Smart Buildings:
The "leaves" of the Smart Grid "tree"

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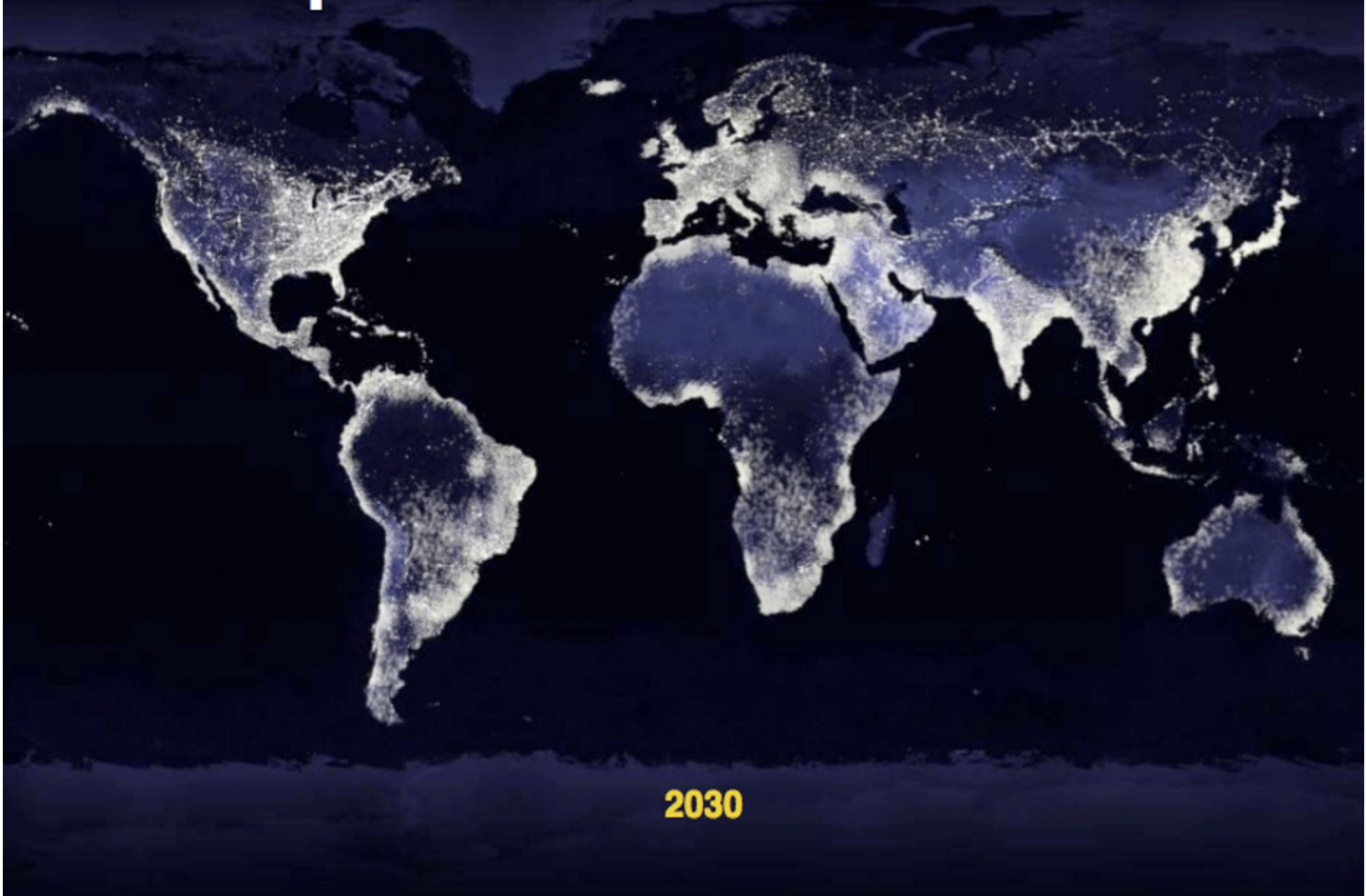
CMU :: SCS :: ISR

Energy consumption growing

Timothy Killeen @ CCC RISES Workshop, 2011

… to unprecedented demands

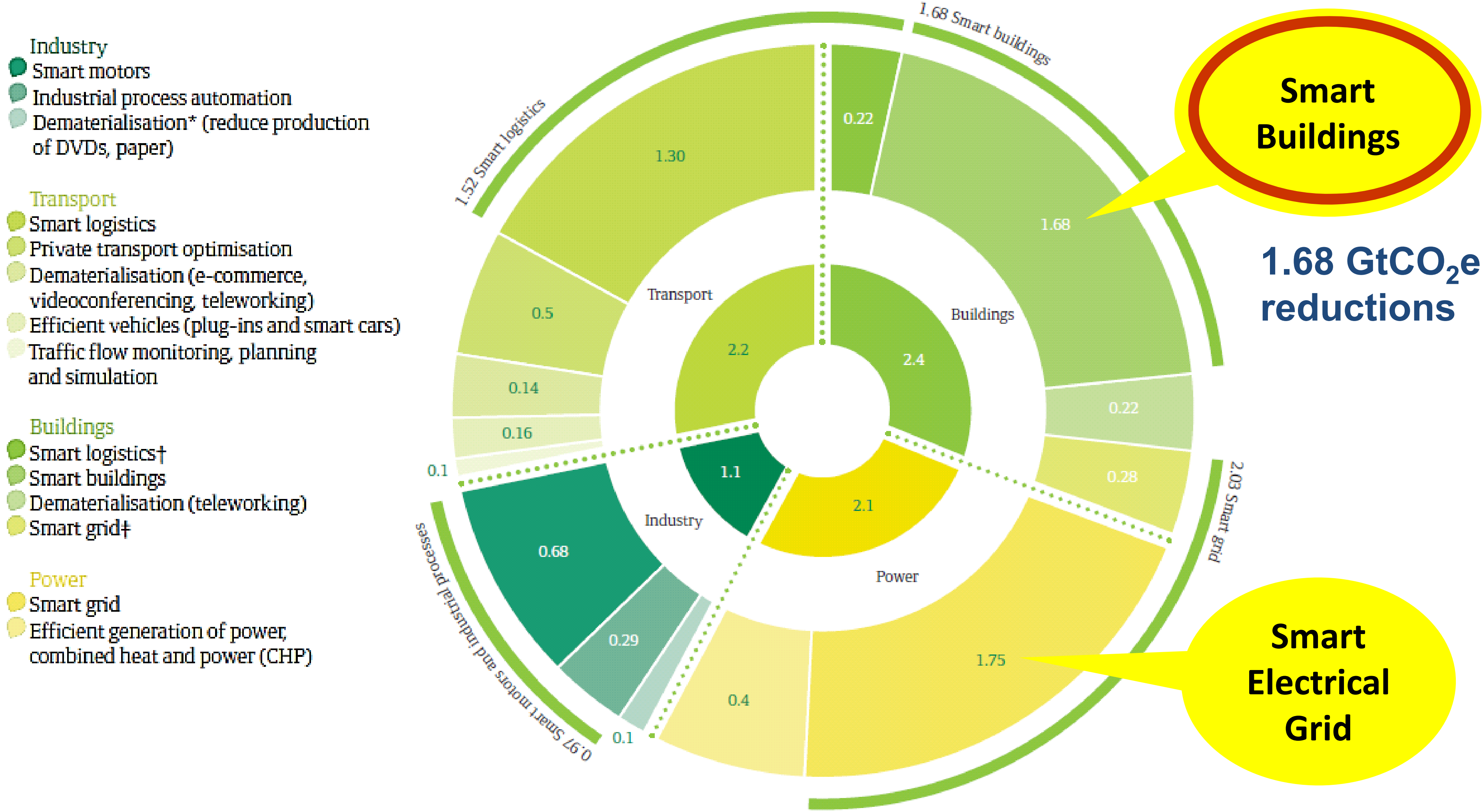


IT energy use as the problem

- Information Technology (IT) equipment is ubiquitous
  – Mobile devices to data centers, telecom + networked devices
- An important and growing component of energy use*
  – PCs and peripherals (57%) + telecom (25%) + data centers (18%)
- Reducing energy consumption of IT is critical
  – For battery life, reducing costs, managing carbon footprint

** "SMART 2020: Enabling the Low Carbon Economy in the Information Age", The Climate Group, 2008*

IT is also part of the solution



*** *Smart2020:* A total of 7.8 $GtCO_2e$ of IT enabled reductions are possible**
For reference total ICT emissions projected in 2020 are 1.43 $GtCO_2e$

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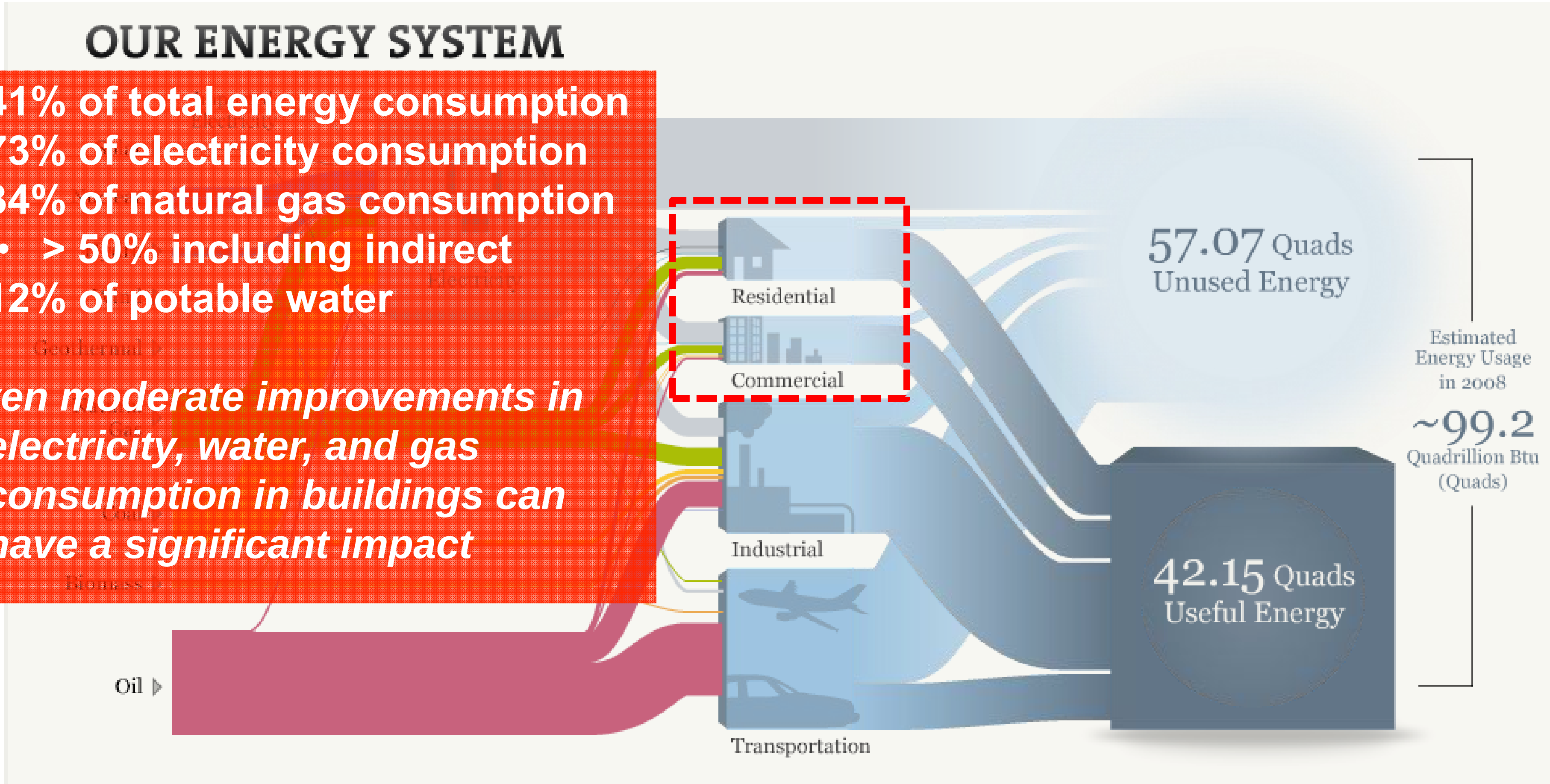
Buildings: The Big Opportunity

- **41% of total energy consumption**
- **73% of electricity consumption**
- **34% of natural gas consumption**
  - **> 50% including indirect**
- **12% of potable water**

Even moderate improvements in electricity, water, and gas consumption in buildings can have a significant impact

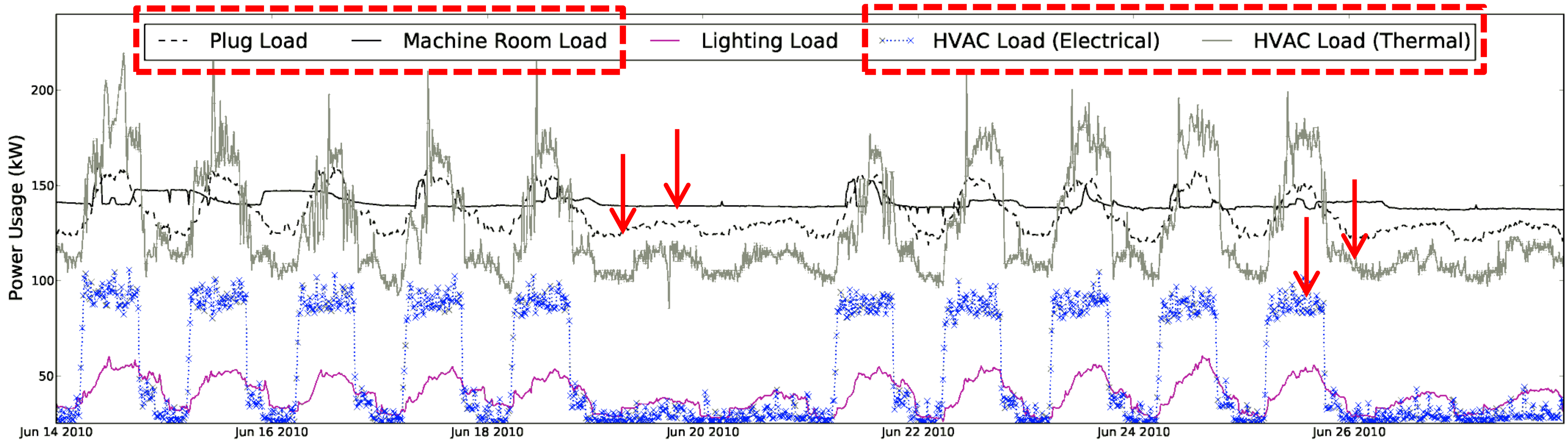


Sankey Diagram for the National Academy of Sciences

According to LLNL: 99.2Q (2008) 94.6Q (2009), 98Q (2010), 97.3Q (2011), 95.1Q (2012)

Adapted from Mani Srivastava

Energy Consumption in a `Mixed-Use' Building



- Plug loads (include IT) + machine room: > 50% of usage
  - Responsible for a significant portion of the 'base-load'
  - Most IT equipment never put to "sleep" -> *SleepServers*
- HVAC loads significant: Electrical (>25%) and Thermal
  - Electrical (air handlers, fans, etc), thermal (chilled water loop)
  - HVAC load independent of the actual occupancy of building

Source: Agarwal et al. "Duty-Cycling Buildings Aggressively", In IPSN 2011

Outline

- Motivation
- Energy Efficient Computing
  - Aggressively duty-cycling using collaborative heterogeneity
  - Reducing PC energy usage *[NSDI'09, USENIX'10]*
- Energy Efficient Buildings
  - Sensing and control within buildings
  - Duty-Cycling the HVAC system *[BuildSys'10, IPSN'11, SenSys'13]*
  - Managing Plug-Loads *[BuildSys'11]*
- *BuildingDepot*: An Open Platform for Smart Buildings

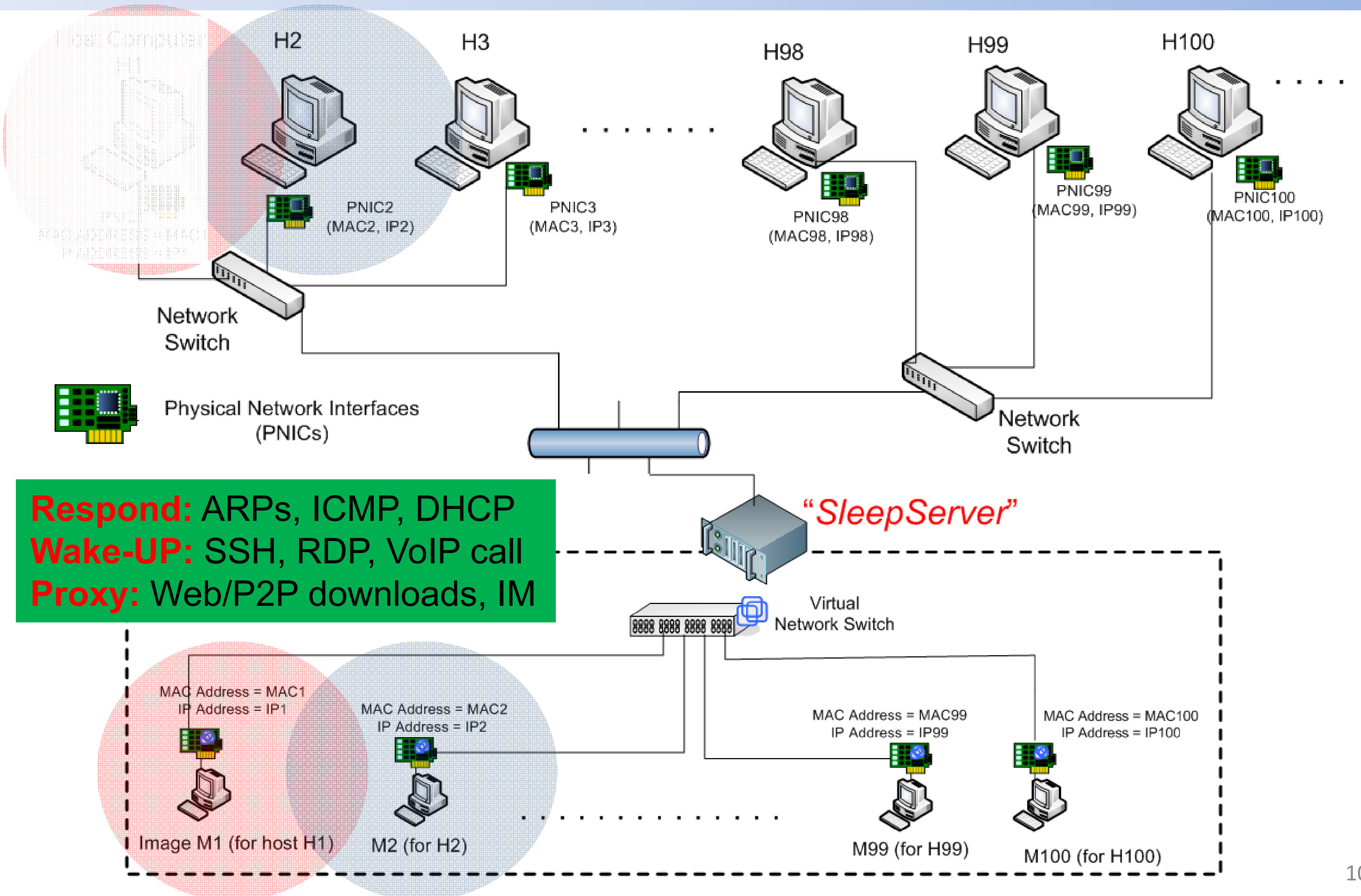
Barriers to “duty-cycling” of Computers

- Must maintain desktop state
- Must maintain availability, network connectivity
  - Background traffic: ICMP, ARPs
  - Occasional access: RDP, SSH, SMB, patches, ..
  - Background applications:
    - Presence/Communication: VoIP (Skype, SIP), IM, Bonjour
    - Unattended Downloads: HTTP, BitTorrent (P2P)
    - Server based applications: Apache, [media streamers]

Low-Power modes (e.g. Sleep, Hibernate) affect usability

Question: can we create “hybrid” states of operation where computers maintain *network presence* even in sleep modes?

Approach: *SleepServer* network proxy

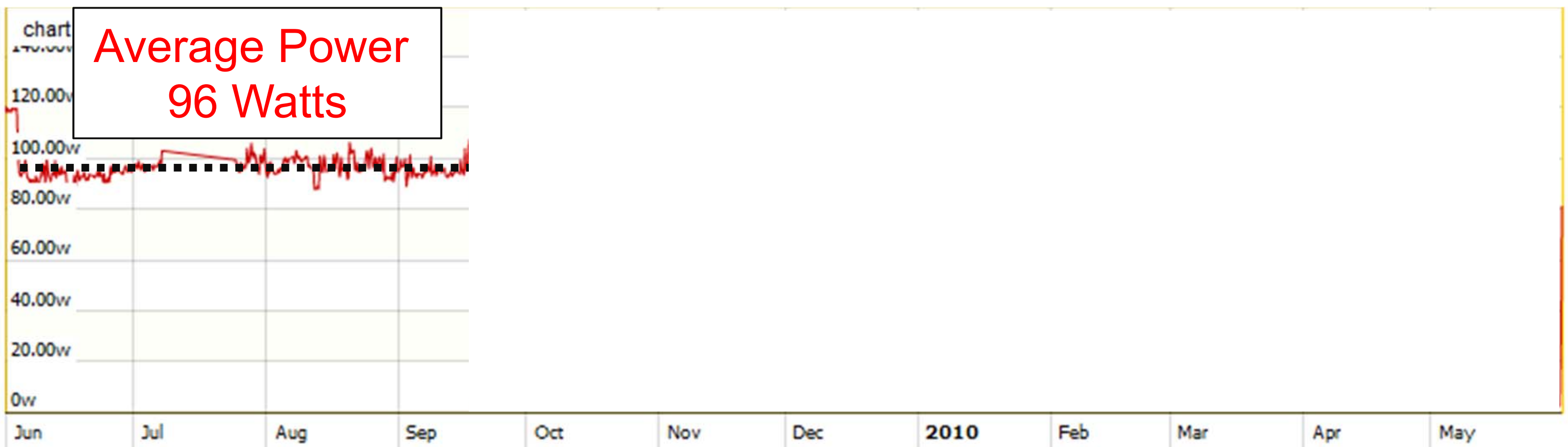


Respond: ARPs, ICMP, DHCP
Wake-UP: SSH, RDP, VoIP call
Proxy: Web/P2P downloads, IM

UCSanDiego | Energy Dashboard http://energy.ucsd.edu

Sample PC: 72% energy savings since *SleepServer* deployment

Energy Use: 113 kWh, **Average Power:**26 W
Energy Savings with Sleep Server: 72%
Annual Cost Savings with Sleep Server: $60



UC San Diego | Energy Dashboard http://energy.ucsd.edu

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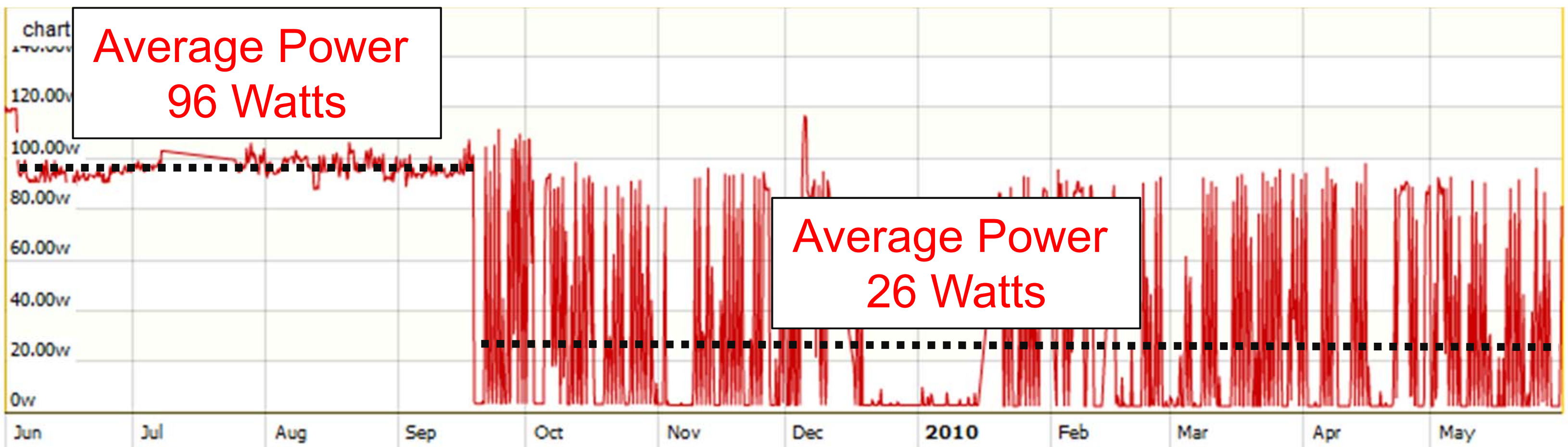

Deployed *SleepServers* across 50 users
Energy Savings: 27% - 85% (average 70%)
***2013*: `Proximity Mode' to save more energy**

Total estimated Savings for CSE (>900PCs) : $60K/year

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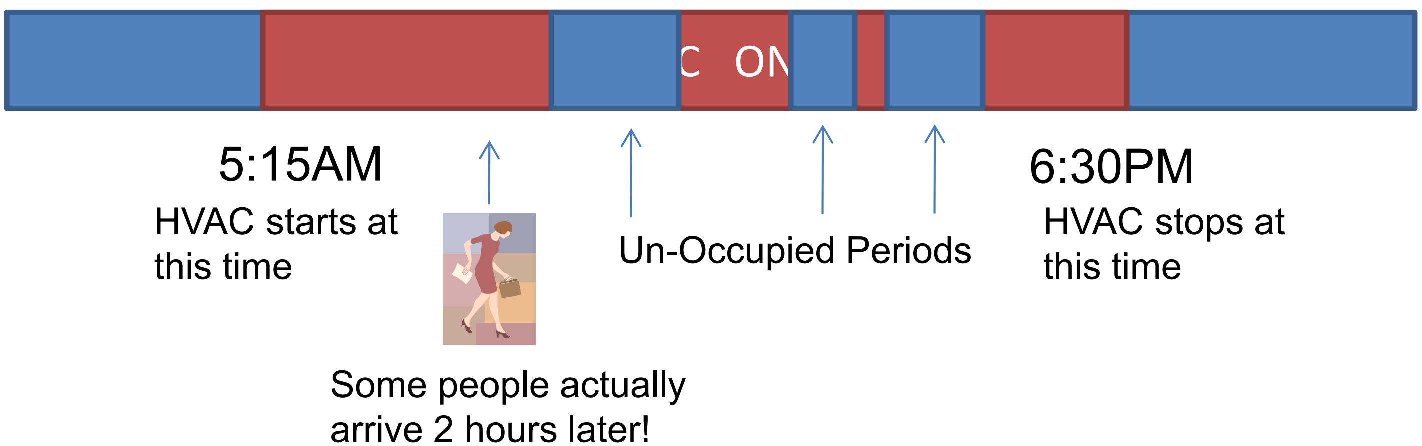
Reducing HVAC energy consumption

- Modern buildings have efficient HVAC systems
  - Central cooling + chilled water loop is common
- Unfortunately, use of static schedules prevalent
  - Energy wasted during periods of low occupancy



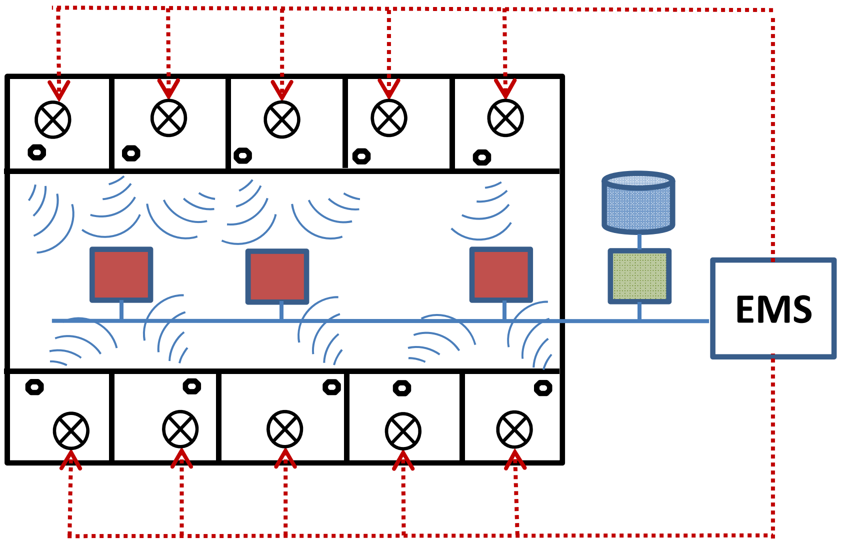
Points to the benefits of occupancy based control

Challenges in Determining Occupancy

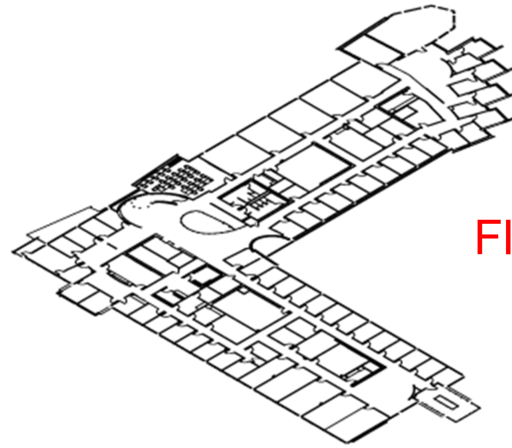
- Need inexpensive occupancy sensing solutions
  - Low (incremental) deployment *and* maintenance cost
  - Leverage existing infrastructure whenever possible
- Need accurate detection
  - False negatives cause discomfort: Actual=Occupied, Detect=Away
  - False positive waste energy: Actual=Away, Detect=Occupied
- Manage privacy, security and policy issues
  - Camera based solutions face significant barriers
  - Controlling HVAC systems affects building occupants

Occupancy Driven HVAC Control

- Key Idea: Use real-time occupancy to drive HVAC
  - Multiple sensors (PIR + door switch), wireless, battery
  - Infer occupancy by network traffic (Sentinel-*SenSys'13*)
  - Data analysis and control → Interface with EMS
  - Use existing HVAC VAV boxes as Actuators



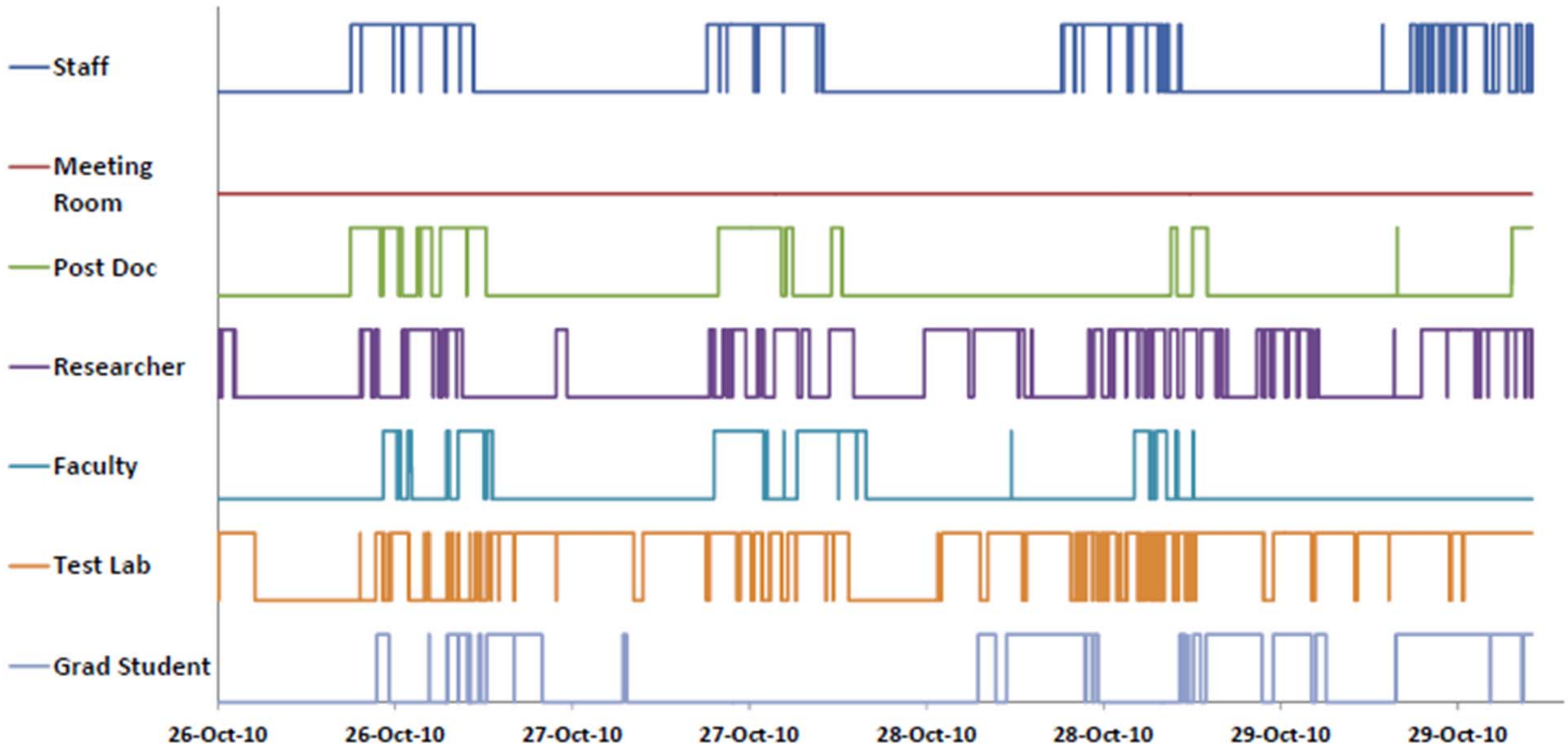
Deployment: One entire floor in CSE



Floormap: 2nd Floor

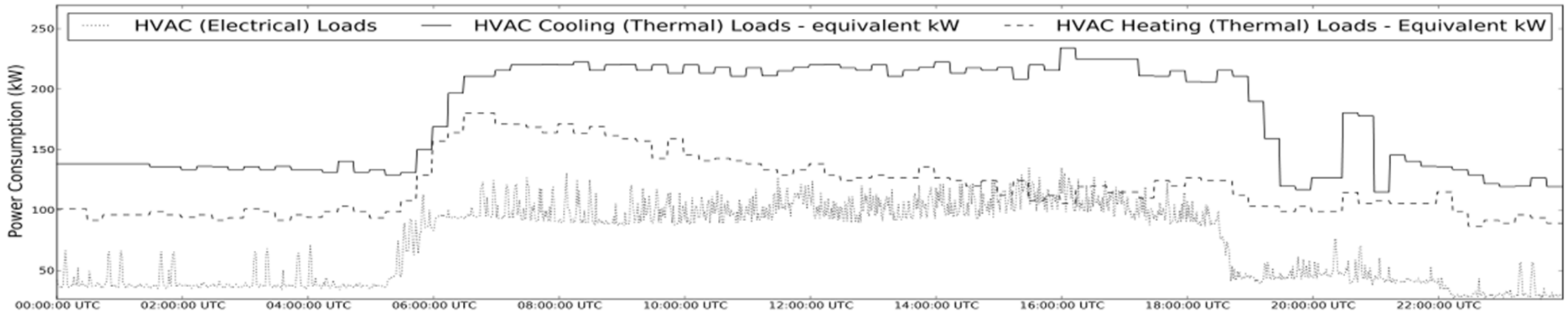
- CSE Building @ UCSD is densely metered
  - Lighting, Machine Room, Plug-Loads, HVAC
  - HVAC Thermal: Chilled/Hot water from campus loop
  - HVAC Electrical: Fans/Air handlers, pumps, dampers,
- 4 Floors+ Basement – we deployed on the 2nd floor
  - 50 Offices, 20 labs → covered using 8 base stations

Example Occupancy Patterns

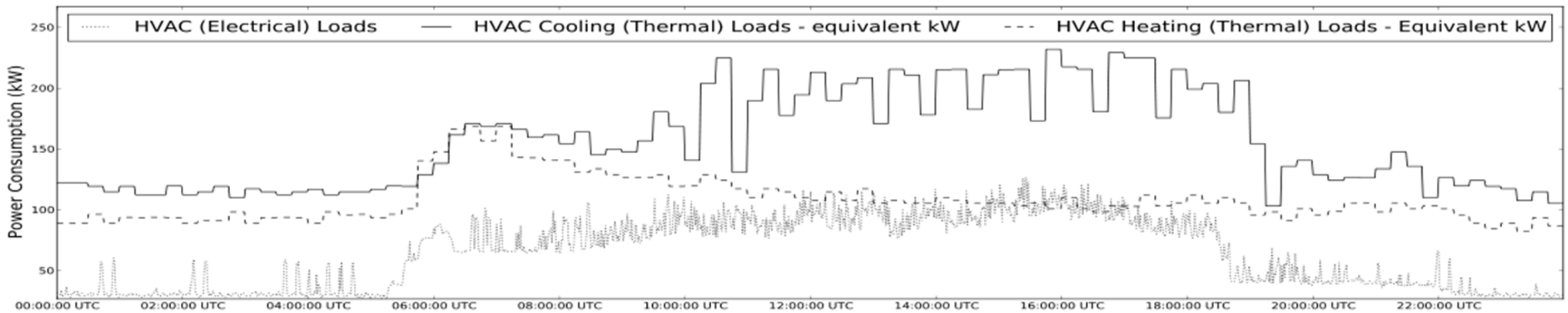


- Clearly shows that faculty work less than grad students!
- Significant diversity in occupancy patterns
- Sensor over 96% accurate, no false negatives

Result: Significant HVAC Energy Savings



HVAC Energy Consumption (Electrical and Thermal) during the baseline day.



HVAC Energy Consumption (Electrical and Thermal) for a test day with a similar weather profile. HVAC energy savings are significant: 11.6% (HVAC-Electrical), 12.4% for cooling and 9.6% for heating (HVAC-Thermal) for just the 2nd floor

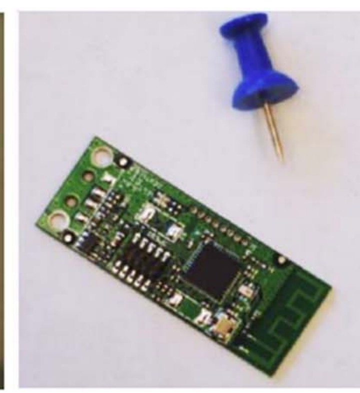
Estimated ~30% savings if deployed across CSE@UCSD

Detailed occupancy can be used to drive other systems

Managing Plug-Loads within Buildings

- Accurate energy accounting, attribution and audit
- Reducing Plug-Load energy consumption
  - "Dark Loads": Distributed, diverse types, multiple owners
  - Key Idea: Measure and actuate based on "policies"
    - Building Administrators: Demand Response, Load Shed, …
    - Building Occupants: occupancy based actuation, …
- "Synergy" Smart Energy Meter (SEM):
  - Metering, control, load type detection, wireless (Zigbee), ….



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Managing Building Sensor Data and Systems

- Buildings generate a lot of data from various sources
  - BACNet, OPC, Custom Sensor Networks, …
  - e.g. UCSD/CSE alone has thousands of BACNet points
- Challenge: How should this data be stored/organized?
  - Capture natural structure and hierarchy of buildings
  - Scalable (data) and flexible (metadata) organization
- Challenge: Standardized interfaces to accessing data
  - Fine-grained mechanisms for accessing and sharing data
  - Standard API that can be used by application developers
- Need open-data driven architecture for buildings

BuildingDepot 2.0* Architecture

Visualize Maintain Analyze Control

Apps

Next generation building applications via standardized API

REST/ Native API

- Scalable, distributed data storage
- Metadata and contextual tagging
- Access control across users
- REST API for app development

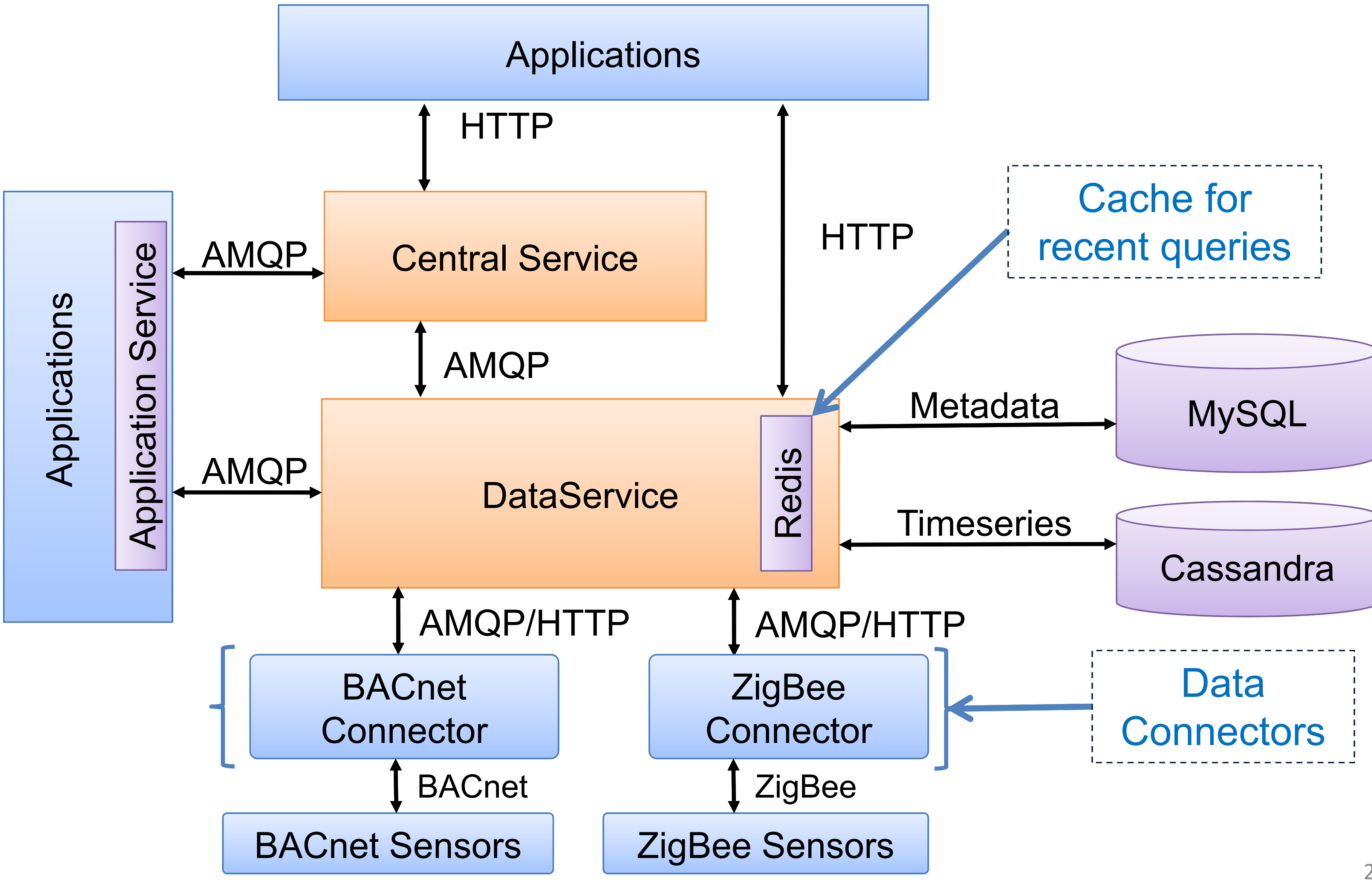
Data management system for sensors and actuators

Data Connectors

Building A Building B Building C Building D

Large amount of data generated in modern buildings

BuildingDepot 2.0: Implementation

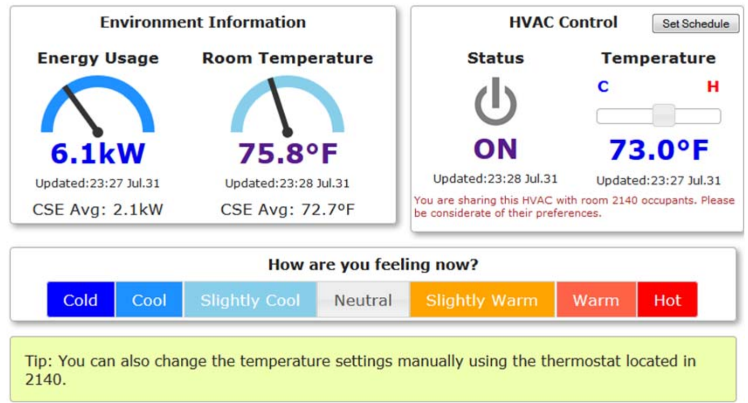


Example Applications: BD 2.0

Visualize

+

Control



- ZonePac*: Real-time feedback of estimated HVAC power and other parameters => control

- *BuildingViz*: Interactive 3D interface to view real time building data and control/interact

Several more Smart Building "Apps" coming!

* ZonePAC: Zone Power Estimation and Control via HVAC Metering and Occupant Feedback. B. Balaji, H. Teraoka, R. Gupta and Y. Agarwal, In BuildSys 2013

Smart Buildings: Opportunities

- Several interesting research challenges
  - – Privacy, Anonymity: rich occupant data
  - – Security, Access Control: ability to actuate
  - – Scalability: real-time processing of data streams
- *BuildingDepot* enables research opportunities
  - – Building control: occupancy based, predictive, …
  - – Data analysis: anomaly and waste detection, …
  - – Empirical modeling: Simulation, cost-benefit analysis
  - – Visualization: Dashboards, 3D models, ...

Open platforms enable community involvement!

ACM BuildSys

Thank you!

:: Energy Efficient Systems
:: Smart Buildings
:: Mobile Computing

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http://www.synergylabs.org