Sentinel: Occupancy Based HVAC Actuation using Existing WiFi Infrastructure within Commercial Buildings

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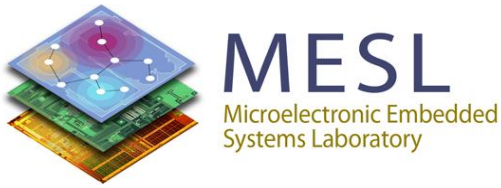

Occupancy-driven Building HVAC

Vacant

Occupied

HVAC Control
(via BACnet)

HVAC: Heating, Ventilation and Air Conditioning

Outline

- Overview
- Motivation
- WiFi Based Sensing
- Challenges
- Implementation
- Results
- Conclusion

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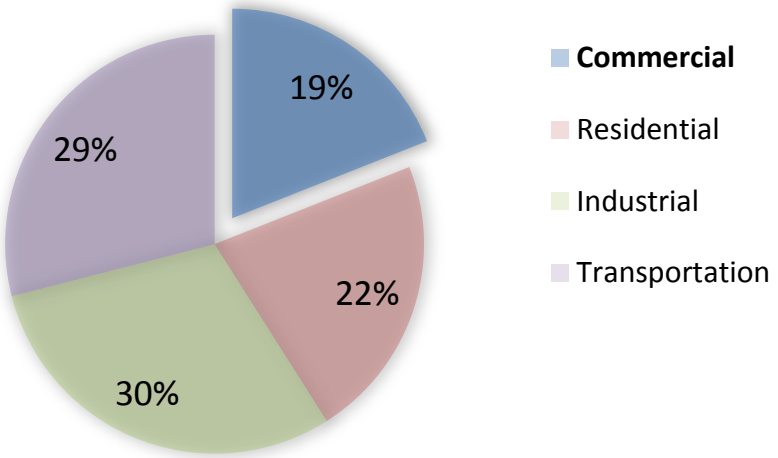
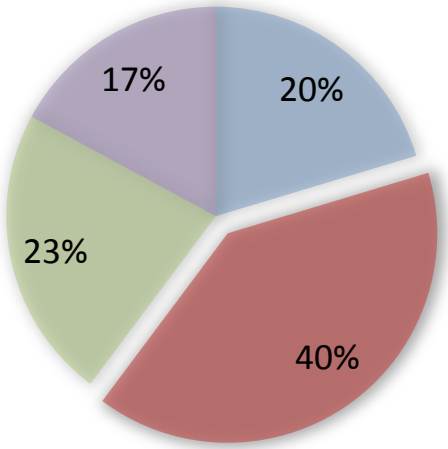
Why is HVAC Efficiency Important?

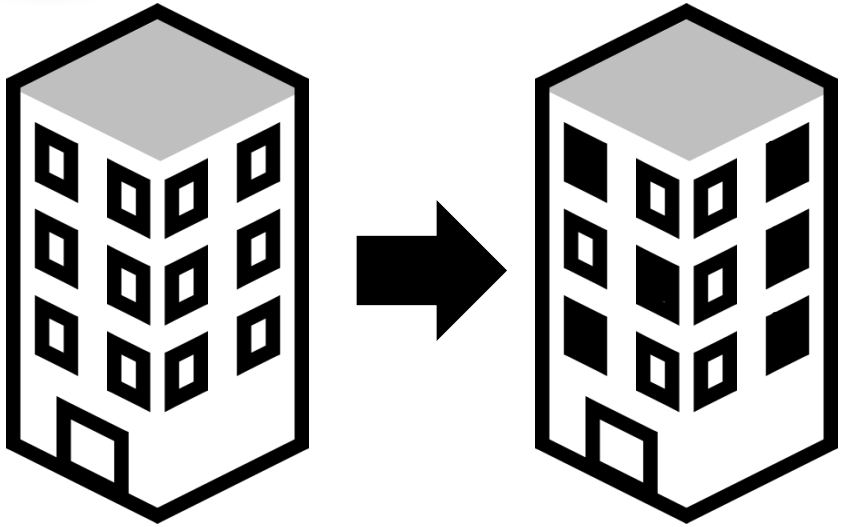
US Energy Consumption[1]



Commercial Buildings Energy Breakdown[1]



36% electricity
39% carbon emissions



Occupancy based control of HVAC can provide 15% – 40% energy savings![2]

1. Building Energy Data Book - http://buildingsdatabook.eren.doe.gov
2. OBSERVE: Occupancy-Based System for Efficient Reduction of HVAC Energy - Erickson et al. IPSN 2011

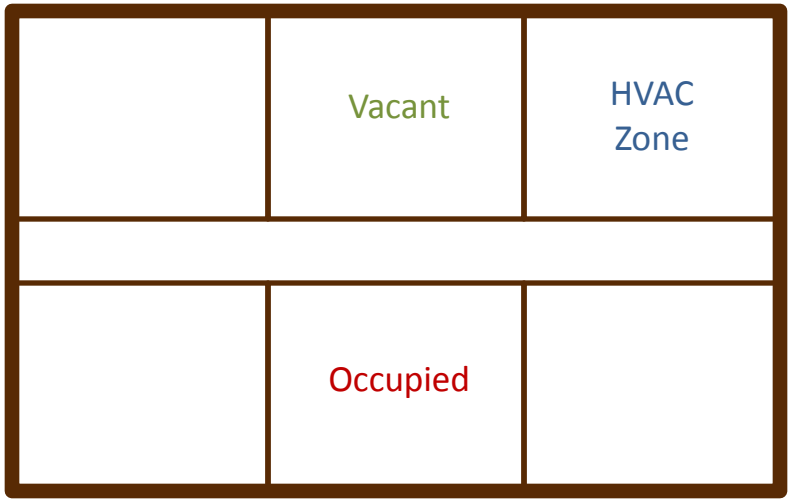
Occupancy Based HVAC Control

Static Occupancy Schedule

6:00AM 10:00PM

Actual Occupancy

Commercial Building



- Building partitioned to zones
- Independent control of each zone
- Occupancy can be used to turn off unused zones

1. Duty-Cycling Buildings Aggressively: The Next Frontier in HVAC Control. Agarwal et al. IPSN 2011

Existing Occupancy Solutions

- Modern buildings use motion sensors
  - Cannot detect stationary occupants[2]
  - Expensive to install in existing buildings

- Wireless sensors based solutions
  - Use of camera[1] or combination of sensors[2]
  - Hard to deploy and maintain at scale[3]

- Leverage existing infrastructure
  - Accurate, scalable
  - Inexpensive, easy to maintain

WiFi

1. POEM: Power-Efficient Occupancy-Based Energy Management System. Erickson et al. In IPSN 2013.
2. Duty-Cycling Buildings Aggressively: The Next Frontier in HVAC Control. Agarwal et al. IPSN 2011
3. @scale: Insights from a large, long-lived appliance energy WSN. Dawson-Haggerty et al. In IPSN 2012

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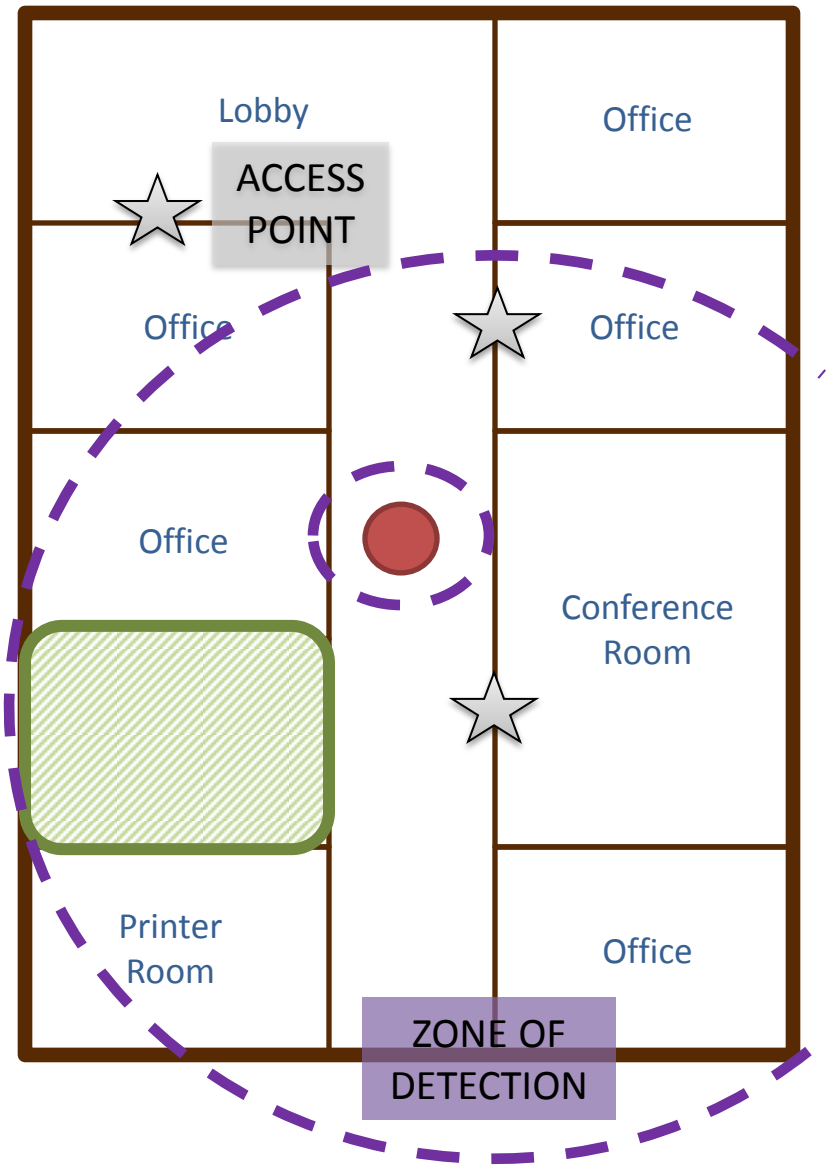
WiFi Based Sensing



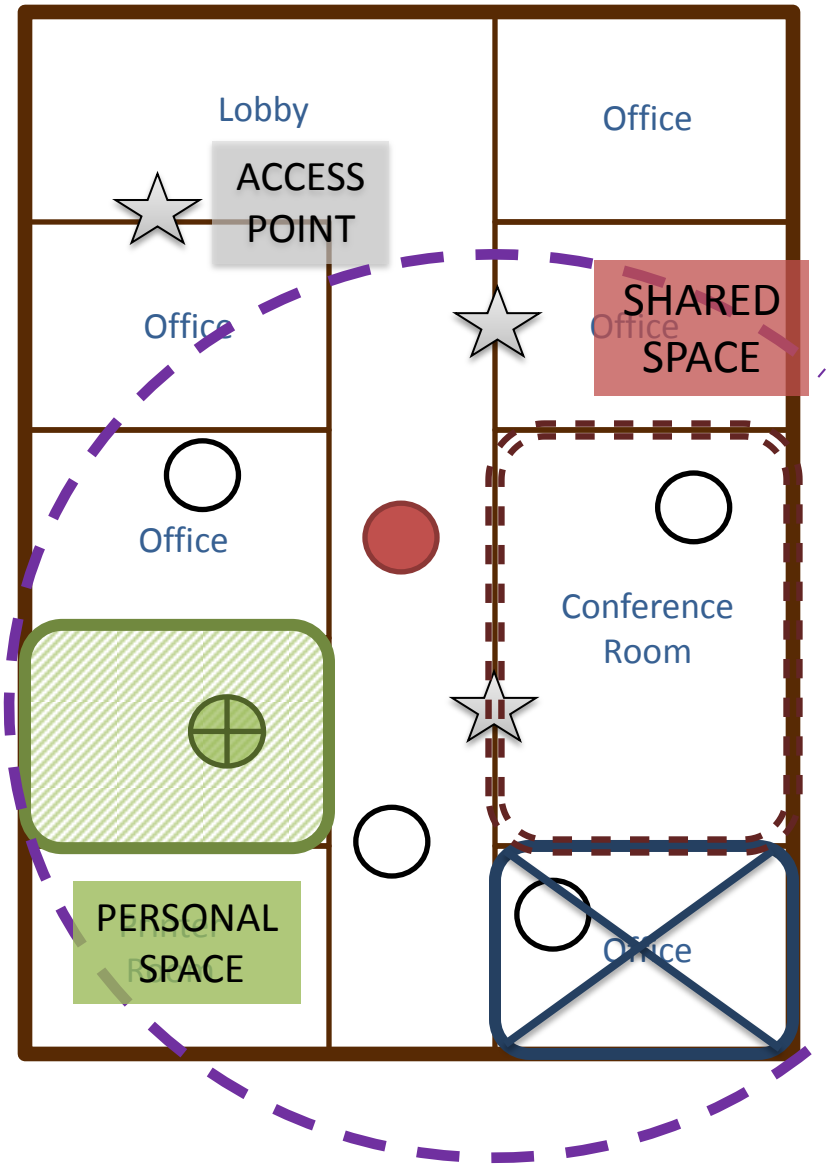
- Self-calibrated indoor localization not accurate
- More accurate solutions require war driving, complex client apps
- Locate up to 1000 devices in real-time
- Significant energy savings even with coarse grained localization

Real Location

Occupant's Office

1. On the Empirical Performance of Self-Calibrating Wifi Location Systems. Turner et al. IEEE LCN 2011

WiFi Based Sensing



- Assume visitor cannot enter without owner present
- Division of spaces into personal and shared
- Assume person in office whenever within vicinity
- Sacrifice savings when occupant is just outside office

Real Location

Possible Location

Assumed Location

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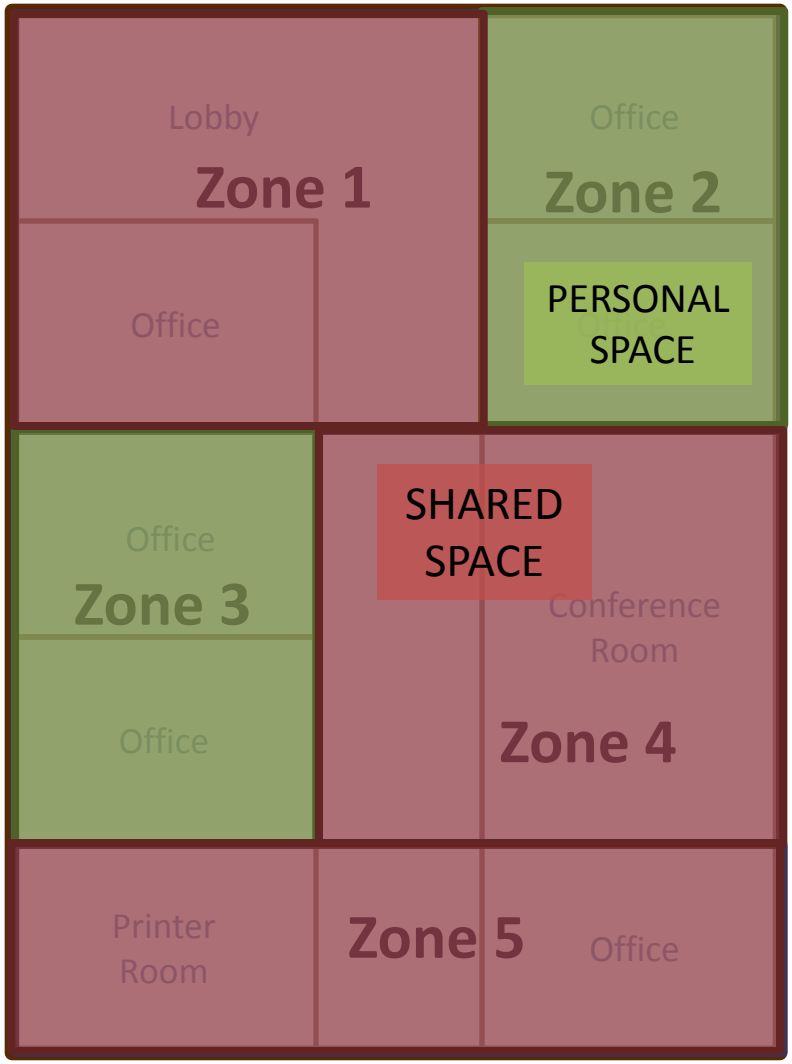
Partitioning the Building



- Zones may consist of more than one room
- Zone contain both personal and shared spaces
- Some personal spaces converted to shared spaces

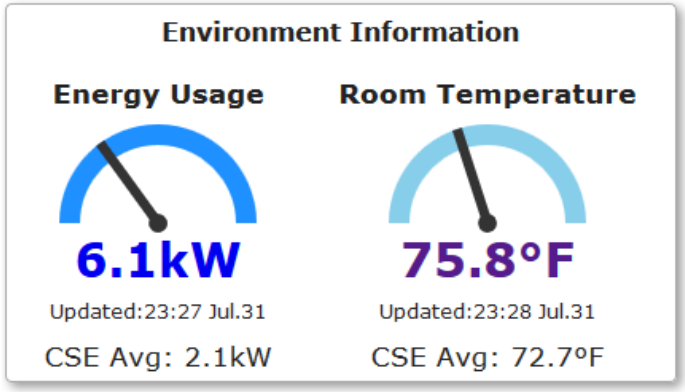
Zone Type	Area	Electric Power
Personal	37.50%	63.90%
Shared	58.30%	66.90%

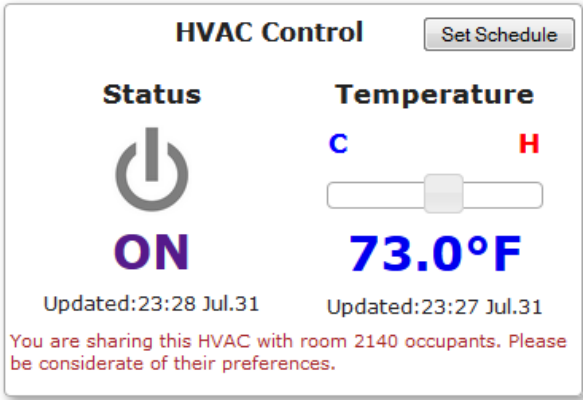
Contribution of each type of space to area and electricity in our building testbed

Max savings of 33.1%

Challenges with Using WiFi for Occupancy Sensing

- Occupant does not use WiFi
- Device battery may run out
- Phone forgotten at home
- Need to lend office to visitor
- Solution: Provide web based manual HVAC override





Leveraging WiFi Connectivity for Occupancy Sensing

- Assumption: WiFi radio is always connected
- Reality: WiFi radio duty cycled to save power
- Android, Windows Phone: Can change settings
- iPhone: Not possible to change settings
  - Change settings to fetch mail every 15 mins
- May impact battery life
  - Smartphone app for reduced battery impact

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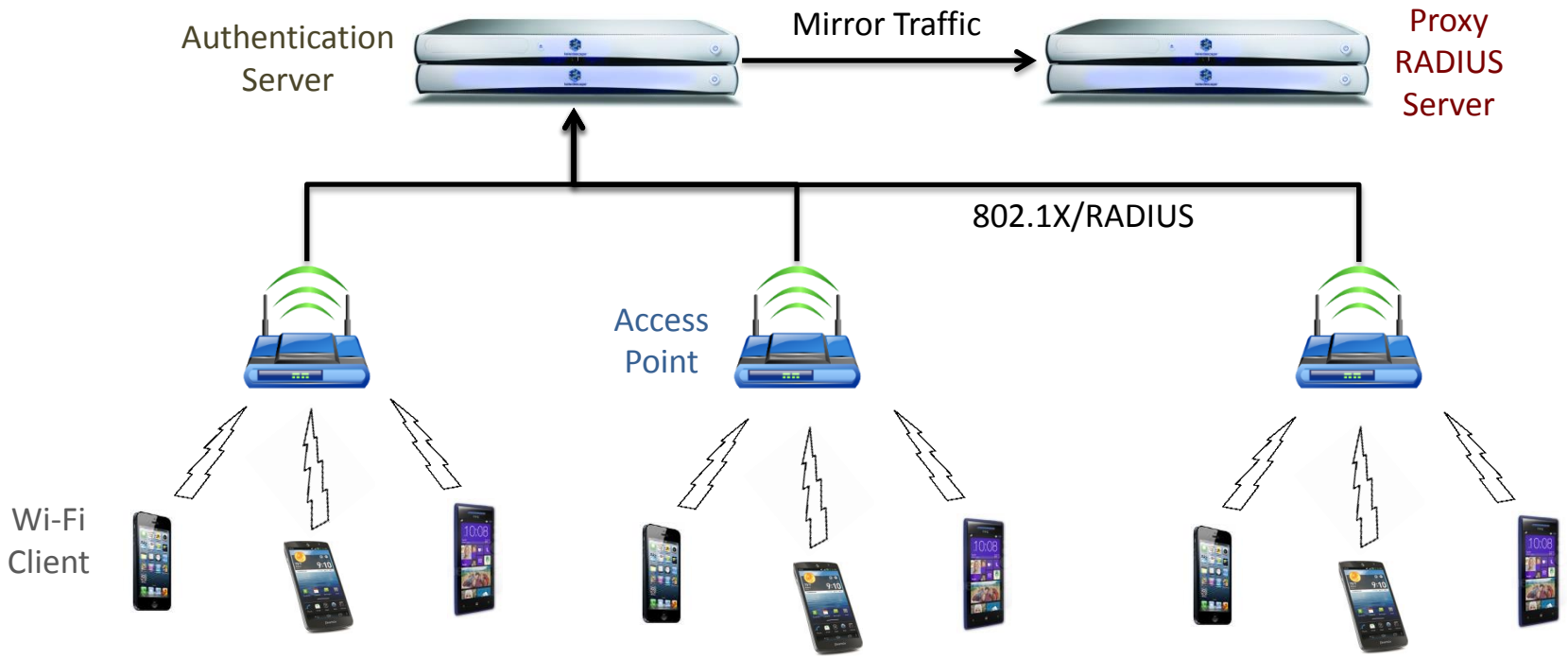
Building Testbed – CSE, UCSD

- Built in 2004, 145,000 sq ft, 5 floors
- HVAC: VAV with reheat coil, 237 zones
- Occupants: Faculty, staff and students

Collecting WiFi Data



- Authentication packets contain:
  - Client MAC, AP MAC, client username
- Book keeping information:
  - Start, stop, hand-off and periodic liveness packets

Acquiring Metadata Information

Occupant

Mapping of occupant offices from HR manager

Office Room

User identity from WiFi logs

Location of AP from network manager

WiFi Devices

Identify smartphone from hand-offs

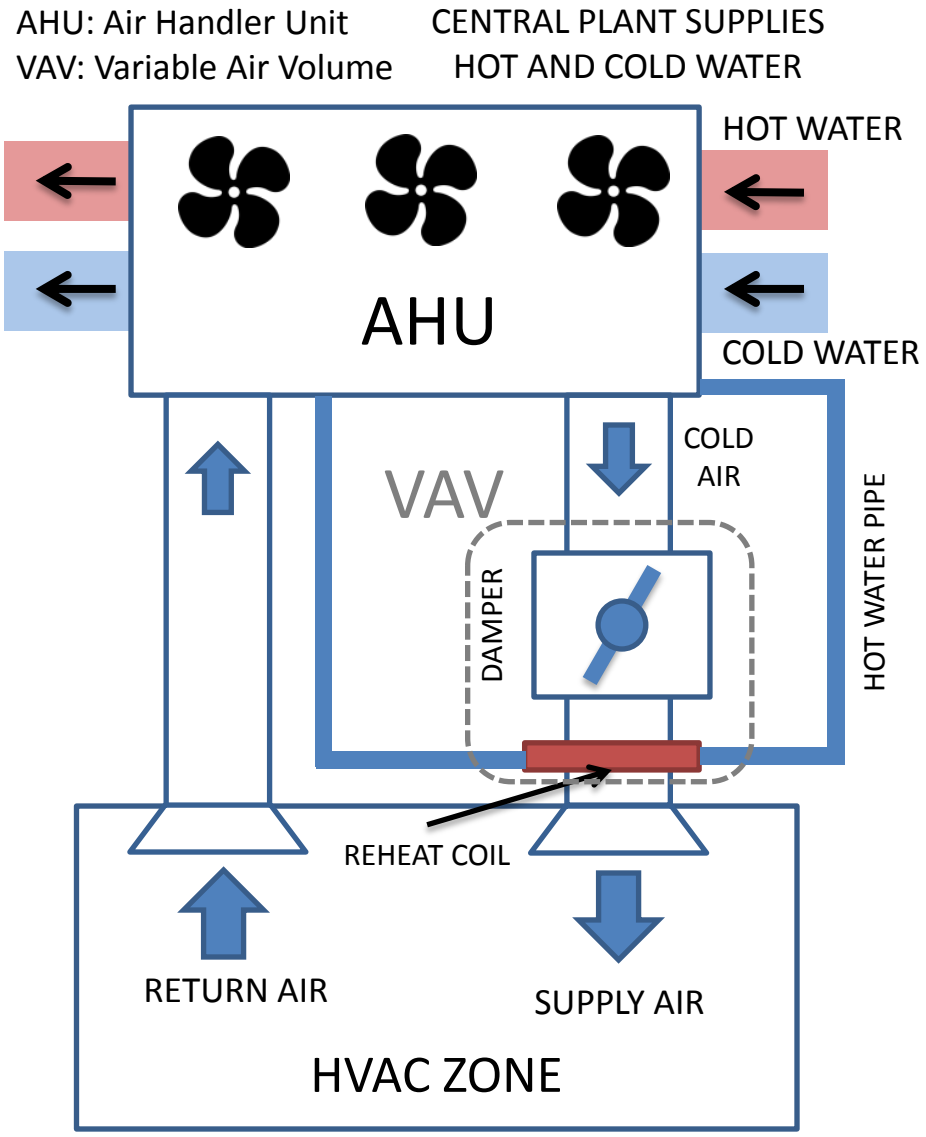
Connectivity info from WiFi logs

Access Point

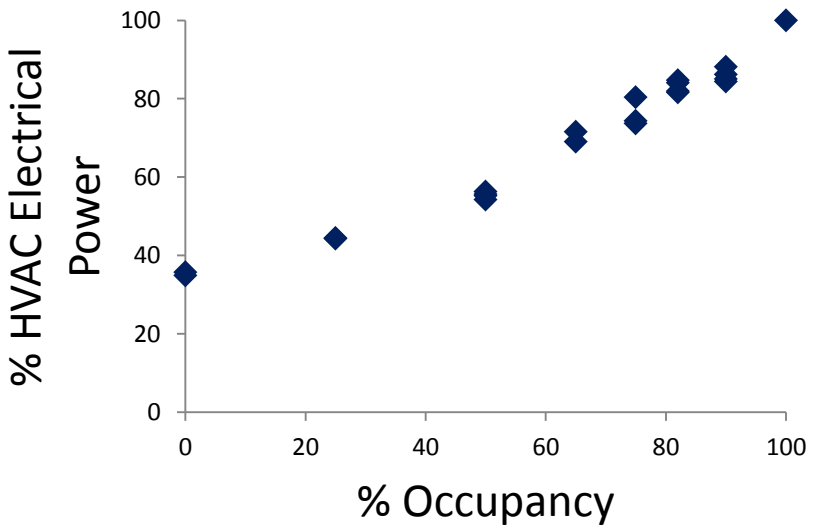
Occupancy Based HVAC Control

- Three modes of operation in each zone
- Occupied (Weekdays 6am – 6pm)
  - Adequate ventilation, 4°F band (e.g. 70°F – 74°F)
- Standby (Weekdays 6pm – 10pm)
  - Minimum ventilation, 8°F band (e.g. 68°F – 76°F)
- Unoccupied (Nights & Weekends)
  - Minimum ventilation, 12°F band (e.g. 66°F – 78°F)
- When we turn “Off” HVAC, we go into Standby mode

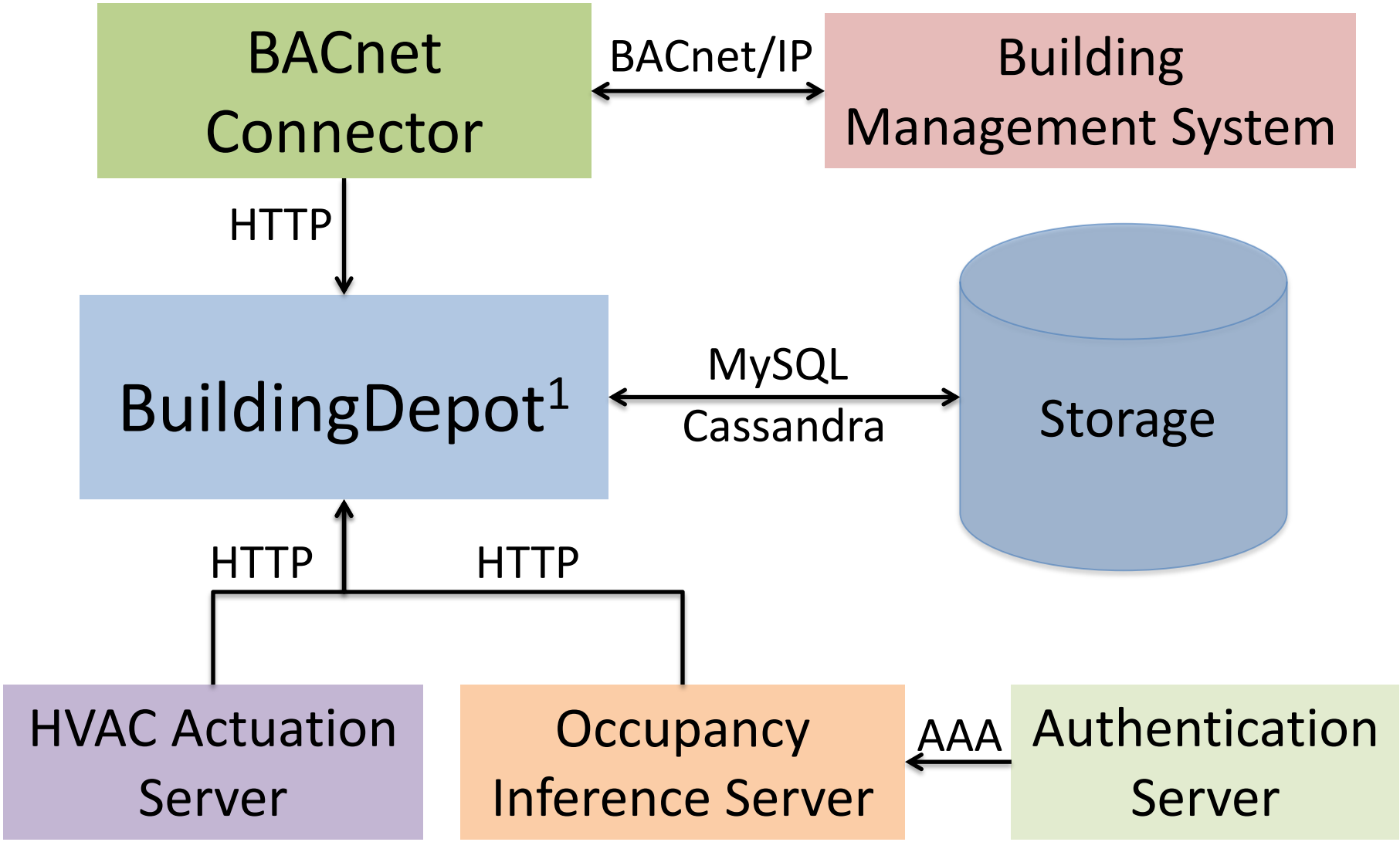
HVAC Working & Savings



- Electrical power is cubic proportional to occupancy
- Only essential ventilation at 0% occupancy



Sentinel: Overall Architecture



1. BuildingDepot: An Extensible and Distributed Architecture for Building Data Storage, Access and Sharing. Y. Agarwal, R. Gupta, D. Komaki, and T. Weng. In BuildSys 2012

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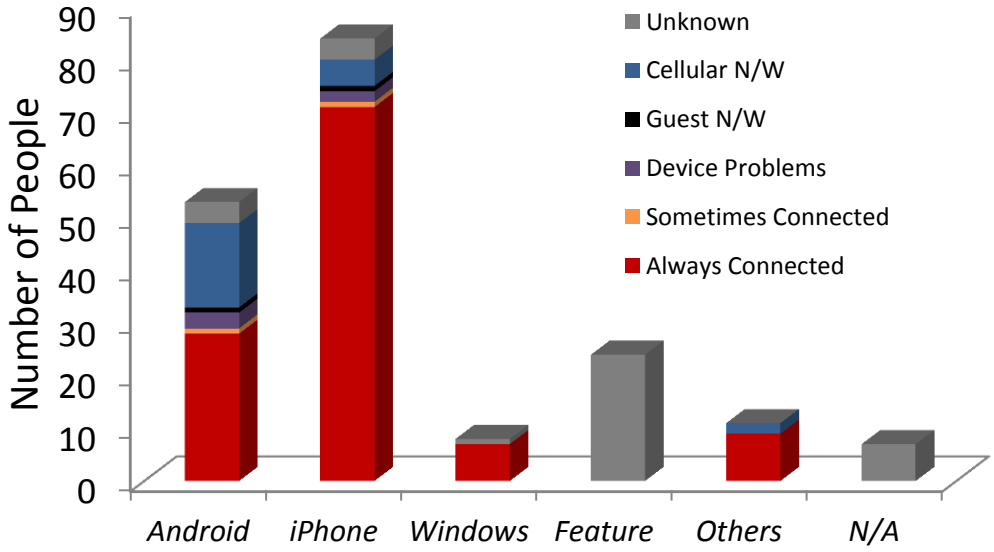
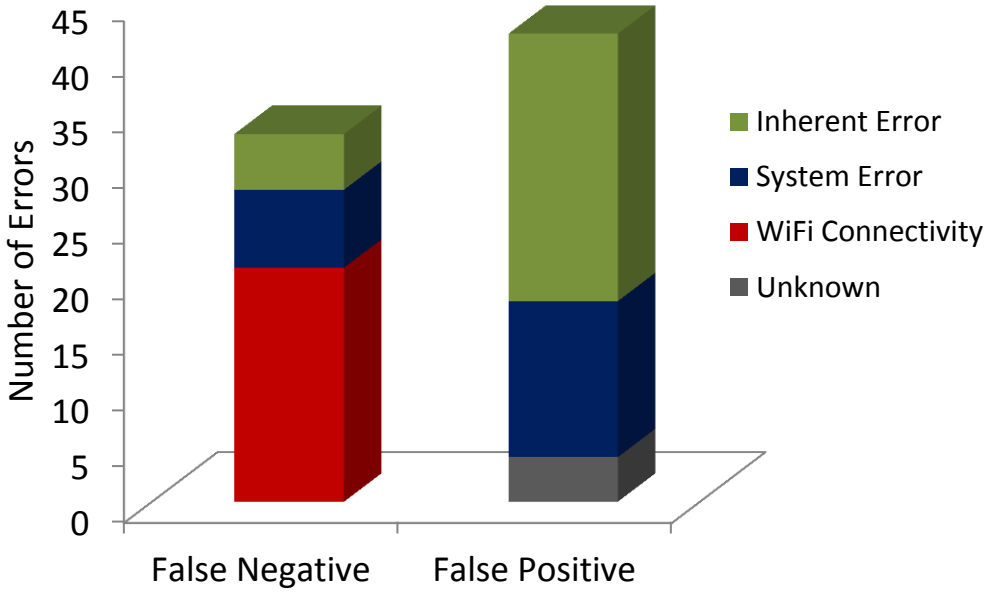
Results – User Study

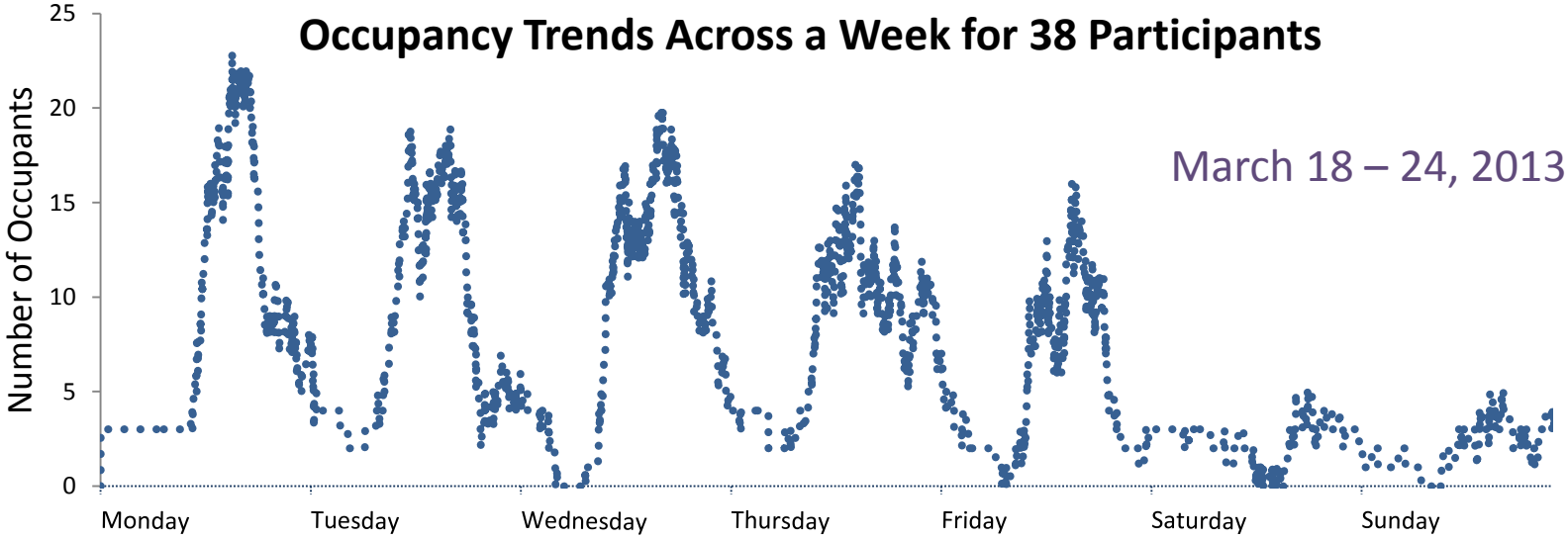
- Survey of 187 out of 415 building occupants
- 61% users always connected to WiFi
- Reasons for not using WiFi:
  - Poor WiFi coverage
  - Good cellular data plan
  - Device connectivity problems with WPA2



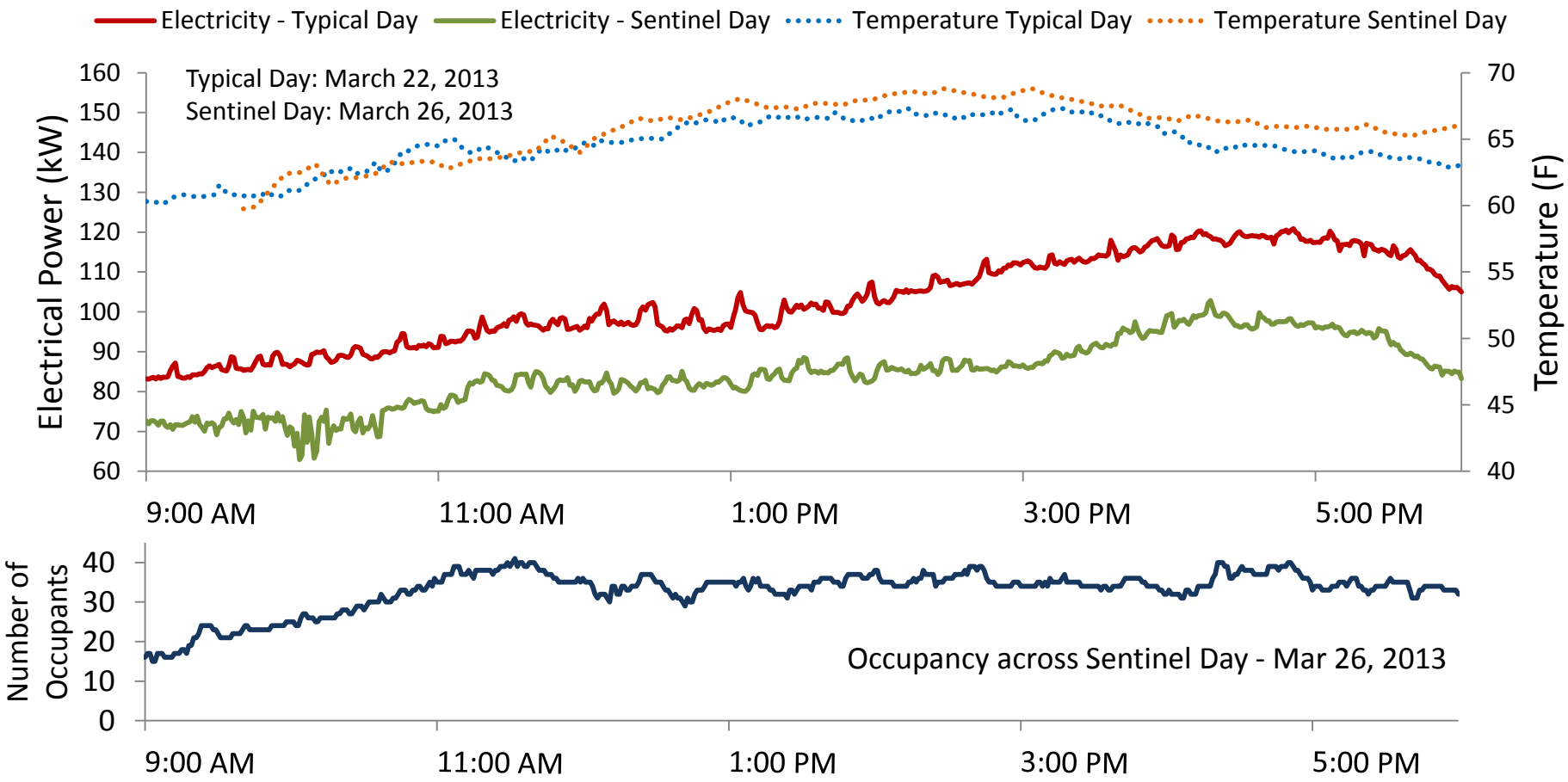
Results – Accuracy

- 116 occupants, 10 days, 436 events
- Ground truth collected manually
- 86% accuracy, 6.2% false negatives





Results – Energy Savings



- Control of 55 out of 237 HVAC zones for 1 day
- 17.8% HVAC electrical energy savings

Conclusion

- Occupancy information is crucial to effective use of HVAC in commercial buildings.
- It is possible to use existing WiFi infrastructure for occupancy detection in building spaces.
- Our occupancy model applies to personal spaces. Shared spaces are currently not subject to HVAC control.
- 86% detection accuracy using WiFi, 6.2% false negatives
  - ➢ WiFi connectivity issues lead to inaccuracies
- 23% of building area controlled using Sentinel
  - ➢ 17.8% HVAC electrical energy savings for 1 day

Thank You!

Questions?

Acknowledgements:
Thomas Weng, Hidetoshi Teraoka, Du Li, UCSD Facilities Management, UCSD Academic Computing Services, Anonymous reviewers

synergy
systems, networking and energy efficiency

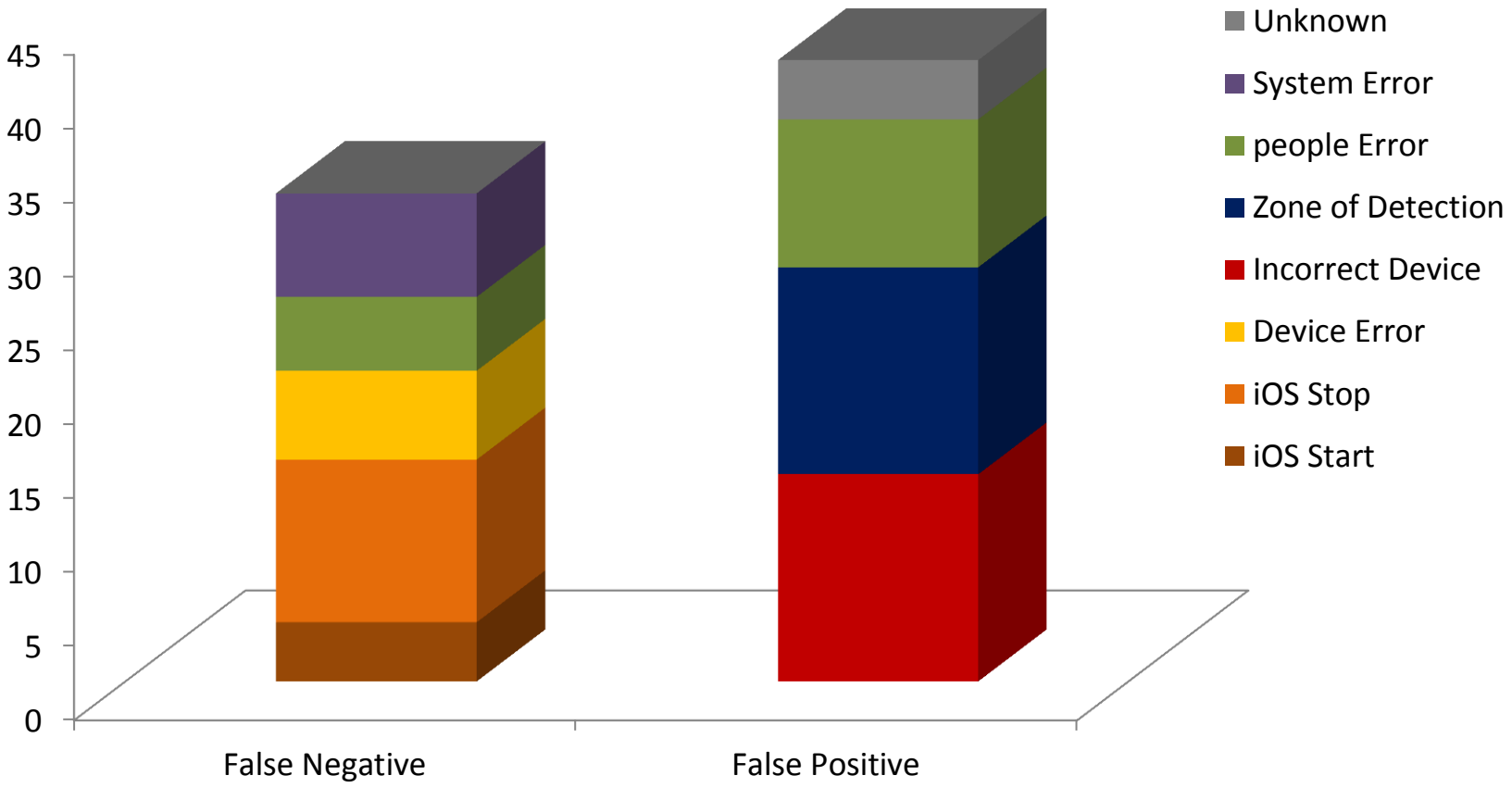
MESL
Microelectronic Embedded Systems Laboratory

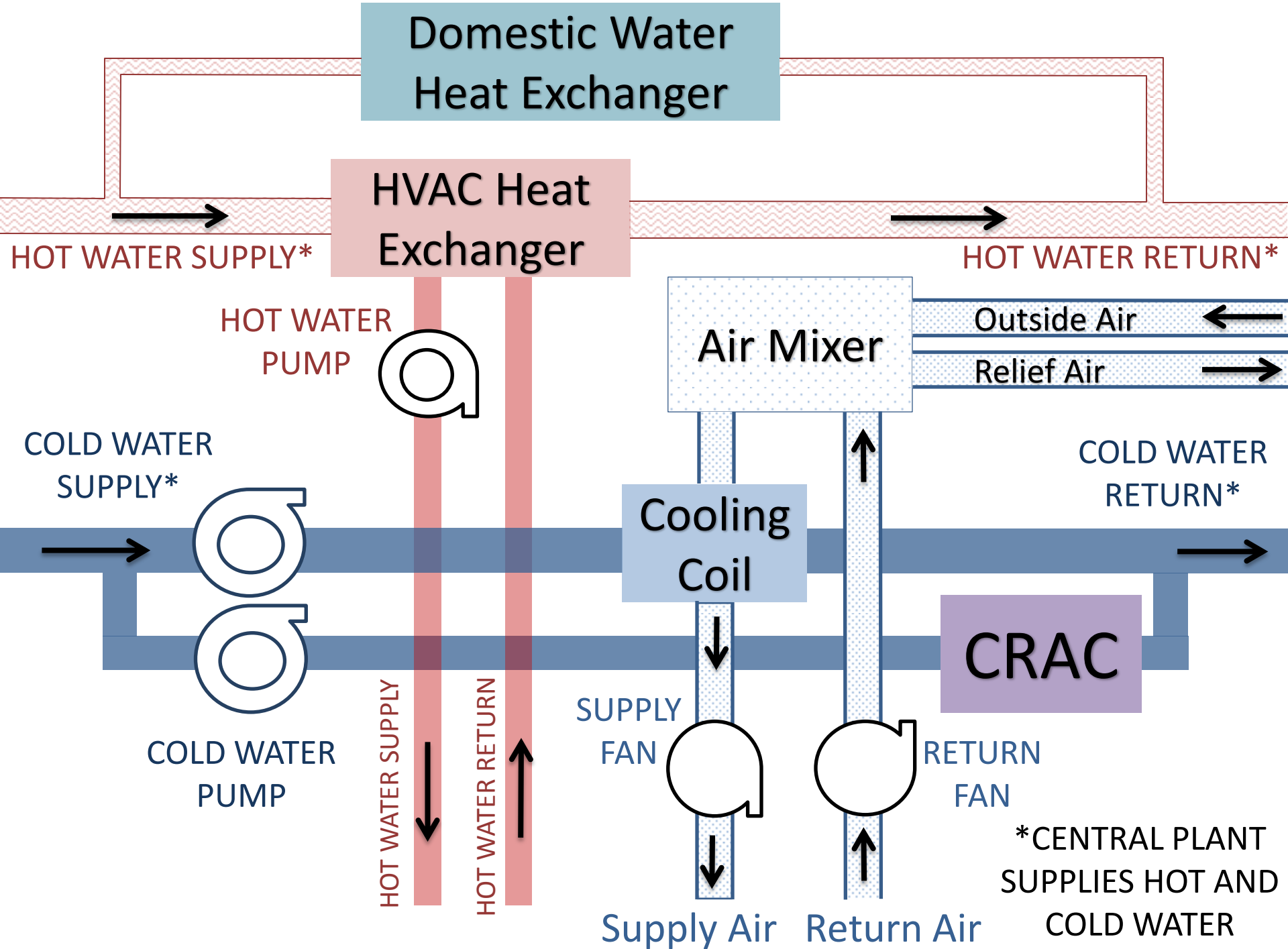
UCSD

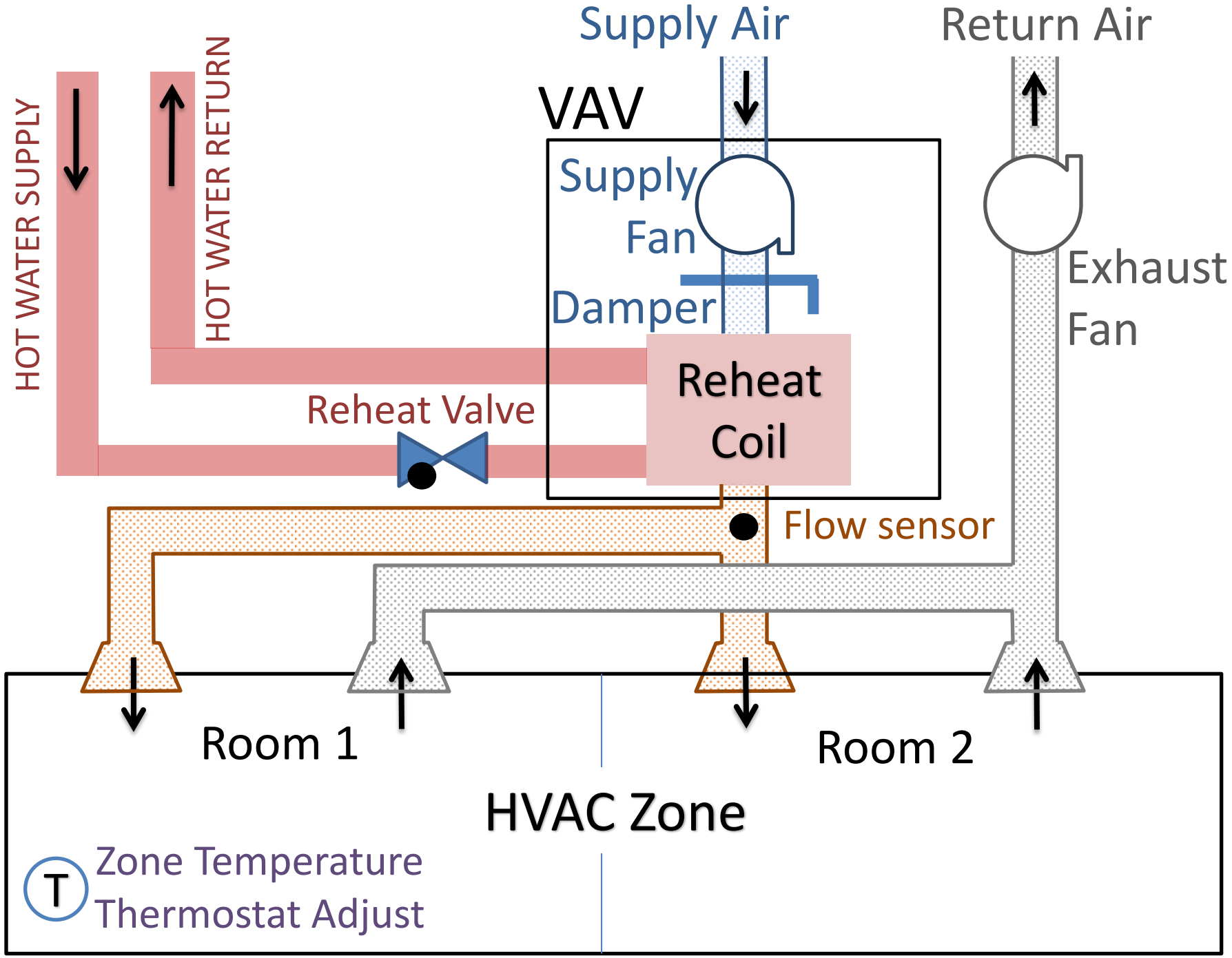
Carnegie Mellon University

Extra Slides

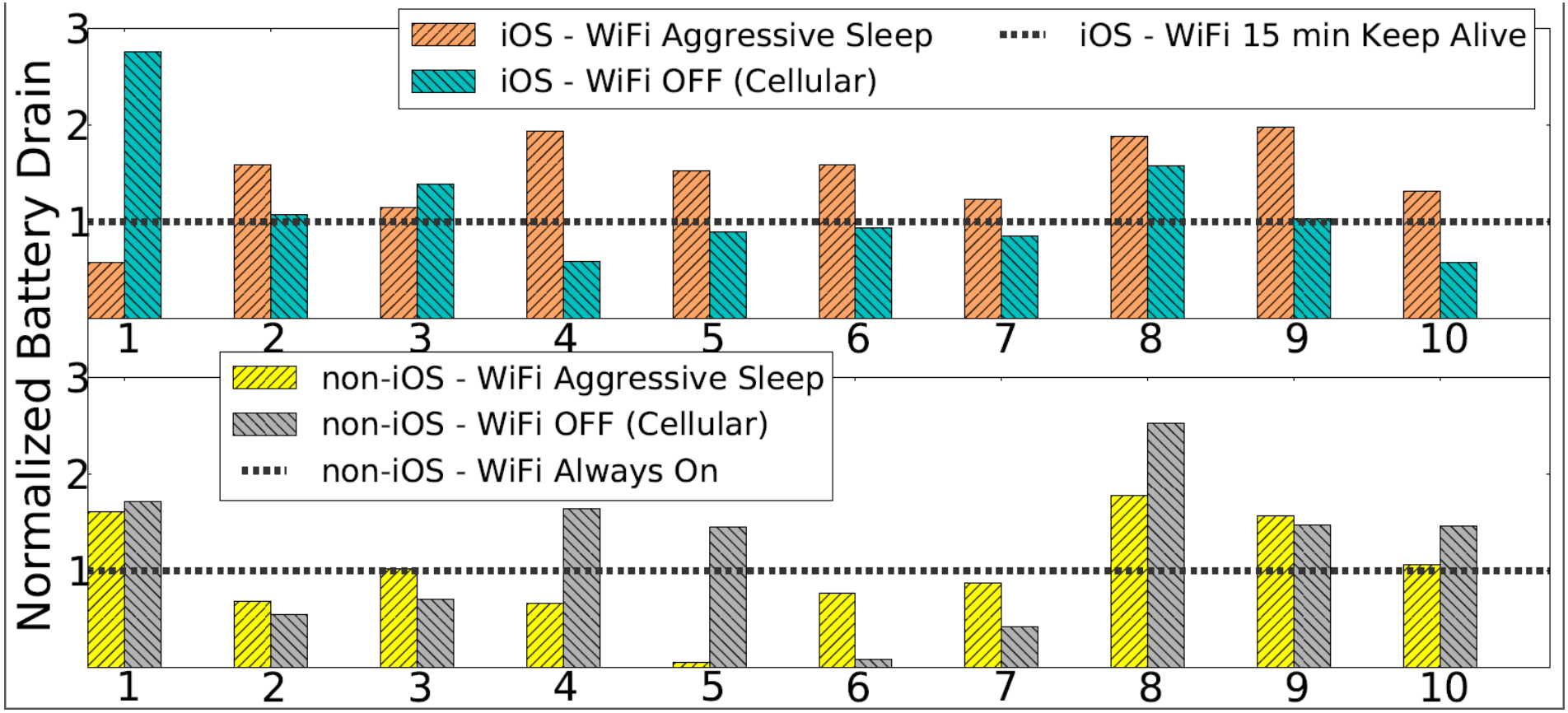
Detailed Error Analysis




Domestic Water Heat Exchanger
HVAC Heat Exchanger
HOT WATER SUPPLY*
HOT WATER RETURN*
HOT WATER PUMP
Air Mixer
Outside Air
Relief Air
COLD WATER SUPPLY*
COLD WATER RETURN*
Cooling Coil
CRAC
COLD WATER PUMP
HOT WATER SUPPLY
HOT WATER RETURN
SUPPLY FAN
RETURN FAN
Supply Air
Return Air
*CENTRAL PLANT SUPPLIES HOT AND COLD WATER


Supply Air
Return Air
VAV
HOT WATER SUPPLY
HOT WATER RETURN
Supply
Fan
Damper
Exhaust
Fan
Reheat
Coil
Reheat Valve
Flow sensor
Room 1
Room 2
HVAC Zone
T
Zone Temperature
Thermostat Adjust

Impact on Battery Life



3 day usage study across 20 smartphone users