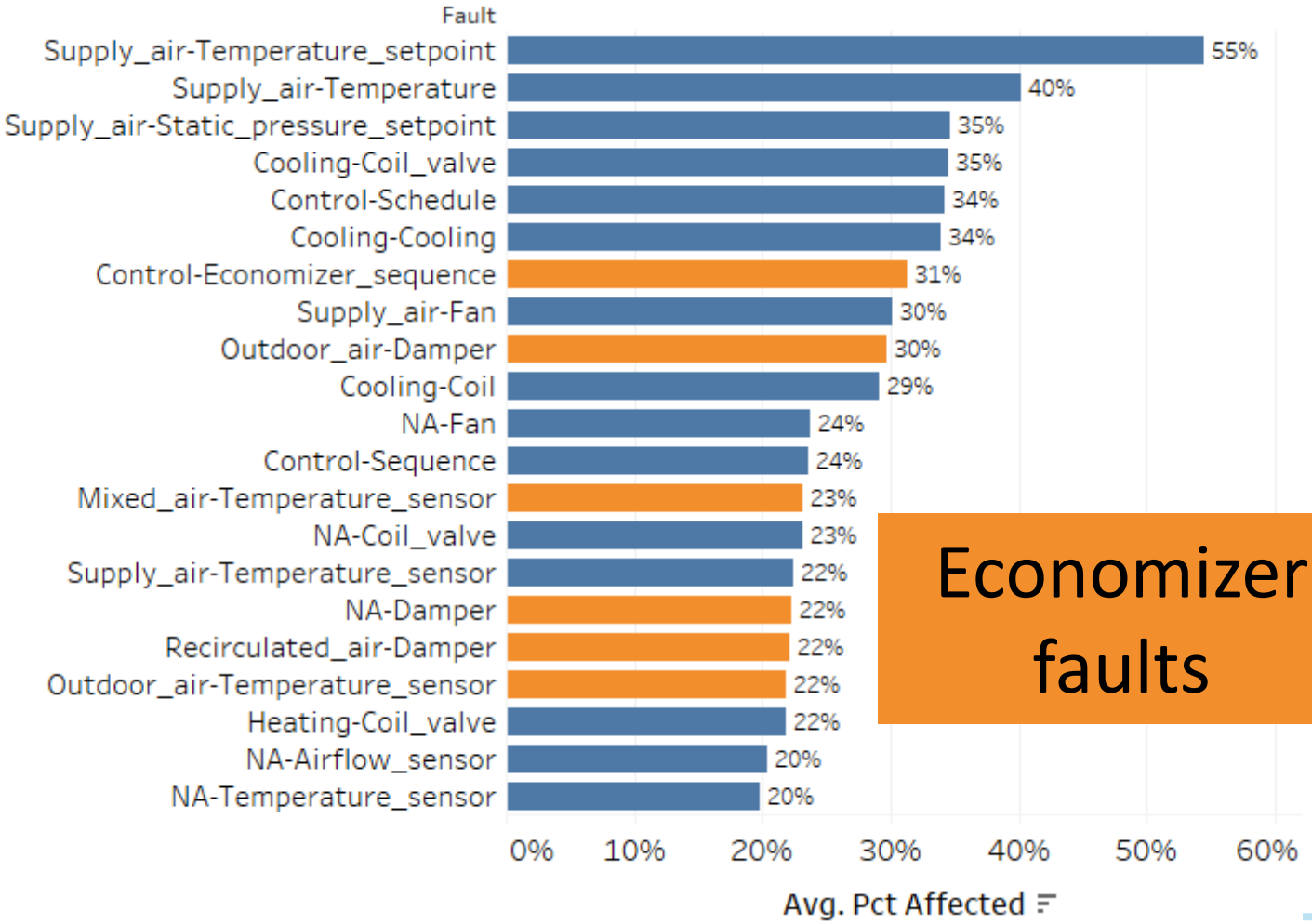
Behavior-based faults

Percent of AHUs Affected



Condition based sensor faults

Percent of AHUs Affected



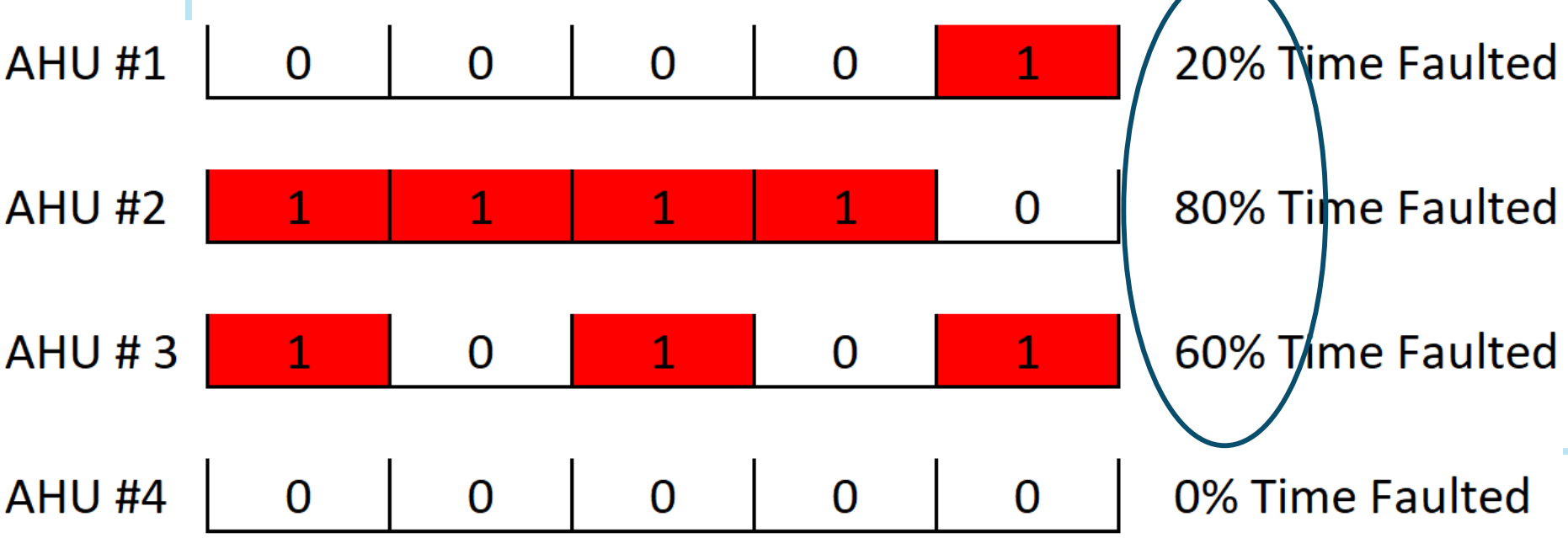
Economizer faults

For equipment that sees the fault, what portion of their time is faulted? (how frequent/persistent?)

53%

Mean Percent Time Faulted (MPTF_Affected)

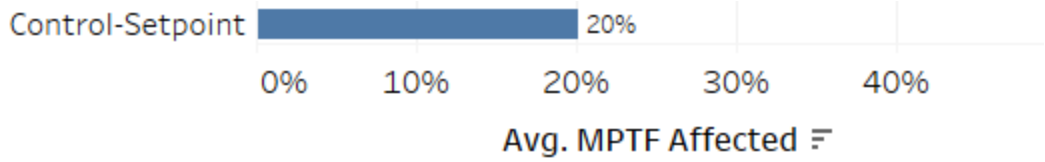
How common is AHU fault ‘x’?



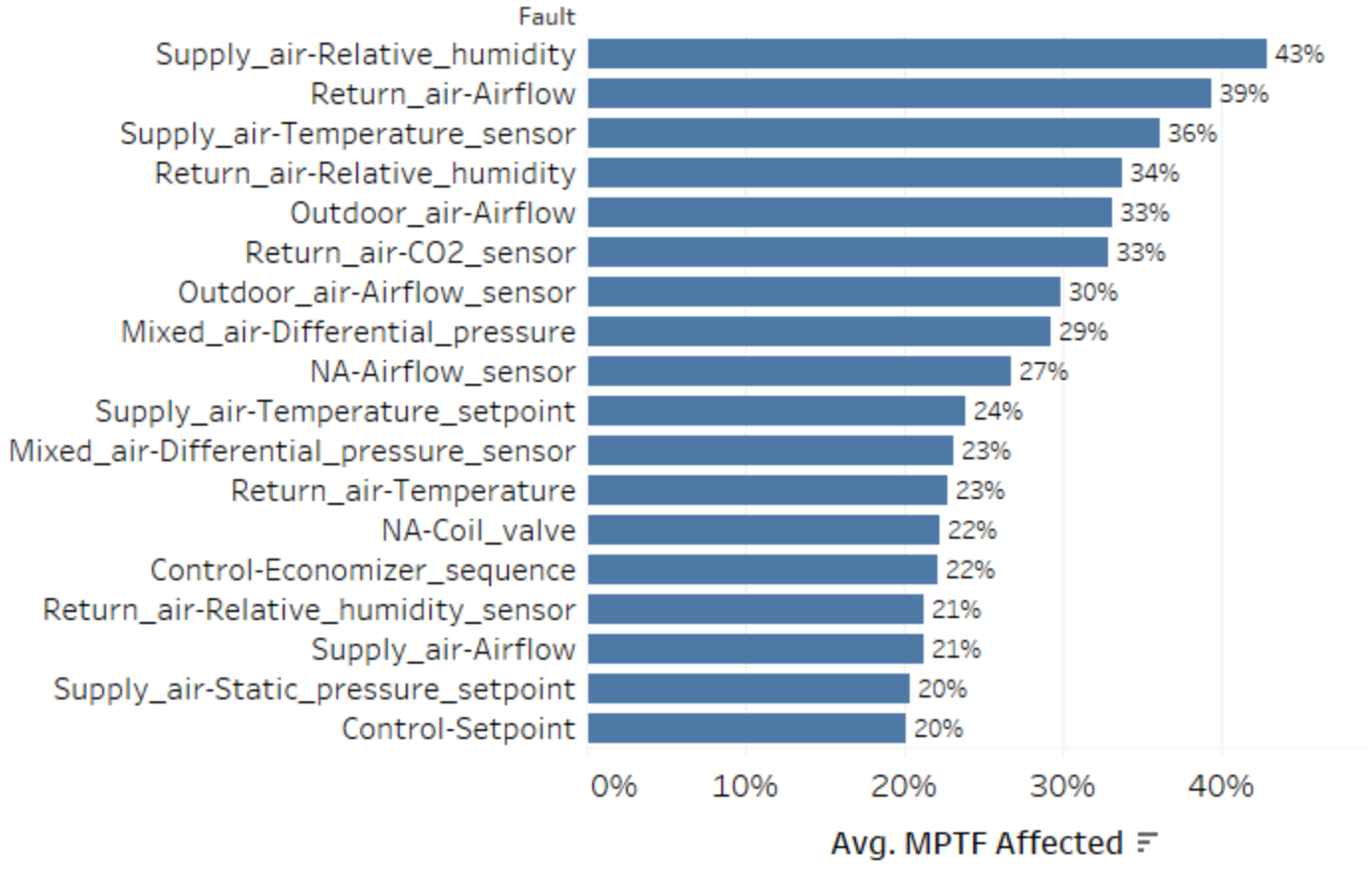
75%

Of AHUs see this fault (Pct_Affected)

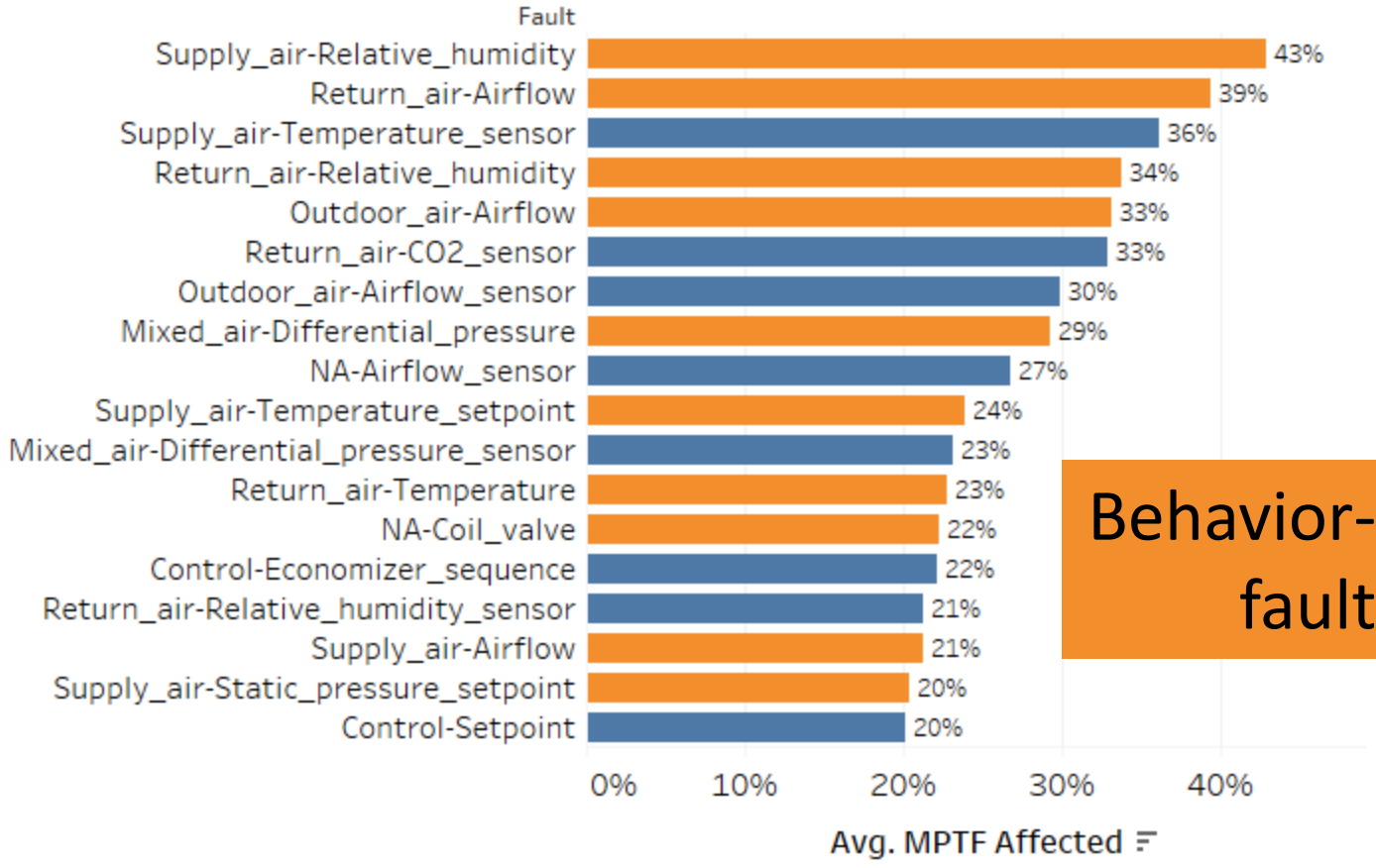
Mean Percent Time Faulted



Mean Percent Time Faulted

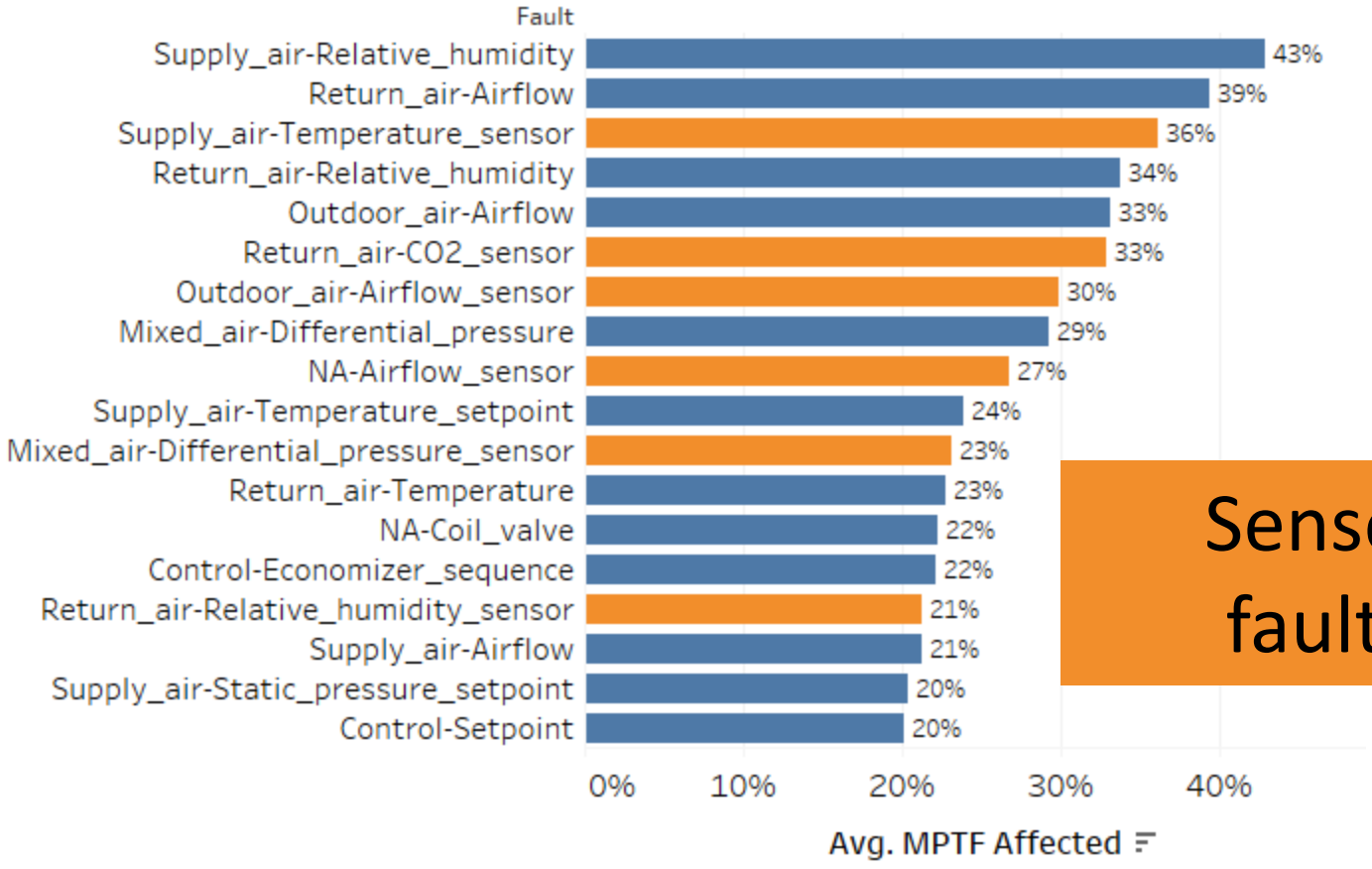


Mean Percent Time Faulted



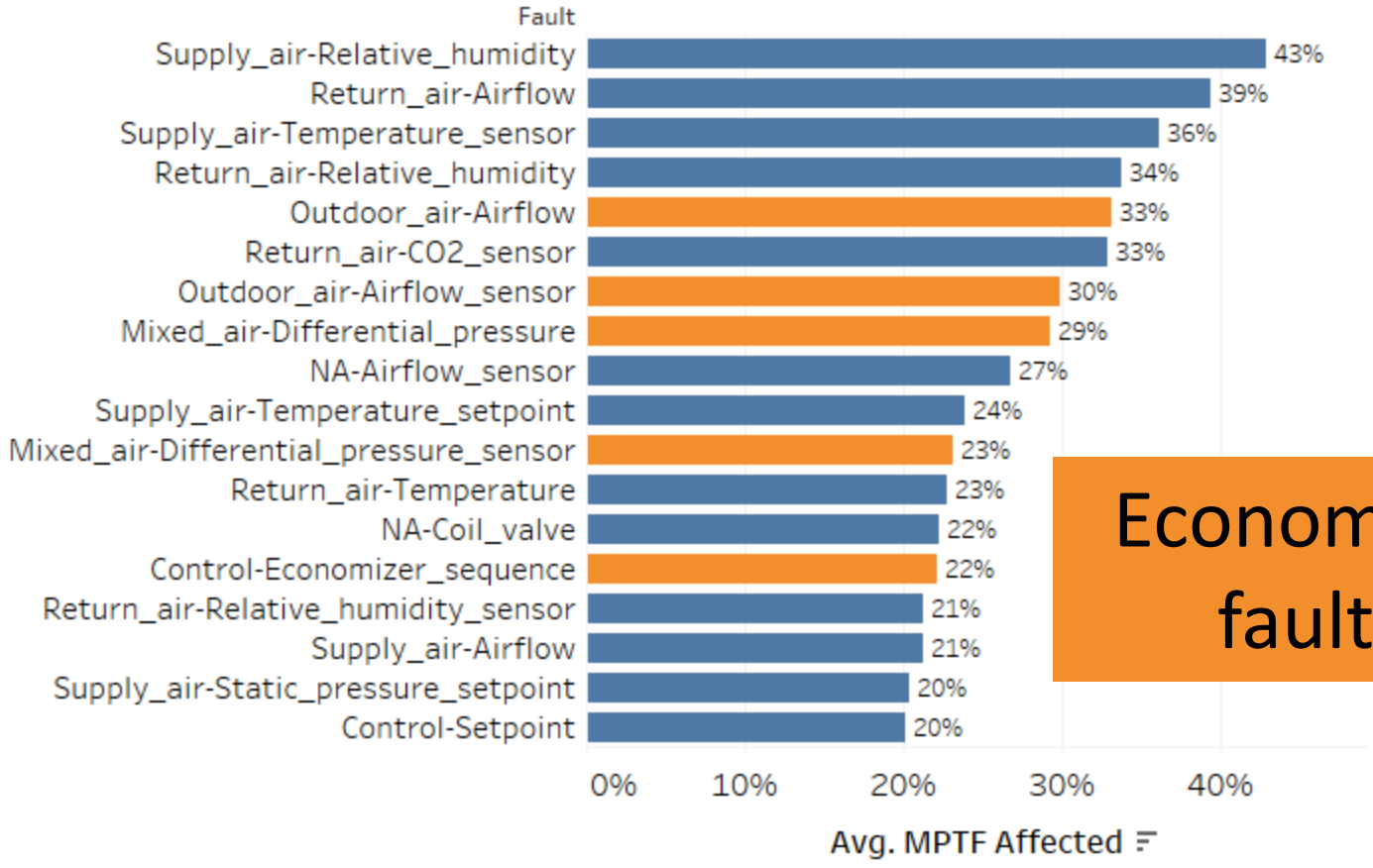
Behavior-based faults

Mean Percent Time Faulted



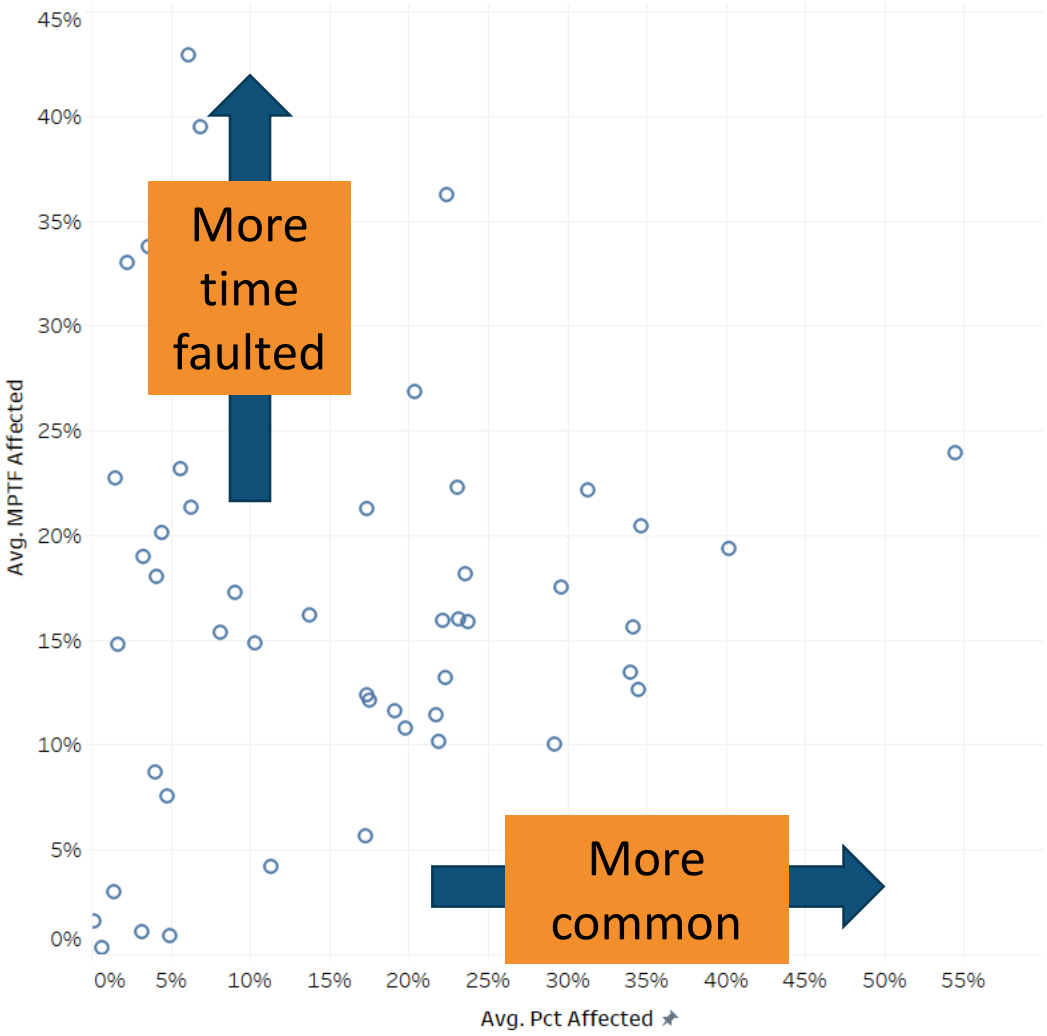
Sensor faults

Mean Percent Time Faulted

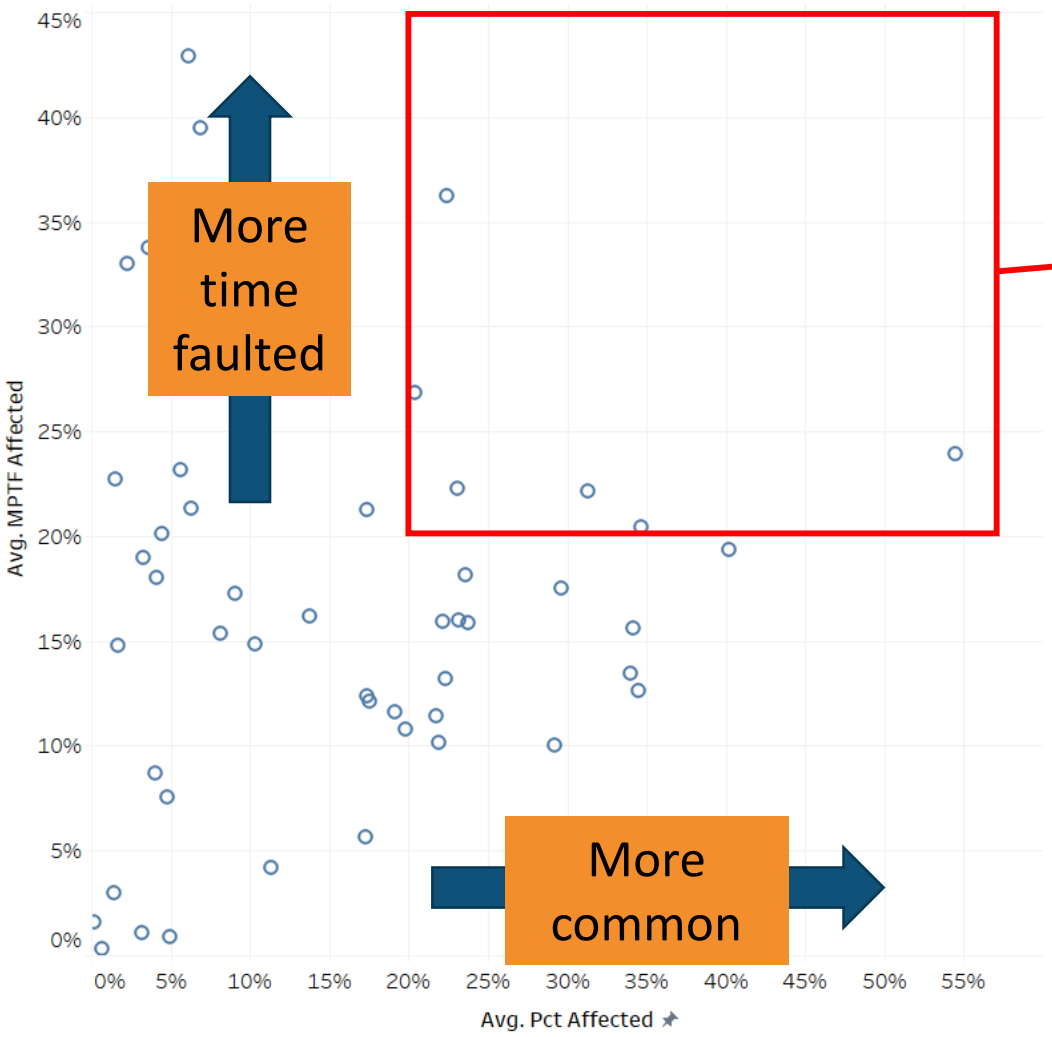


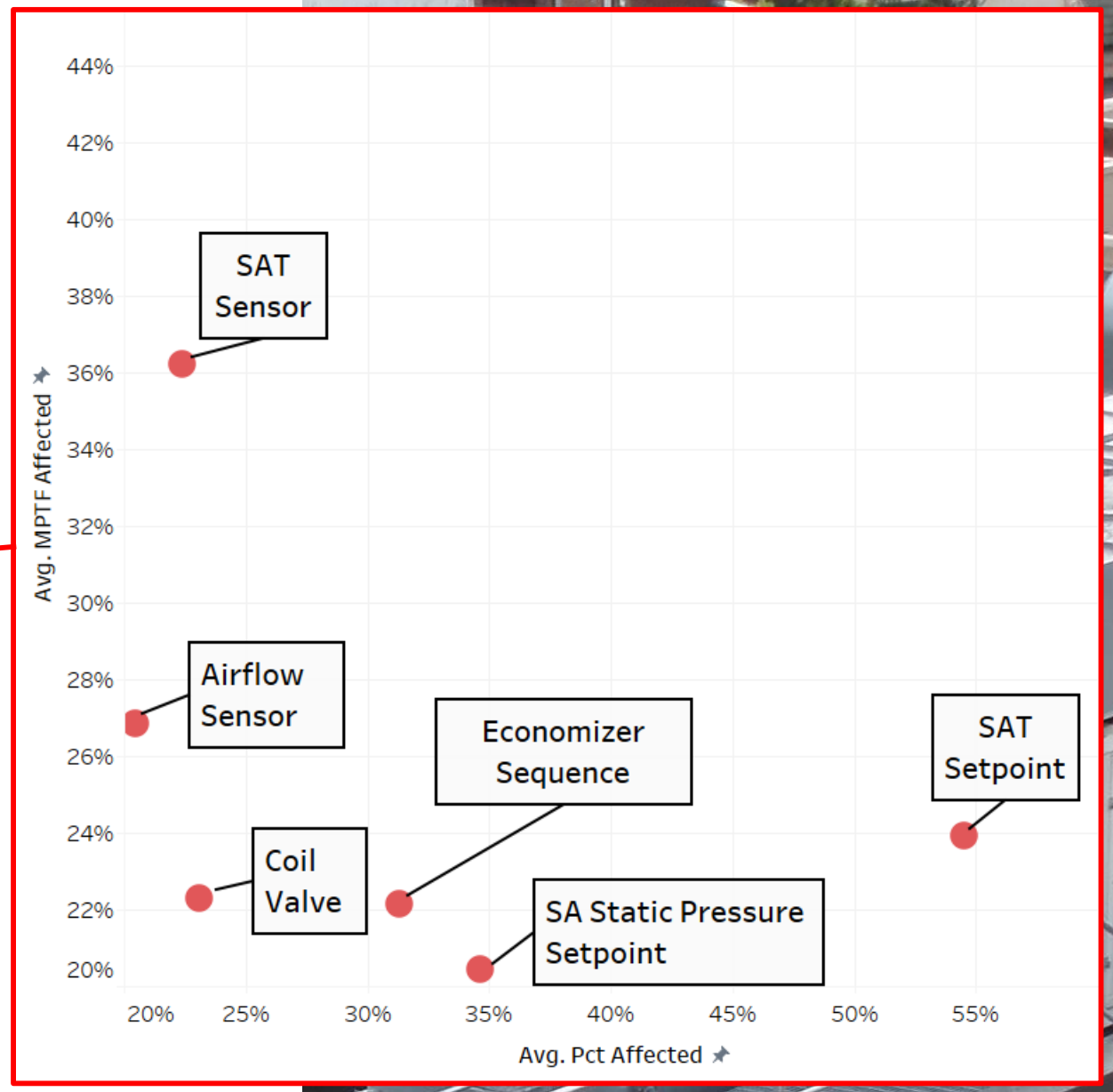
Economizer faults

Most Common vs Most Frequent (AHU)



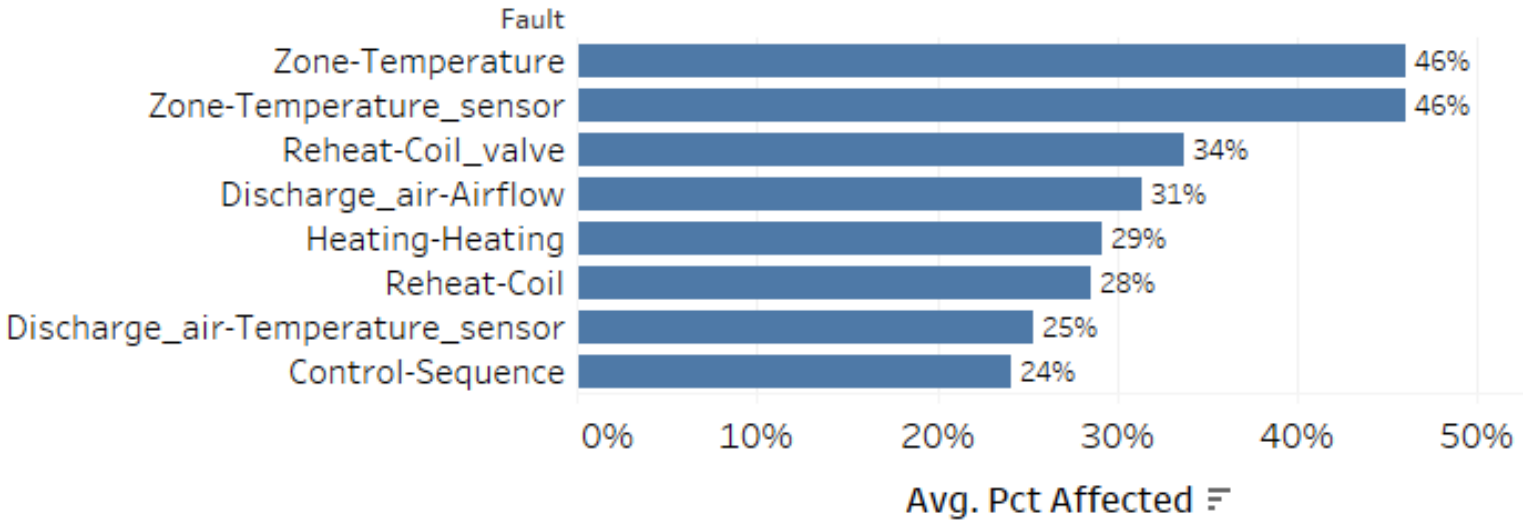
Most Common vs Most Frequent



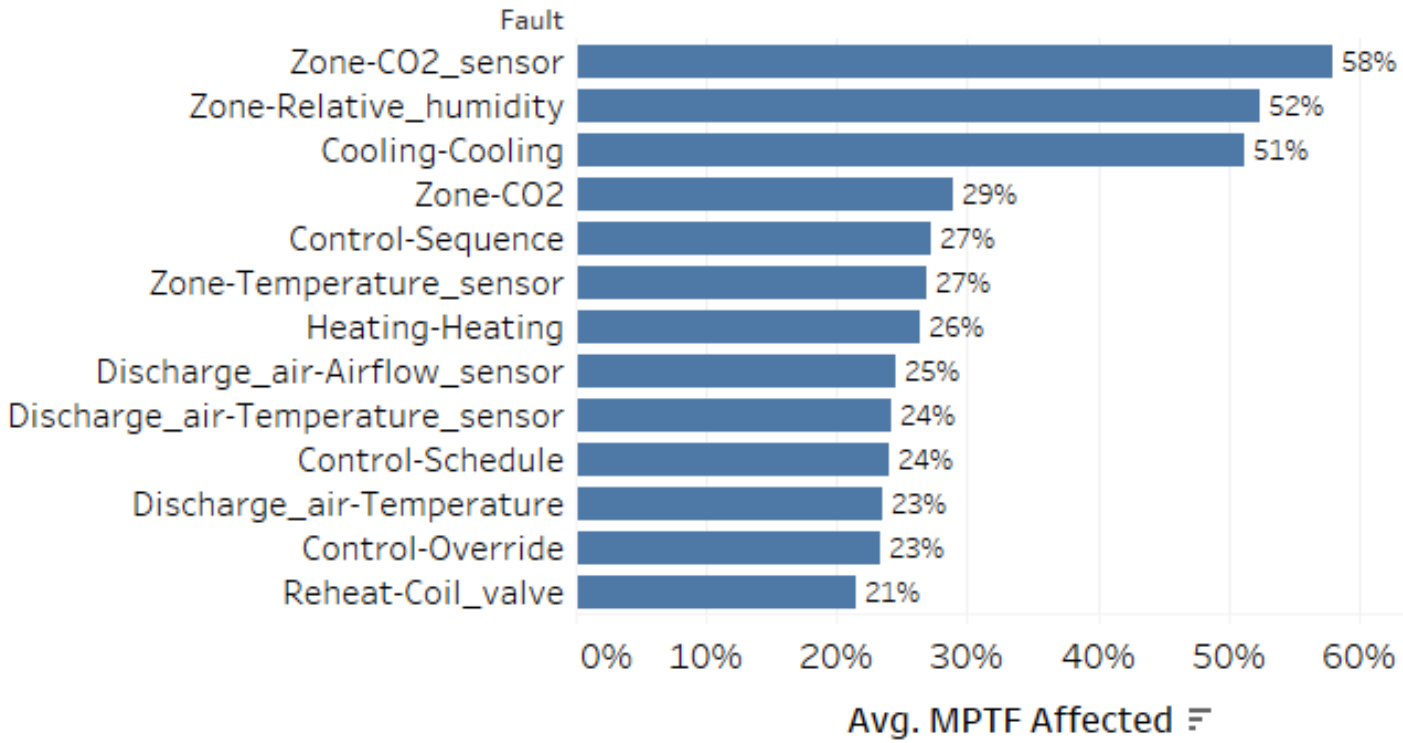


ATUs

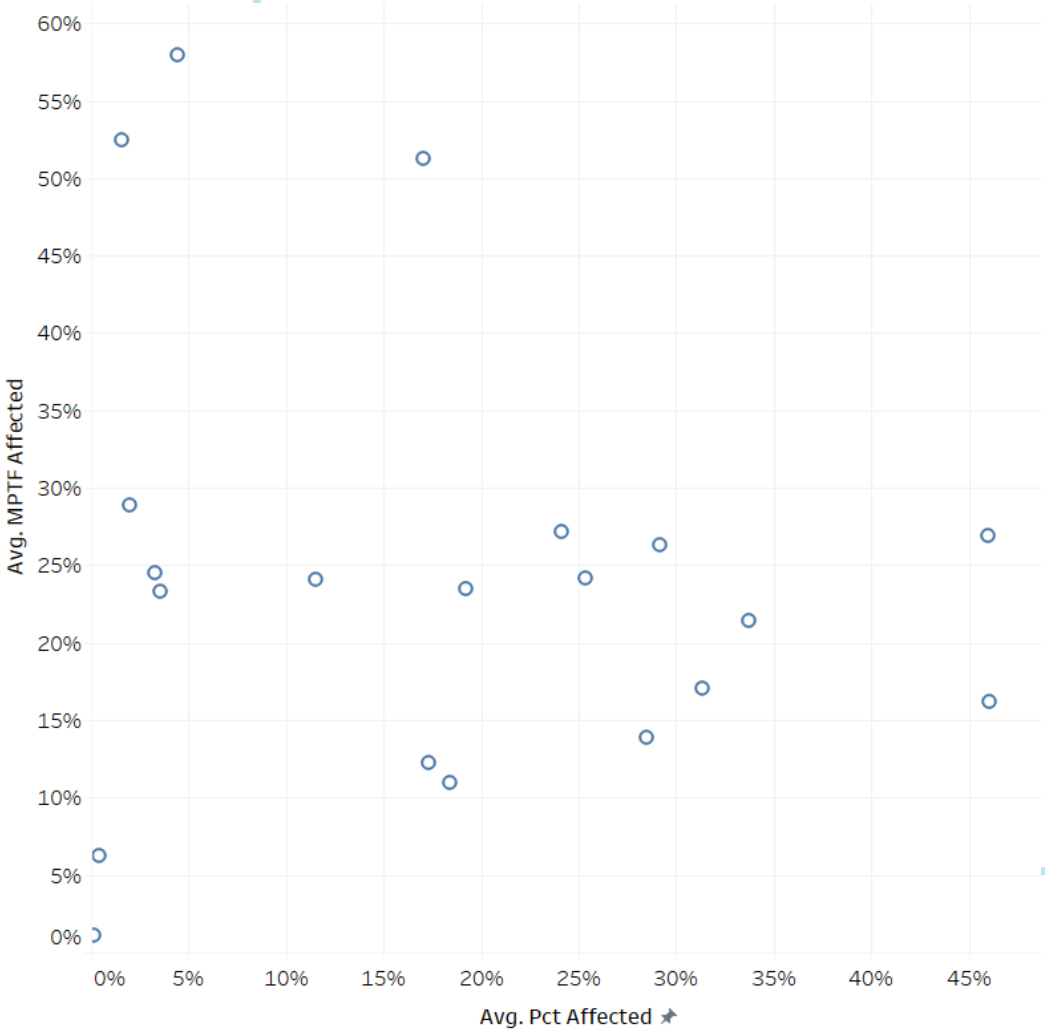
Percent of ATUs Affected



Mean Percent Time Faulted



Most Common vs Most Frequent (ATU)



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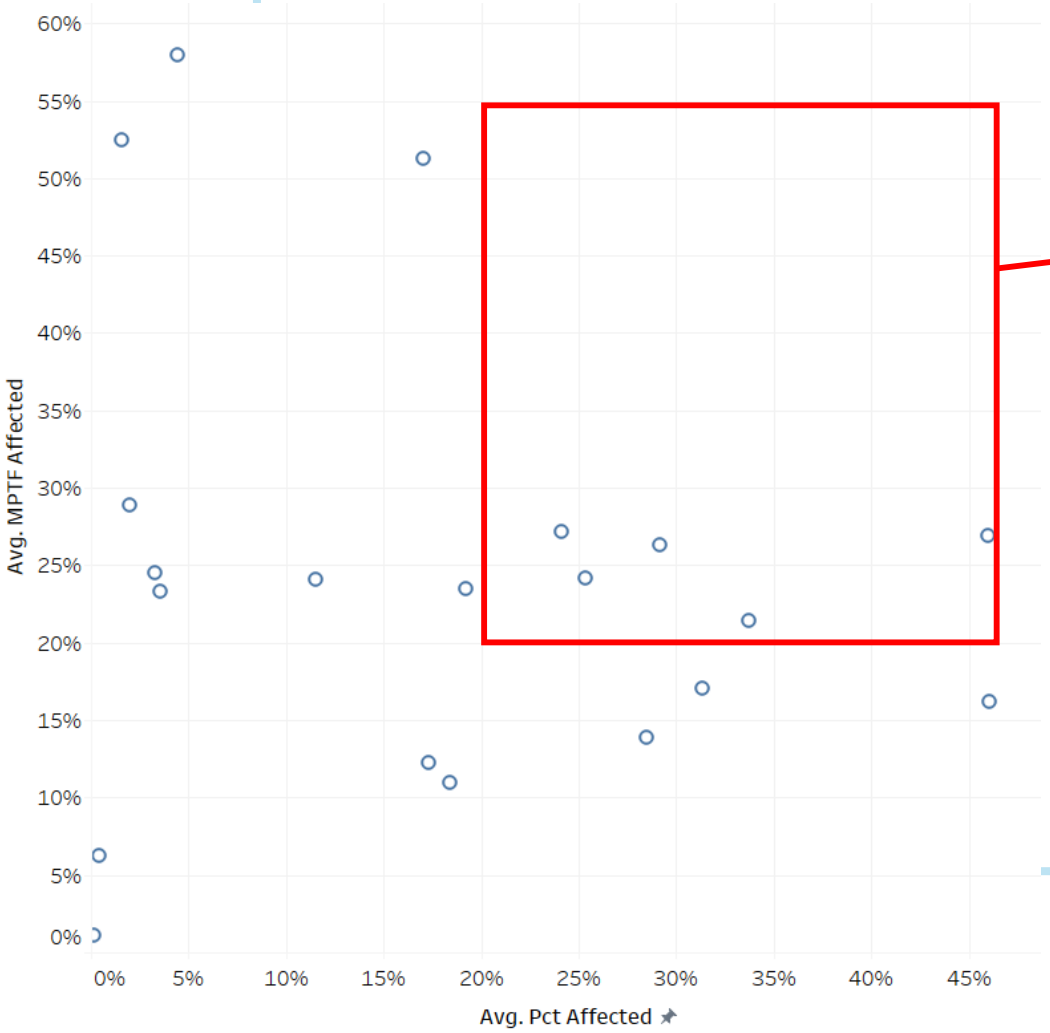
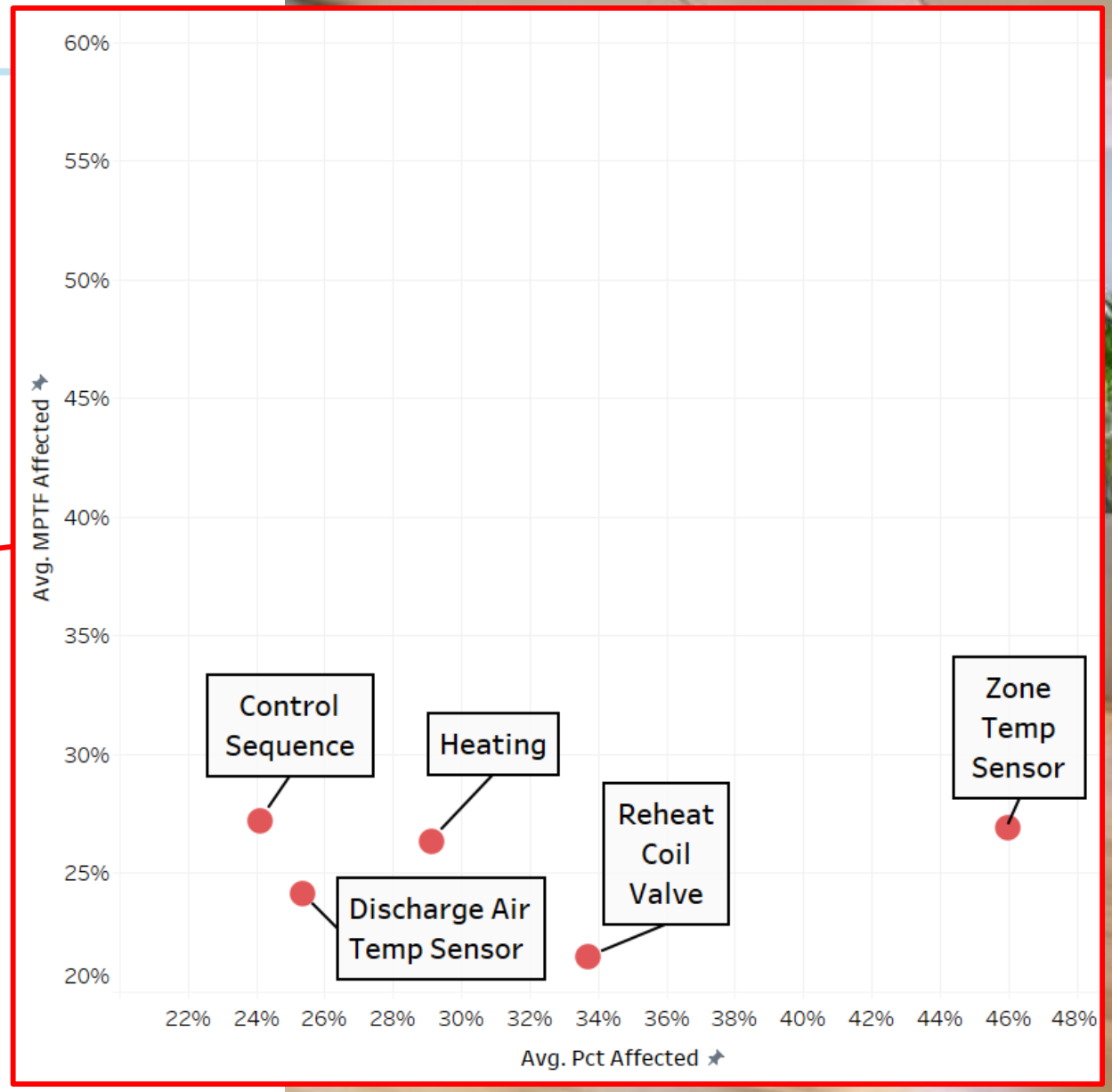


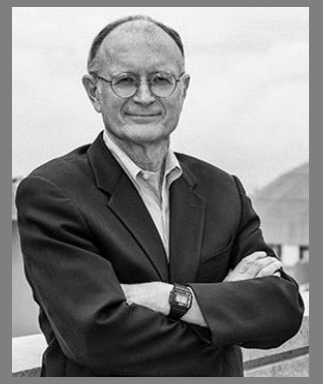


Wrap-Up

- Study addressed key questions:
  - Which faults are most often observed to be present? (just ***how*** common are they?)
  - How many faults occur each month for a given building?
  - What percentage of units are faulted at any given point in time?
- To meet aggressive performance goals (emissions, comfort, flexibility) buildings need to be operating to full potential; study shows we have a way to go – hundreds of faults per building per month
- Ongoing development needs:
  - Improved diagnosis of behavior-based faults to support faster resolution
  - Auto-correction of faults (in progress)
  - Standardized fault identification approaches

Thank You!

Jessica
Granderson
Staff Scientist, Deputy
for Research Programs



Berkeley Lab Director's statement on Inclusion, Diversity, Equity, and Accountability (excerpt)

Fostering a diverse workforce - diverse in experiences, perspectives, and backgrounds - and a culture of inclusion are key to attracting and engaging the brightest minds and advancing our record of scientific excellence and groundbreaking innovations.

https://diversity.lbl.gov/directors-statement/