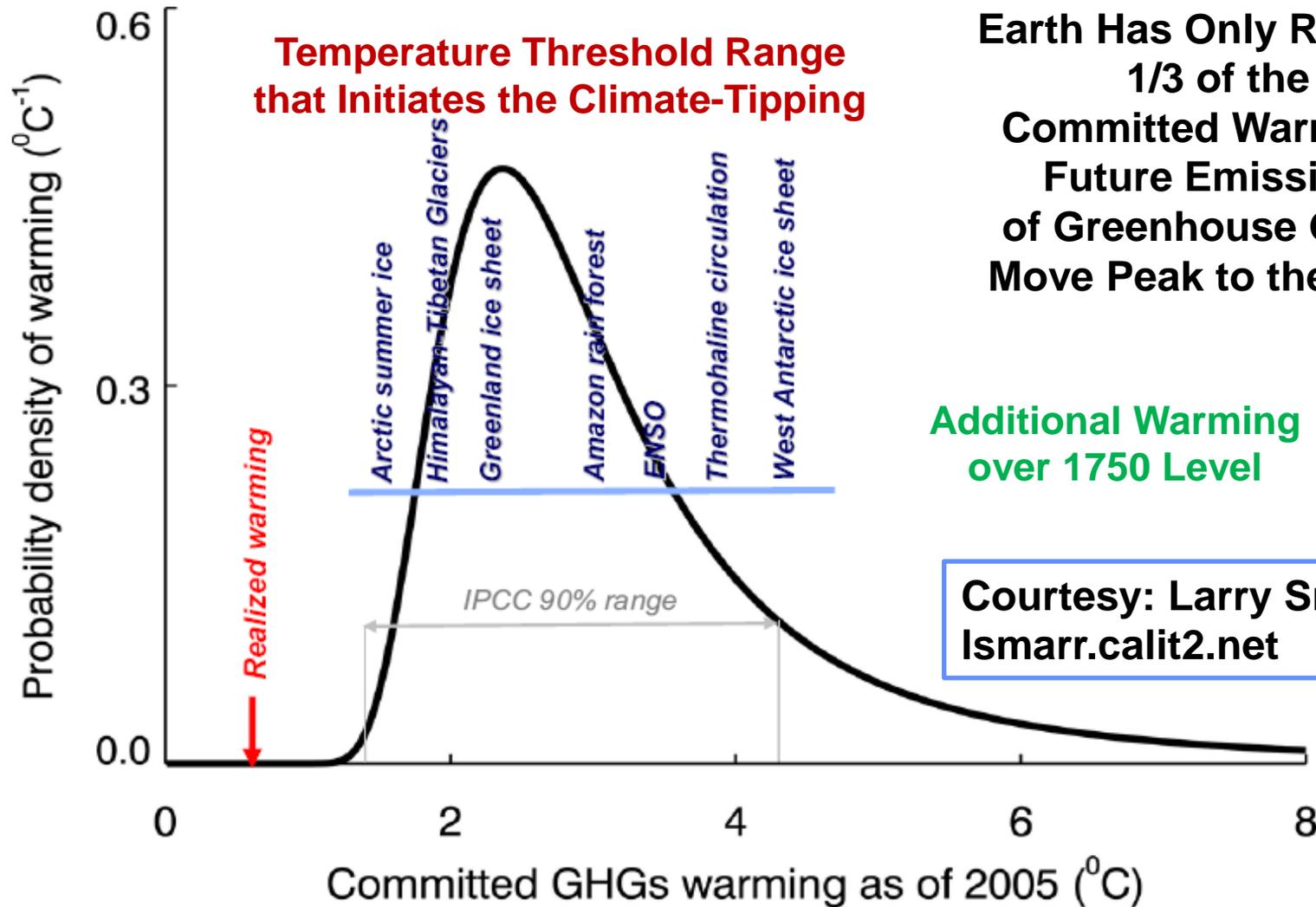


The Planet is Already Committed to a Dangerous Level of Warming



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

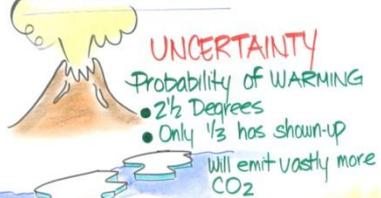
Courtesy: Larry Smarr
lsmarr.calit2.net

A Weekend in April 2009

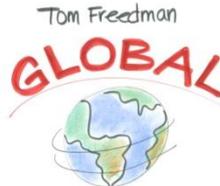
CARBON CONSTRAINED ENVIRONMENT

Director Larry Smarr

I.T. TELECOM APPLICATIONS



Over time
50 excursions — during history, was warmer than now



PROBLEM
It's up to EVERYBODY!



CARBON DRIVERS

2020 U.S./Canada emissions down China
PC Peripherals and Printers Data Centers is smaller Telecom also smaller

MEASURE CONTROL Everything in Building

Turn FACILITY into a RESEARCH LIBRARY

Turn into Inet address

CSIC Buildings

Calit2 WORK

- Clean-up ICT
- Green light Data Center Attracting Scientists
- Wasting vast amounts of Power.
- Rethink BUILDING use of ENERGY = 10 gigabit channels 58% amplifier efficiency
- Wireless infrastructure is big savings area

Redo electric and marry w/ Inet
Move cars to non-carbon instrument

Calit2 Teams across layers

GREEN CITIES



Sources that

- Make Energy Use Visible
- 34 Bldgs online

Apply ICT to infrastructure of the WORLD
make more efficient

SAVINGS PAY-OFF

- SMART BUILDING
- SMART GRID



Losing PLANLIFE
Must educate youth.

TRAVEL LESS

VIRTUAL MEETINGS
Technology of high definition on walls.

LIGHTPATHS
New platform for data sharing.

Calit2 as CONVENING PLATFORM

Extending INET to the PHYSICAL WORLD

Still important, but new infrastructures that exist.

We can make a DIFFERENCE

Participants

Research Breakthroughs

10th
2010-Anniversary

INTRODUCTIONS

OUR FUTURE

VISION



SOCIAL PLANET

RESEARCH SPECIALISTS

- Many humans
- HOT planet



How can we make
POSITIVE IMPACT?

GREEN I.T.

* **JAMAI**
 IFTF - Sustainability
 Astro Physics - Politics
 Outliers and
 Get People to
 LOOK LONG

* **KATHI**
 IFTF - Smart Networking
 Mobilize collective
 Intelligence

* **PHIL**
 Systems Person
 cluster technology
 high performance
 networks
 Decentralized
 computing
 Socan
 CHANGE
 Way for people to
 understand impact
 of their BEHAVIOR

* **TOM**
 Calit2-PhD
 Green light Project
 Energy efficient
 routers & displays

- Big Energy Users
- Don't want to be building more power grids

* **RAJESH**
 Computer Scientist
 Calit2-Systems View
 Reexamine heat
 and energy
 materials. ↑ bandwidth
 Need to: of energy
 consumption

* **STEVE**
 Infrastructure Human
 element
 UCSD-Back Office
 Operations
 Smart Grids
 Make campus model
 of energy/bids/equip.
 Optimally controlled.

* **JAKE**
 IFTF - Tech Horizons
 Futurist/Neuro Science
 Political Systems Design
 21st Century Political
 Design
 Longterm
 Thinking

* **JERRY**
 Calit2 - Political Background
 Legislation can lead
 from effectiveness
 Greening of I-net
 Smart BIDs.

Need SOCIAL REVOLUTION
 Incent - Positive
 BEHAVIOR!
 with virtual
 rewards

* **DAVID**
 Infrastructure
 Project
 Info Sharing

Get IDEAS to
 PEOPLE to
 implement
 Tools for
 Gross roots
 Their: role impact feedback loop

* **BILL**
 Animal Behavior
 Mismatch between:
 human narrow time
 environment
 hundreds/thousands
 of years will

USE IT
 to help boost
 ability to deal
 Broaden horizons

- Help people THINK LONG
- COMPARE across PROJECTS
- Internationalization GLOBAL

* **DONALD**
 Calit2- researcher
 High powered AMPs
 Have crummy battery!
 makes you efficient!

* **GANZ**

- W/Ford in past
- Building applications
 Telematics
- Better sensor
 network for TRAFFIC

* **SHARAD**

- Data Mgt. Research
- Technology re-organizing
- Applications
- Help 1st
 Responders
 mitigate crisis

CREATE AWARENESS

ENERGY

- Minimize waste
- I.T. impact on
 energy consumption

SUPPLY

DEMAND

CALIT2 / IFTF
 April 25, 2009
 San Diego, CA



SWEETSPOTS

THE NEXT 3-5 YEARS

SIMULATION

Geoenineering by Simulation

Creates a "digital social" environment model to understand water, transportation, and land use research.

"Sim. Model + type frame / on the environment to illustrate & model global systems (eco, climate, transport, etc.)"

Simulation of Central Valley Ag. & Water Scenarios e.g. reclamation & de-salinization

INFRASTRUCTURE URBAN SIMULATION

- LAND USE + URBAN FORM
- TRANSPORT
- UTILITIES
- ECONOMIC ANALYSIS

BEHAVIOR MODIFICATION

Tools & Design that Makes Information beautiful, and behavior change FUN.

Music Environment [Identified positive individual client behavior for free downloadable music]

Mobile energy coach

Canopus - scale human behavior modification feedback for lowering carbon lifestyle.

Infrastructure for health monitoring and shared sensor networking.

data sonification

DASHBOARD DECISION SUPPORT TOOLS

Integrated Systems to Deliver your Green 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 VISUALIZATION

REAL-TIME PERSONAL CONTROLS FOR ELECTRICITY SOURCING.

BETTER CARBON CALCULATOR

SENSORS

Data mining of Large Scale Sensor Nets to Learn about resource consumption

Power for large Scale Sensor network

Low energy compact Sensor Devices for Data Collection, Inform feedback to improve management Efficiency, regulation, program.

Sensor Development for Occupant Heat load

MAKING Sensor Data Availability Across Devices

REAL TIME SENSING

PERVASIVE MONITORING

CHEAP POACHING DETECTION

IR GOOGLE STREETVIEW

IR MAPS

ANNOTATED WORLD

Passive RFID WikiPedia Data Base

ENERGY HARVESTING

POWER MGT

Instant ON (NOT ALWAYS ON) Tiled Walls

Aggressive Duty Cycle IT Power Management

GENERAL ENVIRONMENTAL MONITORING (light, temp, ...) that allow to optimize the environment.

LOCAL INERTIAL MANAGEMENT (DR. STORAGE)

CENTRAL WIRELESS APPLIANCE CONTROL

ENERGY STORAGE

ADVANCED ENERGY STORAGE FOR RENEWABLE ENERGY SOURCES

COMPRESSED AIR ENERGY STORAGE

Energy Storage Device for Energy To/From Home.

Large Scale Energy Storage

Small Scalable Solar Pwr 1 Panel + Up

Bi-directional Electrical Line + Load Regulation

MICRO SOLAR UTILIZATION

SMART CAMPUSES and BUILDINGS

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 LINKS

HYBRID BUILDINGS DATA-CENTERS

DRIVERS TO IMPROVE THE MODEL MICRO SMART GRID FOR GLOBAL COMMUNITIES

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

Sustainability 2.0



Rajesh Gupta
UC San Diego

DIMACS, September 2011

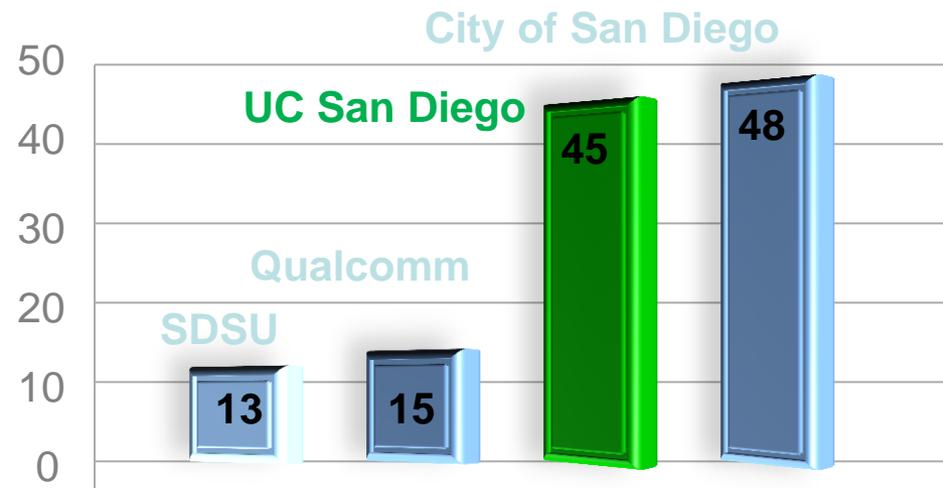
Presentation Courtesy: Steve Relyea, Larry Smarr, David Weil, Yuvraj Agarwal.

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

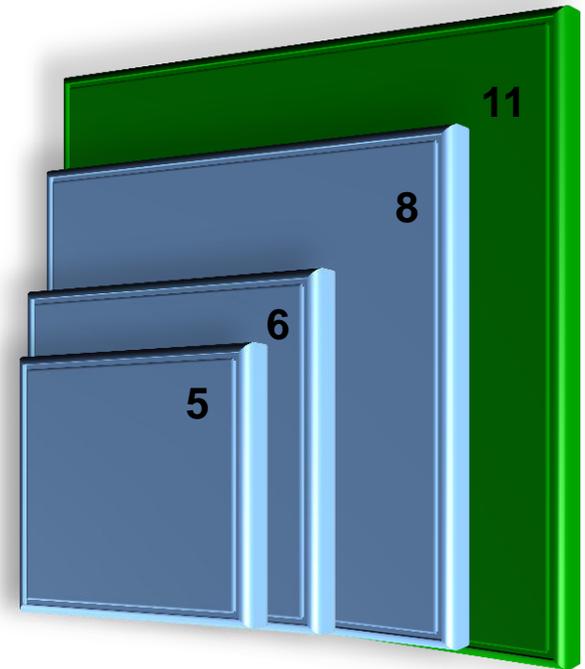
Square Feet of Facility Space *(in millions)*

UC San Diego

City of San Diego

Qualcomm

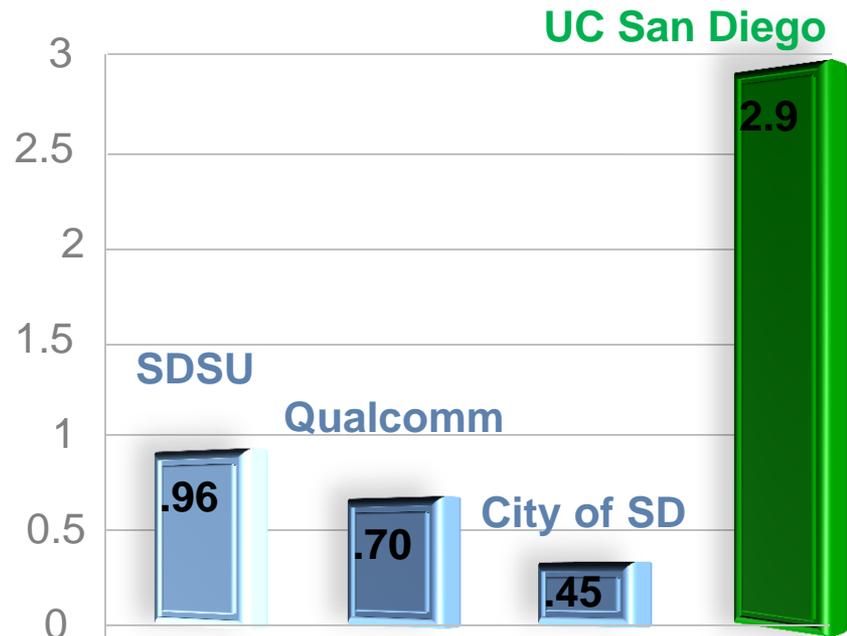
SDSU



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)



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

Operational Challenges





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

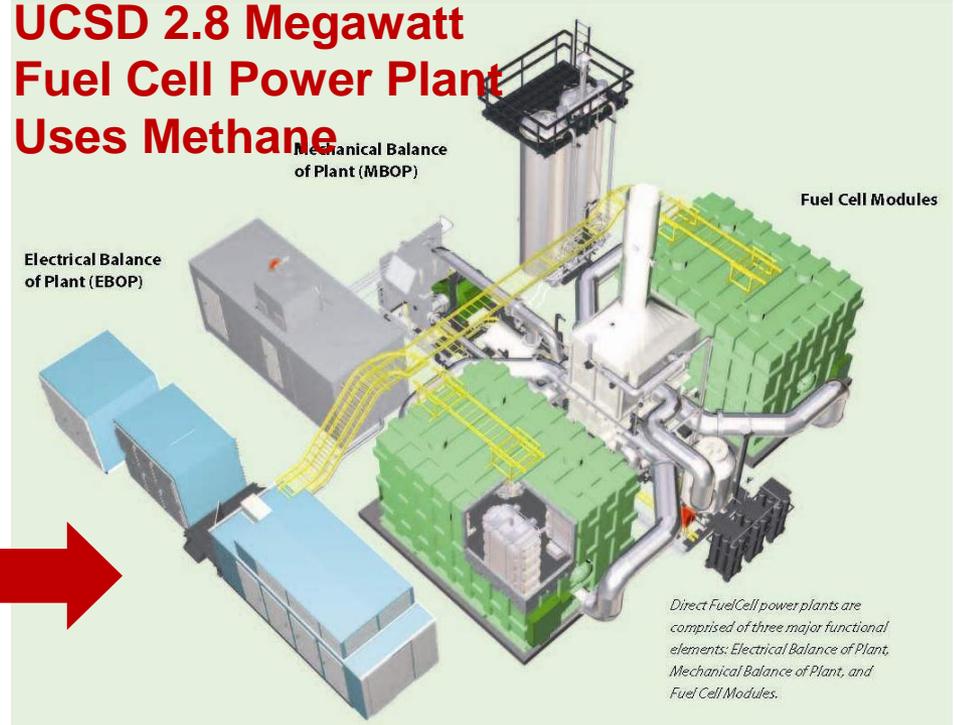
- 12,000 acres, 45,000 occupants, 8,000 residents
- 2 hospitals (with local generation), 15 restaurants
- 450 buildings, 11 million square feet of building space
- Over \$250M in capital construction/year
- **Generates 80% of its own electricity usage including**
 - 2.8 MW fuel cells, 1.2 MW PV, Wind, 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

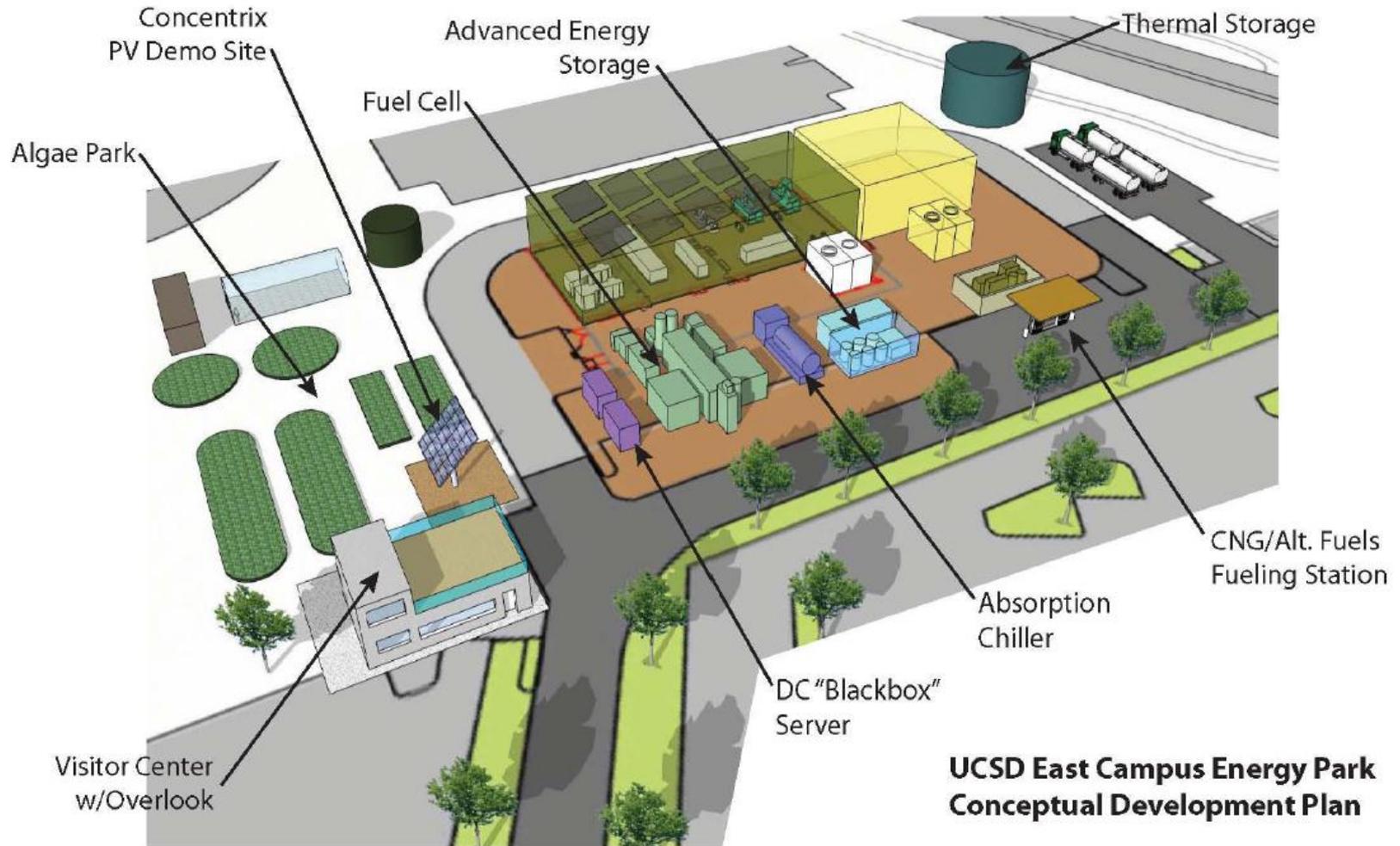


UCSD 2.8 Megawatt Fuel Cell Power Plant Uses Methane



2 Megawatts of Solar Power Cells Being Installed

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



Buildings are important

- 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.



\$3/sq. foot



BuildSys

What is in that 290 TWh/year?

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

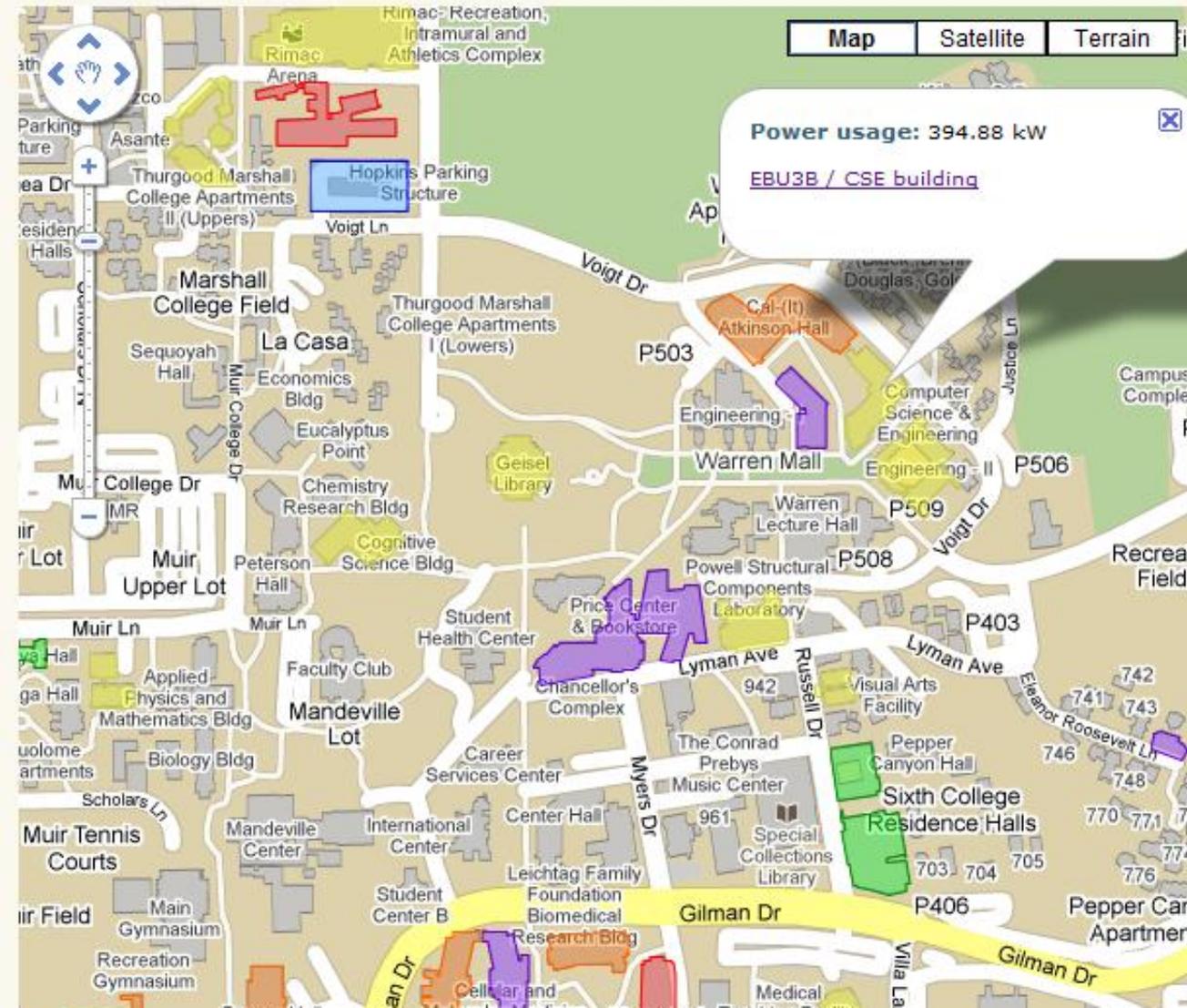
Bruce Nordman, LBNL

Buildings consume significant energy

>70% of total US electricity consumption

>40% of total carbon emissions

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.

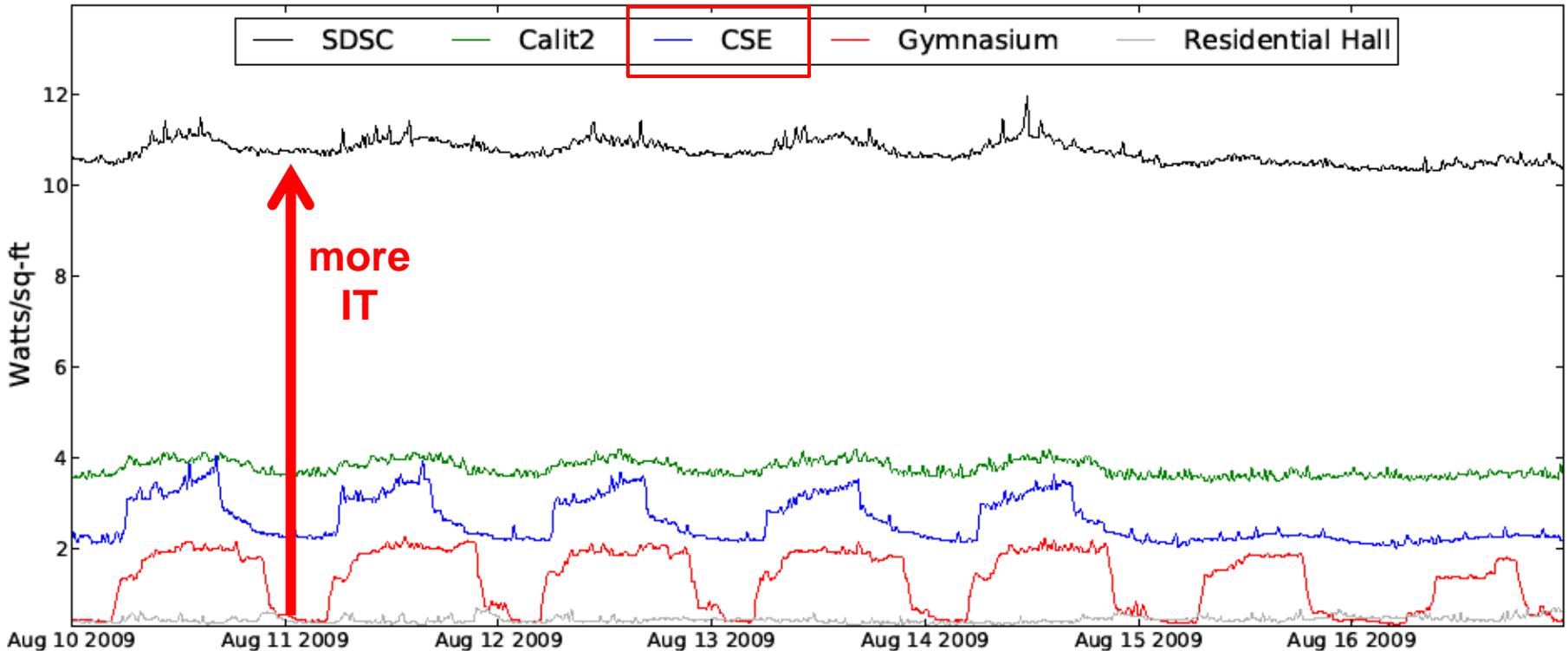
Scripps Institution of Oceanography is southwest of the main campus.

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>

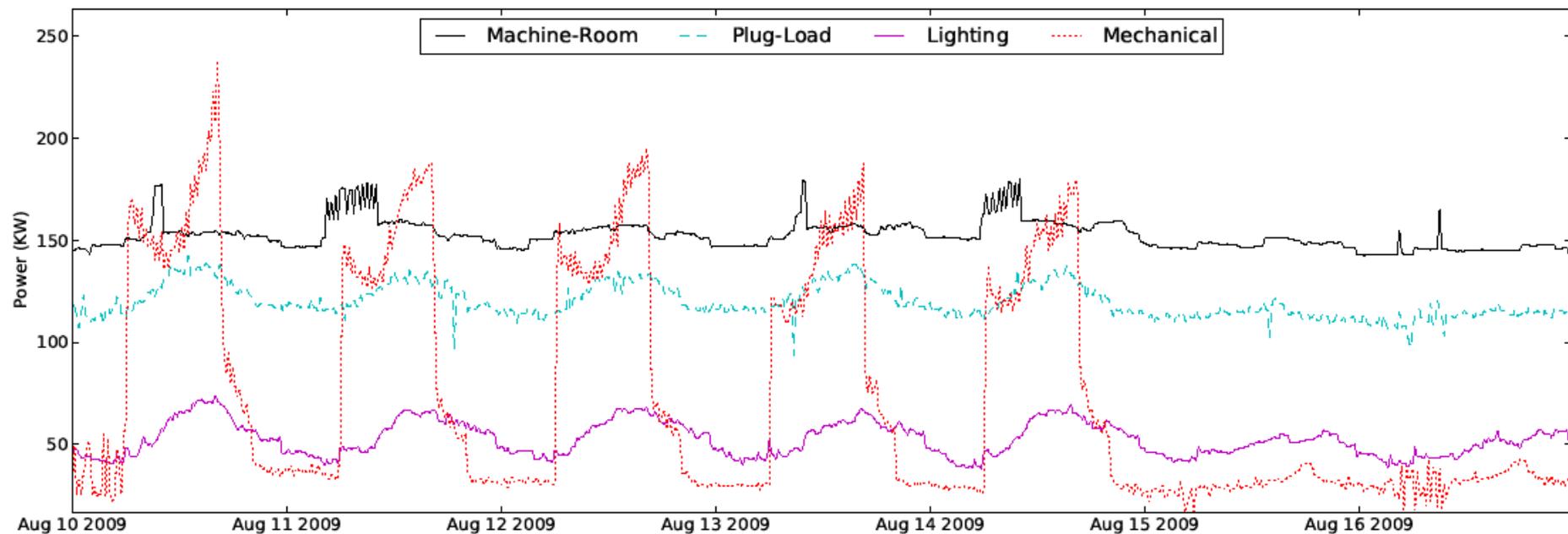
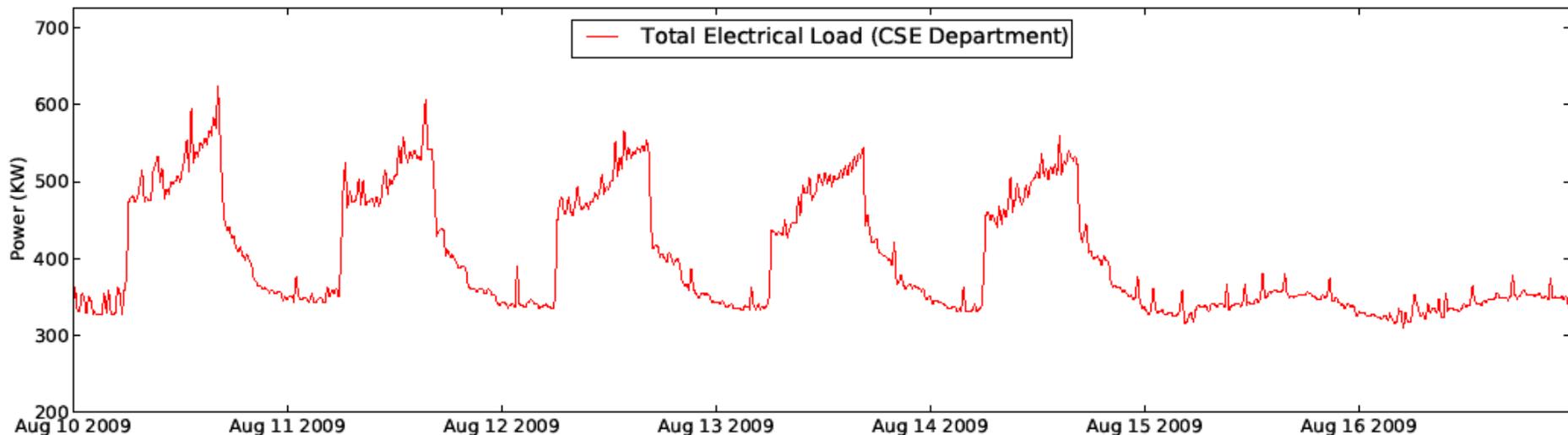
Looking across 5 types of buildings



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

Modern Buildings Are IT Dominated

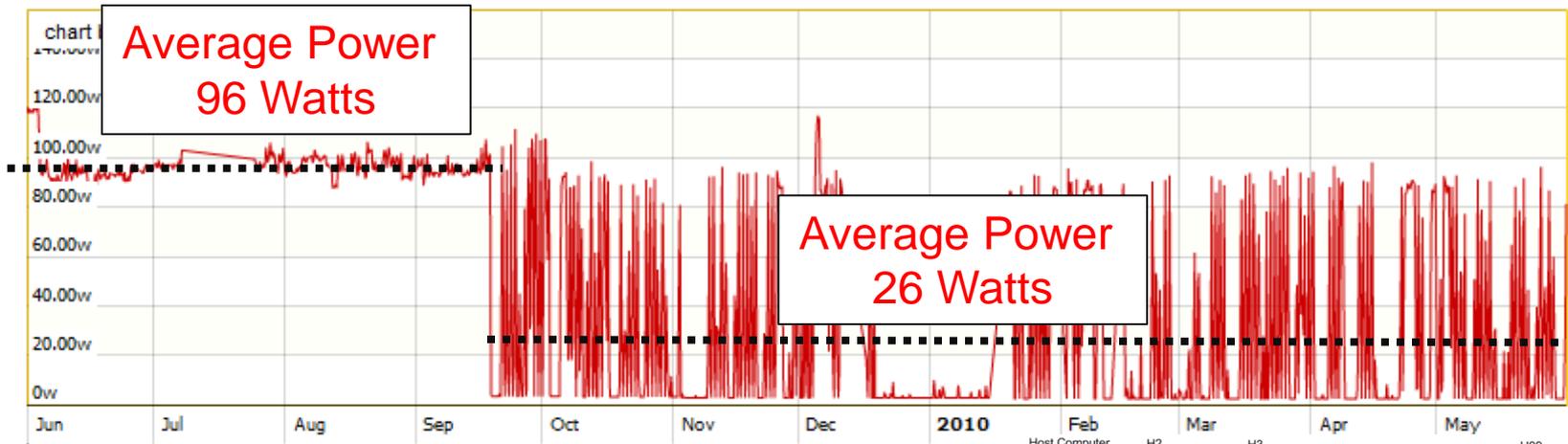
50% of peak load, 80% of baseload



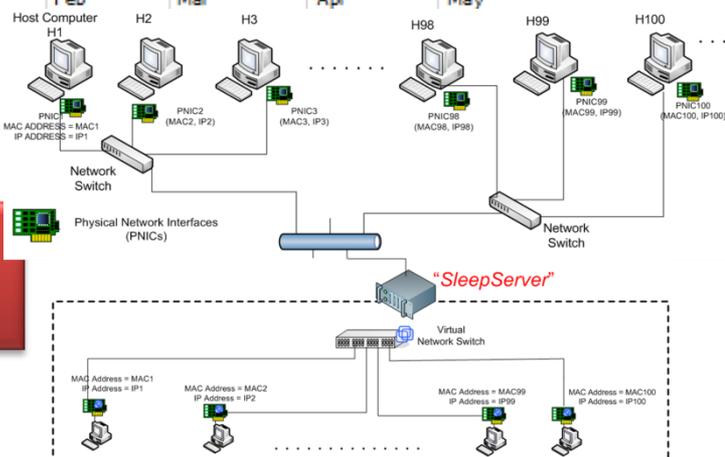
Making Buildings more Energy Efficient

- 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]

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!

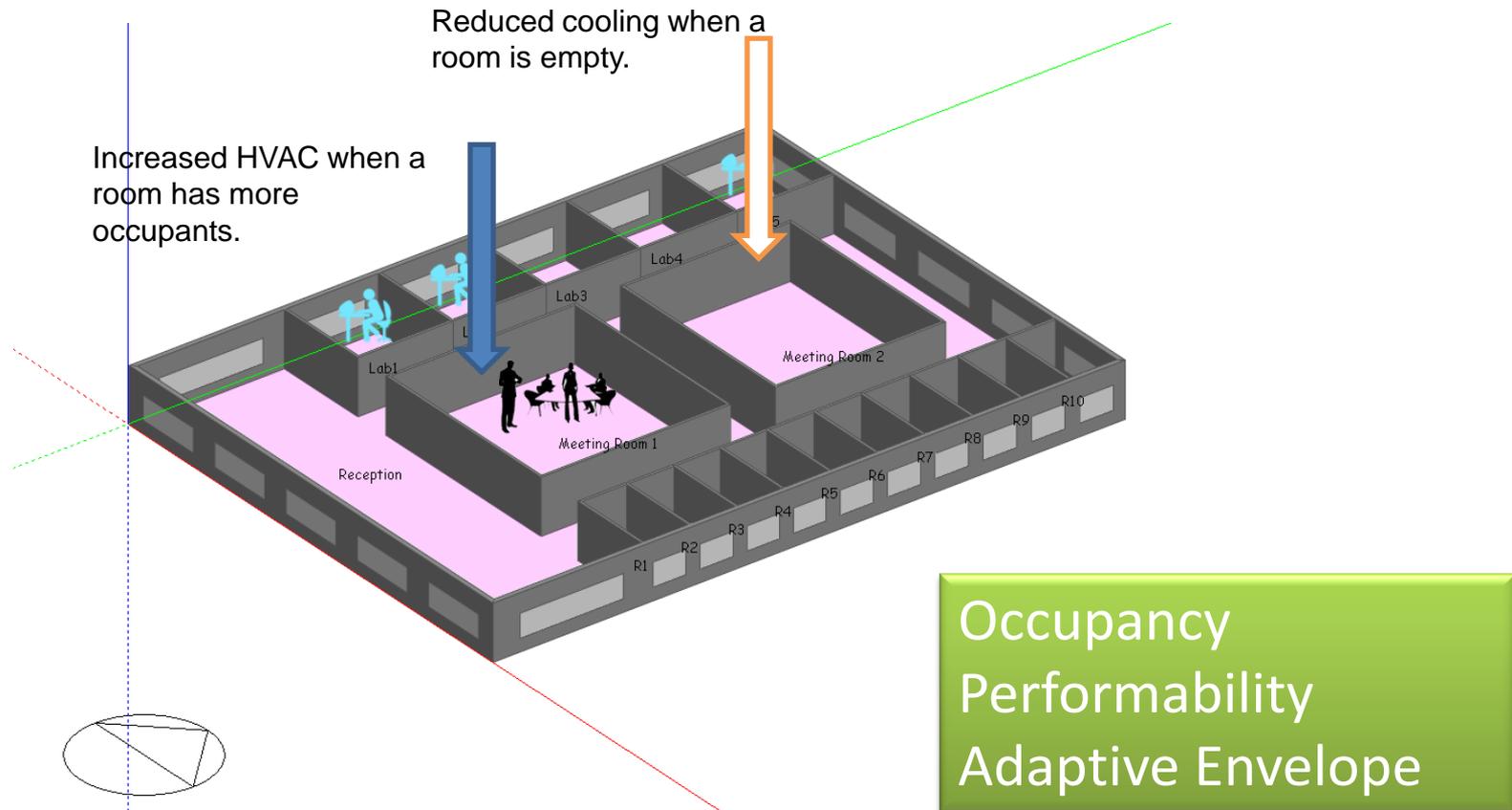
Un-Occupied
Periods

6:30PM
HVAC stops at
this time

Use occupancy information.

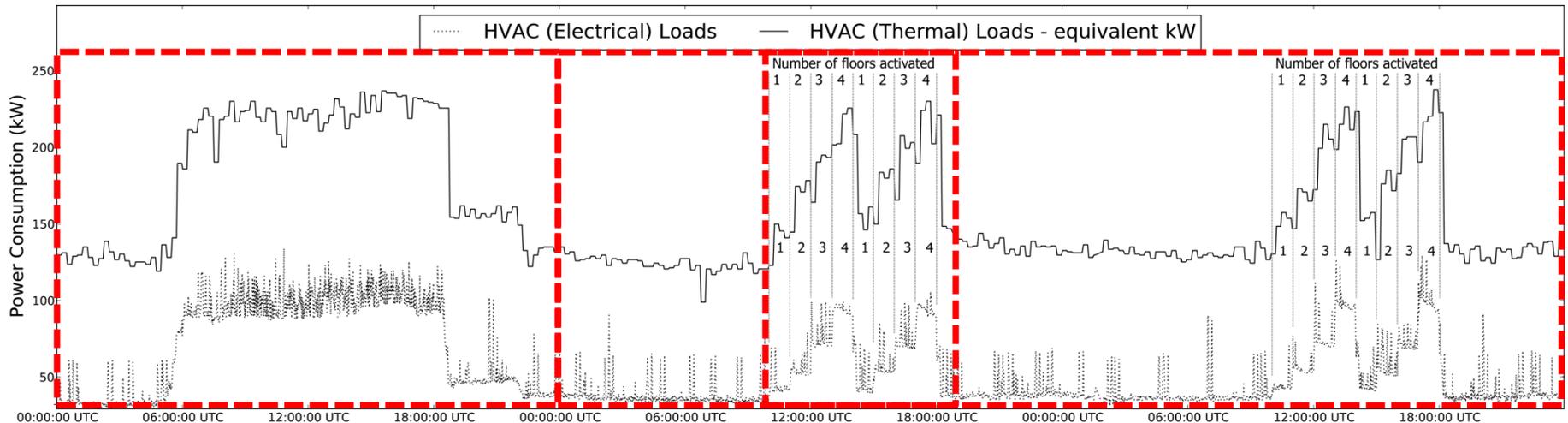
Buildings 2.0: Occupancy-Driven Smart Buildings

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



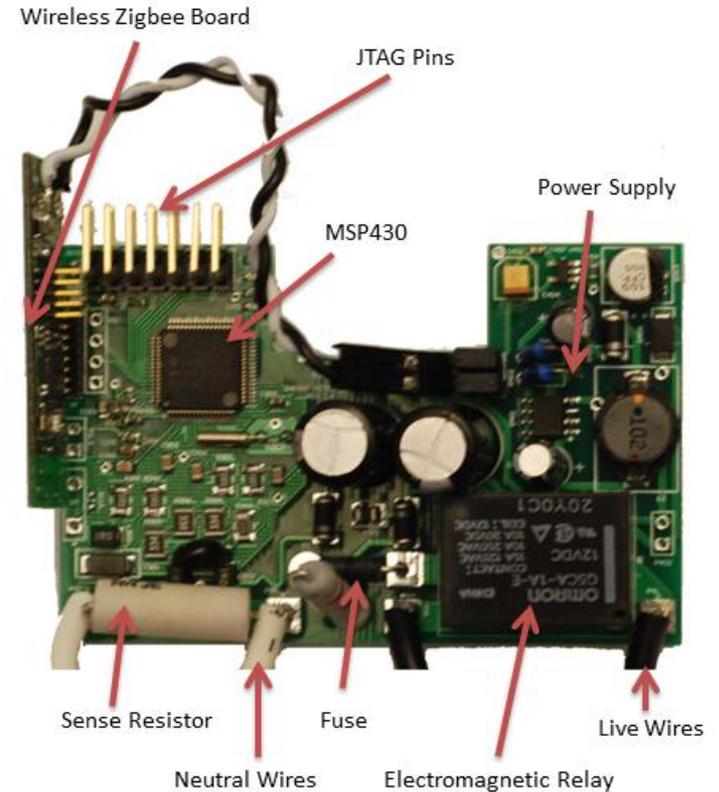
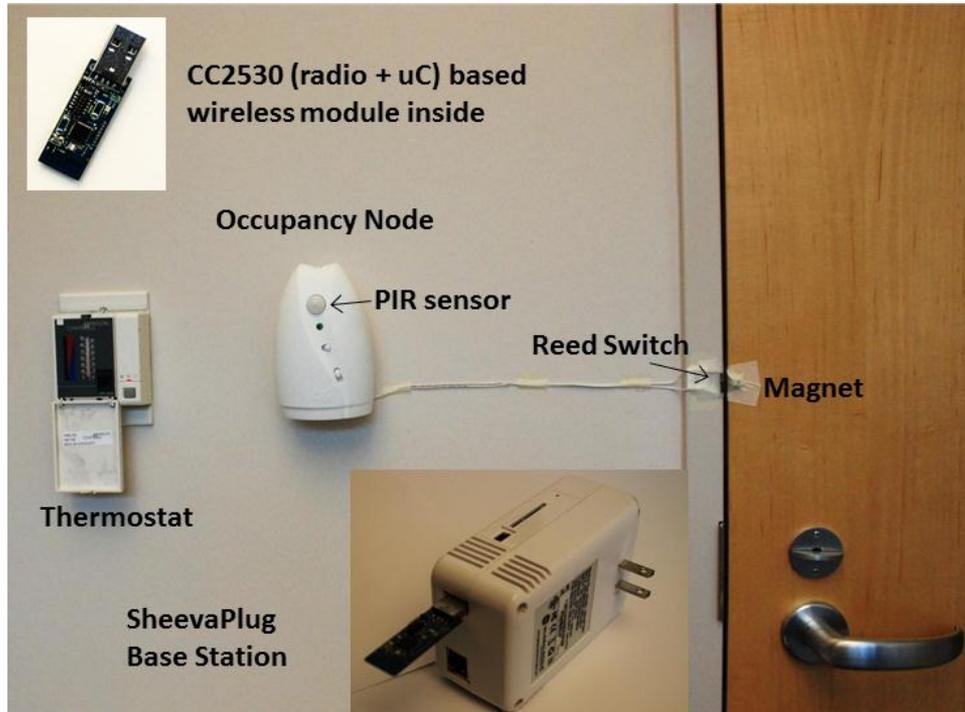
When there are less people in the room, reduce cooling. When there are more, increase cooling as required to maintain comfort.

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

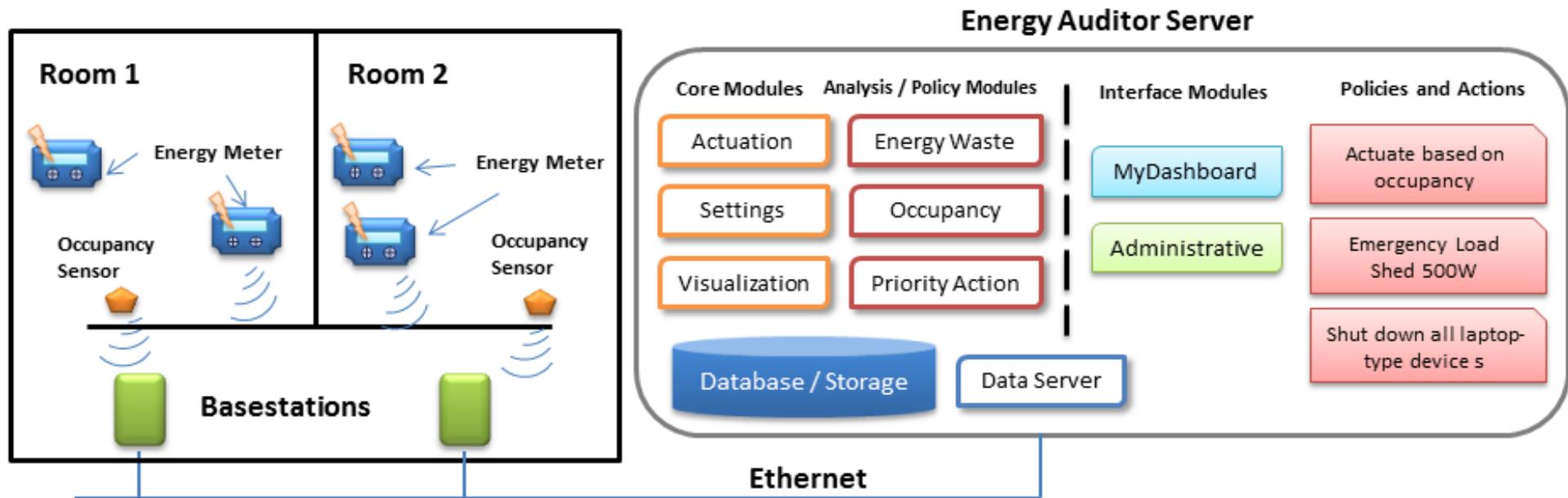


Synergy Occupancy Node

- 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



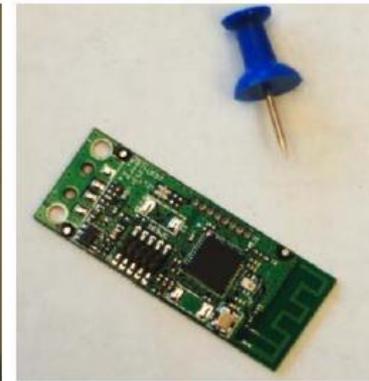
(a)



(b)



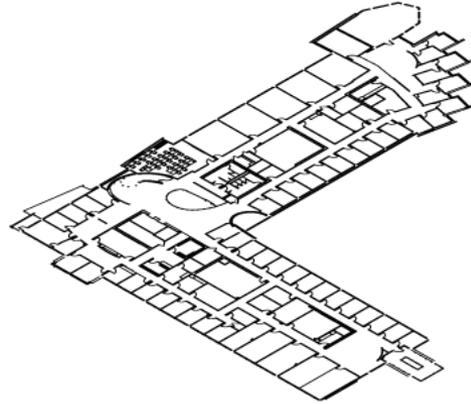
(c)



(d)

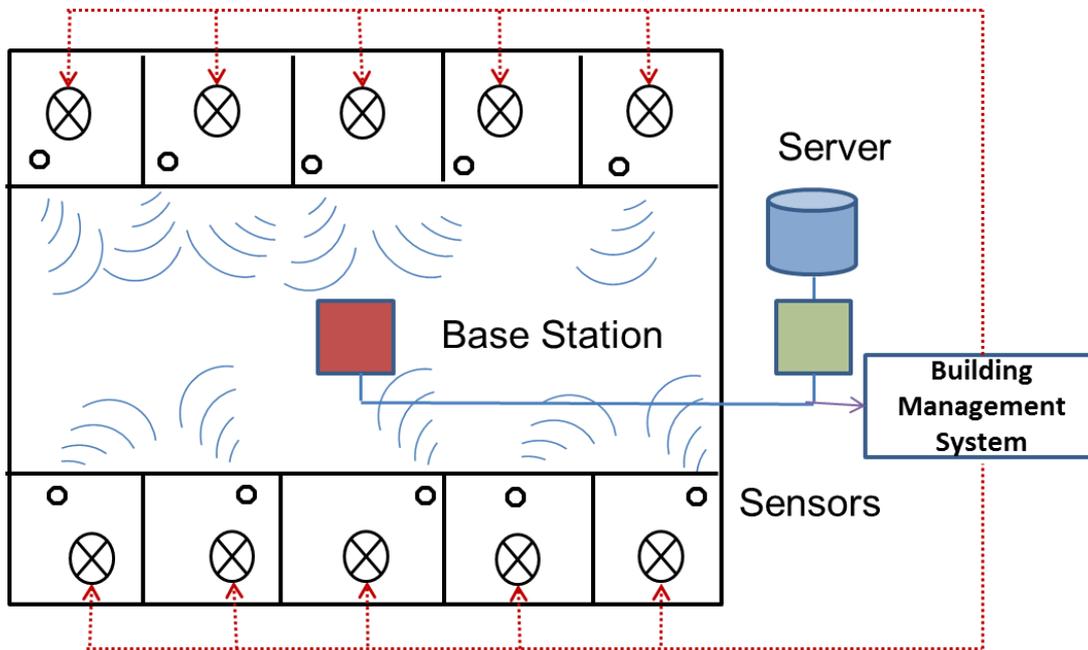
Figure 4. Picture of our energy meter (a, b) along with our SheevaPlug base station (c) that is deployed in the hallways. The CC2530 based wireless module that are in both the base station and the energy meters is also shown (d).

Deployment across 2nd floor of CSE

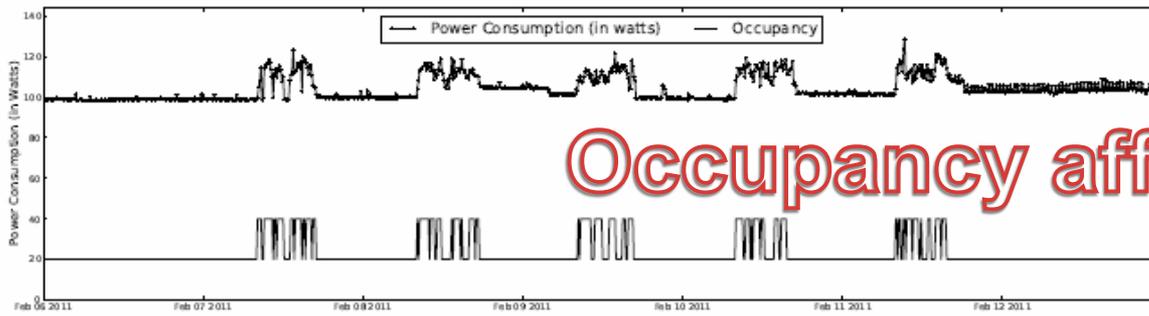


Floormap: 2nd Floor

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



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

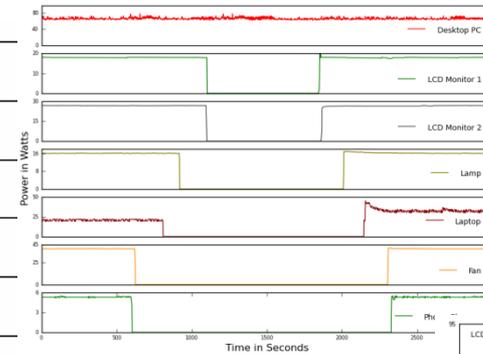


Occupancy affects energy use.

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

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%) |



Priority-based actuation

Occupancy-based actuation

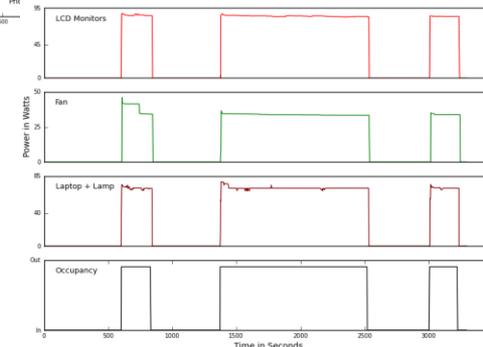
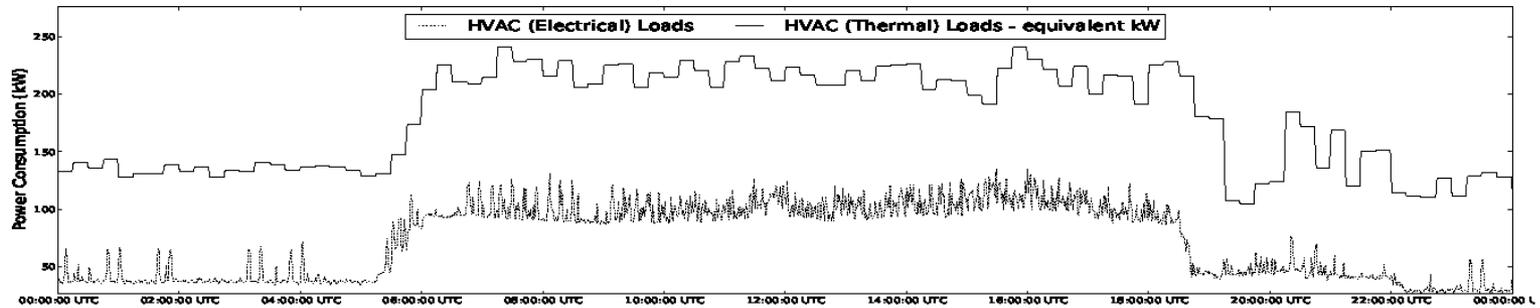
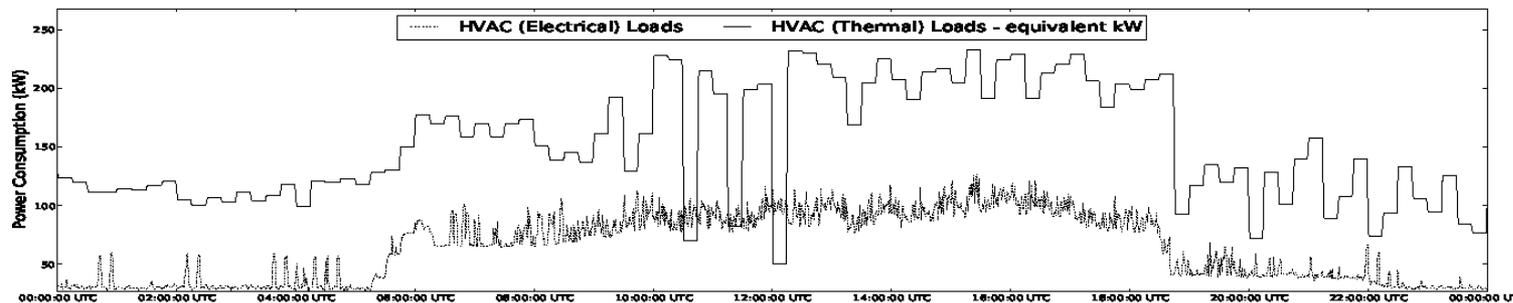


Table 1. Results of our load classification tests. For most general classes of devices, our algorithm works well and can recognize the load.

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.

Summary: Buildings are a great place to start

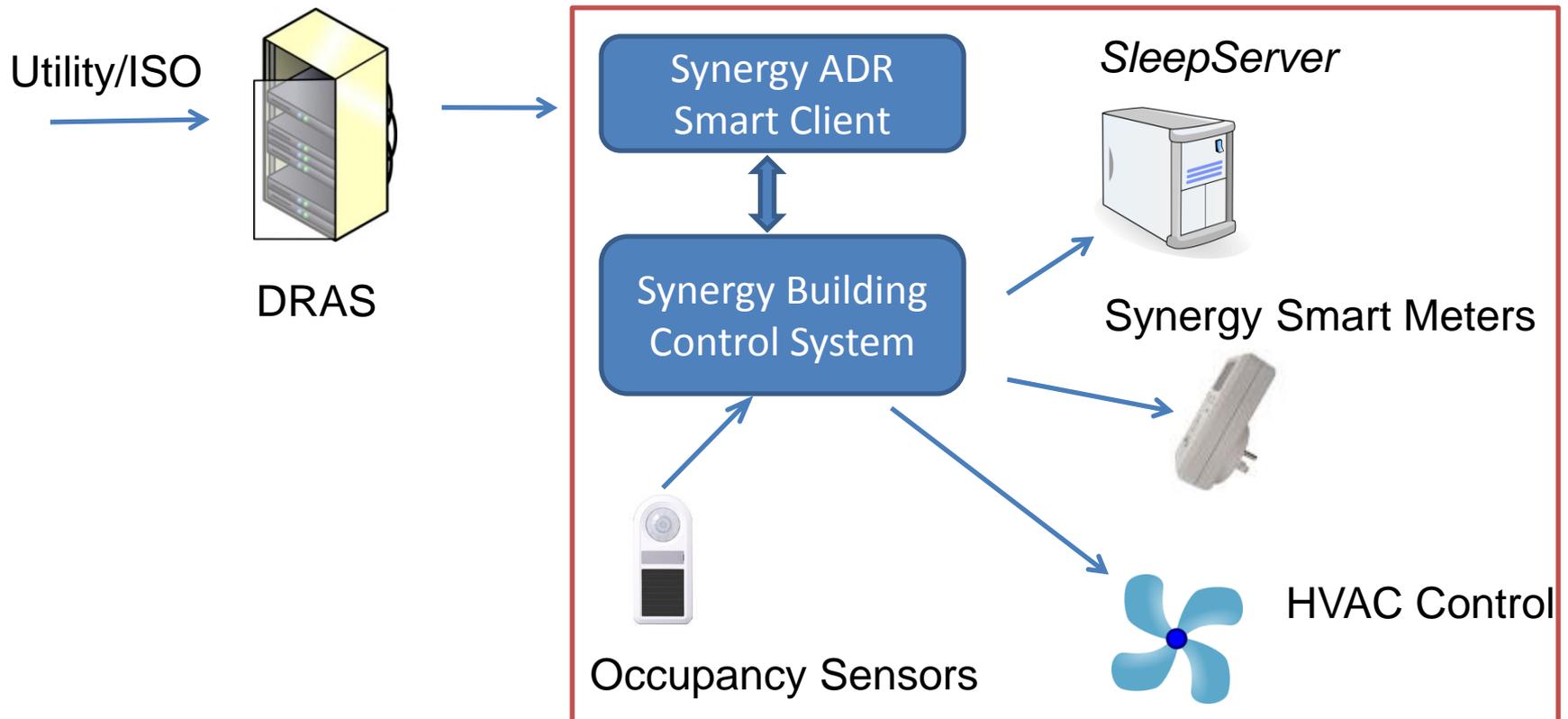
- HVAC energy not proportional to occupancy
 - Use of static schedules is common
 - Significant energy wasted
- Fine-grained occupancy driven HVAC control
 - Occupancy node: accurate, low cost, wireless
 - Interface with existing building SCADA systems
- Evaluation: Deployment in the CSE building/UCSD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

Beyond Energy Efficiency and Towards DR

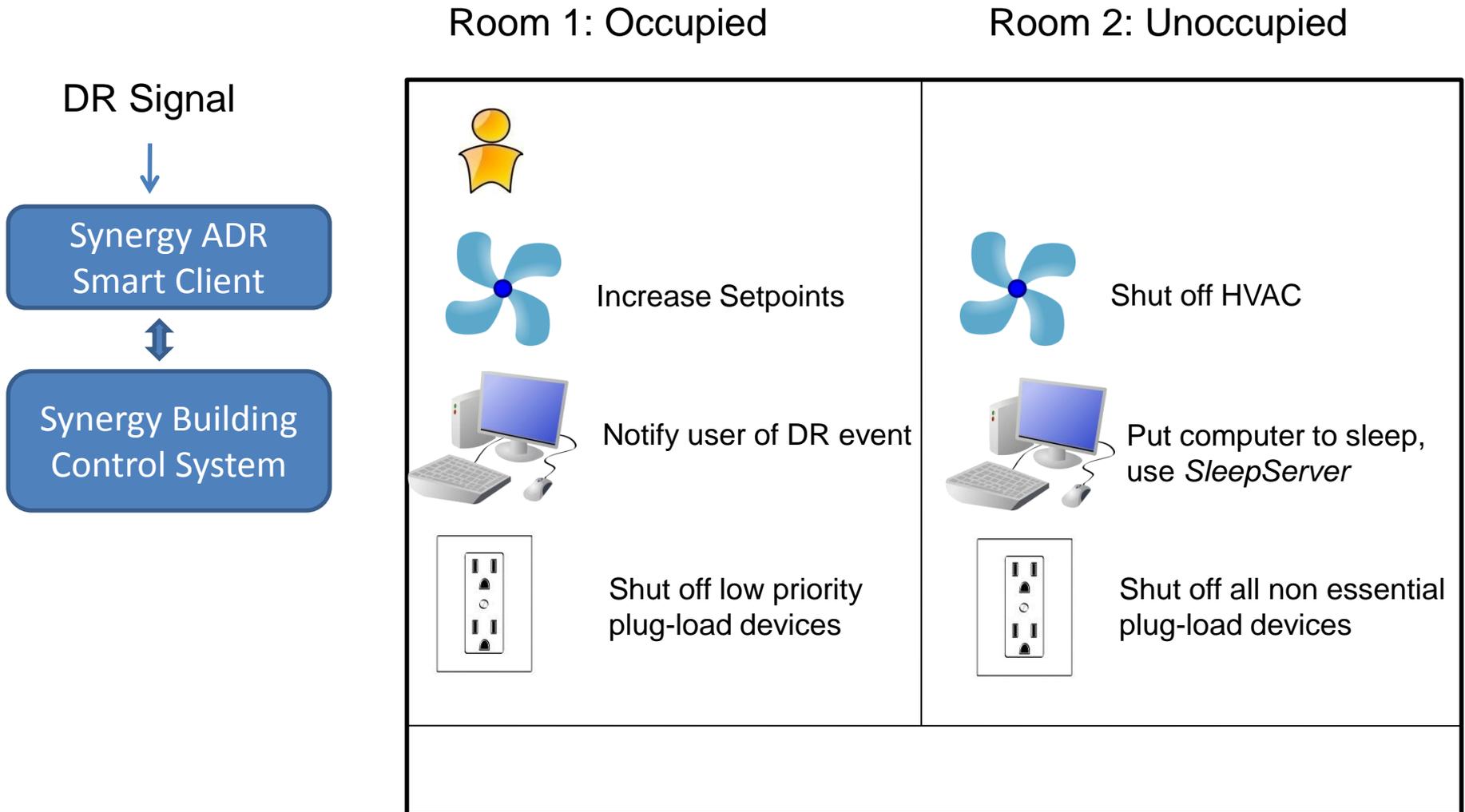
- Interfacing with the smart grid
 - Key feature of the smart grid is handling demand response events during peak days
 - Requires interfacing building with demand response signaling protocols: **OpenADR**
- OpenADR standard
 - Specifies demand response communications between utilities/ISOs and commercial 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

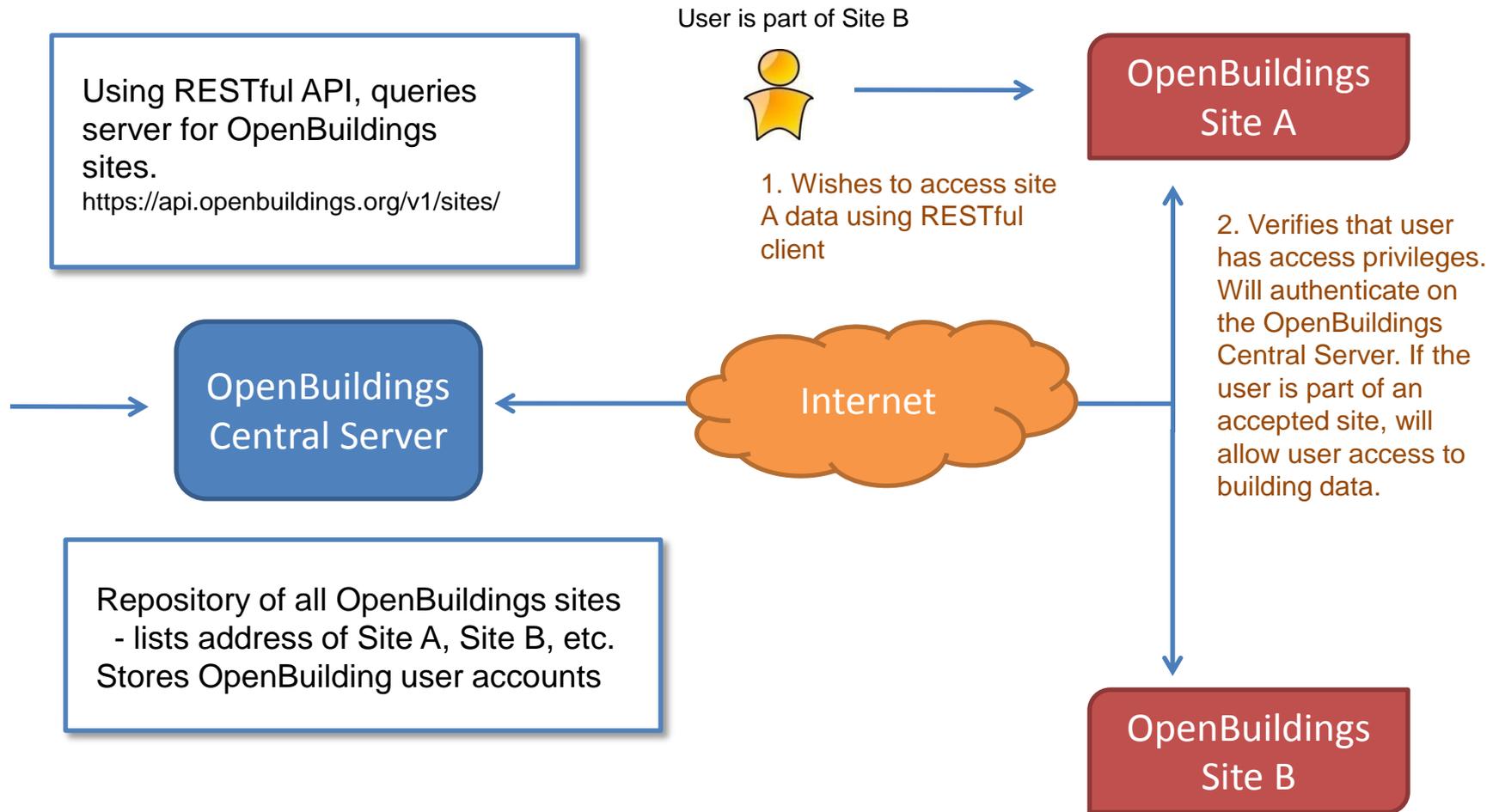


OpenBuildings is WIP with UC Berkeley

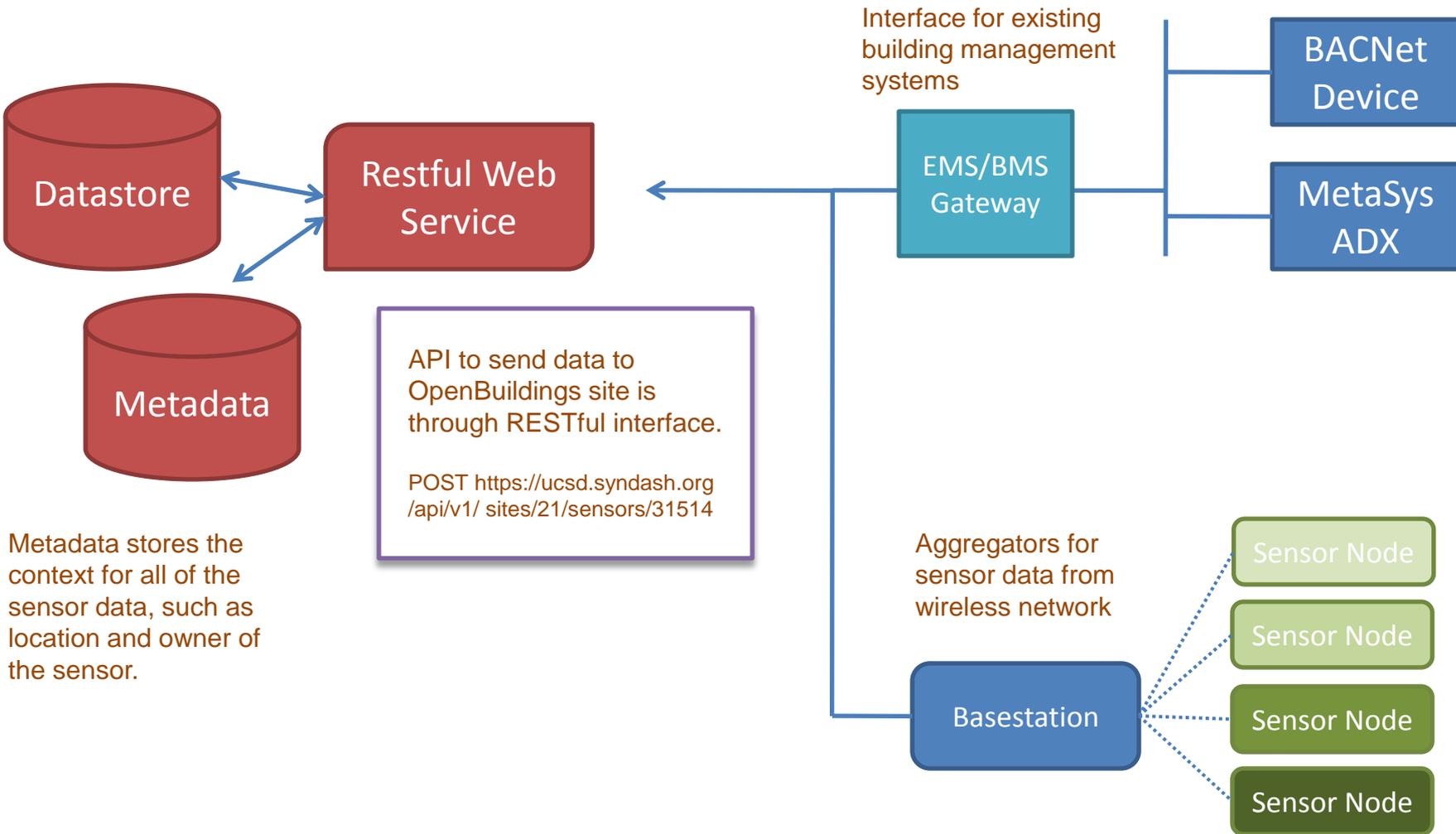
- OpenBuildings API
 - RESTful API for retrieving and storing data
 - Secure distributed ownership and control of data
 - “Energy Dashboard” website is overlaid on top of OpenBuildings API for web visualization.
- Many challenges and design decisions
 - Privacy/Access: Open/Anonymized, user controlled
 - 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



Metadata stores the context for all of the sensor data, such as location and owner of the sensor.

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

