Green Computing

David Irwin

Guest Lecture

What is Green Computing?

- Greening of Computing
  - Sustainable IT
  - How to design energy-efficient hardware/software systems?
- Computing for Greening
  - How to use IT to make physical infrastructure more efficient?
    - Homes, offices, buildings, transportation

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Part 1: Greening of Computing

- Energy-efficient mobile devices a long standing problem
  - **Motivation:** better battery life, not green
- Recent growth of data centers
  - More energy-efficient server design
  - **Motivation:** lower costs, carbon emissions
    - Green systems, lower carbon footprint

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Computing and Power Consumption

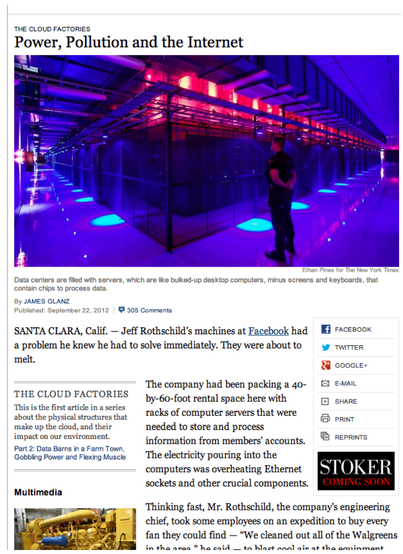
- Energy to Compute
  - 20% power usage in office buildings
  - 50%-80% at a large college
  - 3% of our carbon footprint and growing
- Data centers are a large fraction of the IT carbon footprint
  - PCs, mobile devices also a significant part

What is a data center?

- Facility for housing a large number of servers and data storage
- Google data center (Dalles, OR)
  - 12 football fields in size
    - Compare to box stores!
  - 100 MW of power
    - Enough for a small city
  - ~ 100K servers

Data Center Power

- Power usage
  - Receiving (unwanted) attention
  - NYTimes feature from September 22nd



THE CLOUD FACTORIES

Power, Pollution and the Internet

Ethan Pines for The New York Times

Data centers are filled with servers, which are like bulked-up desktop computers, minus screens and keyboards, that contain chips to process data.

By JAMES GLANZ

Published: September 22, 2012 | 305 Comments

SANTA CLARA, Calif. — Jeff Rothschild's machines at Facebook had a problem he knew he had to solve immediately. They were about to melt.

The company had been packing a 40-by-60-foot rental space here with racks of computer servers that were needed to store and process information from members' accounts. The electricity pouring into the computers was overheating Ethernet sockets and other crucial components.

Thinking fast, Mr. Rothschild, the company's engineering chief, took some employees on an expedition to buy every fan they could find — "We cleaned out all of the Walgreens

THE CLOUD FACTORIES

This is the first article in a series about the physical structures that make up the cloud, and their impact on our environment.

Part 2: Data Barns in a Farm Town, Gobbling Power and Flexing Muscle

Multimedia

FACEBOOK
TWITTER
GOOGLE+
E-MAIL
SHARE
PRINT
REPRINTS

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Energy Bill for a Data Center

- Assume 100,000 servers
- Monthly cost of 1 server
  - 500W server
  - Cost=(Watts X Hours / 1000) * cost per kWh
  - Always-on server monthly cost = $50
- Monthly bill for 100K servers = $5M
- What about cost of cooling?
  - Add 20% to 100% to the bill
  - So add $1M to the $5M (~$6M)

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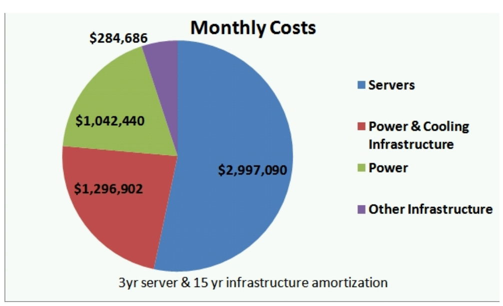
Rough Cost Breakdown

- Power costs on the verge of dominating server costs



For details see http://tinyurl.com/5wwc6g

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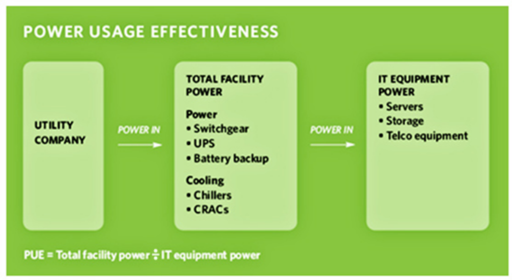
Common Metric: PUE

- PUE = **P**ower **U**sage **E**ffectiveness
  - PUE of 2 means for each watt of IT power, additional watt consumed in overhead

$$PUE = \frac{Total\ Facility\ Power}{IT\ Equipment\ Power}$$



Source: The Green Grid

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Low PUE Design

- Better power infrastructure
- Better air conditioning
- Better server and IT equipment

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Better Power Infrastructure

- Use energy storage (batteries, flywheels, etc.)
  - Shift load to low-price periods
  - Reduce use of on-site generators
- Be more efficient about power
  - Use more DC power (fewer conversions)
  - More flexible/less redundant systems
  - Balance multi-phase power

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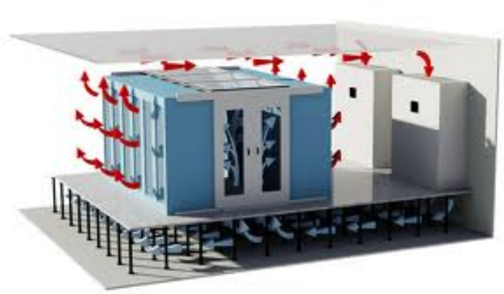
Better Air Conditioning

- Hot aisle/cold aisle containment
- Separate servers from exhaust air



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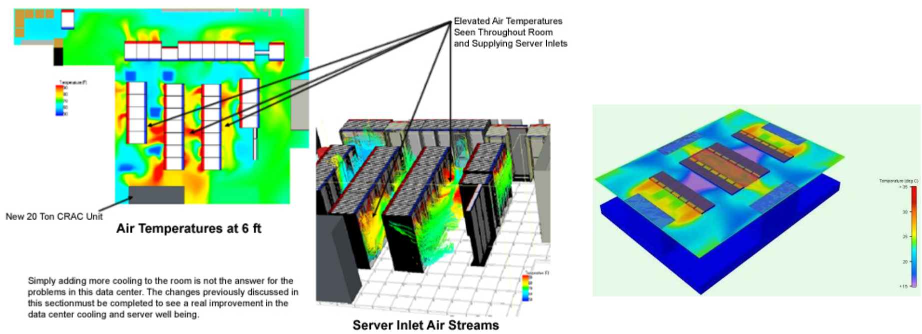
Better Air Conditioning

- Eliminate "hot spots"
  - CRAC may overly react to hotspots
  - Should balance load evenly across center



Data Center with Addition of a Second CRAC Unit Only

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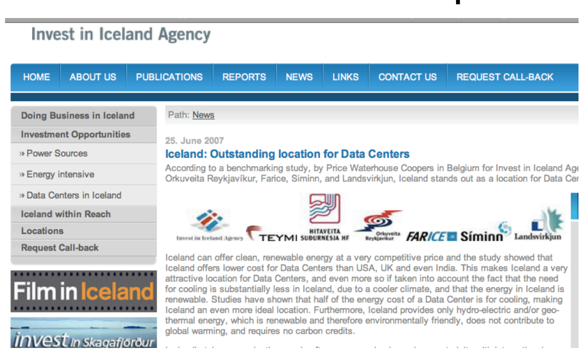
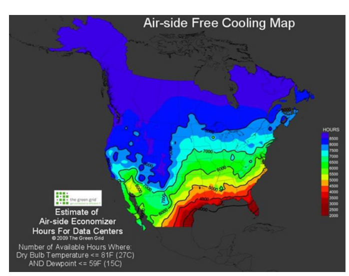
Better Air Conditioning

- Air side economization
  - Bring outside air into building and distribute to servers; exhaust air directed outside
- Build data centers up north





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Better Air Conditioning

- Or, just put servers outside
  - Microsoft experiment
    - http://tinyurl.com/3x3d4gm
  - How to get to a PUE of 1?
    - Thinking out-of-the-box

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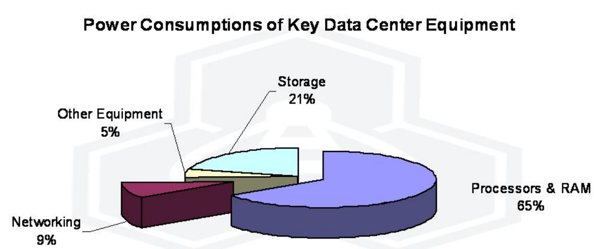
Better Servers and IT equipment

- Breakdown
  - **Servers** (65%)
  - Storage (21%)
  - Networking (9%)



Source: Wikibon 2011, base on detailed figures in the EPA Final Report to Congress 2007, reallocated to extract all the Networking components

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Server Proportionality

- Energy-proportionality
  - Power usage scales linearly with workload intensity
    - 100% utilization uses M watts
    - 50% utilization uses M/2 watts
    - Idle server uses 0W
  - Servers **are not** energy-proportional

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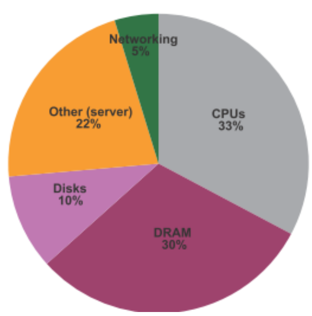
Server Proportionality

- CPUs improving…
  - Multiple power states (C0-C3 ACPI)
- … but other components consume power
  - Disk, RAM, motherboard, network card



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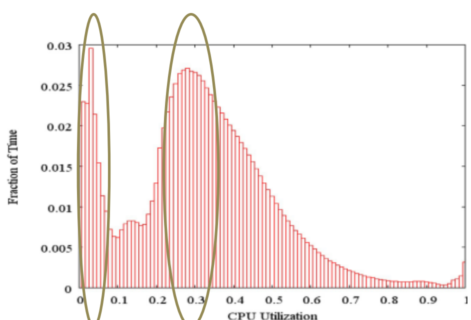
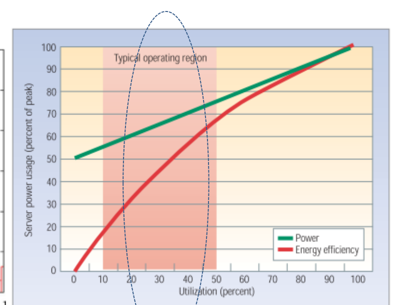
Server Efficiency

- Efficiency also very important
  - How much "work" do you do for each joule of energy used
  - Different from proportionality
    - Could be proportional but not efficient
- **Bad News:** Servers not efficient either

Server Efficiency





Source : Barroso, Holzle: Data Center as a Computer, Morgan Claypool (publishers), 2009

Servers are never completely idle

Most of the time server load is around 30%

But, server is ***least*** energy efficient in it's most common operating region!

Reasons for Inefficiency

- Lots of unused CPU features
  - Large caches; complex architecture features
  - Components always on using power
  - High frequency CPU
    - Higher the frequency, more power used and heat created
- Not necessary if bottleneck not CPU
  - Motivates research on "balanced" systems

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Best way to be Efficient

- **Always be at 100% utilization!**
  - If you're not and still on, you're being wasteful
  - Even if you're off you're being wasteful
    - Wasting the infrastructure that was built
- Efficiency linked with software flexibility
  - Virtualization, Migration, Software-defined Networking, etc.

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Example

- Server Virtual Machines
  - Enables isolation and consolidation of workload on fewer real machines
  - Provides resource management hooks that affect power
    - Limit % of CPU/memory to VM
    - Also limits power
  - Migration enables workload consolidation
    - Compress workload; turn off unused machines

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Common Approach

- Energy-proportional Ensembles
  - Workload distributed across multiple components
    - Disks, servers, memory, switches, etc.
  - As utilization decreases…
    - …turn off components…
    - …and migrate workload onto active components
  - As utilization increases…
    - …turn on components…
    - …and migrate workload across newly active components

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Common Approach

- Energy-proportional Ensembles
  - Problems
    - Workload may store local data on component
      - Moving data might take a long time
      - Turning on/off component may take long time
    - Workload intensity may change…
      - … faster than data transfer
      - … faster than you can turn on new server
      - Problem for latency-sensitive apps
    - Does not work if workload not distributed
      - Single batch job or web server

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Beyond Servers

- Other IT components typically more inefficient than servers
  - Switches/routers
    - Use same power at idle as at 100% utilization
  - Memory
    - Rarely, turn off RAM memory banks
  - Storage
    - Mechanical disks not energy-proportional
    - Flash uses nearly no energy, but expensive

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Renewables in Data Centers

- Motivation
  - Public relations
    - Bad press for using too many fossil fuels
  - Hedge against electricity costs
    - Electricity costs may go up in future
  - Being good citizens
    - Reduce carbon emissions

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Data Center Characteristics

- Recent focus on using renewables
  - **Example:** Apple's NC iCloud data center
  - 20MW (max) of power

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Data Center Characteristics

- Requires 171 acres (or 7.4 million square feet)
  - Powers ~15.8% of facility
  - 3.2MW on average;
  - Grid must absorb variations
    - Can do it today, but scaling is a problem

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Renewables in Data Centers

- Introduce new dynamics
  - Both workload and available power now changing
    - Need to match supply and demand
    - Could use a battery, the grid, or workload scheduling
- May require rethinking PUE metric
  - Care more about "dirty" waste than "clean" waste

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Part 2: Computing for Greening

- How can we use IT to make buildings green?
  - Use sensors, smart software, smart appliances, smart meters …..

Smart Buildings

- Prerequisites
  1. **Must monitor energy usage**
     - Ideally, fine-grained data from each ***load***
  2. **Must be able to control electricity usage**
     - Automatically turn devices on/off
  3. **Must monitor environment**
     - What is the temperature, humidity, etc.?
     - Are people in the building? Where? How many?
     - What are their preferences?
- How do we do all this cheaply and reliably?
  – Also must be aesthetically pleasing

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Smart Buildings

- Existing systems are large, monolithic, closed systems
  - Called **Building Management Systems (BMS)**
  - Akin to large mainframe computers
    - E.g., BacNet, LonWorks, MetaSys
- Also, not efficient in terms of…
  - …fine-grained data collection from many loads
  - …pervasive control load control mechanisms
    - These may need to be device specific

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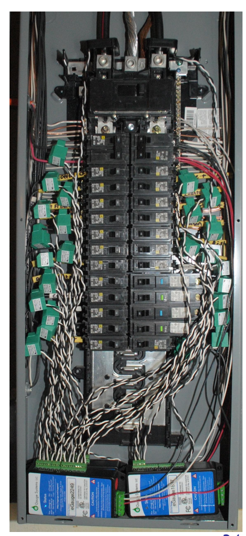
Monitoring Energy Usage

- Possible at multiple levels of wiring tree
  - Entire building at electricity ingress
  - At each circuit in electrical panel
  - At each outlet, switch, or plug
- But how to transfer data in real-time?
  - Most buildings don't have Ethernet running to electric panels, plugs, or outlets



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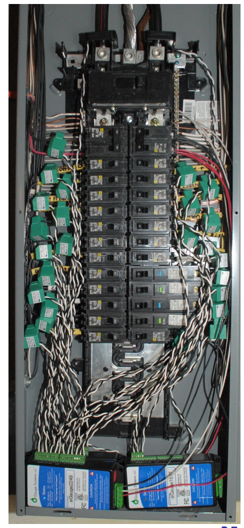
Monitoring Energy Usage

- Wireless networking
  - Zigbee (802.15.4), Wifi (802.11)
- Powerline networking
  - X10 and Insteon
  - HomePlug
- Considerations
  - Form-factor size, heat generation, bandwidth, interference
  - Affects data granularity…
    - …per minute, per second, or even less



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Monitoring Energy Usage

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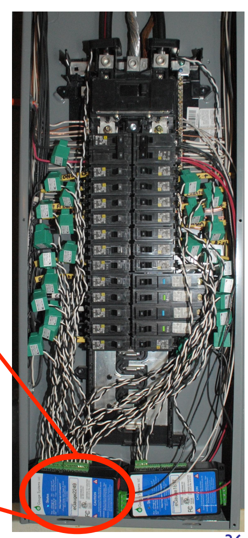

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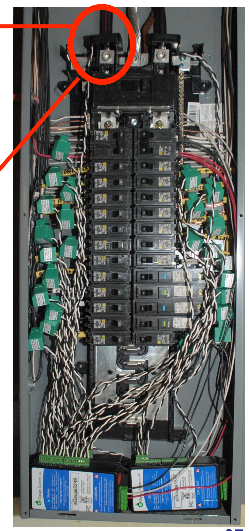

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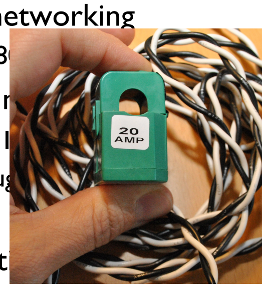

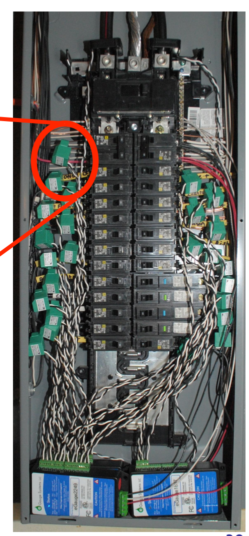

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Monitoring Energy Usage

- Other examples

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Monitoring Energy Usage

- Challenging to place sensor at every load
  - **Expensive** – cost $50-150 per switch or outlet rather than $1
  - **Intrusive** – may not "look" good
  - **Unreliable** - bandwidth constraints
- Alternatives
  - Collect high-bandwidth data at ingress (smart meter)
  - **Disaggregate** data into separate loads
    - Using a few well-placed sensors
    - Or knowledge of the devices in a building
    - Called **N**on-**I**ntrusive **L**oad **M**onitoring (**NILM**)
  - Raises privacy issues

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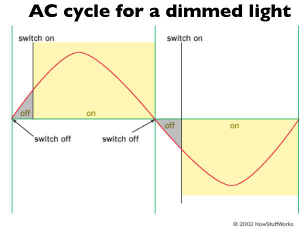
Controlling Energy Usage

- Need programmatic load control switches
  - Generally binary but may be "dimmable"
    - Cut off power for part of each AC cycle
  - May be **external** or **internal**
    - External – mechanism is in outlet or wall switch
    - Internal – mechanism built into device
- Like monitoring, must transmit data to/ from devices
  - Tell them to turn on/off
  - Not as problematic for control
    - Only need brief, infrequent control messages…
    - …not numerous streams of continuous high-bandwidth data

AC cycle for a dimmed light



Example external switch

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Example Internal Switch

- Wifi-enabled washer and dryer

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Environmental Monitoring

- Similar issues as energy monitoring
  - …although powerline networking less useful
  - Predominantly wireless sensor networks
    - Active research area
    - Many commercial products available
    - Other possible useful information?


Motion


Door


Thermostat


Weather

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Smart Buildings

- Prerequisites were monitoring and control
- How do we use these mechanisms?
  1. Provide recommendations via smart phone
  2. Enable remote, but manual, control
  3. Automated scheduling policies
     - Although some loads not amenable to scheduling
     - Energy storage and batteries may help (see SmartCharge)
- Optimize for **lower costs**, **lower energy usage**, **lower peaks**, **aligning consumption with renewable generation**

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Summary

- Greening of computing
  - Design of energy-efficient hardware & software
- Computing for greening
  - Use of IT for monitoring
  - Use of intelligent software for power management