Why study thermostats?
Thermostat design
Thermal comfort

At what temperatures are you comfortable?
Usability

Figure 25: Model for system acceptability (Nielsen, 1993).
Usability test

- Usability test of 5 thermostats
- 31 subjects
- 7 tasks

Table 4. Description of tasks.

<table>
<thead>
<tr>
<th>Tasks</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set heat</td>
<td>Set the thermostat to HEAT mode. (Setting was OFF at the start of the task).</td>
</tr>
<tr>
<td>Set time and day*#</td>
<td>Set the thermostat to the current day and time. (The time settings were programmed to Monday at 12:00 am for the start of the task.)</td>
</tr>
<tr>
<td>Current setting</td>
<td>Identify and read aloud the temperature that the thermostat was set to reach at that current time.</td>
</tr>
<tr>
<td>Future setting</td>
<td>Identify and read aloud the temperature that the thermostat was set to reach at a future period (Thursday at 9 pm). (No need to change any settings).</td>
</tr>
<tr>
<td>Vacation/away/hold</td>
<td>Set the thermostat to maintain the same temperature during a five-day period when one is away.</td>
</tr>
</tbody>
</table>

Note: *not performed on the WEB because time settings could not be modified. #setting the day not performed for the TCH because this required a code from the manual.
Usability

Time on task, success rate, and ideal path length for Task 1: Set to heat.
# Heuristic evaluation

<table>
<thead>
<tr>
<th>Heuristic</th>
<th>Honeywell</th>
<th>Trane</th>
<th>Emerson Sensi</th>
<th>Johnson Controls</th>
<th>Carrier</th>
<th>Google Nest</th>
<th>Pelican</th>
<th>Ecobee</th>
<th>NT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visibility of available options (home)</td>
<td>Only current temp + heat mode + menu</td>
<td>Typical + hold</td>
<td>Words + icons</td>
<td>Can’t turn off from Home screen</td>
<td>Only temp/fan icons, home icon</td>
<td>Can’t easily turn off</td>
<td>Typical words</td>
<td>Icons</td>
<td>Text (small), Icon</td>
</tr>
<tr>
<td>A wide and shallow decision tree</td>
<td>Not easy to find “set time/day”</td>
<td>Many choices</td>
<td>Two deep</td>
<td>Too deep</td>
<td>Must scroll thru 15 icons (6 at a time)</td>
<td>Need to scroll through many choices</td>
<td>Only Tasks 1 and 3 accomplished with wall interface</td>
<td>Menu screen</td>
<td>Poor for setting time/day</td>
</tr>
<tr>
<td>Navigation cues</td>
<td>Done, Back, but lots of scrolling required</td>
<td>Back arrow visible</td>
<td>Full down menu, Scroll dots, right/left arrow swipe</td>
<td>Home icon with two dots left and right—very clear</td>
<td>Linear scroll through choices, easy to get lost</td>
<td>Menu and arrows</td>
<td>Check marks, back arrow, up/down</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clear hierarchy of display</td>
<td>Large display of current temp</td>
<td>Large display of current temp</td>
<td>Large display of current temp</td>
<td>Large display of setpoint but not current temp</td>
<td>Large display of current temp</td>
<td>Large display of current temp</td>
<td>Large display of current temp</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consistency and standards</td>
<td>Terms, icons, orange/blue colors</td>
<td>Terms, icons, orange/blue colors</td>
<td>Terms, icons, orange/blue colors</td>
<td>Ok, Terms, some icons</td>
<td>Icons, colors, means of setting day/time</td>
<td>Terms, icons, orange/blue colors</td>
<td>Up/down arrows</td>
<td>Terms, icons, colors; color of icon very subtle</td>
<td>Icons not standard but intuitive; requires toggling</td>
</tr>
<tr>
<td>Natural mappings</td>
<td>Menu icon, “heating to” text; hold until text</td>
<td>Touch and hold is not easy to use</td>
<td>Not easy to change temperature in auto mode</td>
<td>Two settings have same icon</td>
<td>Touch scroll not easy to use</td>
<td>Target temp shows only at beginning of period</td>
<td>Clean menu navigation</td>
<td>Unclear when icon is a touch button or reflecting state</td>
<td></td>
</tr>
<tr>
<td>Error prevention and recovery</td>
<td>No Save or Confirm; information icon</td>
<td>Text explanation of choices; small arrow buttons</td>
<td>Ok. Cancel, Save</td>
<td>Several ways to access some features</td>
<td>Done</td>
<td>Done</td>
<td>Text explanation</td>
<td>Flashing in set mode</td>
<td></td>
</tr>
<tr>
<td>Feedback from controls</td>
<td>Touch scroll difficult to control</td>
<td>Ok</td>
<td>Ok</td>
<td>Not easy to swipe and scroll</td>
<td>Audible chirp when making selection; sometimes push buttons nonresponsive</td>
<td>Turn knob to scroll and push knob to select</td>
<td>Touchscreen, menu bar, arrow selection</td>
<td>No color feedback</td>
<td></td>
</tr>
</tbody>
</table>


Thermostat takeaways

• Can help save energy, reduce peak loads, keep the lights on
  • both houses and small commercial buildings
• Thermal comfort varies (with season, outdoor temp, activities)
• Usability is important and we have ways of evaluating this
• Good control design includes the human—more satisfied people
  • Provide information that enables insight and provide a means influence
• One size does not fit all
• Calibrate your sensors
Oakland EcoBlock: A Zero Net Energy Neighborhood Retrofit

California Energy Commission Advanced Energy Community project

- Phase I (2015 – 2018), $1.5M + donors
- Phase II (2019-2024), $5M + donors + cost share

Unique features:
Retrofits of older housing stock, combining energy efficiency with electrification, water efficiency, EV car share, and (we hope) a solar microgrid

Community financing, ownership and management via nonprofit Association with fees
Oakland EcoBlock: affordable, clean, resilient energy

- Energy efficiency + electrification retrofits on older urban housing stock
- Rooftop solar and central battery for a microgrid
- Stormwater mitigation and water efficiency
- Curbside EV charger and EV car share
- Innovative legal & financial structures for community ownership & governance
- Provide templates and best practices for a path to scale

Multi-customer microgrid retrofit with urban SF/MF
Retrofitting homes typically happens one at a time....
We think EcoBlock can reduce the time, effort, and materials for retrofitting urban neighborhoods.
We are exploring how EcoBlock leverages Economies of Scale to:

- Reduce capacity for solar/storage by sharing
- Reduce energy transmission losses
- Save construction time
- Fewer vehicles through car share
- Decommission natural gas lines
- Rapidly increase adopters through neighbor/peer effect
Economies of Scale: Neighbor or Peer Effect

• Solar adoption is contagious in neighborhoods regardless of income.

• These new technologies—heat pumps, induction stoves—are hard to understand.

• Trusted source of information: Neighbors talk to each other about new technologies and can reduce the burden.

• Potentially reduces soft costs of acquiring customers (home performance, electrification, solar).
What is a Microgrid?

An islandable distribution circuit section of the utility electric grid
Energy Microgrid Design

- New Transformer/Recloser
- Pole-Mounted Transformer
- Battery Energy Storage System
- New curbside EV charger
- Homes with Rooftop PV System
- Direction of Supply
- 3-Phase Distributor
- 1-Phase Distributor
- Primary Distribution

Change from single phase to 3 phase (due to 3-phase FTM BESS)
Community Microgrid: Normal operation

- **PG&E overhead distribution**
- **Switchgear**
- **Solar PV & battery**
- **Inverter**
- **Load panel**
- **EV & Curbside EV charger**
- **House with EV & EV charger**
- **Central battery & grid-forming inverter**
- **Solar PV**
- **Electric Vehicle (EV) & Curbside EV charger**
- **125 kW/250 kWh LiFePo**
- **Battery charges and discharges to grid based on wholesale market**

**Association collectively owns ~100 kW solar PV, central Battery, EV charger and shared EV**

**Non-participating house**

**Apartments**
Islanded operation

Grid-forming inverter and battery form a microgrid

Not all houses need to join
Energy Home-Based Improvements

- **Improved air quality**
  - Remove natural gas service by replacing cooking and heating/water heating appliances
  - Exhaust fans

- **Improved comfort**
  - Air sealing & insulation
  - Heat pump space conditioning (heat/cool)
Home Energy Control

- Smart circuit breakers or modules
  - Whole building energy monitoring
  - Solar production
  - Monitor & control major loads
    - Heat pump space conditioning
    - Heat pump water heating
    - Clothes dryers
    - EV charger
- Dynamic critical load selection for islanding events
- Management of daily time-of-use loads
- Microgrid controller as supervisory control
Microgrid Control

- Behind the Meter battery
- Front of Meter
- Community battery
- Unit
- Meter
- PG&E distribution network
- Microgrid Control
- HEILA EDGE
- Solar panels
- Batteries
Mobility

- **Curbside EV charger**: one charger with option to add more in the future
- **EV car share** for block participants
- Potential for other e-mobility in the future
- Majority responded they would get rid of a second car if they had access to car share
Water

- Laundry-to-landscape workshop (really helps strengthen community!)
- Block-level stormwater mitigation
- Rainwater collection
- Sidewalk landscaping improvements & tree planting
The Oakland EcoBlock prototype

- Provides energy retrofits to make houses more comfortable
- Lets the community own their source of clean energy
- Keeps the lights on during the next power outage
- Improves local and indoor air quality
- Provides access to an Electric Vehicle car share and local EV charging
- Reduces water costs
- Reduces stormwater runoff

Image credit: People Power Solar Collective
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