Results from the Cory Hall Building-to-Grid (B2G) Testbed

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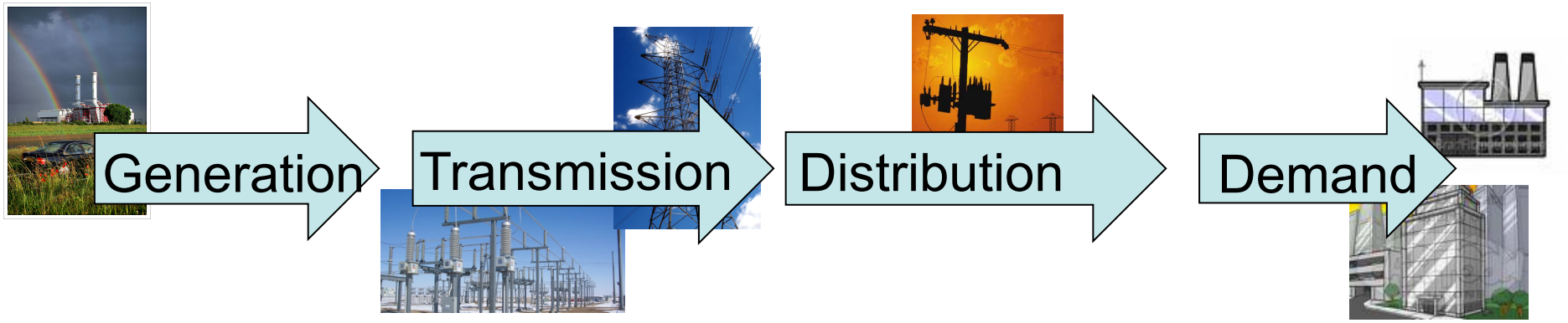
University of California, Berkeley

Sept 24, 2010

"Energy permits things to exist; information, to behave purposefully."
W. Ware, 1997

The Industrial Age Grid

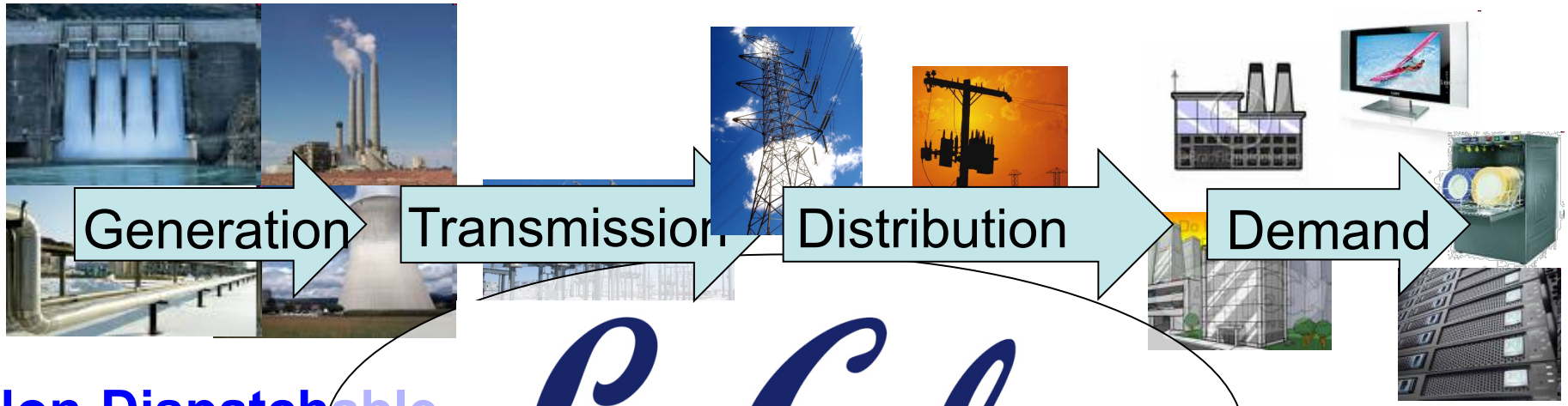
Baseline + Dispatchable Tiers **Nearly Oblivious Loads**



Imagine an Energy "Aware" Infrastructure

Baseline + Dispatchable Tiers

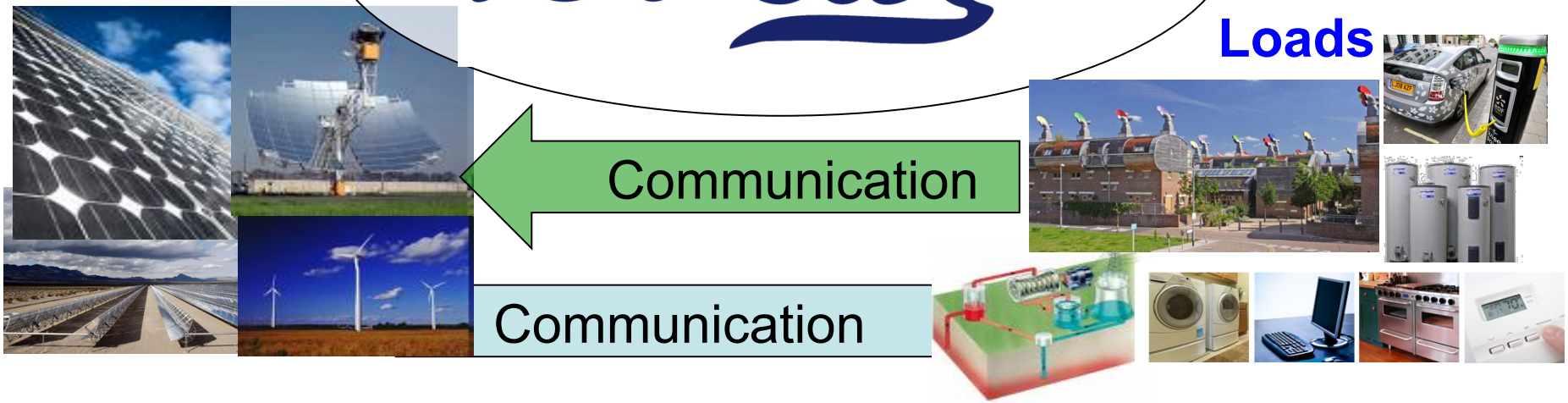
Oblivious Loads



LoCal

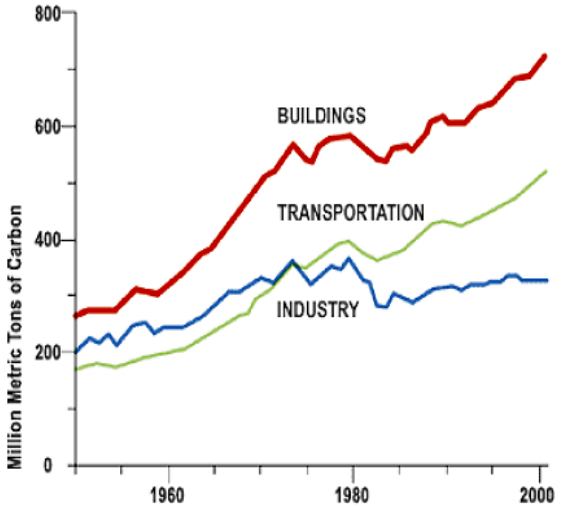
Non-Dispatchable Sources

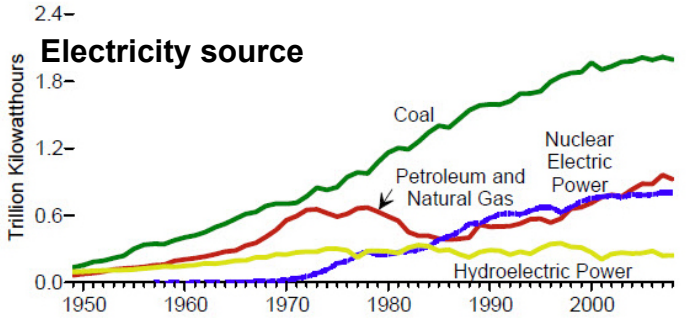
Aware Interactive Loads

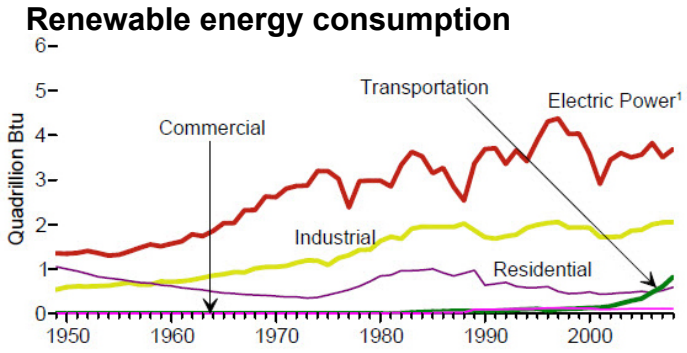


Where to Start?

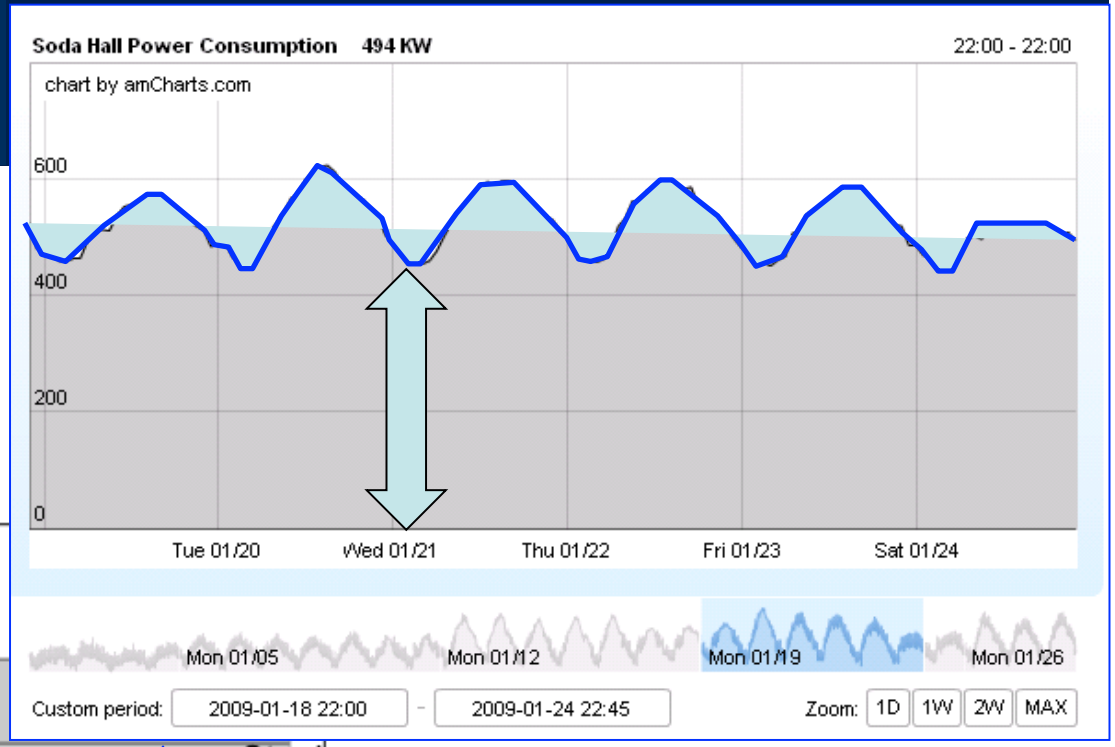
- Buildings
  - 72% of electrical consumption (US),
  - 40-50% of total consumption,
  - 42% of GHG footprint
  - US commercial building consumption doubled 1980-2000, 1.5x more by 2025 [NREL]
- Where Coal is used
- Prime target of opportunity for renewable supplies

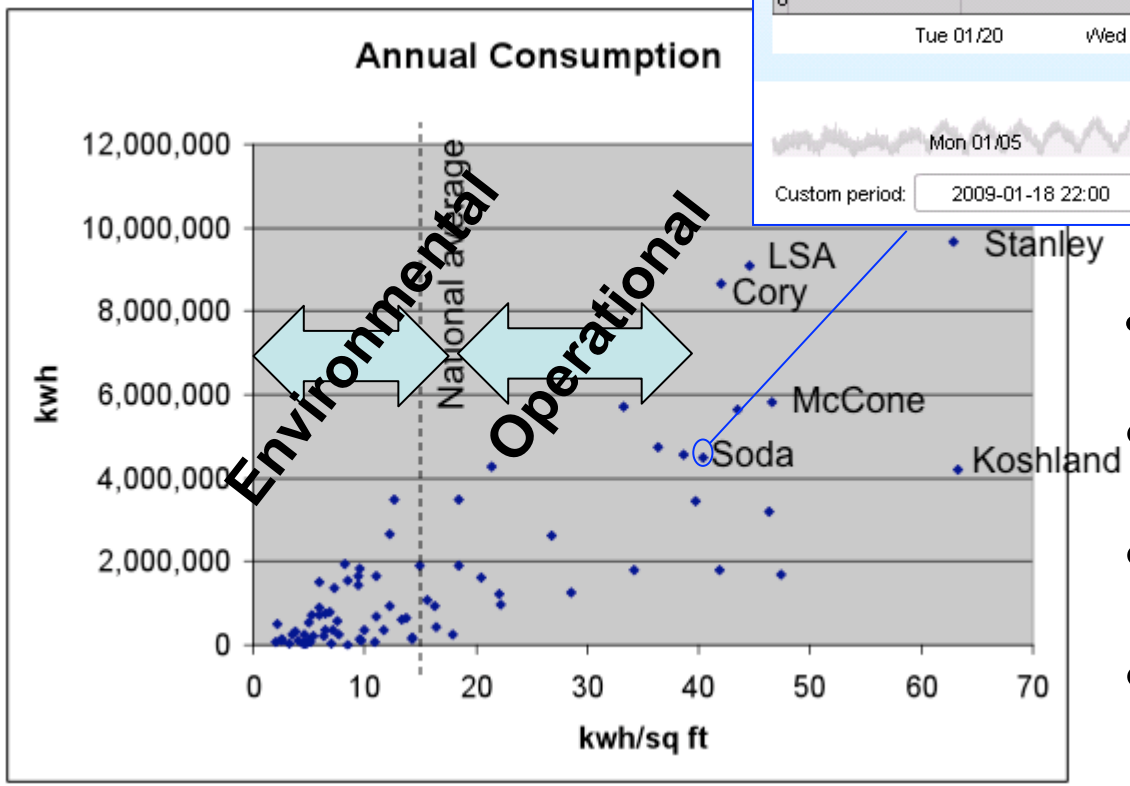






Our Buildings

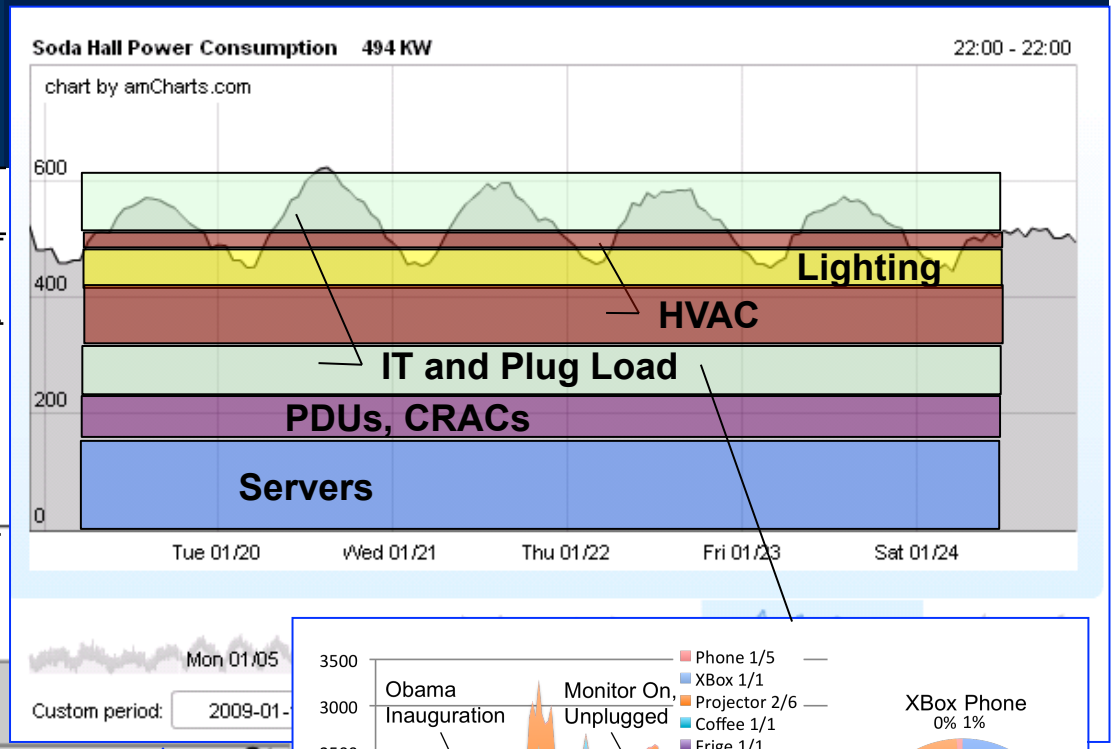


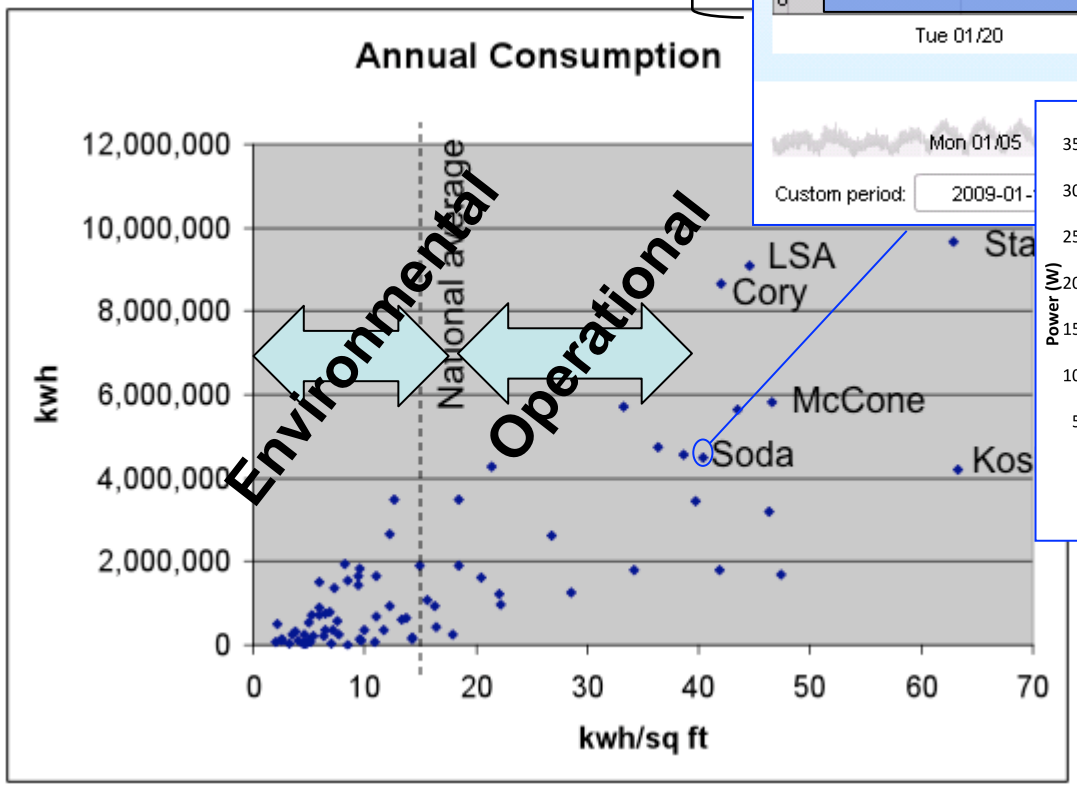


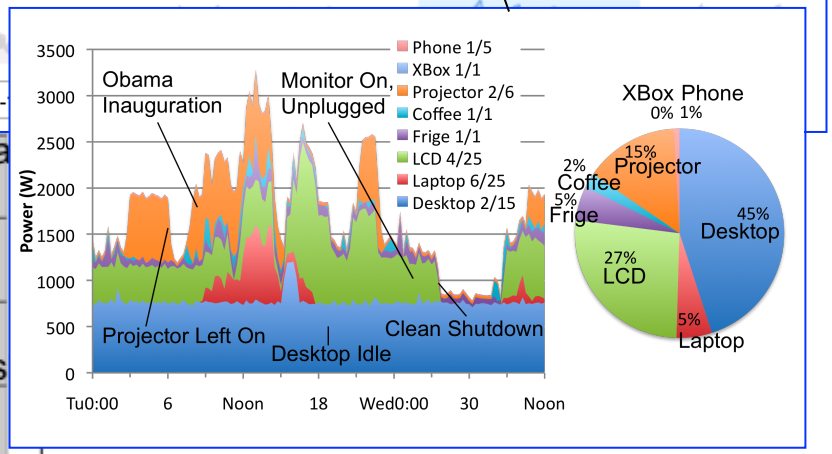
- <20 % Power Prop.
- Wasteful
- Predictable
- Sculptable ?

Our Buildings

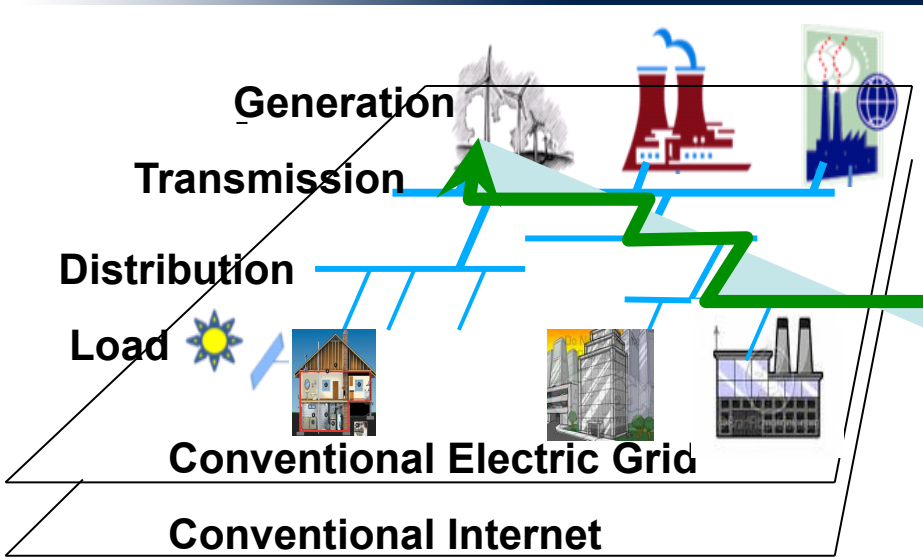
Use **Design**

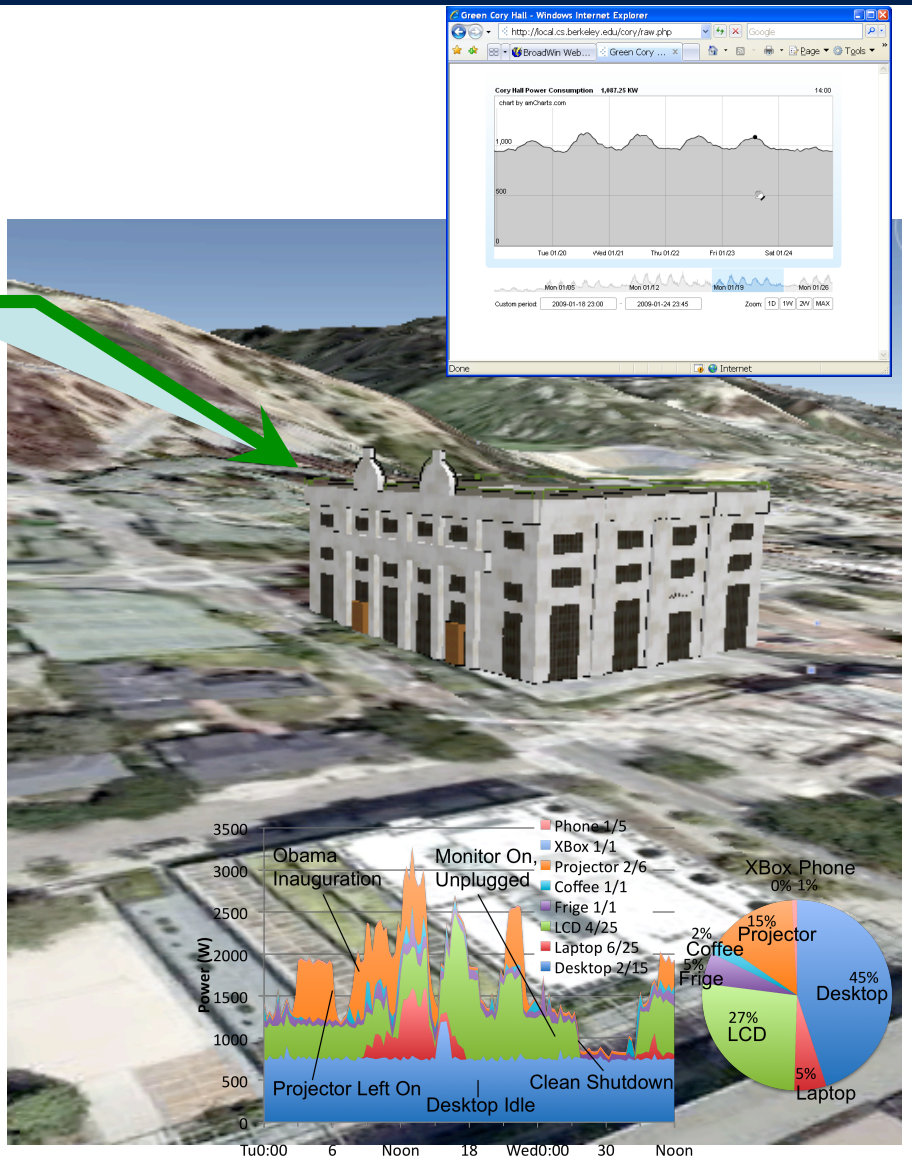






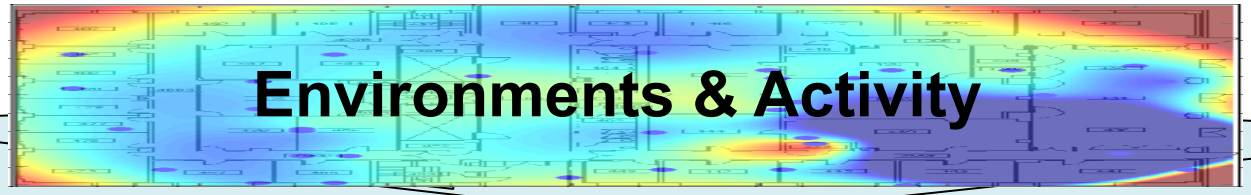
Cory B2G Testbed





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

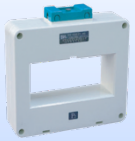
Building-Scale Monitoring Architecture
The 3 Views



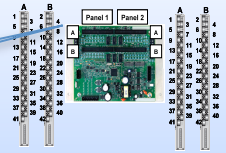
Environments & Activity

Climate Plant

Load Tree



CT: mains power monitoring



panel level power monitoring

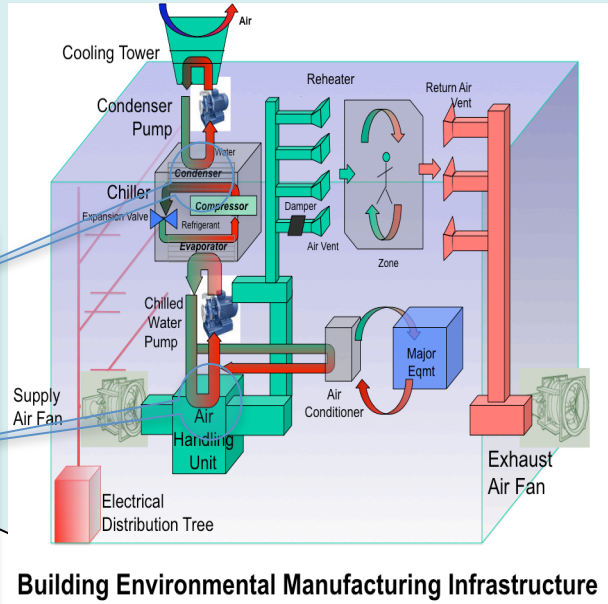
ACme: plug load energy monitor and controller

Vibration

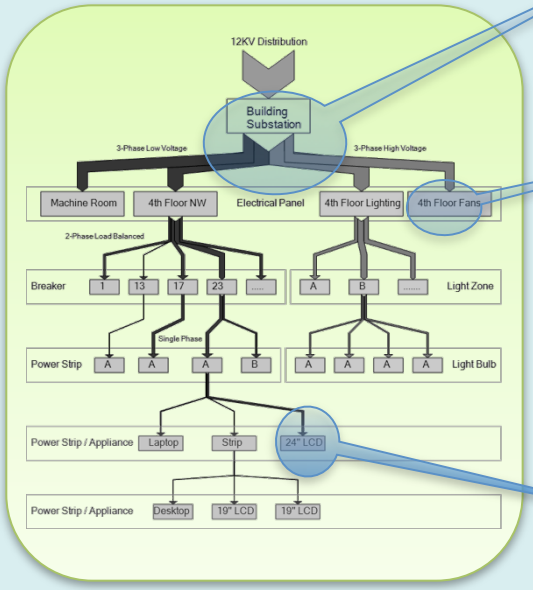
Humidity

Temperature

Pressure



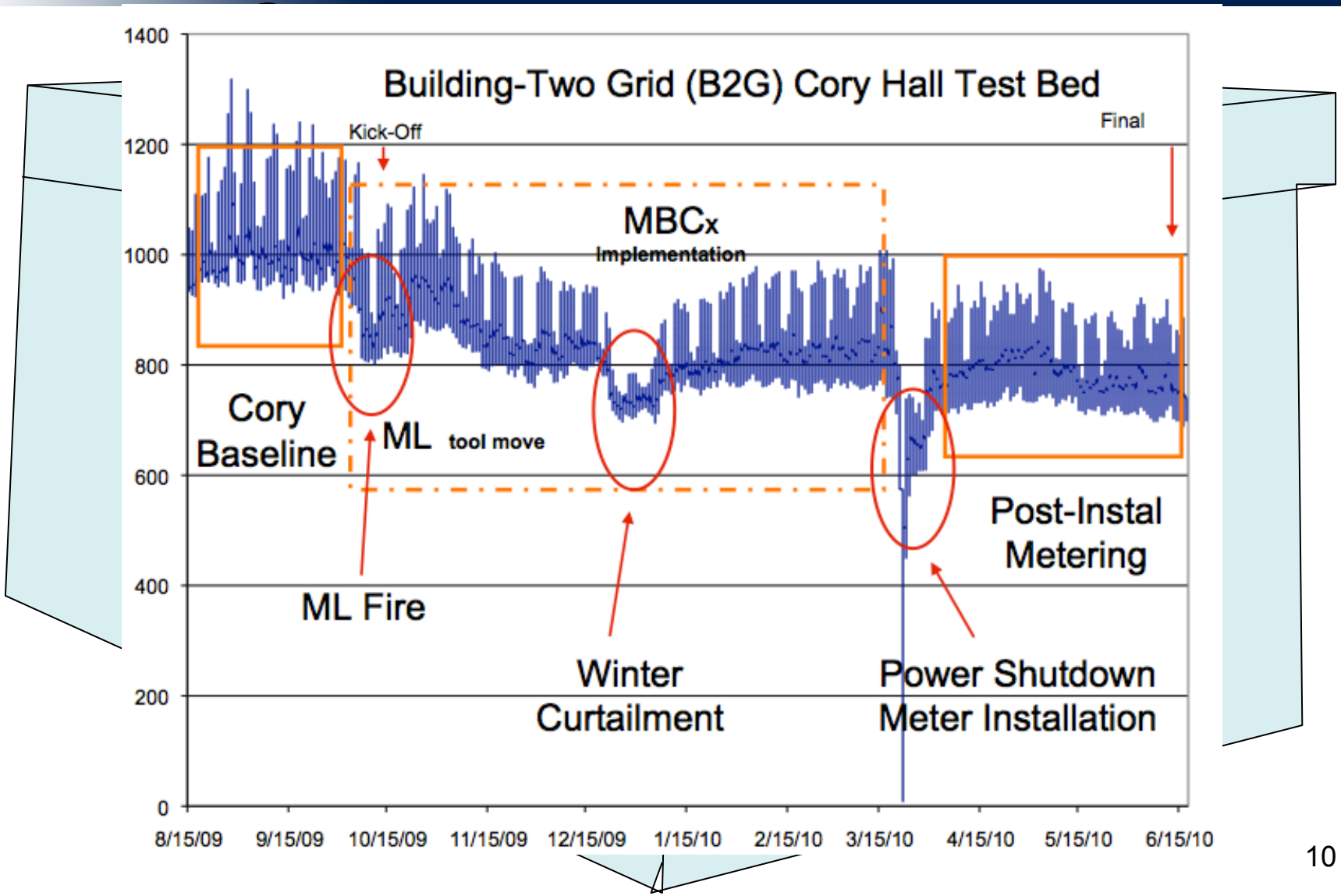
Building Environmental Manufacturing Infrastructure



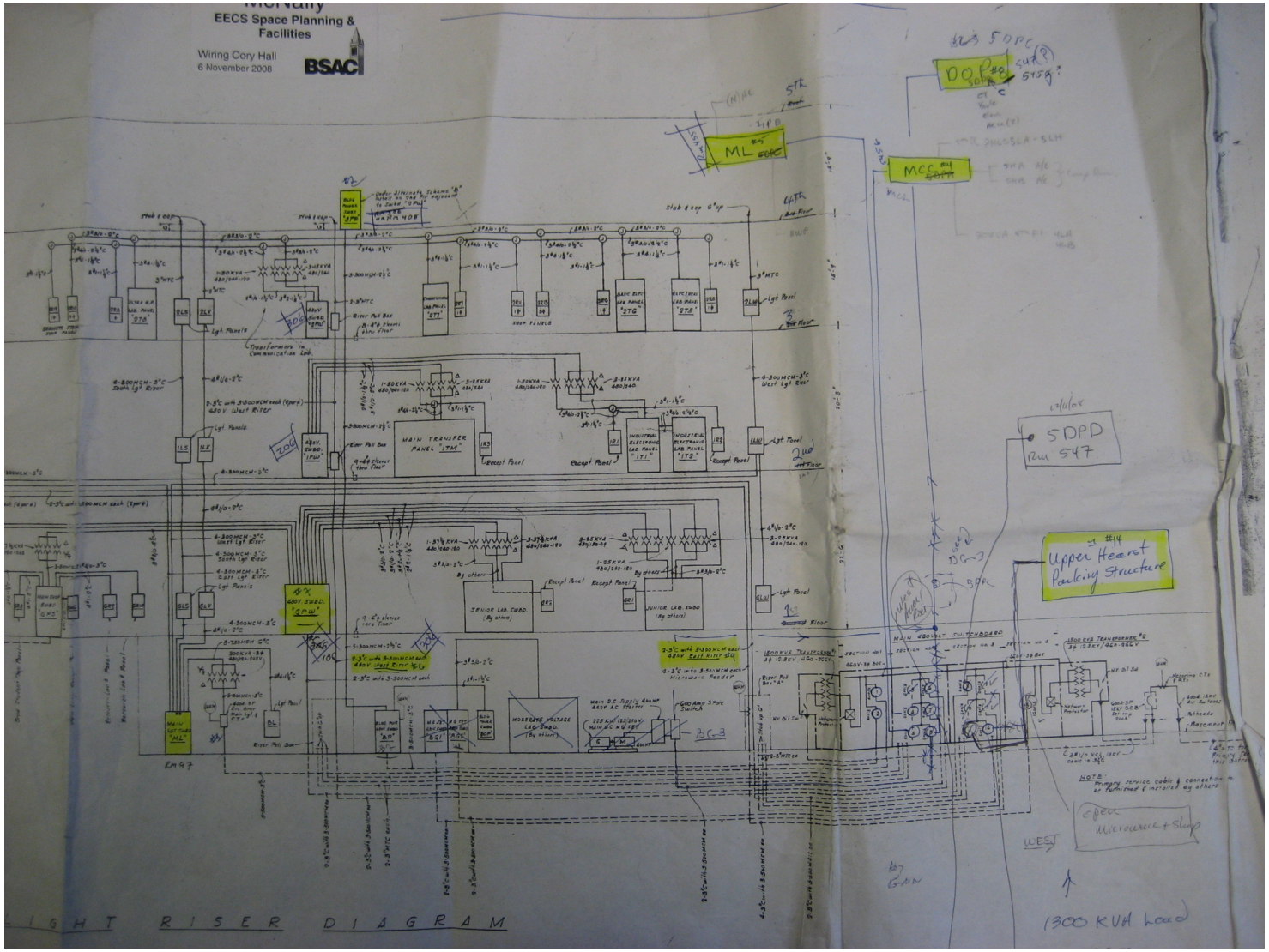
Audit Methodology

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

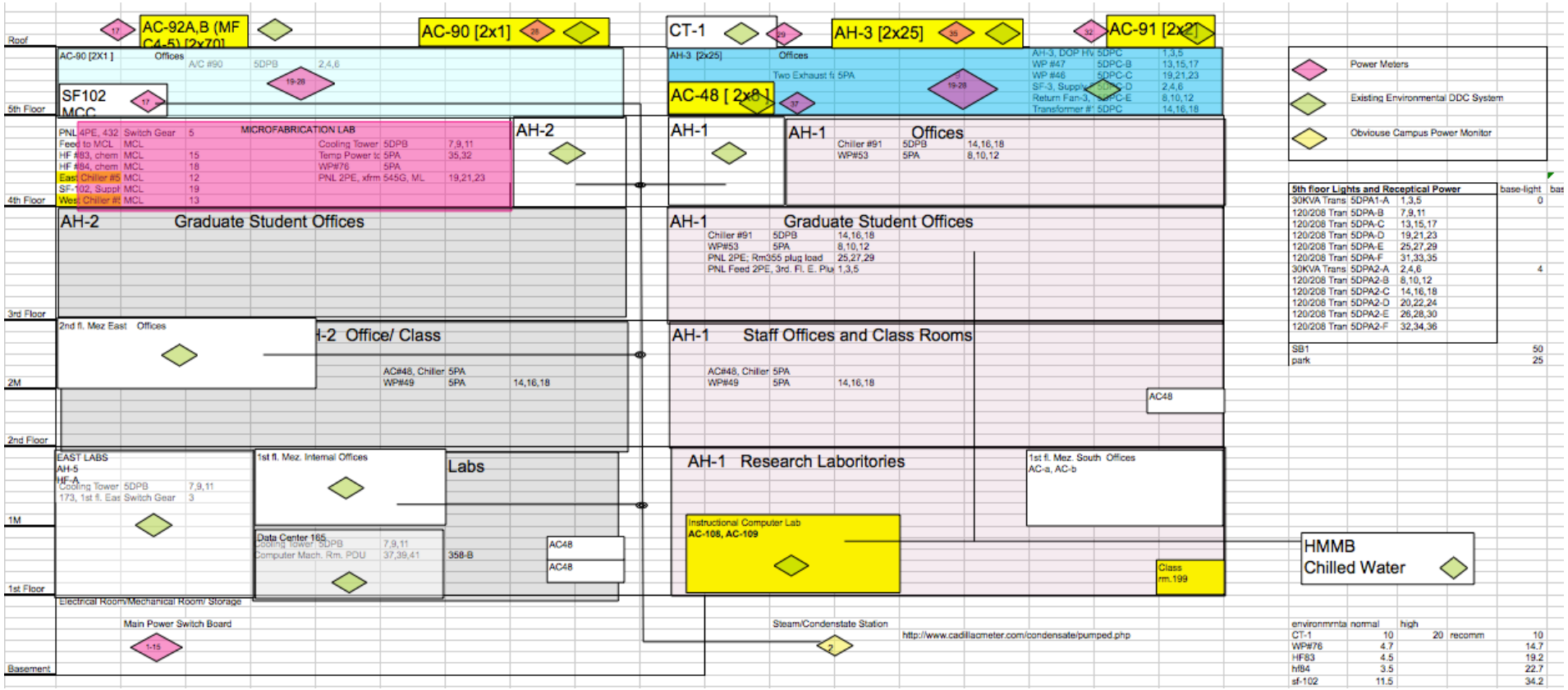
The Total Bldg Envelope



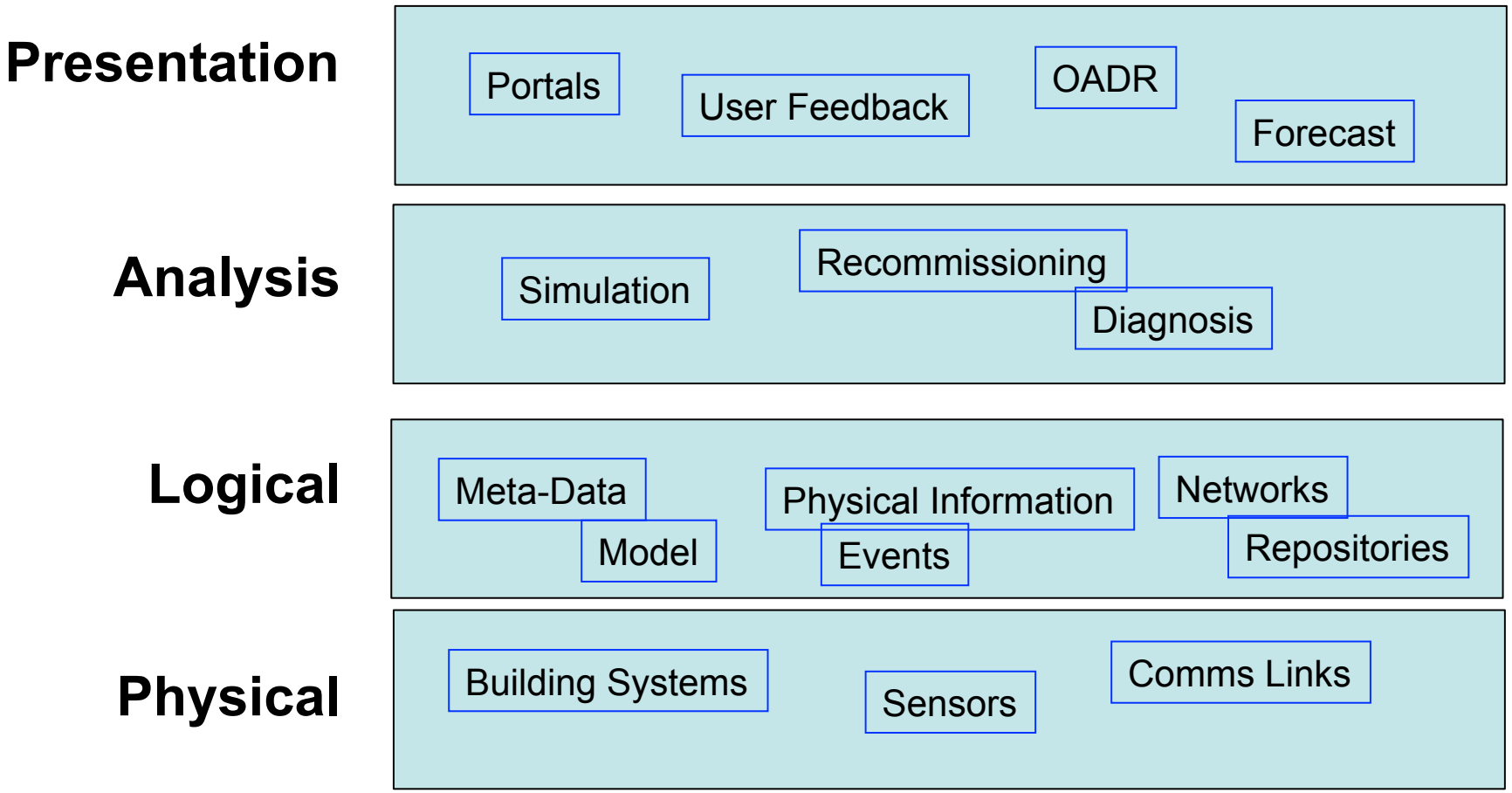
State of the Art …



Buildings within a Building



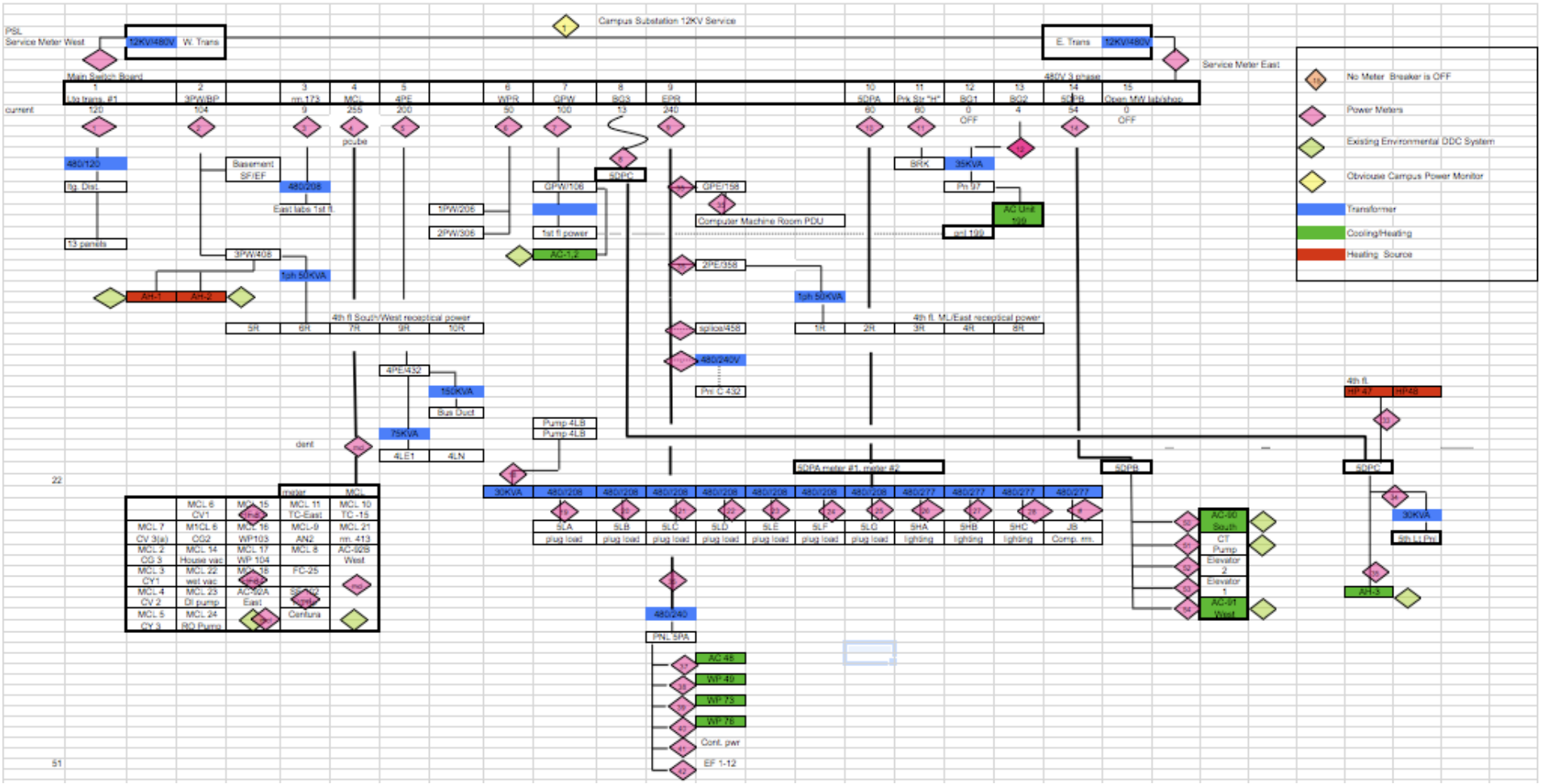
Layered Architecture



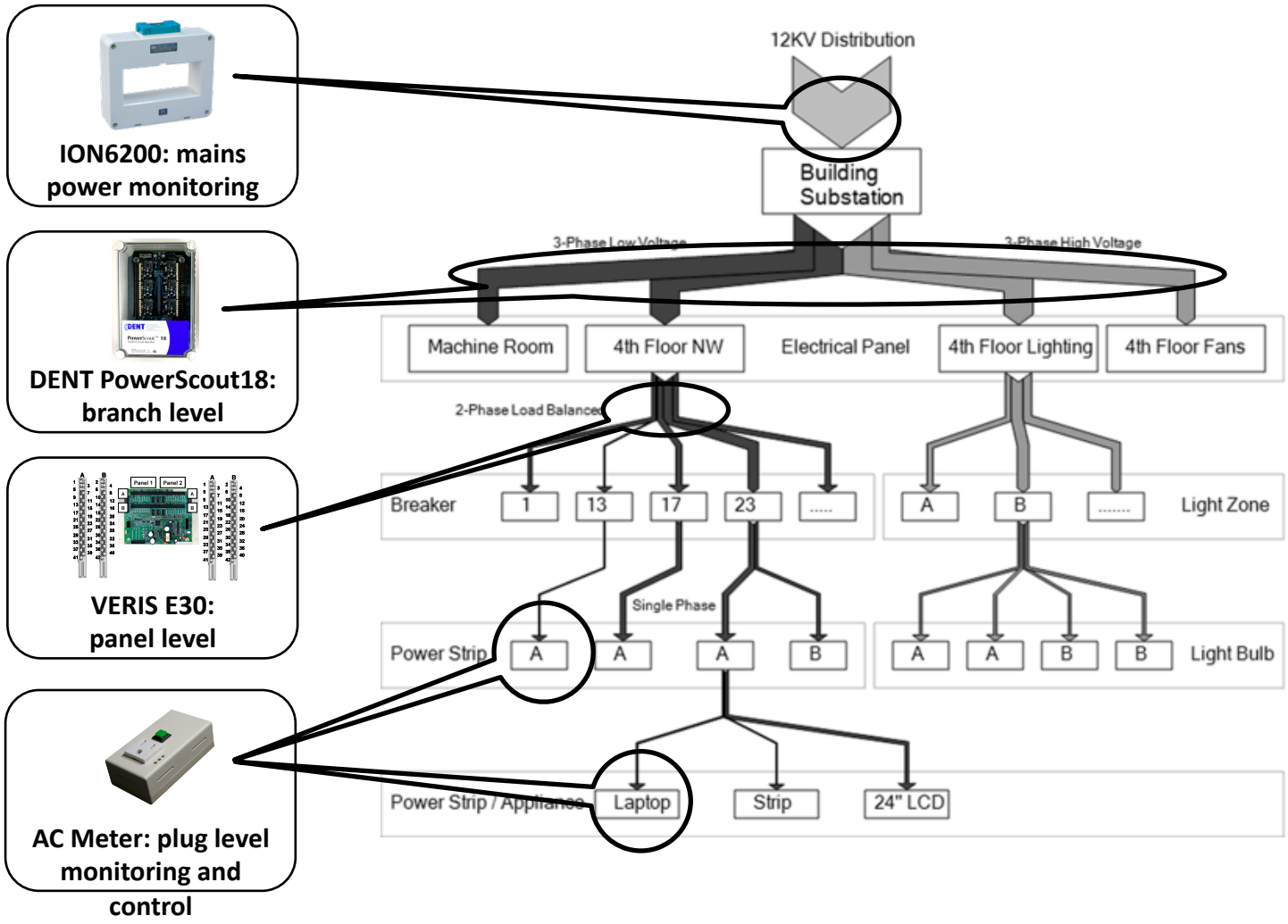
Physical Tier

- 12 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*

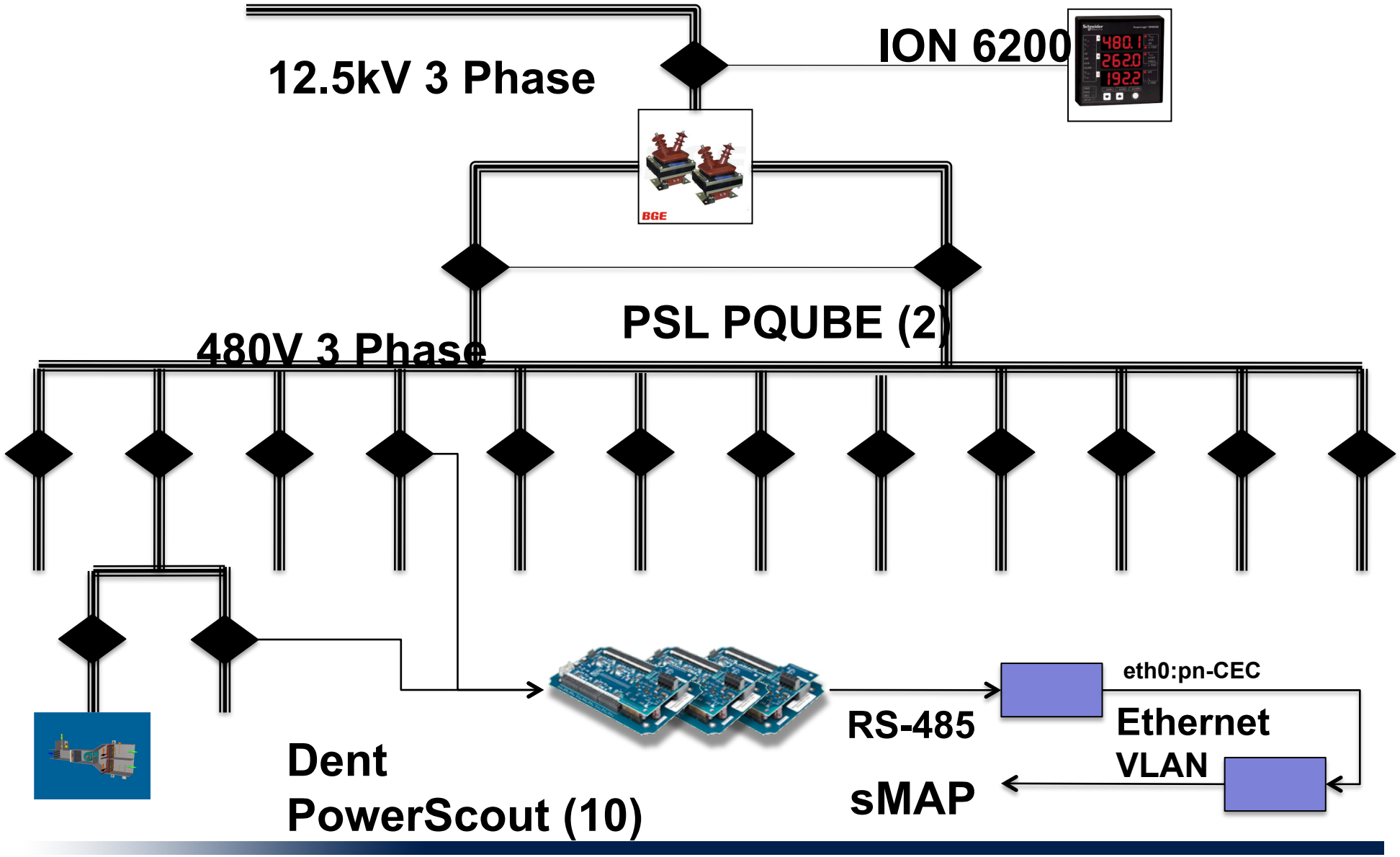
Power Flows


Campus Substation 12KV Service
W. Trans
E. Trans
Service Meter East
Main Switch Board
No Meter Breaker is OFF
Power Meters
Existing Environmental DDC System
Obvious Campus Power Monitor
Transformer
Cooling/Heating
Heating Source
Computer Machine Room PDU
4th fl South/West receptical power
4th fl. ML/East receptical power
SDPA meter #1, meter #2
SDPB
SDPC
AC-60 South
CT Pump
Elevator 2
Elevator 1
AC-61 West
AC-45
WP 40
WP 75
WP 76
Cont. pwr
EF 1-12

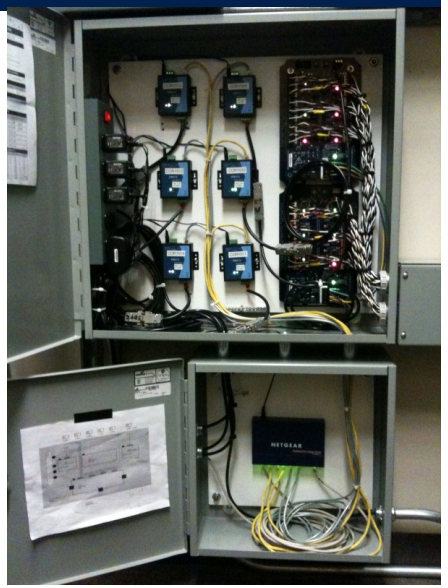
Electric Tree Monitoring



Main Switch Block



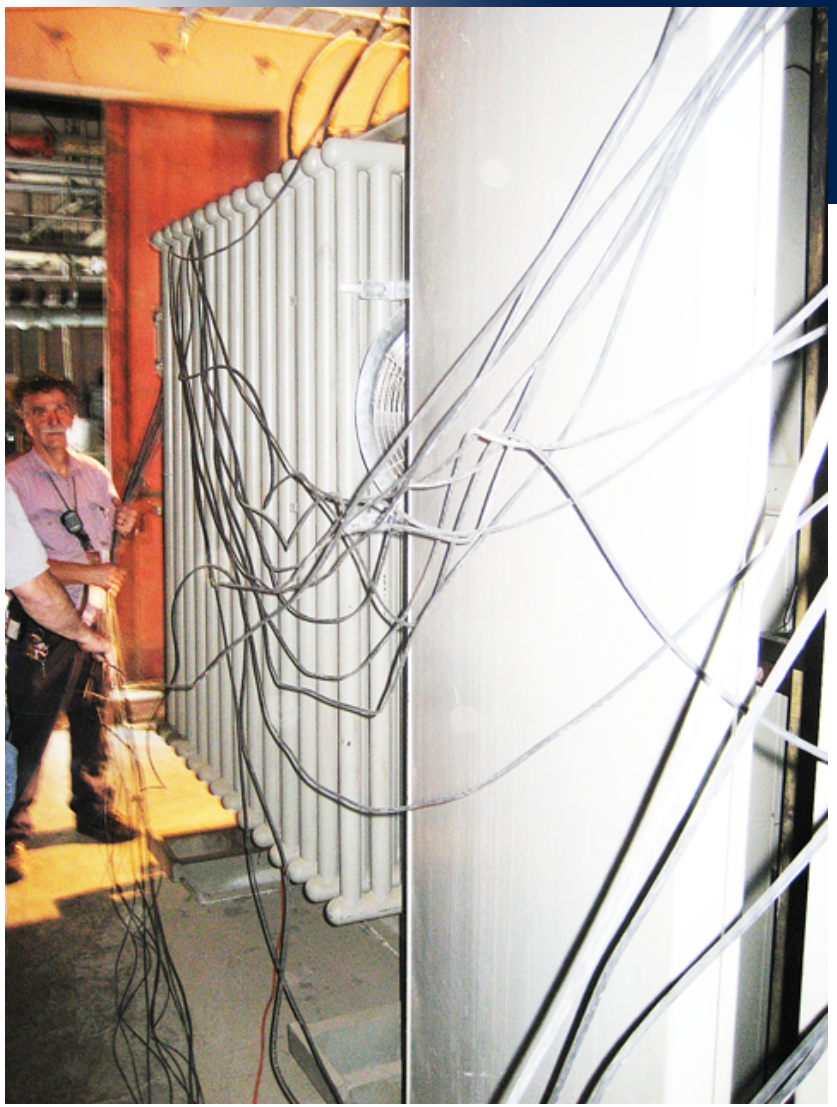
Dent Powerscout 18

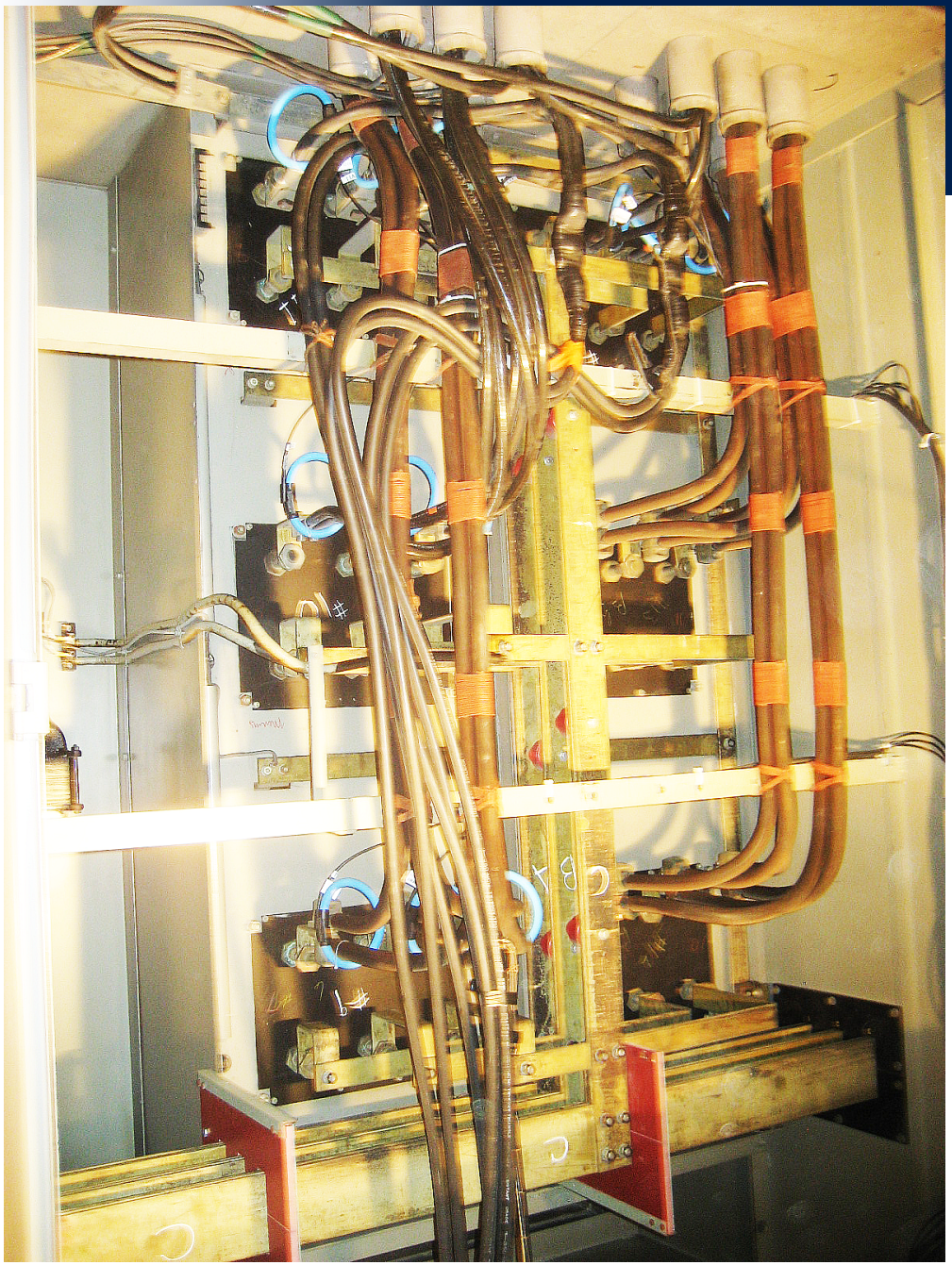


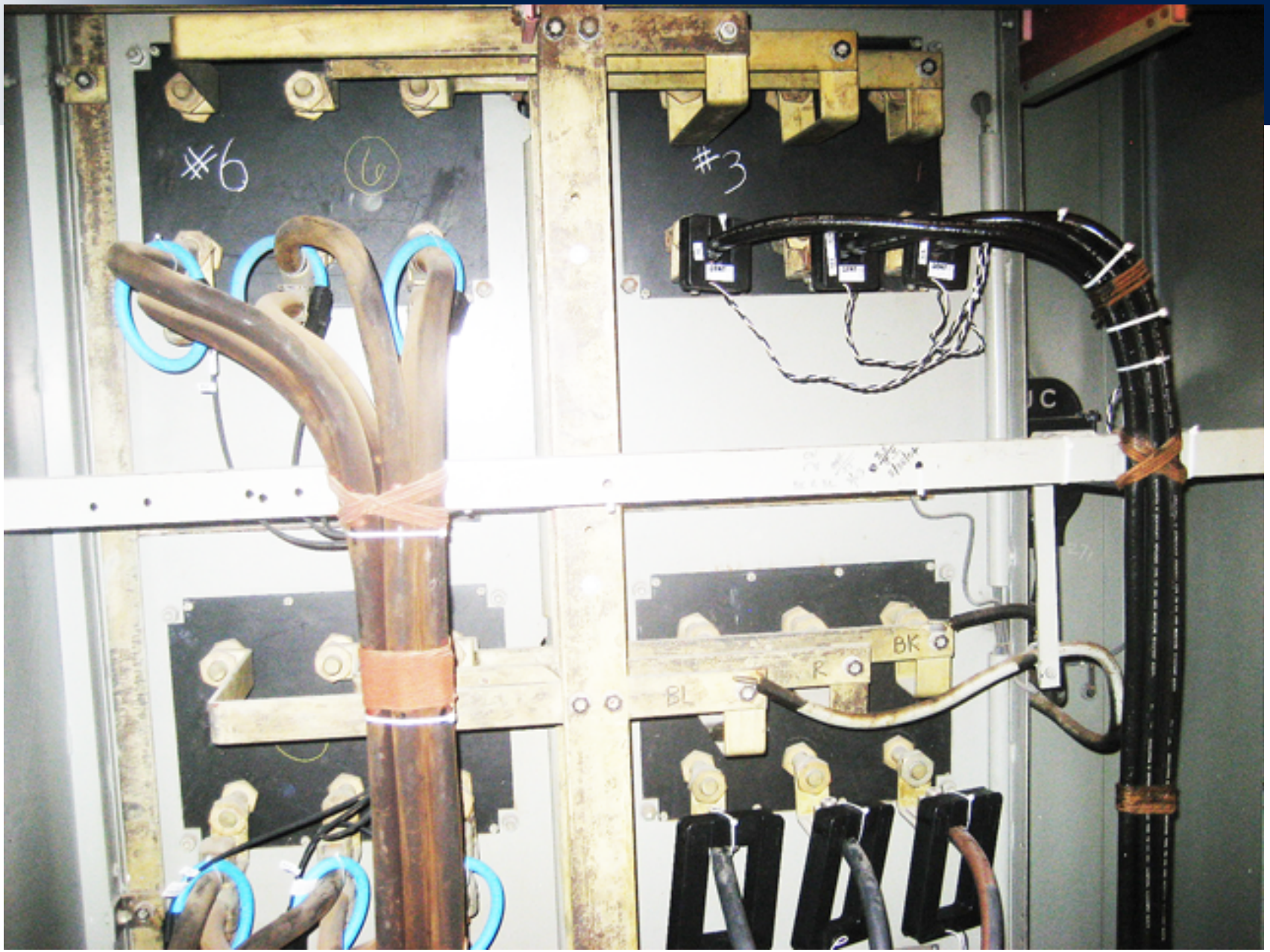
- Connectivity: RS-485 – multi-drop serial protocol
- Data model: Modbus (“everything is a 16-bit register”)
  - need register map to interpret
- Three-phase power measurements
  - about 50 “channels” per three-phase circuit
  - six circuits supported
- Registers updated at 2Hz

Ready for the Shutdown

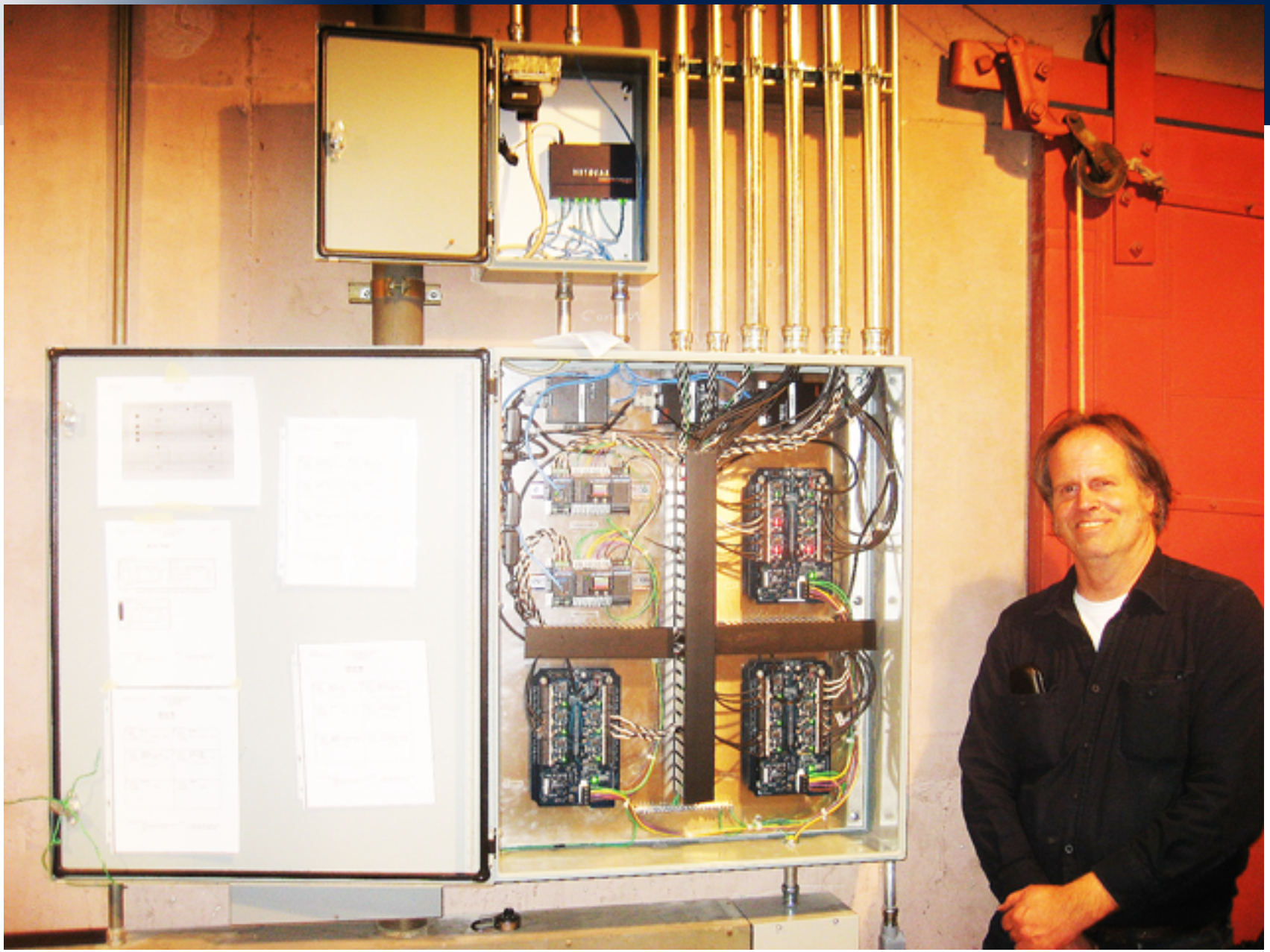
Go



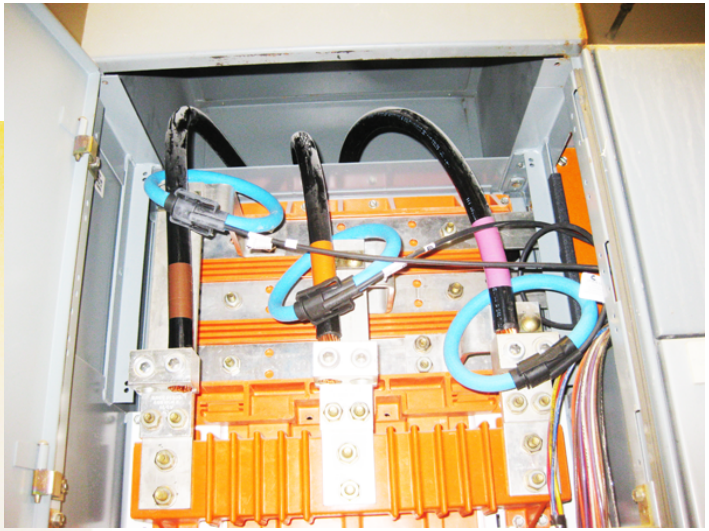



#6
#3
BK
R
BL

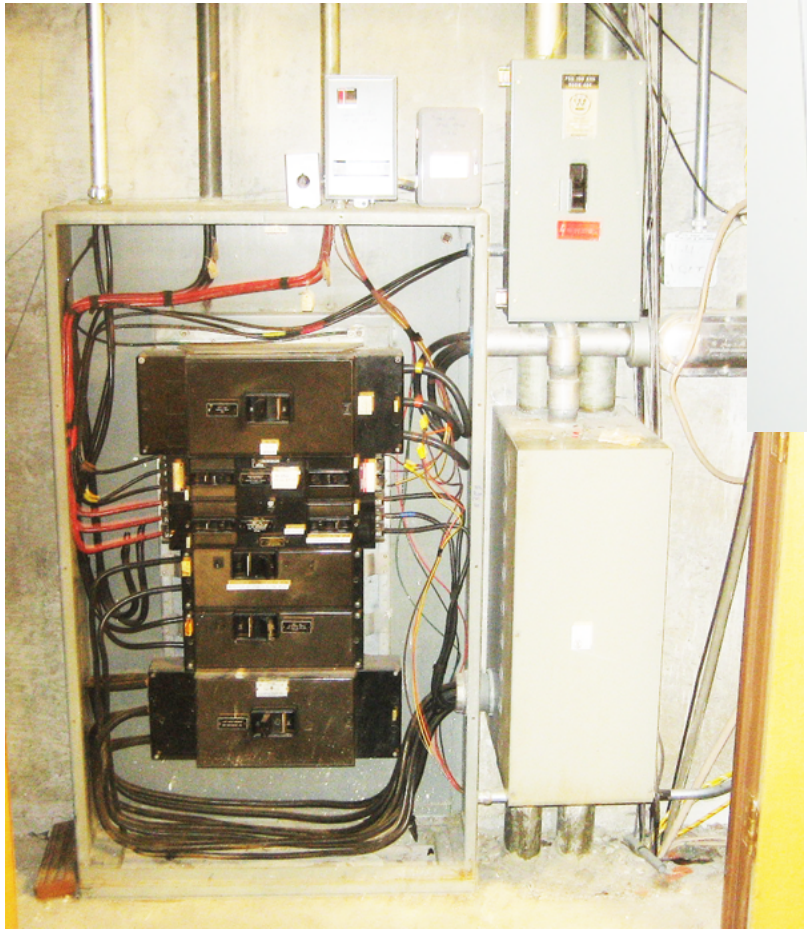

#15
C
B
A



MCL



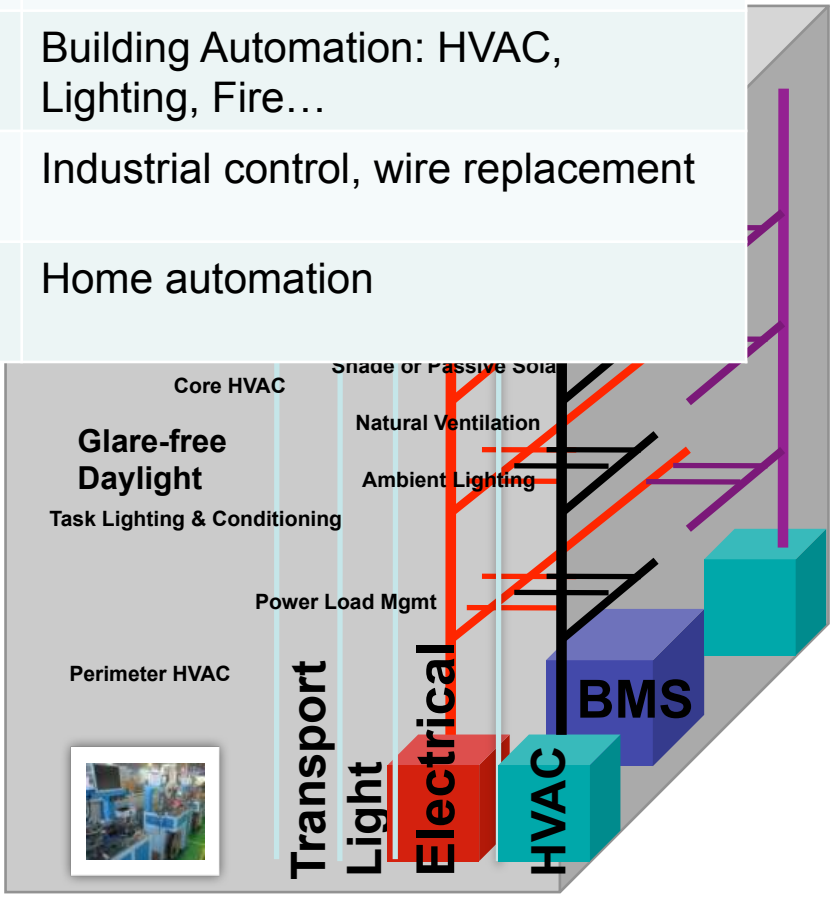
2PE rm358



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, *etc.*	Building Automation: HVAC, Lighting, Fire…
WirelessHART	2007	802.15.4e	Industrial control, wire replacement
SEP 2.0	2010 ?	802.15.4	Home automation

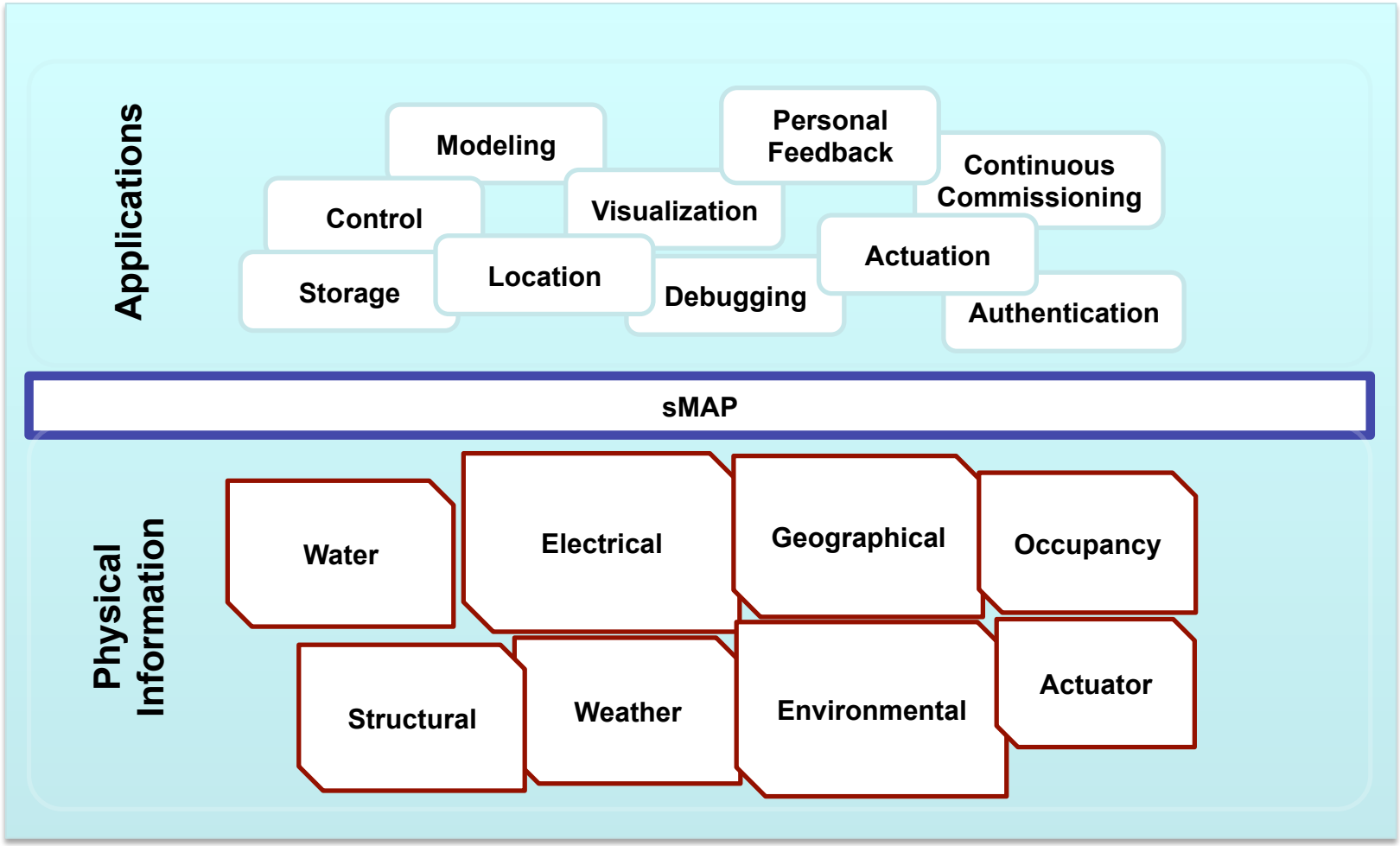
- HUGE installed/legacy base
- **Multiple generations of hardware and software in the same building**
- **Typical integration: proprietary vertical BMS**
  - **Data in at the bottom**
  - **Data products out at the top**



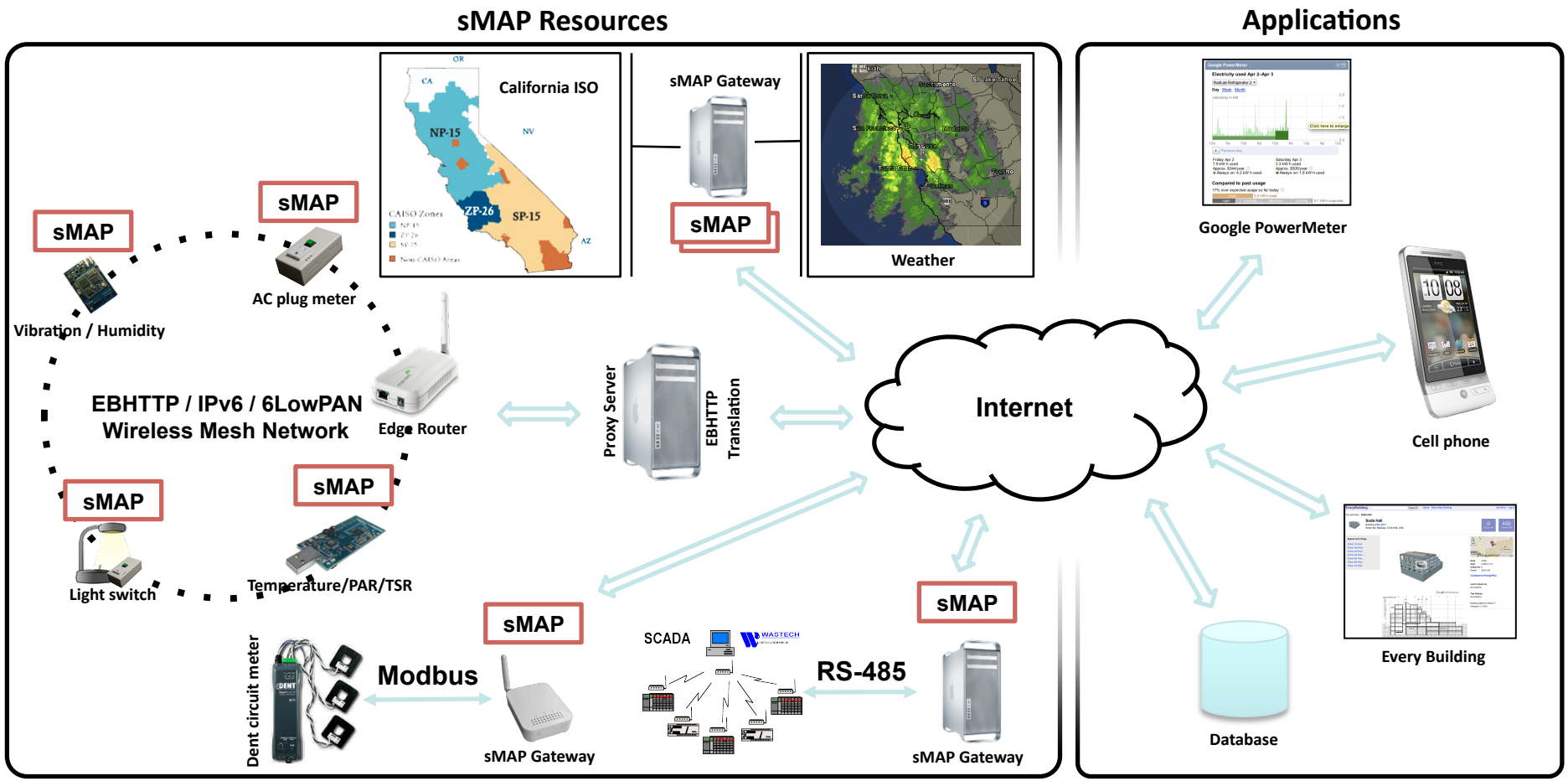
Real Data Feeds

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 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

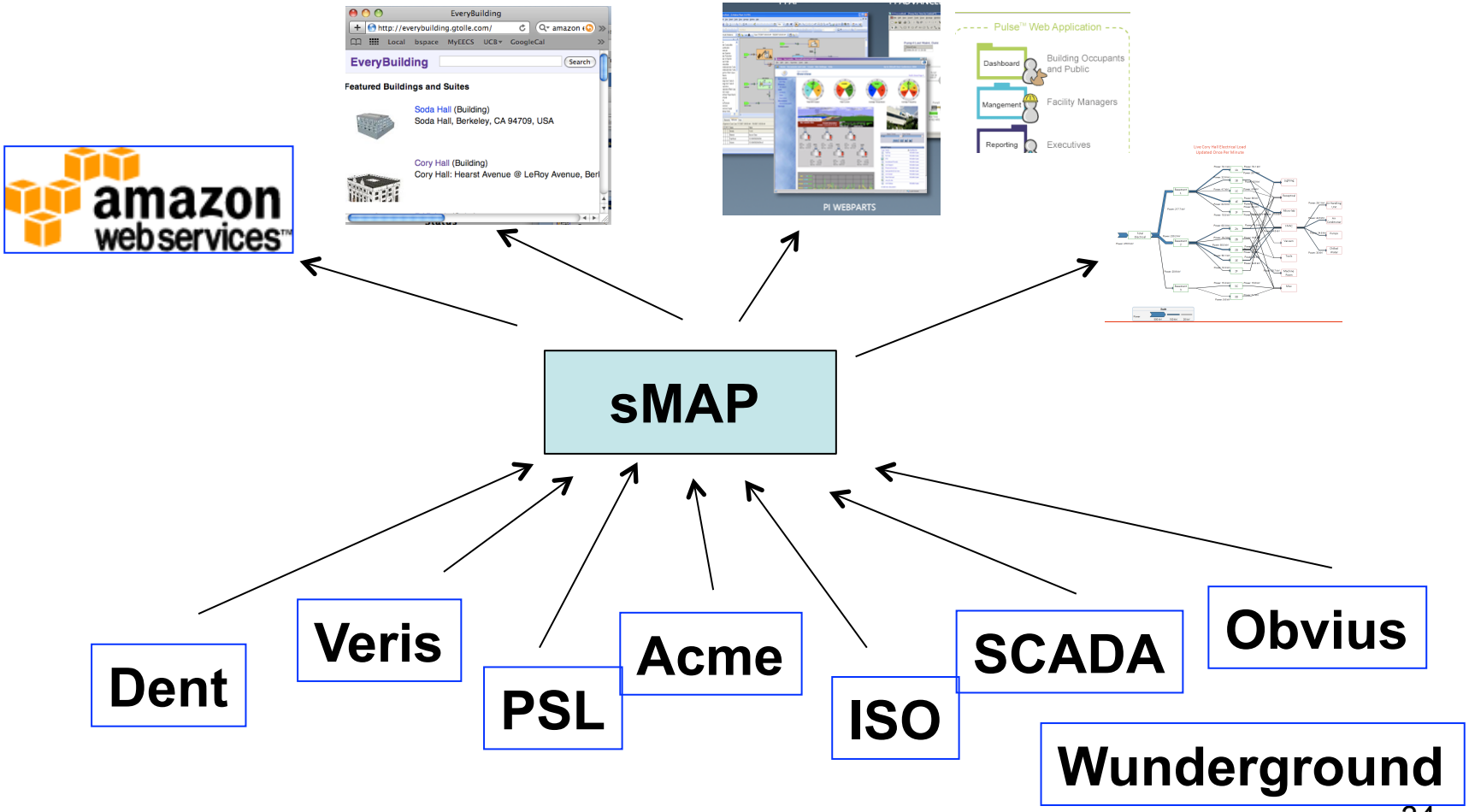
- Discover sMAP Instance
- Read/Poll
  - `GET /data/ABC/sensor/real_power/formatting`
  - `GET /data/*/*/*/reading`
- Subscribe
  - Create reporting instance with HTTP URL for "callback"
  - Specify fixed rate or each new report
  - Persists until deleted, times out, or fails
  - Incremental update (part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

Design: Dent Powerscout 18

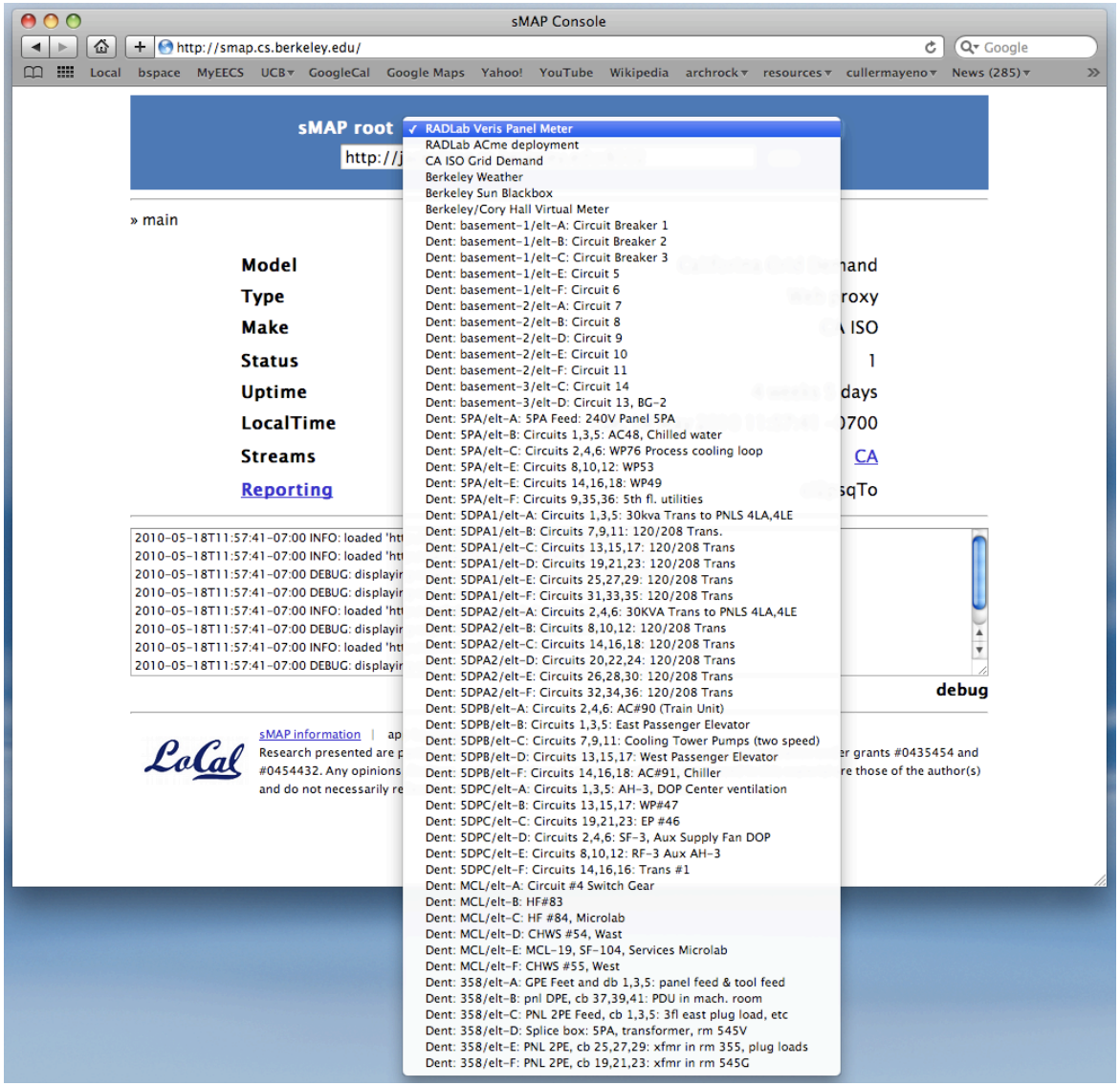
```
/                       # list resource under URI root [GET]
  /data                 # list sense points under resource data [GET]
    /[sense_point]      # select a sense points [GET]
      /meter            # meters provide this service [GET]
        /[channel]      # a particular channel [GET]
          /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

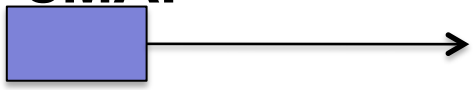


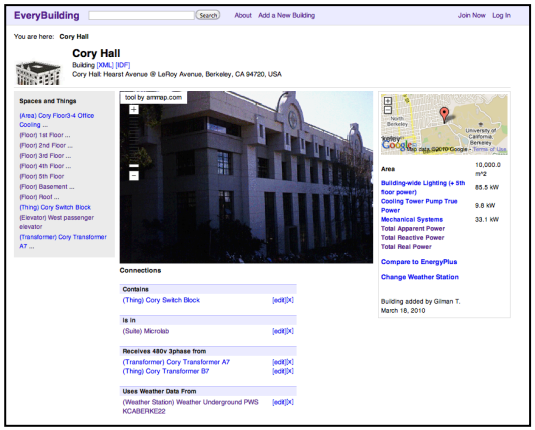
sMAP – homogeneous access to heterogeneous information

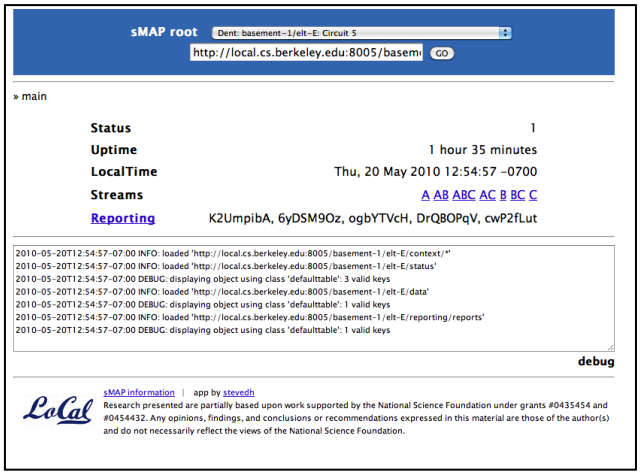


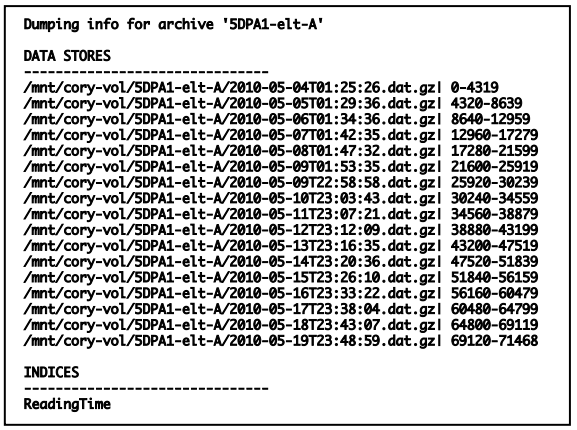
Web Applications

sMAP









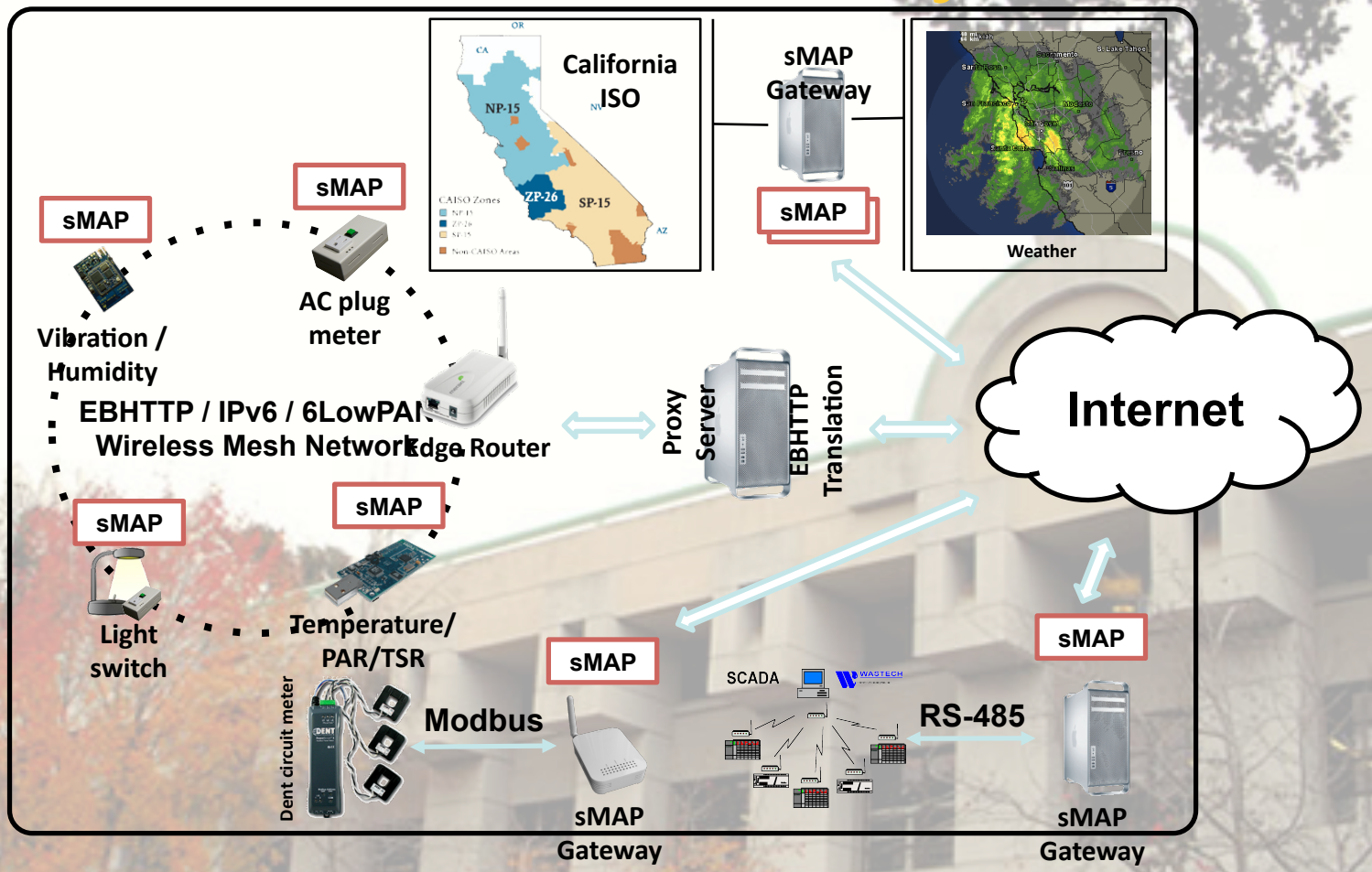
Amazon Cloud EveryBuilding

```
{
 "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"
}
```

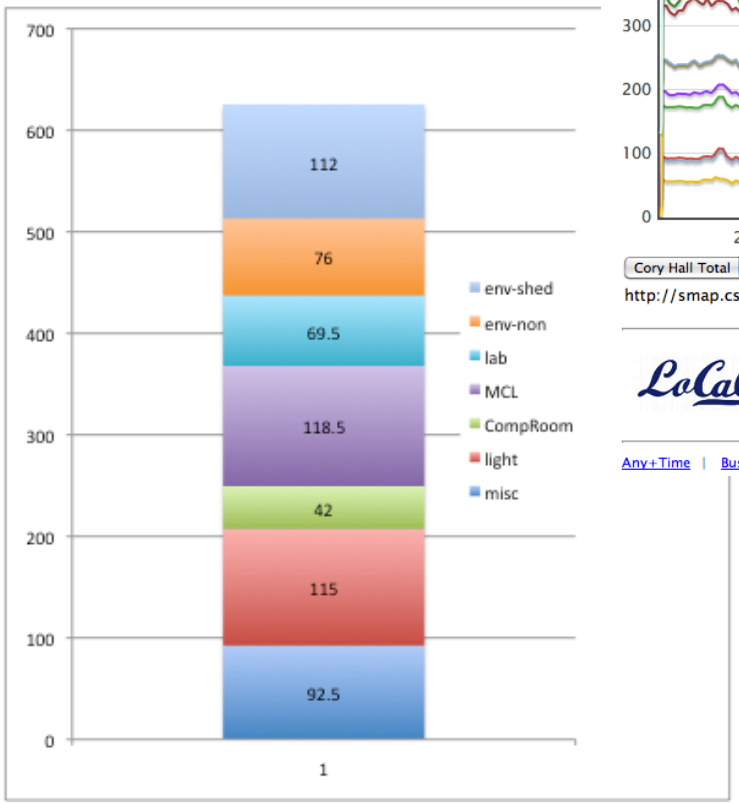
Push

sMAP Ecosystem at Berkeley

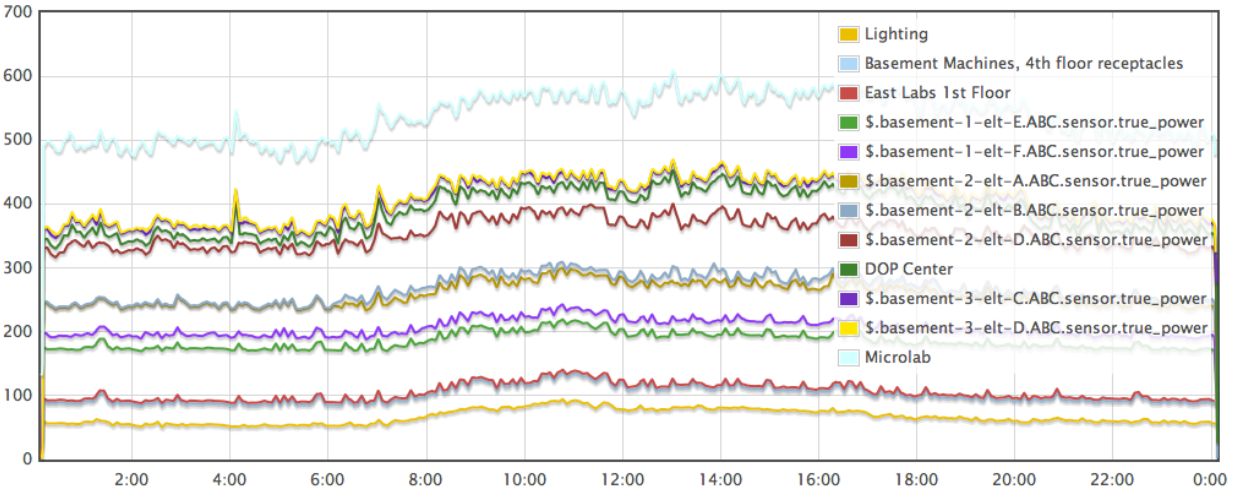


- Gateways for legacy devices; native implementations for new ones
- Library of 8 different devices – currently represents XML/CSV feeds, Modbus, and embedded (mode-class)

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

LoCal

sMAP | status | app by stevedh

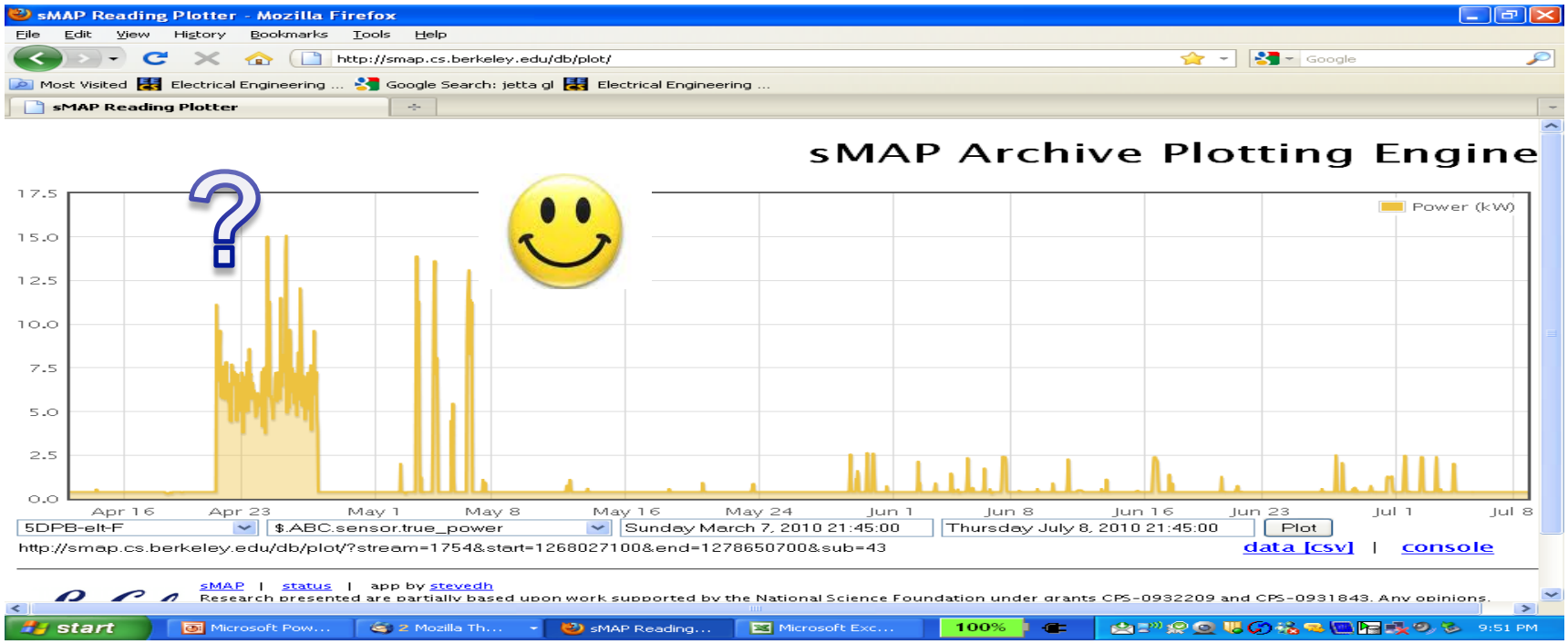
Research presented are partially based upon work supported by the National Science Foundation under grants CPS-0932209 and CPS-0931843. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National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

Any+Time | Busy | jQuery | flot

1.344 seconds

Data tells stories…

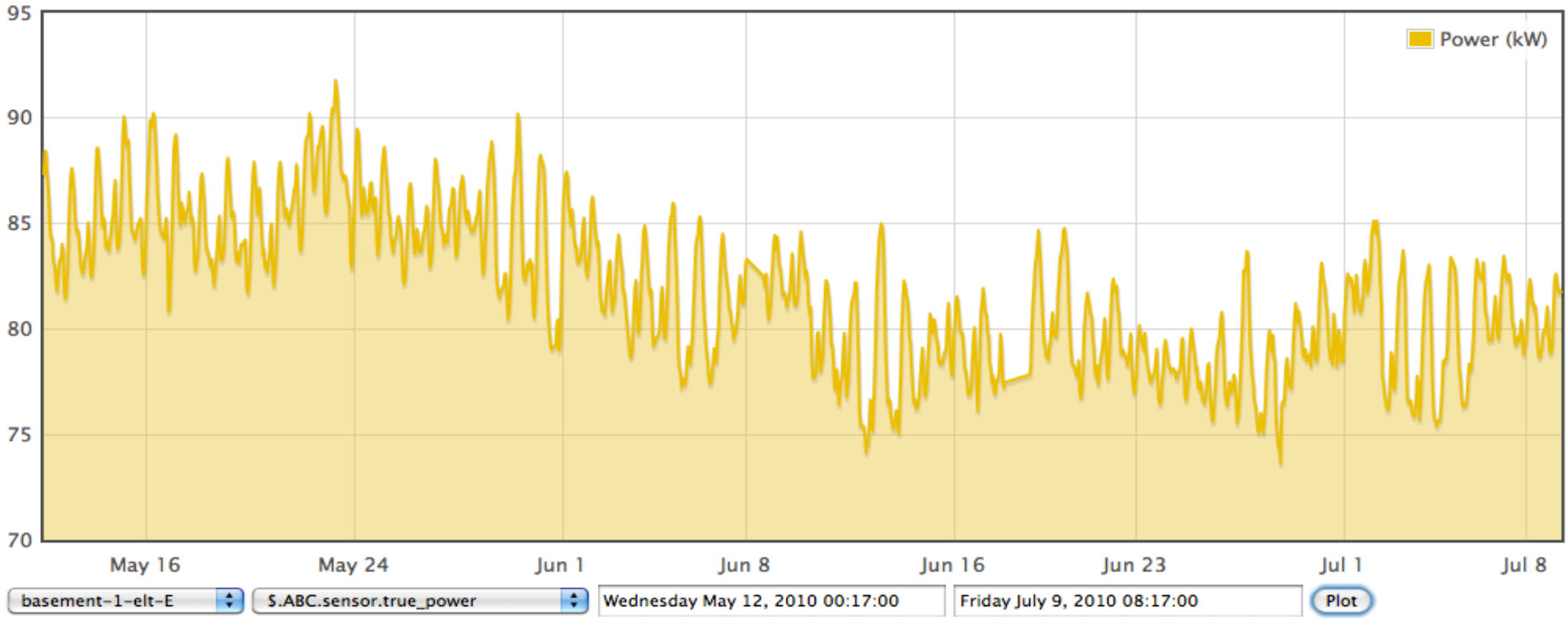
- Monitor Based Commissioning
  - Eliminate simultaneous heat/cool
  - AC91 on schedule



Micro Lab Tool Move

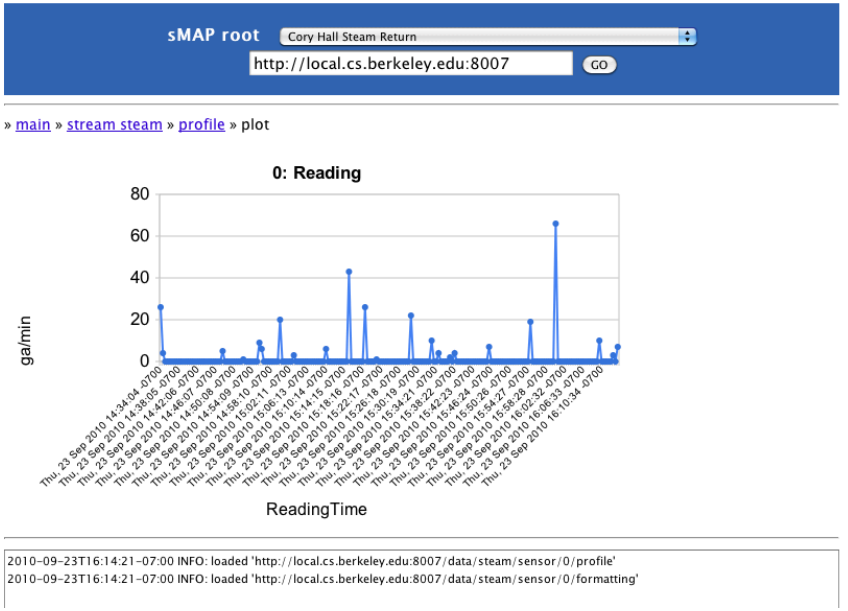
*** Will continue decline on circuit 4PE a**

Name	Description	Location
amst	AMST Molecular Vapor Deposition	582A
asml300	ASML 5500/300 DUV Stepper	384
cpa	CPA three-target sputterer	584
crestec	Crestec EBEAM Lithography	384
diebonder	MRI 779 Die Bonder	380
edwards	Edwards Sputter System	582
edwardseb3	Edwards 306 E-Beam System	582
heatpulse1	Heatpulse rapid thermal annealer for Si	582
heatpulse2	Heatpulse rapid thermal annealer for GaA	582
heatpulse3	AG Heatpulse 610	386
heatpulse4	AG Heatpulse 610	386
hummer	gold evaporator for cuarn samples	384
ionbeam	Ion Beam Deposition System	584
ionmill	Veeco ion mill	582
kruss	Kruss Contact Angle Analyzer	582A
lam6	Lam 4500 oxide etcher	584
lam7	Lam Research Etcher	584
leo	Leo Scanning Electron Microscope	384
linewidth	Linewidth & Feature Measuring System	380
microscopes	Optical microscopes	nanolab
msink16	General purpose fume hood/wet process	582A
msink18	General purpose fume hood/wet process	582A
msink6	furnace pre-clean	384
msink8	post PR cleaning	384
nanodux	Nanospec/DUV Microspectrophotometer	380
nebcope	Leica IMN100 Microscope	382
nrc	NRC evaporator	582
perkjene	Specialty Coating Systems PDS2010	582A
randex	Randex sputtering system	582
sca	Surface Charge Analyzer	386
sopra	Sopra Variable Angle/Frequency Ellips.	380
spinner	Headway Spinner - msink1	382
srdmsink6	Semitool Spin Rinse Dryer 880-S	386
srdmsink8	Vortex Spin Rinser Dryer	386
telephones	Lab, office phone sets and Room 158 PBX	580
tensiometer	Sigma 701 Tensiometer	582A
tgm	Toxic Gas Monitoring System	599
tystar1	Tystar 6" Wet/Dry Oxidation	386
tystar10	Tystar LPCVD Doped Poly	386
tystar11	Tystar LPCVD Doped LTO	386
tystar12	Tystar Doped LTO	386
tystar13	Tystar 6" POCL3	386
tystar14	Tystar 6" Solid-Source Boron	386
tystar15	Tystar 6" LPCVD Silicon Carbide	386
tystar16	Tystar 6" Doped Poly LPCVD	386
tystar17	Tystar LPCVD Low Stress Nitride	386
tystar18	Tystar 6" MOS Sinter	386
tystar19	Tystar LPCVD SiGe, MOS	386
tystar2	Tystar 6" Wet/Dry Oxidation	386
tystar20	Tystar SiGe LPCVD for MEMS	386
tystar3	Tystar 6" Wet/Dry Oxidation	386
tystar4	Tystar 6" Wet/Dry Oxidation	386
tystar9	Tystar LPCVD Nitride/HTO	386
ultek	E- Beam evaporator, 3-hearth	582
vt401	Veeco 401 vacuum system	582
yieldsystem	YES (Yield Eng. Systems) 450PBS-29	582A
westbond	West Bond 7400B	380
westbond2	West Bond 7400B Wedge Bonder	380
wyko	Wyko Optical Profilometer	380
xdif	X-Ray Diffractometer	380



Steam …

Figure 3-7
Condensate flowing to drain



FINAL REPORT

MBCX PROJECT:

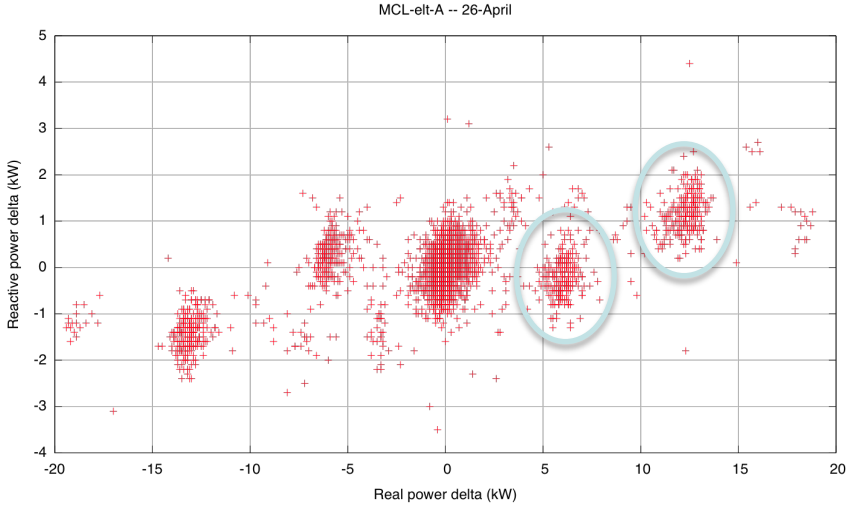
CORY HALL

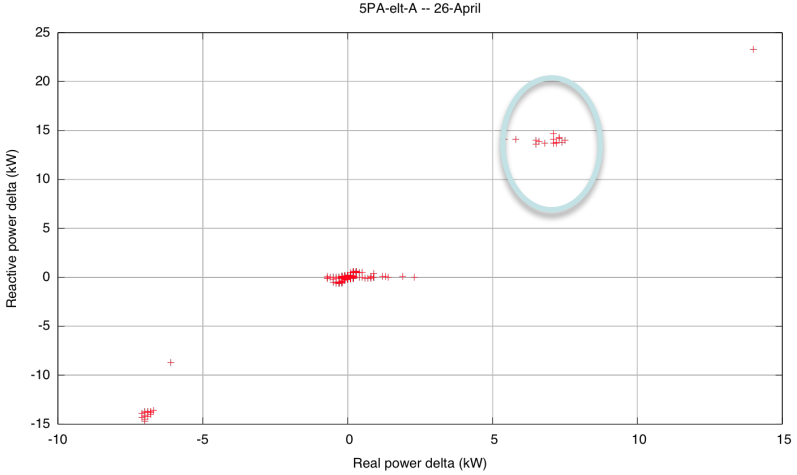
UNIVERSITY OF CALIFORNIA
BERKELEY

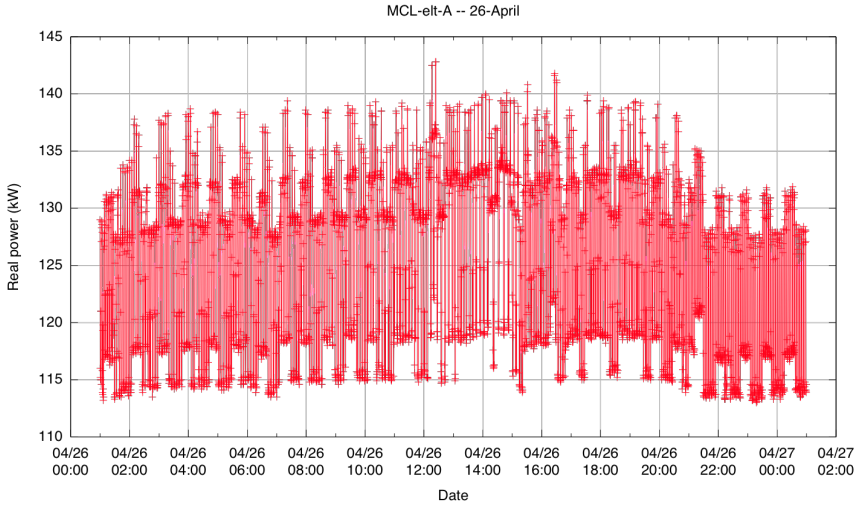
Table 3-1
Condensate pump and steam trap repair savings

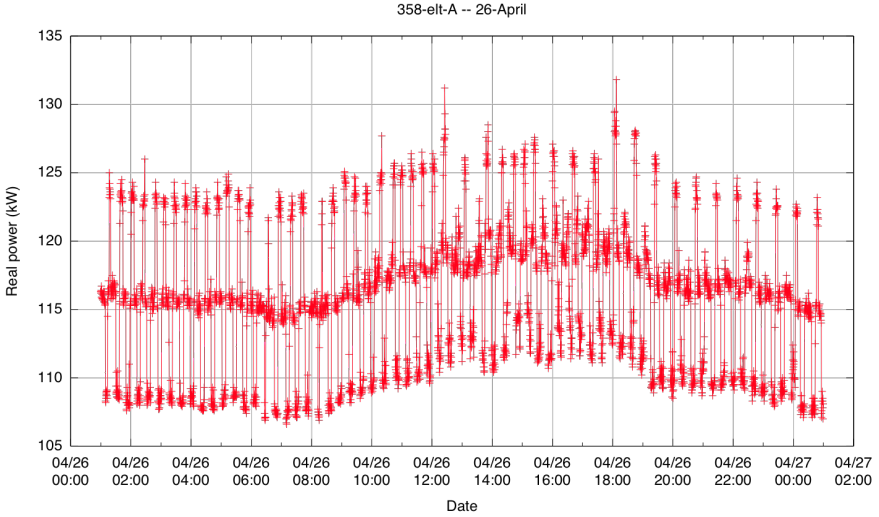
Energy	Savings at Building	Savings at Campus Meter	Cost Savings ($1/therm)
Steam	9,099 Therms	11,734 Therms	$11,374

Extracting Deeper







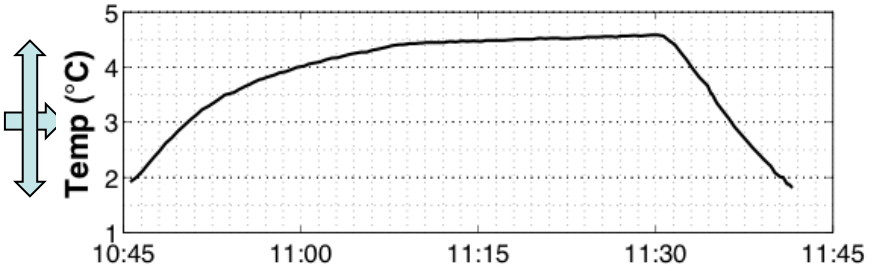


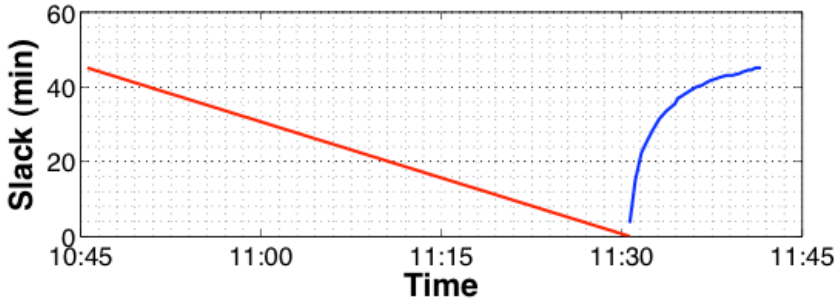
Energy “Slack” Example

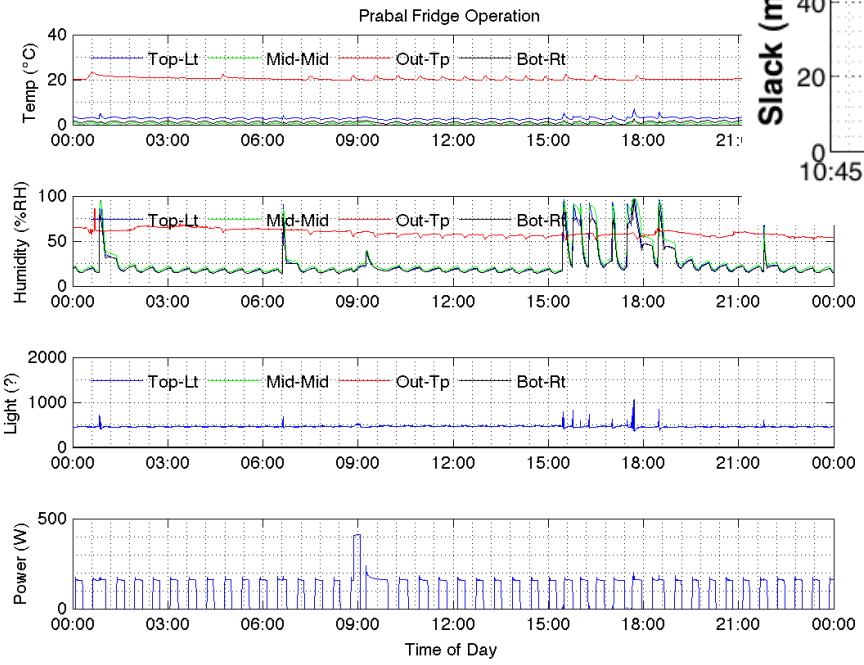
Thermostatically Controlled Load

IPS

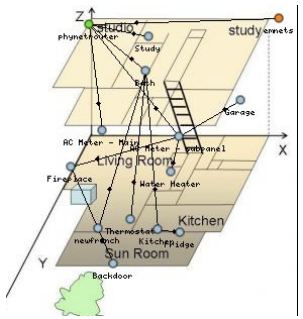
Set Point

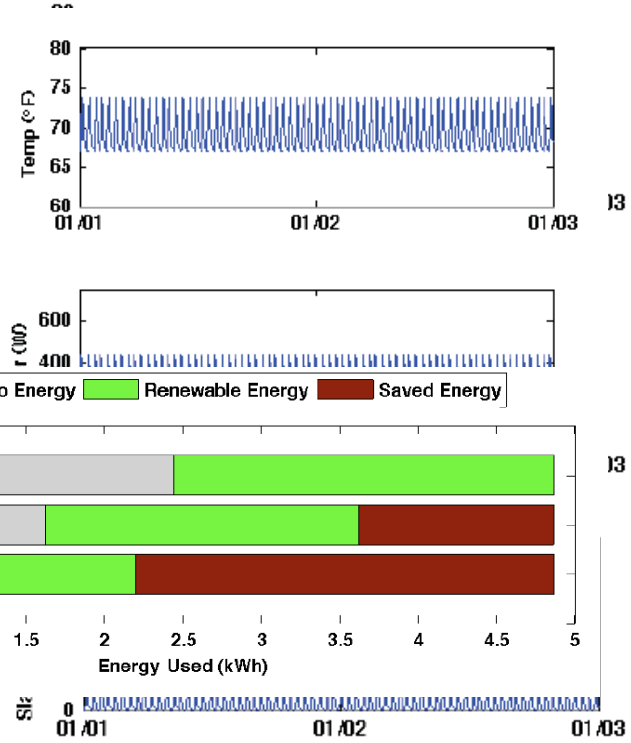


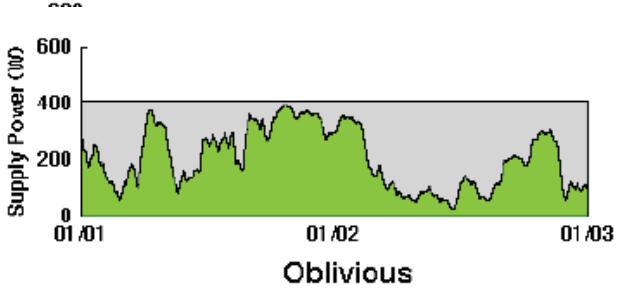


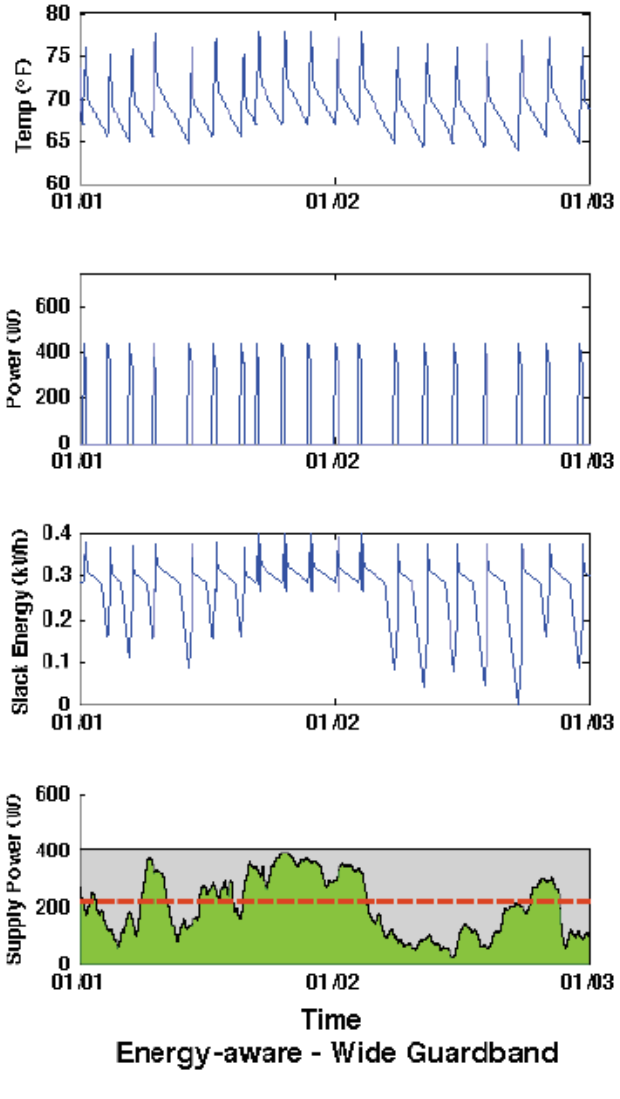


Supply-Following Loads

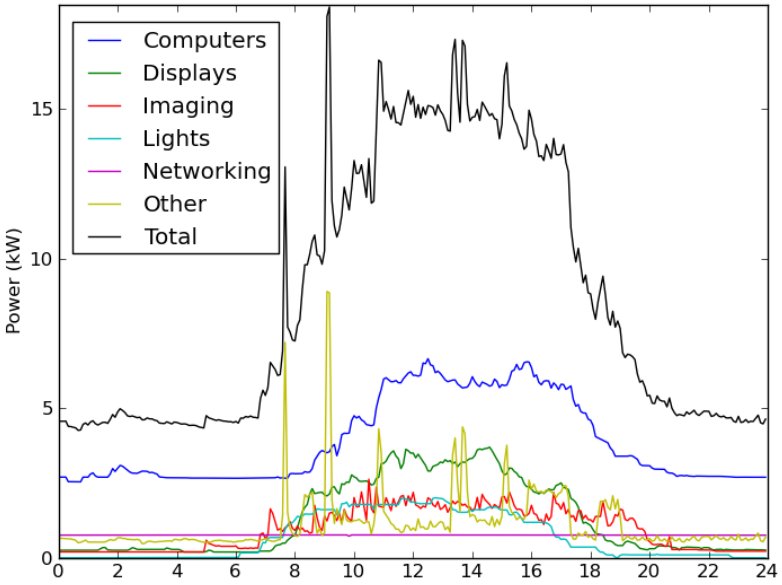


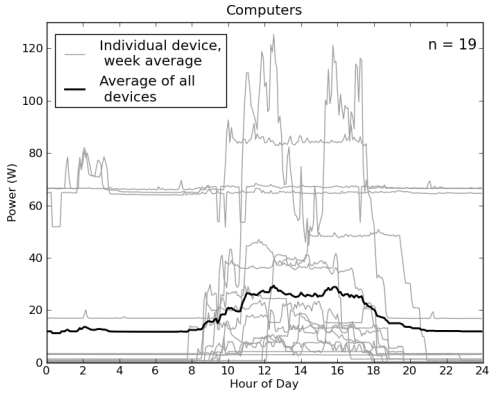






MELs with LBNL





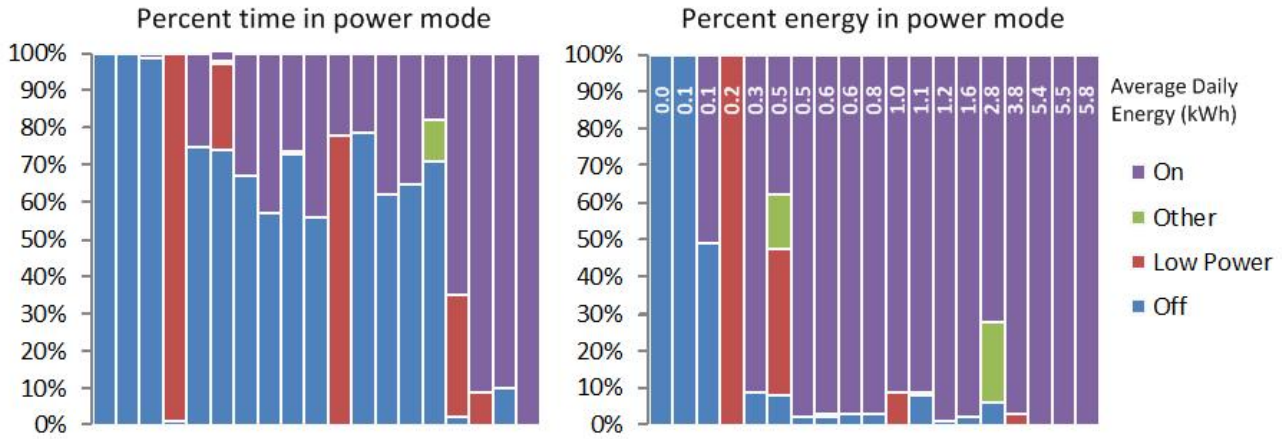


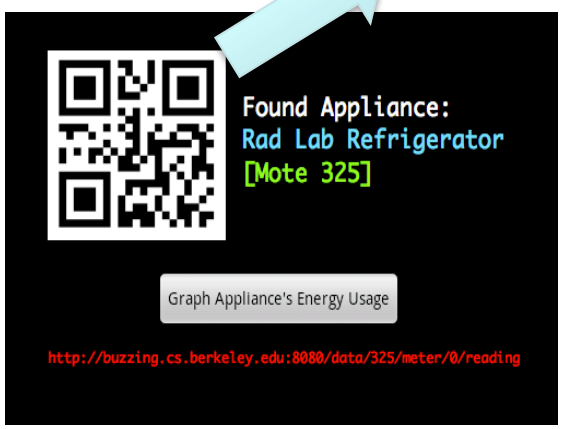
Figure 3.6. Percent time and energy in power modes for 19 computers metered over a work week. Each column represents an individual computer sorted from left to right by increasing energy use. Energy use is dominated by time in the on (active) mode even when time in that mode is small.

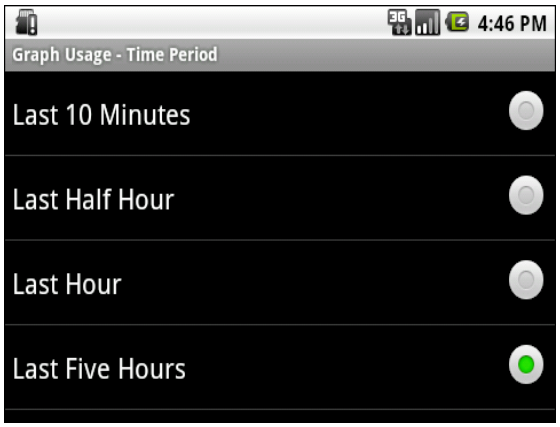
Demos

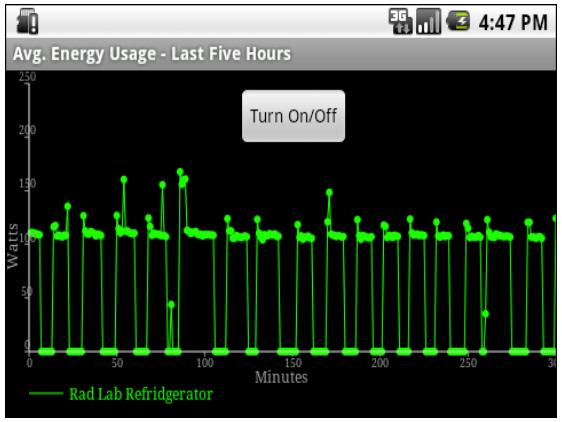
- Schedule and Tree
  - http://jackalope.cs.berkeley.edu:3000/tree
- Time series
  - http://smap.cs.berkeley.edu/db/plot/?stream=249&start=1270702260&end=1278651060&sub=5
- Time-series-difference scatter plot
  - http://smap.cs.berkeley.edu/db/plot/vs.html
- Aggregates
  - http://smap.cs.berkeley.edu/db/plot/agg.html

Phone App

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

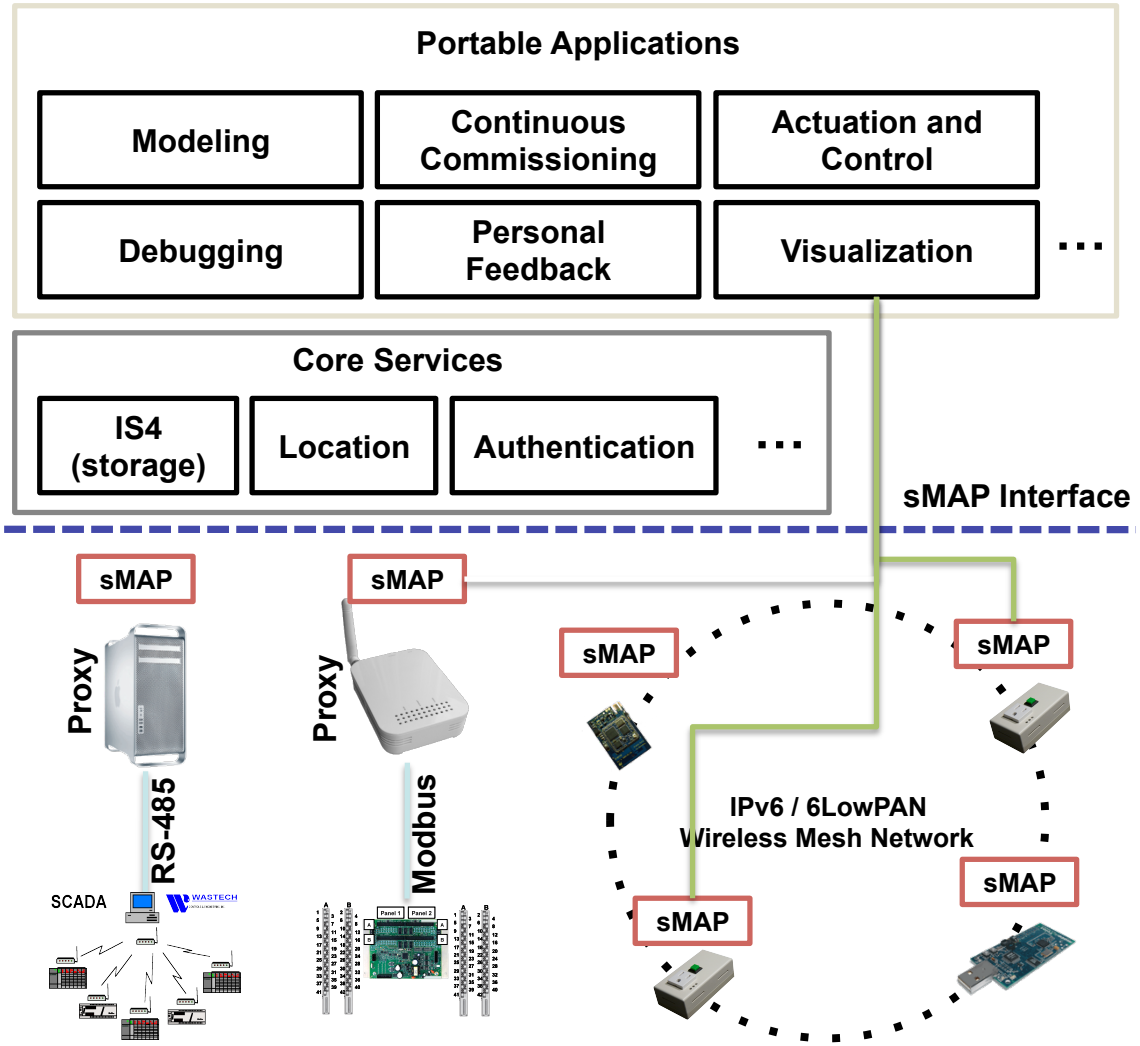






http://local.cs.berkeley.edu:8011/data/325/sensor/real_power/profile

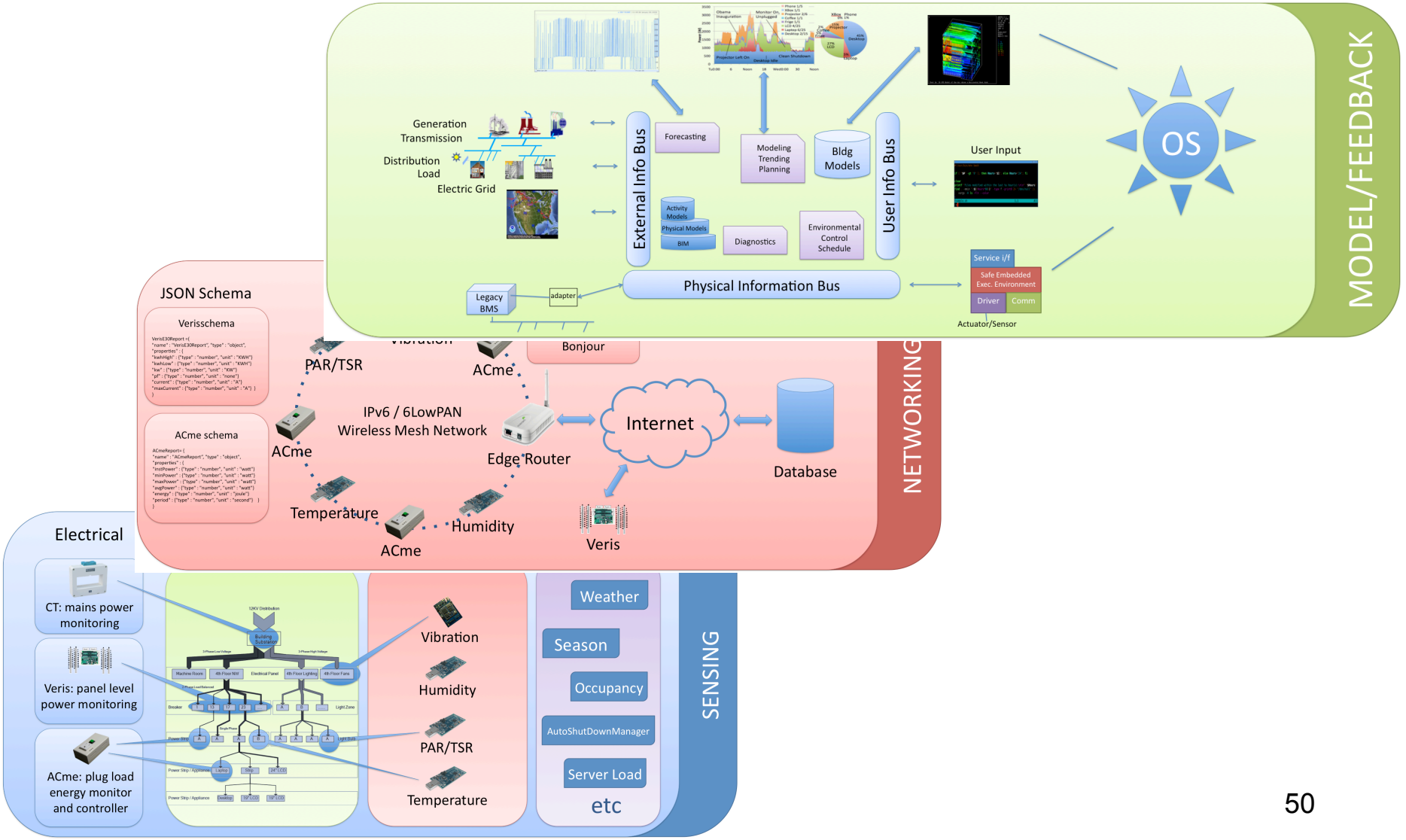
Basis for Grid-Responsive Bldgs



Stages of Energy Effectiveness

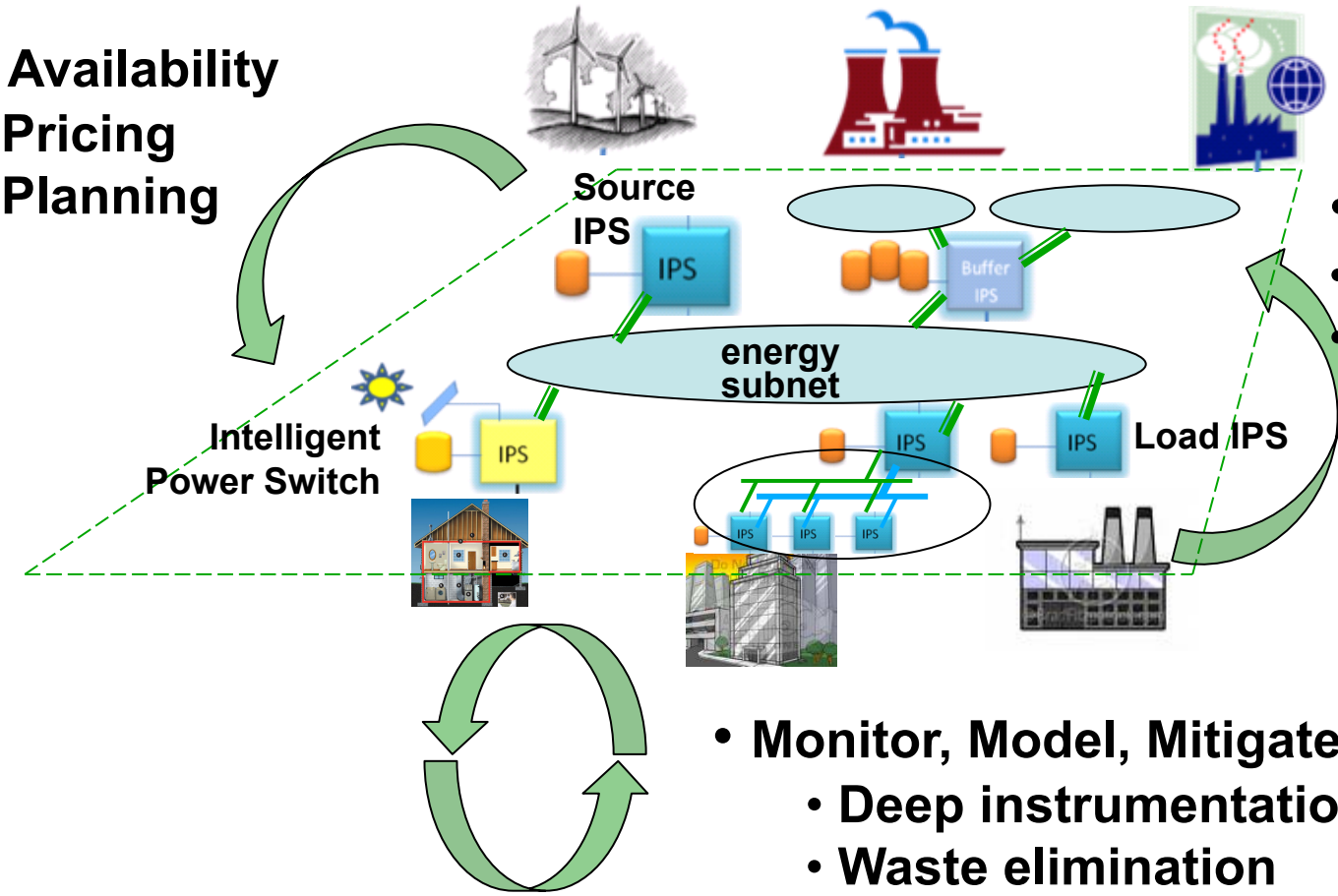
- Waste elimination
  - Do Nothing Well !!!
- Power Proportionality
  - Power : Performance (utilization)
  - Partial Load - from nothing to peakl
- Sculpting
  - Identify the energy slack and utilize it
- Negotiated Grid / Load / Human Interaction
  - Plan, Forecast, Negotiate, Manage

Building Scale Monitoring Architecture



Intelligent Energy Network

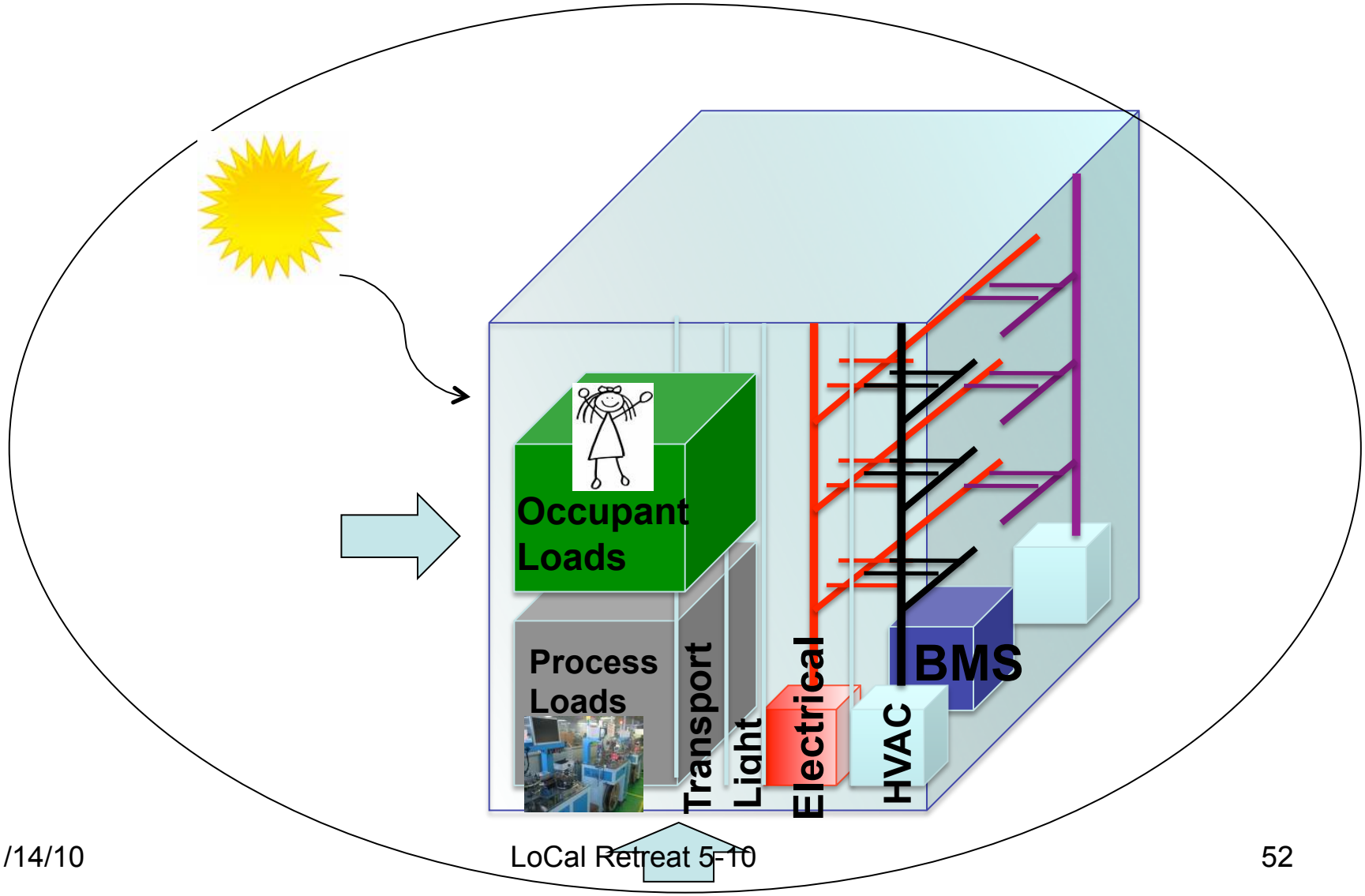
- Availability
- Pricing
- Planning



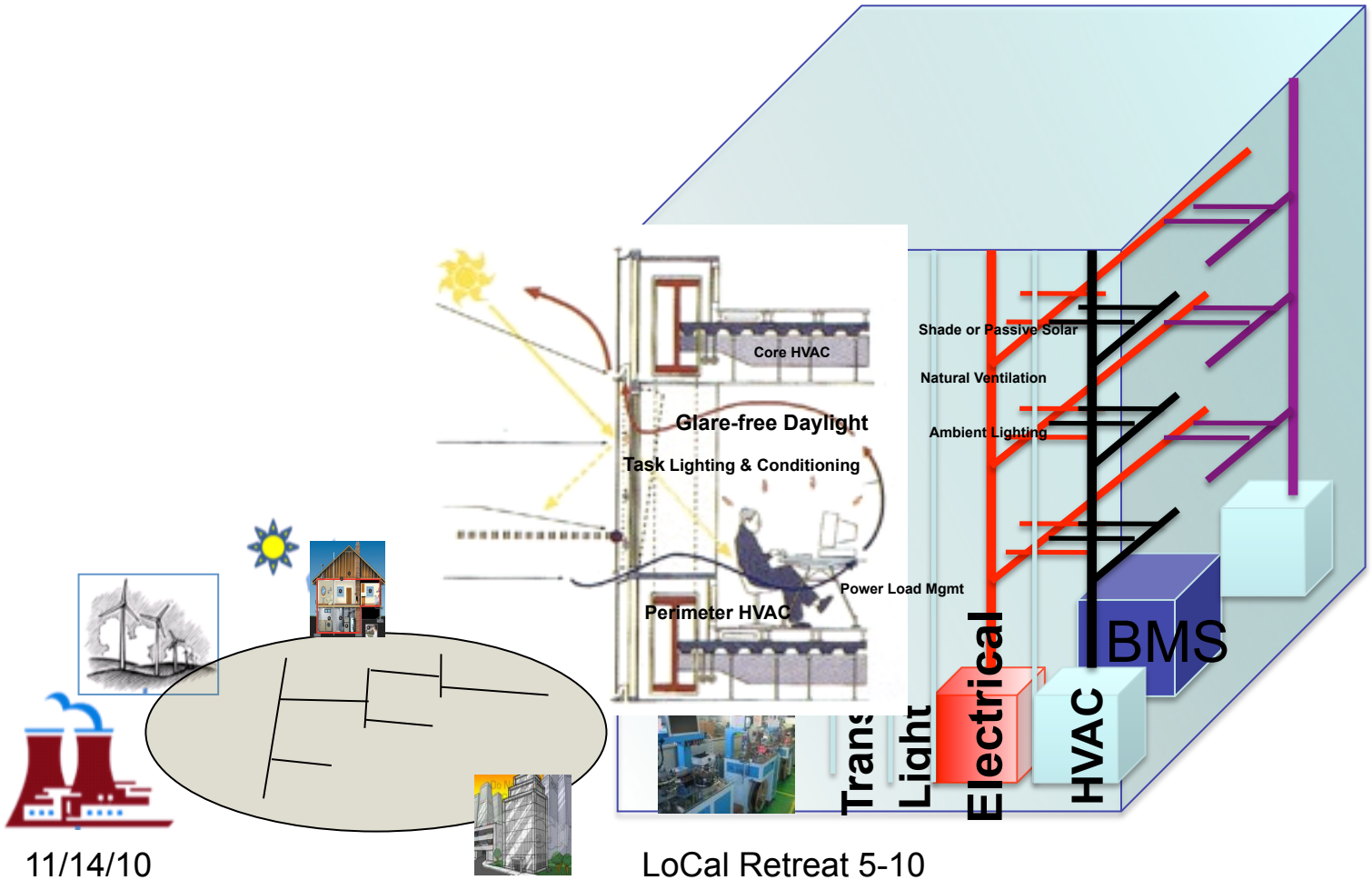
- Forecasting
- Tracking
- Market

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

A New View


Occupant Loads
Process Loads
Transport
Light
Electrical
HVAC
BMS

A New View


Core HVAC
Glare-free Daylight
Task Lighting & Conditioning
Power Load Mgmt
Perimeter HVAC
Shade or Passive Solar
Natural Ventilation
Ambient Lighting
BMS
Electrical
HVAC

Cyber / Physical Buildings