

# Towards the Building Integrated Operating System

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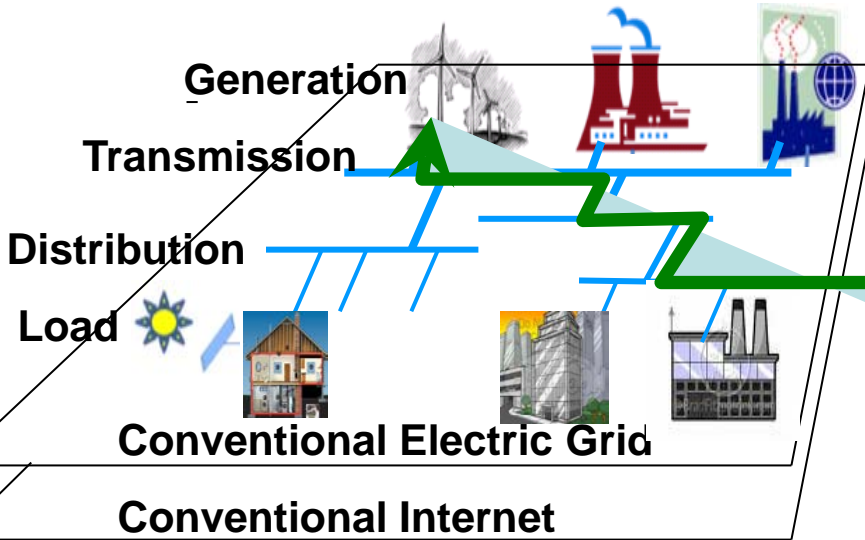
- Action Webs Meeting -

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

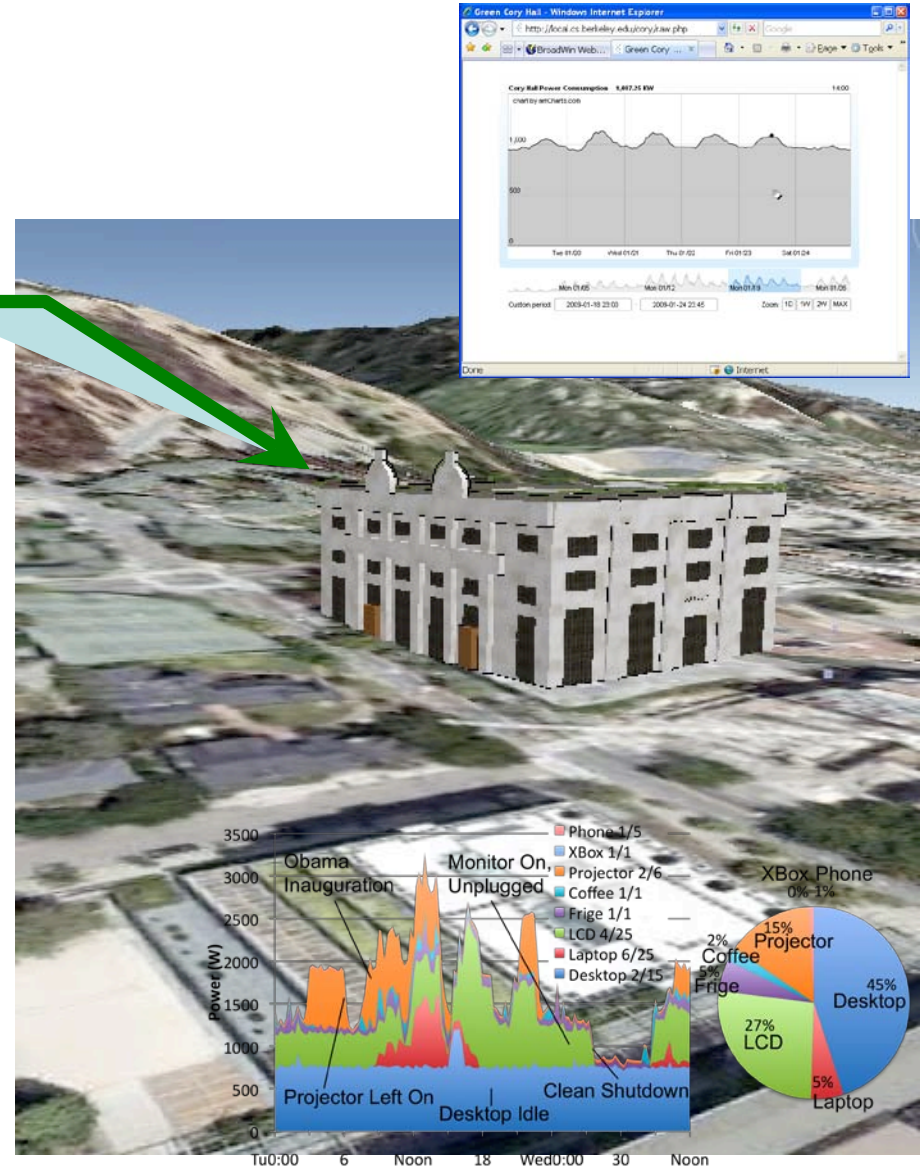
W. Ware, 1997



# Building ↔ Grid as a System

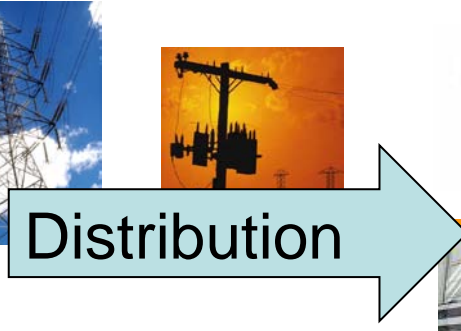
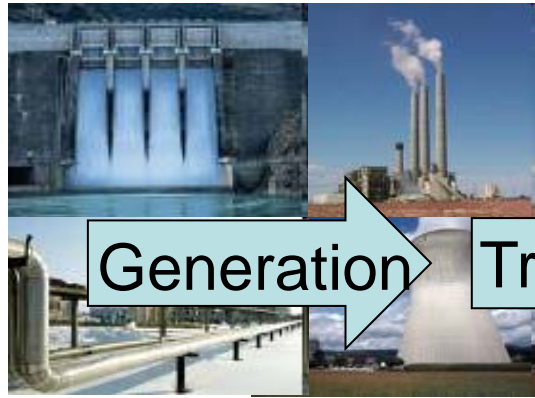


- Pervasive monitoring of a large complex load
- To understand energy spend, reduce it, forecast
- and optimize in concert with an intelligent grid



# Towards an "Aware" Energy Infrastructure

## Baseline + Dispatchable Tiers



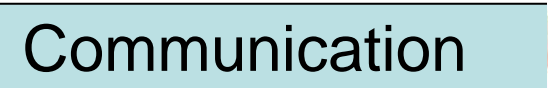
## Oblivious Loads



## Non-Dispatchable Sources



## Aware Interactive Loads

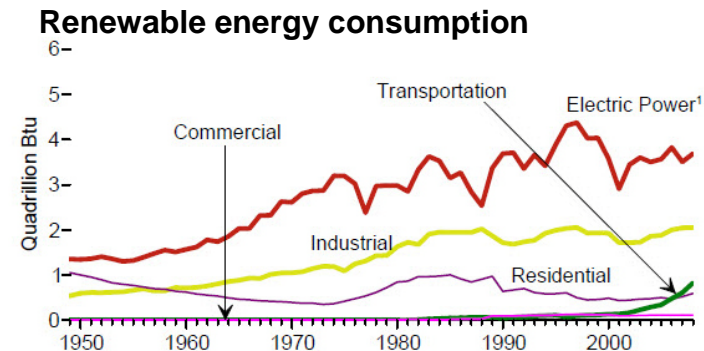
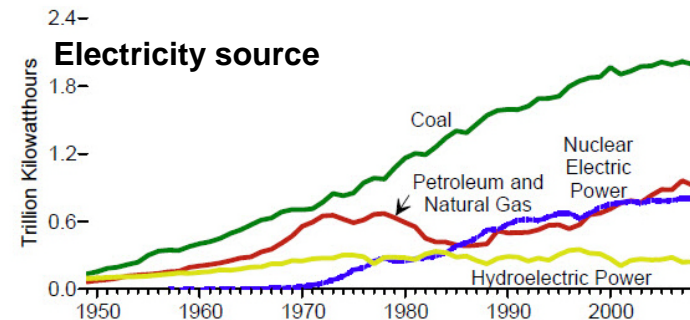
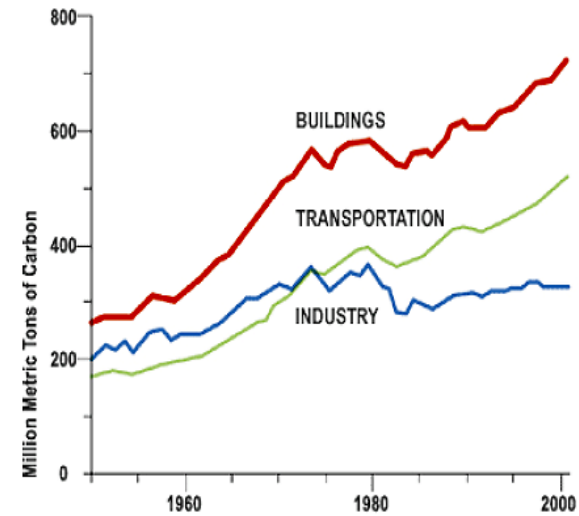


# Where to Start?

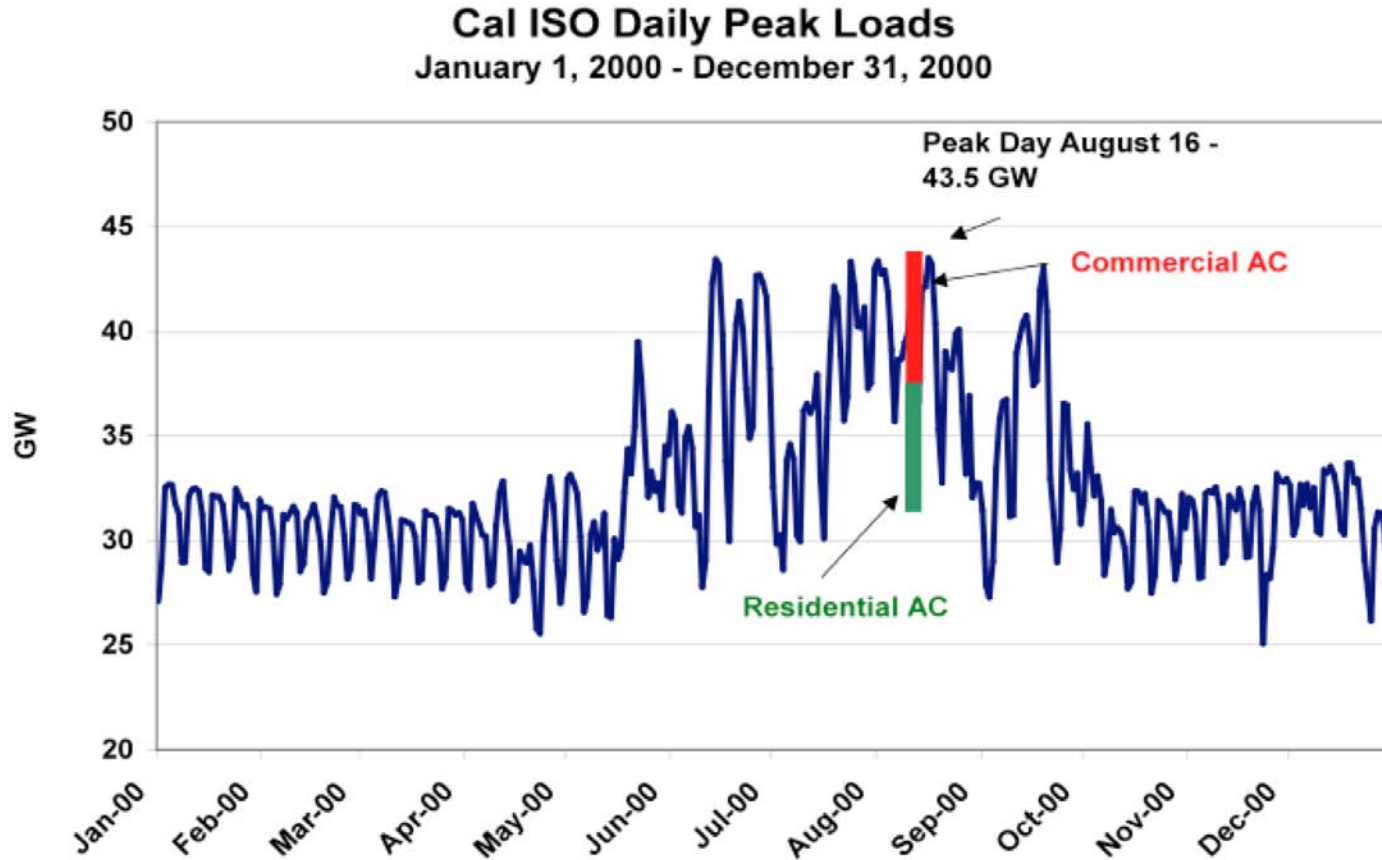
- **Buildings**

- 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

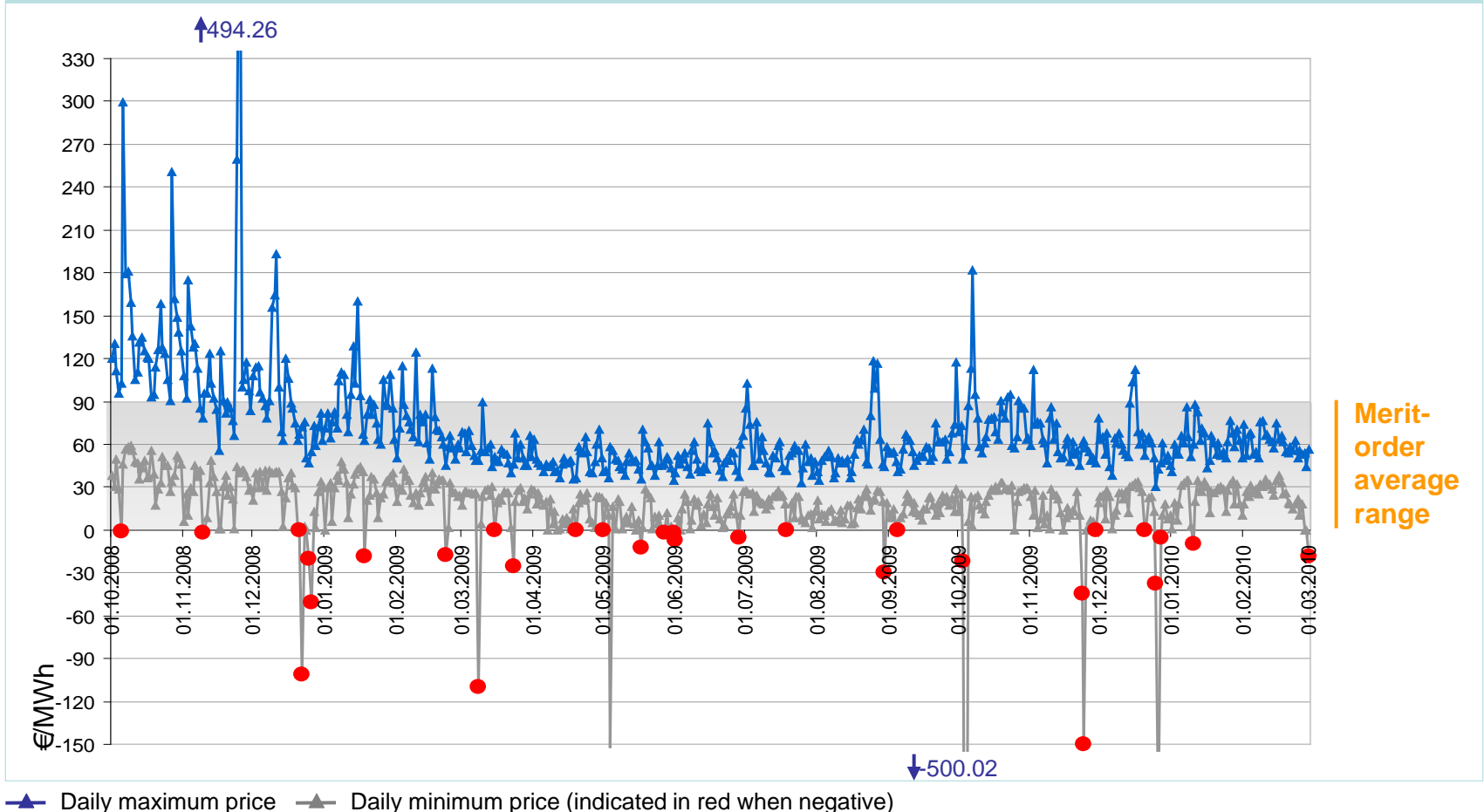


# Load-following Supply



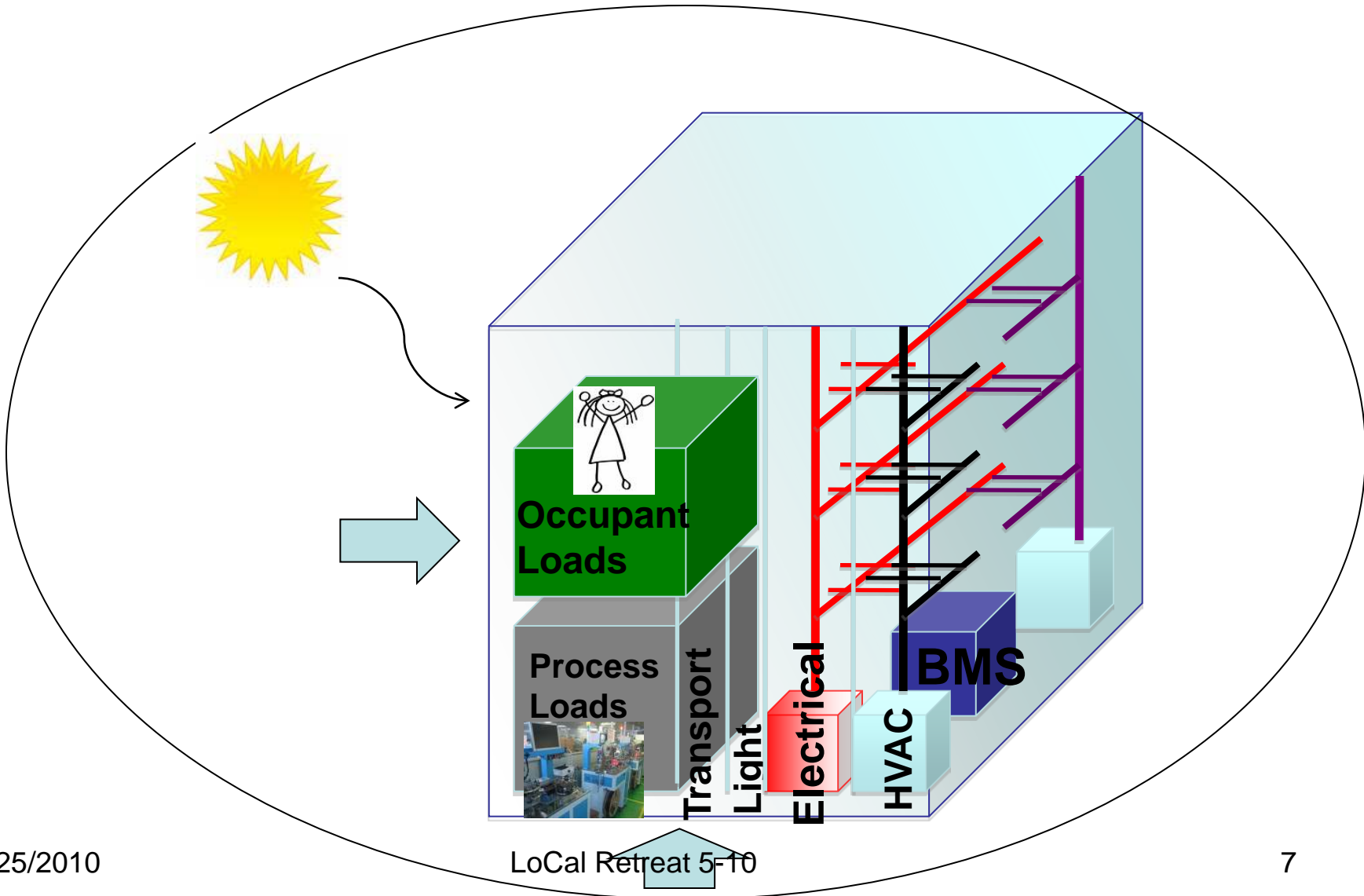
# Load-following Supply (really !)

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

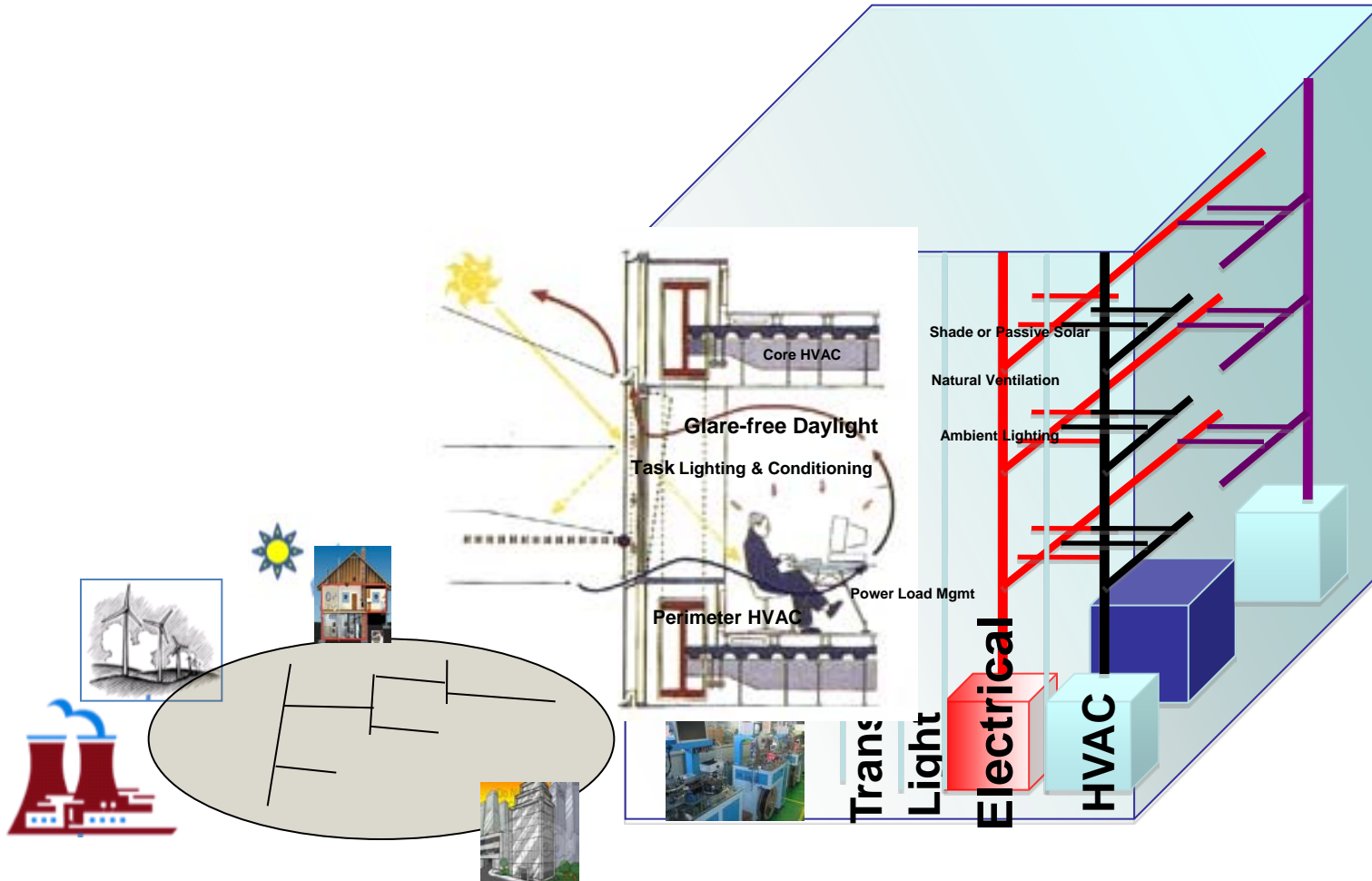


Source: EEX spot prices.

# Traditional Building Models



# Integrated Energy View of Buildings



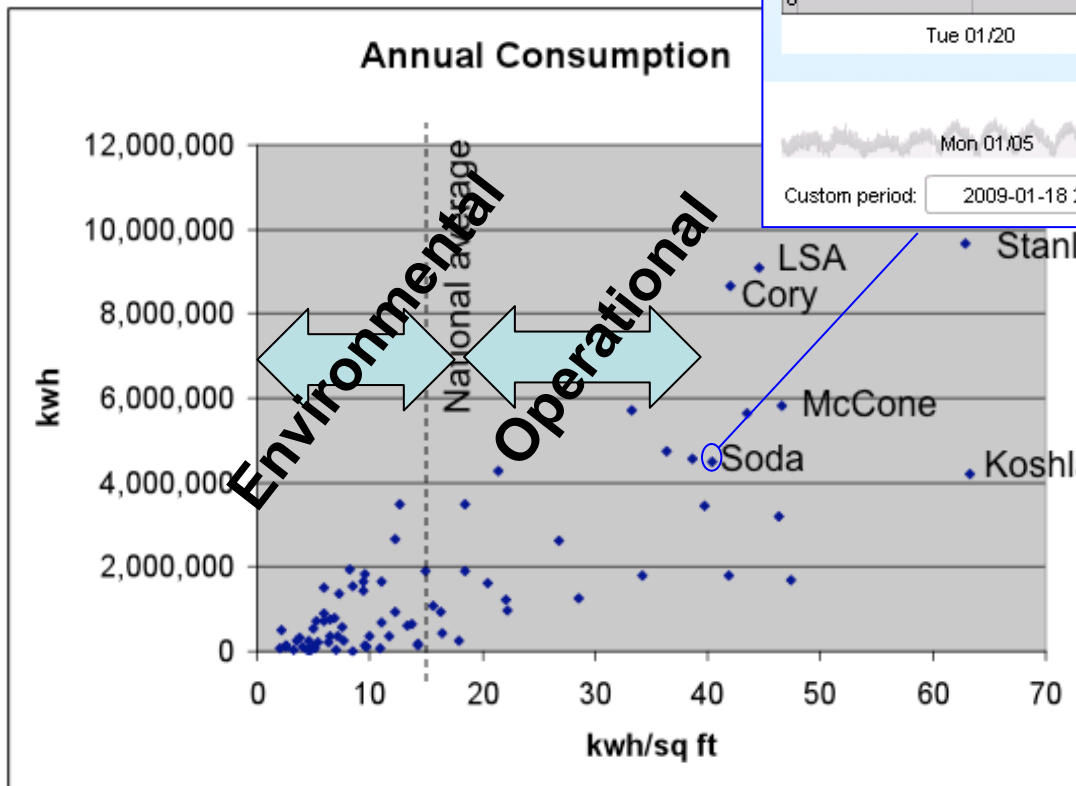
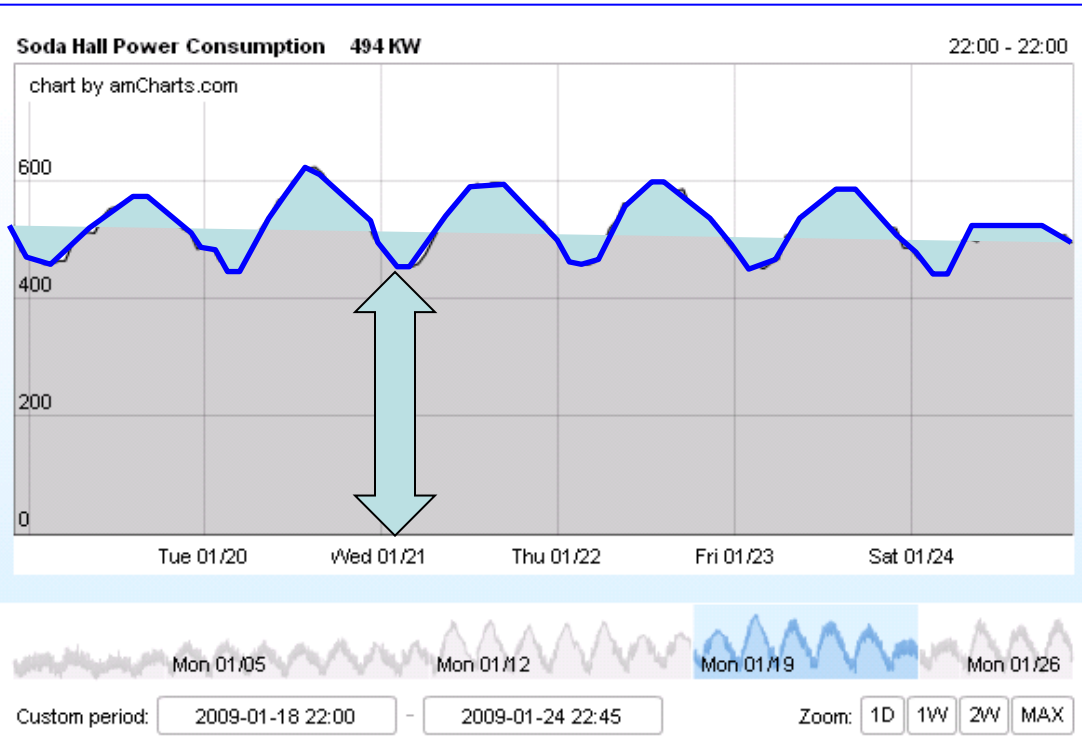


# Stages of Energy Effectiveness

- Waste elimination
  - Do Nothing Well !!!
- Power Proportionality
  - Power : Performance (utilization)
  - Partial Load - from nothing to peak
- Sculpting
  - Identify the energy slack and utilize it
- Negotiated Grid / Load / Human Interaction
  - Plan, Forecast, Negotiate, Manage

# Our Buildings

Do nothing poorly



- Wasteful
- <20 % Power Prop.
- Predictable
- Sculptable ?

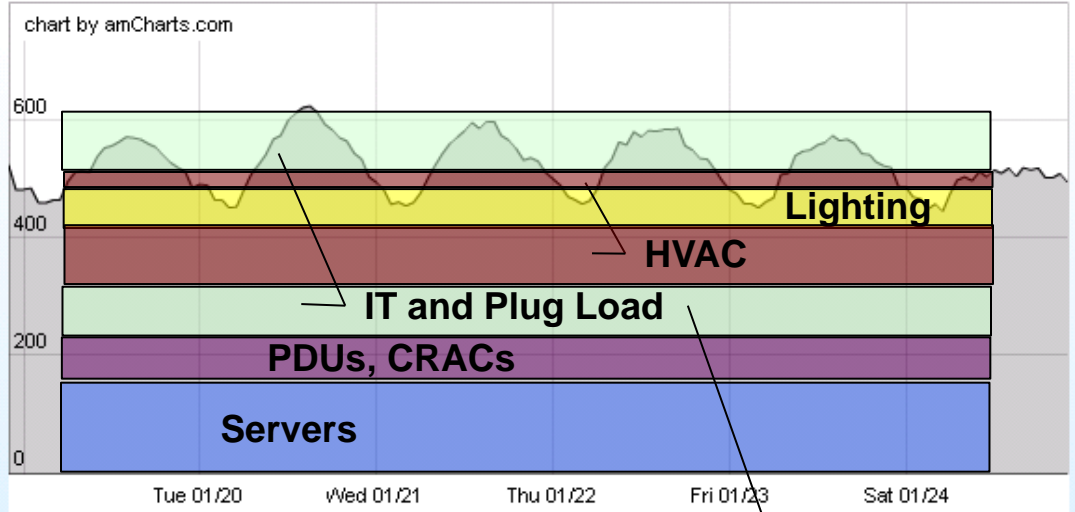
# Our Buildings

Use

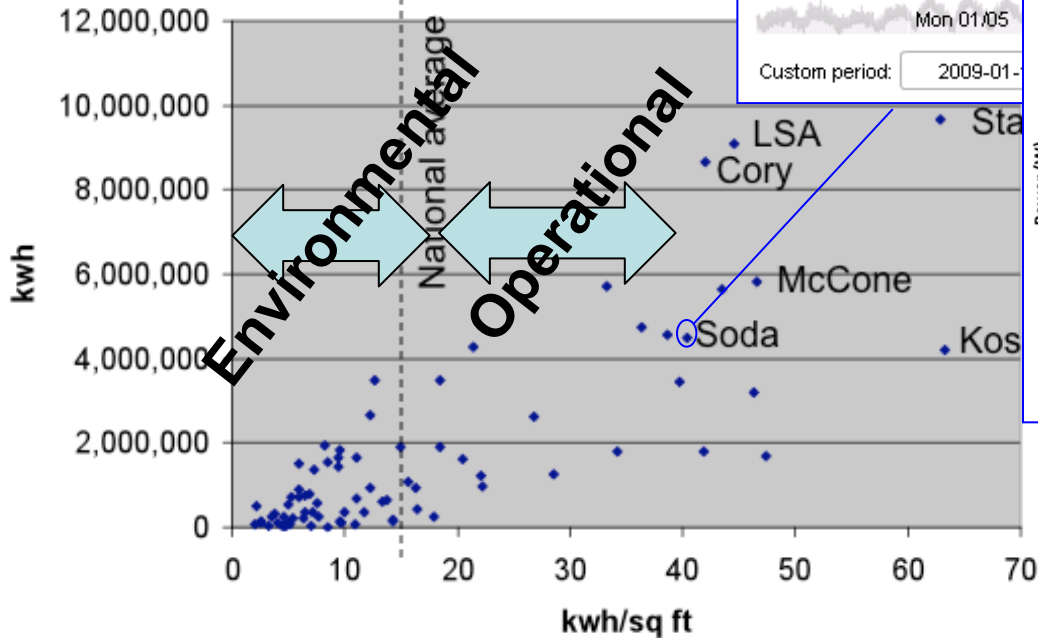
Design

Soda Hall Power Consumption 494 KW

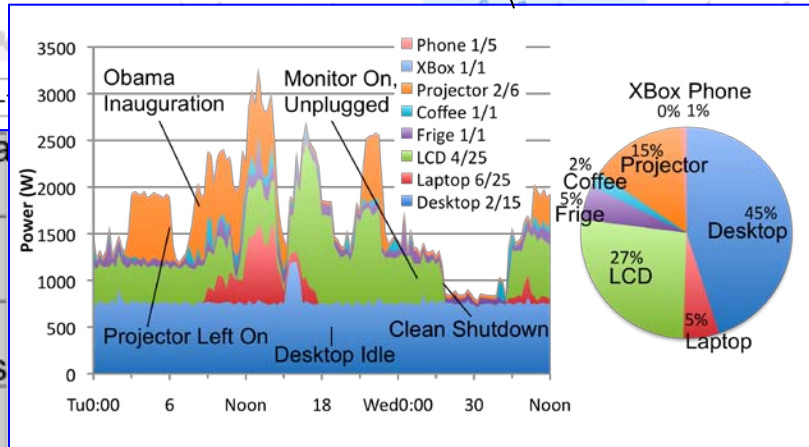
22:00 - 22:00



Annual Consumption

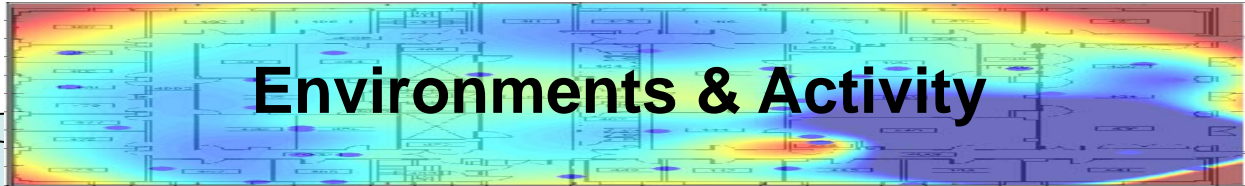


Custom period: 2009-01-



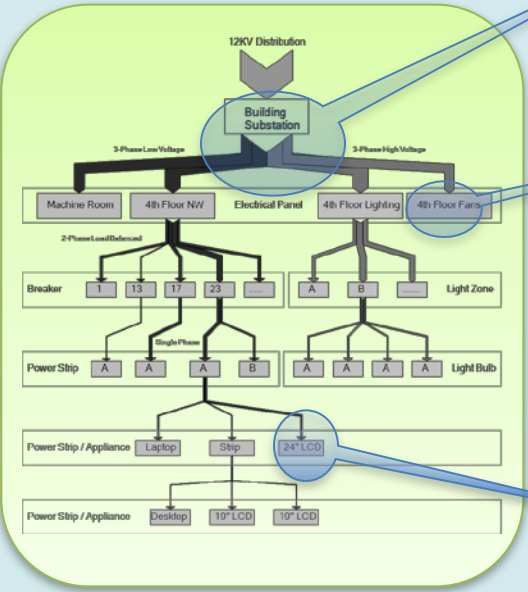
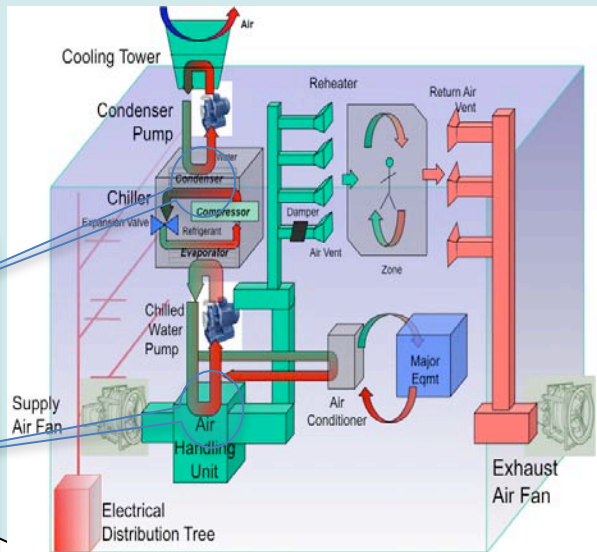
# Building-Scale Monitoring Architecture

## The 3 Views



### Climate Plant

### Load Tree



**Vibration**

**Humidity**

**Temperature**

**Pressure**

**CT: mains power monitoring**

**panel level power monitoring**

**ACme: plug load energy monitor and controller**

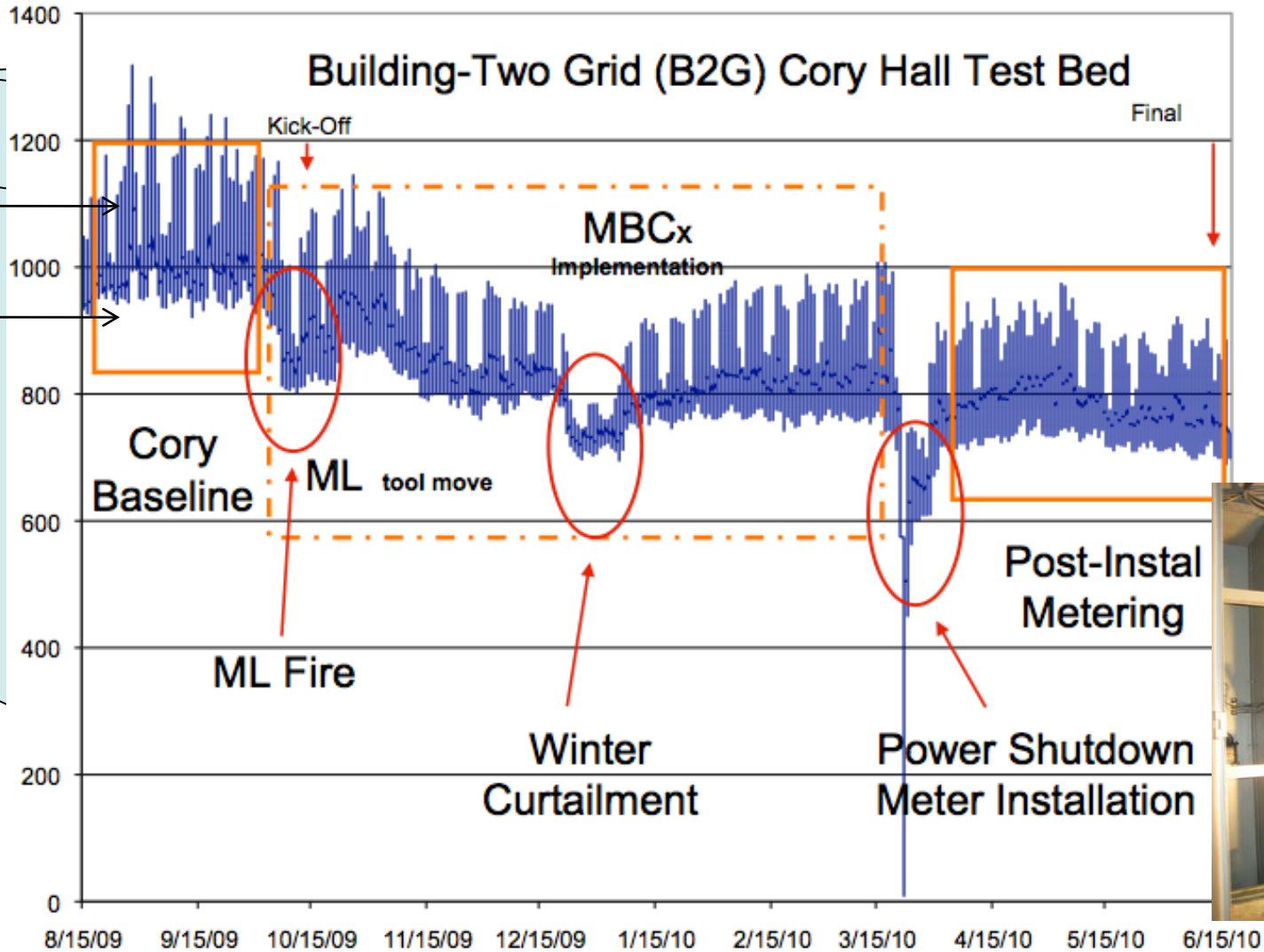
# Audit Methodology

- ***Measure*** the envelope
- ***Map*** the underlying load tree
- ***Identify*** major load points
- **Model, Instrument, Disaggregate**
  - specific instrument and analysis selection
- Apply recursively

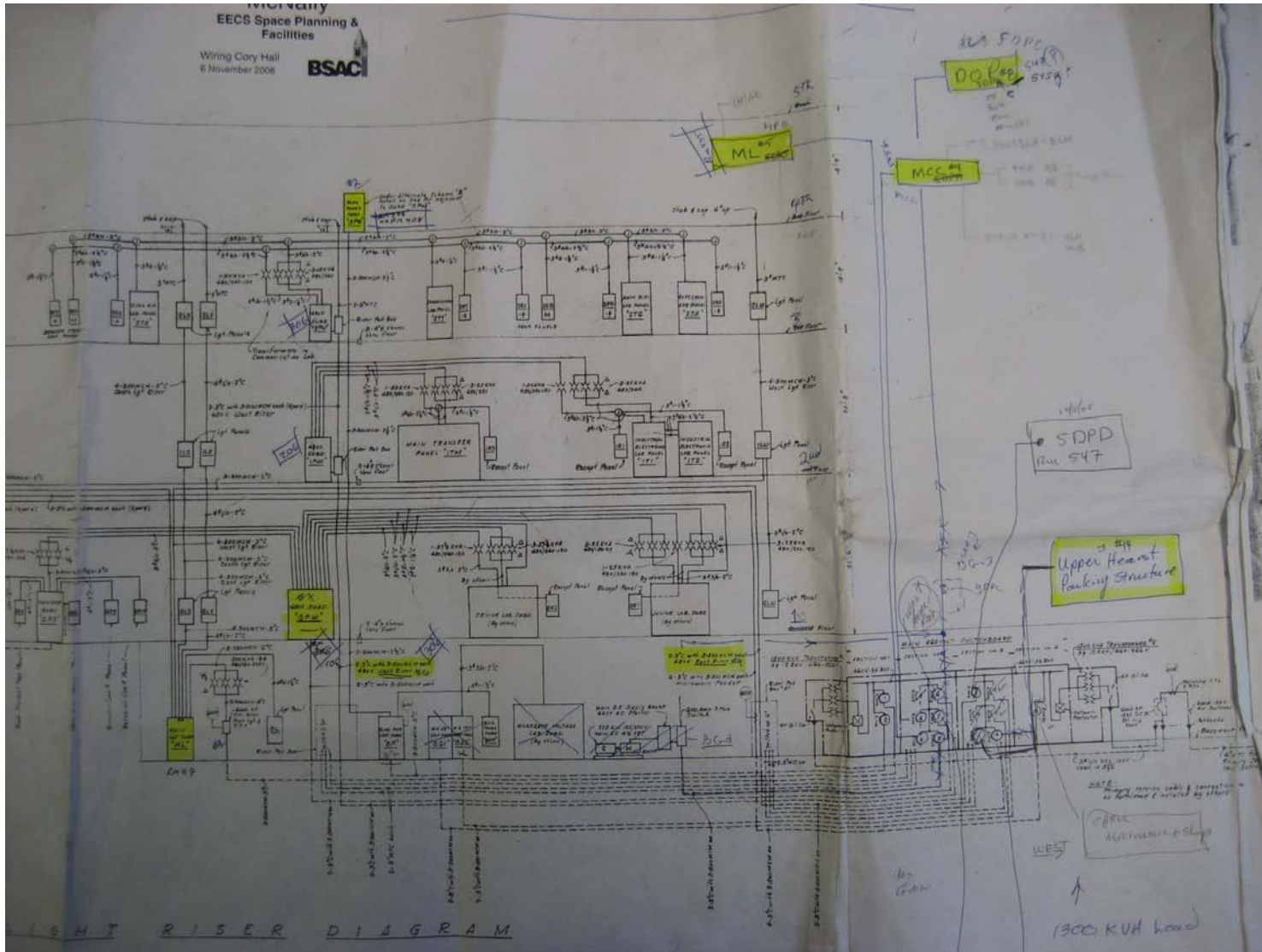
# Methodology Experience

- Guidance Criteria
  - Disambiguation goal isolates usage
  - Reconfiguration focuses on opportunities for mitigation
  - Sculptability focuses on shiftable loads
- Slices Alternative
  - instrument slice from supply to consumption
- Opportunism
  - Measure the best you can get ahold of

# Waste Less

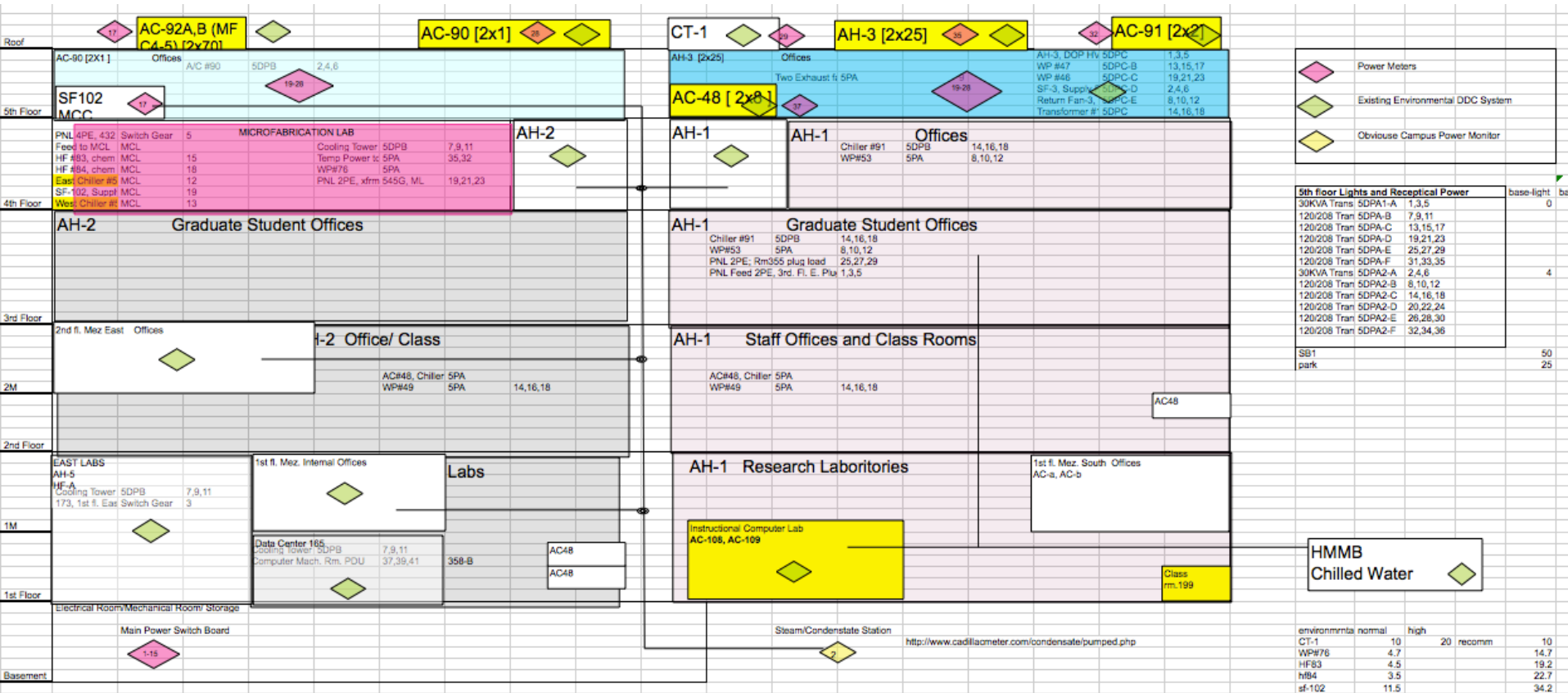


# State of the Art ...



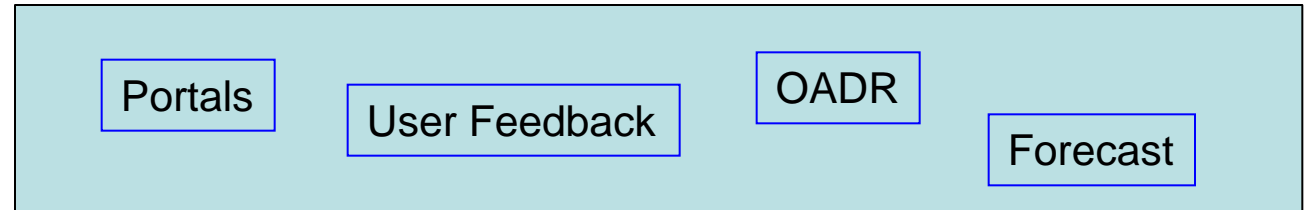


# Buildings within a Building

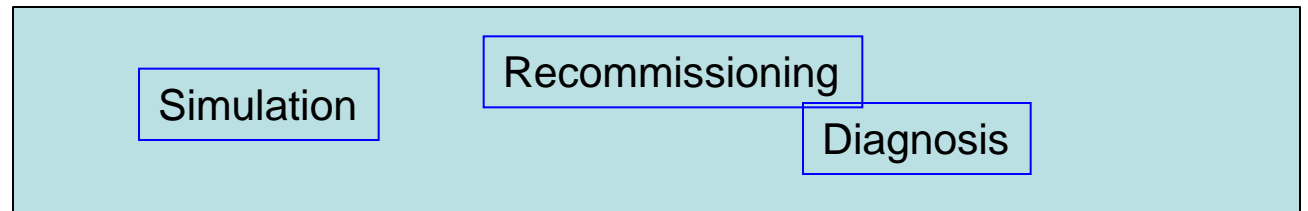


# Layered Architecture

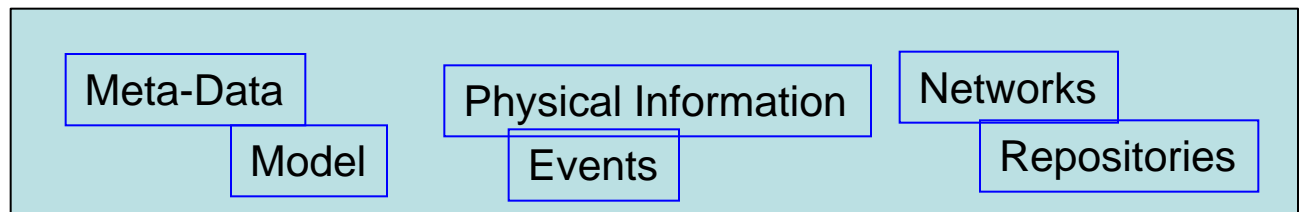
## Presentation



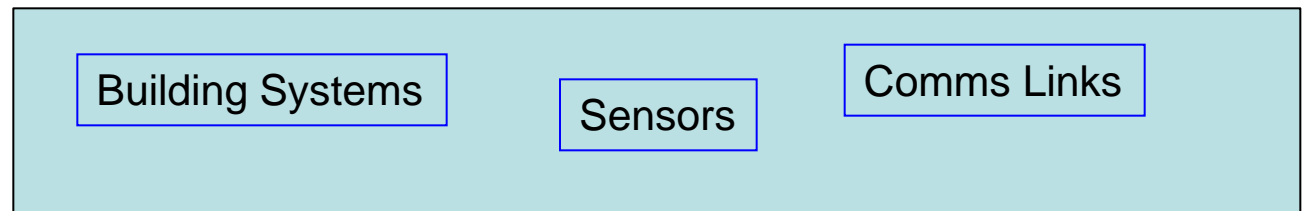
## Analysis



## Logical



## Physical

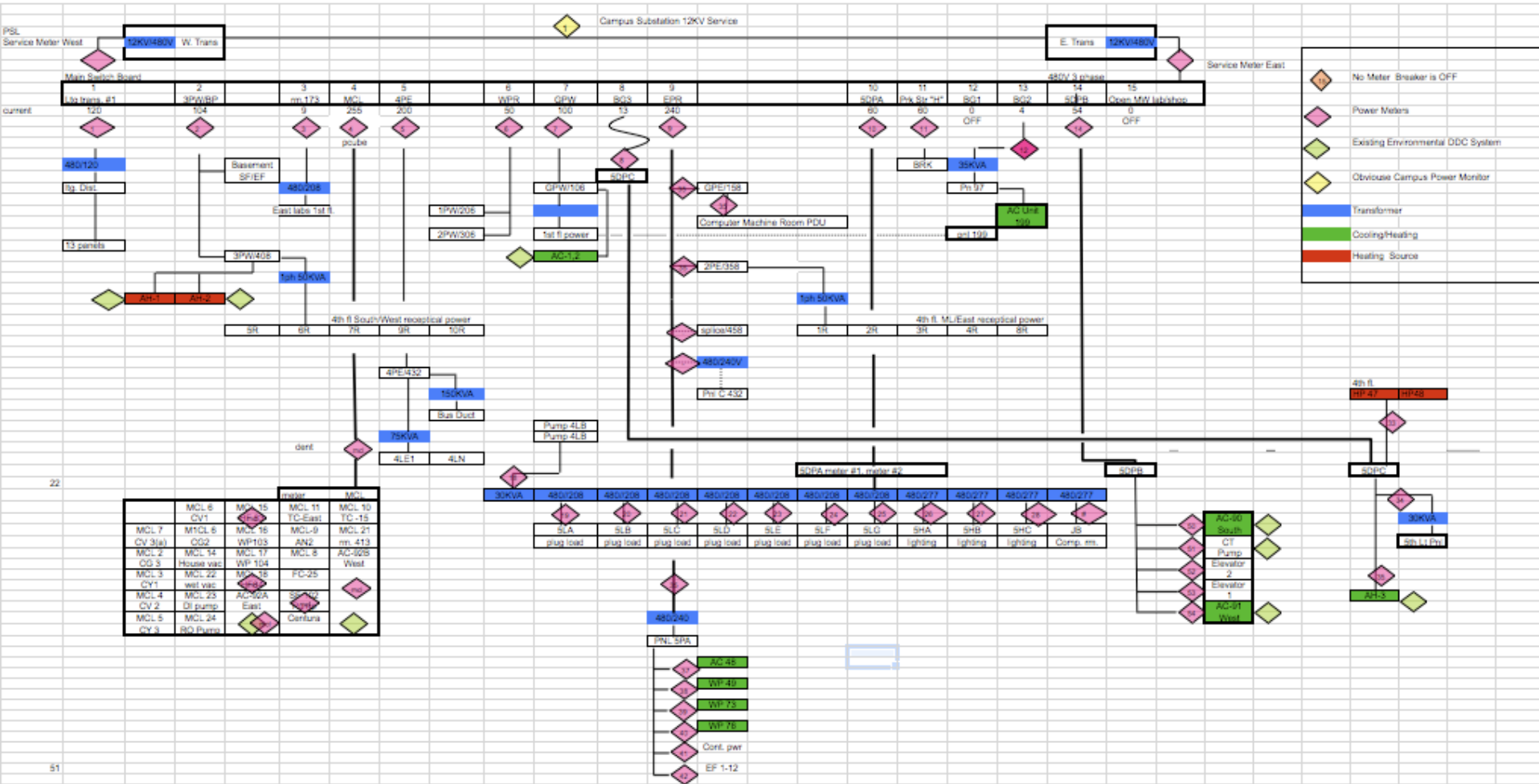


# Physical Tier

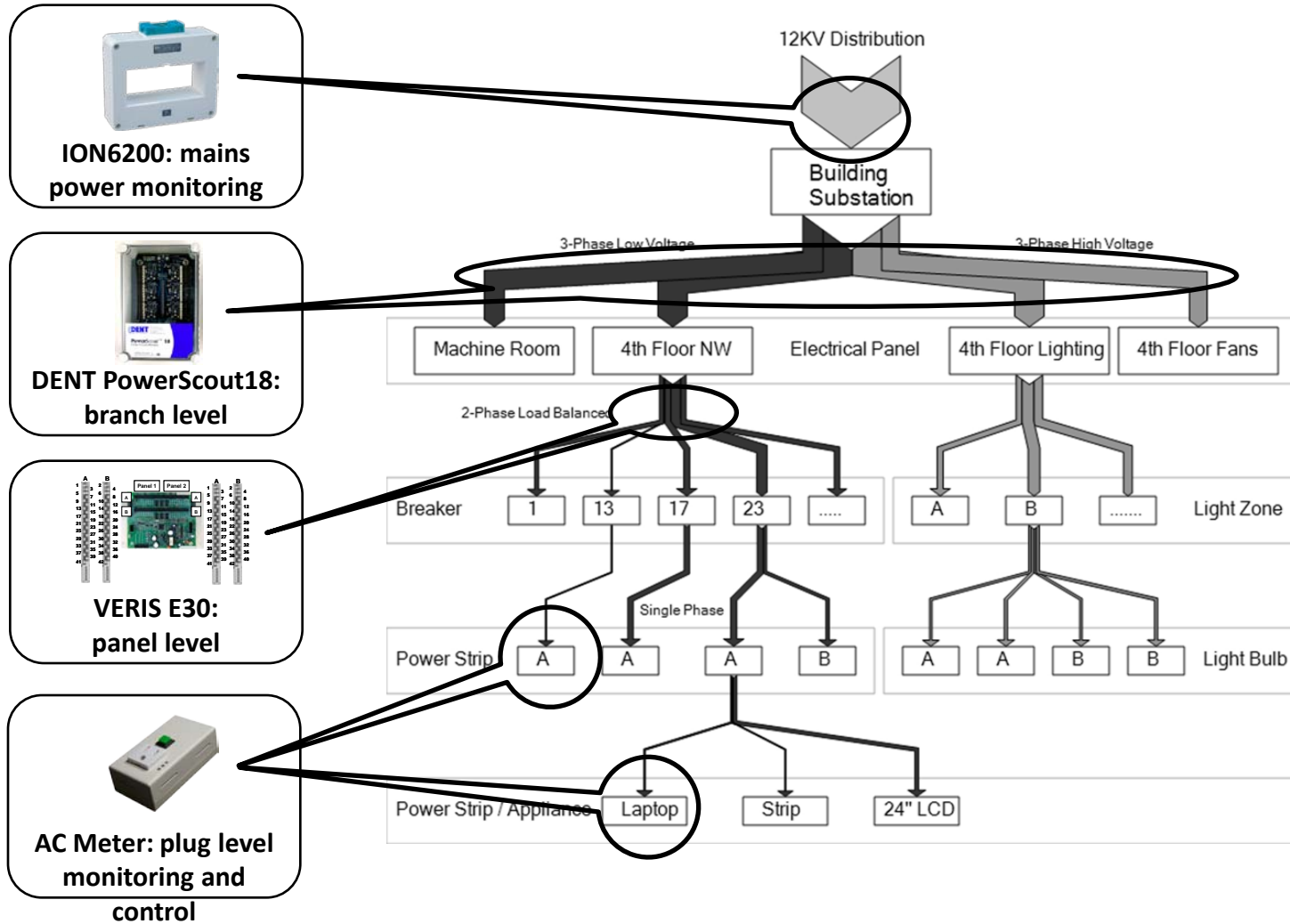
- 10 Dent Powerscout 18-channel (6x3) electrical meters
  - RS485 – Ethernet/IP – sMAP
- 2 Power Standards Labs meters
  - Ethernet
- 2 (existing) ION 6200 meters
- 70 ACME Receptacle meters
  - 802.15.4/LoWPAN/IP
- 4 rooftop Solar/TSR/PAR/Temp/Hum
- Condensate meter, Obvius Steam
- Vaisala Meteorological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



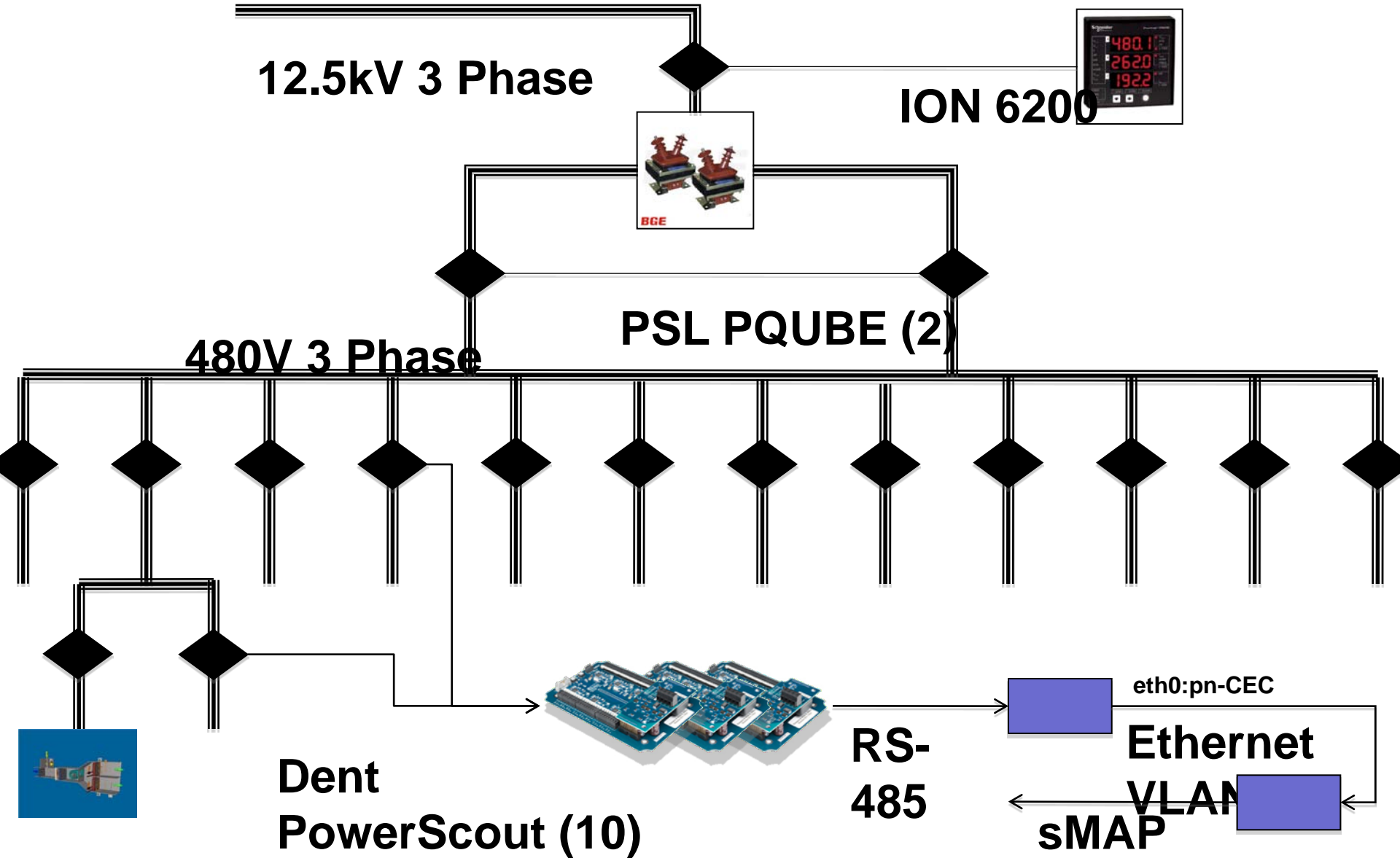
# Power Flows



# Electric Tree Monitoring



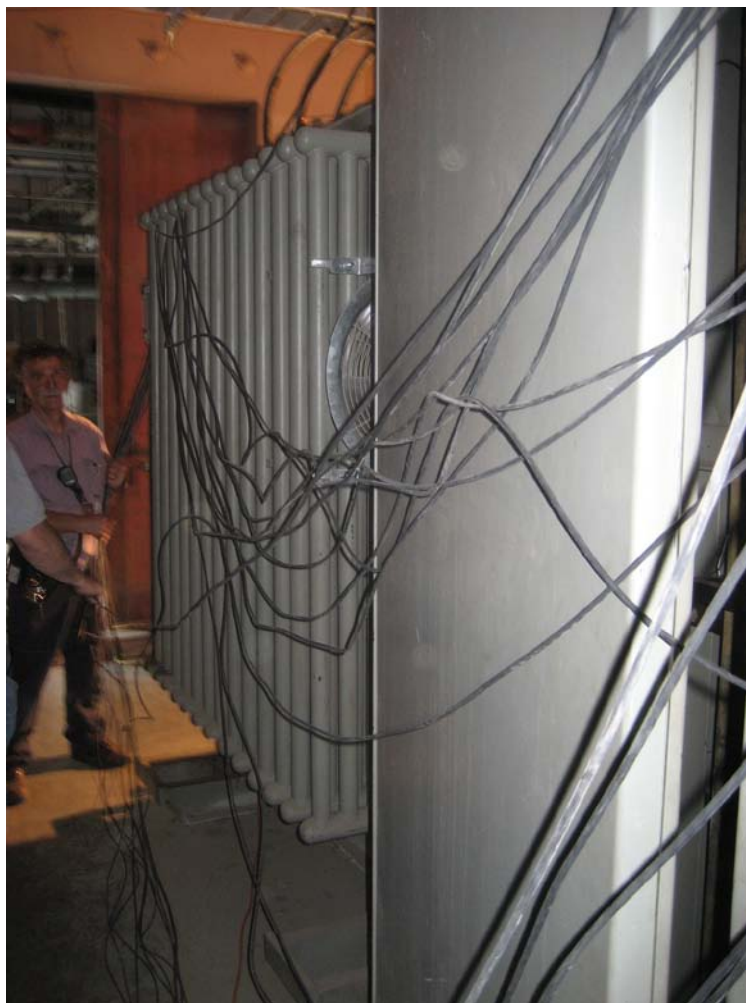
# Main Switch Block



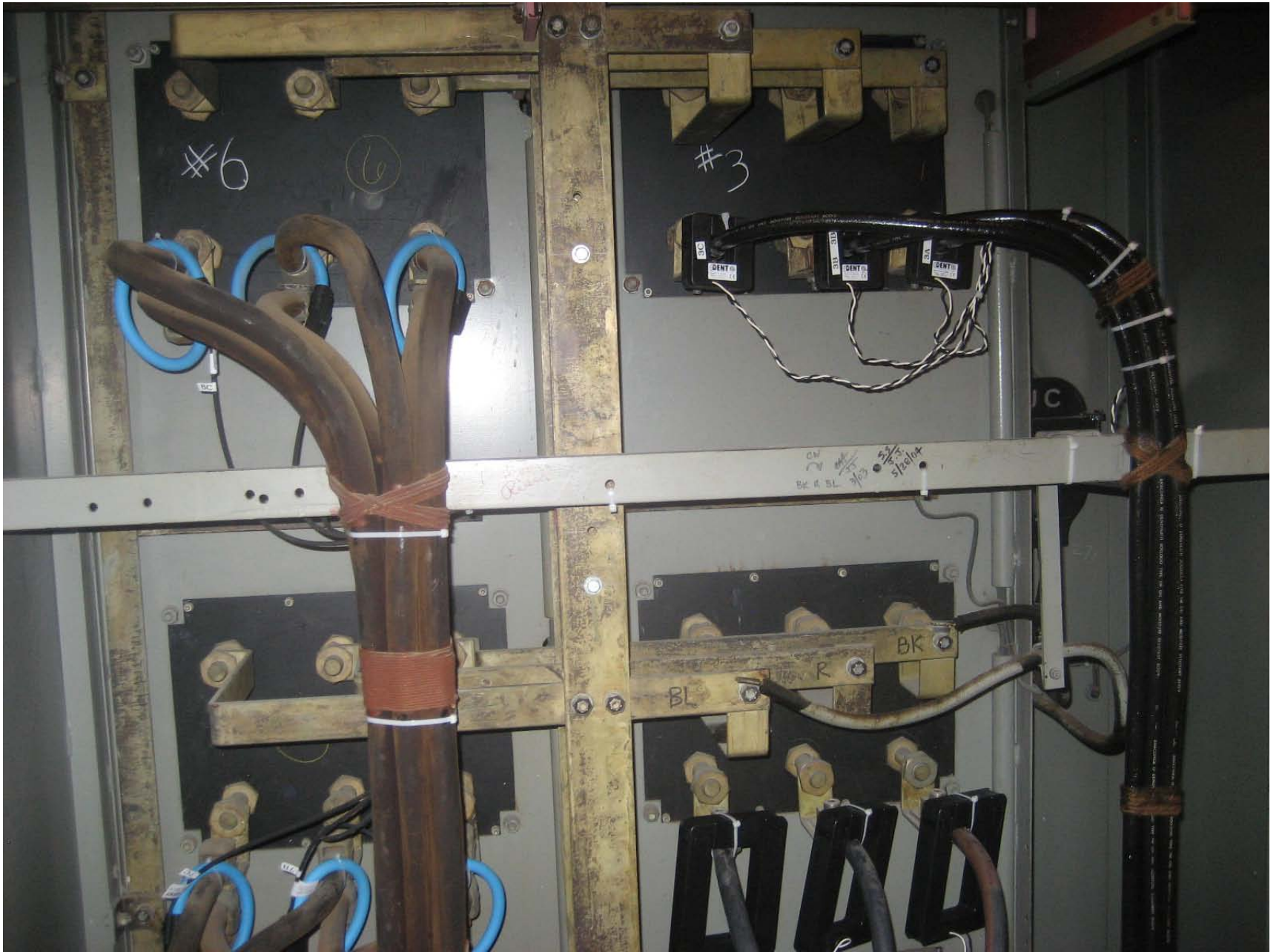
# Dent Powerscout 18

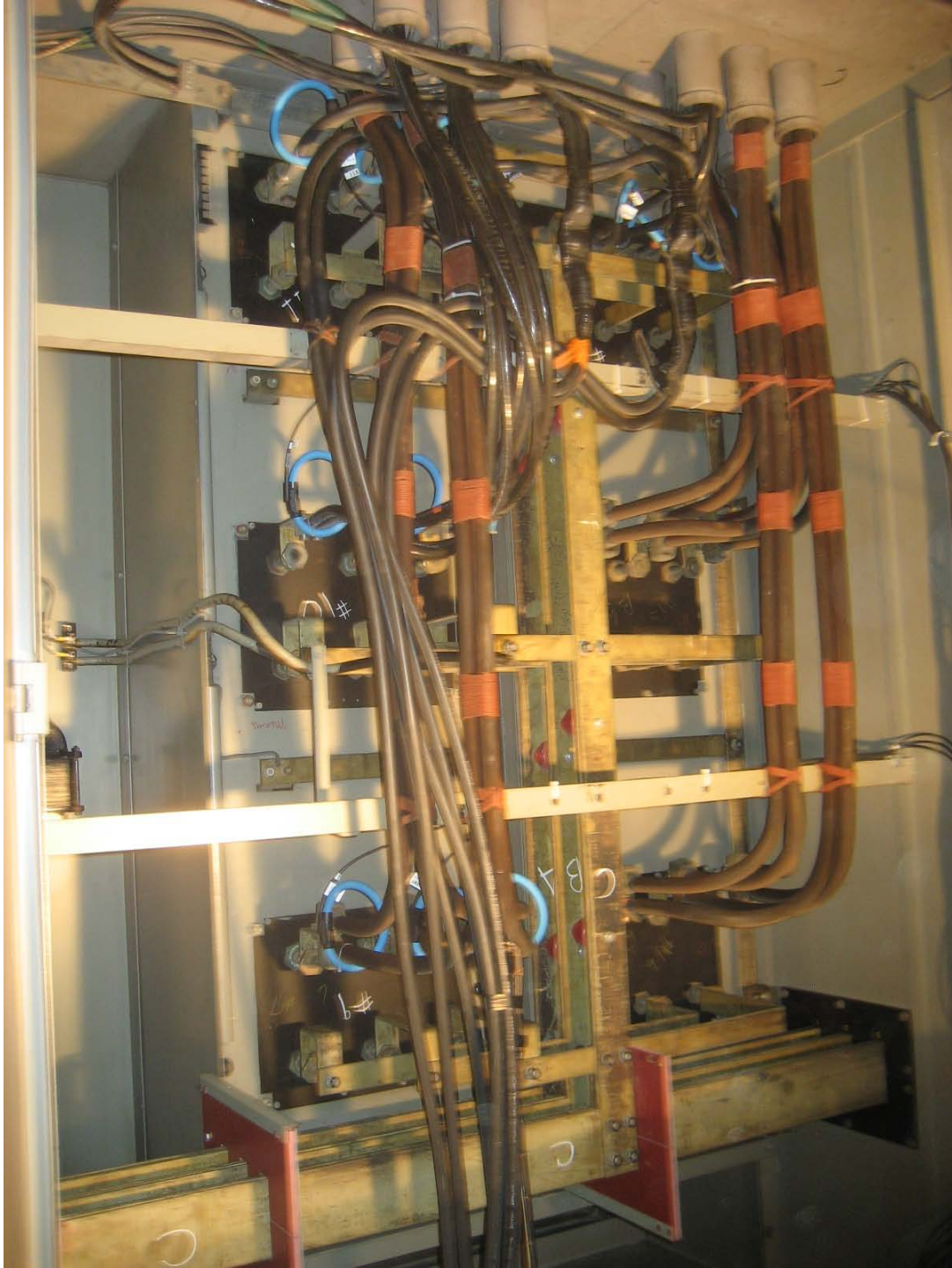
- Connectivity: RS-485 – multi-drop serial protocol
- Data model: Modbus (“everything is a 16-bit register”)
  - need register map to interpret
- Three-phase power measurements
  - about 50 “channels” per three-phase circuit
  - six circuits supported
- Registers updated at 2Hz





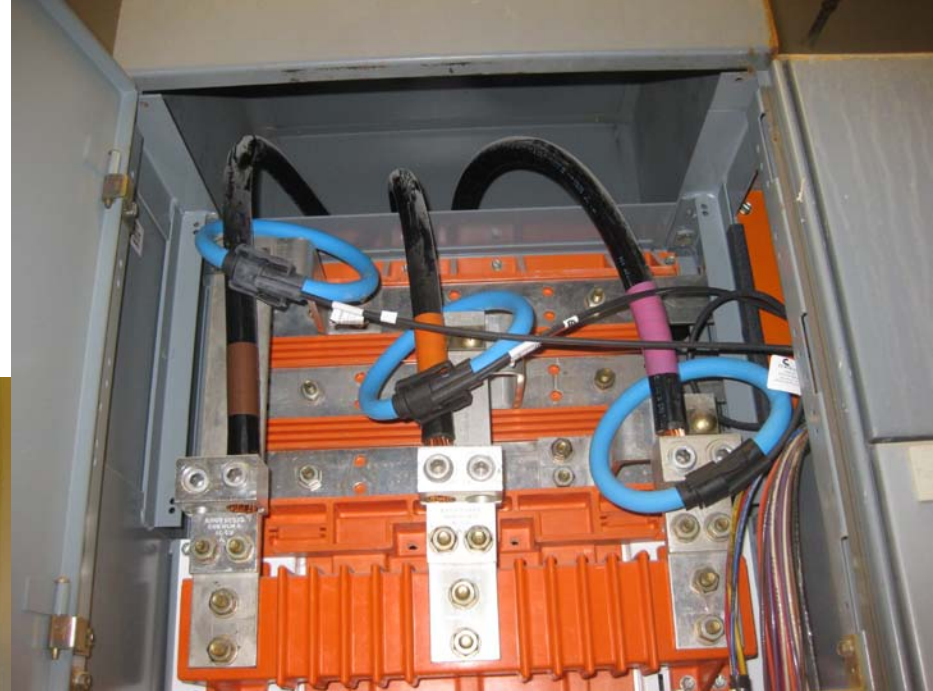










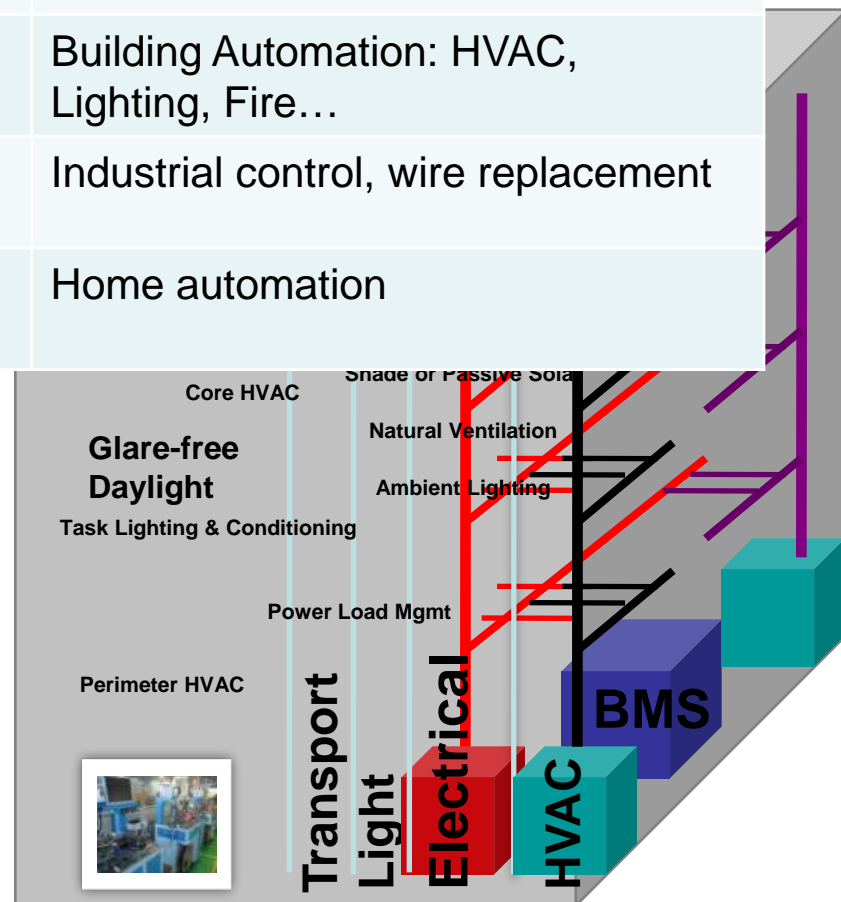




# Interconnect

Protocol	Year	Network	Target Application
Modbus	1979	RS-485, TCP/IP	Industrial Control
Fieldbus/HART	1988	various	Industrial Control
BACnet	1995	ARCNET, Ethernet, IP, RS-232, <i>etc.</i>	Building Automation: HVAC, Lighting, Fire...
WirelessHART	2007	802.15.4e	Industrial control, wire replacement
SEP 2.0	2010 ?	802.15.4	Home automation

- HUGE installed/legacy base
- **Multiple generations of hardware and software in the same building**
- **Typical integration: proprietary vertical BMS**
  - **Data in at the bottom**
  - **Data products out at the top**



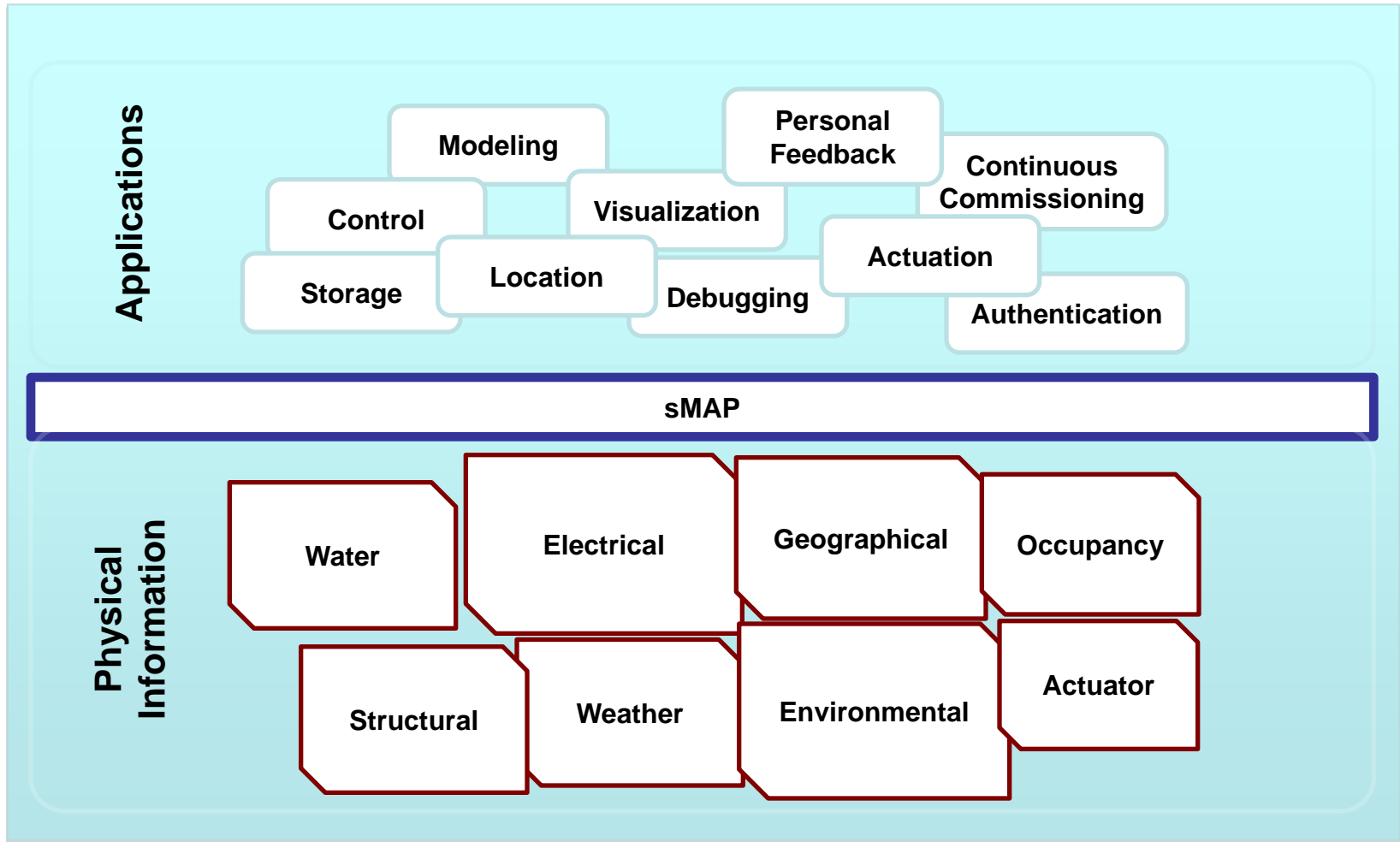
# Real Data Feeds



Type	Name	Connectivity
Electric	ION6200	XML/proprietary
Electric branch meter	Dent Powerscout 3/18	Modbus/RS-485
Electric branch meter	PSL PQube	HTML table
Electric panel meter	Veris E30	Modbus/RS-485
Electric home meter	GE	ANSI C12.19/IR
Chilled water		4-20mA current loop
Steam condensate		Modbus/TCP
Environmental	Sun Blackbox	XML/proprietary
PCT (programmable thermostat)	Basys QW Series	Zigbee
Climate	Hydrowatch node	6lowpan/IPv6



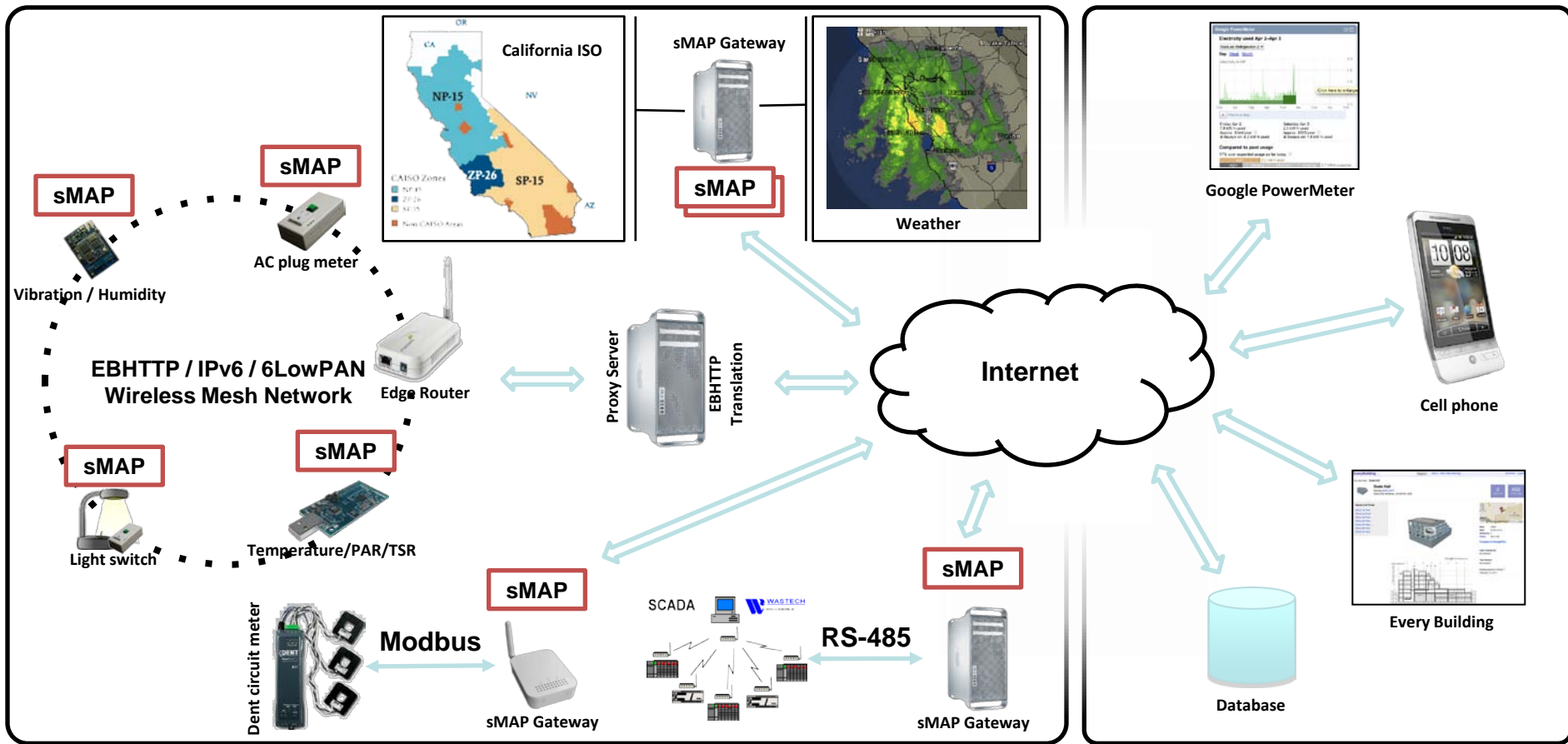
# Key Enabler: Hardware Abstraction



# IP Everywhere

## sMAP Resources

## Applications



# sMAP restful web services

```
/          # 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]
/reporting # create and query periodic reports [GET/POST]
```

POST requests supply JSON objects as arguments:

```
POST: http://meter1.cs.berkeley.edu/reporting/create
{ "ReportResource" : "/data/325/meter/*/reading",
  "ReportDeliveryLocation" :
    "http://webs.cs.berkeley.edu/recv.php",
  "Period" : 0, "Minimum" : 50, "Maximum" : 100 }
```

# Typical Interaction

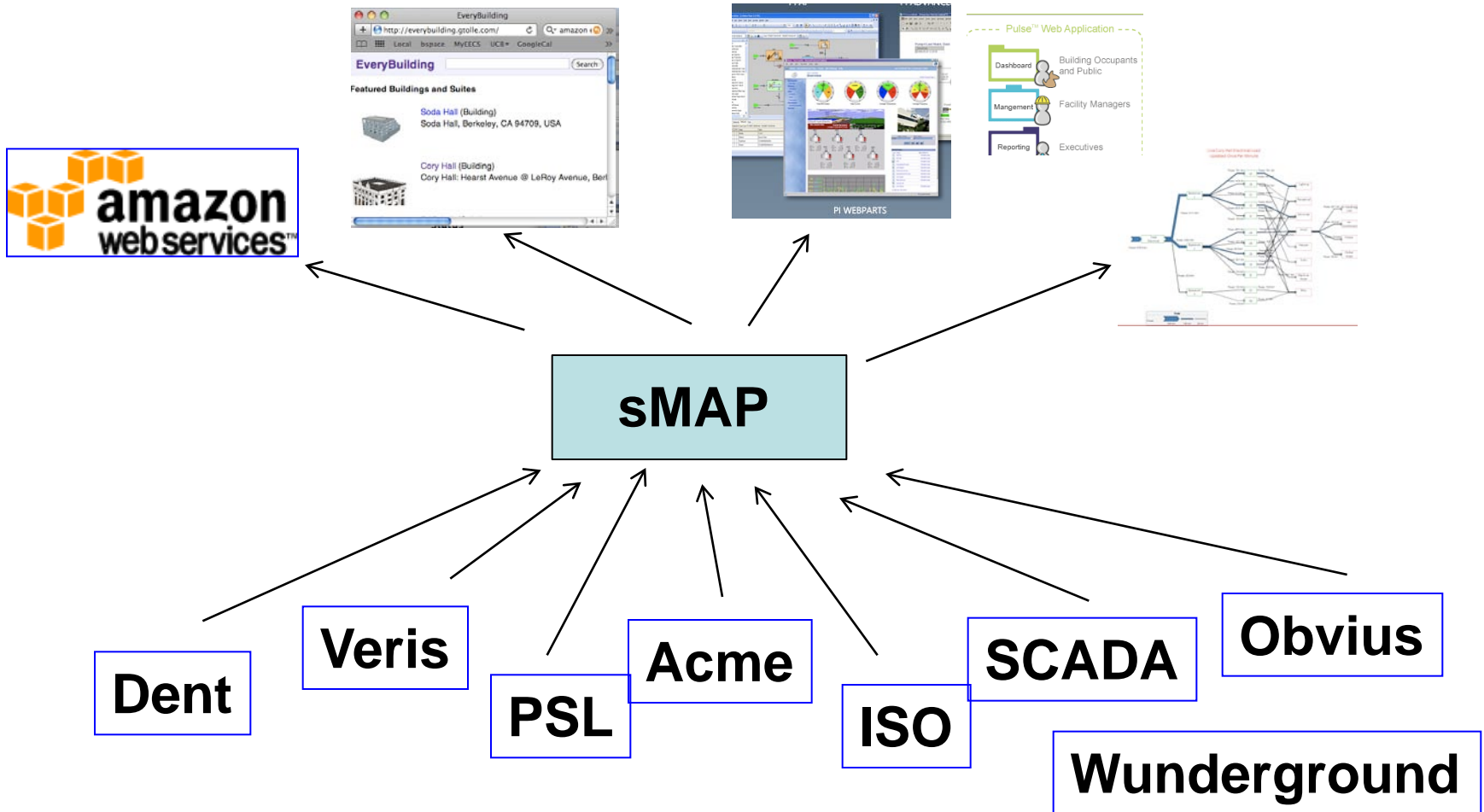
- Discover sMAP Instance
- Read/Poll
  - GET /data/ABC/sensor/real\_power/formatting
  - GET /data/\*/\*/\*/reading
- Subscribe
  - Create reporting instance with HTTP URL for “callback”
  - Specify fixed rate or each new report
  - Persists until deleted, times out, or fails
  - Incremental update (part of a resource) sometimes necessary

# Design: Dent Powerscout 18

```
/ # 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]
/reporting # create and query periodic reports [GET/POST]
```

Sense Point	Description	Channels
A, B, C	Single-phase	real, apparent, reactive power + energy. power factor. current. phase-neutral voltage
AB, BC, AC	Phase-to- phase	voltage
ABC	Whole-circuit	real, apparent, reactive power + energy. power factor. current. phase-neutral voltage. line frequency

# Open Standards => Horizontal Integration



# sMAP – homogeneous access to heterogeneous information

The screenshot shows the sMAP Console web interface. The browser address bar displays `http://smap.cs.berkeley.edu/`. The main content area is titled "sMAP root" and includes a navigation menu with links for "main", "Model", "Type", "Make", "Status", "Uptime", "LocalTime", "Streams", and "Reporting". A dropdown menu is open, listing various equipment and circuit details, including:

- RADLab Veris Panel Meter
- RADLab ACme deployment
- CA ISO Grid Demand
- Berkeley Weather
- Berkeley Sun Blackbox
- Berkeley/Cory Hall Virtual Meter
- Dent: basement-1/elt-A: Circuit Breaker 1
- Dent: basement-1/elt-B: Circuit Breaker 2
- Dent: basement-1/elt-C: Circuit Breaker 3
- Dent: basement-1/elt-E: Circuit 5
- Dent: basement-1/elt-F: Circuit 6
- Dent: basement-2/elt-A: Circuit 7
- Dent: basement-2/elt-B: Circuit 8
- Dent: basement-2/elt-D: Circuit 9
- Dent: basement-2/elt-E: Circuit 10
- Dent: basement-2/elt-F: Circuit 11
- Dent: basement-3/elt-C: Circuit 14
- Dent: basement-3/elt-D: Circuit 13, BG-2
- Dent: SPA/elt-A: SPA Feed: 240V Panel 5PA
- Dent: SPA/elt-B: Circuits 1,3,5: AC48, Chilled water
- Dent: SPA/elt-C: Circuits 2,4,6: WP76 Process cooling loop
- Dent: SPA/elt-E: Circuits 8,10,12: WP53
- Dent: SPA/elt-E: Circuits 14,16,18: WP49
- Dent: SPA/elt-F: Circuits 9,35,36: 5th fl. utilities
- Dent: 5DPA1/elt-A: Circuits 1,3,5: 30kva Trans to PNL5 4LA,4LE
- Dent: 5DPA1/elt-B: Circuits 7,9,11: 120/208 Trans.
- Dent: 5DPA1/elt-C: Circuits 13,15,17: 120/208 Trans
- Dent: 5DPA1/elt-D: Circuits 19,21,23: 120/208 Trans
- Dent: 5DPA1/elt-E: Circuits 25,27,29: 120/208 Trans
- Dent: 5DPA1/elt-F: Circuits 31,33,35: 120/208 Trans
- Dent: 5DPA2/elt-A: Circuits 2,4,6: 30KVA Trans to PNL5 4LA,4LE
- Dent: 5DPA2/elt-B: Circuits 8,10,12: 120/208 Trans
- Dent: 5DPA2/elt-C: Circuits 14,16,18: 120/208 Trans
- Dent: 5DPA2/elt-D: Circuits 20,22,24: 120/208 Trans
- Dent: 5DPA2/elt-E: Circuits 26,28,30: 120/208 Trans
- Dent: 5DPA2/elt-F: Circuits 32,34,36: 120/208 Trans
- Dent: 5DPB/elt-A: Circuits 2,4,6: AC#90 (Train Unit)
- Dent: 5DPB/elt-B: Circuits 1,3,5: East Passenger Elevator
- Dent: 5DPB/elt-C: Circuits 7,9,11: Cooling Tower Pumps (two speed)
- Dent: 5DPB/elt-D: Circuits 13,15,17: West Passenger Elevator
- Dent: 5DPB/elt-F: Circuits 14,16,18: AC#91, Chiller
- Dent: 5DPC/elt-A: Circuits 1,3,5: AH-3, DOP Center ventilation
- Dent: 5DPC/elt-B: Circuits 13,15,17: WP#47
- Dent: 5DPC/elt-C: Circuits 19,21,23: EP #46
- Dent: 5DPC/elt-D: Circuits 2,4,6: SF-3, Aux Supply Fan DOP
- Dent: 5DPC/elt-E: Circuits 8,10,12: RF-3 Aux AH-3
- Dent: 5DPC/elt-F: Circuits 14,16,16: Trans #1
- Dent: MCL/elt-A: Circuit #4 Switch Gear
- Dent: MCL/elt-B: HF#83
- Dent: MCL/elt-C: HF #84, Microlab
- Dent: MCL/elt-D: CHWS #54, West
- Dent: MCL/elt-E: MCL-19, SF-104, Services Microlab
- Dent: MCL/elt-F: CHWS #55, West
- Dent: 358/elt-A: GPE Feet and db 1,3,5: panel feed & tool feed
- Dent: 358/elt-B: pnl DPE, cb 37,39,41: PDU in mach. room
- Dent: 358/elt-C: PNL 2PE Feed, cb 1,3,5: 3fl east plug load, etc
- Dent: 358/elt-D: Splice box: 5PA, transformer, rm 545V
- Dent: 358/elt-E: PNL 2PE, cb 25,27,29: xfmr in rm 355, plug loads
- Dent: 358/elt-F: PNL 2PE, cb 19,21,23: xfmr in rm 545G

At the bottom of the page, there is a logo for "Lalal" and a link to "sMAP information".

# IS4



CT mains power monitoring



ACme: plug load energy monitor and controller



Temperature



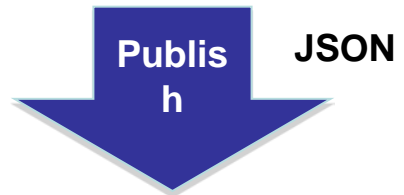
PAR/TSR



Humidity



Vibration

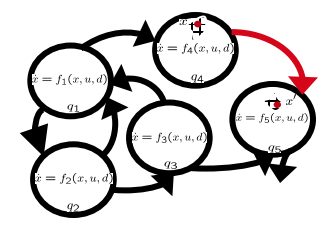
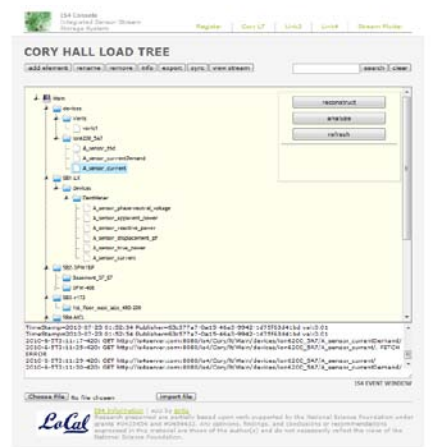
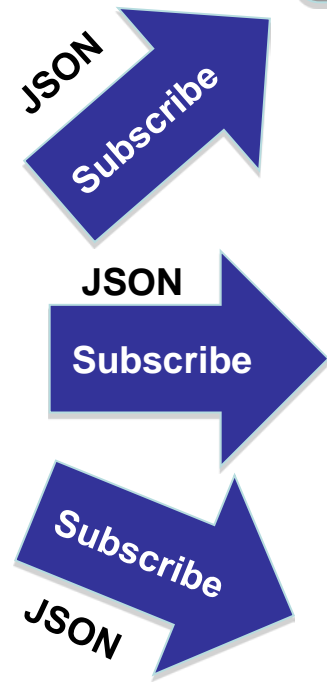


HTTP/REST

Metadata Manager	Publish Manager
Query Processor	Subscribe Manager
Data processing	Security Manager

Storage

IS4





# IS4 Interface Overview

**/** #root – status information [GET]  
**/is4** # a particular channel [GET]  
**/info** # statistical system information [GET]  
**/publish** # publishing resource [GET/PUT]  
    **/all** # list of all publishers [GET]  
    **/id** # sub-children [GET]  
        **/**<id>**** # id of publisher [GET/POST]  
            **/name** # name alias for this id [GET]  
            **/mysubs** # list/add to pub subscriptions  
            [GET/PUT/DELETE]

## POST requests supply JSON objects as arguments:

POST:

[http://is4server.com:8080/is4/Cory/lt/Main/devices/ion6200\\_5A7/A\\_sensor\\_currentDemand](http://is4server.com:8080/is4/Cory/lt/Main/devices/ion6200_5A7/A_sensor_currentDemand)

DATA:

```
{"SummationDelivered": 6824953.0, "$schema": {"$ref": "http://webs.cs.berkeley.edu/schema/meter/reading"},  
"Version": 1, "ReadingTime": 1279859526, "SummationInterval": 30}
```

# IS4 Load Tree Visualization



IS4 Console  
Integrated Sensor-Stream  
Storage System

[Register](#)

[Cory LT](#)

[Link3](#)

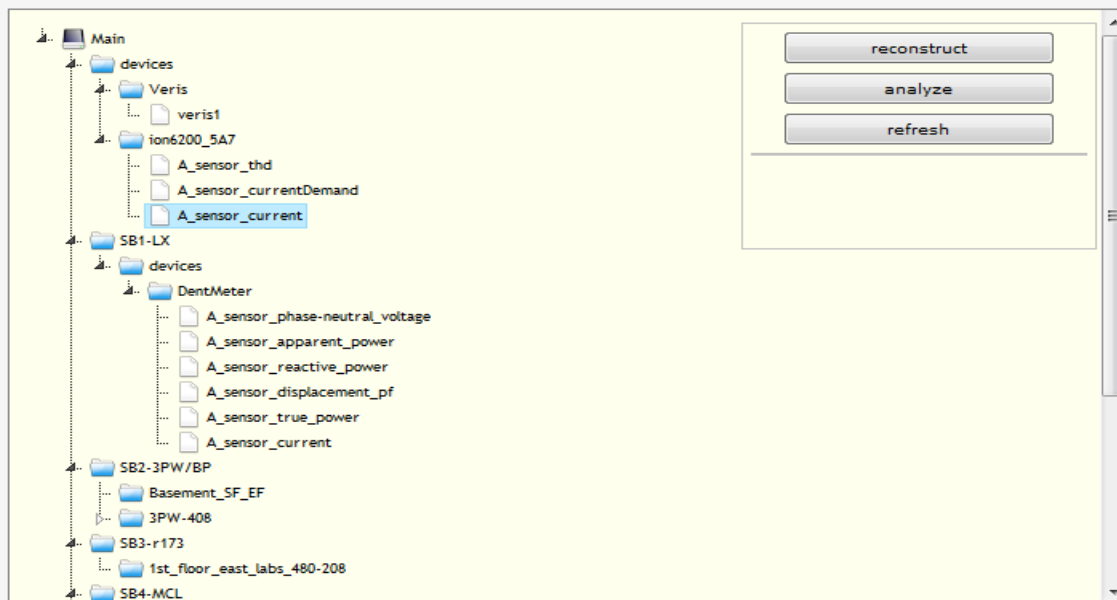
[Link4](#)

[Stream Plotter](#)

## CORY HALL LOAD TREE

[add element](#) [rename](#) [remove](#) [info](#) [export](#) [sync](#) [view stream](#)

[search](#) [clear](#)



[reconstruct](#)

[analyze](#)

[refresh](#)

```
TimeStamp=2010-07-23 01:52:34 Publisher=63c577a7-0a15-46a3-9942-1d75f63d41bd val:0.01
TimeStamp=2010-07-23 01:52:54 Publisher=63c577a7-0a15-46a3-9942-1d75f63d41bd val:0.01
2010-6-5T3:11:17-420: GET http://is4server.com:8080/is4/Cory/Lt/Main/devices/ion6200_5A7/A_sensor_currentDemand/
2010-6-5T3:11:25-420: GET http://is4server.com:8080/is4/Cory/Lt/Main/devices/ion6200_5A7/A_sensor_current/, FETCH
ERROR
2010-6-5T3:11:29-420: GET http://is4server.com:8080/is4/Cory/Lt/Main/devices/ion6200_5A7/A_sensor_current/
2010-6-5T3:11:30-420: GET http://is4server.com:8080/is4/Cory/Lt/Main/devices/ion6200_5A7/A_sensor_currentDemand/
```

IS4 EVENT WINDOW

[Choose File](#) No file chosen

[import file](#)

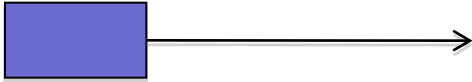


IS4 Information | app by iortiz

Research presented is partially based upon work supported by the National Science Foundation under grants #0435454 and #0454432. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

# Web Applications

## sMAP



Amazon

Cloud

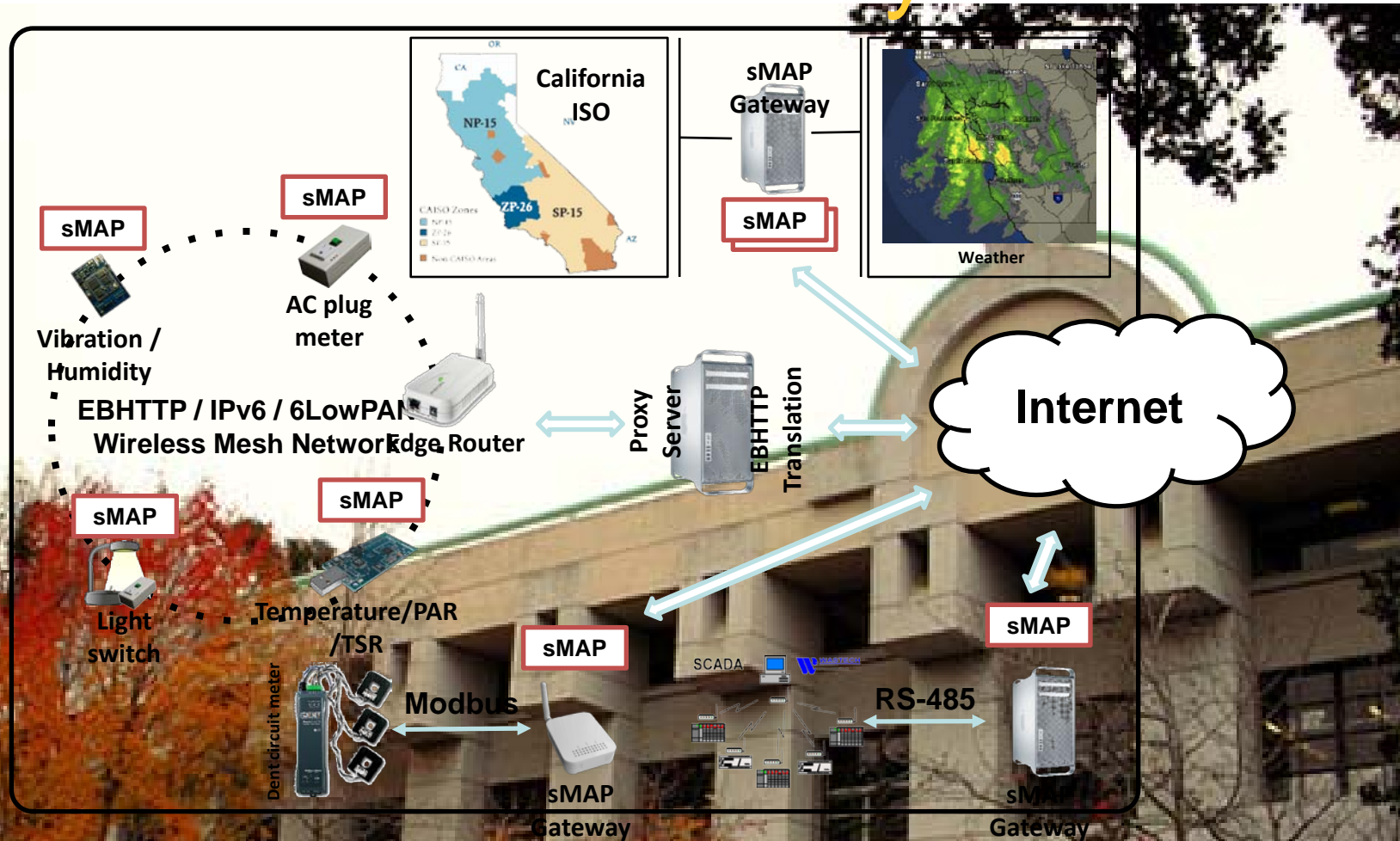
EveryBuil

ding

```
{  
  "ReportResource" : "/data/*/*/*/*/reading",  
  "ReportDeliveryLocation" : "http://...amazonaws.com/append/basement-1-elt-A"  
}  
  
{  
  "ReportResource" : "/data/ABC/sensor/true_power/reading",  
  "ReportDeliveryLocation" : "http://everybuilding./sensors/109/report.json?p=smap"  
}
```

## Push

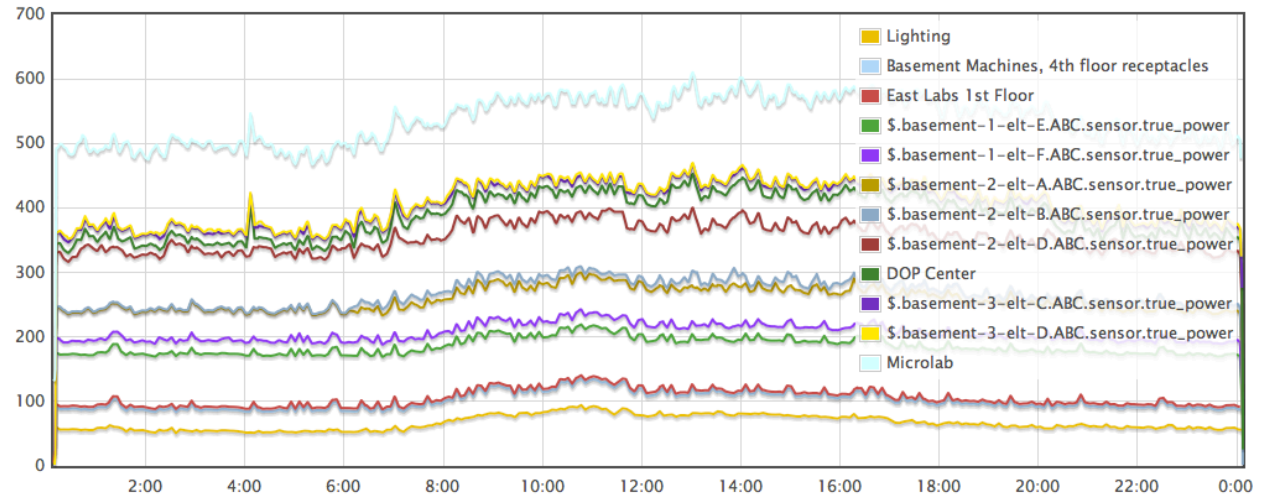
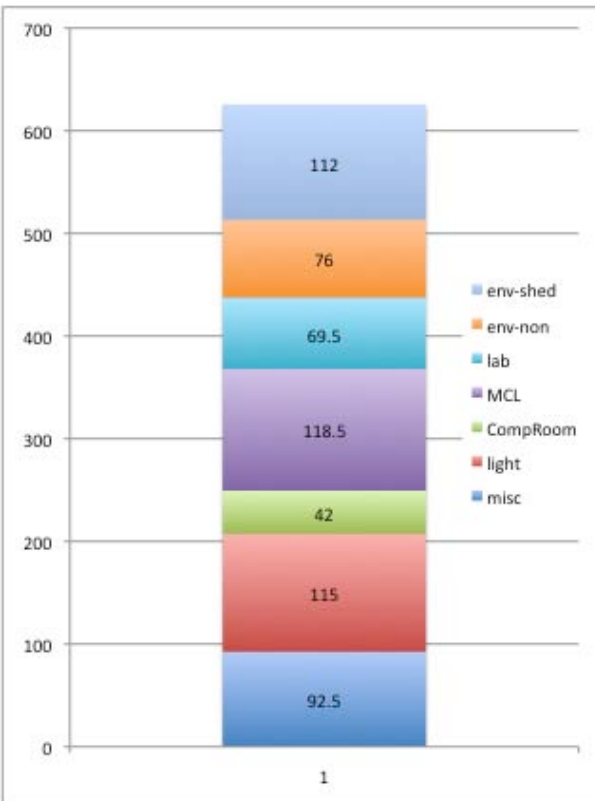
# sMAP Ecosystem at Berkeley



- Gateways for legacy devices; native implementations for new ones
- Library of 8 different devices – currently represents XML/CSV feeds, Modbus, and embedded (mode-class)

# Power Breakdown

## sMAP Aggregate Plotting Engine



Cory Hall Total Thursday July 8, 2010 00:08:00 Friday July 9, 2010 00:08:00 Plot  
<http://smap.cs.berkeley.edu/db/plot/?aggid=1&start=1278572880&end=1278659280>



sMAP | status | app by [stevedh](#)  
 Research presented are partially based upon work supported by the National Science Foundation under grants CPS-0932209 and CPS-0931843. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

[Any+Time](#) | [Busy](#) | [jQuery](#) | [flot](#)

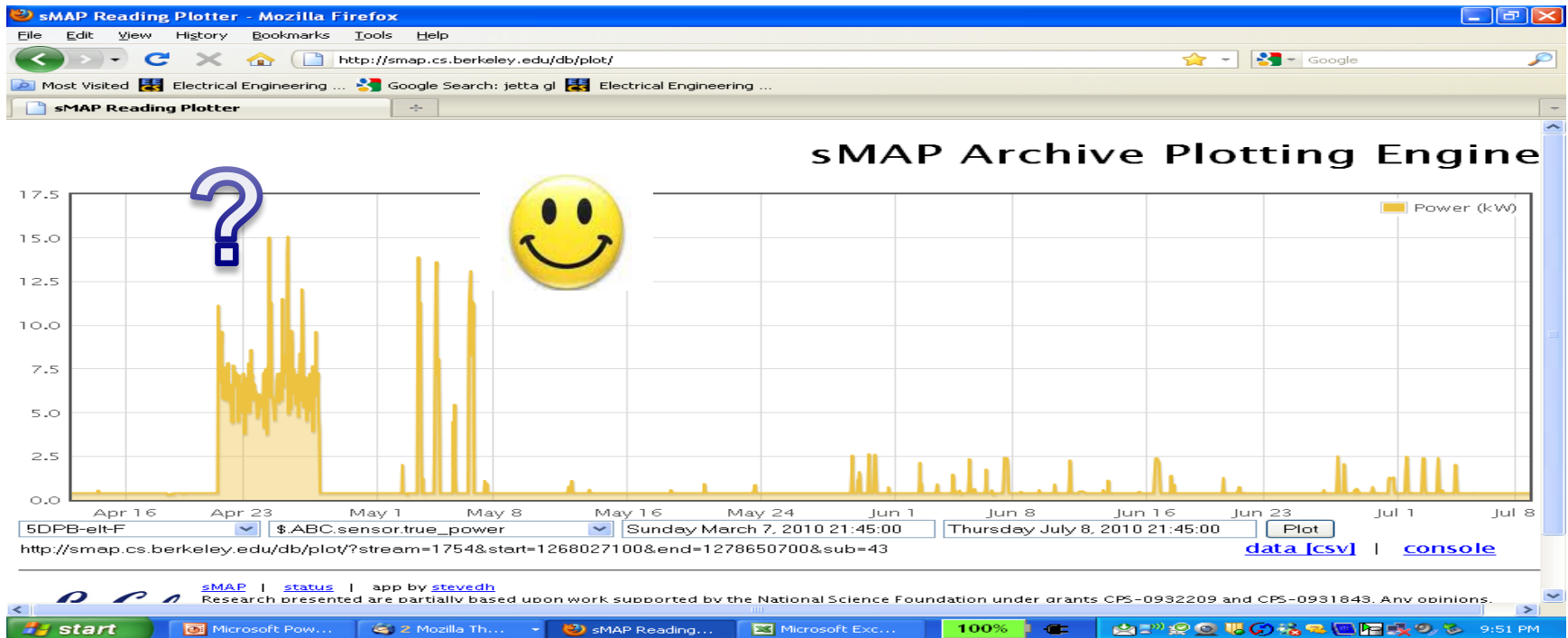
1.344 seconds

# Operational Efficiency and Fine-Grained monitoring

- Pump settings
- Elimination of simultaneous heating and cooling
- ...

# The Data tells the story...

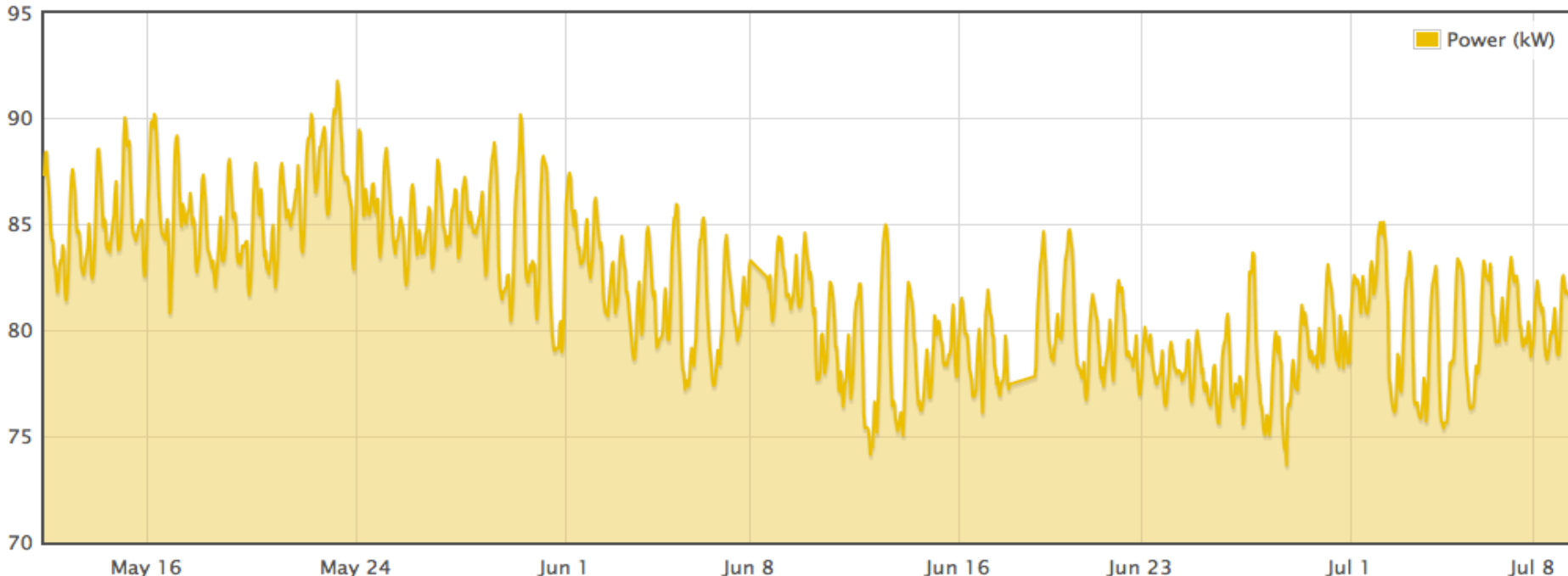
- Monitor Based Commissioning
  - Eliminate simultaneous heat/cool
  - AC91 on schedule



# Micro Lab Tool Move

\* Will continue decline on circuit 4PE a

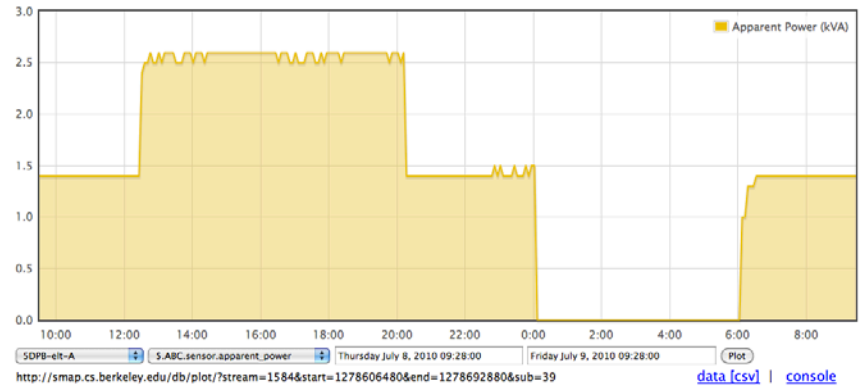
Name	Description	Location
agat	AMST Molecular Vapor Deposition	SR2A
asm1300	ASML 5500/300 DUV Stepper	SR4
cpa	CPA three-target sputter	SR4
creste	Cretec EB/AM Lithography	SR4
mei779	MEI 779 Die Bonder	SR0
edwards	Edwards Sputter System	SR2
edwards3	Edwards 306 E-Beam System	SR2
heatpulse1	Heatpulse rapid thermal annealer for Si	SR2
heatpulse2	Heatpulse rapid thermal annealer for GaAs	SR2
heatpulse3	AG Heatpulse 610	SR6
heatpulse4	AG Heatpulse 610	SR6
hummer	gold evaporator for copper samples	SR4
ionbeam	ion Beam Deposition System	SR4
kyocera	Kyocera ion mill	SR2
kyocera	Kyocera Contact Angle Analyzer	SR2A
lam6	Lam 4500 oxide etcher	SR4
lam7	Lam Research Etcher	SR4
lsc	Leica Scanning Electron Microscope	SR4
leicadith	Leicadith & Feature Measuring System	SR0
microscopes	Optical microscopes	SR0/4/6
msink16	General purpose fume hood/wet process	SR2A
msink18	General purpose fume hood/wet process	SR2A
msink6	furnace pre-clean	SR4
msink8	post PR cleaning	SR4
notosop	Notosop/DUV Microsputter/atomometer	SR0
notosop2	Notosop/DUV Microsputter/atomometer	SR2
ntc	NRC evaporator	SR2
patco206	Specialty Coating Systems PDS2010	SR2A
radex	Radex sputtering system	SR2
scs	Surface Charge Analyzer	SR6
sopta	Sopta Variable Angle/Frequency Ellips	SR0
spinner	Headway Spinner -msink1	SR2
rdmsink6	Spinco Spin Rinse Dryer 880-S	SR6
rdmsink8	Spinco Spin Rinse Dryer	SR6
telephones	lab, office phone sets and Room 158 PBX	SR0
temaatometer	Sigma 701 Temaatometer	SR2A
tema	Toxic Gas Monitoring System	SR9
tystar1	Tystar 6" Wet/Dry Oxidation	SR6
tystar10	Tystar LPCVD Doped Poly	SR6
tystar11	Tystar LPCVD Doped LTO	SR6
tystar12	Tystar Doped LTO	SR6
tystar13	Tystar 6" POC1.3	SR6
tystar14	Tystar 6" Solid Source Boron	SR6
tystar15	Tystar 6" LPCVD Silicon Carbide	SR6
tystar16	Tystar 6" Doped Poly LPCVD	SR6
tystar17	Tystar LPCVD Low Stress Nitride	SR6
tystar18	Tystar 6" MOS Sinter	SR6
tystar19	Tystar LPCVD SiGe, MOS	SR6
tystar2	Tystar 6" Wet/Dry Oxidation	SR6
tystar20	Tystar SiGe LPCVD for MEMS	SR6
tystar3	Tystar 6" Wet/Dry Oxidation	SR6
tystar4	Tystar 6" Wet/Dry Oxidation	SR6
tystar9	Tystar LPCVD Nitride/ITO	SR6
ubek	E-Beam evaporator, 3-bearth	SR2
v401	Kyocera 401 vacuum system	SR2
xyonzen	YVES (Yield Eng. Systems) 450PHS-29	SR2A
xyonbond	West Bond 7400B	SR0
westbond2	West Bond 7400B Wedge Bonder	SR0
xyon	Block Optical Metrology	SR0
xyon	X-Ray Diffractometer	SR0





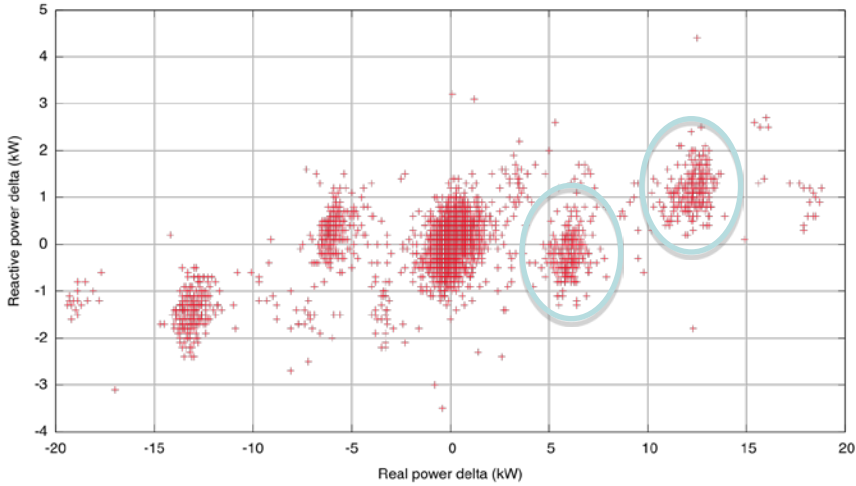
# MBCx

## AC 90 Scheduling HVAC on/off.

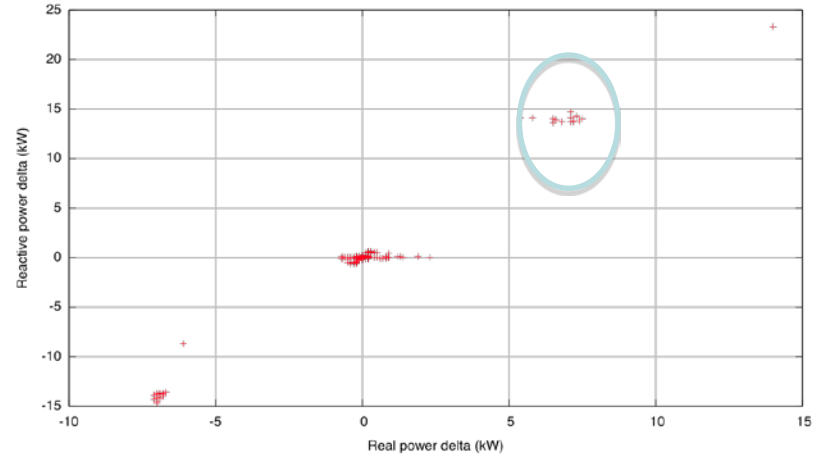


# Extracting Deeper

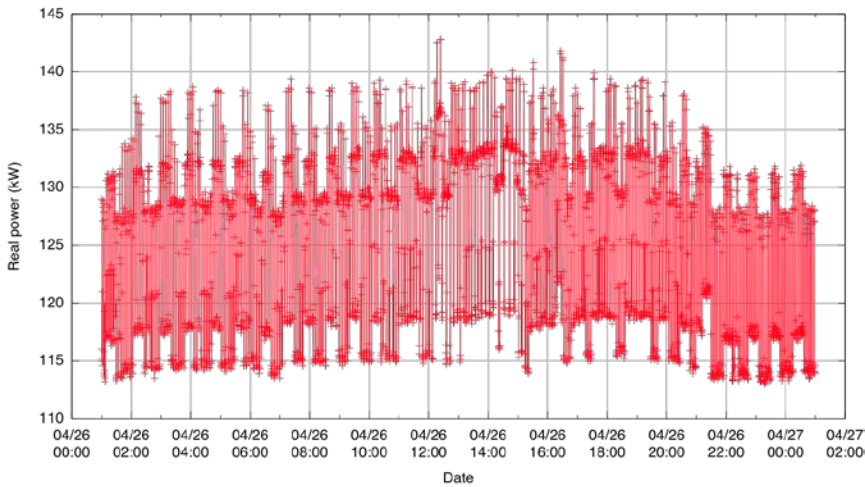
MCL-elt-A -- 26-April



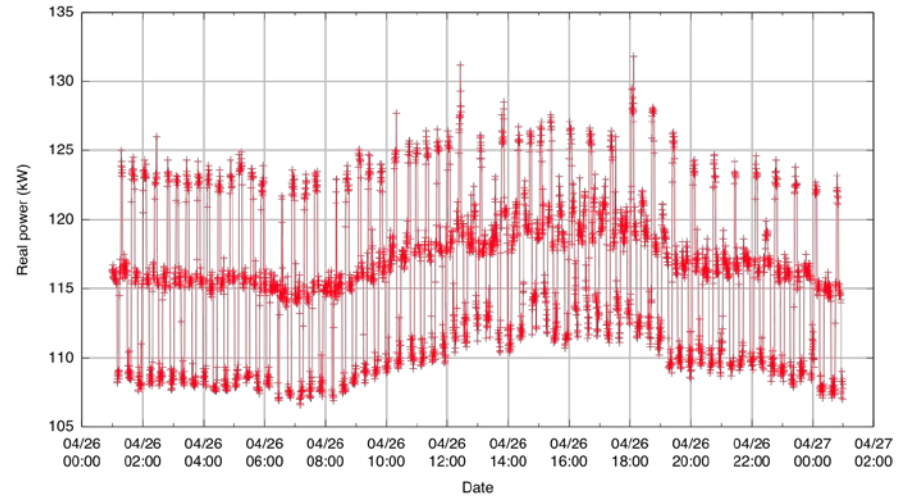
5PA-elt-A -- 26-April



MCL-elt-A -- 26-April



358-elt-A -- 26-April



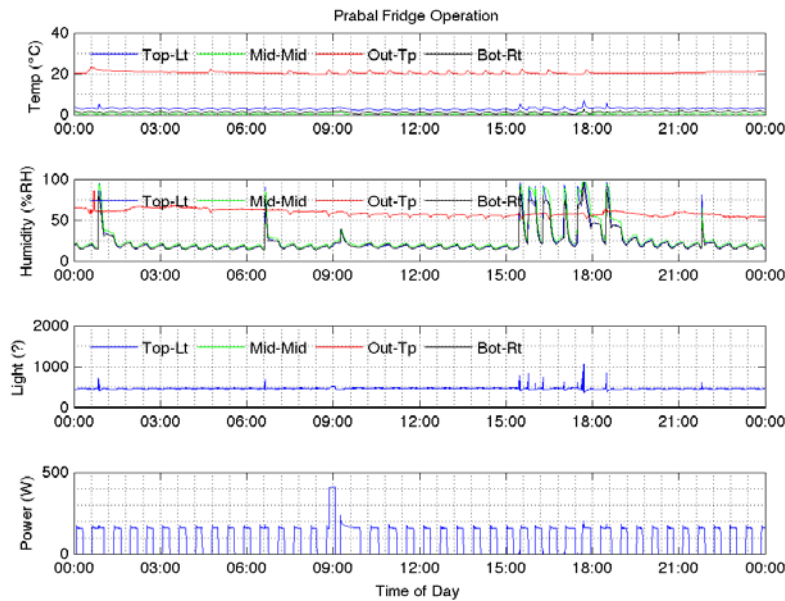
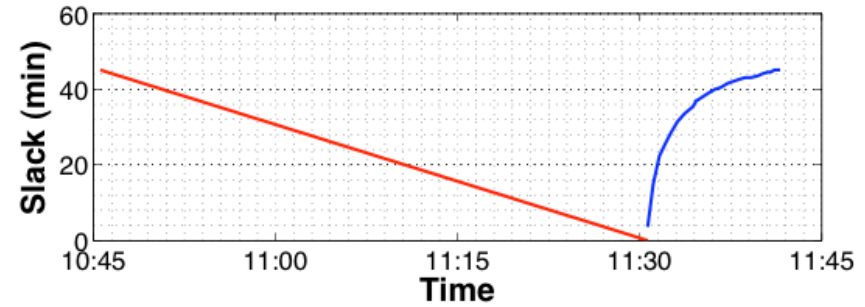
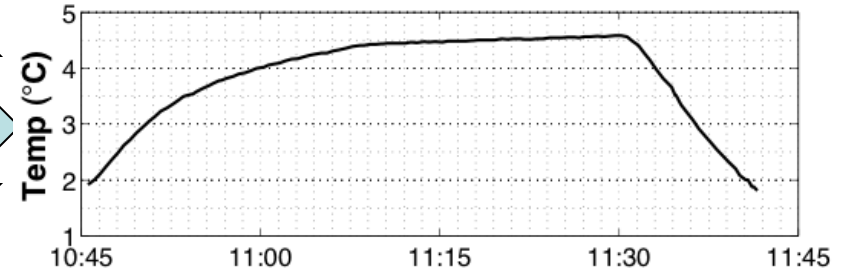
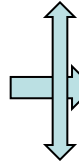
# Energy “Slack”

## Thermostatically Controlled Load

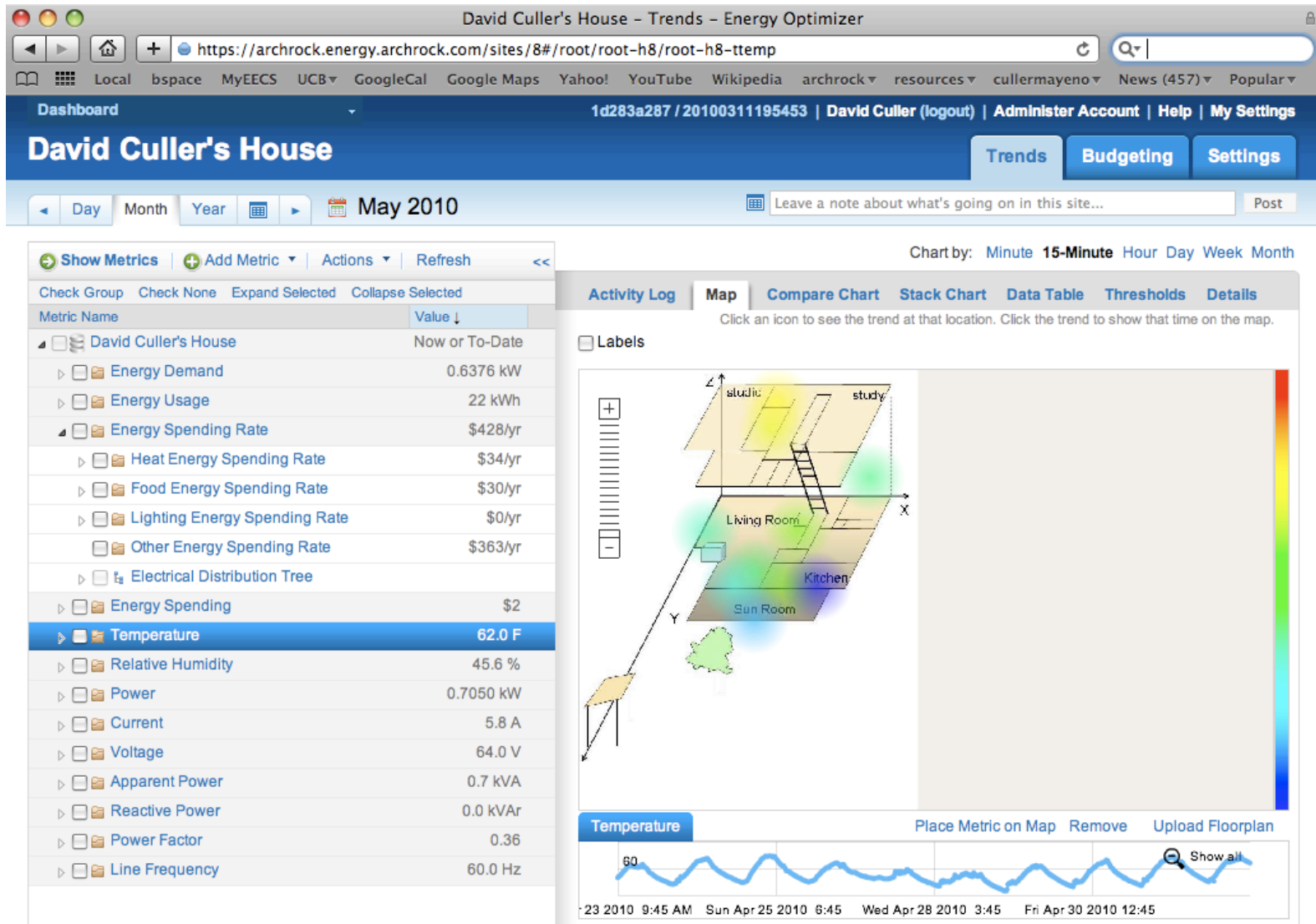


IPS

Set Point

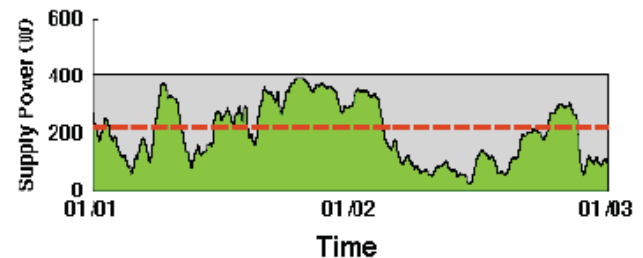
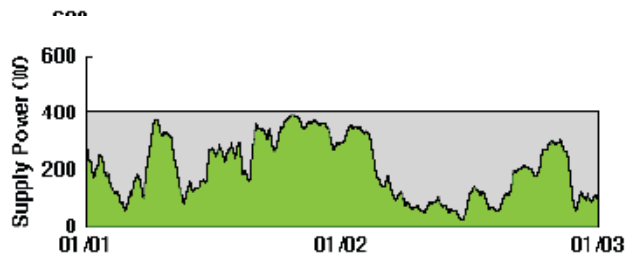
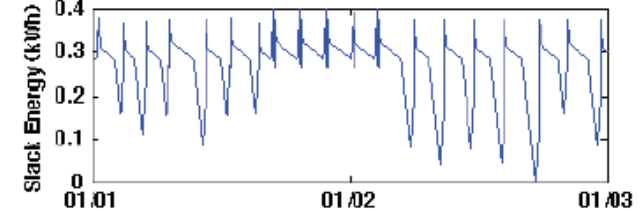
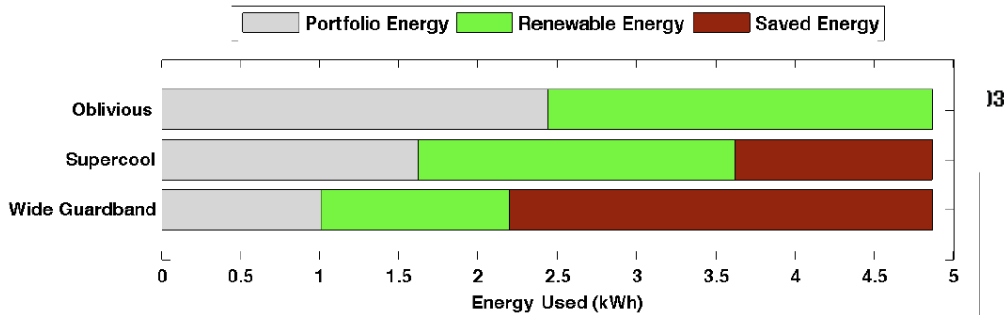
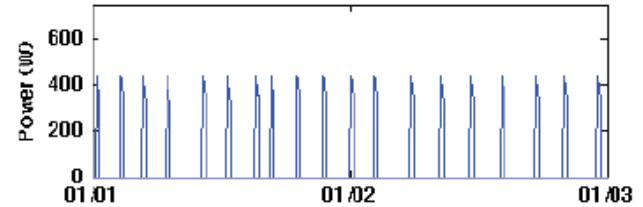
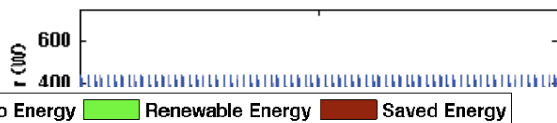
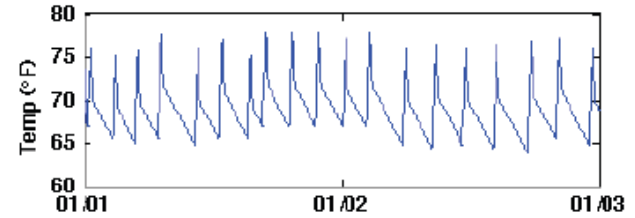
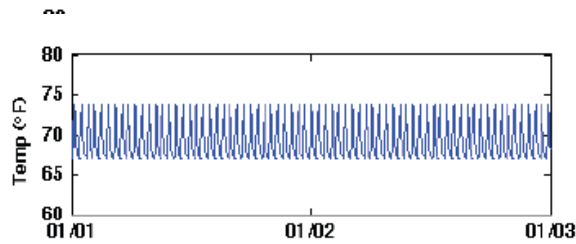
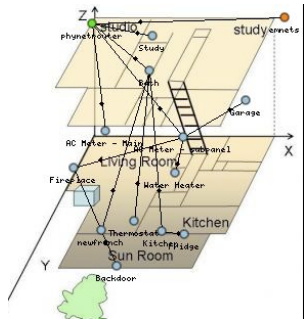


# An Aware House



Last updated: May 2, 2010 9:55:05 PM.

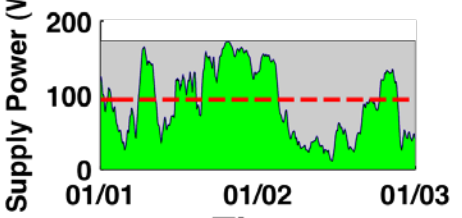
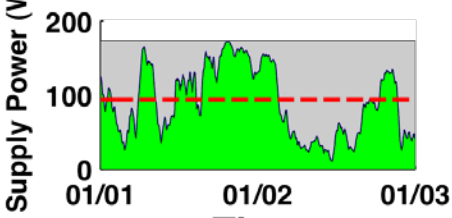
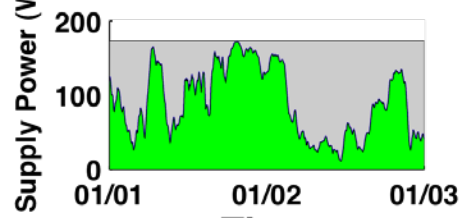
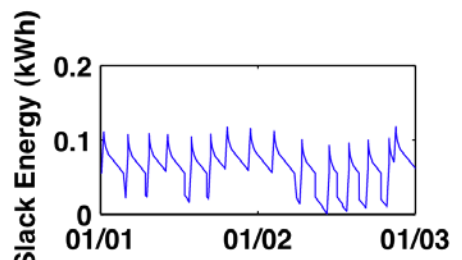
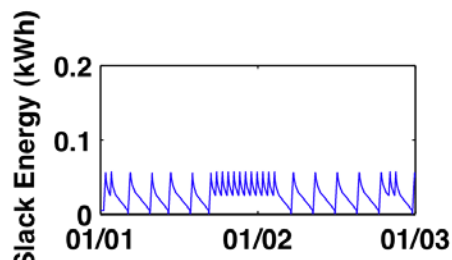
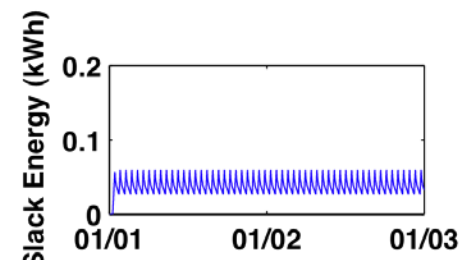
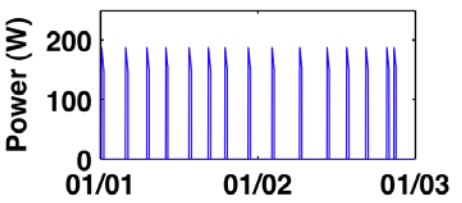
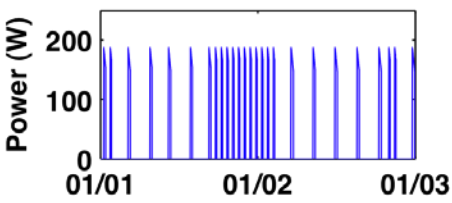
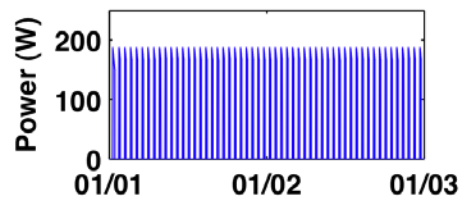
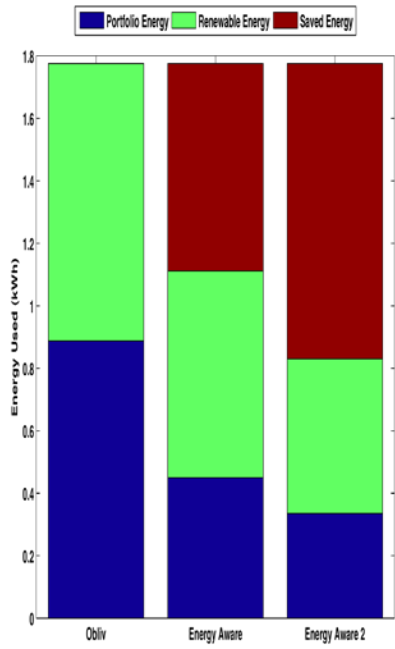
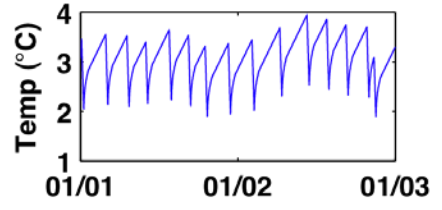
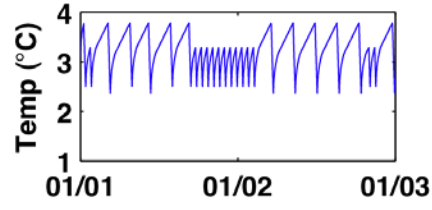
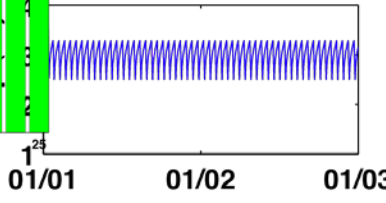
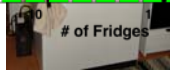
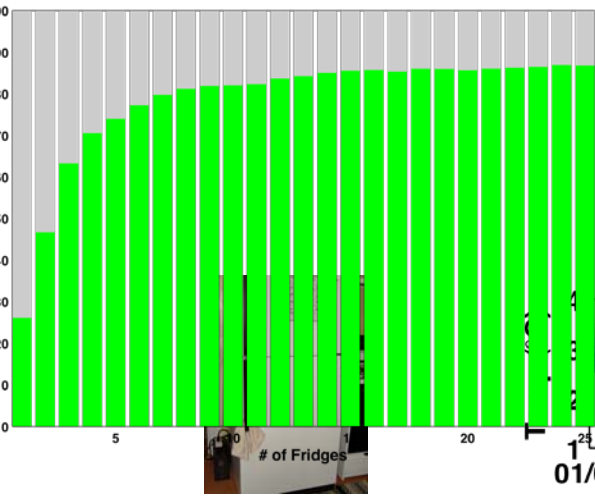
# Supply-Following Loads



Oblivious

Energy-aware - Wide Guardband

# Supply-Following Loads

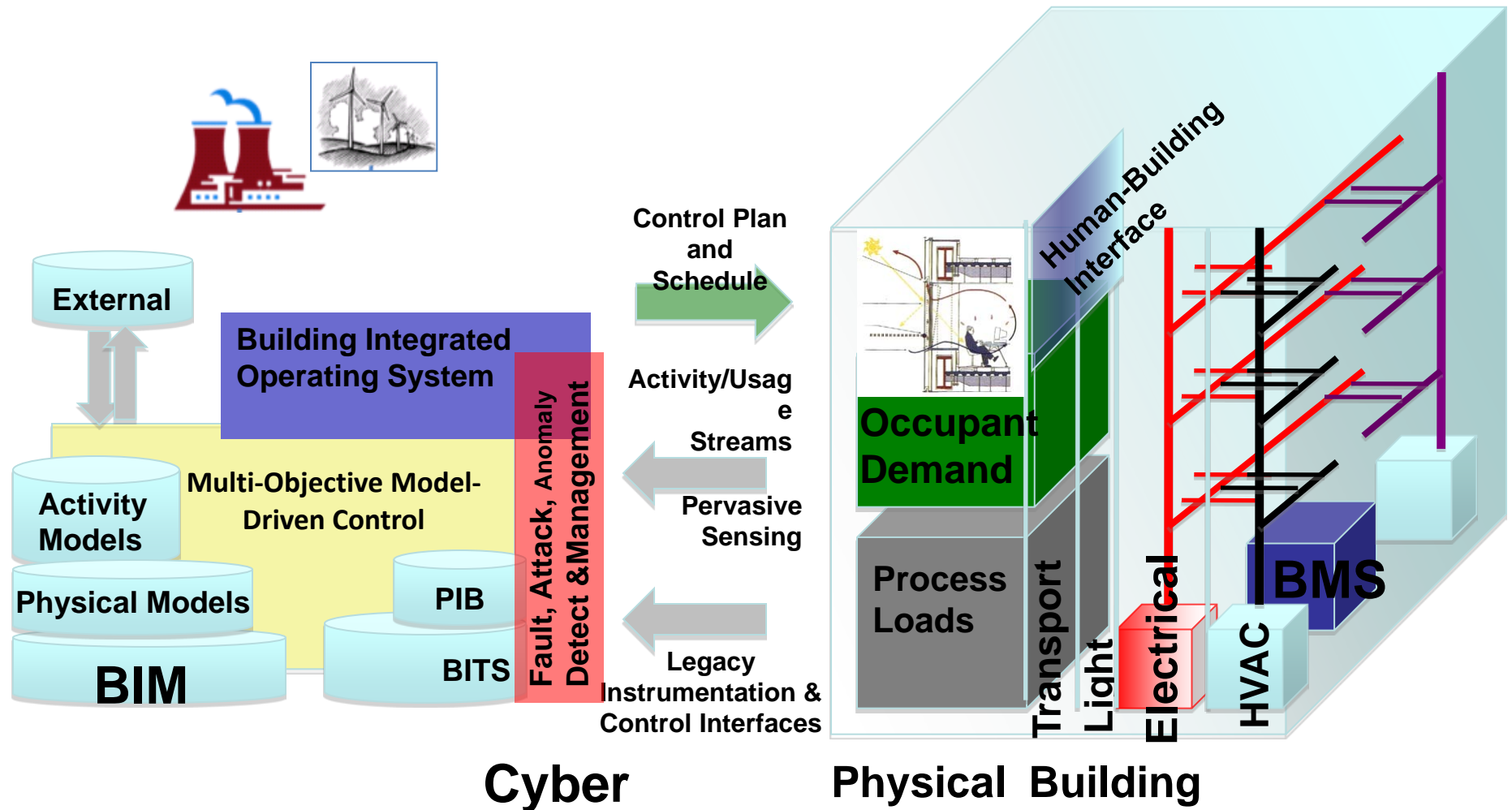


**Oblivious**

**Energy-aware**

**Energy-aware 2**

# Towards Cyber / Physical Building



# Demos

- Time series

- <http://smap.cs.berkeley.edu/db/plot/?stream=249&start=1270702260&end=1278651060&sub=5>

- Time-series-difference scatter plot

- <http://smap.cs.berkeley.edu/db/plot/vs.html>

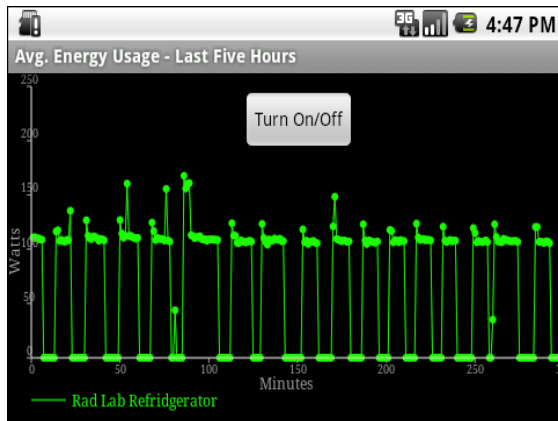
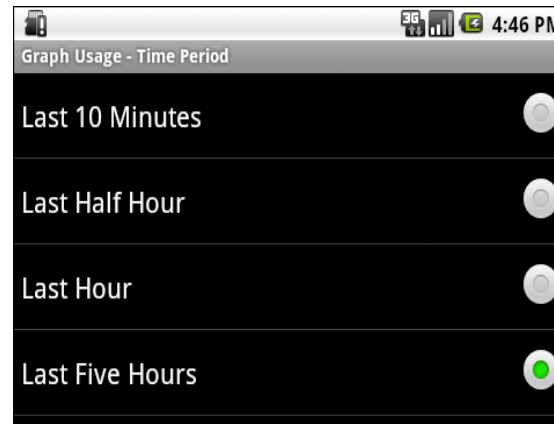
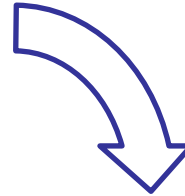
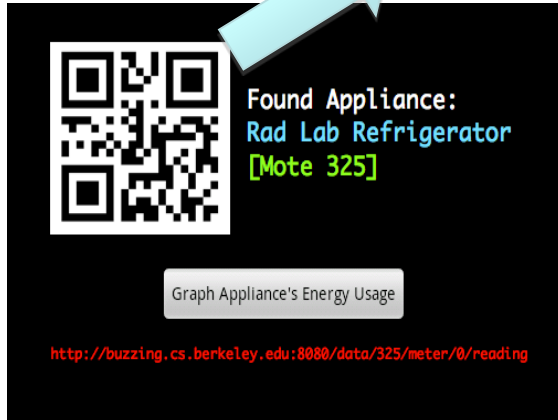
- Aggregates

- <http://smap.cs.berkeley.edu/db/plot/agg.html>



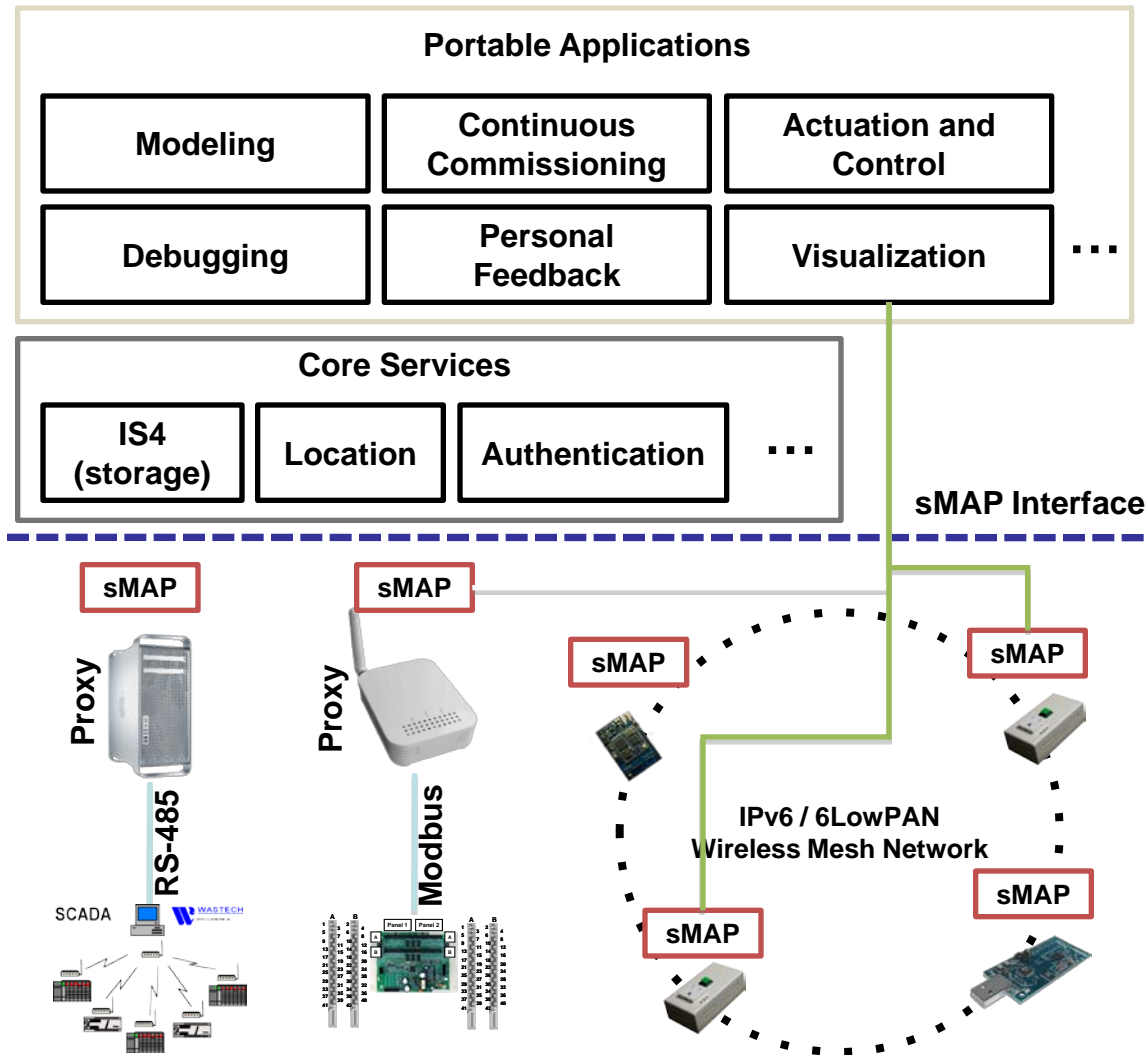
# Phone App

<http://local.cs.berkeley.edu:8011/data/325/>



[http://local.cs.berkeley.edu:8011/data/325/sensor/real\\_power/profile](http://local.cs.berkeley.edu:8011/data/325/sensor/real_power/profile)

# Basis for Grid-Responsive Bldgs



# Building Scale Monitoring Architecture

