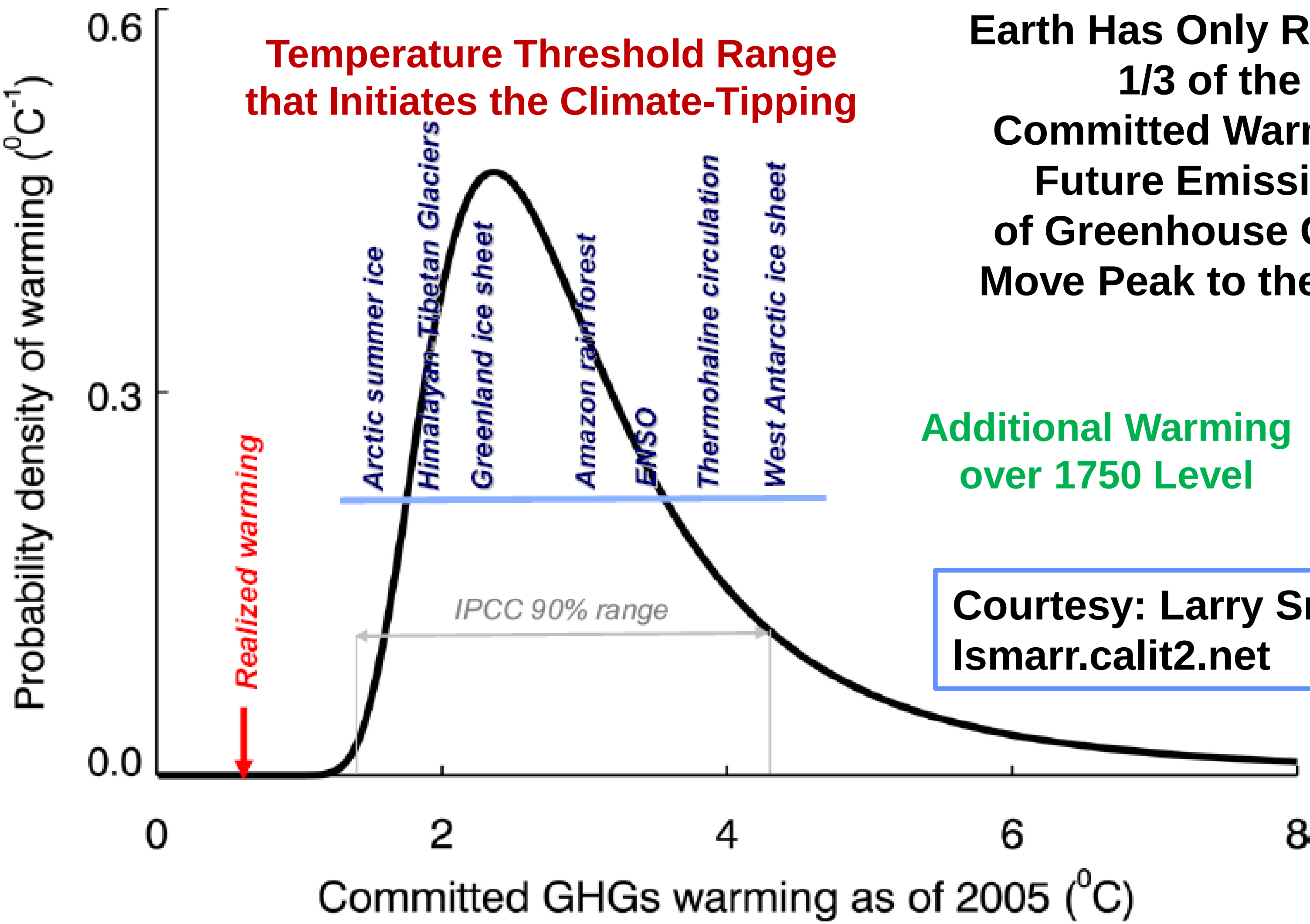
The Planet is Already Committed to a Dangerous Level of Warming



Earth Has Only Realized 1/3 of the Committed Warming - Future Emissions of Greenhouse Gases Move Peak to the Right

Additional Warming over 1750 Level

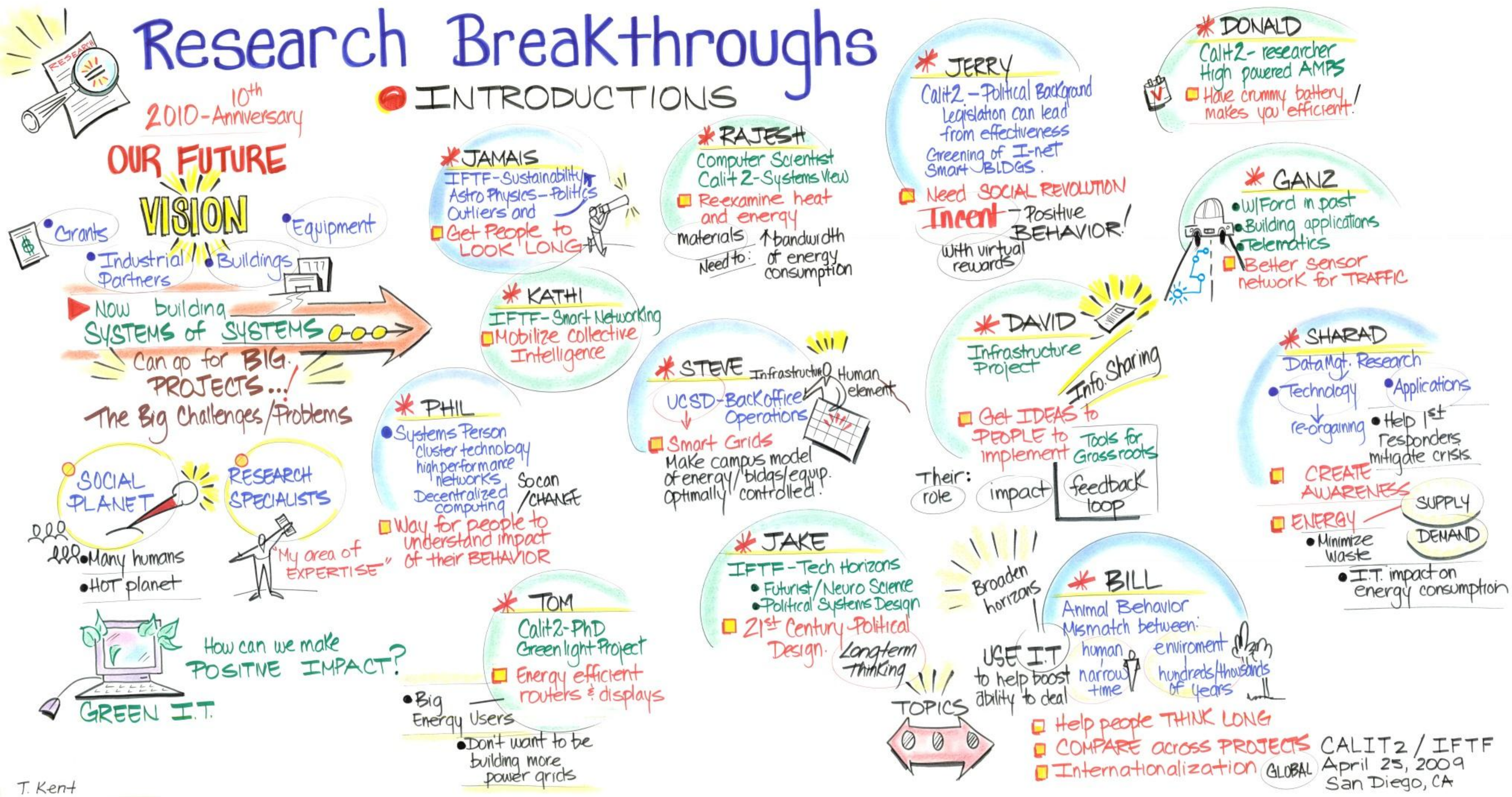
Courtesy: Larry Smarr
lsmarr.calit2.net

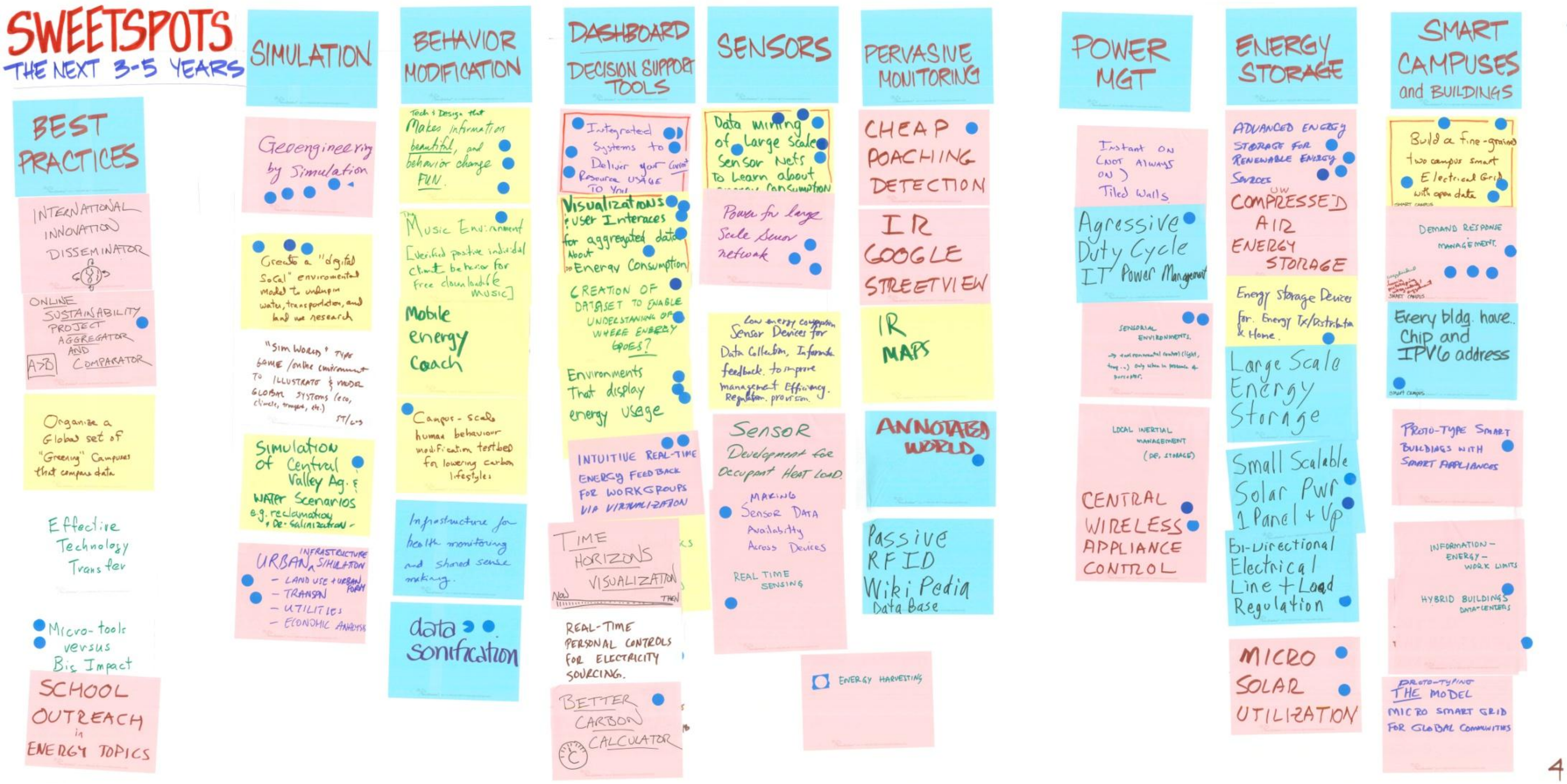
V. Ramanathan and Y. Feng, Scripps Institution of Oceanography, UCSD
September 23, 2008
www.pnas.orgcgidoi10.1073pnas.0803838105

UCSD UCIrvine

A Weekend in April 2009

Participants




SWEETSPOTS
THE NEXT 3-5 YEARS
SIMULATION
BEHAVIOR MODIFICATION
DASHBOARD DECISION SUPPORT TOOLS
SENSORS
PERVASIVE MONITORING
POWER MGT
ENERGY STORAGE
SMART CAMPUSES and BUILDINGS
BEST PRACTICES
INTERNATIONAL INNOVATION DISSEMINATOR
ONLINE SUSTAINABILITY PROJECT AGGREGATOR AND COMPARATOR
Organize a Global set of "Greening" Campuses that compare data
Effective Technology Transfer
Micro-tools versus Big Impact
SCHOOL OUTREACH in ENERGY TOPICS
Geoengineering by Simulation
Simulation of Central Valley Ag. & WATER Scenarios
Tech & Design that Makes information beautiful, and behavior change FUN.
Mobile energy Coach
Campus-scale human behavior modification testbed for lowering carbon lifestyles
Infrastructure for health monitoring and shared sense making.
data sonification
Integrated Systems to Deliver your Resource USAGE TO You
Visualizations & user Interfaces for aggregated data About Energy Consumption
CREATION OF DATASET TO ENABLE UNDERSTANDING OF WHERE ENERGY GOES?
Environments That display energy usage
INTUITIVE REAL-TIME ENERGY FEEDBACK FOR WORKGROUPS VIA VIRTUALIZATION
TIME HORIZONS VISUALIZATION
REAL-TIME PERSONAL CONTROLS FOR ELECTRICITY SOURCING.
BETTER CARBON CALCULATOR
Data mining of Large Scale Sensor Nets To Learn about energy Consumption
Power for large Scale Sensor network
Low energy consumption Sensor Devices for Data Collection, Information feedback to improve management Efficiency
Sensor Development for Occupant Heat Load
MAKING Sensor DATA Availability Across Devices
REAL TIME SENSING
ENERGY HARVESTING
CHEAP POACHING DETECTION
IR GOOGLE STREETVIEW
IR MAPS
ANNOTATED WORLD
Passive RFID Wiki Pedia Data Base
Instant ON (NOT ALWAYS ON) Tiled Walls
Agressive Duty Cycle IT Power Management
CENTRAL WIRELESS APPLIANCE CONTROL
ADVANCED ENERGY STORAGE FOR RENEWABLE ENERGY SOURCES
COMPRESSED AIR ENERGY STORAGE
Energy storage Devices for Energy Tx/Distribution & Home
Large Scale Energy Storage
Small Scalable Solar Pwr 1 Panel + Up
Bi-Directional Electrical Line + Load Regulation
MICRO SOLAR UTILIZATION
Build a fine-grained two campus smart Electrical Grid with open data
DEMAND RESPONSE MANAGEMENT
Every bldg. have Chip and IPV6 address
PROTO-TYPE SMART BUILDINGS WITH SMART APPLIANCES
INFORMATION - ENERGY - WORK LIMITS
HYBRID BUILDINGS DATA-CENTERS
PROTO-TYPING THE MODEL MICRO SMART GRID FOR GLOBAL COMMUNITIES
4

Sustainability 2.0

Rajesh Gupta
UC San Diego

DIMACS, September 2011

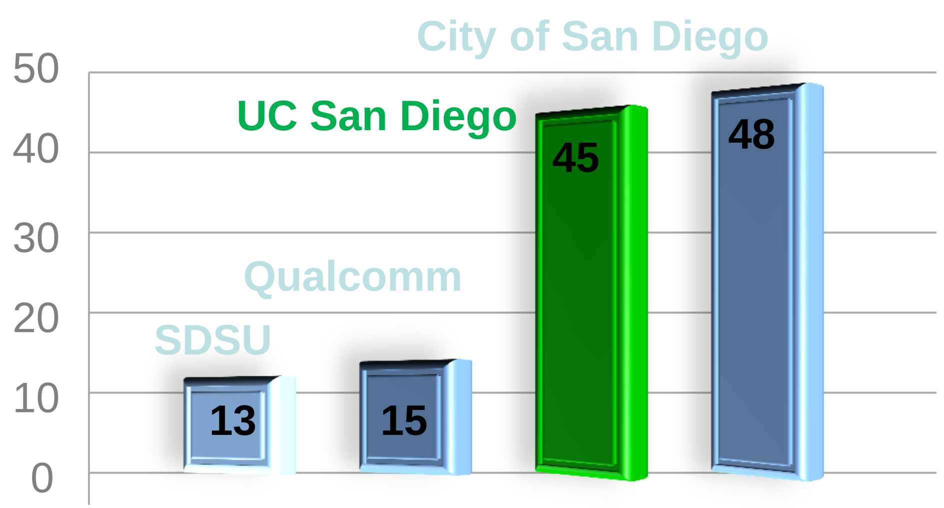
Presentation Courtesy: Steve Relyea, Larry Smarr, David Weil, Yuvraj Agarwal.

With a daily population of over 45,000, UC San Diego is the size and complexity of a small city.

As a research and medical institution, we have a higher consumption of energy than comparable communities.

Electricity

Peak demands (MW)

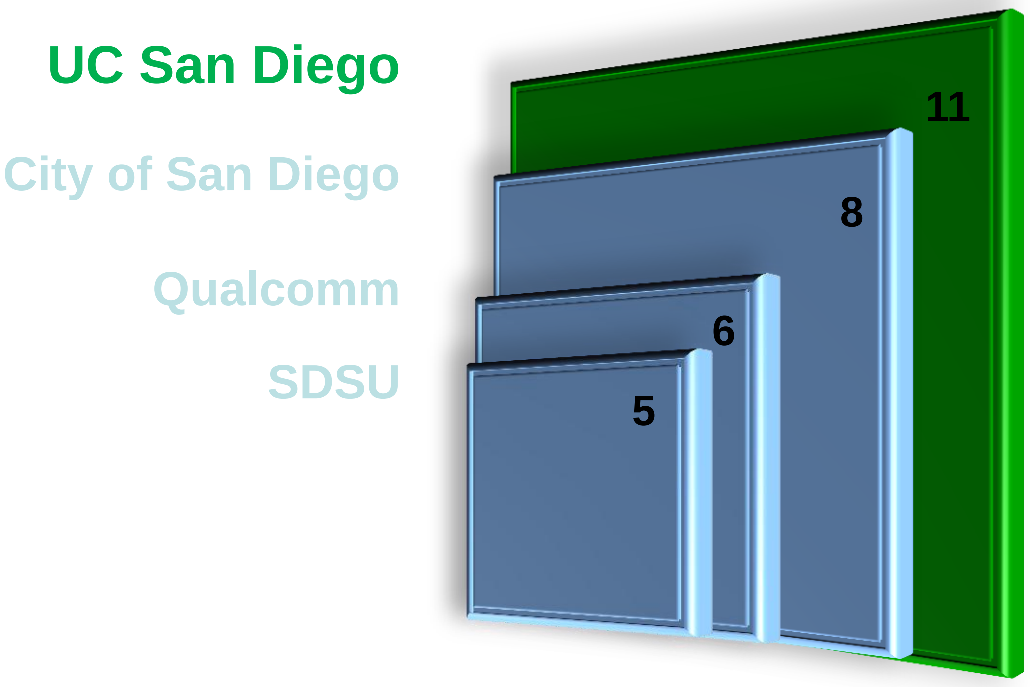


11 million sq. ft . of facility space, if we were a landlord, we would be one of the largest in San Diego

Included in the daily population of 45,000, we have over 8,000 student residents living on campus

Square Feet of Facility Space

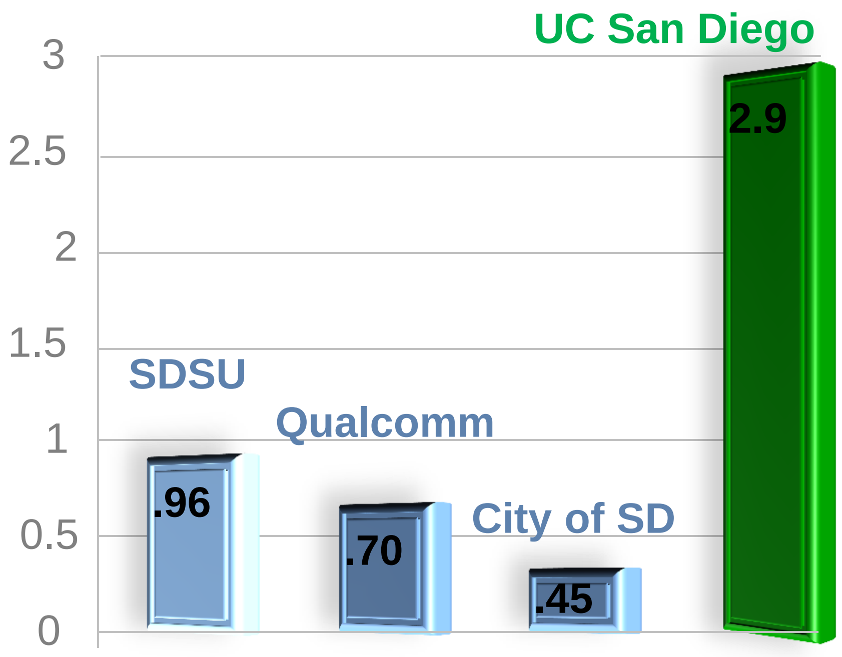
(in millions)



UC San Diego uses natural gas to fuel its power plant.

In order to reduce our dependence on natural gas, we are in the process of securing diverse sources of renewable energy

Annual Natural Gas Consumption (Million MMBtu)



Our Challenges

Future Energy Costs and Emissions Regulations may Inhibit UCSD'S Growth

- ☑ Energy Intensive Research University
- ☑ $1B of new buildings every 5 years
- ☑ Severe Operating Budget Reductions
- ☑ Restrictions from State and University

[redacted]

Sustainability 1.0

UC San Diego
Sustainability 2.0

Sustainability 1.0	UC San Diego Sustainability 2.0
Solar panels	**Large scale, high efficiency solar**
Timers & thermostats	**Real-time weather-optimized systems**
Ethanol fuel	**Advanced bio-fuels**
Water conservation	**Ocean water cooling, reclaimed systems**
Wind when available	**Wind optimization, storage, smart grid**
Recycling	**Targeting zero waste**
Measuring Emissions	**Emissions as a trade-able commodity**

Translating the Vision to

12 Key Elements of Strategy

12 Key Elements of Strategy

Facilities & Operations E1	Transportation E2	Building Design E3	Smart Grid & Human UI E4	Recycling & Conservation E5	Advanced Energy Storage E6
Photovoltaic E7	Methane & Fuel Cells E8	Water Resources and Wind Energy E9	Faculty Leadership E10	Strategic Partnerships E11	Student Involvement E12

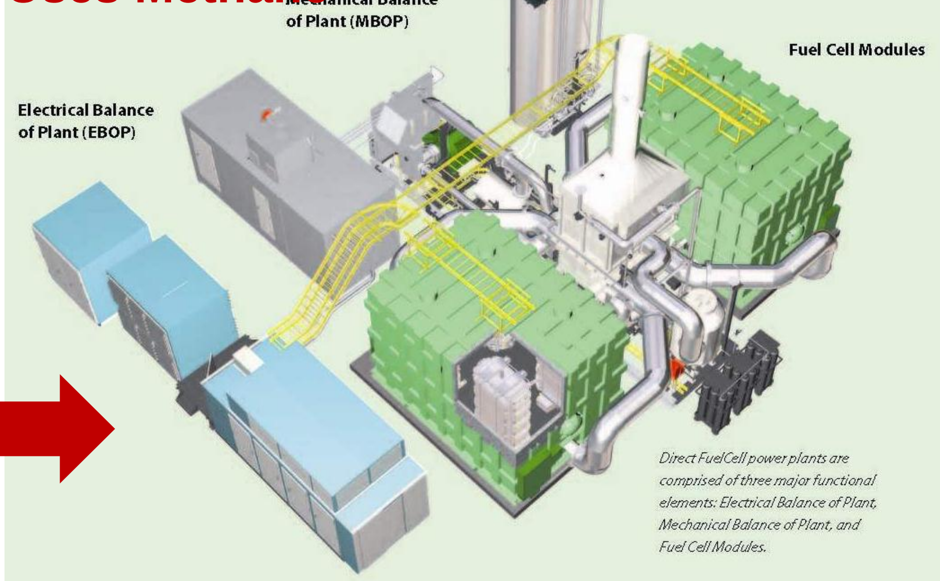
A Compelling Testbed

- 12,000 acres, 45,000 occupants, 8,000 residents
- 2 hospitals (with local generation), 15 restaurants
- 450 buildings, 11 million square fee of building space
- Over $250M in capital construction/year
- Generates 80% of its own electricity usage including
  - 2.8 MW fuel cells, 1.2 MW PV, Wind, 15% of daily energy stored
- Meters & Monitors everything:
  - 50K meters, 4.5K thermostats
- 16 weather stations, real-time monitoring,
  - tracks moving clouds across the campus to drive dynamic PV load shifts from 50 kW/sec to 1 kW/sec.
- Self-regulating entity, its own police.

UCSD is Installing Zero Carbon Emission Solar and Fuel Cell DC Electricity Generators

San Diego's Point Loma Wastewater Treatment Plant Produces Waste Methane

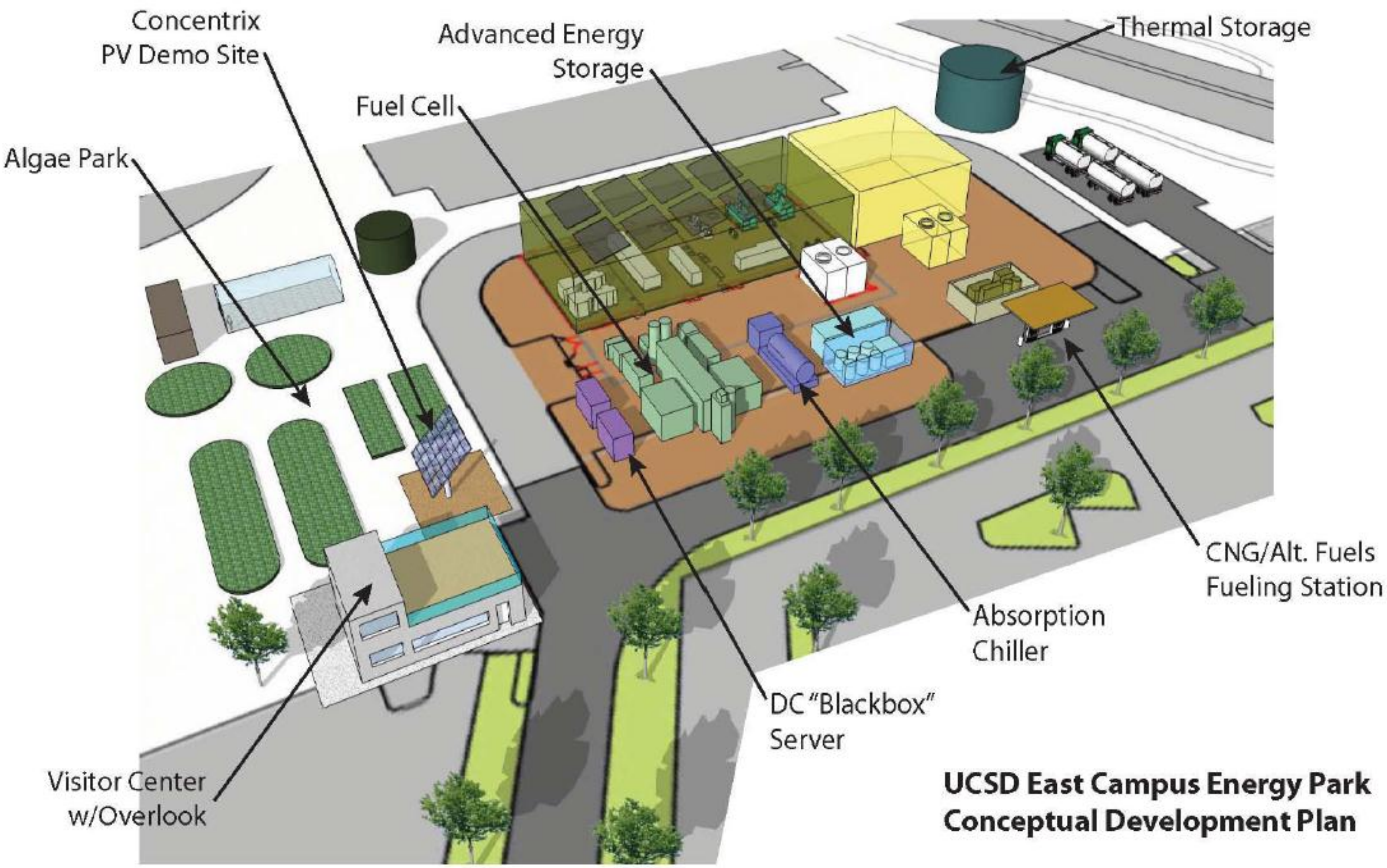
UCSD 2.8 Megawatt Fuel Cell Power Plant Uses Methane



2 Megawatts of Solar Power Cells Being Installed

UCSD
UCIrvine

Localized Co-Generation and storage of energy on the UCSD microgrid



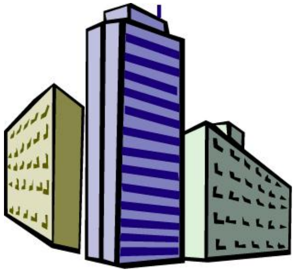
UCSD
UCIrvine

Buildings are important

BuildSys

- All electricity in the US: 3,500 TWh
  - ~500 power plants @7TWh
- Buildings: 2,500 TWh
- All electronics: 290 TWh

1 PC per 200 sq. foot
1 PC = $100
1W saved = ~2W less imported
= 5W less produced.



What is in that 290 TWh/year?

Location		Function	
Data Centers	13%	Computing	35%
Commercial	30%	Communication	19%
Residential	57%	Storage	4%
		Display	42%

Bruce Nordman, LBNL

$3/sq. foot

Buildings consume significant energy

>70% of total US electricity consumption

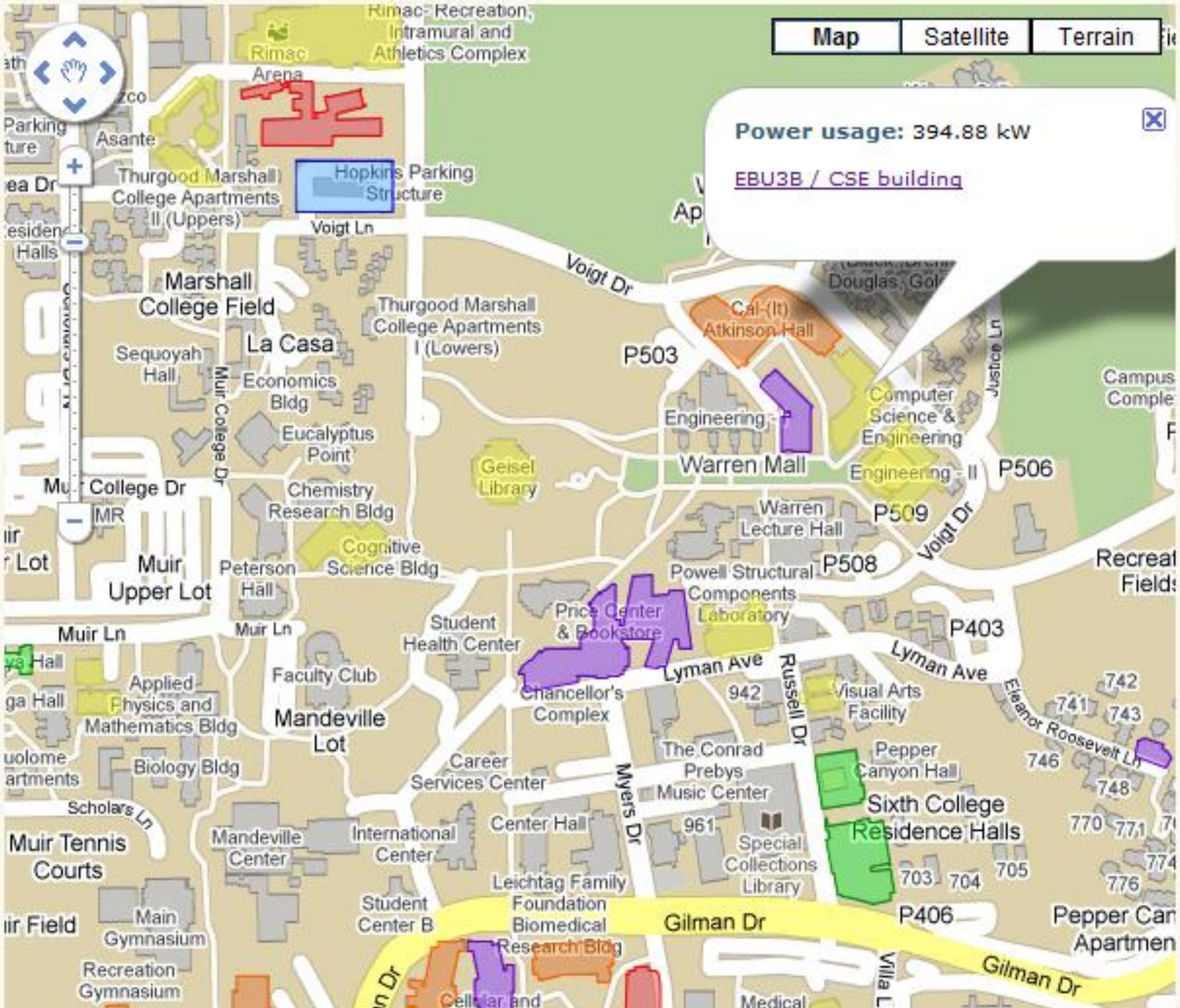
>40% of total carbon emissions

UCSanDiego | Energy Dashboard

Login

Home | Individual Devices | Campus Meters | Research | About

Campus Map



For the best view, keep the map set to the normal road map. The map can also be viewed in satellite and terrain formats.

To view the meters for a building, click the highlighted area of the building. An info window containing a link to the building meters will pop up.

Navigation is the same as in Google Maps.

- To zoom in/out, scroll the mouse wheel up/down.
- To recenter the map at another point, click and drag the mouse.

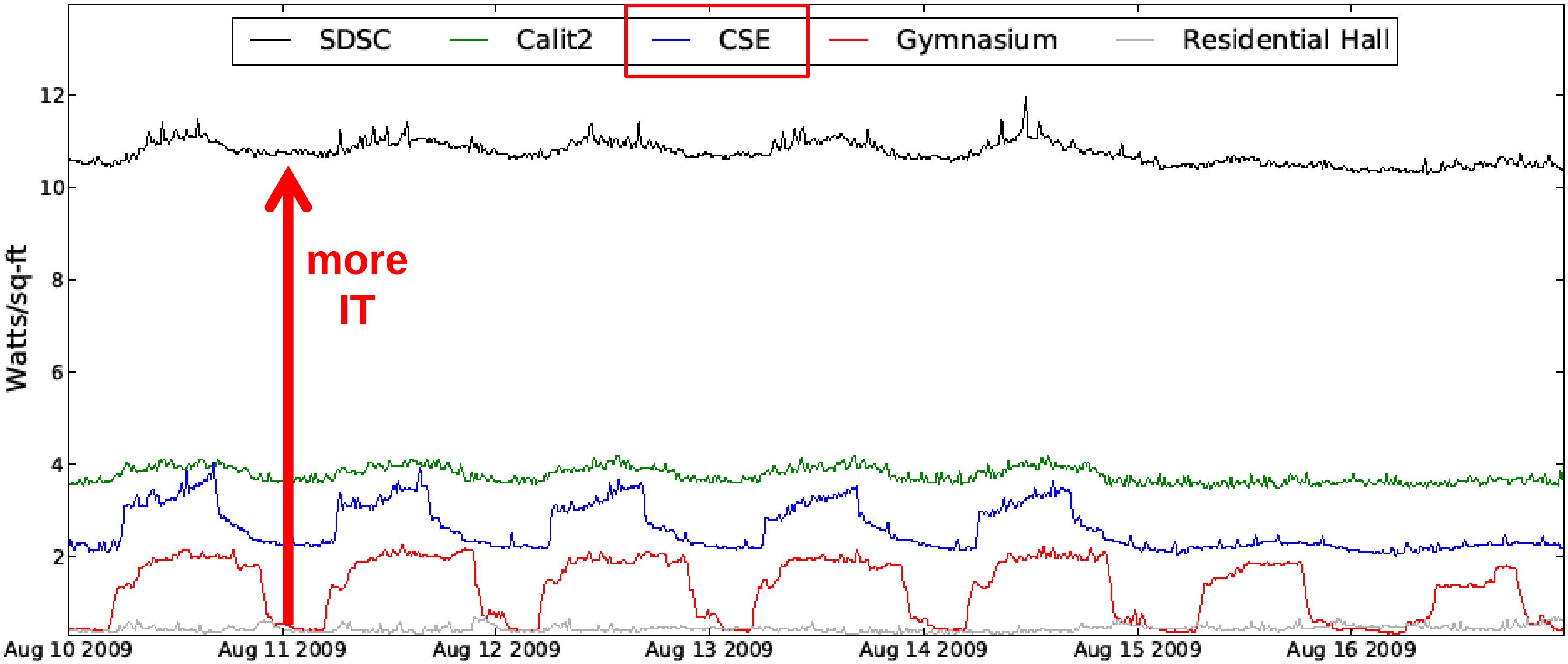
Scripps Institution of Oceanography is southwest of the main campus.

Colors for the buildings correspond to their individual power usage (on average):

- Red: 1000+ kW
- Orange: 500-1000 kW
- Yellow: 100-500 kW
- Green: 50-100 kW
- Blue: 50- kW
- Purple: Meter is currently out of service

Energy Dashboard
http://energy.ucsd.edu

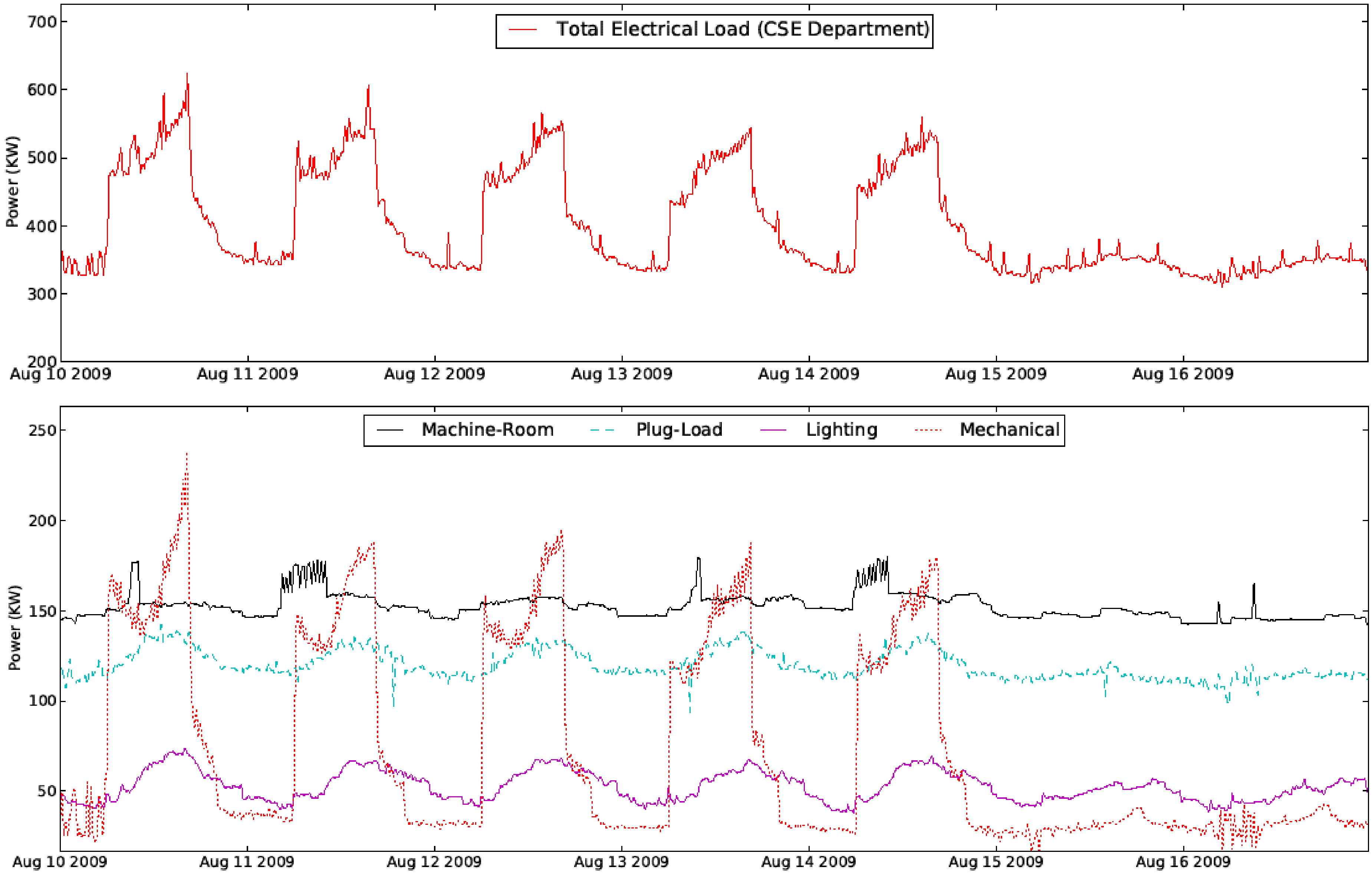
Looking across 5 types of buildings



From: Yuvraj Agarwal, et al, BuildSys 2009, Berkeley, CA.

Modern Buildings Are IT Dominated

50% of peak load, 80% of baseload

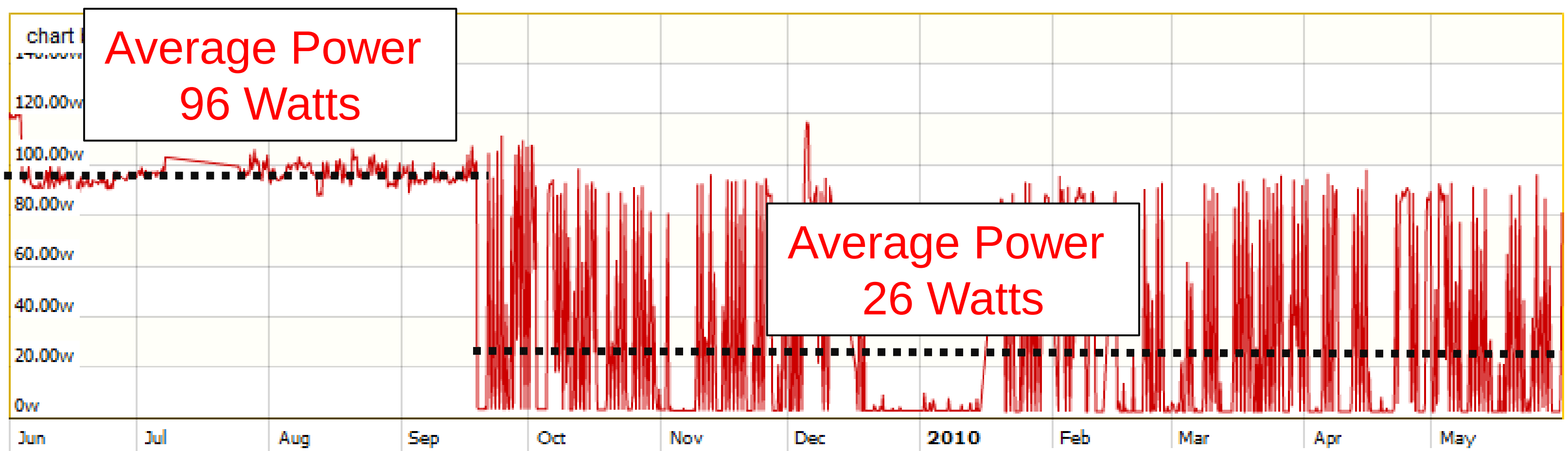


Making Buildings more Energy Efficient

- Reduce energy consumption by IT equipment
  - Servers and PCs left on to maintain network presence
  - Key Idea: "Duty-Cycle" computers aggressively
  - *Somniloquy [NSDI '09]* and *SleepServer [USENIX '10]*
- Reduce energy consumption by the HVAC system
  - Energy use is not proportional to number of occupants
  - Key Idea: Use real-time occupancy to drive HVAC
  - *Synergy occupancy* node *[BuildSys '10], HVAC Control [IPSN '11]*
- Reduce energy consumption by Plug-Loads
  - "Dark-loads" distributed over a building, diverse types
  - Key Idea: Measure and actuate based on "policies" *[BuildSys'11]*

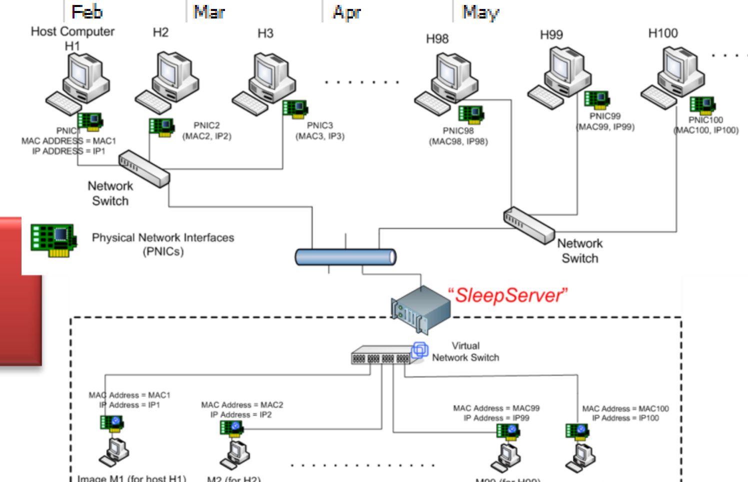
UCSanDiego | Energy Dashboard

Energy Use: 113 kWh, **Average Power:**26 W
Energy Savings with Sleep Server: 68%
Annual Cost Savings with Sleep Server: $60



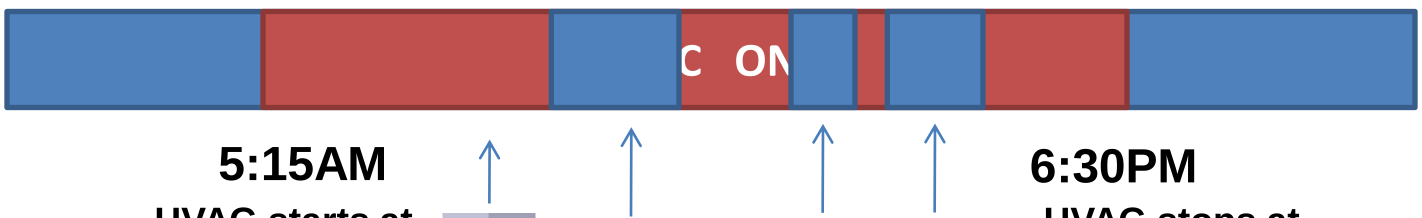
Deployed *SleepServers* across 50 users
Energy Savings: 27% - 85% (average 70%)

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



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



5:15AM
HVAC starts at this time

Some people actually arrive 2 hours later!

Un-Occupied Periods

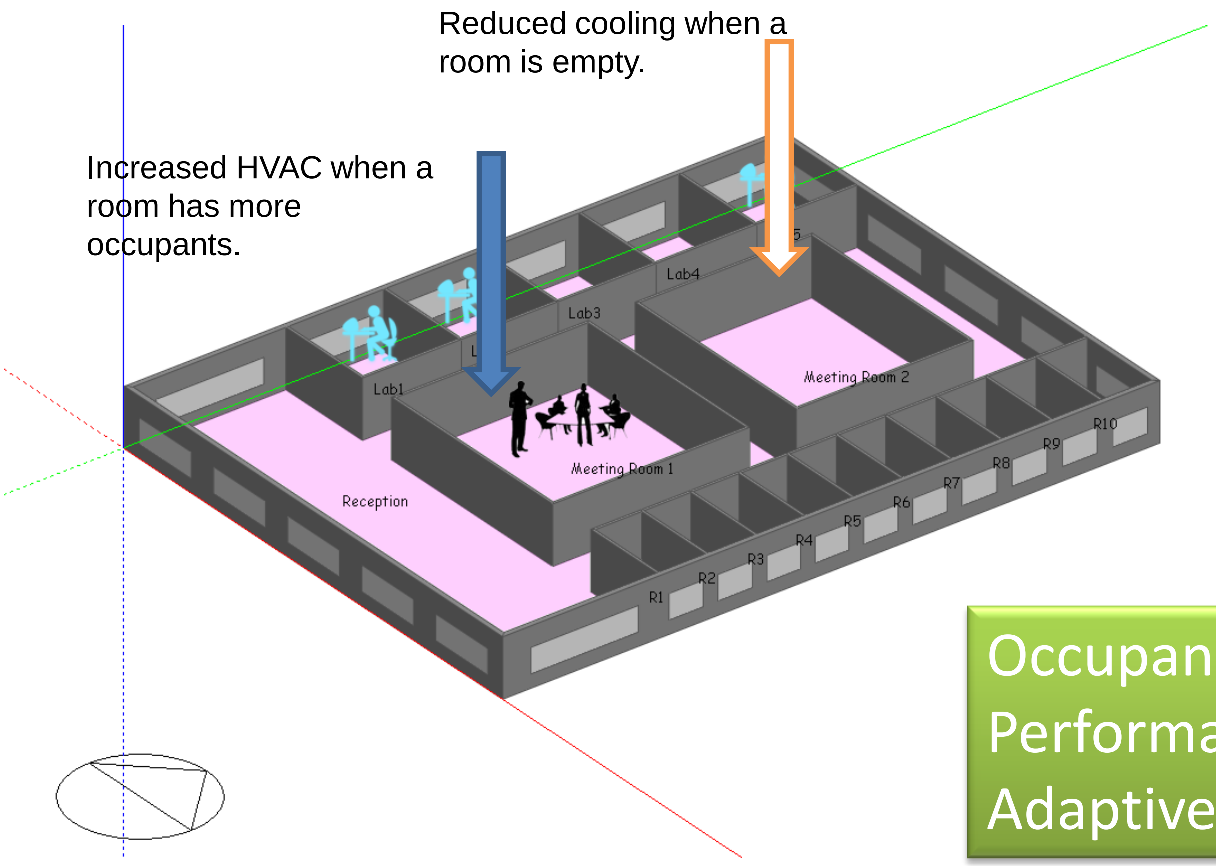
6:30PM
HVAC stops at this time

Use occupancy information.

24

Buildings 2.0: Occupancy-Driven Smart Buildings

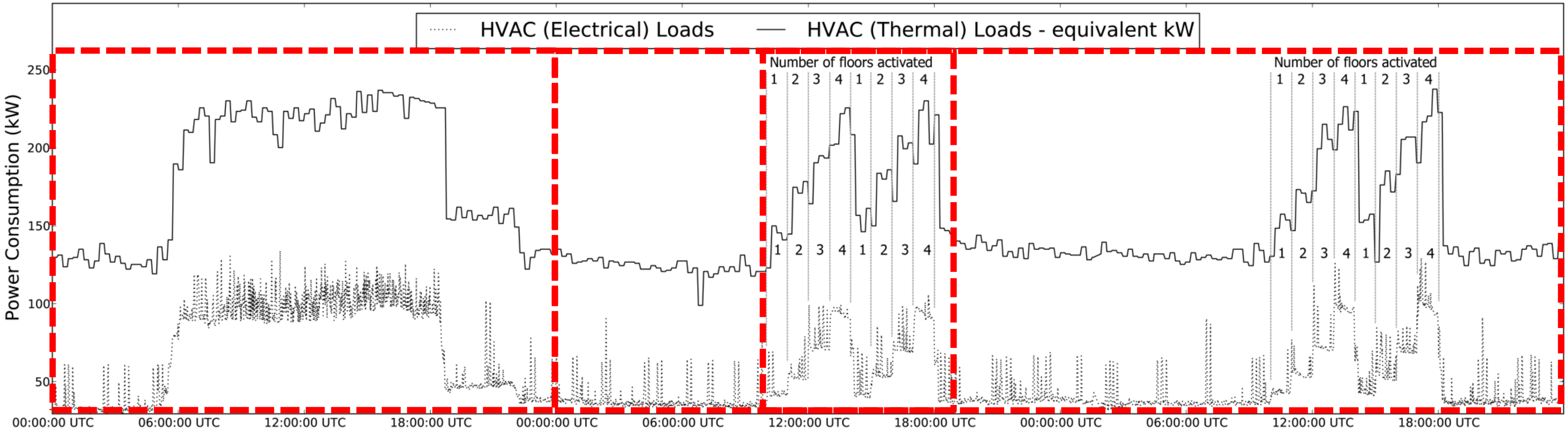
Use occupancy and activity to drive energy efficiency in HVAC system usage.



Occupancy
Performability
Adaptive Envelope

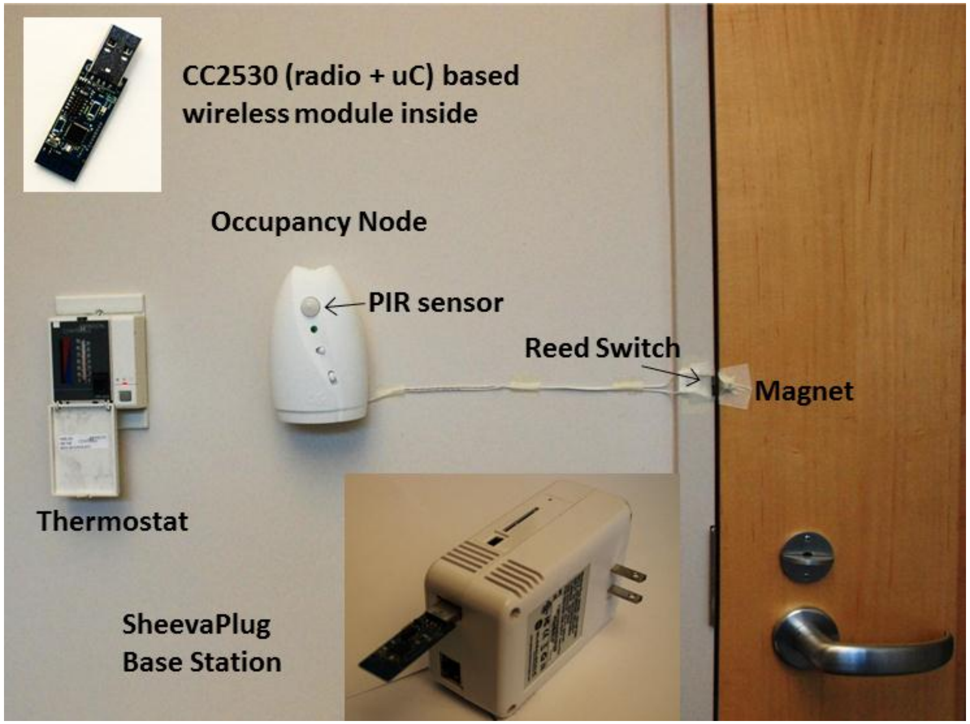
When there are less people in the room, reduce cooling. When there are more, increase cooling as required to maintain comfort.

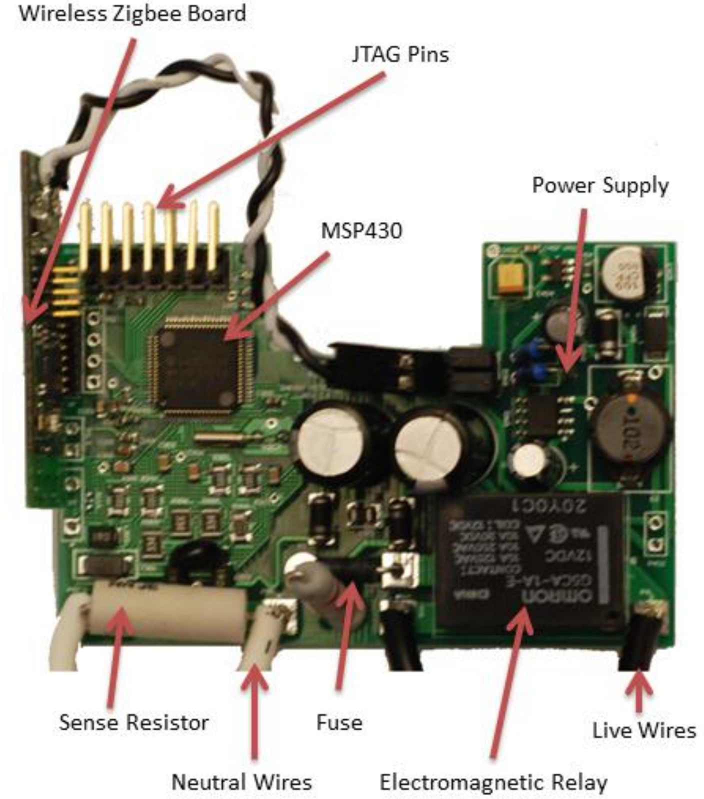
Relating HVAC Energy Use and Occupancy



- Controlled experiment in CSE over 3 days: Fri, Sat, Sun
  - Friday: Operate HVAC system normally
  - Weekend: HVAC duty-cycled on a floor-by-floor basis
  - 1 floor (10am – 11am), 2 floors (11am – 12pm), ….., …..
- Occupancy affects HVAC energy
  - Points to the benefits of fine-grained control

Occupancy Driven HVAC control

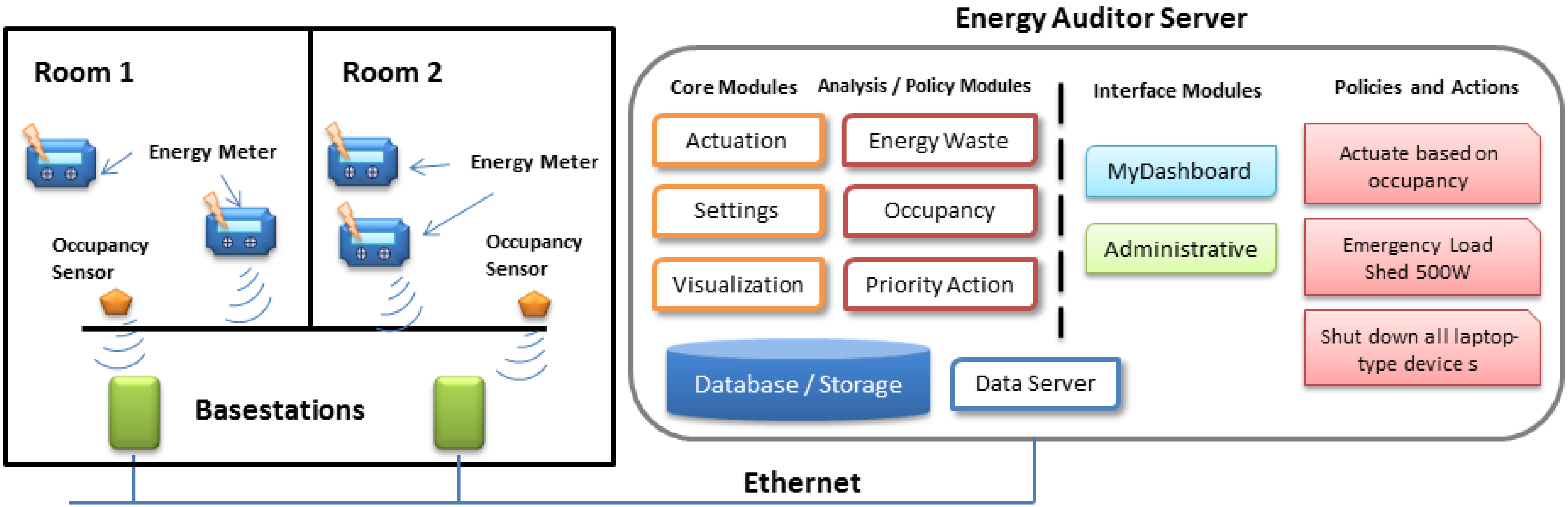




Synergy Occupancy Node
- CC2530 based design
- 8051 uC + 802.15.4 radio
- Zigbee compliant stack
- PIR + Magnetic reed switch

Key Design Requirements:
- Inexpensive (less than 10$)
- Battery powered – 4-5 year life
- Multiple sensors for accuracy

27



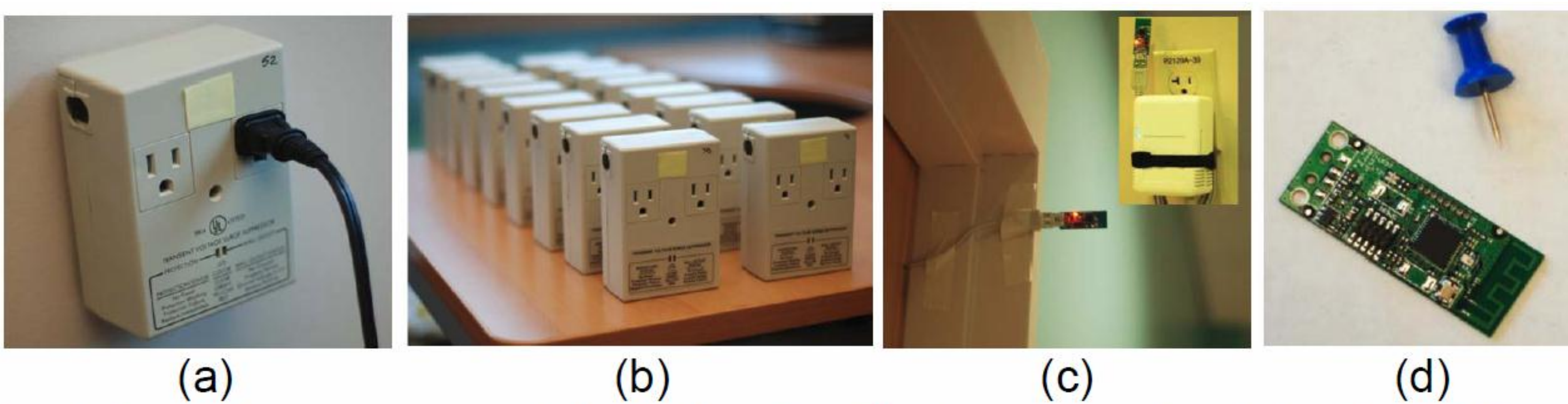
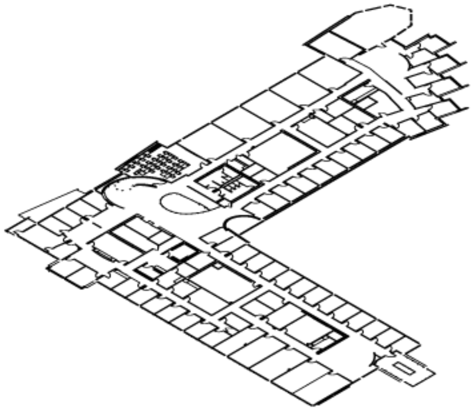


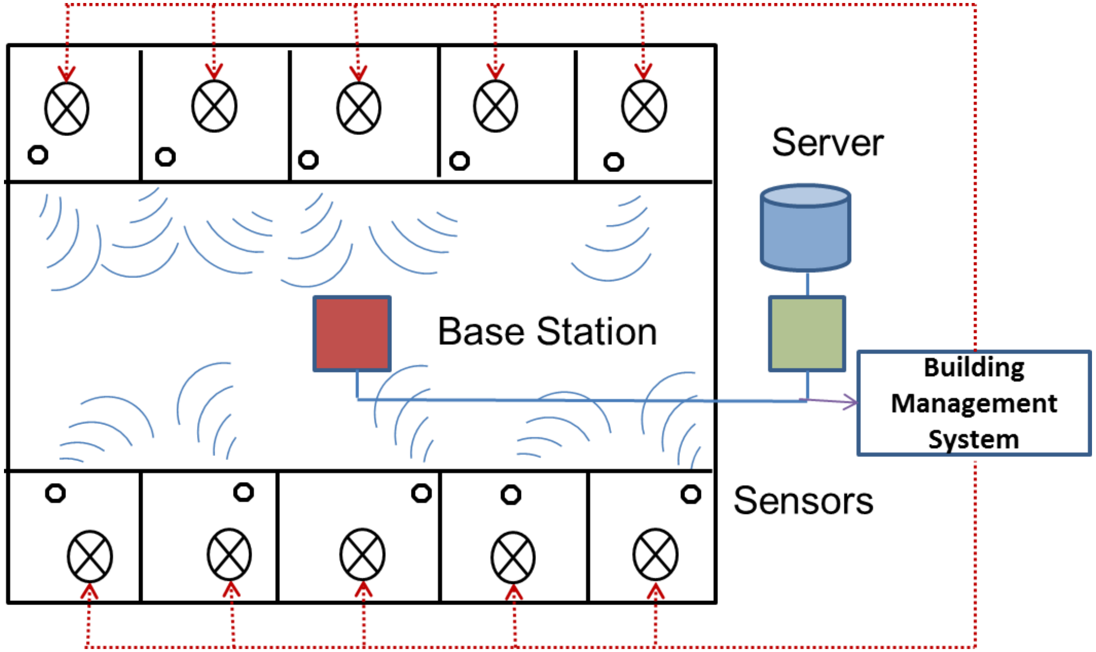
Figure 4. Picture of our energy meter (a, b) along with our SheevaPlug base station (c) that is deployed in the hallways. The CC2530 based wireless module that are in both the base station and the energy meters is also shown (d).

Deployment across 2nd floor of CSE



Floormap: 2nd Floor

- 50 Offices, 20 Labs.
- 8 Synergy Base Stations



Control individual HVAC zones based on real-time occupancy information!

29

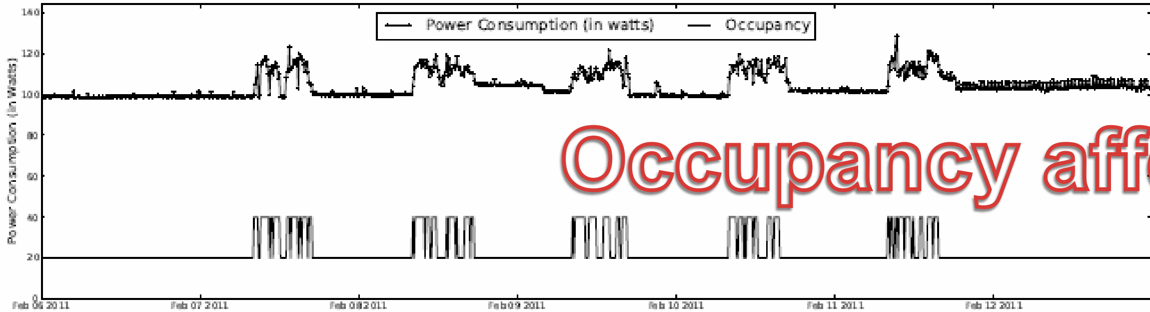


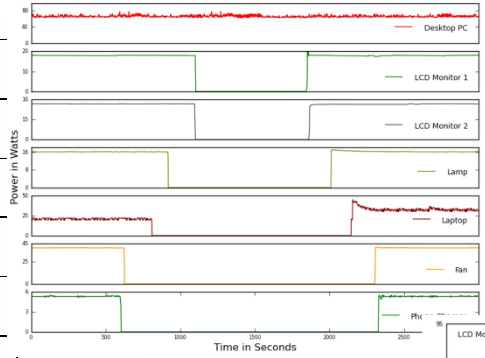
Figure 9. Occupancy of a staff worker and energy consumption of her computer. It becomes clear how much energy is wasted.

Occupancy affects energy use.

Plug loads vary but can be detected accurately.

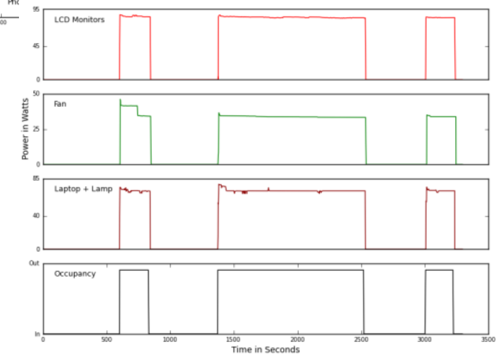
Load Type	Results
Monitors	14/17 (82.35%)
Desktop	8/8 (100%)
Lamp	4/4 (100%)
Laptop	4/4 (100%)
Others	6/7 (85.7%)
Total	36/40 (90%)

Table 1. Results of our load classification tests. For most general classes of devices, our algorithm works well and can recognize the load.

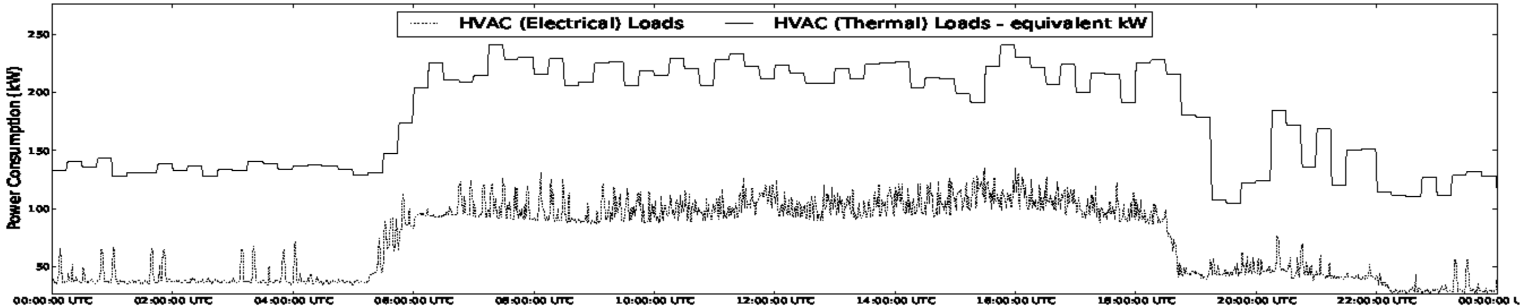


Priority-based actuation

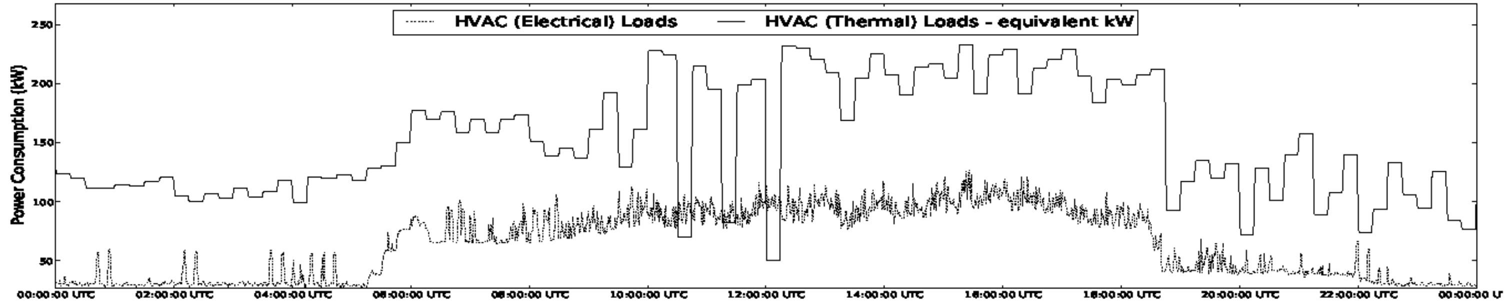
Occupancy-based actuation



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: over 13% (HVAC-Electrical) and 15.6% (HVAC-Thermal) for just the 2nd floor

Estimated 40% savings if deployed across entire CSE!

Detailed occupancy can be used to drive other systems.

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Summary: Buildings are a great place to start

- HVAC energy not proportional to occupancy
  - Use of static schedules is common
  - Significant energy wasted
- Fine-grained occupancy driven HVAC control
  - Occupancy node: accurate, low cost, wireless
  - Interface with existing building SCADA systems
- Evaluation: Deployment in the CSE building/UCSD
  - 11.6% (electrical) and 12.4% (thermal) savings
  - Estimate over 40% savings across entire building

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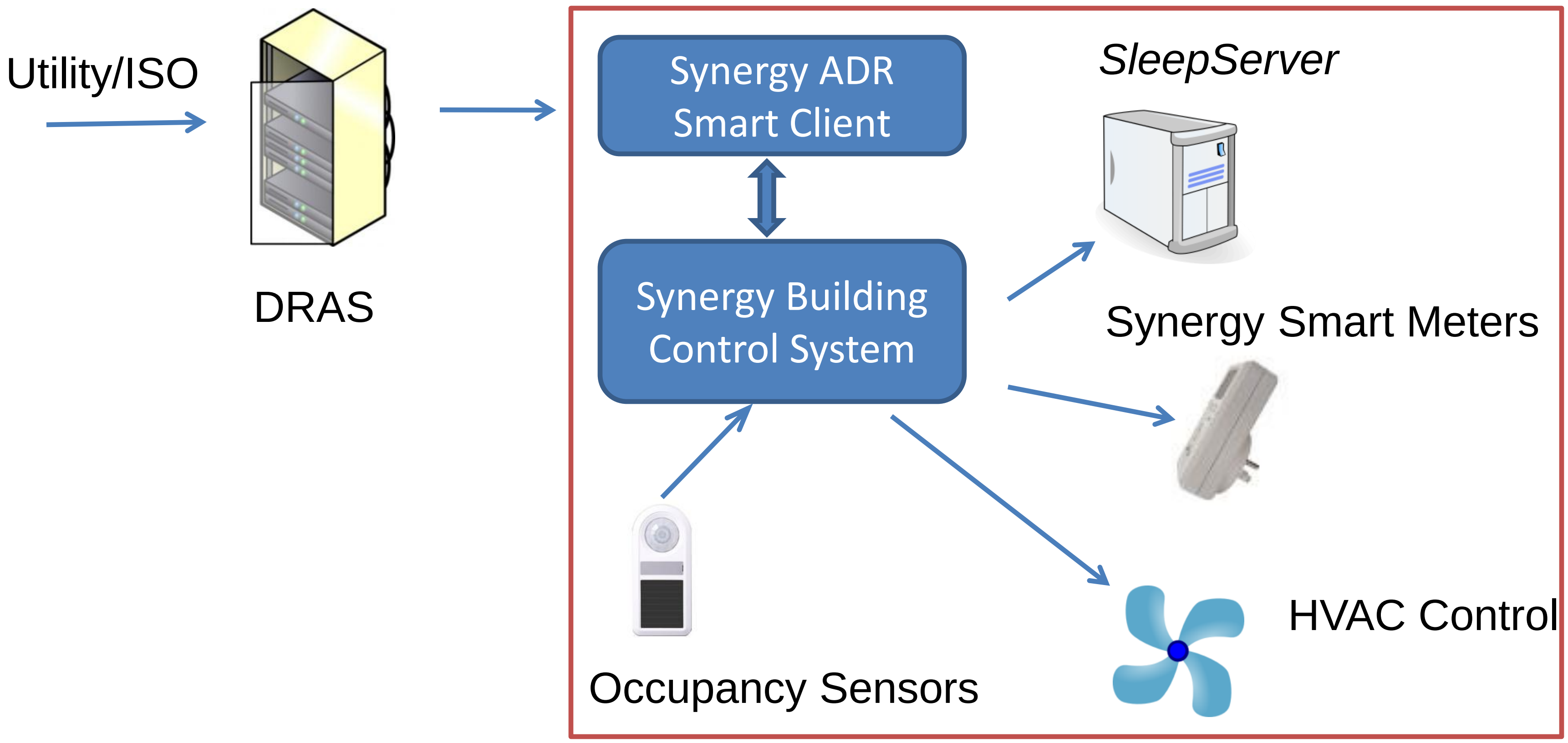
Beyond Energy Efficiency and Towards DR

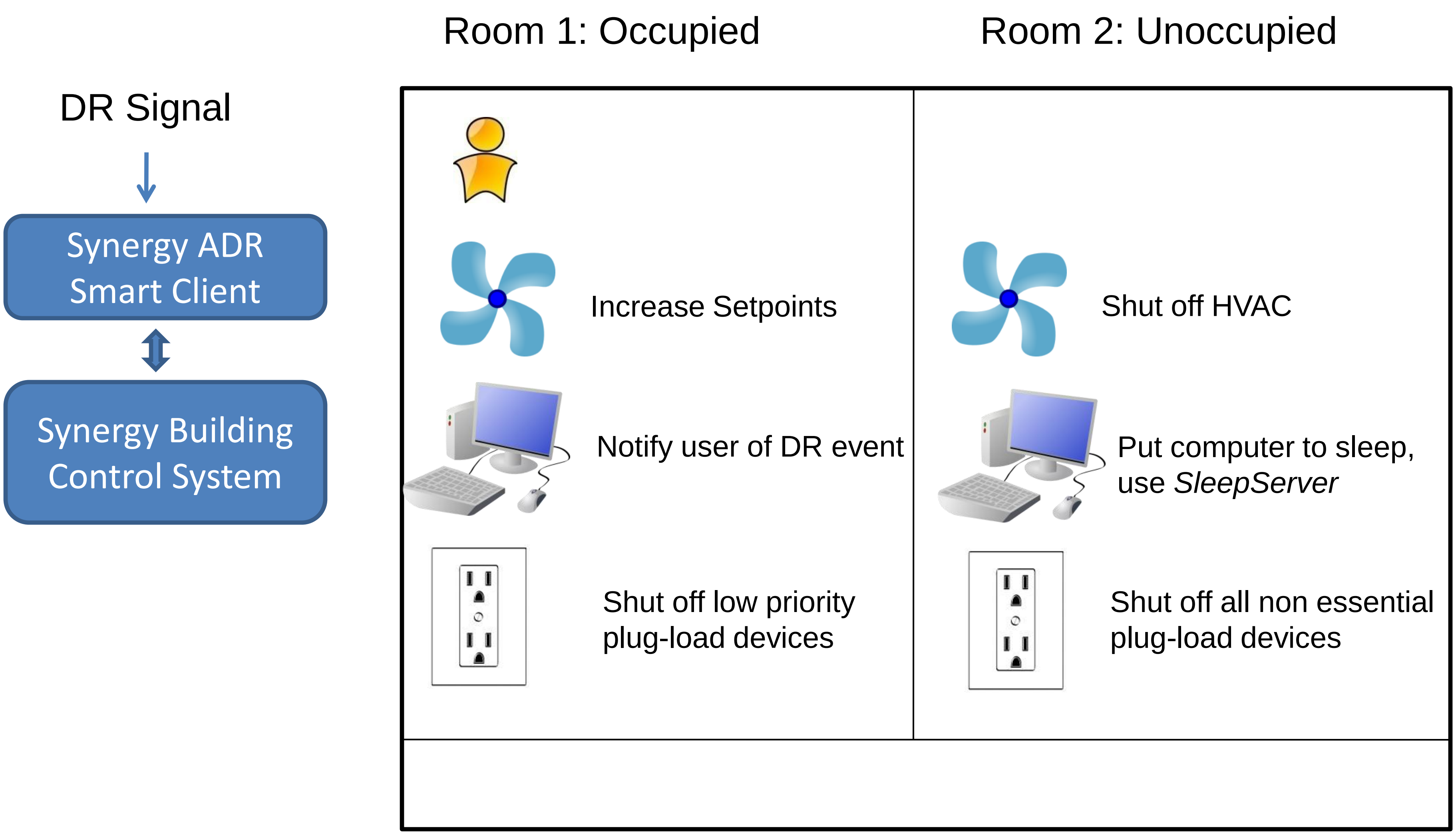
- Interfacing with the smart grid
  - Key feature of the smart grid is handling demand response events during peak days
  - Requires interfacing building with demand response signaling protocols: OpenADR
- OpenADR standard
  - Specifies demand response communications between utilities/ISOs and commercial buildings
    - NIST supported effort out of LBNL (OASIS, SGIP)
  - Critical challenge is in developing building clients that can take full advantage of these signals.

Interfacing with OpenADR

- Connecting our system with demand response automation server (DRAS)



Example Demand Response Scenario

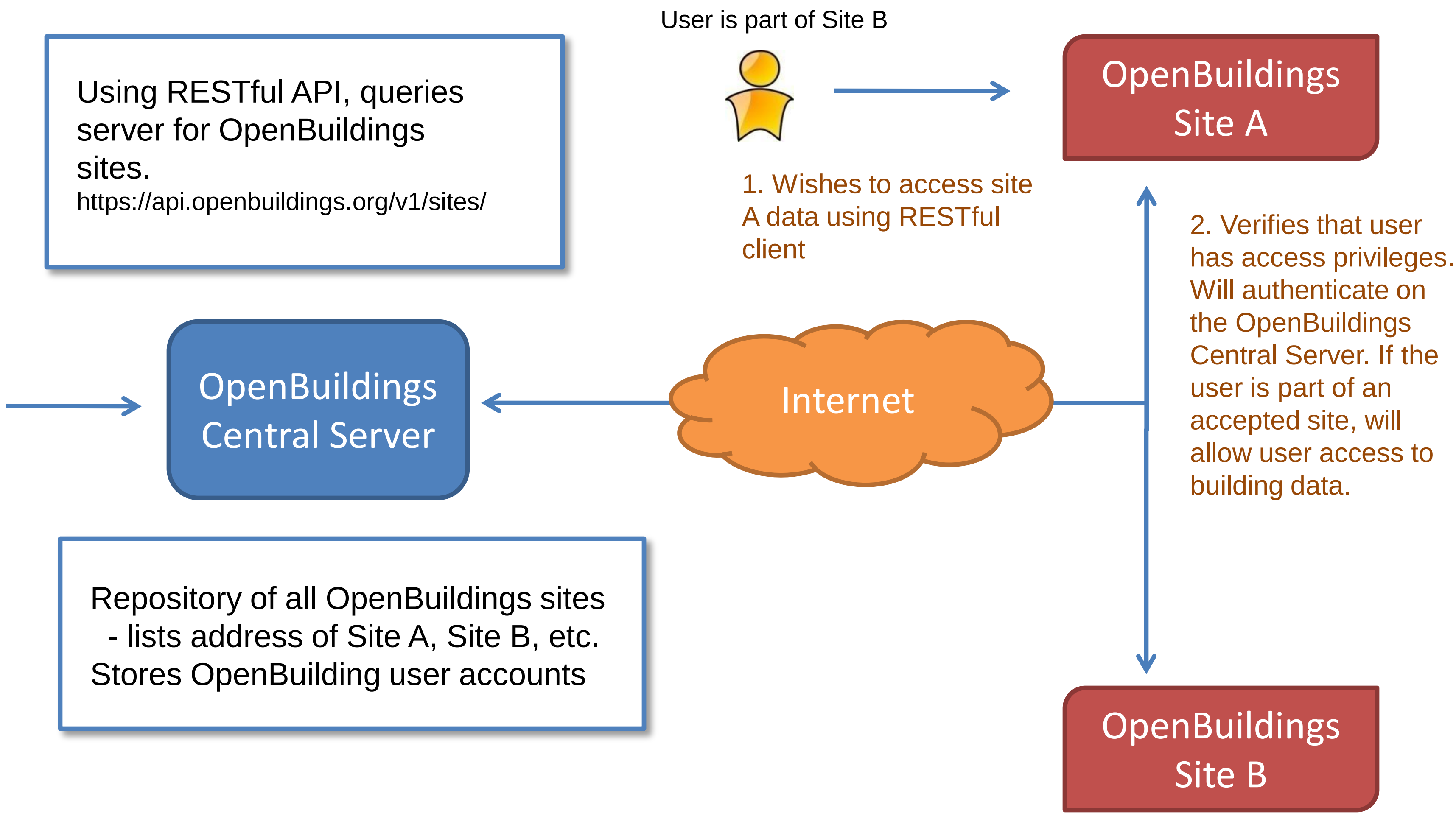


OpenBuildings is WIP with UC Berkeley

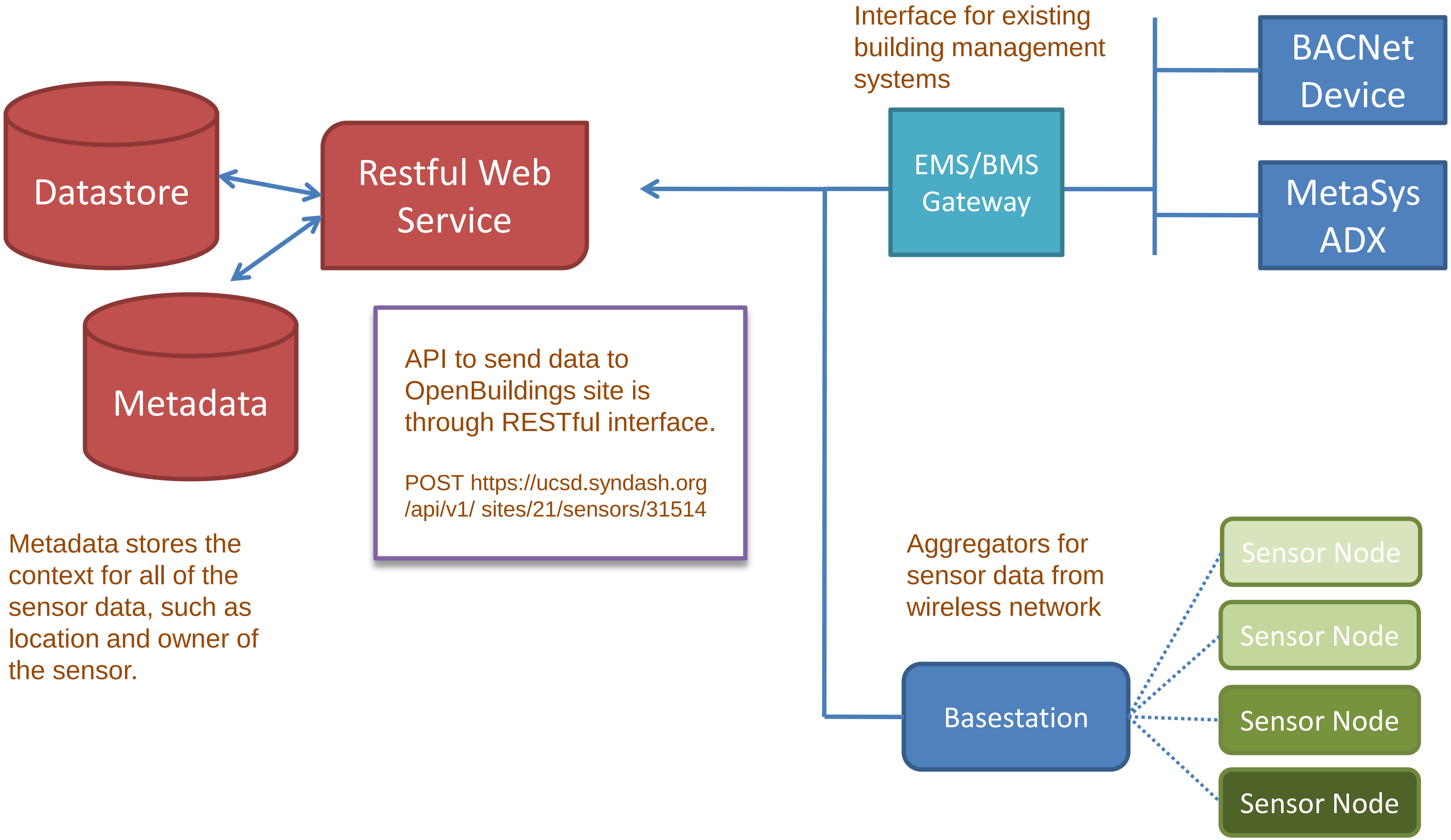
- OpenBuildings API
  - RESTful API for retrieving and storing data
  - Secure distributed ownership and control of data
  - “Energy Dashboard” website is overlaid on top of OpenBuildings API for web visualization.
- Many challenges and design decisions
  - Privacy/Access: Open/Anonymized, user controlled
  - Storage: Centralized or Distributed or Hybrid
  - Scalability, Security, Extensibility, legacy systems, …

An open platform will enable new research in this space!

OpenBuildings Architecture



OpenBuildings Architecture: A Specific Site



Some (Recent) Pointers

- “Managing Plug-Loads for Demand Response within Buildings”, BuildSys, 2011.
- “Evaluating the Effectiveness of Model-Based Power Characterization”, USENIX Advanced Technical Conference (ATC), 2011.
- "Duty-Cycling Buildings Aggressively: The Next Frontier in HVAC Control" , ACM/IEEE IPSN/SPOTS, 2011.
- "Occupancy-Driven Energy Management for Smart Building Automation" , ACM BuildSys 2010.
- "SleepServer: A Software-Only Approach for Reducing the Energy Consumption of PCs within Enterprise Environments" , USENIX ATC, 2010.
- "Cyber-Physical Energy Systems: Focus on Smart Buildings" , DAC 2010.
- "The Energy Dashboard: Improving the Visibility of Energy Consumption at a Campus-Wide Scale“, ACM BuildSys 2009.
- "Somniloquy: Augmenting Network Interfaces to Reduce PC Energy Usage" , NSDI 2009.

Thank You

An exciting time to be doing research in embedded systems with tremendous potential to solve society's most pressing problems.

Rajesh Gupta

gupta@ucsd.edu