Pacific Northwest
NATIONAL LABORATORY

State of the Art in Visualization for Building Systems

September 25, 2019

Lyndsey Franklin, Yi Huang, and Dustin Arendt

VOLTTRON™

Pacific Northwest
NATIONAL LABORATORY

Agenda

- Survey of relevant literature
- Exploration with Tableau (exploratory data analysis platform)
- Exploration with CHISSL (interactive machine learning)

Pacific Northwest
NATIONAL LABORATORY

Literature

Pacific Northwest
NATIONAL LABORATORY

[1] A Systematic Review of Visualization in Building Information Modeling

P. Ivson, A. Moreira, F. Queiroz, W. Santos and W. Celes, "A Systematic Review of Visualization in Building Information Modeling," in *IEEE Transactions on Visualization and Computer Graphics*.
doi: 10.1109/TVCG.2019.2907583

URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8674573&isnumber=4359476

- Results from a survey of visualizations in current Building Information Modeling practice
- Taxonomy of main application areas
  - Use Cases: Design Review, Work Planning, Work Execution, Sustainability Analysis, and Facility Management
  - Information: Scope, Schedule, Cost, Sustainability, Facility, Risk, Resource, Supply Chain, Security, Mechanical, Quality
- 200+ papers surveyed

Simulation and visualization of energy-related occupant behavior in office buildings

Chen, Y., Liang, X., Hong, T., & Luo, X. (2017, December). Simulation and visualization of energy-related occupant behavior in office buildings. In Building Simulation (Vol. 10, No. 6, pp. 785-798). Tsinghua University Press.

DOI: https://doi.org/10.1007/s12273-017-0355-2

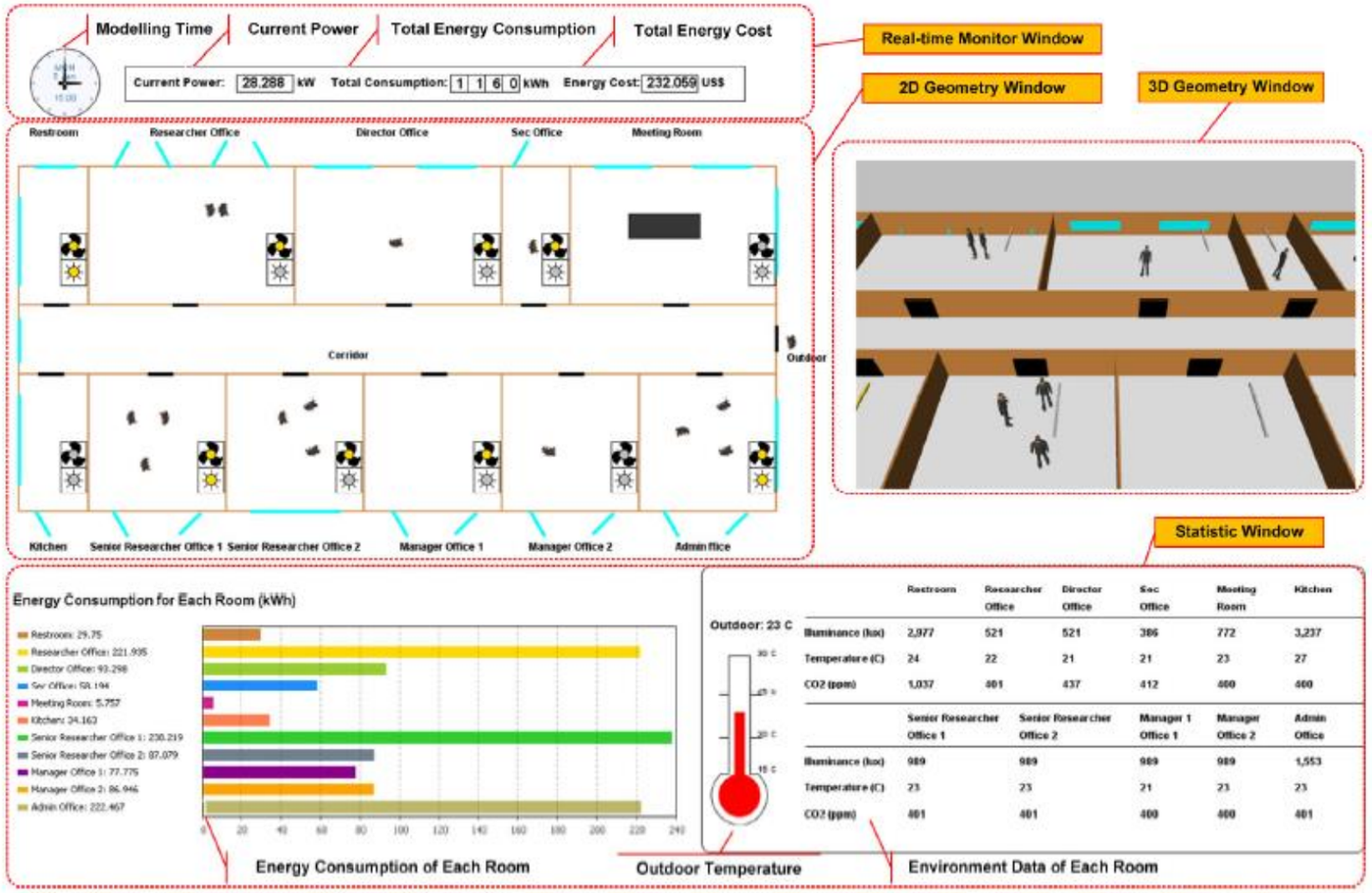


Fig. 11 The interface of the visualization model in AnyLogic (Note: the lighting illuminance is only for the daylighting and doesn't include the artificial lights)

Pacific Northwest
NATIONAL LABORATORY

Enabling Complex Building Energy Visualization by Integrative Event-Driven Data Provisioning

R. Kurpatov, M. Schmidt and A. Schülke, "Enabling complex building energy visualization by integrative event-driven data provisioning," *2015 International Conference and Workshops on Networked Systems (NetSys)*, Cottbus, 2015, pp. 1-6.
doi: 10.1109/NetSys.2015.7089085

URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7089085&isnumber=7089054

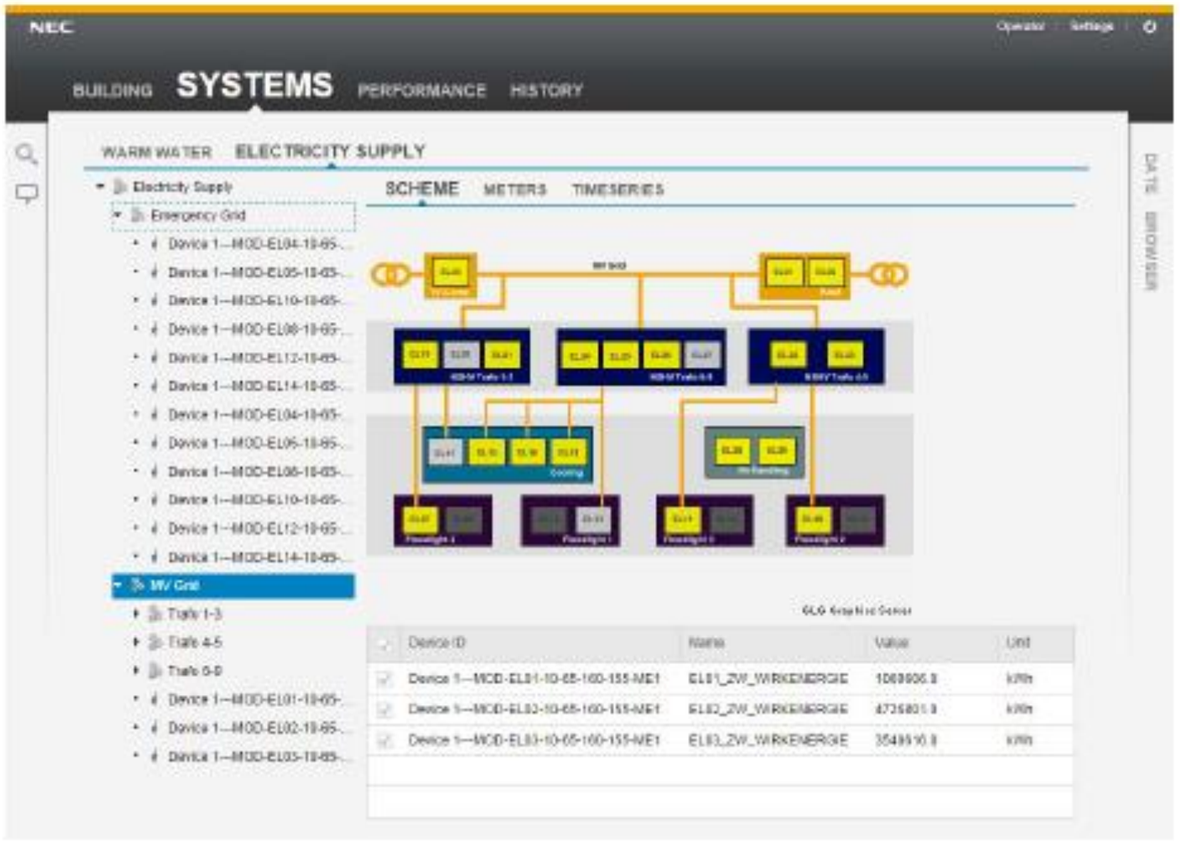


Fig. 5. Systems view. Contains device list with current meter values, tree structure of building systems and its visual representation.

A Visualization Tool for Building Energy Management System

T. Itoh, M. Kawano, S. Kutsuna and T. Watanabe, "A Visualization Tool for Building Energy Management System," 2015 19th International Conference on Information Visualisation, Barcelona, 2015, pp. 15-20.

doi: 10.1109/iV.2015.15

URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7272573&isnumber=7272518

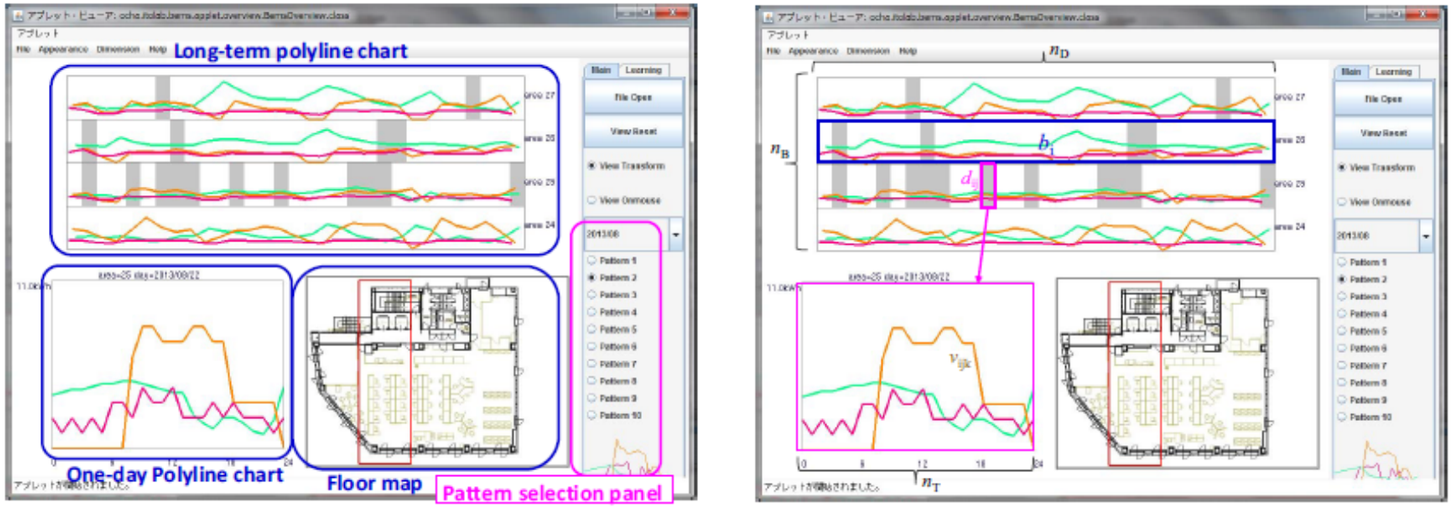


Figure 1. Snapshots of the presented visualization tool for building energy management. Long-term polyline chart is clickable so that users can specify blocks of the building on the particular day. The energy consumption and other values corresponding to the clicked position are displayed in one-day polyline chart. The values of each block, each day are divided into the meaningful number of patterns so that users can interactively focus on specific patterns.

Pacific Northwest
NATIONAL LABORATORY

Chasing the Negawatt: Visualization for Sustainable Living

Bartram, L., Rodgers, J., & Muise, K. (2010). Chasing the negawatt: visualization for sustainable living. IEEE Computer Graphics and Applications, 30(3), 8-14.

DOI: 10.1109/MCG.2010.50

Figure 3. The Adaptive Living Interface System (ALIS) Dashboard provides access to high-level information regarding home energy use.

Pacific Northwest
NATIONAL LABORATORY

Chasing the Negawatt: Visualization for Sustainable Living

Bartram, L., Rodgers, J., & Muise, K. (2010). Chasing the negawatt: visualization for sustainable living. IEEE Computer Graphics and Applications, 30(3), 8-14.

DOI: 10.1109/MCG.2010.50

Figure 5. The Neighborhood Bulletin lets residents compare energy use and share conservation tips.

Pacific Northwest
NATIONAL LABORATORY

Time-pie visualization: Providing contextual information for energy consumption data

M. Masoodian, B. Endrass, R. Bühling, P. Ermolin and E. André, "Time-Pie visualization: Providing Contextual Information for Energy Consumption Data," *2013 17th International Conference on Information Visualisation*, London, 2013, pp. 102-107. doi: 10.1109/IV.2013.12

URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6676549&isnumber=6676523

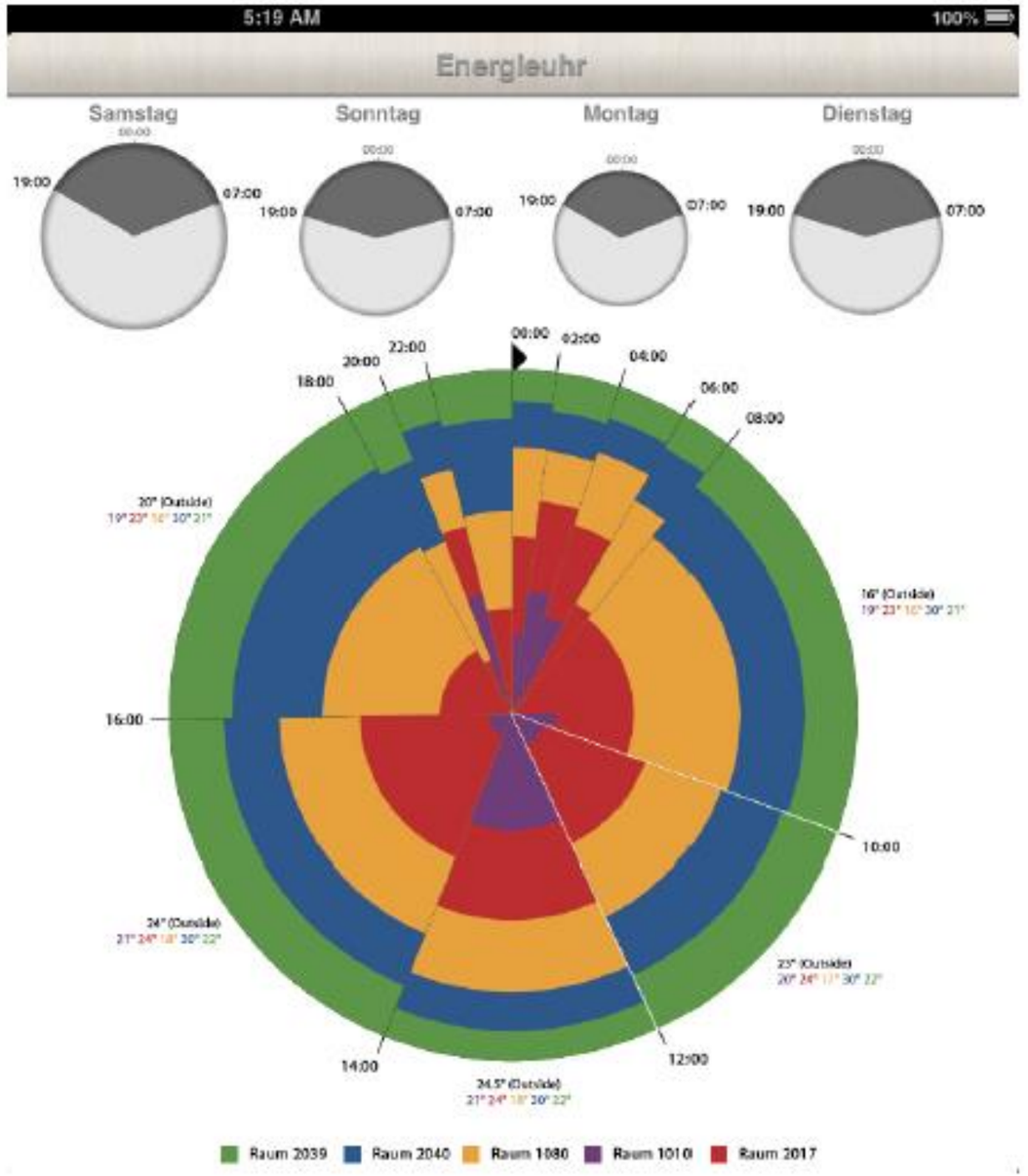


Figure 6. A prototype implementation of time-pie visualization, showing the proportions of energy usage by five different offices in a 24-hour period.

TimeNotes: A Study on Effective Chart Visualization and Interaction Techniques for Time-Series Data

Walker, J., Borgo, R., & Jones, M. W. (2015). TimeNotes: a study on effective chart visualization and interaction techniques for time-series data. *IEEE transactions on visualization and computer graphics*, *22*(1), 549-558.

DOI: 10.1109/TVCG.2015.2467751

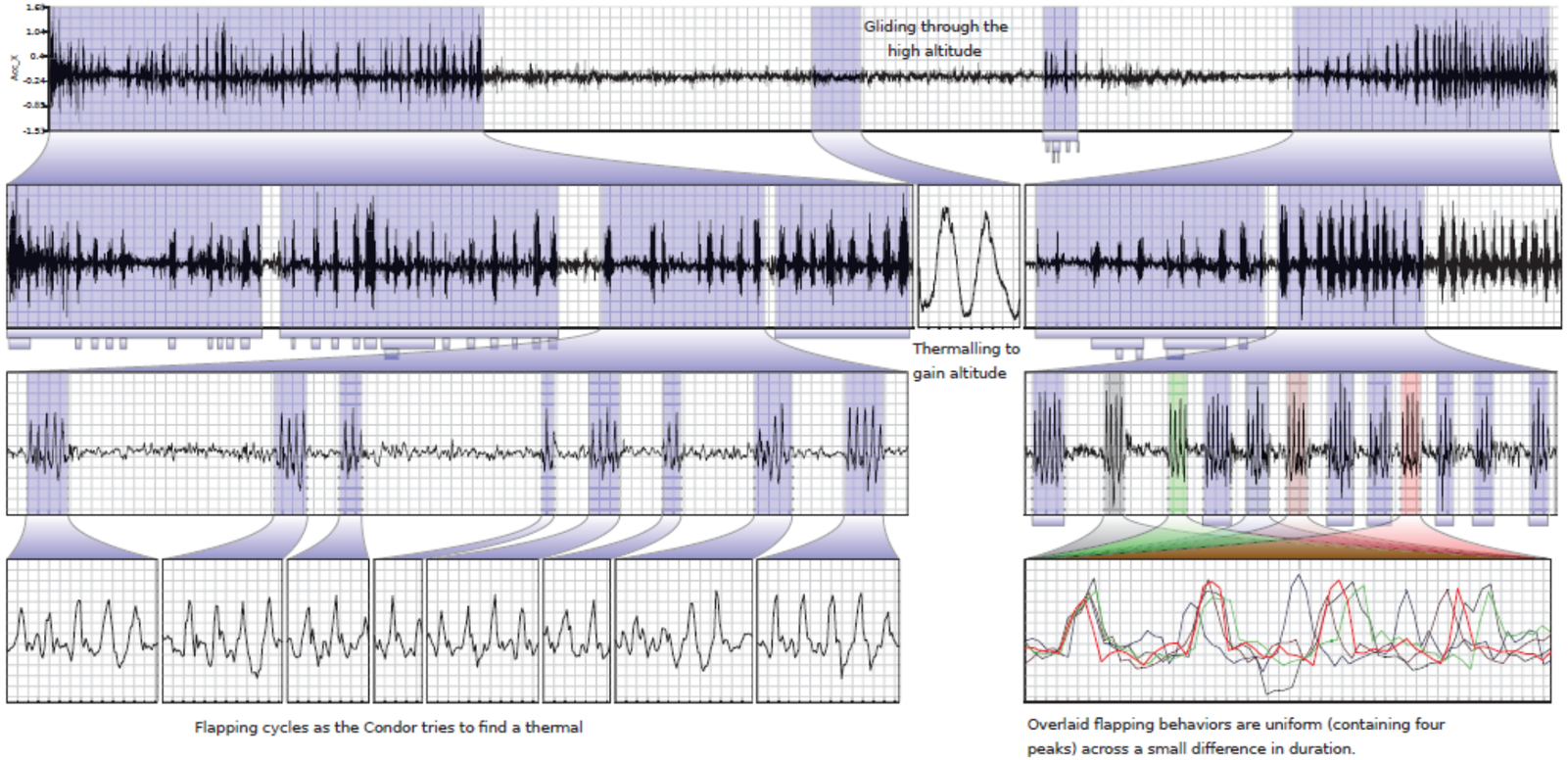


Fig. 13: TimeNotes displaying several flapping patterns across the data series. Firstly using the standard zoom approach (left tree) and using the stretched overlay view containing five segments overlaid (right tree). A thermalling activity is shown (center tree) using the magnetometer data.

Pacific Northwest
NATIONAL LABORATORY

Automated daily pattern filtering of measured building performance data

Miller, C., Nagy, Z., & Schlueter, A. (2015). Automated daily pattern filtering of measured building performance data. Automation in Construction, 49, 1-17.

https://doi.org/10.1016/j.autcon.2014.09.004

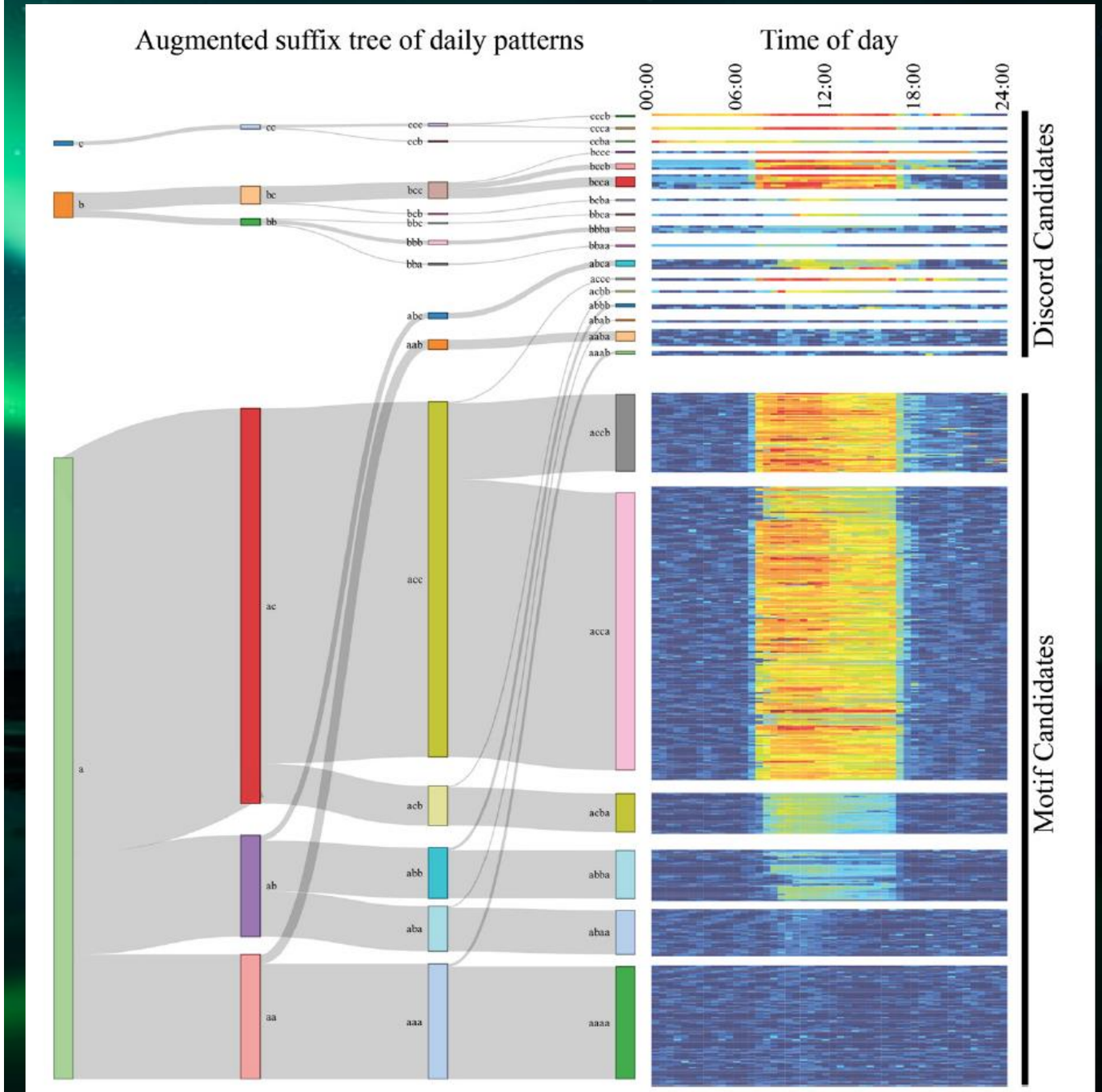


Fig. 7. Case Study 1 cooling electricity consumption representation of the day-types from the DayFilter process.

Pacific Northwest
NATIONAL LABORATORY

Tableau

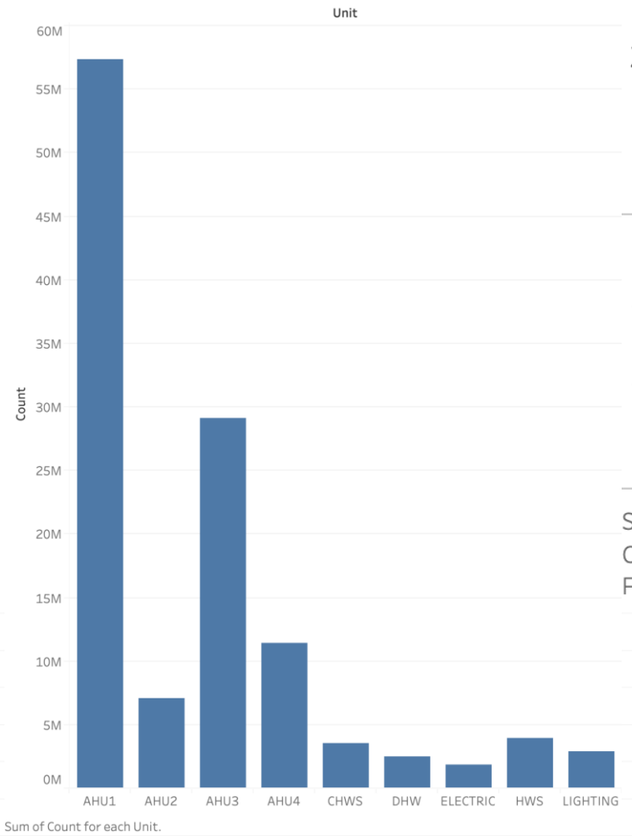
Data Prep for Tableau

- Each row is a a timeseries for a measurement on a specific day
- Meta-data: feature name, unit, etc.
- Derived data: min, max, quartile edges

	25%	50%	75%	building	category	count	date	feature	max	mean	min	std	unit
83456	67.340740	70.415009	72.750656	SEB	AHU3	1440.0	2018-06-18	HotWaterValveTemperature	77.464874	70.161647	62.096008	3.535294	AHU3
83457	63.931633	67.843529	77.565971	SEB	AHU3	1440.0	2018-06-19	HotWaterValveTemperature	79.510117	69.983278	62.507225	6.404742	AHU3
83458	74.019852	76.064362	77.956318	SEB	AHU3	1440.0	2018-06-25	HotWaterValveTemperature	79.551529	75.738767	70.781693	2.339049	AHU3
83459	68.175169	72.446365	75.937805	SEB	AHU3	1440.0	2018-06-27	HotWaterValveTemperature	78.624588	71.967529	65.460236	4.317397	AHU3
83460	67.408081	72.497002	75.979980	SEB	AHU3	1440.0	2018-06-26	HotWaterValveTemperature	77.565971	71.740754	64.692688	4.194294	AHU3

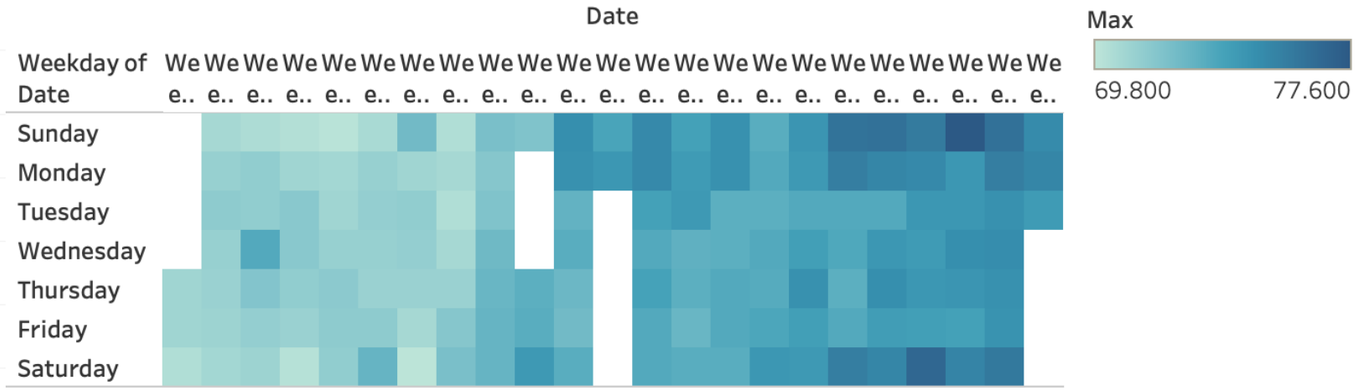
Tableau Visualizations

unit distribution



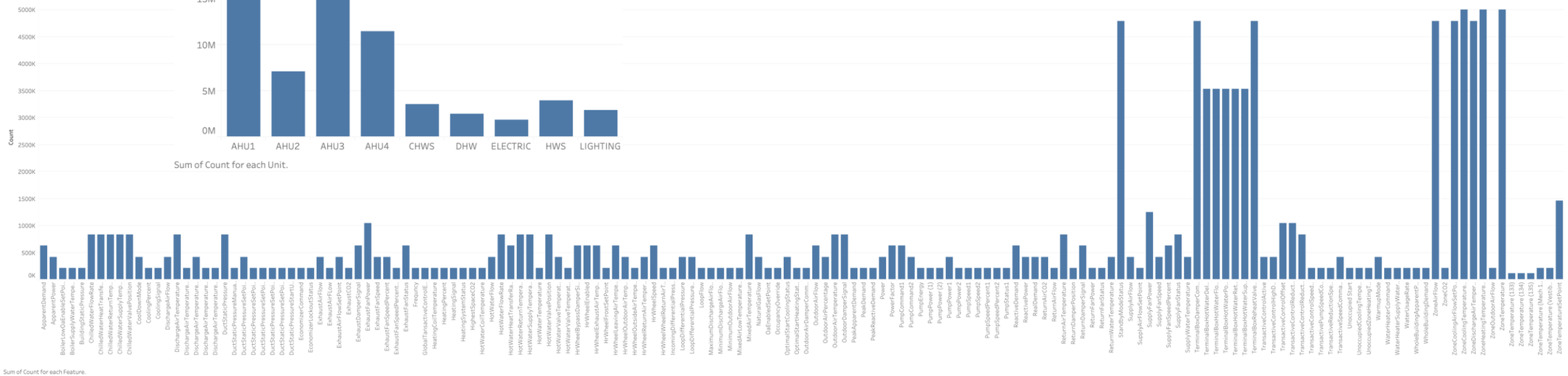
Sum of Count for each Unit.

zone temp_max



Sum of Max (color) broken down by Date Week vs. Date Weekday. The data is filtered on Unit, Category and Feature. The Unit filter keeps AHU1. The Category filter keeps VAV100. The Feature filter keeps ZoneTemperature.

feature distribution



Sum of Count for each Feature.

Pacific Northwest NATIONAL LABORATORY

Alternate Data Prep for Tableau

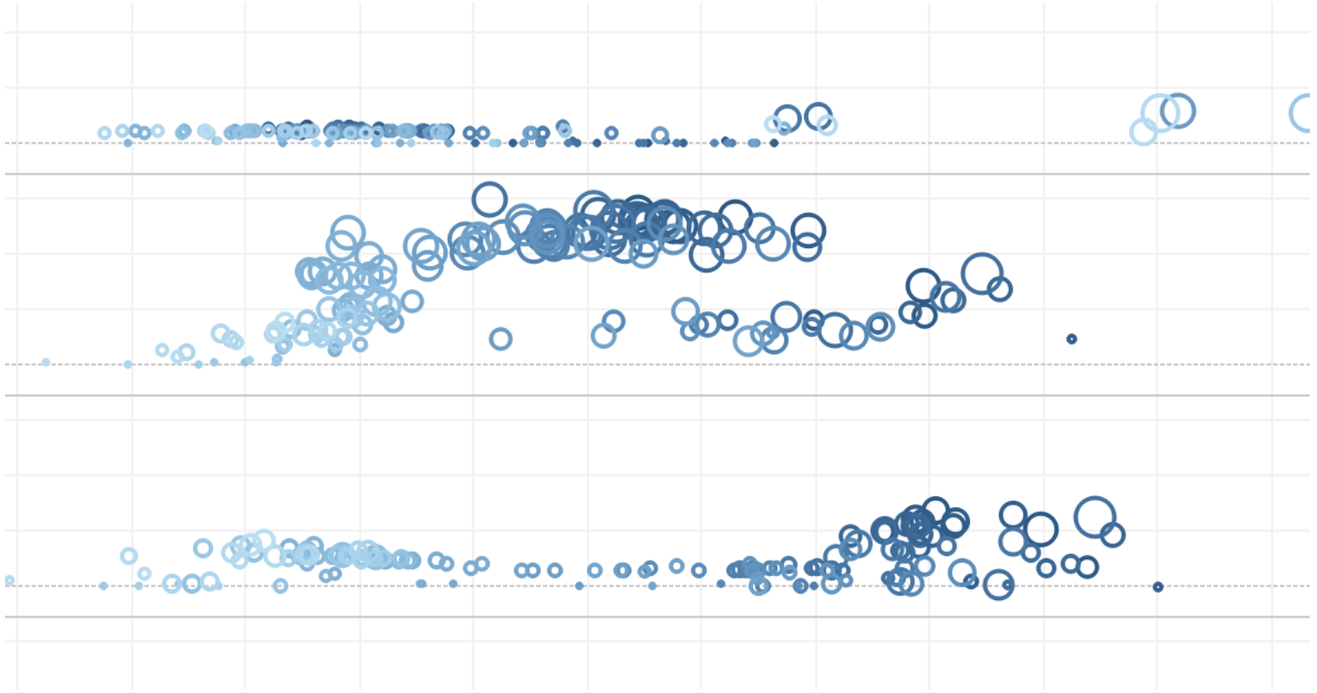
- Each sensor reading is a row
  - Timestamp
  - Metadata: building, unit, etc
  - Features: Temperature, Air Flow, etc.

	building	unit	category	date	ZoneAirFlow	ZoneCoolingAirFlowSetPoint	ZoneCoolingTemperatureSetPoint	ZoneDischargeAirTemperature	ZoneHeating
0	SEB	AHU1	VAV100	2018-03-01	267.922222	699.637370	74.000000	70.259376	
1	SEB	AHU1	VAV100	2018-03-02	268.040972	740.907332	74.000000	70.865001	
2	SEB	AHU1	VAV100	2018-03-03	133.712500	1020.551399	74.000000	72.765418	
3	SEB	AHU1	VAV100	2018-03-04	172.254167	1095.598916	74.000000	76.862918	
4	SEB	AHU1	VAV100	2018-03-05	266.668056	842.179365	74.000000	75.198960	
5	SEB	AHU1	VAV100	2018-03-06	257.555556	621.763671	74.000000	71.995001	

Pacific Northwest NATIONAL LABORATORY

Tableau Visualizations

Zone Temp vs Zone Air Flow by VAV



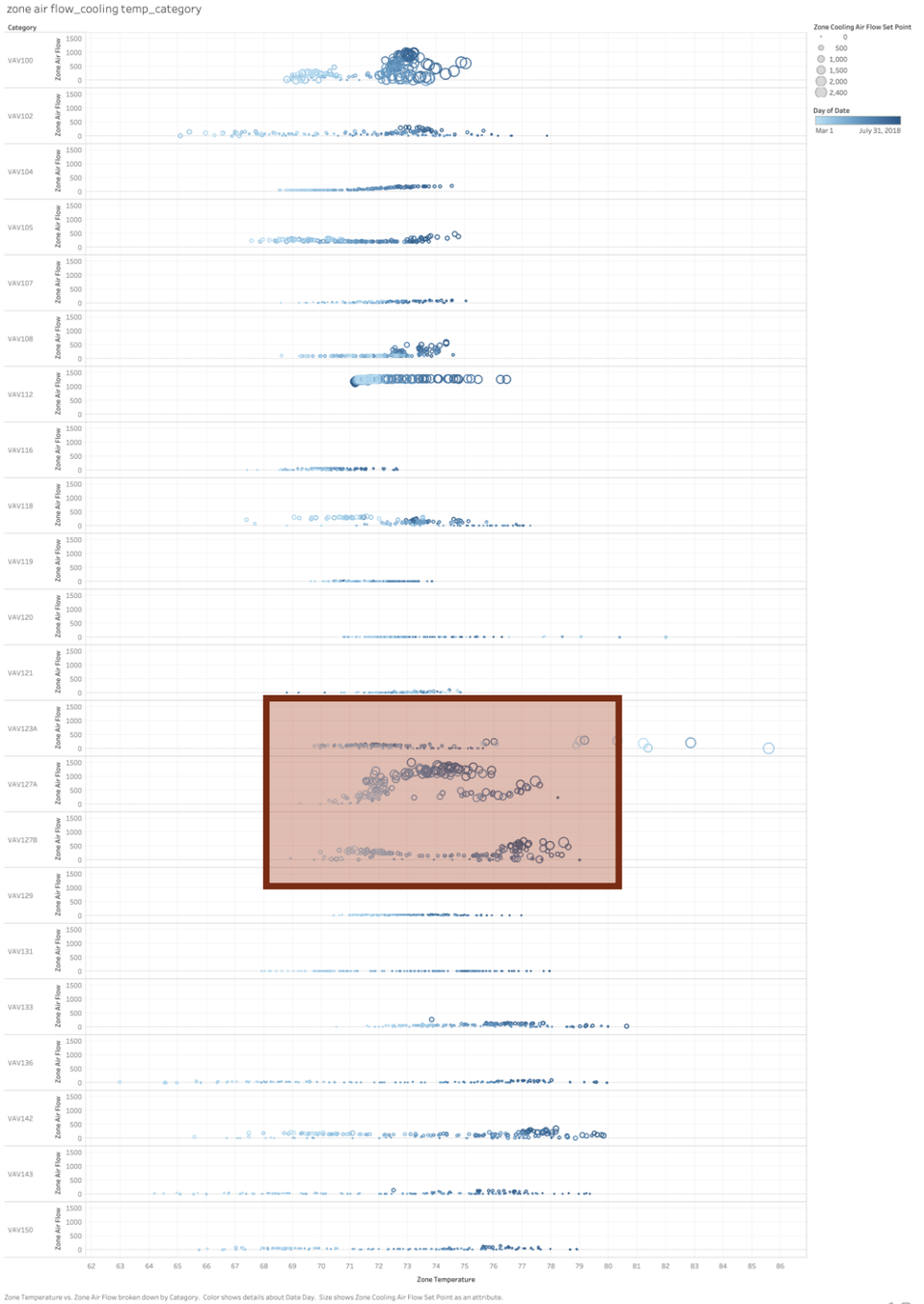
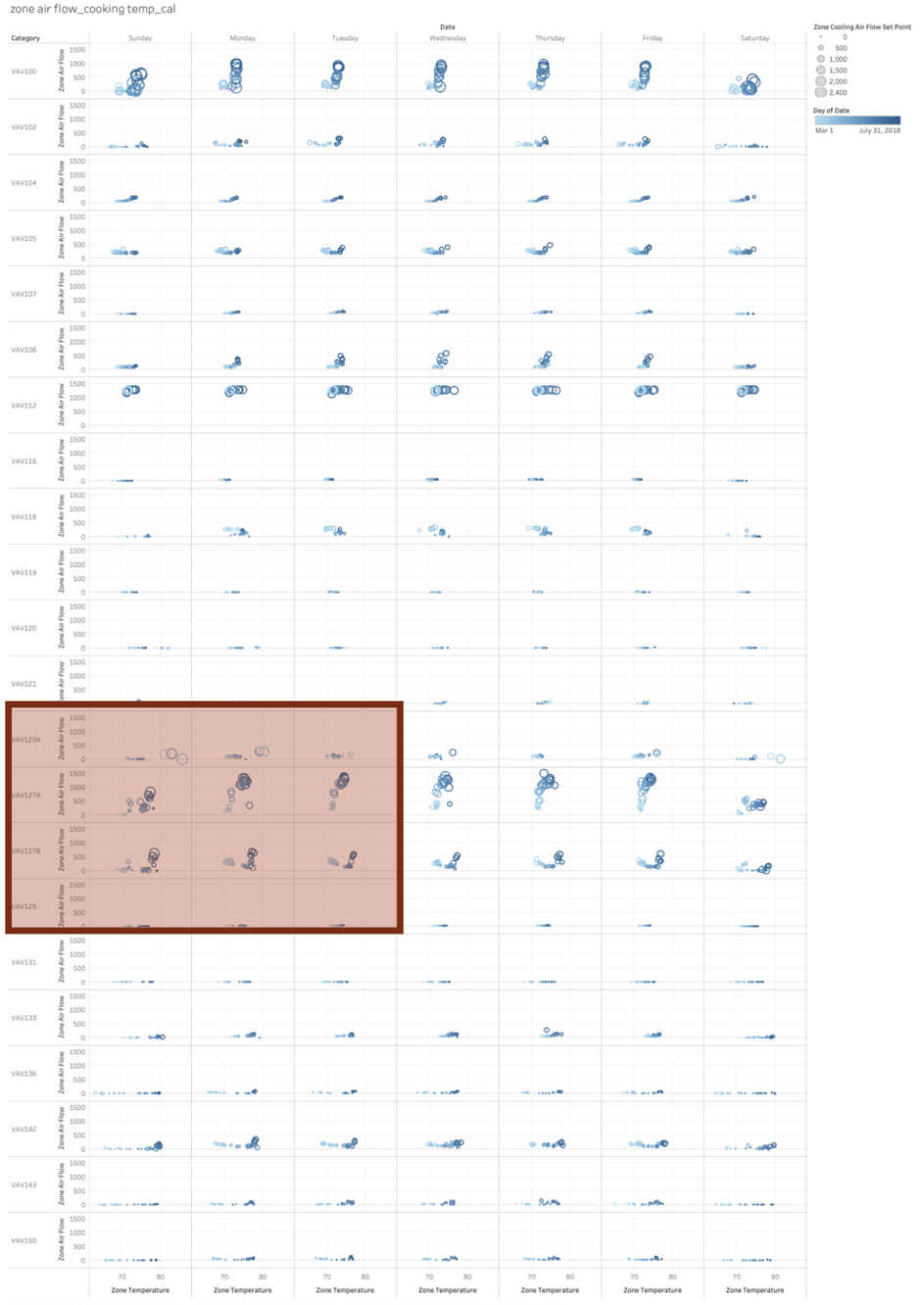


Tableau Visualizations

Zone Air Flow vs Zone Temp by Day of Week and VAV



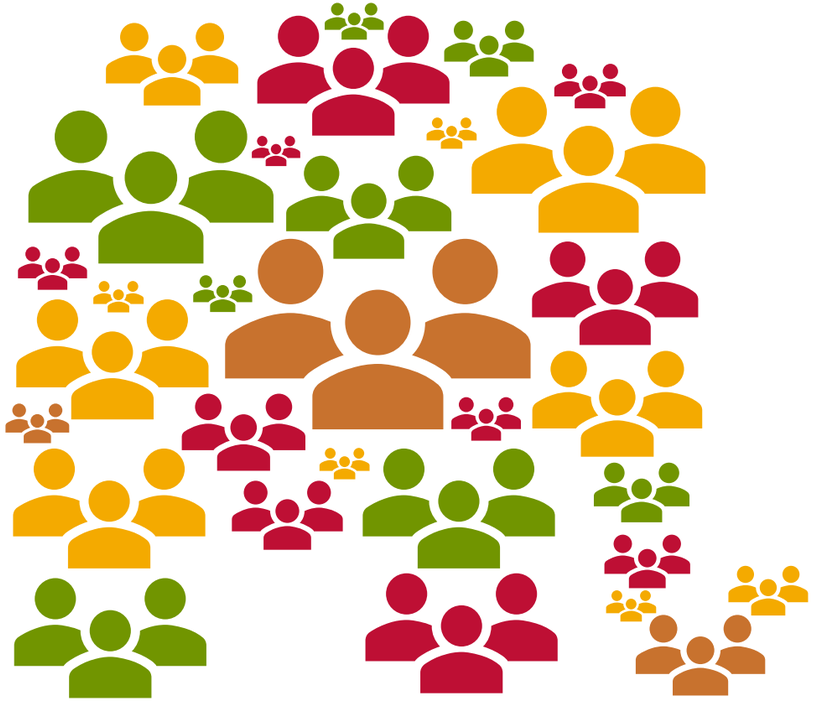
Pacific Northwest
NATIONAL LABORATORY

CHISSL

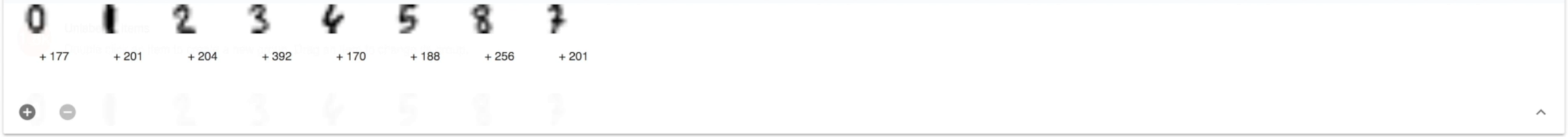
Necessity of Large, High-Quality, Labeled Datasets:
Machine Learning's "Elephant in the Room"

- Because, crowdsourcing requires
  - A well defined task
  - Users with expertise
  - A large population

- Alternatives may not be satisfying
  - Active Learning
  - Visual Interactive Labeling

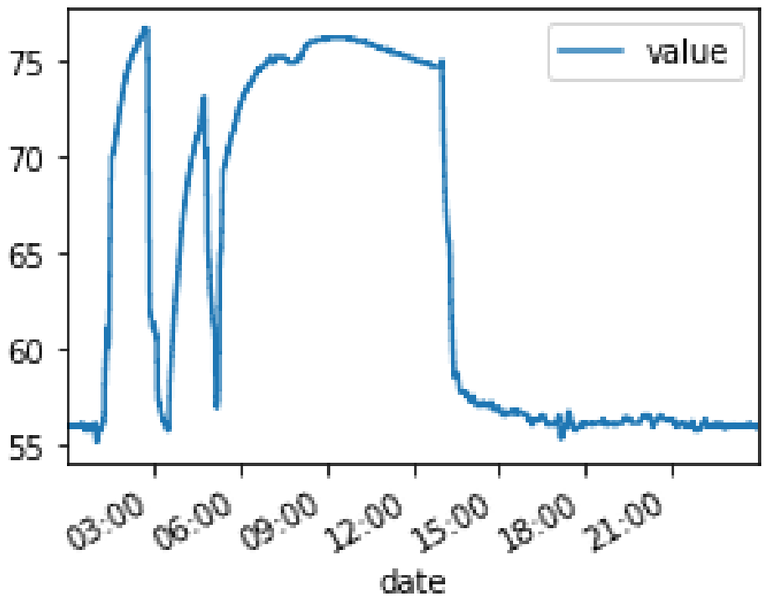


CHISSL—Rapidly Organize Data and Build Models

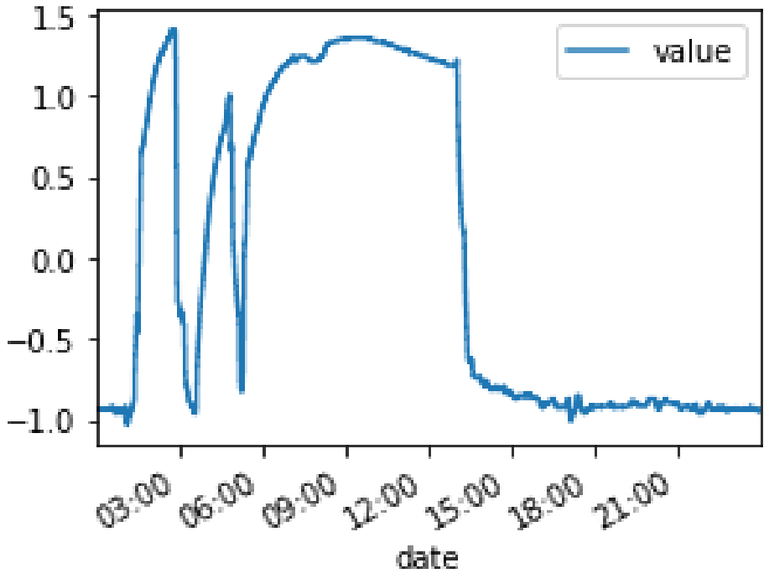


CHISSL Applied to VOLTTRON
Univariate time series

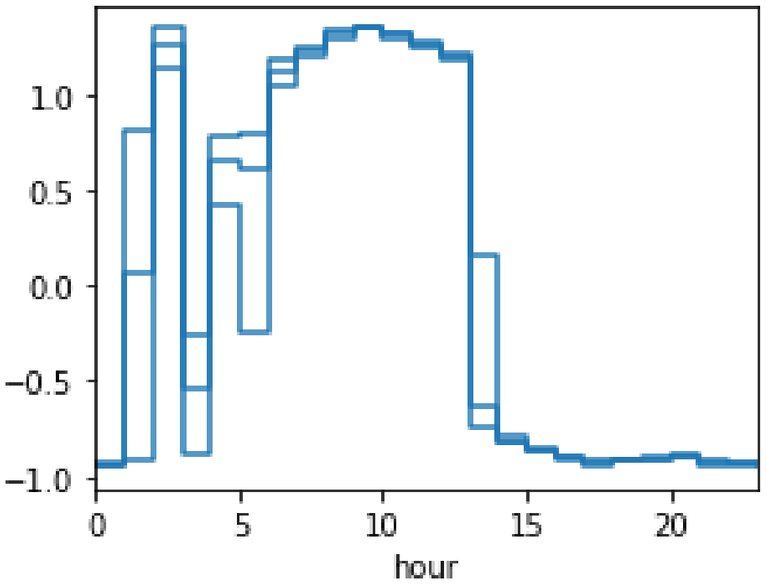
1-minute samples



Normalized



Featurized



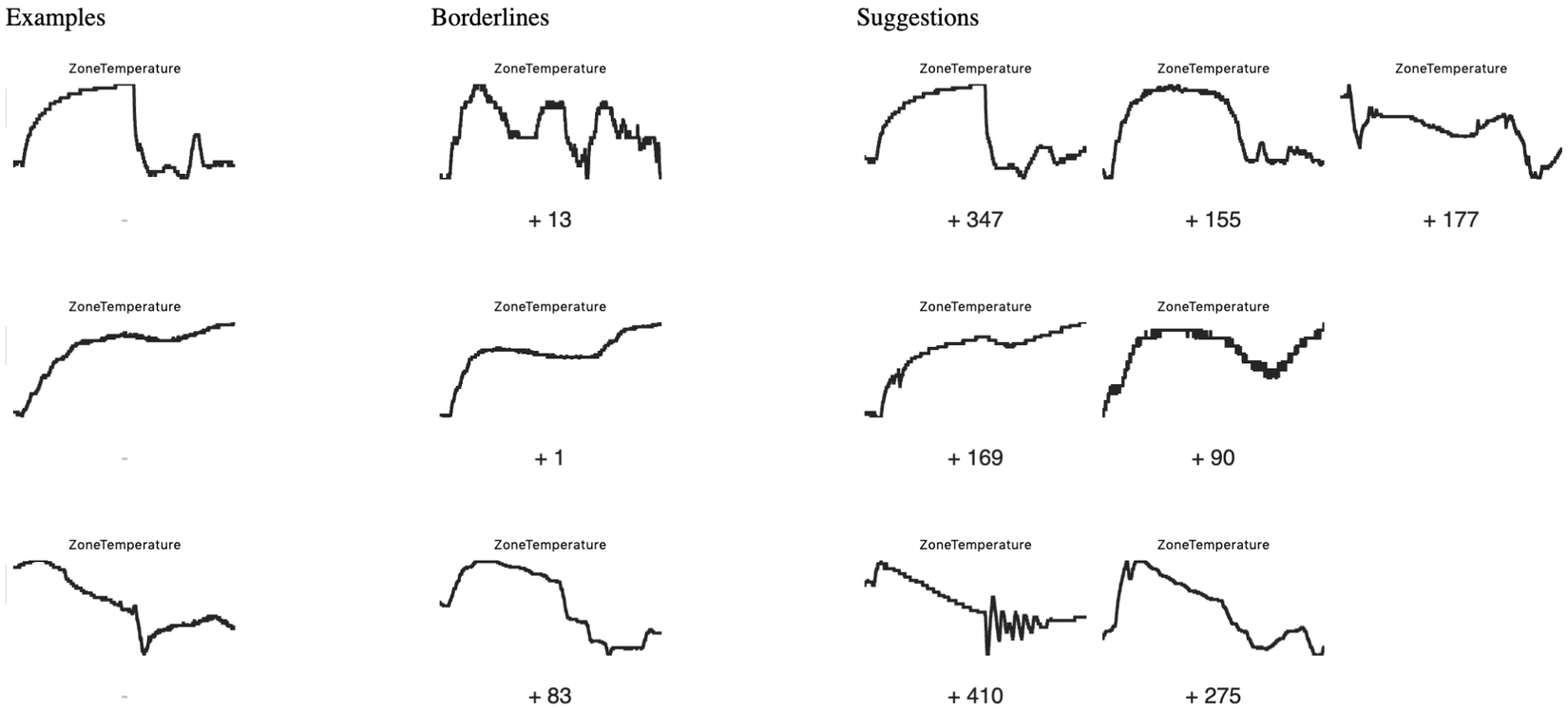
CHISSL Applied to VOLTTRON
Univariate time series

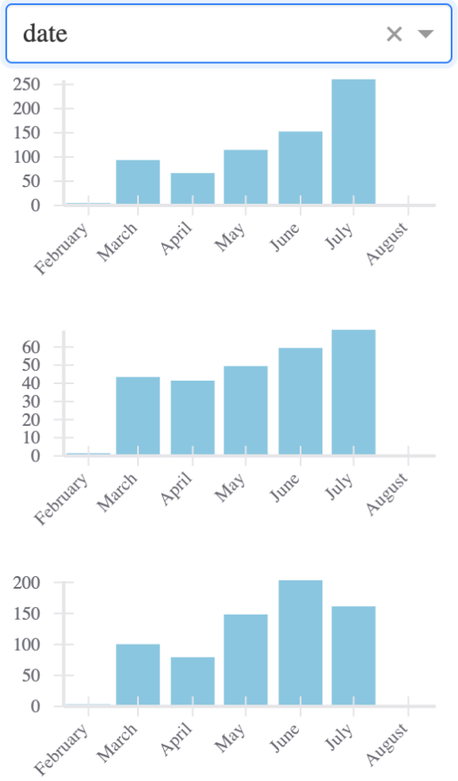
	25%	50%	75%
hour			
0	0.751880	0.851194	0.950507
1	1.073342	1.128226	1.170042
2	1.211858	1.211858	1.232767
3	1.211858	1.232767	1.253674
4	1.222312	1.248448	1.264128
5	-1.043600	-0.361475	-0.047853
6	0.576775	0.757108	0.827673
7	0.898237	0.919146	0.919146
8	0.898237	0.919146	0.929599
9	0.845967	0.856421	0.877329
10	0.770175	0.793697	0.804151
11	0.689156	0.704837	0.720519
12	0.605524	0.615978	0.636886

flattened

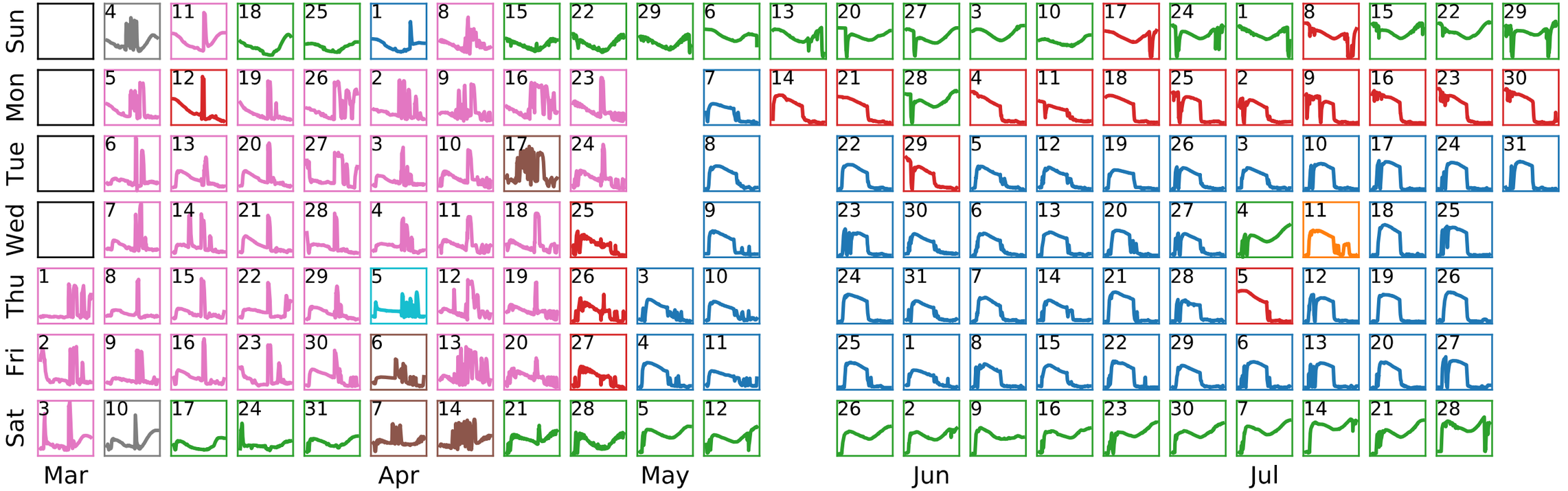
hour	0			1			2	
	25%	50%	75%	25%	50%	75%	25%	50%
0	0.75188	0.851194	0.950507	1.073342	1.128226	1.170042	1.211858	1.211858

CHISSL Applied to VOLTTRON
User Interface





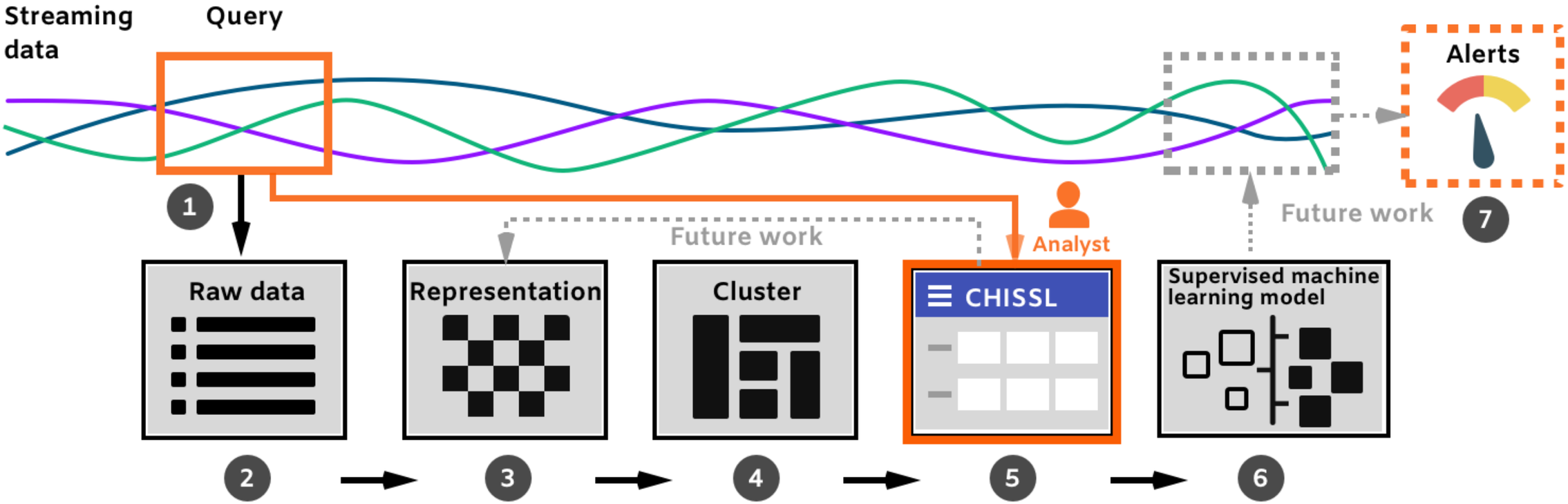
CHISSL Applied to VOLTTRON
Post-hoc Findings



Patterns found

- Spring vs Summer weekdays
- Weekends & Holidays
- Monday (Summer)
- Anomaly 1, Anomaly 2, Anomaly 3

Future Applications of CHISSL



Pacific Northwest
NATIONAL LABORATORY

CHISSL is on GitHub!
github.com/pnnl/chissl

Thank you