LoCal

A Network Architecture for Localized Electrical Energy Reduction, Generation and Sharing

David Culler

Randy Katz, Seth Sanders, and Team

University of California, Berkeley

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

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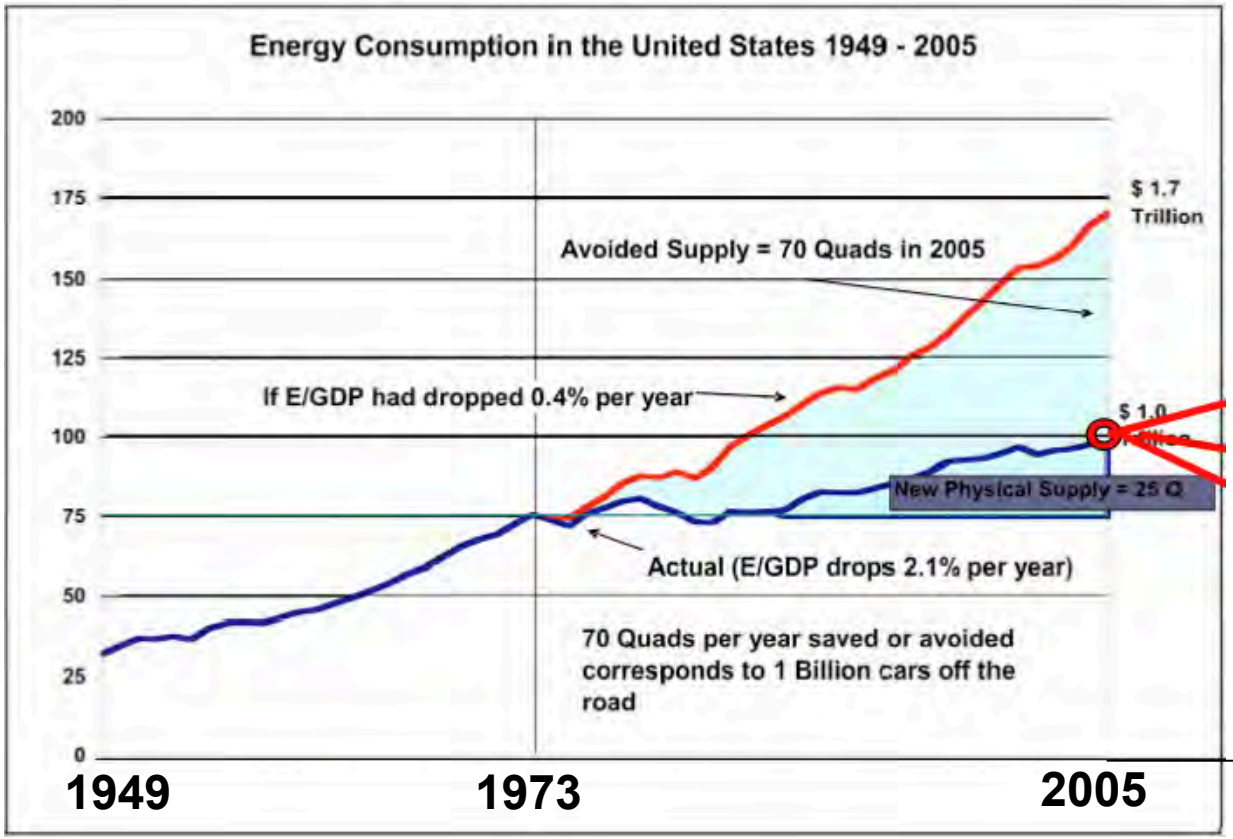
A new kind of Roadmap for CS



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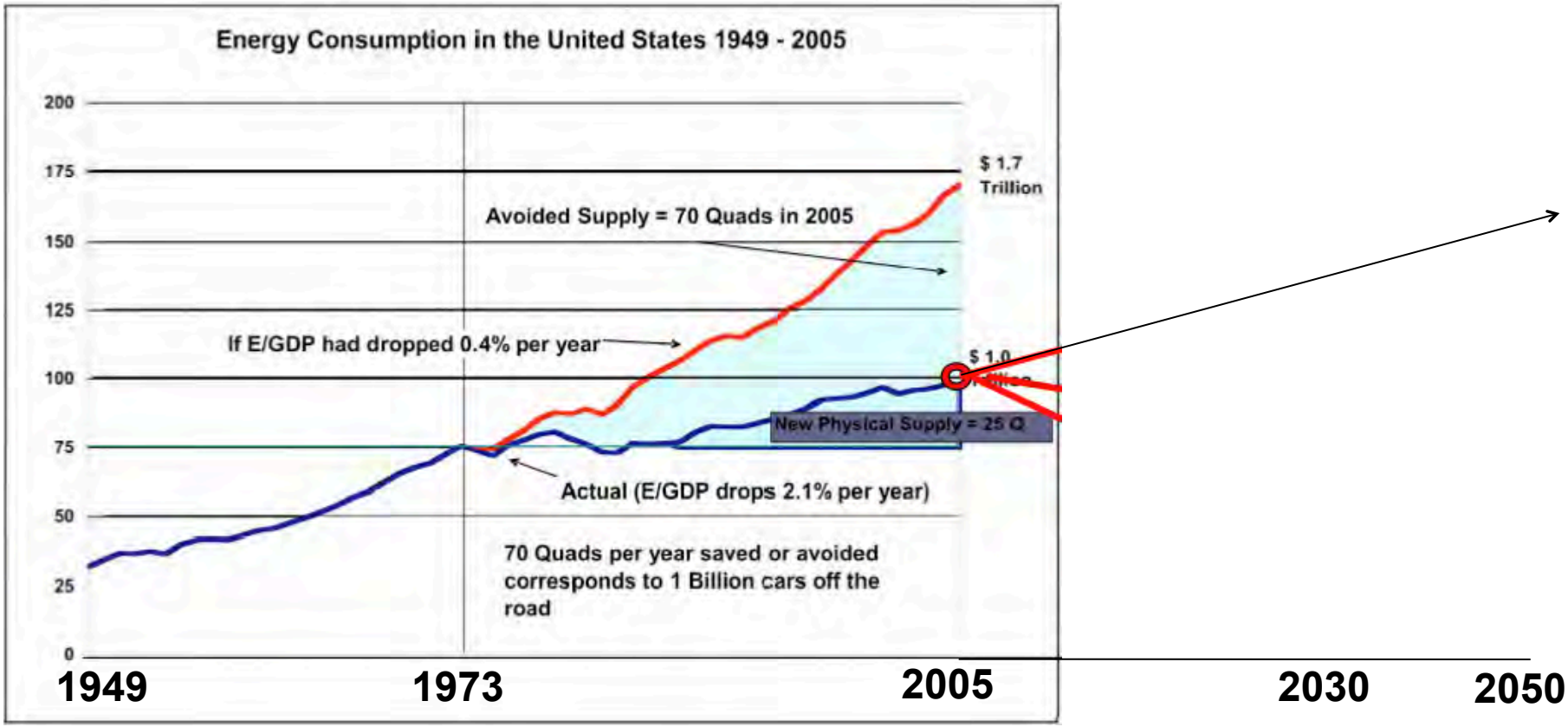

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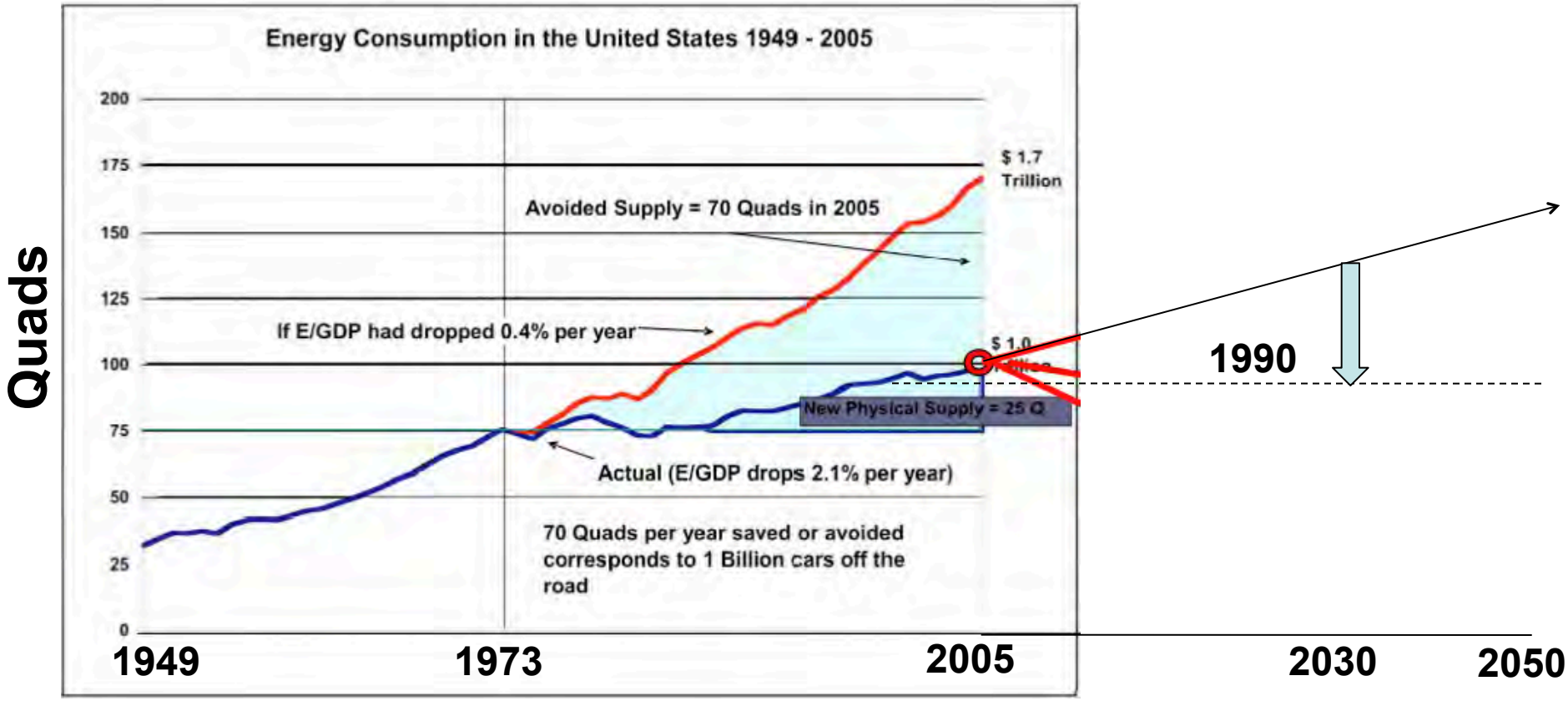

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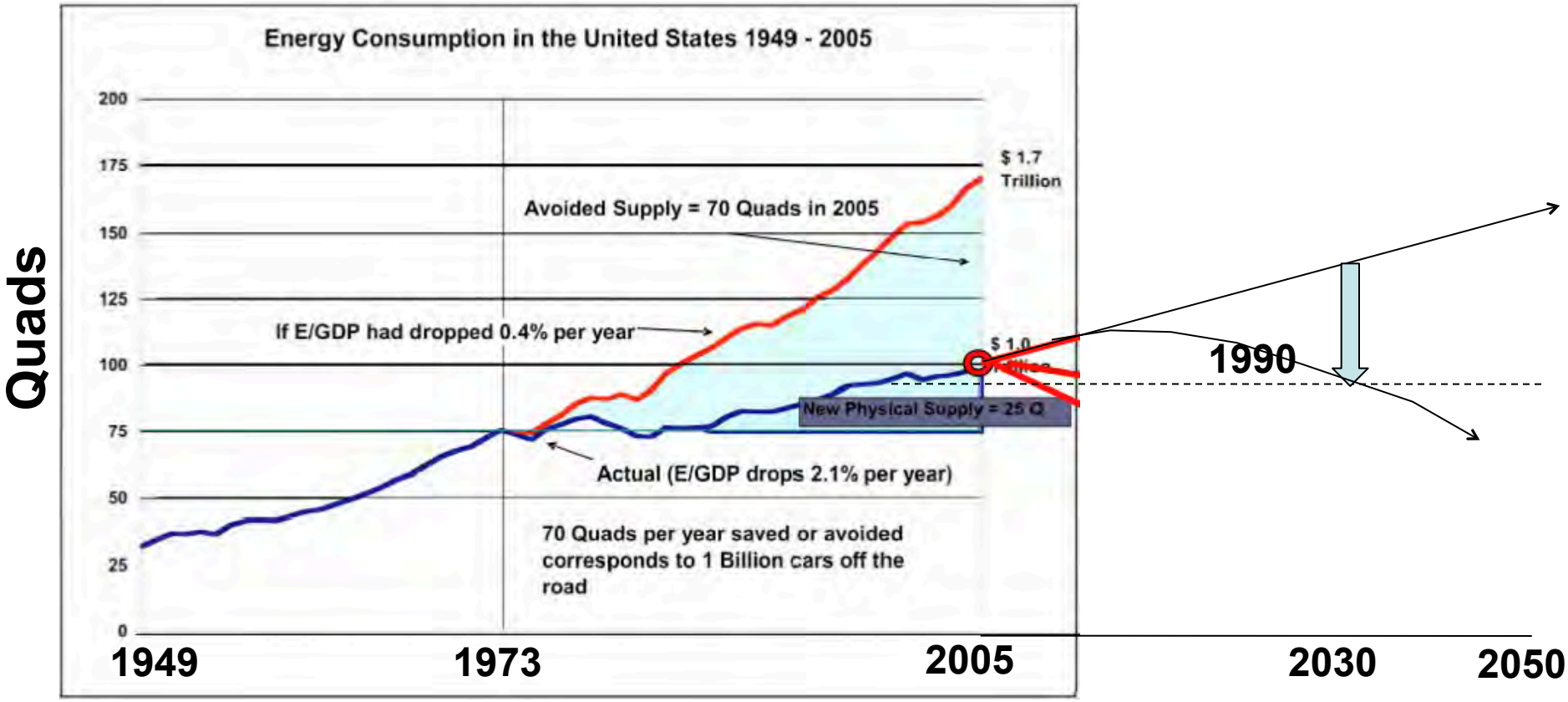

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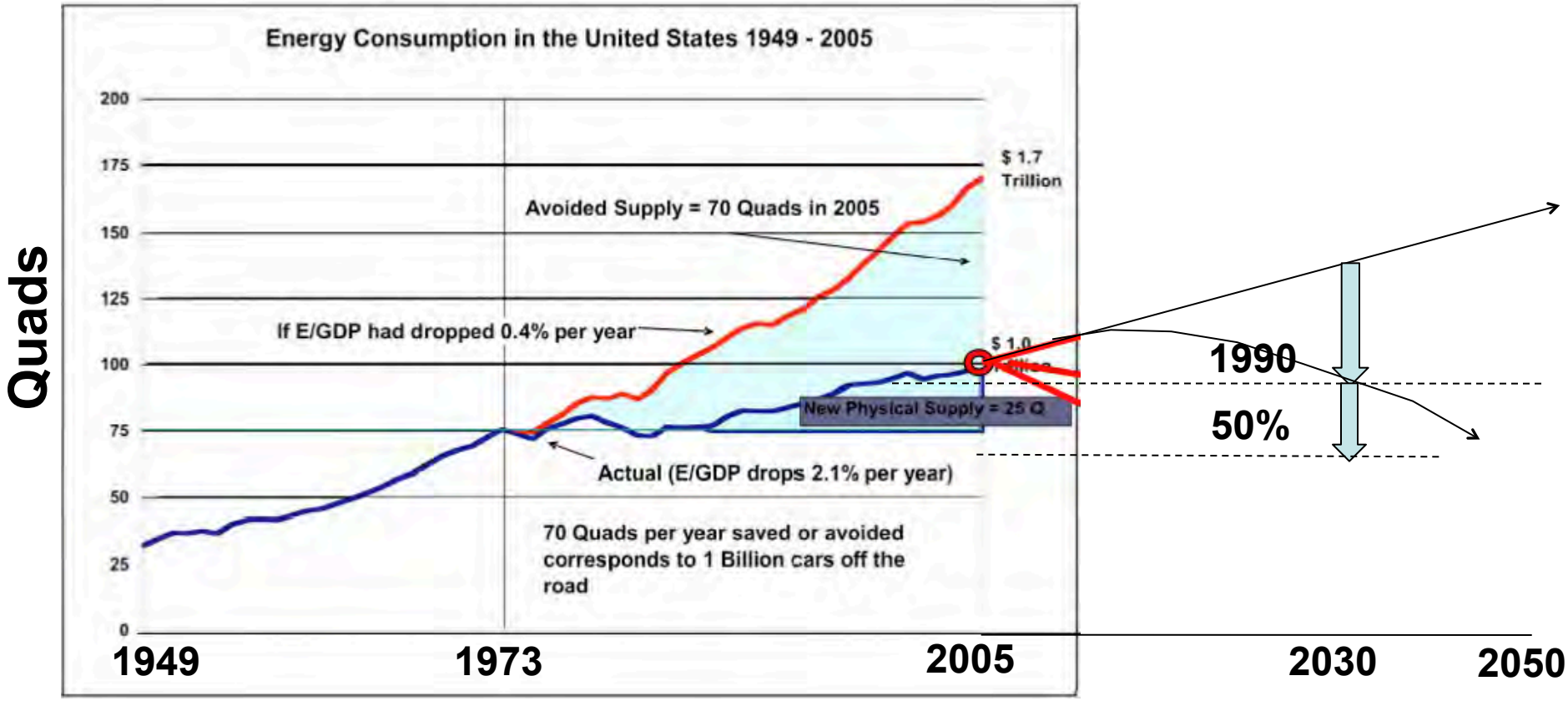

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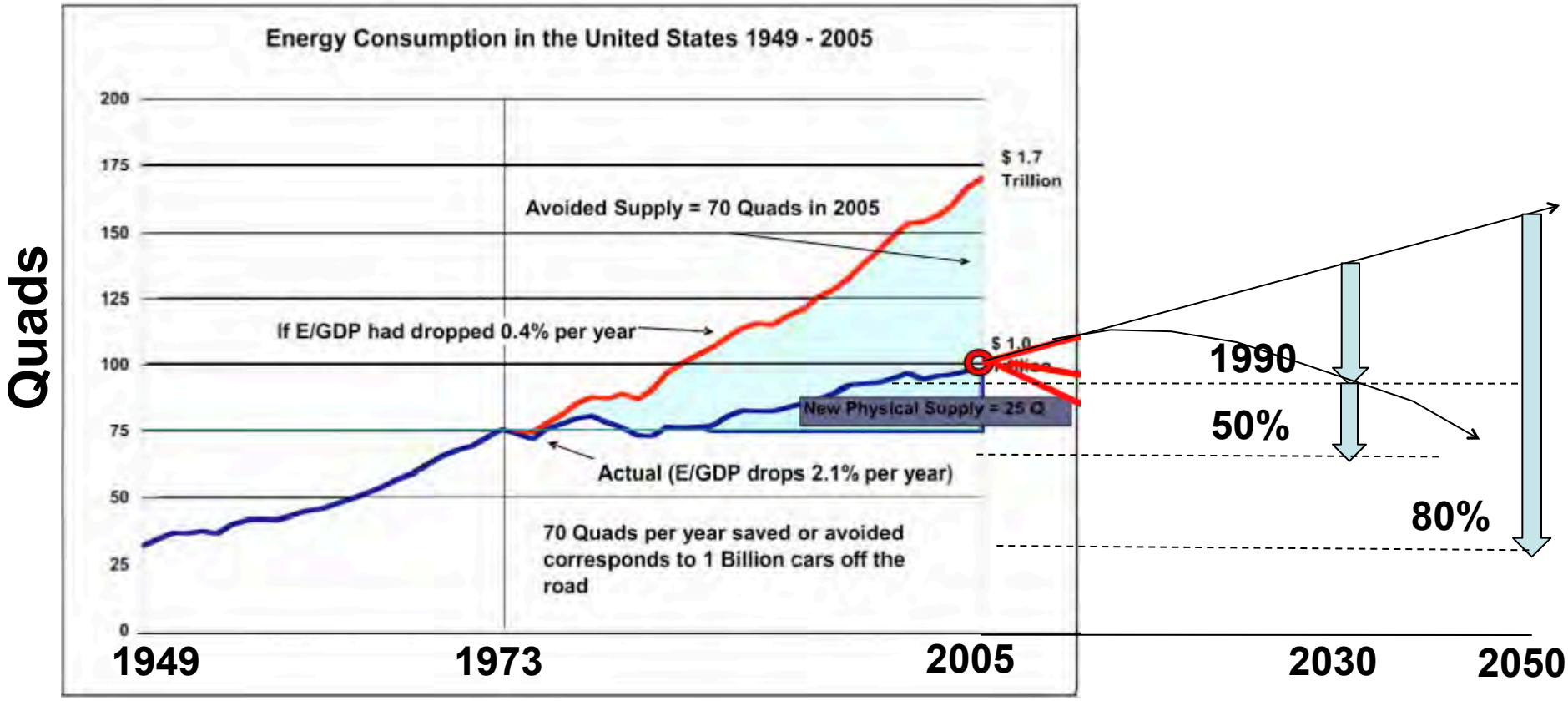

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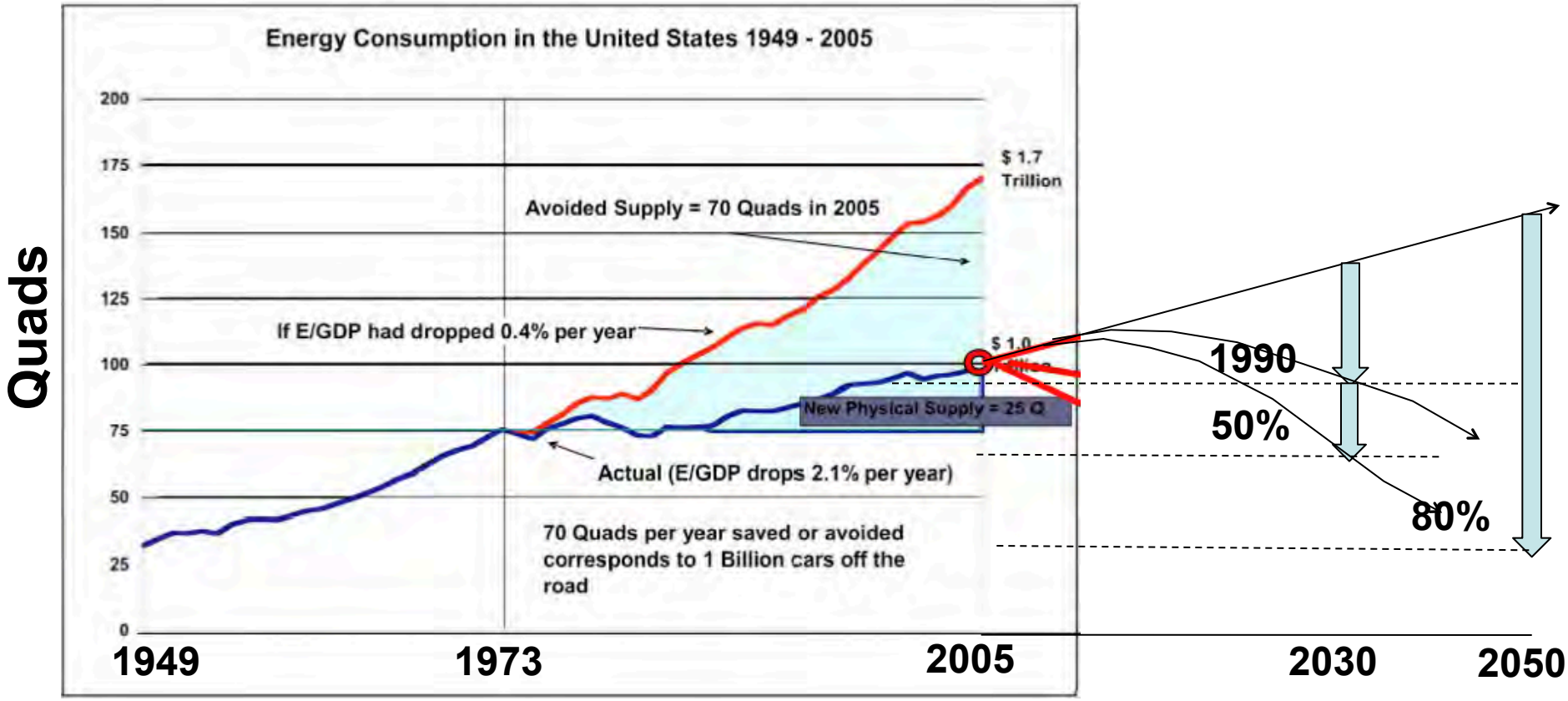

Towards an "Aware" Energy Infrastructure

Baseline + Dispatchable Tiers

Oblivious Loads

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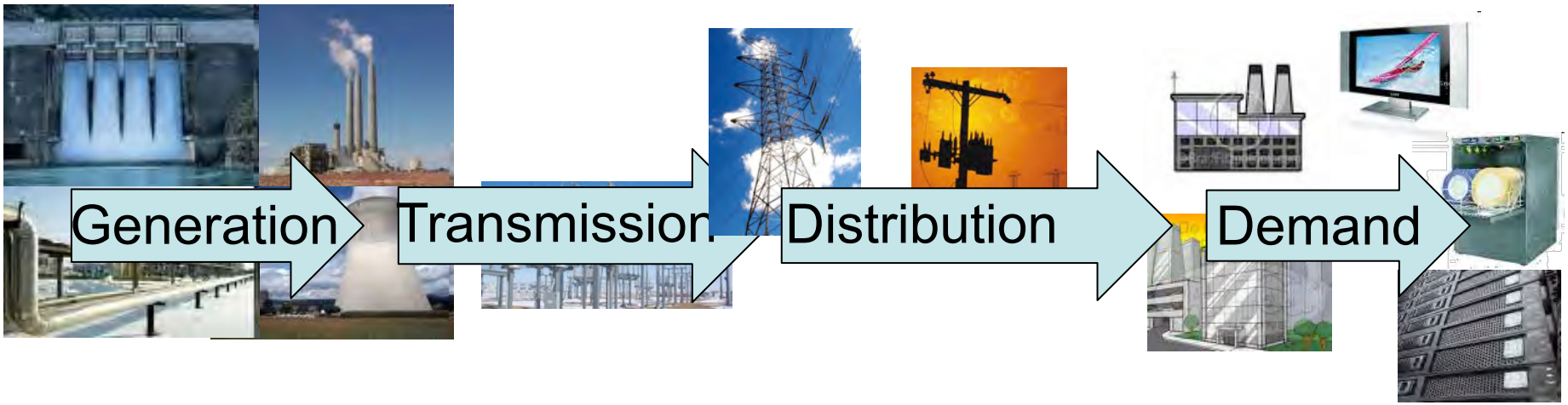
Baseline + Dispatchable Tiers **Oblivious Loads**



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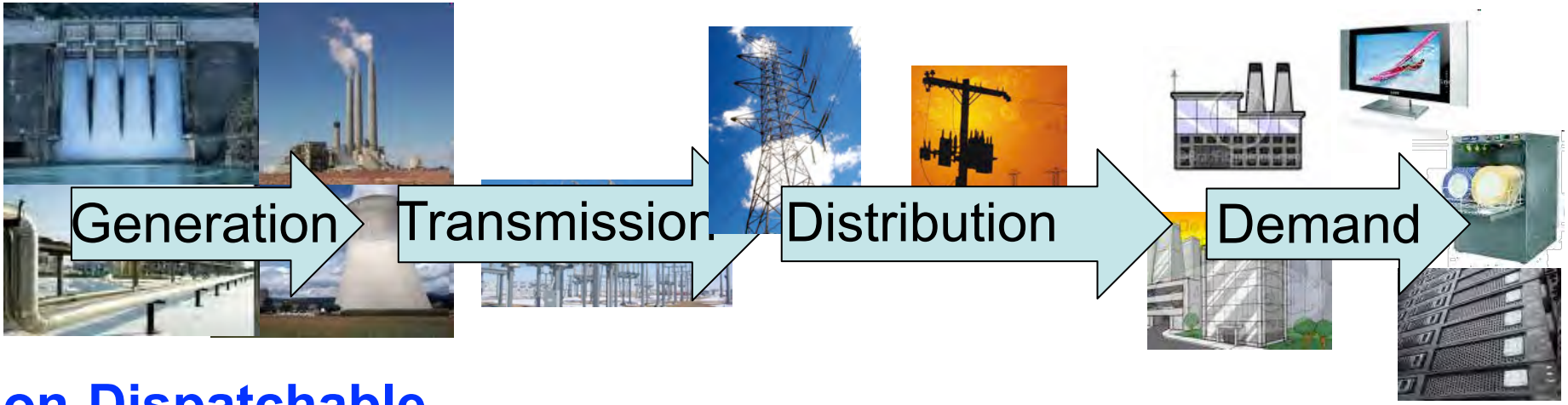

Non-Dispatchable Sources

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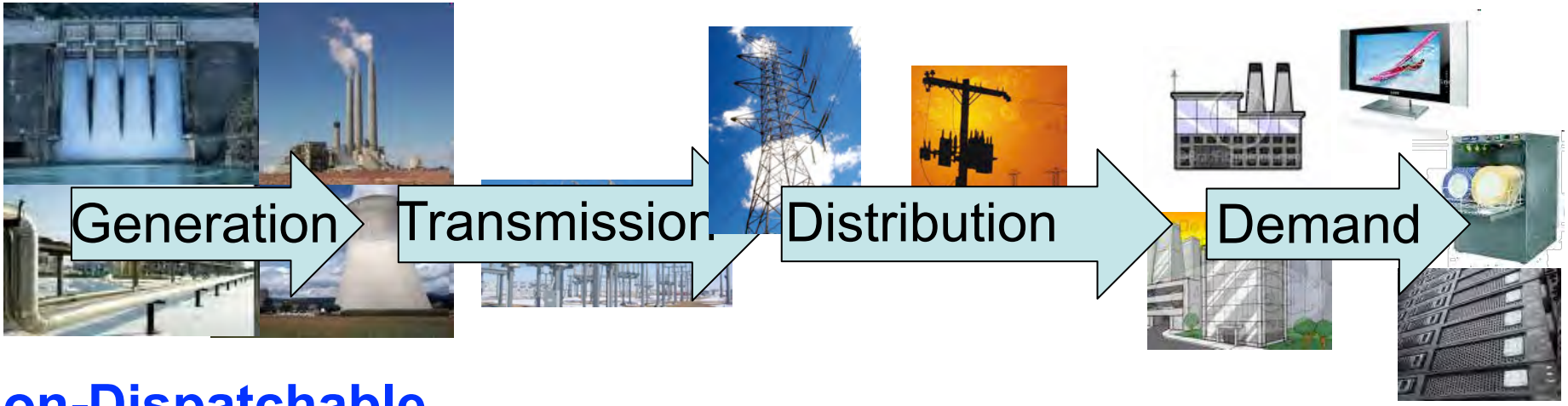

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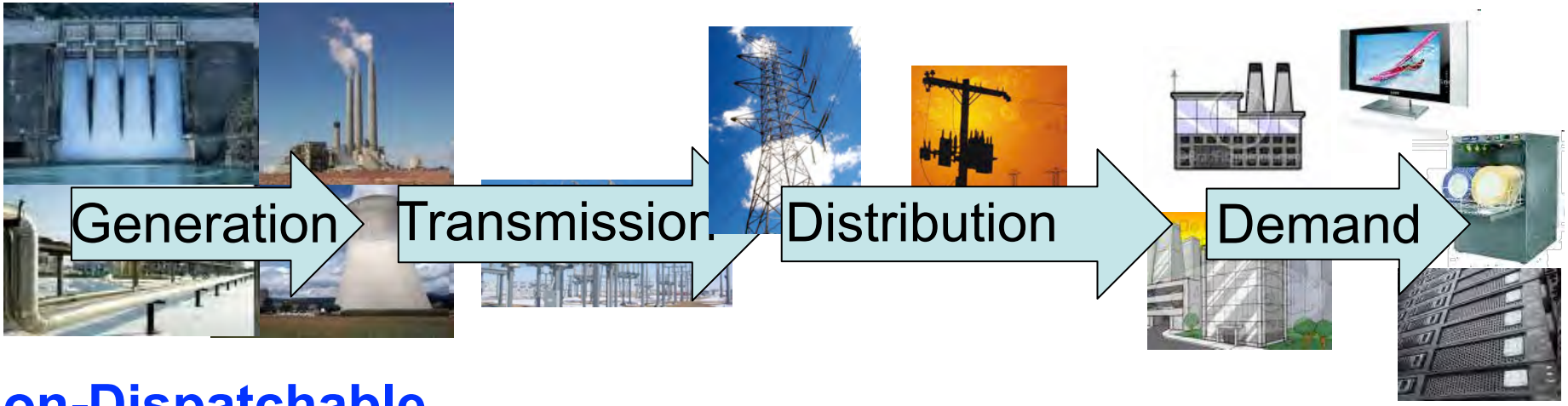

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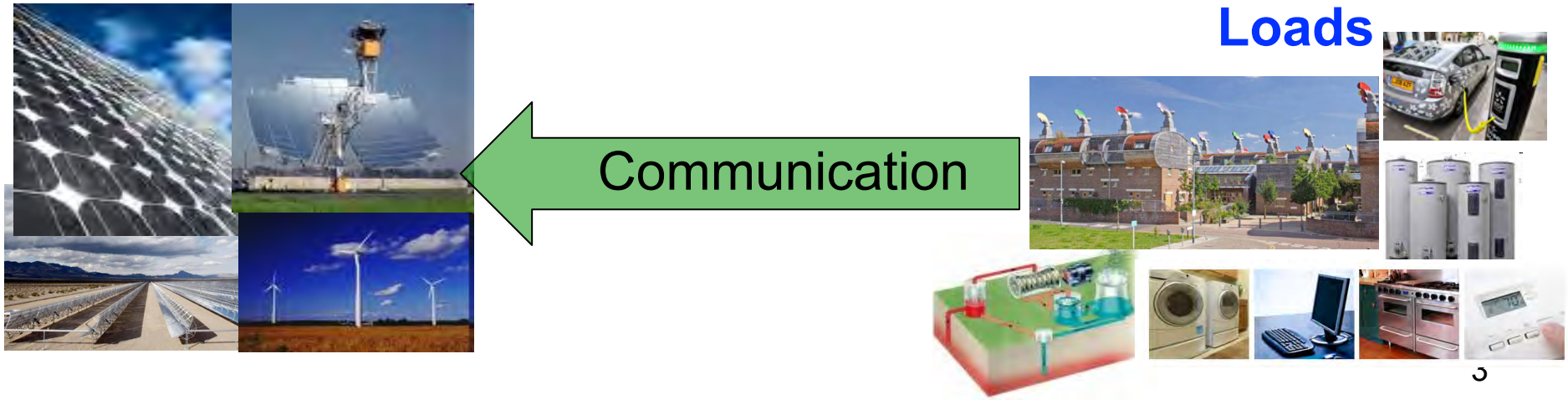

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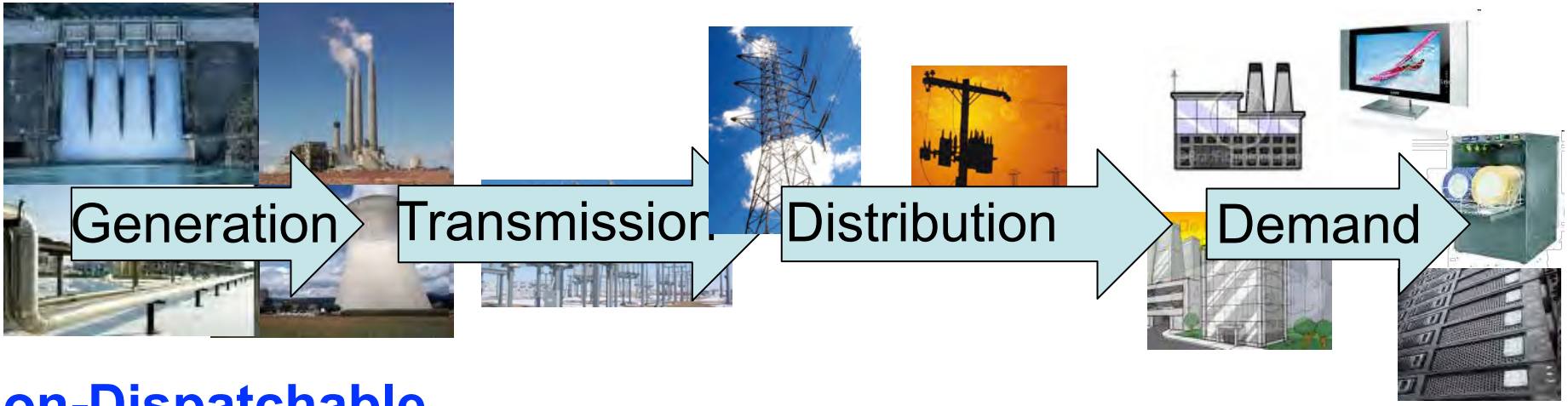

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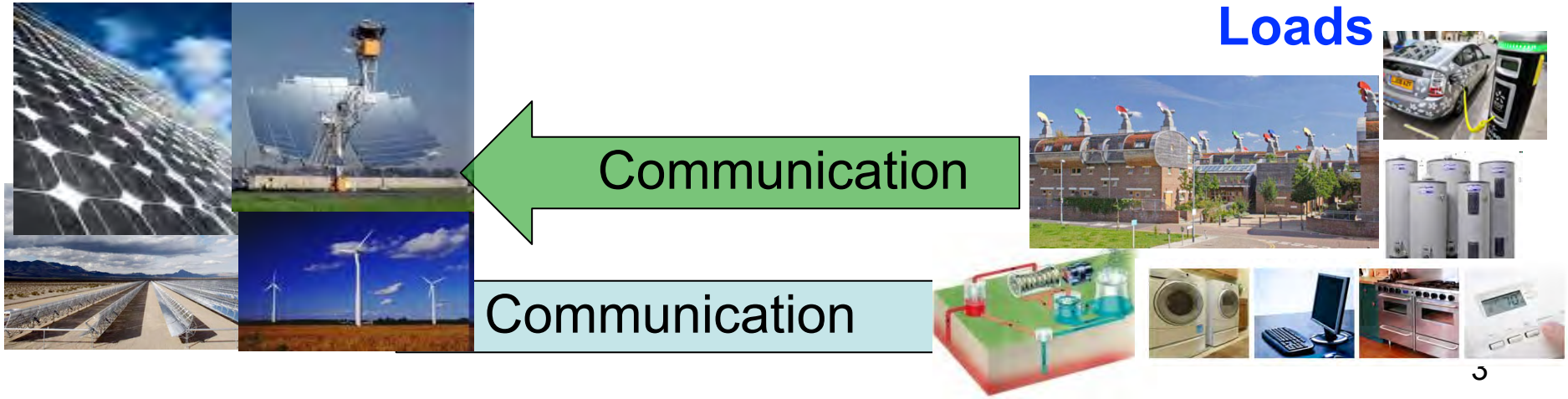

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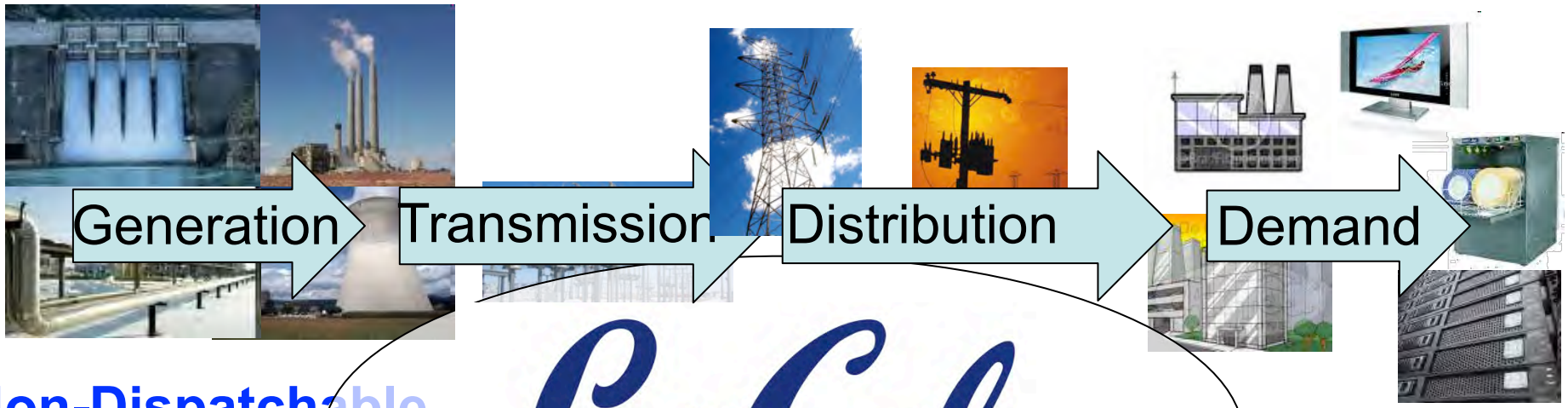


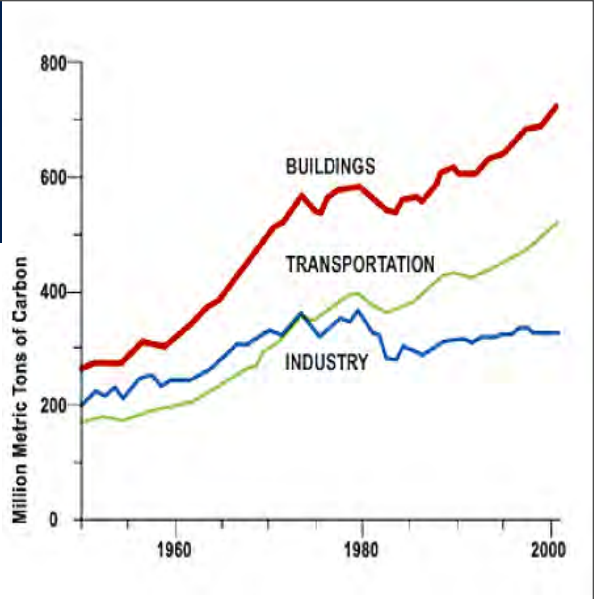
Non-Dispatchable Sources

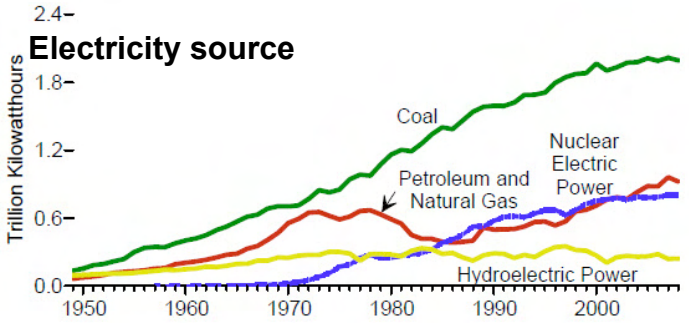
Aware Interactive Loads

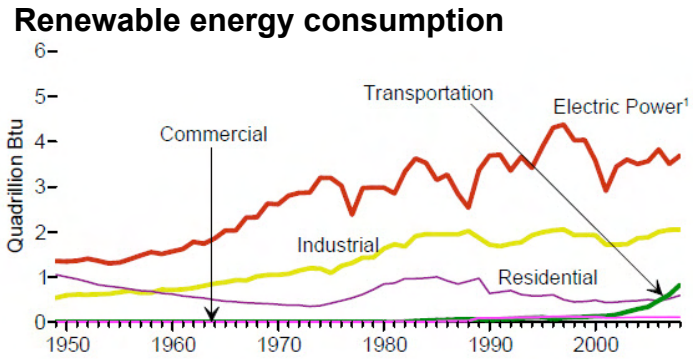
Communication

Communication

Where to Start?







Where to Start?

- Buildings
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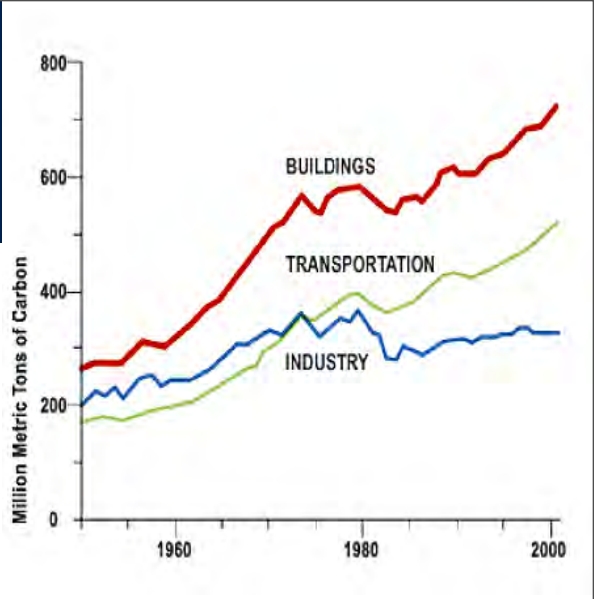

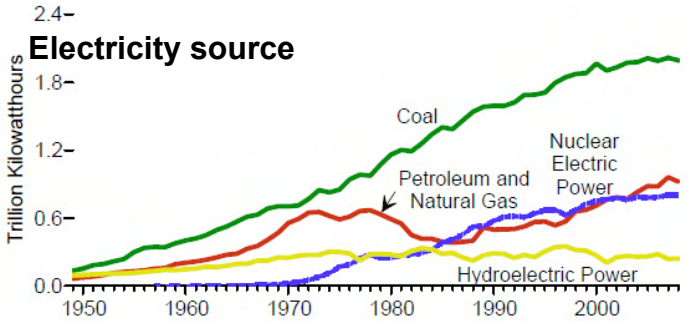

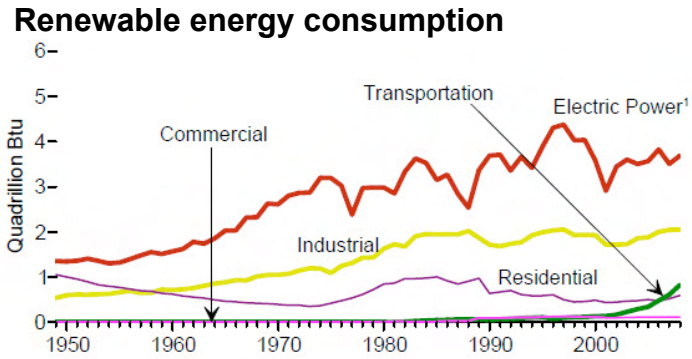

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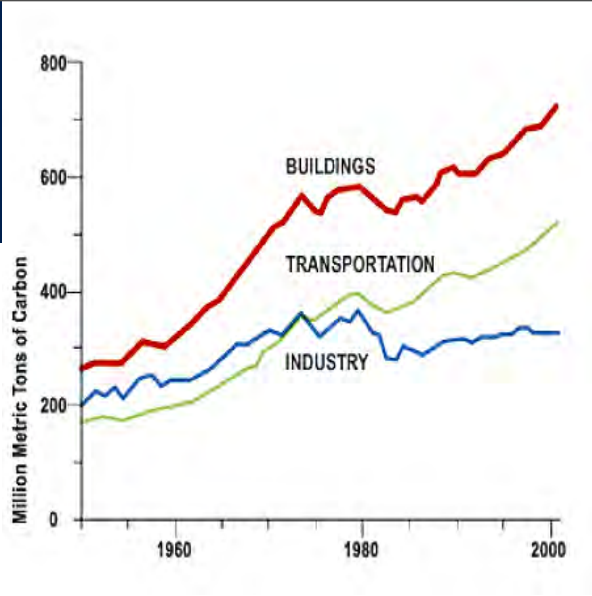

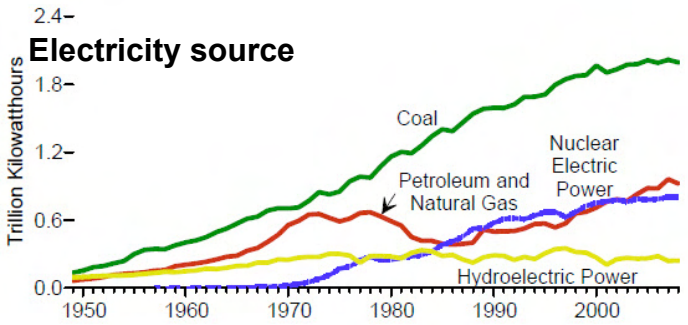

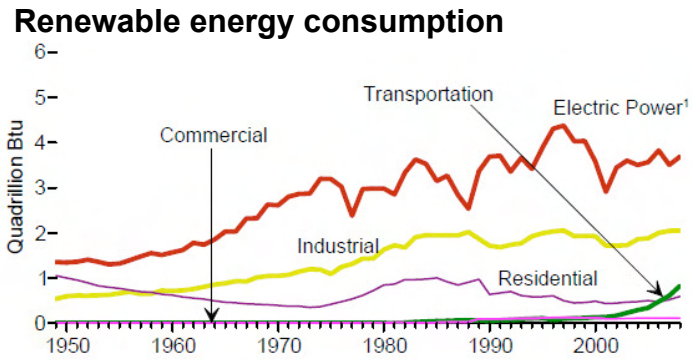

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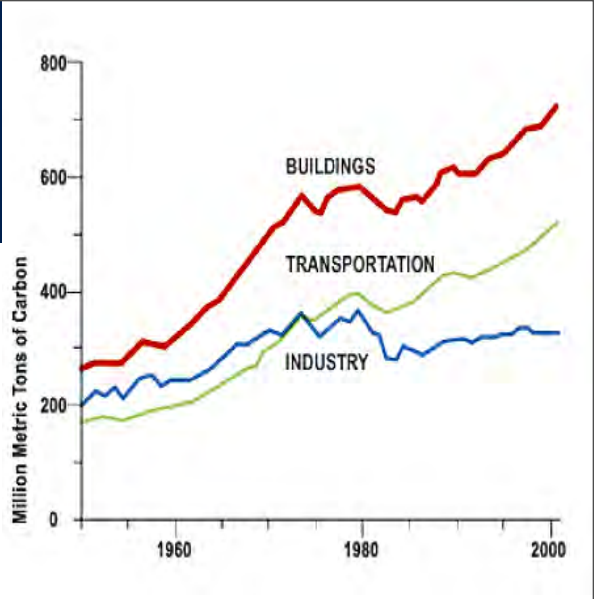
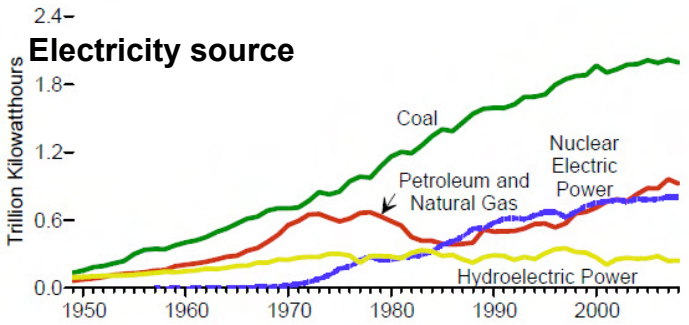
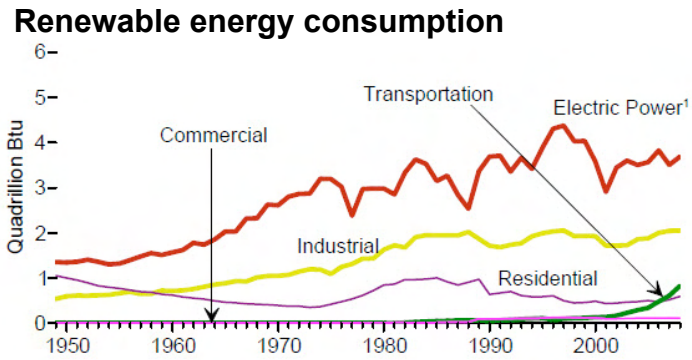
- Prime target of opportunity for renewable supplies







Load-following Supply

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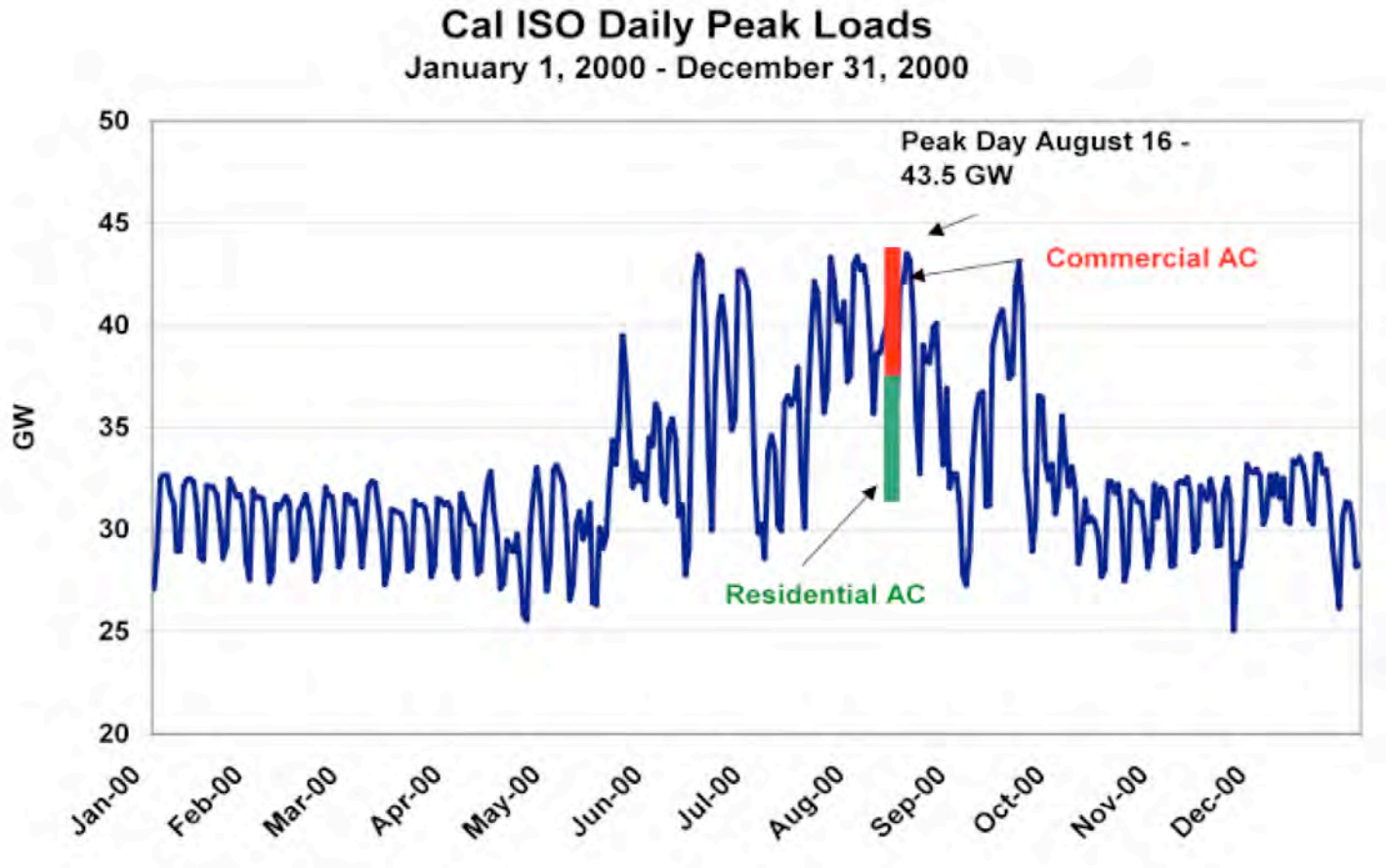
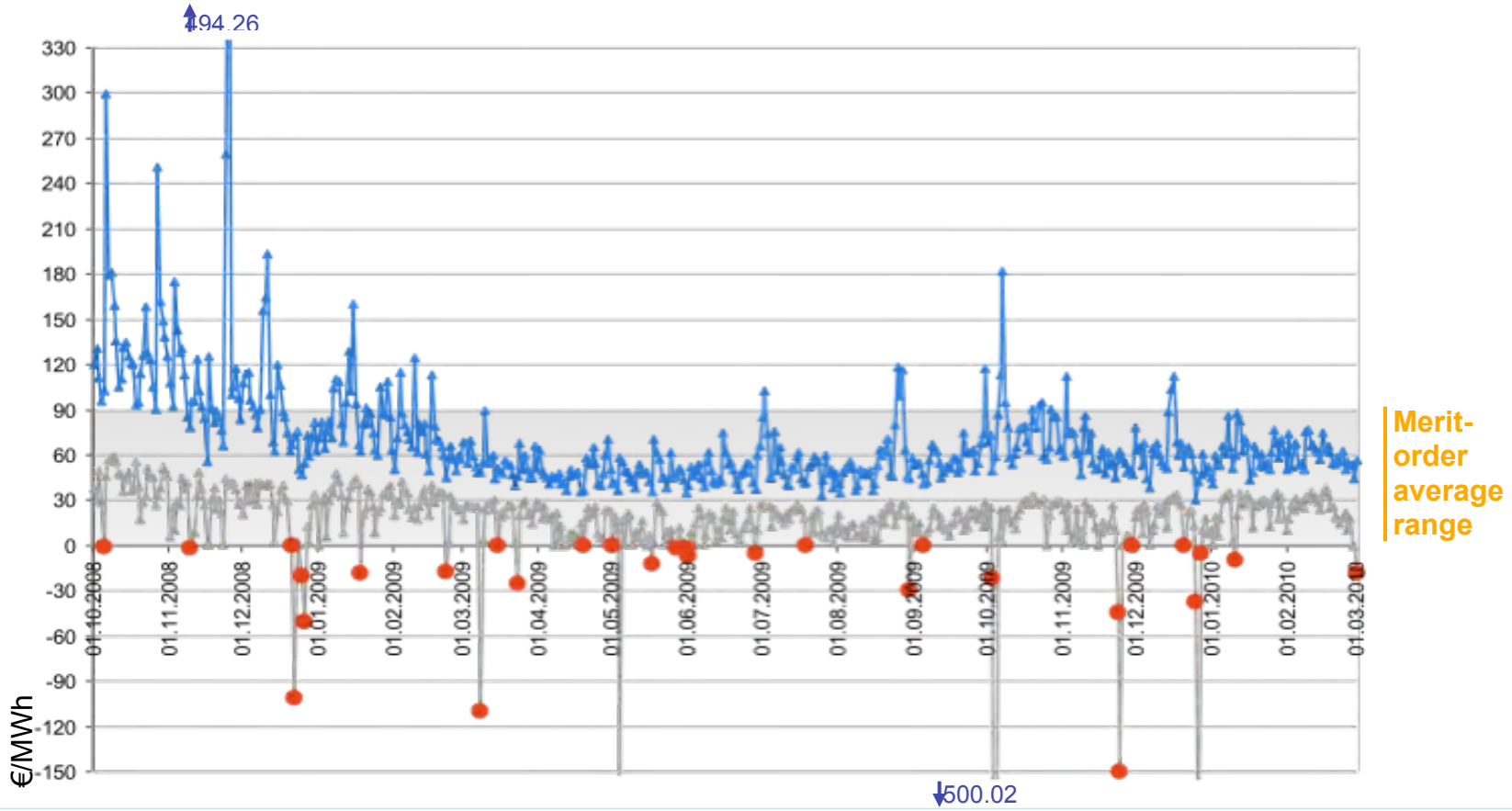


Load-following Supply (really !)

Growing proportion of renewables leads to higher price volatility. October 2008 to March 2010:



Source: EEX spot prices.

Start from Scratch?

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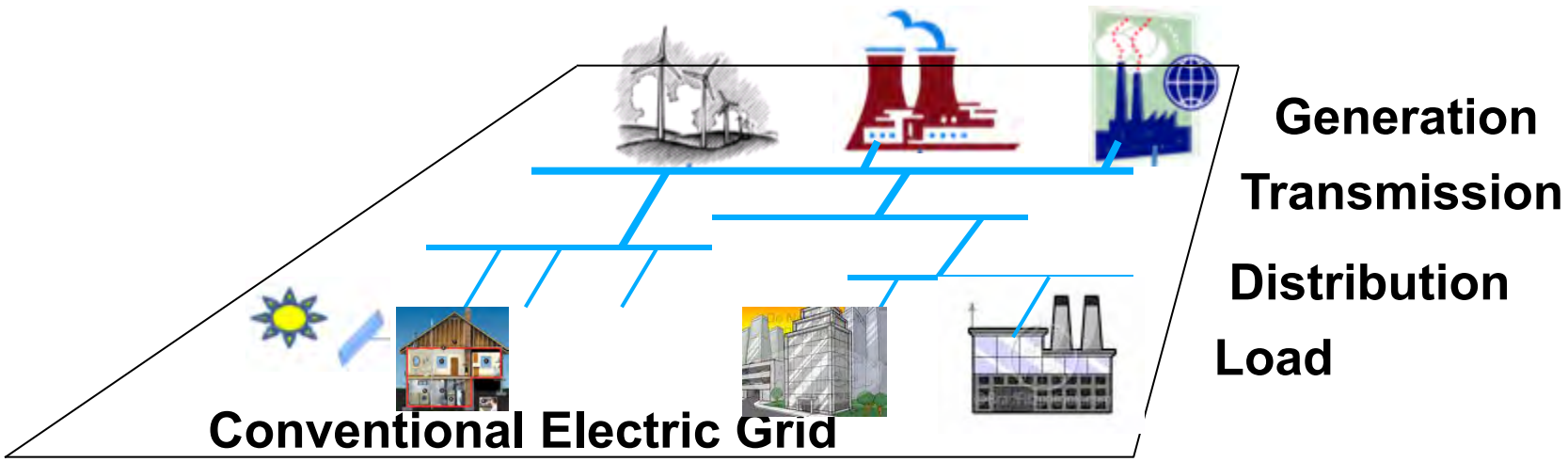
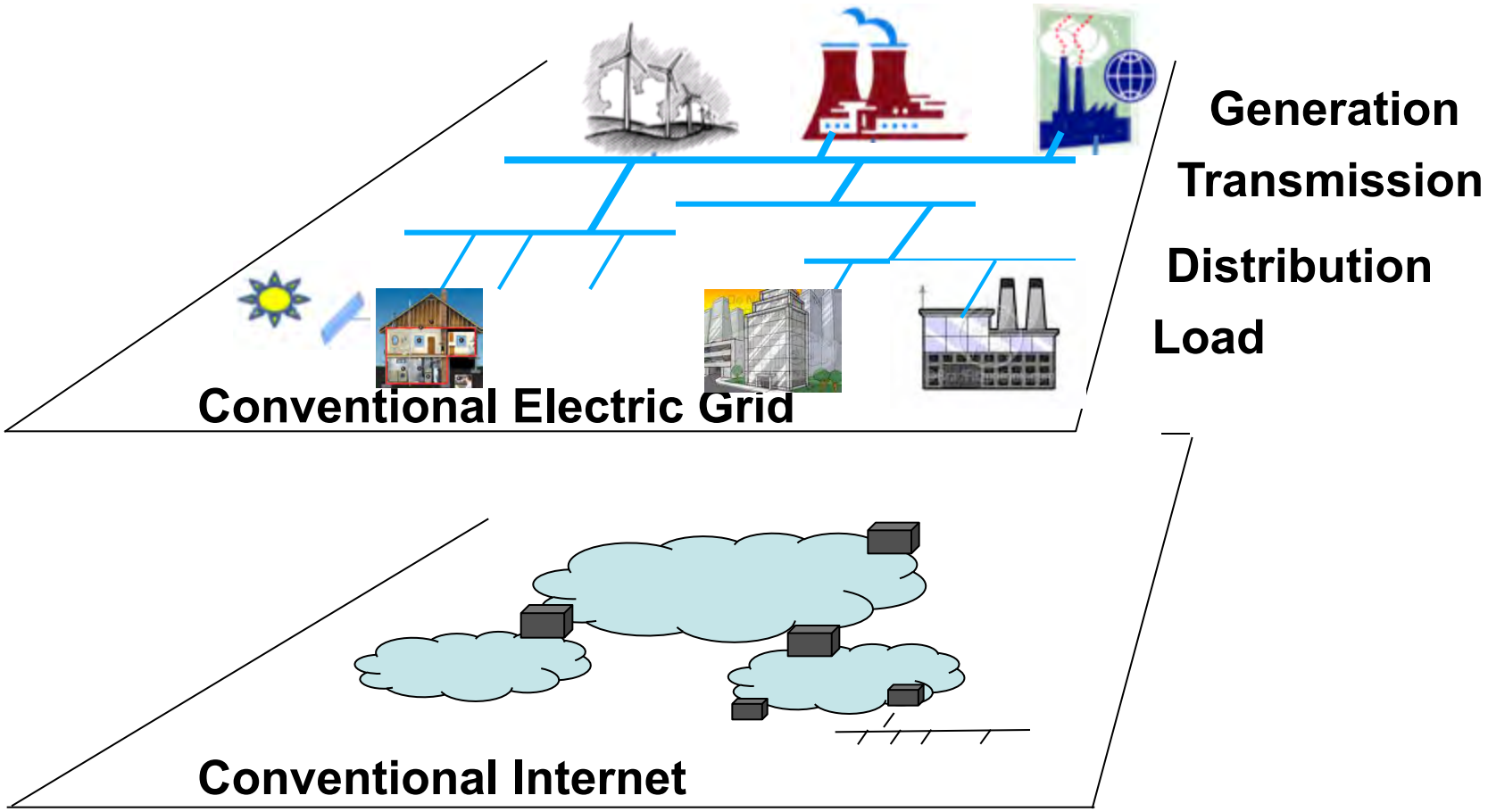
- No!

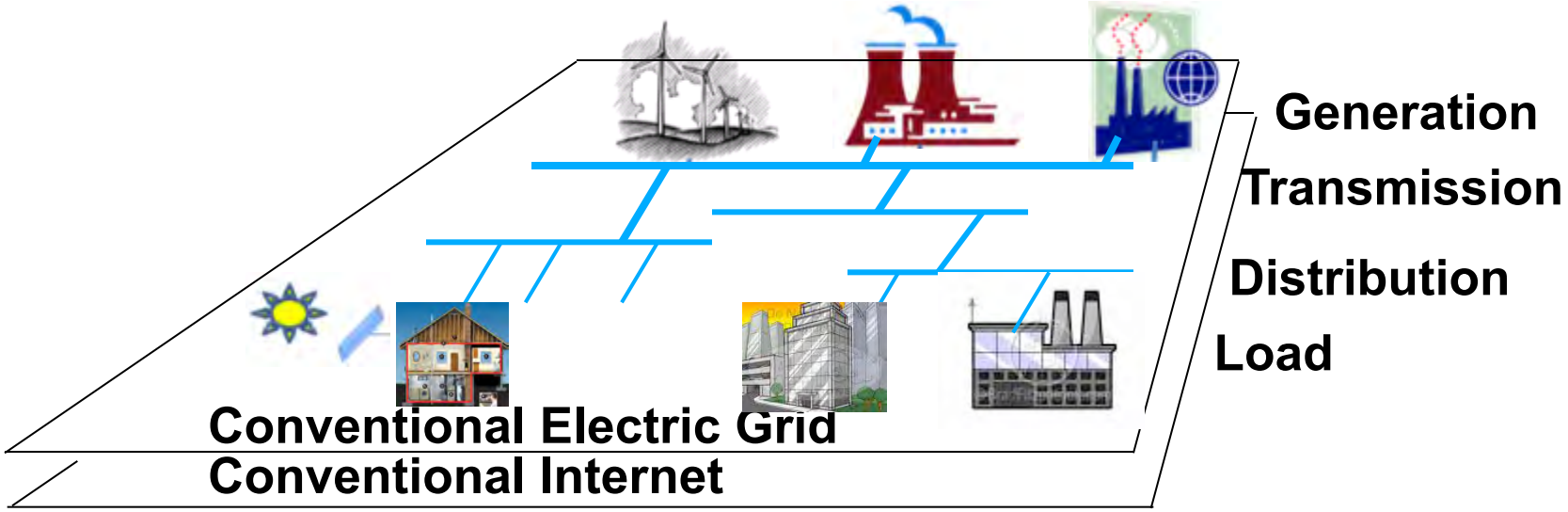
Grid Exists


Generation
Transmission
Distribution
Load
Conventional Electric Grid

Internet Exists



Intelligent Energy Network as Overlay on Both



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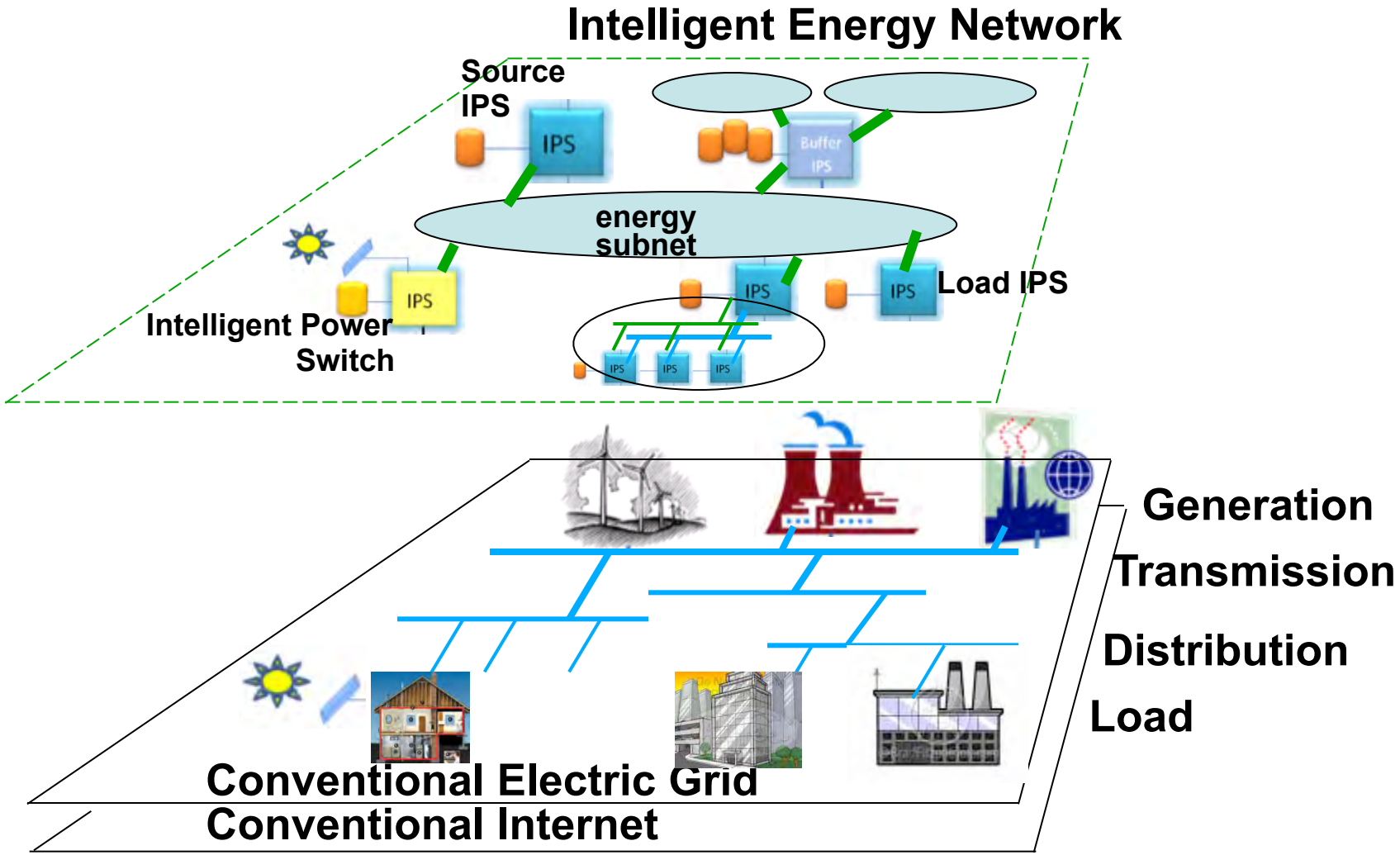

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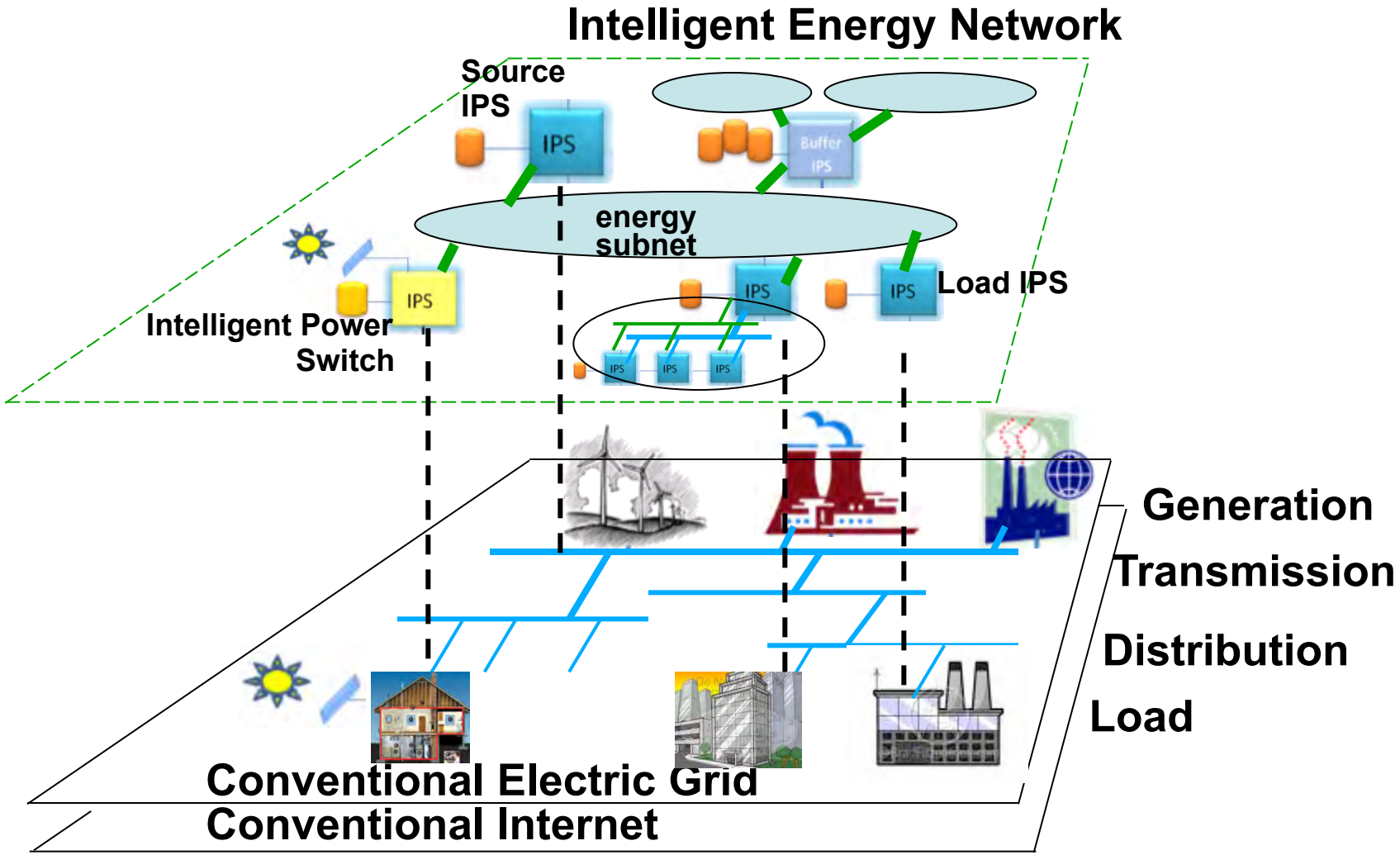

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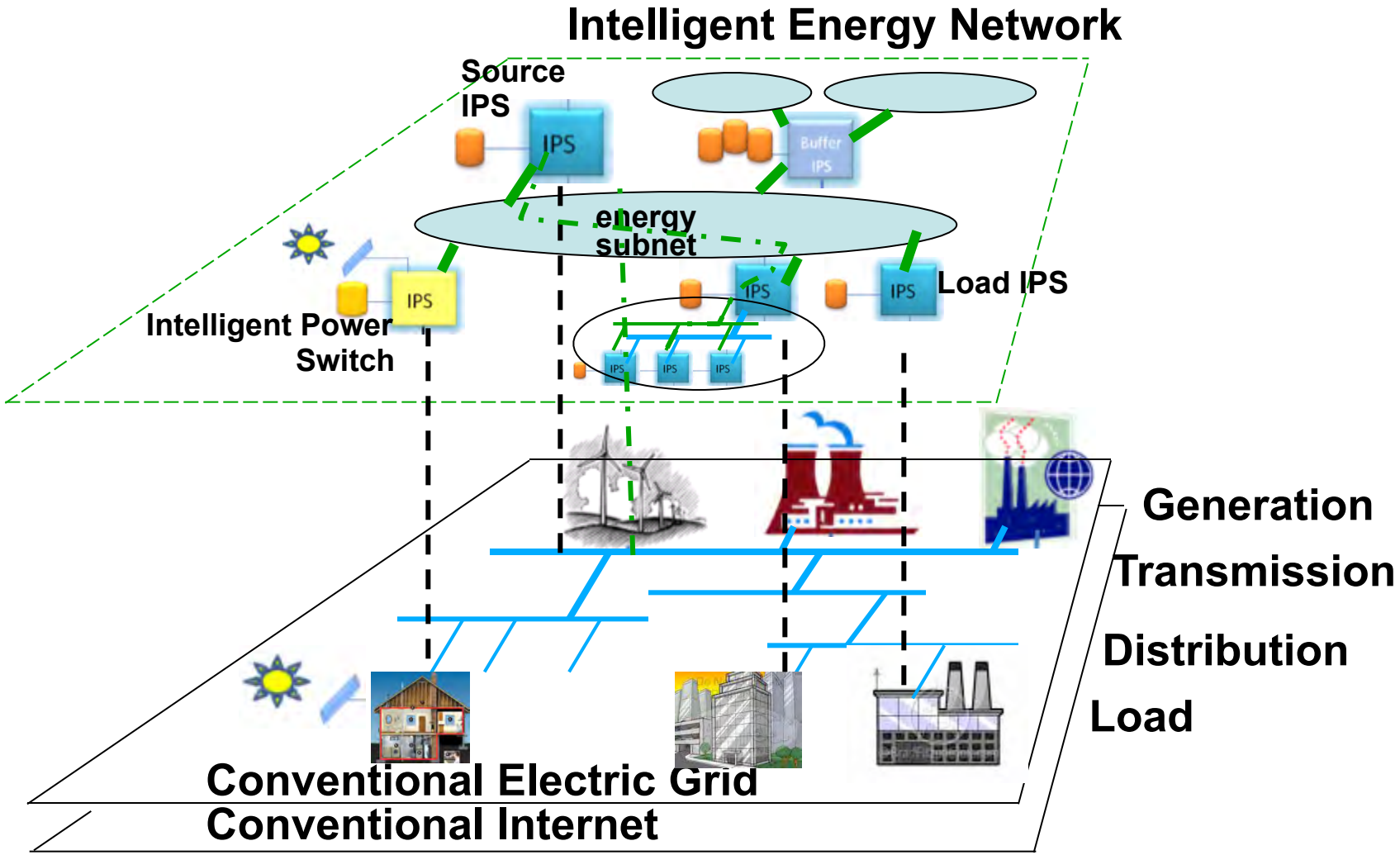
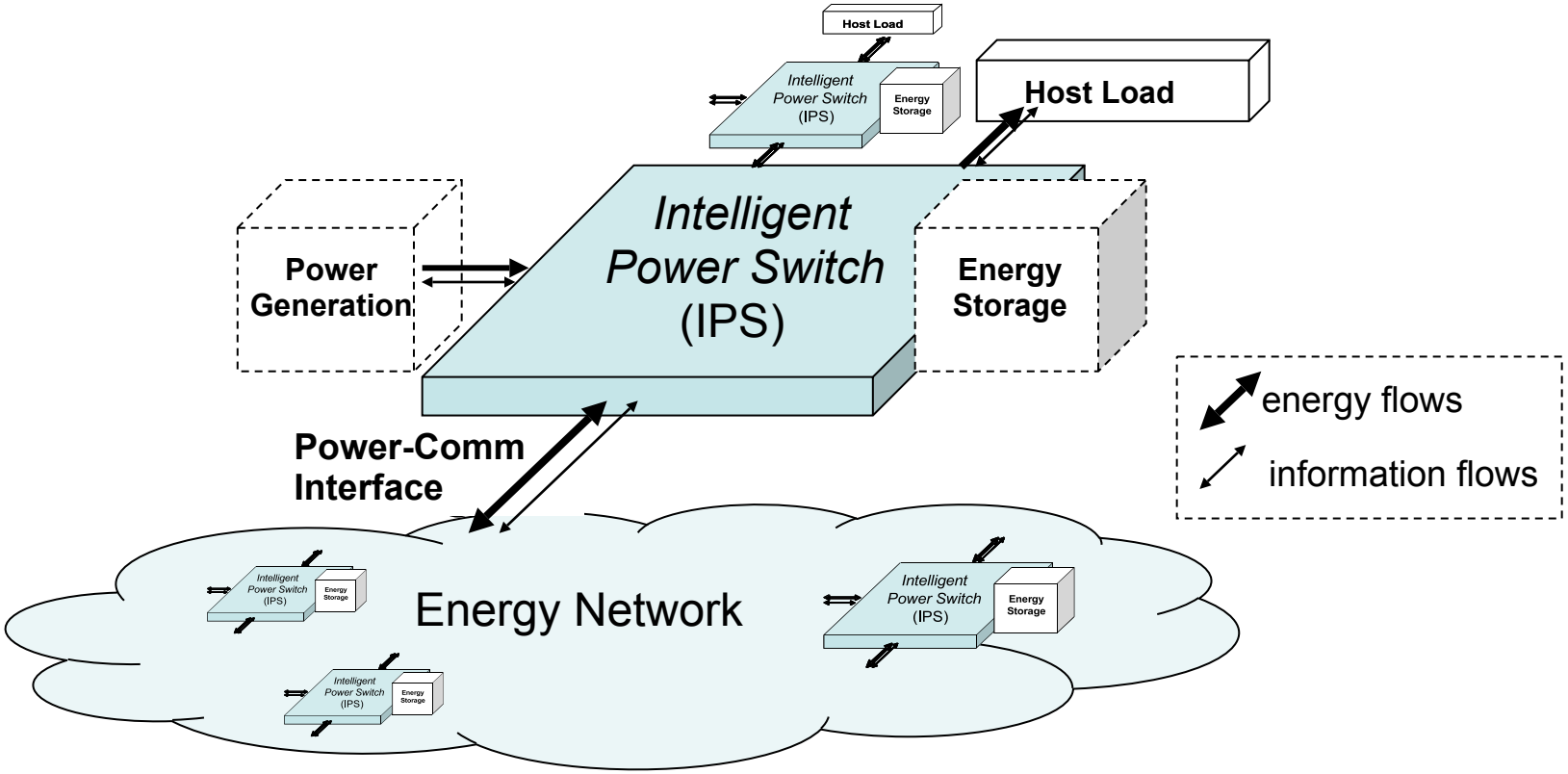


Intelligent Power Switch



- Scalable Building Block
  - Network + Power
  - Monitor, Predict, Communicate, Control
- Decouple: Buffering vs Scheduling

A Cooperative Grid

Internet

Grid

comm

power

CT

AHU

Chill

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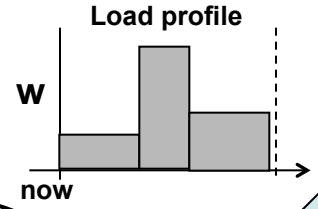

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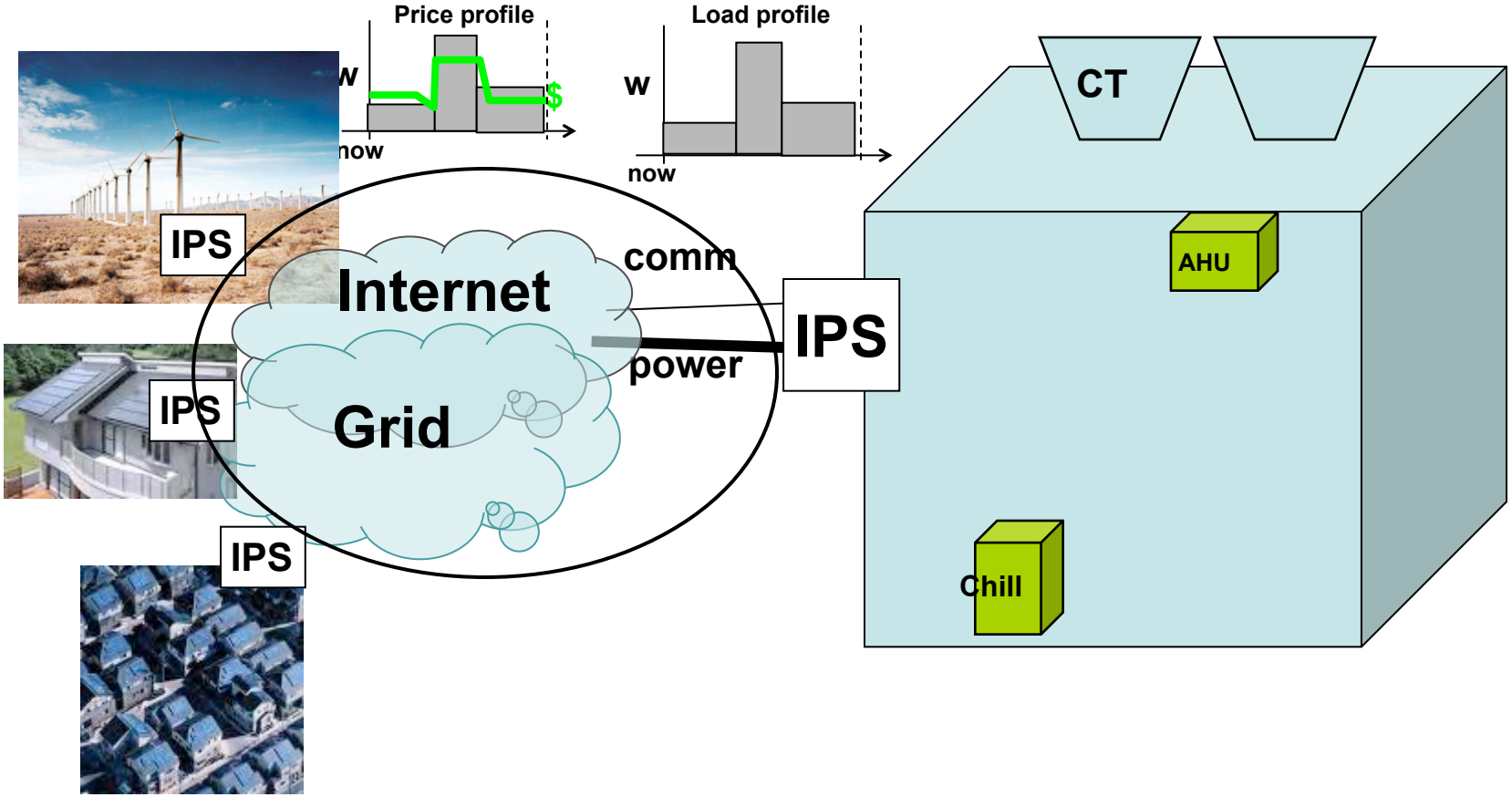

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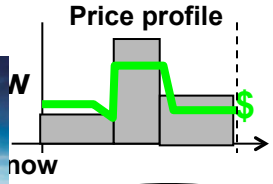

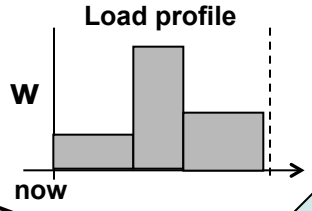

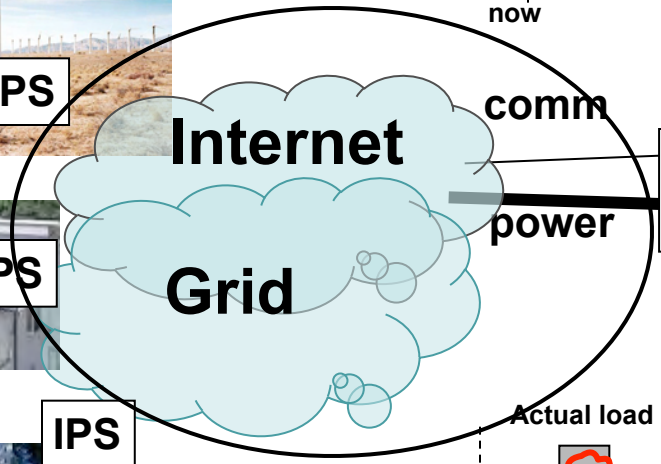

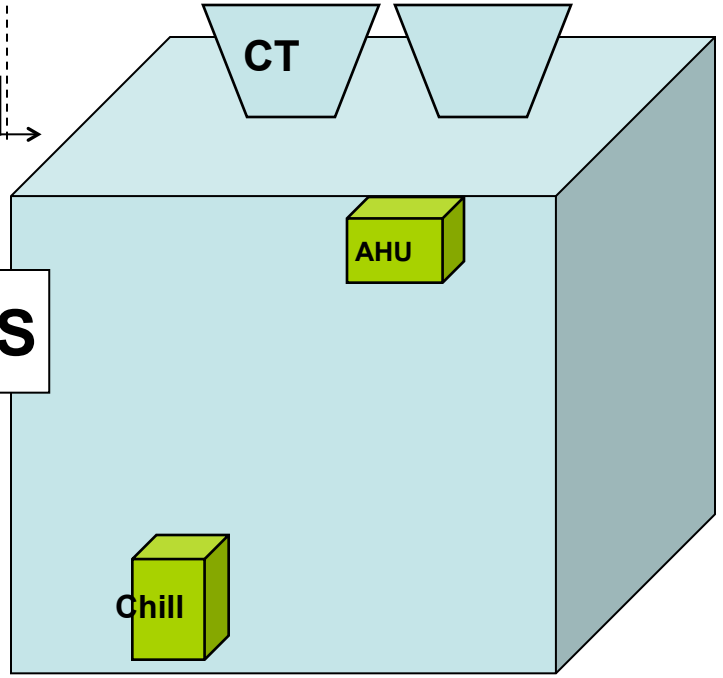

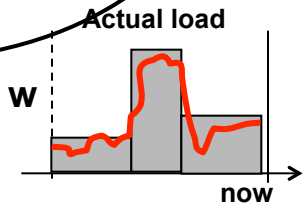

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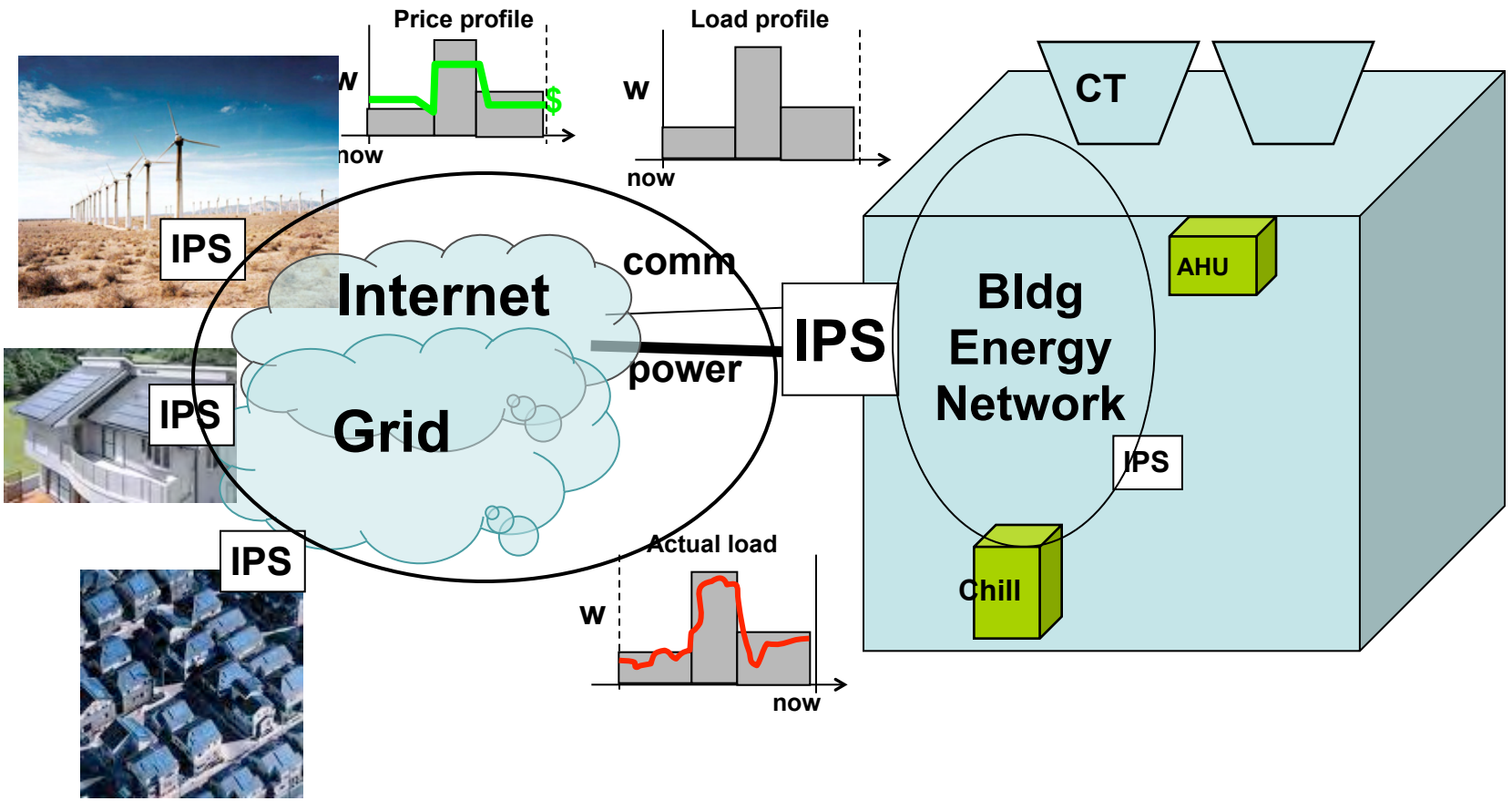

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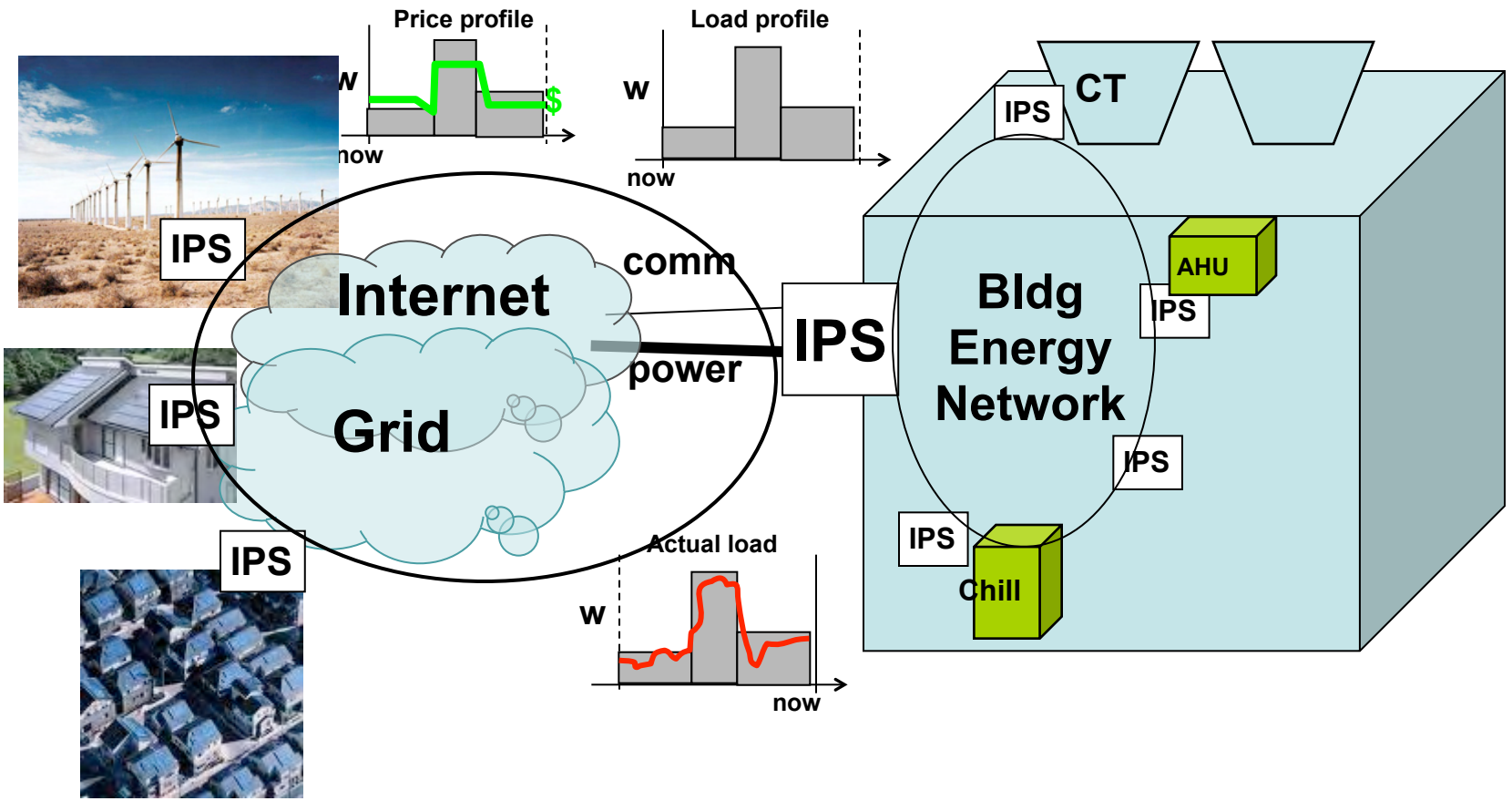

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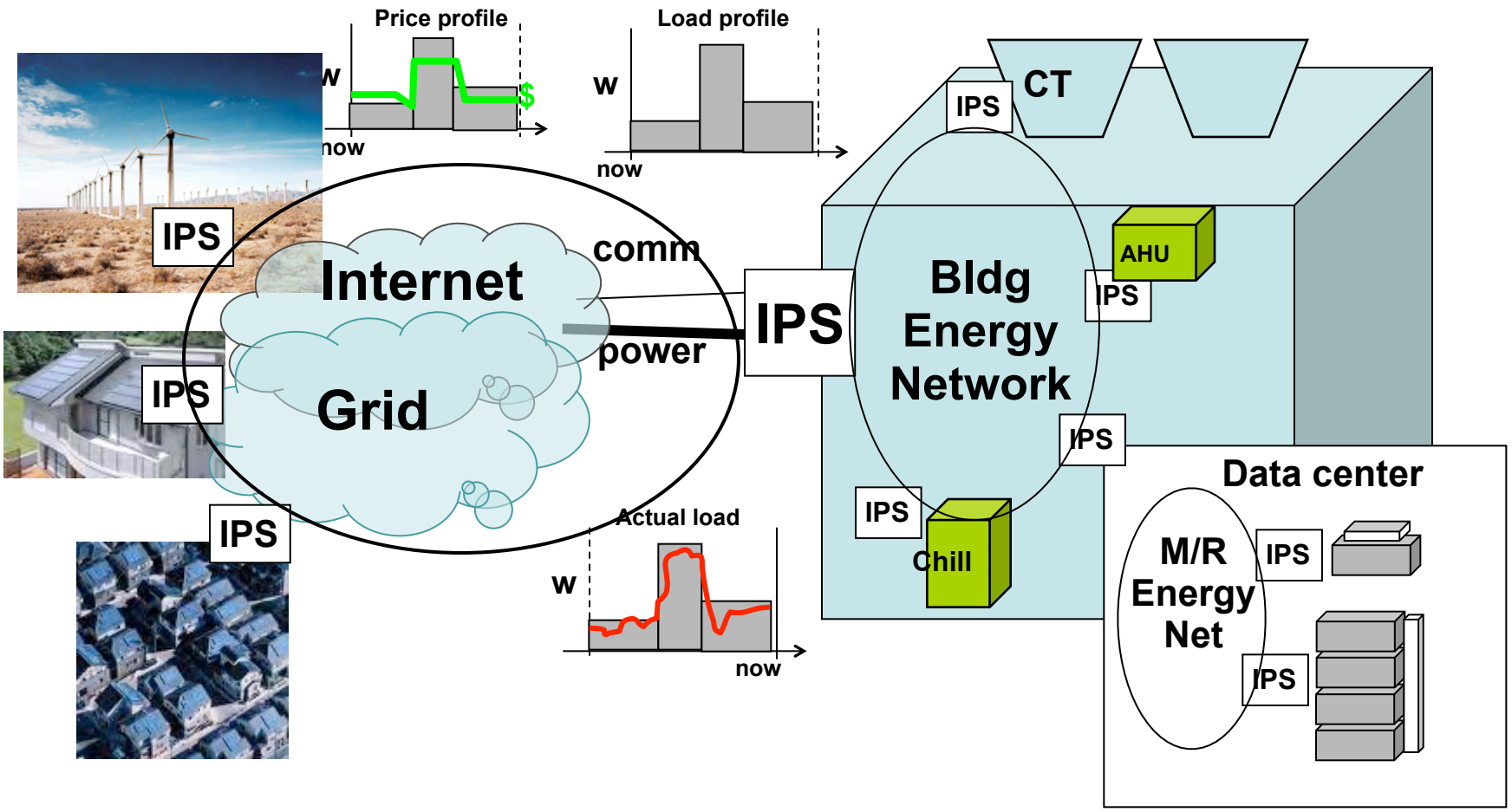

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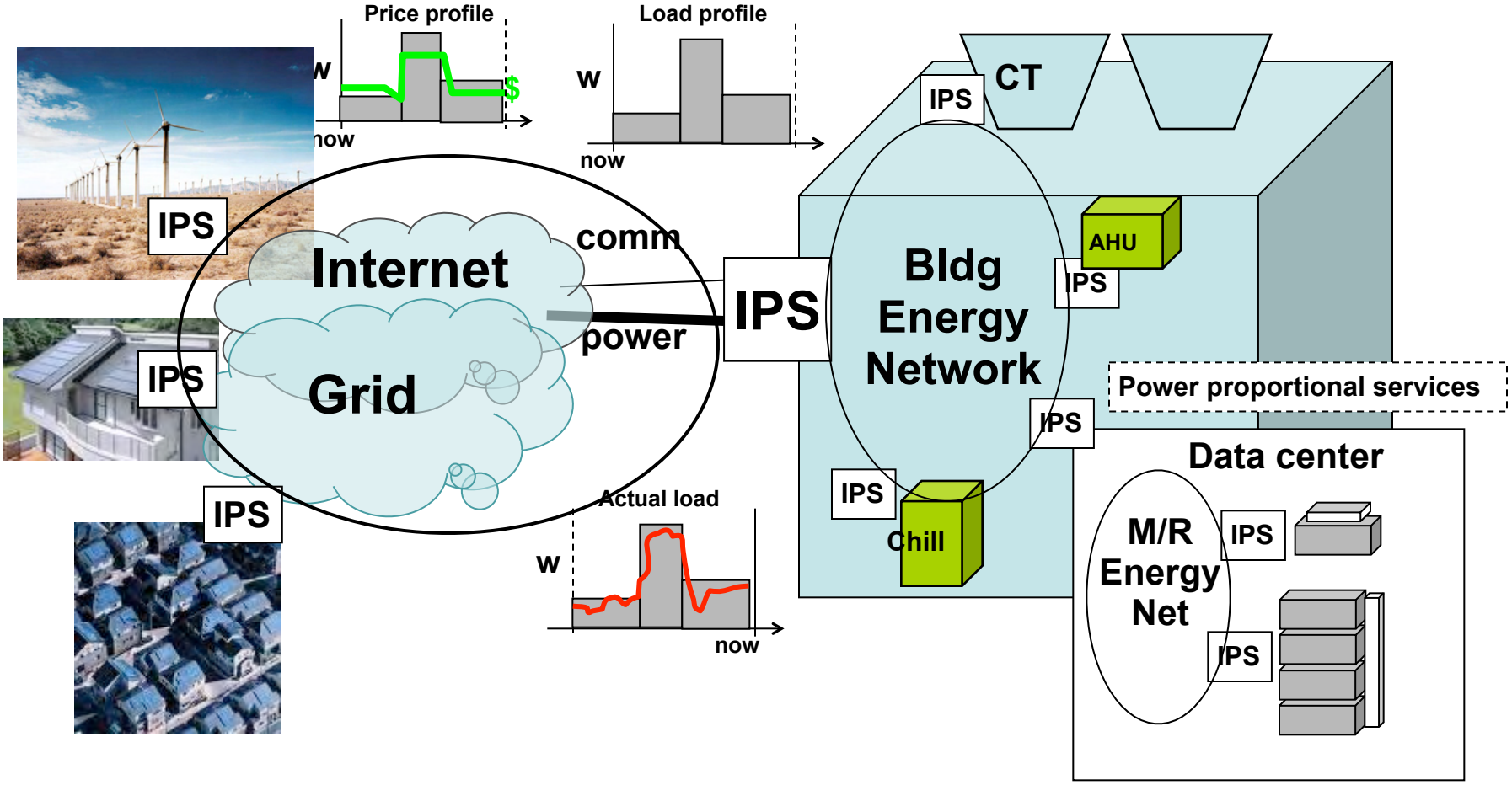

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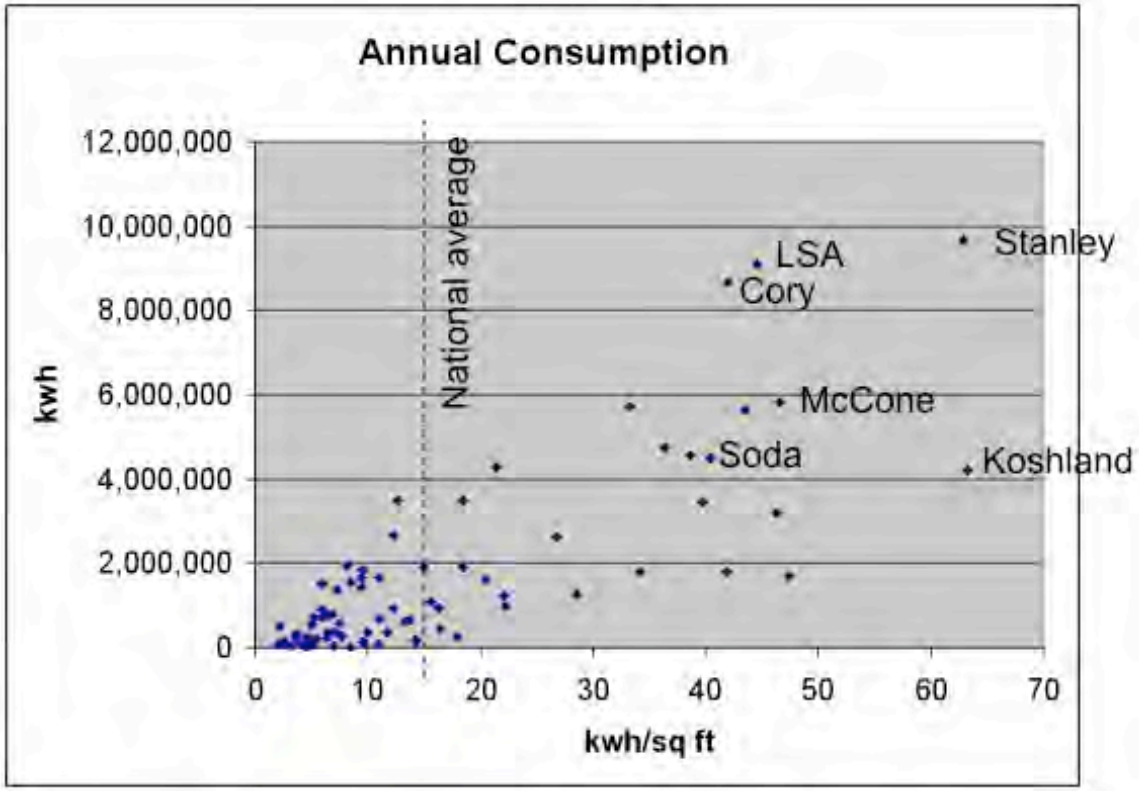
- Negotiated Grid / Load / Human Interaction
  - Plan, Forecast, Negotiate, Manage

Our Buildings



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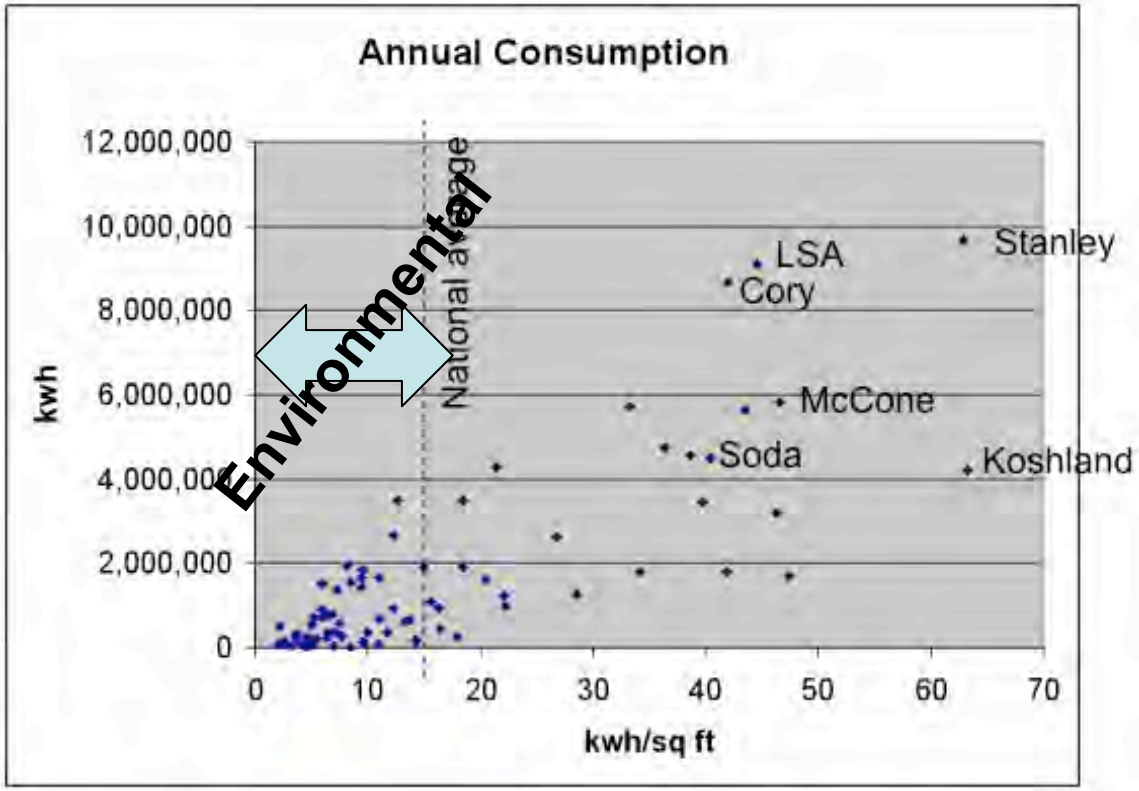

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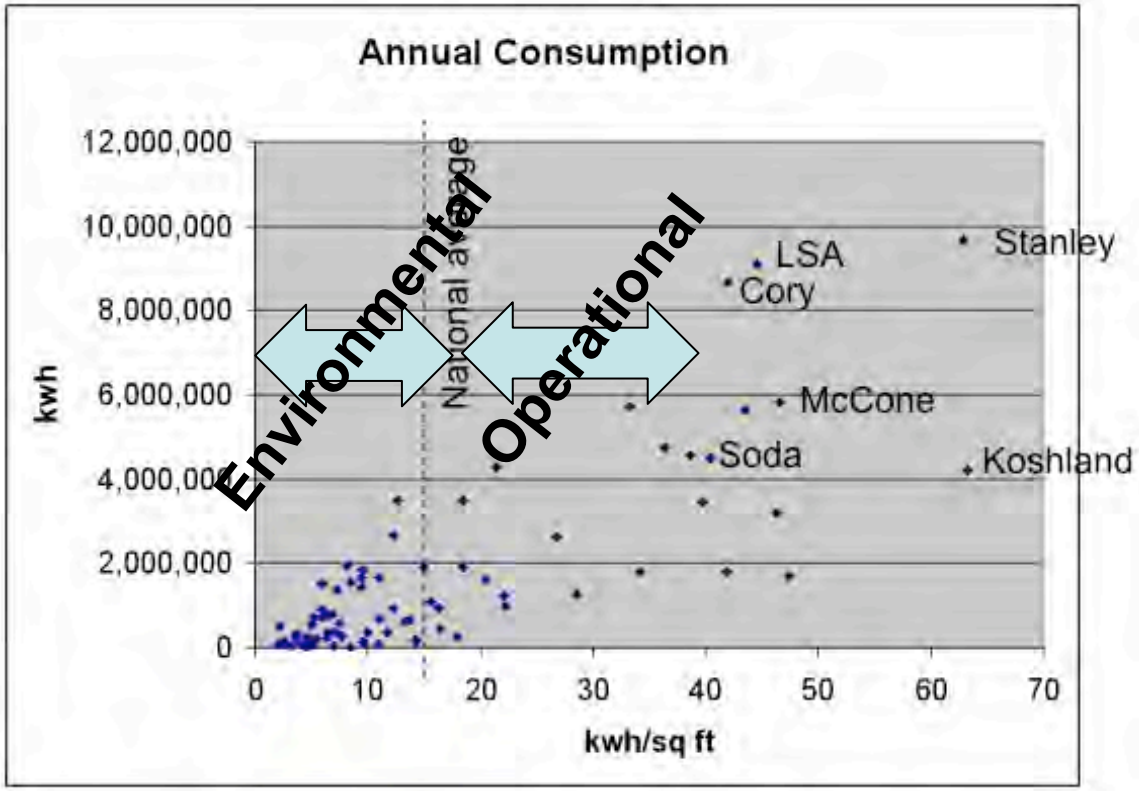

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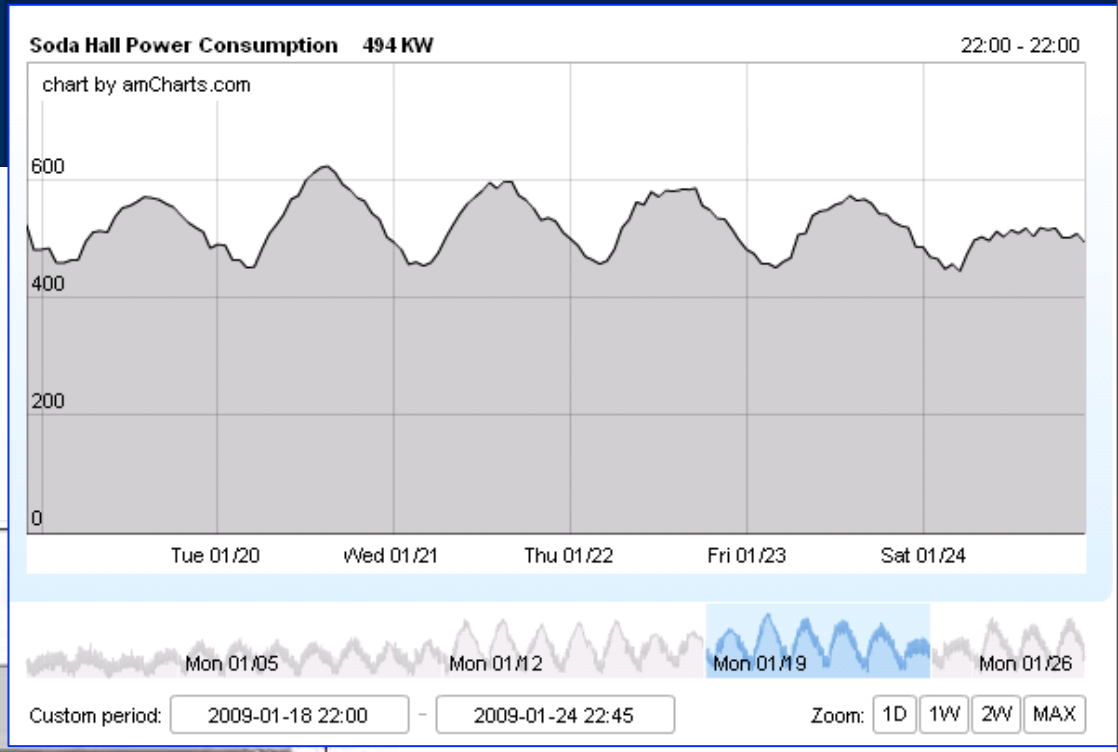

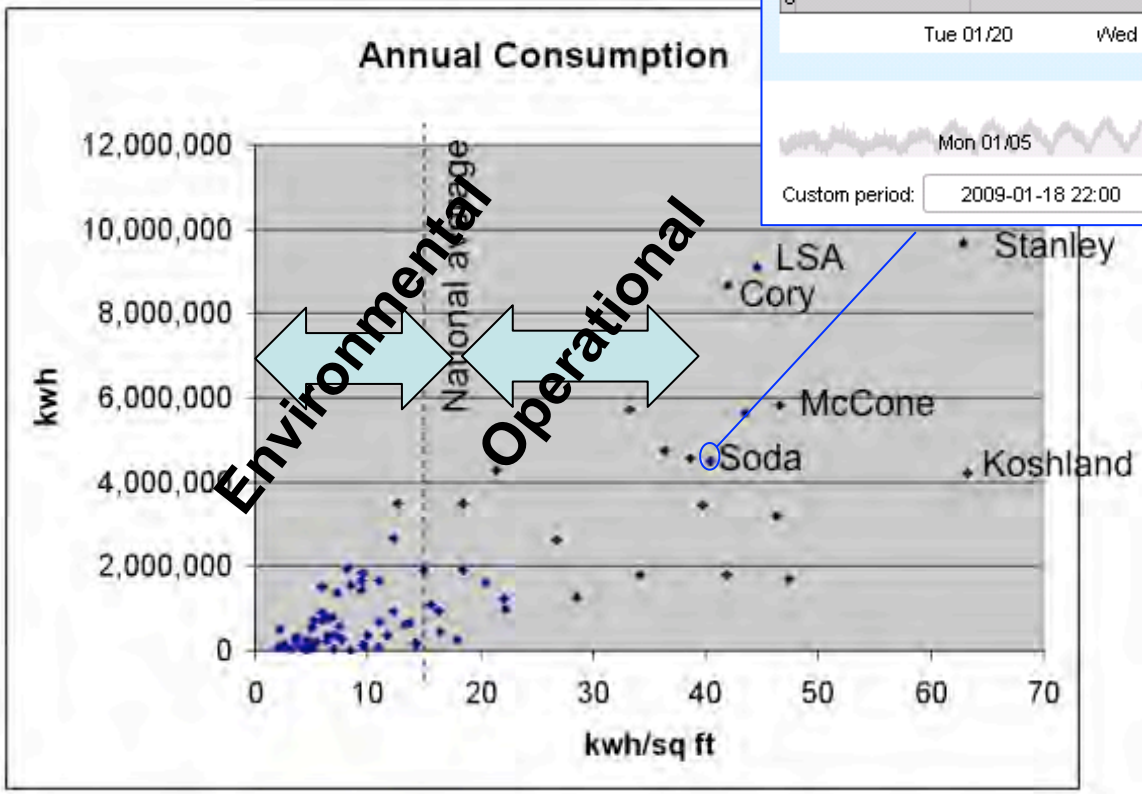

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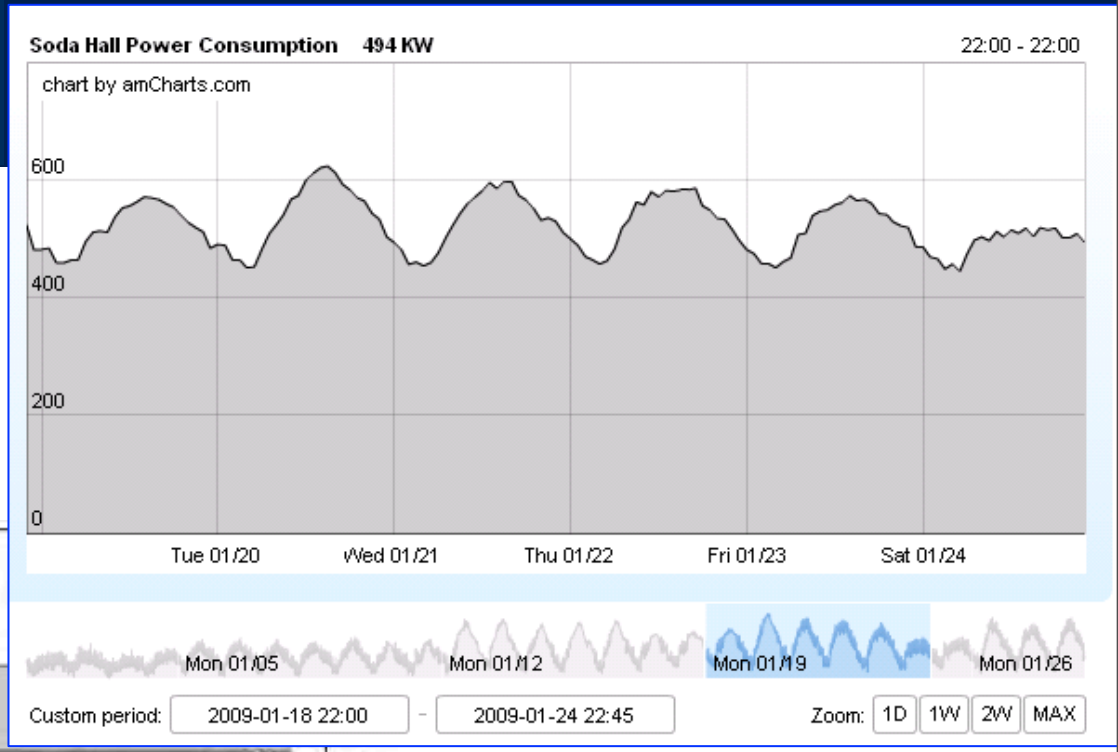
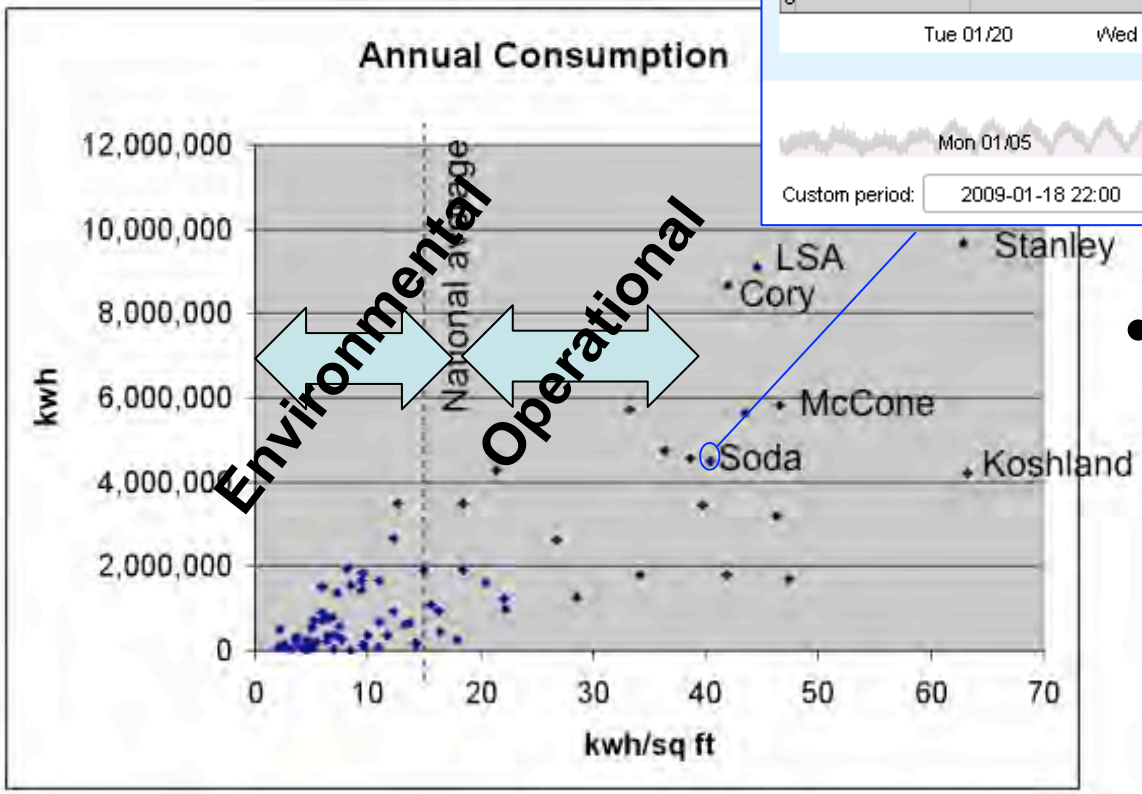
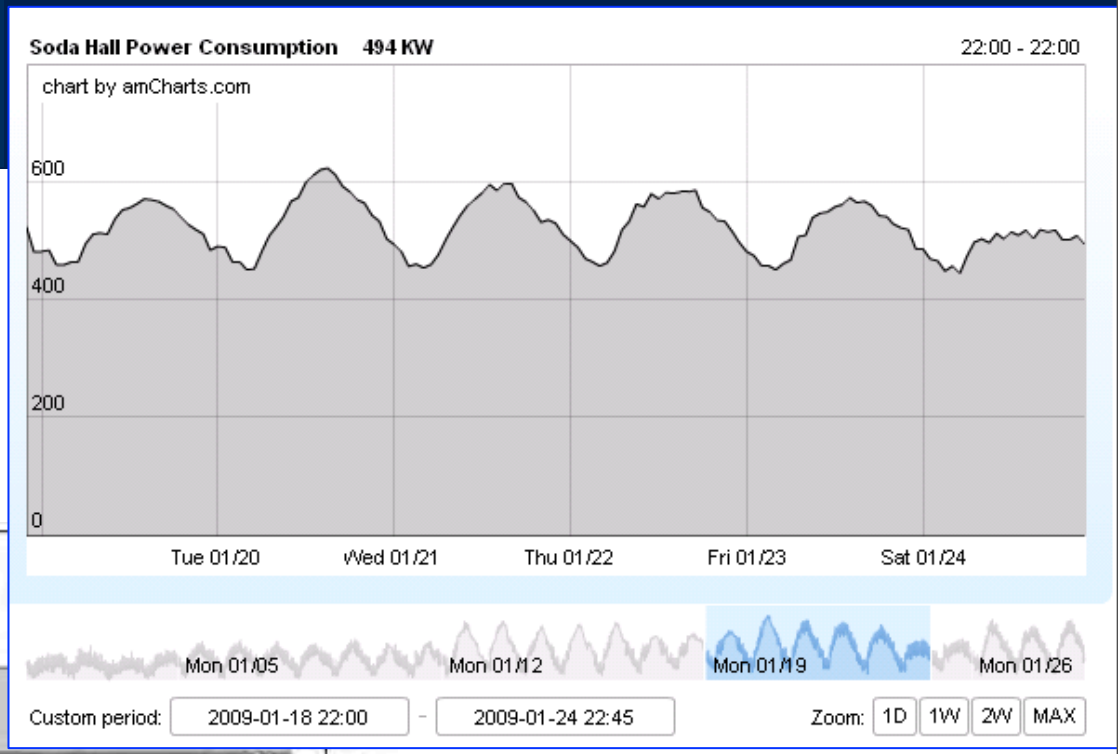
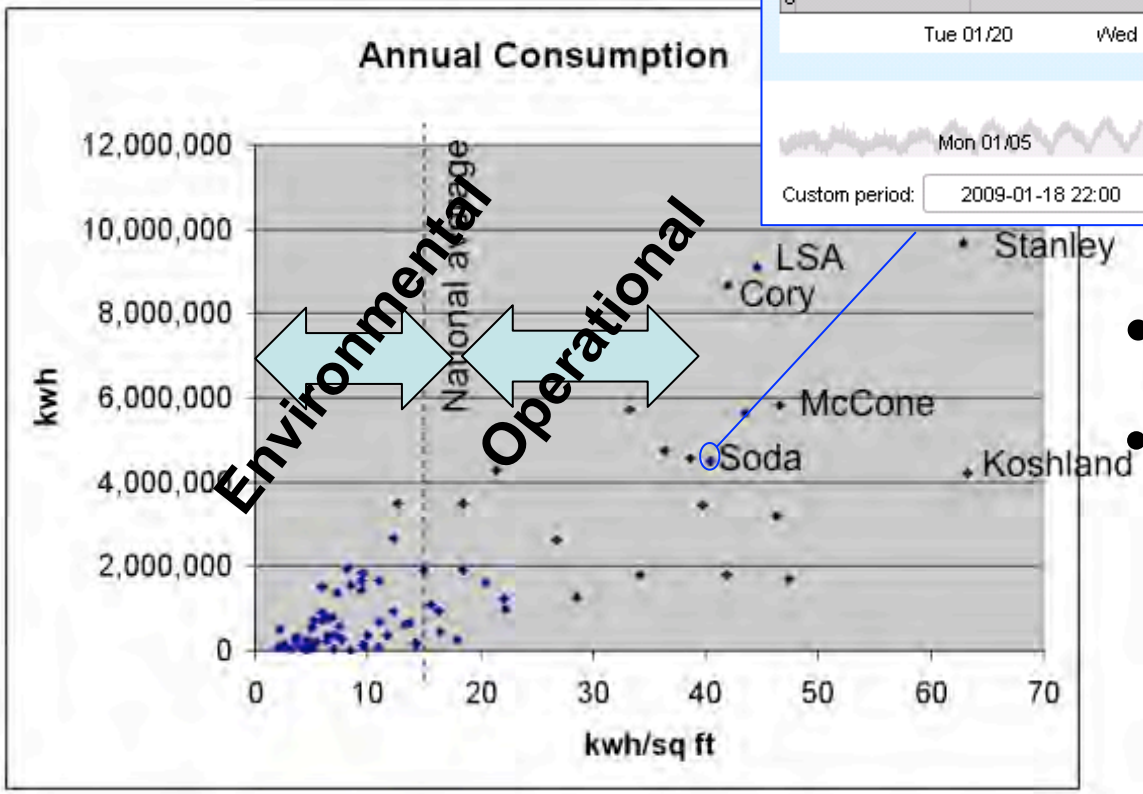




- Wasteful

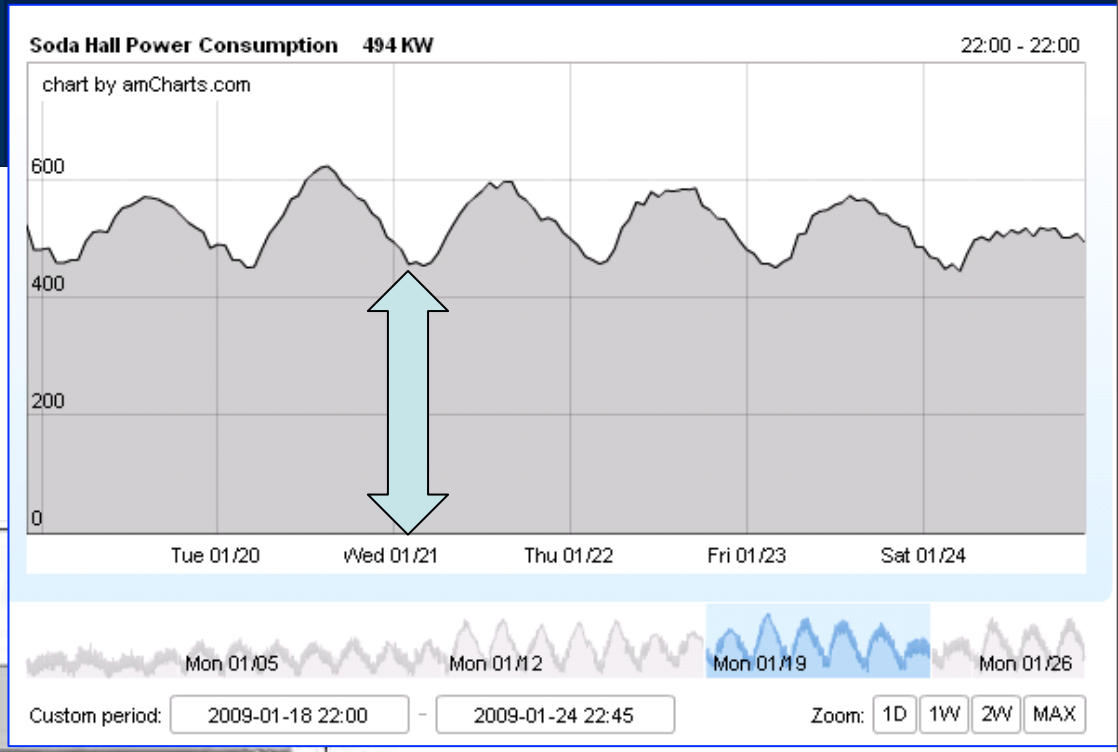
Our Buildings

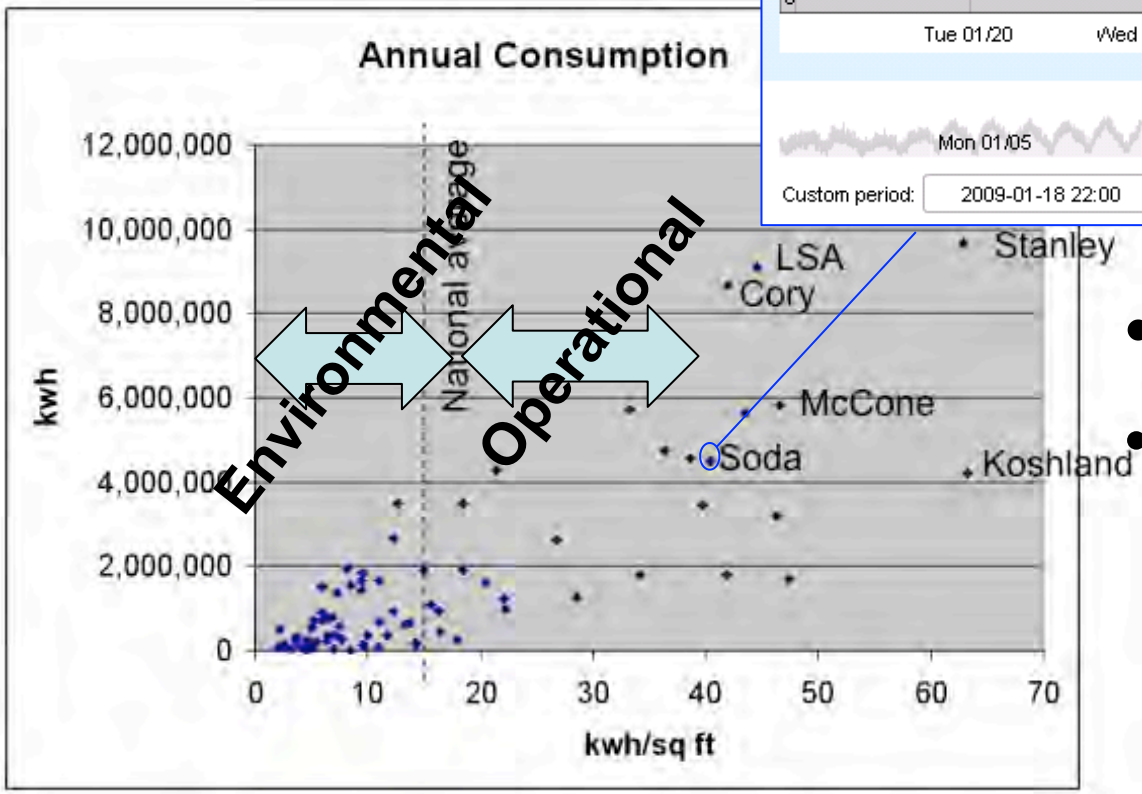




- Wasteful
- <20 % Power Prop.

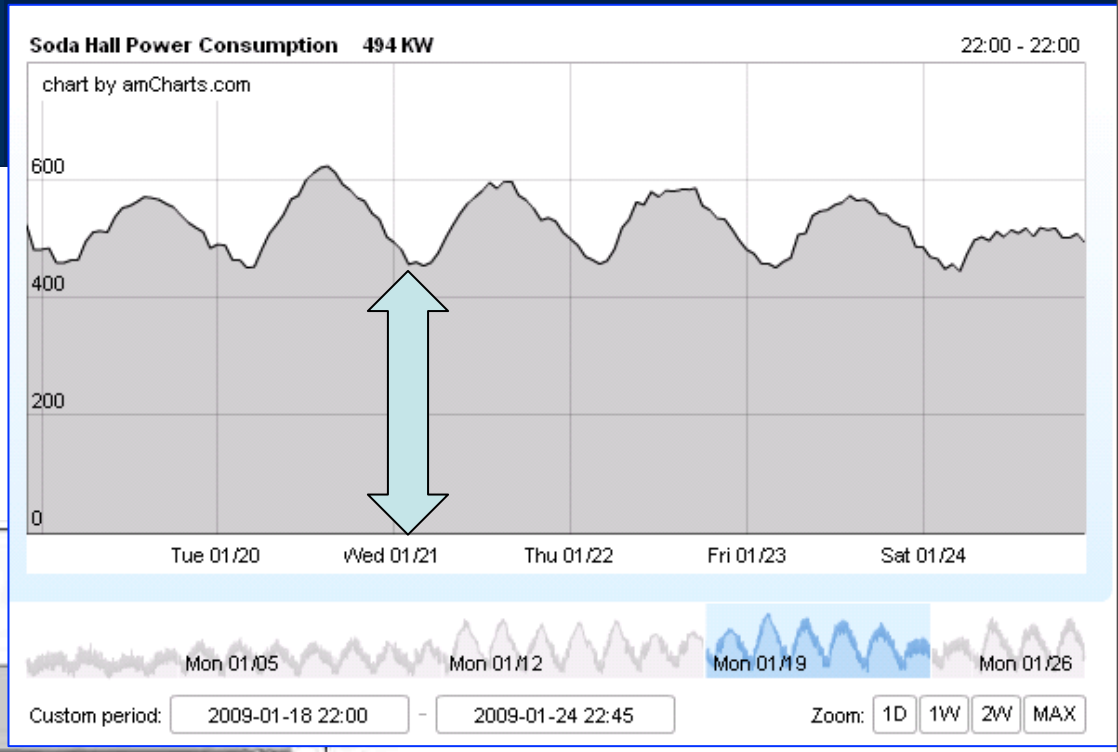
Our Buildings

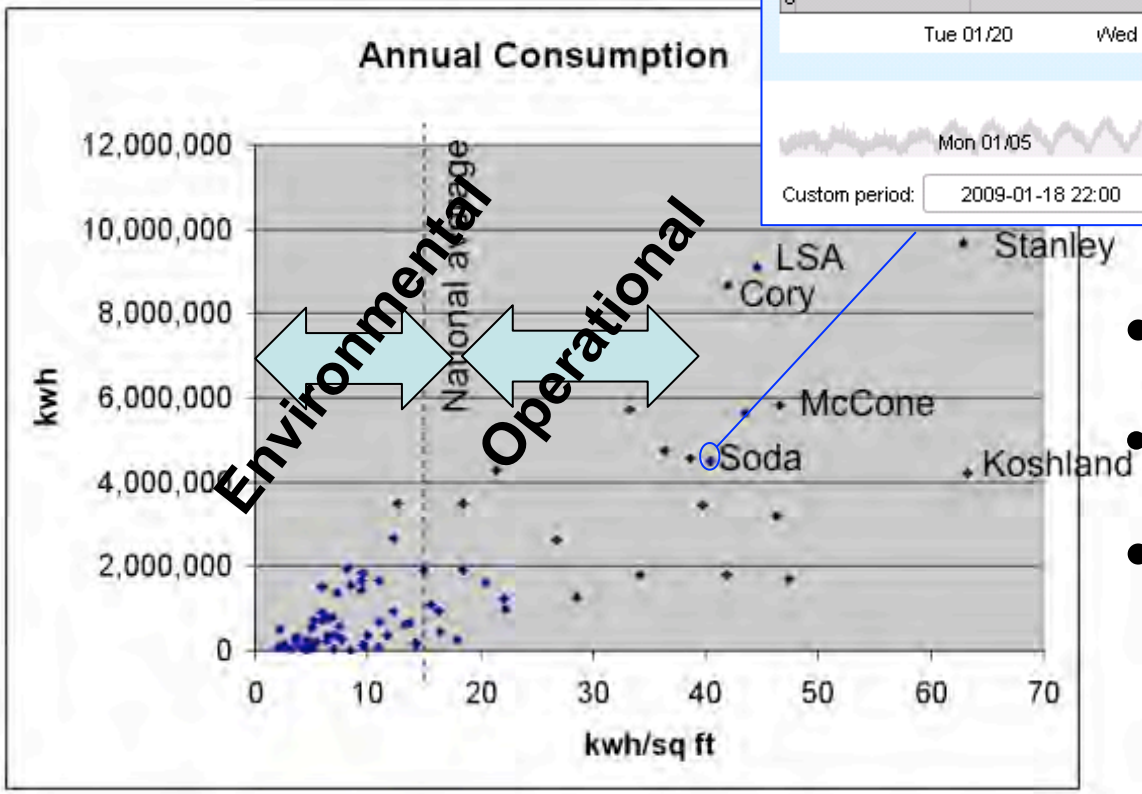




- Wasteful
- <20 % Power Prop.

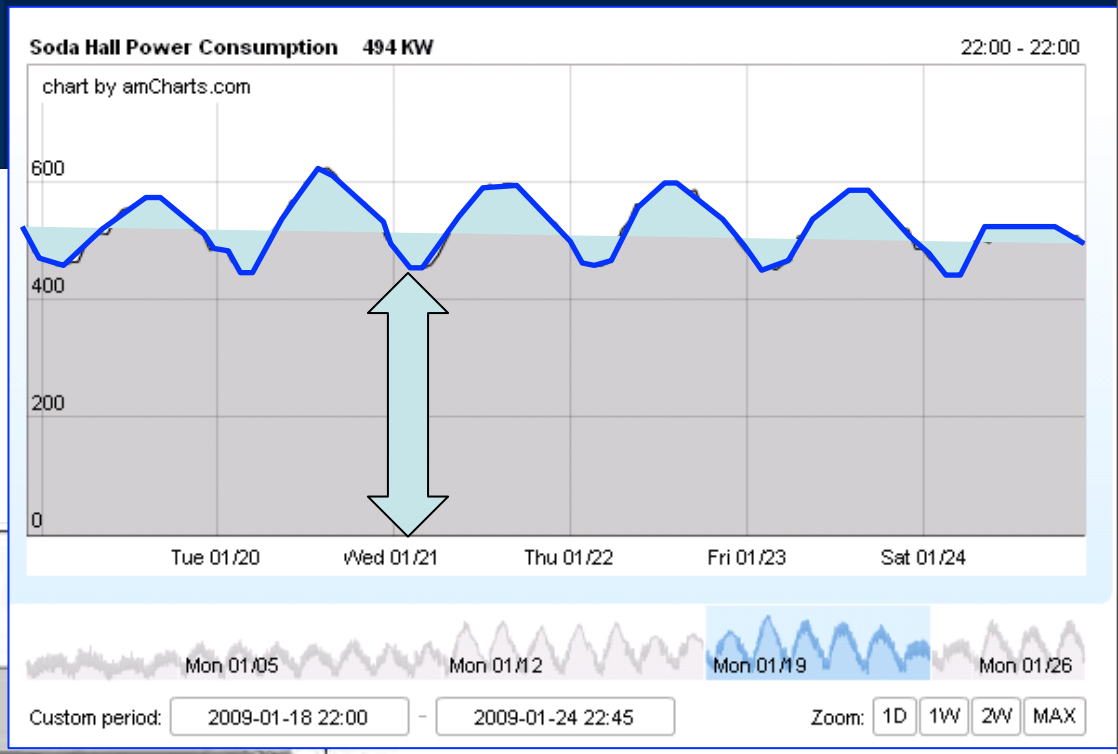
Our Buildings

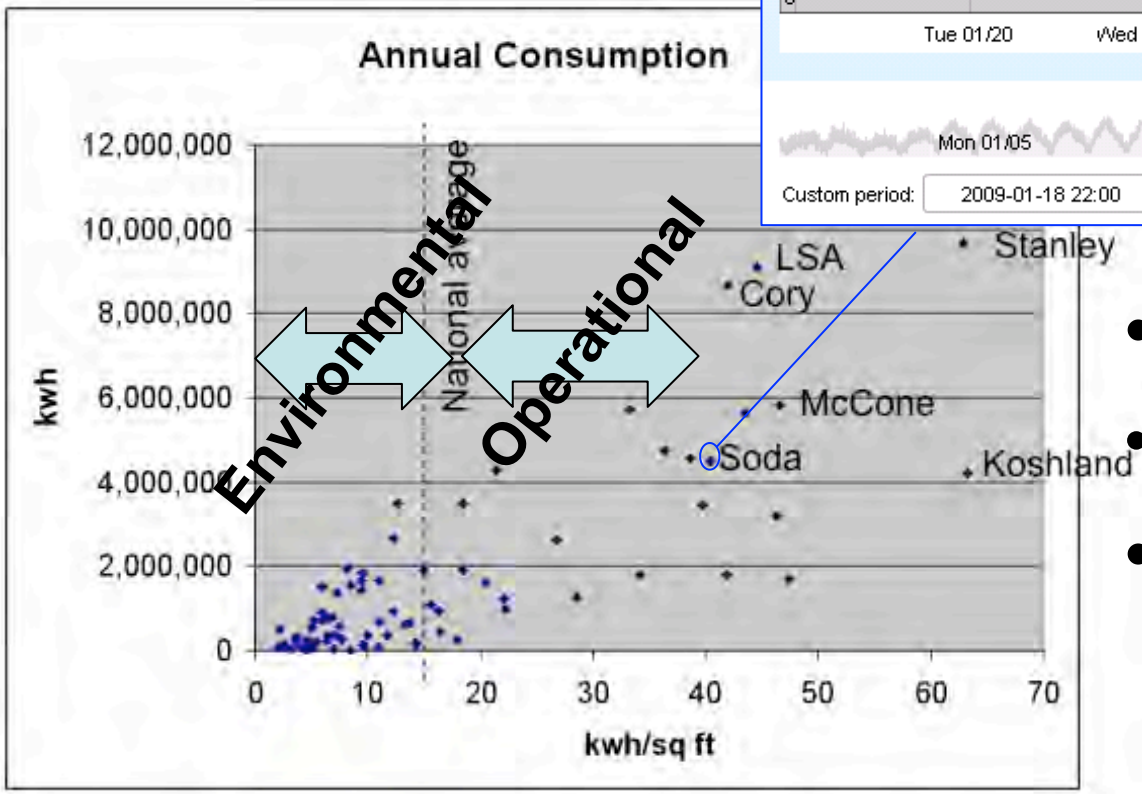




- Wasteful
- <20 % Power Prop.
- Predictable

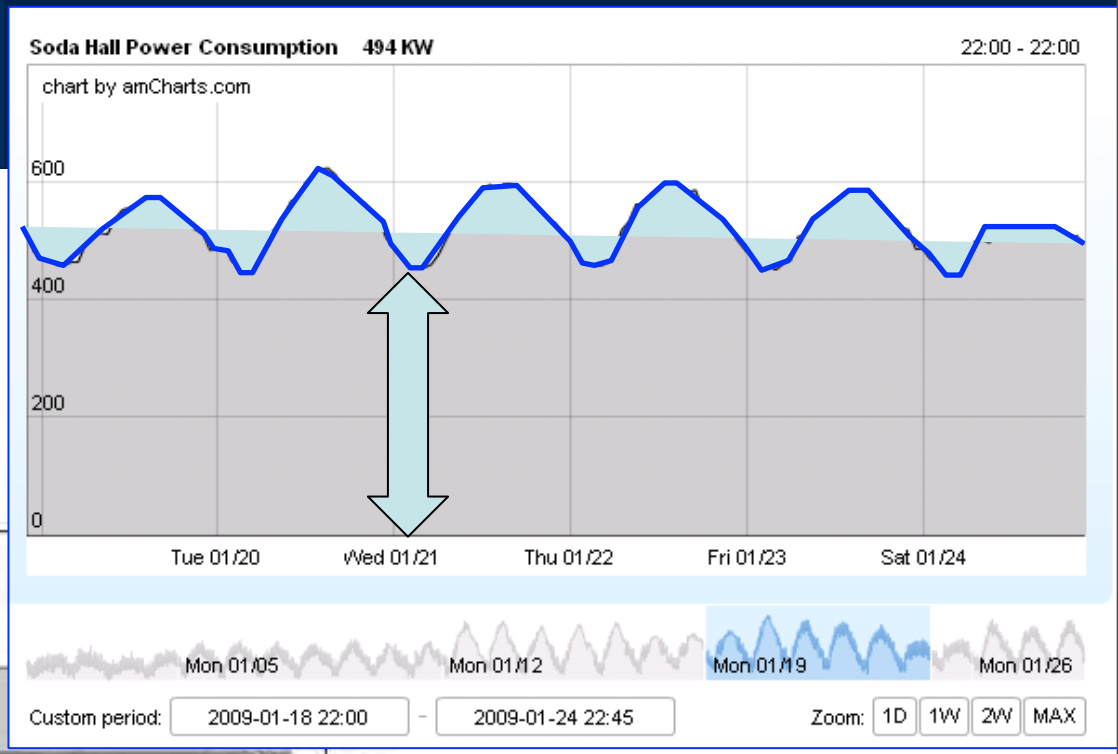
Our Buildings

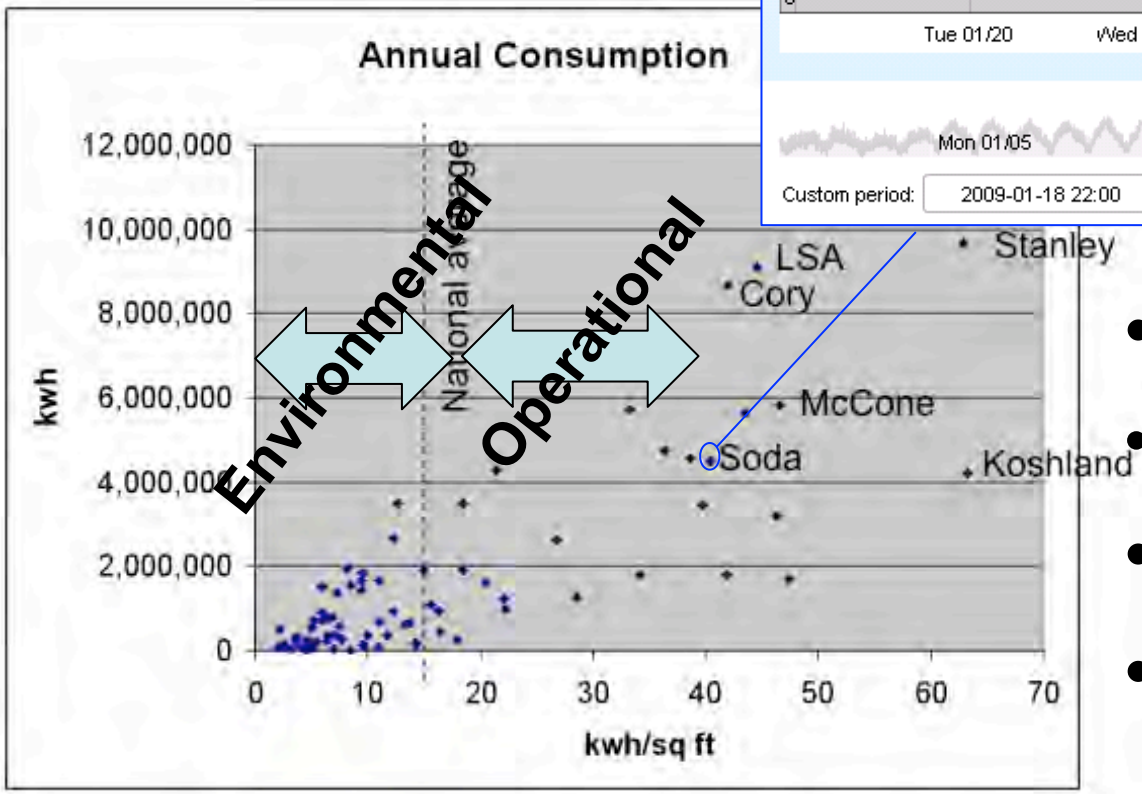




- Wasteful
- <20 % Power Prop.
- Predictable

Our Buildings

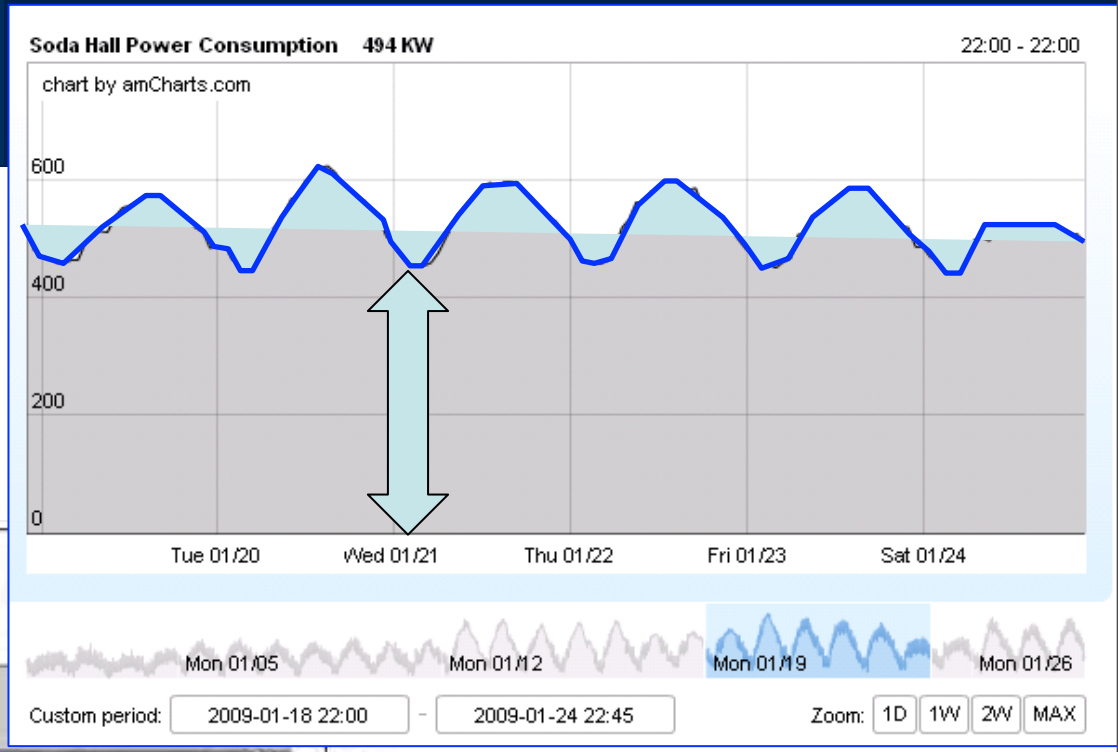


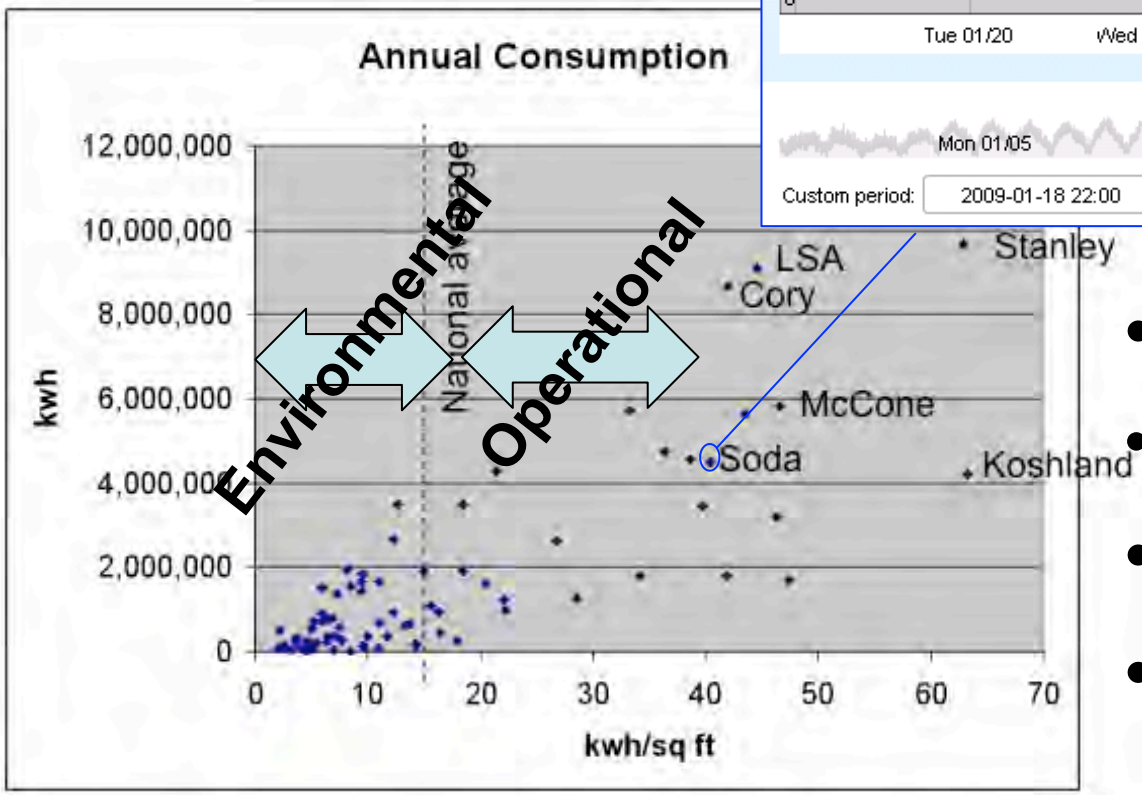


- Wasteful
- <20 % Power Prop.
- Predictable
- Sculptable ?

Our Buildings

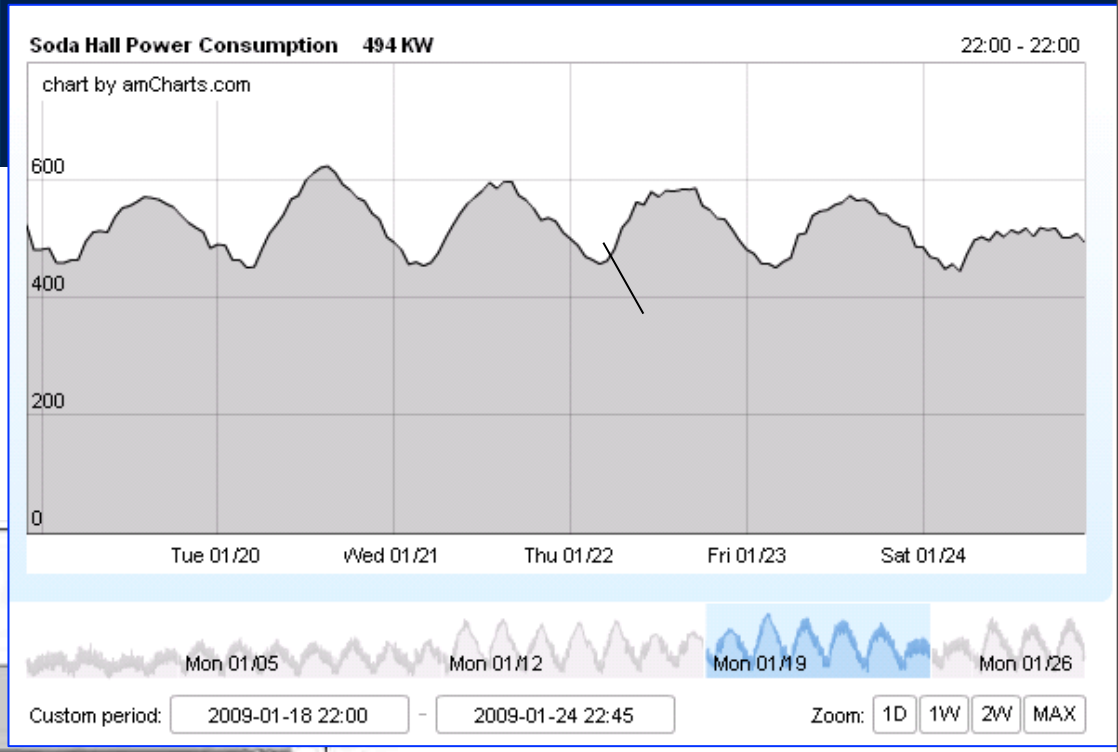
Do nothing poorly

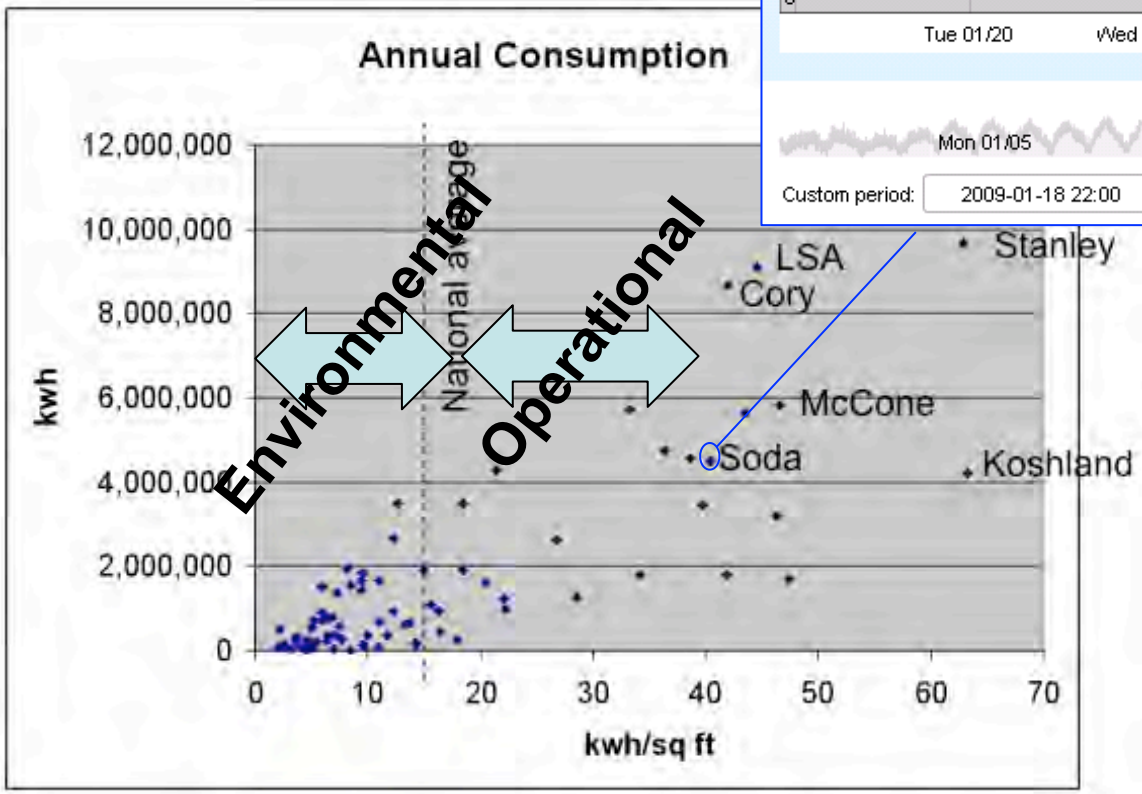




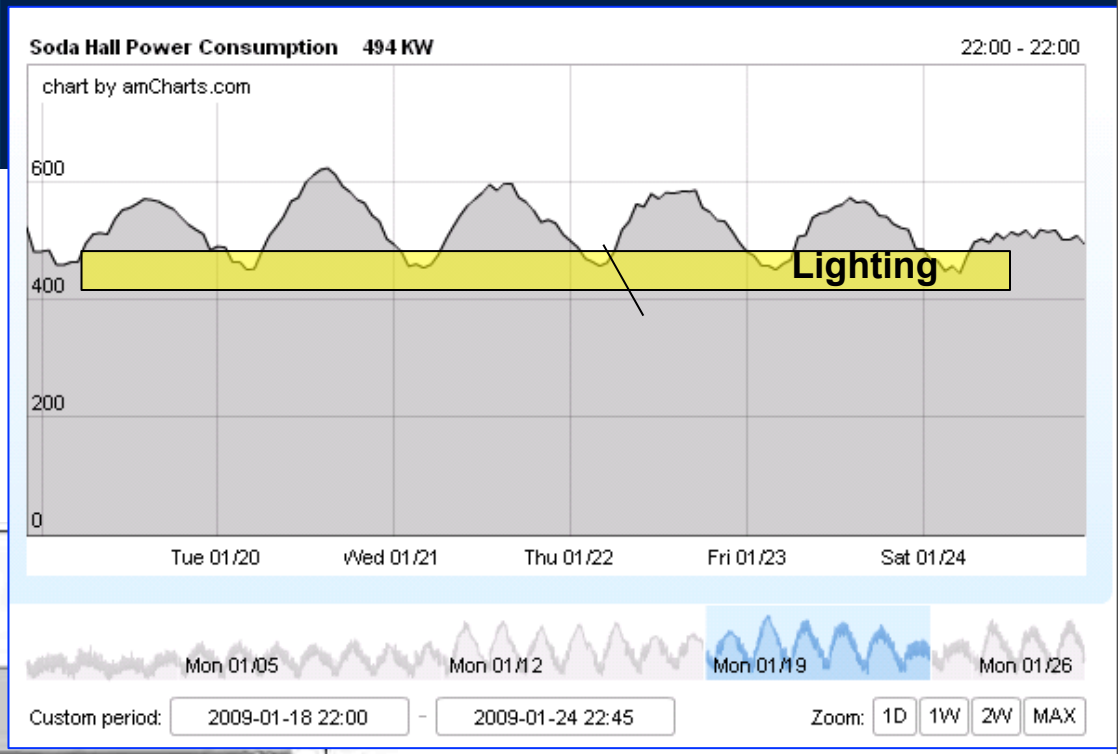
- Wasteful
- <20 % Power Prop.
- Predictable
- Sculptable ?

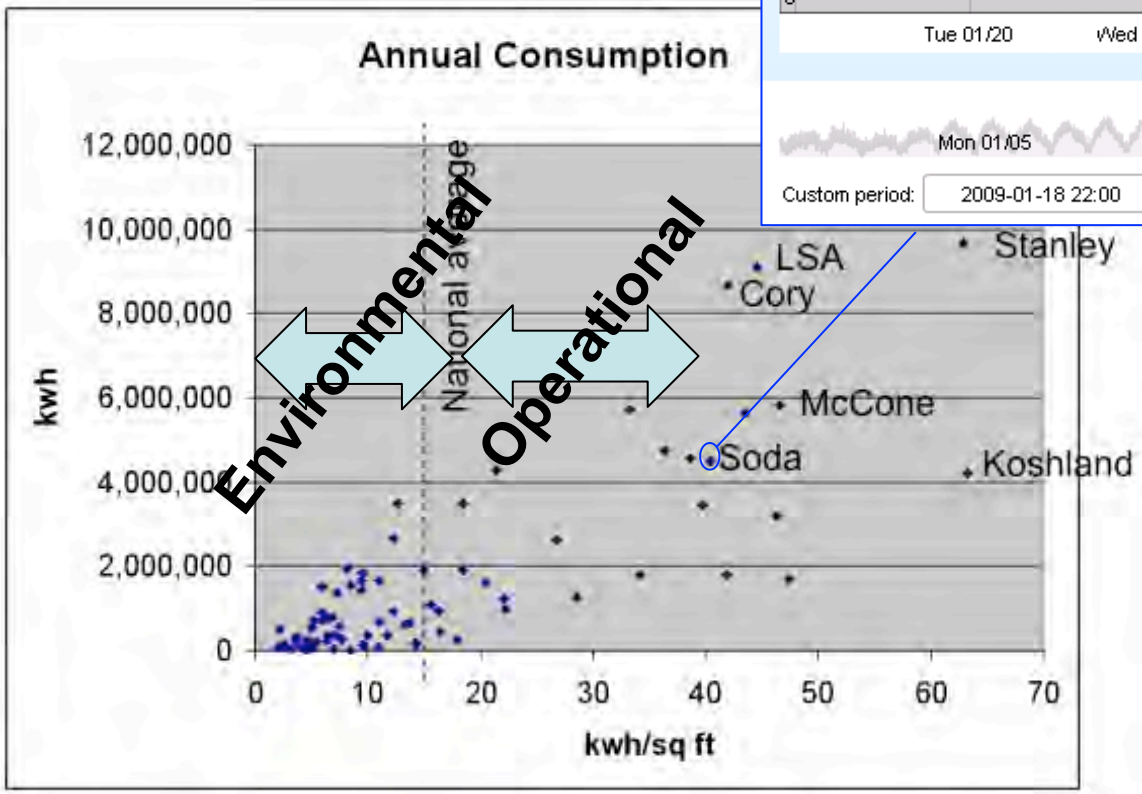
Our Buildings



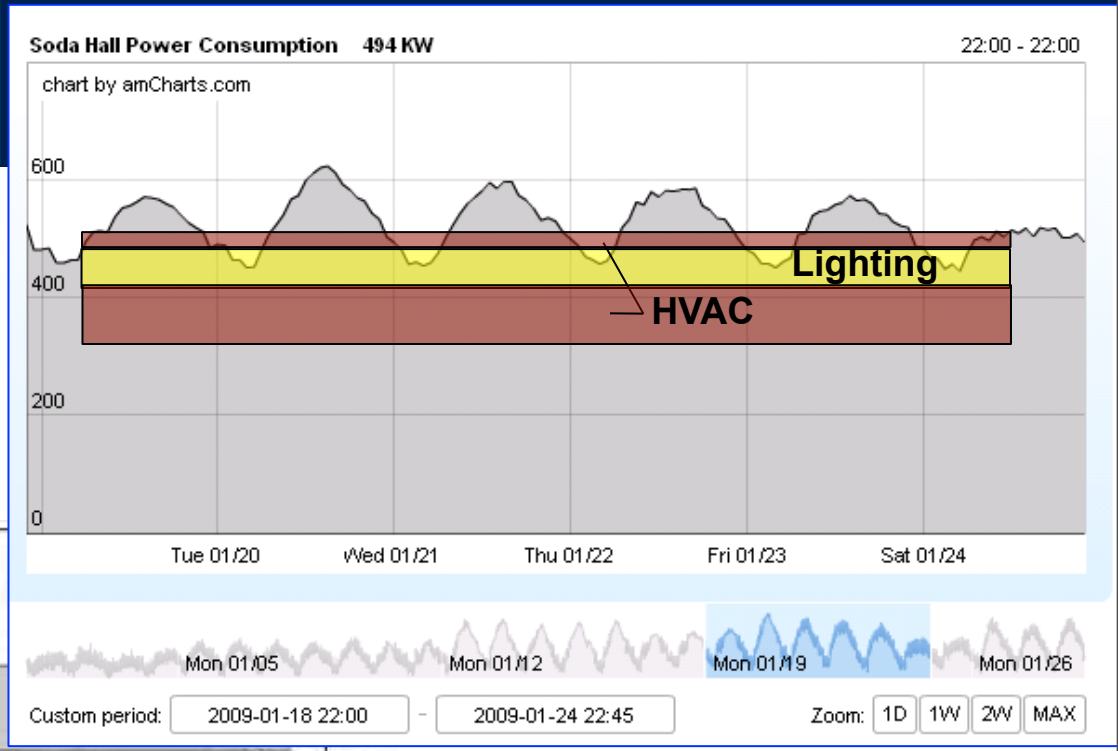


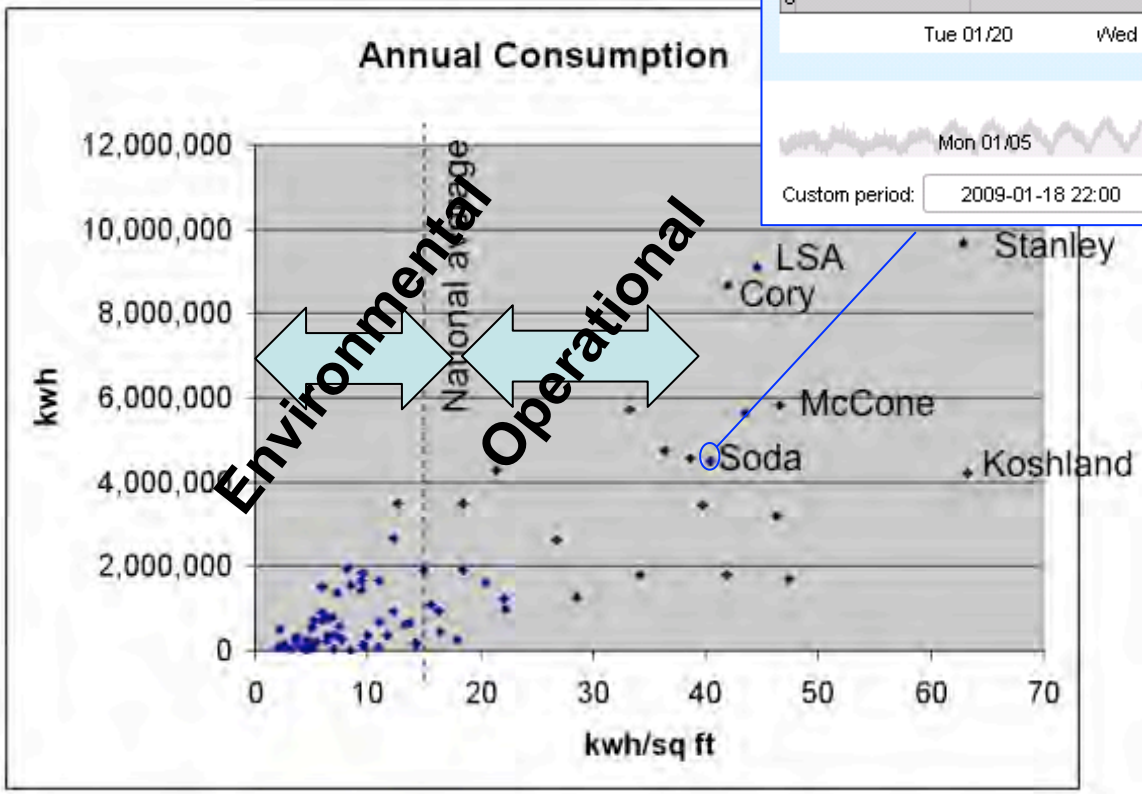
Our Buildings





Our Buildings





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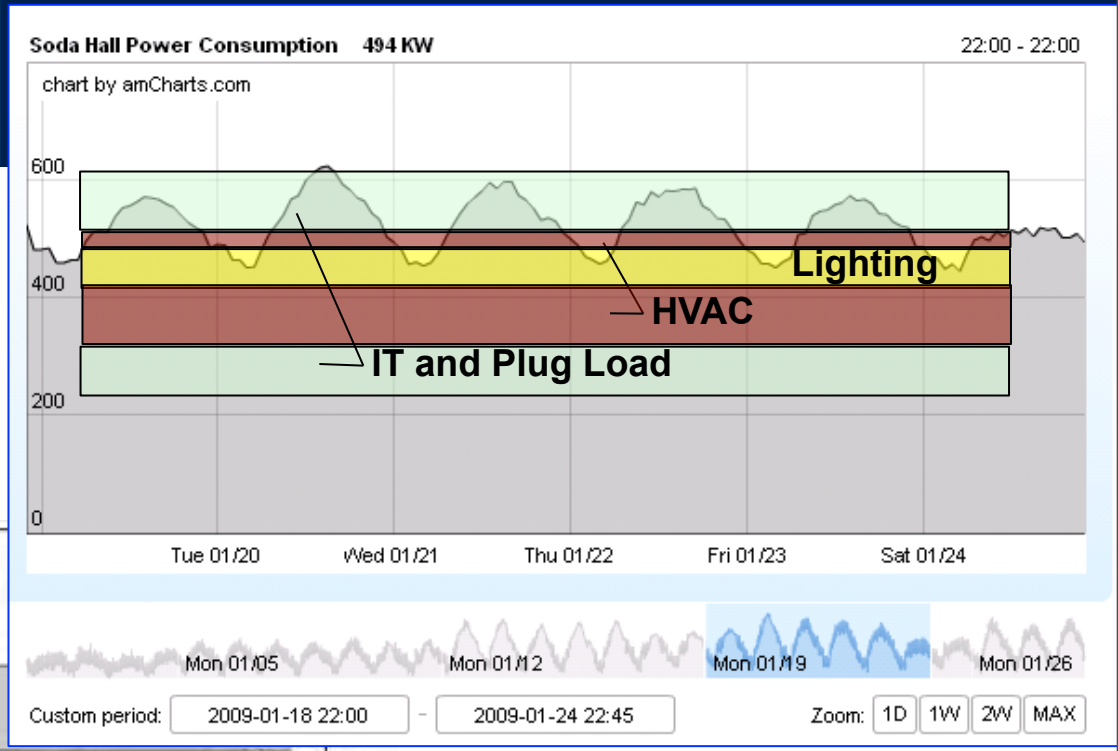
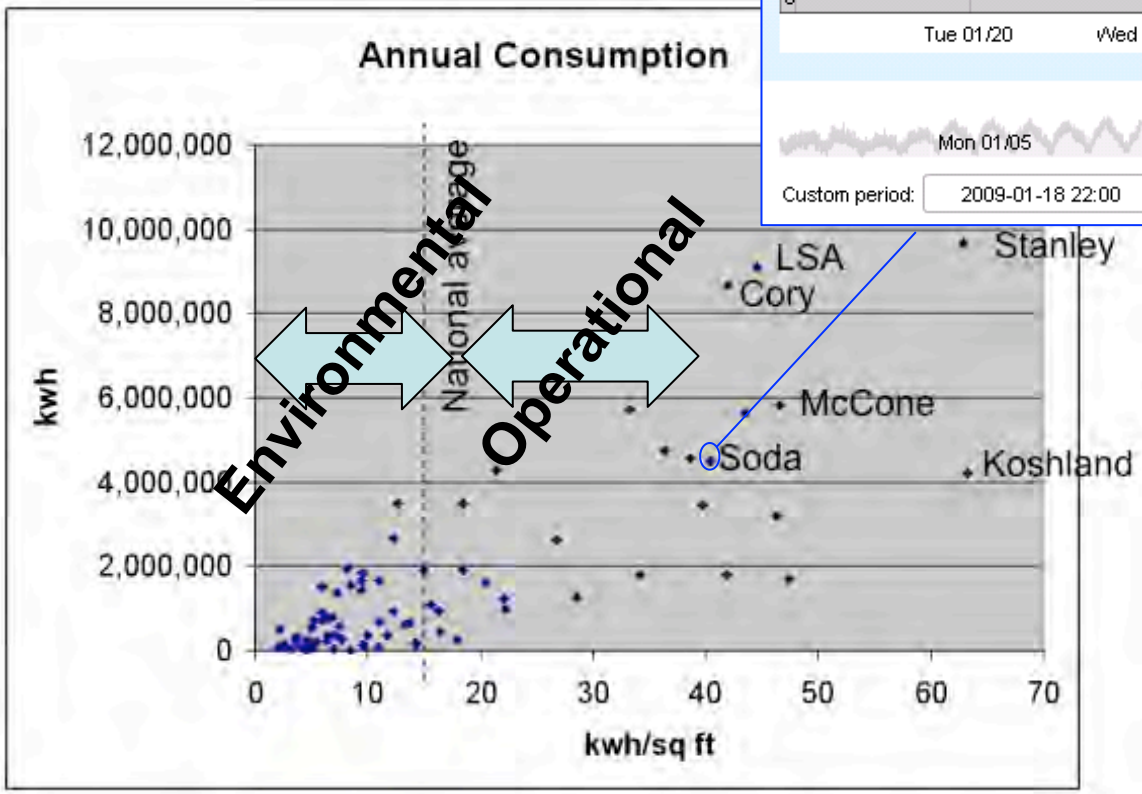
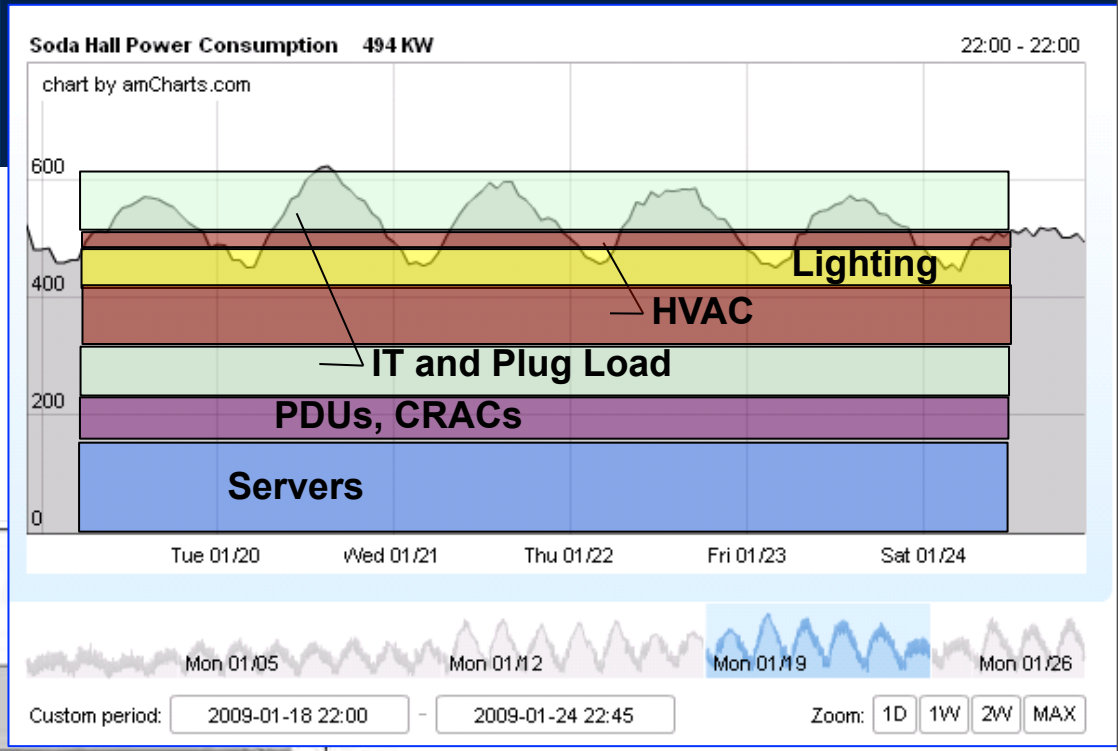
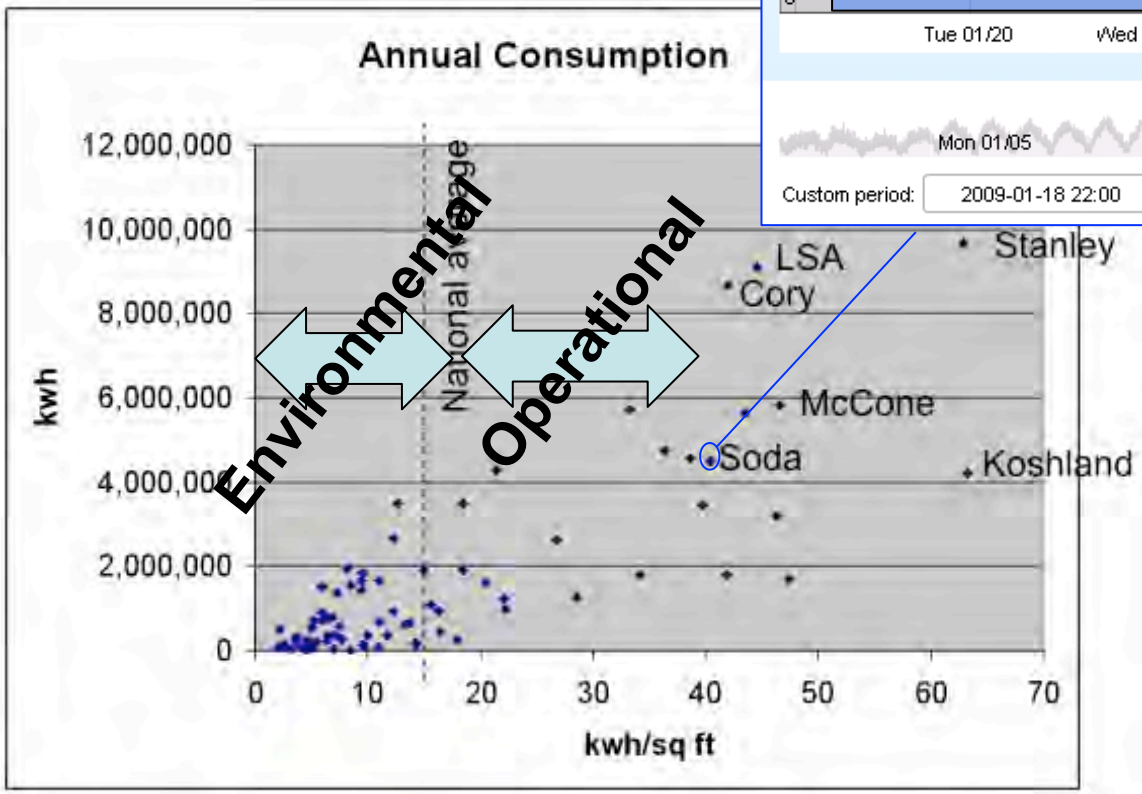




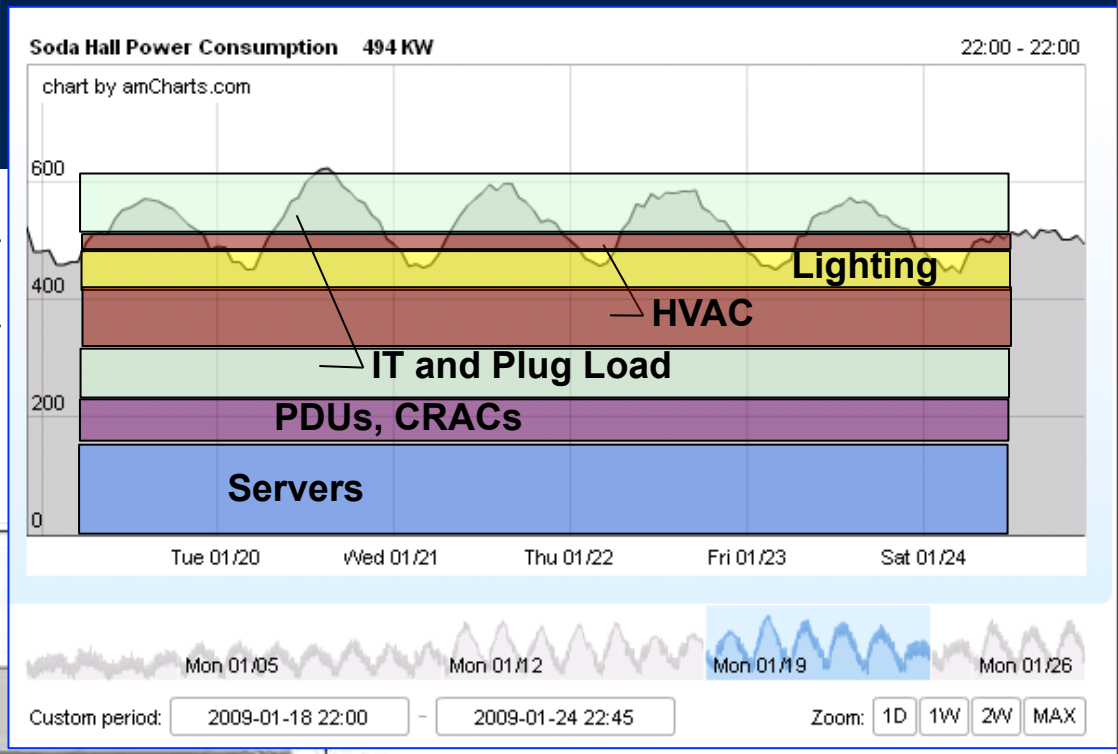
Our Buildings

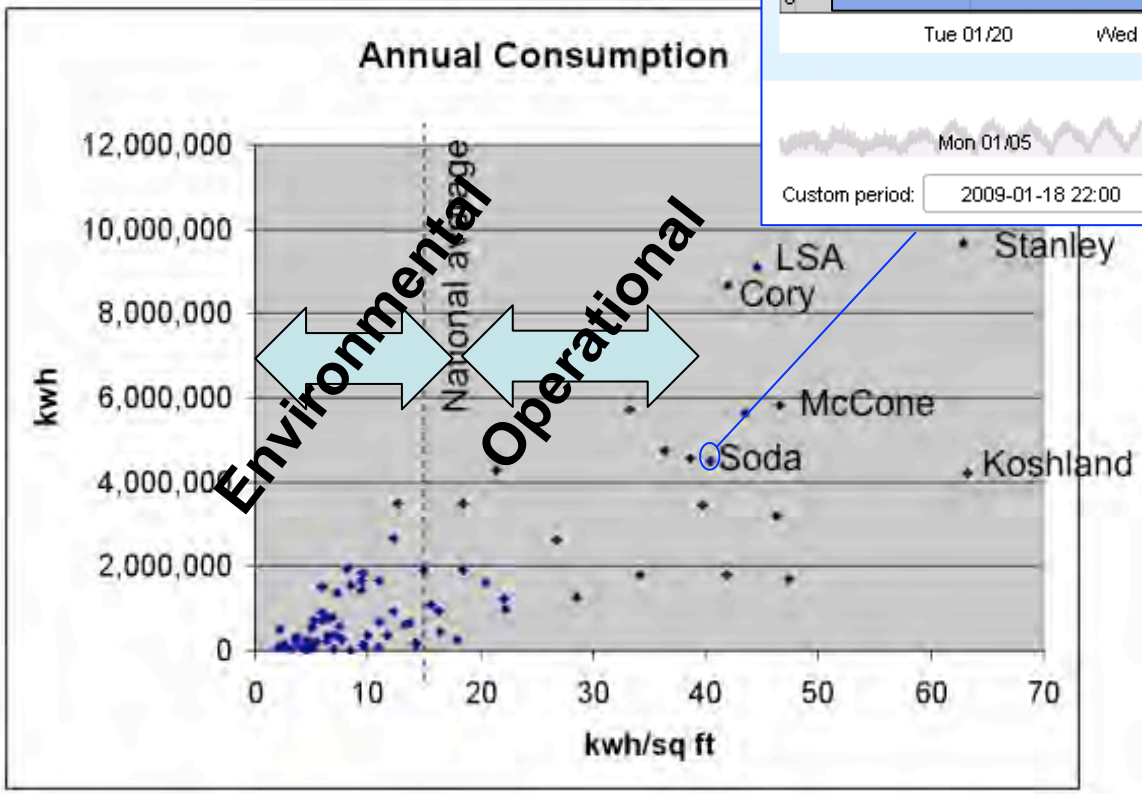




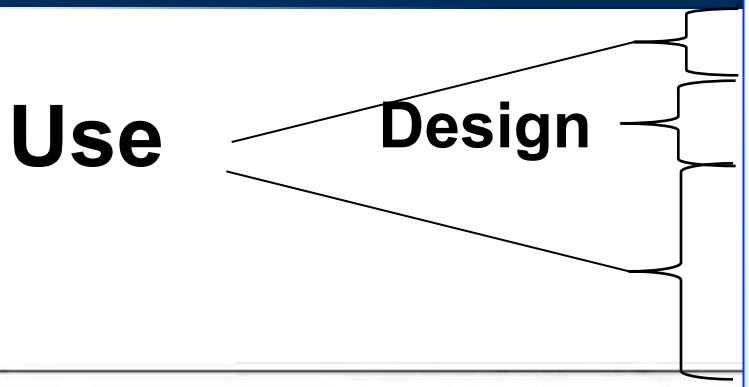
Our Buildings

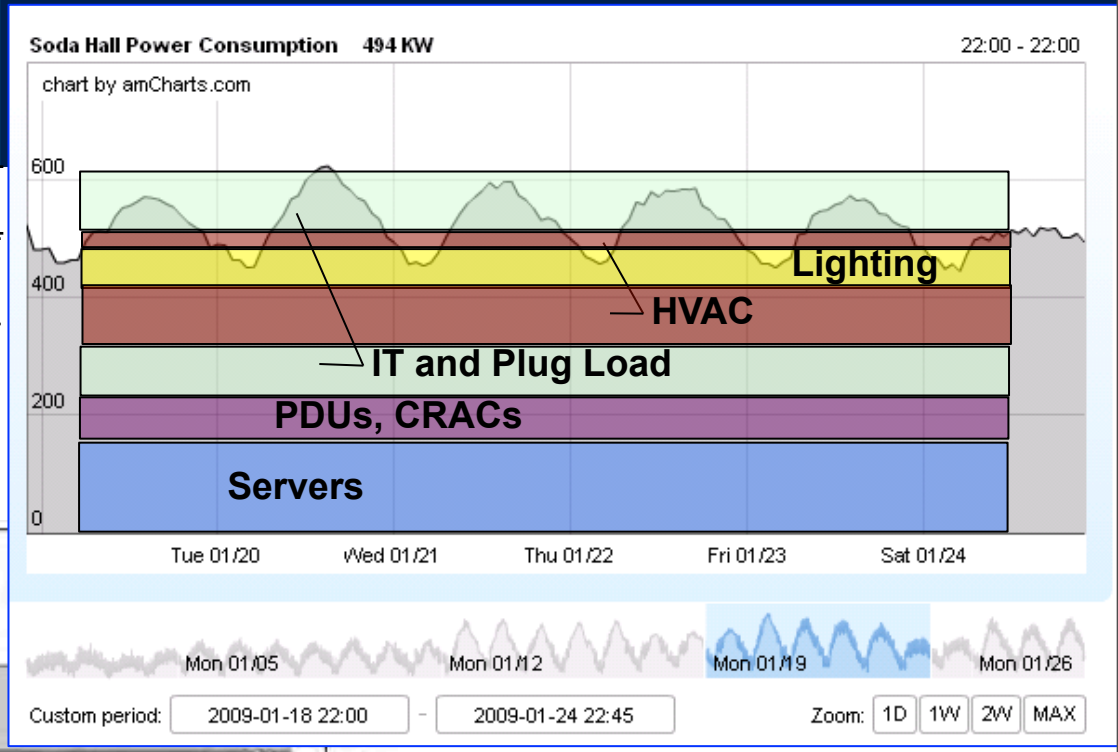
Design

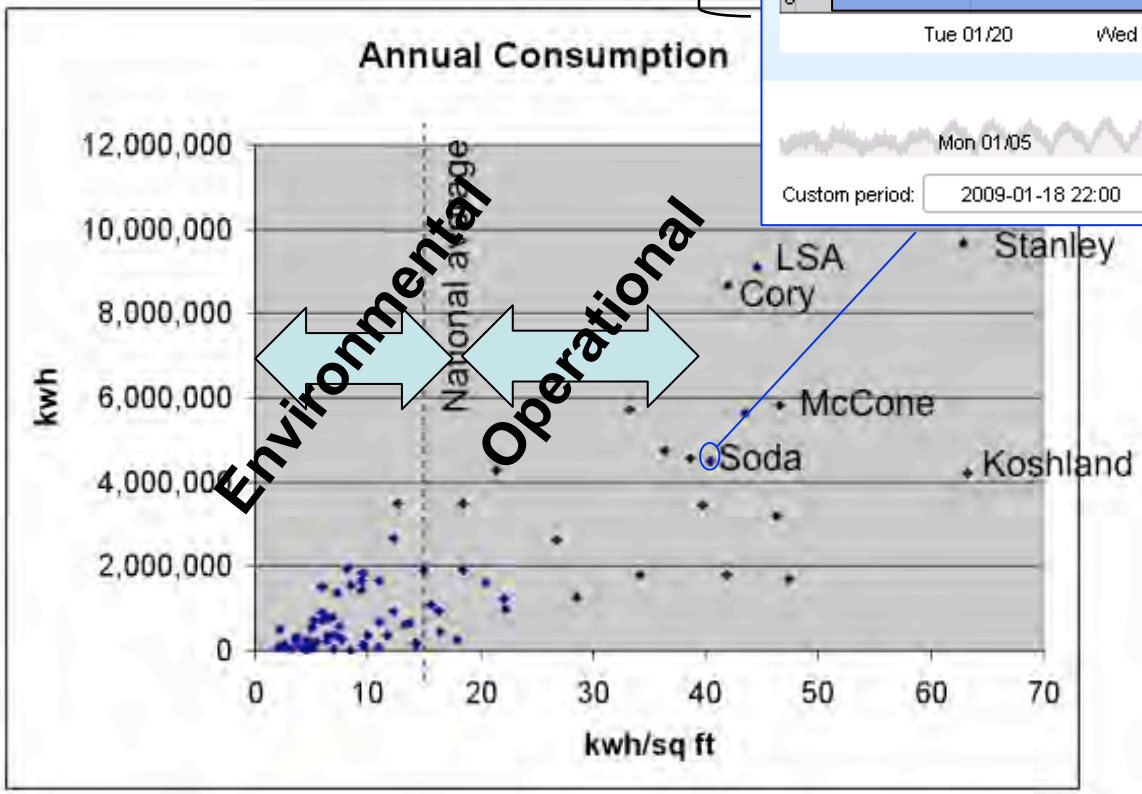




Our Buildings

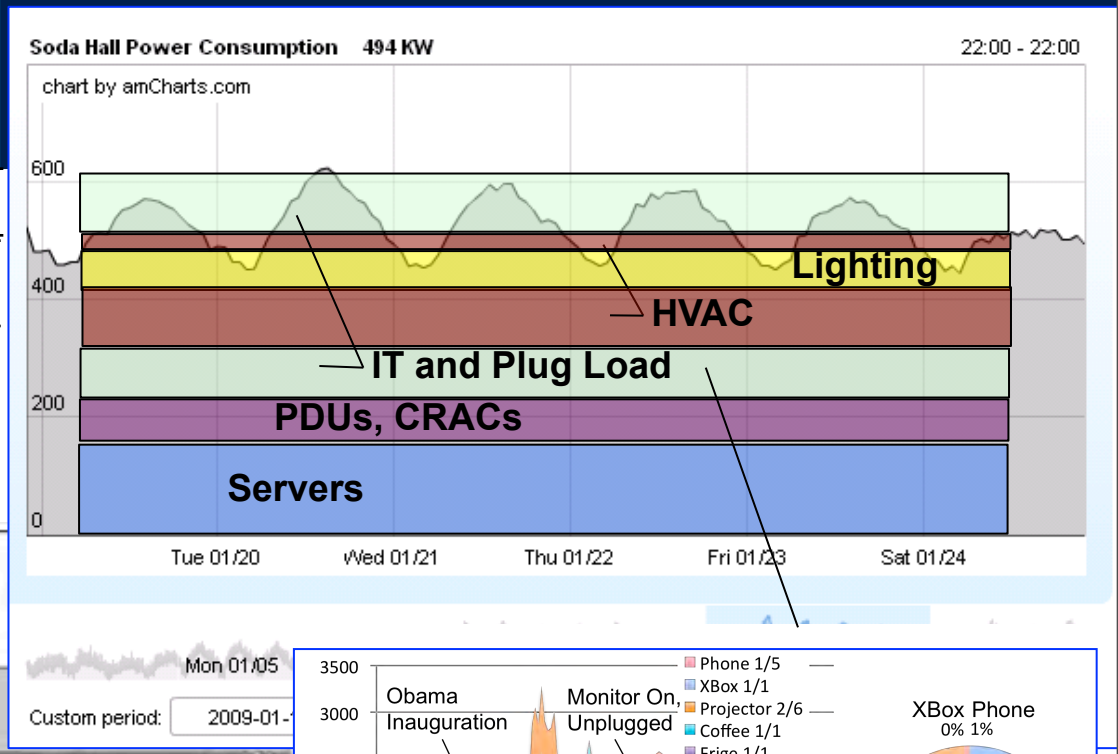


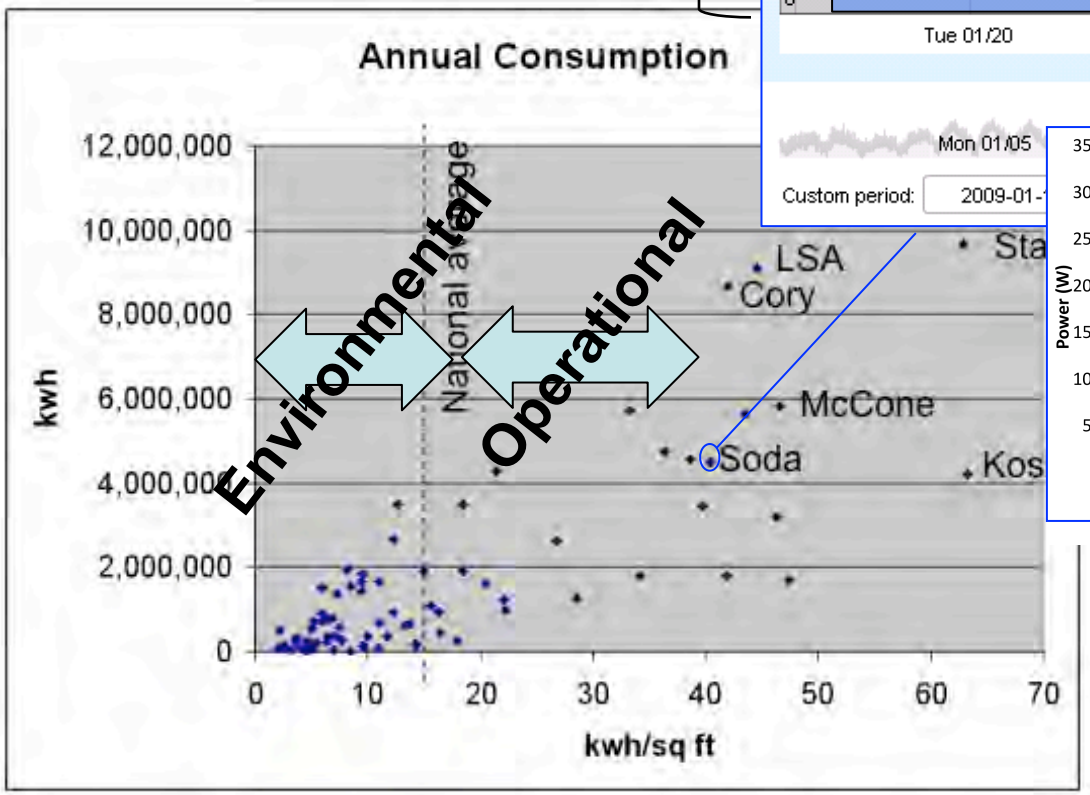


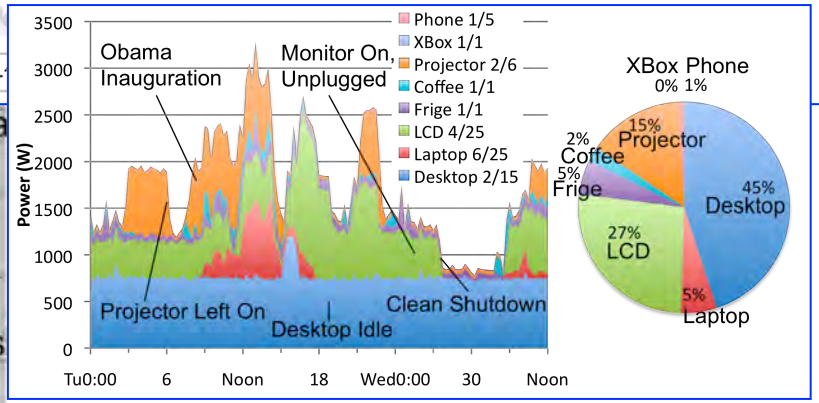


Our Buildings

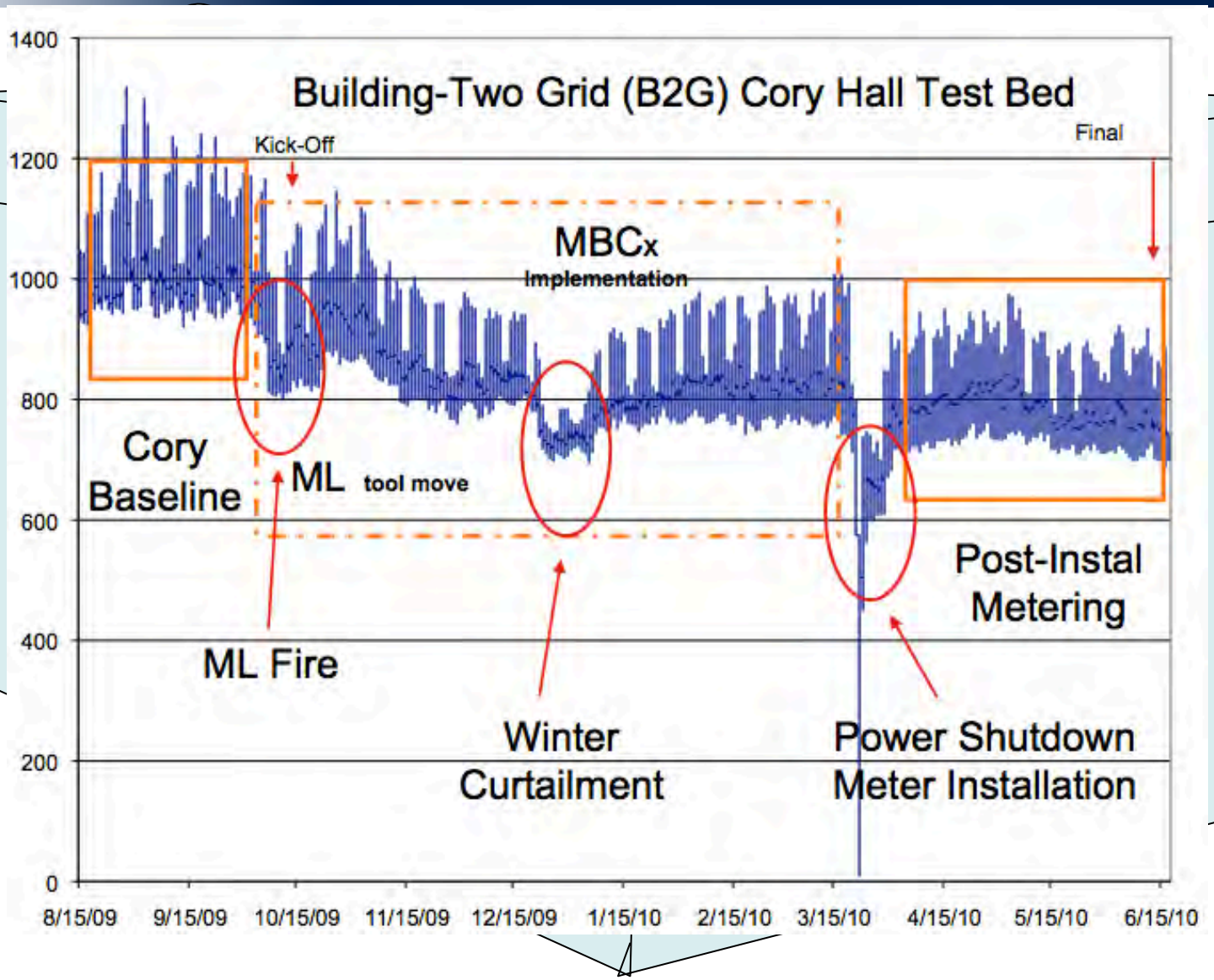
Use — **Design**







Waste Less


Building-Two Grid (B2G) Cory Hall Test Bed
Kick-Off
Final
MBCx
Implementation
Cory
Baseline
ML tool move
ML Fire
Winter
Curtailment
Power Shutdown
Meter Installation
Post-Instal
Metering
1400
1200
1000
800
600
400
200
0
8/15/09
9/15/09
10/15/09
11/15/09
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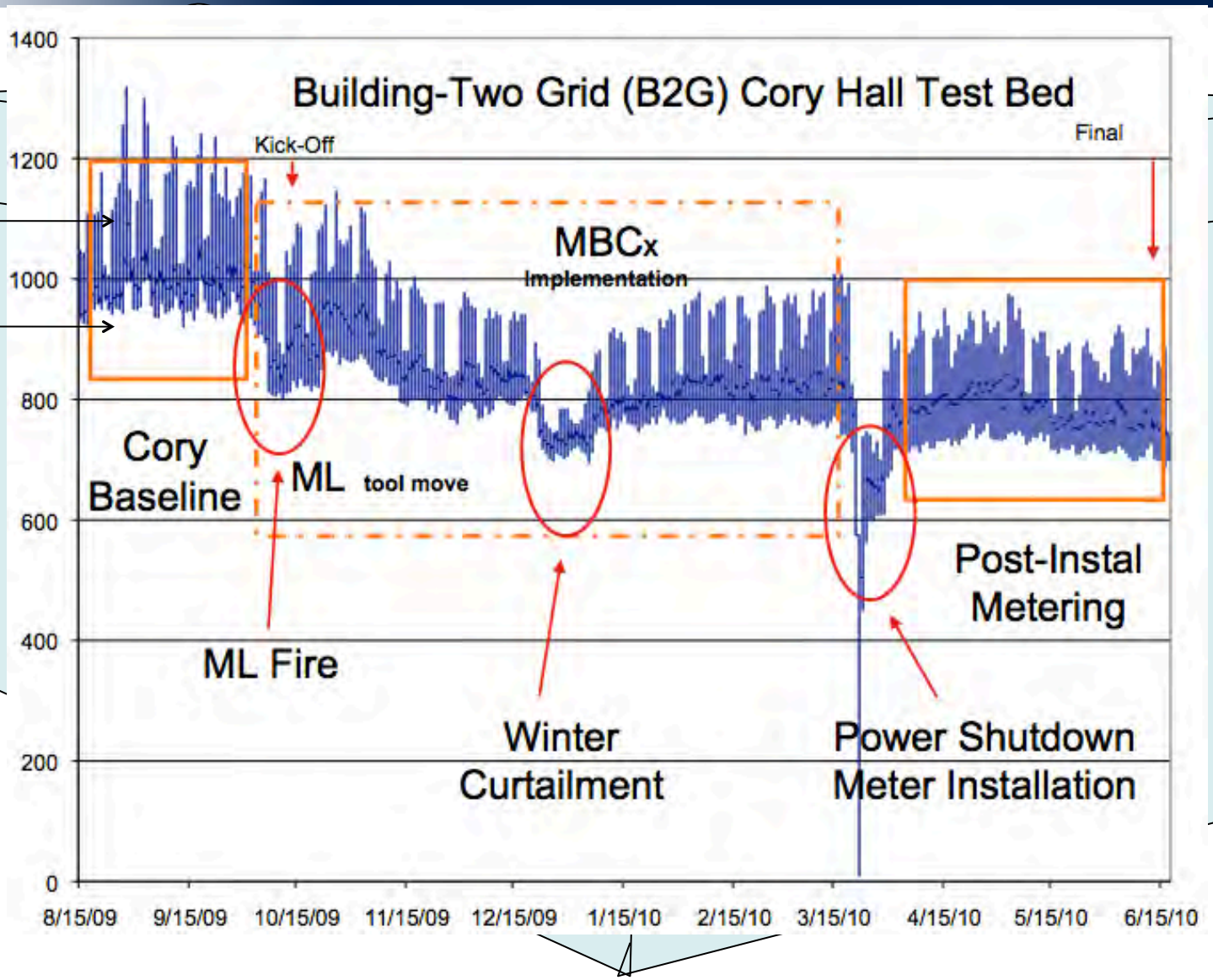
2/15/10
3/15/10
4/15/10
5/15/10
6/15/10

Waste Less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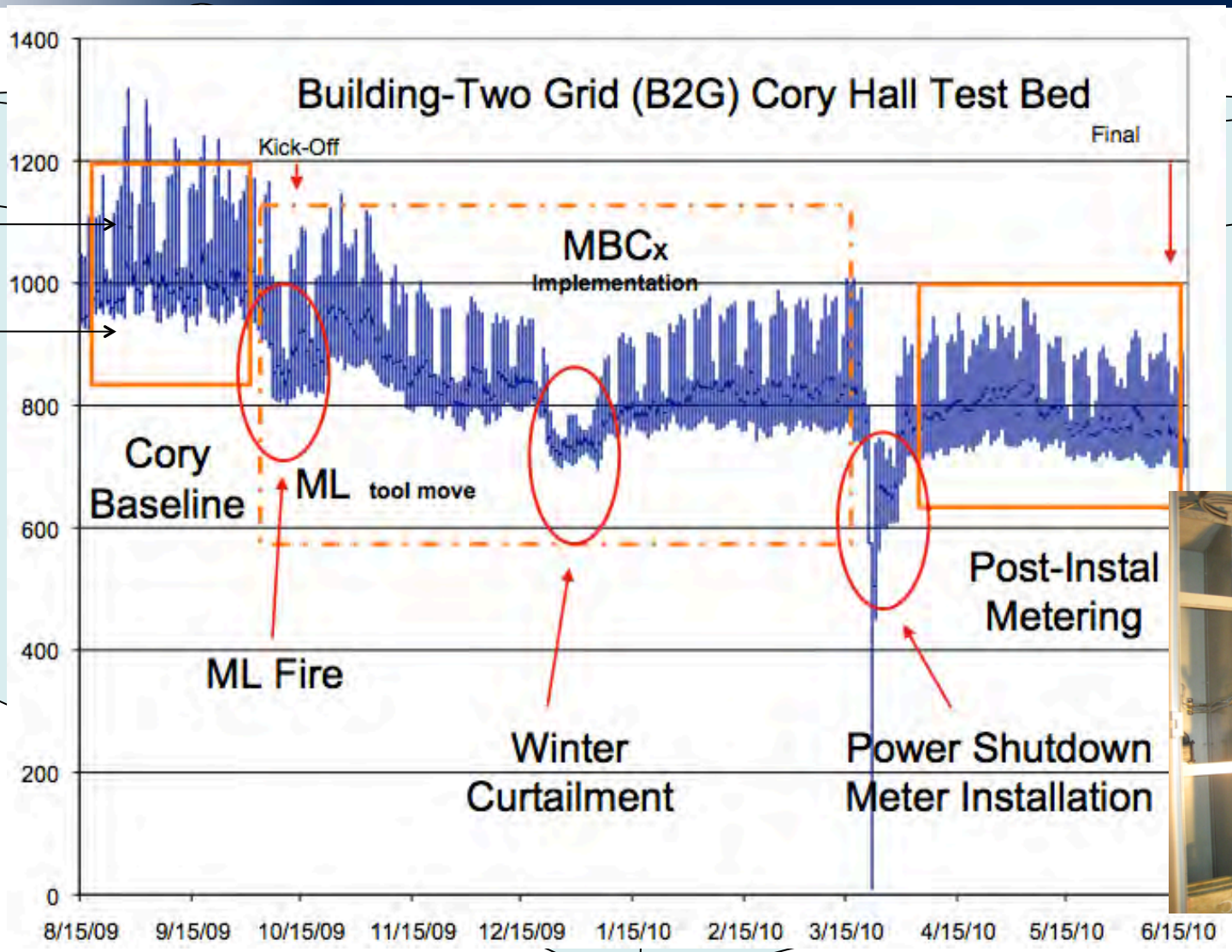
Waste Less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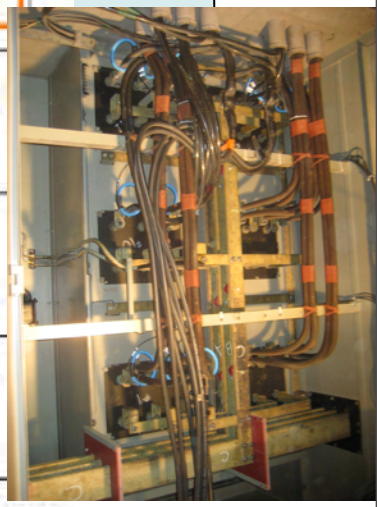
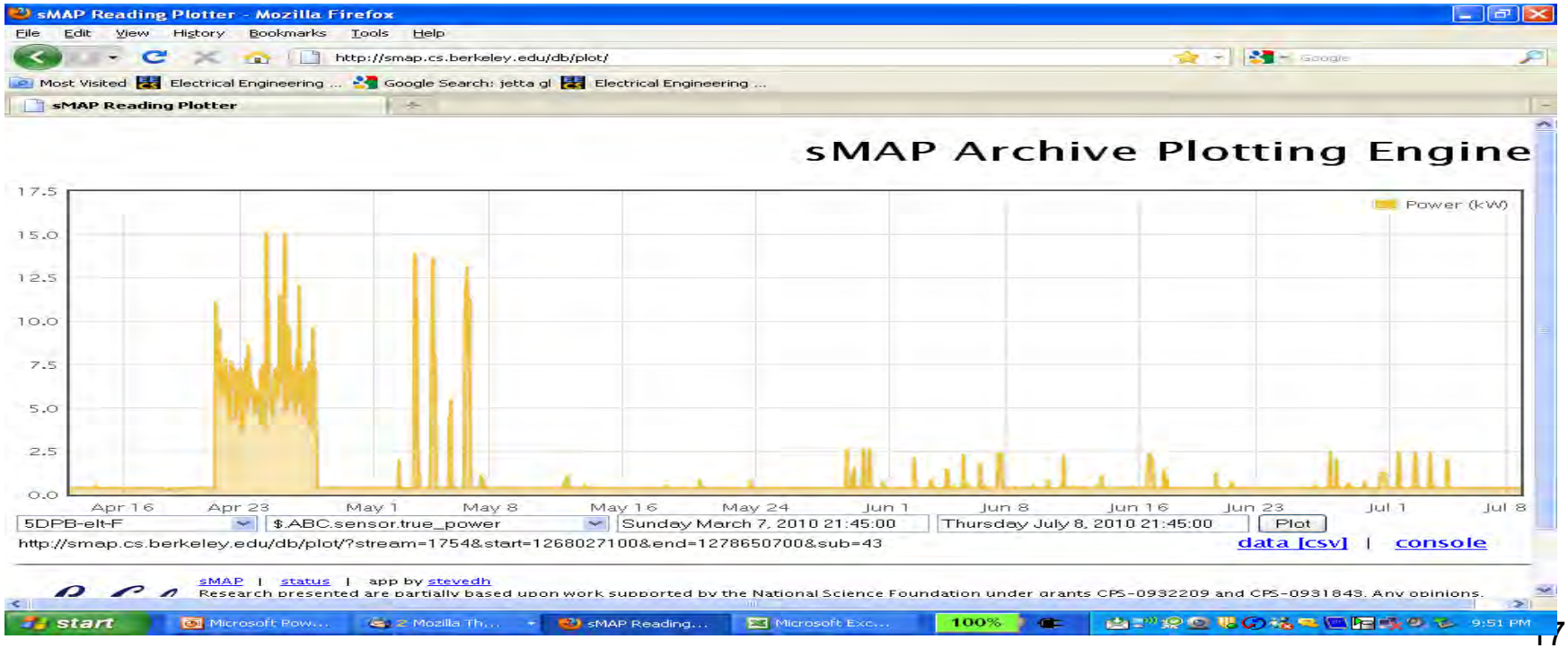


The Data tells the story…

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



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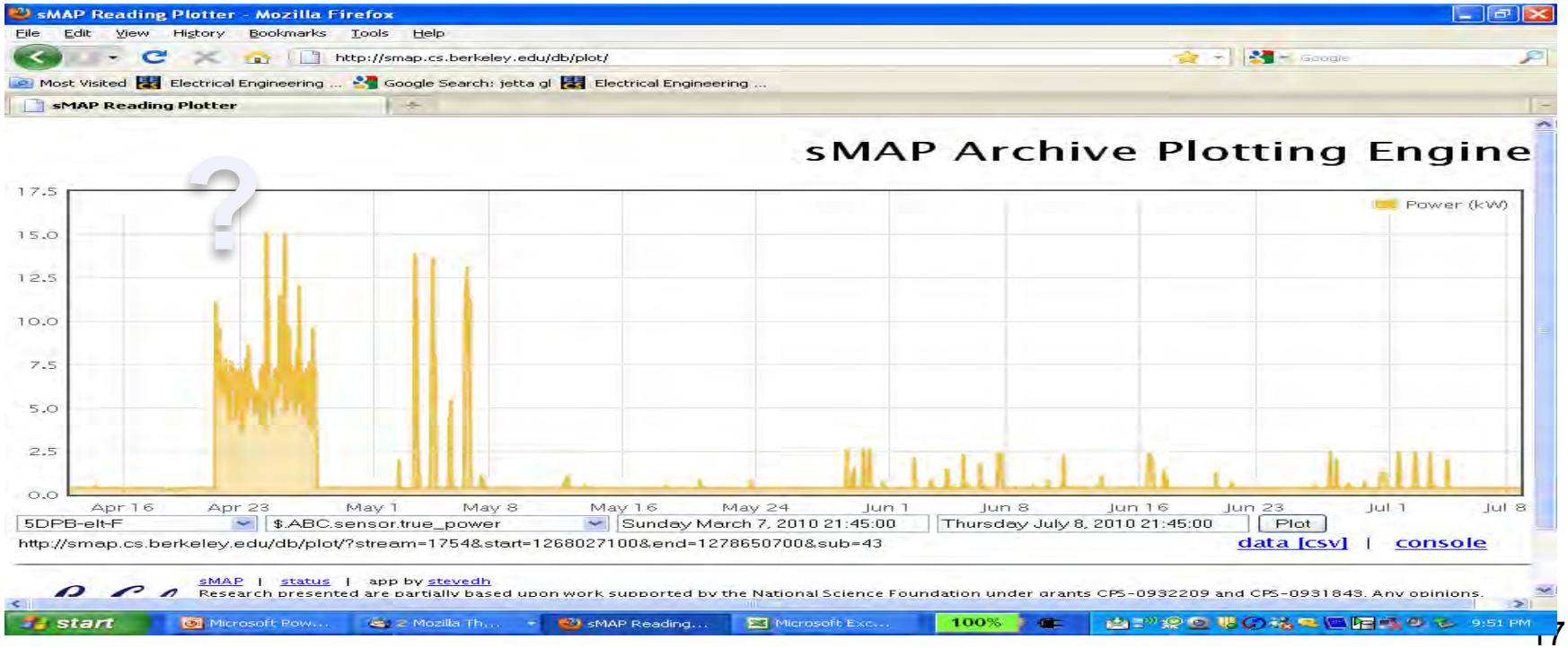

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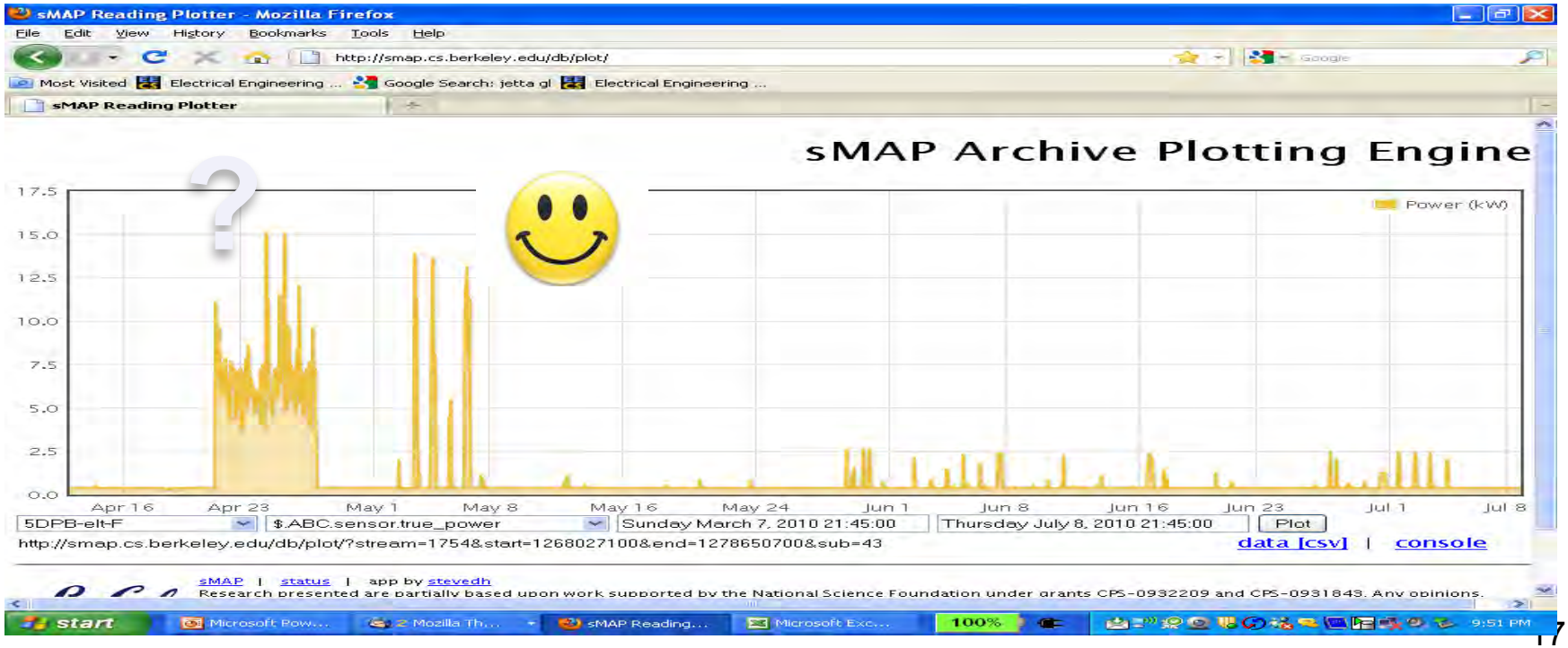
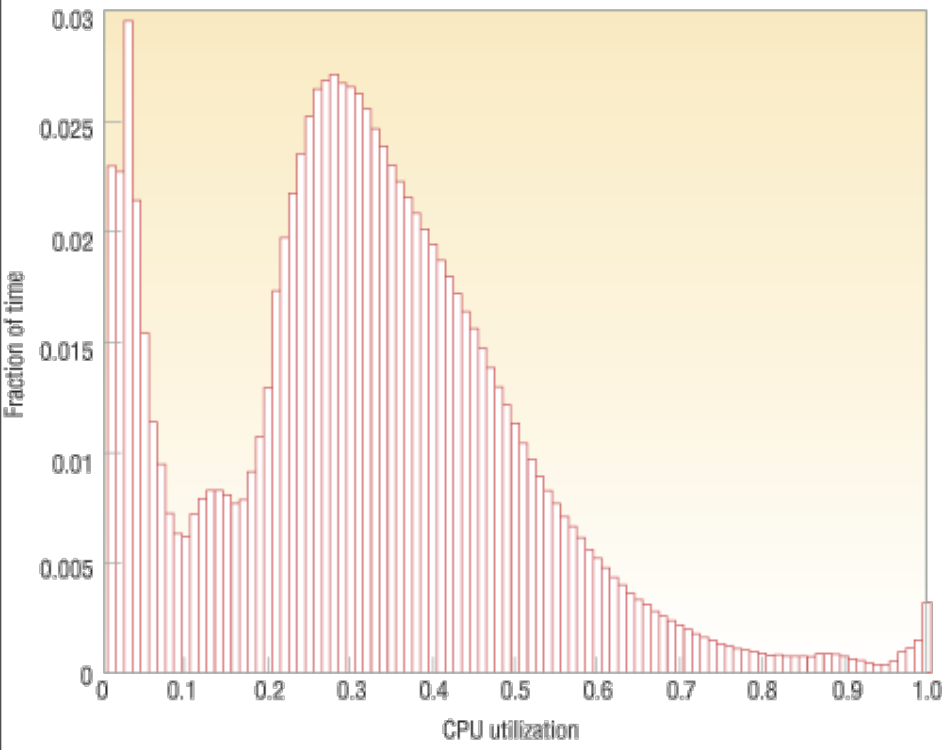


IT does nothing poorly too



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

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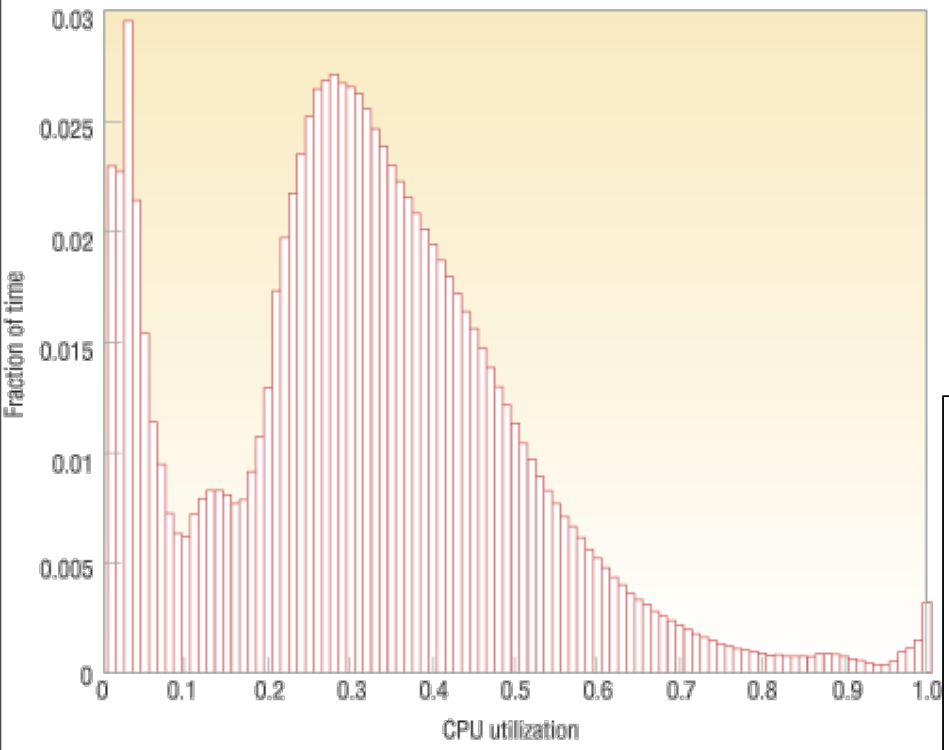

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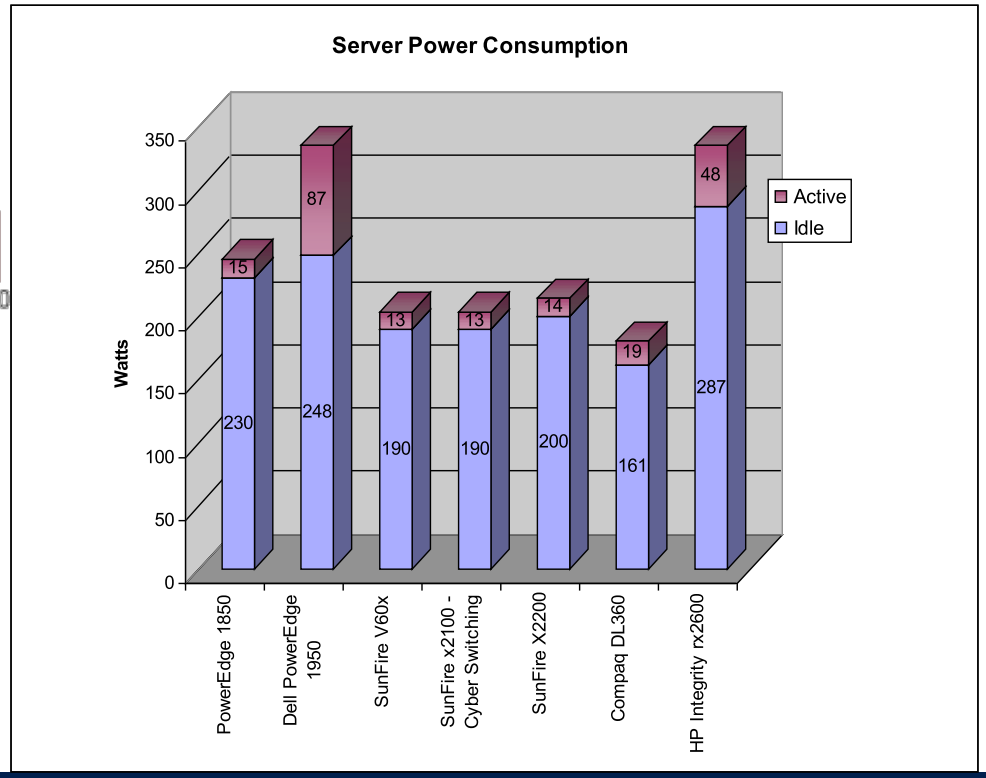

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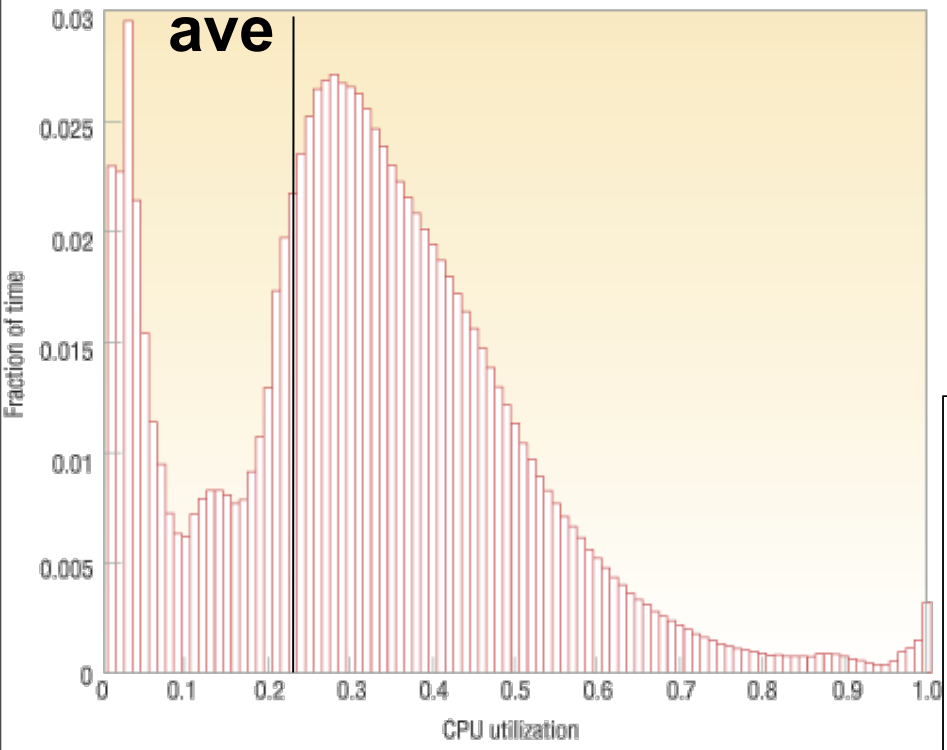

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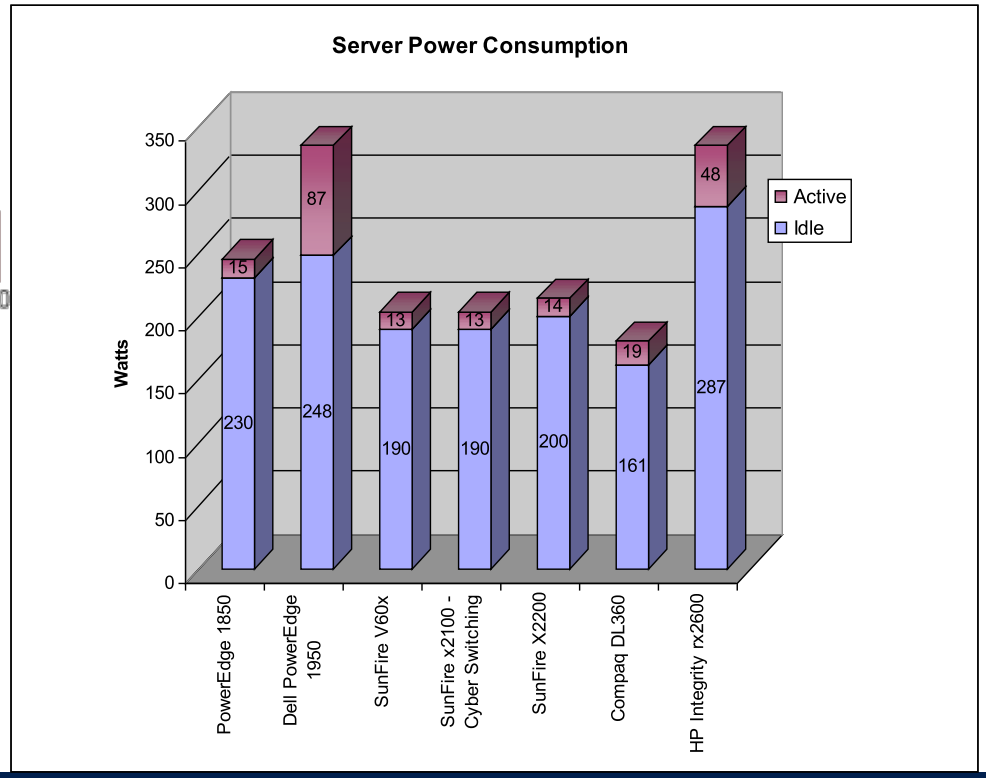

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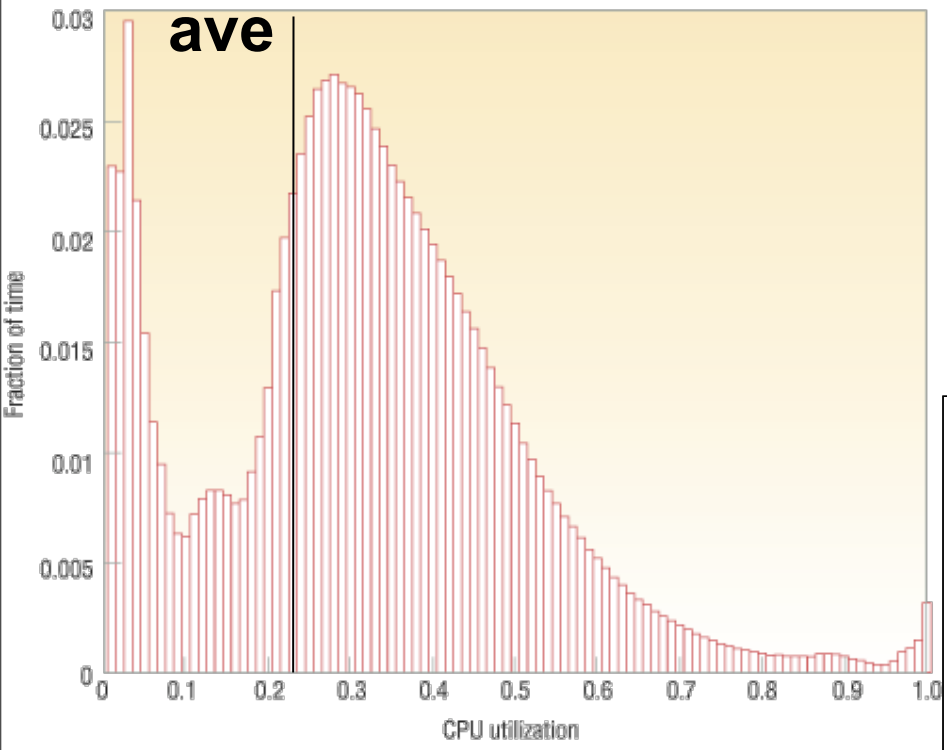

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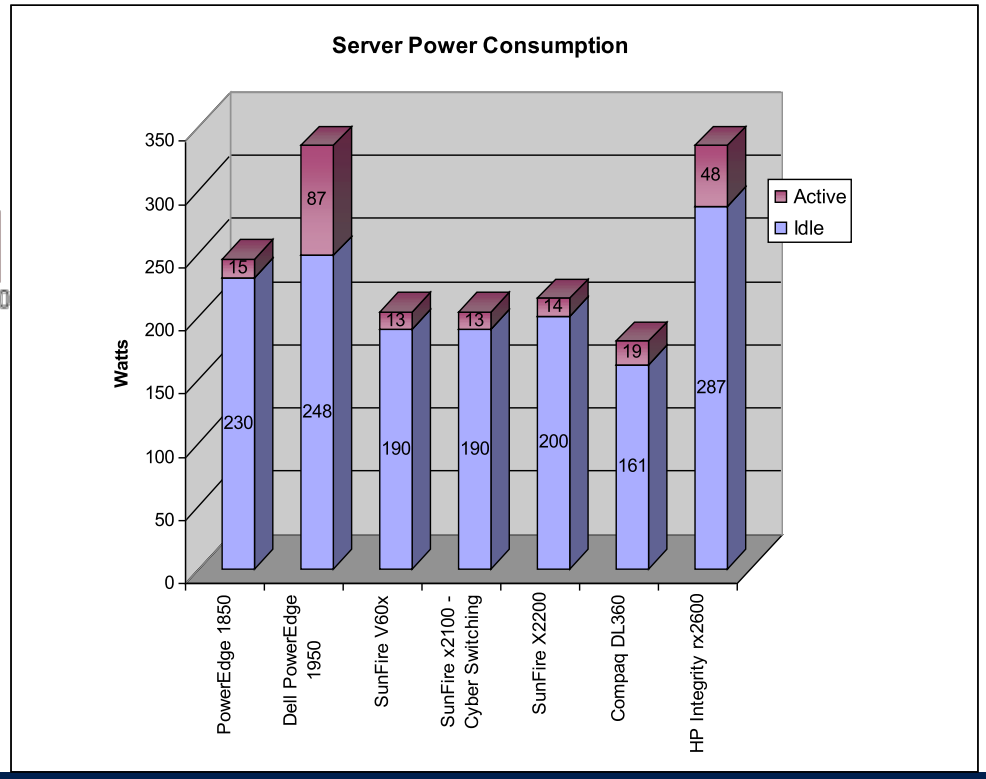
- Designed for peak



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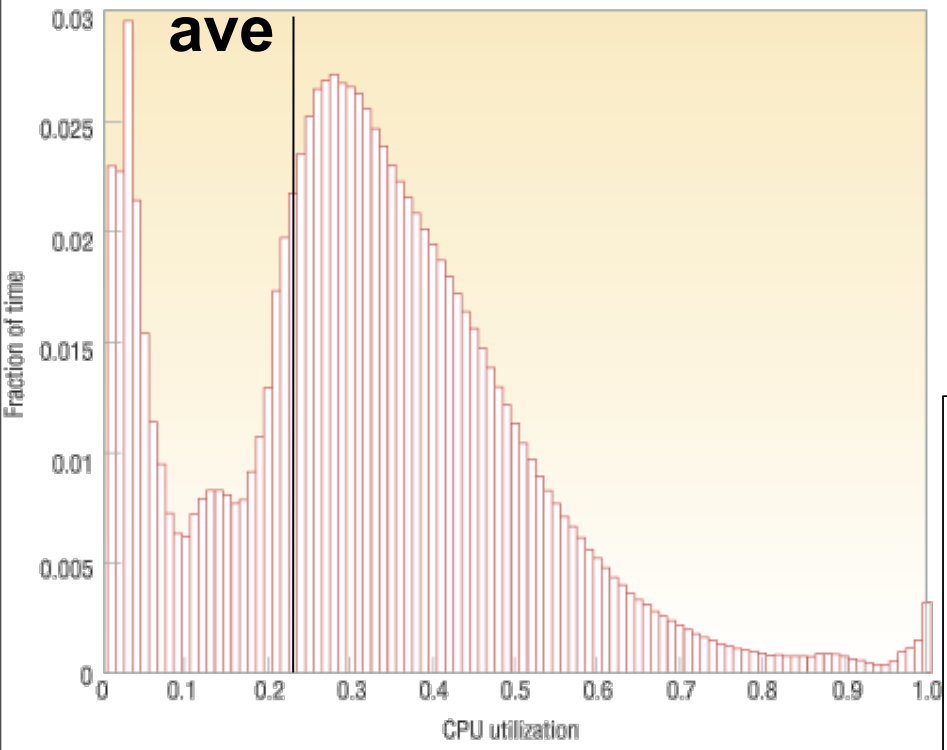
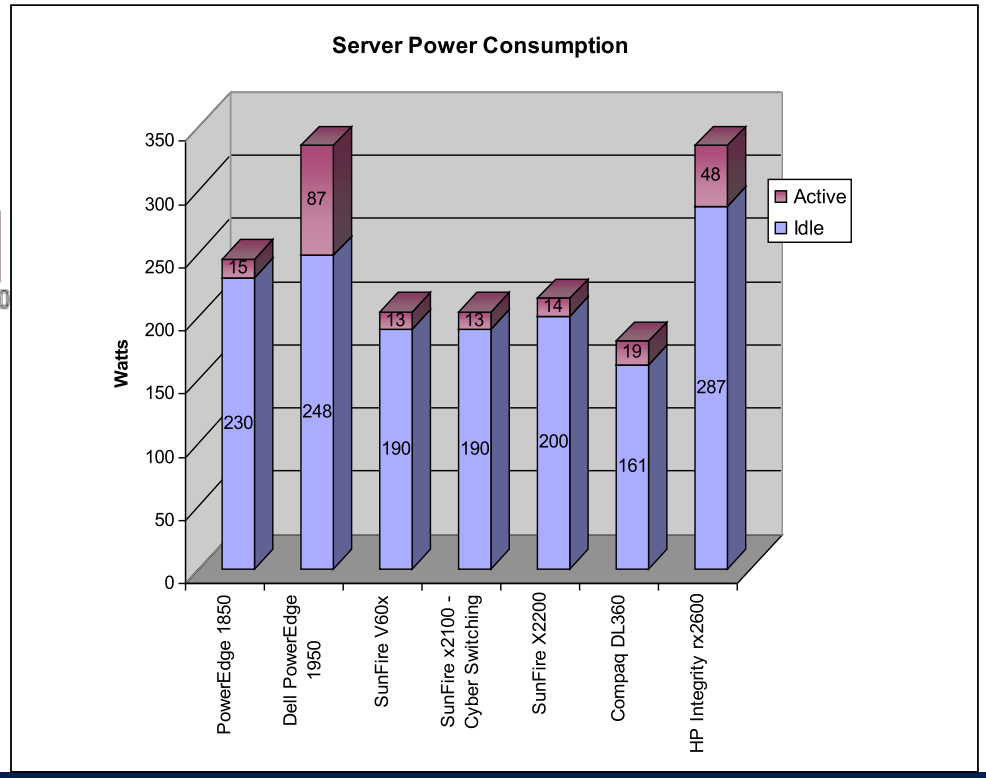


"The Case for Energy-Proportional Computing," Luiz André Barroso, Urs Hölzle, *IEEE Computer* December 2007 – study of 5,000 servers

- Designed for peak
- 10-50% Power Prop.



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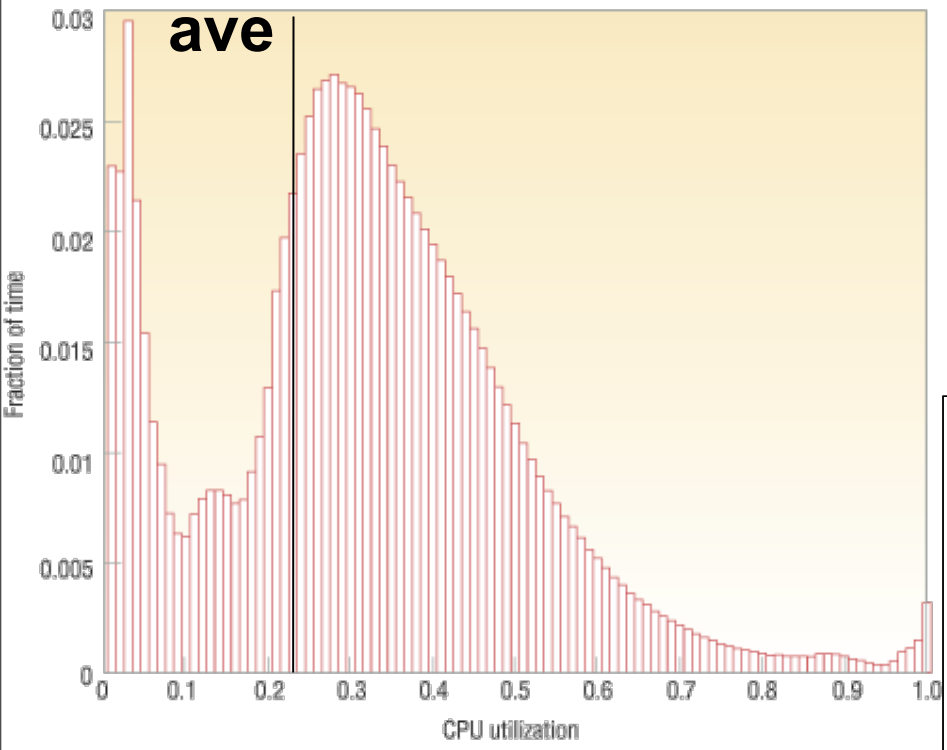
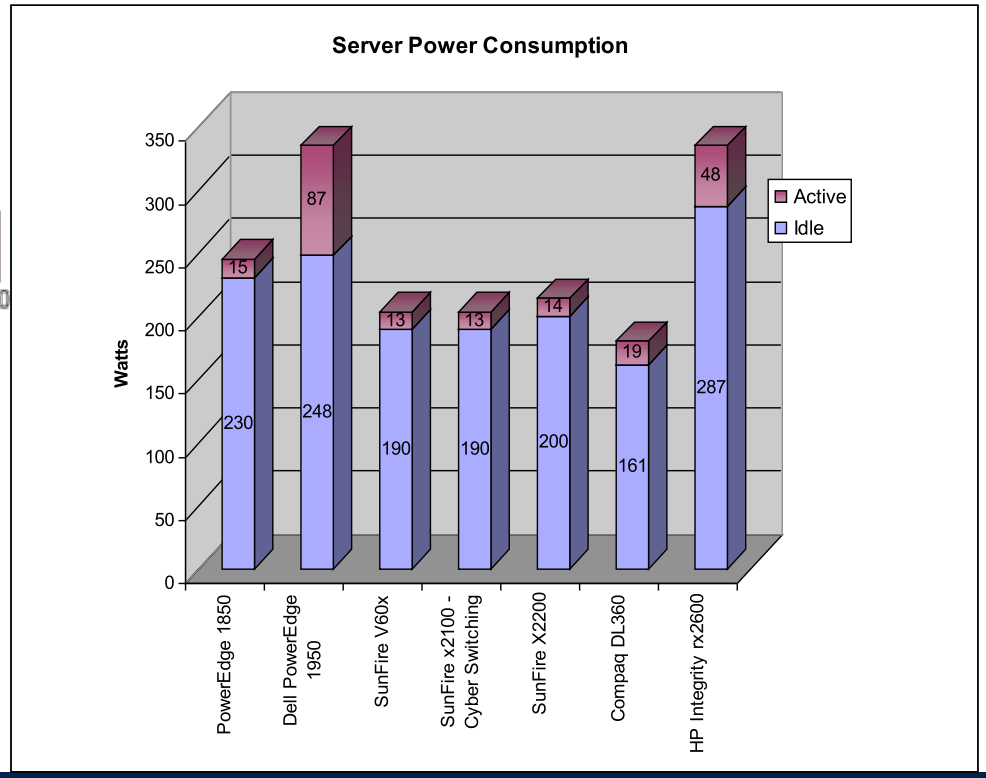
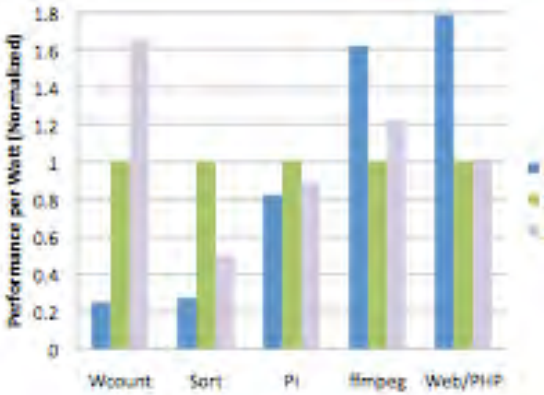


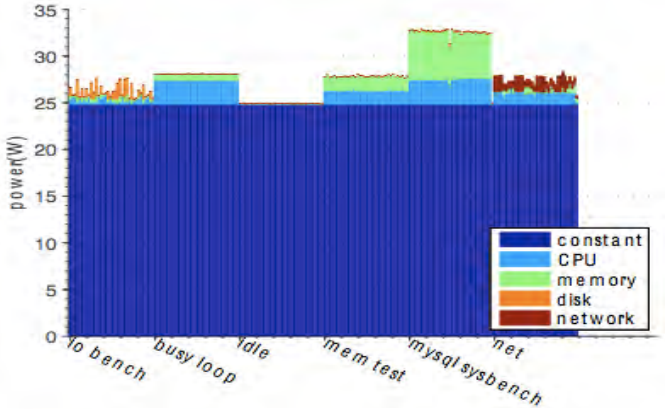
"The Case for Energy-Proportional Computing," Luiz André Barroso, Urs Hölzle, *IEEE Computer* December 2007 – study of 5,000 servers

- Designed for peak
- 10-50% Power Prop.
- As bad as buildings

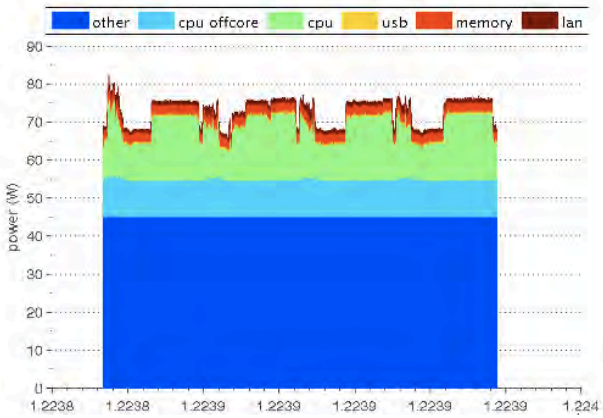


Where does the Power go?

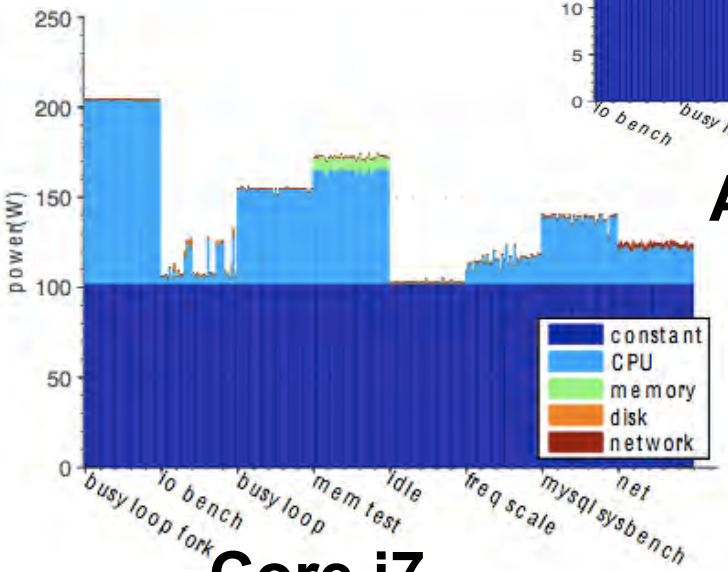




Atom 333



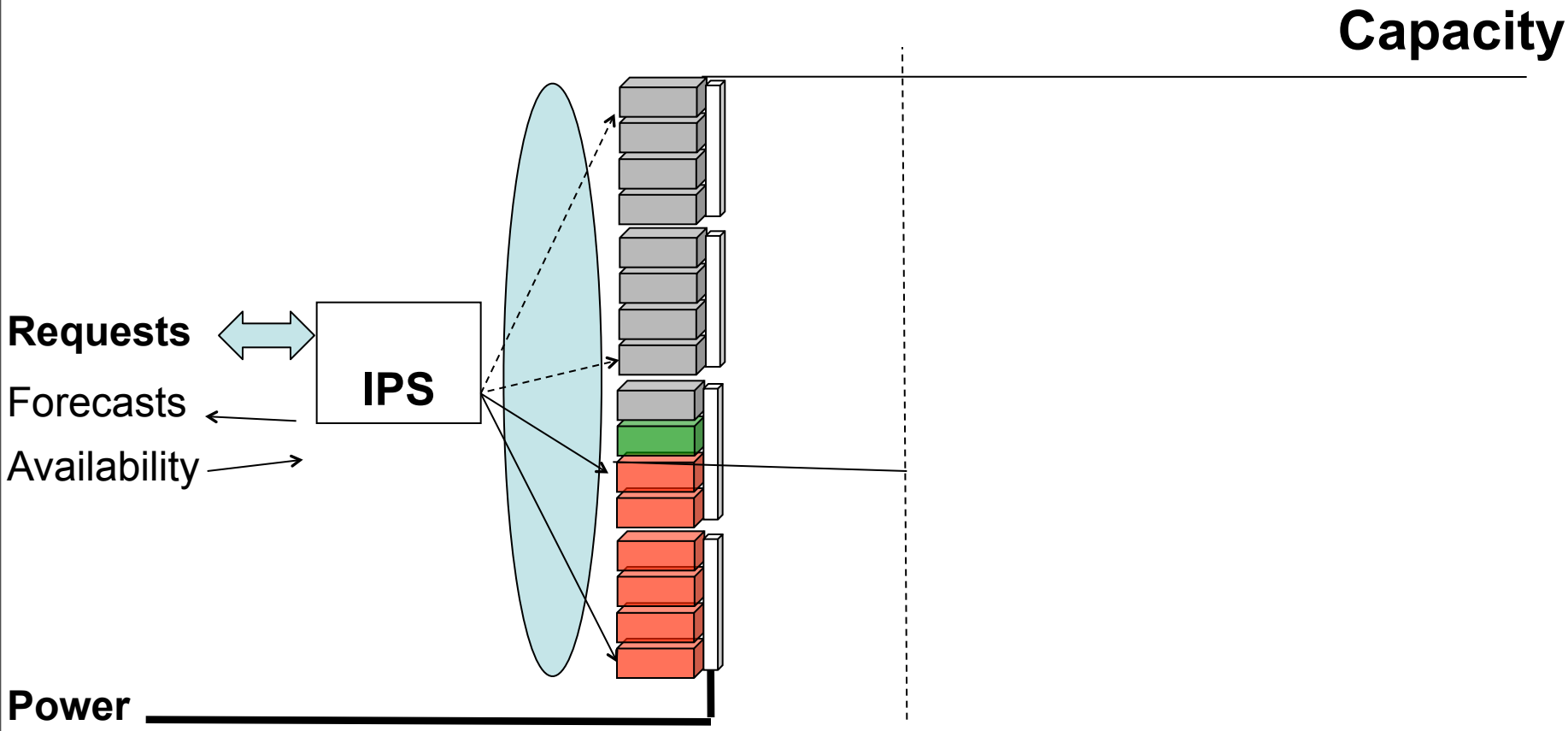
Westmere



Core i7

- The Glue, not the processor

Power Proportional IT Cloud



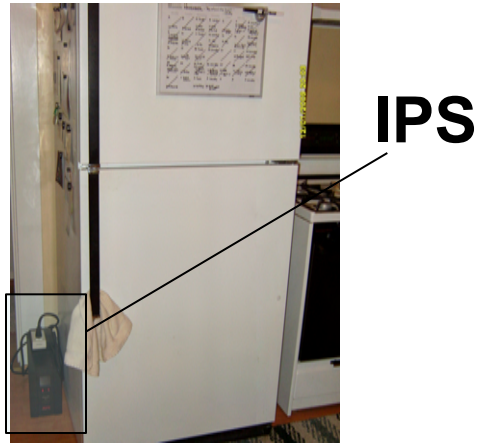
Power Proportional IT Cloud

Energy “Slack”

Thermostatically Controlled Load

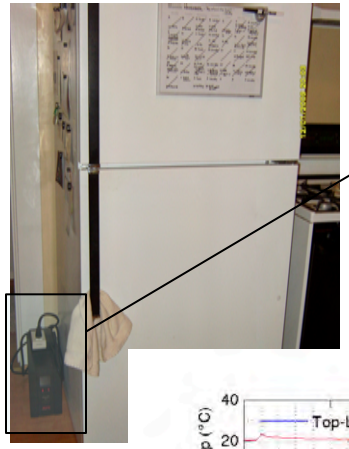
Energy “Slack”

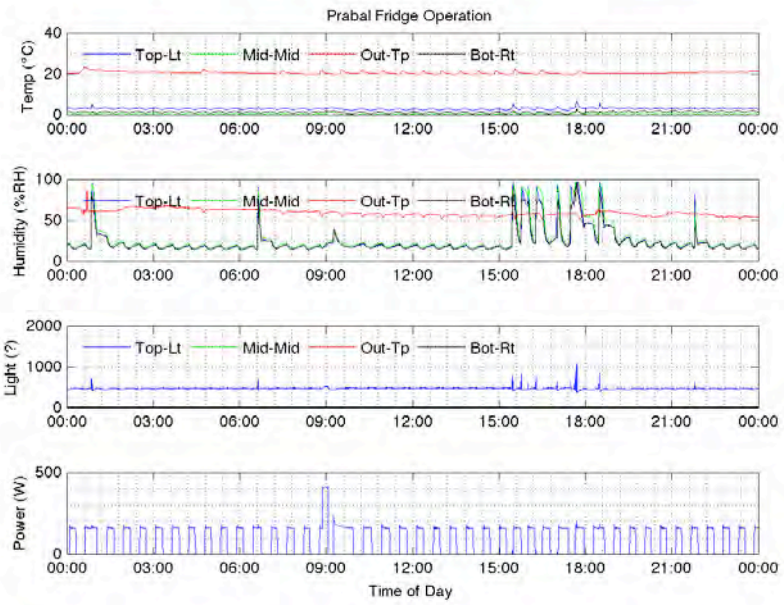
Thermostatically Controlled Load



Energy “Slack”

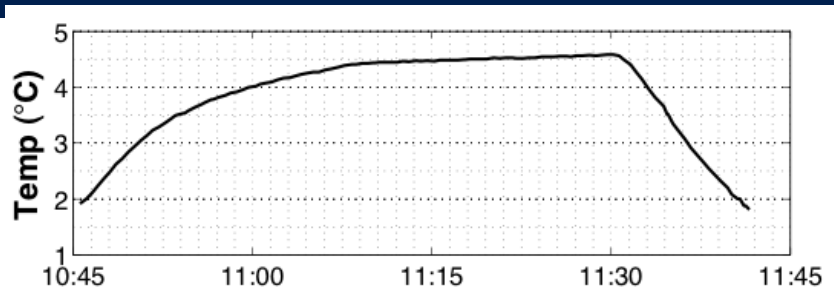
Thermostatically Controlled Load

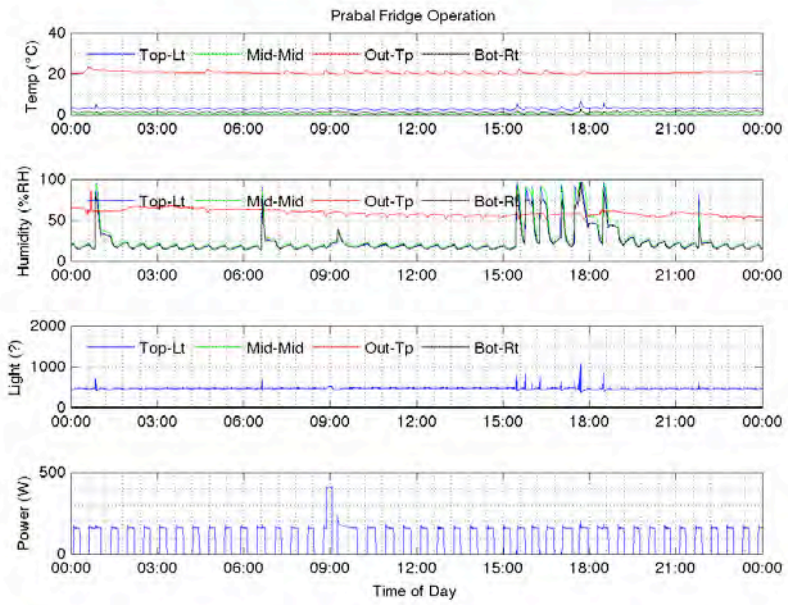




Energy “Slack”

Thermostatically Controlled Load

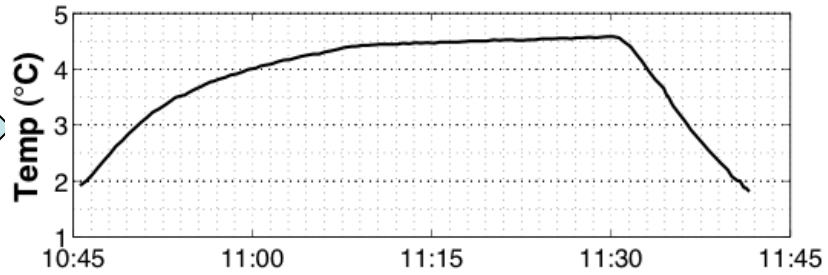


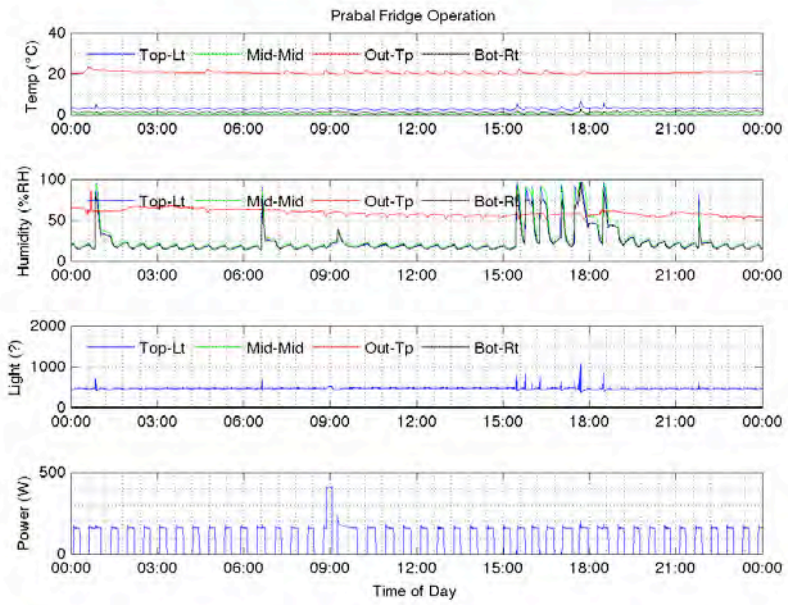


Energy “Slack”

Thermostatically Controlled Load

Set Point

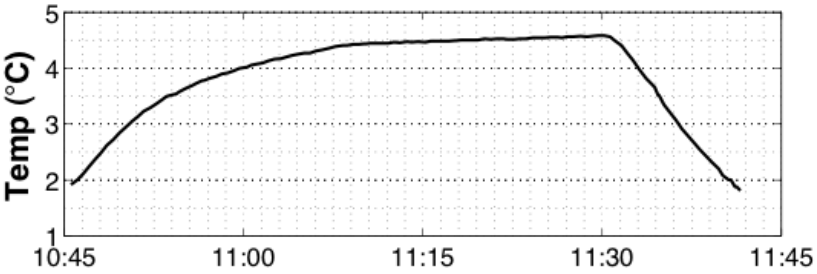


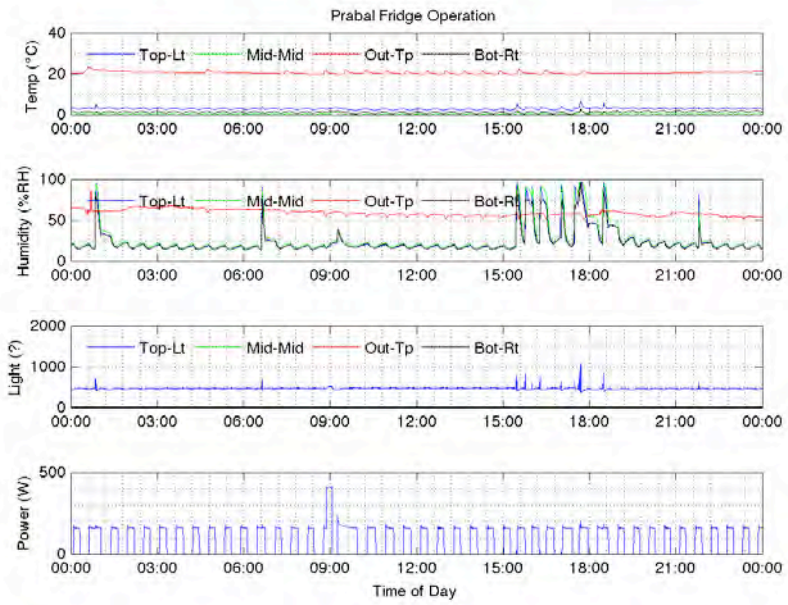


Energy “Slack”

Thermostatically Controlled Load

Set Point

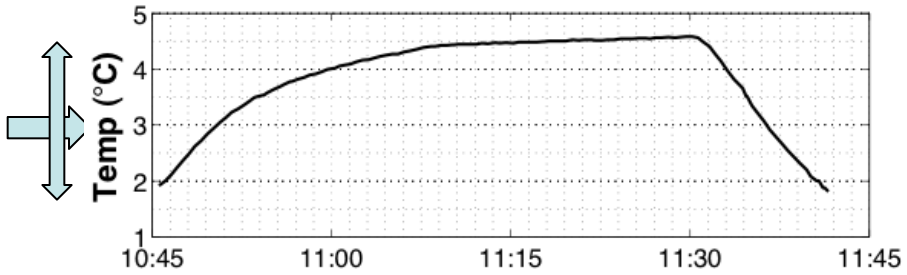


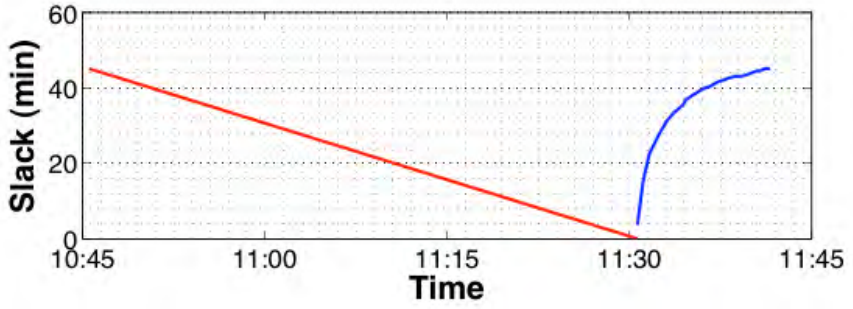


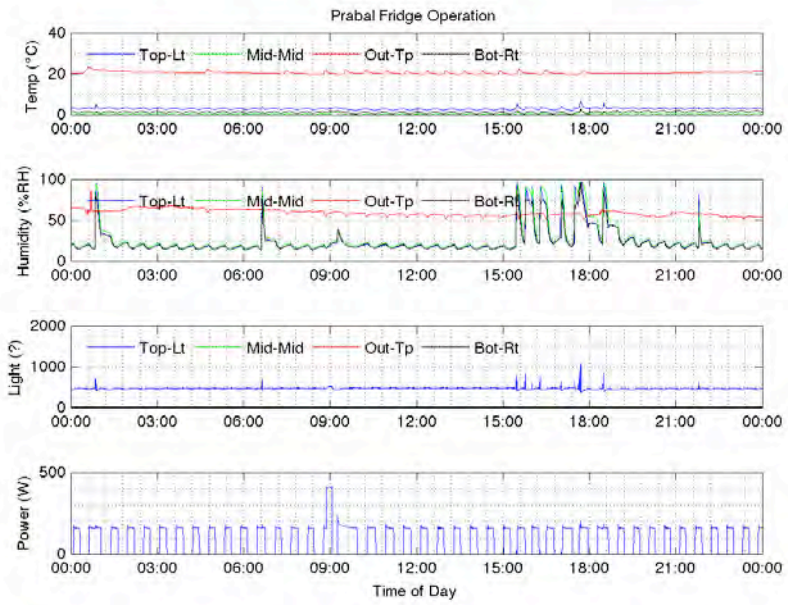
Energy "Slack"

Thermostatically Controlled Load

Set Point

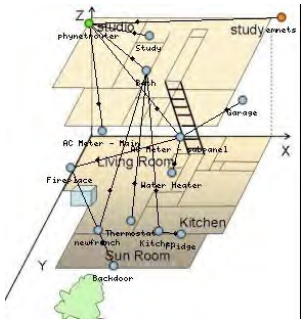


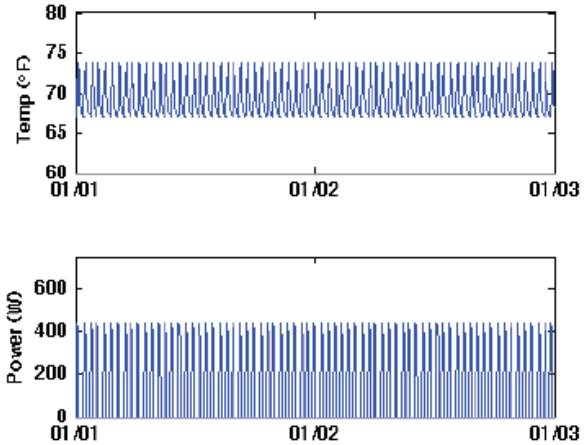




Supply-Following Loads

Supply-Following Loads





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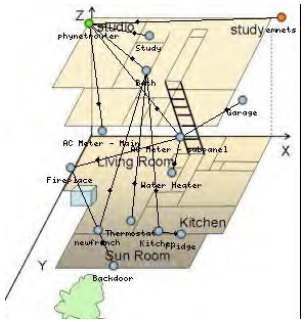

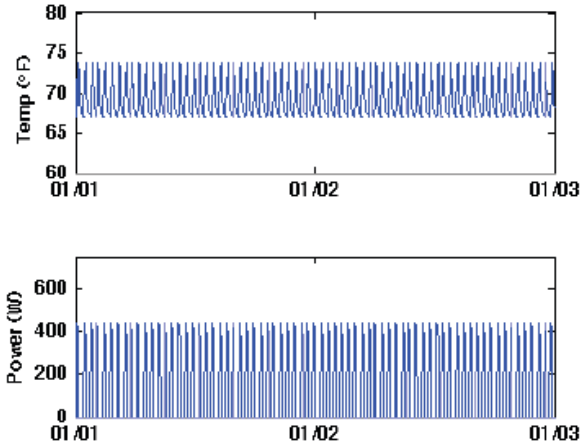

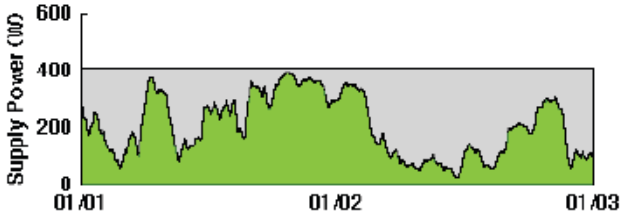

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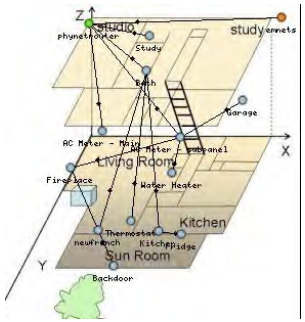

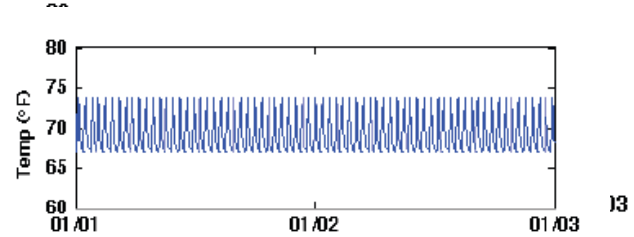

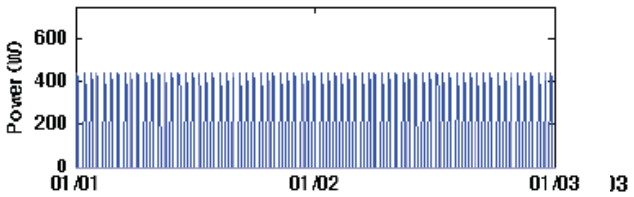

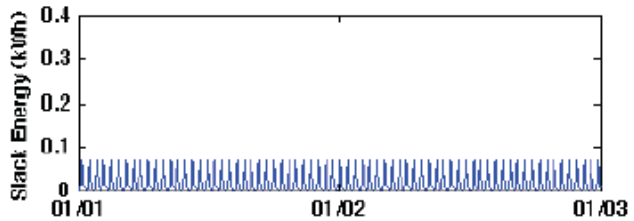

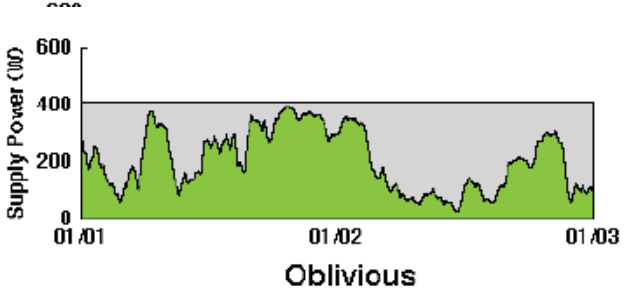

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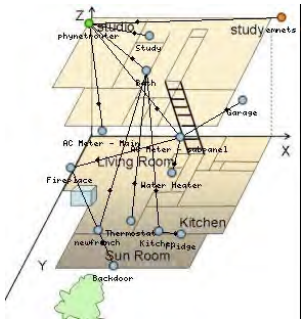

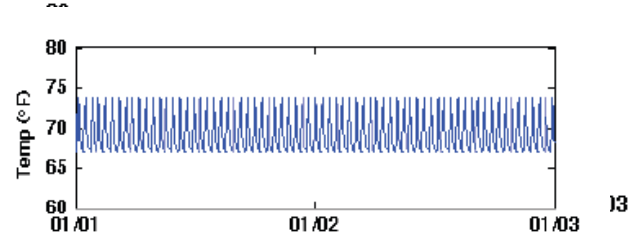

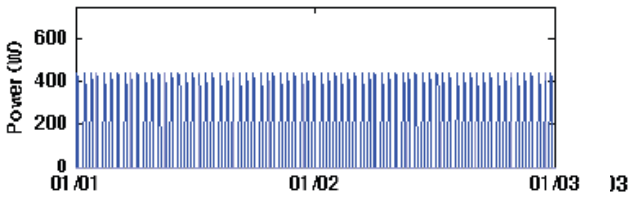

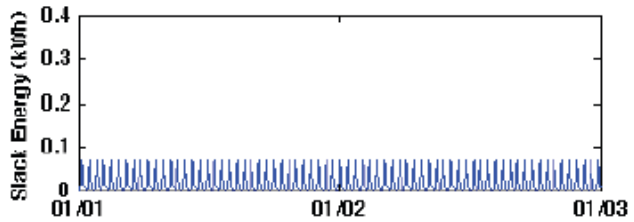

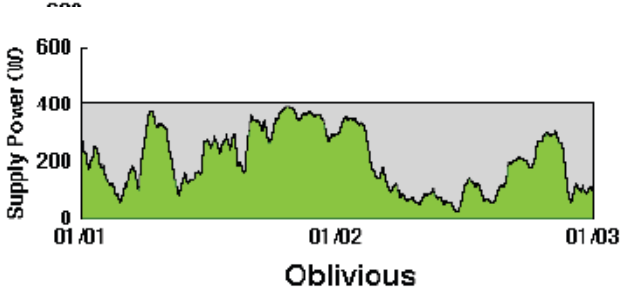

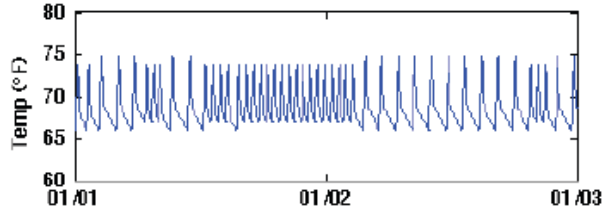

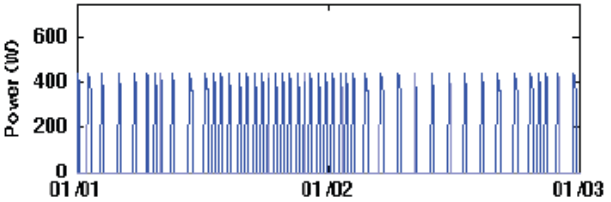

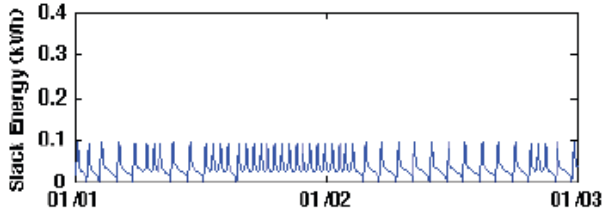

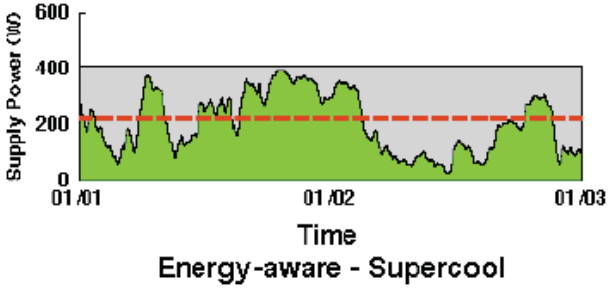

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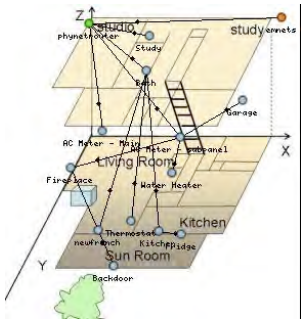

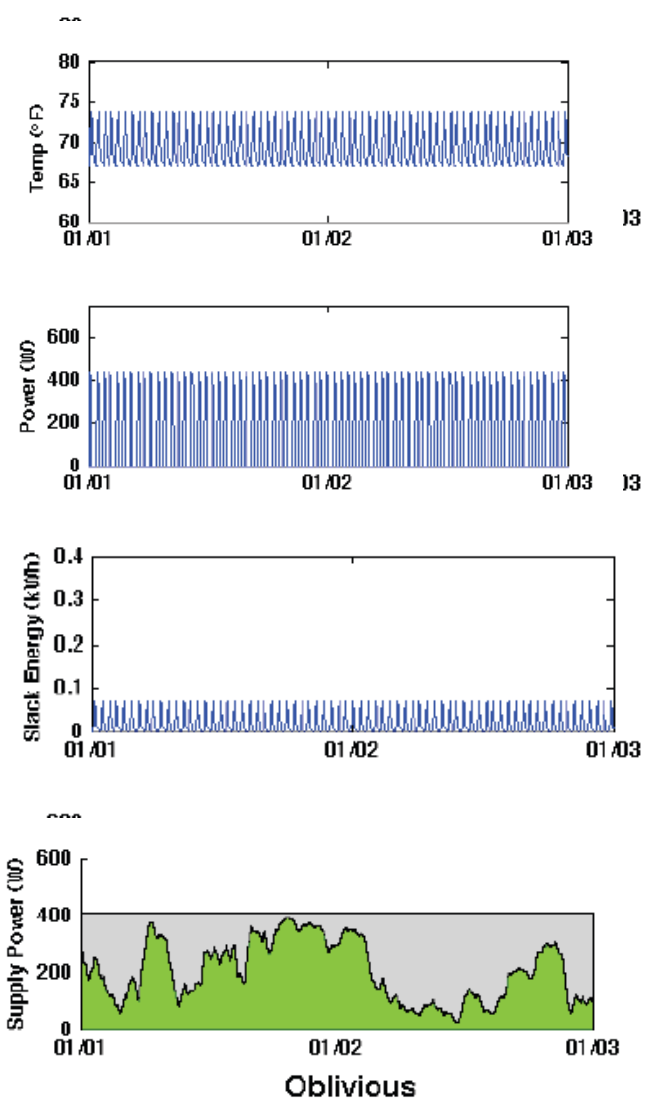

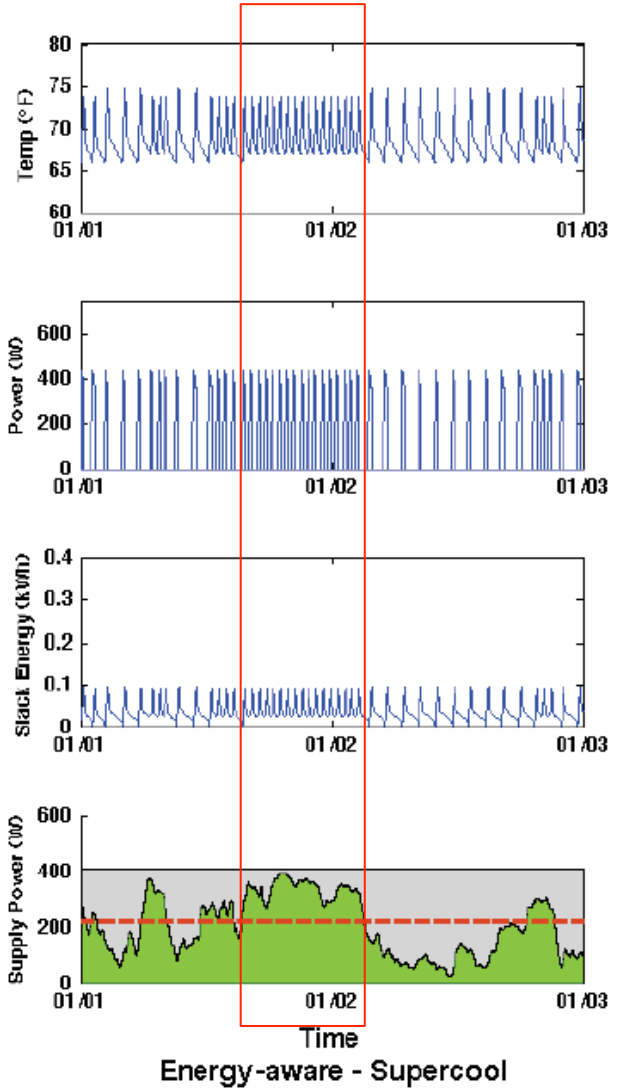

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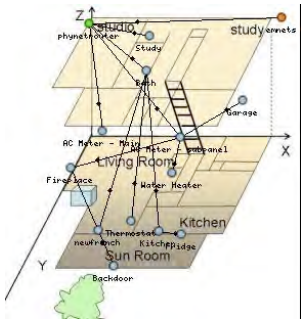

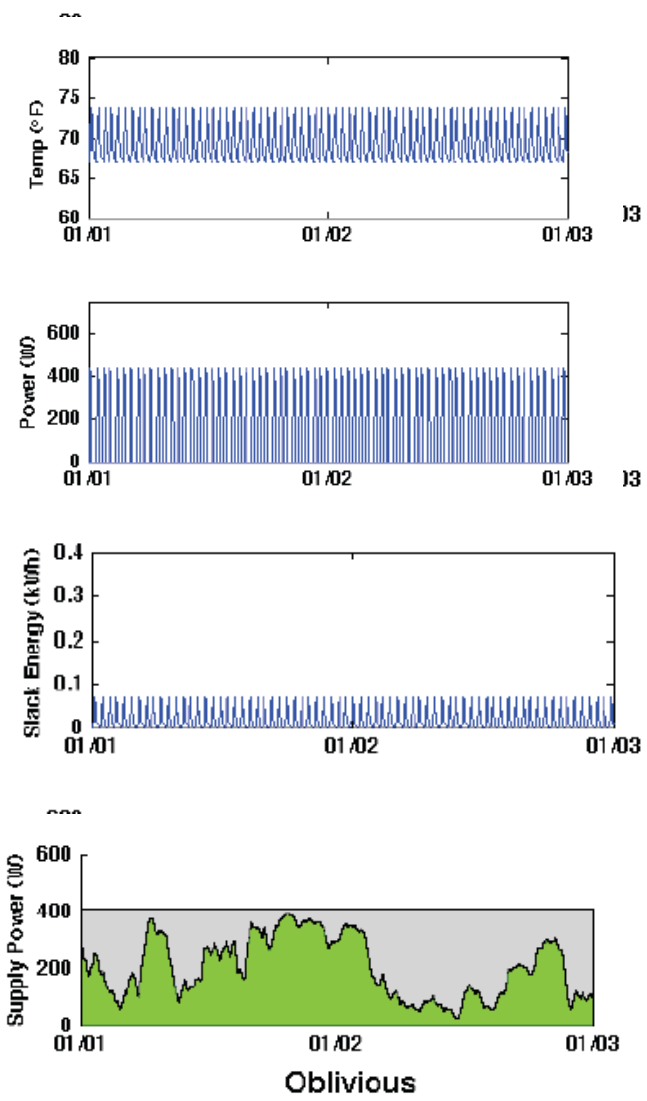

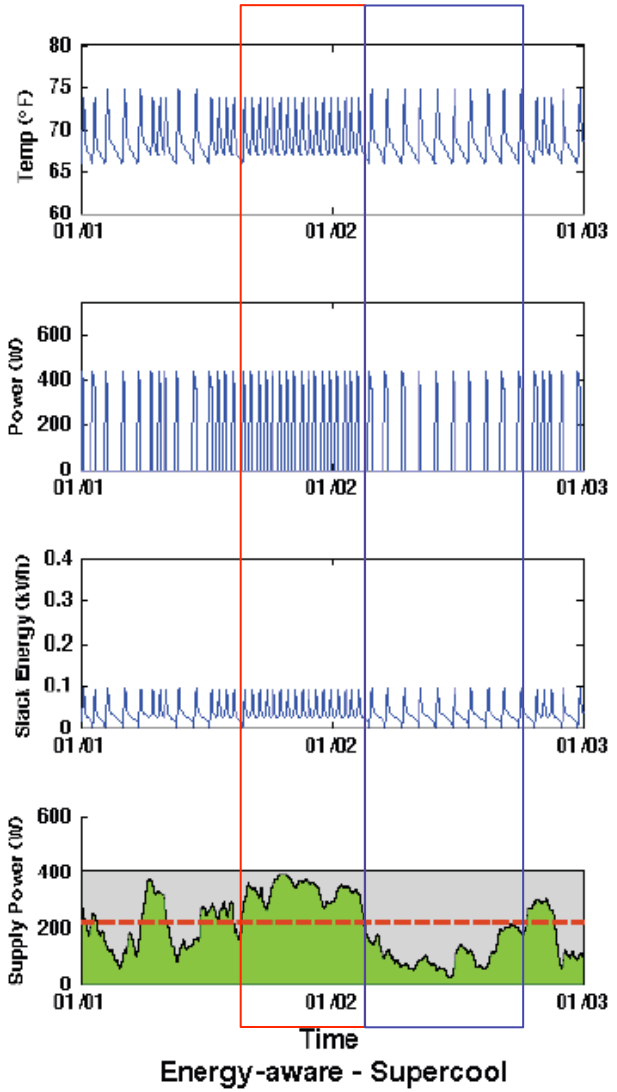

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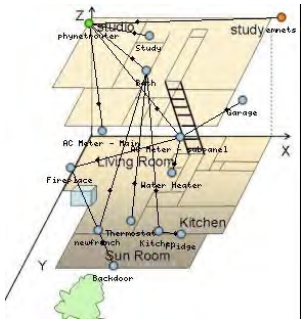

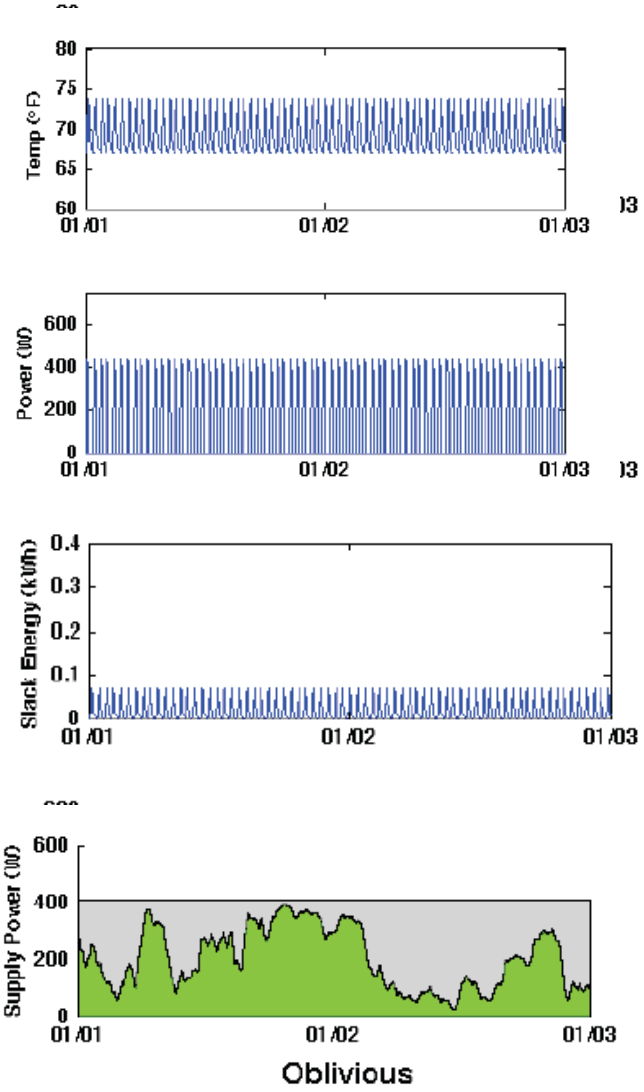

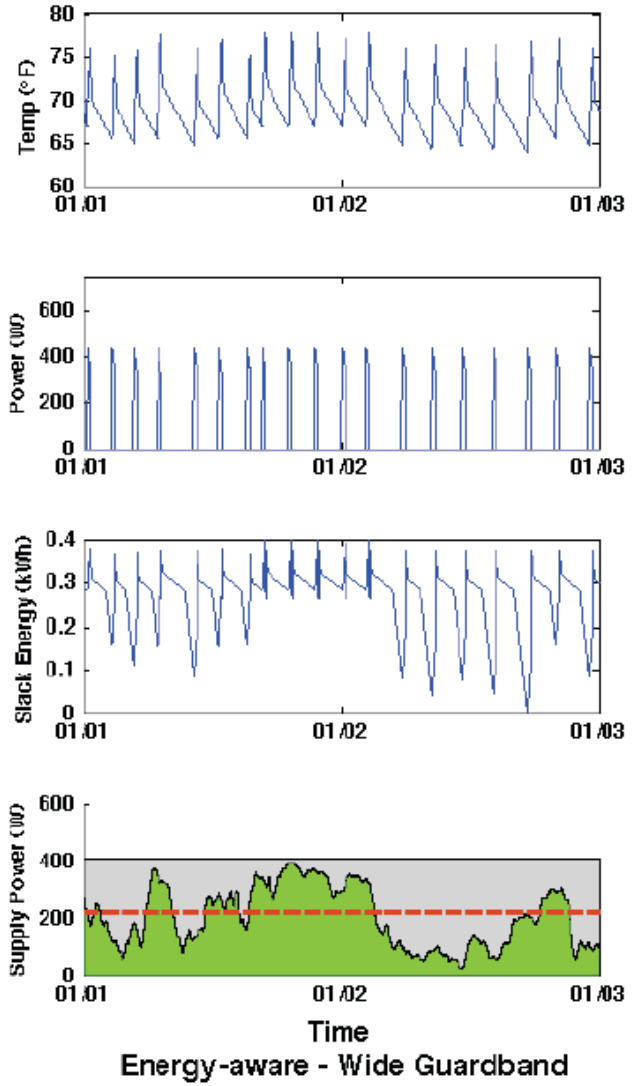

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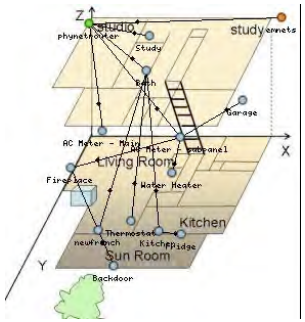
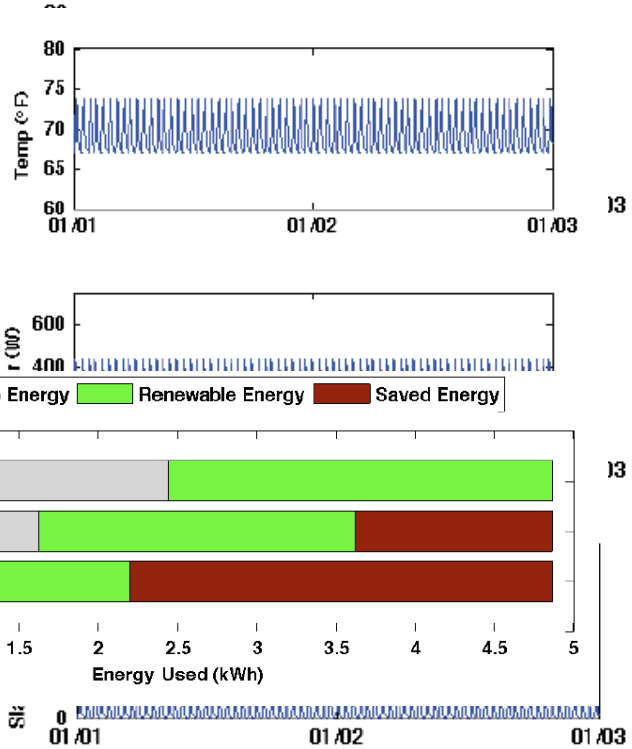
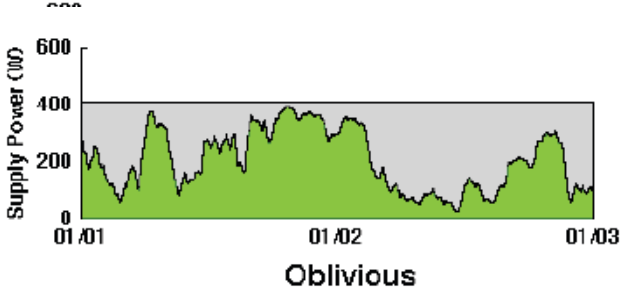
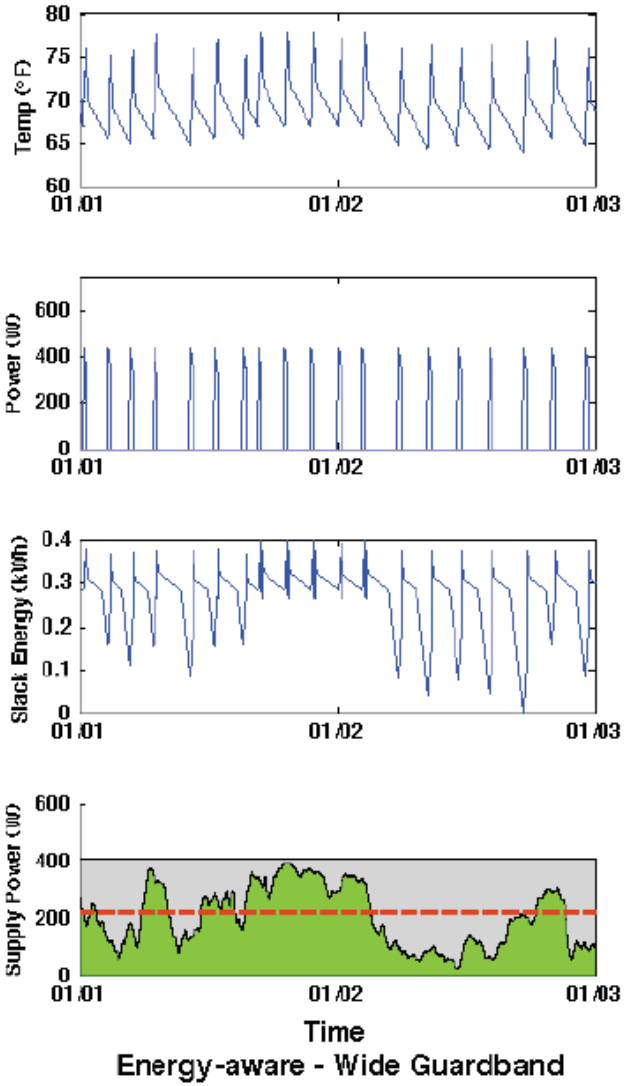
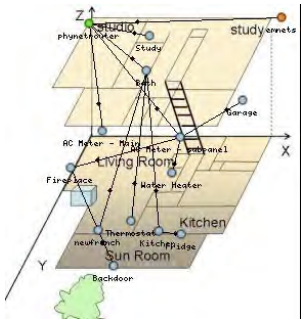


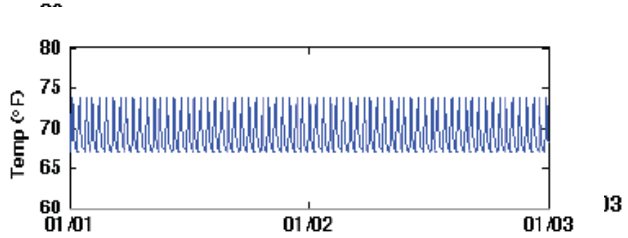


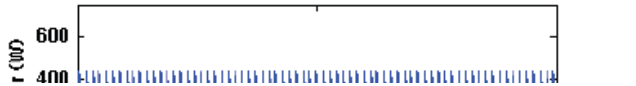


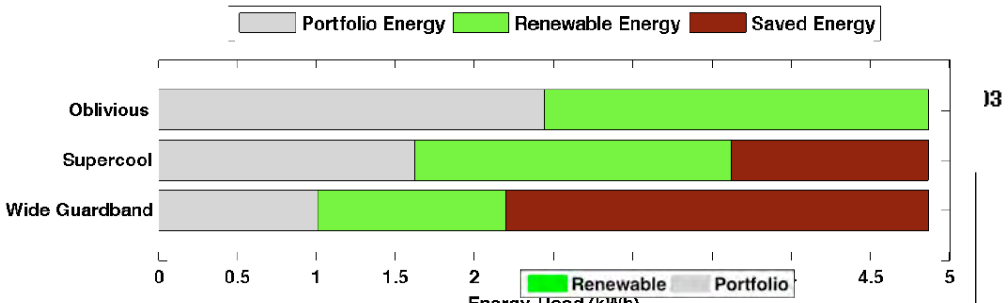


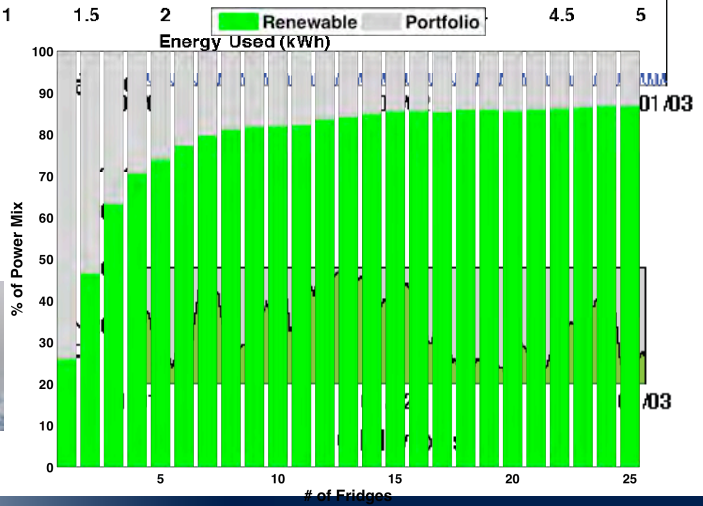
Supply-Following Loads

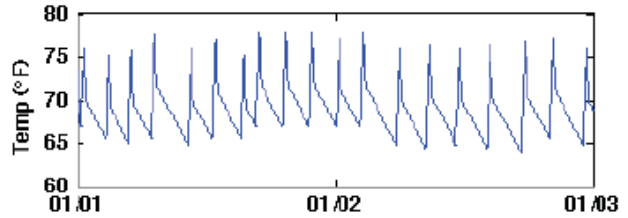


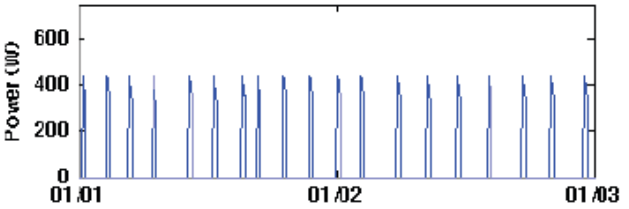


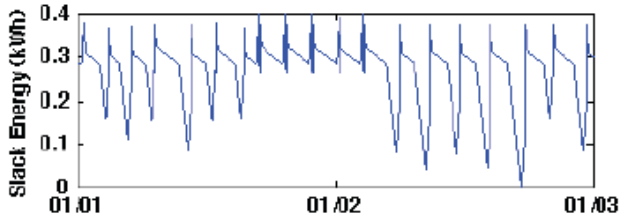


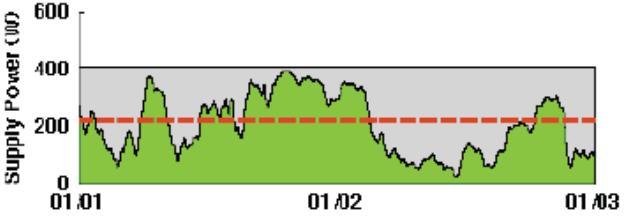






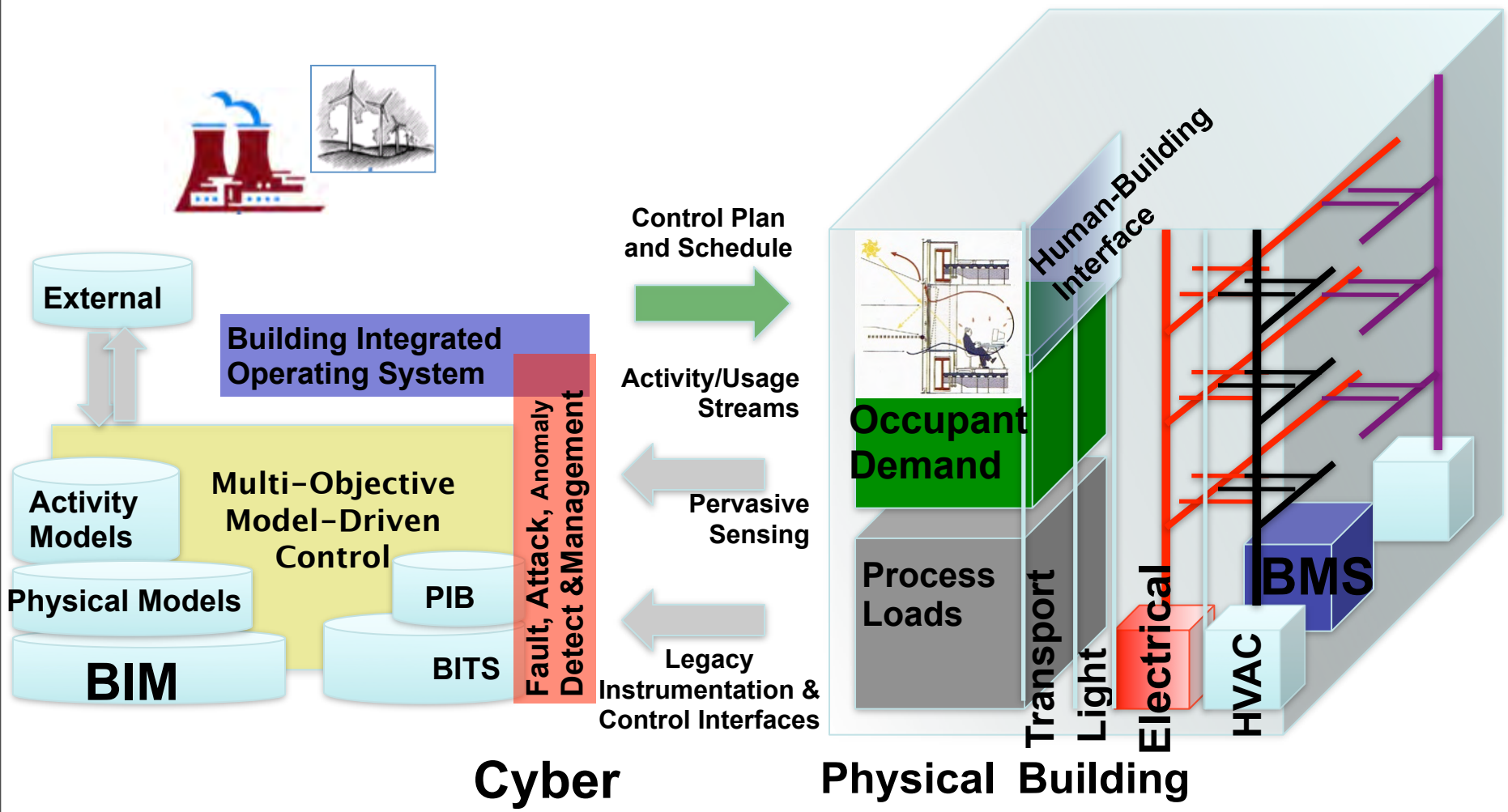




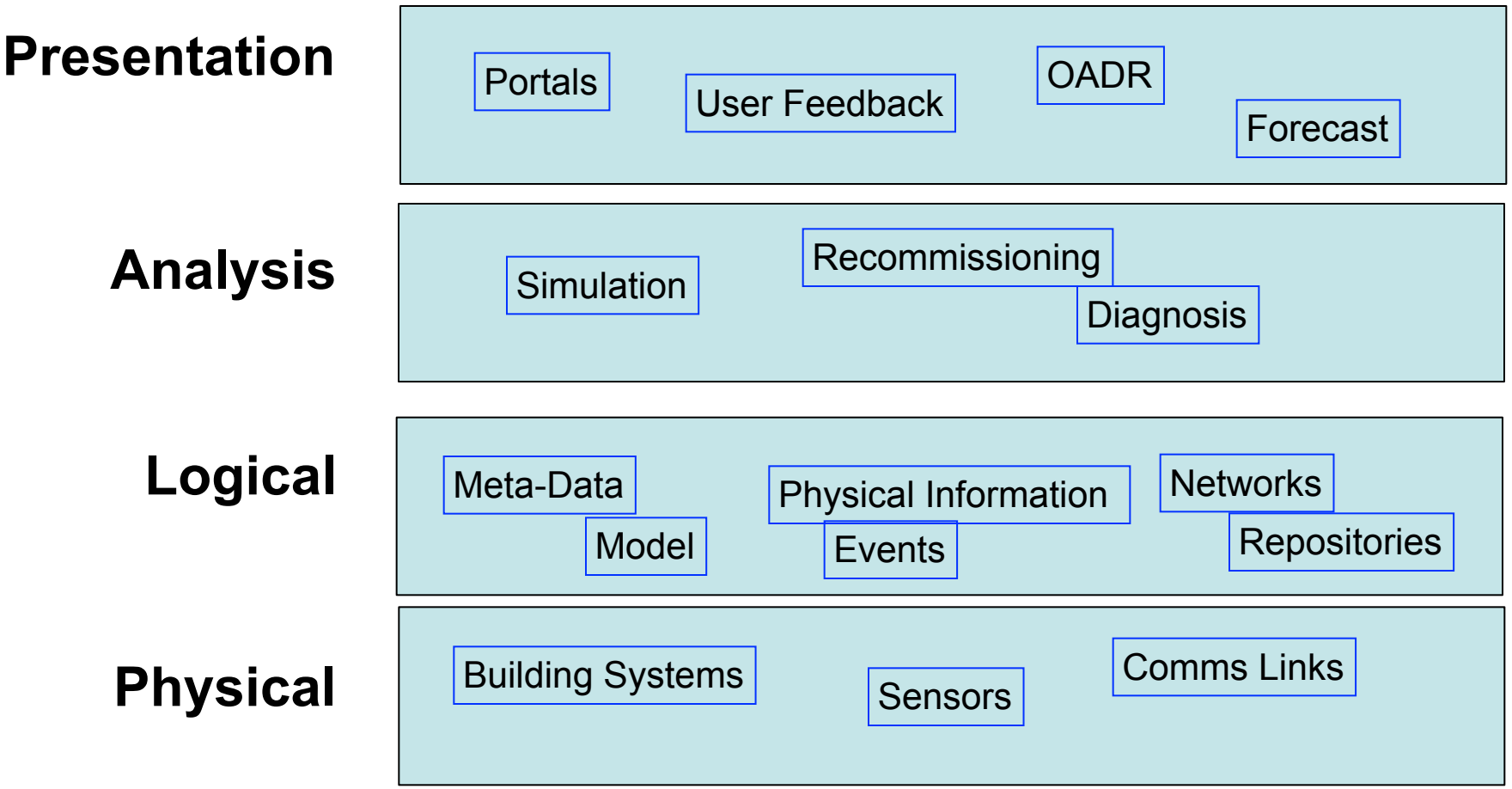


Energy-aware - Wide Guardband

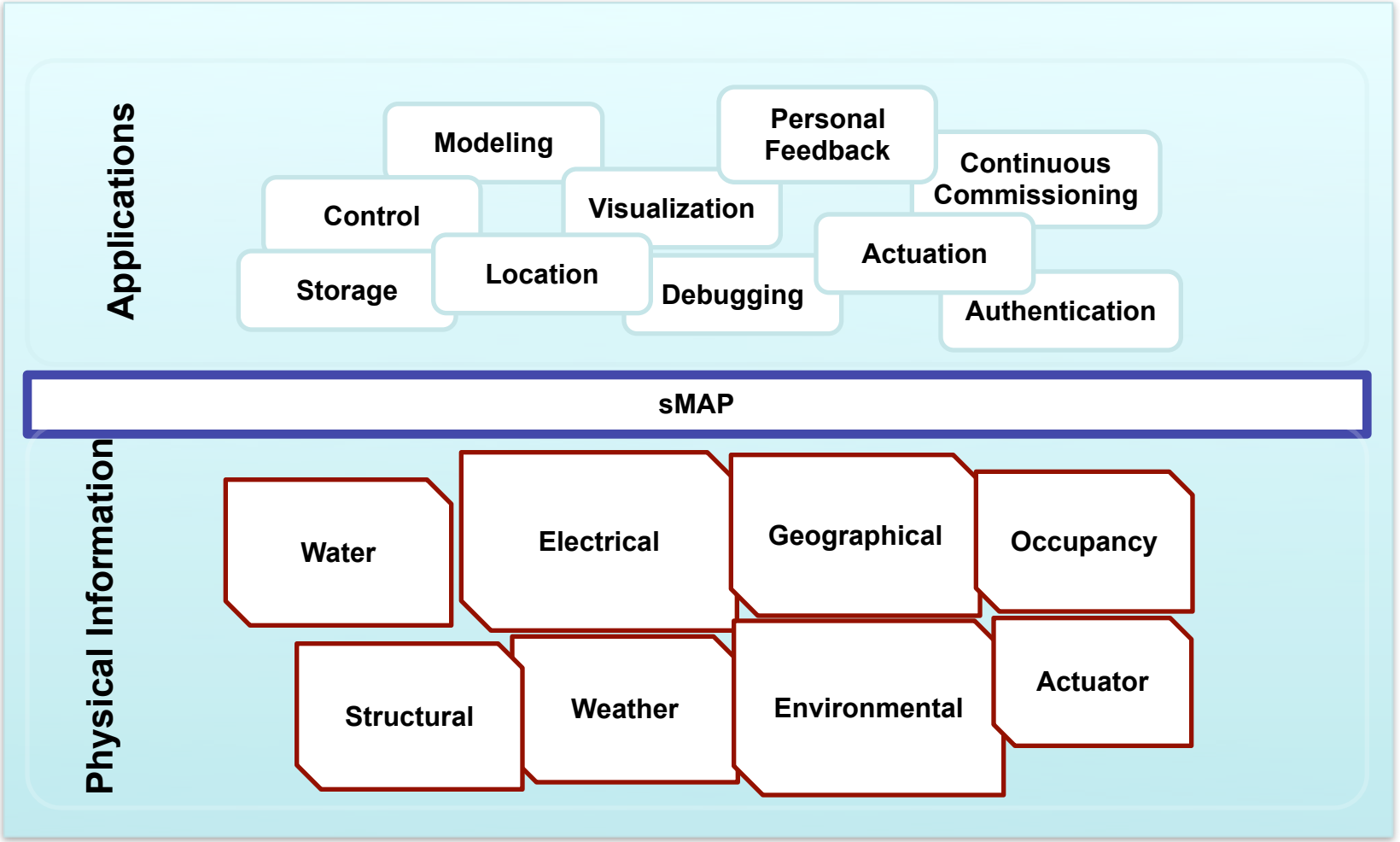
Cyber / Physical Buildings



Layered Arch. for Physical Info



Narrow Waist ?

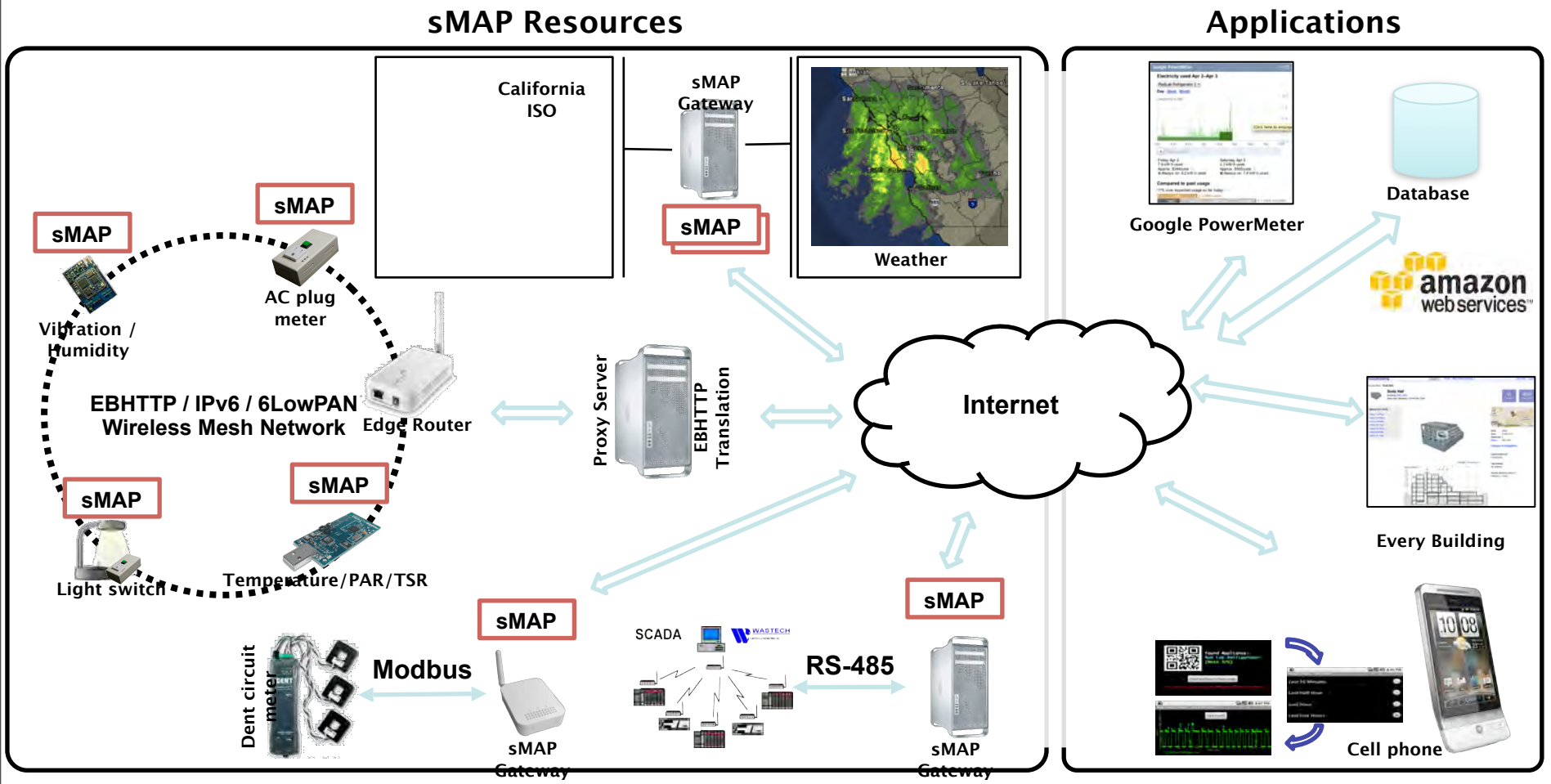


sMAP restful web services

```
/                       # 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]
```

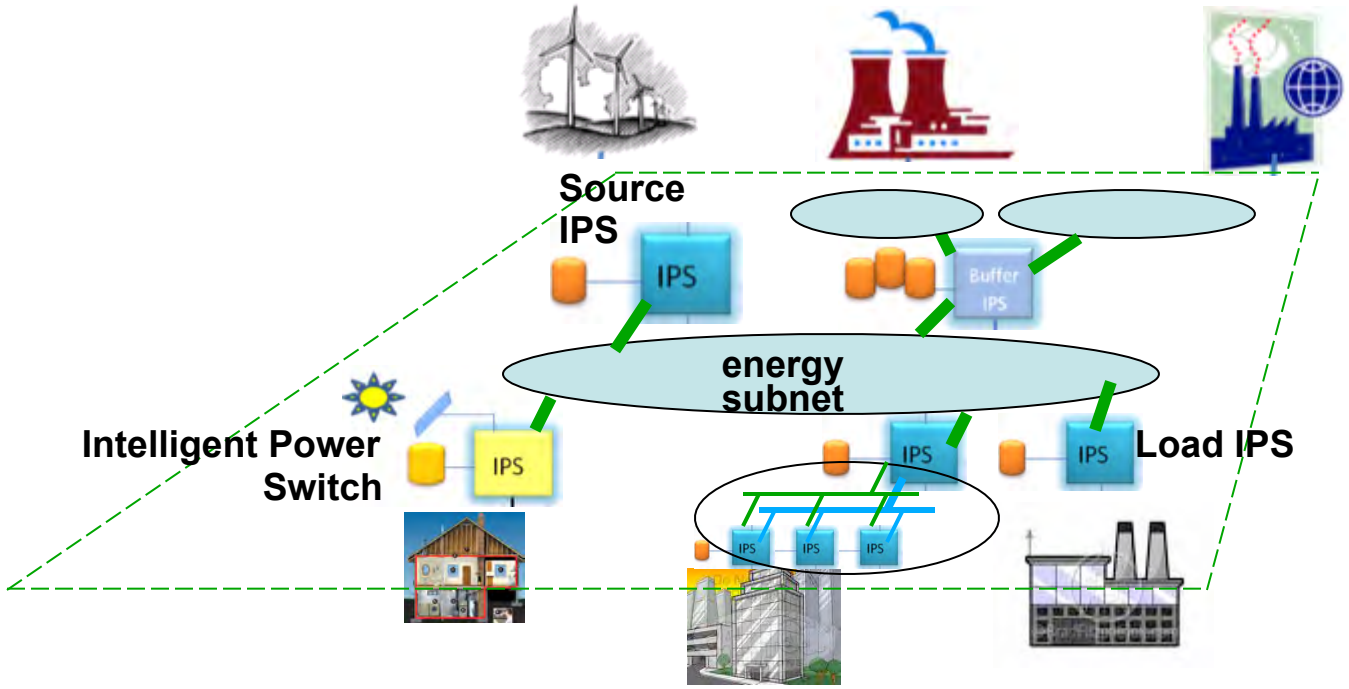
```
POST requests supply JSON objects as arguments:
        POST: http://meter1.cs.berkeley.edu/reporting/create
        { "ReportResource" : "/data/325/meter/*/reading",
          "ReportDeliveryLocation" :
                "http://webs.cs.berkeley.edu/recv.php",
          "Period" : 0, "Minimum" : 50,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

IP everywhere / Real World Web

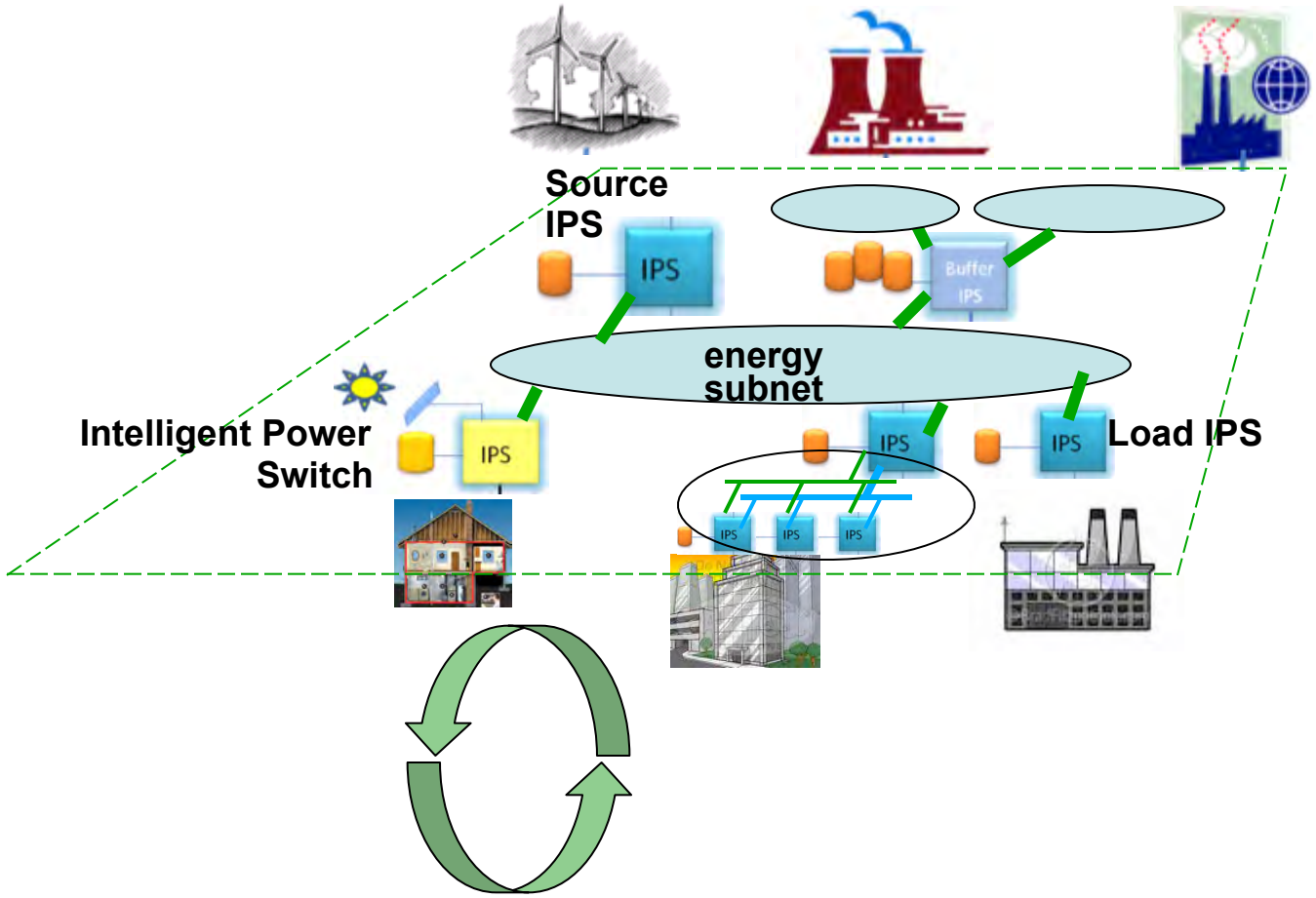


IP everywhere / Real World Web

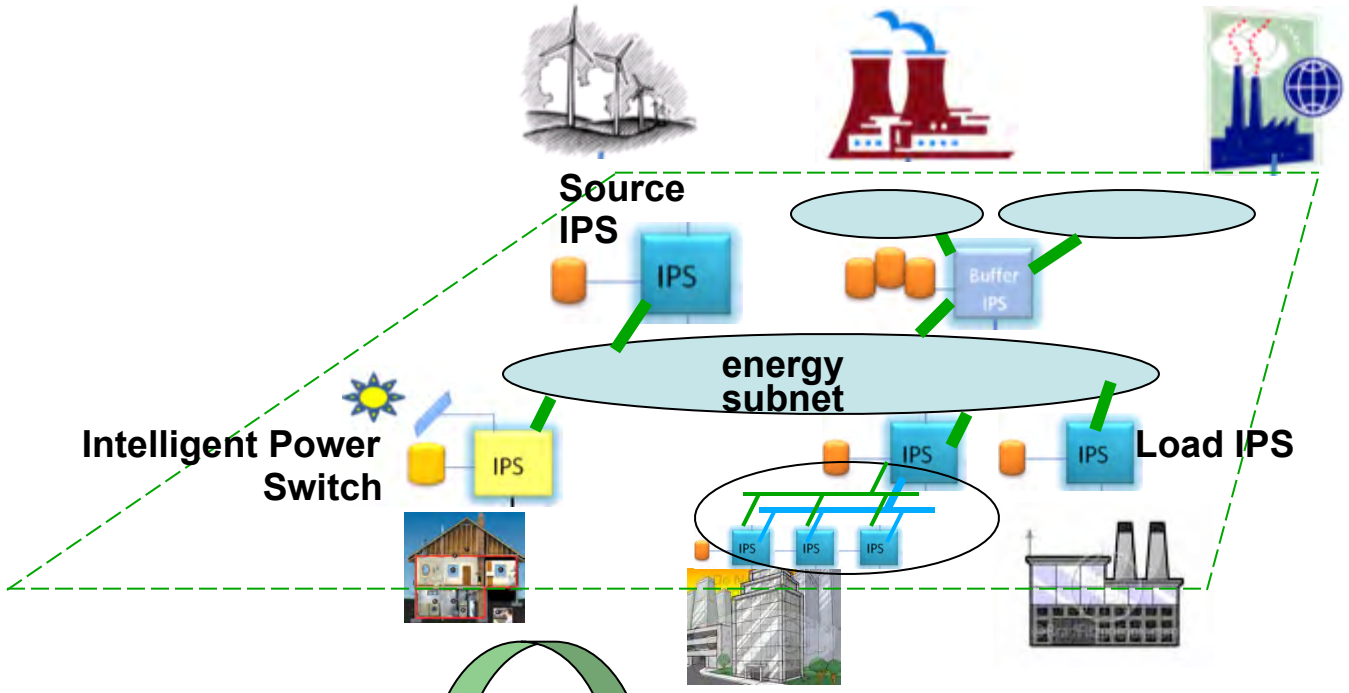
In an Intelligent Energy Network

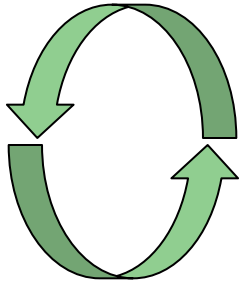


In an Intelligent Energy Network



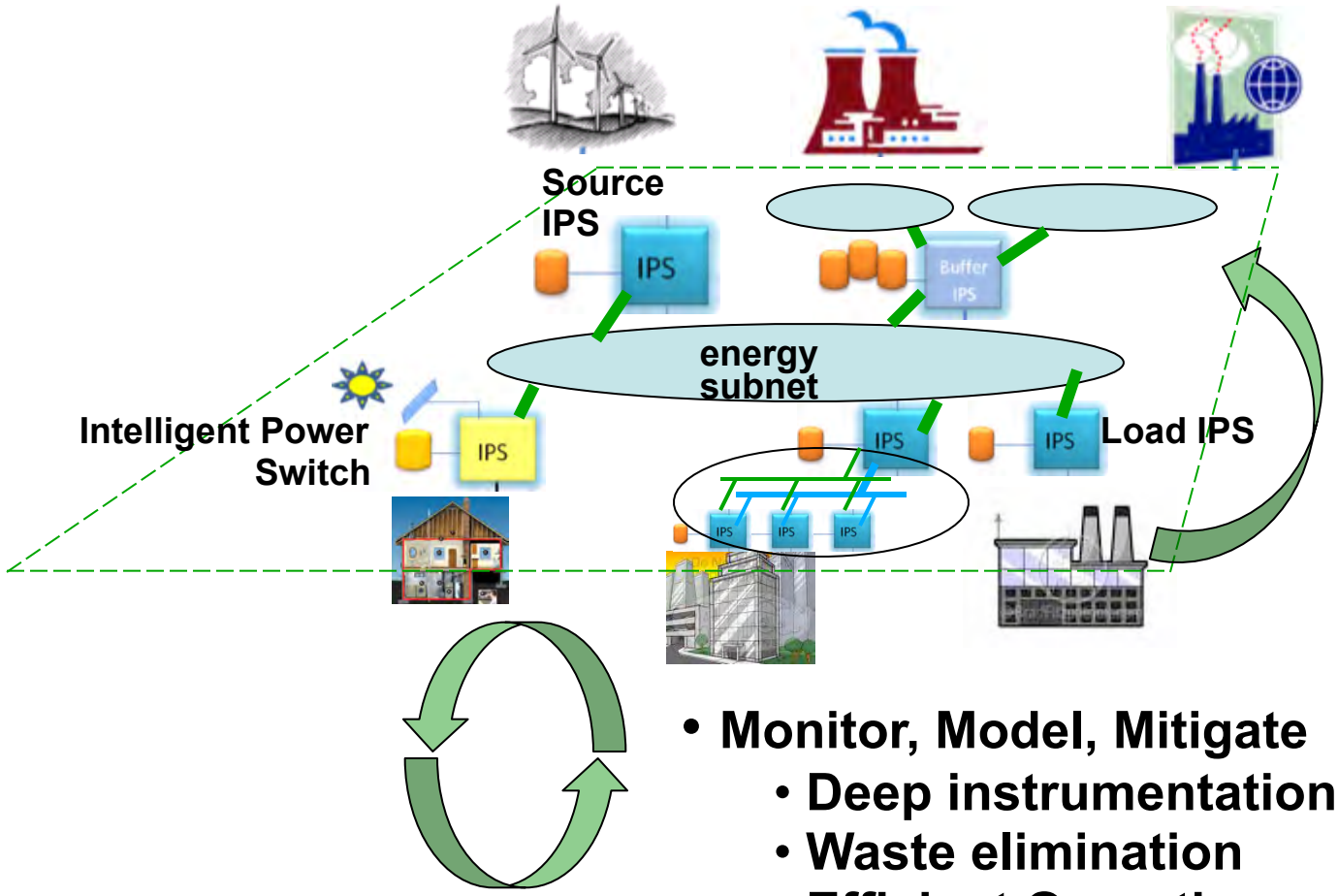
In an Intelligent Energy Network





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

In an Intelligent Energy Network



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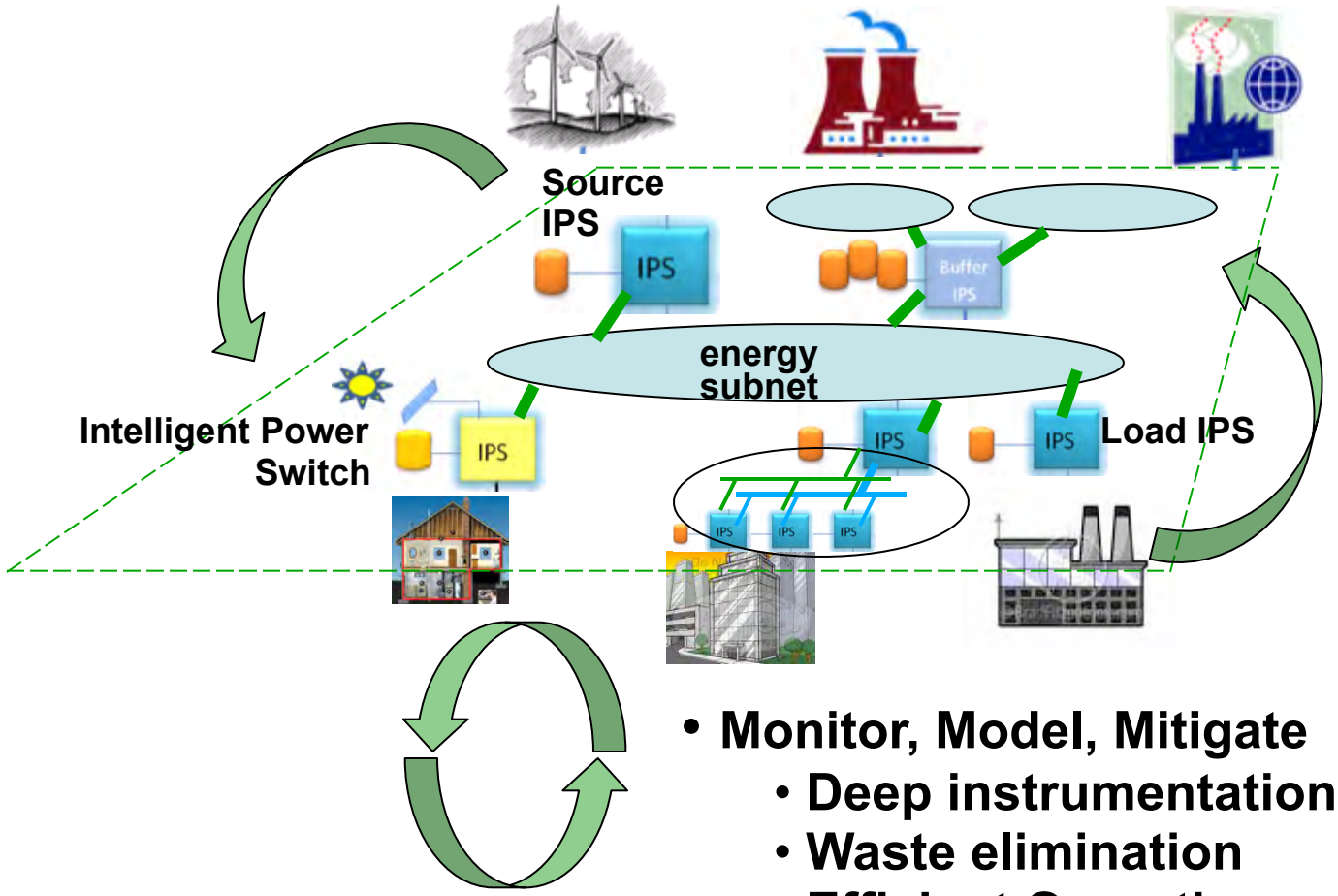
In an Intelligent Energy Network



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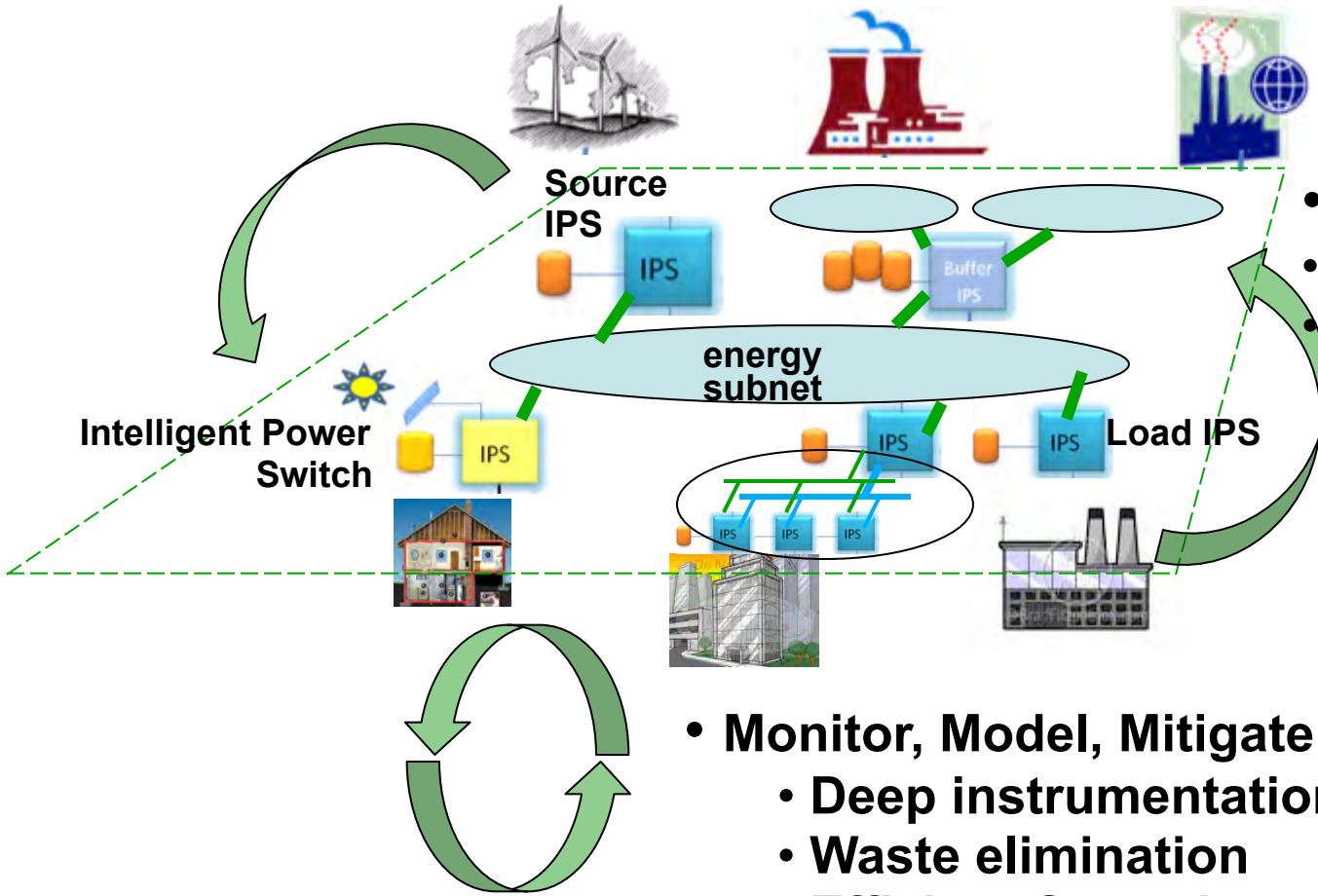

- Forecasting
- Tracking
- Market

- Monitor, Model, Mitigate
  - Deep instrumentation
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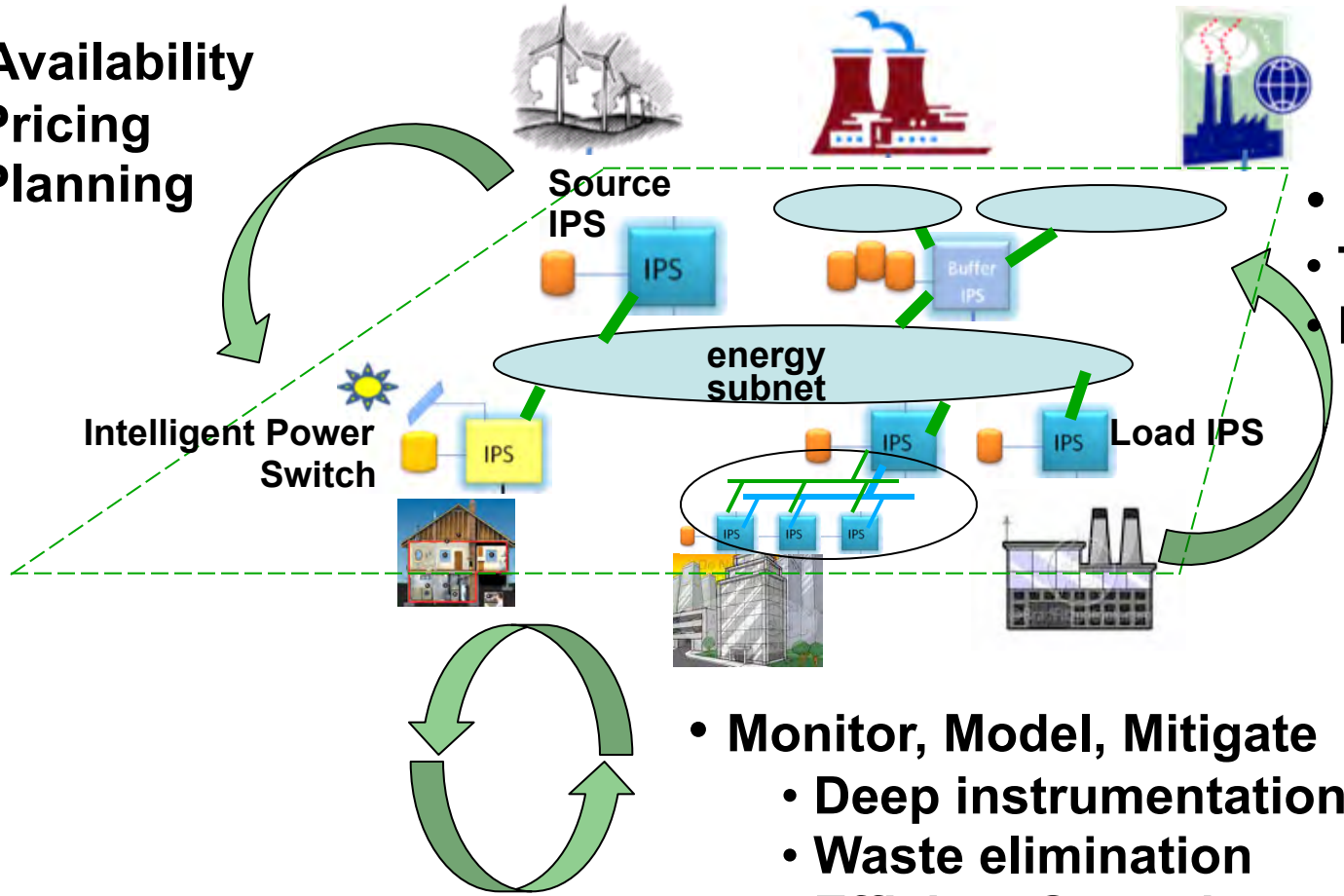
In an Intelligent Energy Network

- Availability
- Pricing
- Planning



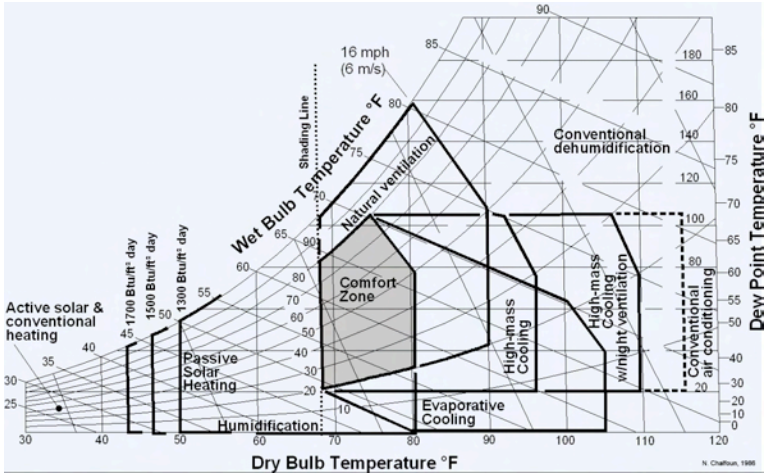
- Forecasting
- Tracking
- Market

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

Path Forward

Path Forward

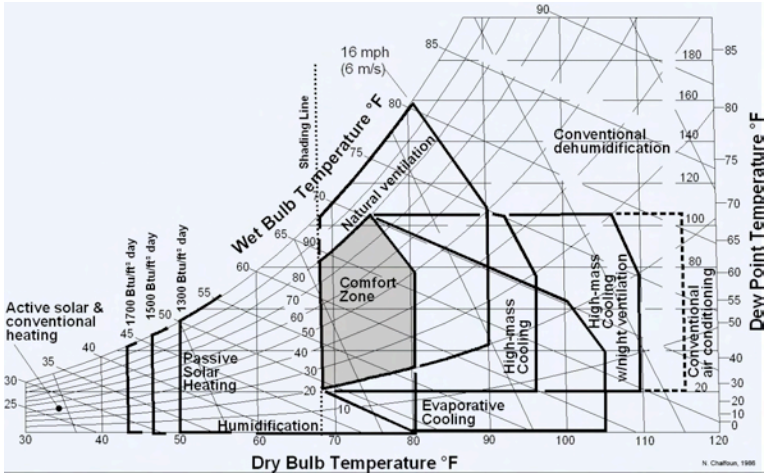
Design



Use

Path Forward

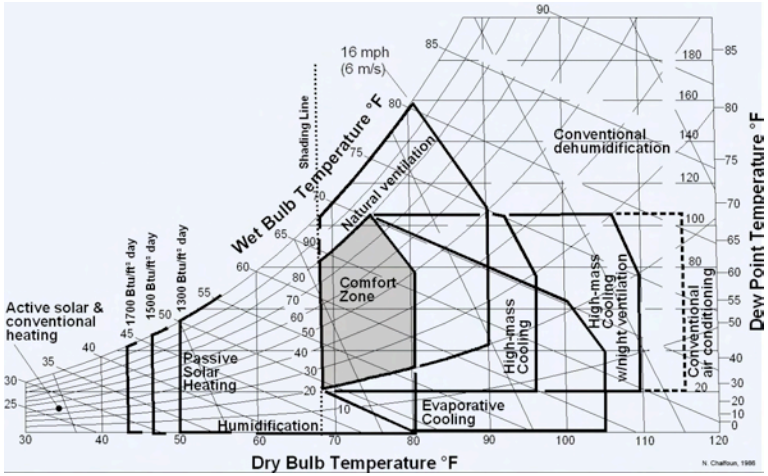
Design

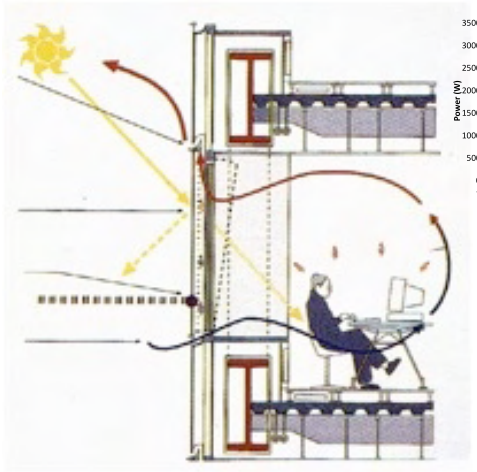


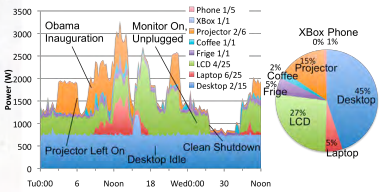
Use

Path Forward

Design



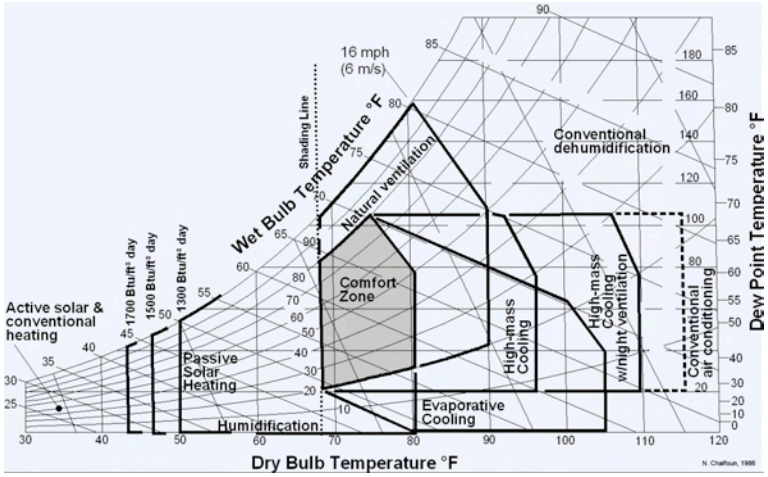


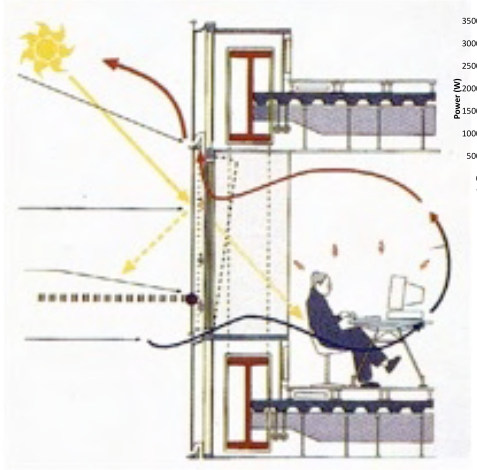


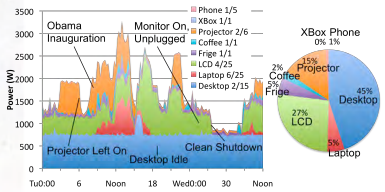
Use

Path Forward

Design





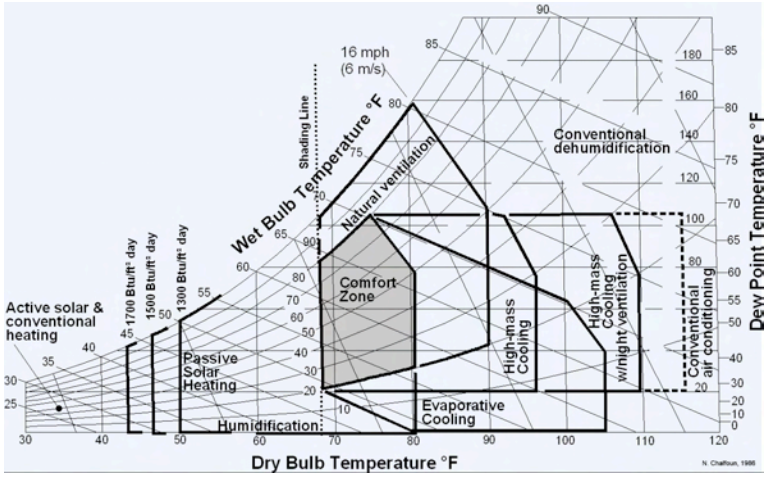


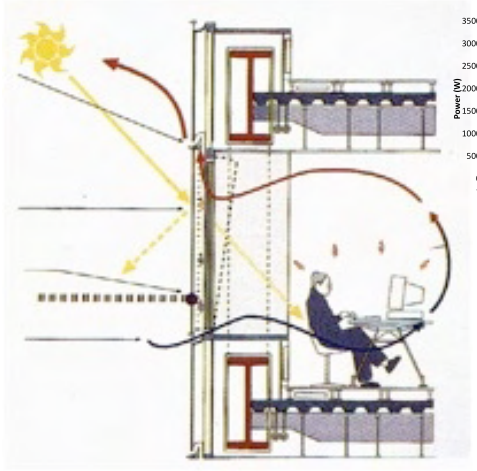
Use

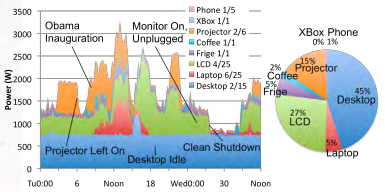
- Any Power Consumer can …
  - Measure its Performance and Consumption,
  - Communicate, and have Intelligence and Control

Path Forward

Design







Use

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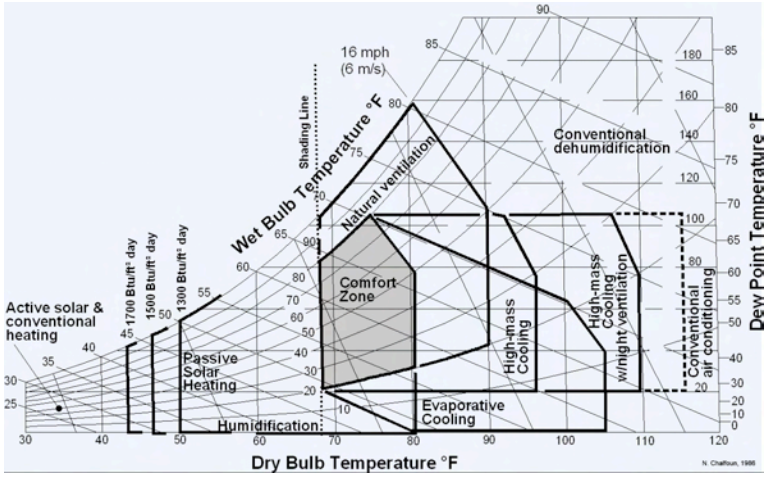
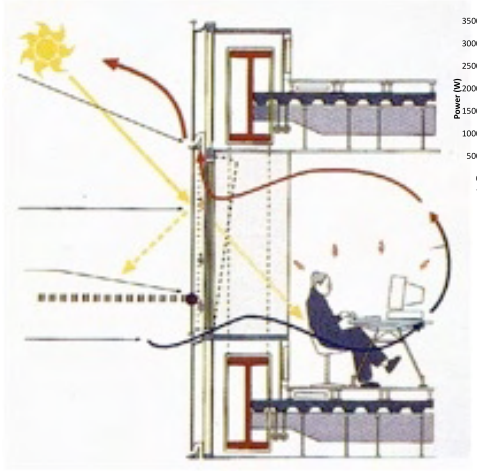
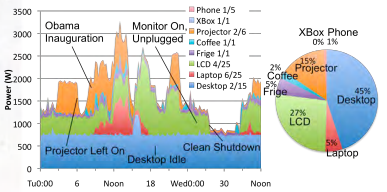
  - Communicate, and have Intelligence and Control
- Eliminate waste

Path Forward

Design







Use

- Any Power Consumer can …
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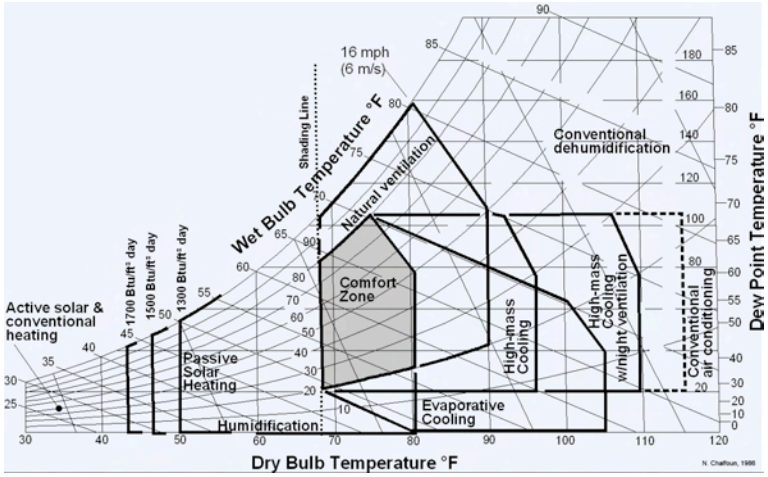
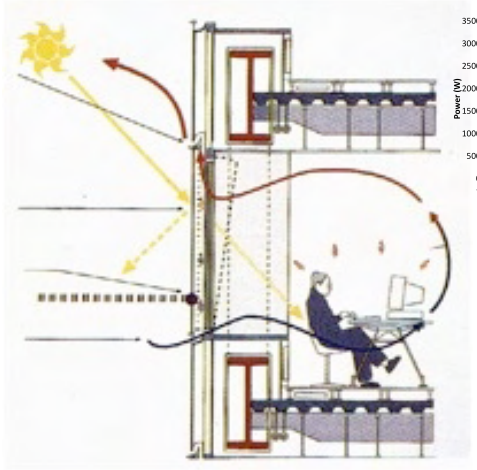
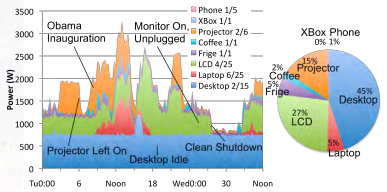
- Eliminate waste
- Schedule Consumption

Path Forward

Design







Use

- Any Power Consumer can …
  - Measure its Performance and Consumption,
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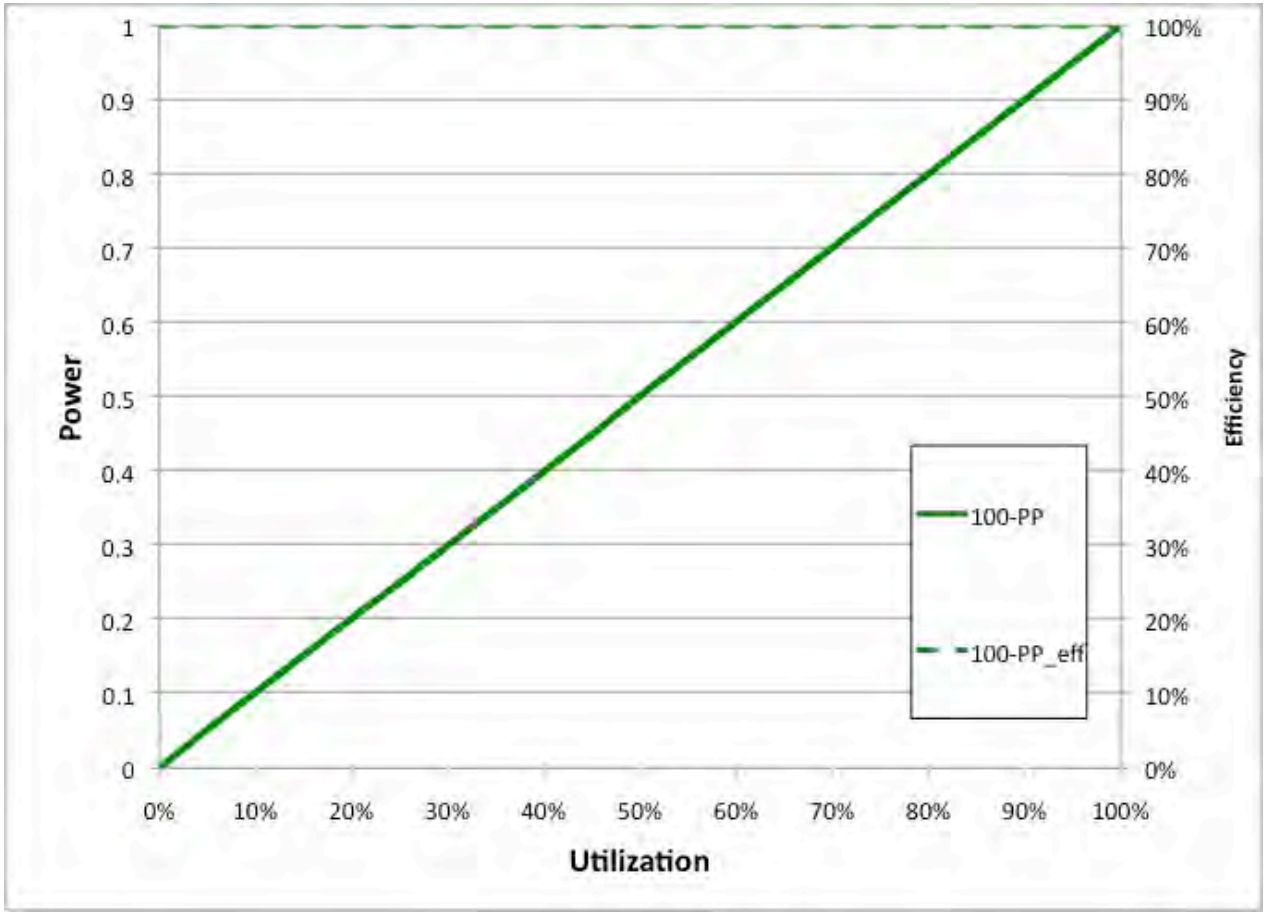
- Eliminate waste
- Schedule Consumption
- Adapt Quality of Service

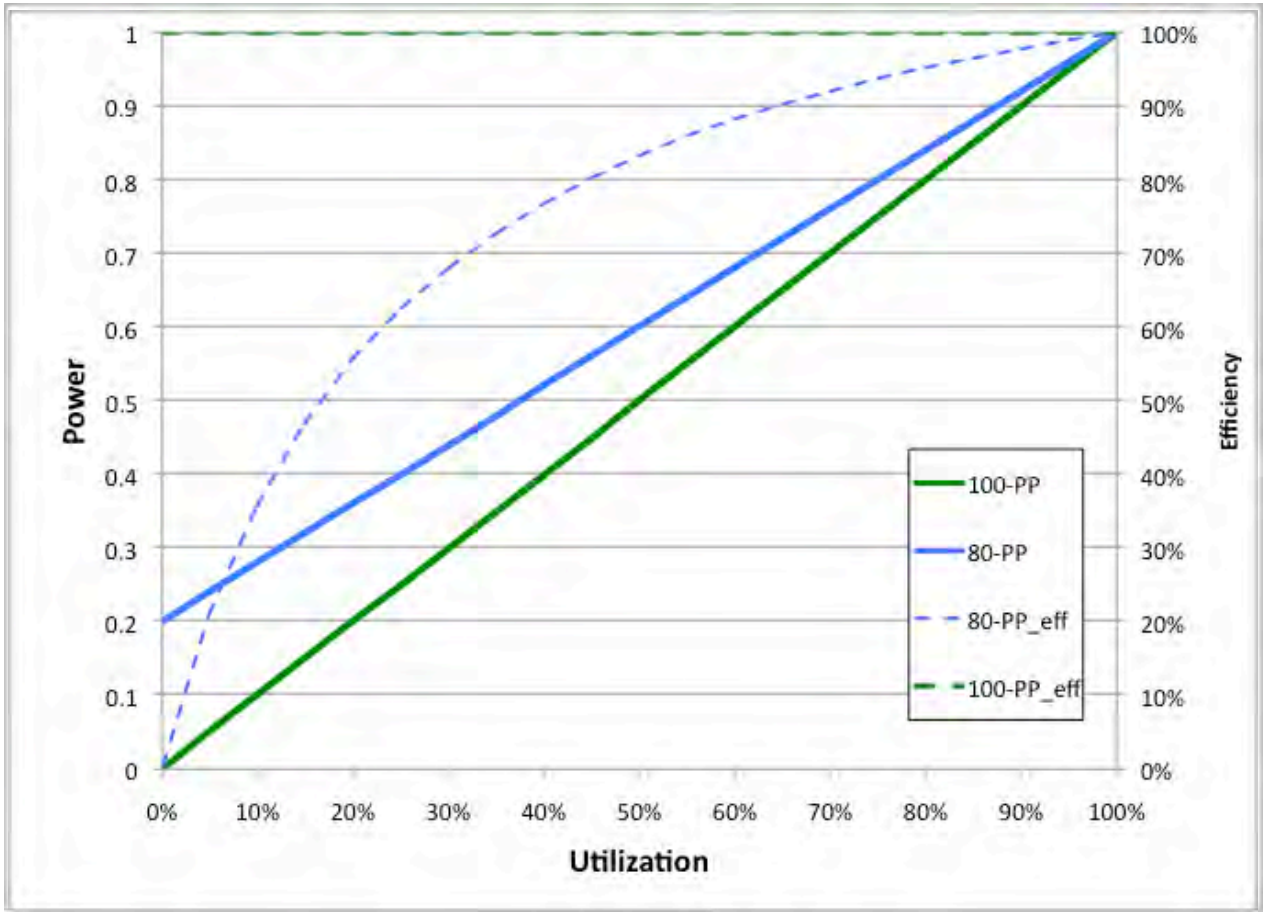
Thanks

Power Proportionality



- Measure of scaling down to partial load

Power Proportionality



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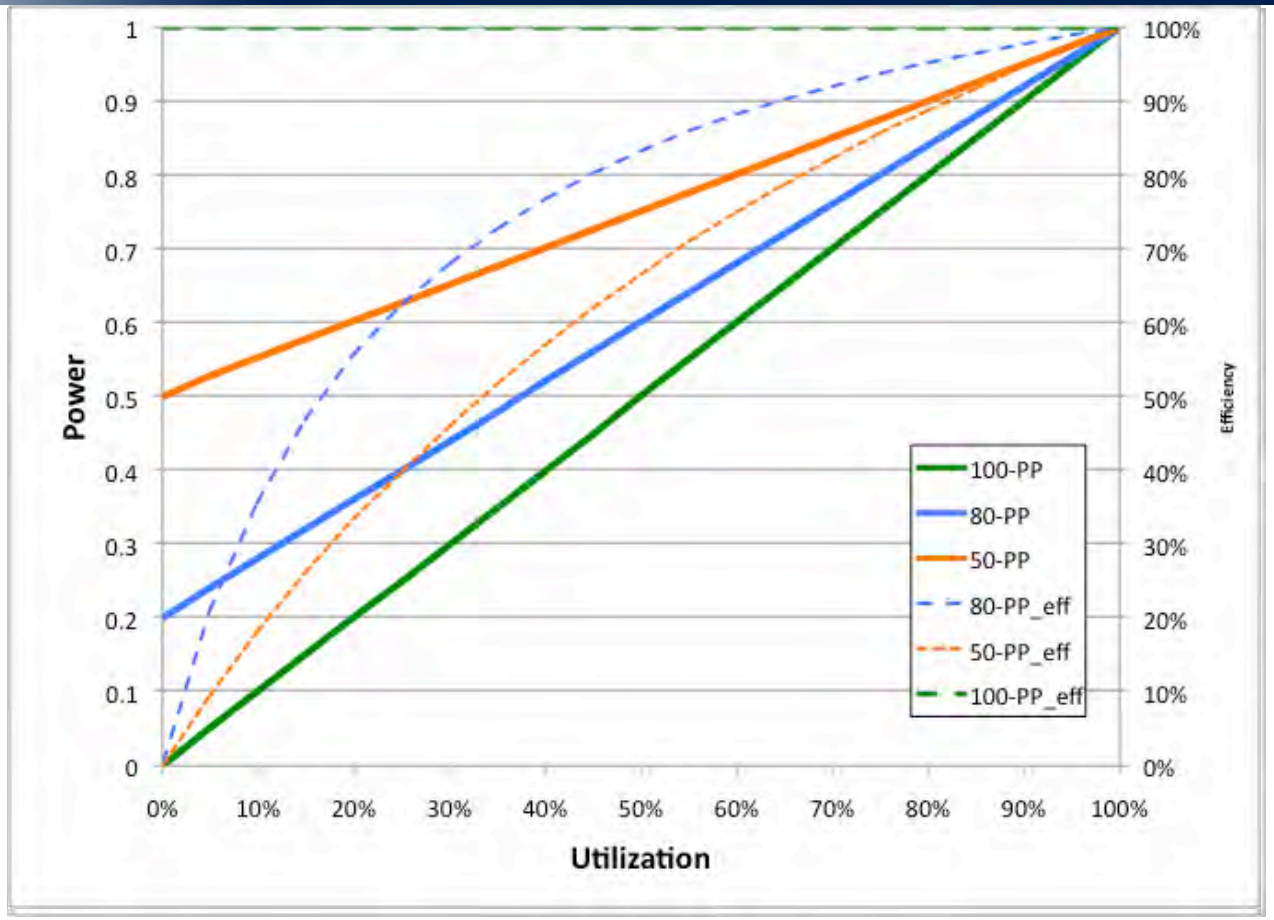

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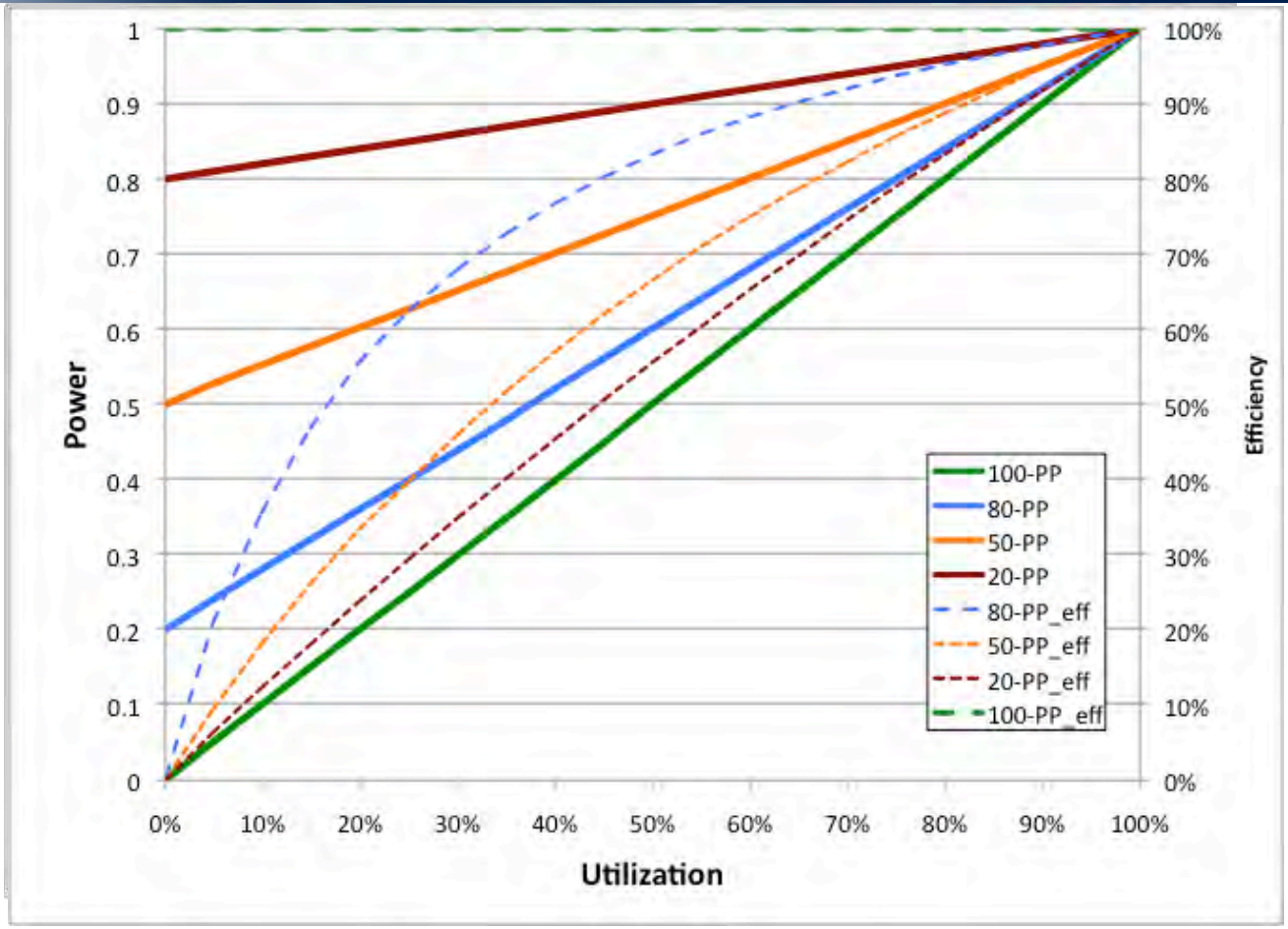

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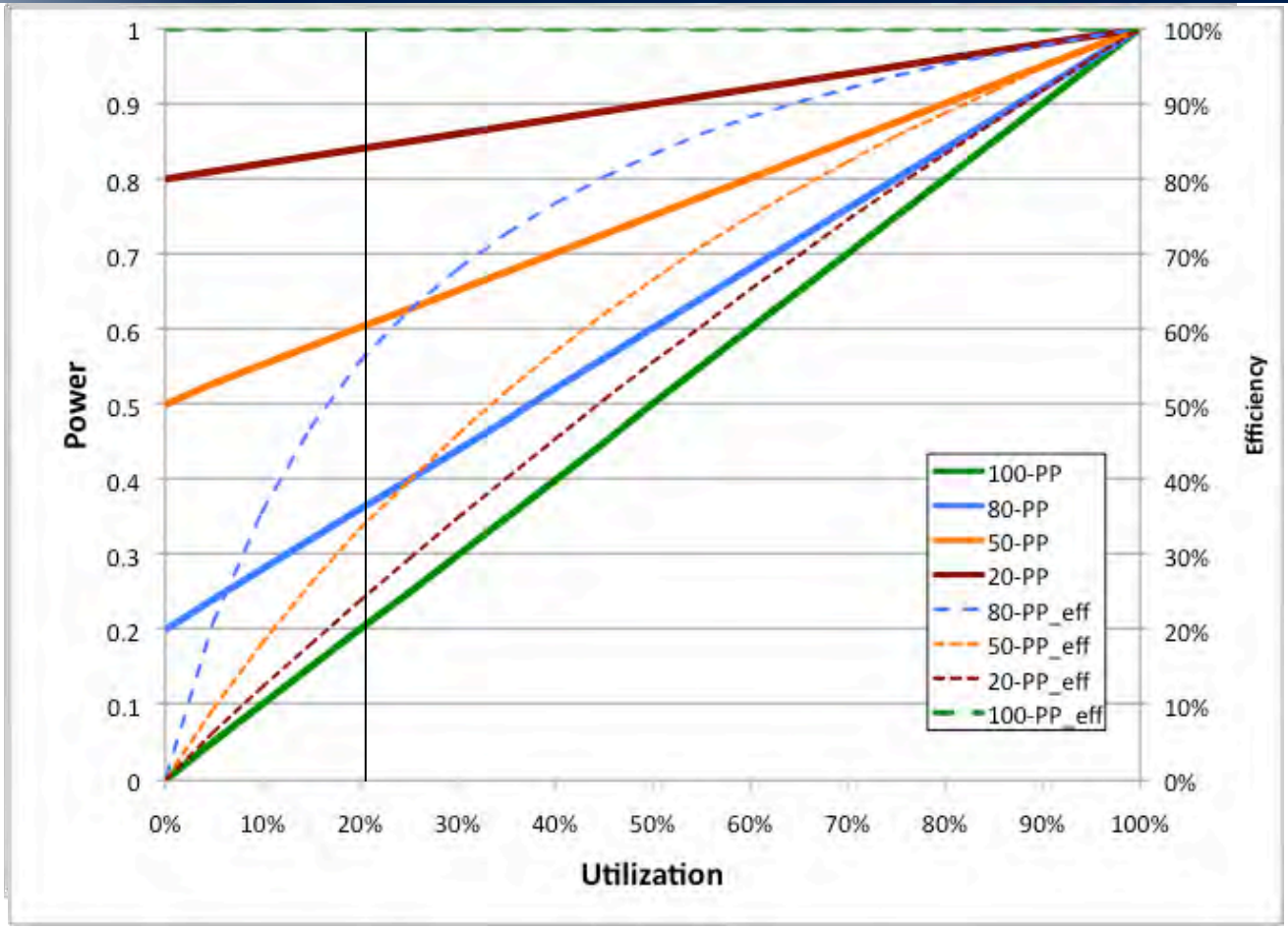

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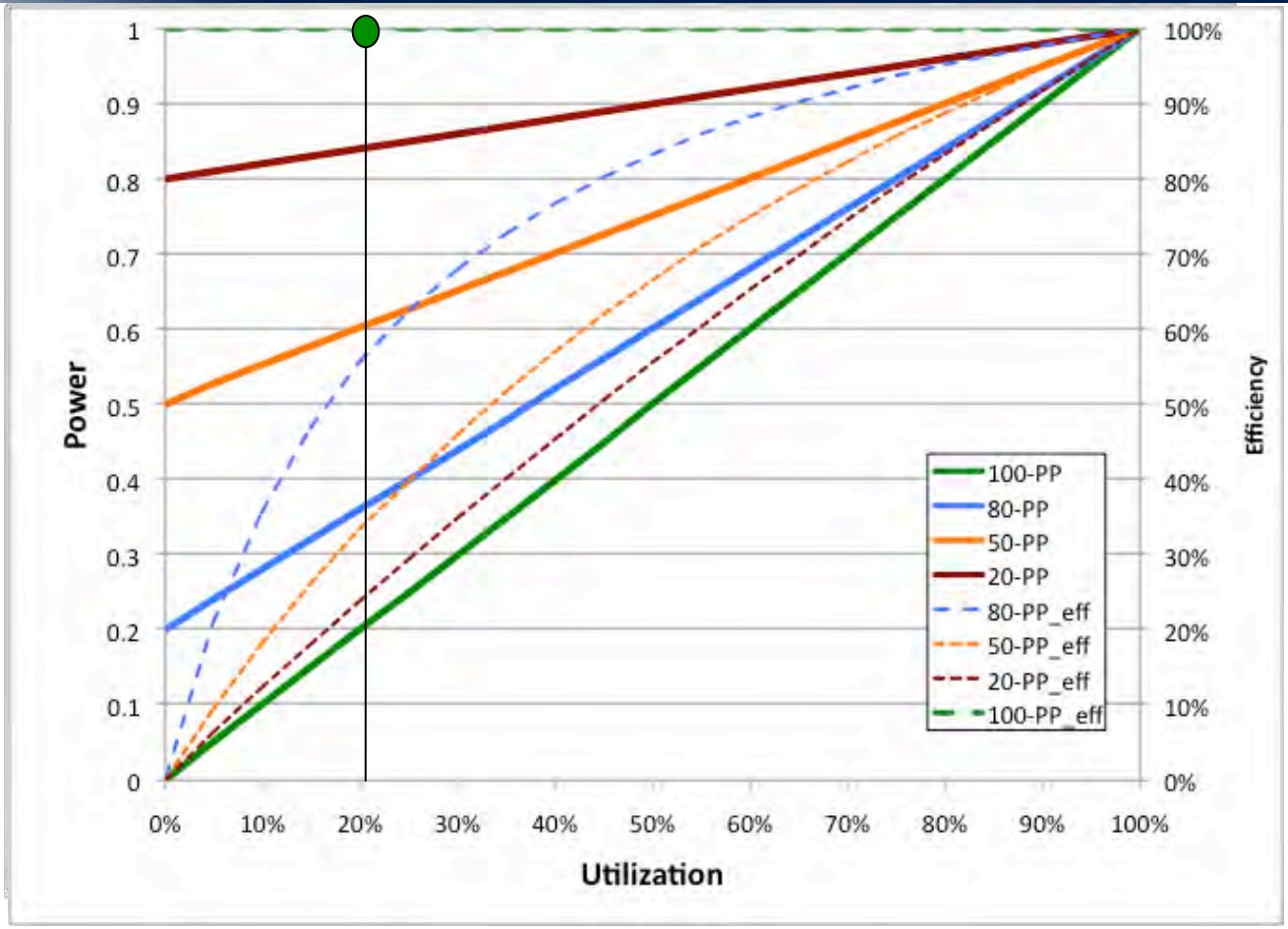

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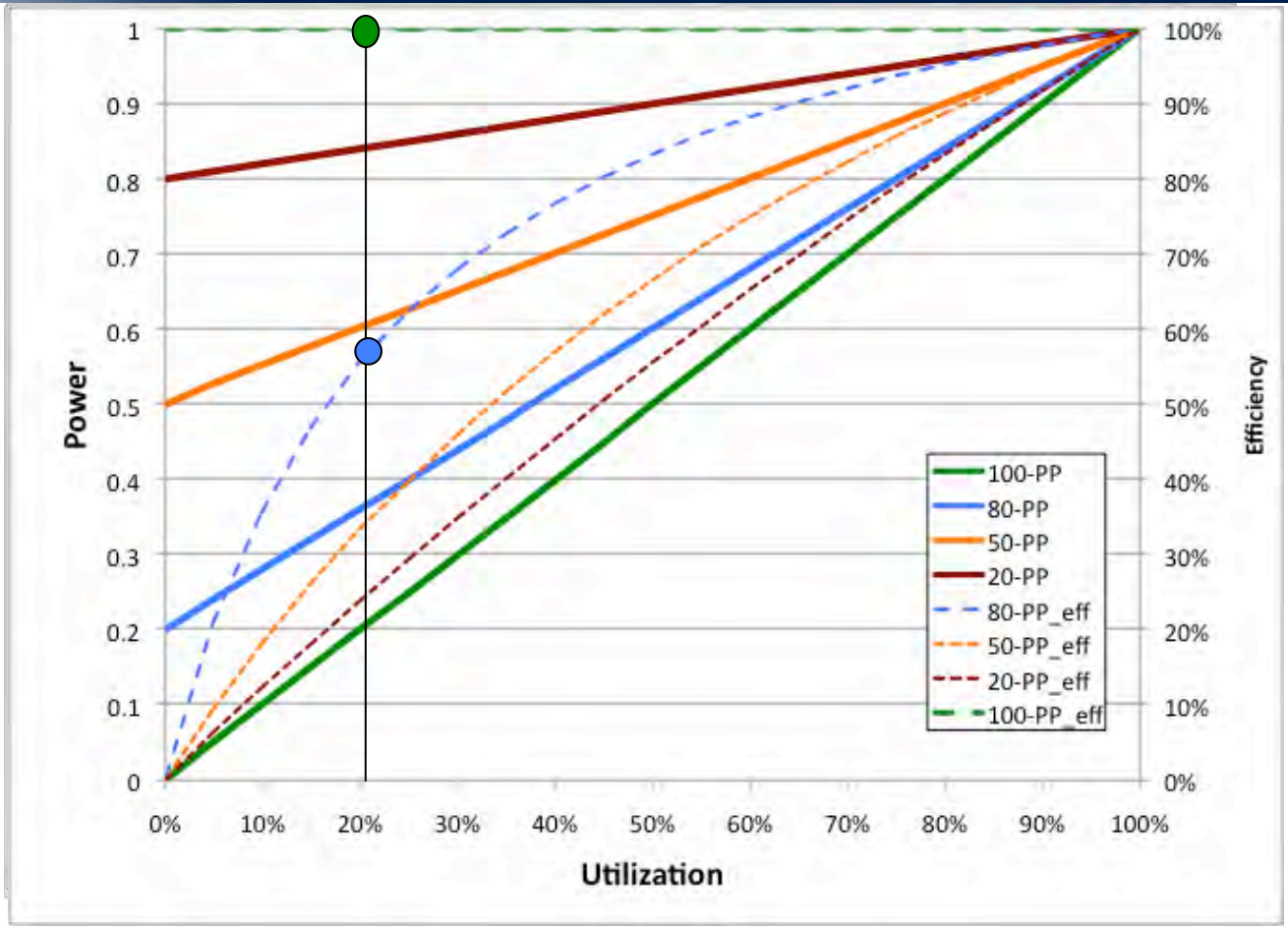

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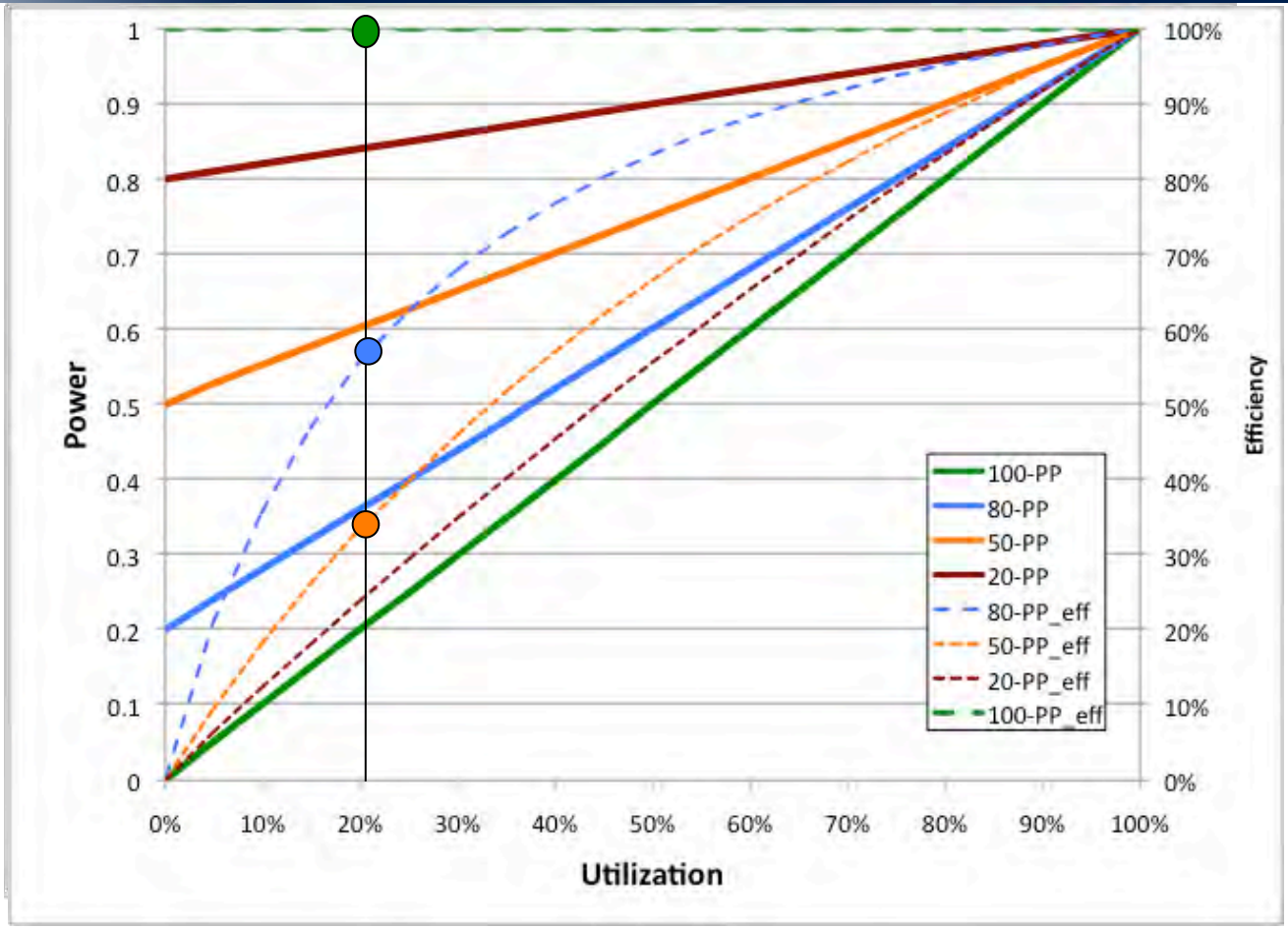

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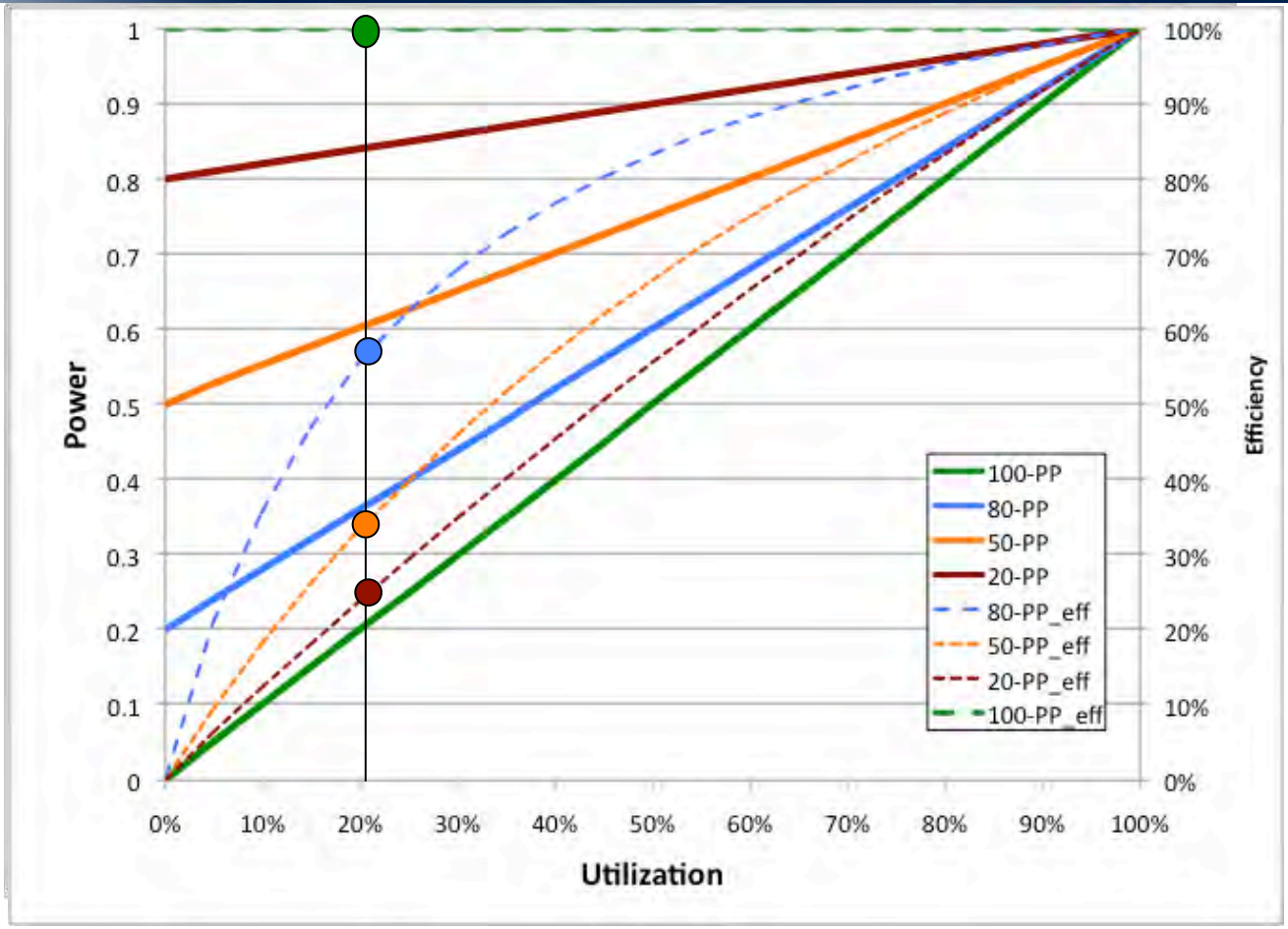
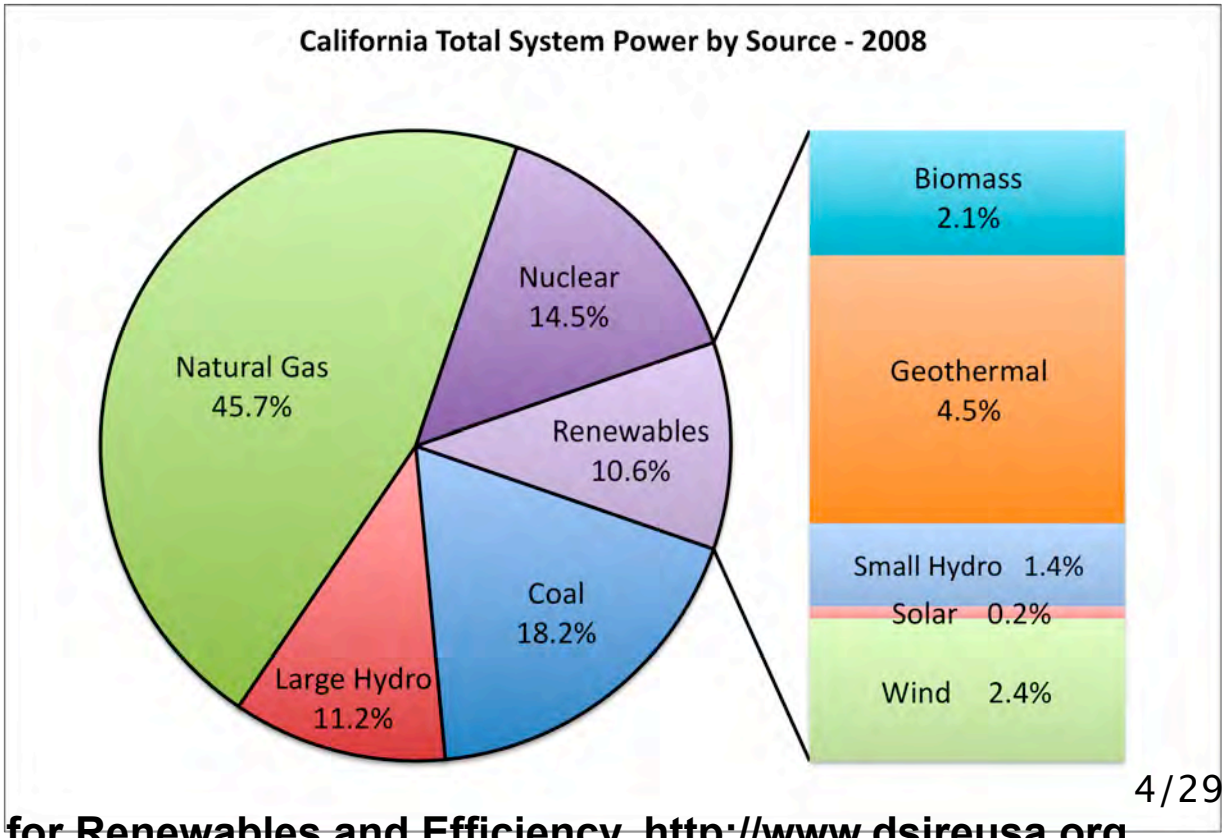


- Measure of scaling down to partial load

California Energy Mix

- **Renewables Portfolio Standard (RPS)**
  - **36 of 50 states have set goals**
  - **Near-term goals range from 10% to 25%**

- **California RPS**
  - **2008: 10%**
  - **2010: 20%**
  - **2020: 33%**



Database of State Incentives for Renewables and Efficiency. http://www.dsireusa.org

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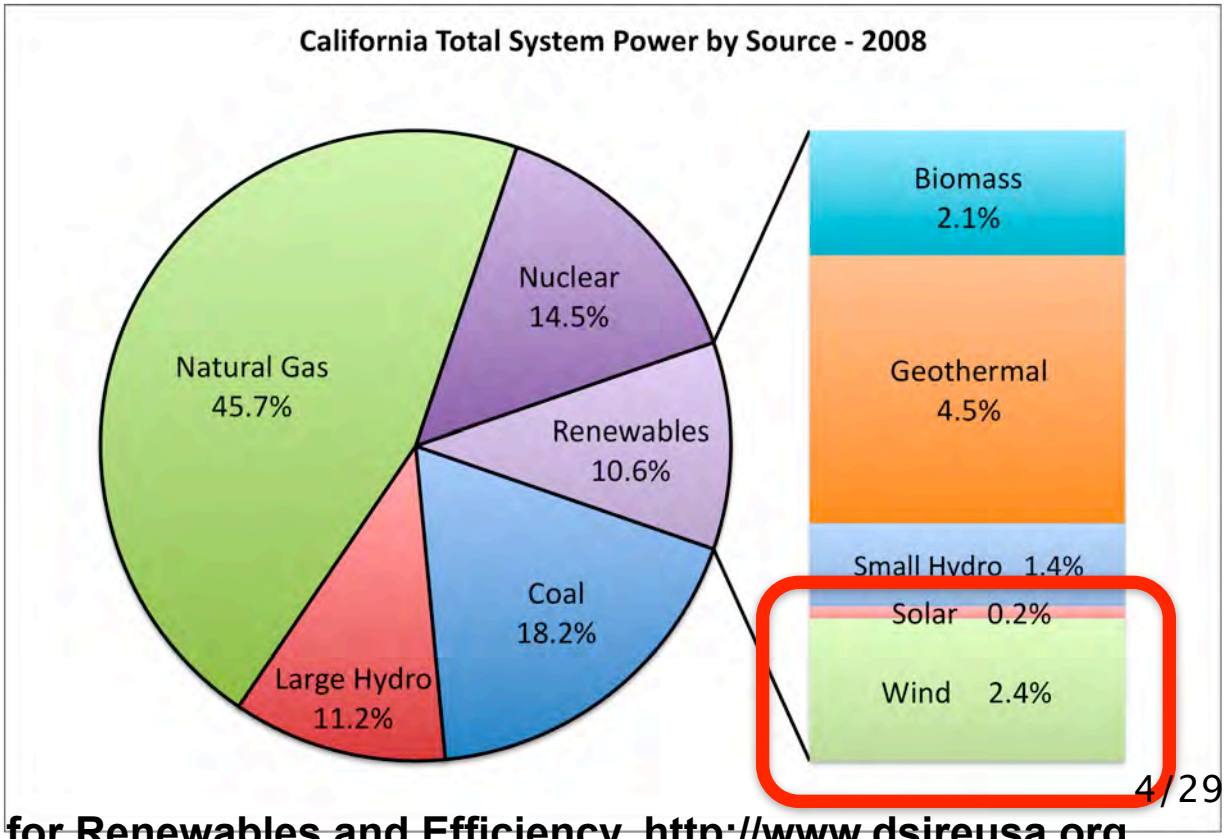

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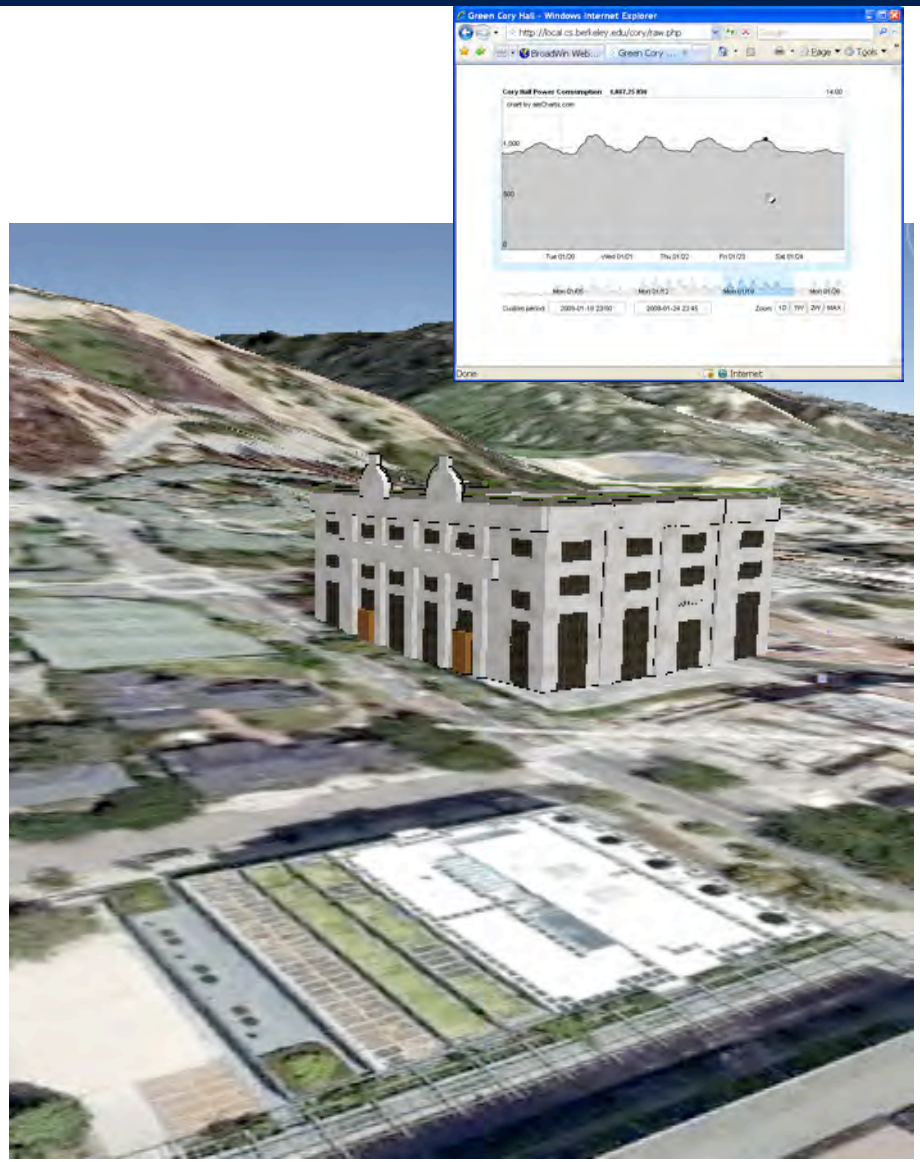
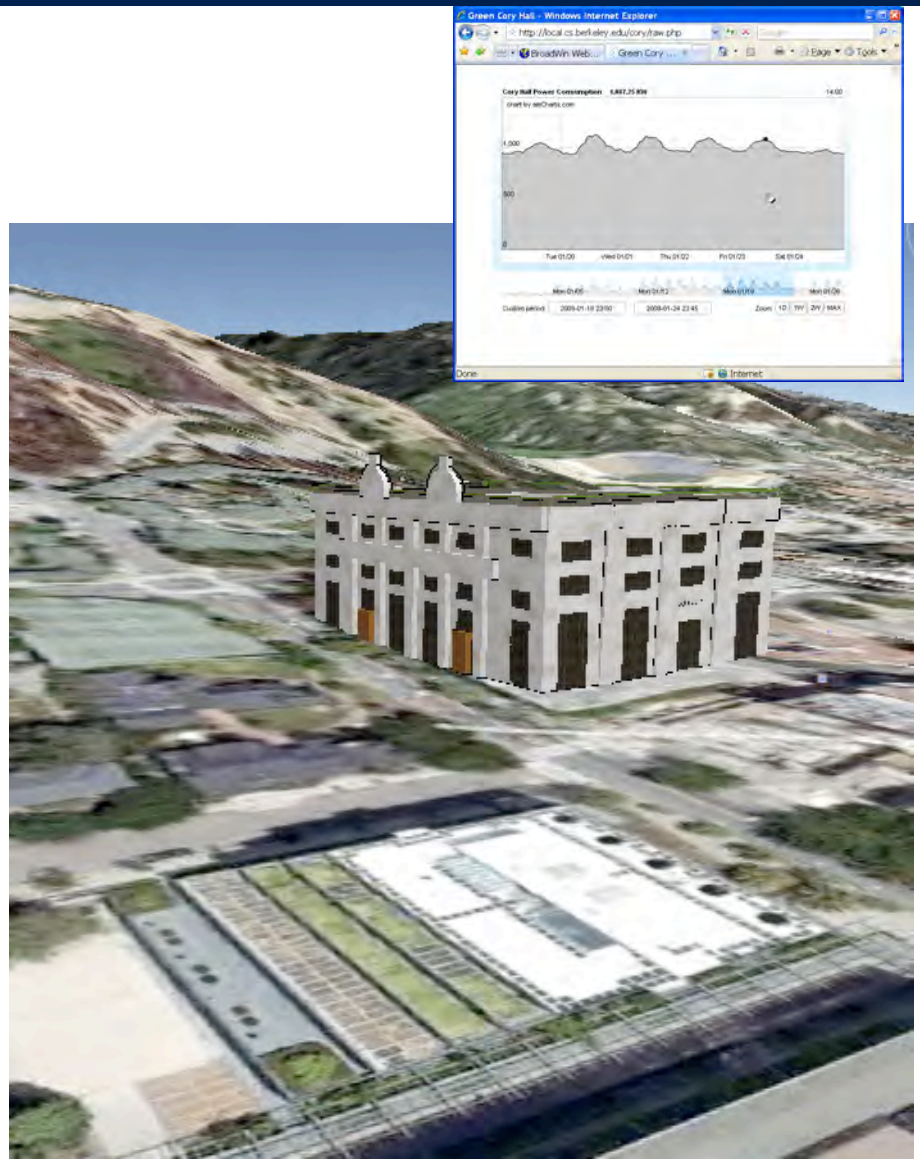
Building ⇔ Grid

Building ⇔ Grid



Building ⇔ Grid

- large complex loads



Building ⇔ Grid

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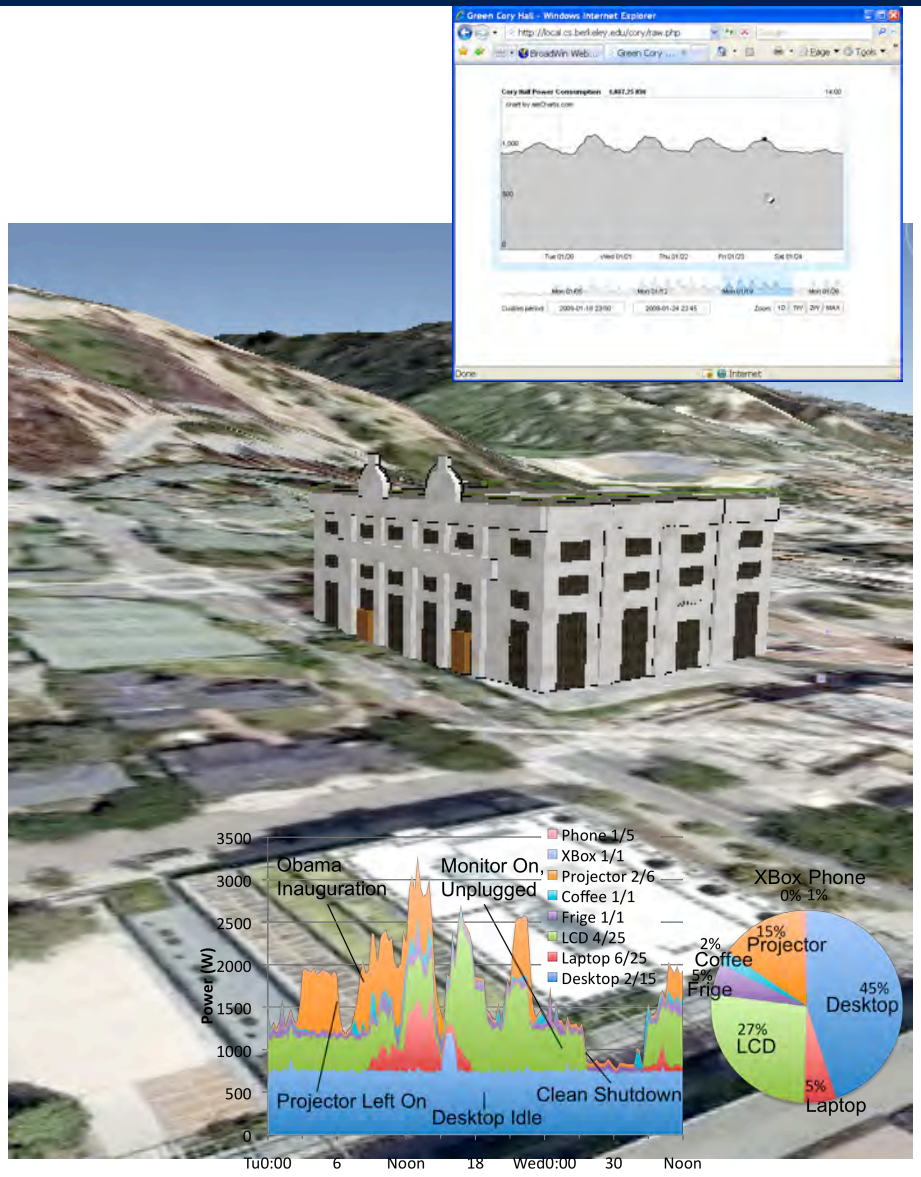
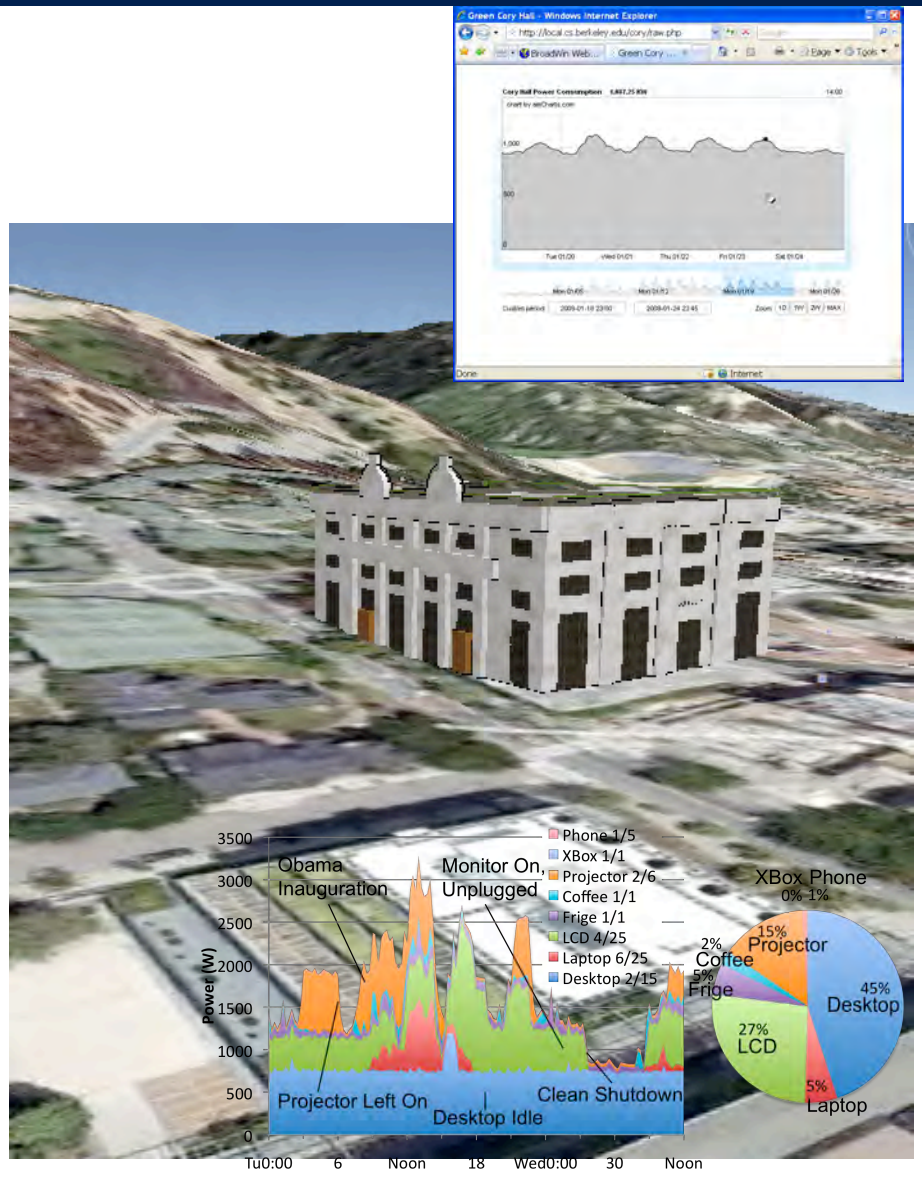
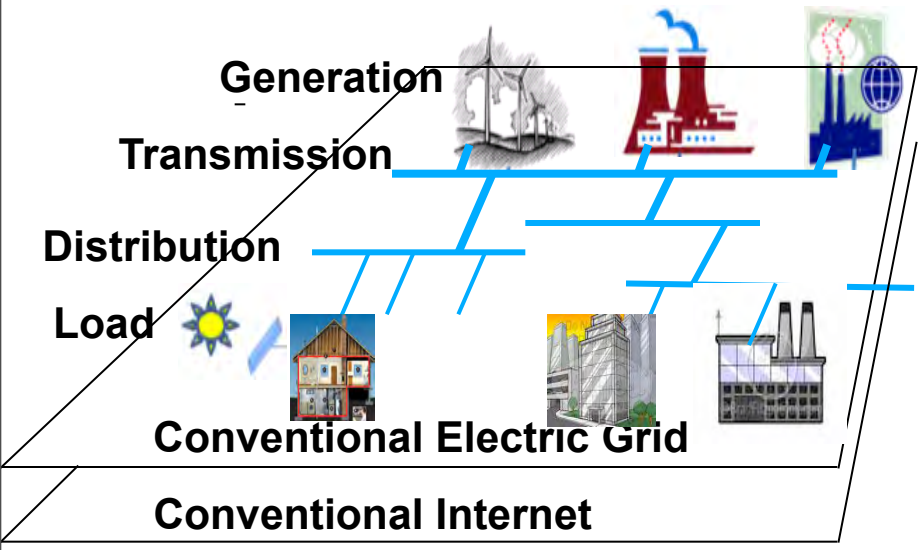


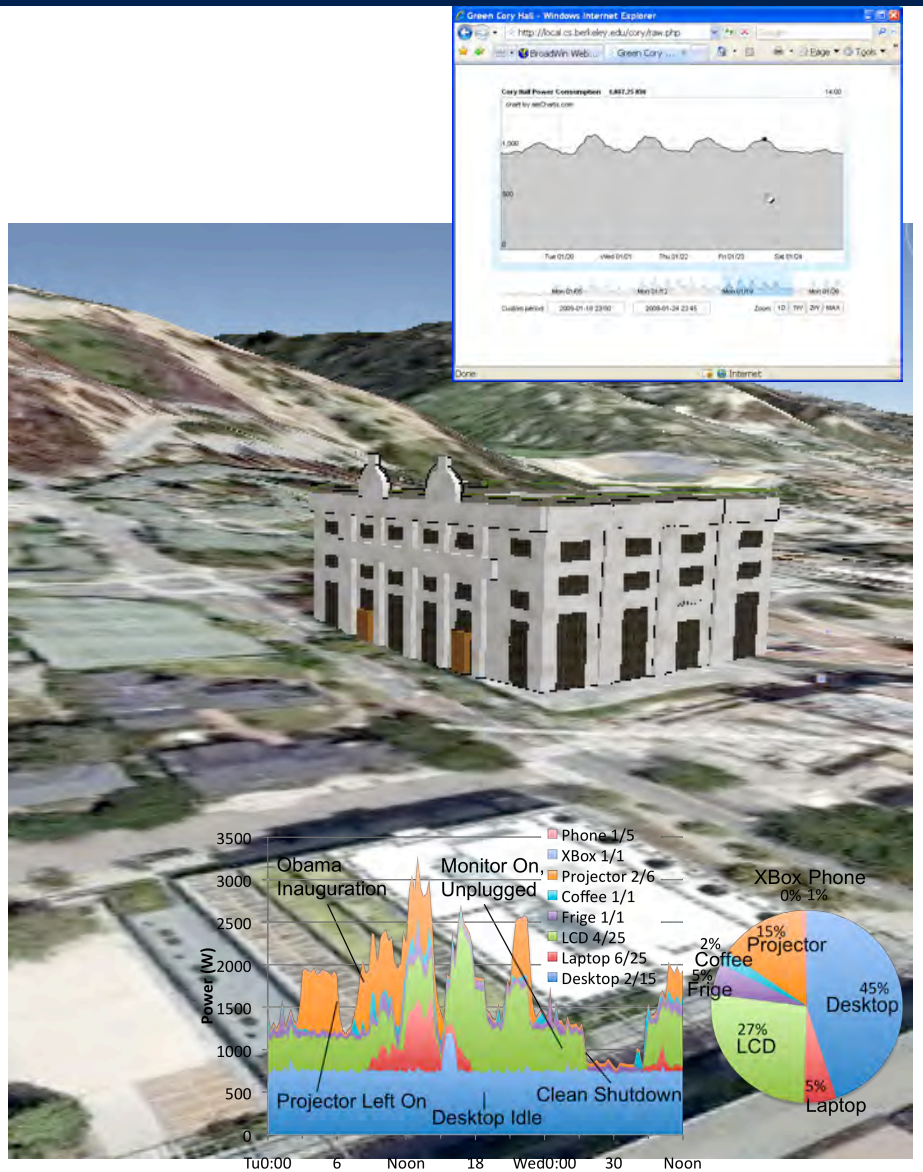
Building ⇔ Grid

- large complex loads
- Monitor, Model, Mitigate



Building ⇔ Grid





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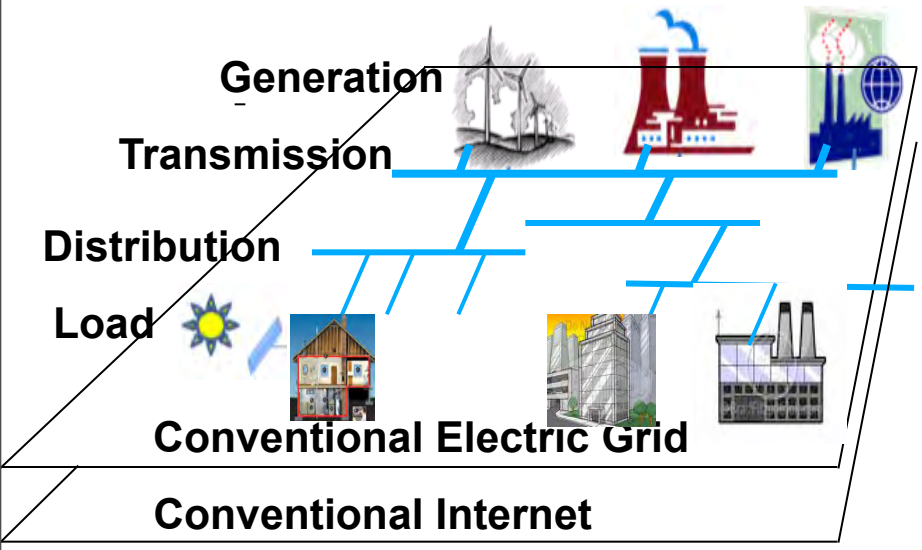
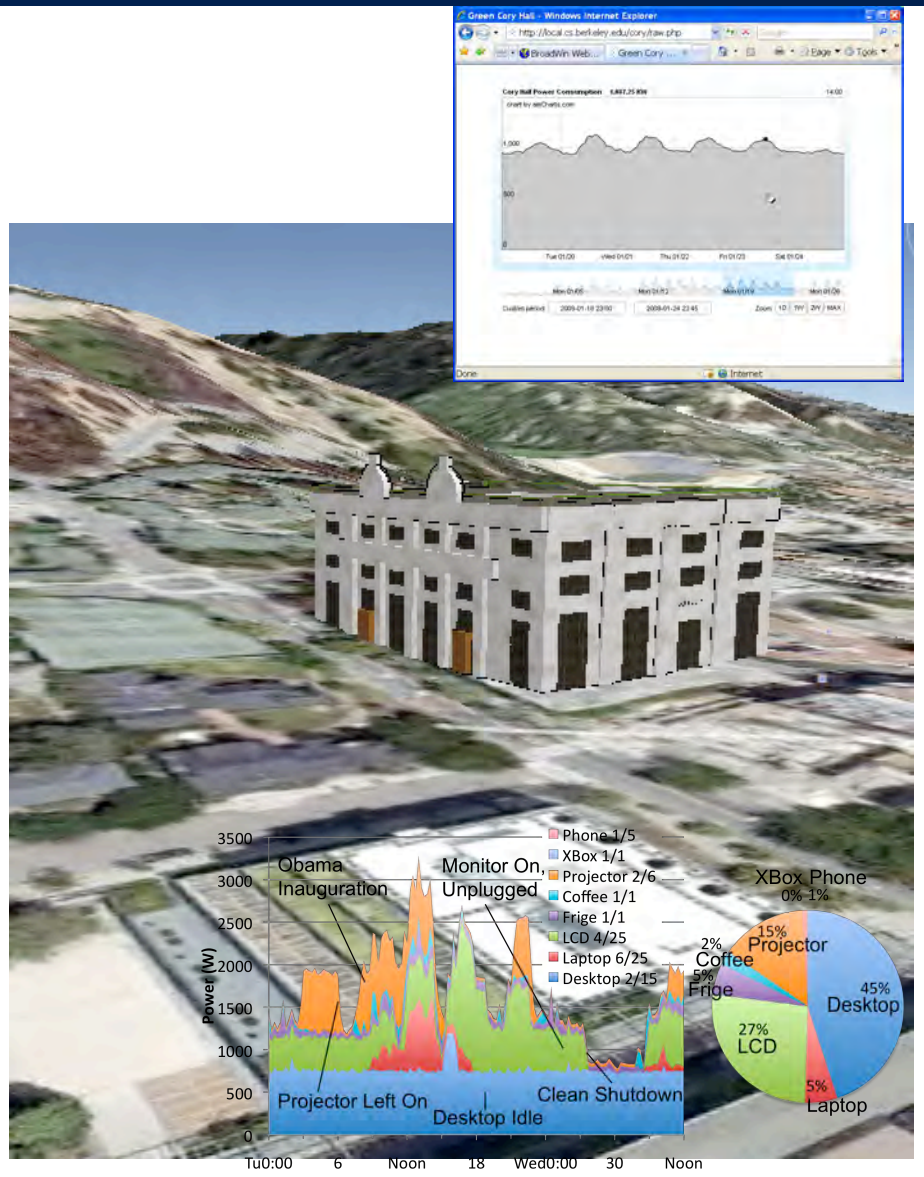
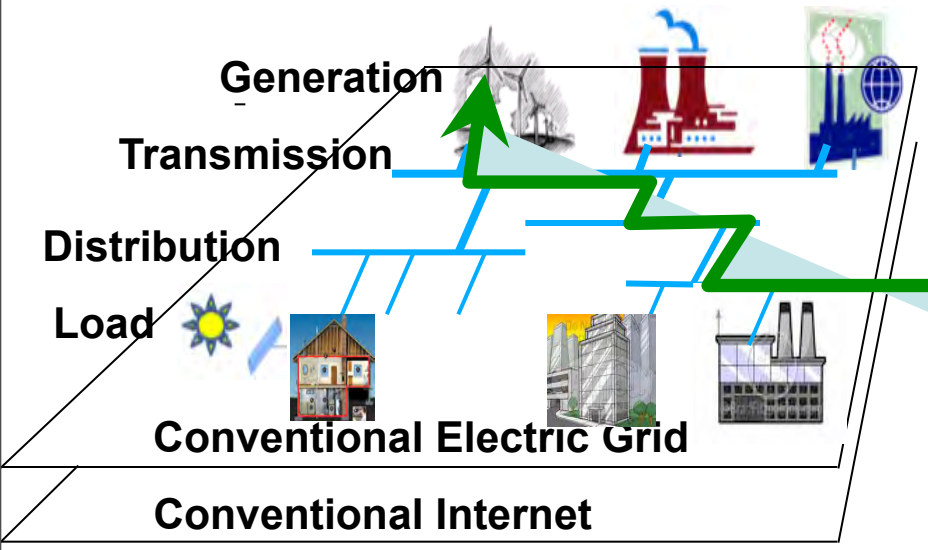
Building ⇔ Grid

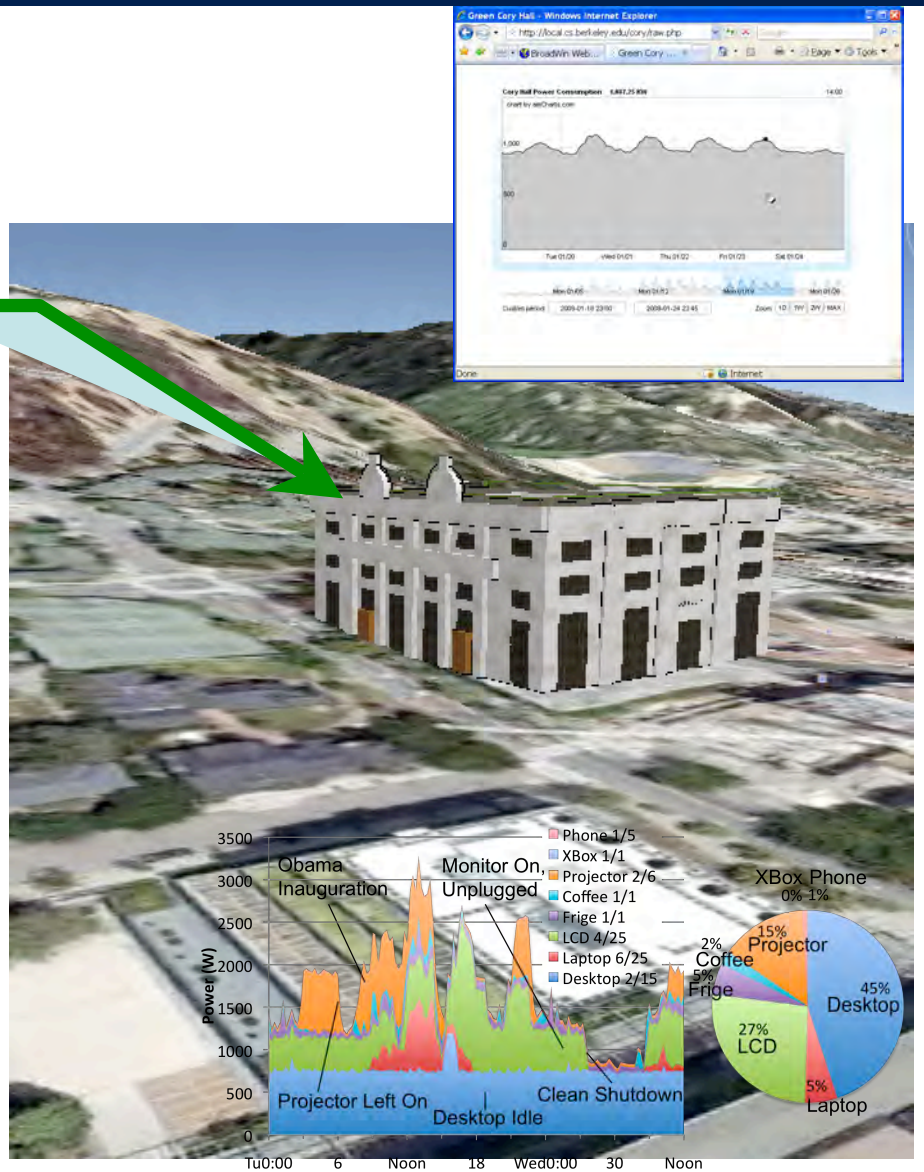




- large complex loads
- Monitor, Model, Mitigate
- In concert with an intelligent grid

Building ⇔ Grid





- large complex loads
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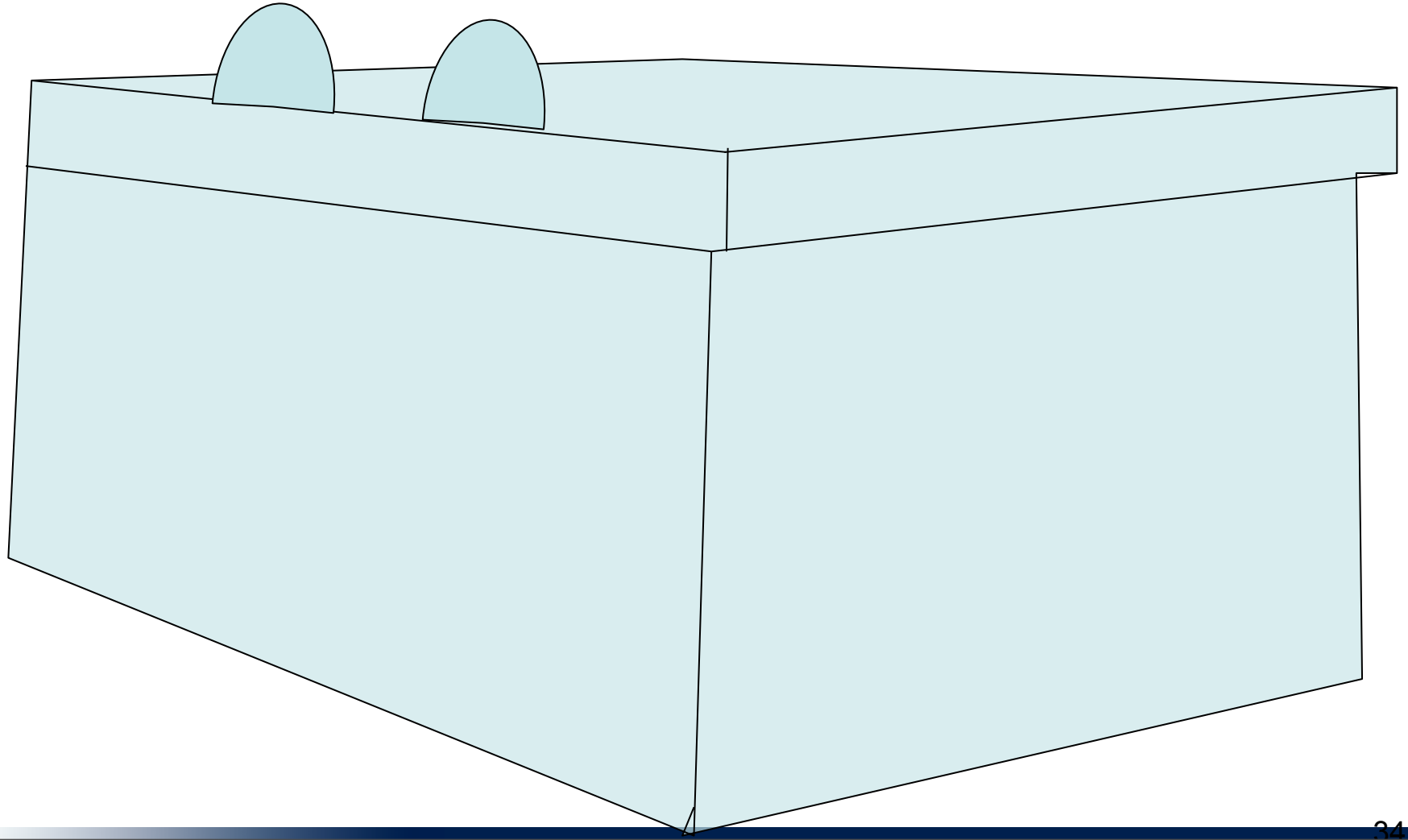
Building Information



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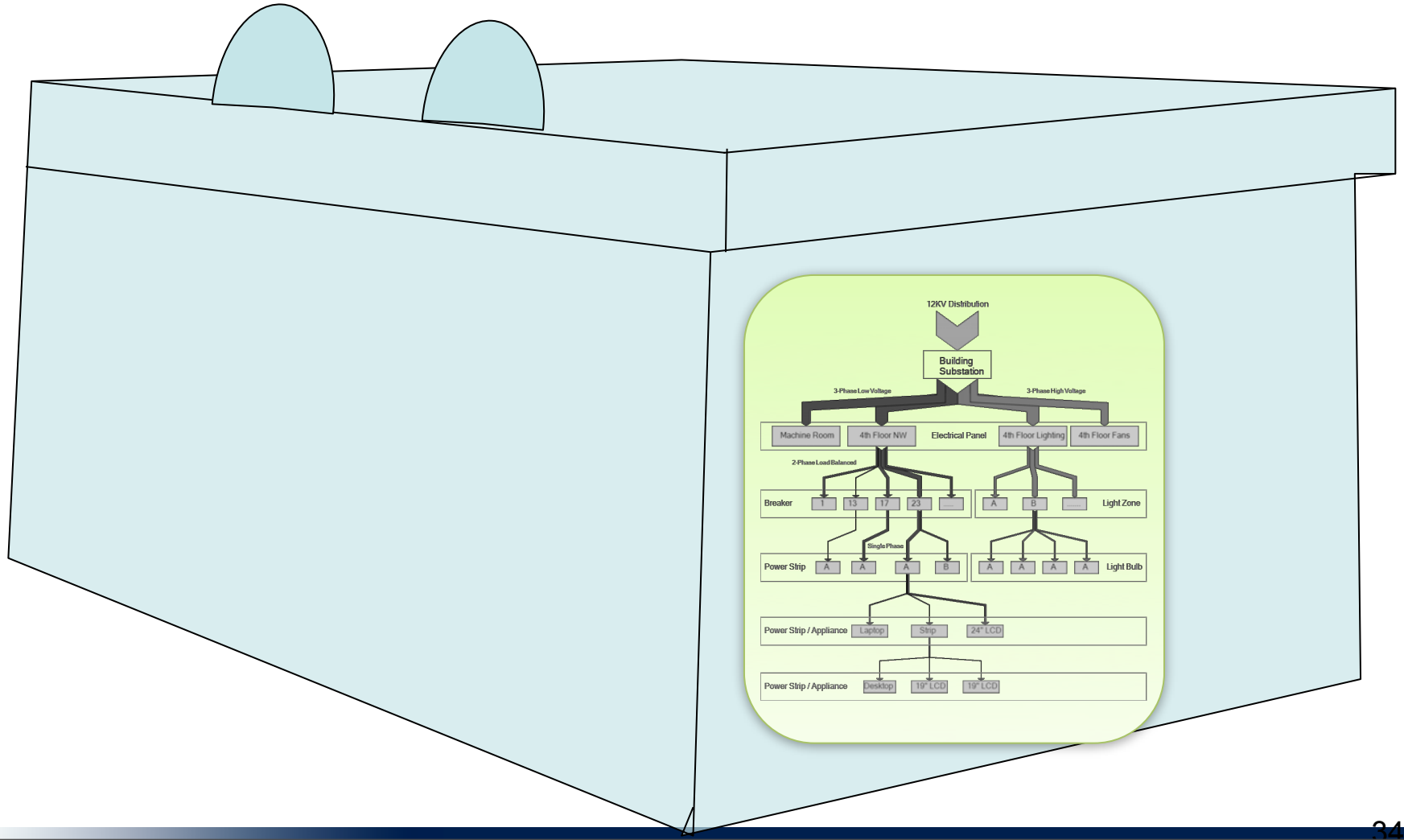
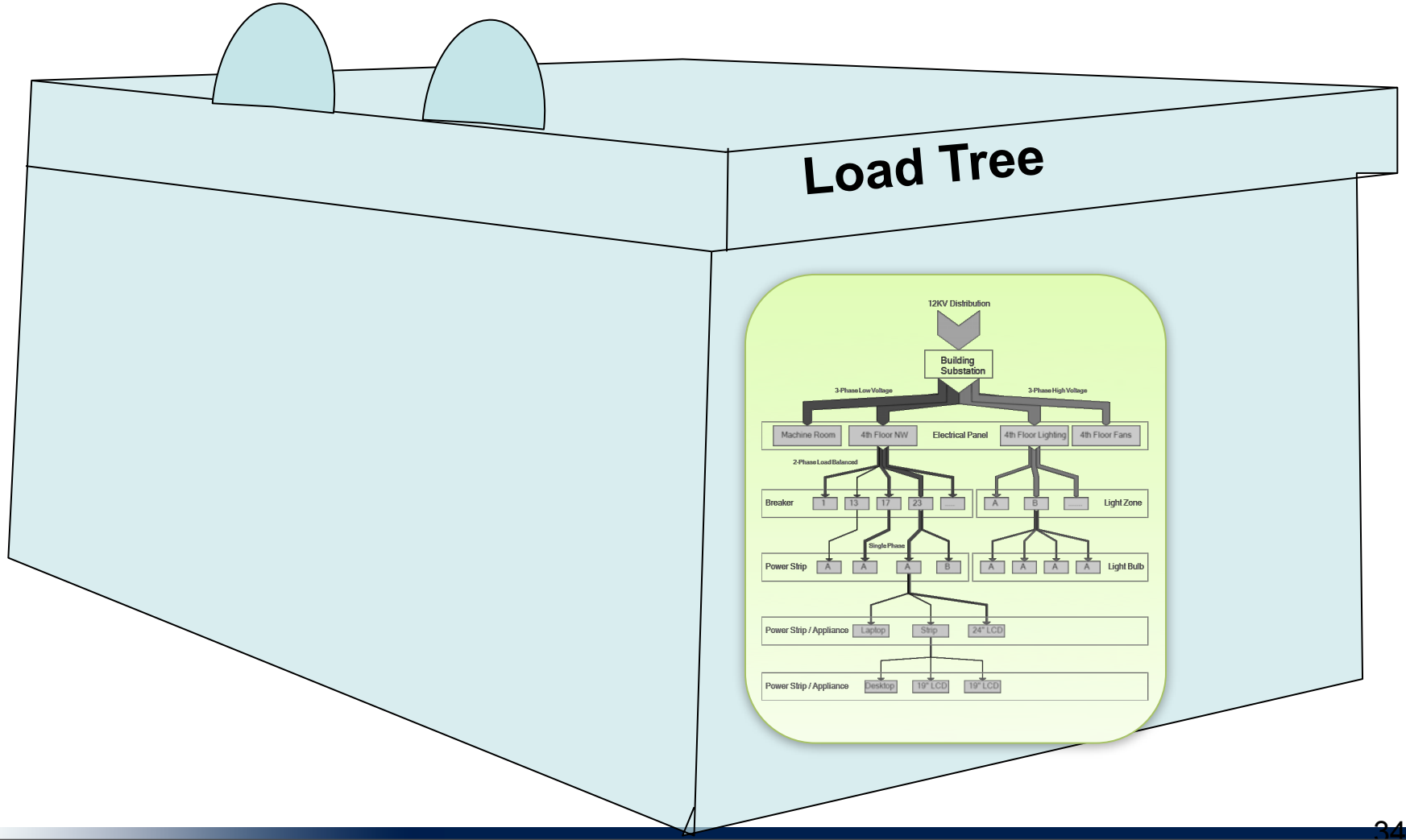


Building Information



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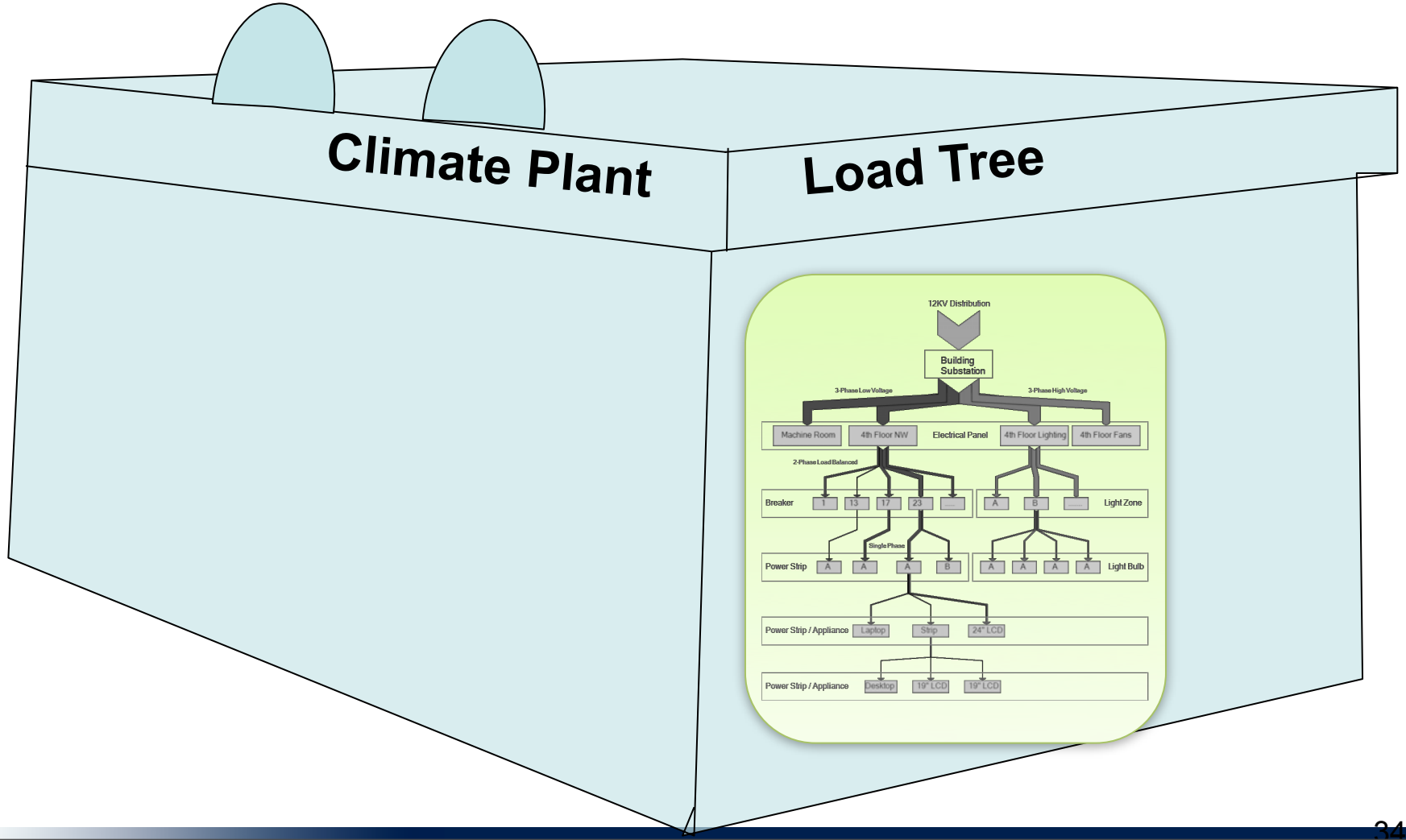

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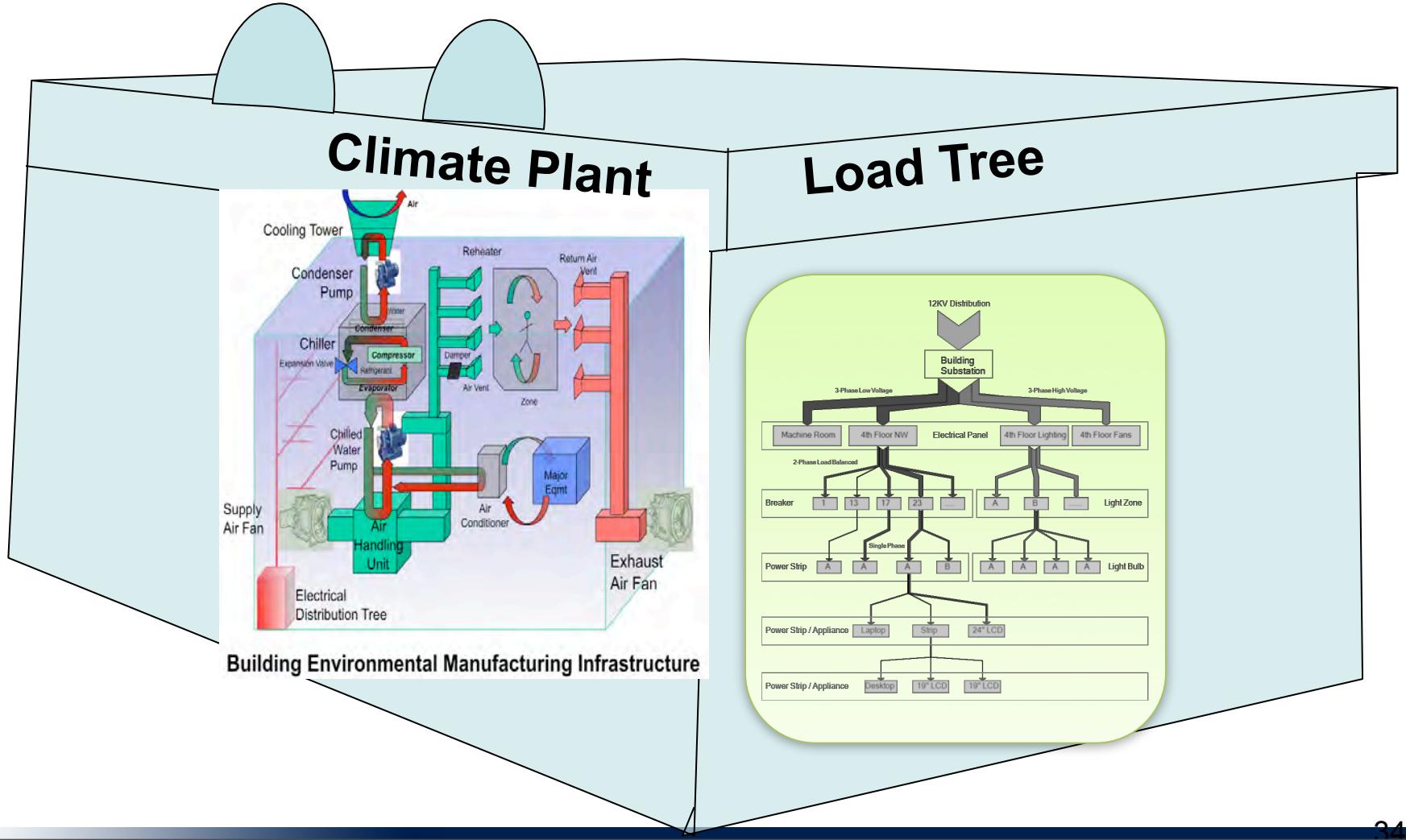

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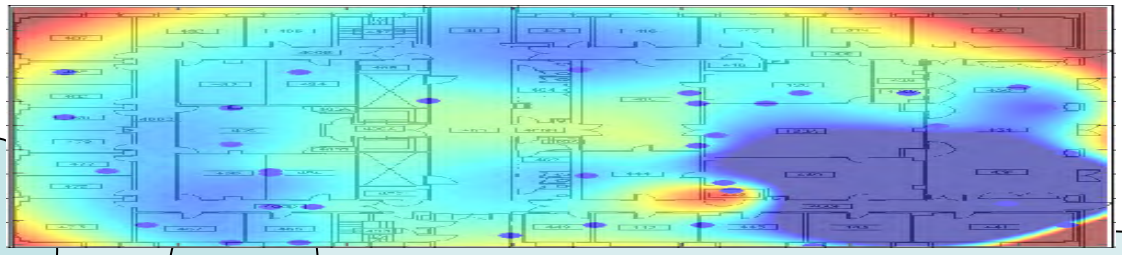
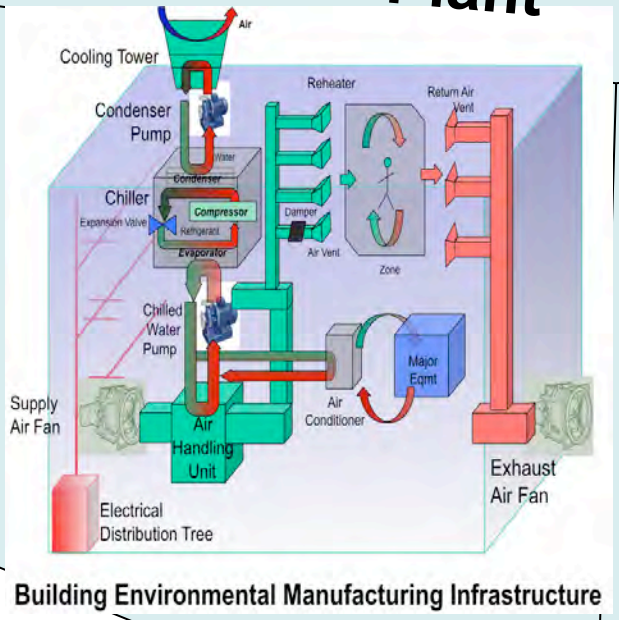
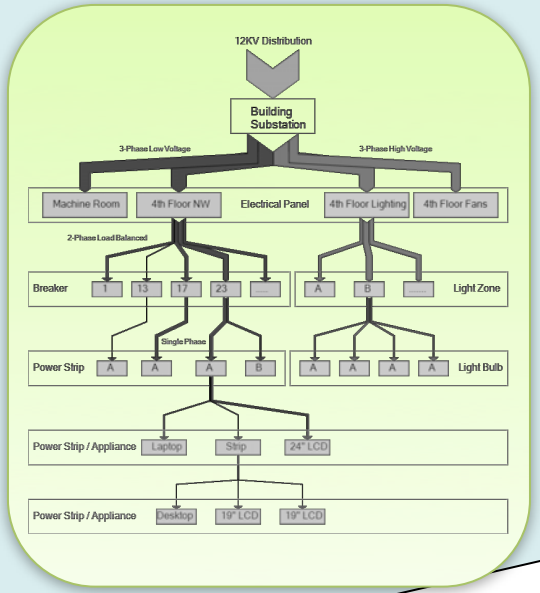


Climate Plant

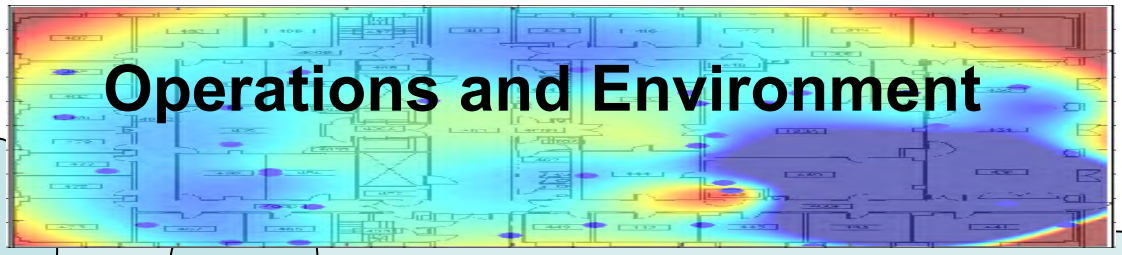


Building Environmental Manufacturing Infrastructure

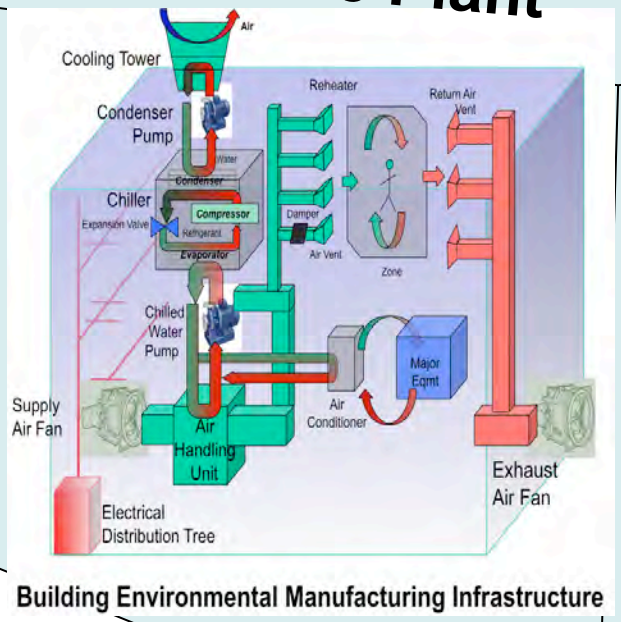
Load Tree



Building Information

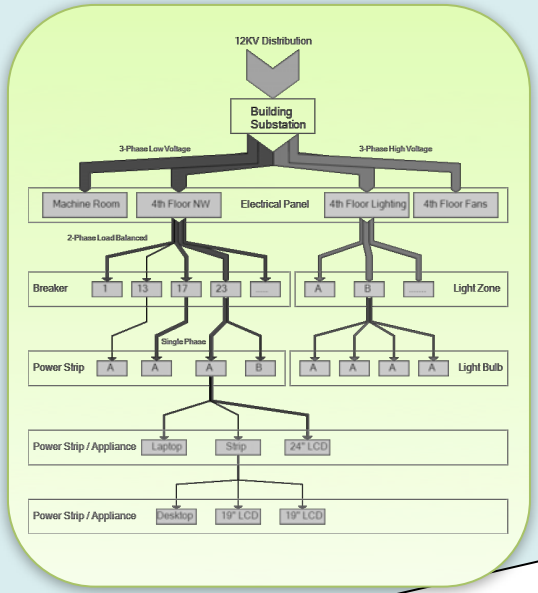


Climate Plant

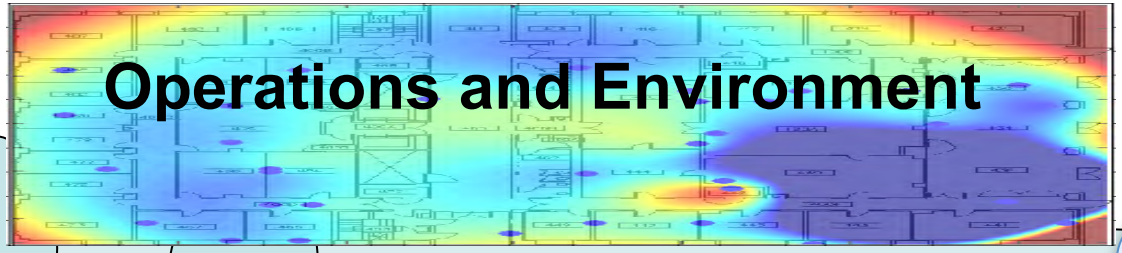


Building Environmental Manufacturing Infrastructure

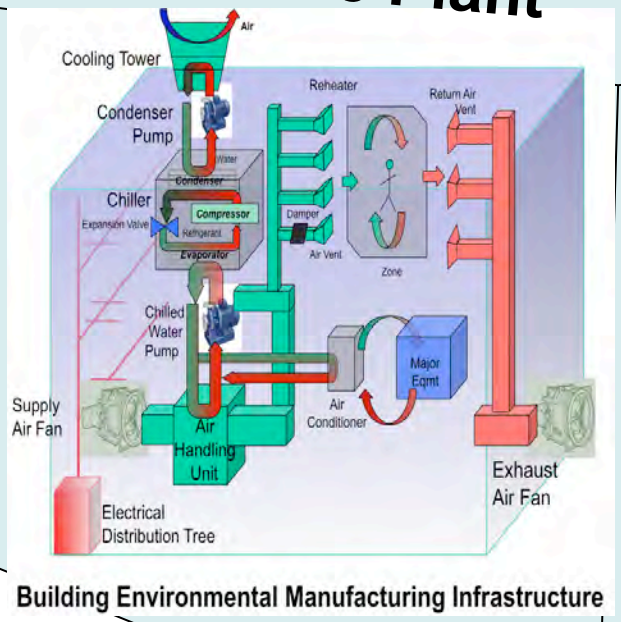
Load Tree



Building Information

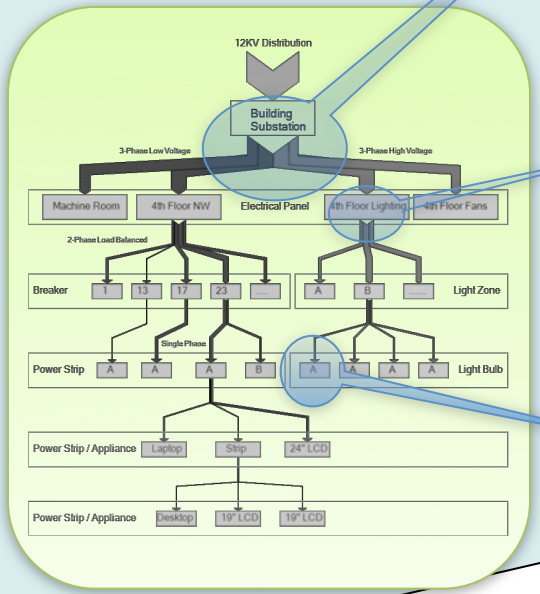


Climate Plant

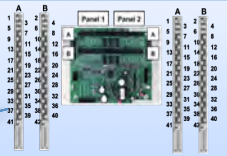


Building Environmental Manufacturing Infrastructure

Load Tree



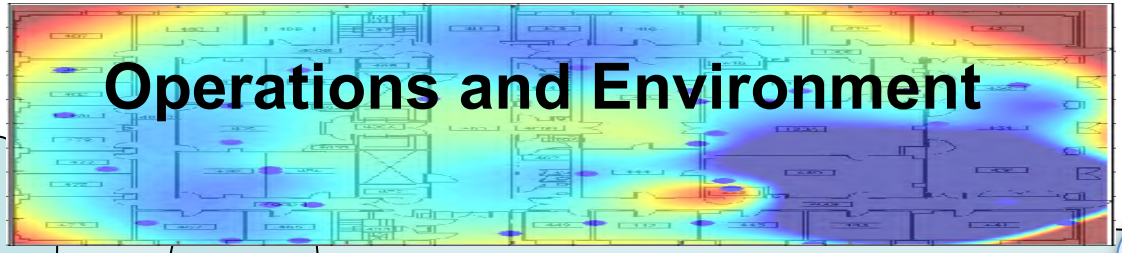
CT: mains power monitoring



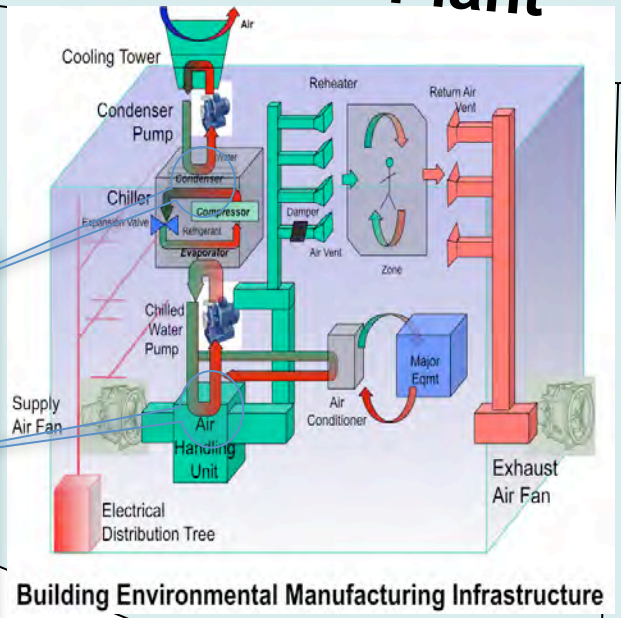
panel level power monitoring

ACme: plug load energy monitor and controller

Building Information

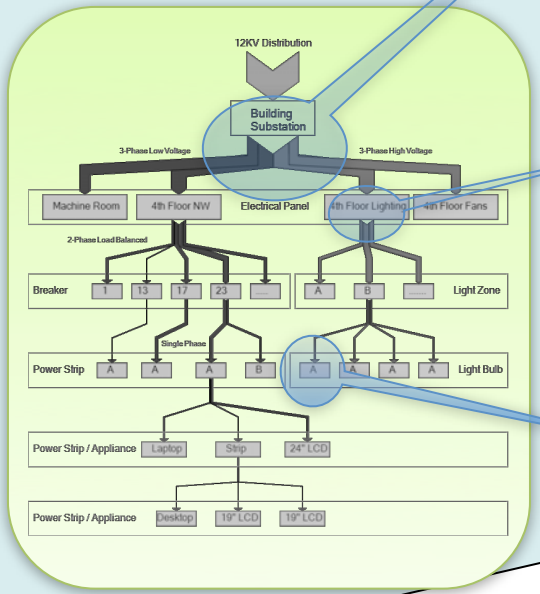


Climate Plant

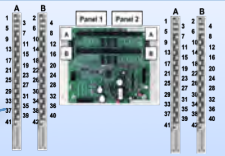


Building Environmental Manufacturing Infrastructure

Load Tree



CT: mains power monitoring



panel level power monitoring

ACme: plug load energy monitor and controller

Vibration

Humidity

Temperature

Pressure