Non-Intrusive Techniques for Establishing Occupancy-Related Energy Savings in Commercial Buildings

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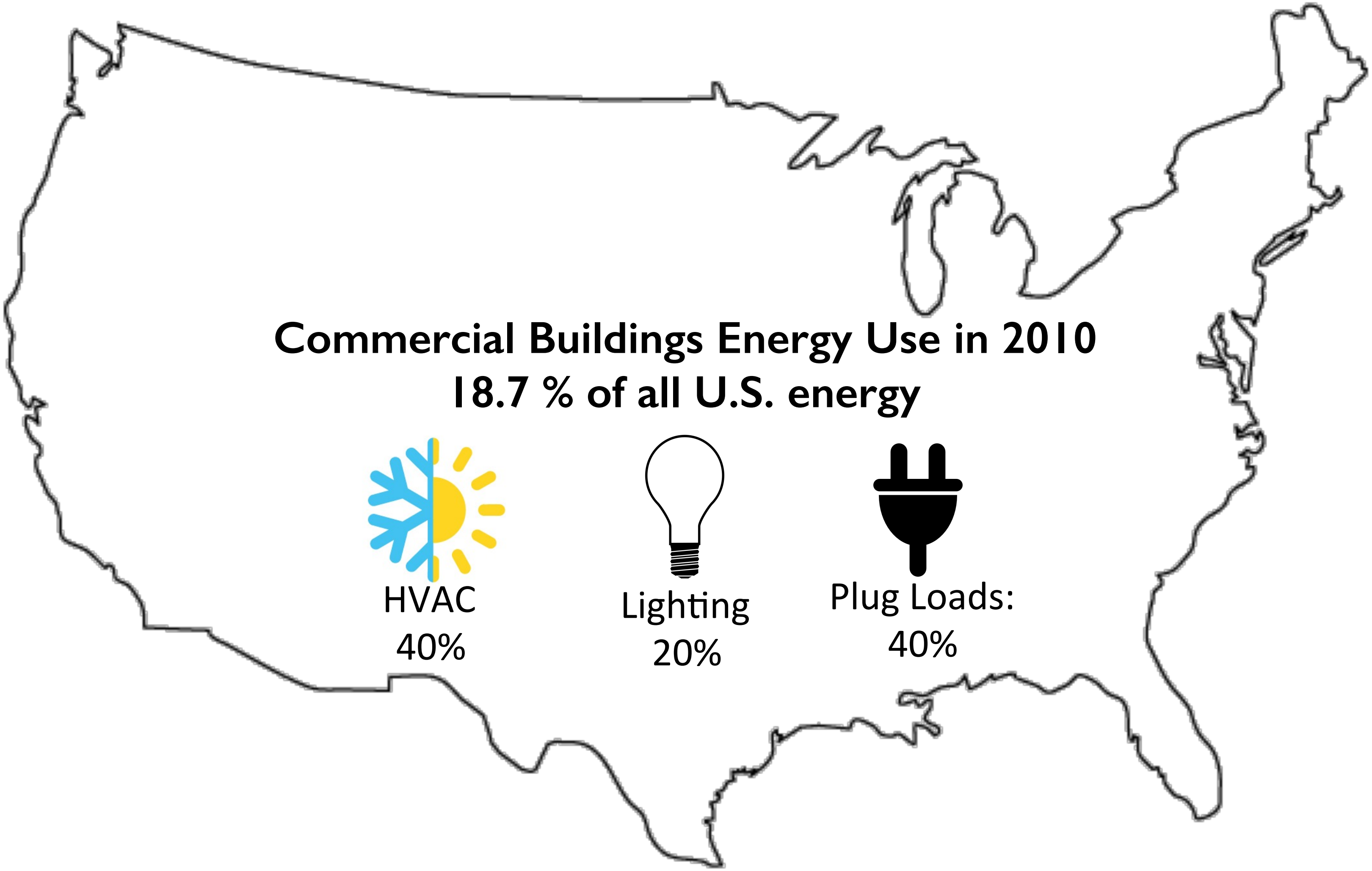
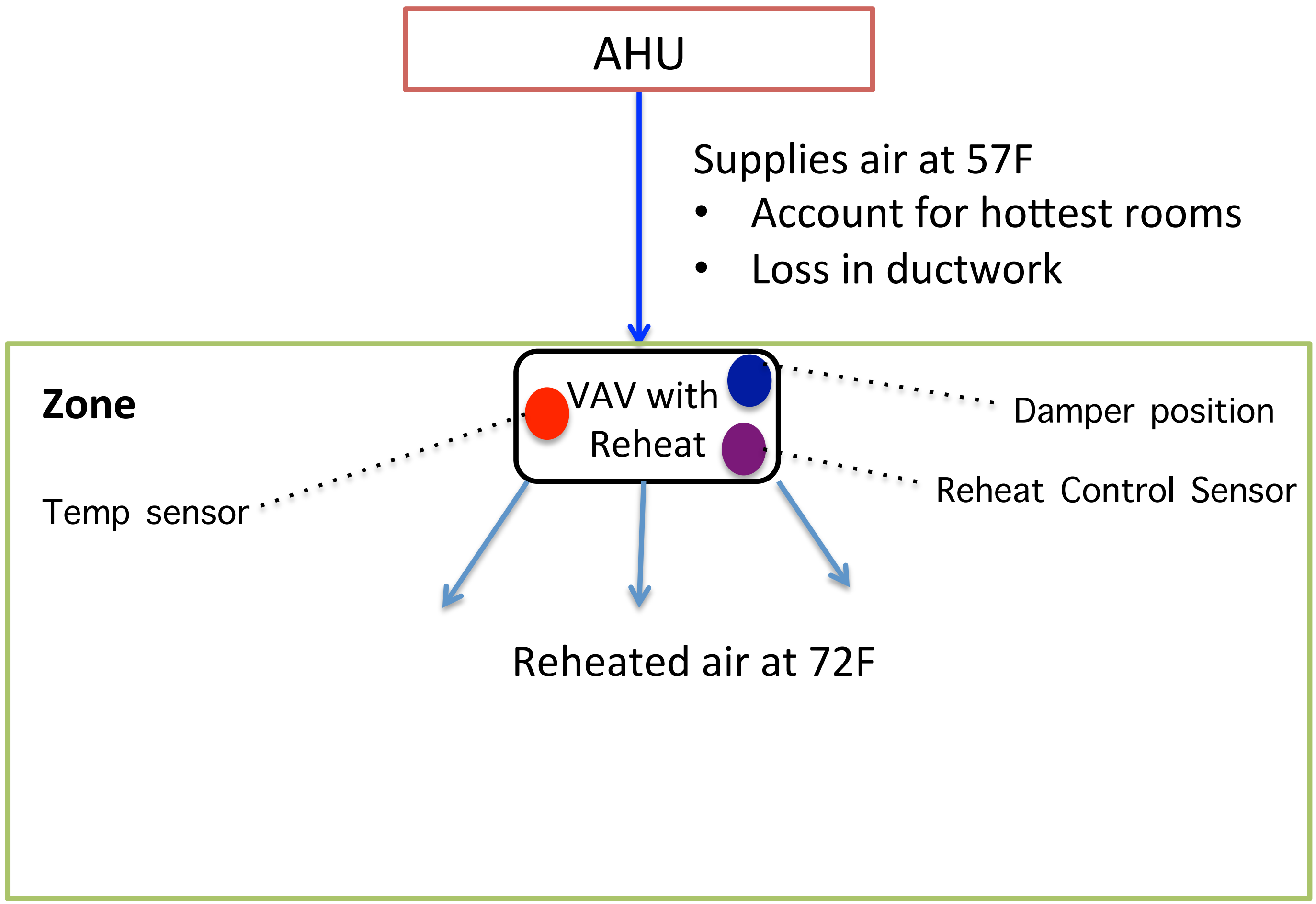
BuildSys'16



10% Saving in HVAC Energy Consumption ≈ $14.4 Billion per year

Source: Buildings Energy Data Book (2011), Table 3.1.1

HVAC Systems in Moderate Climates



Reheating Cold Air Considered Not Good

- HVAC system first over-cools and then reheats the air
  - Inefficient

- State of the art: HVAC systems run on a static schedule, or simple schedule based on building manager's intuition.
  - Does not take occupancy into account
  - Wastes reheat energy in conditioning empty or partially-occupied spaces

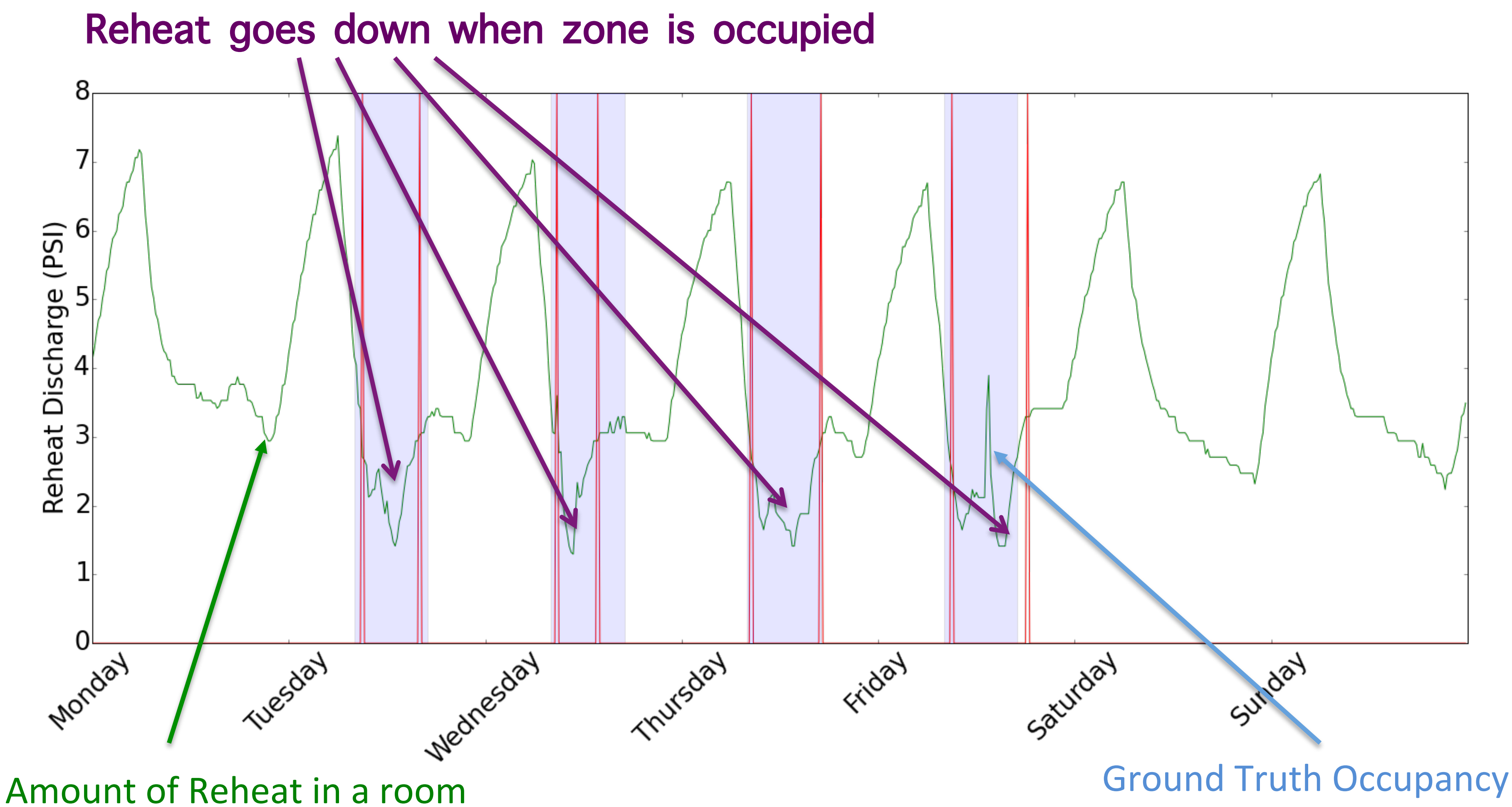
Solution: Conditioning zones only when occupied.

Install occupancy sensors !!

Problem with Occupancy Sensors

- Not available in all commercial buildings
  - 5 million commercial buildings in the US
- Retrofitting is costly and intrusive
- High accuracy is not guaranteed
  - This is an active area of research!

Can we exploit existing HVAC zone sensors?



Our claim

If occupants inject enough heat into a room so that the HVAC system responds, we should be able to detect the response and use it to estimate occupancy.

There is at least one zone sensor (*occupancy indicative sensor*) which picks up this response.

- reheat sensor, damper position, temperature sensor, etc.

HVAC Sensor-based Occupancy Detection: Advantages

- Widely applicable to commercial buildings with BMS systems.

- Does not require additional infrastructure

Summary of This Work

- We infer per-zone occupancy through techniques that are
  - *Non-Intrusive*
  - *Widely-Applicable*
- We use these occupancy estimates to reduce reheat energy consumption through smarter *adaptive* schedules.

Our results are promising enough to warrant larger scale investigation and validation against actual occupancy data

Rest of the Talk

- Overview of Technique
- Results
- Implications & Summary

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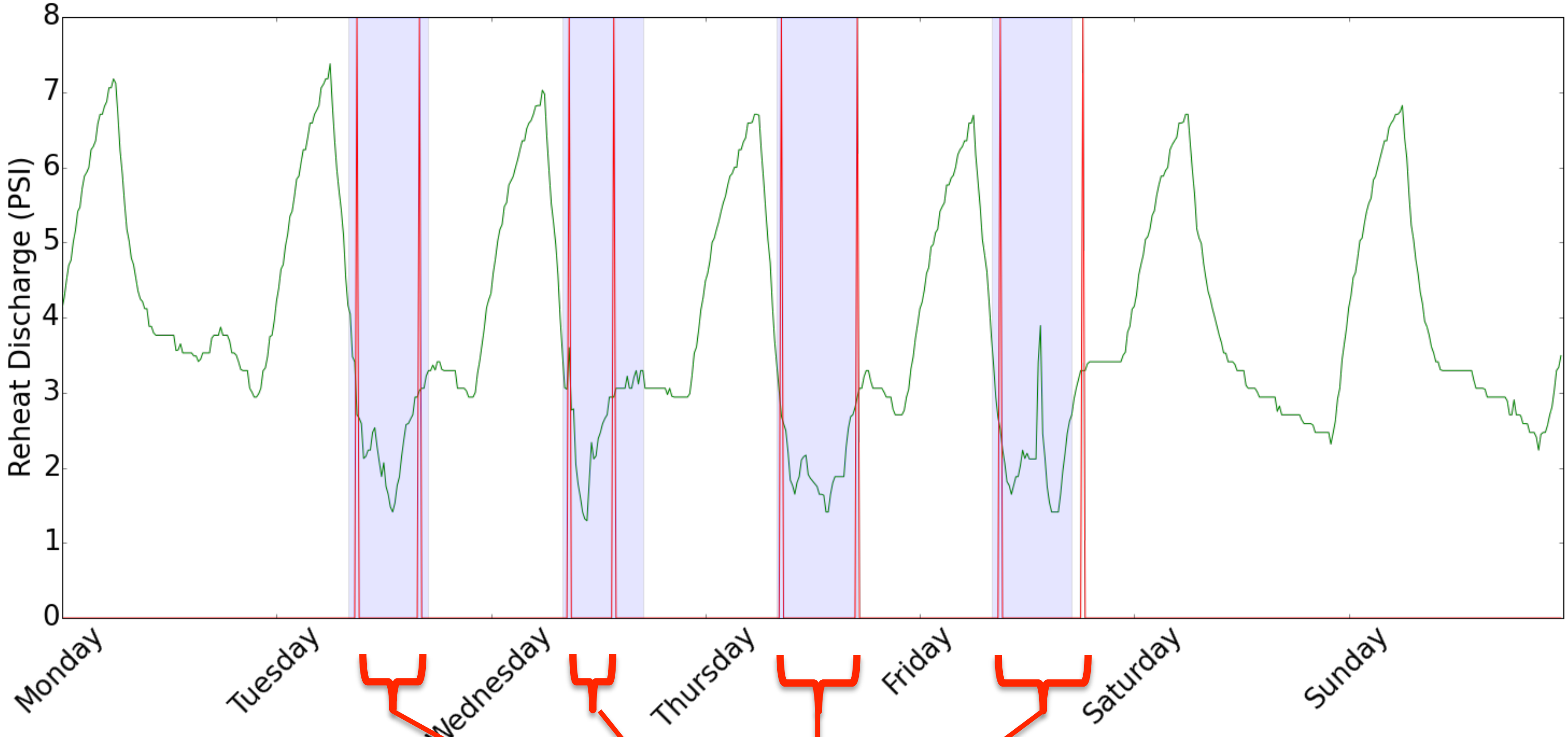
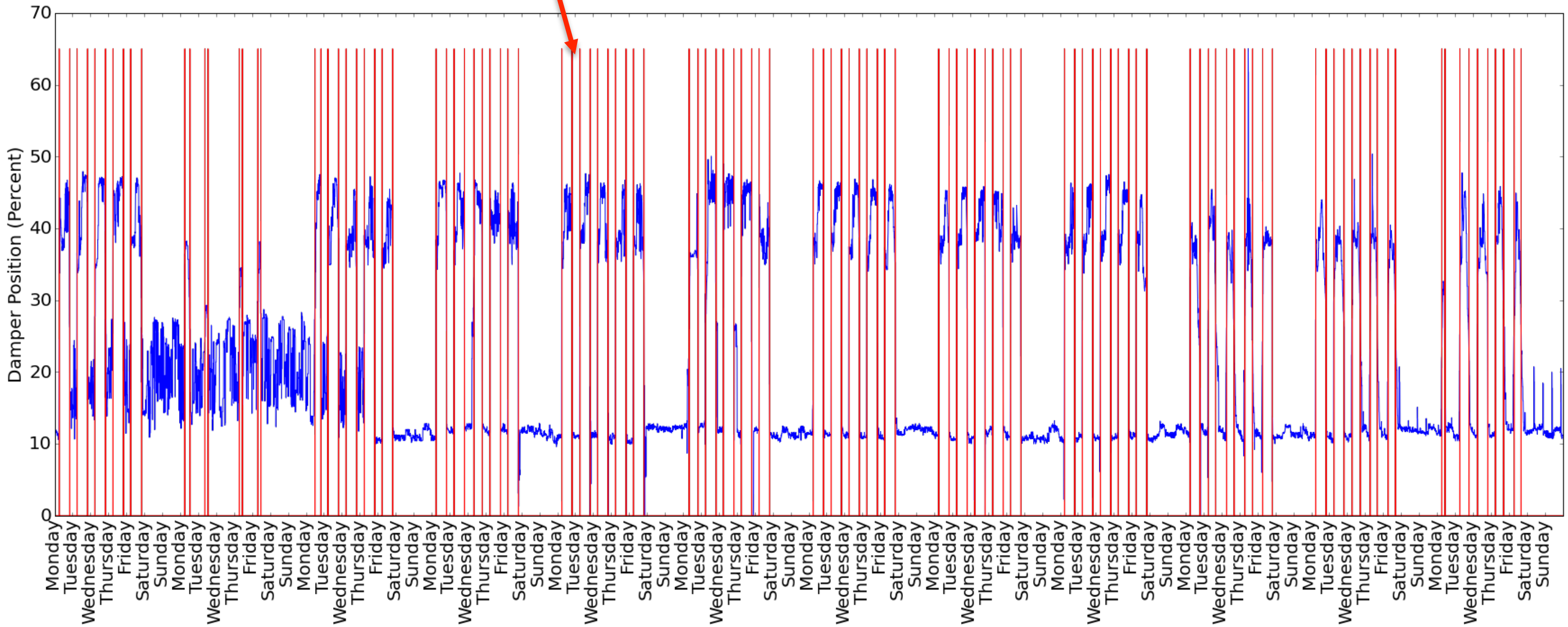
Detection of Occupancy Periods



Systematically determine edges in signal (Canny Edge Detector)

Edge Detection Over Extended Time Duration

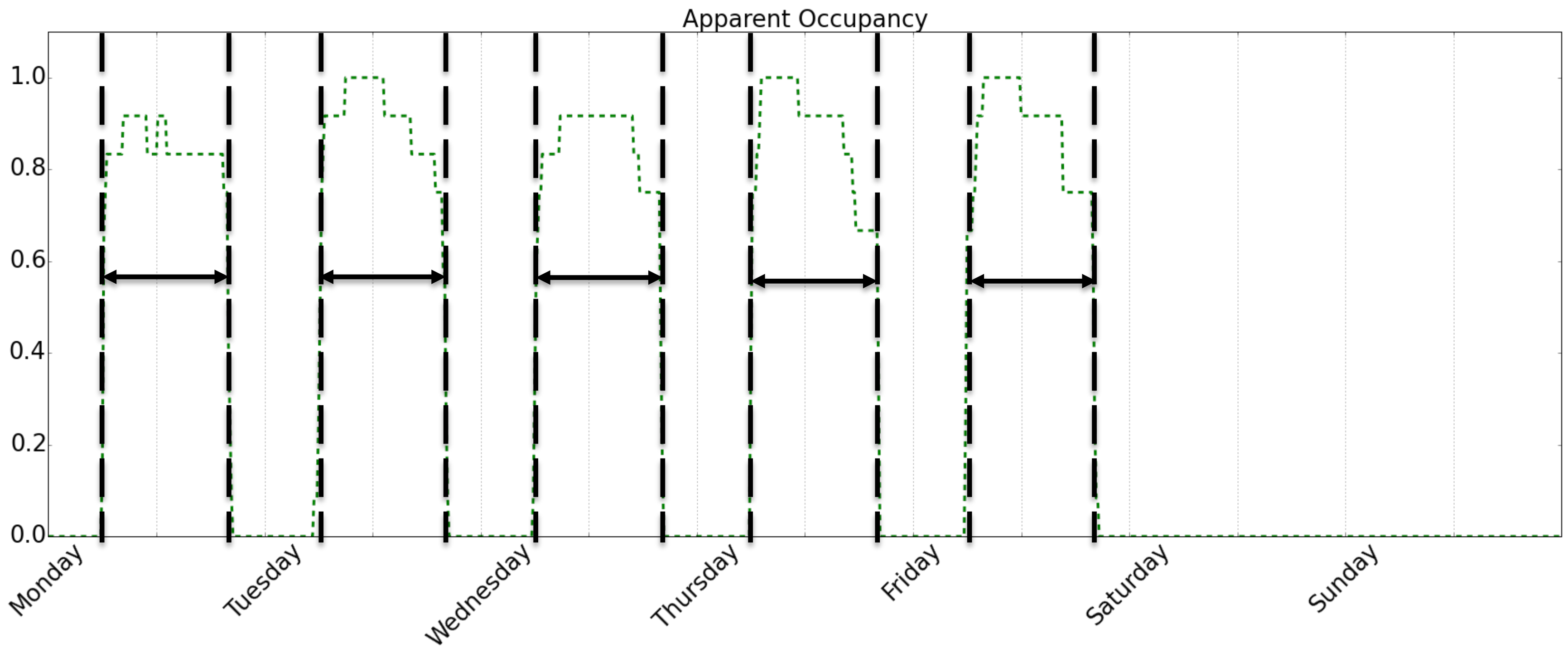
When our technique thinks there is occupancy



We are not interested in 100% accuracy.

Averaging over long periods of time mitigates inaccuracies in edge detection.

Determining Apparent Occupancy of a Zone



Compute occupancy probability vs time.

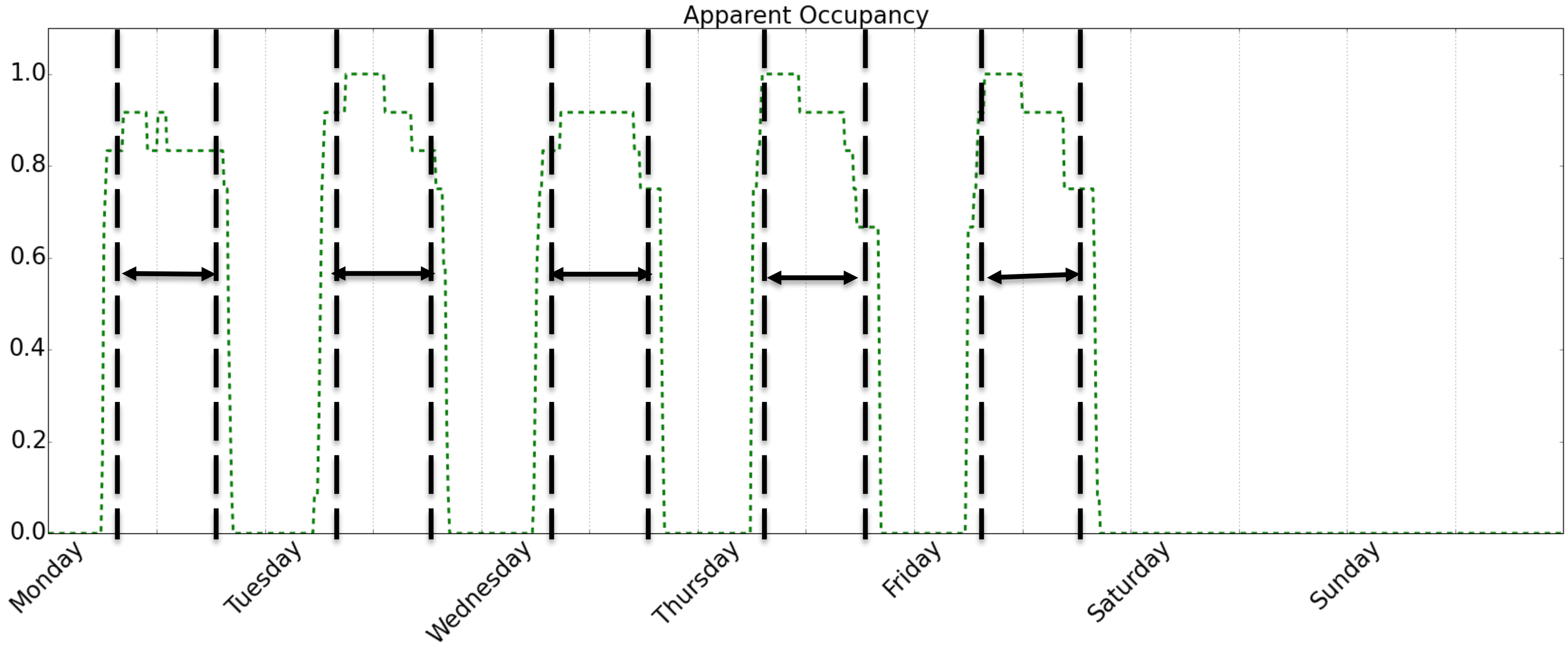
Determine schedule start and end-times to envelope occupancy.

Reheat only operating during scheduled hours.

More Aggressive Schedules

schedule start: *x*th percentile of the start times

schedule end: (100-*x*)th percentile of the end times

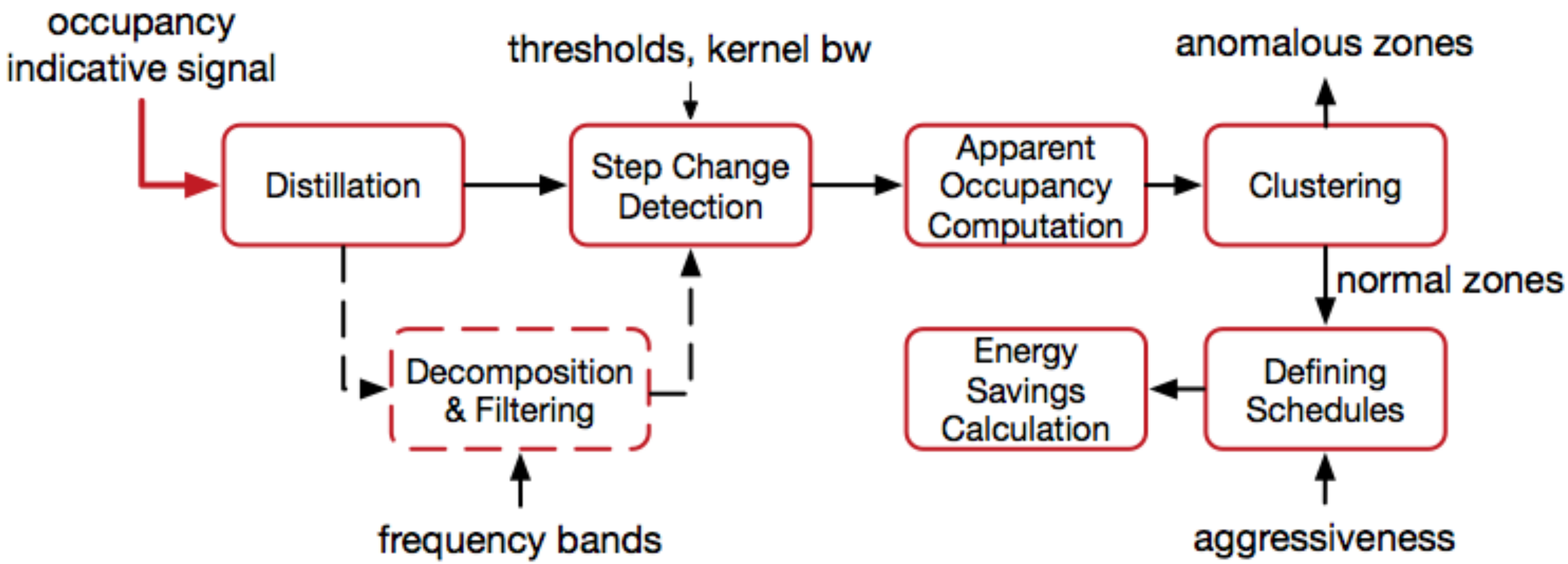


Tradeoff:

Less time the HVAC system is operating, hence more energy savings

However, there are times when an occupant comes in and finds their room unconditioned

Overall Analysis Pipeline



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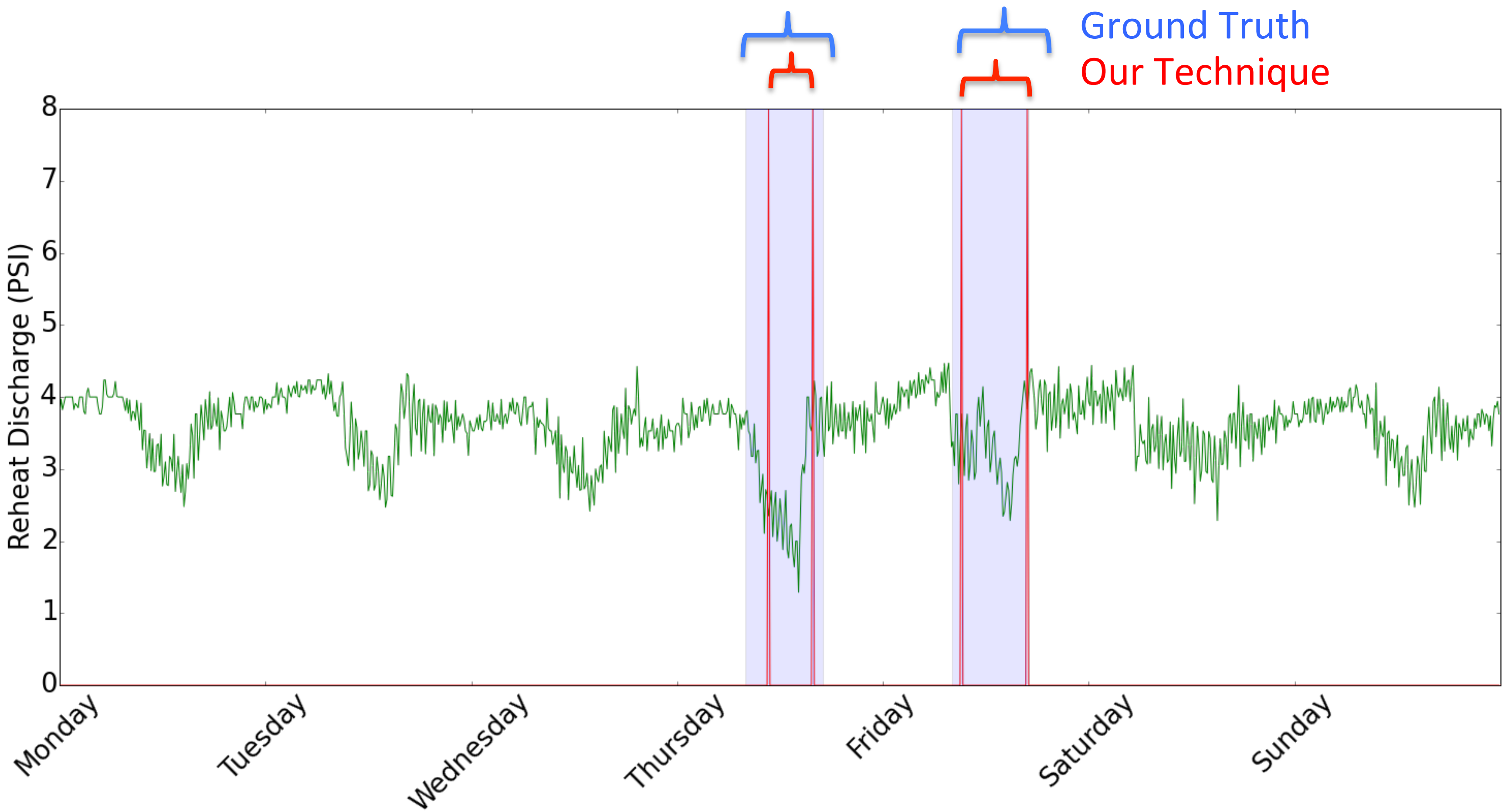
Testbed

- Three large UC Berkeley campus buildings
  - 117, 109 and 270 zones respectively
  - Each building had different BMS systems
  - Different HVAC zone sensors in each building
  - 3-6 months of data analyzed.

- The occupancy indicative sensors used for the three buildings are
  - the pneumatic control sensors in Building 1
  - the air flow sensors in Building 2
  - the reheat sensors in Building 3

Validation against Occupant-Responses

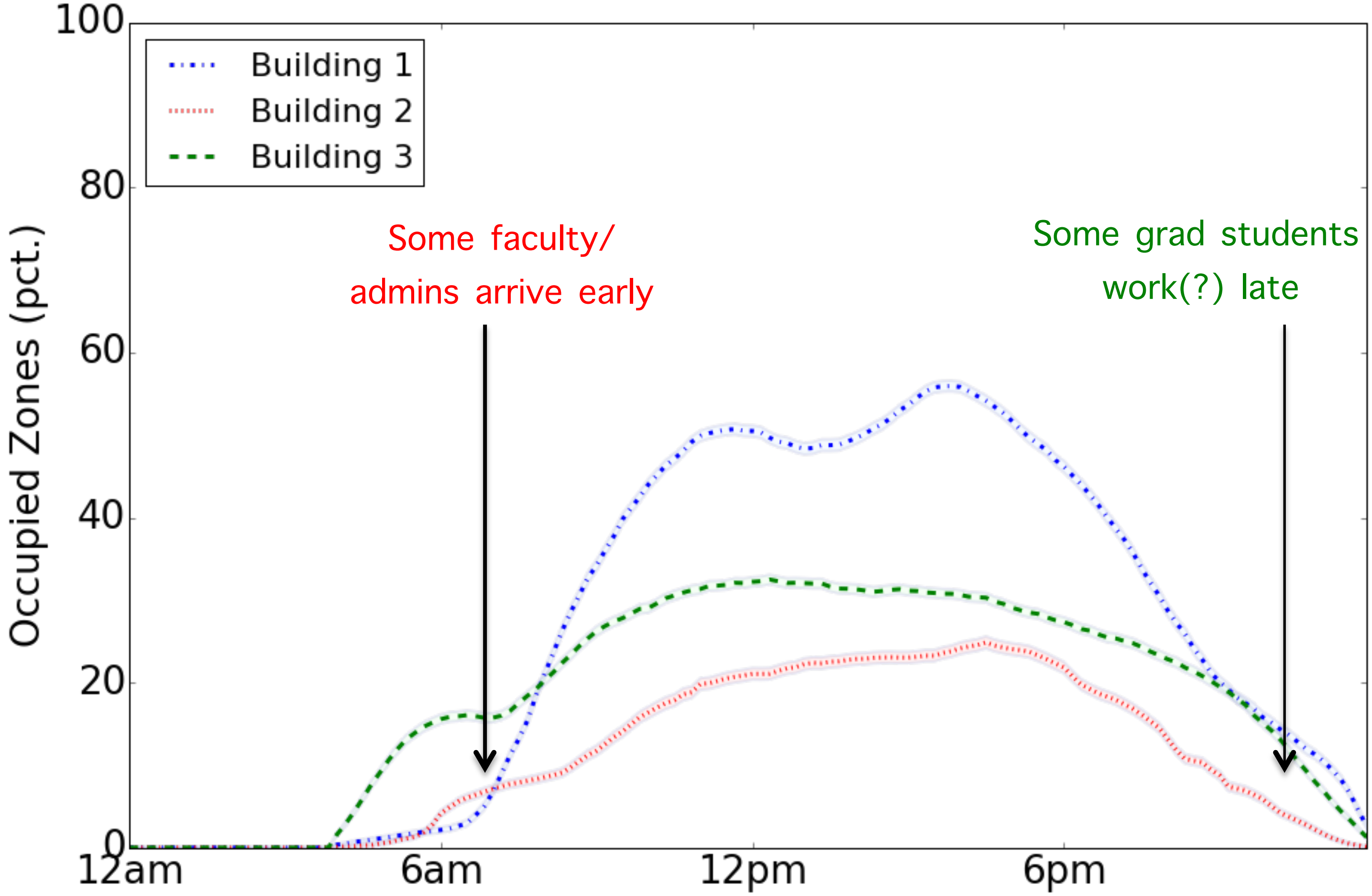


Limited ground truth data:

a) Manually logged occupancy hours of 7 shared and private offices in our testbed

b) Extracted occupancy hours from video recordings (a security camera installed in a lab)

Overall Building Occupancies (Weekdays)



What does each of the individual zones' occupancy look like?

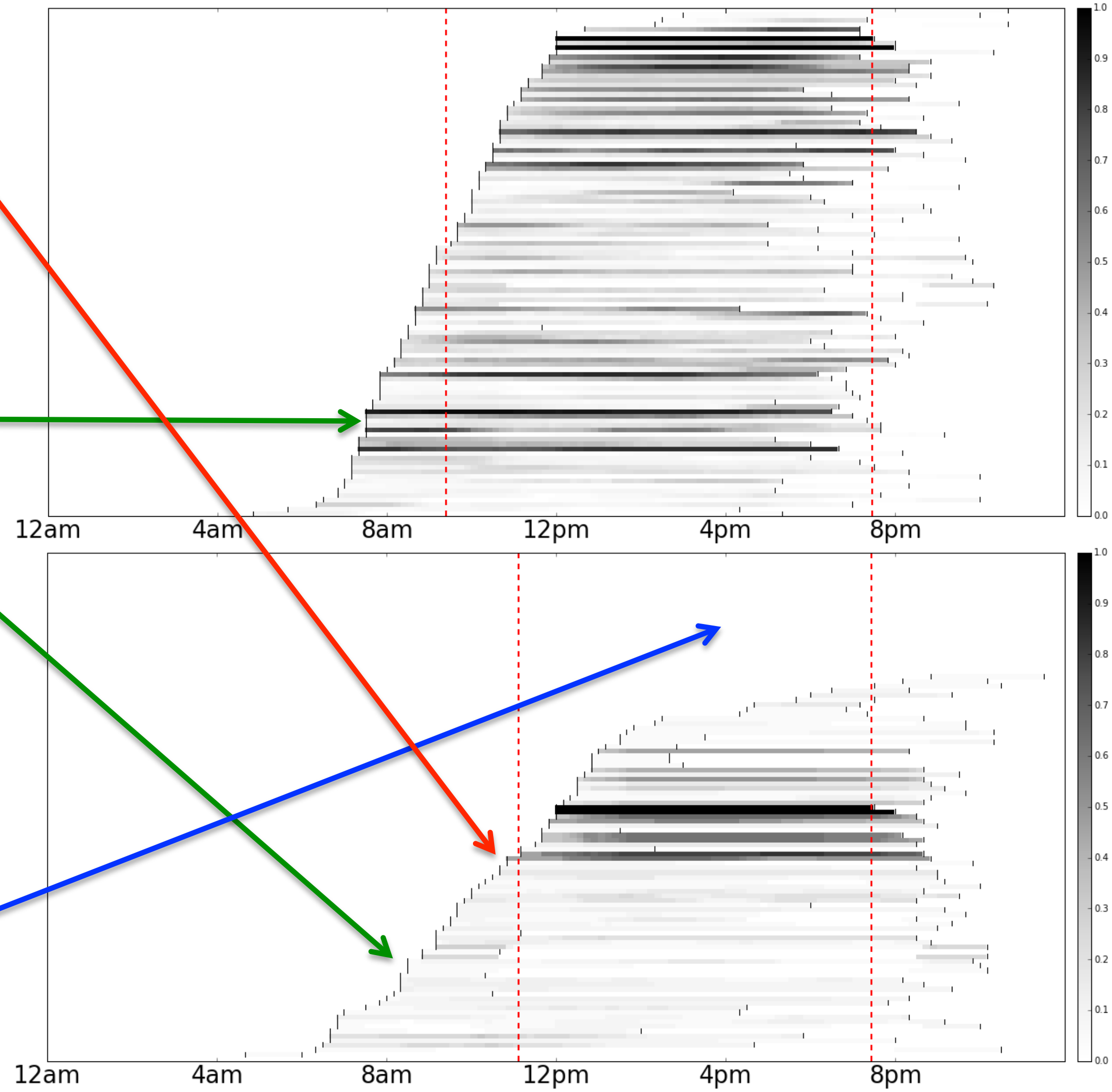
People come in later on weekends

Occupancy profile (Weekdays)

95th percentile occupancy envelopes for each zone

Occupancy profile (Weekends)

Fewer people come in to work on weekends



Static Schedules

- Naïve:
  - predefined schedules for all zones based on the facilities manager's intuition
- Learned:
  - customized per-zone schedules learned over a short period of time
    - If occupancy is not stationary then sub-optimal.

Could achieve between 37%–57% energy savings and between 3%–13% comfort violations across the buildings

Easy to implement, requires less data

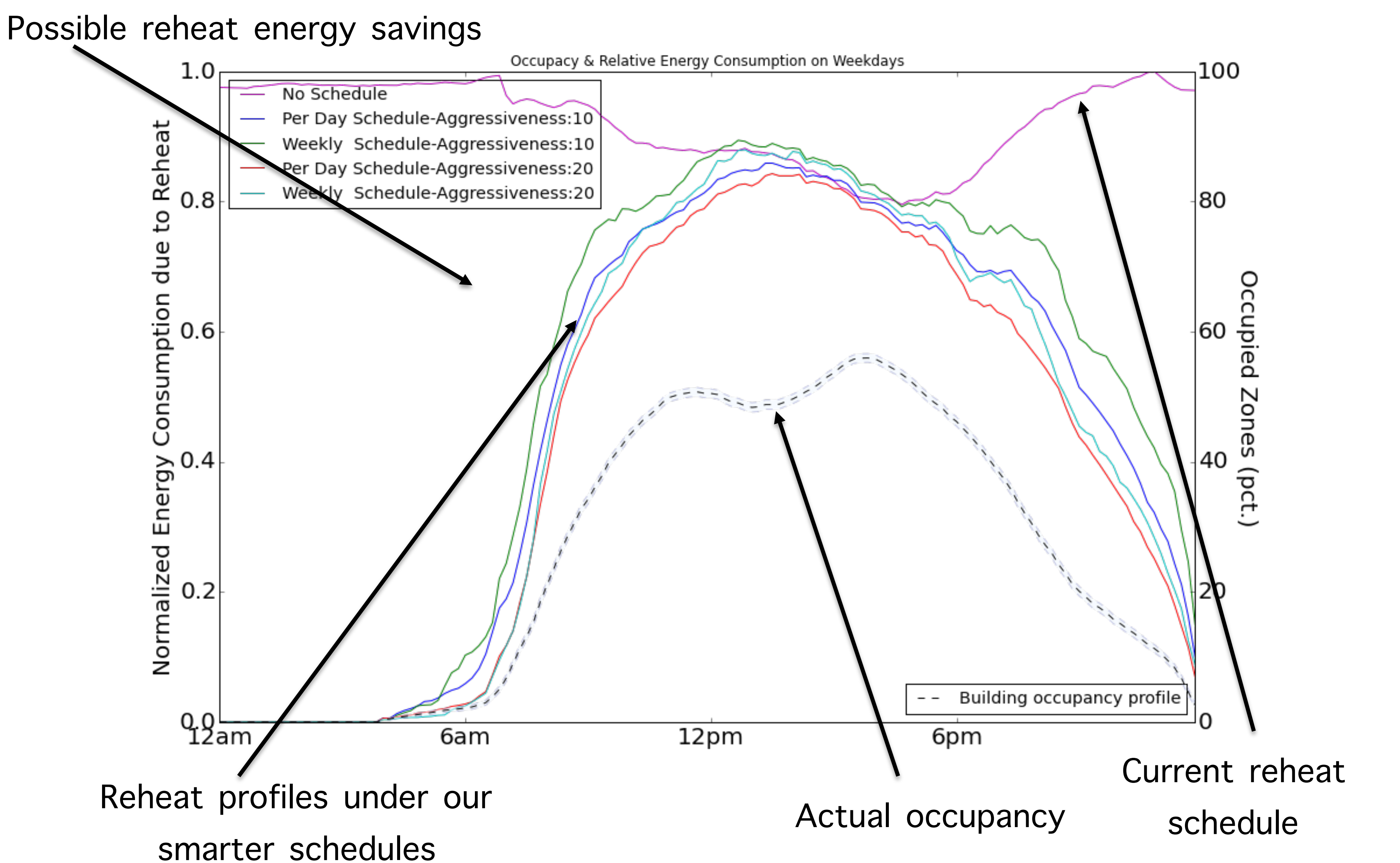
Adaptive Schedules w/ Sliding Training Window

- Weekly:
  - a customized per-zone schedule for all days of the week
- Per-Day:
  - a customized per-zone schedule for each day of the week
- Weekday-Weekend:
  - a customized per-zone schedule for weekdays and another one for weekends

- Could achieve between 37%–76% energy savings and between 1%–8% comfort violations across the buildings

Difficult to program into a legacy BMS

How we are actually saving reheat energy?



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Insights from 3 buildings

- Naïve schedules are <u>not great in terms of occupancy comfort violation</u>

- Learning a schedule on even a small amount of data (~2 weeks) helps save ~50% of reheat energy, with negligible (<2%) estimation errors (occupancy comfort violations)

- If the underlying occupancy patterns are static, then increasing the length of the training window has <u>diminishing returns</u>

- Having different schedules for each particular day <u>might be an overkill</u>.

- <u>Learned static schedules seem to be the sweet spot</u>

Takeaways

- The proposed approach can be applied to any building with a BMS that archives data from HVAC sensors
- The plausibility of our results underlines that much value can be extracted from existing building data streams through careful analytics
- This justifies the effort to collect ground truth data on a larger set of buildings where occupancy sensors are pervasive
- This can expose larger efficiency problems in the building, e.g anomalous zones, supply temperature resets, etc.

Conclusion

- We infer per-zone occupancy through techniques that are
  - *Non-Intrusive*
  - *Widely-Applicable*
- Use these occupancy estimates to reduce reheat energy consumption through smarter *adaptive* schedules.

- Future work :
  - Compare against intrusive occupancy detection

Thank You !