Functional Identification

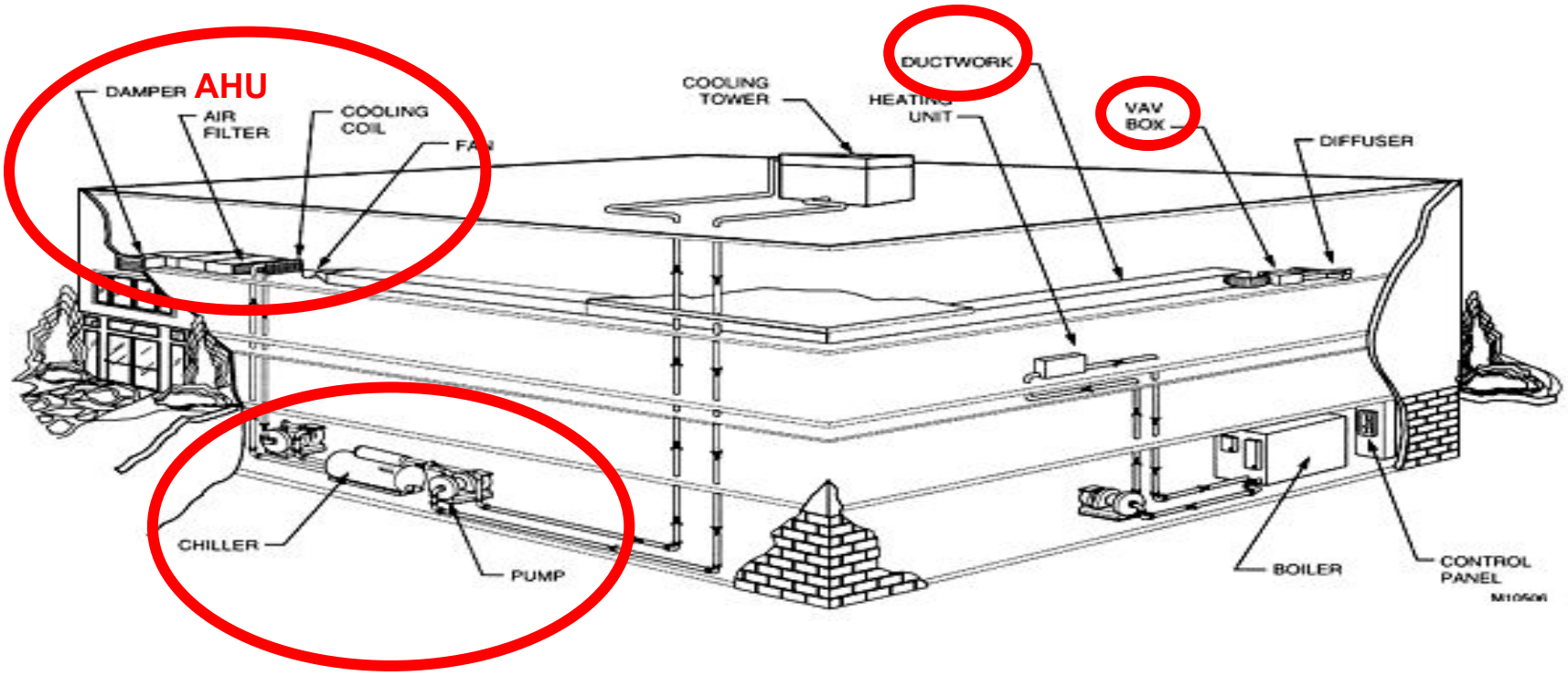
Marco Pritoni, Arka Bhattacharya, David Culler, Mark Modera

AKA:
“Short Paper: A Method for Discovering Functional Relationships Between Air Handling Units and Variable-Air-Volume Boxes From Sensor Data”

Marco Pritoni, Arka Bhattacharya, David Culler, Mark Modera

BuildSys 2015

Building HVAC Systems



HVAC Loops

Chiller

water

Air Handling Unit

air

VAV boxes

Occupants

...in Stanley Hall

Air Handling Unit **4**

1

air **Functional Relationship**

N

VAV boxes **179**

1

1

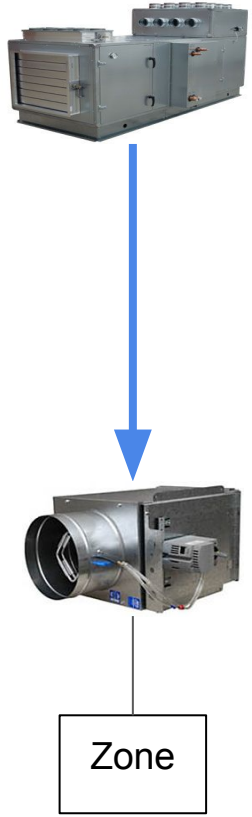
Zones

Zone | Zone | Zone | Zone

Why do we care about Functional Relationship?

Knowing what is connected to what is **necessary** to:

- implement advanced control strategies (e.g. resets, MPC …)
- run system-level analytics (for fault detection, performance evaluation, benchmark)
- find the root of some problems



So what is the problem?

BAS Metadata <u>should</u> capture all functional relationships

Unfortunately,

(1) Metadata often does not capture all such relationships (especially in Legacy BAS)

(2) Erroneous metadata.

...in Stanley Hall

Air Handling Unit **4**

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air **Functional Relationship**

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VAV boxes **179**

1

1

Zones

Zone | Zone | Zone | Zone

Any correlation ?

Both intuition and literature* suggest some “variation” of a correlation method should identify this Functional Relationship

high corr

low corr

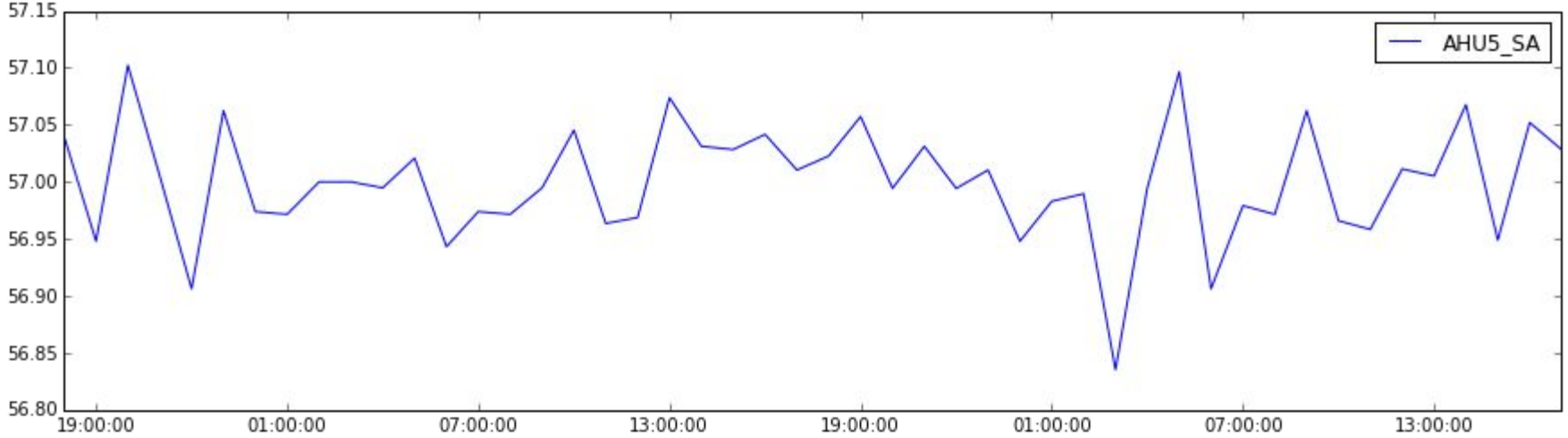
each **AHU** has:
- a **temperature** sensor
- an **airflow** sensor

Zone

each **VAV**/ZONE box has:
- an **airflow** sensor
- a **reheat valve position** sensor
- a **ZONE temperature** sensor

*

-R. Fontugne, et alt. 2013. Strip, bind, and search: a method for identifying abnormal energy consumption in buildings.
-M. Koc, et alt. 2014. Comparison of linear correlation and a statistical dependency measure for inferring spatial relation of temperature sensors in buildings.
-B. Narayanaswamy, et alt. 2014. Data driven investigation of faults in HVAC systems with model, cluster and compare (MCC).
-D. Hong, et alt 2013. Towards Automatic Spatial Verification of Sensor Placement in Buildings.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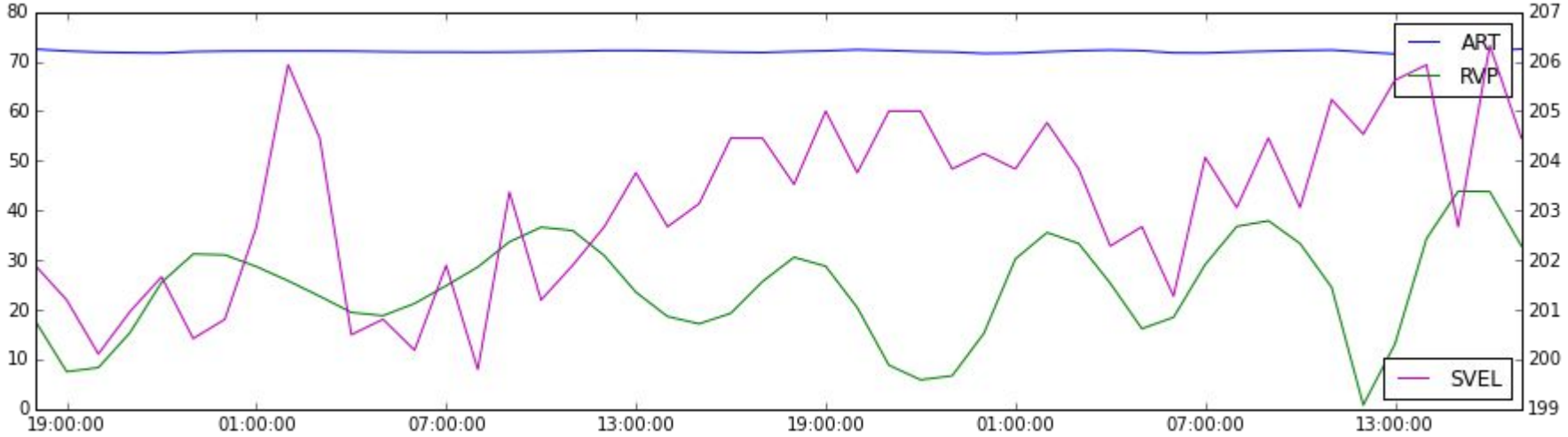
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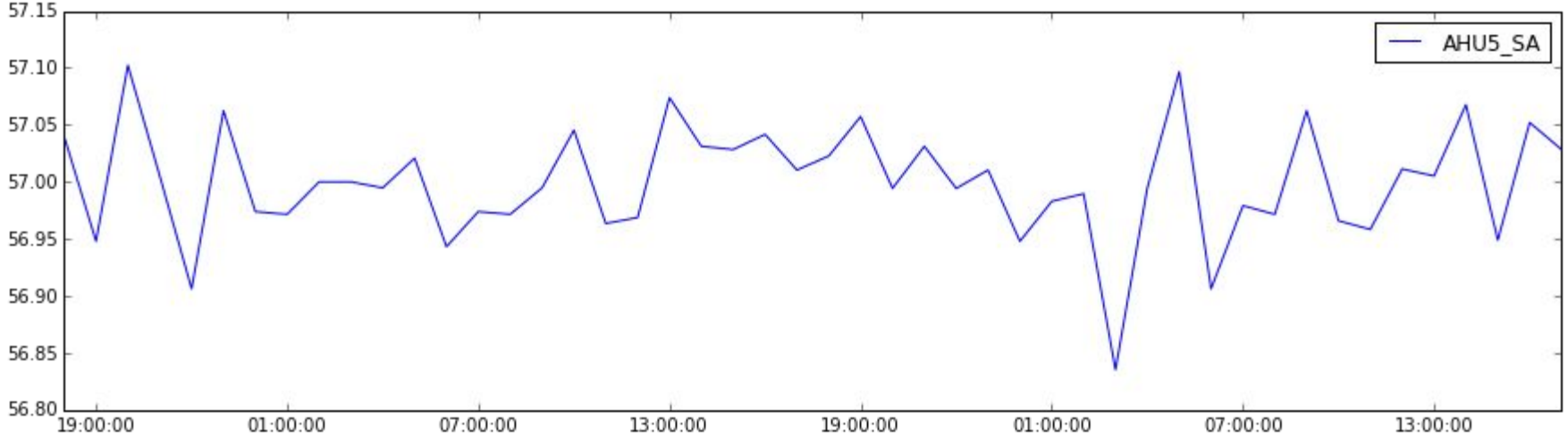
1) Correlation on raw data

Methodology

correlation coefficients		Example VAV_{AHU2}			Example VAV_{AHU4}		
		T_{zone}	DMP	RVP	T_{zone}	DMP	RVP
AHU 2	T_{sa}	-0.06	0.06	0.11	-0.11	0.24	0.29
AHU 4	T_{sa}	-0.20	-0.19	-0.06	-0.04	-0.01	0.02

Results

Technique	AHU Attribution Details	% ROOMS correctly identified
Correlation (Raw)	AHU whose supply air temperature has max. correlation to VAV sensors	38%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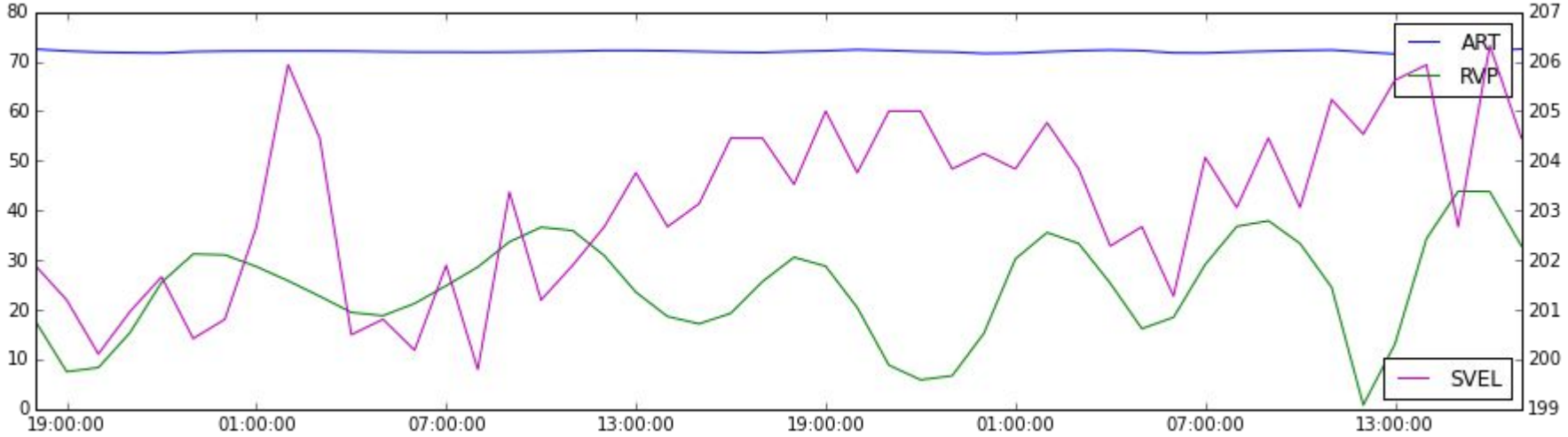
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2) PCA + Correlation

Methodology

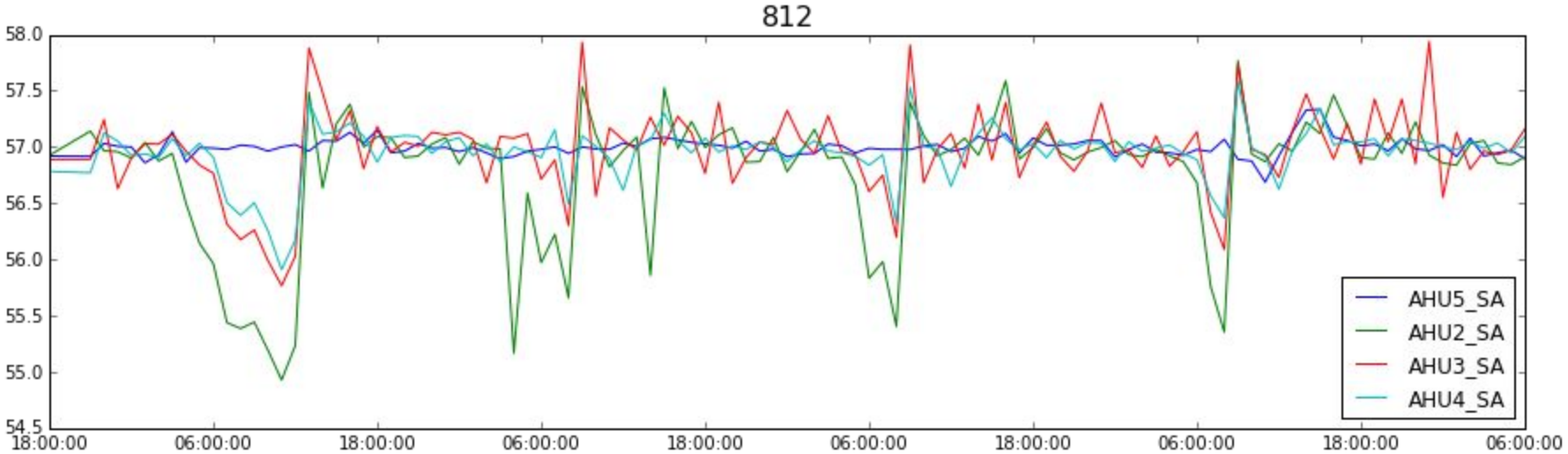
correlation coefficients		Example VAV_{AHU2}	Example VAV_{AHU4}
		Eig1	Eig1
AHU 2	T_{sa}	0.12	0.20
AHU 4	T_{sa}	-0.12	-0.04

Results

Technique	AHU Attribution Details	% ROOMS correctly identified
Correlation (Raw)	AHU whose supply air temperature has max. correlation to VAV sensors	38%
Correlation (PCA)	Same as above but with principal components	32%

Why?

1) How different is the behavior of each AHU?



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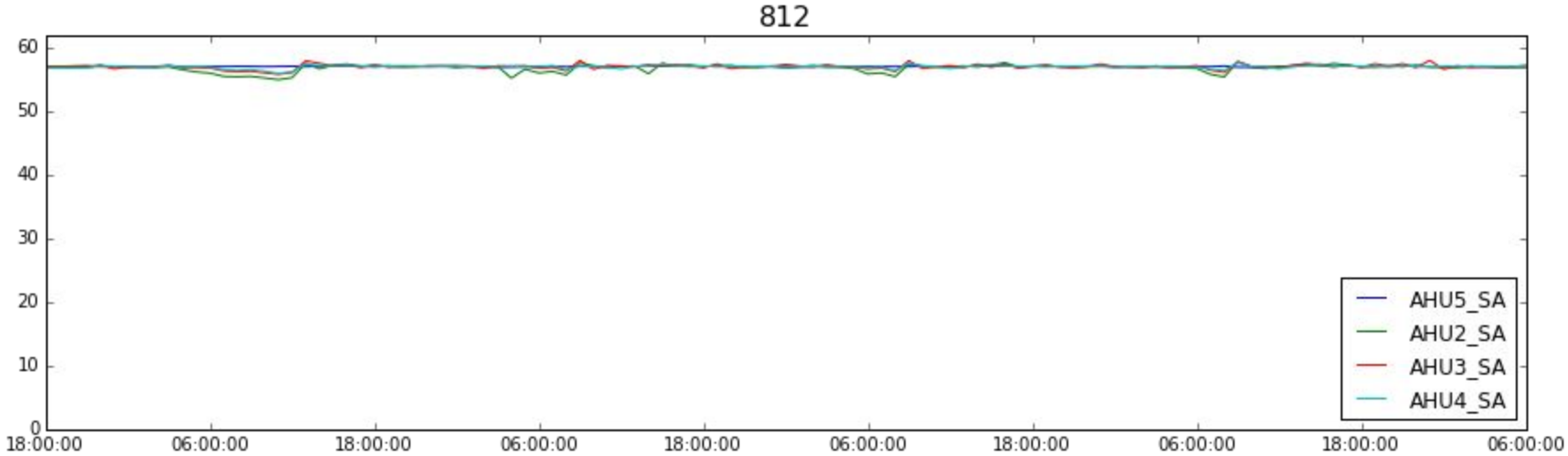
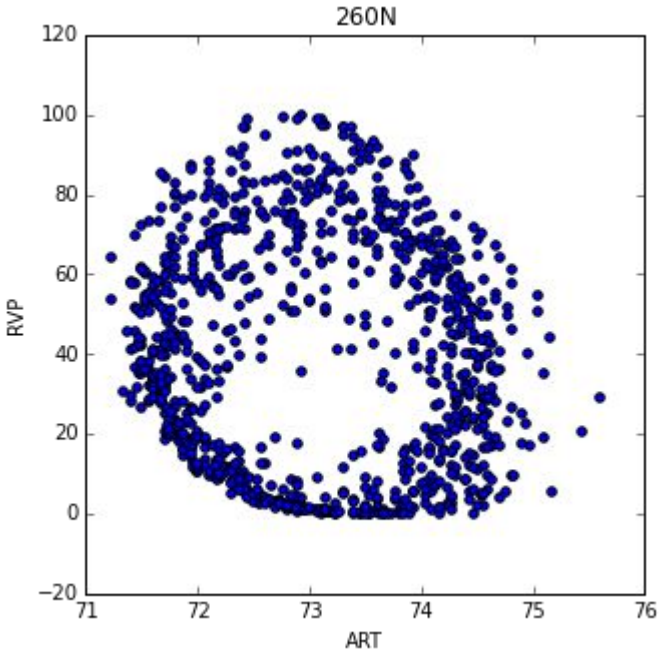
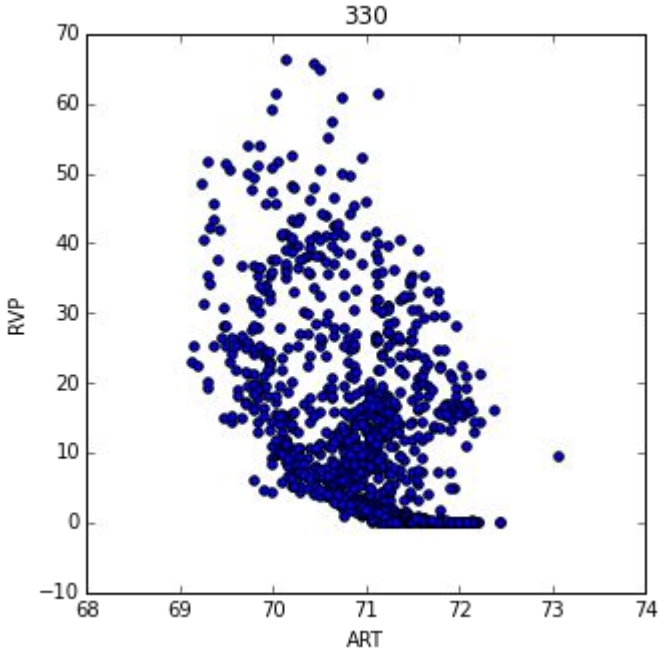


Why?

1) How different is the behavior of each AHU?
2) How about time lags?

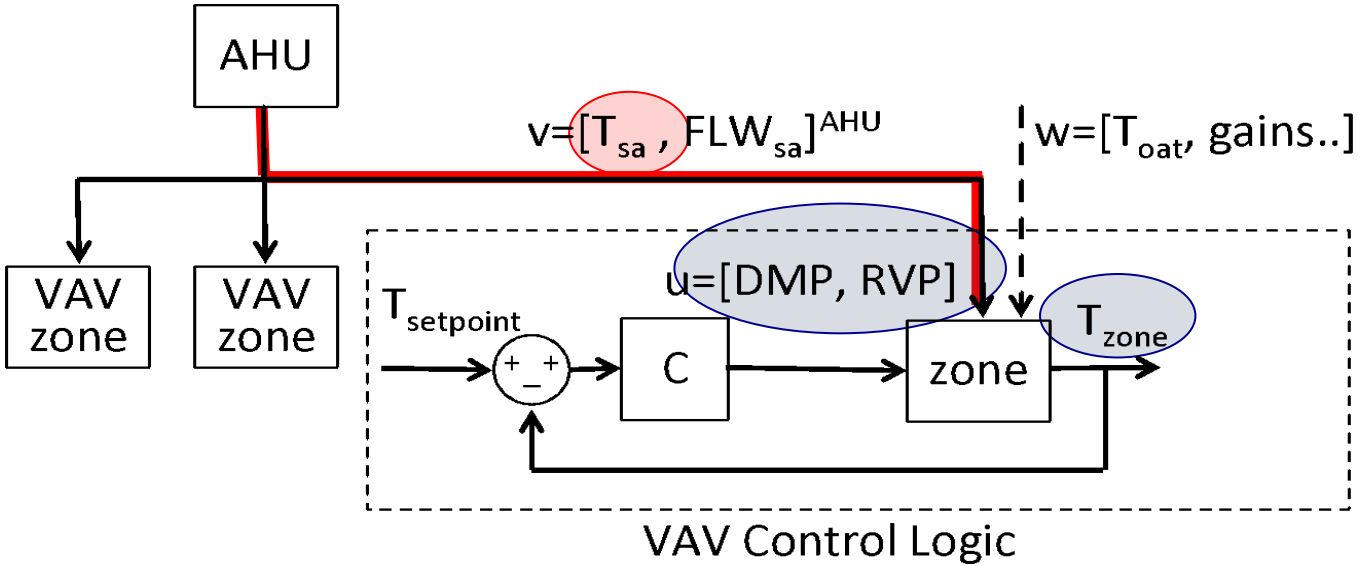




Why?

1) How different is the behavior of each AHU?
2) How about time lags?
3) Are we measuring all major variables that influence the system ?
4) Are variables we measure independent ?

Control loop



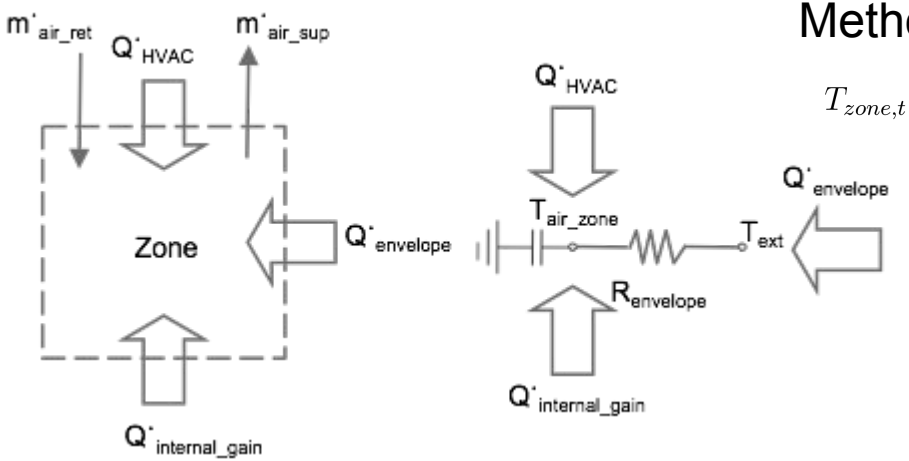
FLW : air flow

DMP : damper (air flow into room)

RVP : reheat valve position

T : temeprature

3) System Identification



Methodology

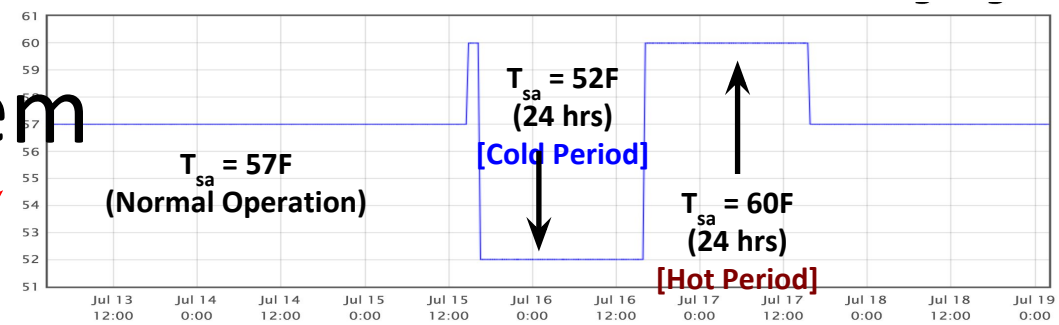
$$T_{zone,t} = \beta_1 \cdot T_{zone,t-1} + FLW_t \cdot \sum_{t}^{t-k} \beta_2 \cdot RVP_i + \beta_3 \cdot FLW_t \cdot T_{sa,t}^{AHU} + \beta_4 \cdot T_{oat,t}$$

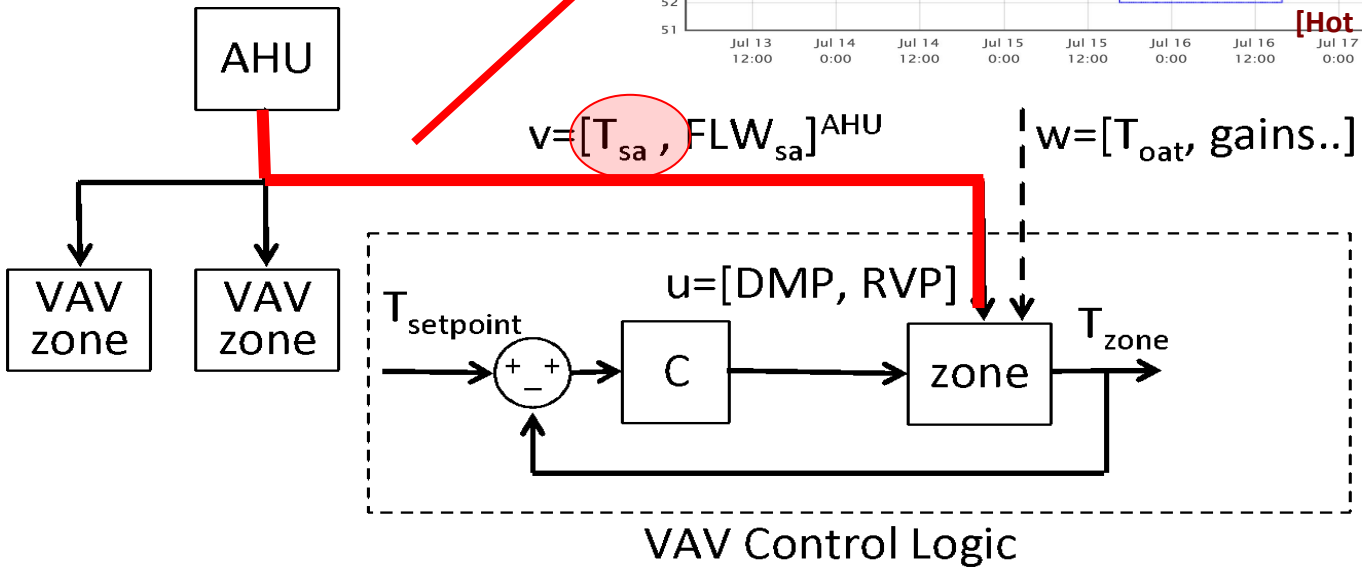
Classification Metric = R^2

Results

Technique	AHU Attribution Details	% ROOMS correctly identified
Correlation (Raw)	AHU whose supply air temperature has max. correlation to VAV sensors	38%
Correlation (PCA)	Same as above but with principal components	32%
System Identification	AHU whose supply air temp gives lowest error	32%

4) Perturb the system





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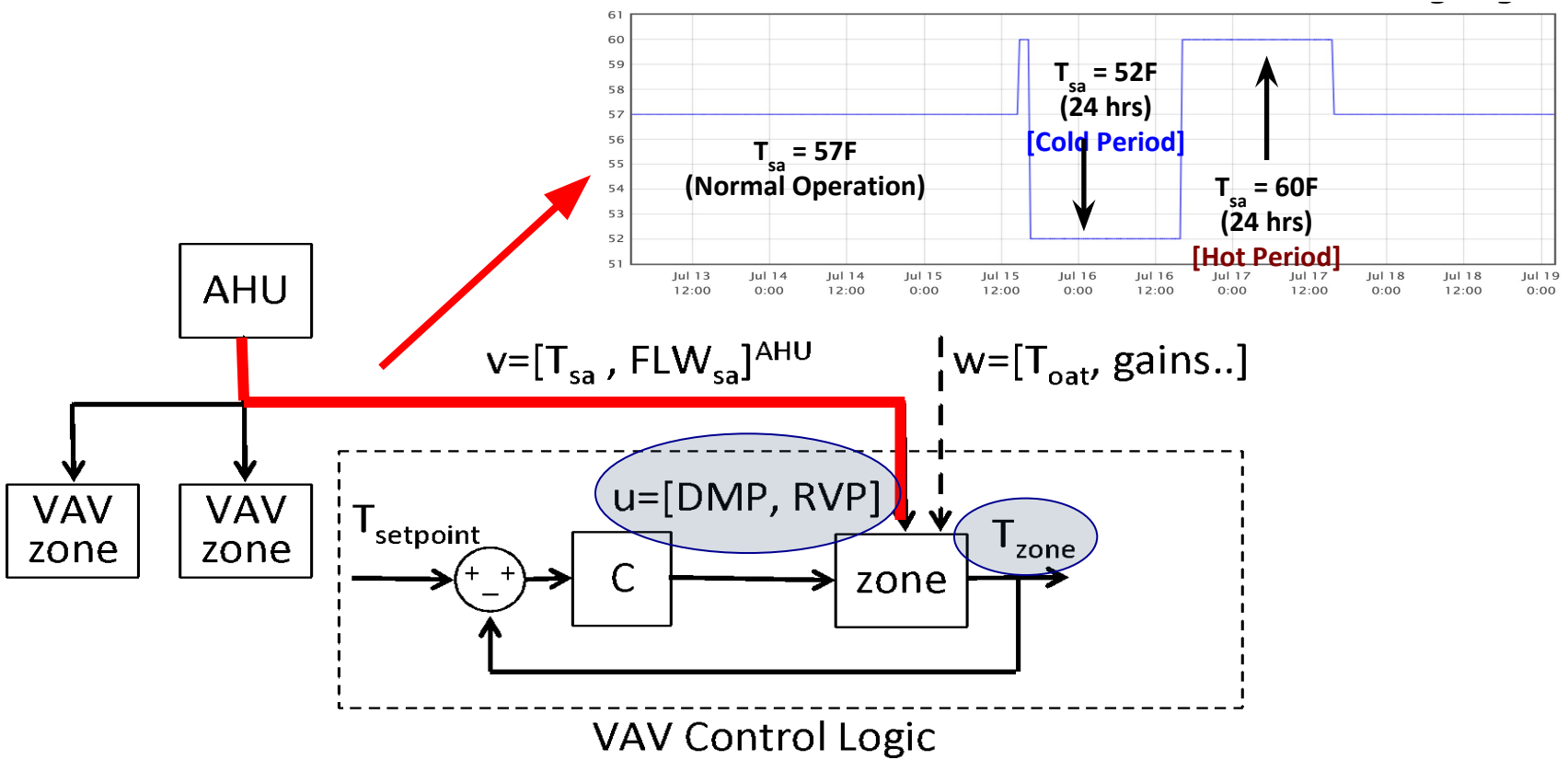


FLW : air flow

DMP : damper (air flow into room)

RVP : reheat valve position

T : temeprature

Perturb Cluster and Vote

1) perturb one AHU at the time (1 day hot 1 day cold)
2) calculate euclidean distance between two days:

$$[\text{mean(zone temp)}, \text{mean(reheat)}, \text{mean(airflow)}]_{hot}$$
$$-$$
$$[\text{mean(zone temp)}, \text{mean(reheat)}, \text{mean(airflow)}]_{cold}$$

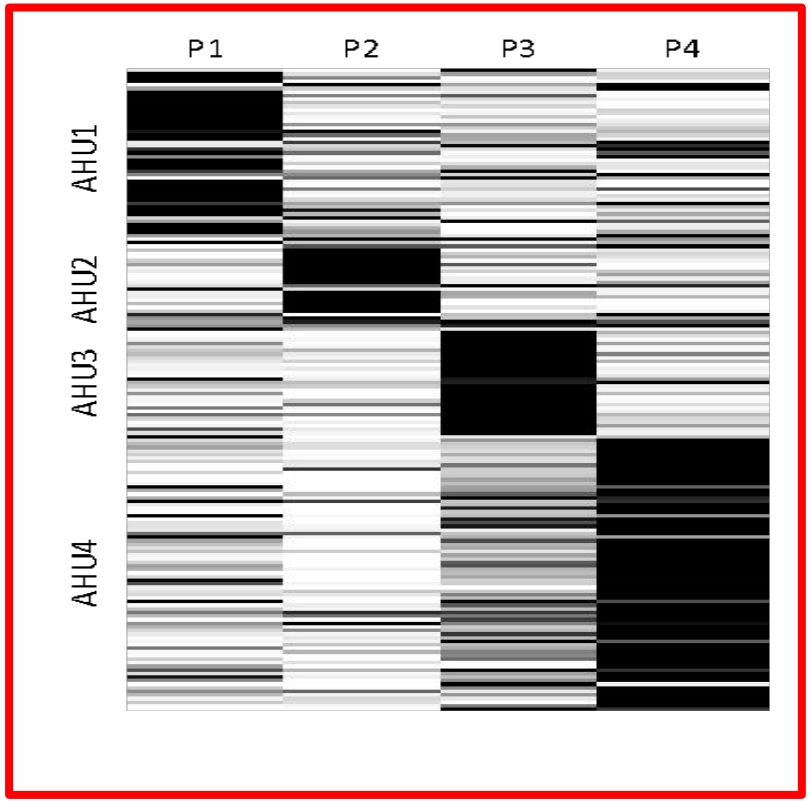
3) for each VAV vote to select the AHU corresponding to the highest score

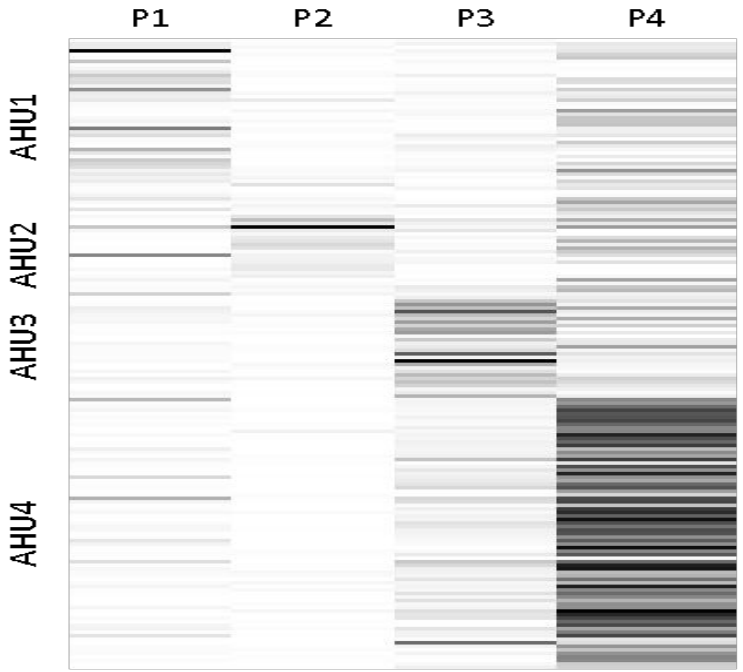
Results

Technique	AHU Attribution Details	% ROOMS correctly identified
Perturb Cluster and Vote	**Perturb all AHUs and attribute VAV to AHU which caused max internal perturbation**	**79%**

Results

79% rooms identified correctly





Number of AHUs: 4
Number of VAVs : 179

Comparison

Technique	AHU Attribution Details	% ROOMS correctly identified
Random	Randomly allocate VAV boxes to AHUs	25%
Correlation (Raw)	AHU whose supply air temperature has max. correlation to VAV sensors	38%
Correlation (PCA)	Same as above but with principal components	32%
State Identification	AHU whose supply air temp gives lowest error	32%
Perturb Cluster and Vote	**Perturb all AHUs and attribute VAV to AHU which caused max internal perturbation**	**79%**

Future Work

- Utilize other techniques and compare them (ML classification, process control …)
- Verify the how valuable is having “some physics” in the technique
- Verify if this is generalizable to other buildings
- Evaluate how long the perturbation should last
- Perturb Flow Rate ?
- Obtain relationships without perturbation
- Test other relationships

Last Sec Update