Controls and User Interface

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Thermostatic to ‘Thermodynamic’ Control

- Electromechanical Thermostat
- Digital Programmable Thermostat
- Demand Response House
- Virtual DR Thermostat
- Learning Mobile DR Thermostat
**Demand-response system**

- **Power**
- **Existing Meter**
- **Indoor Sensors**
- **Outdoor Sensors**
- **DR Thermostat**
- **User Interface**
- **Panel**

**(Radio link to:) Electrical Utility**

Price schedules in, Electric usage out

- **Wattmeters, Switches, Action-suggesting alerts and displays**
- **Sun control blinds, Lighting dimmers**
- **Appliances**
- **Refrigerator**

- **Heating System**
- **Air Conditioner**
- **Smart Ventilator**
- **Hot Water Heater**
- **Pool Pump**
Occupant interface concepts
Interface and Controls

Challenges:

• Interface that’s easy to understand and intuitive to use—covering both comfort and cost.

• Algorithms that optimize energy savings and comfort as energy prices vary.

• Ability to manage environmental energy usage to a fixed user-selected monthly bill.

• Control strategies that can account for low network quality or complete network failure.
Thermostat: Simple to Install, Simple to Use

- As delivered, the thermostat must work adequately in any size or shape of house
- Installers should be responsible only for physical installation
- The thermostat must be able to set all of its internal parameters
- The users (occupants) express feelings (too cold) and preferences (too expensive) only
- The thermostat learns from the occupants to respond to environmental and price changes
Learning about the house

- As delivered, the thermostat must work adequately in any size or shape of house

- Even if the occupants never touch the thermostat, it will learn about house dynamics (how long it takes for changes to take effect), zonal differences (many sensors in the house even if there is only one actuation zone), etc.

- It will use this knowledge for appropriate setbacks, preconditioning, pre-cooling to reduce load in a peak (DR) period, matching conditions to desired cost, ...

- Diagnostics of sensors and actuators based on learned "normal" behavior
Learning about the occupants

- As delivered, the behavior should work for a significant portion of the population
- Even though it must be VERY easy to use, many users will not have to do anything
- Context-based interface - the user only sees a few items at a time (think ATM)
- Provide linguistic input wherever possible ("I'm very cold now") - temperatures can be used if desired, but not necessary
- Simple timelines for schedule changes
- Cost targets in accessible terms (monthly bill)
- Explanations for actions ("it's probably warmer than you'd like but it would be more expensive to make it cooler")
DR Thermostat (Controller) Design

- Built hierarchically for maximum flexibility
- Built from portable code (Java) so that the same controller can be used in:
  - Pure simulation on a workstation to develop concepts, study variability across very wide variety of houses, optimize algorithms, test abnormal operation (malfunctions)
  - Model house (see our demo!) to prove concepts in a near-real-world environment
  - Real house
Demand Response Thermostat Control Levels

- Realtime pricing from Utility via meter
- Weather forecast (WWW)
- Operator
- Energy cost vs. thermal comfort and power need

Thermal comfort vs. price
- Heat or cool
- Use economizer fan or ac
- On/off
- On/off high/med/low
- Sensor/Actuator
- Mote interface (radio to hub)
- Heat control (wired)
- AC control (wired)
- Fan/economizer control (wired)
- Wireless motes
- Scavenged power
- Tiny OS

Power consumption vs. price
- Operator
- Power to which appliance
- On/off
- On/off
- On/off
- Operator actuated
- Wireless power sensor
- Wireless relay
- Temp mote in Ref
- Window/blinds
- Pool equipment
- Refrigerator
- Stove, Washer, Dryer, Dishwasher
- Blow dryer

- Operator presents typical setback Temperature setpoints
- Operator presents Demand Response temperature setpoints
- Amount of temperature discomfort acceptable based on price
- Operator maintains manual override

- Auto control of water heater, refrigerator, pool equipment depending on price
- Send notice to motes on stove, washer, dryer, dishwasher (current price and upcoming price)

- Typical energy saving setback Temperature setpoints
- Preheat or precool based on advance notice of price increase
- Expert system optimizes cooling or heating (temp sensors, weather forecast)
- Manual override
- Shut off

- Auto control of appliances based on price
- Send notice to motes on appliance (current price and upcoming price)

- Operator presets typical setback Temperature setpoints
- Operator presets Demand Response temperature setpoints
- Amount of temperature discomfort acceptable based on price
- Operator maintains manual override
DR System Simulation and Control

Java code simulates:

- House thermal behavior
- DR control algorithms
- Wireless network communications
- Will actually control model and full-sized test houses via the wireless motes
Model House with Sensor/actuator Motes
Simulated House Using Two DR Control Strategies

Demand Response Thermostat: Price Setpoints

Demand Response Thermostat: Price Setpoints + Precooling, Insulated house
We have examined various versions of interface—the challenge is to balance energy cost and comfort.
Thermostat Prototyping

Working, interactive thermostat simulated on PC screen

Thermostat and signaling motes fabricated using rapid prototyping
Broader Context: Sensor Nets for Building Control

- **Thermal comfort**: Temperature, radiation, air velocity, humidity, preference
- **Occupancy**: Motion, sound, CO₂, schedule
- **Envelope**: Window position, blind position, air velocity
- **Lighting**: Illumination, glare
- **HVAC**: Temperature, humidity, pressure, air velocity
- **Energy and Power**: Voltage, current, power factor, fuel flow, price

New integrated building control system
Expanded user interface for input, data output, advice

- **Provide information**
- **Suggest action**
  - Informing occupants;
  - Manual actuation
  - Automatic actuation

- **Adjust position**
- **Start/stop on/off**
- **Reset setpoint**

- **Shading**
- **Window**
- **Blinds**
- **AC**
- **Vent**
- **Refriger**
- **Lights**
- **Computer**
- **Office devices**