Zodiac: Organizing Large Deployment of Sensors to Create Reusable Applications for HVAC Management

UCSD CSE Computer Science and Engineering
synergy systems, networking and energy efficiency
MESL Microelectronic Embedded Systems Laboratory

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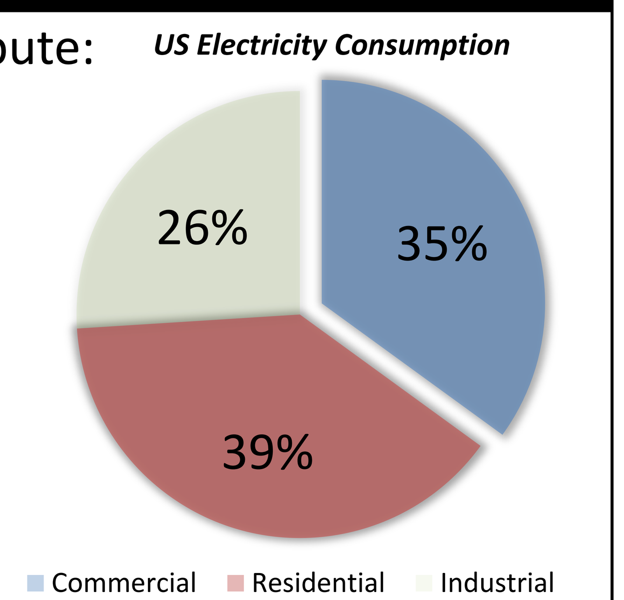
Smart Buildings

- Commercial buildings contribute:
  - 19% of primary energy
- HVAC systems contribute:
  - 25%-40% of electricity
  - 50% of primary energy
- People spend 87% of their time indoors.



- Lot of Building sensors
  - UCSD → 180,000 sensor points across 55 buildings
  - How do we exploit sensor information?
- Smart building applications
  - Fault detection
  - Occupancy-based control
  - Smart grid
  - Demand response

HVAC Background

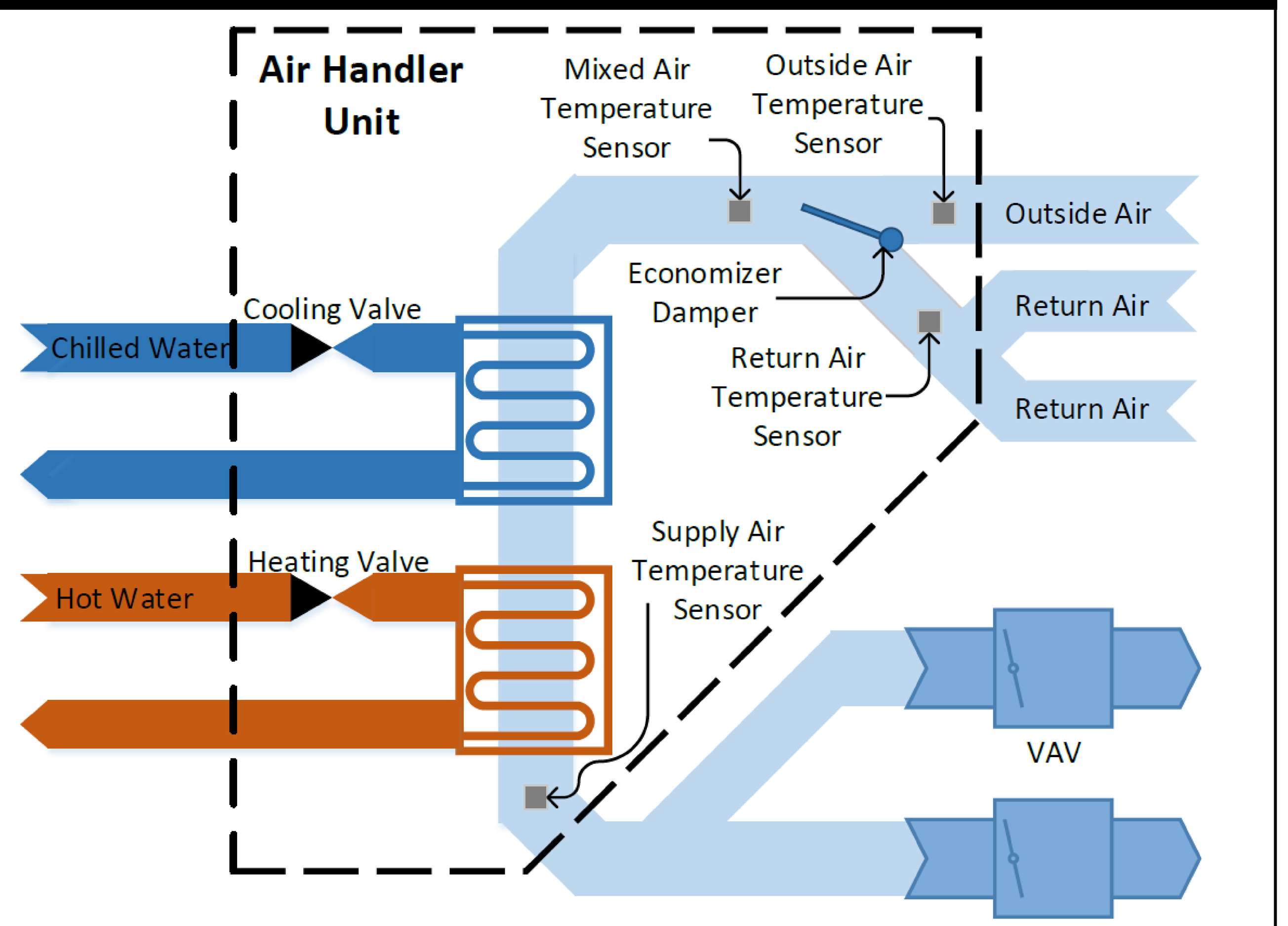


Figure depicture HVAC Air Handler Unit. Sensors monitor equipment and provide feedback to control system

Sensors & Naming

- ✓ Each sensor and its metadata is named differently
  - Variation in vendor, equipment, manual input
  - Example: Zone Temperature, Zone Temp, Temp Rm 23, ZN-T
- ✓ Commercial Solution: Regular expression
  - It requires domain expertise
  - Fails to exploit additional metadata and sensor data

Vendor Given Name	Description
BLDG2.RM-2819.SUP-FLOW	Supply Air Flow
BLDG3 1stFl RM-111.SUPFLOW	Process Variable

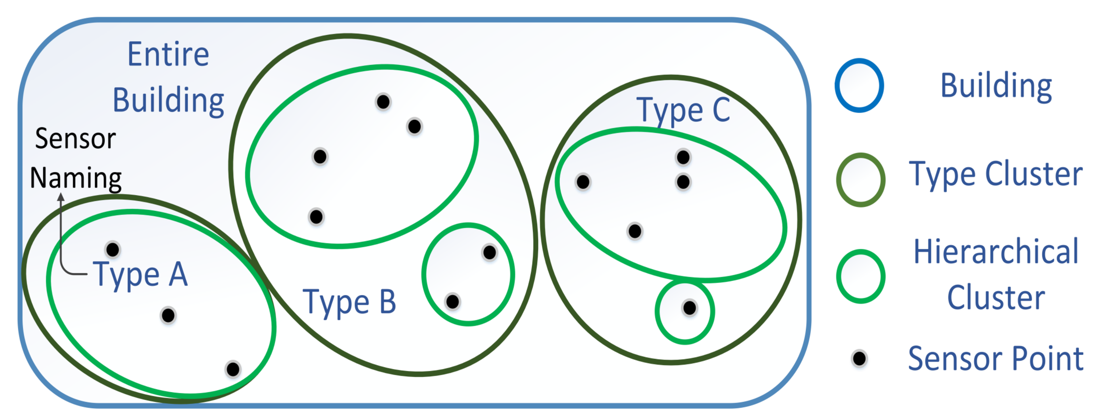
Building # Room # Sensor Type

Identifying Sensor Types

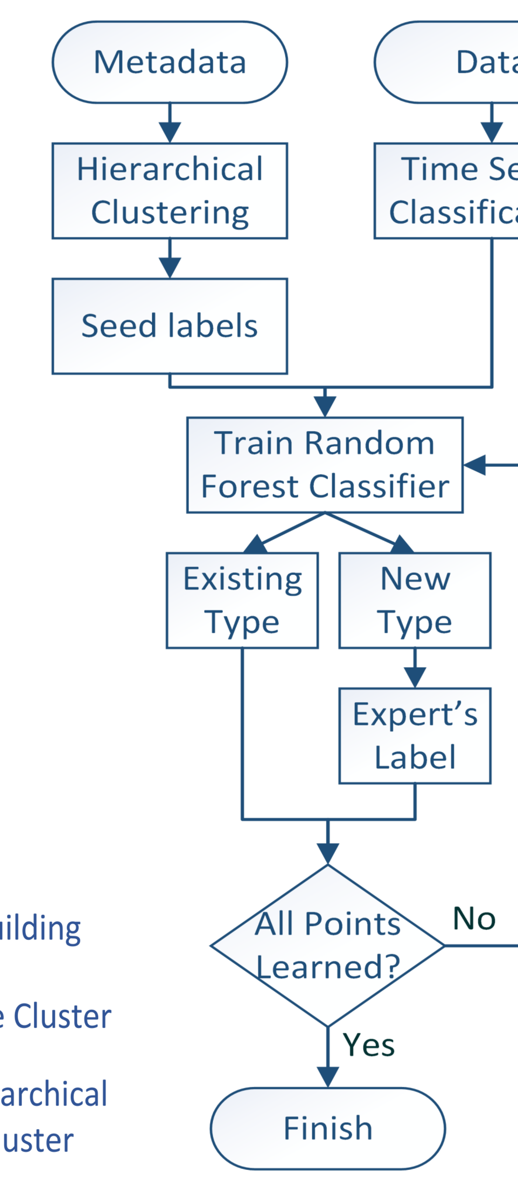
Hierarchical Clustering

- Agglomerative clustering of *bag of words* from tokenization of metadata
- Clusters together sensors of same type
- Advantages of clustering
  - Exploits intrinsic similarities
  - Does not require domain expertise
- For four buildings, accuracy of clustering sensors of same type is 98.7 %

Building	Sensor Points	Unique Sensor Types	Hierarchical Clusters
Bonner Hall	3213	251	300
Biomedical Science	11910	367	1105



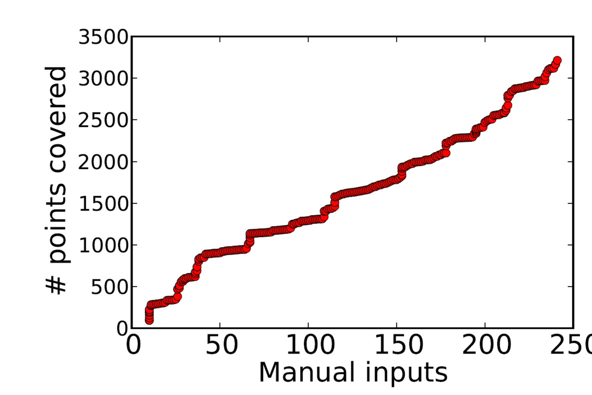
• Distance: Manhattan • Linkage: Complete



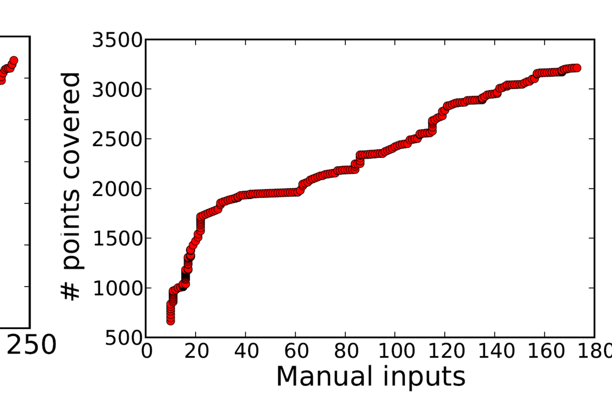
Identifying Sensor Types Algorithm

Active Learning

- Some sensor points of same type cannot be clustered together
  - "supply flow", "airflow rate" and "supply flow feedback".
- We use *active learning* for mapping metadata and point type automatically
- Accuracy of labeling a building is 99.3 %
- Manual labeling is reduced by 27%
- Able to learn sensor types across buildings from metadata



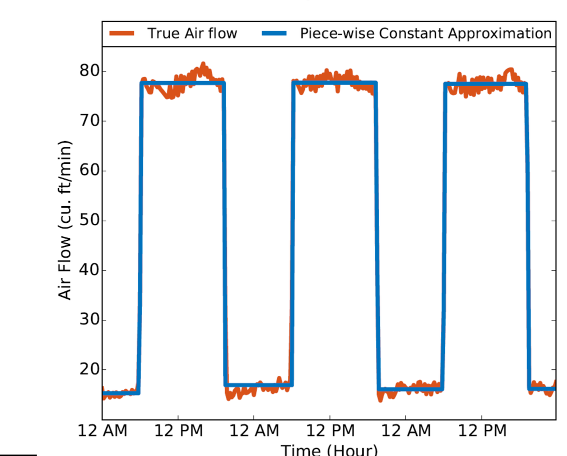
Active Learning for one building



Learning across multiple buildings

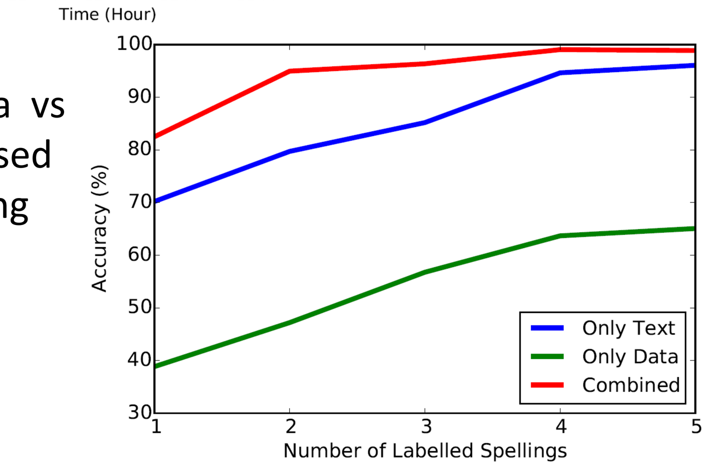
Exploiting Sensor Data

- Extract feature from sensor data:
  - Scale-based
  - Pattern-based
  - Texture-based
  - Shape-based
- Flow sensor and flow setpoint have same shape, but different texture.



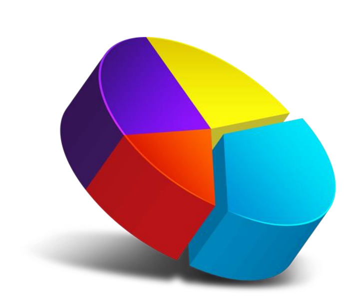
Comparison of actual air flow and air flow setpoint

Metadata vs Data-based Learning



HVAC Working & Energy Analysis

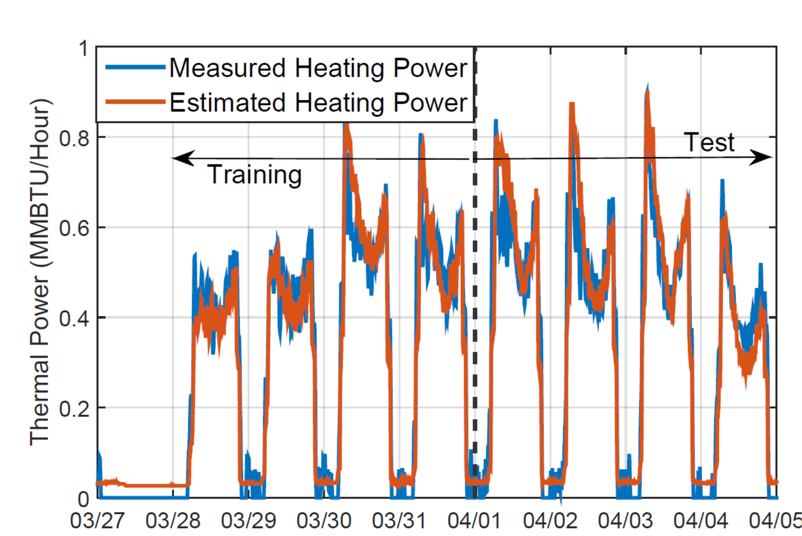
- Installed power meters only provide building level consumption
- Cannot breakdown power by individual equipment and rooms



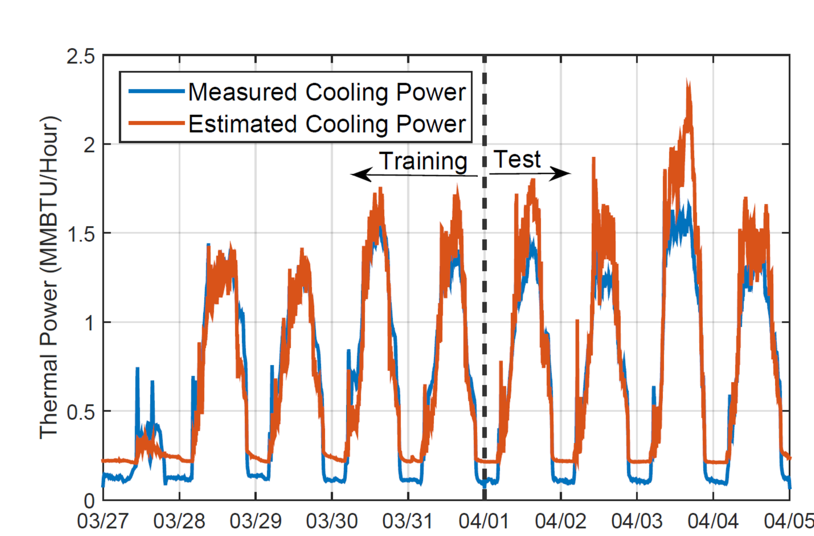
- We use simple power estimation model using heat transfer equations
  - Cooling power= $C_1 * (T_{mixed\ air} - T_{supply\ air}) * \sum air\ flow_{vav}$
  - Heating power= $C_2 * (T_{supply\ water} - T_{supply\ air}) * air\ flow_{vav} * H_{valve}$

T = Temperature, H = Heating Valve, VAV = Variable Air Volume Box
Learn constants C_1, C_2 using linear regression

- Linear correlation of estimation and measurement is 89.2% in average



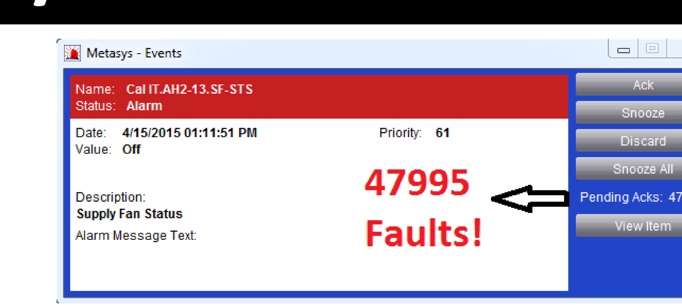
Heating Power Estimation of VAV & AHU



Cooling Power Estimation of AHU

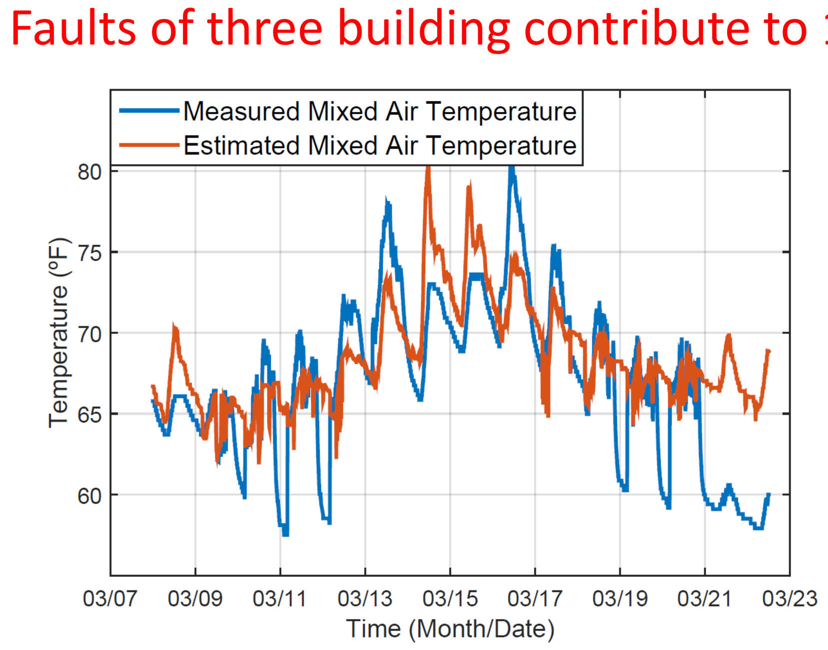
Fault Analysis

- Current system reports *too many* faults, so building managers ignore them
- We give priorities to faults by their impact on energy consumption
- We use rule based fault detection method

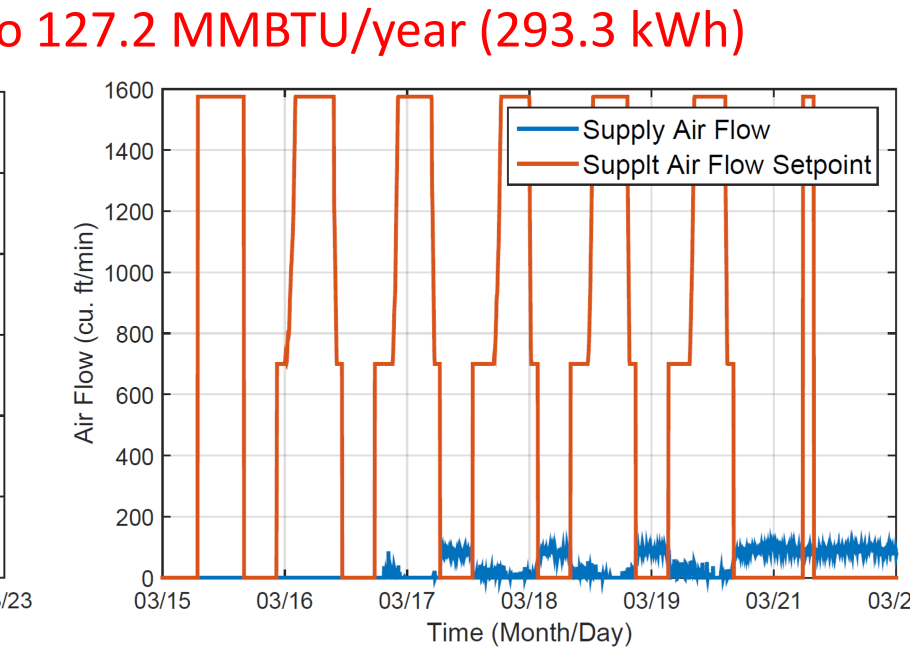


Screenshot from current building management system shows too many faults to manage

- Example of rules
  - Estimated and measured mixed air temperature should be correlated
  - Supply and mixed air temperature are equal when cooling is off
- Our platform detects 135 faults across seven buildings with 83 % accuracy.
- Faults of three building contribute to 127.2 MMBTU/year (293.3 kWh)



Fault example: measured and estimated mixed air temperature are not correlated



Fault example 2: Supply air flow and supply air flow setpoint do not match.