Smart Building Facilitated by Wireless Sensor Networks and Integrated Terminal Control

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Why Smart Buildings? – U.S.

US ENERGY CONSUMPTION

In the US, buildings are responsible for

- 38% of CO2 emissions
- 71% of electricity consumption
- 39% of energy use
- 12% of water consumption
- 40% of non-industrial waste
- 90% of our time indoors.

Public Commercial Residential

Source: 2008 EIA Buildings Energy Data Book
Why Smart Buildings? – China

If no actions are taken, China will become No. 1 CO2 emissioner by 2020.
Renewable Energy?
Why Smart Buildings? – Big Potential

Actual utilization of coal fired electrical energy in China

1 penny saved is 12.5 pennies earned.
We need

Green, Comfort, Secure, and Safe Buildings!!
The Only Formula in This Talk

Energy Cost \( (E) \) = Cost per unit of load \( (C) \) \times \text{Load} \( (L) \)

- Energy efficiency
- Better envelope
- Smart materials
- Smart controls
- New HVACs
- PV panels
- E-cars
- ...
Why Controlling the Demand?

- There are limits of improving building energy efficiency (i.e., reducing C)
  - Most of the new devices and materials are suitable for new buildings
  - Better control can be used for both new and existing buildings, but no magic in energy saving, 10-20% saving.
- Without control, the demand in buildings will rise up very sharply! (i.e., fast growing L)
  - E.g., modern buildings, fancy, energy monsters
  - Examples around us
A Case Study in Tsinghua

- Tsinghua National Lab for Information Science and Technology (FIT building)
  - 10,000 m²
  - Electricity cost: 3M RMB/yr

- Pick two labs
- 36 students, 52 desktops
- Electricity cost: 105,120 RMB in yr 2010
- Educate the students
- One year later
- Electricity cost increased!
Why Increased?

Consume power.  
Don’t pay the bill.

The students don’t have the motive to reduce the demand.

Pay the bill.  
Don’t control the building.

Control the building.  
Don’t control the demand.
How to Control the Demand?
Information Systems - Environment

- Temperature
- Humidity
- CO2 level
- Luminance
- Wind speed
- Noise level
- Radiant temperature
Information Systems - Devices

- HVAC
  - Chilled water temperature
  - Water pump
  - Fan speed of Fan-Coil-Unit (FCU)
  - Fan speed of Fresh-Air-Unit (FAU)
  - Valve
  - Output air temperature
- Lights, blinds, windows
- Energy consumption
  - Traditional power meters
  - Plug-in loads
  - MAC addresses (Zhang et al. 2010)
### Information Systems - Occupants

<table>
<thead>
<tr>
<th>Systems</th>
<th>Cost (RMB)</th>
<th>Approach</th>
<th>Accuracy</th>
<th>Disadvantage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Active sensors</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WSN/RFID</td>
<td>200</td>
<td>Localization</td>
<td>2m-5m</td>
<td>Multipath effect</td>
</tr>
<tr>
<td>RFID</td>
<td>3,000(r) 200(t)</td>
<td>Localization</td>
<td>2m-5m</td>
<td>Multipath effect</td>
</tr>
<tr>
<td>UWB</td>
<td>30,000(r) 200(t)</td>
<td>Localization</td>
<td>0.30m</td>
<td>High cost</td>
</tr>
<tr>
<td>Cricket</td>
<td>2,000</td>
<td>Localization</td>
<td>0.10m</td>
<td>Ultrasonic, orientation constrained</td>
</tr>
<tr>
<td><strong>Passive sensors</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Video</td>
<td>5,000~200</td>
<td>Image Processing</td>
<td>90%~95%</td>
<td>Privacy, cost</td>
</tr>
<tr>
<td>CO2</td>
<td>2,000~100</td>
<td>Signal Processing</td>
<td>50%~80%</td>
<td>Drift</td>
</tr>
<tr>
<td>Infrared</td>
<td>100</td>
<td>Counting</td>
<td>80%~95%</td>
<td>No identity</td>
</tr>
</tbody>
</table>

Fusing cheap sensors to get high accuracy. (Wang et al. 2012, Jia et al. 2012)
Information Systems - HMI

- Multi-dimensional satisfaction feedback
- System state query
- Comfort profile learning
  - (Zhao et al. 2010)
- Energy consumption prediction
  - (Wang et al. 2011)
- Group dynamics
  - A single HMI
  - Multiple HMIs
  - No HMIs
Integrated Terminal Control

- To improve the energy efficiency (reducing C)
  - 10-20% energy saving using natural ventilation, sun shine (Sun et al. CASE 2010, T-ASE 2012)

- To reduce the load (i.e., L)
  - Respond: to complaint
  - Responsive: guaranteed service
  - Prioritized: differentiate different needs
  - (Wu et al. 2013)
Integrated Control to Improve Energy Efficiency

Comfort requirement

Average price curve of electricity

Supply

Terminal devices
- Light
- HVAC
- Blinds
- Windows

Integrated Terminal Control

Building load profile on electricity, heating & cooling

(Guan et al. 2010, Jia et al. 2012, Xu et al. 2013)

Energy systems
- PV-panels
- Battery
- Wind power
- CHP
- Power grid
- E-vehicles

Multiple-Supply Management

Dynamic price of electricity and natural gas
Motivation Mechanism

- Meter/Estimate the energy consumed by each student (Zhang et al. 2010, Lei 2012)
  - Individual cost (desktop, laptop, other plug-ins)
  - Shared cost (HVAC, lights, etc.)
- Feedback (Lei 2012)
  - Relative rank (peer pressure)
  - Suggested actions
- Give each student a budget (200RMB/month). Then let them pay the bill. (on going research…)
- Location-based pricing (Xu et al. 2013)
iBuilding

Complaints
- Glare/Dark
- Hot/Cold
- Humid/Dry
- Stuffy
- Noisy

Interpreter

Set points
- Illuminance
- Temperature
- Humidity
- CO2
- Fan speed

Controller

Devices
- Lights
- Blinds
- Ceiling

Occupants

AHU
- Heater
- Humidifier
- Valve
- Fan

Fresh air Fan

HMI
Conclusion

- Building energy saving is of great practical interest.

- **Control the demand** is important.
  - Information systems supported by wireless sensor networks save energy by 10%.
  - Integrated terminal control saves energy by 10%.
  - Mechanism changes are predicted to save 30%.

- And …
Some Other Applications

- Building fault diagnosis (Sun et al. T-ASE 2012)

- Real-time fire source identification and risk map calculation (Qiao et al. 2010, Yang et al. 2012)

- Real-time evacuation guidance (Zhang et al. 2012)

- Reservation-based HVAC control (Xu et al. 2010, 2013)

- Storage devices analysis (Xu et al. 2011)
Smart Buildings TC in IEEE RAS

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(Samuel) Qing-Shen Jia

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Here is a brief introduction to SBTC:

- [http://www.ieee-ras.org/technical/committees.html](http://www.ieee-ras.org/technical/committees.html)
- Smart Building special sessions in CASE 2013
Thank you!

Any questions?

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