

Data Driven Buildings

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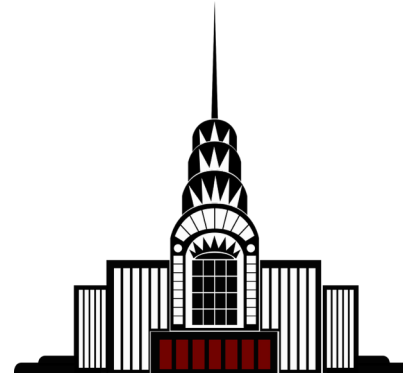
Buildings are evolving..



Shelter



Water
Electricity



Security
Thermal Comfort
Fire Safety

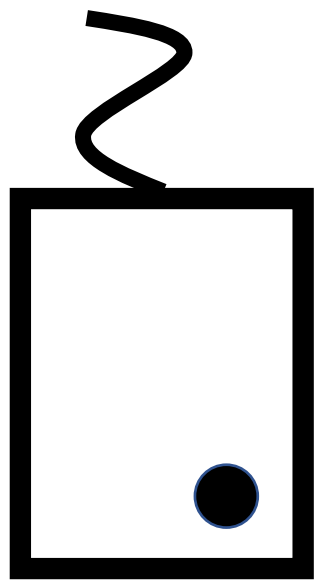


Connectivity
Sensors
Software

Data: Interact. Optimize. Innovate.

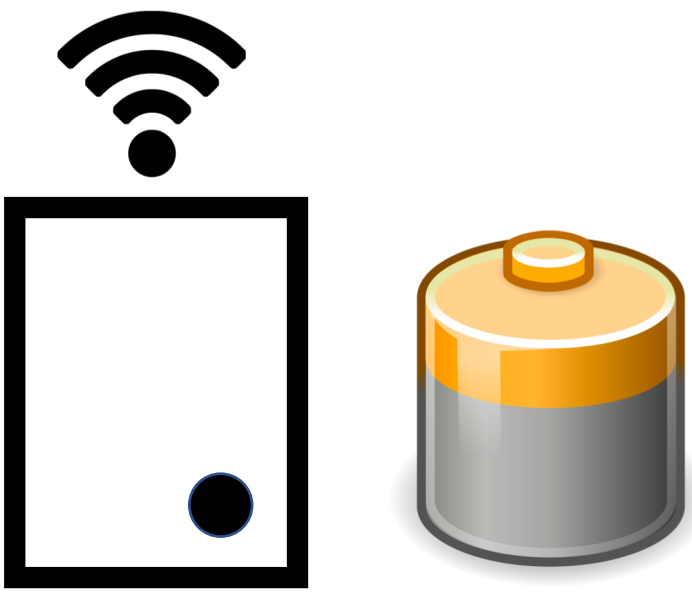
Data Generation Bottleneck: Sensors

Wired



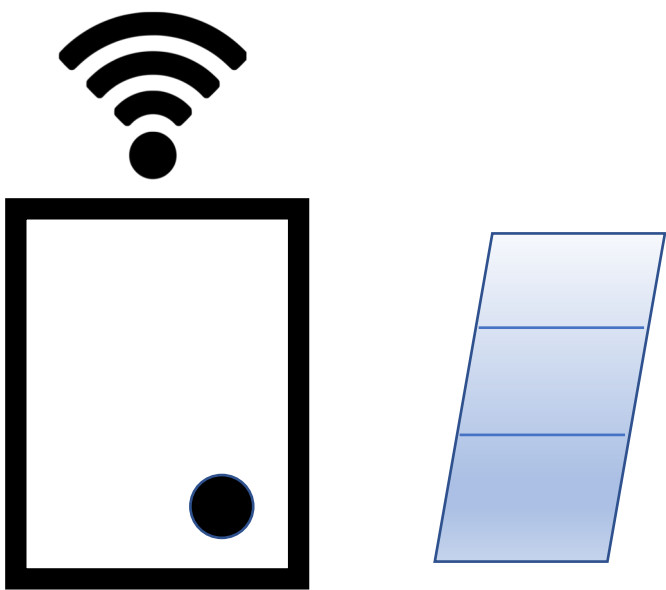
Reliable
Expensive
Not Flexible

Wireless + Battery



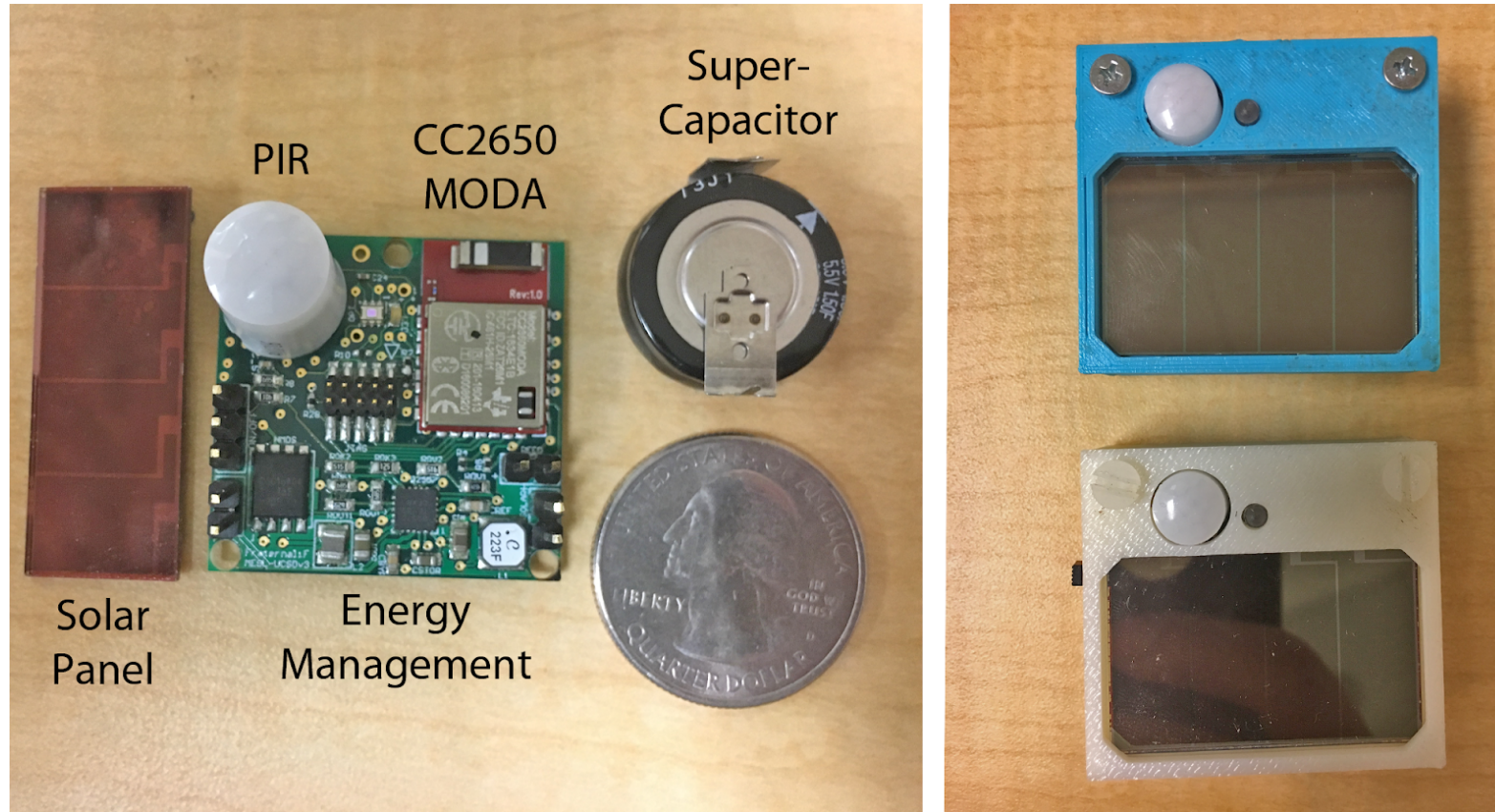
Battery Maintenance
Inexpensive
Flexible

Wireless + Harvesting



Unreliable
Inexpensive
Flexible

Pible: Perpetual Indoor BLE Sensor

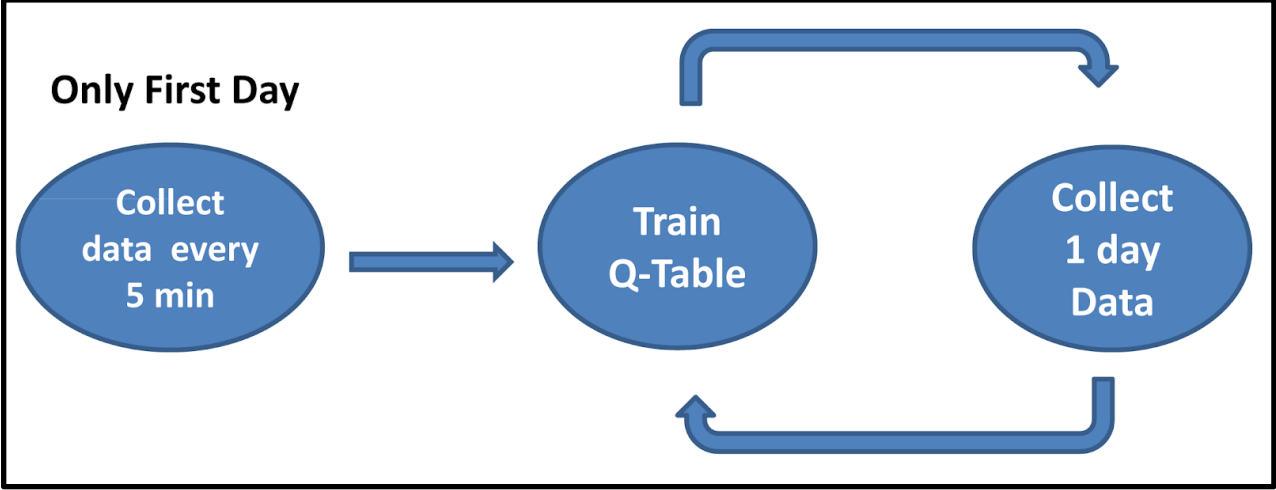
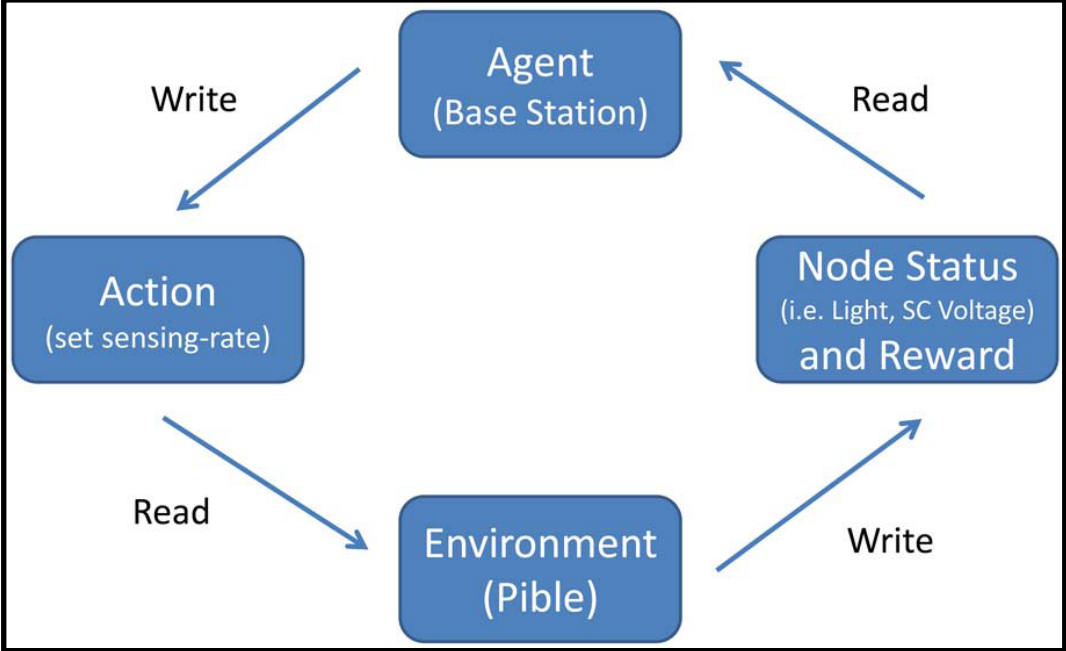


- Sensors
 - Light
 - Temperature
 - Humidity
 - PIR
 - Door Event
 - Bluetooth beacon
- Bluetooth Low Energy
- Solar harvesting
- Super capacitor

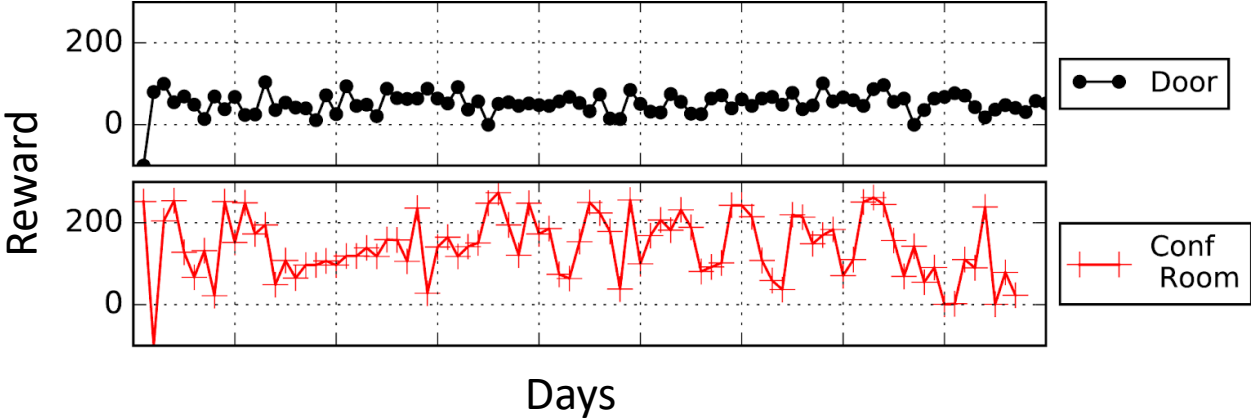
Limitation: Manual configuration

Pible: BuildSys 2018

Duty Cycle with Reinforcement Learning



- Automatically adapts to each lighting condition
- 1 sample every 56 seconds on average



Scaling Energy Harvesting Configuration: EnsSys 2018

Best Demo Award: BuildSys 2018

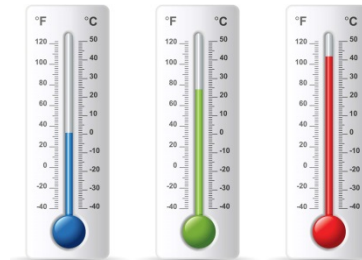
Data Collation Bottleneck: Vertical Systems



Lighting System



Plug Loads



Heating, Ventilation and Air Conditioning (HVAC)

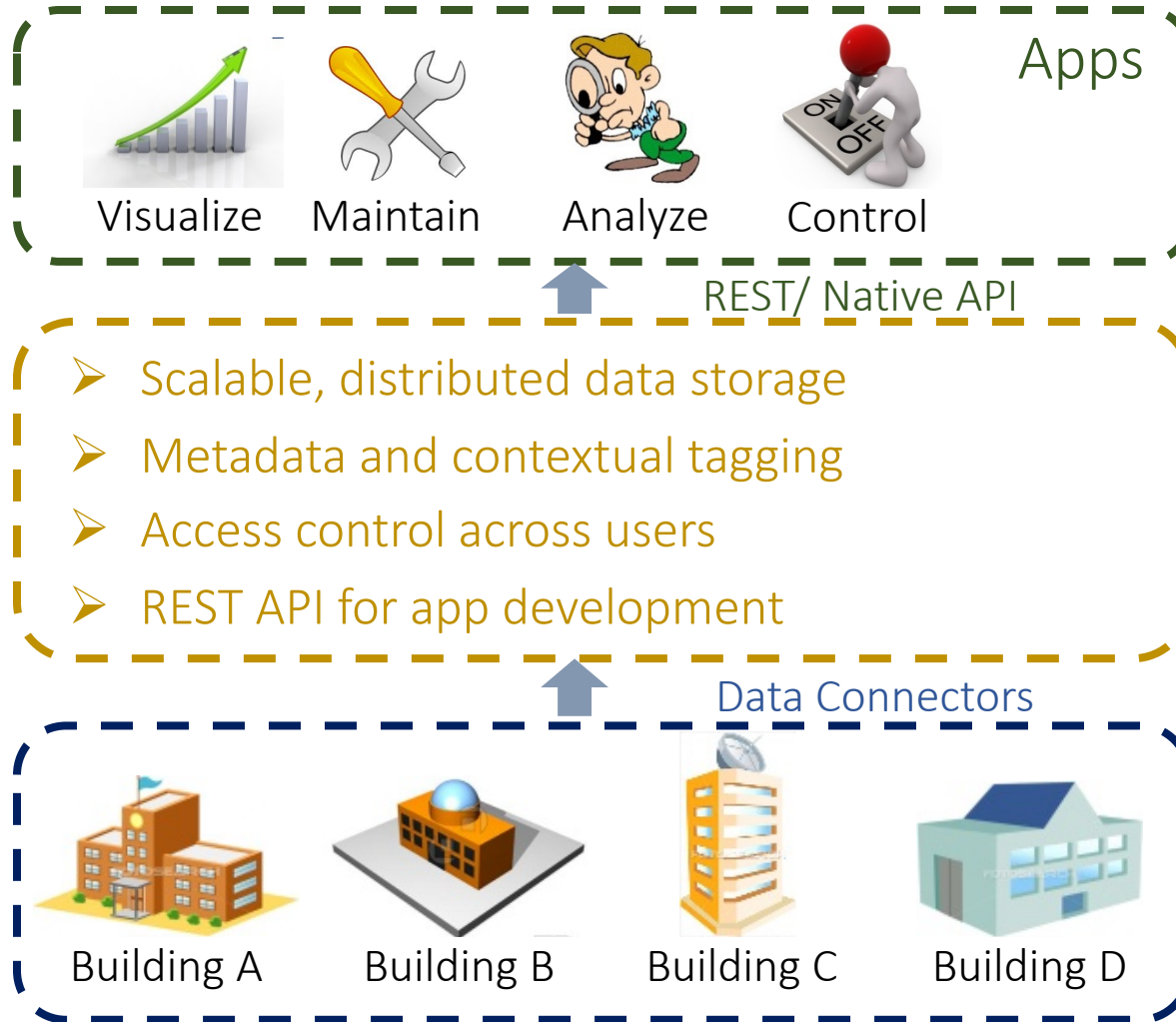


Enterprise Network



Security System

Integration Platform for Applications

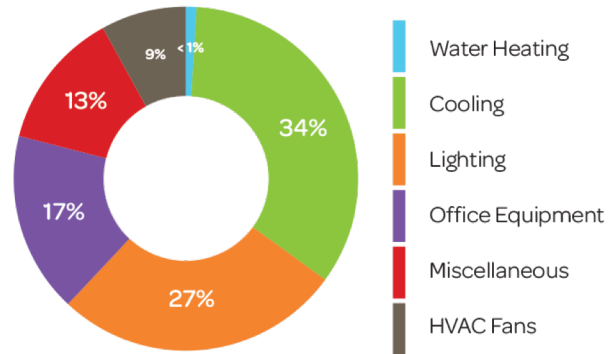


Next generation building applications via standardized API

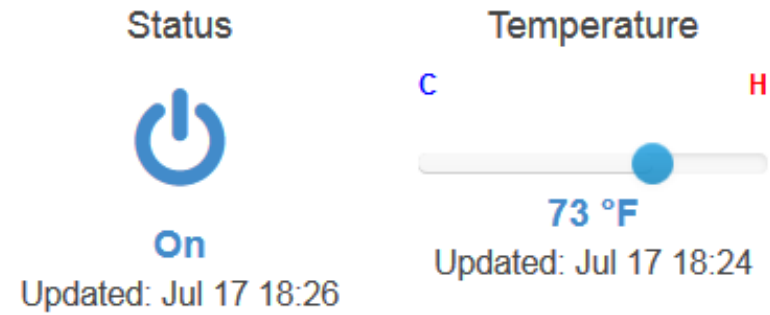
Data management system for sensors and actuators

Large amount of data generated in modern buildings

Smart Building Applications



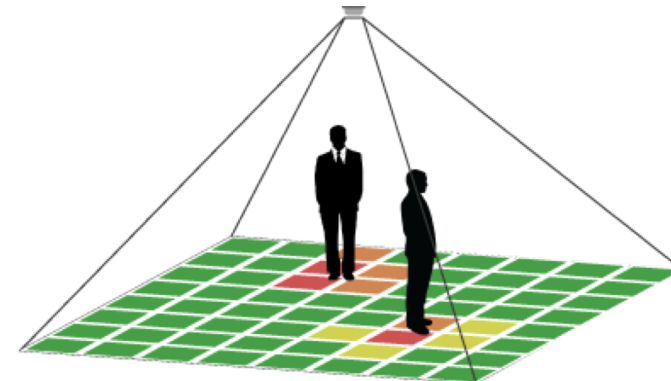
Energy Disaggregation
BuildSys '10, BuildSys '13



Personalized Control
BuildSys '13, Ubicomp '16

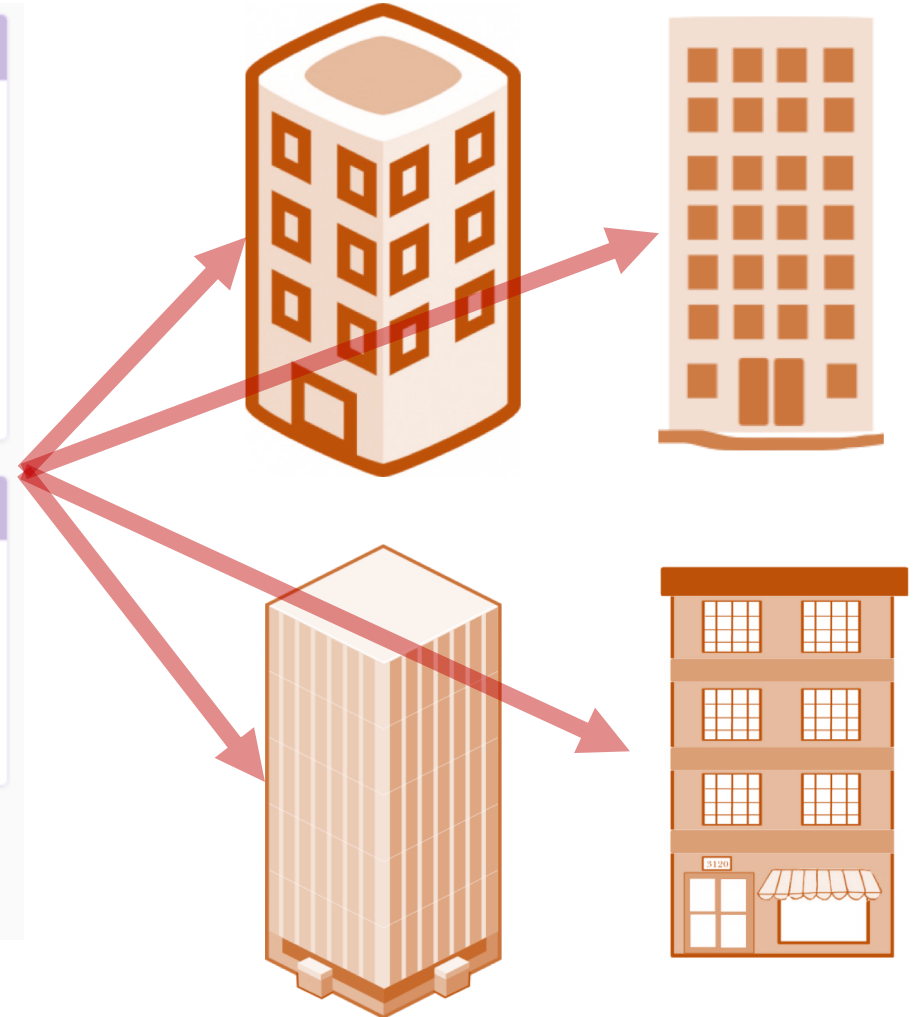
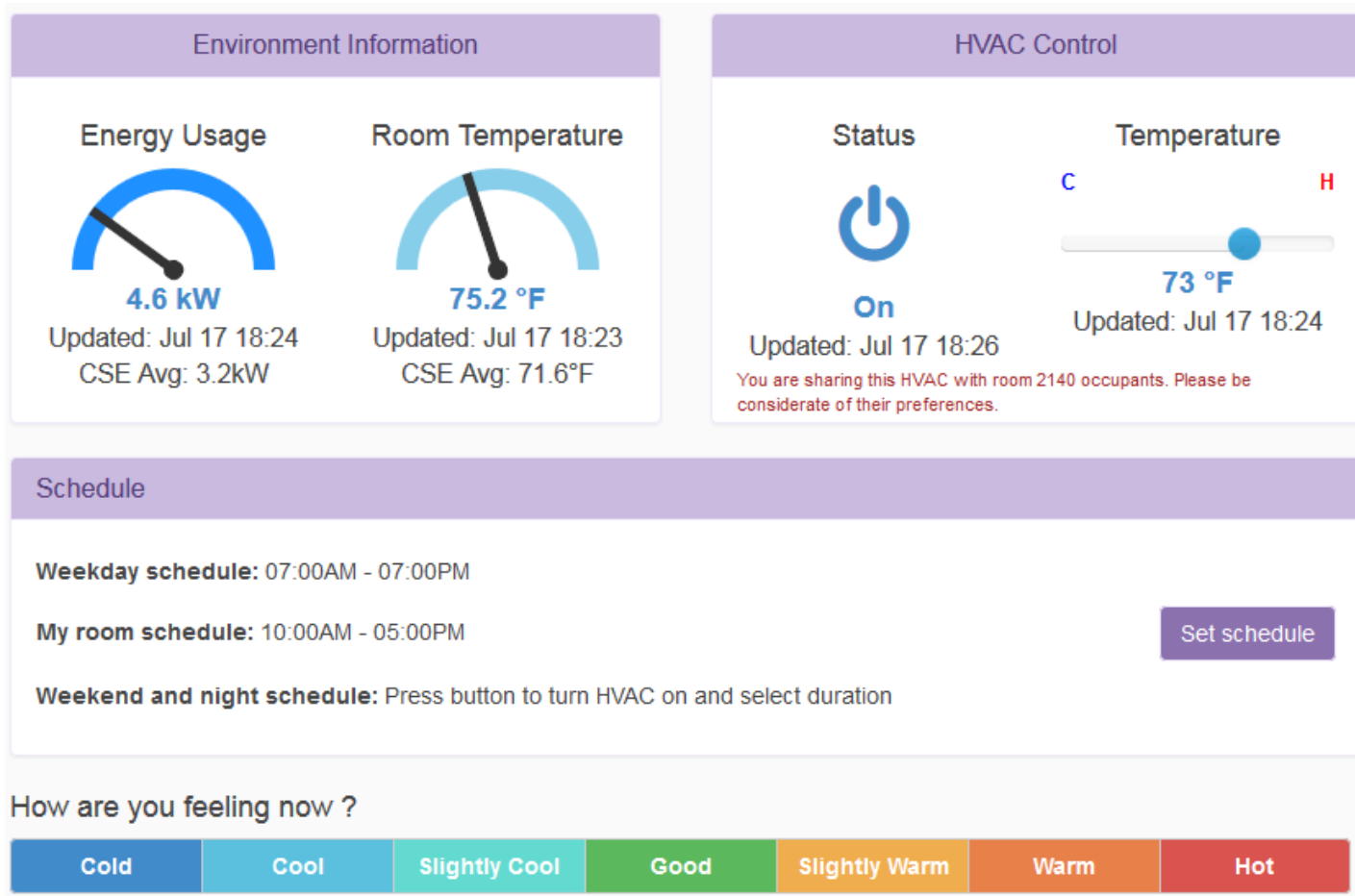


Fault Detection and Diagnosis
BuildSys '14



Occupancy Based Control
IPSN '11, SenSys '13

App Portability Bottleneck: Naming Semantics

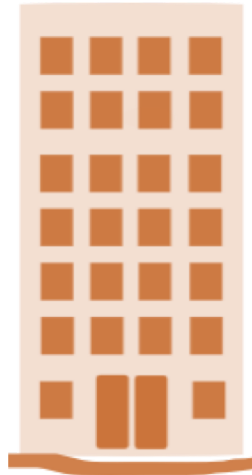


Each Building is Different

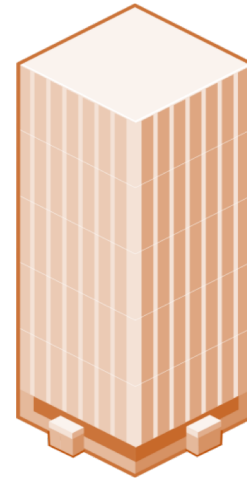
❖ University, Hotels, Hospitals, Shopping Malls



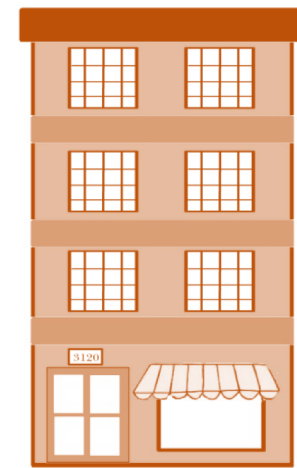
Lecture Hall



Bio Labs



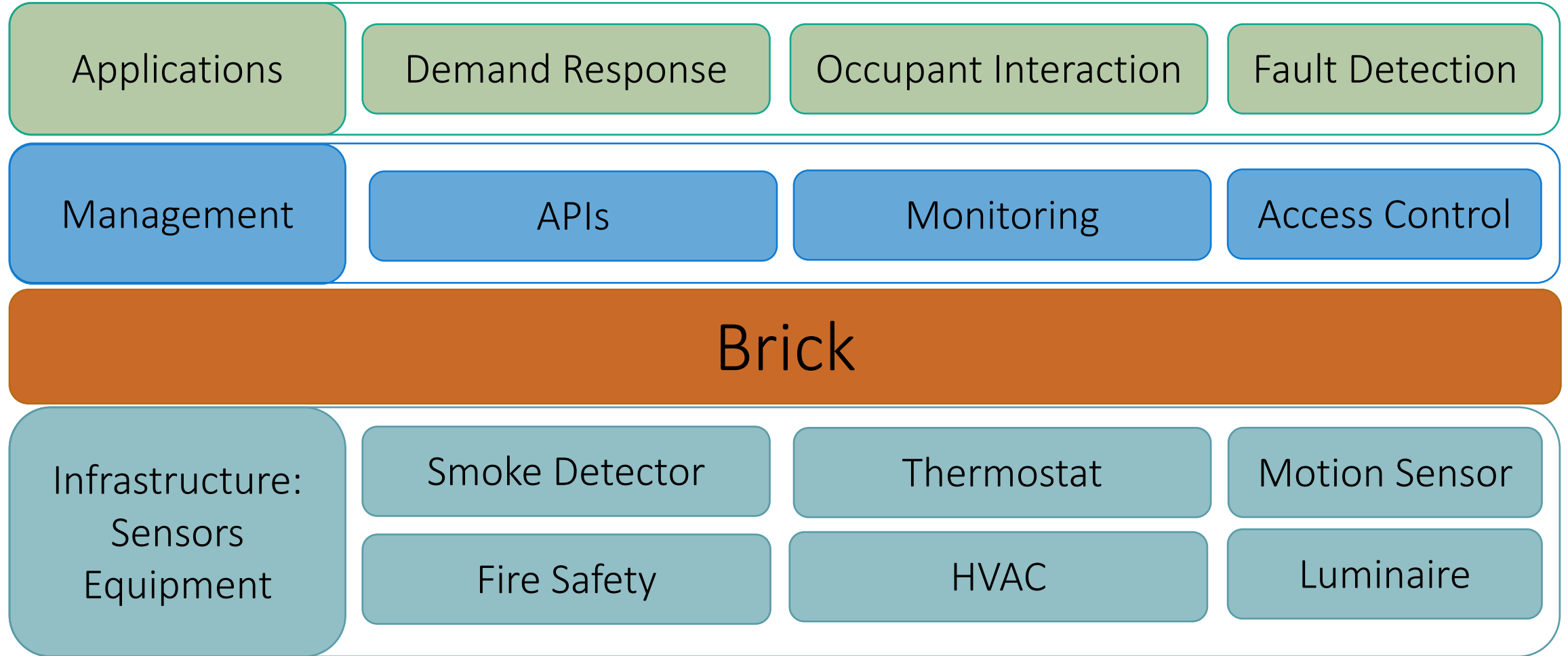
Mixed Use



Library

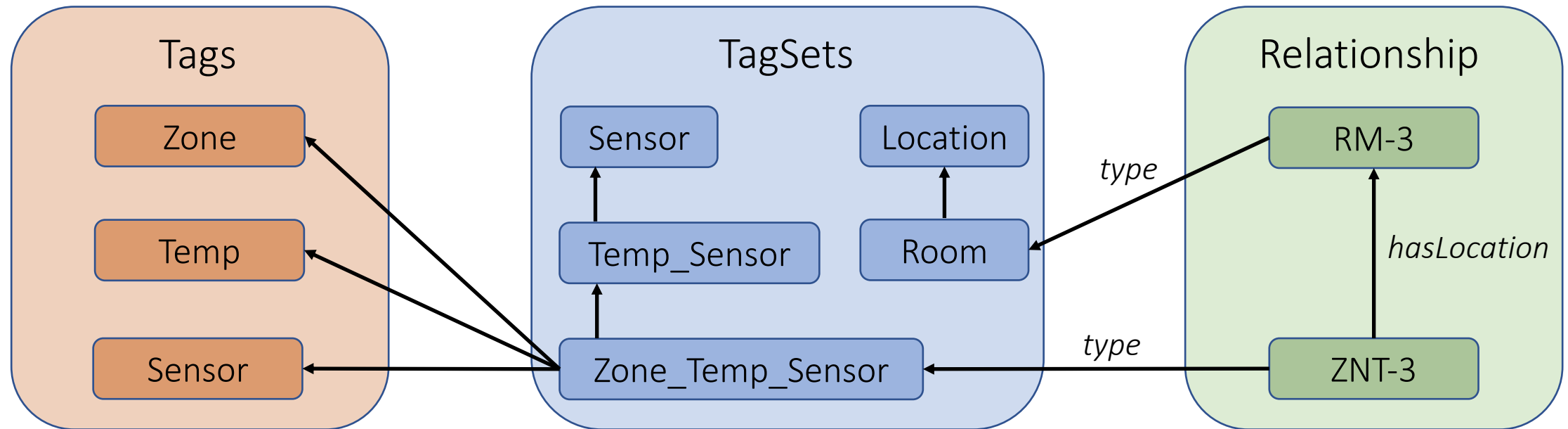
- Equipment, Vendor, Institution
- Changes with time: Repairs, Retrofits

Brick: Building Metadata Schema

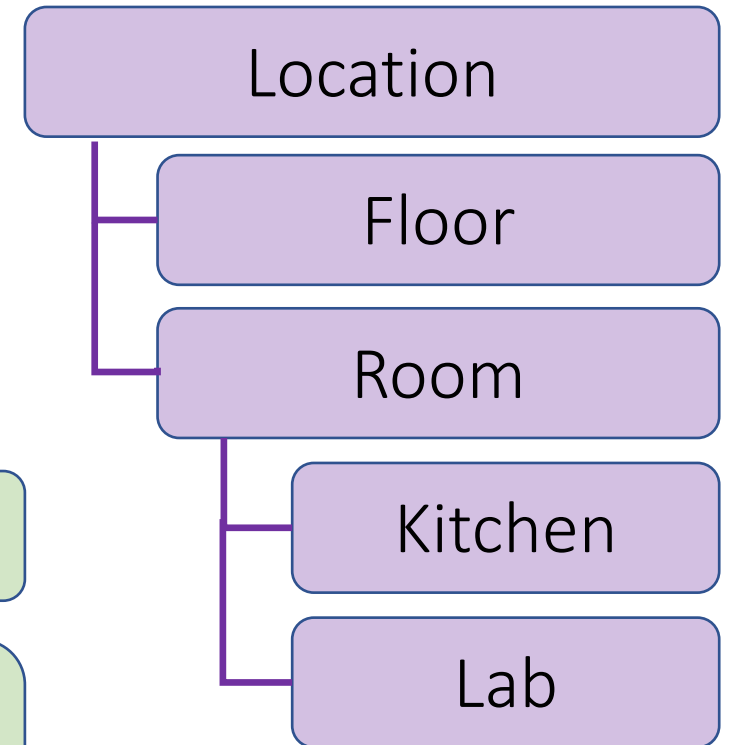
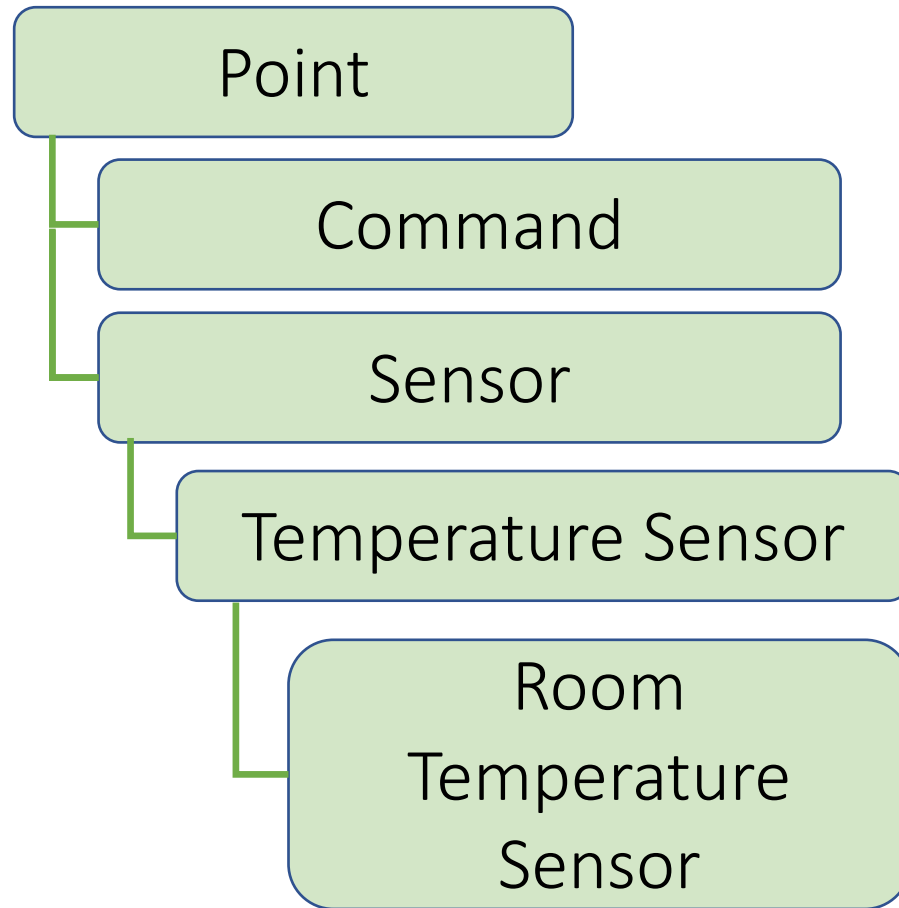
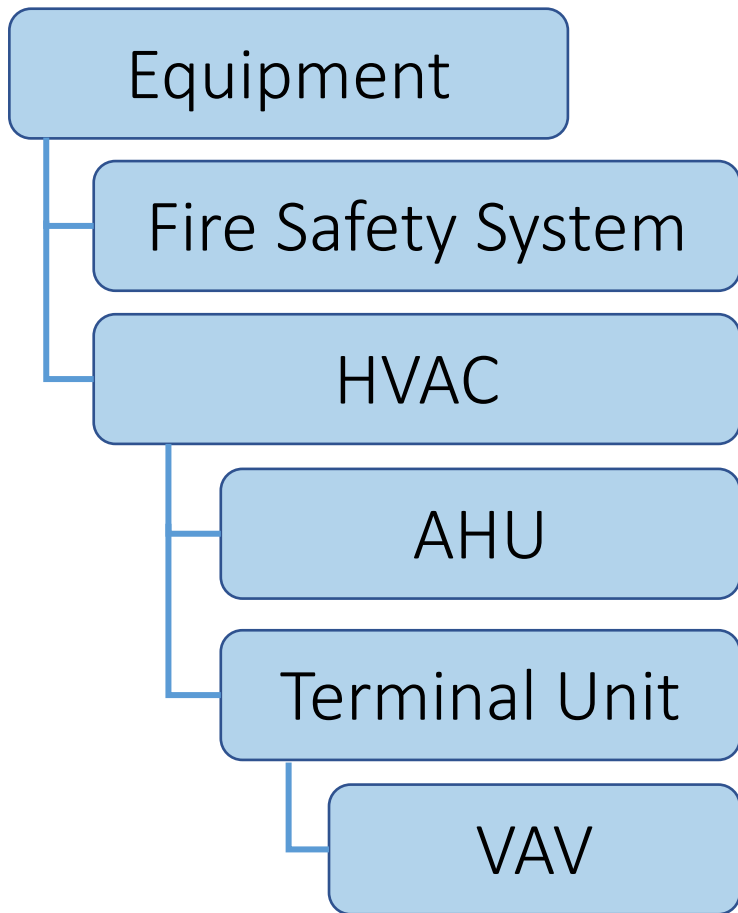


Brick: BuildSys 2016, Applied Energy 2018 <https://brickschema.org>

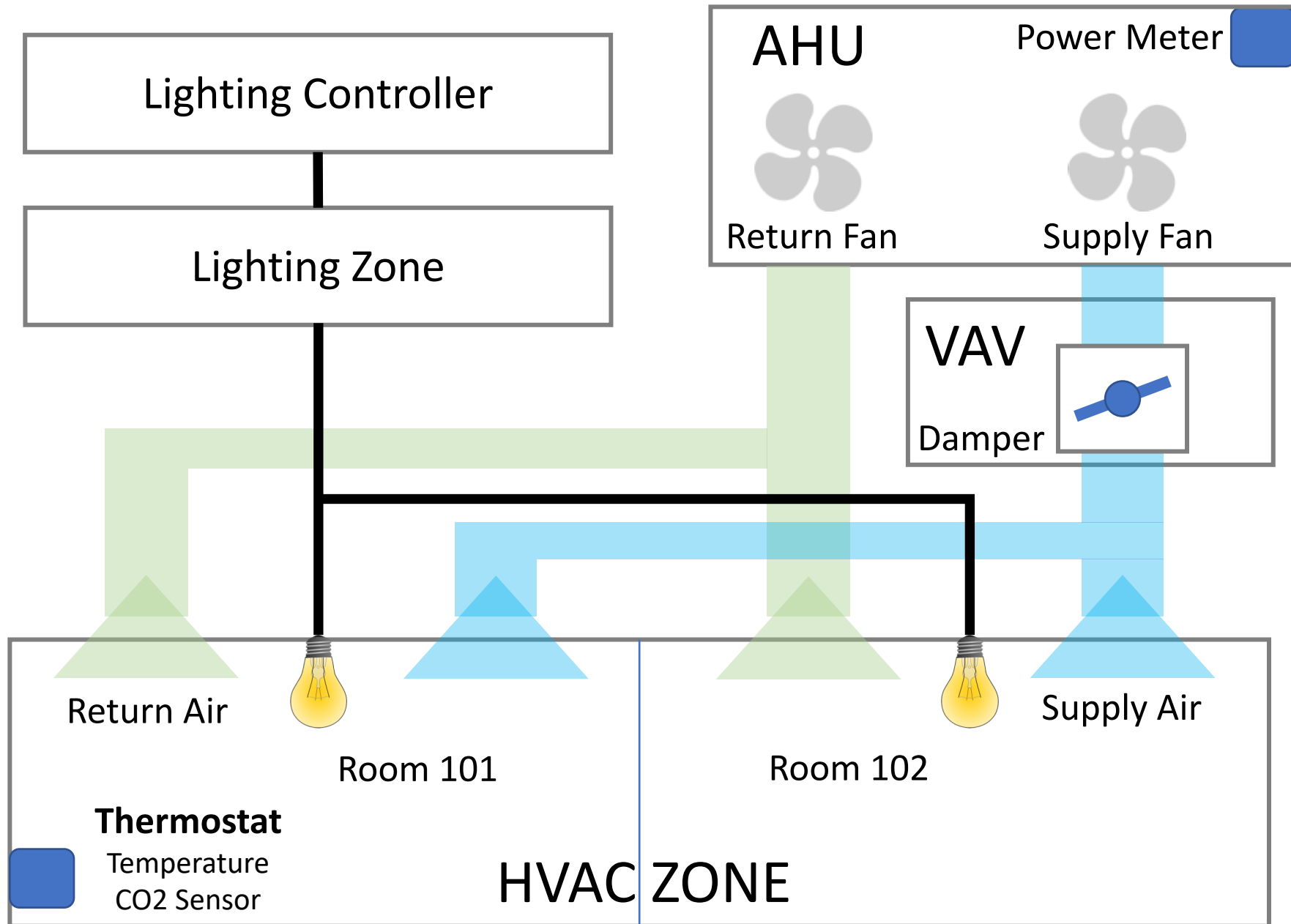
Brick Fundamentals



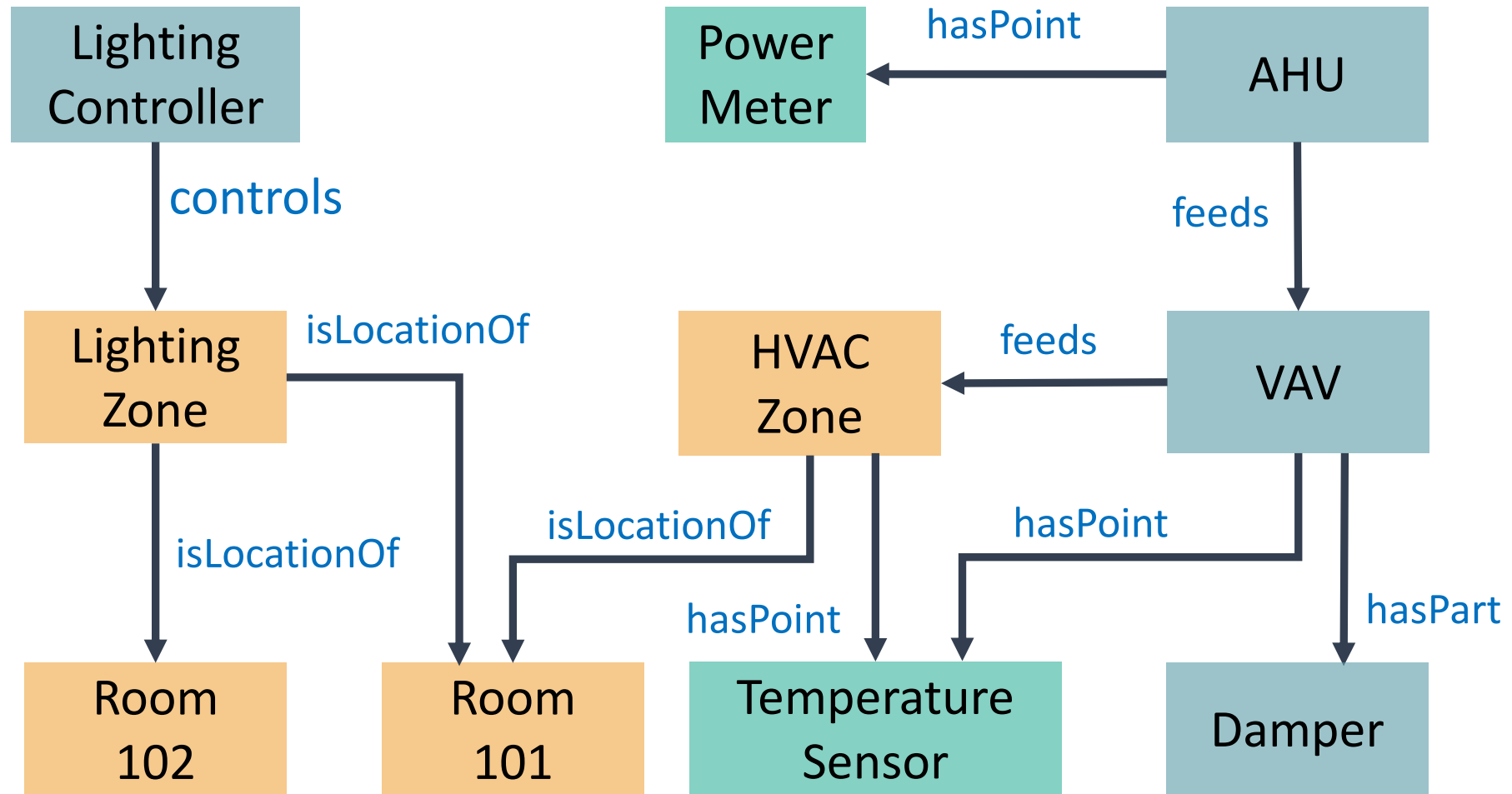
Brick Class Hierarchy



An Example "Model" Building



Relationships in Example Building



Legend

Location

Equipment

Point

Relationship

1. Complete Vocab, Extensible Framework
2. Represent all necessary relationships -> Using RDF
3. Usable query mechanism -> SPARQL over RDF
4. Open Source -> BSD and RFC

<https://brickschema.org>

UC San Diego

Berkeley
UNIVERSITY OF CALIFORNIA

SDU 

UCLA

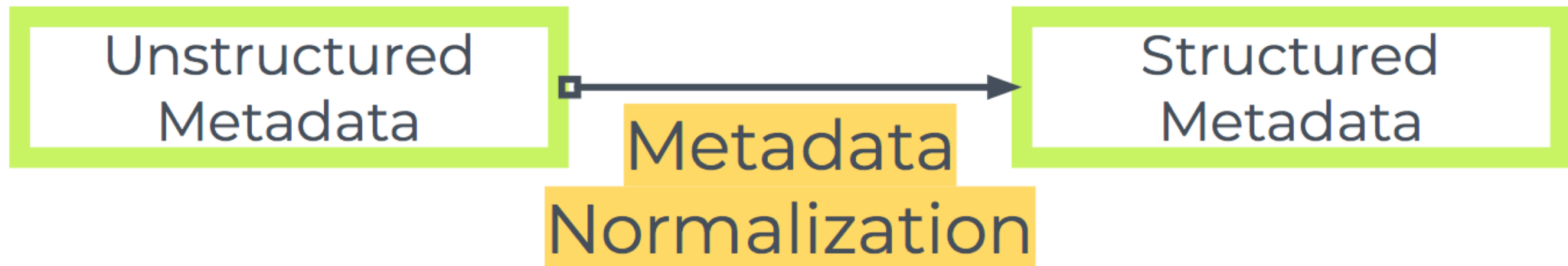
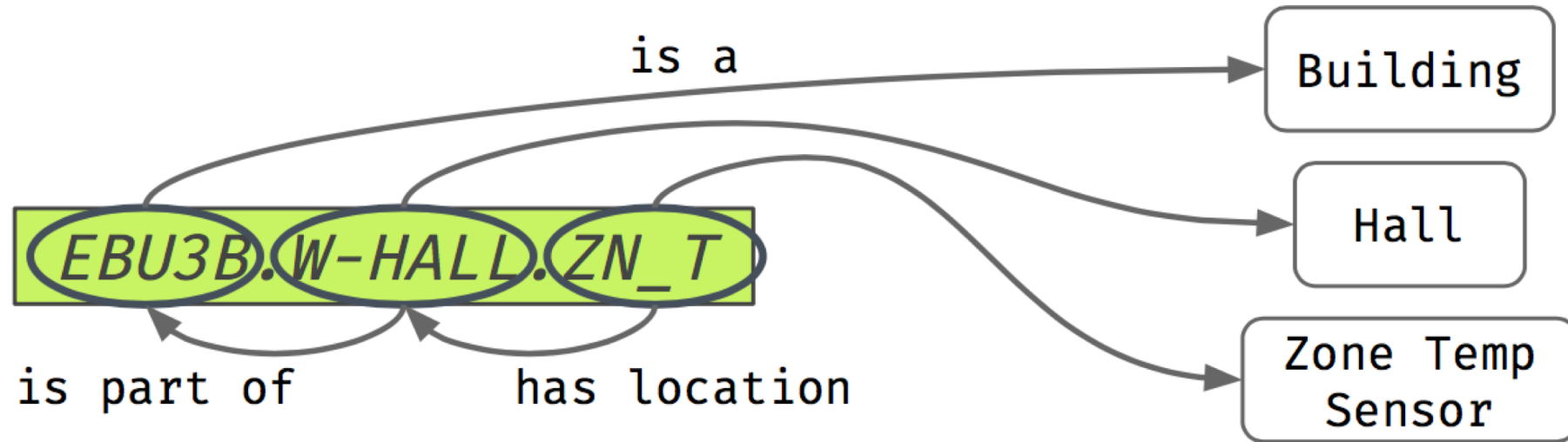

UNIVERSITY
of VIRGINIA

Johnson
Controls 

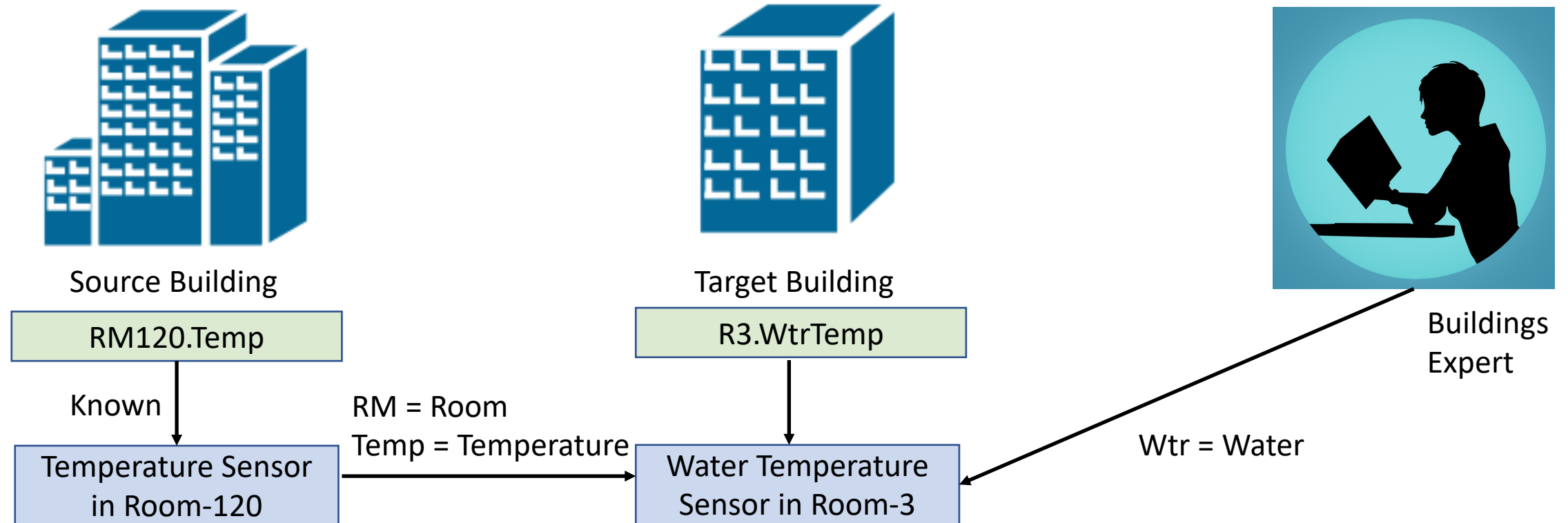
IBM®

Carnegie
Mellon
University

Need to Map Existing Building Metadata

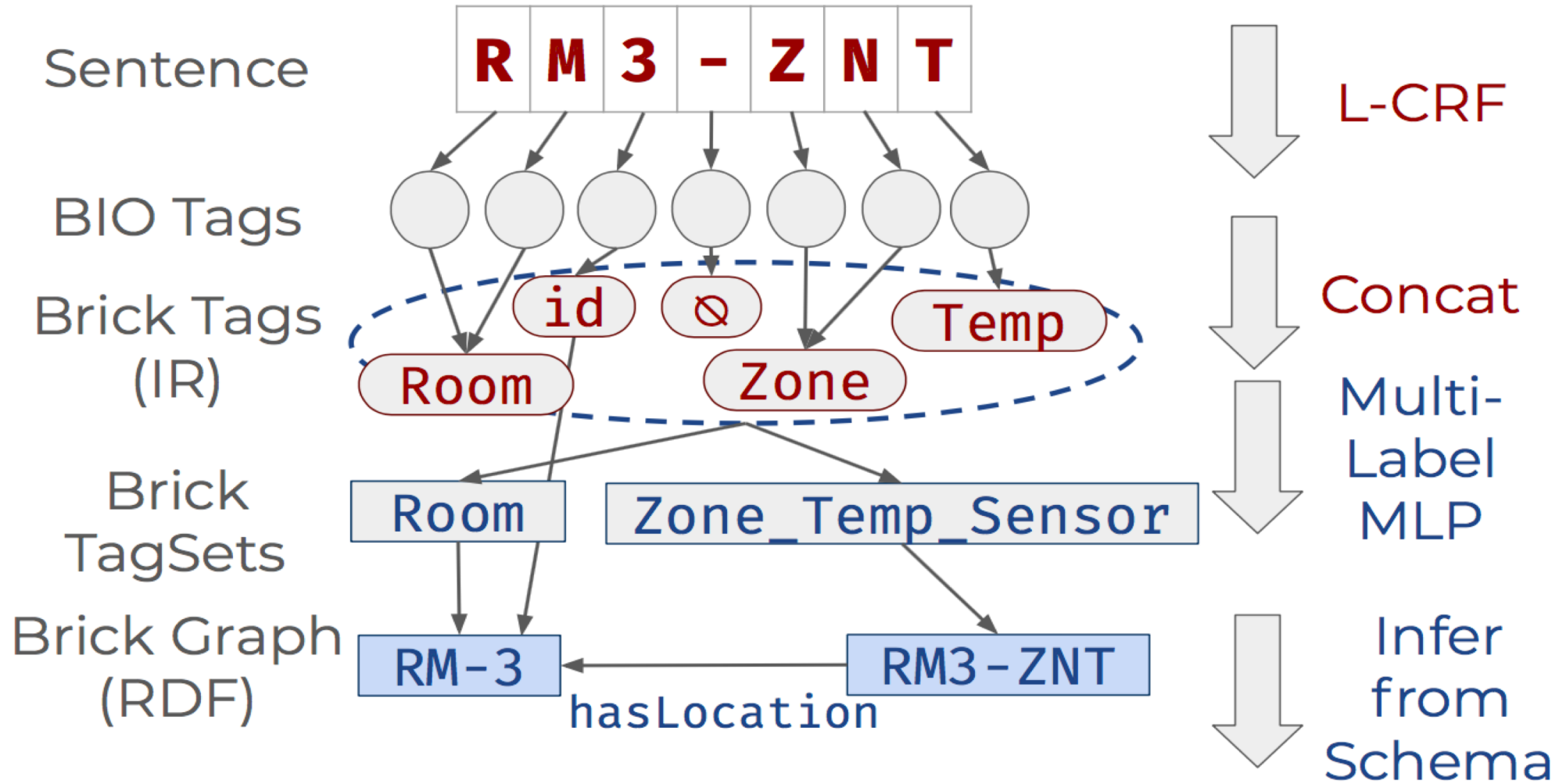


Scrabble: Map existing buildings to Brick

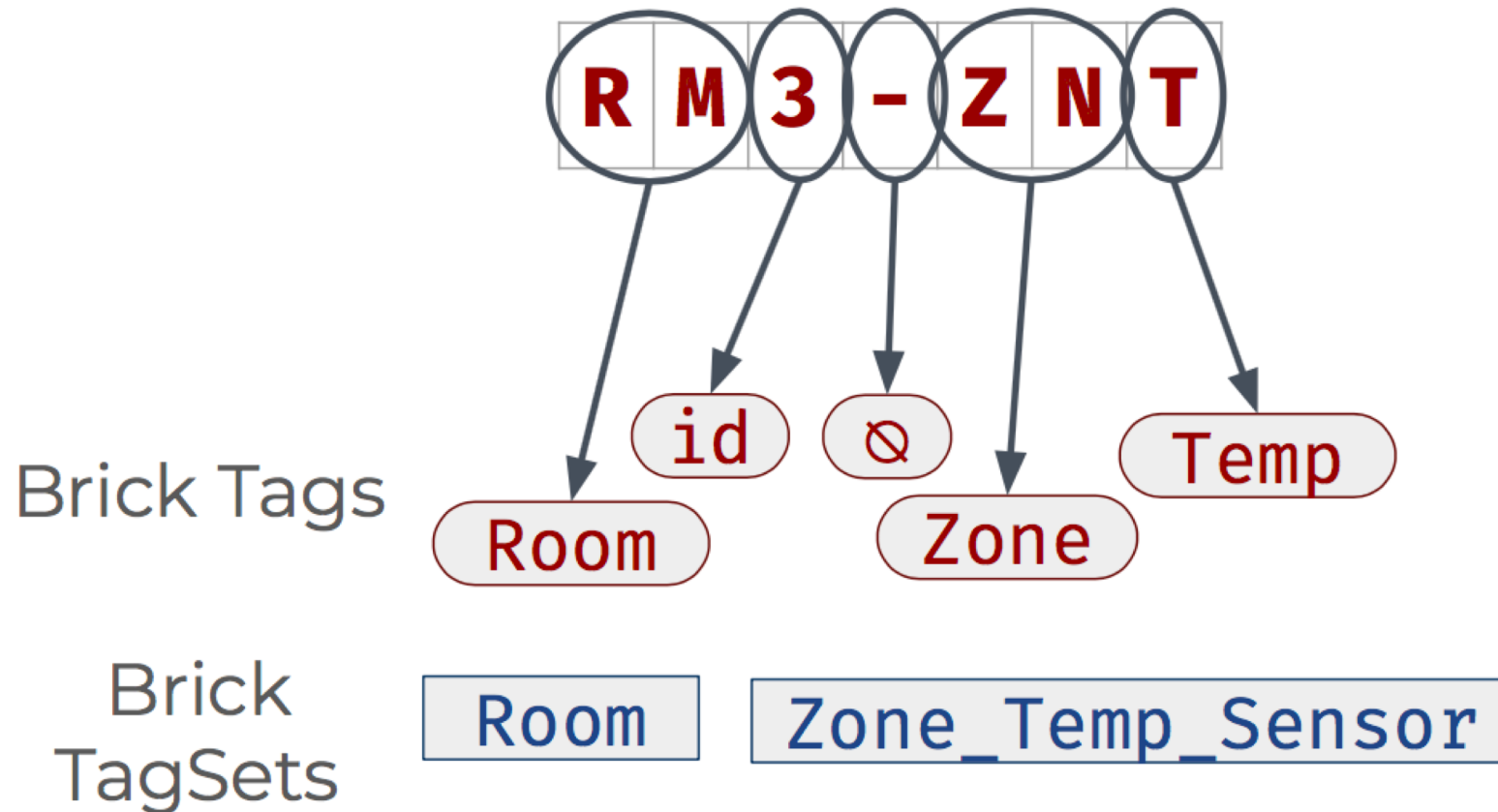


- Learn from prior examples
- Ask expert when known examples are not enough

Scrabble: Multi-Stage Algorithm



Experts Give Examples at Two Stages



Dataset

- University of California, San Diego – 3 buildings, 3000 data points

```
{  
  'vendor_name':  
    'NAE 99 N2 0 VMA999 SA T',  
  'bacnet_desc':  
    'Supply Air Temp',  
  'bacnet_unit':  
    '64',  
}
```



VAV
Supply Air Temp Sensor

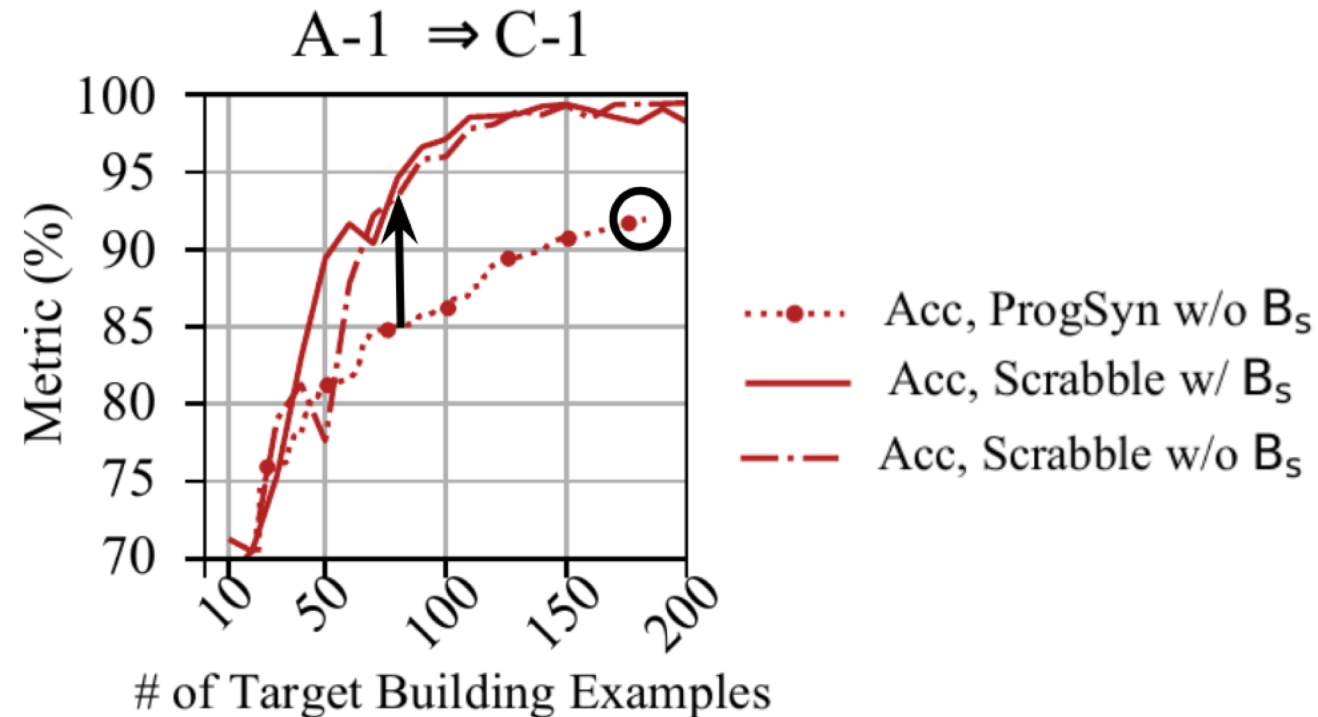
- Carnegie Mellon University – 1 building, 1000 datapoints

```
'CMU/CMPS BLDG/First Floor/VAV  
Corridor 9900 Central/  
Airflow Setpoint'
```



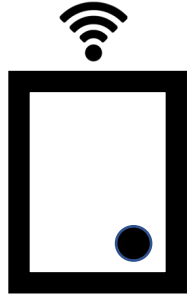
Building
Floor
Corridor
VAV
Air Flow Setpoint

Results: Compared to State of the Art Baseline

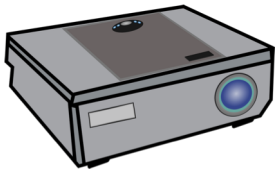
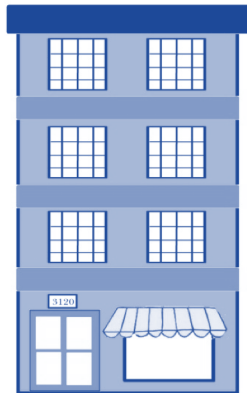
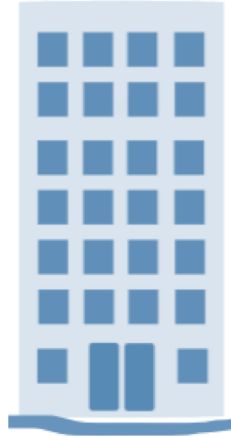


- Faster learning speed than baseline
- Capable of accumulating examples given by expert

Data Driven Buildings



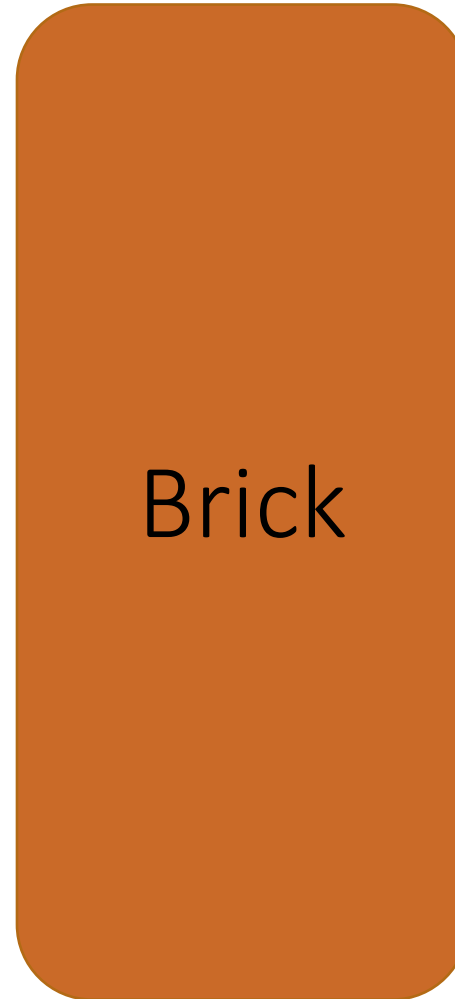
Sensor



Devices



Equipment



Brick



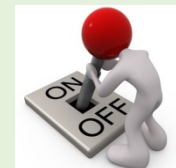
Visualize



Maintain



Analyze



Control



“Alexa, join
the meeting”



Alexa for Business

<https://aws.amazon.com/alexaforbusiness>

Alexa for Hospitality

<https://www.amazon.com/alexahospitality>

Thank you!

Amazon AI Labs – Reinforcement Learning Team

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Acknowledgements

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Mani Srivastava, Rajesh Gupta, Yuvraj Agarwal

Results: Buildings in the Same Campus

