Monitoring and control systems to mitigate energy use in residences

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21% of total US energy in 2004
  - Increased 16% in last 4 years

Structural shift: electrification (47% of primary energy in 1978 versus 54% in 2001)

Energy intensity (energy/ft²) roughly constant 1980-2000

House size increasing (1500 ft² in 1970 -> 2,350 ft² in 2004 for avg. new home)
Structure of Household primary energy use

<table>
<thead>
<tr>
<th>Energy use per household (MJ)</th>
<th>Energy Share</th>
<th>Expenditures per household ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space heating</td>
<td>53,000</td>
<td>29%</td>
</tr>
<tr>
<td>AC</td>
<td>19,000</td>
<td>10%</td>
</tr>
<tr>
<td>Water heating</td>
<td>23,000</td>
<td>13%</td>
</tr>
<tr>
<td>Appliances</td>
<td>88,000</td>
<td>48%</td>
</tr>
<tr>
<td>Total</td>
<td>183,000</td>
<td></td>
</tr>
</tbody>
</table>

Source: US DOE RECS Survey 2000
Technical versus Service efficiency

- Technical efficiency: measured at product/process level (e.g. mpg of automobile, SEER rating of air conditioner)
- Service efficiency: measures delivery of energy service (mobility, climate control) – larger scope including additional external conditions and behavioral aspects.
Monitoring and control systems often play a important role in improving service efficiency. Deliver energy (or water) only when and where needed. Provide feedback to inform efficiency decisions. Widely adopted in manufacturing and business operations.
Monitoring and Control Technologies in Buildings

Elements:
- Smart meters
- Networked thermostats, (X10, ZWave, WiFi)
- Controllable vents (for zone heating)
- Sensors (temperature, light, energy)
- Software systems and graphical interfaces

System examples:
- Remote control of HVAC via cellphone,
- Time pricing, peak shifting, remote meter reading for utilities
- Information system to provide feedback to residents on home energy use
Control:
- Mainstay is programmable thermostats: 27% adoption in 2001. Most programmable thermostats are not actually used.
- Central HVAC (in US, Japan, for instance, is all room-by-room)

Monitoring:
- Monthly billing statement (or sneaker-pencil net)
Status of monitoring and control technology adoption in residences

Huge technology gap between:

On the desk

On the wall
Is there potential to instigate changes in monitoring/control/behavior so as to substantially reduce home energy use?

Working hypothesis: there could purely economic rationale for households to adopt, but suppressed by “behavioral” market failures
Earth systems engineering & management (ESEM)

1. Characteristics and dynamics of systems as systems
2. Identify real world system linkages
3. Evaluate, then implement
4. Minimum needed intervention
5. Not only science/technology, important political/human dimensions
6. Recognize difference between technical engineering and social engineering
Some important aspects of the system:

- Technical engineering – pilot/feasibility done for variety of monitoring/control systems (mostly past R&D stage).
- Consumer – what are cost/benefits of different systems? willingness to pay, pedagogy requirements
- Private sector – utility pilot projects and programs (e.g. peak shifting), IT manufacturers – firm structure, economies of scale should be analyzed
First step: Characterizing “Unneeded” energy use

A. Heating/cooling of unoccupied houses
B. Heating/cooling of unoccupied rooms
C. Overheating/cooling due to temperature variations
D. Leakage/standby power
E. Appliance choice
A. Heating/cooling of unoccupied houses

- Based on DOE Residential Energy Consumption Survey (RECS), only 11% of people turn off heating when not at home.
- No observable difference in thermostat settings.
- 54% of residents responded that noone is home on a typical workday.
- Using the above, estimate that $100 \times 10^{10}$ MJ are used heating unoccupied homes, 5.2% of primary residential energy use.
- Similarly, air conditioning empty homes accounts for 1.8% of household energy use.
B. Heating/cooling of unoccupied rooms

- According to RECS, on average 46% of home area is bedrooms, assume that heating the remaining 54% for 8 hours every night can be counted as unneeded energy.

- Allocating proportional to area and time used, total wasted energy heating non-bedroom spaces is $140 \times 10^{10}$ MJ, or 5.2% of total primary energy.

- Using similar assumptions, including air conditioning total increases to 7% of primary energy.
Many appliances, such as TVs, VCRs and stereo equipment draw electricity even when turned off: leakage/standby power.

Researchers at the Lawrence Berkeley National Laboratory estimate that 44.7 TWh of electricity is lost as leakage current. Their definition of leakage includes devices turned off and in standby mode. This corresponds to $49 \times 10^{10}$ MJ, or 2.5% of primary household energy consumption.
E. Appliance choice

- Qualitatively distinct from previous categories: considers hardware itself, rather than how used.
- Wide variation of efficiencies for different models of appliances
- Monitoring systems could make consumers more aware of costs to operate per appliance, thus affect decision.
- Unneeded energy use is gap between current stock and efficient. Different ways to think about defining efficient stock.
- Future work, for the time being borrow figure from Koomey et. Al (1998) on efficiency standards, suggesting 15% gap.
### Summary of Preliminary evaluation

<table>
<thead>
<tr>
<th>Category</th>
<th>Unneeded energy use ($10^{10}$ MJ)</th>
<th>Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Heating/cooling of unoccupied houses</td>
<td>136</td>
<td>7%</td>
</tr>
<tr>
<td>B. Heating/cooling of unoccupied rooms</td>
<td>260</td>
<td>13%</td>
</tr>
<tr>
<td>C. Overheating/cooling due to temperature variations</td>
<td>65</td>
<td>3%</td>
</tr>
<tr>
<td>D. Leakage/standby power</td>
<td>49</td>
<td>2.5%</td>
</tr>
<tr>
<td>E. Appliance choice</td>
<td>300</td>
<td>15%</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>~40%</td>
</tr>
</tbody>
</table>
At this stage

- First cut estimate suggests ~40% of energy use in residences (~8% of US total) is “unneeded”
- Average per household expenditures for this energy is $620
- Monitoring and control systems could play a role in reducing a significant portion.
Water – Ctrl F Ctrl H energy and water in previous slides, much of the discussion applies

Water & Energy interlinkages – hot water: monitoring system could stimulate purchase of water/energy efficient clothes/dish washers

West (AZ)
- Managing AC versus heating becomes much more important
- Residential water scarcer (in principle)
Future

- Refine estimates, incorporate into economic cost-benefit analyses (economic, time, convenience) for different monitoring and control system options
- Scale-up analyses of hardware/software
- Explore consumer perceptions of economic/time/convenience and bridging of gaps
- Examine business case
Thanks for your attention!

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