

Software Augmented Buildings

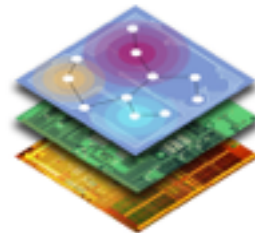
Focused on Improving Energy Efficiency and Comfort

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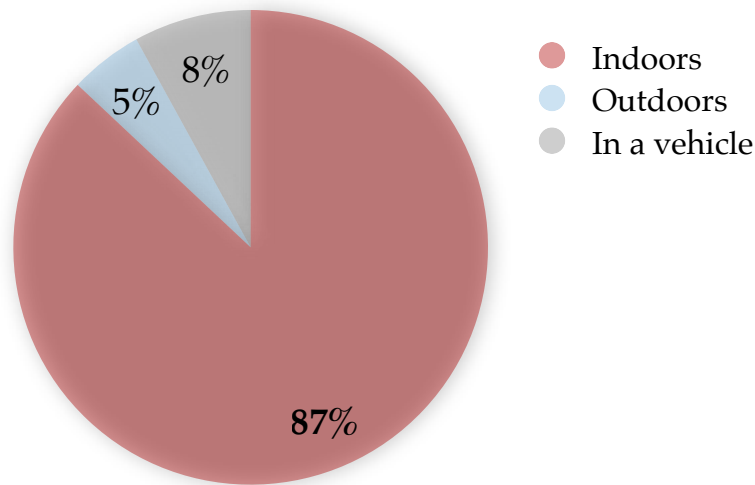


MESL
Microelectronic Embedded
Systems Laboratory



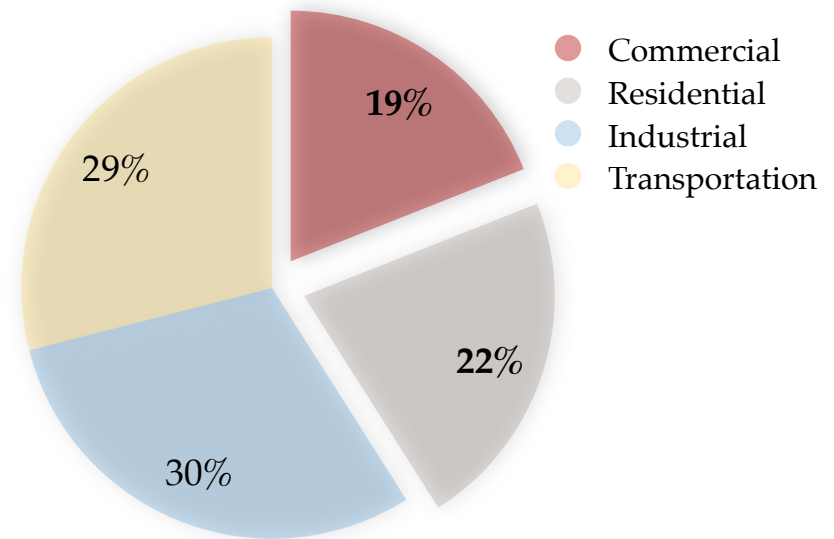
Why Focus on Buildings?

Time Spent by People in the US*



Comfort

US Energy Consumption**



Energy Efficiency

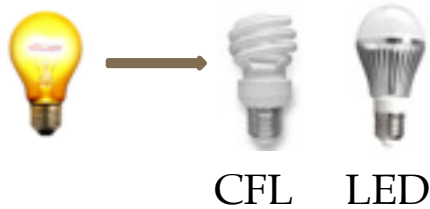
* Klepeis, Neil E., et al. "The National Human Activity Pattern Survey (NHAPS): a resource for assessing exposure to environmental pollutants." Journal of exposure analysis and environmental epidemiology , 2001.

** Building Energy Data Book - <http://buildingsdatabook.eren.doe.gov>

Modern Building Systems



Lighting System



Motion Sensor



Photo Sensor



Plug Loads



Smart appliances



Heating, Ventilation and Air Conditioning (HVAC)



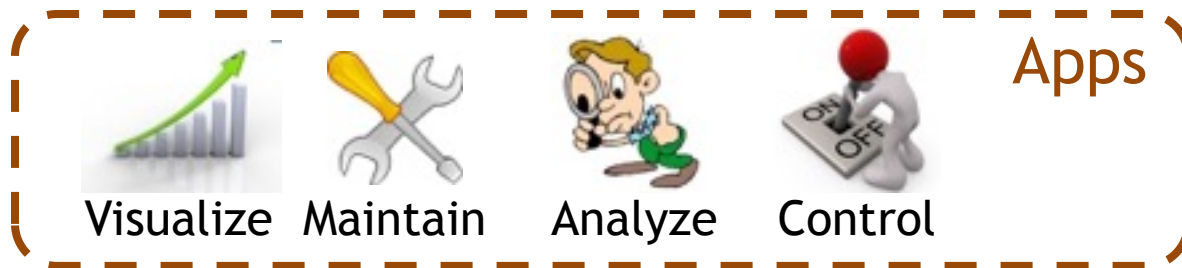
Better equipment, improved monitoring

- ❖ Observation 1: Focus on hardware improvements and retrofits
- ❖ Observation 2: Vertically integrated systems, no mutual communication

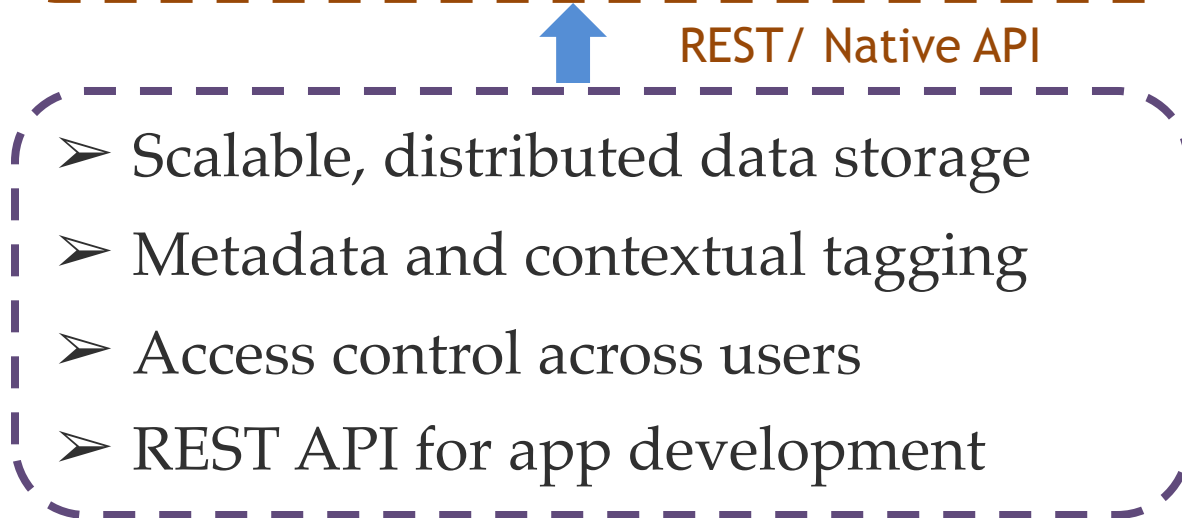
Towards Smarter Buildings

- ❖ Connected infrastructure can lead to holistic solutions
- ❖ Software systems to support innovative applications
- ❖ Benefits:
 - Contextual information
 - Data analytics
 - Control optimizations
 - User experience

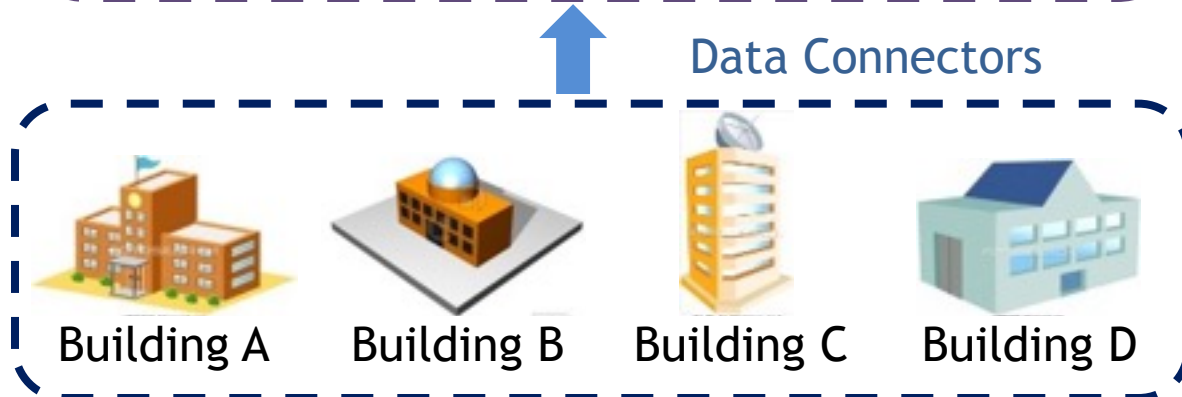
BuildingDepot - RESTful API Service



Next generation building applications via standardized API



Data management system for sensors and actuators



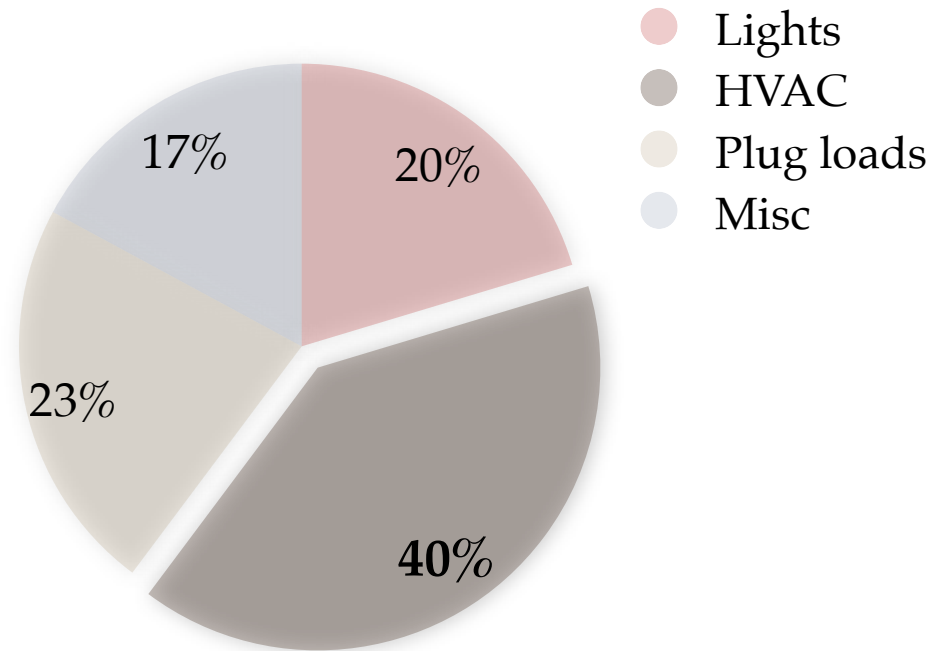
Large amount of data generated in modern buildings

Smart Building Applications

- ❖ Occupancy based Control
- ❖ Improved Infrastructure Interaction
- ❖ Fault detection and diagnosis

Focus on HVAC

Commercial Buildings Energy Breakdown*



Networked sensors and actuators

* Building Energy Data Book - <http://buildingsdatabook.eren.doe.gov>

Smart Building Applications

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Occupancy Based HVAC Control



Commercial Building

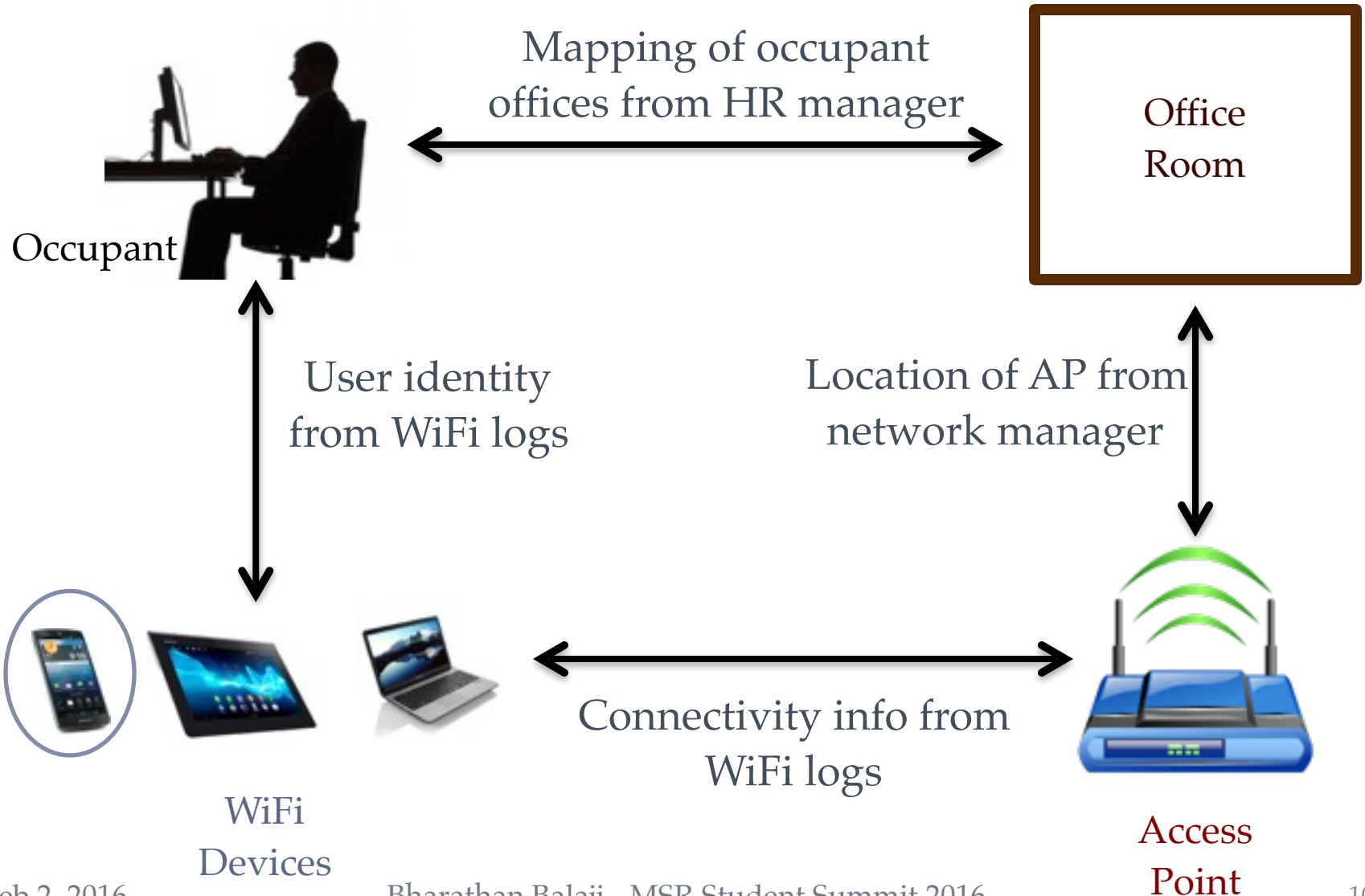
	Vacant	HVAC Zone
	Occupied	



- ❖ Building partitioned to zones
- ❖ Independent control of each zone
- ❖ Occupancy based control saves 15-40%¹
- ❖ How to detect occupancy inexpensively?

1. Agarwal, Y., Balaji, B., Dutta, S., Gupta, R. K., & Weng, T. Duty-cycling buildings aggressively: The next frontier in HVAC control. In IPSN 2011.

Occupancy Inference from WiFi Usage



Summary of Control Experiments

- ❖ CSE building: 5 floors, built in 2004
- ❖ WiFi Authentication Logs: 802.11x RADIUS proxy
- ❖ 86% detection accuracy: 116 occupants, 10 days¹
- ❖ 23% of building area controlled
 - 17.8% HVAC electrical energy savings for 1 day

1. Balaji, B., Xu, J., Nwokafor, A., Gupta, R. and Agarwal, Y. Sentinel: occupancy based HVAC actuation using existing WiFi infrastructure within commercial buildings. In SenSys 2013.

Smart Building Applications

- ❖ Occupancy based Control
- ❖ Improved Infrastructure Interaction
- ❖ Fault detection and diagnosis

Thermostats



Occupants Dissatisfied

- Insufficient feedback
- Functionality not clear
- Inadequate control



Replace Old Thermostats?

- Many problems resolved
- Installation cost: ~\$1000 / thermostat

Need a low cost solution


1. Huizenga, C., et al. "Air quality and thermal comfort in office buildings: results of a large indoor environmental quality survey." Center for the Built Environment (2006).
2. Karjalainen, S. and Koistinen, O. User problems with individual temperature control in offices. Building and Environment, 2007.

Genie: Web Interaction with HVAC

EBU3B - 2140 (Research Laboratory/Studio)


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

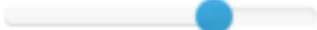
Status



On
Updated: Jul 17 18:26

Temperature

C H



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 Set schedule

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

How are you feeling now ?

Cold	Cool	Slightly Cool	Good	Slightly Warm	Warm	Hot
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Genie: Web Interaction with HVAC

EBU3B - 2140 (Research Laboratory/Studio)

The screenshot displays the Genie HVAC control interface, divided into two main sections: Environment Information and HVAC Control.

Environment Information:

- Energy Usage:** A gauge showing 4.6 kW. Updated: Jul 17 18:24. CSE Avg: 3.2kW.
- Room Temperature:** A gauge showing 75.2 °F. Updated: Jul 17 18:23. CSE Avg: 71.6°F. This panel is highlighted with a red border.

HVAC Control:

- Status:** A power button icon with the text "On". Updated: Jul 17 18:26. Below it, a note reads: "You are sharing this HVAC with room 2140 occupants. Please be considerate of their preferences."
- Temperature:** A slider control showing 73 °F. Updated: Jul 17 18:24. This panel is also highlighted with a red border.

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

How are you feeling now ?

A horizontal bar with seven buttons: Cold, Cool, Slightly Cool, Good, Slightly Warm, Warm, Hot.

Annotations:


- A red box labeled "Zone Temperature" points to the Room Temperature gauge.
- A red box labeled "Common Setpoint" and "Can change setpoint ± 3°F" points to the Temperature slider.

Genie: Web Interaction with HVAC

EBU3B - 2140 (Research Laboratory/Studio)


Environment Information

Energy Usage



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Room Temperature



75.2 °F
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HVAC Control

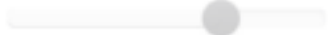
Status



On
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Temperature

C H



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

Comfort feedback and complaints. Sends an email to admin

How are you feeling now ?

Cold	Cool	Slightly Cool	Good	Slightly Warm	Warm	Hot
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Smart Building Applications

- ❖ Occupancy based Control
- ❖ Improved Infrastructure Interaction
- ❖ Fault detection and diagnosis

Detecting HVAC Faults

- ❖ Maintenance overwhelmed with information

More than 10,000 alarms per day on the UC San Diego campus.

- ❖ Current tools fail to detect many faults

 - ❖ ~20% savings

- ❖ Comparative data mining¹:

 - ❖ 88 faults, 8.7% est. savings



1. Narayanaswamy, B., Balaji, B., Gupta, R. and Agarwal, Y. Data driven investigation of faults in HVAC systems with model, cluster and compare (MCC). In BuildSys 2014.

Conclusion



Software Management Layer [BuildingDepot]

Occupancy based Control

17.8% electrical
energy savings

Web app HVAC Interaction

44% improved
comfort

Fault Detection

88 faults, 8.7%
est. savings

Thank You!



Questions?

Webpage: <http://www.synergylabs.org/bharath/>

Acknowledgements:

Anna Levitt, Nadir Weibel, Thomas Weng, Anthony Nwokafor, Hidetoshi Teraoka, Du Li, Jian Xu, Balakrishnan Narayanaswamy, Jason Koh, Chetan Verma, Rizhen Zhang, Charles Cowart