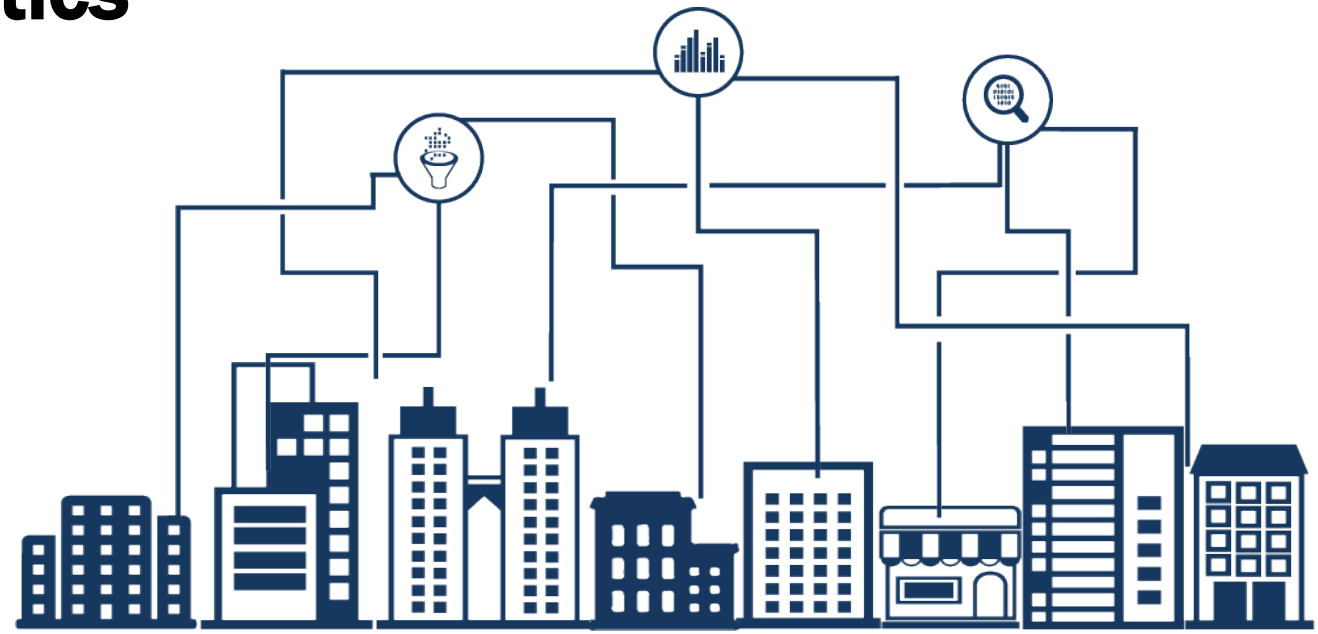
U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

The Building Adapter: Automatic Mapping of Commercial Buildings for Scalable Building Analytics



Computer Science, University of Virginia

Hongning Wang - Assistant Professor

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Project Summary

Timeline:

Start date: 2018-01-01

Planned end date: 2020-12-31

Key Milestones:

1. Basic evaluation framework released to industry partners and research collaborators; 2018-10-31
2. >90% mapping accuracy in <10% of buildings with <10% of the points manually mapped; 2020-09-30

Budget:

Total Project $ to Date:

- DOE: $163,204
- Cost Share: $18,134

Total Project $:

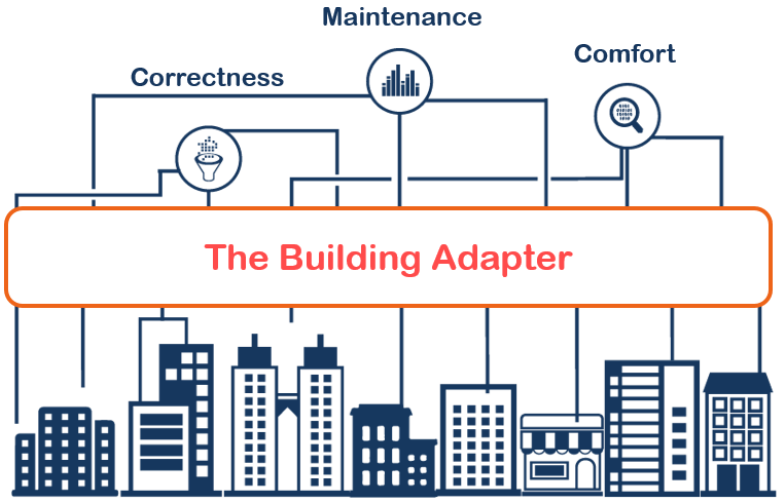
- DOE: $499,994
- Cost Share: $55,858

Key Partners:

TRANE

Project Outcome:

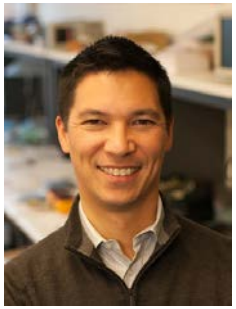
This project will create new solutions to automate the costly process of creating a match between a building's sensor data stream and building analytics engine inputs.



Team

Hongning Wang

Over eight years of experience in data mining and machine learning research, with a special emphasis on human-centric knowledge discovery. Focus on learning-based metadata inference and mapping solutions.



Kamin Whitehouse

Over a decade on developing techniques in various fields, including occupancy sensing, smart buildings, safety-critical wireless communication. Focus on wireframe evaluation framework for metadata inference and industry collaboration.

Madhur Behl

Over seven years of finding analytical and practical solutions to problems of modeling, control, simulation, operation, safety, and implementation of CPS. Focus on evaluation with building analytics engine and industry collaboration.

Background

- **Buildings are complex cyber-physical systems with profound impact on human health, productivity, comfort, and energy consumption**
  - Average Americans spend 90% of their time in buildings [1]

Background

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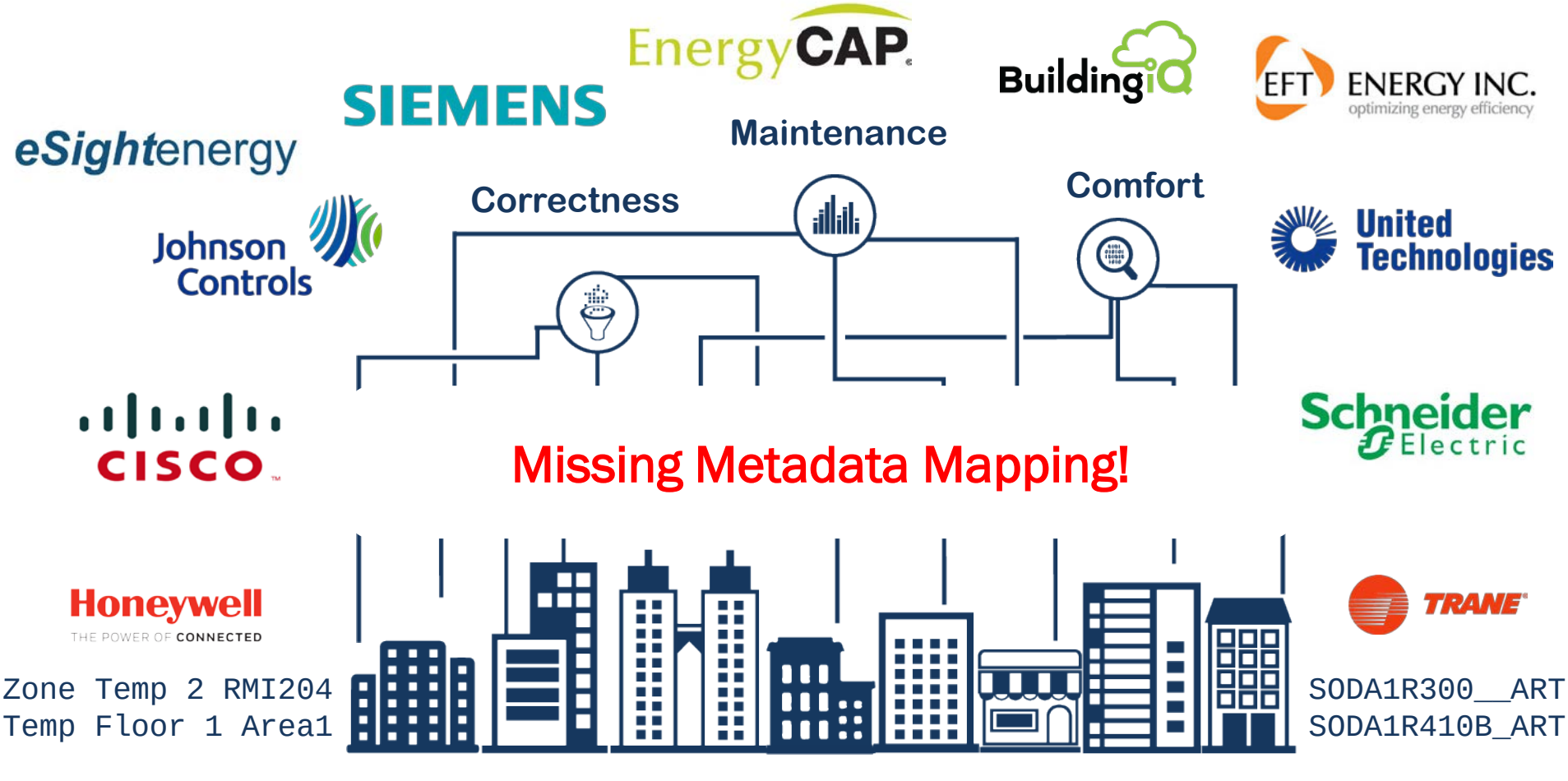
  - Indoor conditions affect human productivity by 8-11% [2]

Background

- **Buildings are complex cyber-physical systems with profound impact on human health, productivity, comfort, and energy consumption**
  - Account for almost 20 percent of the country's total energy use and a good 30 percent of that energy is used "inefficiently or unnecessarily." [3]

Challenge

- An analytics engine cannot be applied to a new building without first addressing the issue of mapping [4]



Challenge

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SODA1R300__ART

Bldg: SOD
Zone: 1
Room: 300
Type: Room Temperature

Zone Temp 2 RMI204
Temp Floor 1 Area1

SODA1R300__ART
SODA1R410B_ART

Challenge

- **Dilemma: mapping must be done to know the value of the analytics engine, but the value of the analytics engine must be known to decide whether to invest in manual mapping**
  - Microsoft's 88 Acres project that aims to apply analytics to 125 buildings, the mapping process alone would take over two years [4]

Zone Temp 2 RMI204
Temp Floor 1 Area1

SODA1R300__ART
SODA1R410B_ART

Challenge

- Dilemma: mapping must be done to know the value of the analytics engine, but the value of the analytics engine must be known to decide whether to invest in manual mapping

SODA1R300__ART
Bldg: SOD
Zone: 1
Room: 300
Type: Room Temperature

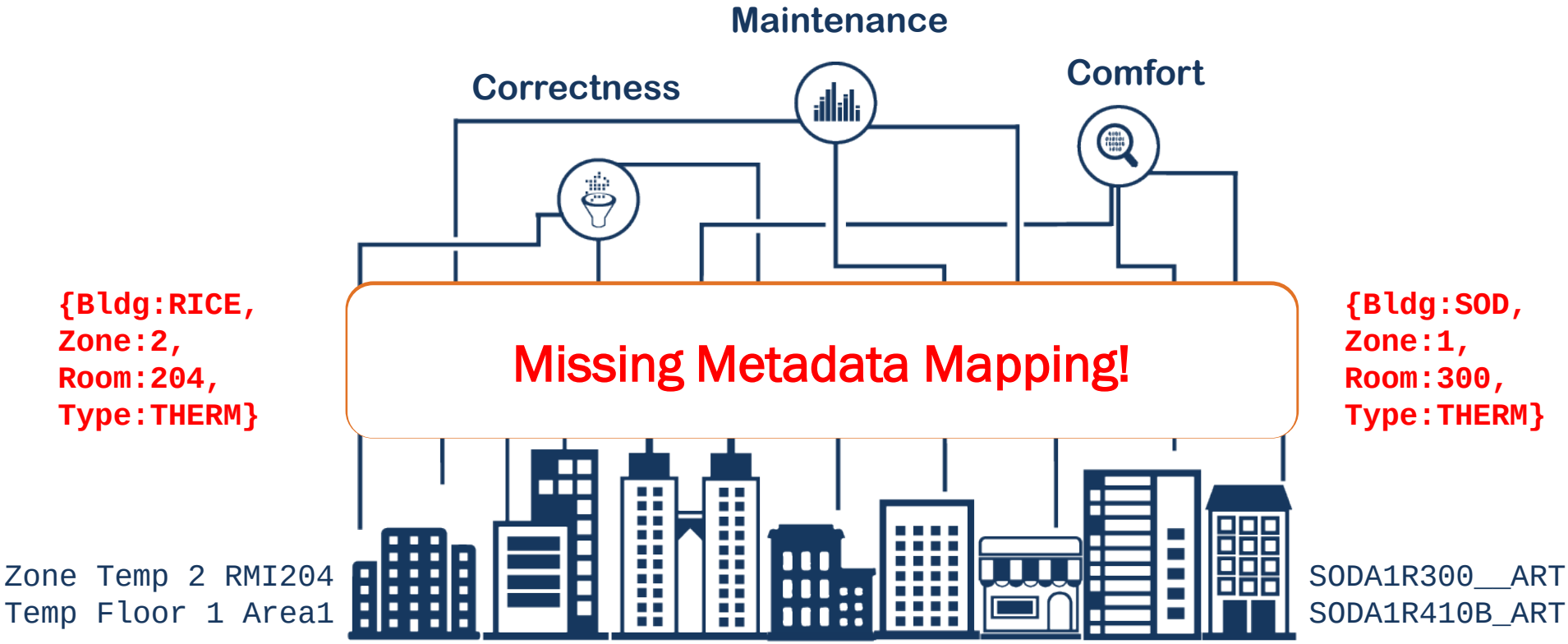
Maintenance
Correctness
Comfort

Zone Temp 2 RMI204
Temp Floor 1 Area1

SODA1R300__ART
SODA1R410B_ART

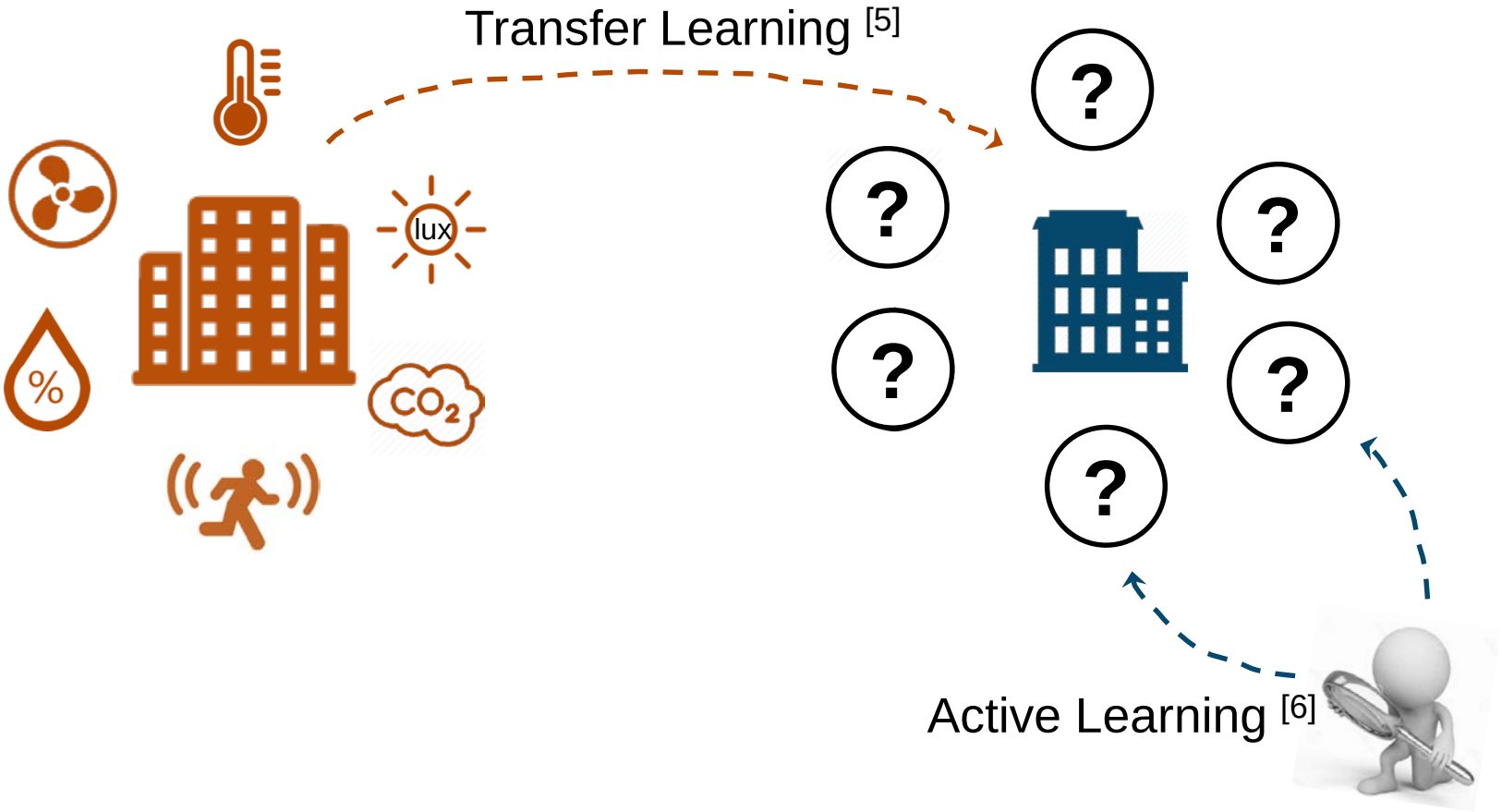
Goal

- Automatically infer sensor context using names and data so that analytics can be quickly applied to all buildings with minimal or none manual effort



Insights and Proposed Solutions

- Developing statistical models that exploit structure and redundancy in sensor point names and time series readings



Approach I

- **Transferring metadata from mapped buildings to new buildings** [7]
  - Patterns in sensor reading streams are more transferrable

Approach I

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  - Improve confidence via transferring from multiple buildings

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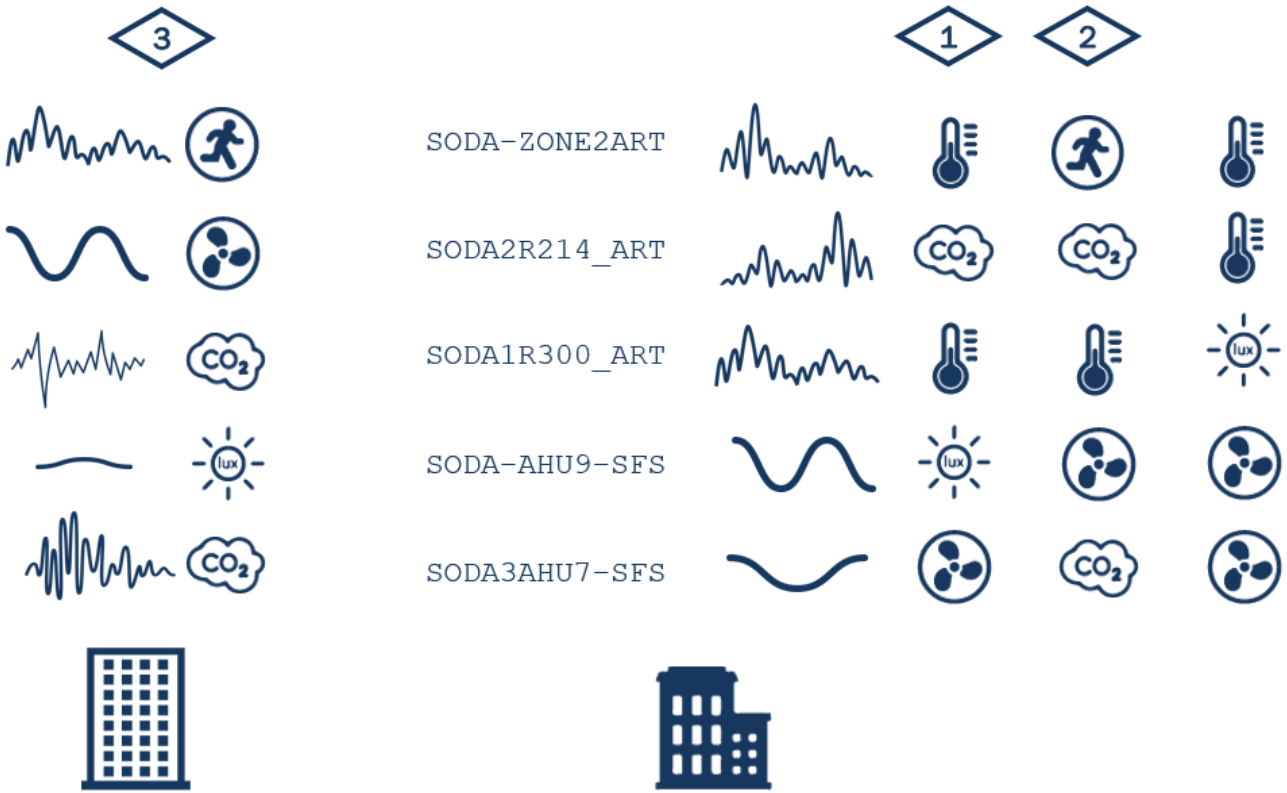
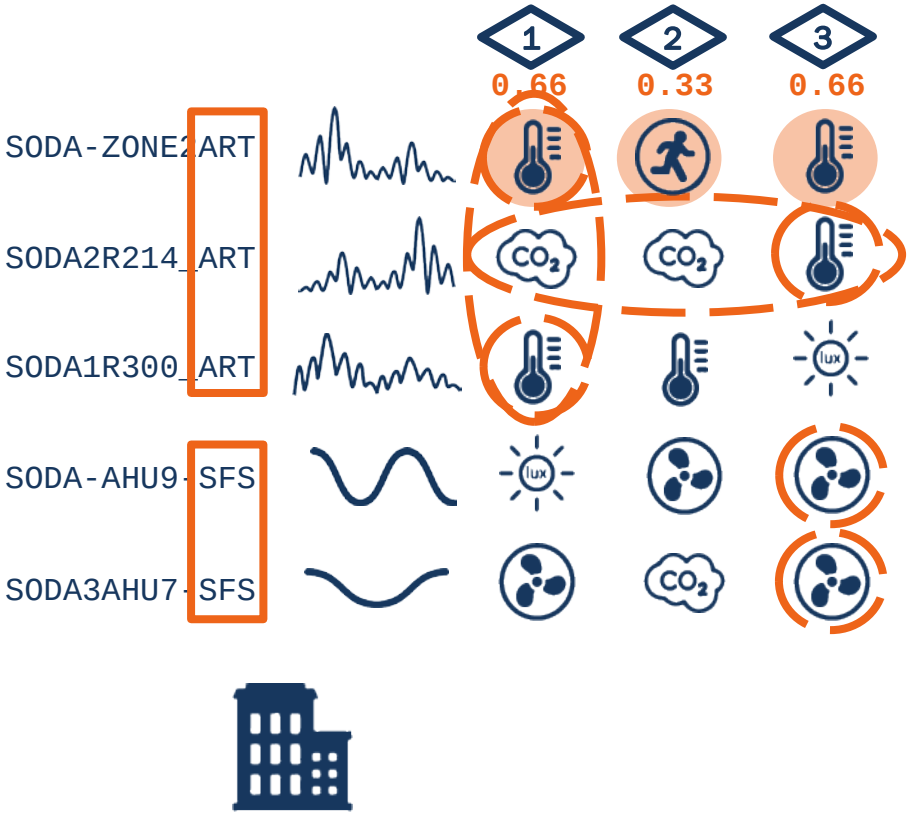


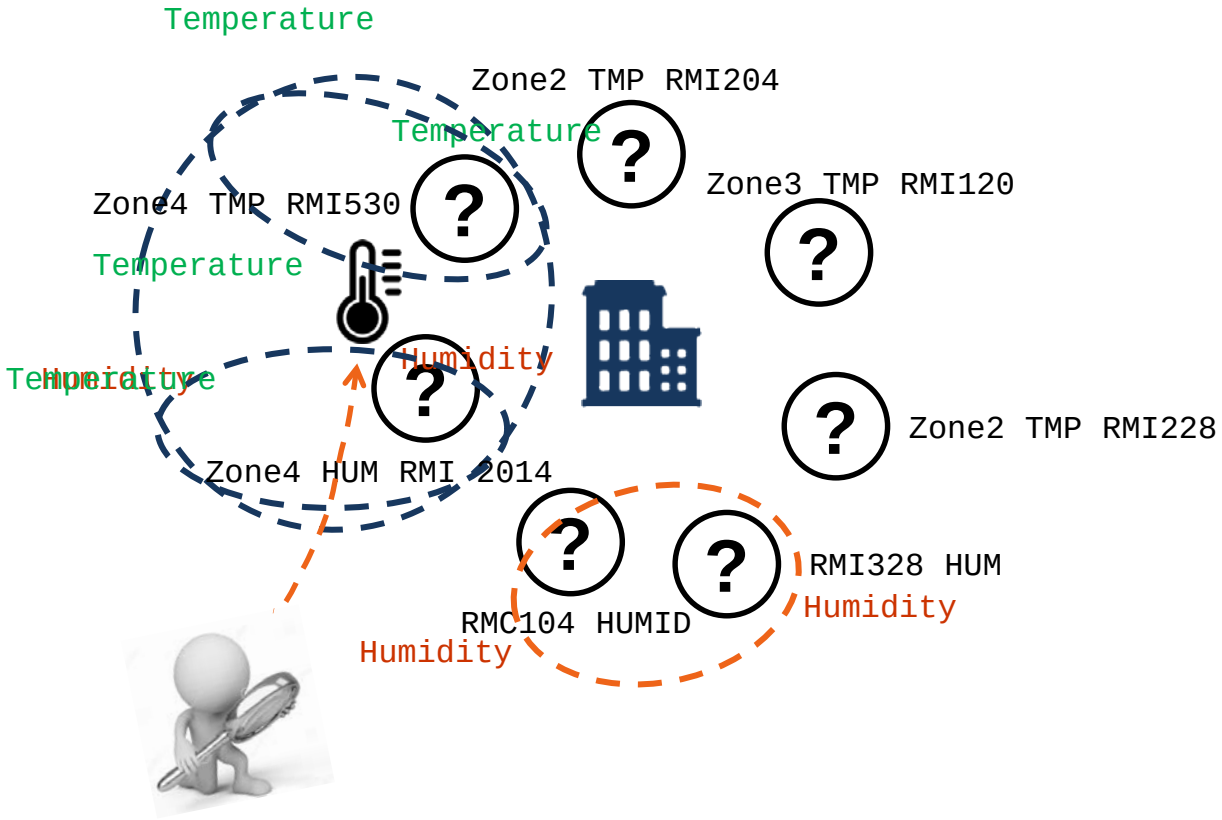
Approach I

- **Transferring metadata from mapped buildings to new buildings** [7]
  - Exploiting naming structure within target building



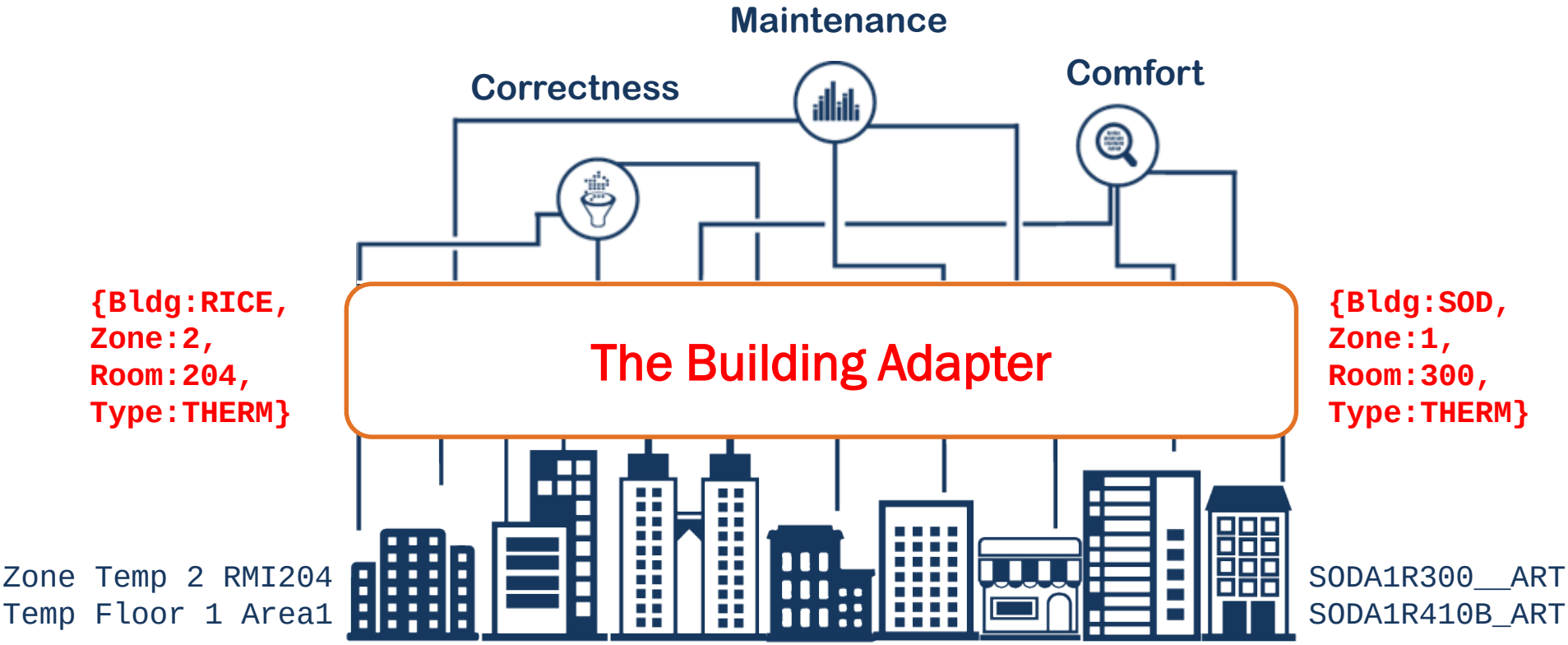
Approach II

- **Actively querying the most informative point names for manual inspection [8]**
  - Exploiting redundancy in naming structure



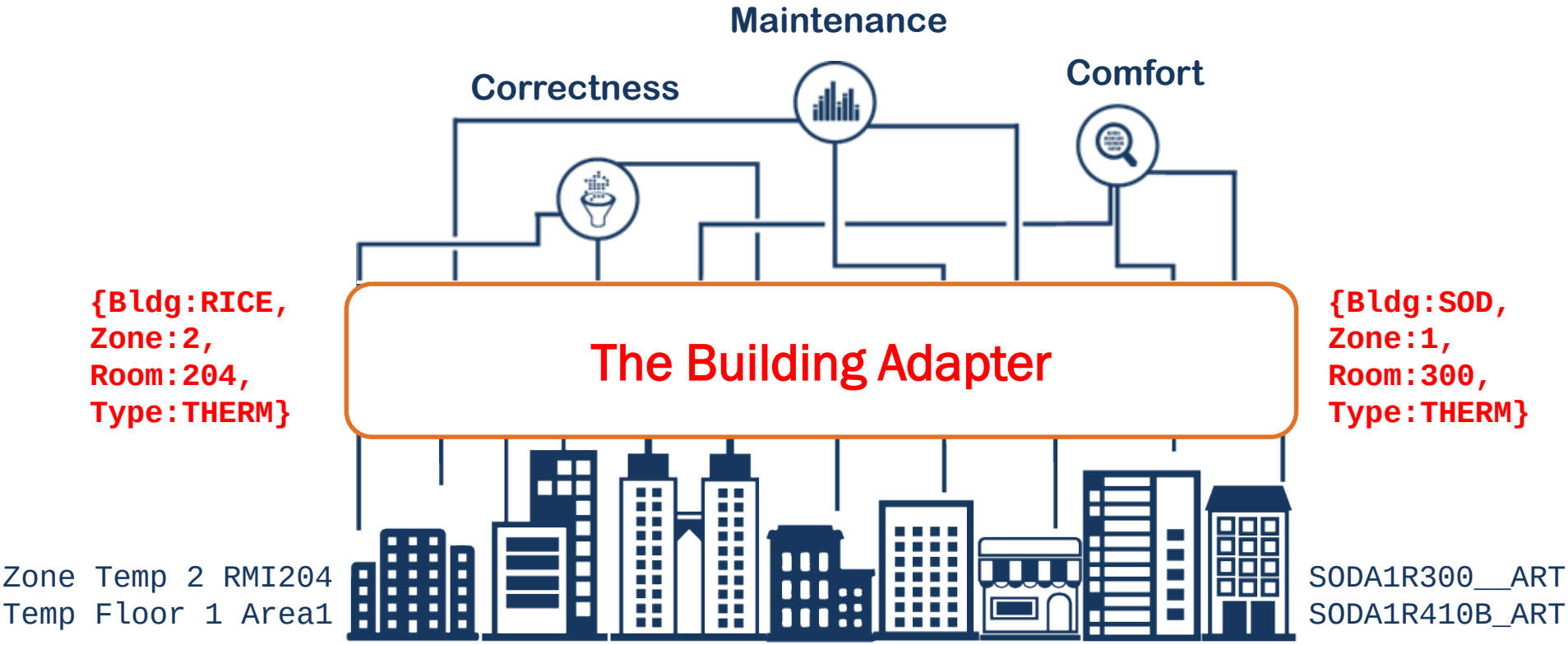
Impact

- Building analytics can reduce energy consumption by 8% or more, for a 2030 primary energy savings technical potential of 0.464 Quads [9]



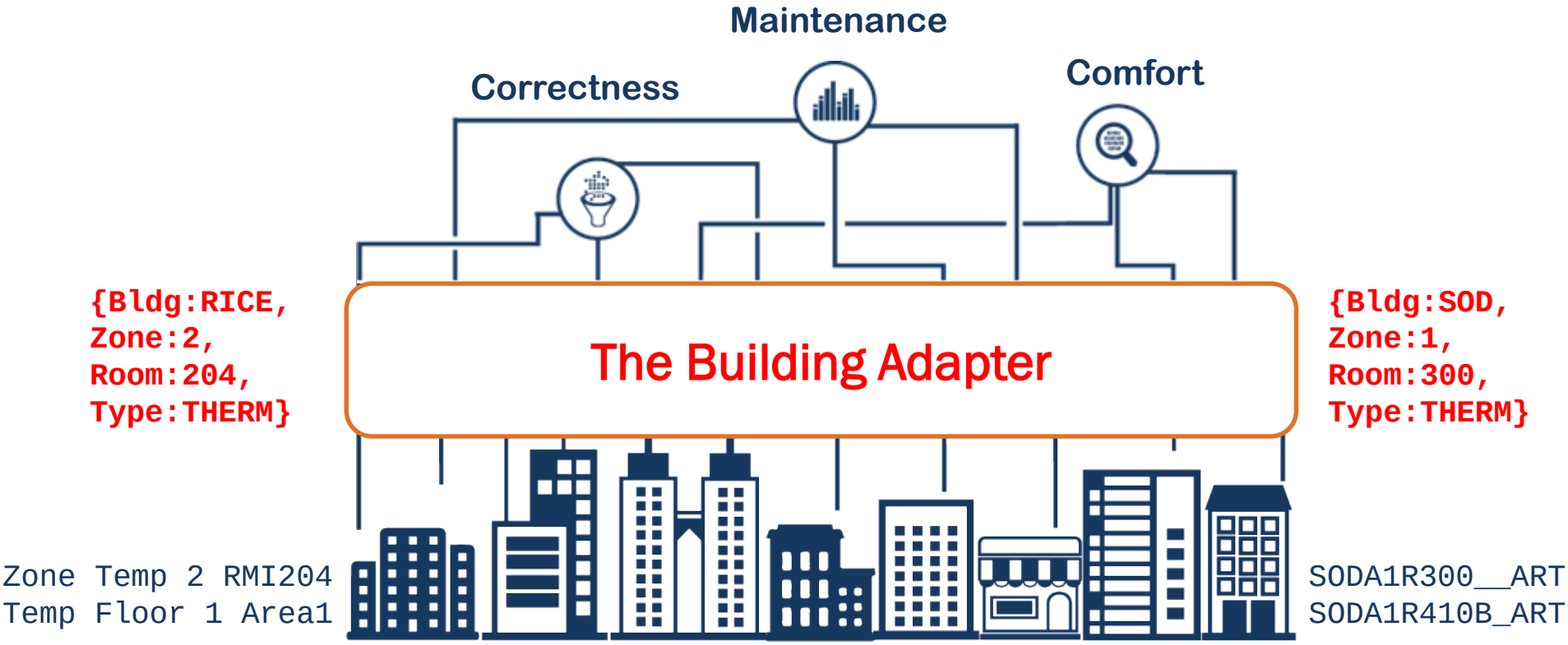
Impact

- Our technique will enable a vendor to apply building analytics to 90% of buildings with no manual mapping, and to 10% of buildings with a 90% reduction in manual mapping



Impact

- Create a wireframe framework for open evaluation in both academia and industry to spur additional innovation

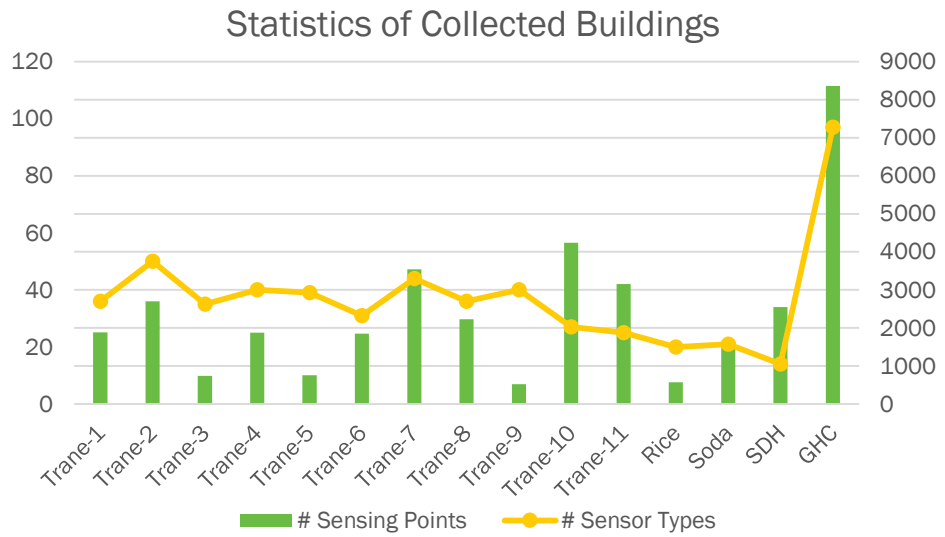


Progress

- **Still at its early stage of this project**
  - Current focuses
    - Develop a Technical Advisory Panel to receive feedback on our research progress, disseminate research achievements, and acquire and create new benchmark data sets
    - Dataset aggregation: a minimum total of about 20 fully mapped buildings, including at least 4 different types of buildings
    - Wireframe evaluation framework
    - Data-driven type and relationship inference

Progress

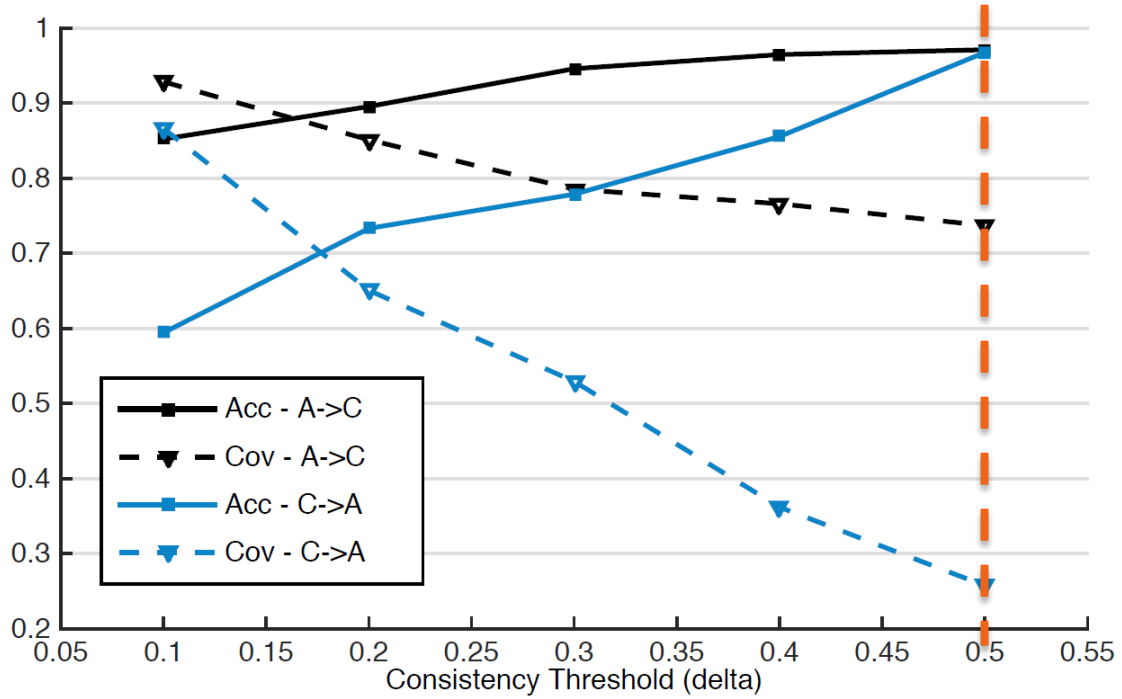
- **A collection of manually mapped buildings as our evaluation framework**
  - # buildings: 15
  - Duration of sensor stream readings: 12-52 weeks






Progress

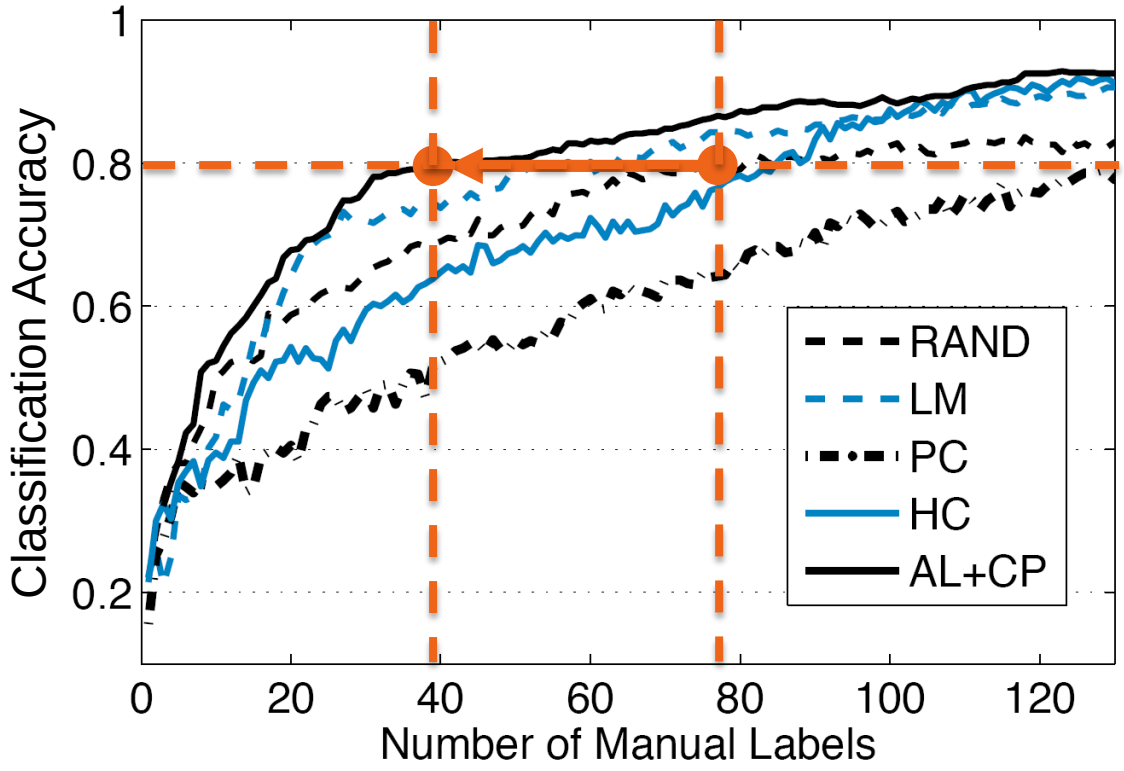
- Transfer learning enables more than 75% accurate labeling and 60% coverage without any manual labeling effort [7]



Cov: % labeled
Acc: accuracy of labels

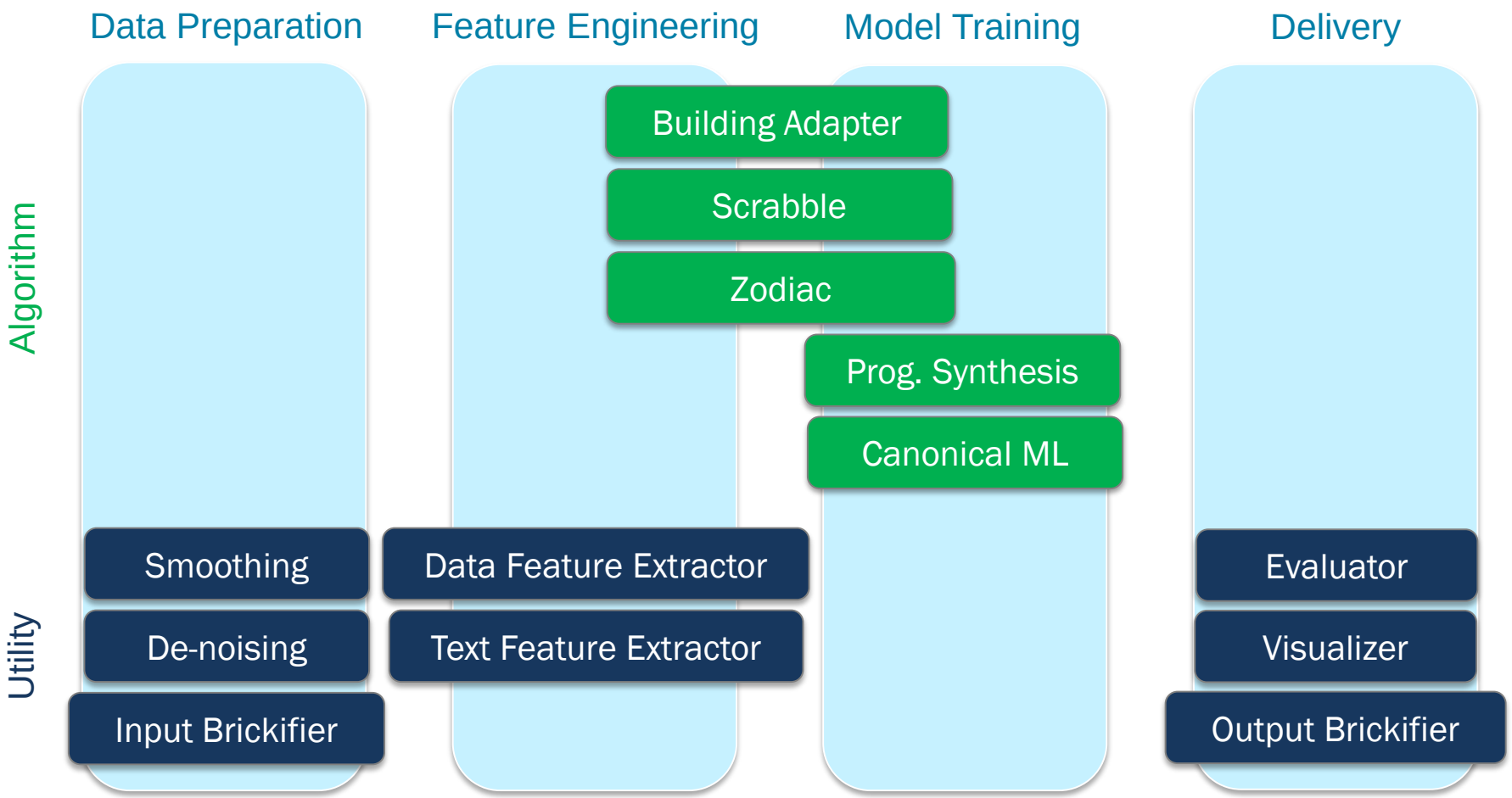
Progress

- Active learning enables 50% reduction of manual labeling effort [8]



Progress

- A wireframe evaluation framework

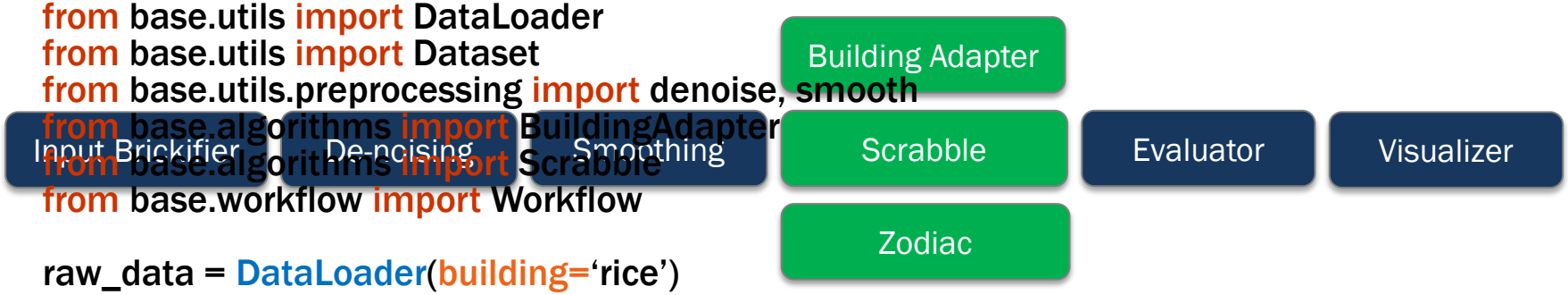


Progress

- A wireframe evaluation framework
  - Use case


```
from base.utils import DataLoader
from base.utils import Dataset
from base.utils.preprocessing import denoise, smooth
from base.algorithms import BuildingAdapter
from base.algorithms import Scrabble
from base.workflow import Workflow

raw_data = DataLoader(building='rice')
dataset = Dataset(raw_data, type='time_series', preprocessing=[denoise,smooth])
model1 = BuildingAdapter(batch_size=1, threshold=0.6, ...)
model2 = Scrabble(batch_size=10, ...)
eval_f1 = F1(average='macro')
workflow = Workflow(dataset=dataset, model=[model1,model2], eval=eval_f1, out_format='brick')
```



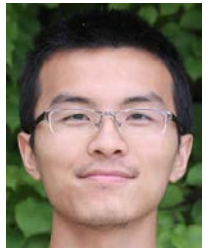
Stakeholder Engagement

- **Technical Advisory Panel**
  - Receive periodic updates about the research progress
  - Provide feedback to the team from across the vendor community,
  - Help identify or create additional datasets for analysis

PIs:

T1: Development of Technical Advisory Panel

GRAs:



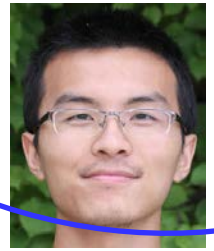
Stakeholder Engagement

- **Dataset aggregation**
  - Different types of manually mapped buildings from a variety of geographic locations and vendors
  - With explicit/implicit evaluation metric

PIs:

T2: Data set collection and annotation

GRAs:



Stakeholder Engagement

- **A wireframe framework**
  - Best-of-breed baseline algorithms for benchmarking
  - Common evaluation metrics for quantitative comparison

PIs:



T3: Development of wireframe evaluation framework

GRAs:


Stakeholder Engagement

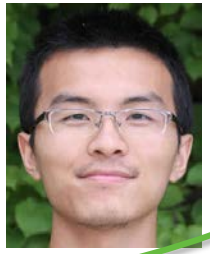
- **Sensor type and relationship inference**
  - Data-driven feature engineering
  - Statistical learning based inference algorithms

PIs:



T4: Development of learning-based metadata mapping algorithms

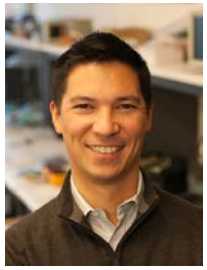
GRAs:

Stakeholder Engagement

- **Connecting buildings with analytics engines**
  - In field assessment of the Building Adapter

PIs:


T5: Integration with building analytics engines

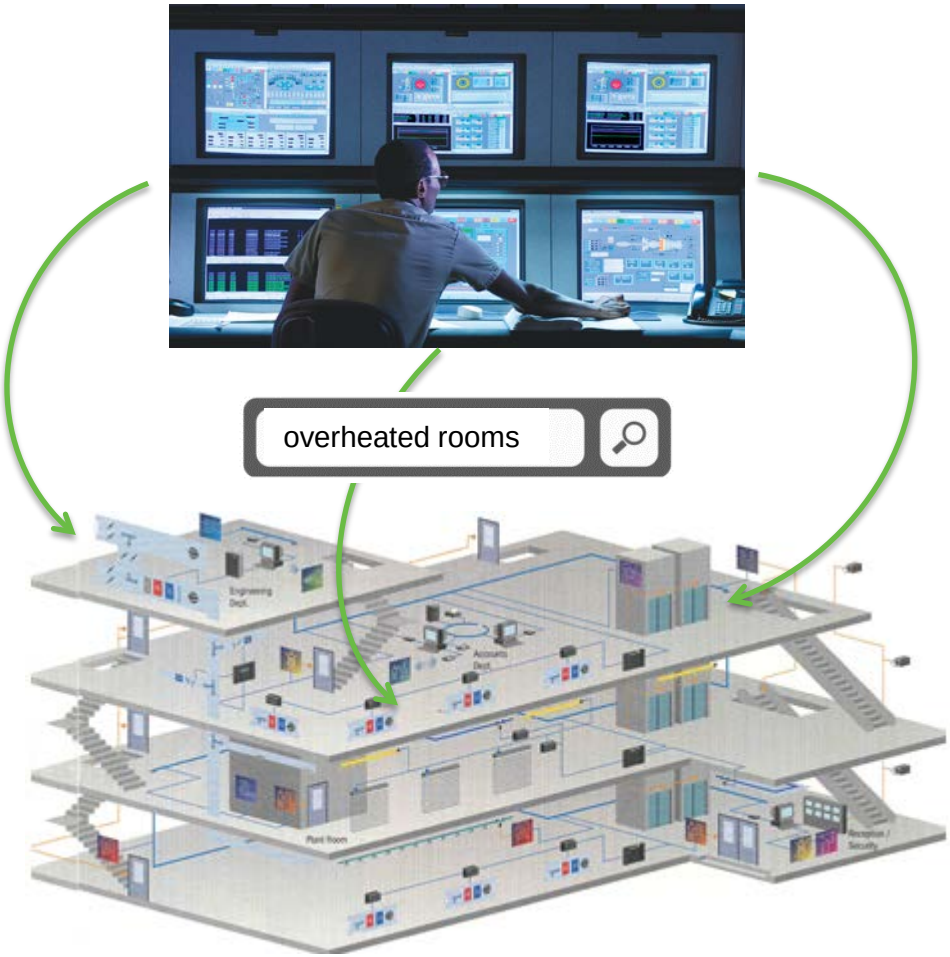
GRAs:


Remaining Project Work

- **We have built a solid foundation to achieve the project goal**
  - At least 40 commercial building datasets with manual mapping data identified
  - Release our basic evaluation framework to industry partners and research collaborators
  - Name and relation inference errors >60% reduced in comparison to baseline techniques
  - Overall reduction in buildings that need manual mapping by 60% over baseline techniques

Expected Outcomes

- In a not far future, the success of this project will enable



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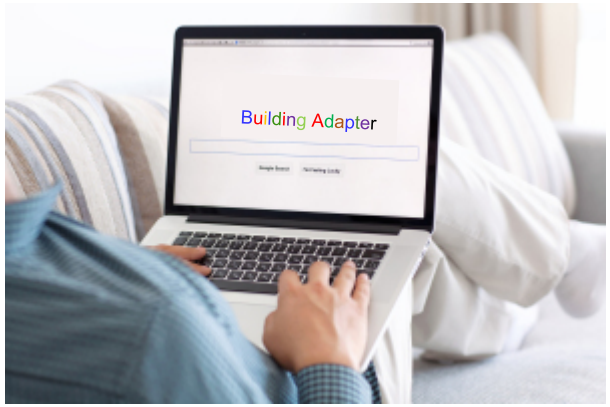

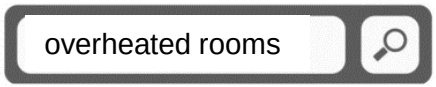

Thank You

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References

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2. B Richter, D Goldston, G Crabtree, L Glicksman, D Goldstein, D Greene, D Kammen, M Levine, M Lubell, and M Savitz. Energy future: Think efficiency. American Physical Society, College Park, MD, 2008.
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5. Pan, Sinno Jialin, and Qiang Yang. "A survey on transfer learning." IEEE Transactions on knowledge and data engineering 22.10 (2010): 1345-1359.
6. Settles, Burr. "Active learning." Synthesis Lectures on Artificial Intelligence and Machine Learning 6.1 (2012): 1-114.
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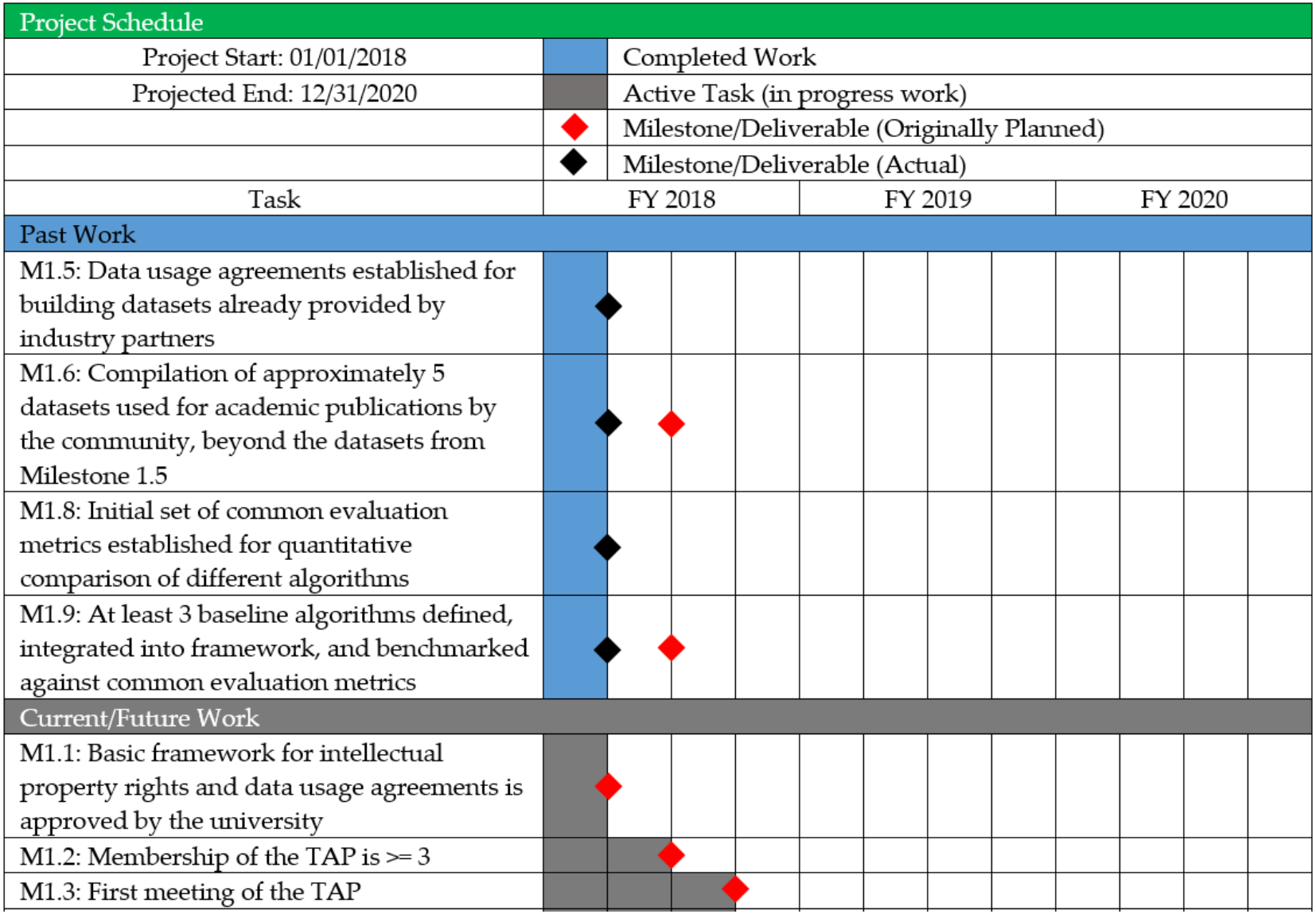
8. Hong, Dezhi, Hongning Wang, and Kamin Whitehouse. "Clustering-based active learning on sensor type classification in buildings." Proceedings of the 24th ACM International on Conference on Information and Knowledge Management. ACM, 2015.
9. DOE, US. "Quadrennial Technology Review: An Assessment of Energy Technologies and Research Opportunities." *no. September* (2015): 1-505.

Project Budget

- **Project Budget**
  - DOE's commitment: $499,994
  - Cost sharing: $55,858
- **Variances**: N/A
- **Cost to Date**: $0
- **Additional Funding: N/A**

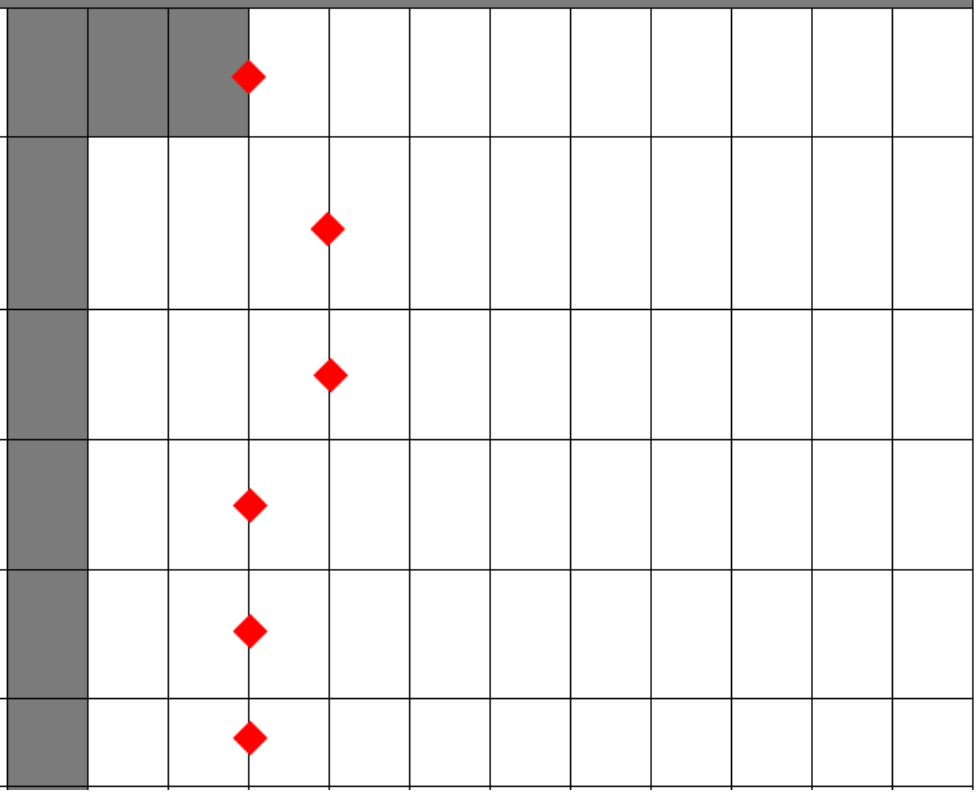
Budget History					
01/01/2018– FY 2017 (past)		FY 2018 (current)		FY 2019 – 12/31/2020 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$0	$0	$163,204	$18,134	$336,790	$37,724

Project Plan and Schedule



Project Plan and Schedule

Project Schedule		
Project Start: 01/01/2018		Completed Work
Projected End: 12/31/2020		Active Task (in progress work)
	◆	Milestone/Deliverable (Originally Planned)
	◆	Milestone/Deliverable (Actual)



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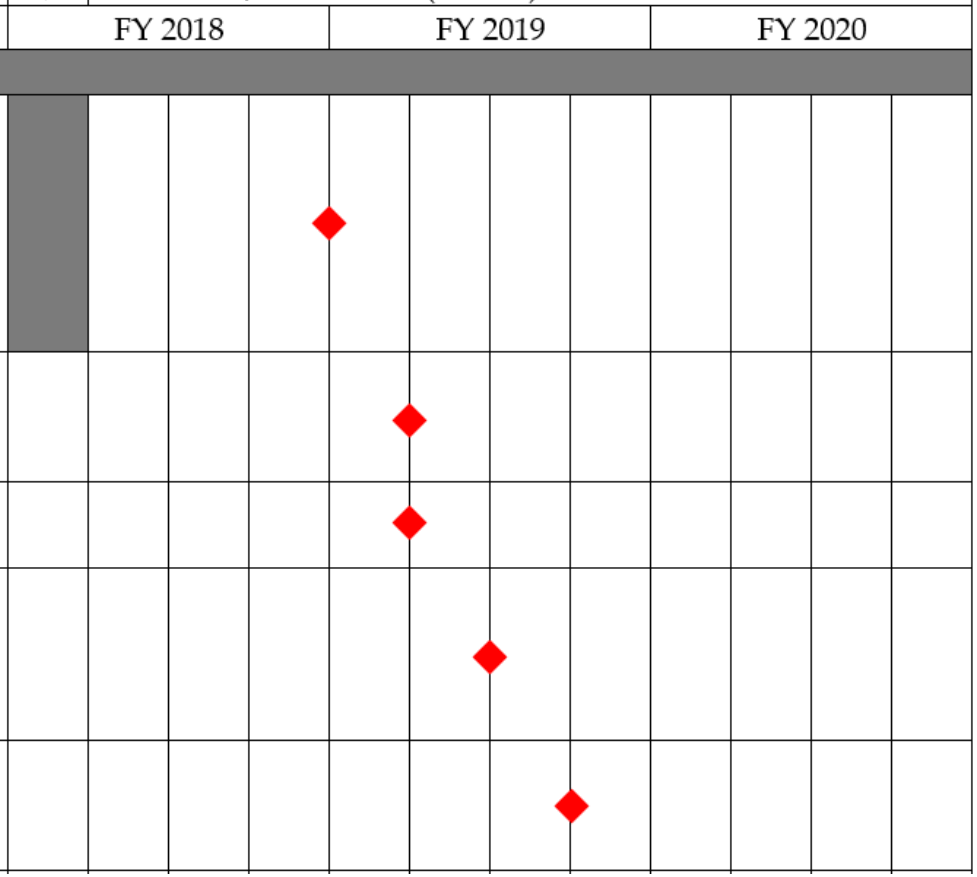

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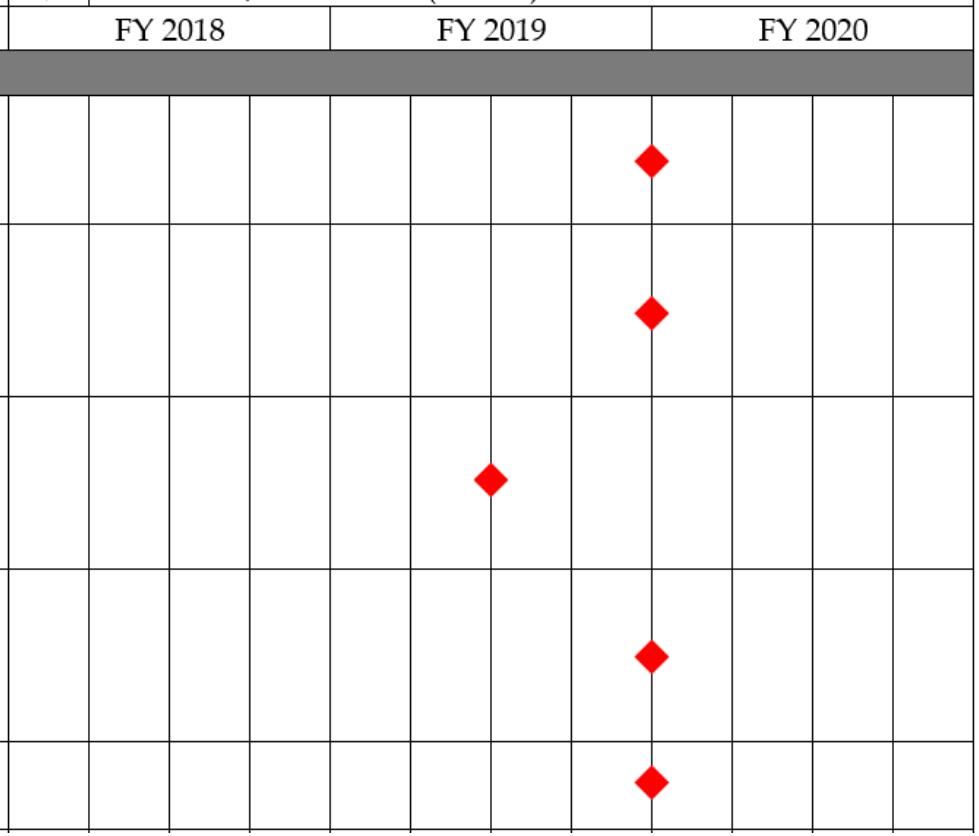

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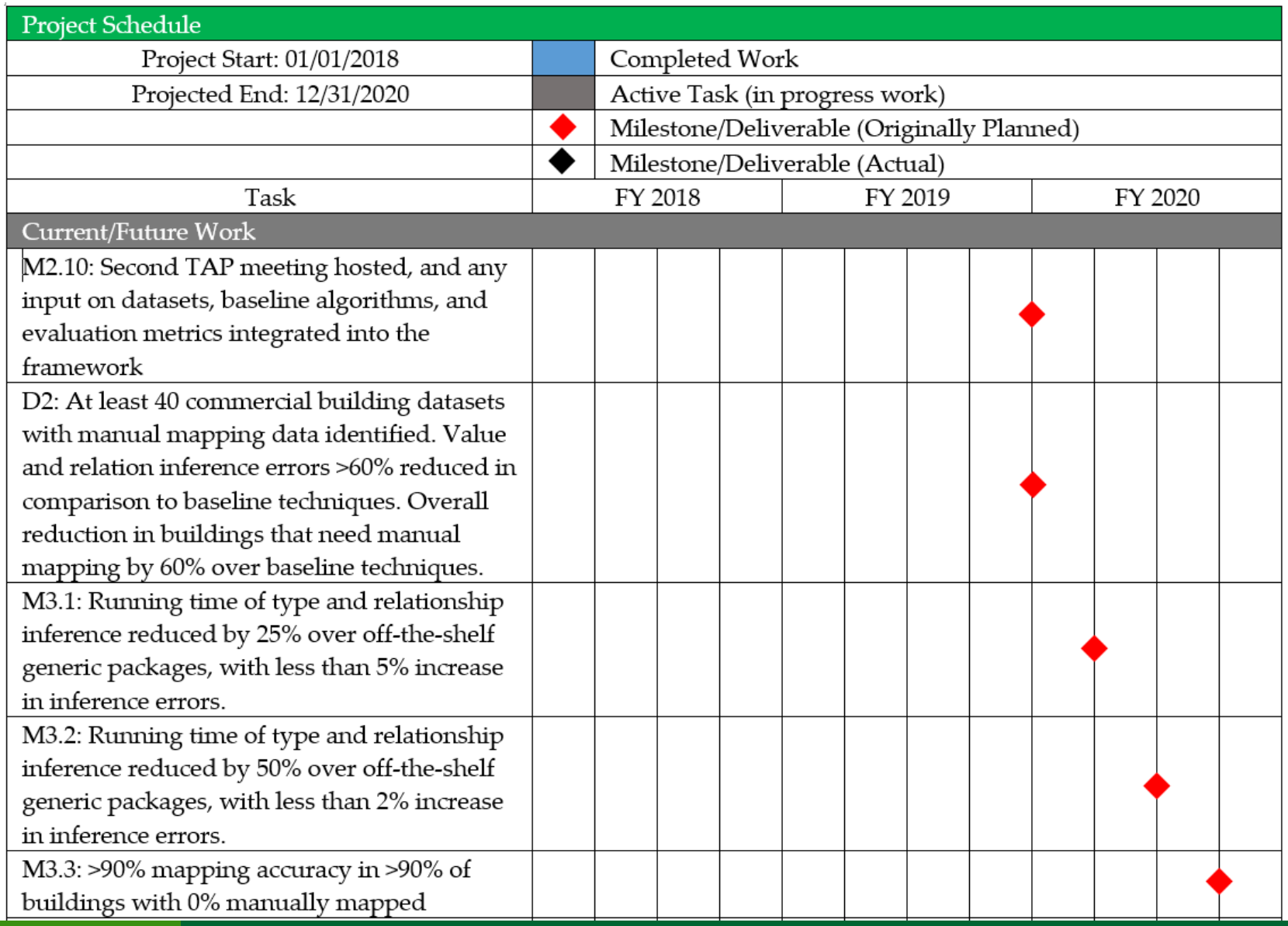

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Projected End: 12/31/2020	Active Task (in progress work)											
	Milestone/Deliverable (Originally Planned)											
	Milestone/Deliverable (Actual)											
Task	FY 2018				FY 2019				FY 2020			
Current/Future Work												
M3.4: >90% mapping accuracy in <10% of buildings with <10% of the points manually mapped											◆	
M3.5: New approaches and data sets integrated into the extensible software framework												◆
D3: The Building Adapter will be a solution to the manual mapping problem that can automatically map industry data sets with no manual mapping for 90% of buildings, and a 90% reduction in manual mapping for 10% of buildings.												◆