



Rethinking the Energy Infrastructure from an IT Perspective

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UW 12/7/2010

“Energy permits things to exist; information, to behave purposefully.”

W. Ware, 1997



Energy is THE Problem

- Energy and the environmental impact of extraction, use, and disposal
- THE problem of the Industrial Age
- We need to find Information Age solutions to THE Industrial Age Problem

- it starts with the Faustian bargain of oblivious consumption





The Grid: Marvel of Industrial Age Design

- Deliver high quality low-cost power
- To millions of customers over thousands of miles
- Synchronized to $\ll 16$ ms cycle (60 Hz)
- With no orders, no forecasts, no plans
- No inventory anywhere in the supply chain
- To enable rapid economic & industrial growth through oblivious consumption

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The Industrial Age Grid

Baseline + Dispatchable Tiers

Oblivious Loads





A New Reality ...

1. Energy becoming increasingly dear
 - increased cost of acquisition
 - inclusion of environmental costs
2. Improvements in energy efficiency cause high dynamic variability in the load
 - high peak-to-ave ratio, bursty
3. Limitations of existing grid present transmission and distribution bottlenecks
4. Incorporation of renewable resources reduces control over supply
 - most are non-dispatchable (solar, wind)



LaCal



Towards an "Aware" Energy Infrastructure

Baseline + Dispatchable Tiers

Oblivious Loads



Non-Dispatchable Sources

Aware Interactive Loads



LaCal

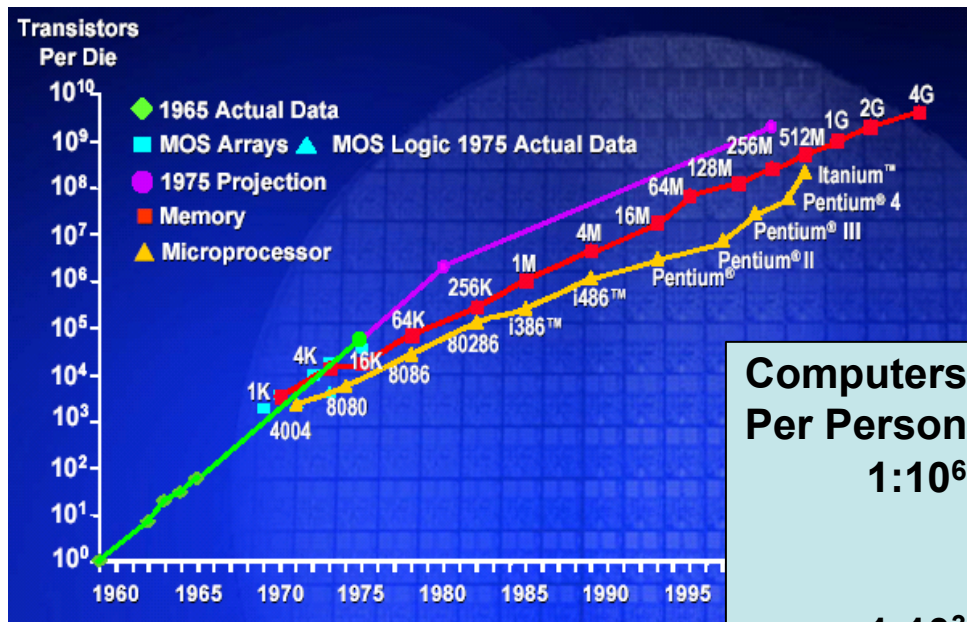
Communication

Communication

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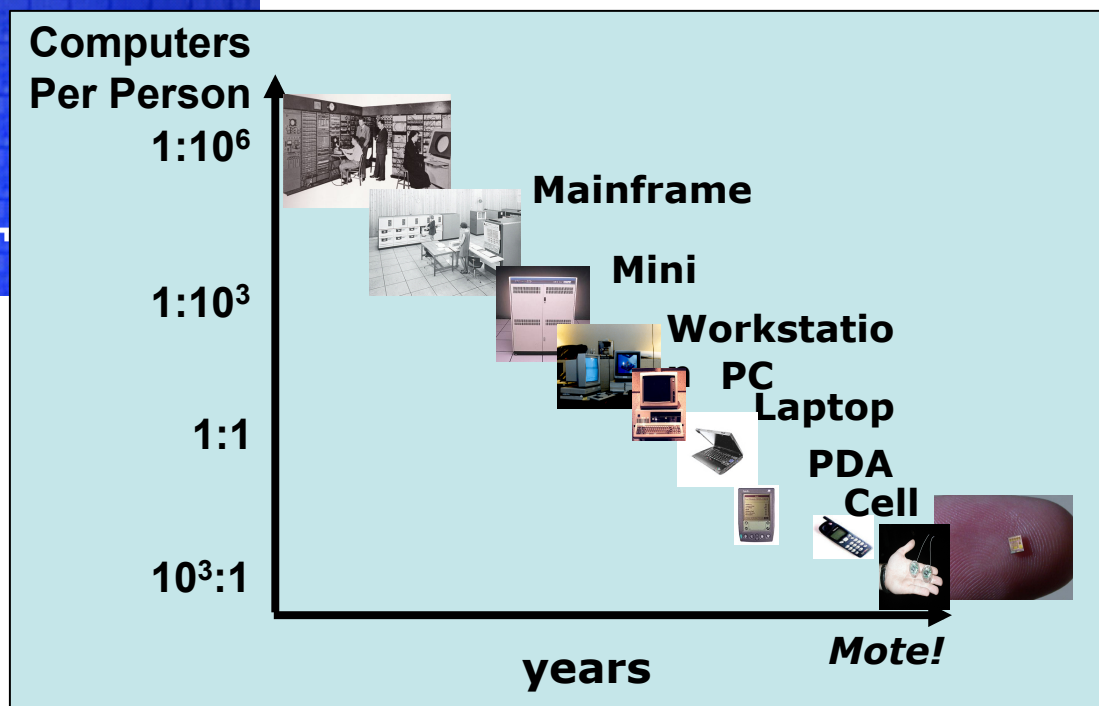


The Roadmaps We're Used to



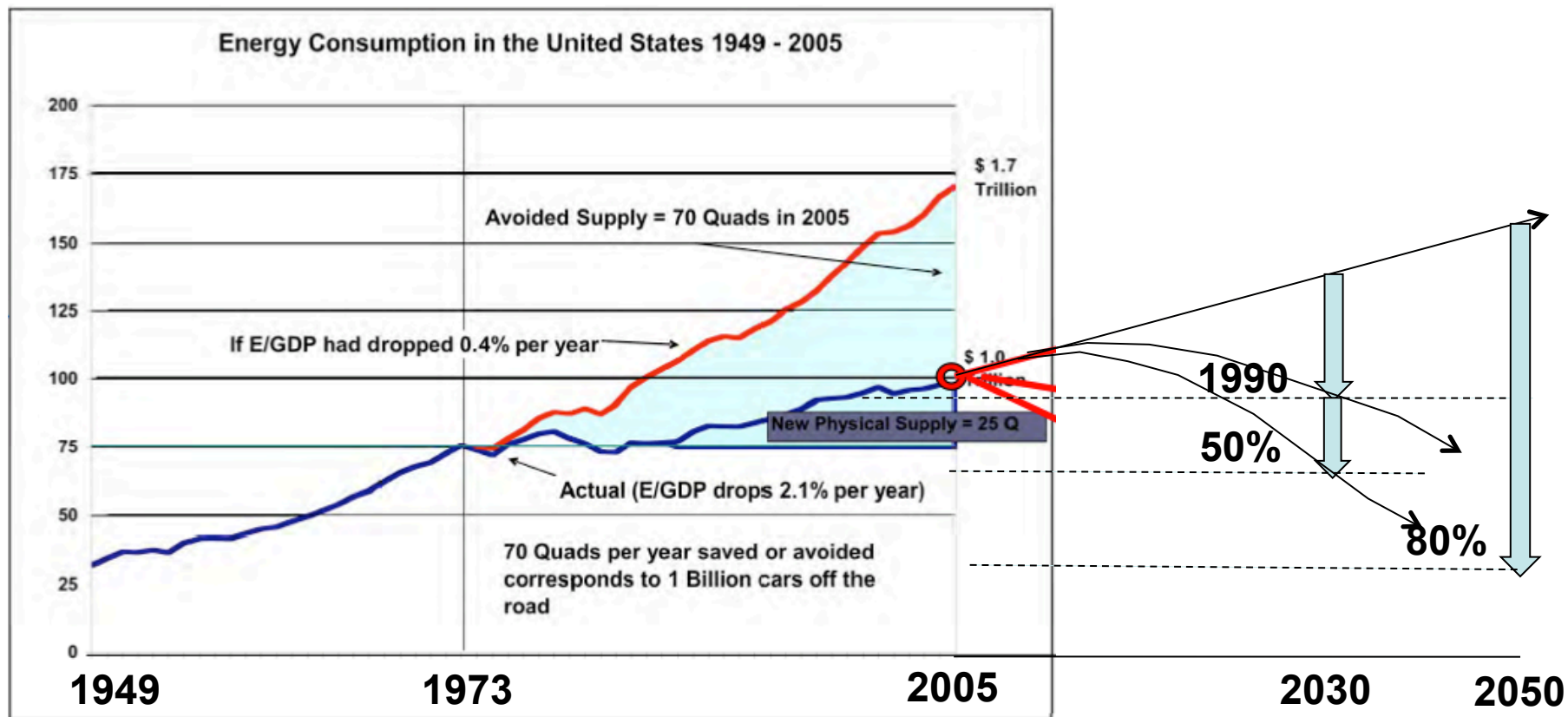
Moore's Law

Bell's Law





A Different Kind of RoadMap

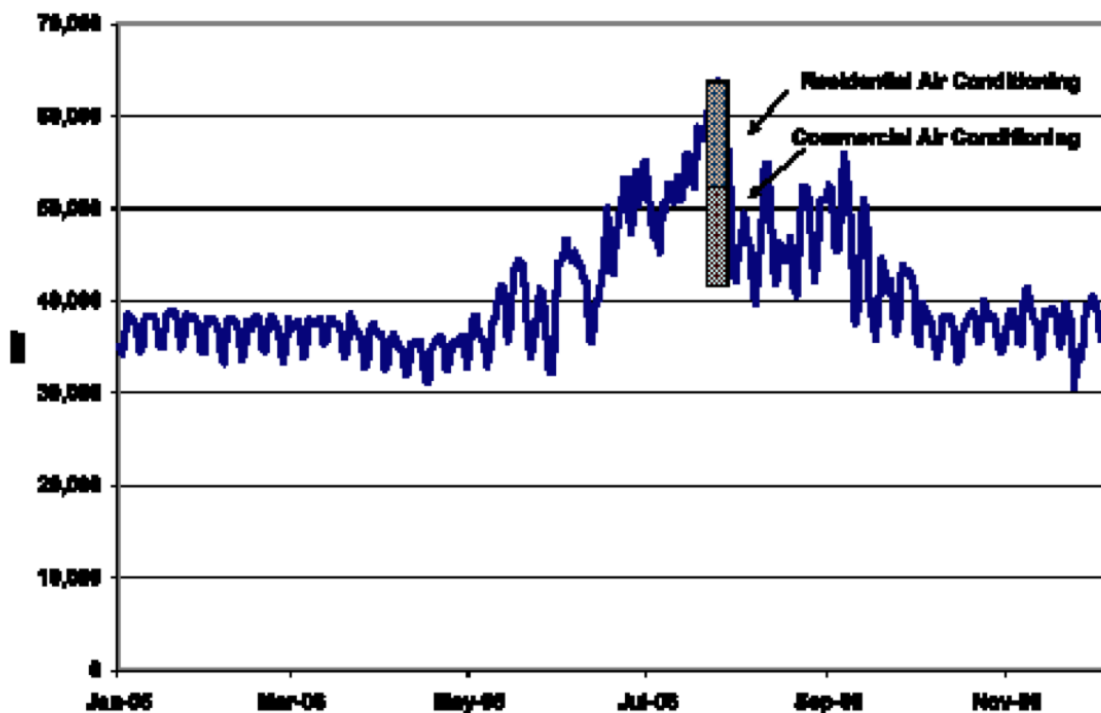


Source: LBNL



Load-following Supply

California Daily Peak Loads - 2006



POWER CONTENT LABEL

	PRODUCT	2007 CA POWER MIX**
ENERGY RESOURCES	NAME* (projected)	(for comparison)
Eligible Renewable	55%	10%
-- Biomass & waste	10%	<1%
-- Geothermal	11%	2%
-- Small hydroelectric	13%	6%
-- Solar	10%	<1%
-- Wind	11%	2%
Coal	16%	32%
Large Hydroelectric	12%	24%
Natural Gas	16%	31%
Nuclear	1%	3%
Other	<1%	0%
TOTAL	100%	100%

* 50% of this product is specifically purchased from individual suppliers.

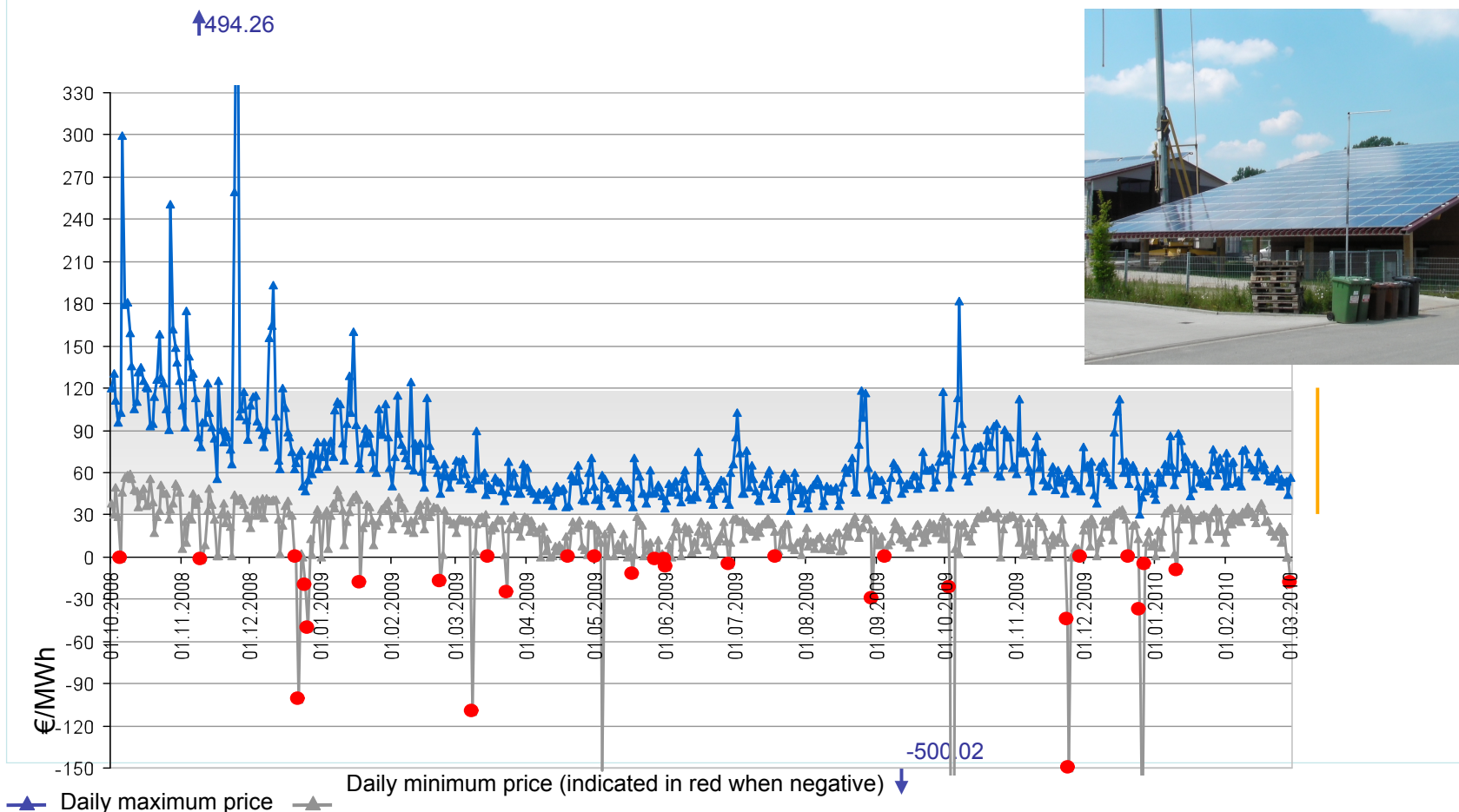
** Percentages are estimate annually by the California Energy Commission based on electricity sold to California consumers during the previous year.

For specific information about this electricity product, contact Company Name. For general information about the Power Content Label, contact the California Energy Commission at 1-800-555-7794 or www.energy.ca.gov/consumer



Load-following Supply (?)

Growing proportion of renewables leads to higher price volatility. October 2008 to March 2010:
>90 hours with negative prices; highest price reached: +€500/MWh, lowest -€500/MWh



▲ Daily maximum price ▲ Daily minimum price (indicated in red when negative)
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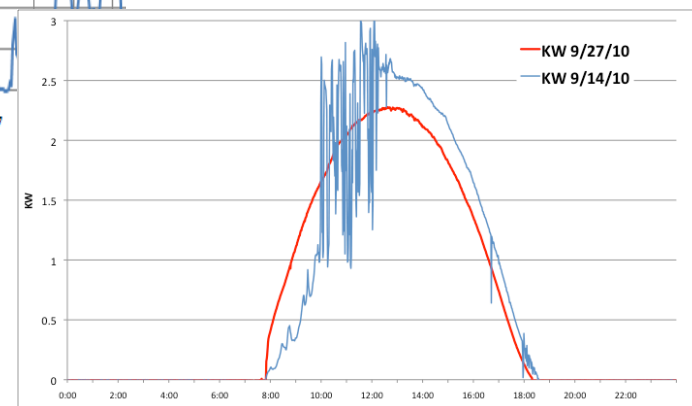
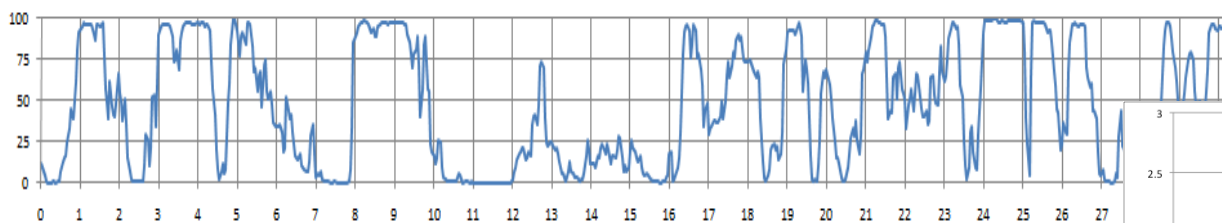
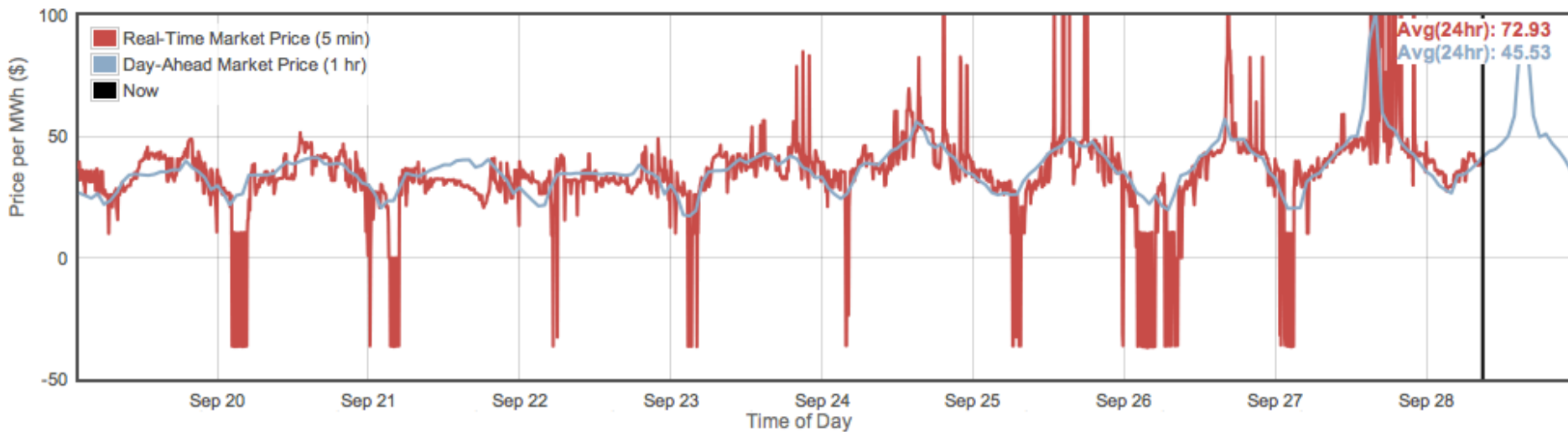
Source: EEX spot prices.

Lokal



... and @ CA

Energy Price



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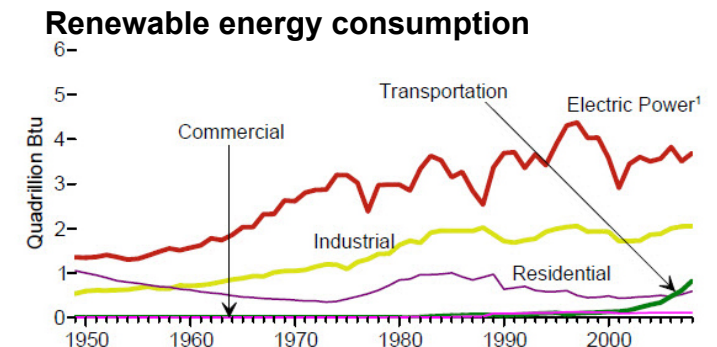
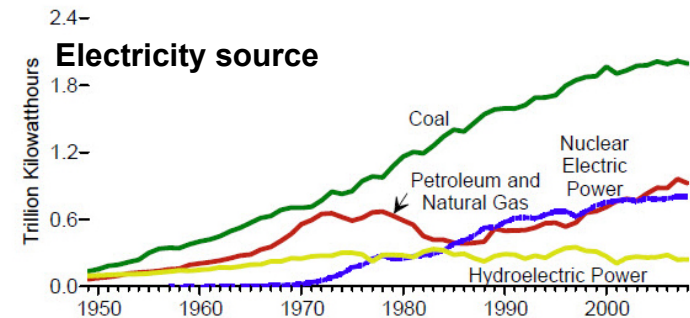
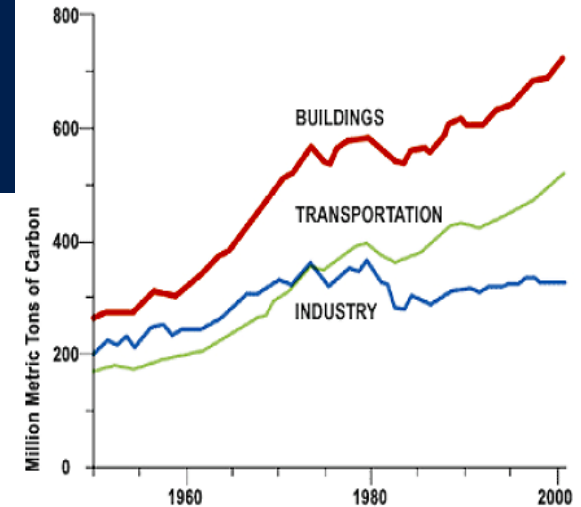
Where to Start?

- **Buildings**

- 72% of electrical consumption (US),
- 40-50% of total consumption,
- 42% of GHG footprint
- US commercial building consumption doubled 1980-2000, 1.5x more by 2025 [NREL]

- Where Coal is used
- Prime target of opportunity for renewable supplies

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Lessons from the Internet

- Universal “narrow waist” – IP
- Horizontal Layering, not Vertical Integration
- Intelligence at the end-points, simple core
- Measure everywhere, continuously adapt

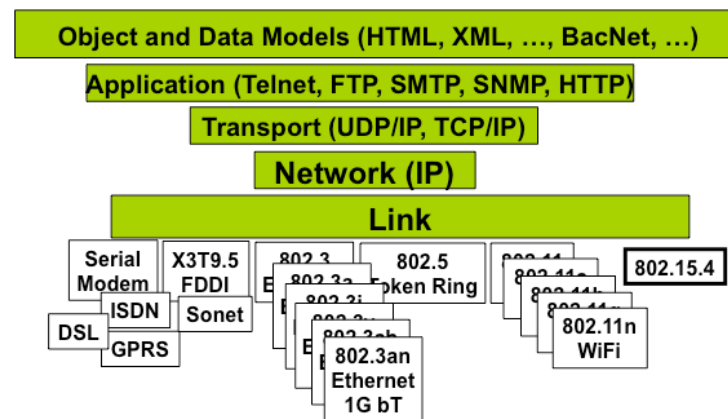
⇒ Design for Change

⇒ Accommodate new technology

⇒ Enable new applications

⇒ Innovate in the Overlay

⇒ Web: simple, open, machine readable formats



LaCal

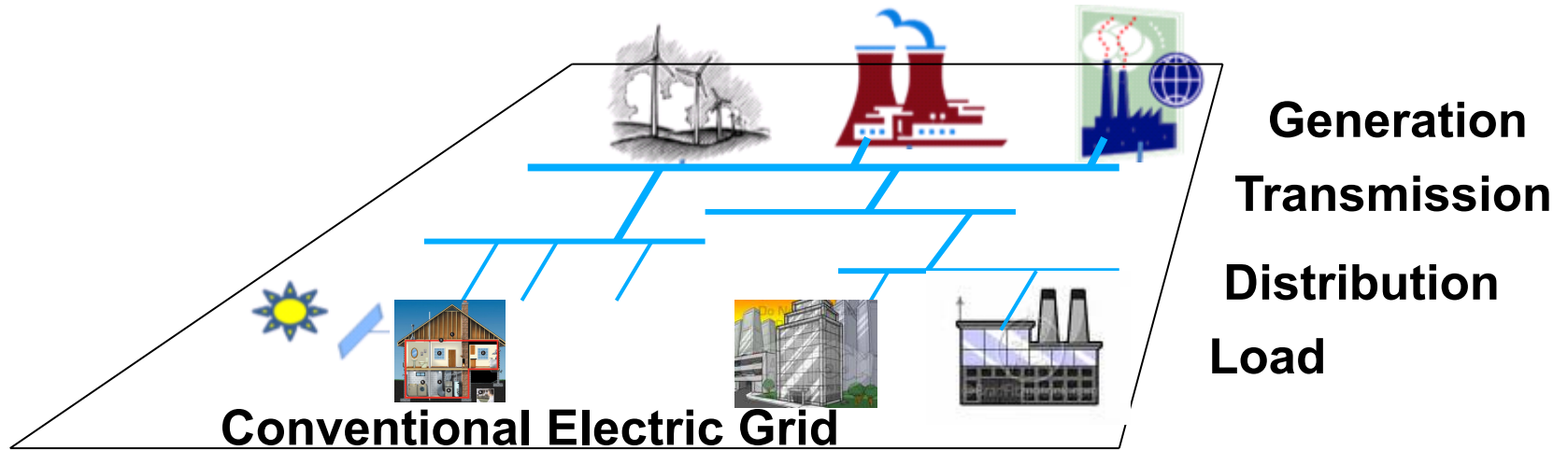


Start from Scratch?

- No!

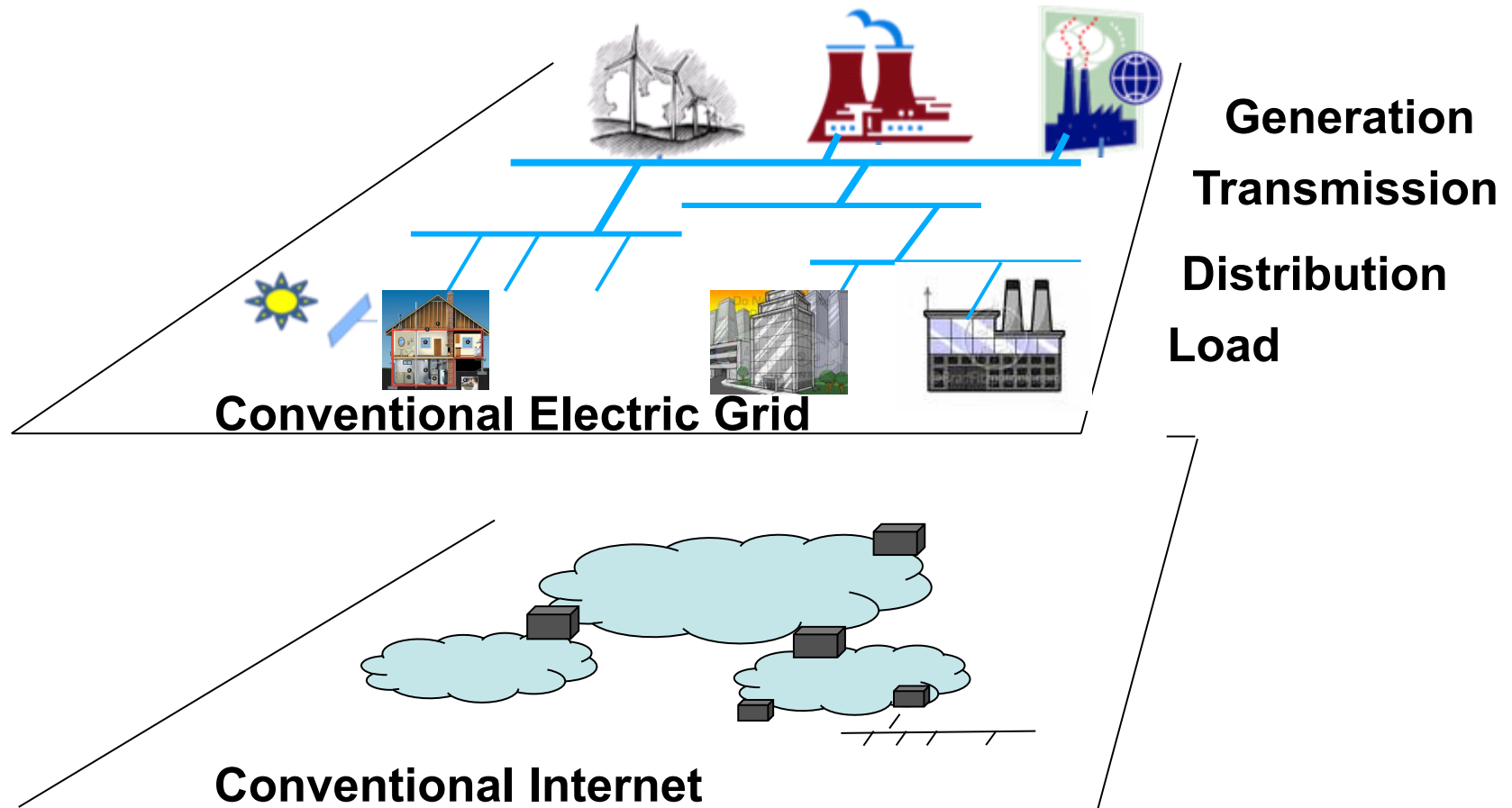


Grid Exists



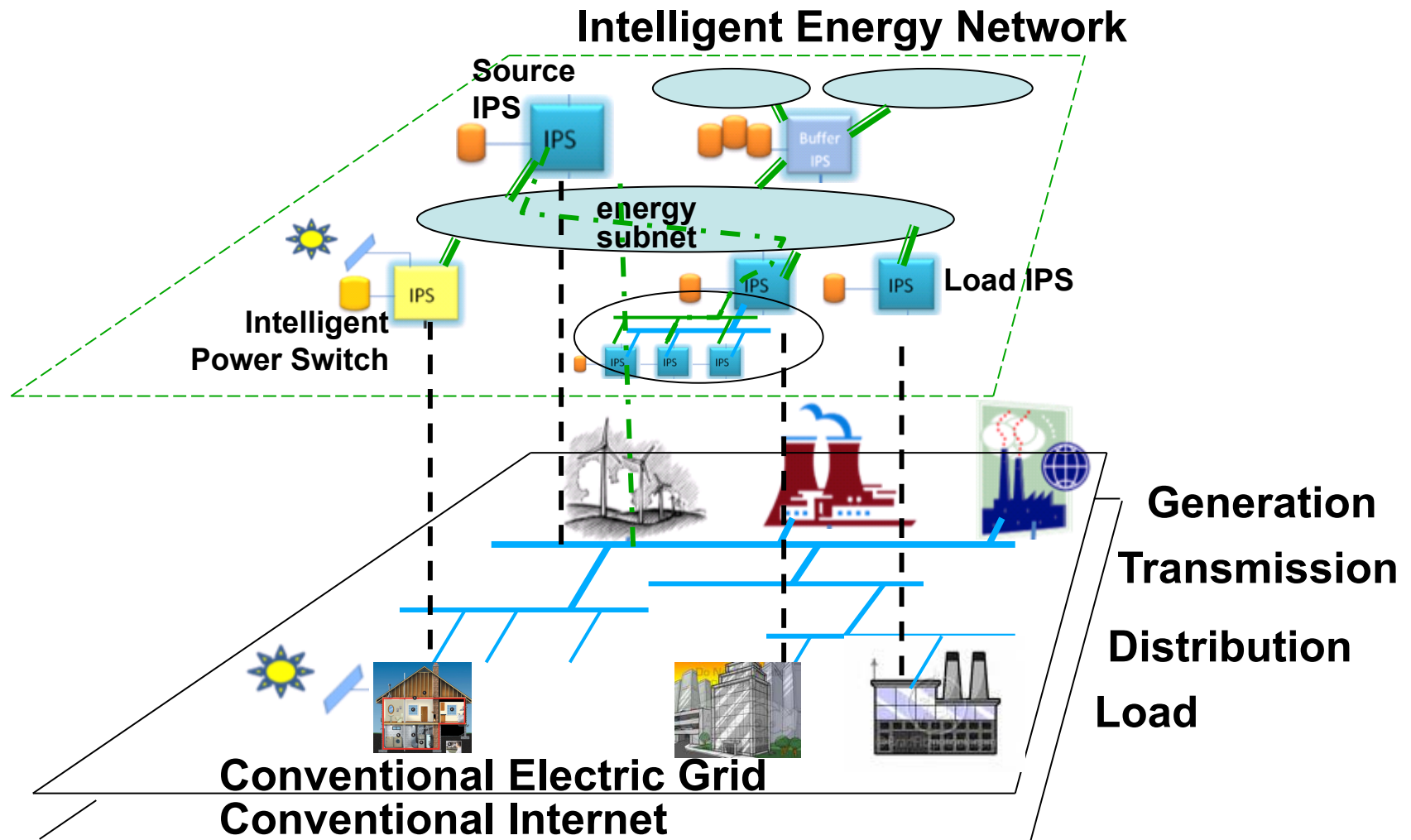


Internet Exists



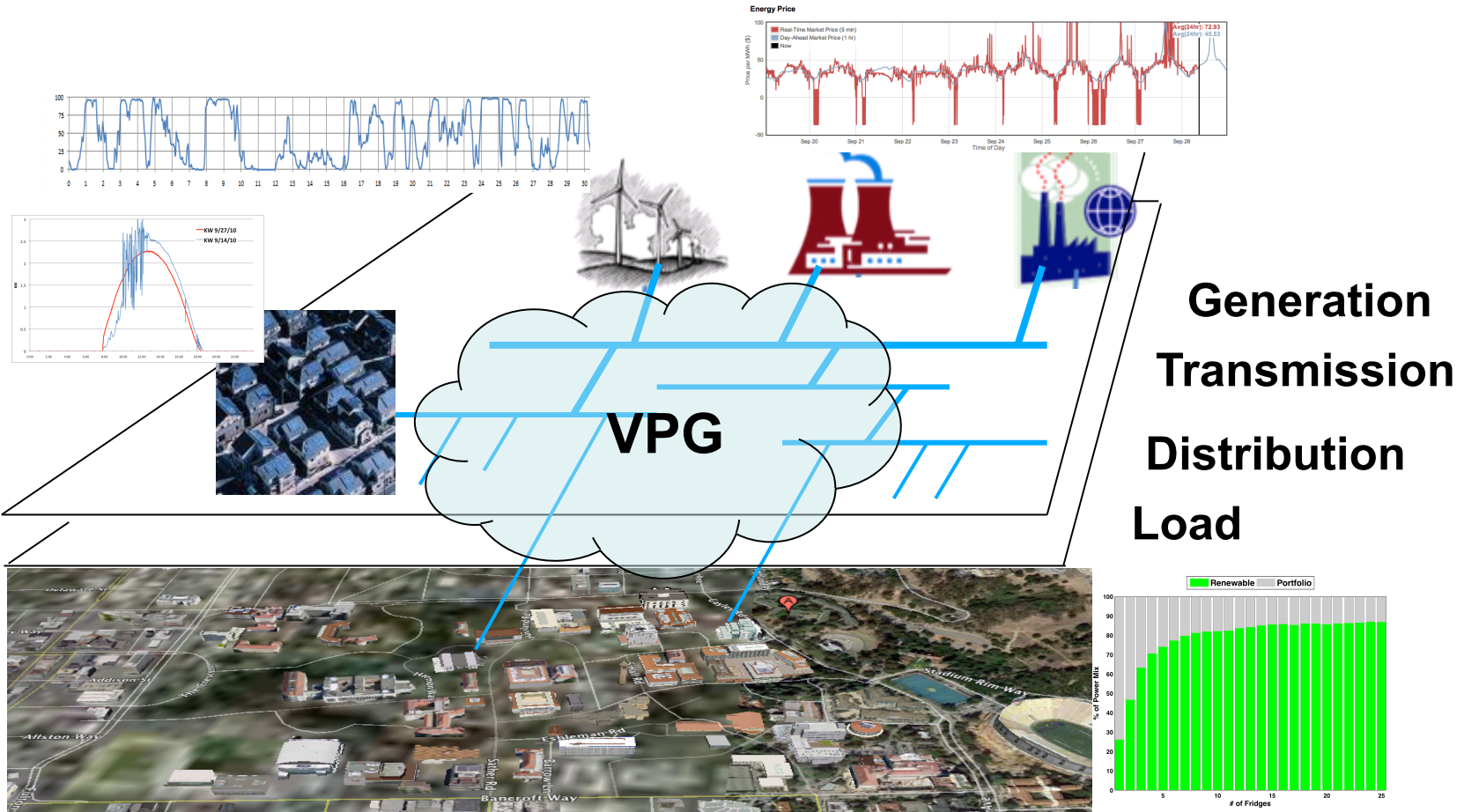


Intelligent Energy Network as Overlay on Both



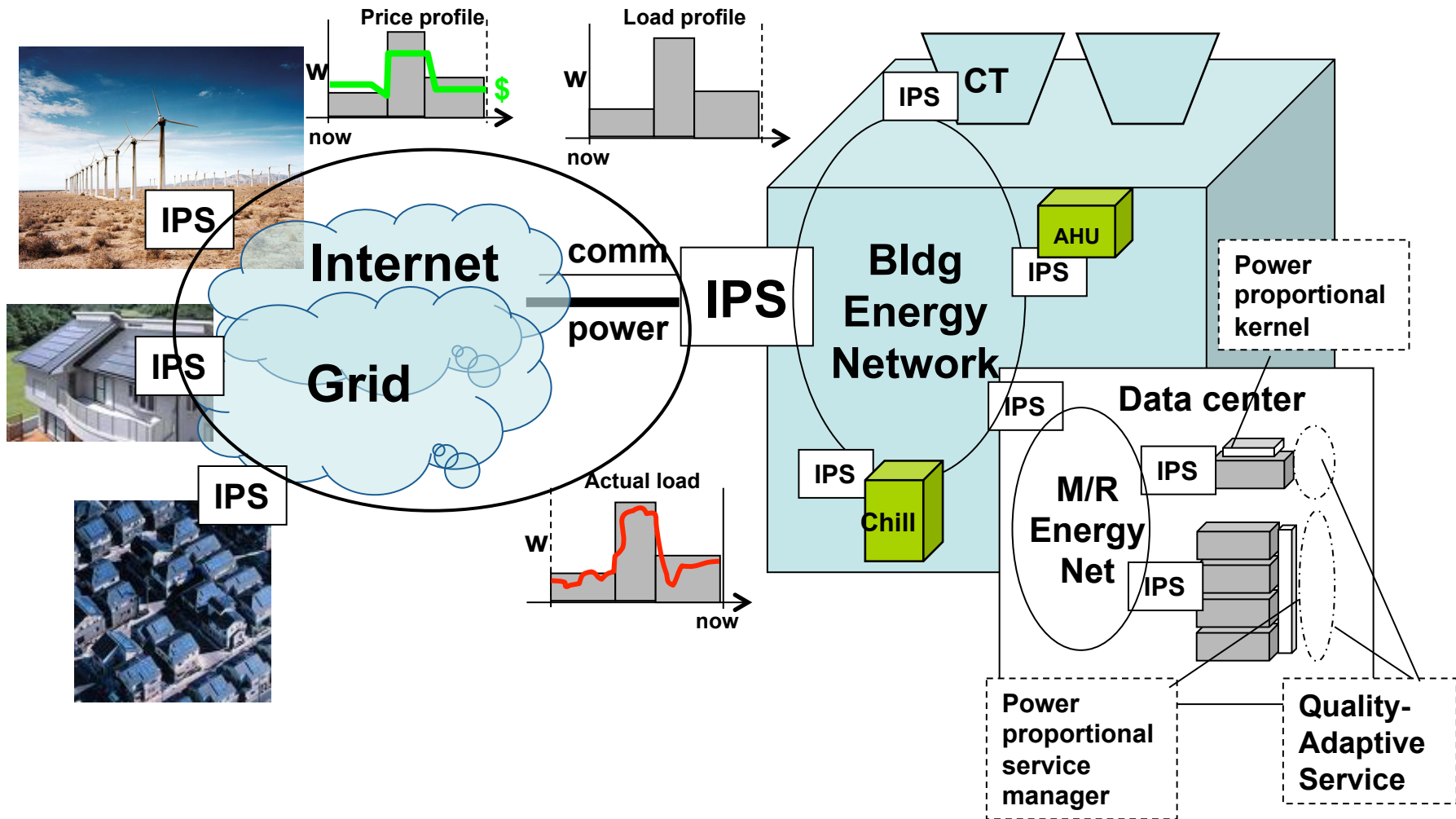


Innovate in a Virtual Private Grid



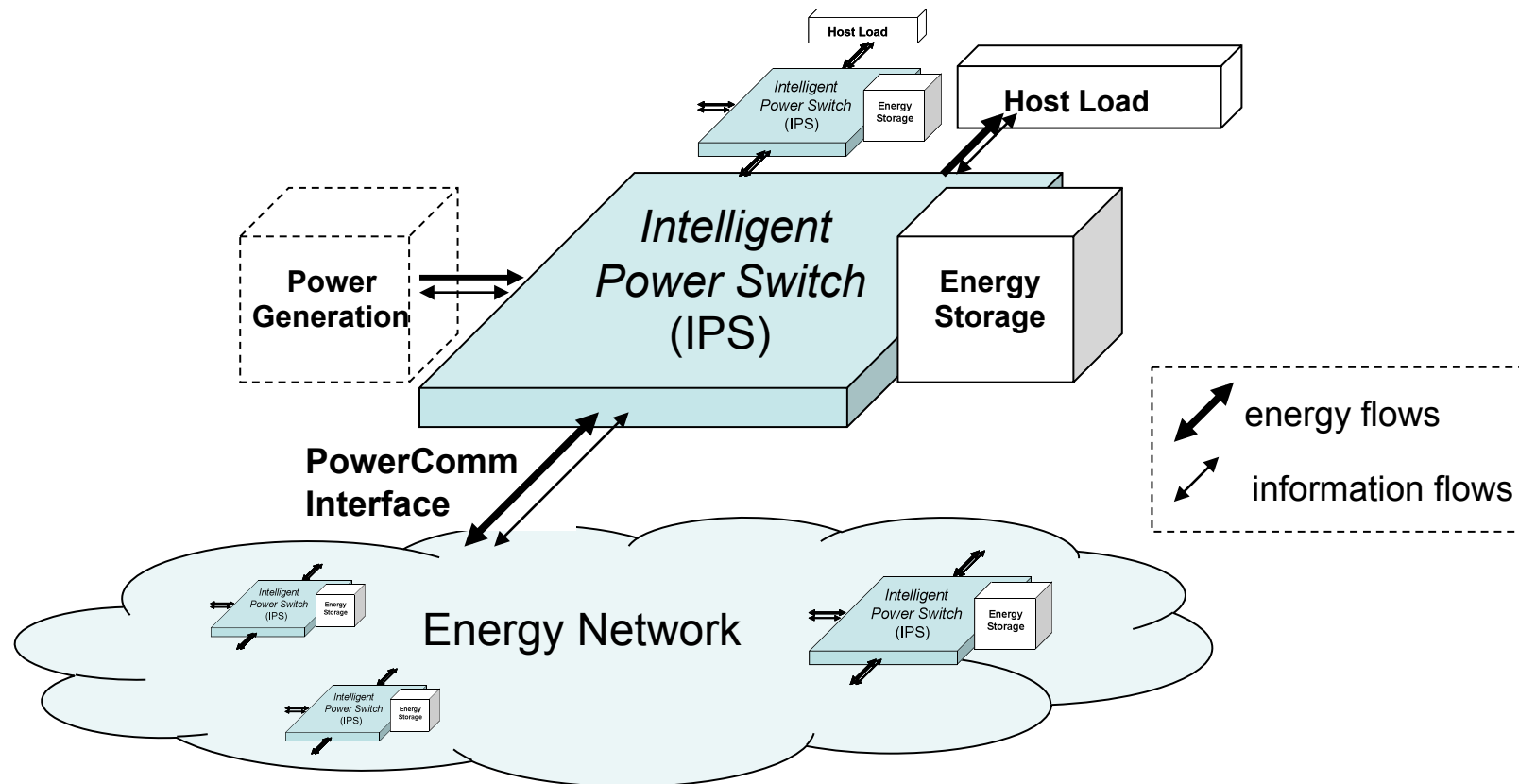


A MultiScale Study





Intelligent Power Switch



- PowerComm Interface: Network + Power connector

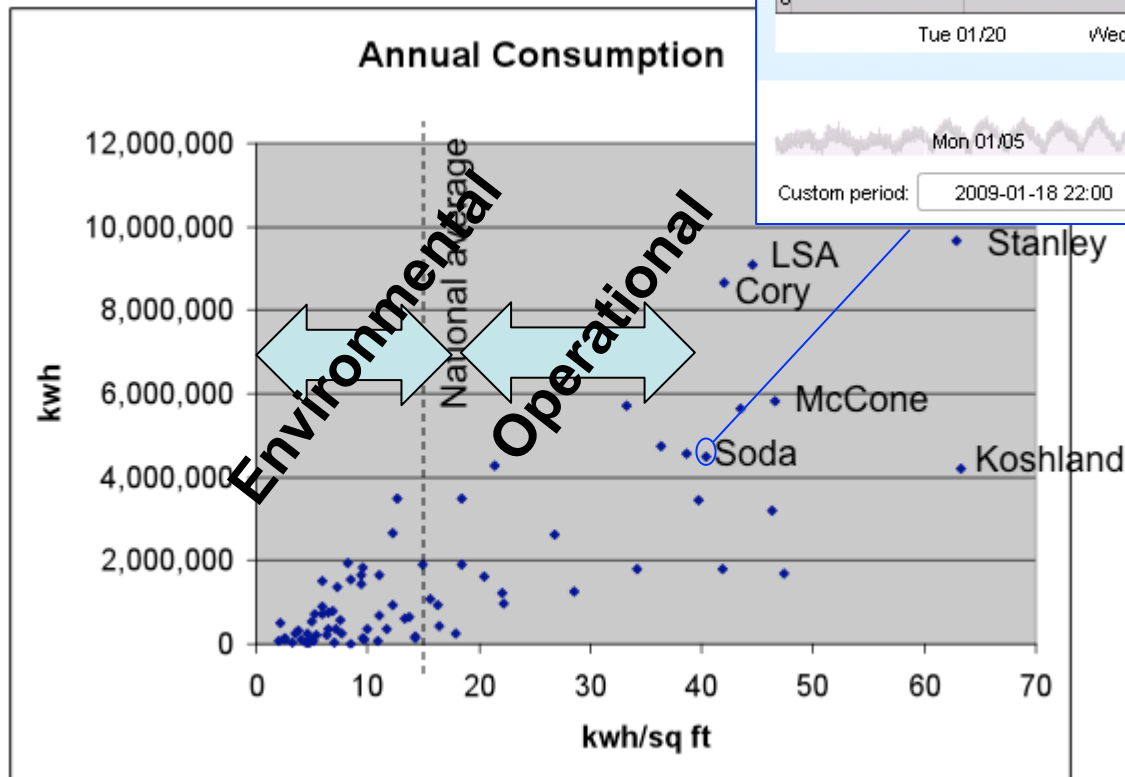
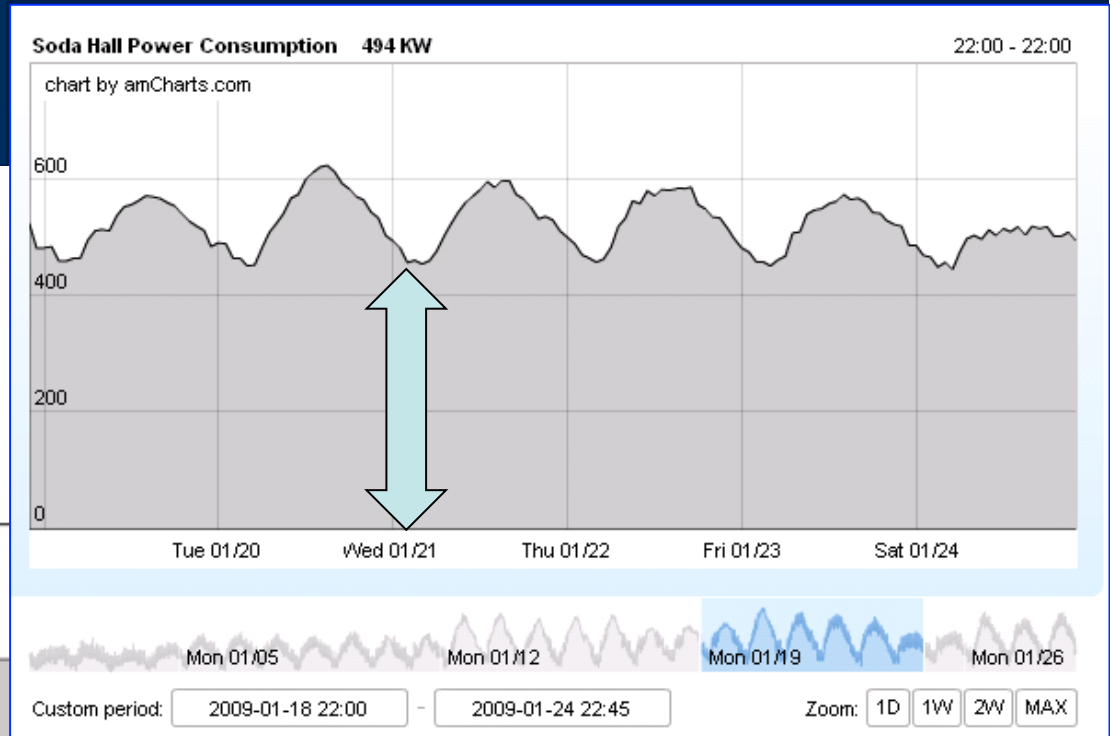
12/7/10 • Scale Down, Scale Out



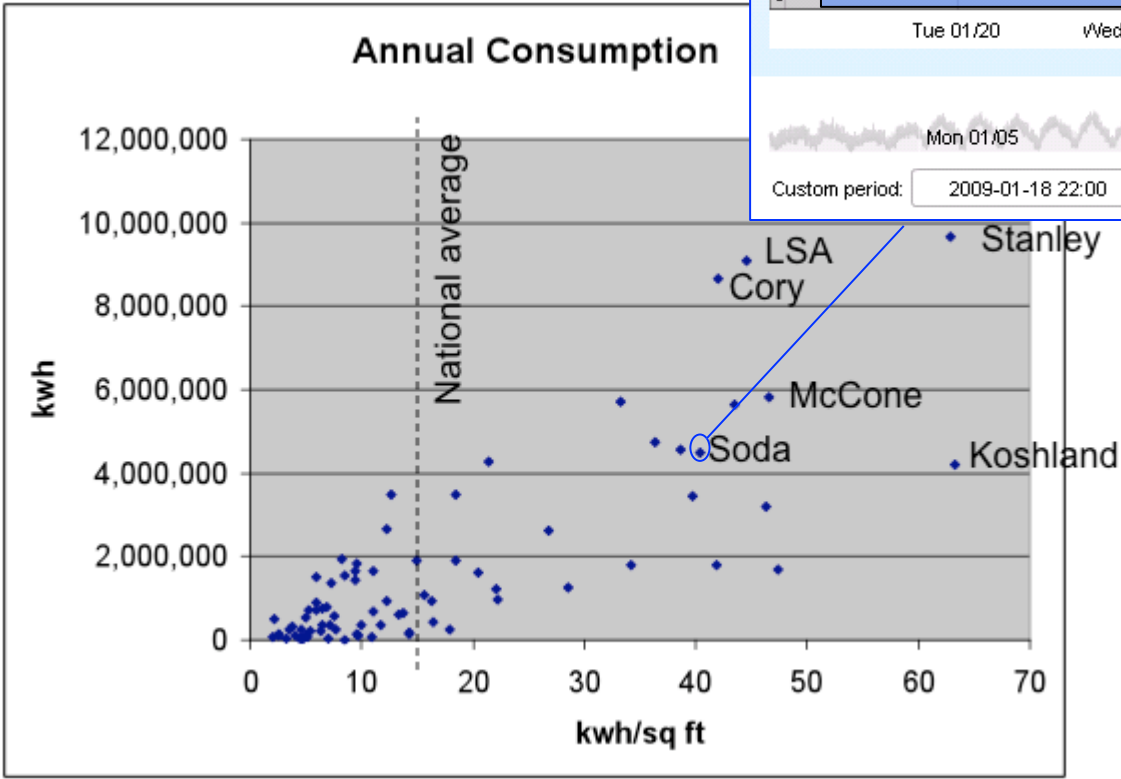
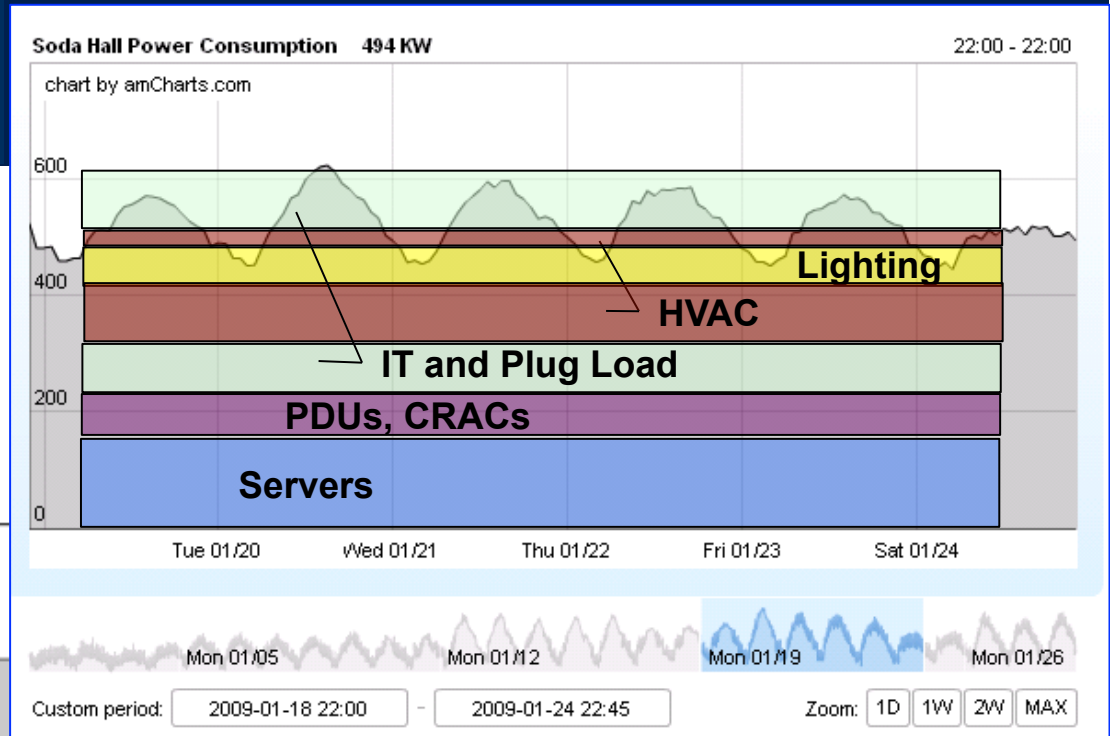
Questions...

- Where does the energy go?
 - how much is wasted?
 - how can the rest be optimized?
- How much *slack* is there?
 - Can it be exercised?
 - Energy storage? Electrical Storage?
- What limits renewable penetration?
 - vs storage, scheduling, cooperation
- What are the protocols involved?
- What is the System and network design?

Our Buildings



Soda Hall



1:



2020 IT Carbon Footprint

IT footprints

Emissions by sub-sector, 2020

820m tons CO₂

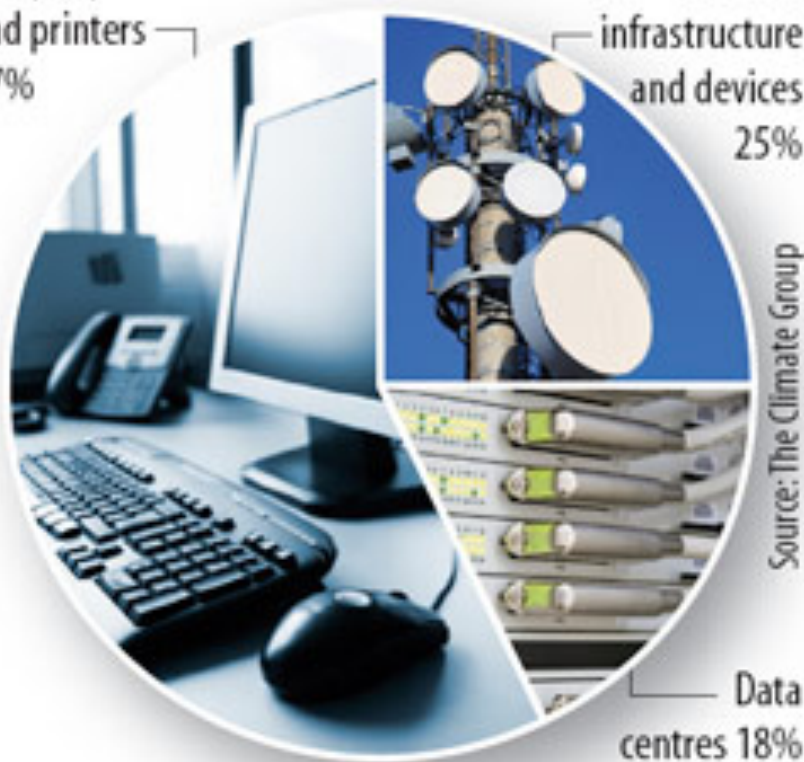
PCs, peripherals
and printers
57%

Telecoms
infrastructure
and devices
25%

360m tons CO₂

2007 Worldwide IT
carbon footprint:
2% = 830 m tons CO₂
Comparable to the
global aviation
industry

Expected to grow
to 4% by 2020



260m tons CO₂

Total emissions: 1.43bn tonnes CO₂ equivalent

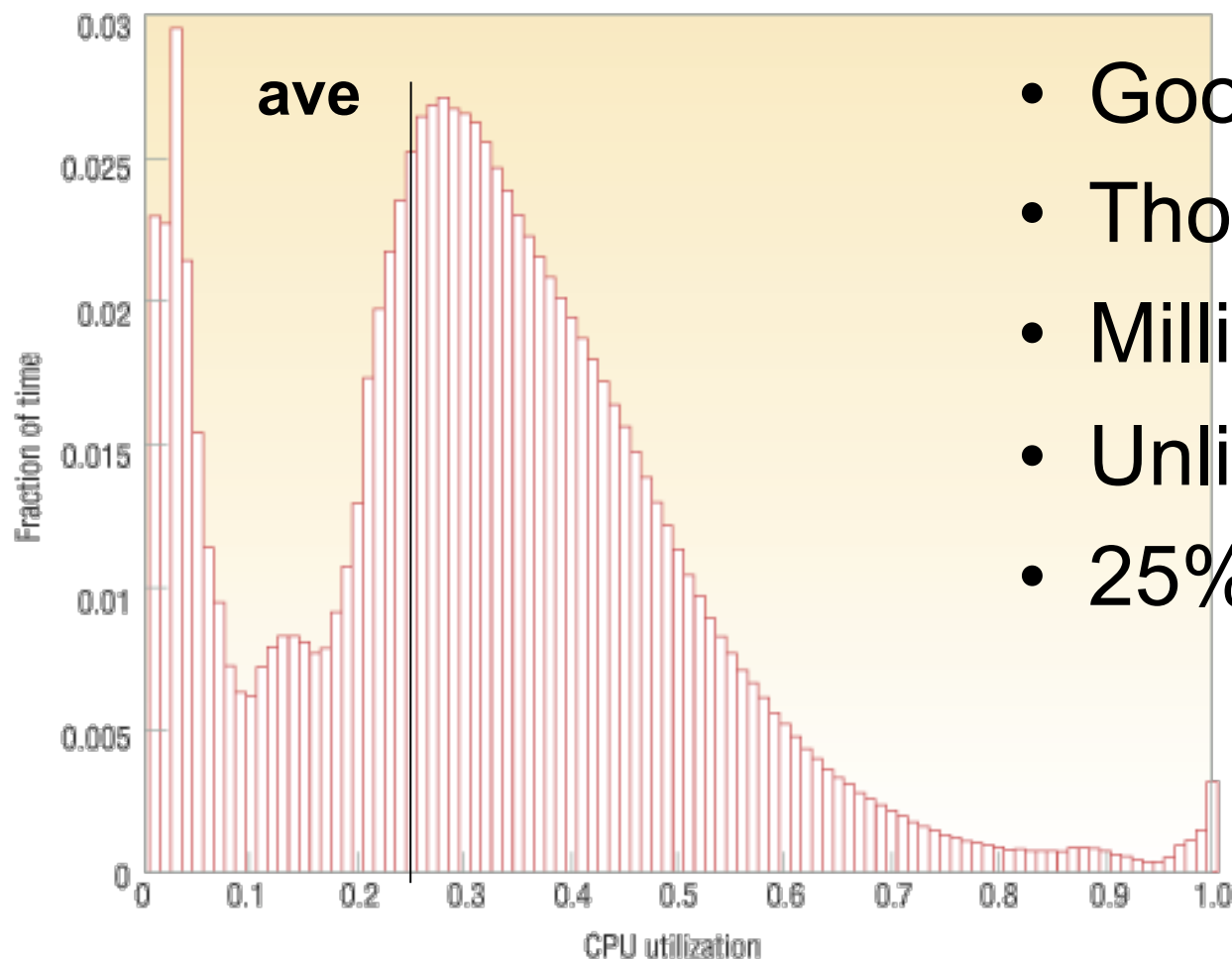


Engineering 101

- Design, Plan, Size, and Test at **Full Load**
 - Performance measured at full Load
- Add headroom and safety margin
- Operate at **Partial Load**



A Prime IT Example



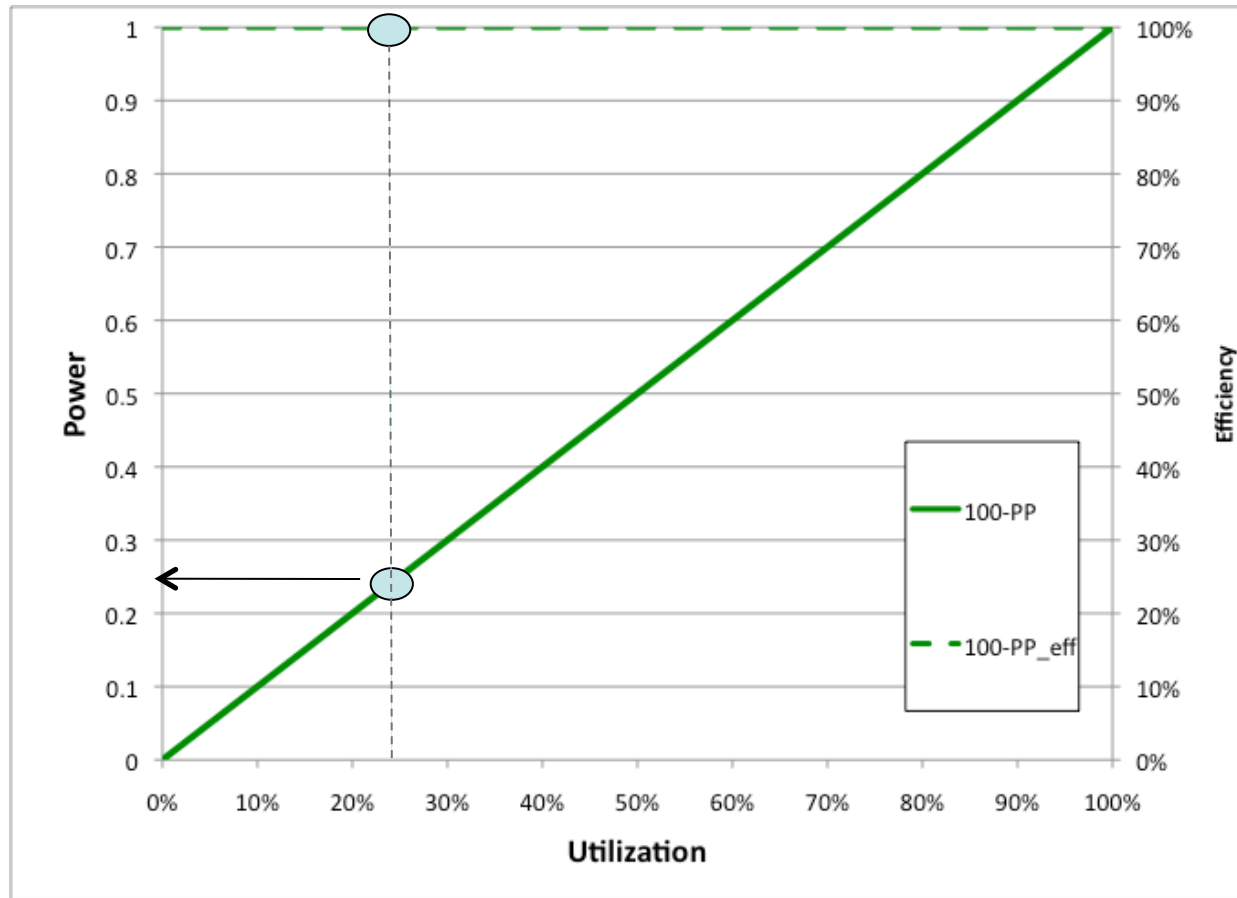
- Google
- Thousand of servers
- Millions of users
- Unlimited demand
- 25% utilized

“The Case for Energy-Proportional Computing,” Luiz André Barroso, Urs Hölzl, *IEEE Computer* December 2007 – study of 5,000 servers



Power Proportionality

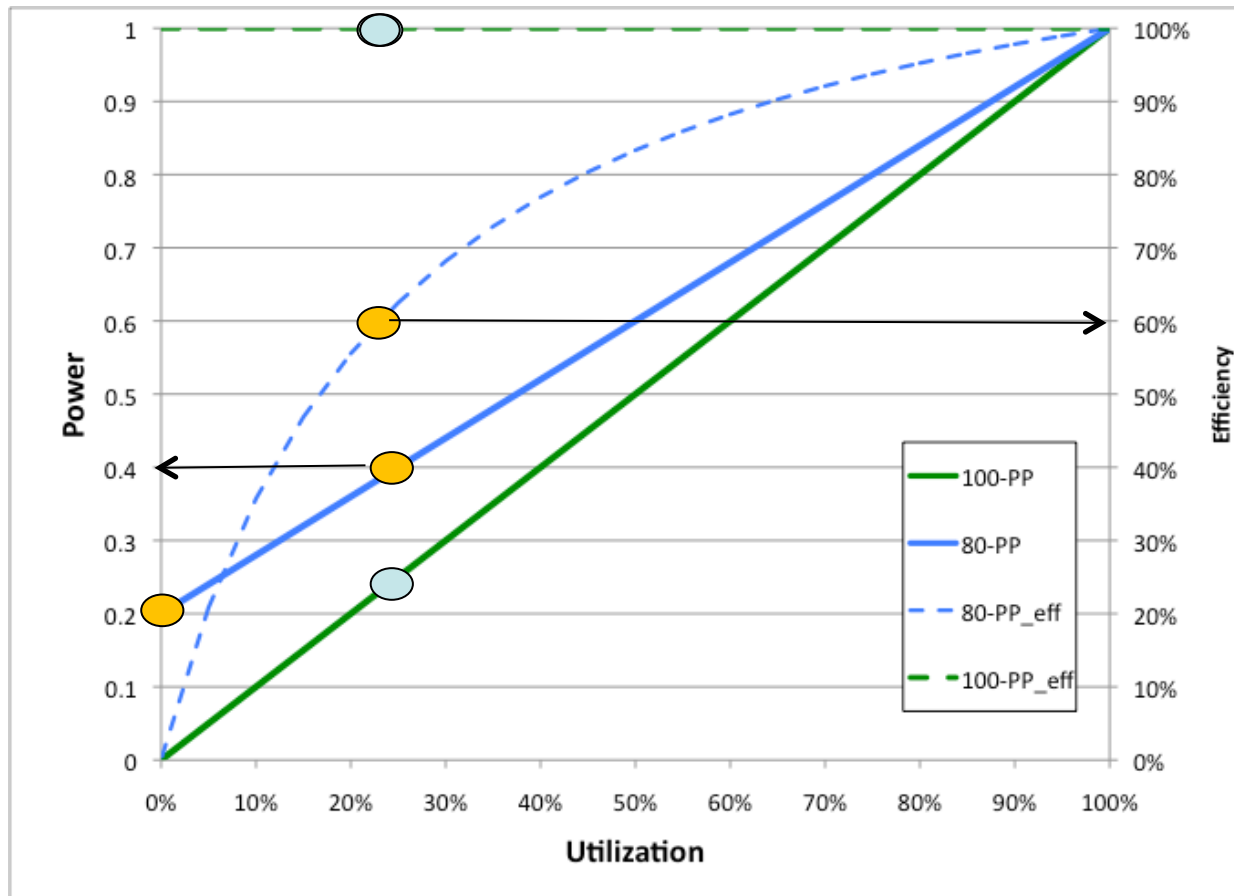
Consumption



Productivity

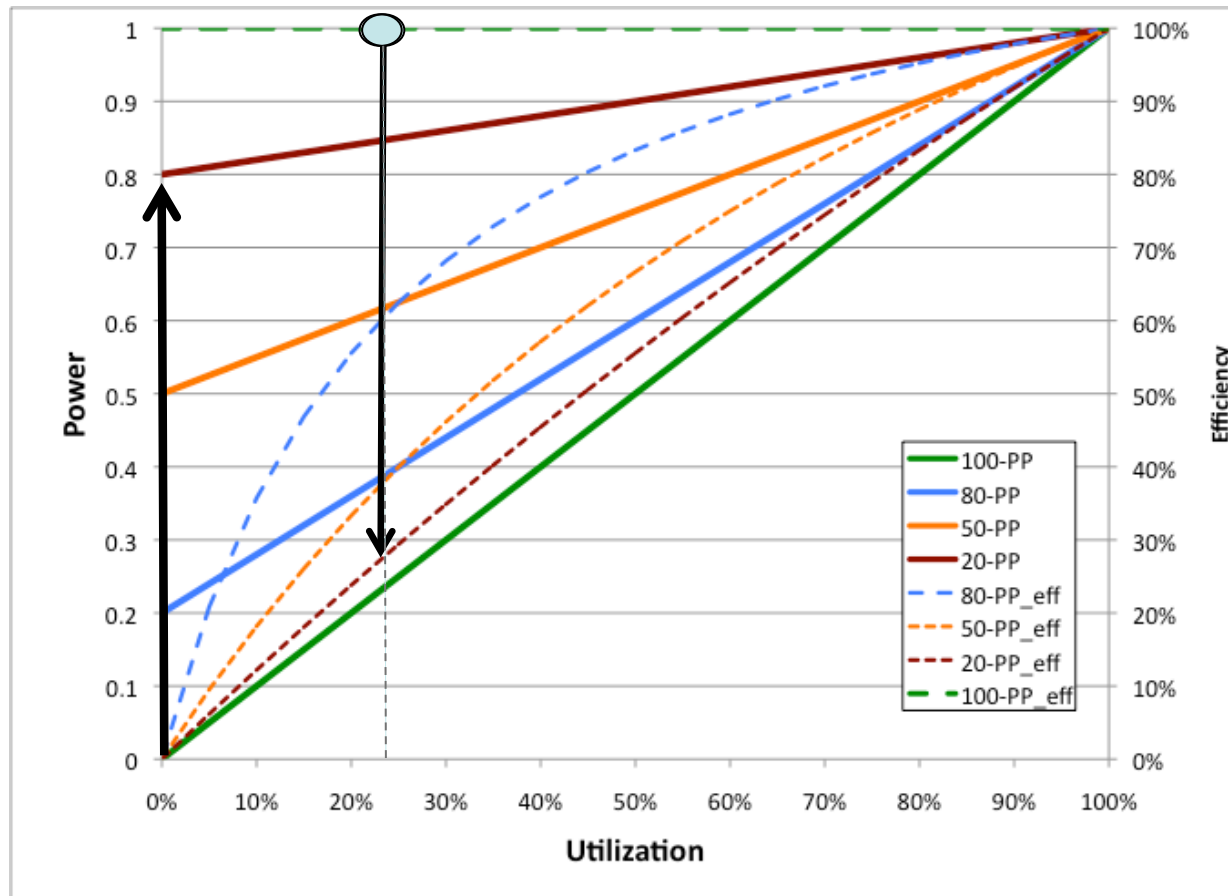


Power Proportionality



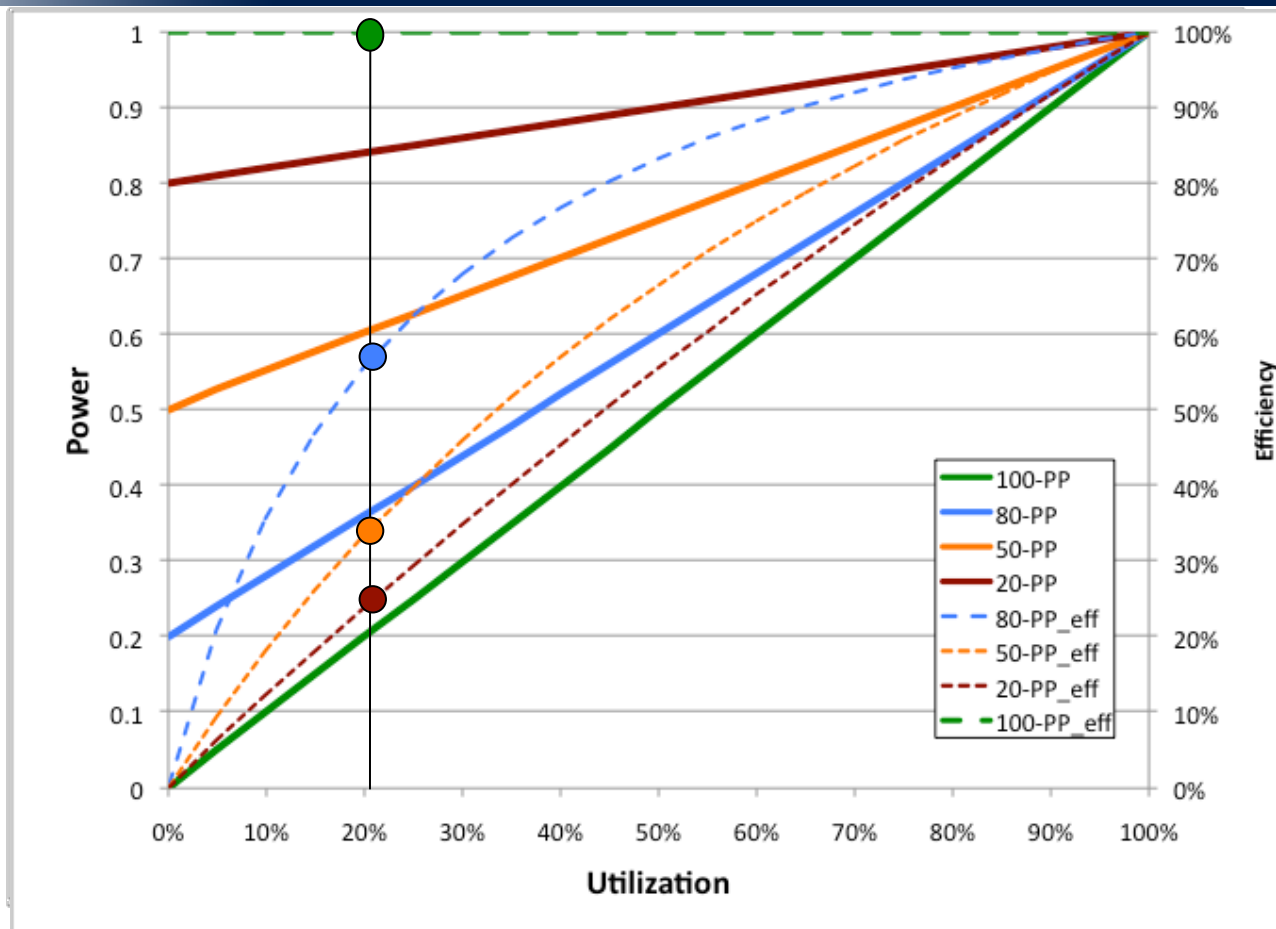


Power Proportionality





Power Proportionality



- Measure of scaling down to Partial Load

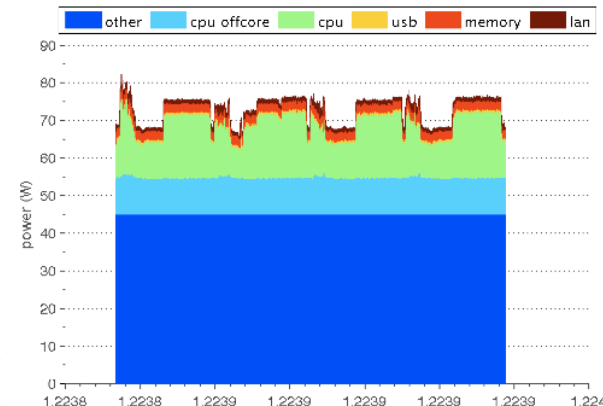
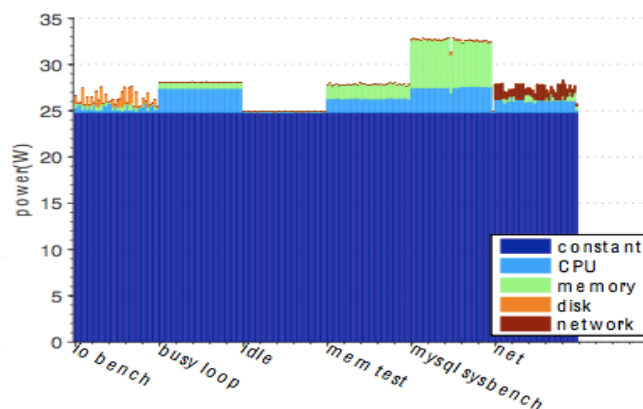
12/7/10 • Do Nothing Well !



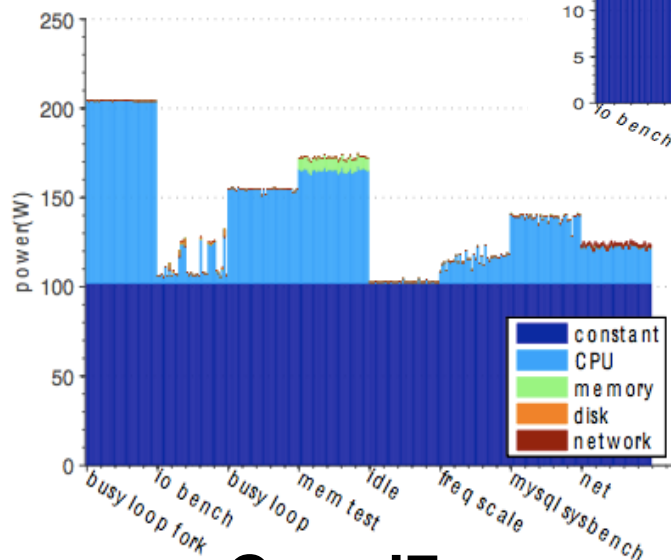
Where does the Power go?



The Glue, not the processor

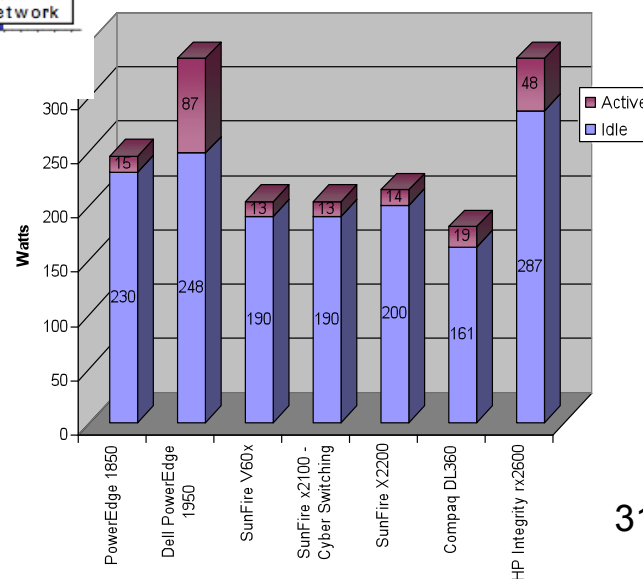


Westmere



Atom 333

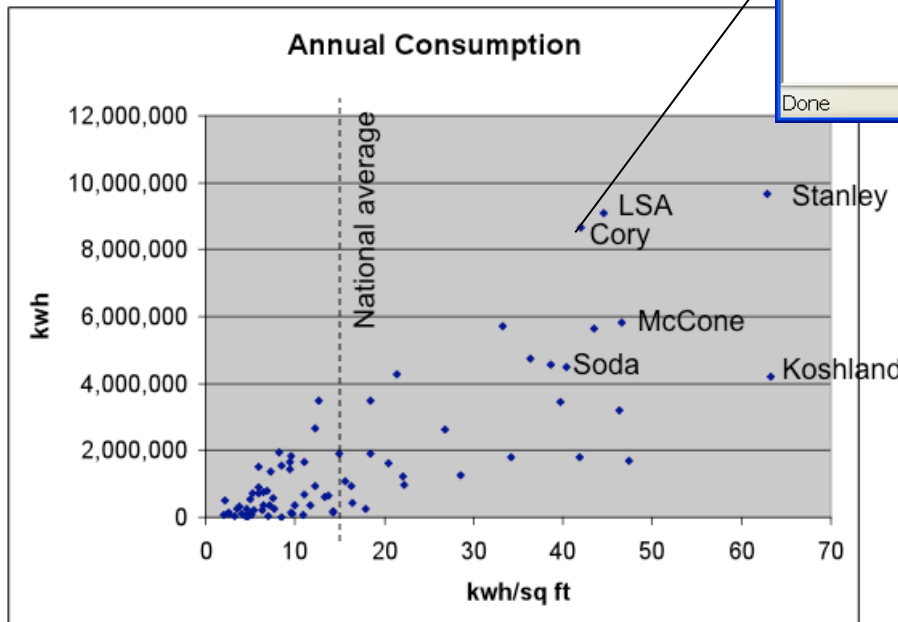
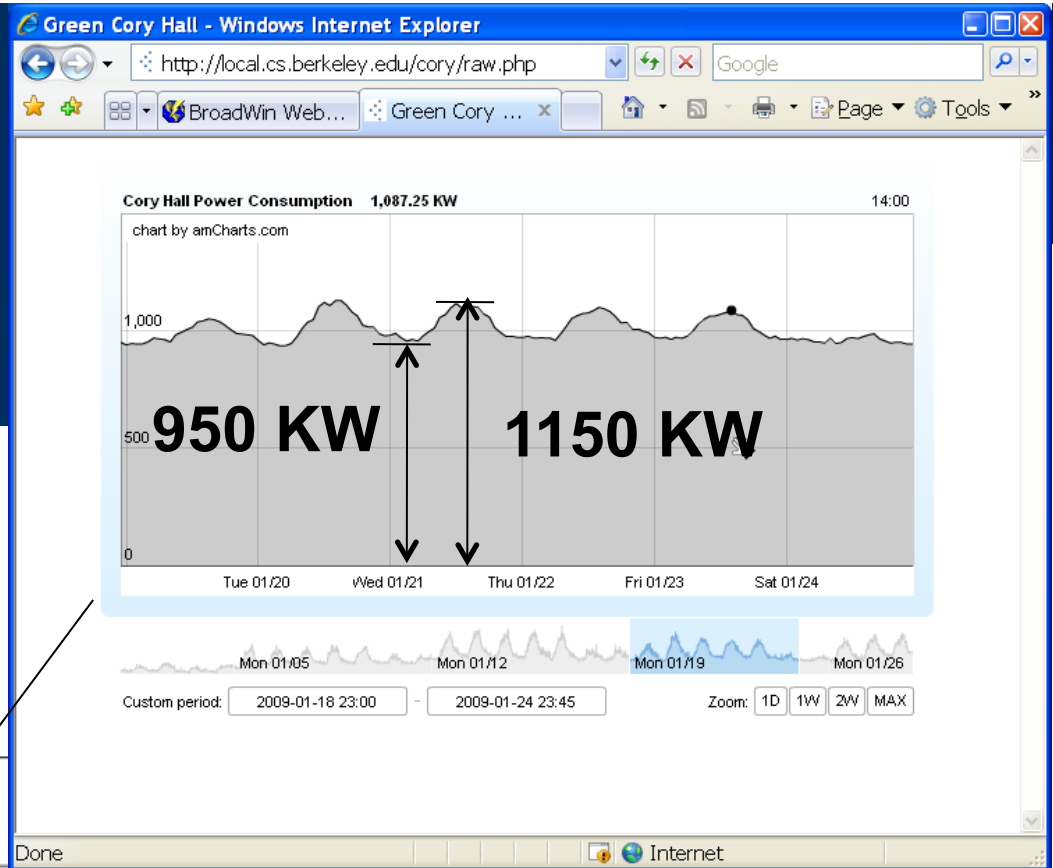
Server Power Consumption



12/7/10 Core i7

Power-Proportional Buildings ?

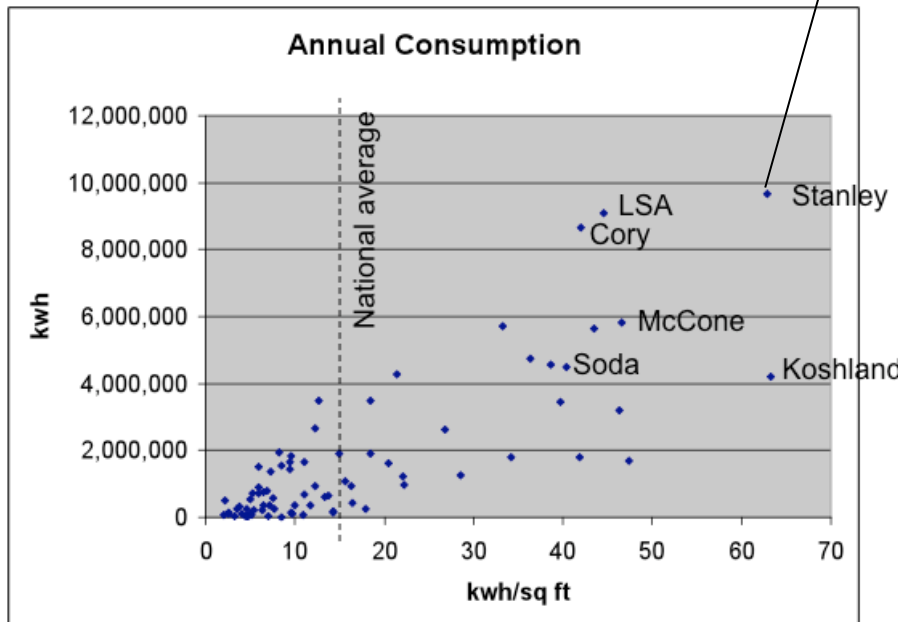
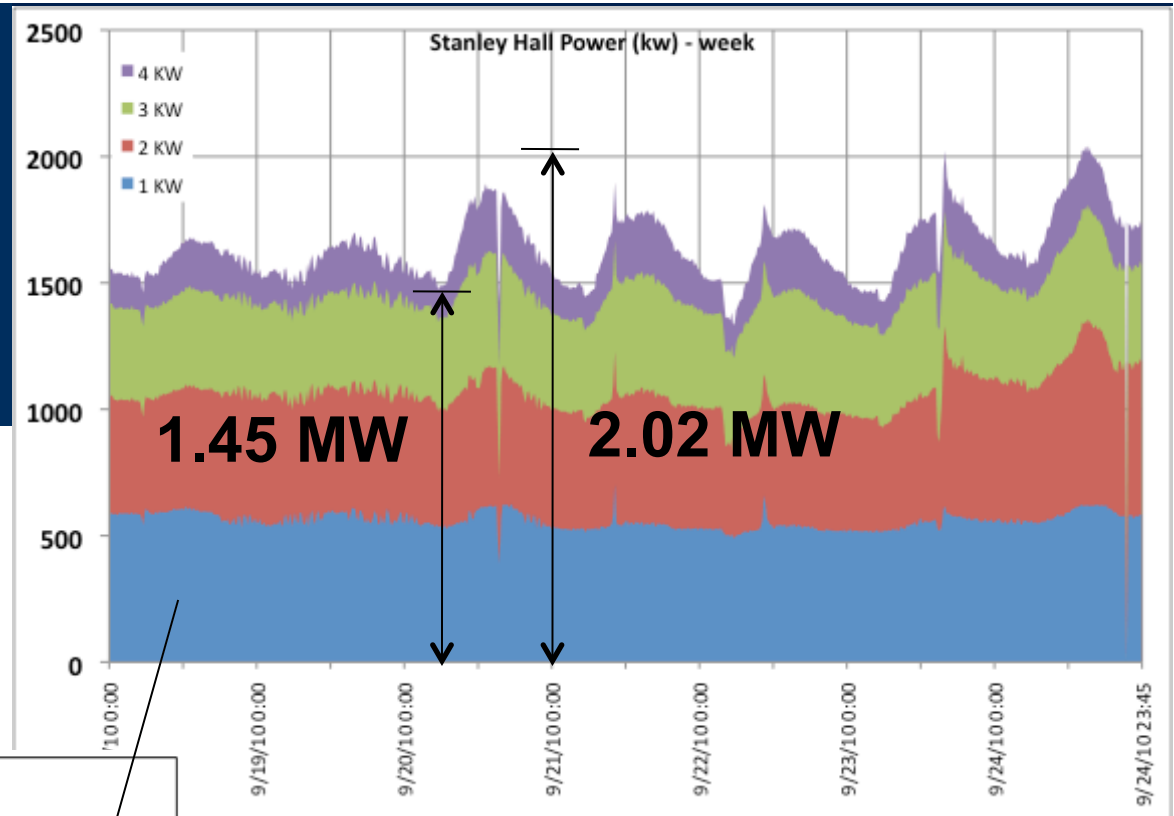
Cory Hall: Office + Semiconductor + IT



Min = 82% of Max

Power-Proportional Buildings ?

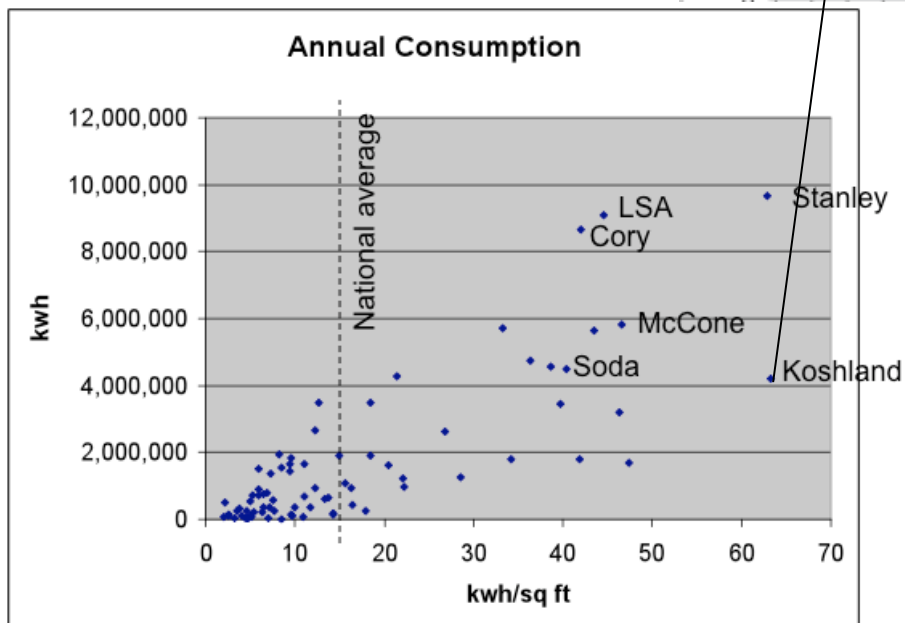
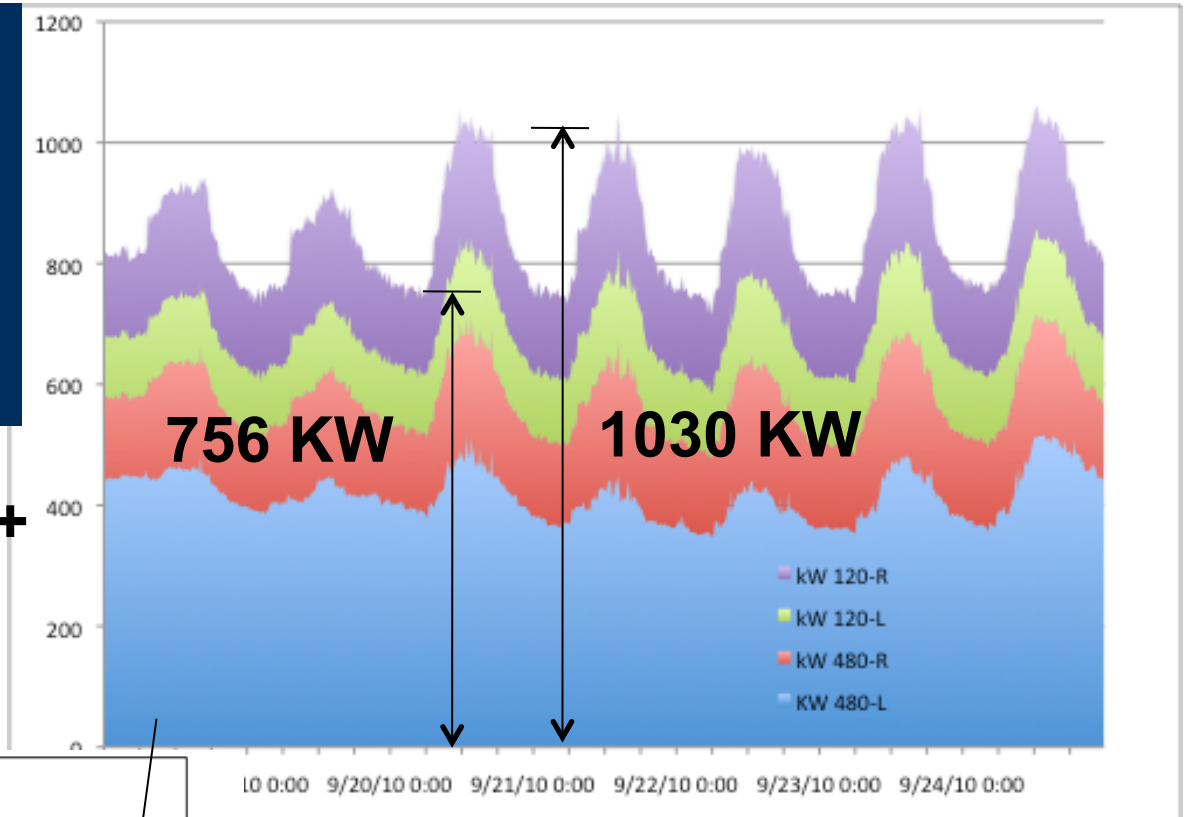
**Stanley Hall:
Office + BioScience
- 13 NMRs**



Min = 72% of Max

Power-Proportional Buildings ?

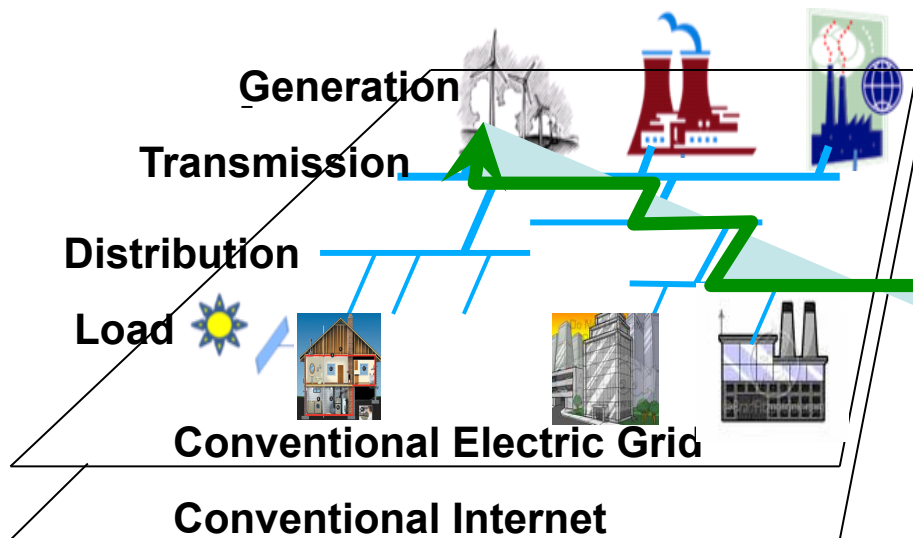
Koshland Hall: Office +



Min = 69% of Max

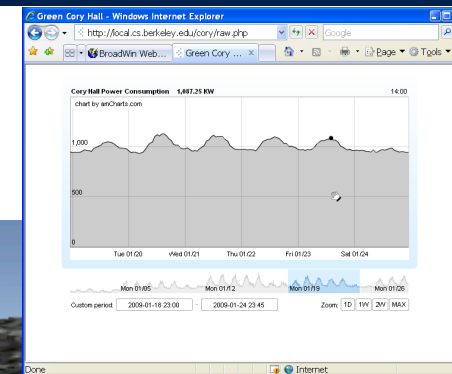
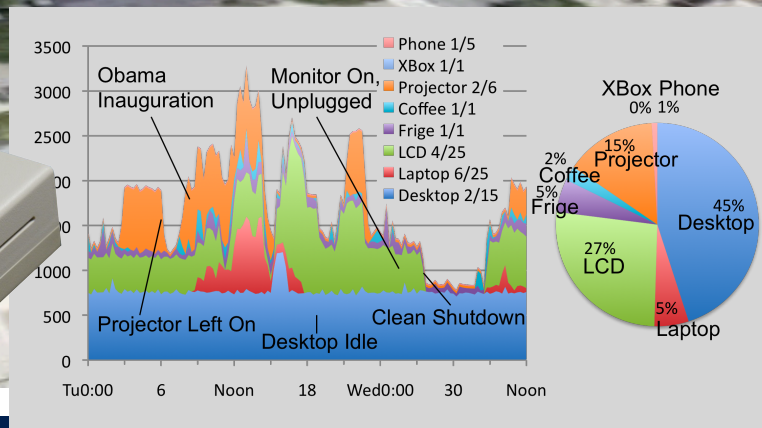


Building ↔ Grid Testbed



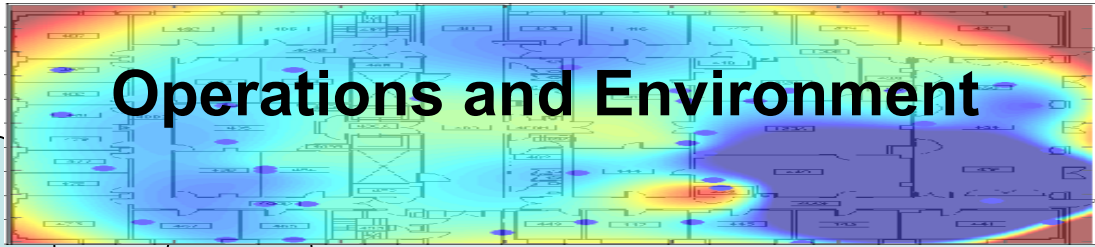
- large complex load
- >1,000 sense points
- Monitor, Model, Mitigate
- In concert with an intelligent grid

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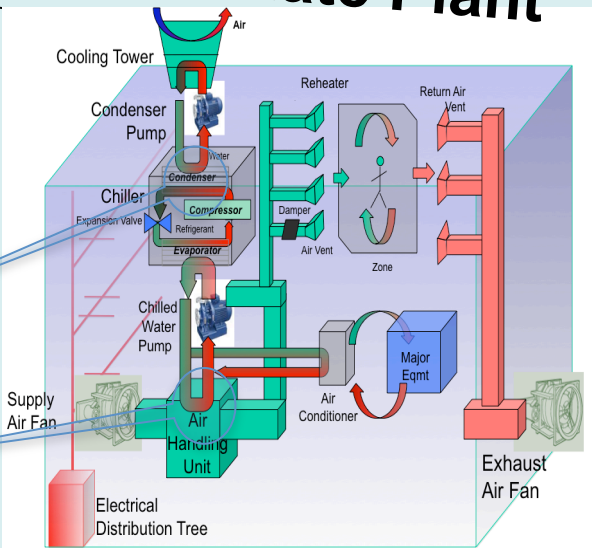




The 3 Views

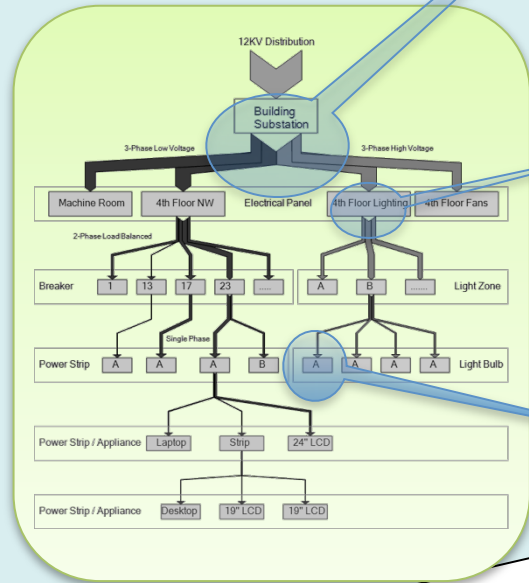


Climate Plant



Building Environmental Manufacturing Infrastructure

Load Tree



Vibration

Humidity

Temperature

Pressure

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CT: mains power monitoring

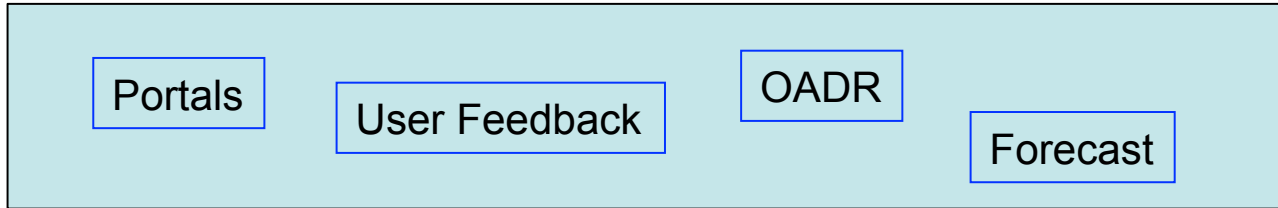
panel level power monitoring

ACme: plug load energy monitor and controller

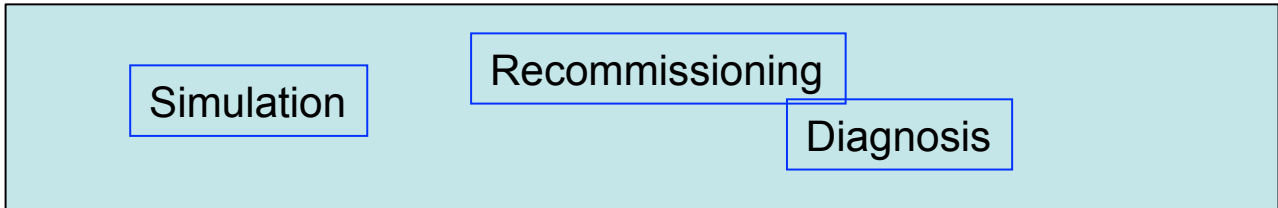


Layered Arch. for Physical Info

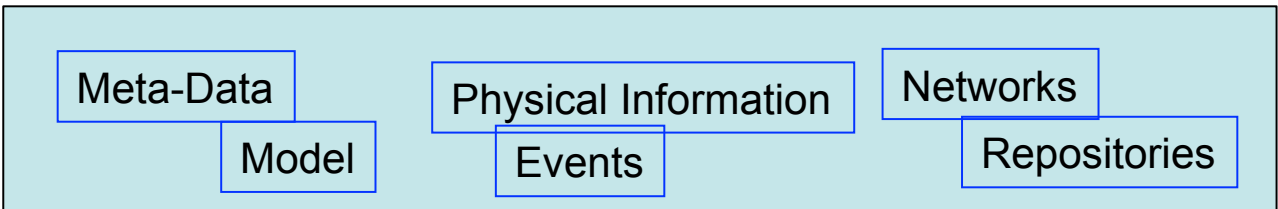
Presentation



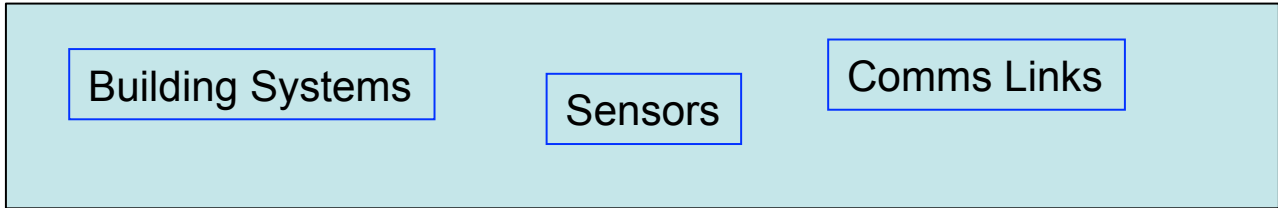
Analysis



Logical



Physical





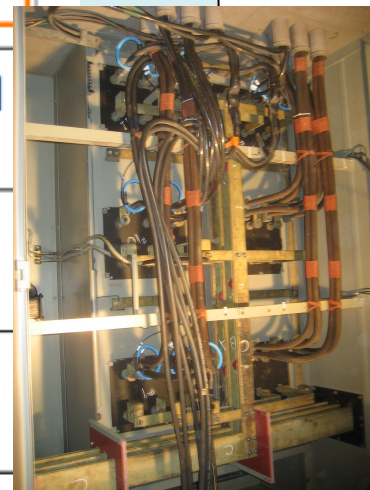
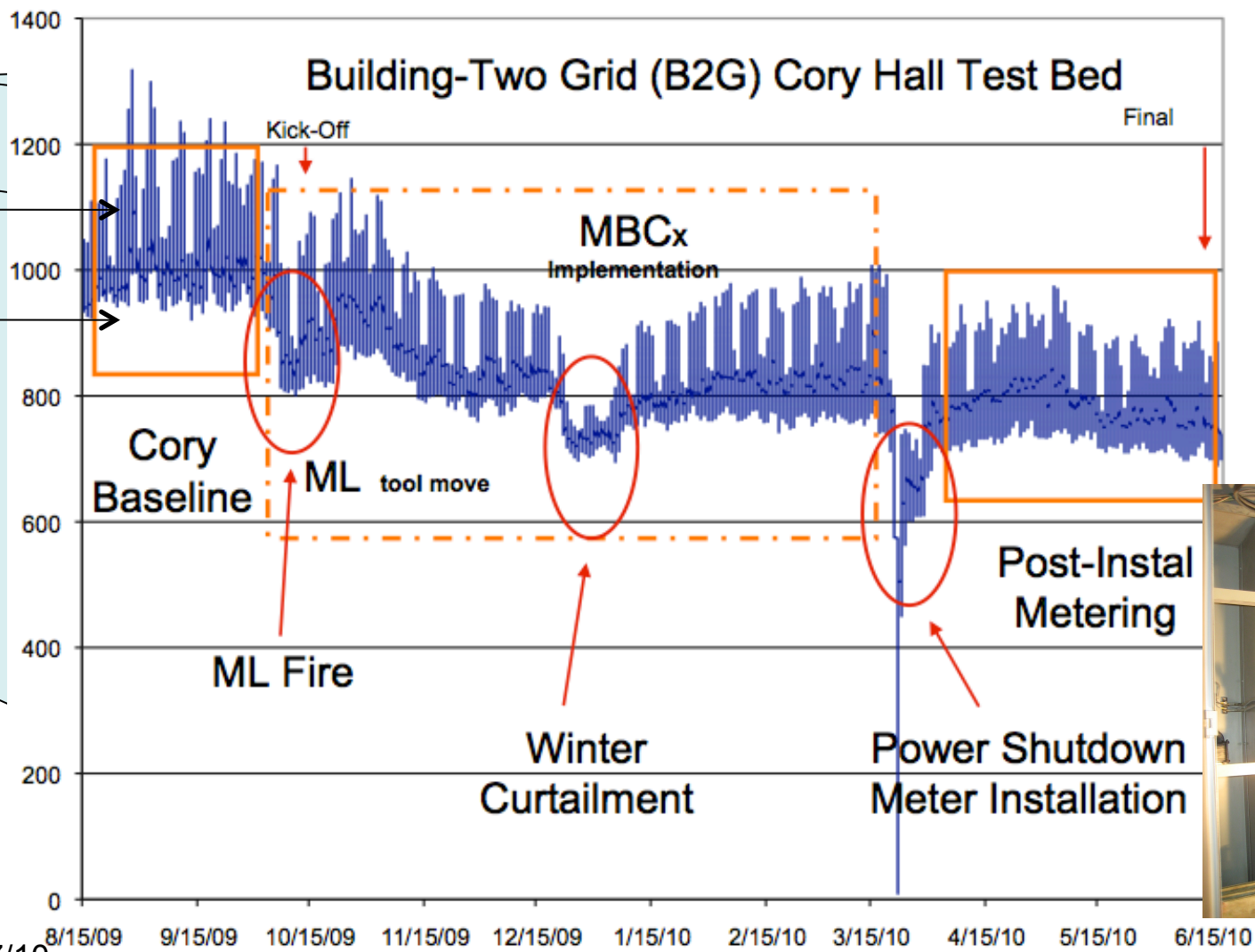
Physical Tier

- 10 Dent Powerscout 18-channel (6x3) electrical meters
 - RS485 – Ethernet/IP – sMAP
- 2 Power Standards Labs meters
 - Ethernet
- 2 (existing) ION 6200 meters
- 70 ACME Receptacle meters
 - 802.15.4/LoWPAN/IP
- 4 rooftop Solar/TSR/PAR/Temp/Hum
- Condensate meter, Obvius Steam
- Vaisala Meteorological Station
- *Existing SCADA integration*
- *Remote Programmable PCT => Action*
- *Interior usage, activity, environmental condition*





Along the way ...

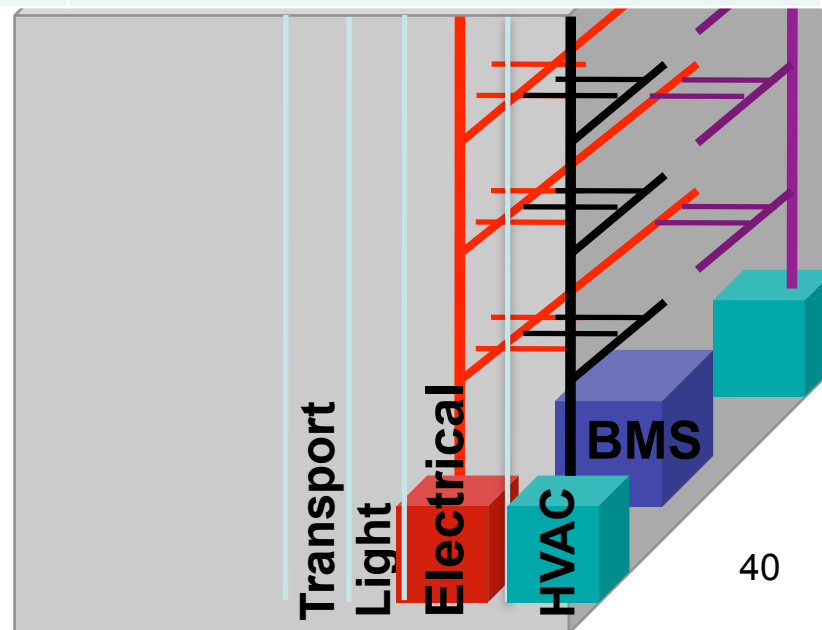




Building Information “standards”

Protocol	Year	Network	Example Applications
Modbus	1979	RS-485, TCP/IP	Panel monitoring, alarms
Fieldbus/HART	1988	various	Industrial Control
BACnet	1995	ARCNET, Ethernet, IP, RS-232, etc.	HVAC, Lighting, Fire...
WirelessHART	2007	802.15.4e	Industrial control, wire replacement
Zigbee SEP 2.0	2011?	802.15.4	Plug-load monitoring

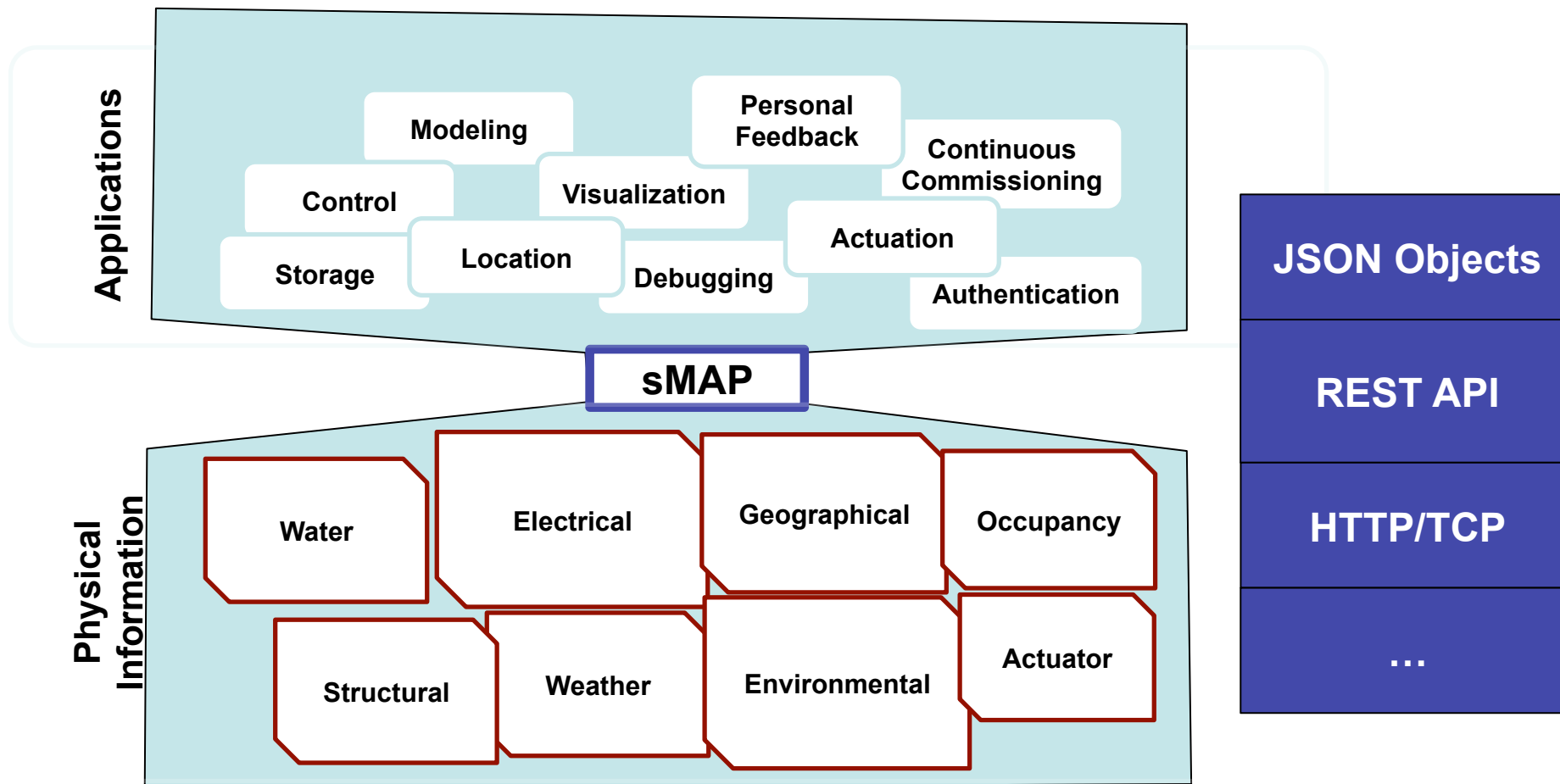
- **HUGE installed/legacy base**
- **Multiple generations of hardware and software in the same building**
- **Typical integration: proprietary vertical Building Management System (BMS)**



12/7/10



Narrow Waist ?





sMAP Interaction



smap.cory.berkeley.edu



```
GET /data  
["weather"]
```

Discover

```
GET /data/weather  
["sensor", "meter"]
```

```
GET /data/weather/sensor  
["temperature", "wind", "humidity"]
```

```
GET /data/weather/sensor/temperature/reading  
{ "Reading" : 23,  
  "ReadingTime" : 1288385832,  
  "ReadingSequence" : 123123 }
```

Access

12/7/10



sMAP Design

- KISS: Sensing, Metering, Actuation
- Identify Sense Points and Channels
 - Sense point: physical point of instrumentation (e.g. weather station)
 - Channel: Stream of scalar readings (e.g, temperature)
- Map these to HTTP resources

```

/           # list resource under URI root [GET]
/data      # list sense points under resource data [GET]
  / [sense_point] # select a sense points [GET]
    /meter      # meters provide this service [GET]
      / [channel] # a particular channel [GET]
        /reading # meter reading [GET]
          /format # calibration and units [GET/POST]
            /parameter # sampling parameter [GET/POST]
              /profile # history of readings [GET]
    
```



Event Reporting

```
POST /reporting/create
{"Period" : 60, "Minimum" : 50, "Maximum" : 100
  "ReportResource" : "~/data/**/*/reading",
  "ReportDeliveryLocation" : "http://www.openbms.org/add/2133"
}
```

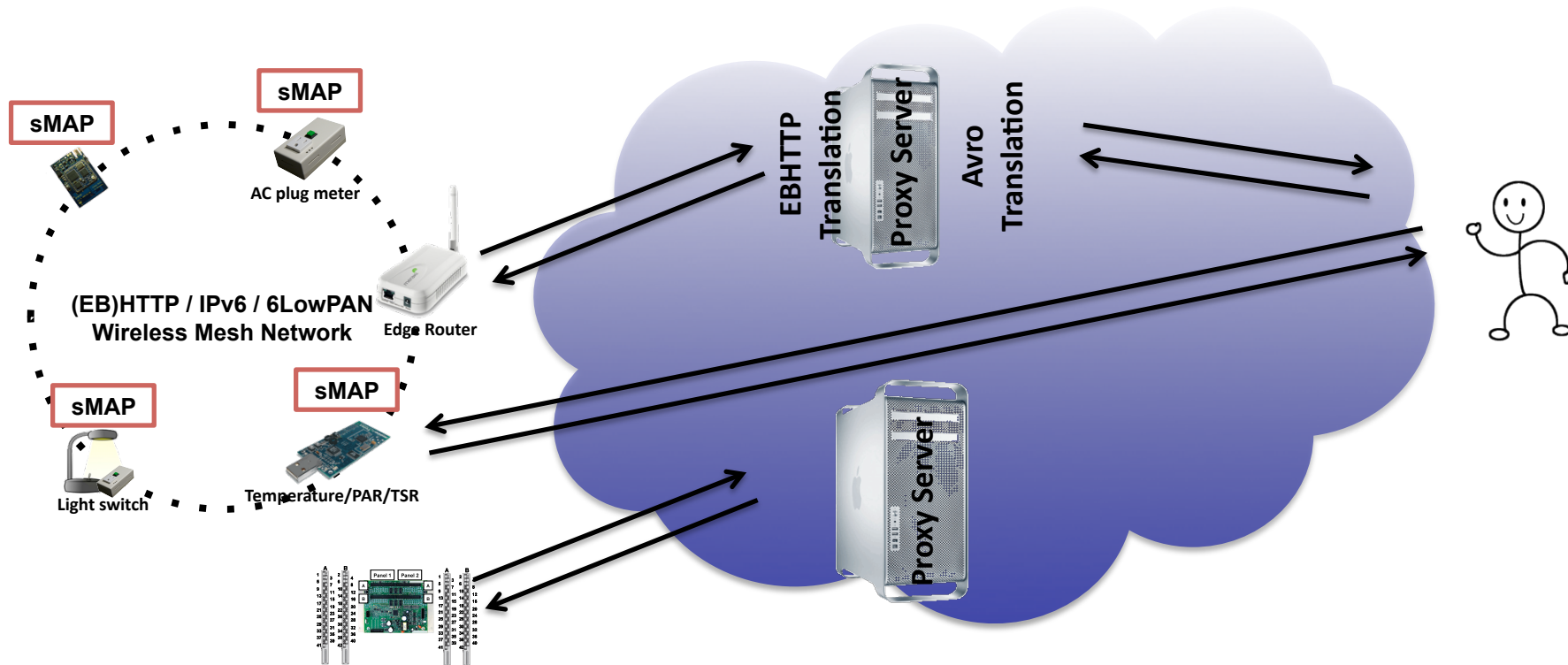
Add “callbacks” to HTTP

- POST requests supply JSON objects as arguments
- Same semantics as a GET on ReportResource
- Alternatives are “long get,” webevents/multipart HTTP style



Embedding sMAP

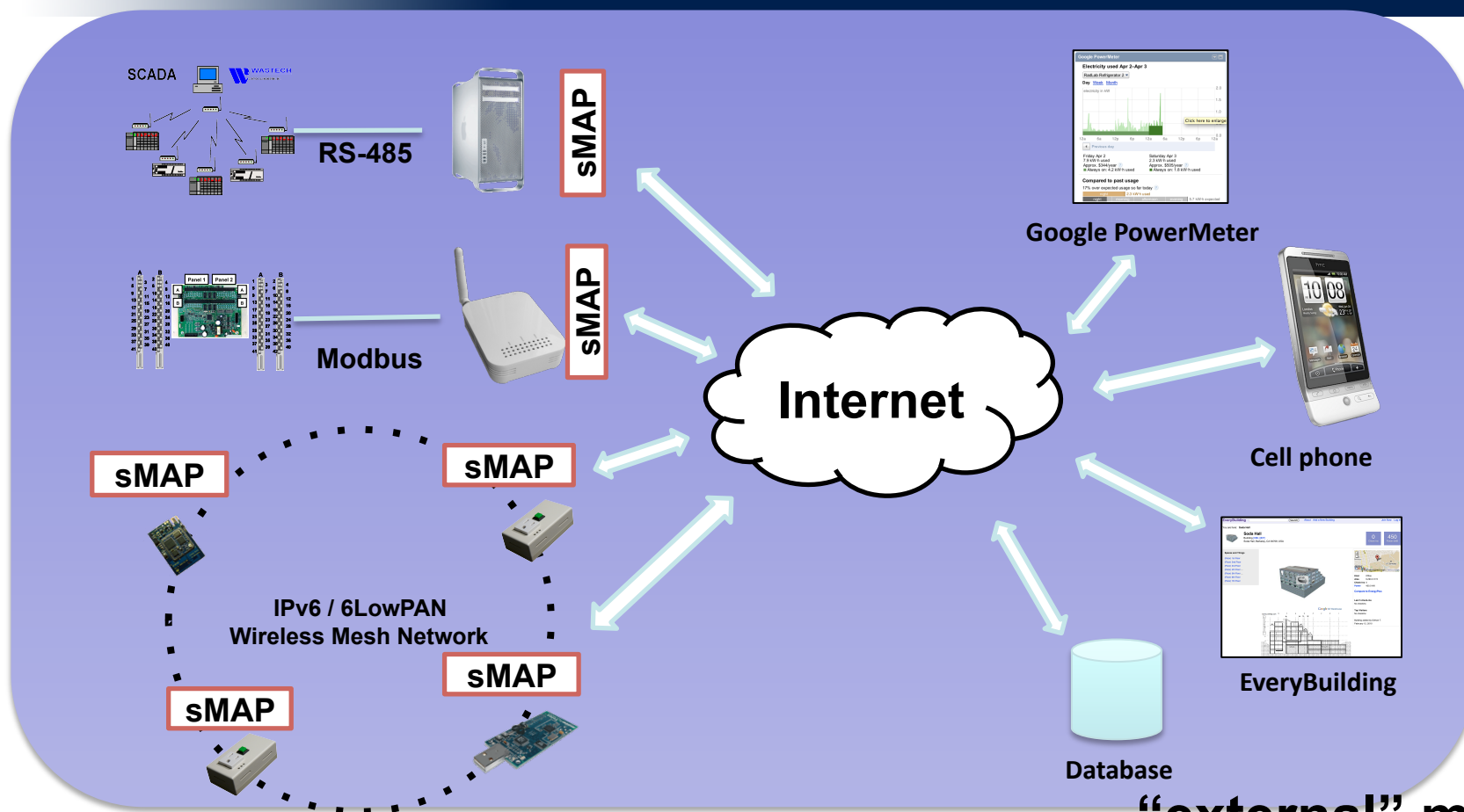
Emerging design pattern: define Internet-scale protocol, use adaptation layer where necessary



➔ Preserve extensibility and self-describing properties of JSON



Keep it Simple



**no...
“external” metadata
data repository
credentials database
...anything not an instrument property**



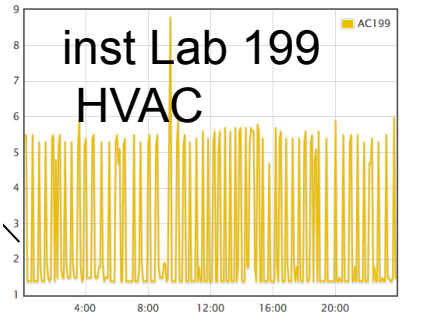
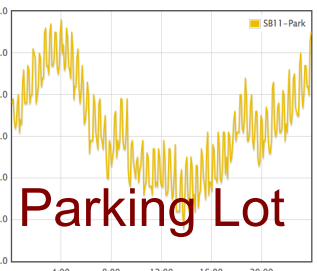
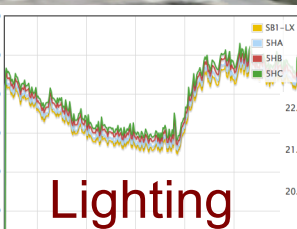
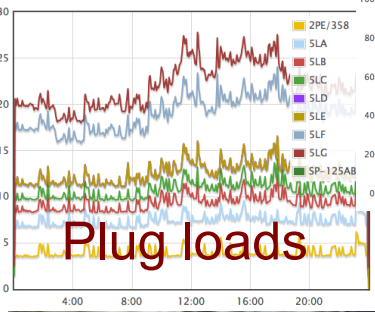
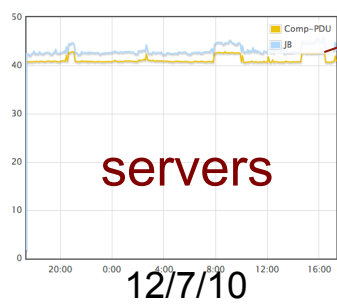
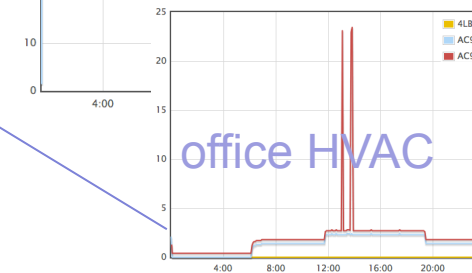
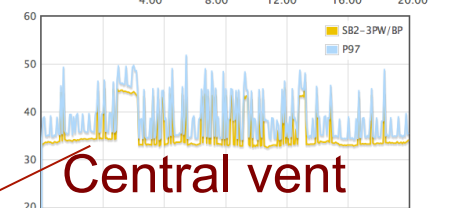
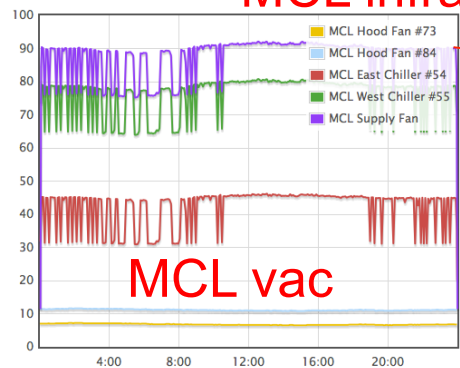
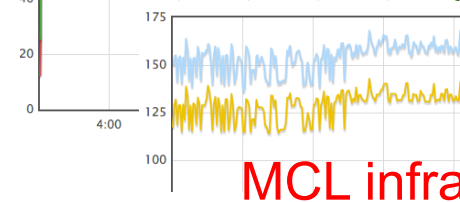
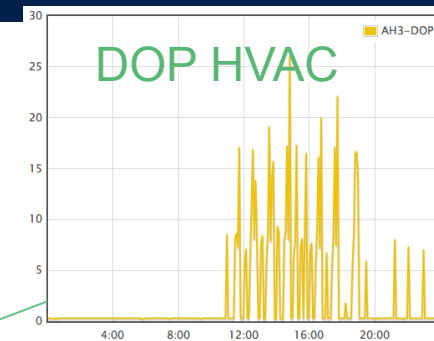
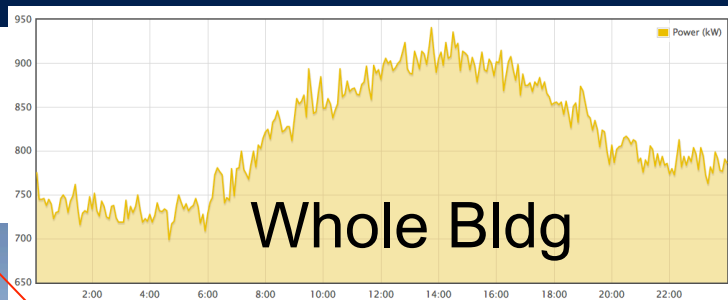
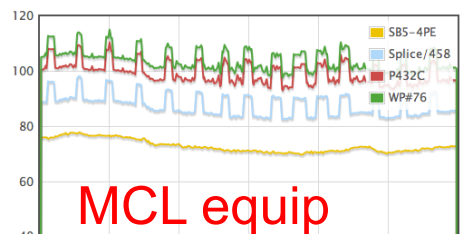
sMAP Library

- 15 different underlying sensors and stacks
- More than 100 instruments, > 200 ACme plug-load meters
- 4400 channels of high-resolution data
 - 80 sMAP “instances”
 - together 250 samples/sec
- It's easy: simplest service is ~3 lines of Python

Name	Sensor Type	Physical Layer	Sense Points	Channels
Cory Hall Submetering	Dent 3-Phase	Modbus/Ethernet	40	1600
Cory Hall Building Power	ION and PQube	HTTP/Ethernet	3	150
Cory Lab Temperature	TelosB [28]	802.15.4 + Ethernet	4	8
Cory Lab Machines	ACme [15]	802.15.4 + Ethernet	8	16
Cory Chilled Water	HeatX Meter	Modbus/Ethernet	1	11
Cory Roof Environmental	Hydrowatch Node [34]	802.15.4 + Ethernet	4	36
Soda Sun Blackbox	Fan Speed; Environmental	HTTP/Ethernet	10	84
Soda Lab Machines	ACme	802.15.4 + Ethernet	40	80
Soda Lab Panel	Veris E30 Meter	Modbus/Ethernet	1	42
LBNL Building 90	ACme	802.15.4 + Ethernet	70	140
Berkeley Weather	wunderground and Viasala WXT520	HTTP + Serial	2	20



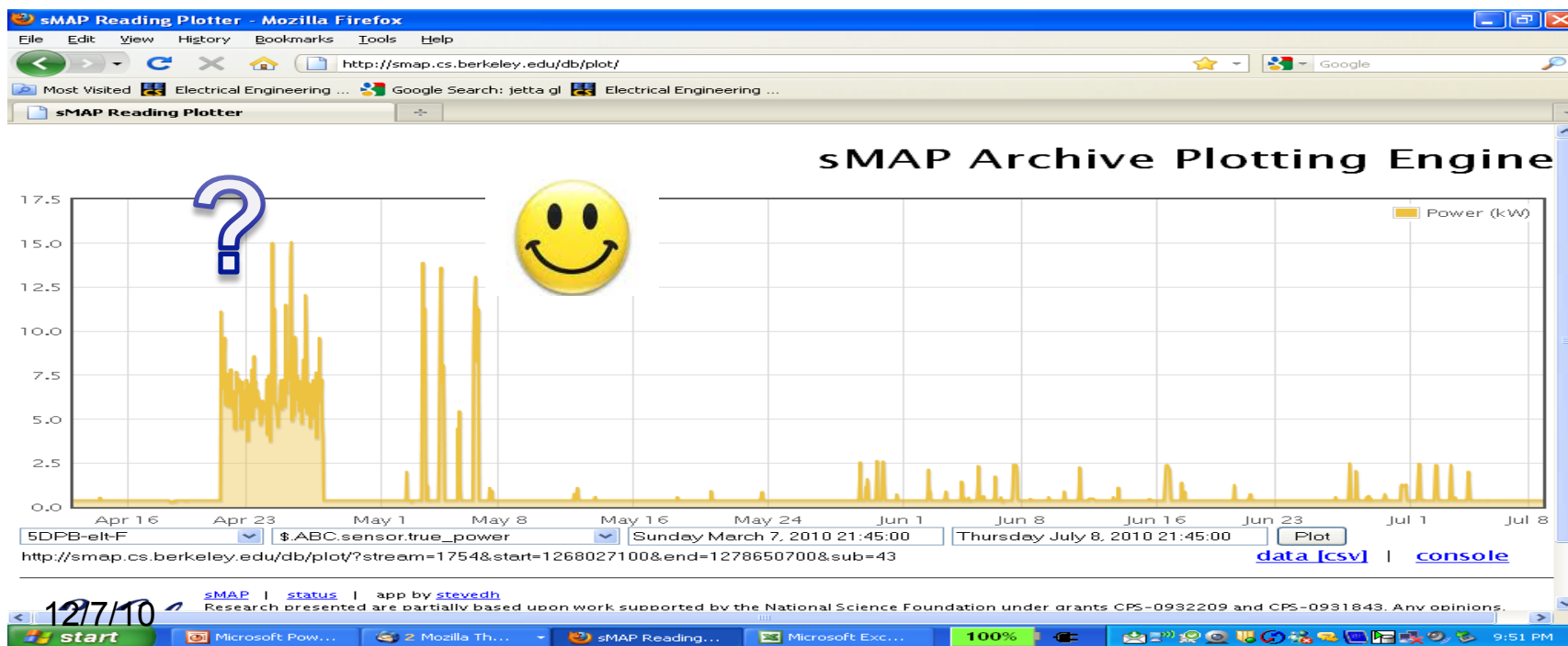
Energy Transparent Building





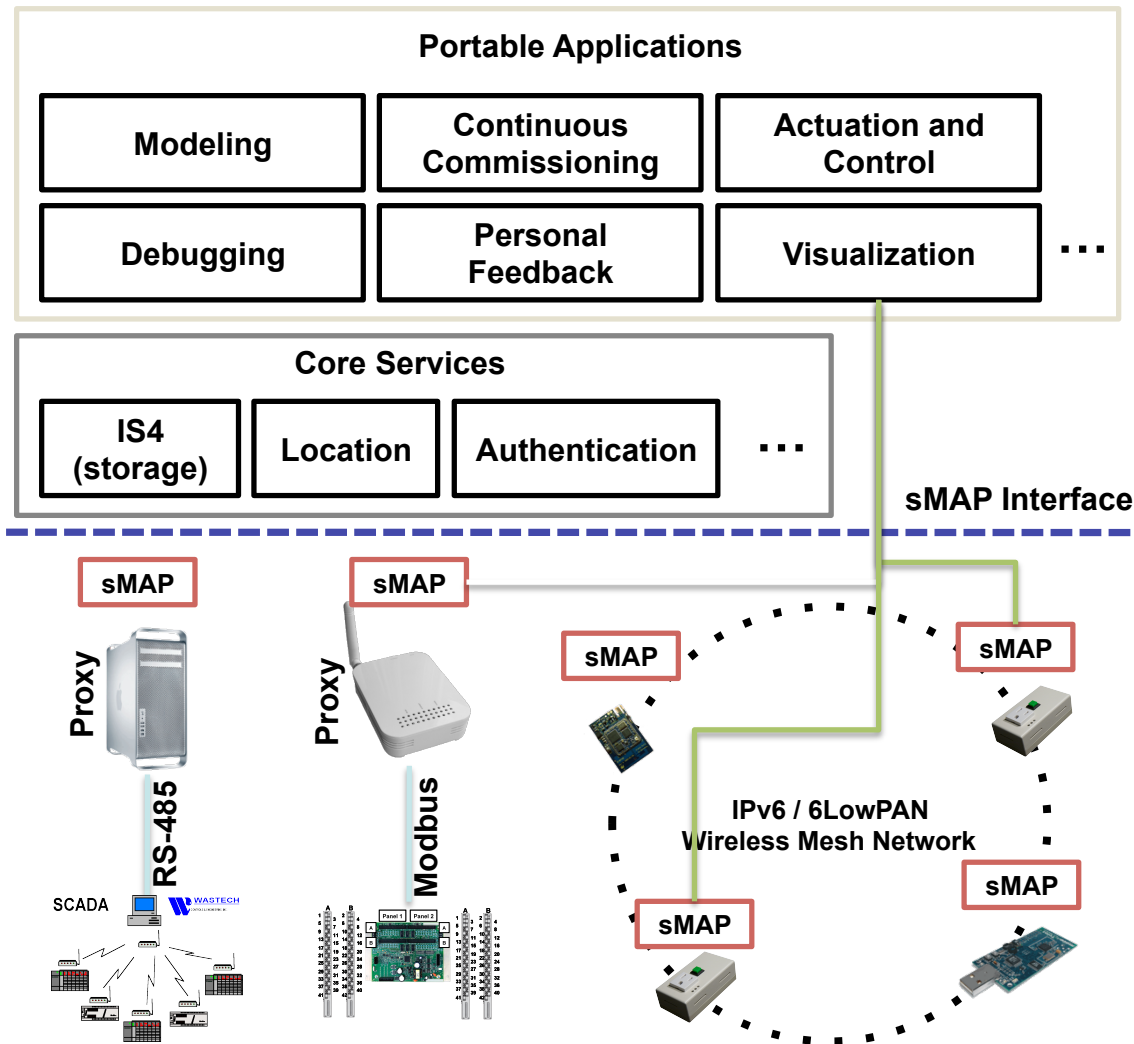
Keeping an Eye on the Prize

- Monitor Based Commissioning
 - Eliminate simultaneous heat/cool
 - AC91 on schedule





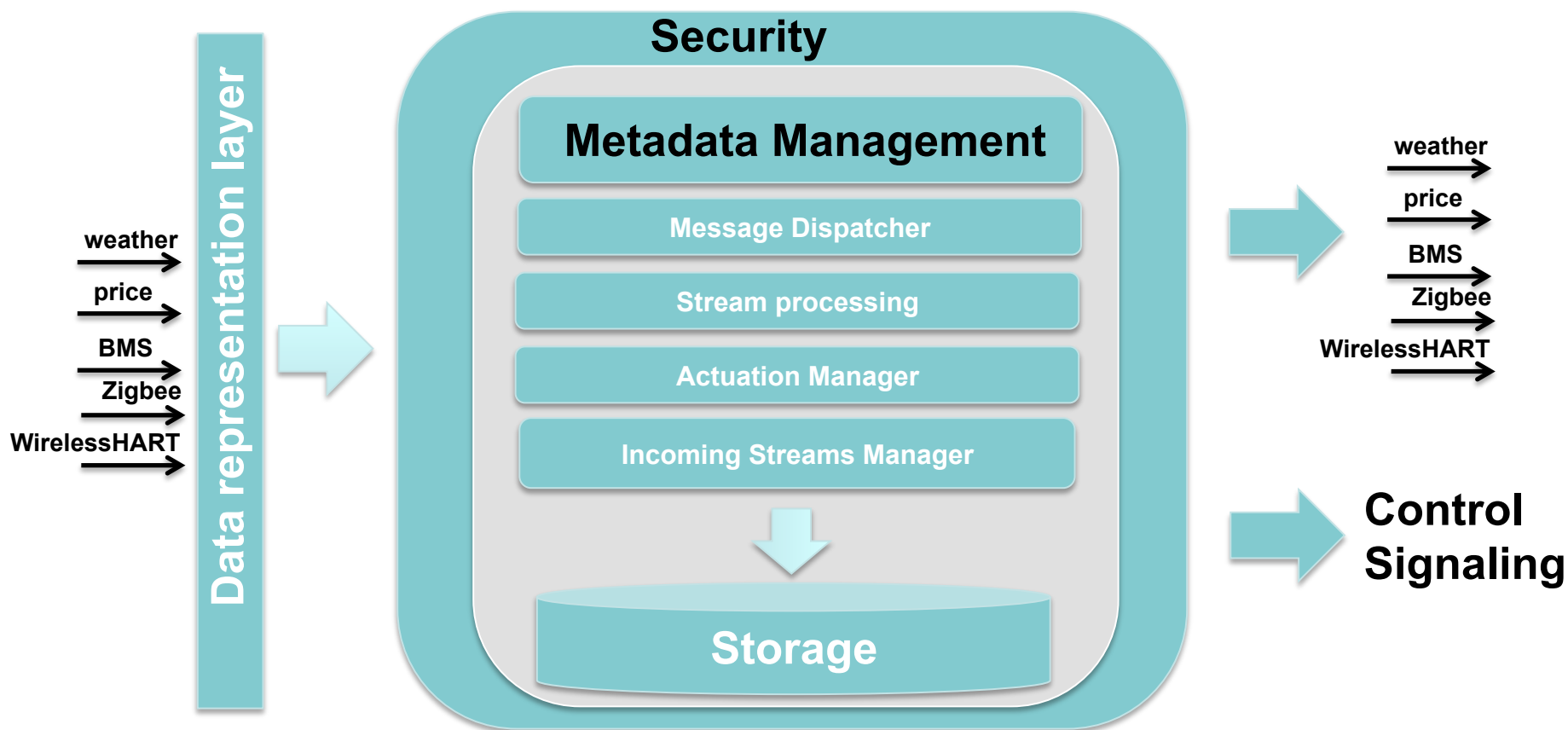
Building Scale Monitoring Architecture





File System Interface + sMAP + DB

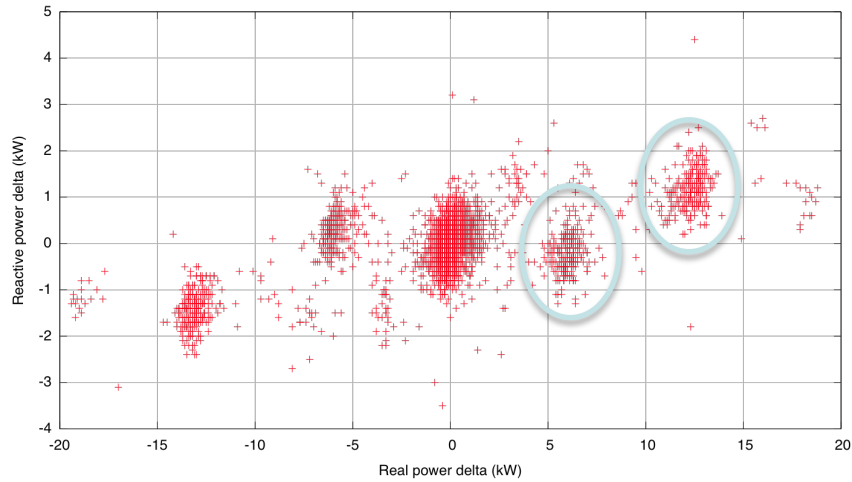
HTTP/REST + JSON + Pub/Sub



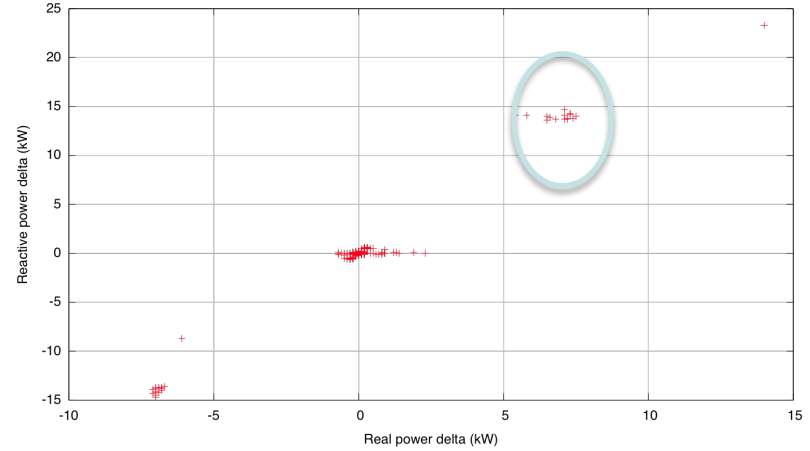


Extracting Deeper

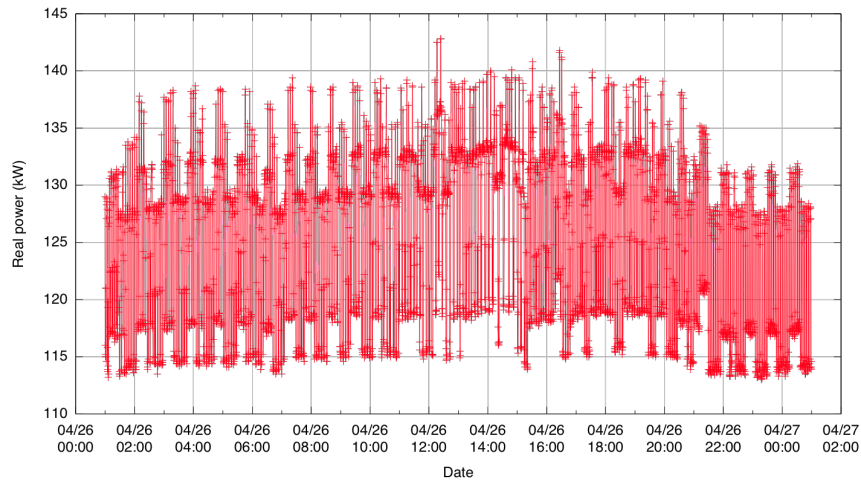
MCL-elt-A -- 26-April



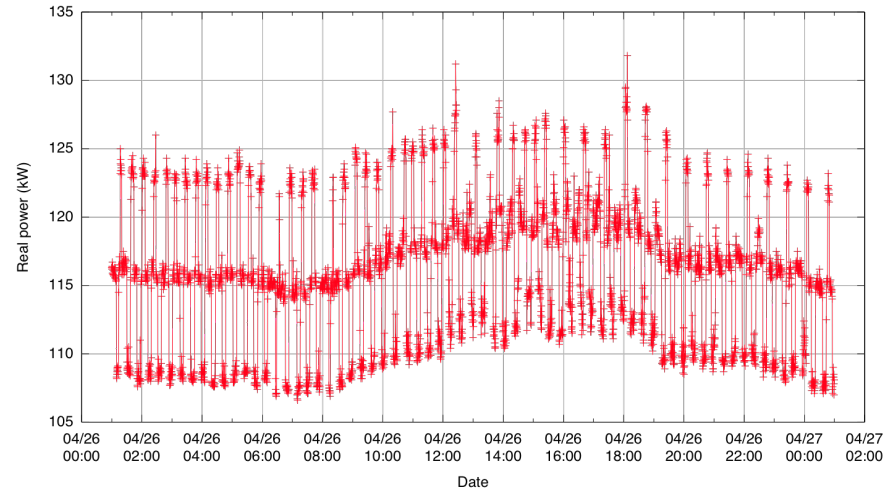
5PA-elt-A -- 26-April



MCL-elt-A -- 26-April

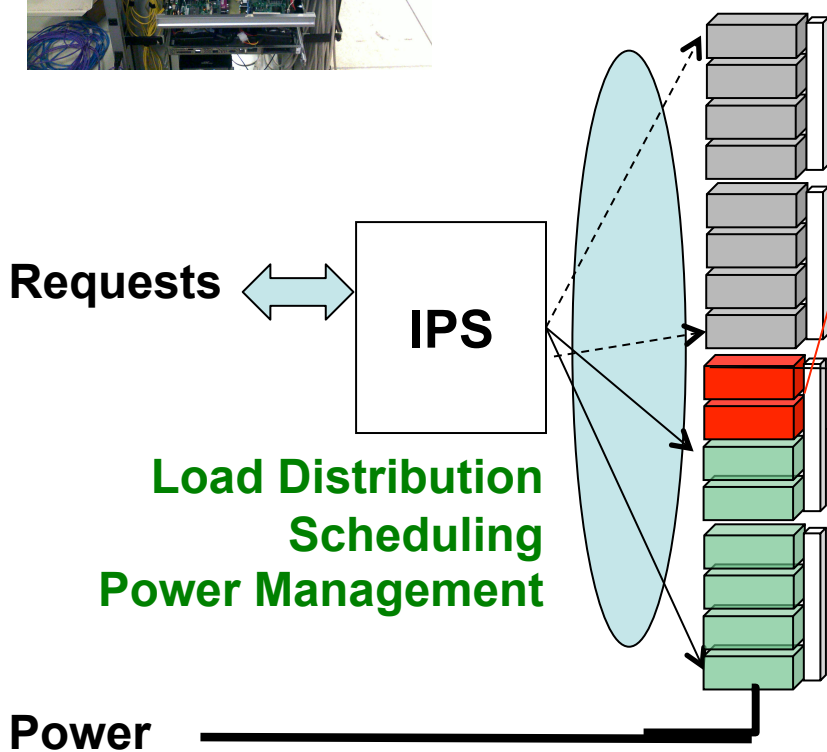


358-elt-A -- 26-April

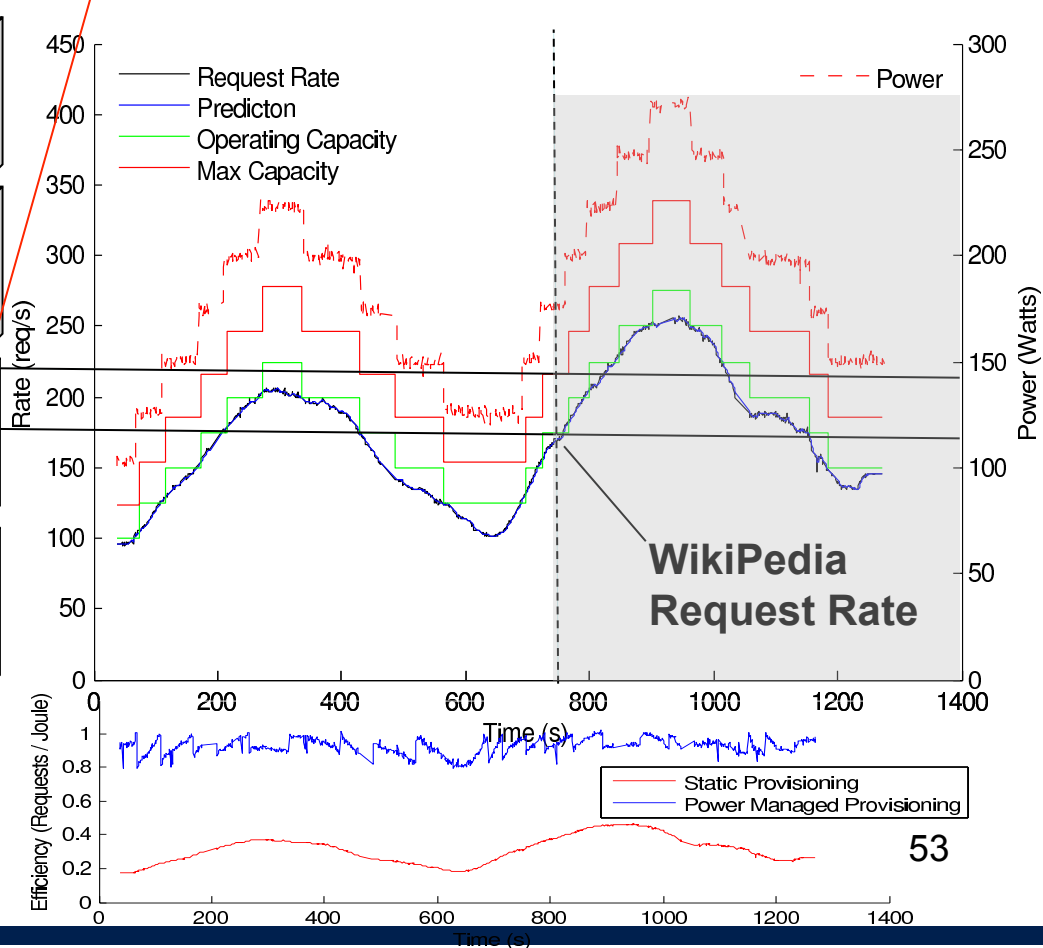




PP Systems of nonPP pieces



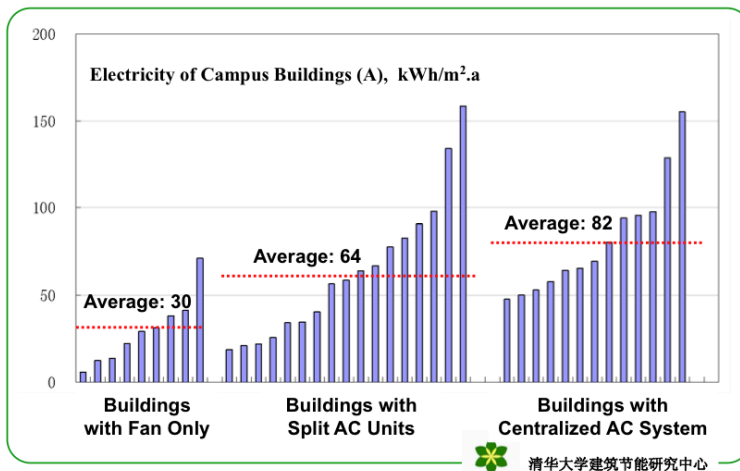
Computational "Spinning Reserve"





Power Proportional Buildings?

Observations on a Campus in Beijing



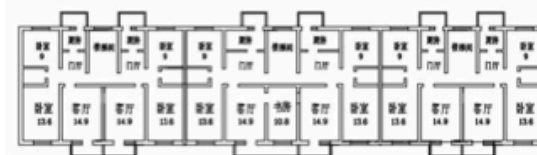
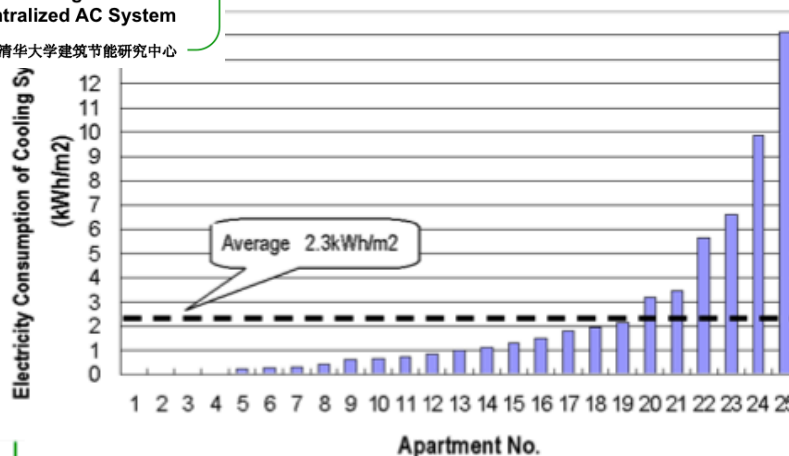
清华大学建筑节能研究中心
THUBERC

Case study: AC in Residential buildings



measured energy consumption
in every units of a residential
building in Beijing, 2006, split unit

Key reason:
Part time
Part space
Open windows



Centre AC for residential buildings in Beijing: 19.8 kWh/m².a

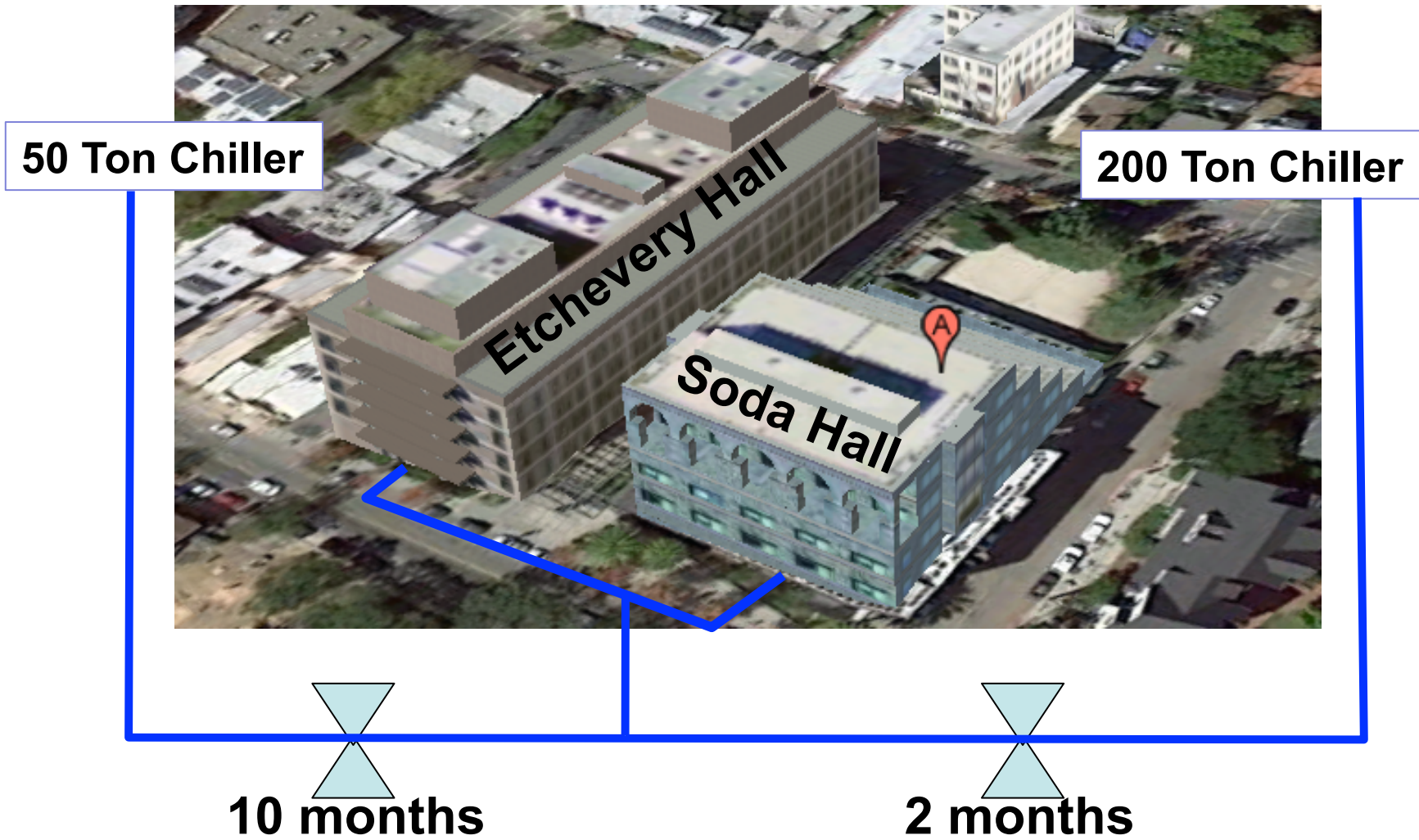
Yi Jiang

Building Energy Research Centre
Tsinghua University P R China

- Part-time, Part-space, Natural venting and light



Power Proportional Buildings?





Stages of Energy Effectiveness

- Waste Not
 - Do Nothing Well !!!
- Power Proportionality
 - Peak Performance : Power => Safety
 - Optimize Partial Load - from nothing to peak
- Sculpting
 - Identify the energy *slack* and utilize it
- Negotiated Grid / Load / Human Interaction
 - Plan, Forecast, Negotiate, Manage



Energy "Slack"

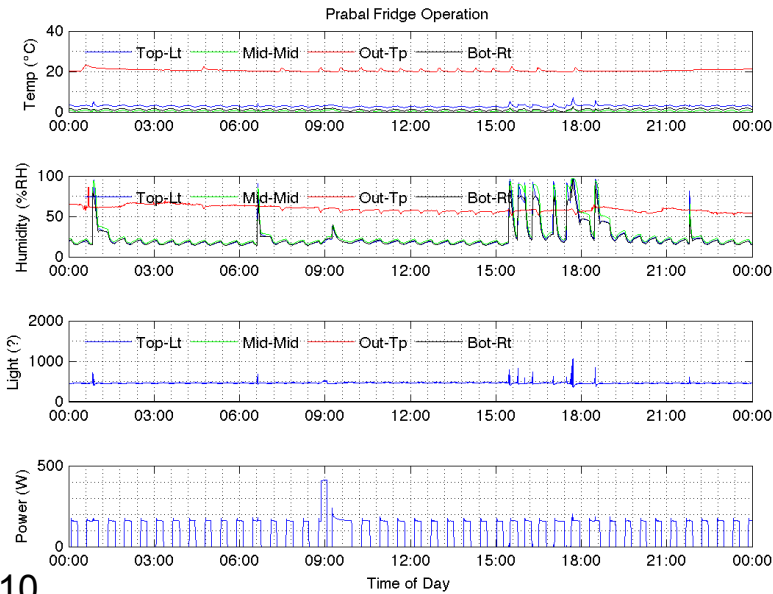
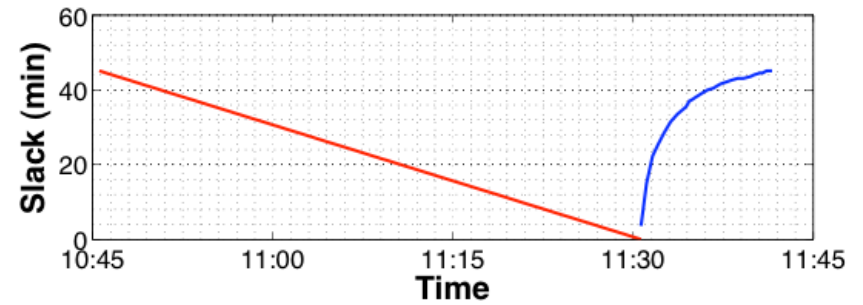
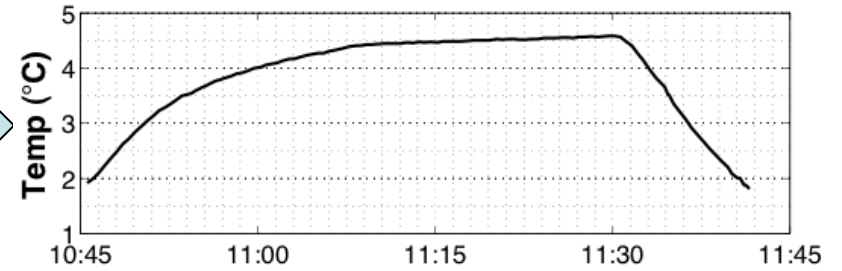
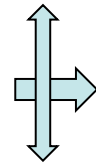
Thermostatically Controlled Load



IPS

Set Point

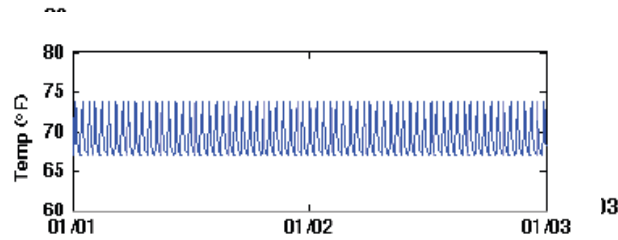
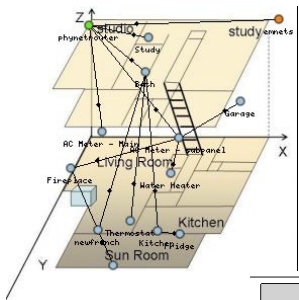
Guard band



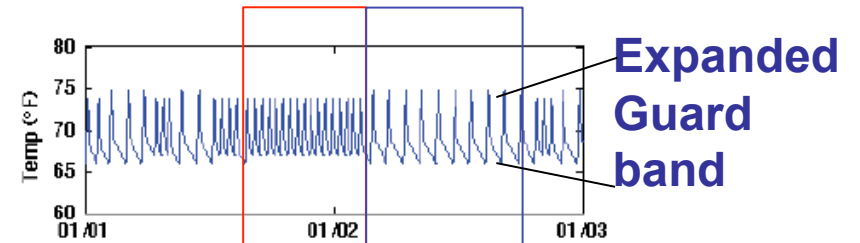
12/7/10



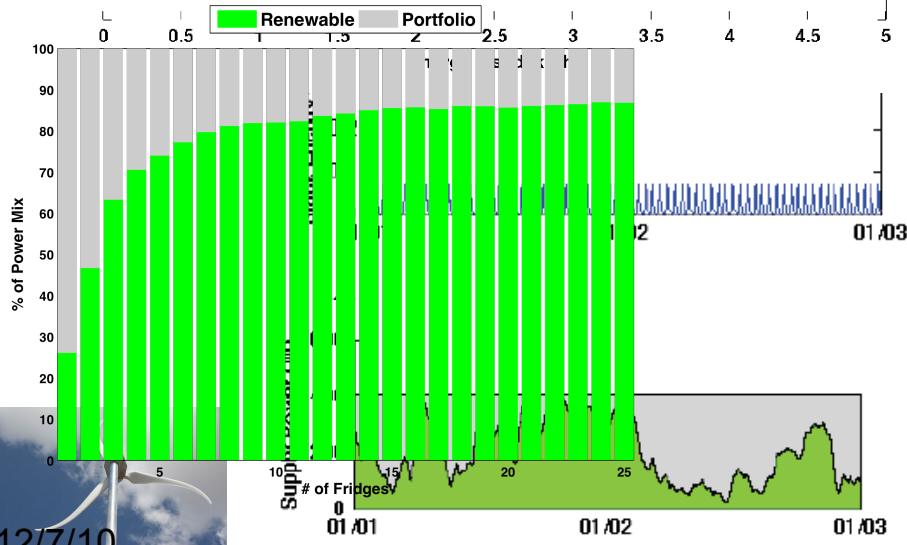
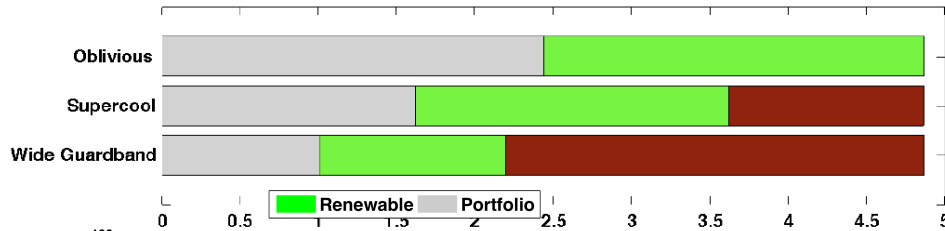
Supply-Following Loads



13

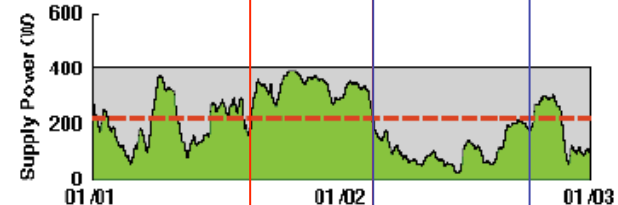
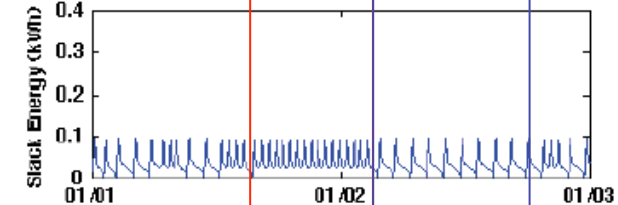
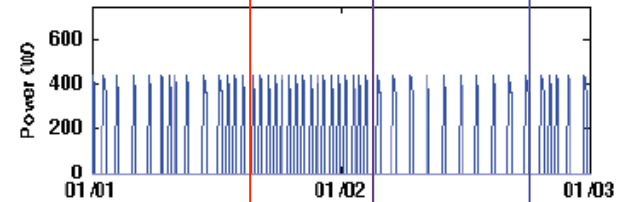


Portfolio Energy Renewable Energy Saved Energy



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Oblivious



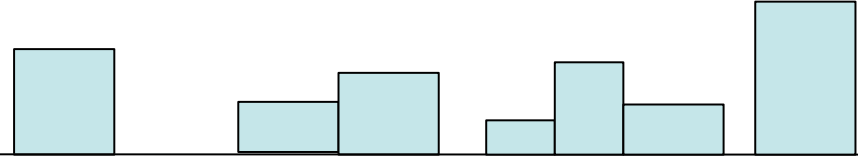
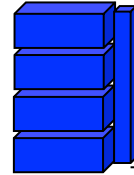
Energy-aware - Supercool



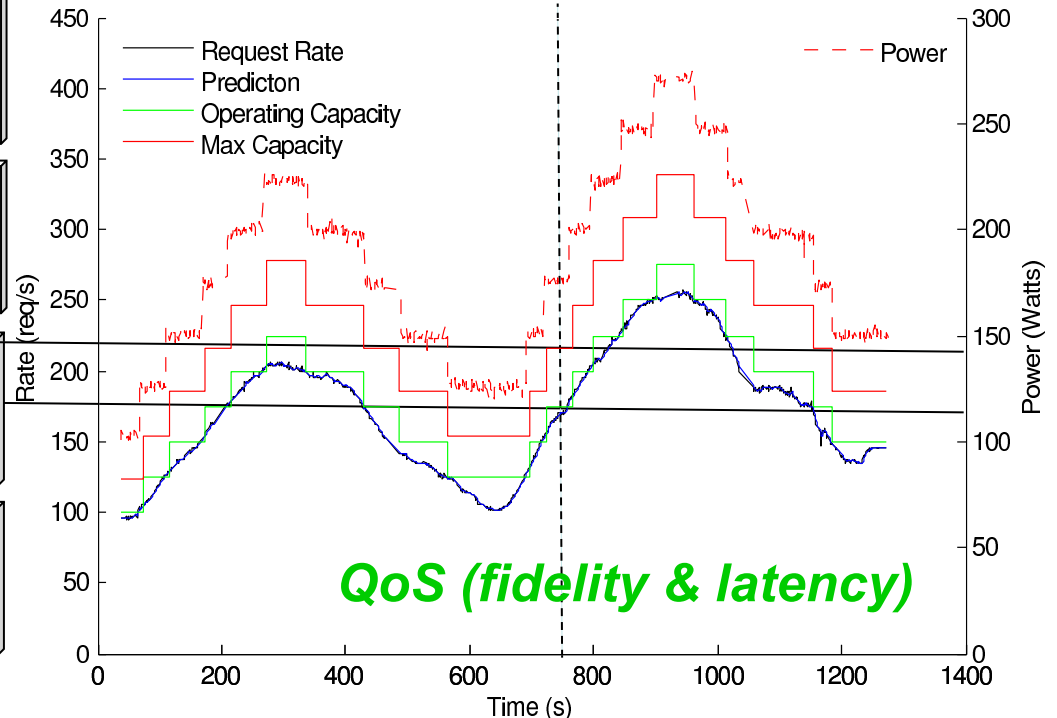
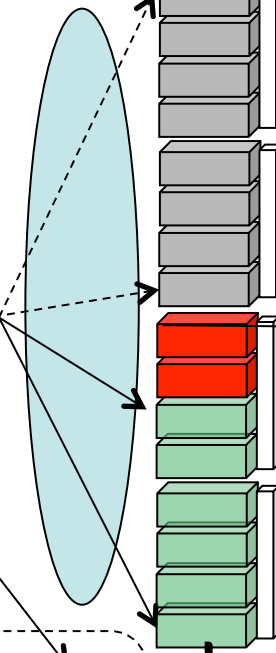
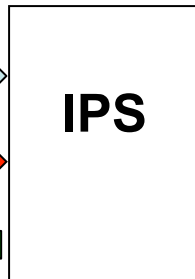
Supply-Following Computational Loads



Background Processing (shiftable)

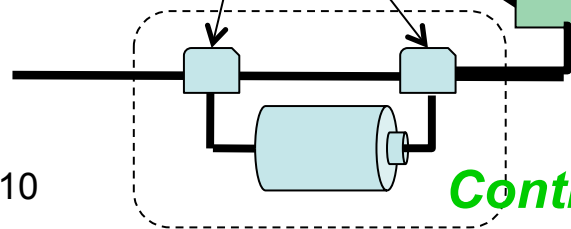


Requests ↔
Availability →
Forecasts ←



QoS (fidelity & latency)

Power



Controllable Storage



... and in buildings



CENTER FOR THE BUILT ENVIRONMENT
Industry/University Research Collaboration

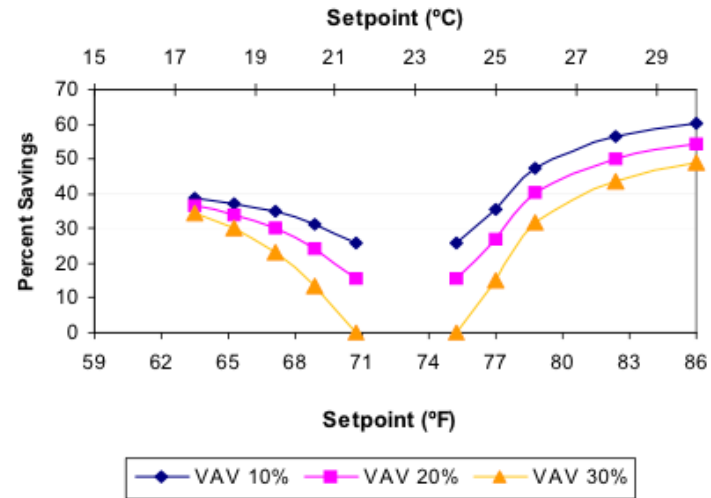
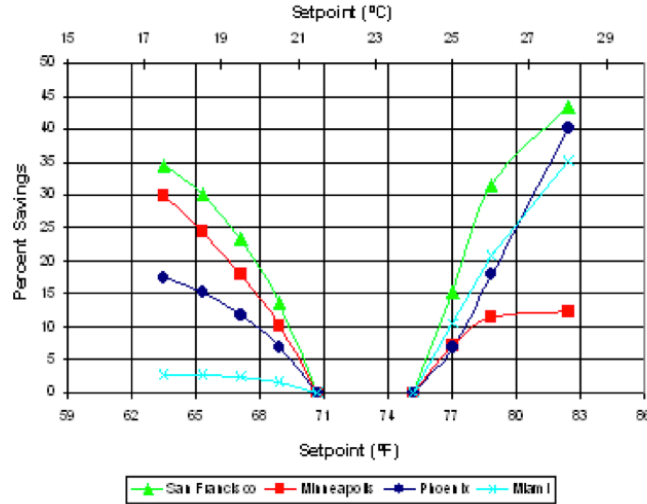


Figure 3. Annual energy use for the prototype in San Francisco with VAV minimum fractions at 10%, 20%, and 30%.

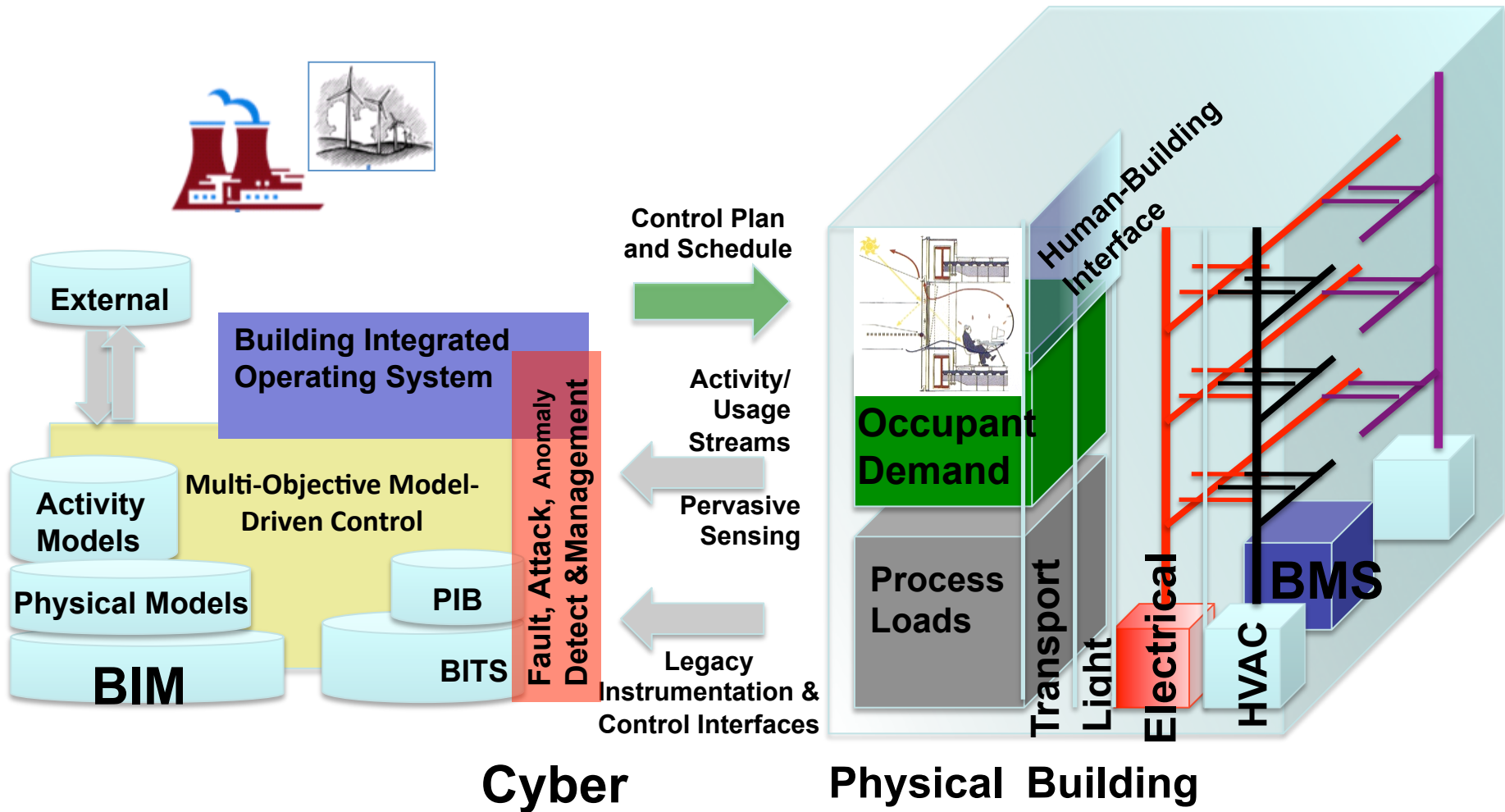
ENERGY SAVINGS FROM EXTENDED AIR TEMPERATURE SETPOINTS AND REDUCTIONS IN ROOM AIR MIXING

Taylor Hoyt, Kwang Ho Lee, Hui Zhang, Edward Arens, Tom Webster

12/7/10

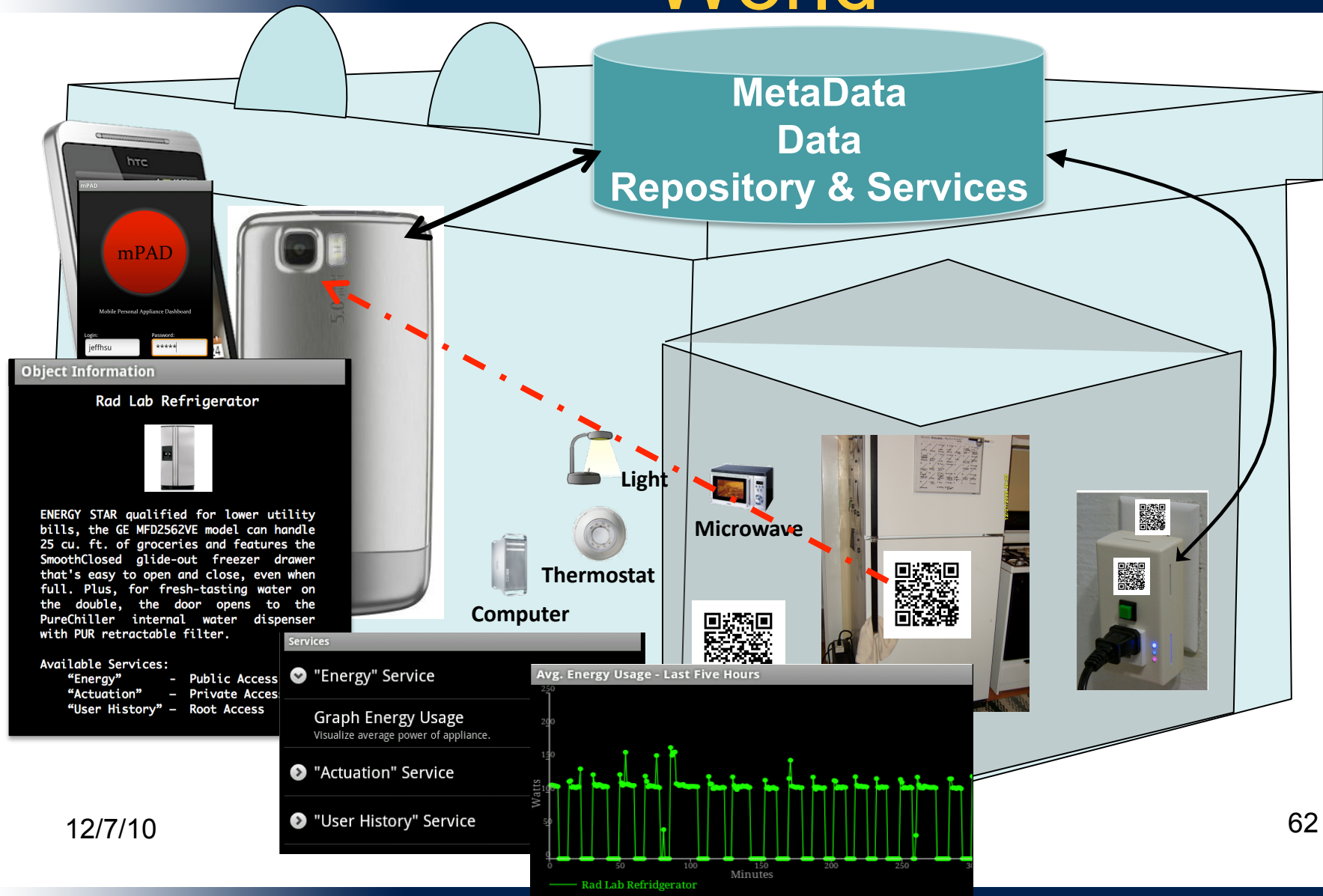


Cyber / Physical Buildings





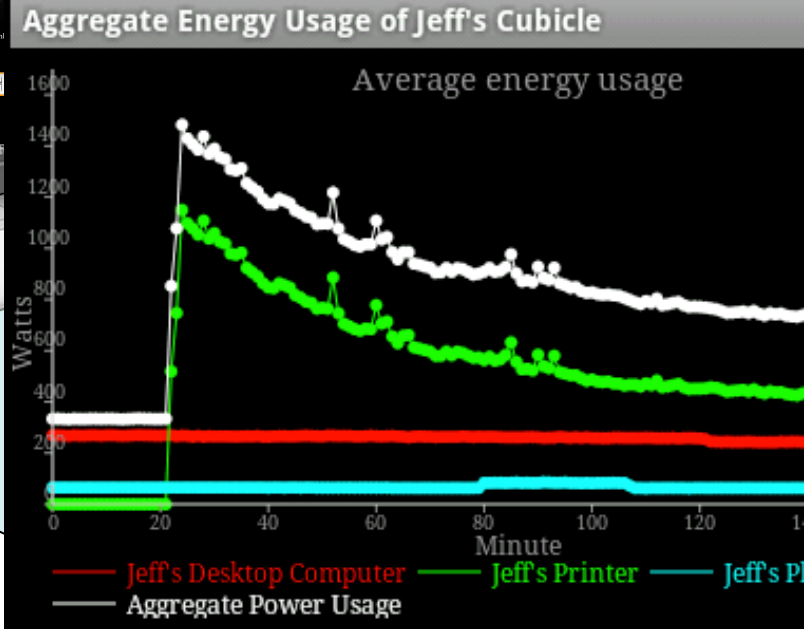
Personal View into the Energy World





Personal View into the Energy World

MetaData
Data
Repository & Services



Apportionment

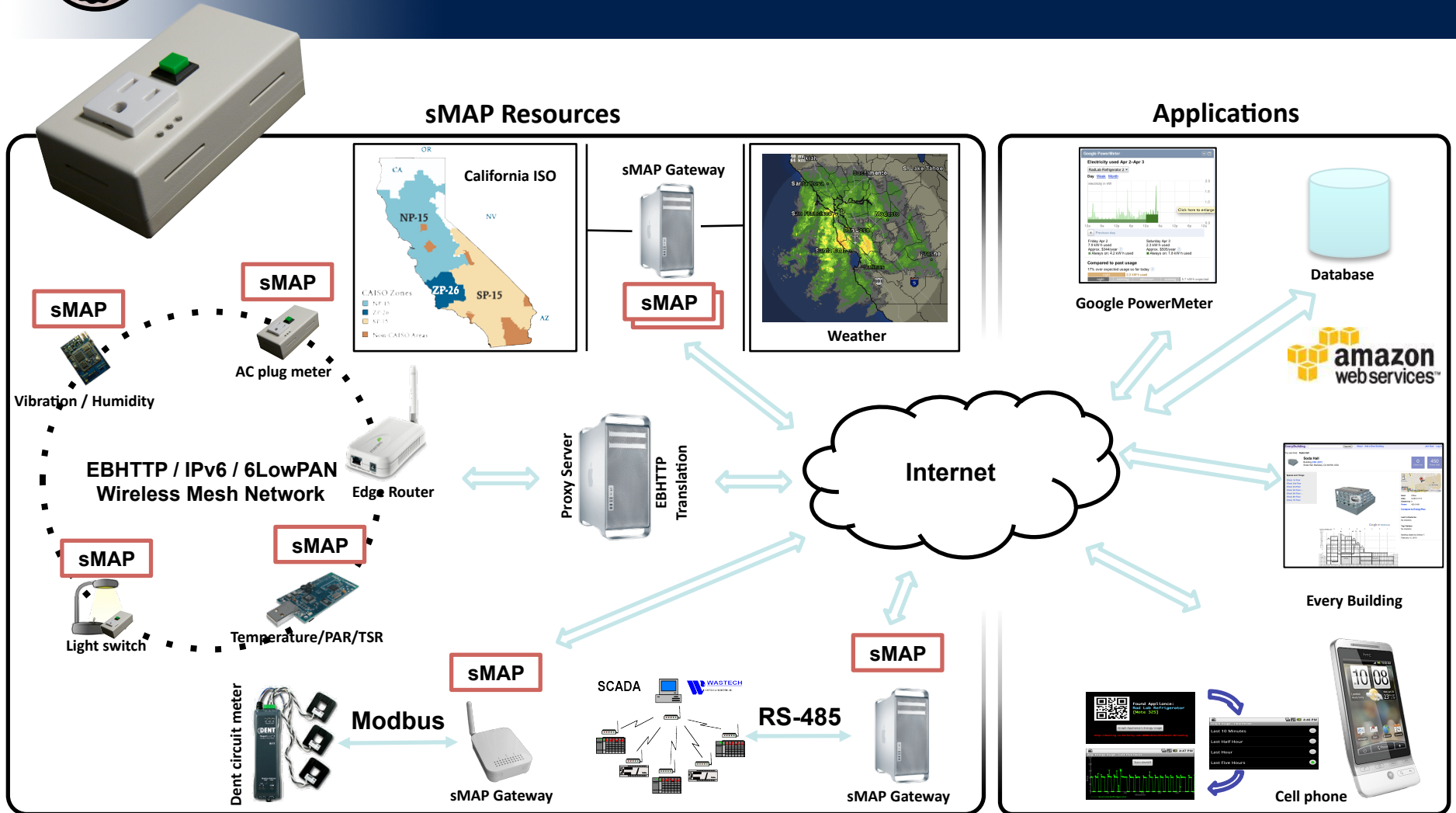
Jeff Hsu's Average Energy Usage
June 8th, 2010

Category	Item	Usage (Watts)
Privately Owned Objects:	Desktop Computer:	257W
	Printer:	497W
	Phone:	66W
TOTAL FOR TODAY:		827.4W
Shared Objects:	Rad Lab Fridge:	74W
	10 Users:	7.4W
	Jeff:	7.4W





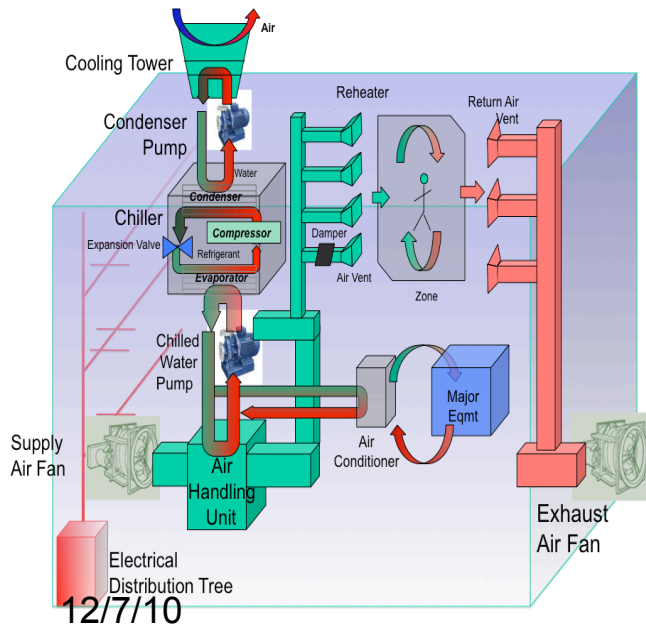
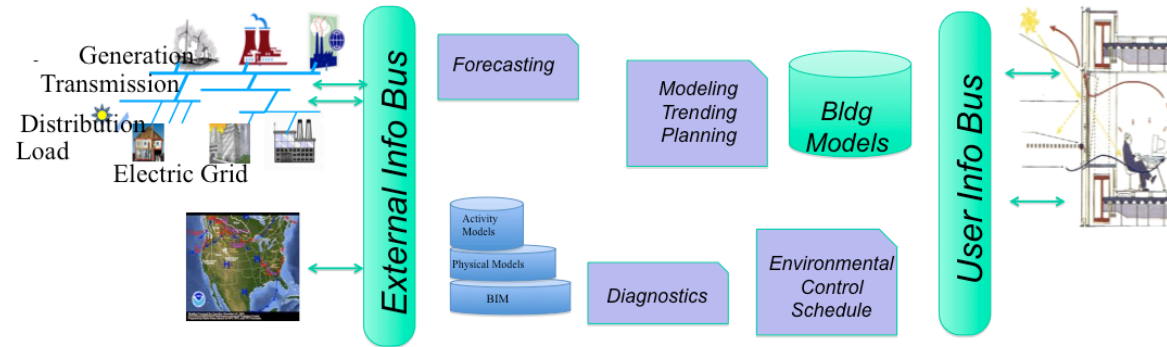
IP Everywhere - A Real World Web



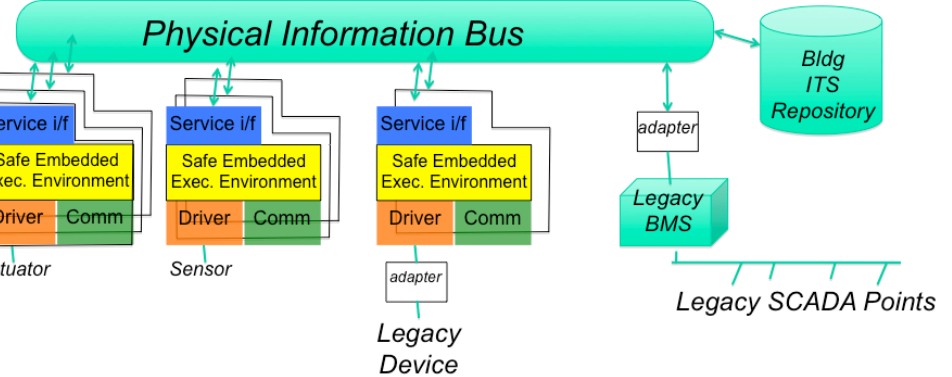


OS for Building, Datacenter, Grid, ...

Building-wide Distributed Operating System

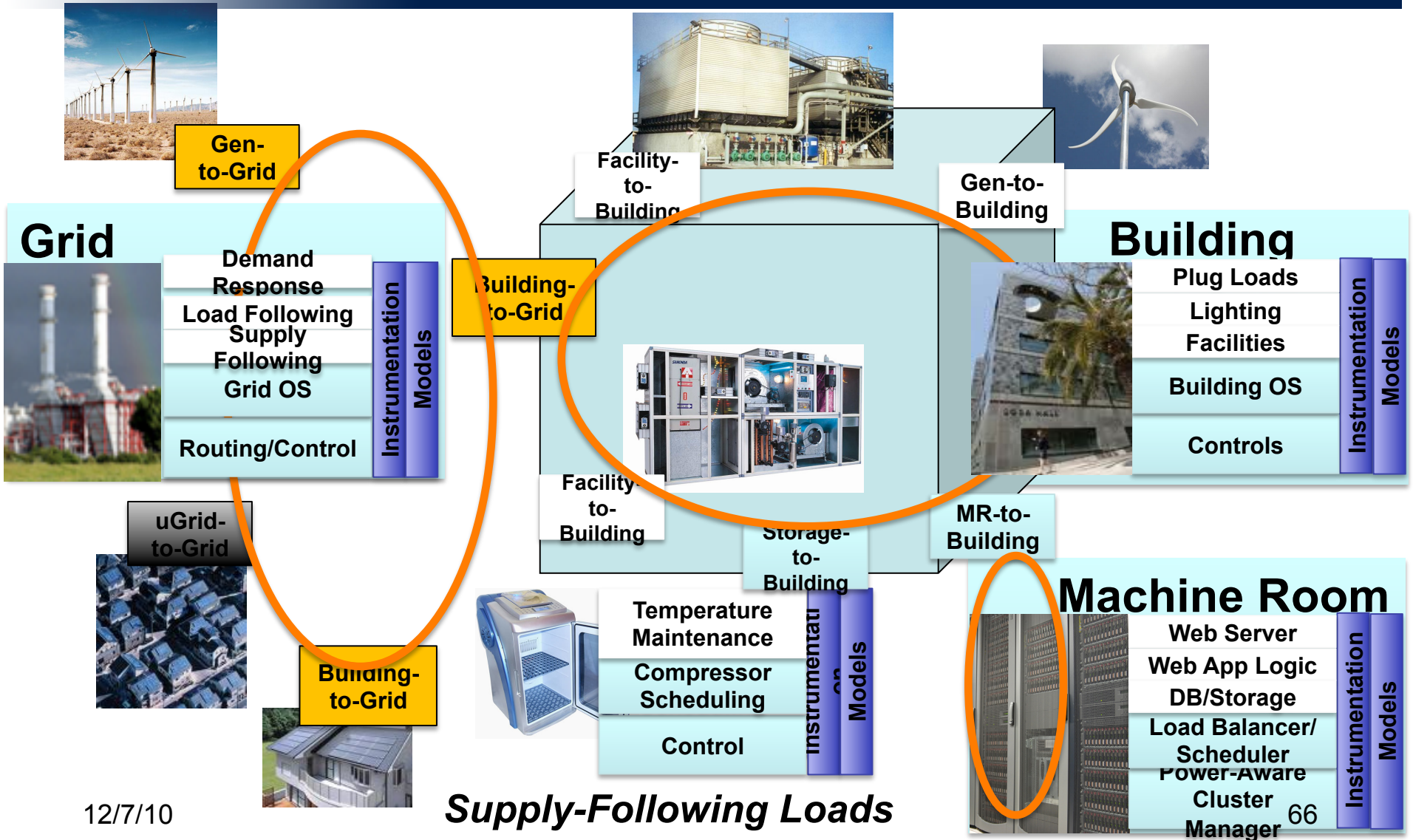


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LoCal by the Pieces





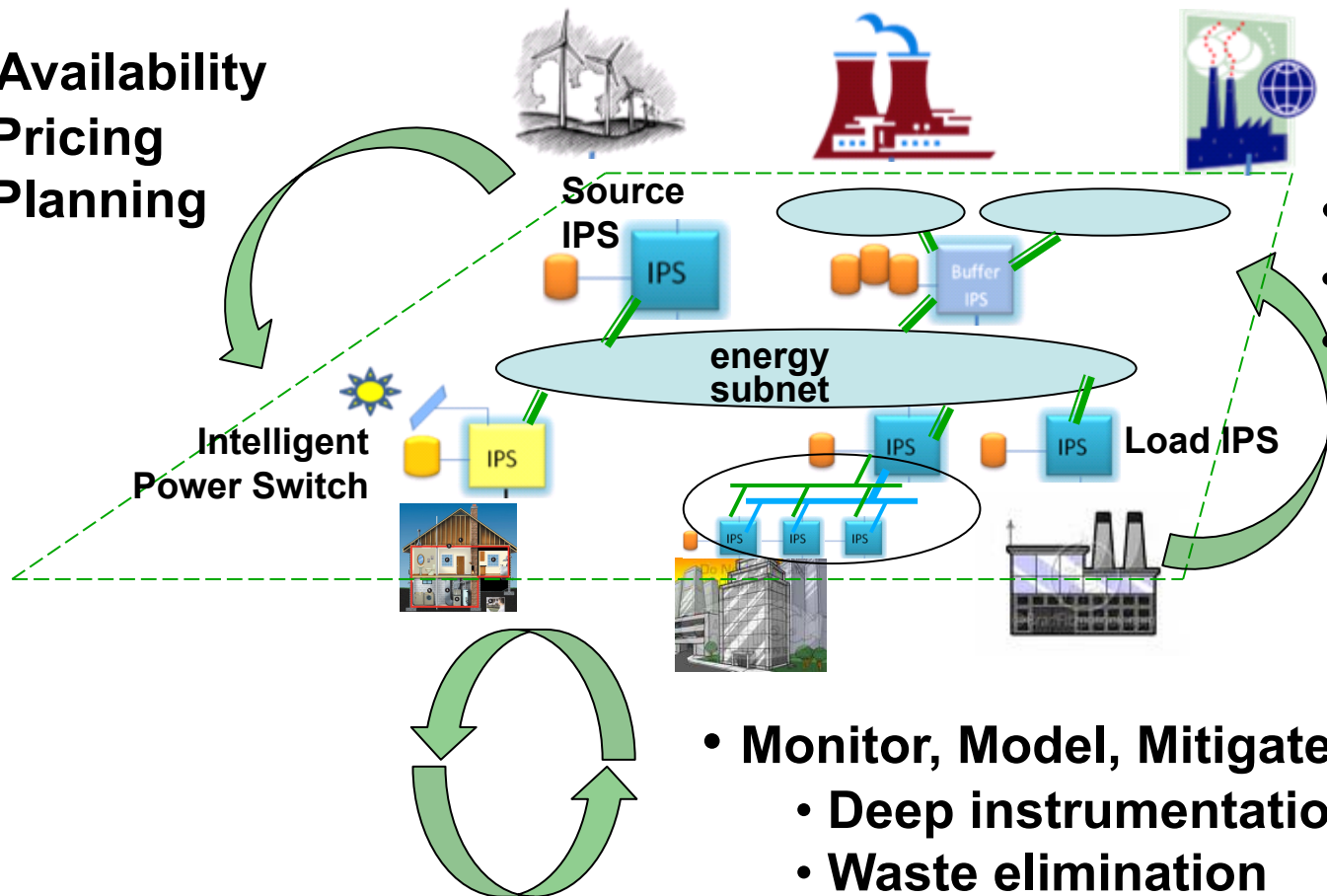
“Doing Nothing Well”

- Existing systems sized for peak and designed for continuous activity
 - Reclaim the idle waste
 - Exploit huge gap in peak-to-average power consumption
- Continuous demand response
 - Challenge “always on” assumption
 - Realize potential of energy-proportionality
- From IT Equipment ...
 - Better fine-grained idling, faster power shutdown/restoration
 - Pervasive support in operating systems and applications
- ... to the OS for the Building
- ^{12/7/10} to the Grid



In a Cooperative Grid

- Availability
- Pricing
- Planning



- Forecasting
- Tracking
- Market

- Monitor, Model, Mitigate
 - Deep instrumentation
 - Waste elimination
 - Efficient Operation
- Shifting, Scheduling, Adaptation⁶⁸

LaCal



Thanks



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