

# Data Driven Buildings

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Amazon AI Labs

UC San Diego



**UCLA**

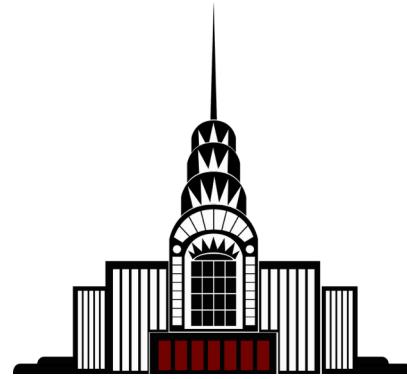
# Buildings are evolving..



Shelter



Water  
Electricity



Security  
Thermal Comfort  
Fire Safety

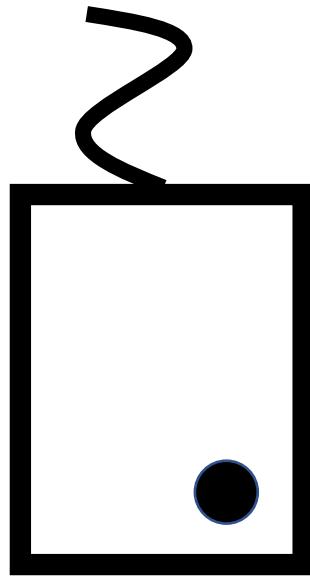


Connectivity  
Sensors  
Software

Data: Interact. Optimize. Innovate.

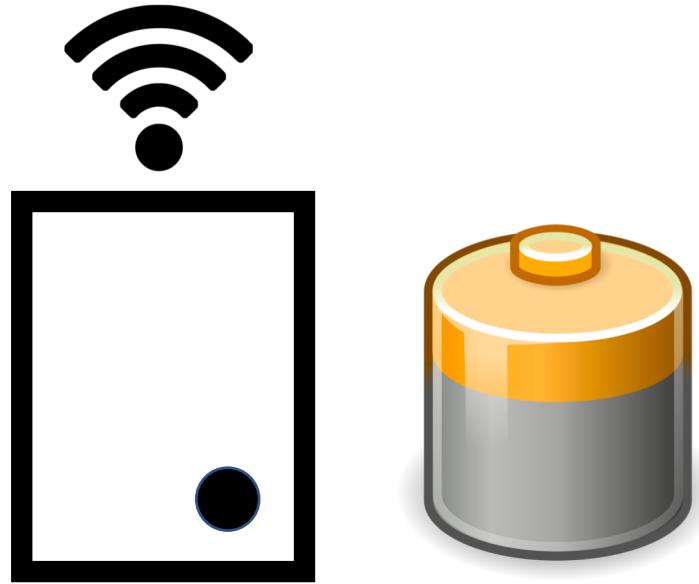
# Data Generation Bottleneck: Sensors

Wired



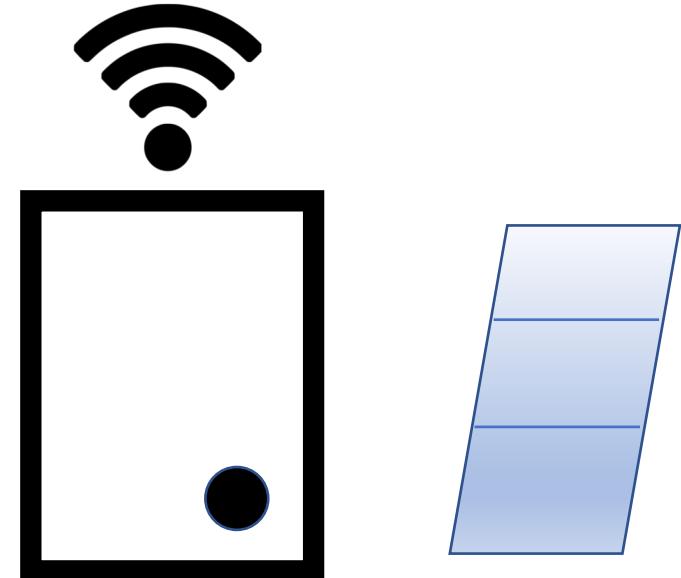
Reliable  
Expensive  
**Not Flexible**

Wireless + Battery



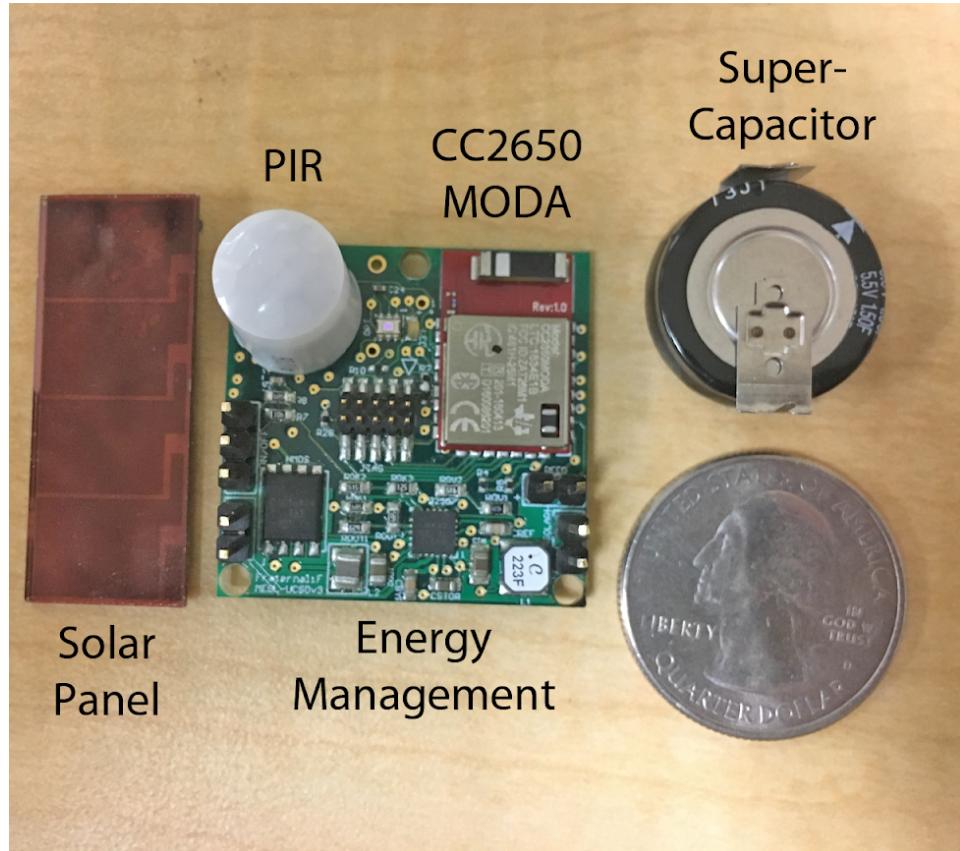
**Battery Maintenance**  
Inexpensive  
Flexible

Wireless + Harvesting



**Unreliable**  
Inexpensive  
Flexible

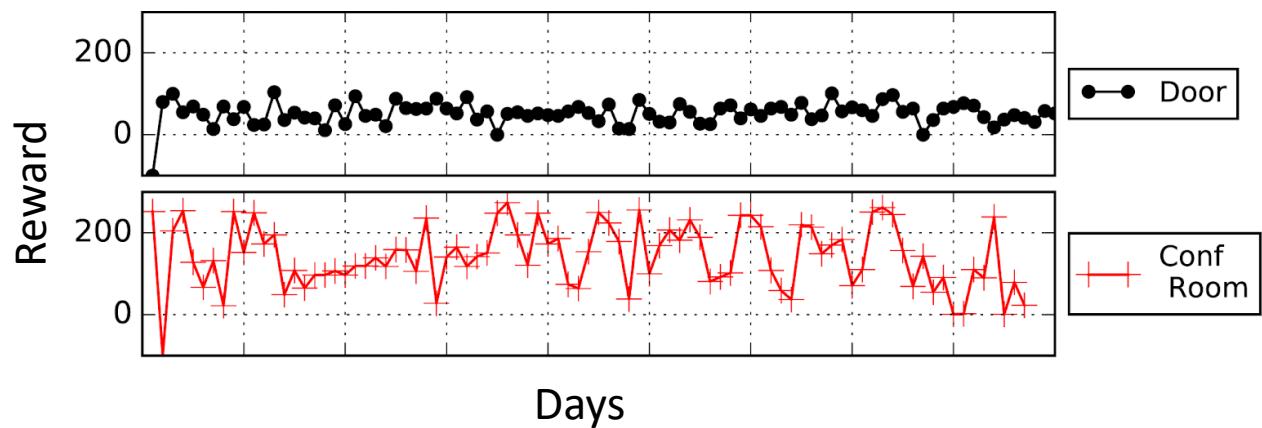
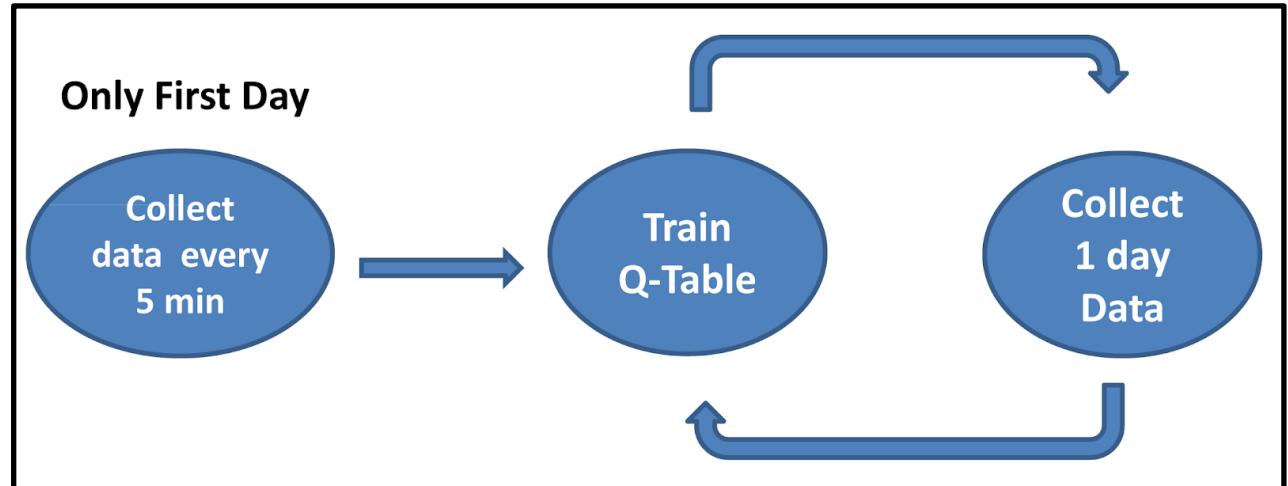
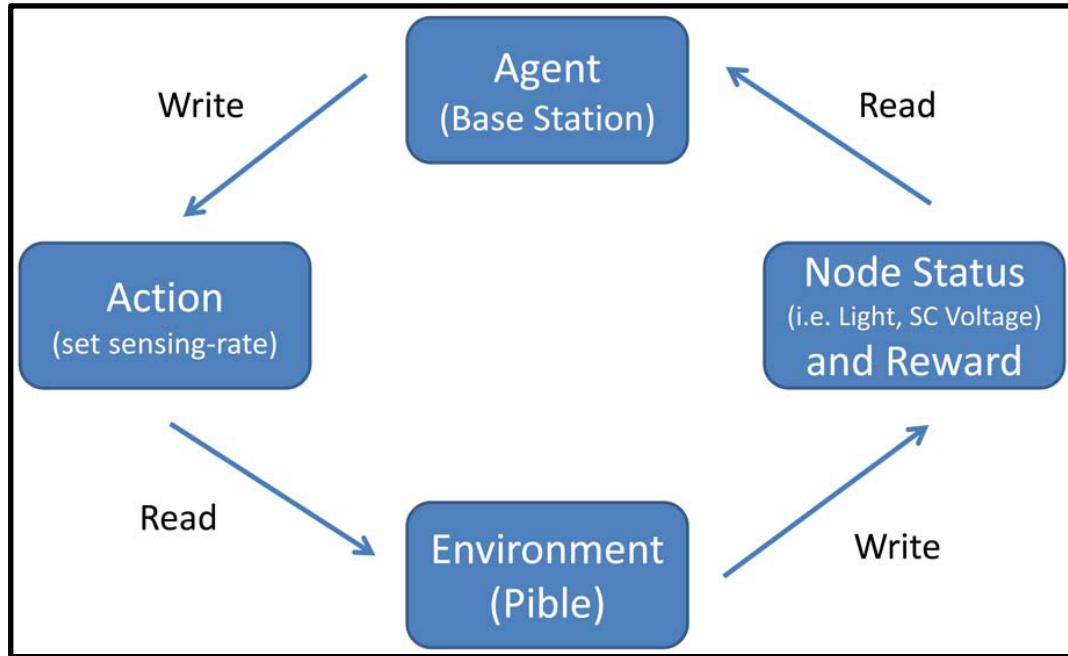
# Pible: Perpetual Indoor BLE Sensor



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

Limitation: Manual configuration

# 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

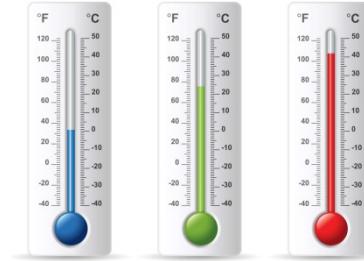
# Data Collation Bottleneck: Vertical Systems



Lighting System



Plug Loads



Heating, Ventilation and Air Conditioning (HVAC)

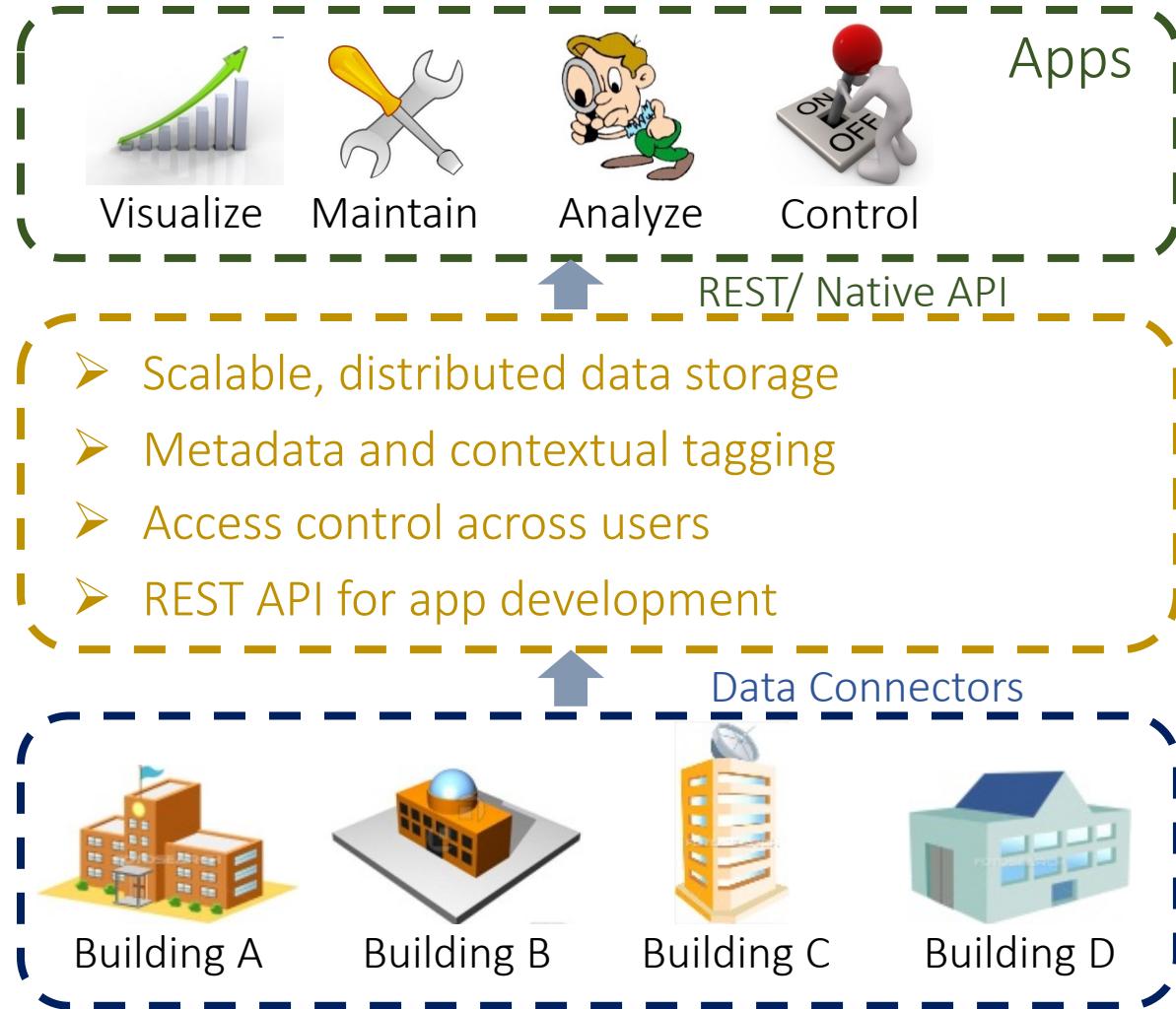


Enterprise Network



Security System

# Integration Platform for Applications

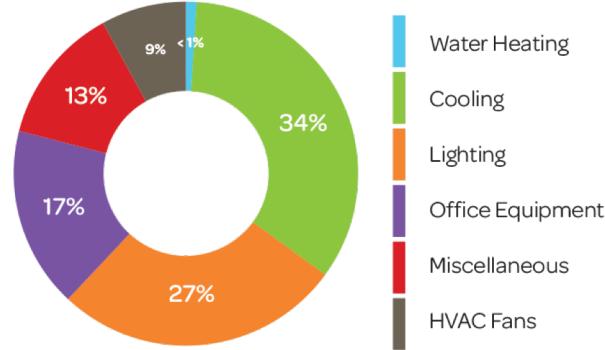


Next generation  
building applications  
via standardized API

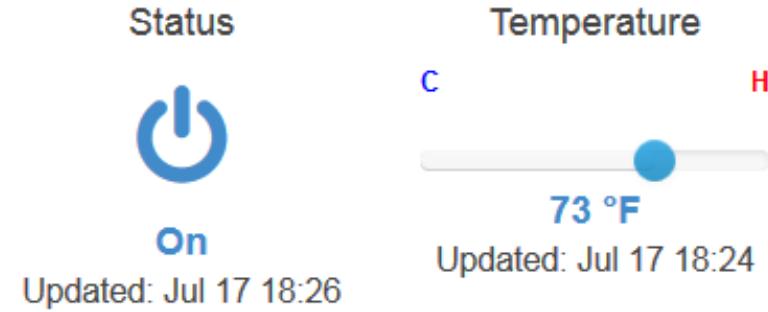
Data management  
system for sensors and  
actuators

Large amount of data  
generated in modern  
buildings

# Smart Building Applications



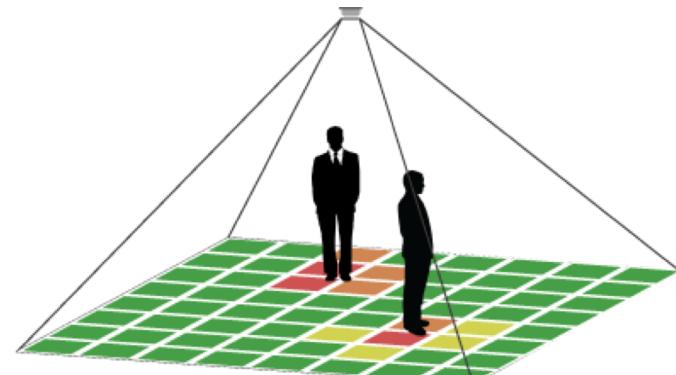
Energy Disaggregation  
BuildSys '10, BuildSys '13



Personalized Control  
BuildSys '13, Ubicomp '16



Fault Detection and Diagnosis  
BuildSys '14



Occupancy Based Control  
IPSN '11, SenSys '13

# App Portability Bottleneck: Naming Semantics

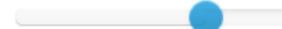
**Environment Information**

**Energy Usage**  
  
4.6 kW  
Updated: Jul 17 18:24  
CSE Avg: 3.2kW

**Room Temperature**  
  
75.2 °F  
Updated: Jul 17 18:23  
CSE Avg: 71.6°F

**HVAC Control**

**Status**  
  
On  
Updated: Jul 17 18:26

**Temperature**  
  
73 °F  
Updated: Jul 17 18:24

You are sharing this HVAC with room 2140 occupants. Please be considerate of their preferences.

**Schedule**

**Weekday schedule:** 07:00AM - 07:00PM

**My room schedule:** 10:00AM - 05:00PM

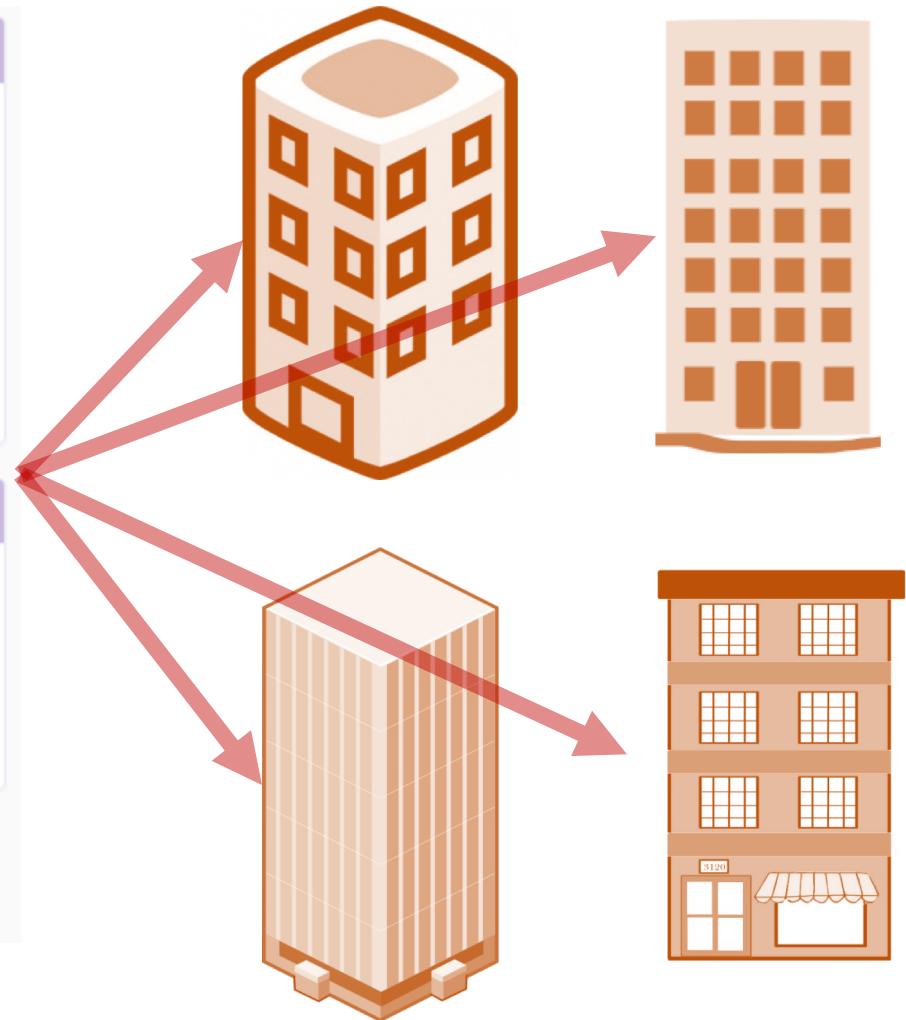
**Weekend and night schedule:** Press button to turn HVAC on and select duration

**Set schedule**

**How are you feeling now ?**



Cold   Cool   Slightly Cool   Good   Slightly Warm   Warm   Hot

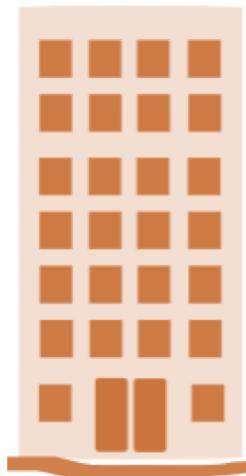


# Each Building is Different

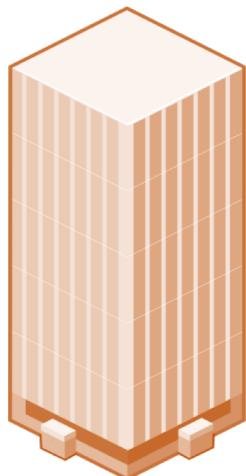
- ❖ University, Hotels, Hospitals, Shopping Malls



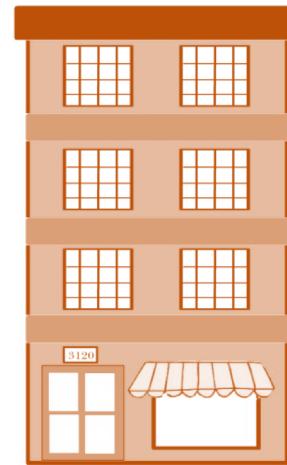
Lecture Hall



Bio Labs



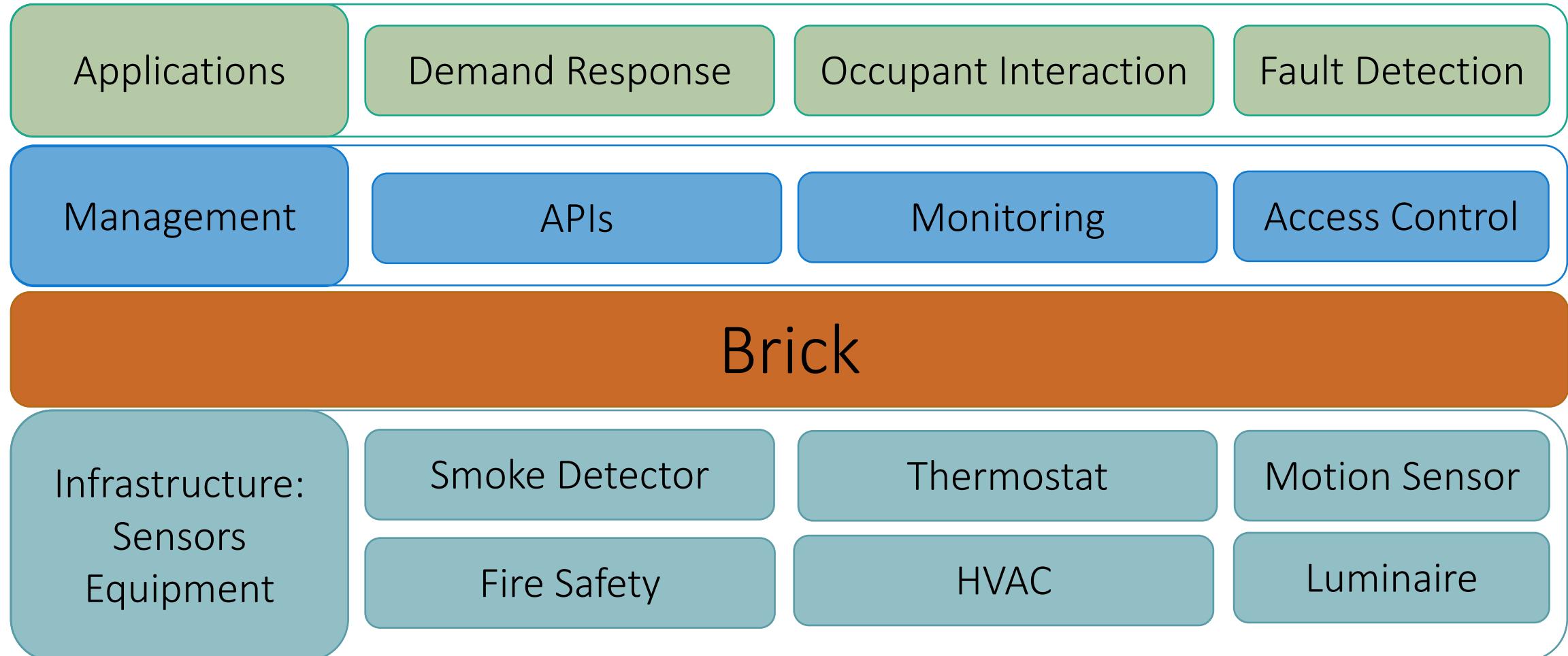
Mixed Use



Library

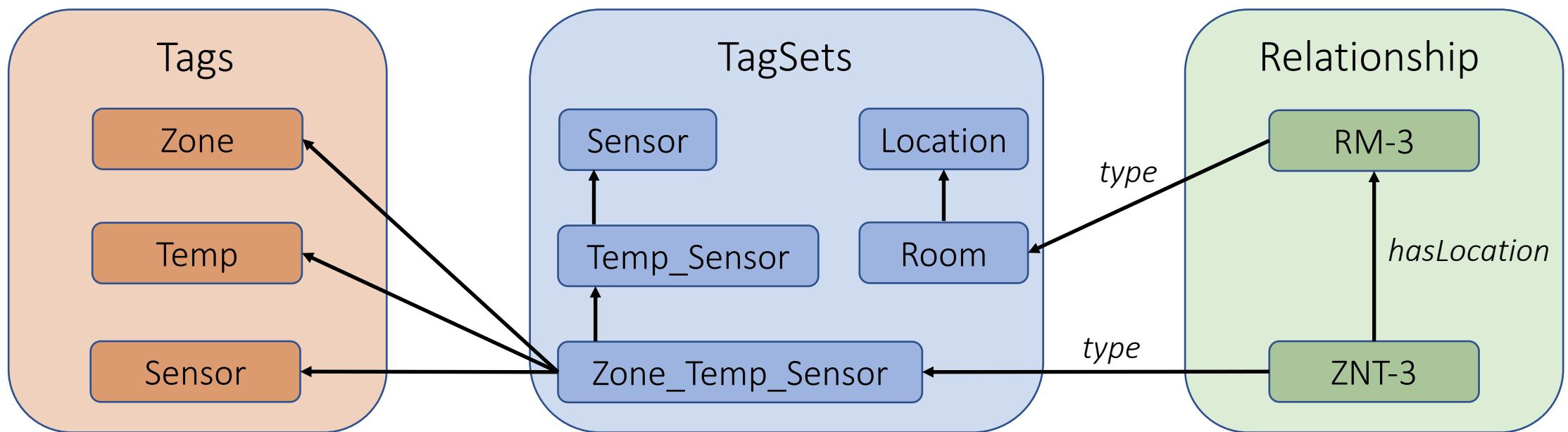
- Equipment, Vendor, Institution
- Changes with time: Repairs, Retrofits

# Brick: Building Metadata Schema

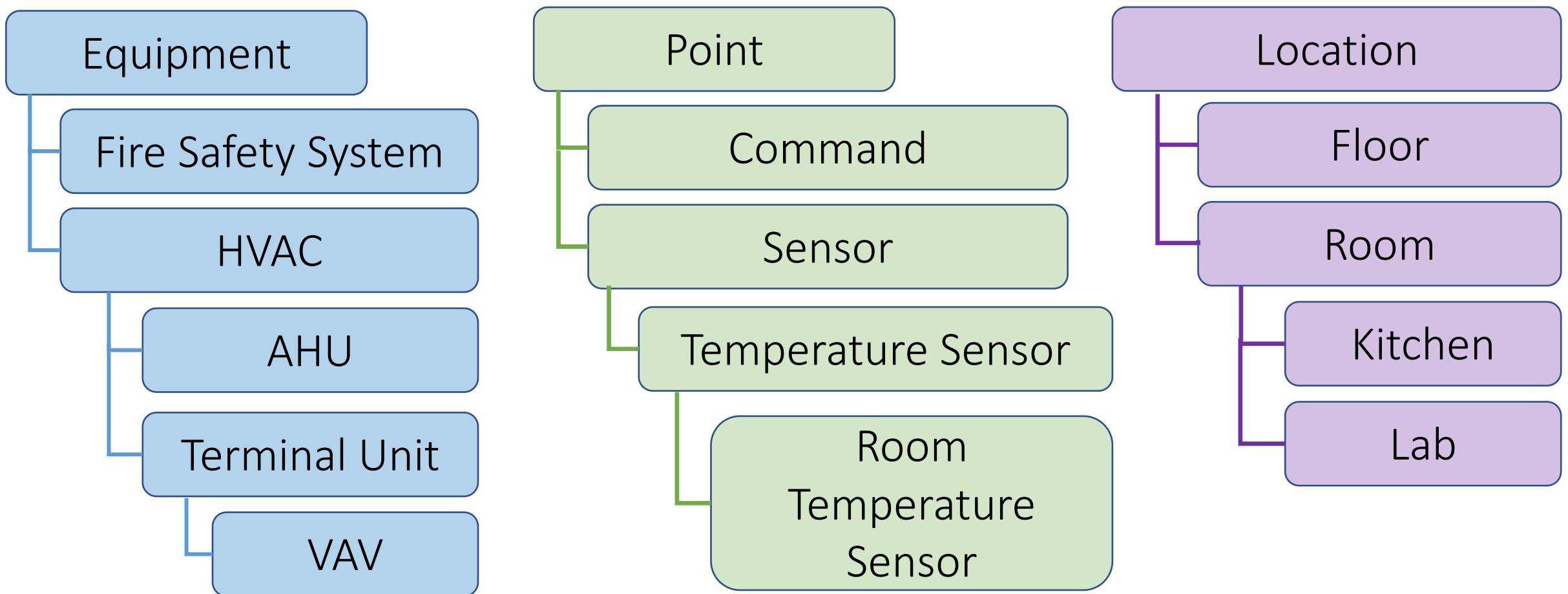


Brick: BuildSys 2016, Applied Energy 2018 <https://brickschema.org>

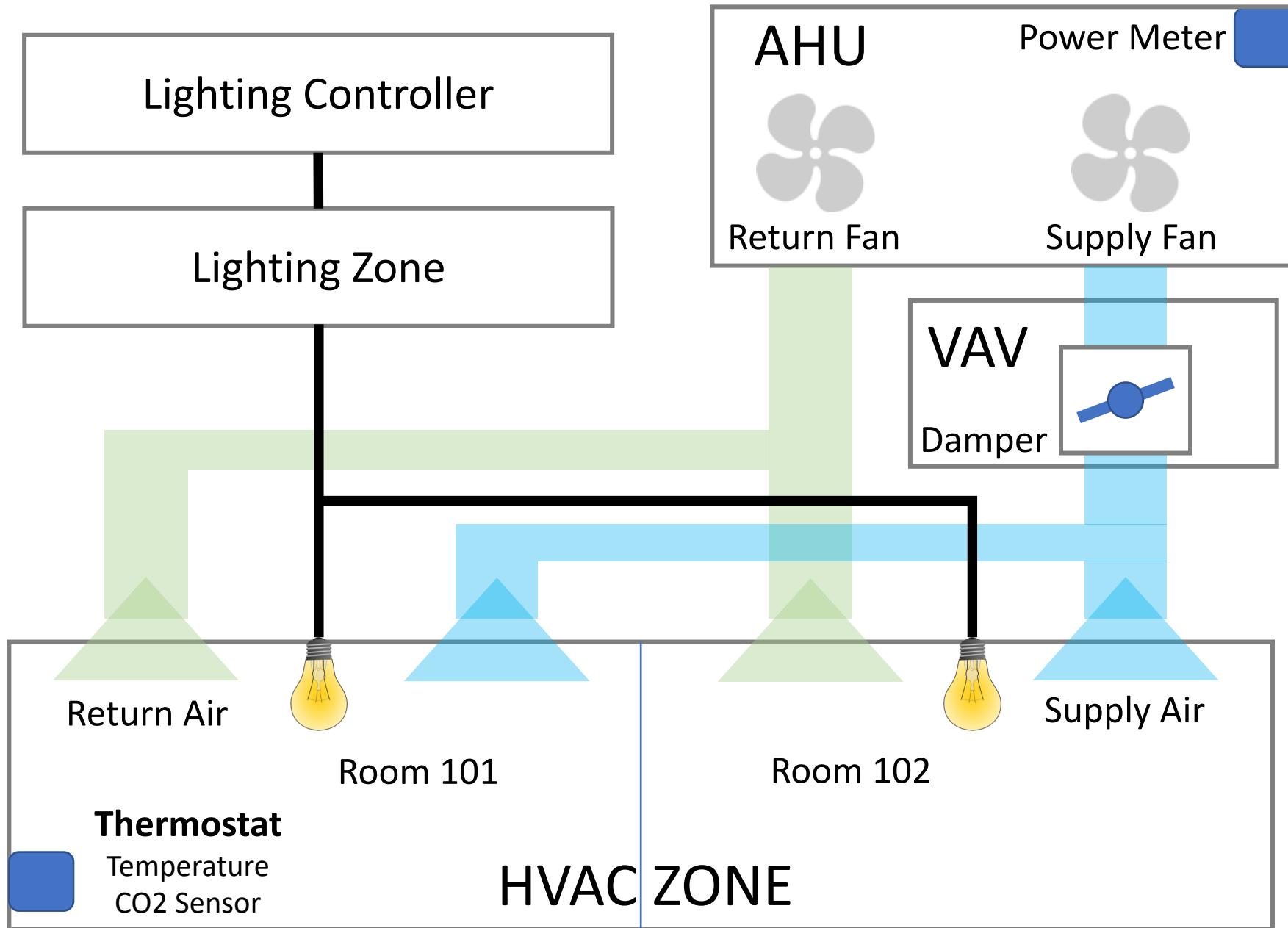
# Brick Fundamentals



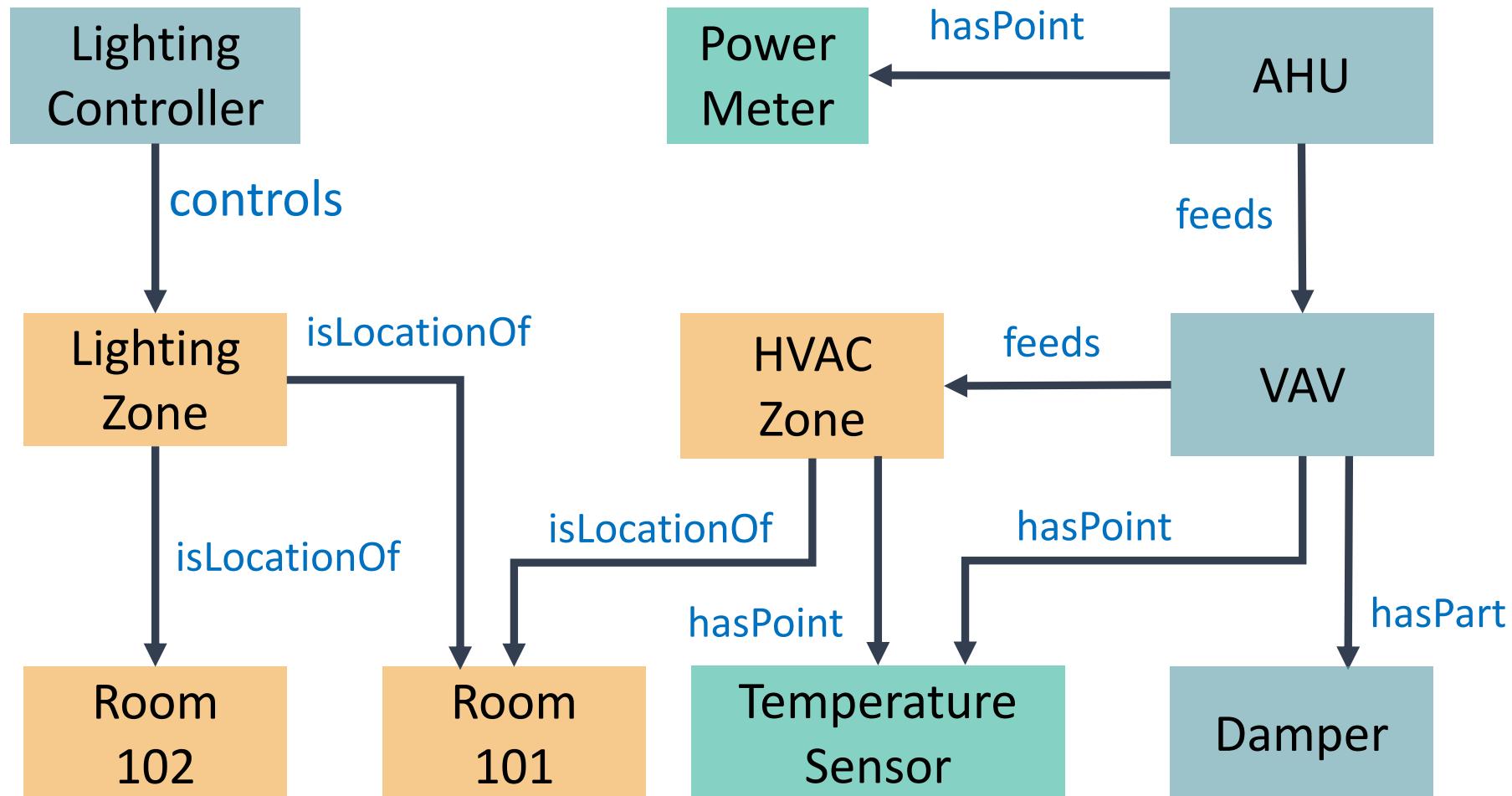
# Brick Class Hierarchy



# 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

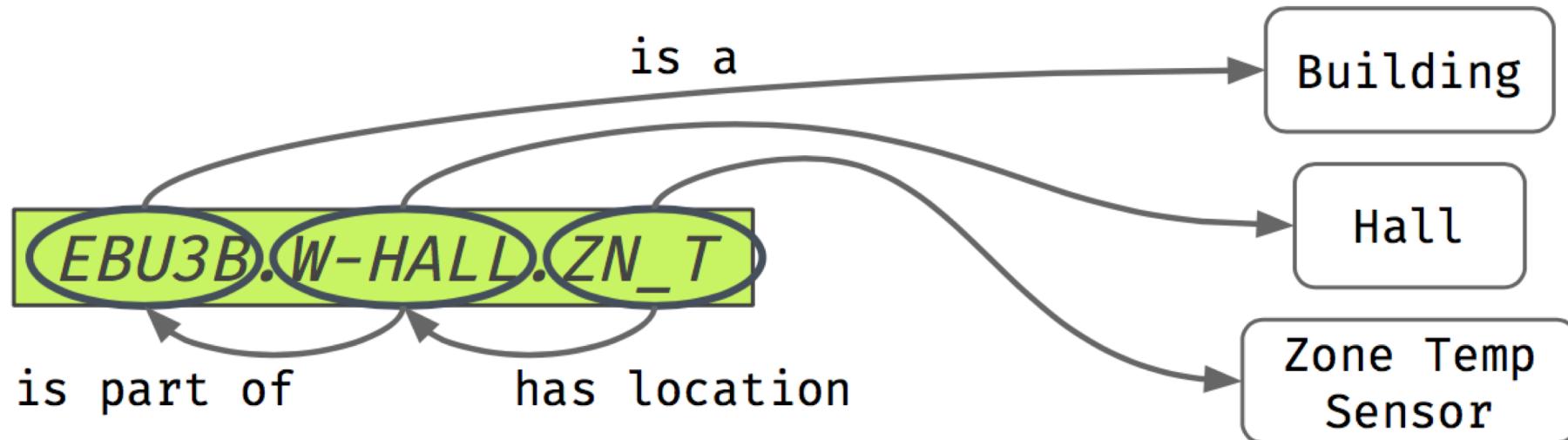
SDU 

UCLA

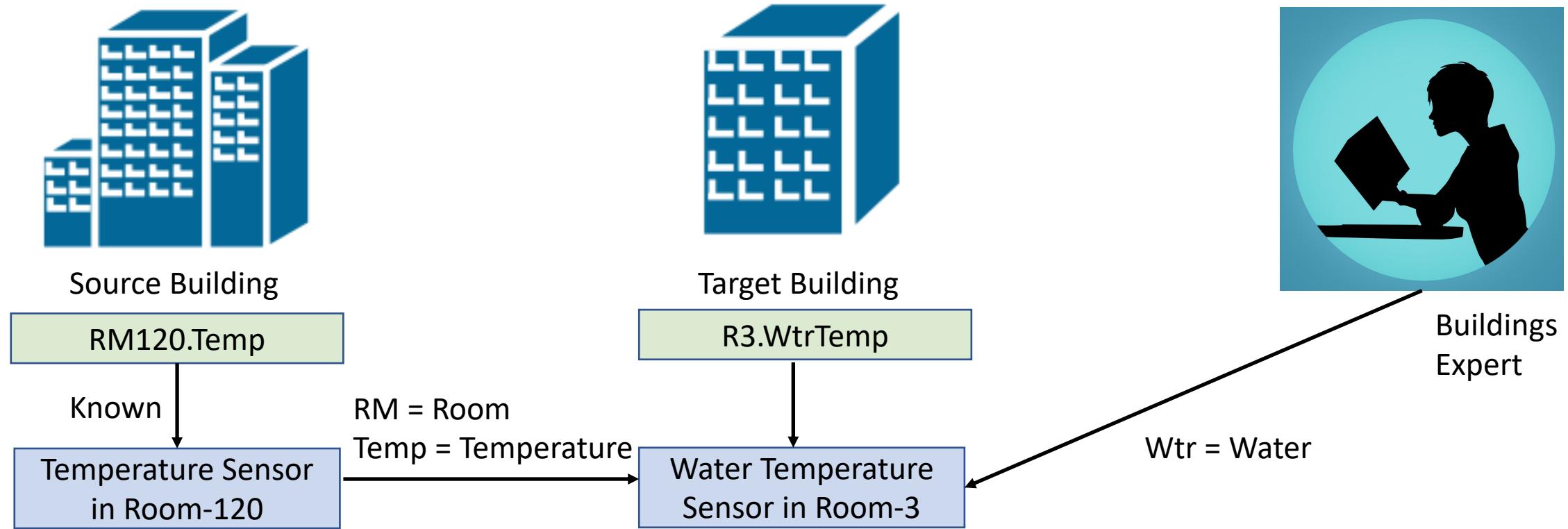


Carnegie  
Mellon  
University

# Need to Map Existing Building Metadata

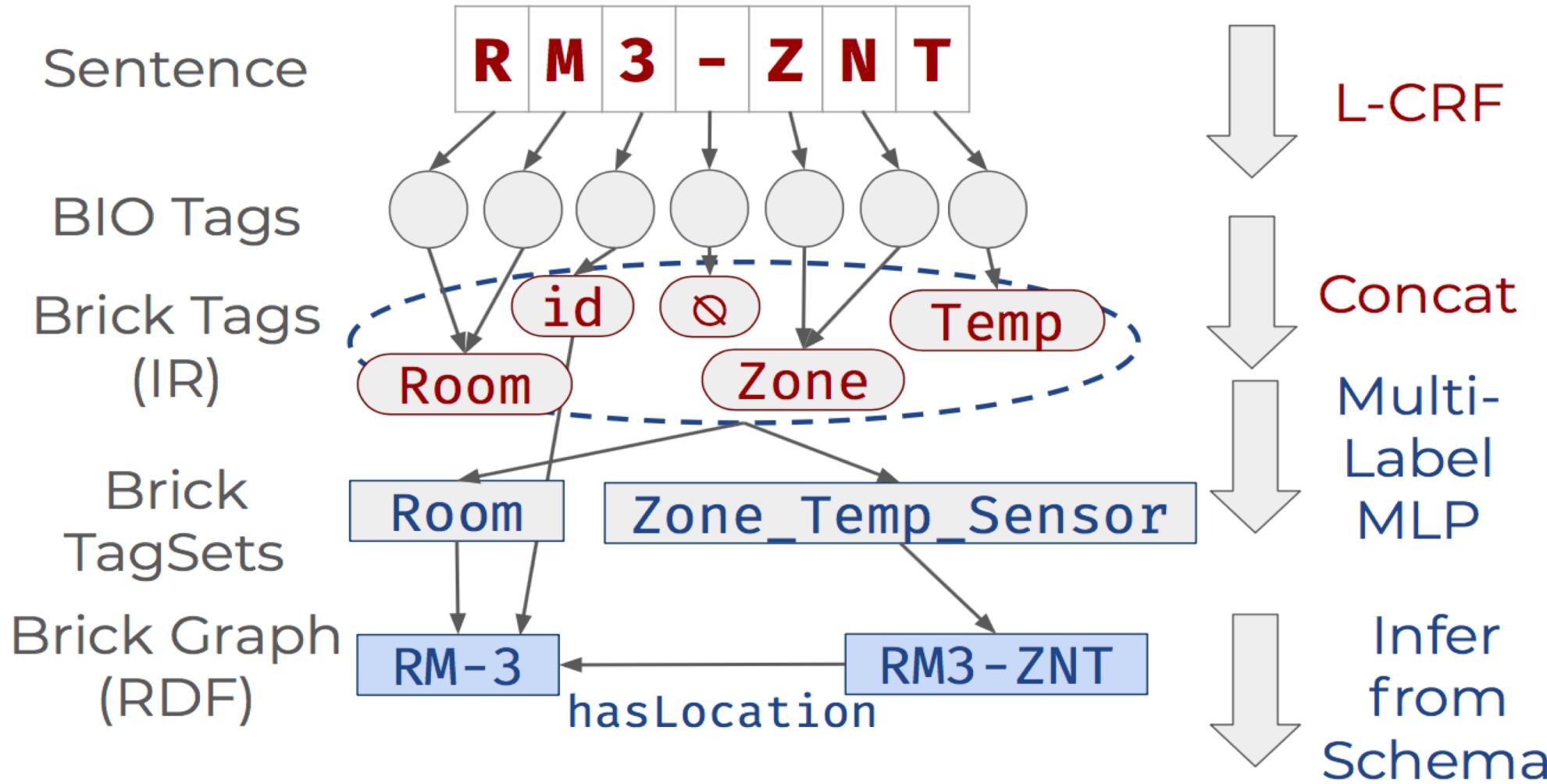


# Scrabble: Map existing buildings to Brick

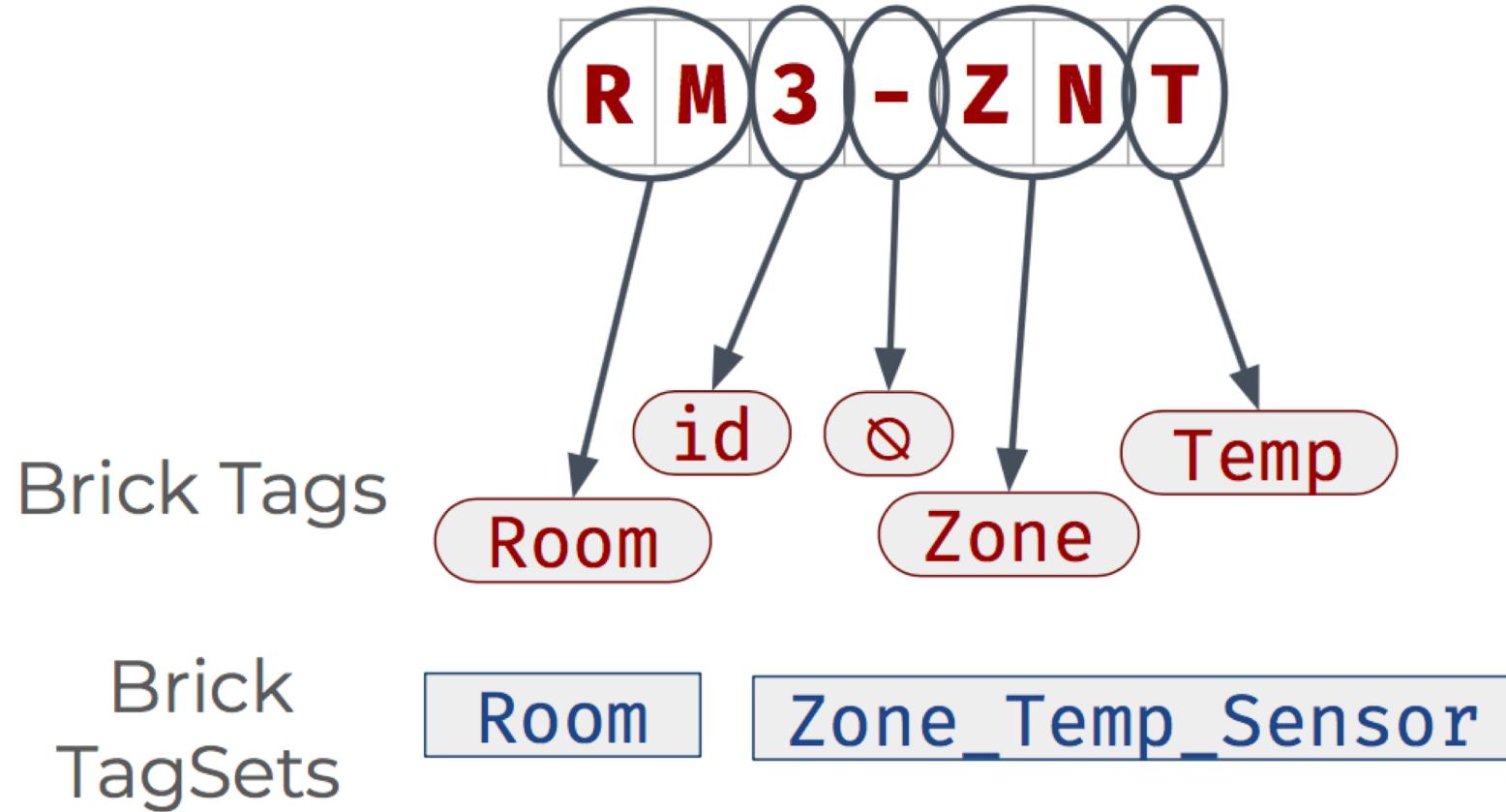


- Learn from prior examples
- Ask expert when known examples are not enough

# 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**

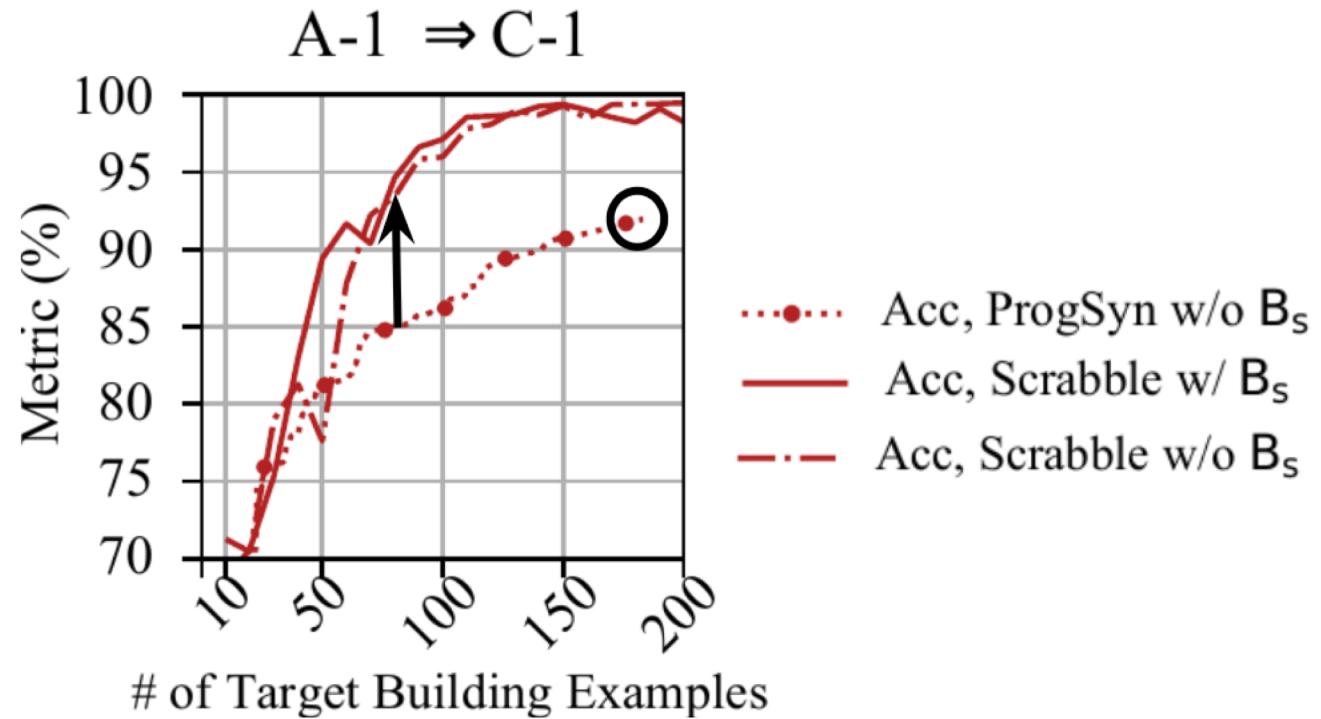
- Carnegie Mellon University – 1 building, 1000 datapoints

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



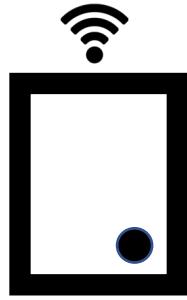
**Building**  
**Floor**  
**Corridor**  
**VAV**  
**Air Flow Setpoint**

# Results: Compared to State of the Art Baseline

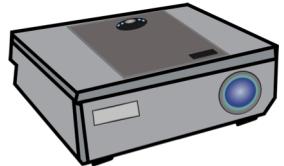
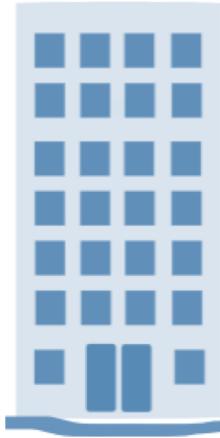


- Faster learning speed than baseline
- Capable of accumulating examples given by expert

# Data Driven Buildings



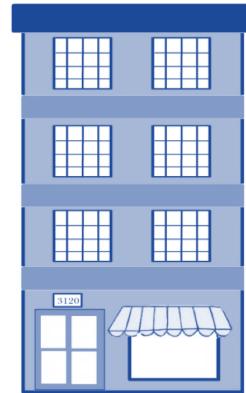
Sensor



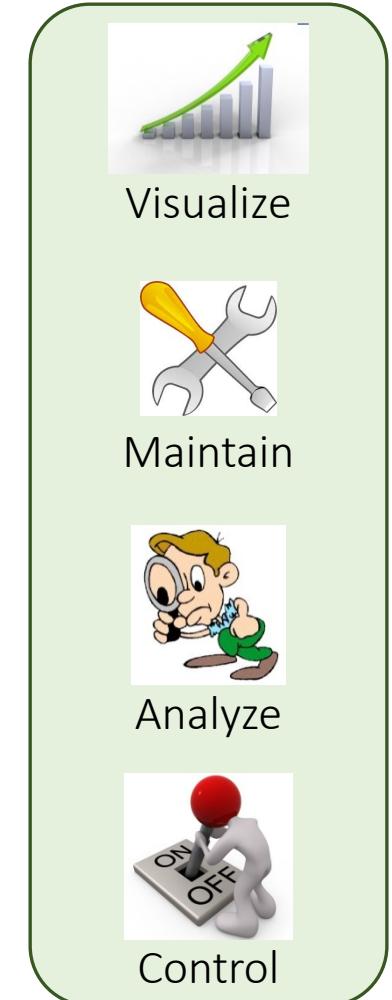
Devices

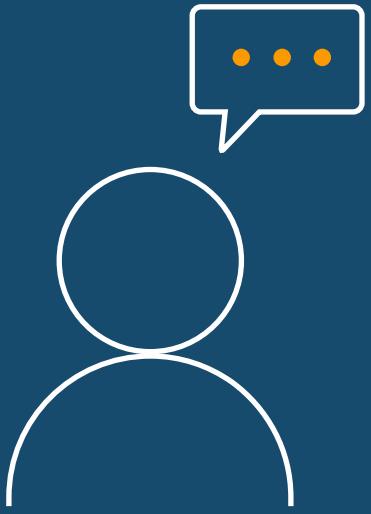


Equipment



Brick





“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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Email: bhabalaj@amazon.com

## Acknowledgements

Francesco Fraternali, Jason Koh, Anna Levitt, Gabe Fiero  
Mani Srivastava, Rajesh Gupta, Yuvraj Agarwal

# Results: Buildings in the Same Campus

