Intelligent Building: Energy Efficiency and Networking Perspective

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CSE Seminar
Agenda

- PART I: Introduction and Research Context
- PART II: A Green Building Energy Data Analysis
- PART III: A Location Based Energy Control Solution for Energy Proportionality
Introduction

• **Fact #1:** In U.S., 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

• **Fact #2:** Intelligent building concept since 1980’s, but the reality fell short for multiple reasons

• **Fact #3:** The energy price is skyrocketing and urge for sustainability

• **Fact #4:** New networking and Internet technologies such as mobile smart phone and cloud computing create new opportunities
Research Context

• Study intelligent building in a combined perspective

- Rising energy price
- Renewable energy usage
- Energy efficiency

- Building subsystem integration
- New networking technologies applications

- Consumer-side grid important
- Microgrid perspective
Related Work

- Architecture Design, Construction, Materials..
  - Certifying organizations: LEED, Energy Star, GreenGlobe, etc.
- Physical Characteristics and Energy Simulation
  - EnergyPlus by DOE
  - Climate Modeling Efforts
- Many Subsystems
  - Lighting, HVAC, Water, Fire and Safety, Access, other appliances, etc., by different vendors
- Automation and Standardization
- Smart Home, Smart Health, Smart Thermostat

Buildings are Complex Systems, many things involved!
Building Related Concepts

- Energy generation & conservation capability
- Conventional buildings
- Net-Zero Energy Building
- Future buildings
- Material, Physical design, environment, & sustainability
- Intelligent & Green Converged Building
- Intelligent building
- Intelligence and communication capability
Intelligent Building Framework

- **Voice**
- **Video**
- **Data**
- **Other APP.**

**Comm. and Networking, building management IT system**

① Integrated networking backbone; standard protocols

② Modeling and analysis; policy and pricing

③ Energy operation and interaction

- **Energy Management and Grid Interaction**
- **Building Automation System (BAS)**
- **Renewable Energy Generation**
- **Energy Storage**
- **Metering Infrastructure**
- **Lighting, HVAC, Air/Water, Other Utilities etc**
- **Security and Access**
- **Fire and Life Safety**
- **Monitoring**
- **Control**
PART II: Green Building Energy
Data Analysis
Energy Consumption Analysis

- **Problem**: 1) building is complex; 2) need to find major factors & patterns; 3) reduce consumption for all buildings
- **Key Sequential Steps**: 1) energy monitoring; 2) energy modeling and evaluation; 3) practical changes and strategy adjustments
Correlation Data Analysis

- Correlations are relatively low $\implies$ building design not responsive to weather condition $\implies$ not efficient

"Green" building $\neq$ Energy efficient in operation
$\implies$ Building Partitioning

$Z=$Electricity, $X=$Temperature, $Y=$Humidity

$C=$Cooling Energy

Z=Electricity, X=Temperature, Y=Humidity
C=Cooling Energy
Occupancy Impact Analysis

- The analysis clearly shows that the *actual occupancy rate has very low impact to the energy consumption.*

Non-office Hours NOT as low as expected

Almost consume same amount of energy

![Graphs showing energy consumption](image-url)
Three Types of Energy Proportionality

• Energy Proportionality in Computing
  – Old Computing and communication: Energy consumption was independent of load
  – New CPUs and network devices are designed to be energy proportional ⇒ \textit{Energy} \propto \textit{Load}
  – CPU: “\textit{wide dynamic power range}” and “\textit{active low-power modes}”

• Energy Proportionality in Building
  – consume less energy when unoccupied or when the weather is good
  – Imitate CPU features in buildings

Key Basic Steps:
  – 1. Building Deep Partitioning
  – 2. Enable features using networking technologies

• Energy Proportionality in User-level
  – Users use actual energy that they really need, avoid waste
PART III: Location Based Energy Estimation
Vision

• Achieving building-level and user-level Energy Proportionality by the Location Based Solution

• Other Benefits: Awareness, sensitiveness, Participation, and social factors
  – Providing energy feedback: 10% energy saving
  – In-home energy display: 15% energy saving
  – “Green Cup” and “Green Lab” in Wash. U.
  – Social awareness and broad education for sustainability
User-level Energy Proportionality

• User-oriented Energy Control
• User’s Energy Consumption Reflects Actual Usage
• User-oriented Location-based Inter-building Cooperation
• Multi-organization Energy Policy Formation and Enforcement
Basic Idea: Location Based Networking and Control

- **Office control plane**
  - Office building
  - Dept. 1 Policy Server
  - Dept. 2 Policy Server
  - Dept. 3 Policy Server
  - Lab 1 Policy Server
  - Lab 2 Policy Server
  - Lab 3 Policy Server

- **Home control plane**
  - Home building
  - Lab 2 Policy Server (②)
  - Lab 3 Policy Server (②)

- **3G network, Internet**
  - Data storage in the cloud
  - Data centers
  - Users with mobile devices

- **Users with mobile devices**
  - Office control plane
  - Home control plane
Benefits

• **1. Distributed** energy-saving policies and control instead of the centralized and fixed running policies

• **2.** Virtually introduces the “*wide dynamic power range*” and “*active low-power modes*” into the building environment

• ➔ Essentially enable Energy Proportionality in Building Environment

• ➔ Real case: we propose to use “*deep building section partitioning*”
Experiments: Hardware Devices

• Kill-A-Watt

• WeMo
Tuning and Measurement
Software

• Location Software:
  – iOS: Life360, GPS Kit, Location Man, Location Recorder, Open Paths
  – Android: Google Map with Location History Feature

• Control Software:
  – iOS: WeMo
  – Android: TBA
## Appliances’ Real Working Power Measurement

### Home Appliances:

<table>
<thead>
<tr>
<th>Type</th>
<th>Lighting</th>
<th>Refrigerator (GE)</th>
<th>Microwave Stove (Philips)</th>
<th>Laptop (Mac Pro 15”)</th>
<th>HVAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Items</td>
<td></td>
<td>Start: 200w, gradually to 170w</td>
<td>1.3kw</td>
<td>Normal: 41w Active or charging: 60w</td>
<td>N/A In winter. Can be significant in other cases</td>
</tr>
<tr>
<td>Porch:</td>
<td>54w</td>
<td></td>
<td></td>
<td>54w</td>
<td>1.3kw</td>
</tr>
<tr>
<td>Bedroom:</td>
<td>18*2 = 36w</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Living Room:</td>
<td>54*2+42 = 150w</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kitchen:</td>
<td>52*5 = 260w</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bathroom:</td>
<td>54w</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Avg. Power</td>
<td>550w</td>
<td>185/2 w</td>
<td>1.3kw</td>
<td>50w</td>
<td></td>
</tr>
</tbody>
</table>
# Assuming Three Consumption Modes

### Home

<table>
<thead>
<tr>
<th></th>
<th>Lighting</th>
<th>Refrig.</th>
<th>Microwave</th>
<th>Laptop</th>
<th>HVAC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Luxury Mode</strong></td>
<td>Always ON except sleeping</td>
<td></td>
<td></td>
<td>Always ON at home</td>
<td></td>
</tr>
<tr>
<td>(user is energy insensitive)</td>
<td>550w<em>24</em>2/3= 8.8kwh</td>
<td></td>
<td></td>
<td>50w<em>24</em>2/3= 0.8kwh</td>
<td></td>
</tr>
<tr>
<td><strong>Moderate Mode</strong></td>
<td>Only ON when at home awake</td>
<td>Constantly, 185w/2*2 4 = 2.22 kwh</td>
<td>Constantly, 1.3kw*0.05 = 0.065 kwh</td>
<td>Only ON when at home awake</td>
<td>Only ON when at home awake</td>
</tr>
<tr>
<td></td>
<td>550w<em>24</em>1/3= 4.4 kwh</td>
<td></td>
<td></td>
<td>50w<em>24</em>1/3= 0.4 kwh</td>
<td></td>
</tr>
<tr>
<td><strong>Frugal Mode</strong></td>
<td>Only 60% ON when at home awake</td>
<td></td>
<td></td>
<td>Only 60% ON when at home awake</td>
<td></td>
</tr>
<tr>
<td>(user is energy sensitive)</td>
<td>4.4 *0.6 =2.64kwh</td>
<td></td>
<td></td>
<td>0.4*0.6 = 0.24kwh</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>L: 11.90kwh ; M: 7.09kwh; F: 5.17kwh</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Assuming 8 hours working in office, 8 hours at home awake, and 8 hours sleeping*
## Appliances’ Real Working Power Measurement (Contd.)

- **Office Appliances:**

<table>
<thead>
<tr>
<th>Type</th>
<th>Lighting</th>
<th>Desktop</th>
<th>Laptop (Mac Pro 15”)</th>
<th>HVAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Items</td>
<td>32w * 6 = 192w</td>
<td>Host: Boot – 110w Normal – 67w</td>
<td>Normal: 41w Active or charging: 60w</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Monitor: Normal—72w, Active—80~90w</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Avg. Power</td>
<td>192w</td>
<td>160w</td>
<td>50w</td>
<td></td>
</tr>
</tbody>
</table>
# Assuming Three Consumption Modes

- Office

<table>
<thead>
<tr>
<th></th>
<th>Lighting</th>
<th>Desktop</th>
<th>Laptop</th>
<th>HVAC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Luxury Mode</strong></td>
<td><strong>Always ON when at office 192w*8 = 1.54kwh</strong></td>
<td>Always ON 24/7</td>
<td>Always ON when at office</td>
<td></td>
</tr>
<tr>
<td>(user is energy insensitive)</td>
<td></td>
<td>160w*24 = 3.84kwh</td>
<td>50w<em>24</em>1/3 = 0.4kwh</td>
<td></td>
</tr>
<tr>
<td><strong>Moderate Mode</strong></td>
<td><strong>Always ON when at office</strong></td>
<td>Only ON when at office</td>
<td>Only 50% ON when at office</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>160w<em>24</em>1/3 = 1.28kwh</td>
<td></td>
<td>0.4*0.5 = 0.2 kwh</td>
<td></td>
</tr>
<tr>
<td><strong>Frugal Mode</strong></td>
<td><strong>Only 60% ON when at office</strong></td>
<td>Only 60% ON when at office</td>
<td>OFF when at office, use desktop</td>
<td></td>
</tr>
<tr>
<td>(user is energy sensitive)</td>
<td></td>
<td>1.28*0.6 = 0.77kwh</td>
<td>0kwh</td>
<td></td>
</tr>
</tbody>
</table>

**Total**

- L: 5.78kwh
- M: 3.02kwh
- F: 2.31kwh

*Assuming 8 hours working in office, 8 hours at home awake, and 8 hours sleeping*
Comparison of Three Modes

<table>
<thead>
<tr>
<th>Mode</th>
<th>Daily Energy (kwh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luxury</td>
<td>11.9</td>
</tr>
<tr>
<td>Moderate</td>
<td>7.09</td>
</tr>
<tr>
<td>Frugal</td>
<td>5.17</td>
</tr>
</tbody>
</table>

- **Office**: 5.78
- **Home**: 11.9

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**Luxury**

- **Office**: 2.31
- **Home**: 9.58

**Moderate**

- **Office**: 3.02
- **Home**: 7.09

**Frugal**

- **Office**: 2.31
- **Home**: 5.17
Location Trace Example

- Life360 one day location trace
  - Intentionally been to many places... :)

Add or edit a place to get alerts when family members come and go

Jianli’s Office
Jianli’s Home
Add Place

14:39 - 16:59 University City
6914 Forest Park Pkwy, University City, MO

Monday, Mar 18

15:35

12 am 11:59 pm
Location Trace Example (Contd.)

• In list
“Semi-Real” Energy After Applying Location Based Control

• At Home:
  – 14 hours (8: sleep, 2: lunch, 4: work)
  – Energy Estimation: lighting (0.45*6=2.7kwh), Refg. (2.22kwh), Microwave(0.065kwh), Laptop (0.05*6=0.3kwh)
  – Total: 5.285kwh

• At Office:
  – 6 hours, half use desktop, half use laptop
  – Energy Estimation: lighting (0.192*6=1.15kwh), Desktop (0.16*6=0.96kwh), laptop (0.05*3=0.15kwh)
  – Total: 2.26kwh

• Outside:
  – 4 hours
  – All devices are off except refrigerator
Putting Together

- Total real consumption reduced by 57% comparing with Luxury mode and 25% with Moderate mode

Key Message: very Close to Frugal Mode!
Real Gains

• HVAC is not considered yet, but can be a huge part; for the given example, lighting make the major difference

• Depends on the building type, and the habits of the occupants, but saving is obvious

• Multiple policies can involve, enabling the key components for building energy proportionality

• Awareness, sensitiveness, participation, with social plugin...more potential for energy saving
In Progress..

- Need more meters with networking and offline programming supports
- Need more WeMo-like but open-sourced devices
- Need software integrating the location and control functions in one software
- Need backend cloud data storage, policy formation, and devices monitoring
- Essentially combine several small iOS or Android applications and formed a brand new and bigger energy application
Cyber-assisted Dynamic Microgrid Optimization

- **Problem**: Energy efficiency in larger-scale distributed environments;
- **Perspective**: 1) Buildings as both energy consumers and providers; 2) Buildings networked into a microgrid
- **Approach**: 1) Create a “knowledge plane” by networking the control planes of the buildings altogether; 2) Dynamical schedule energy generating and consuming with appropriate algorithms; 3) Smart prediction over the distributed energy provisioning and consuming pattern
Networking and Control Structure

Users: monitor and control
--Monitoring agent
--Policy agent
--Interaction agent

Central control domain

Data centers, Clouds
Internet

Microgrid
central server

Building domain
Energy Storage

Two-way
Power
connection

Comm. connection

Info. Gathering & control instruction

Buildings with renewable energy generators

Power Grid
**Problem:** Assume the network control working well, the microgrid optimization problem is modeled as a distributed computing optimization problem.

**Formulation:**

\[ T = \sum_{i=1}^{N} \left( \sum_{j \neq i} \left( C_i - G_i + I_{ij} \right) \right), \text{ subject to conditions of}\]

\[ C_i - G_i + \left( \sum_{j \neq i} I_{ij} \right) - \left( \sum_{j \neq i} O_{ij} \right) = 0, \text{for every building } B_i \text{ where } i \in [1, N], \text{ and}\]

\[ I_{ij} + O_{ij} - L_{ij} = 0, \text{for every link } S_{ij} \text{ between buildings } i \text{ and } j. \]
Thanks!