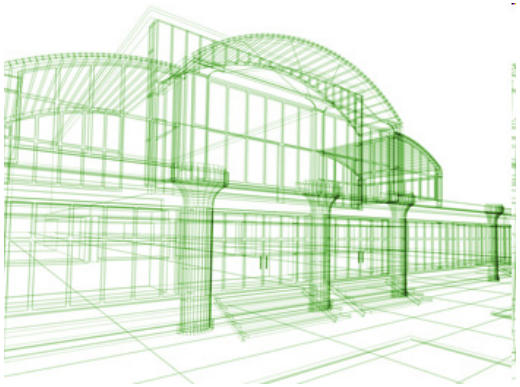
Toward an Energy-Proportional Building Prospect



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Third Annual IEEE EnergyTech Conference 2013, Cleveland, OH

These slides and audio recordings are available at
http://www.cse.wustl.edu/~jain/talks/etechp.htm

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Overview

Buildings are responsible for around 38% of the total carbon dioxide emissions; 71% of the total electrical energy consumption; 39% of the total energy usage

1. Three Key Steps of the Research
2. Energy Consumption Data Analysis in a Green Building
3. Energy-Proportional Buildings Concept

Research Motivations and Key Steps

- Motivations:
  - Building energy consumption: Big Problem
  - Buildings are complex systems
  - Need to find major factors and patterns
- Three Key Sequential Steps:
  - 1. Energy Monitoring
  - 2. Energy Modeling and Evaluation
  - 3. Practical changes and Strategy Adjustments

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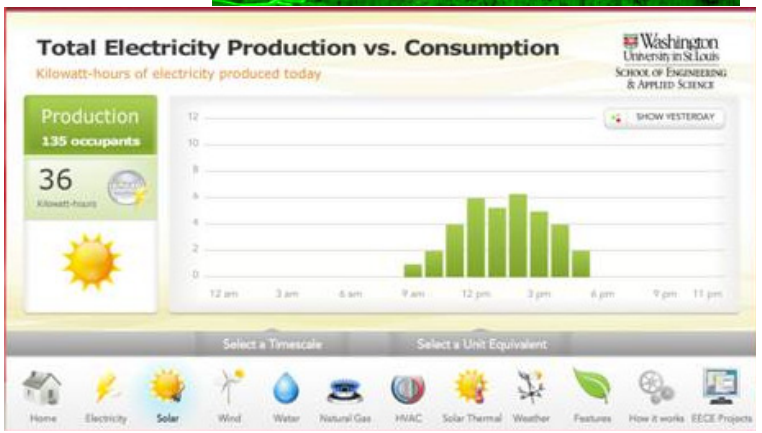
Large Office Green Building Testbed

- Gold certificate for Leadership in Environment and Energy Design (LEED) by US Green Building Council
- High Albedo Roof: Reduce solar radiation heating
- Rainwater collected in cistern
- 8 Solar panels with power of 9.8kw
- A vertical axis wind turbine
- Solar water heater
- Centralized Meters
- Real-time energy data display by online webpage
- Goal: Analyze the energy consumption data



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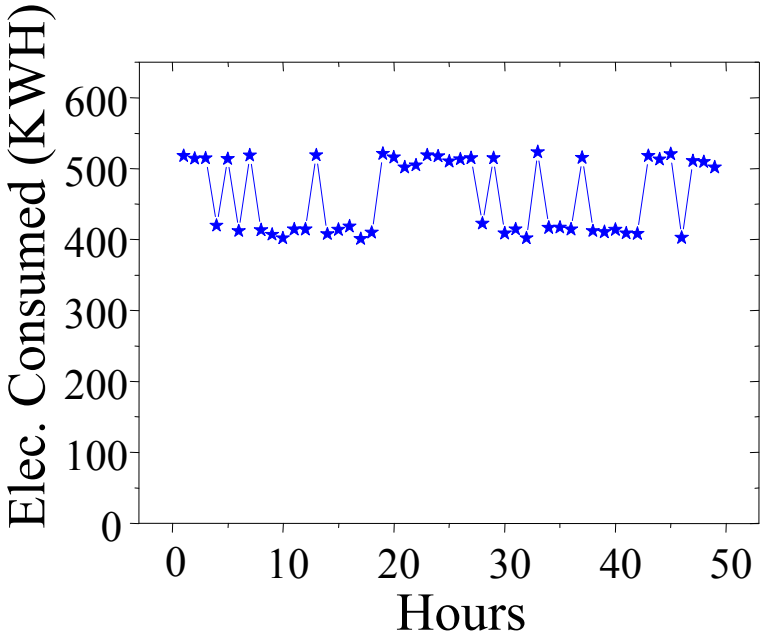
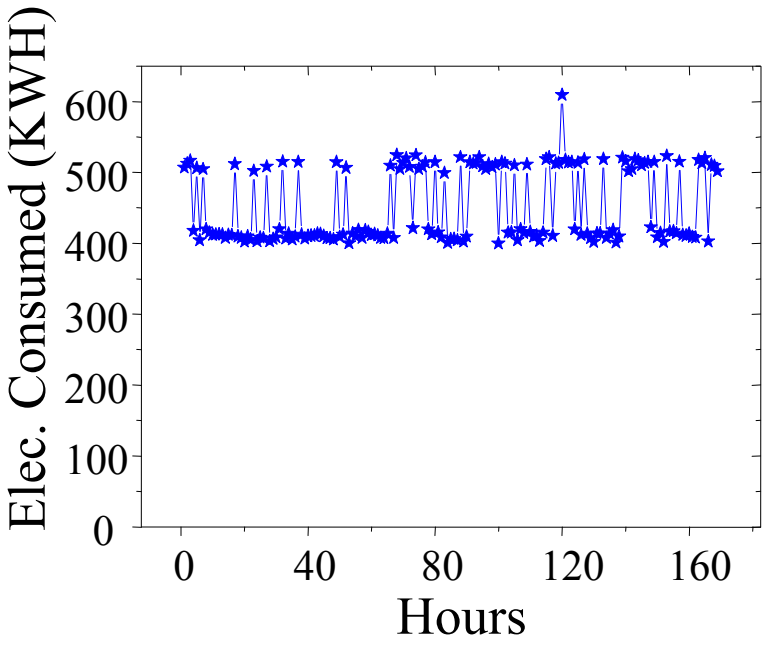
Electricity





- Total hourly electricity consumption traces for 2 days (from 4/14/2010 to 4/15/2010) and 7 days
- Pattern shows very little variation between the busiest hours and the idlest hour ⇒ ***the total electricity consumption possibly has low connection with occupancy***.

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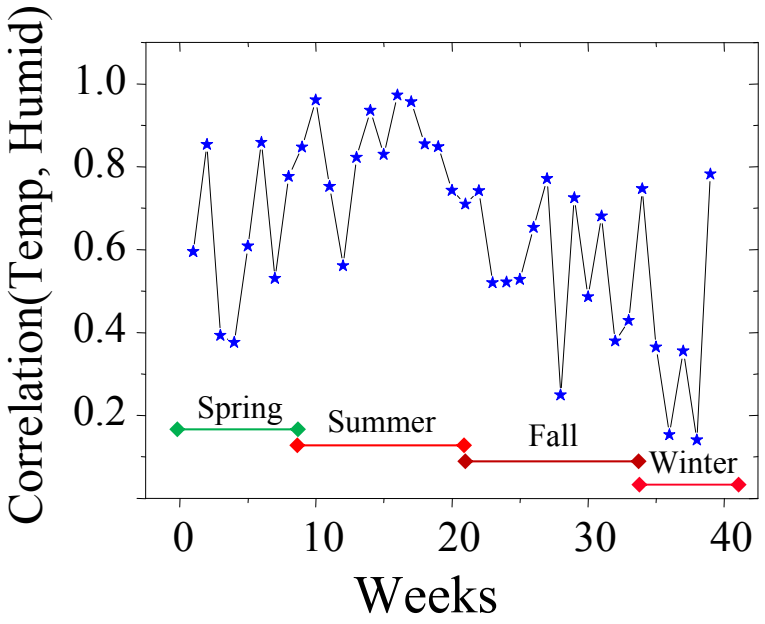
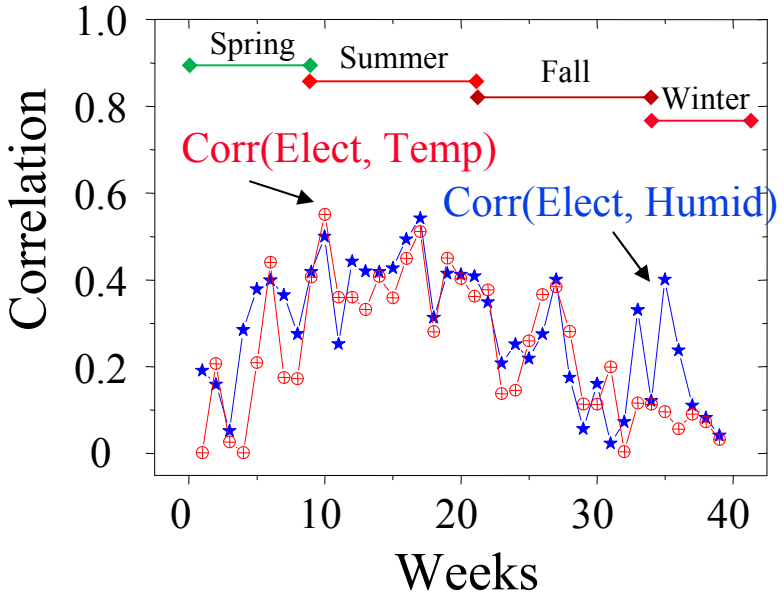
Long Period (Weekly) Correlation





- Temperature (X), Humidity (Y), Electricity (Z)
- A continuous dataset for about 10 months (39 weeks) from 3/18/2011 to 12/31/2011
- Corr(temp, humid) from 0.2 to 0.9; Corr(elect, temp) and Corr(elect, humid) mostly below 0.5
- **Observation**: Electric consumption has low correlation with outside weather conditions or occupancy

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Analysis Phase II

- Central heating and cooling systems
- The building's heating and cooling system is shared with five or six other building
- The same air is circulated to different buildings and is locally cooled or heated as needed
  $\Rightarrow$ Study heating energy and cooling energy separately

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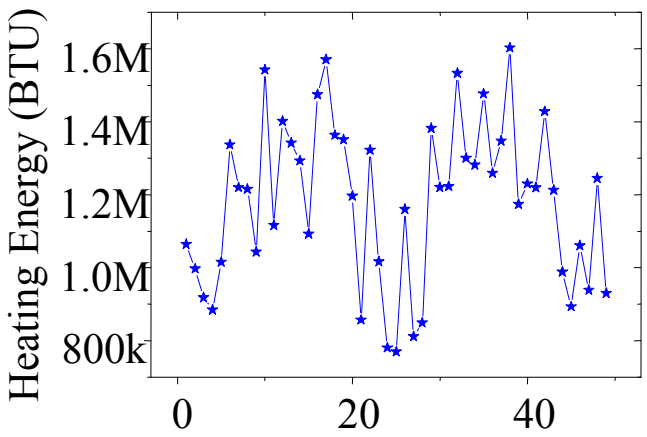
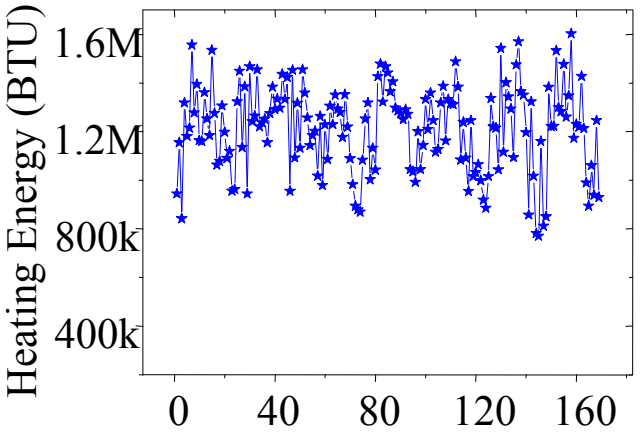
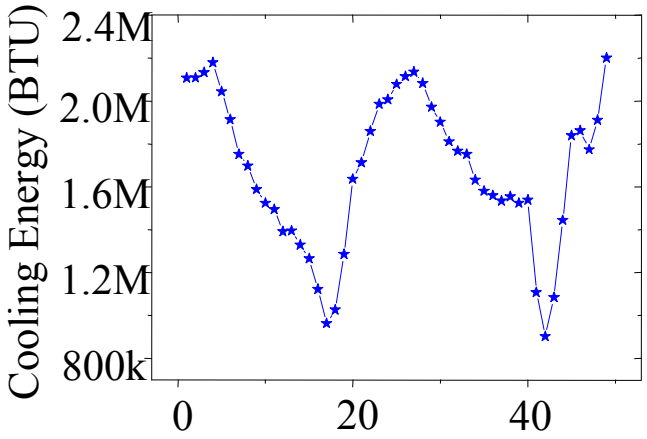
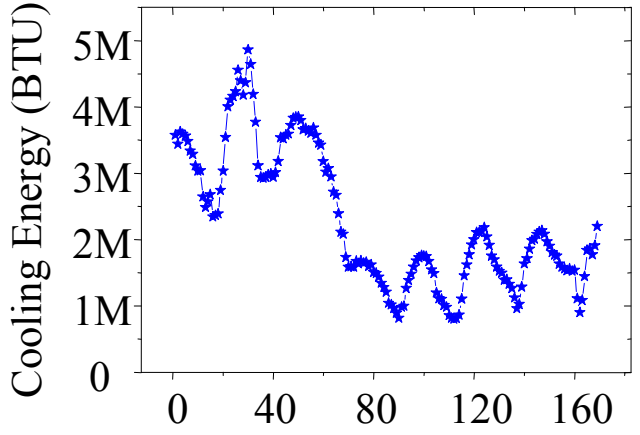
Heating and Cooling Energy









- Traces for 48 hours (2 days) and 168 hours (7 days)
- Heating peak approximately comes with cooling trough.

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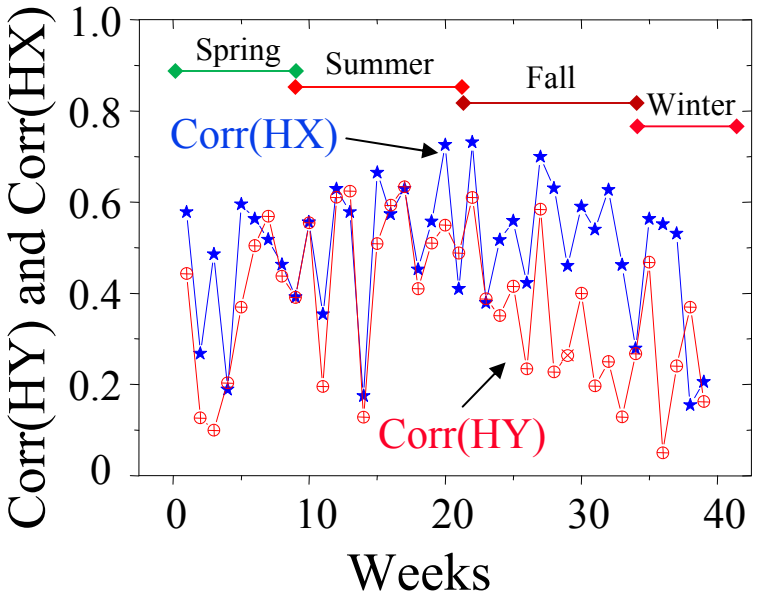
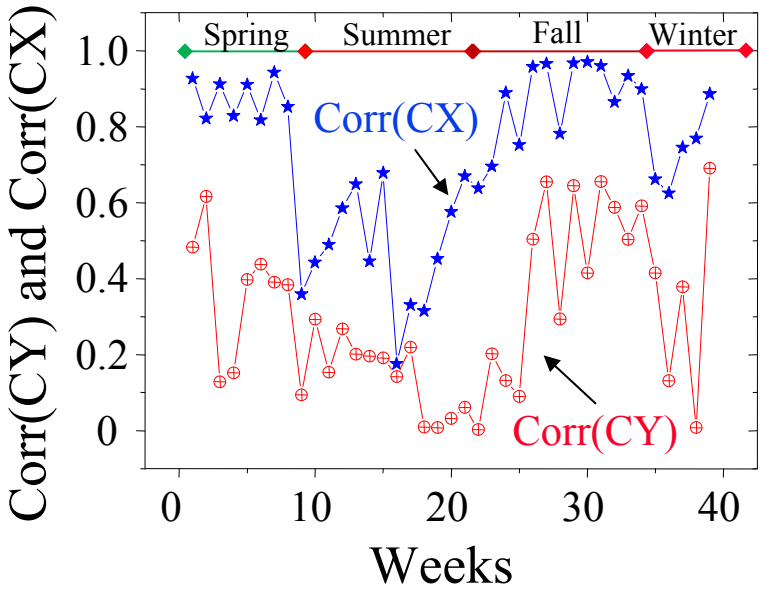
Long Period Correlation Analysis





- H=Heating Energy, C=Cooling Energy, X=Temperature, Y=Humidity
- Heating energy correlations are mostly below 0.6.
- Cooling energy correlations are around 0.8 and 0.9 in spring, fall, and winter seasons, while struggling around 0.5 for summer

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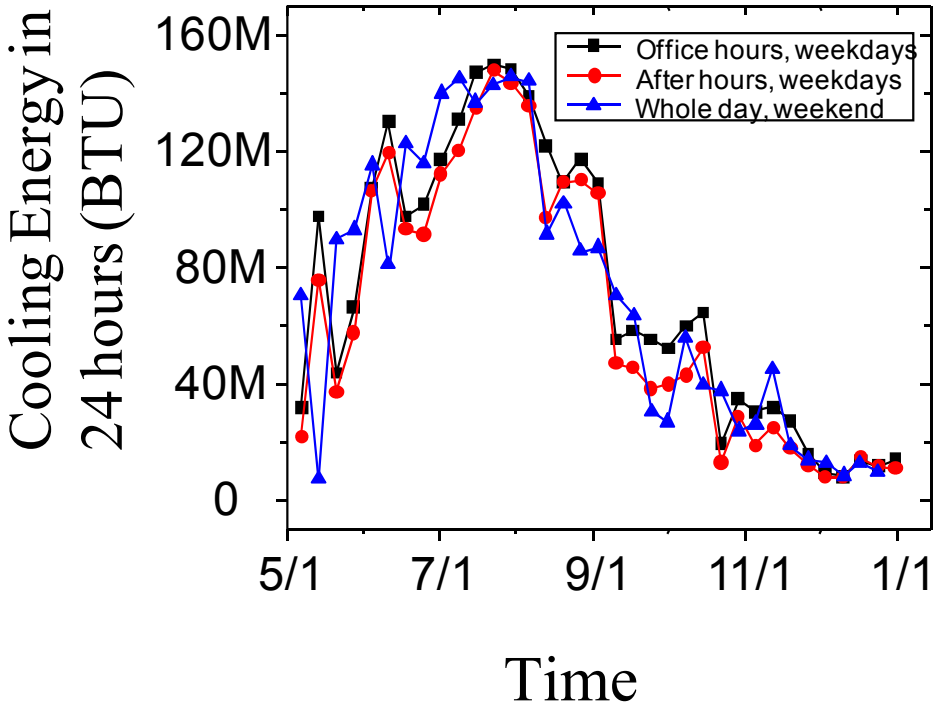
Occupancy Impact Analysis

- The actual occupancy rate has very low impact to the energy consumption.



Observations

- ***The heating and cooling designs do not actively take the outdoor weather condition and occupancy as factors to dynamically adjust the running schedule and policies.***

"Green" building ≠ Energy efficient in operation

⇨ ***Centralized Control, Fixed Running Pattern***

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Energy Proportional Buildings

- Similar to Energy Proportional Computing
- Old Computing and communication:
  - Same power for idle or busy state
    idle = execute null instructions
    or send zeros on wire to keep the clocks synchronized
  - Energy consumption was independent of load
- New CPUs and network devices are designed to be energy proportional $\Rightarrow$ Energy $\propto$ Load
- We coined the term "Energy Proportional Building" for buildings that consume less energy when unoccupied or when the outside weather is good

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Energy Proportional Buildings

- Energy proportionality can be obtained by occupancy sensors, and sensor controlled energy consumption
  - Much cheaper than Solar Panels, wind turbines, …
  - Easily done for residential buildings and small office buildings.
  - Can be done for old or new buildings
- Universities are planning to spend millions on renovating old buildings for energy efficiency
- We believe more Carbon Dioxide Equivalent (CDE)/Dollar can be achieved by making them energy proportional

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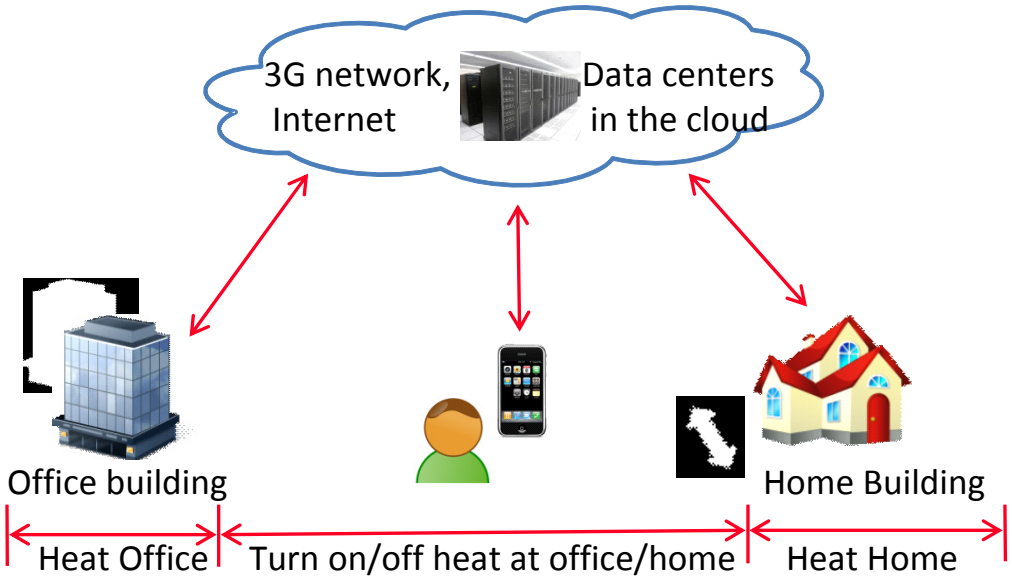
Location-Based Energy Control

- **Goal**: enable **building**- and **user**-level energy proportionality
- **Approach**: smart location-based automated control



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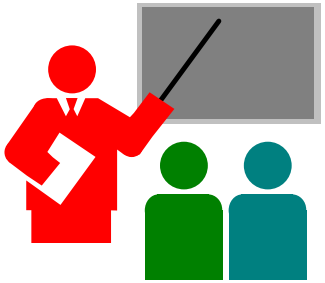

Summary

1. Green buildings = Energy efficient by design
   ≠ Energy efficient in operation
2. Centralized heating and cooling systems = Cost Efficient
   ≠ Energy efficient
3. Energy Proportional Buildings are those whose energy consumption reduces depending on occupancy and weather
4. Energy proportionality is more cost effective than green renovations
5. Using Smart Location-based Automation in Creating Energy Proportionality

Energy Proportional Buildings are more CDE/$ efficient

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