Thermostat/Control Group

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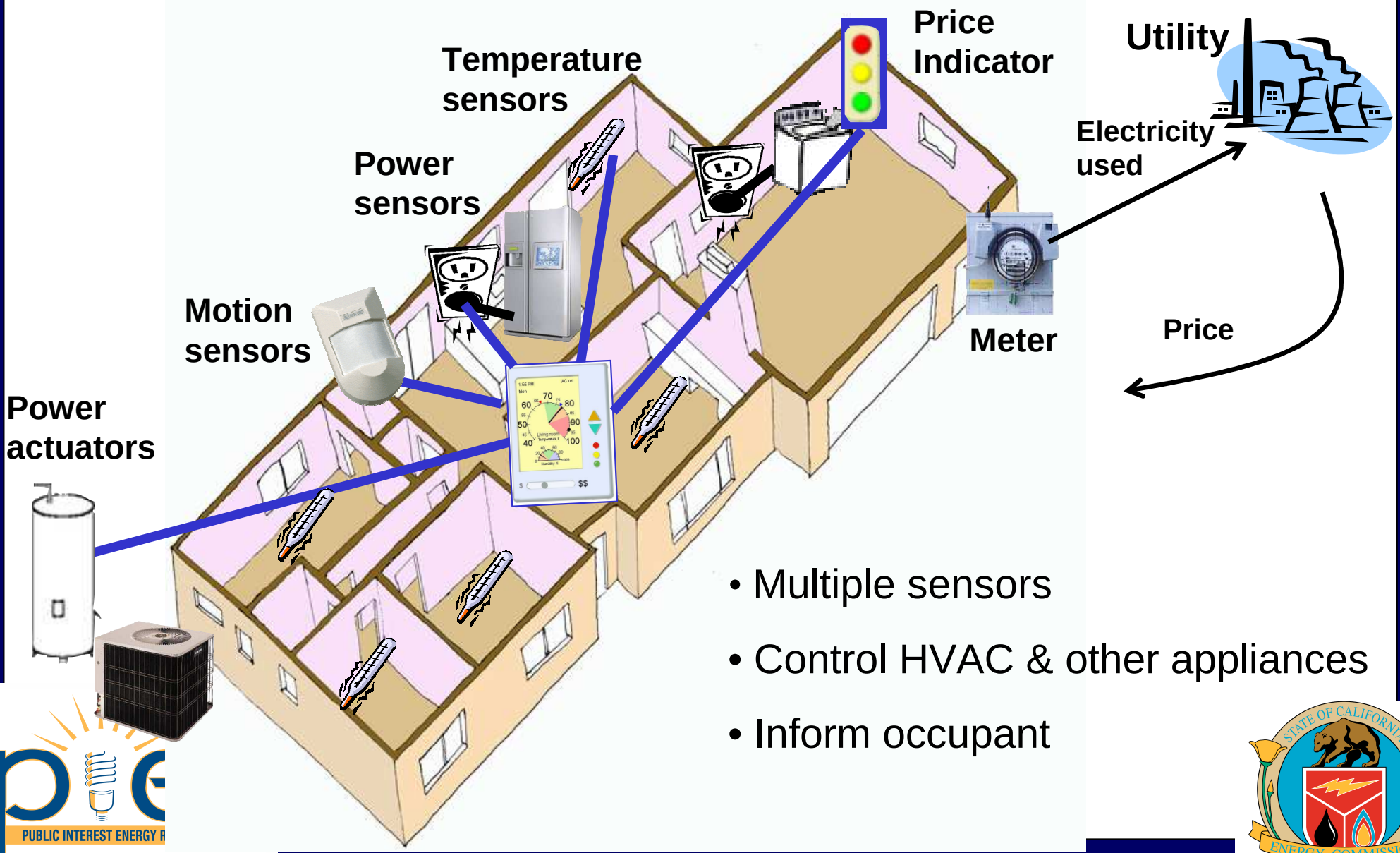
Thermostat/Control Group

- **Vision/Objective**
- **Review of previous years' work**
- **Summer 2007 Field Test of DREAM System**
  - Optimization
  - Learning
  - User Interface
  - Behavior
- **Post DRETD Work**
  - EcoFactor
  - User interface testing

Demand Response Electrical Appliance Manager (DREAM)



- Multiple sensors
- Control HVAC & other appliances
- Inform occupant

DREAM Goals

- Automatic control in response to price
- Work out of box (built-in defaults)
- Simple to use
- Occupant-influenced optimization
- Learn (occupant & house & climate) & adapt
- Educate & inform (energy use, price)

DREAM Control Code

Control of simulated, model, or real houses

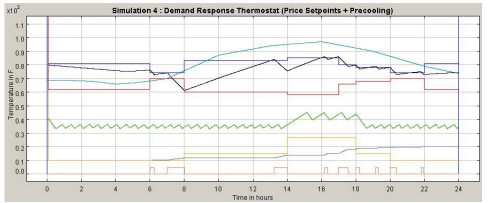
Controller

Java

Sensor/ Actuator Module

XML

Simulation



Java

RF

Physical Model

Interface

RF

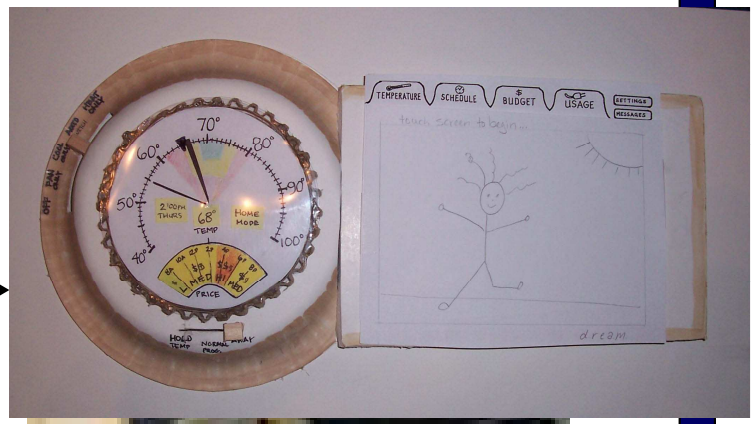
Real House

Review of Work

	'03-'04
Software Control User Interface Communication	Java control hierarchy Basic tstat fx Simple DR PDA motes/ computer
Hardware	Mica/Mica2dot, temperature sensor, outlet actuator
Simulation	Internal
Test	Plastic house

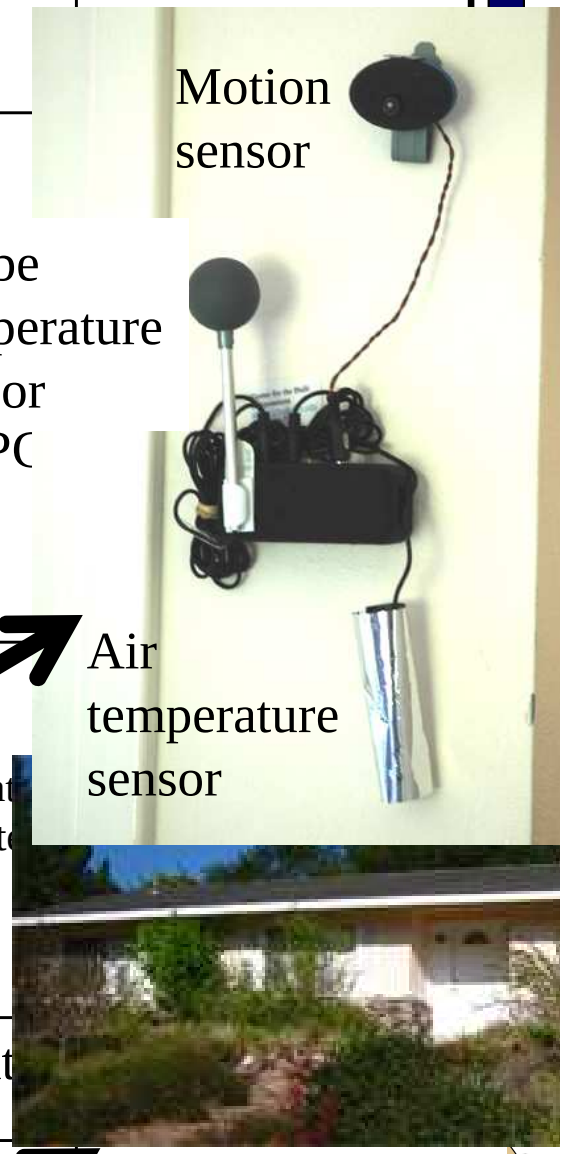
Review of Work

	'03-'04	'04-'05
Software Control User Interface Communication	Java control hierarchy Basic tstat fx Simple DR PDA motes/ computer	Reorganized controller Precooling Price Simulator Paper prototype init testing database
Hardware	Mica/Mica2dot, temperature sensor, outlet actuator	Mica2/ T-mote Sky RH, wind, solar, motion, whole house power, price indicator, HVAC relay
Simulation	Internal	MZEST built
Test	Plastic house	The Wall



Review of Work

	'03-'04	'04-'05	'05-'06
Software Control User Interface Communication	Java control hierarchy Basic tstat fx Simple DR PDA motes/ computer	Reorganized controller Precooling Price Simulator Paper prototype init testing database	Optimization and learni Touchscreen PC Web/server database
Hardware	Mica/Mica2dot, temperature, outlet actuator	Mica2/ T-mote Sky RH, wind, solar, motion, whole house power, price indicator, HVAC relay	T-mote Sky, power sensor at breaker/outlet, tstat tstat switch, repeate lower power communication betweeen motes
Simulation	Internal	MZEST built	MZESTvalidat
Test	Plastic house	The Wall	Test House



Review of Work

	'03-'04	'04-'05	'05-'06	'06-'07
Software Control User Interface Communication	Java control hierarchy Basic tstat fx Simple DR PDA motes/ computer	Reorganized controller Precooling Price Simulator Paper prototype init testing database	Optimization and learning Touchscreen PC Web/server database	Integrate optimization/ Learning/ Adaptive setpts Load graphics Revised Web Cx, db structure
Hardware	Mica/Mica2dot, temperature sensor, outlet actuator	Mica2/ T-mote Sky RH, wind, solar, motion, whole house power, price indicator, HVAC relay	T-mote Sky, power sensor at breaker/outlet, tstat-tstat switch, repeater, lower power communication betweeen motes	T-mote Sky, calibrated sensors, revised outdoor weather station (temp, RH, solar), occupant switch
Simulation	Internal	MZEST built	MZESTvalidate	MZEST refined
Test	Plastic house	The Wall	Test House	Lab, test houses

Testing the DREAM: Summer 2007

1500 sf, 1-story, built 1984

Two adults, usually at work during day

Setback thermostat

1700 sf, 2-story, built 1991

Adult male works from home, teenage female 50%

Programmable thermostat

Test Details

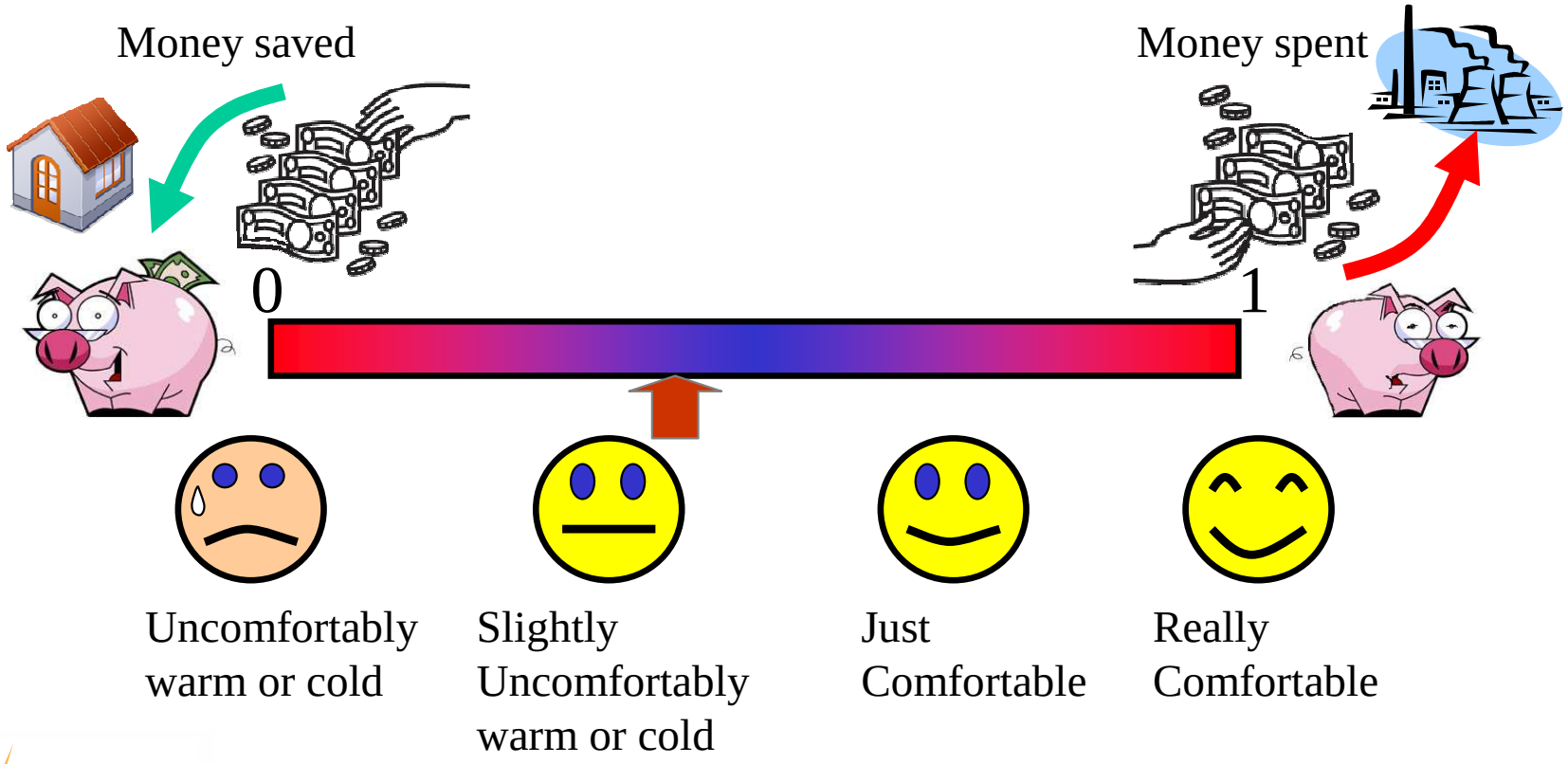
- **Replaced thermostat for six weeks**
- **13-14 motes per house**
  - Indoor & outdoor air temperature
  - Motion
  - Indoor & outdoor relative humidity
  - Solar radiation
  - Electrical current
    - Whole house, ac compressor & fan, clothes dryer, washer, dishwasher, kitchen, machine shop

Tests

- Cost/Comfort optimization index
- Learning occupancy patterns
- Internal model validation
- Learning house parameters
- Precooling
- Feedback on system/user interface

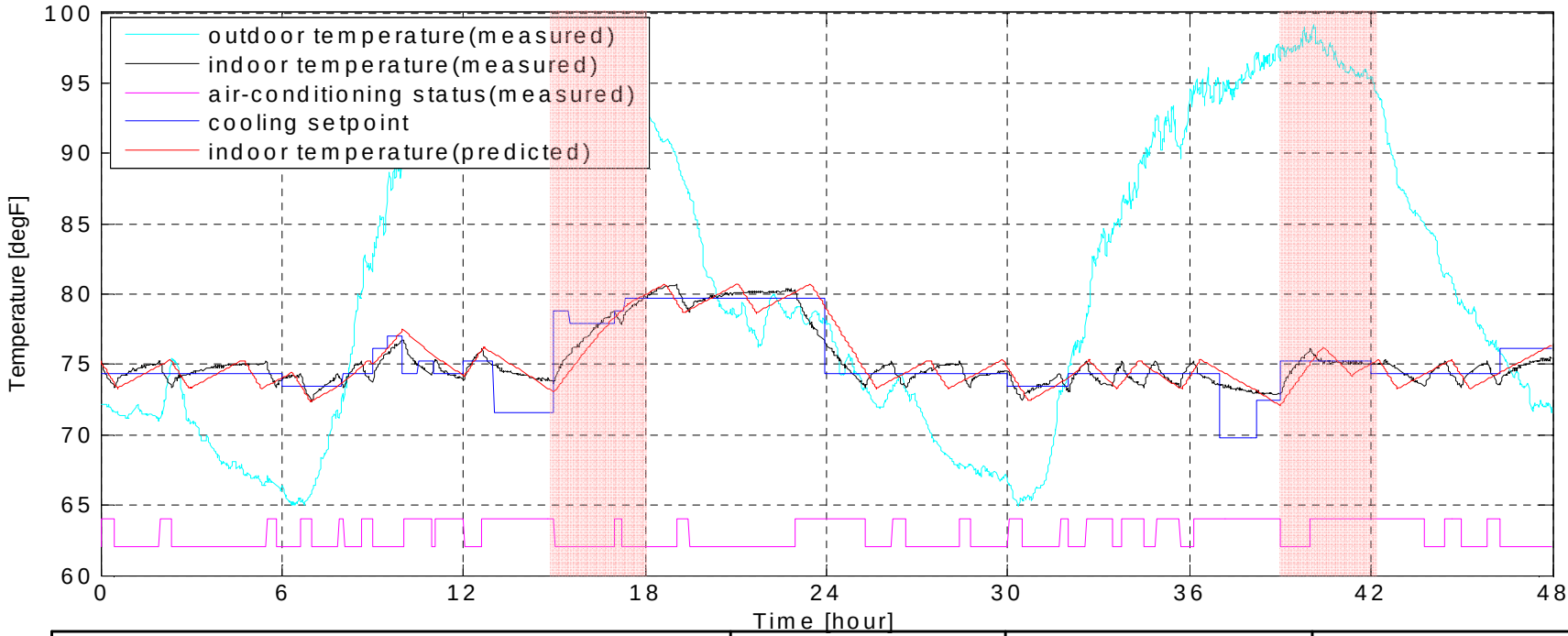
Cost/Comfort Index: User-Influenced Optimization

Cost of Energy vs. Thermal Comfort



Cost/Comfort Index: User-Influenced Optimization

Optimization generates reasonable setpoints based on price



Index	*Low Price*	*Med Price*	*High Price*
*Day 1: **0.3** (less comfort/cost)*	74F	76F	79F
*Day 2: **0.7** (more comfort/cost)*	74F	74F	75F

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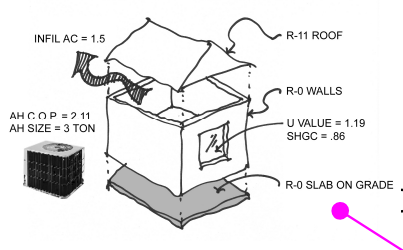
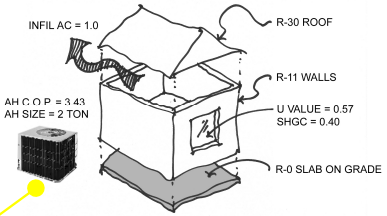
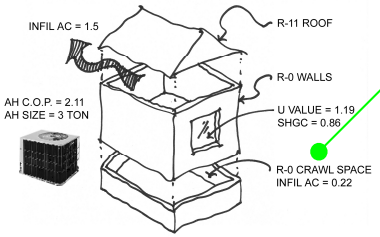
Default Internal House Model



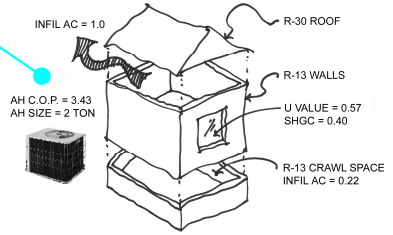
Pre1978 Slab on Grade



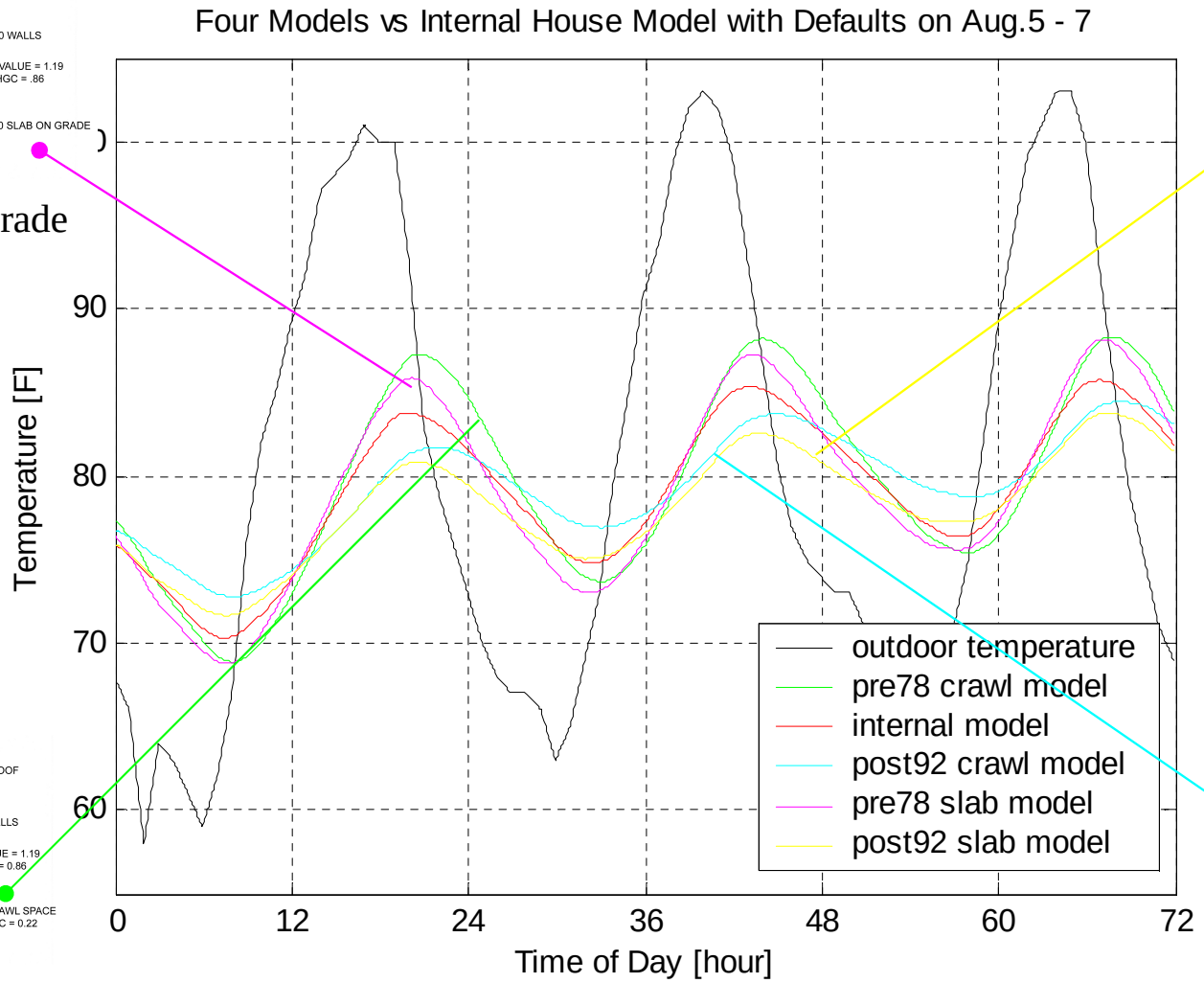
Post1992 Slab on Grade



Pre1978 Crawl Space



Post1992 Crawl Space



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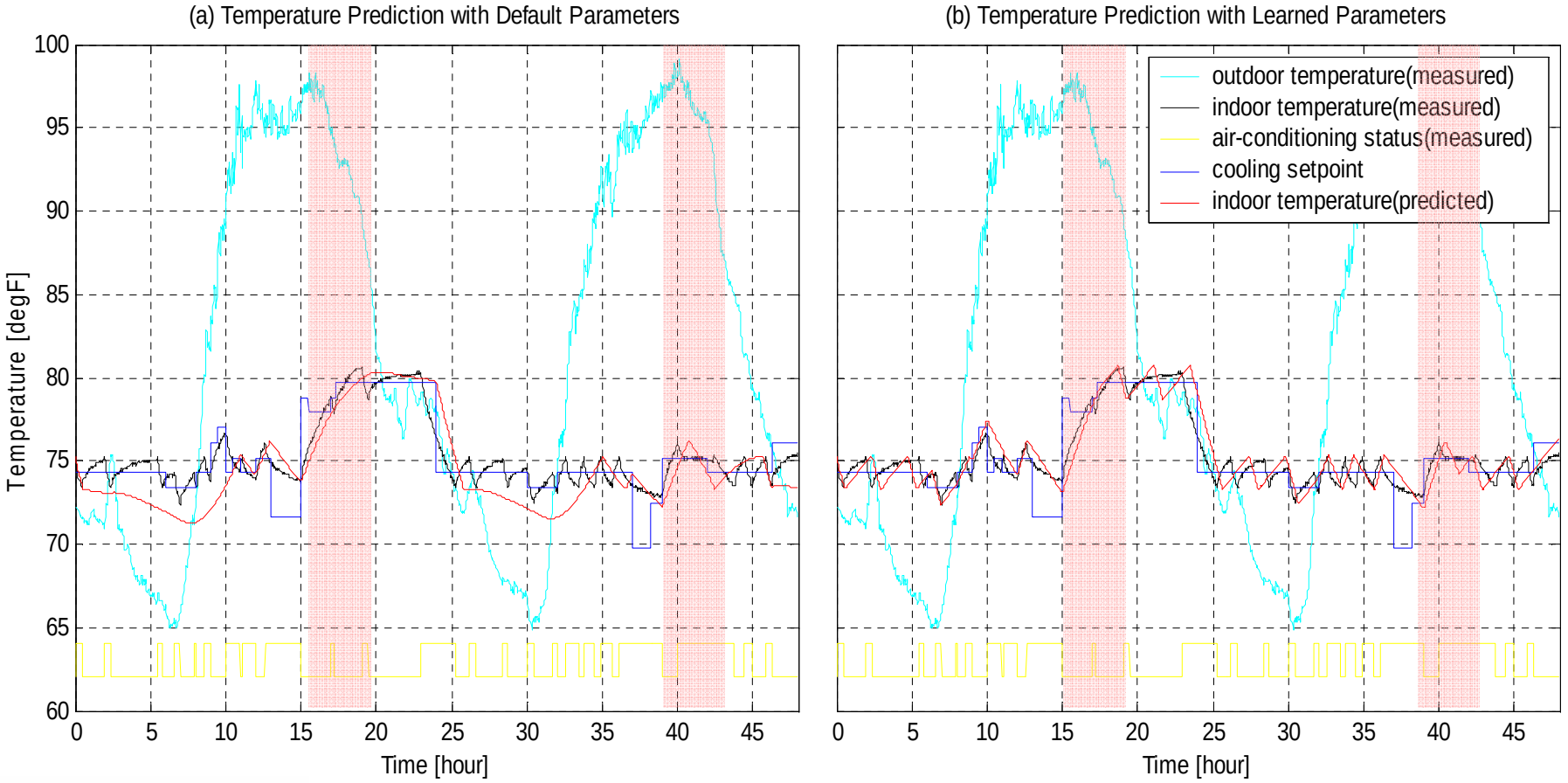
Default Internal House Model

- House learning algorithm is promising

Indoor Temperature Prediction with/without Parameter Learning



Antioch, California from Sep.1, 2007 – Sep.2, 2007

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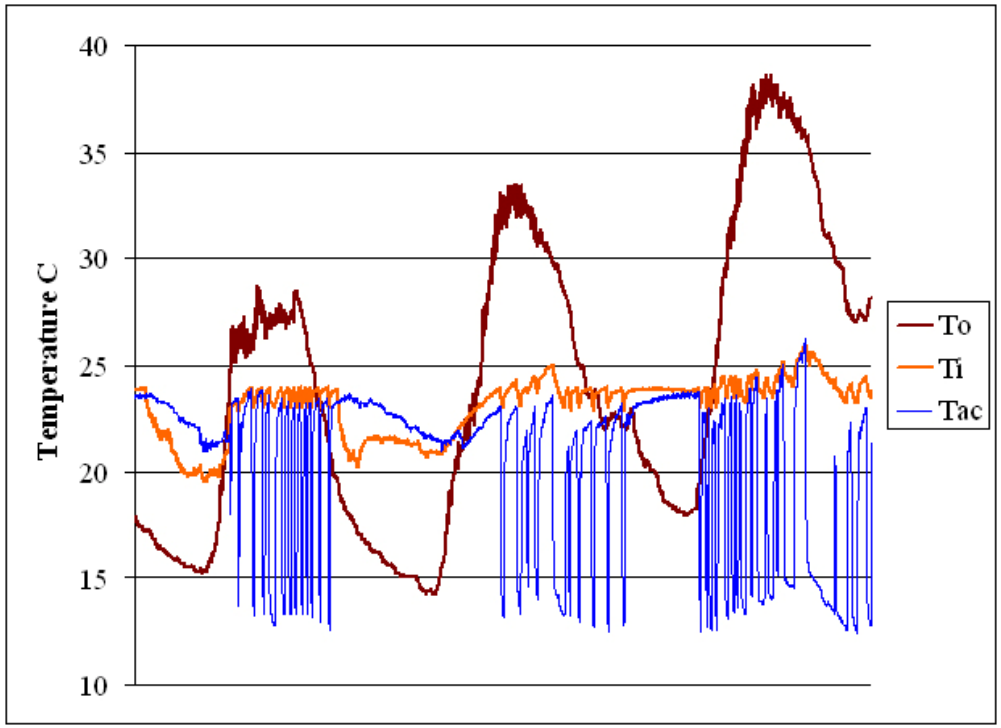
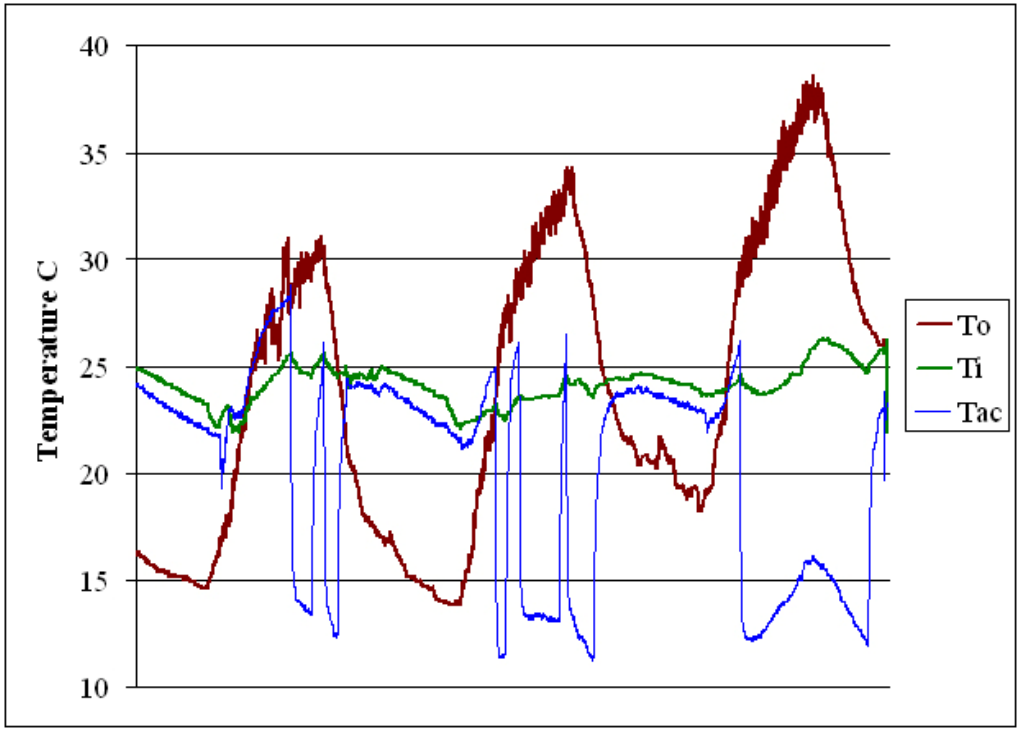
Precooling

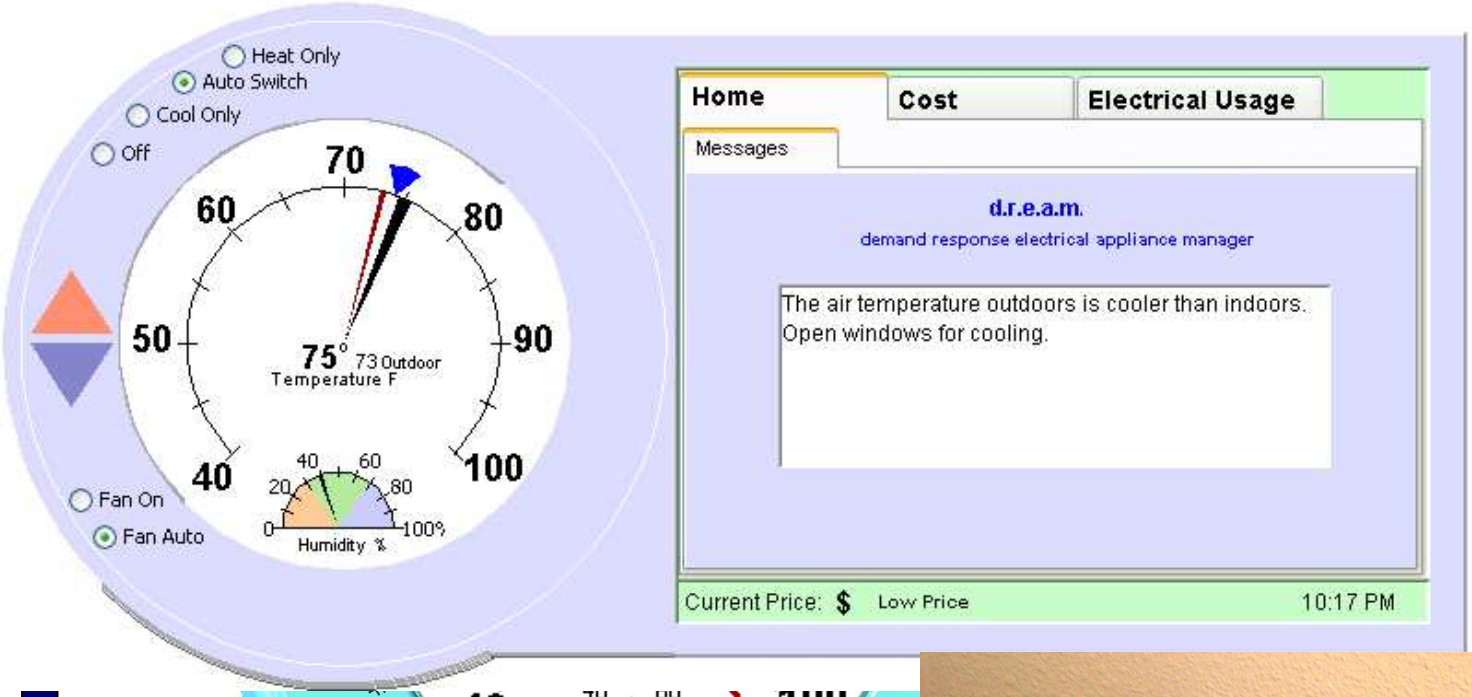


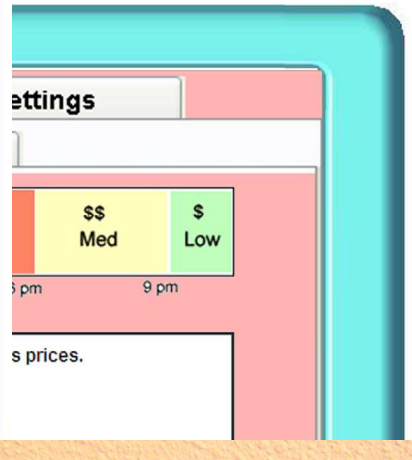
House 1

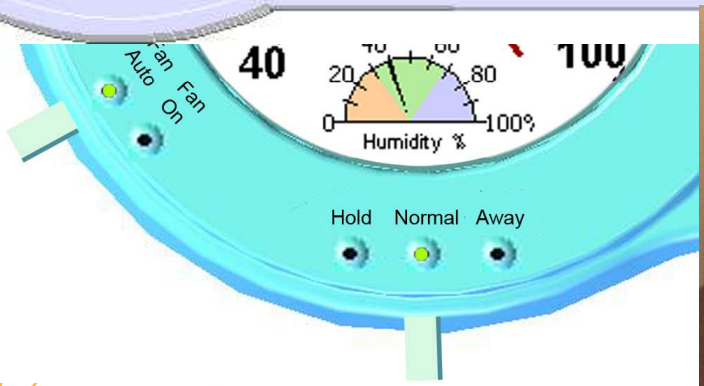


House 2

User Interface







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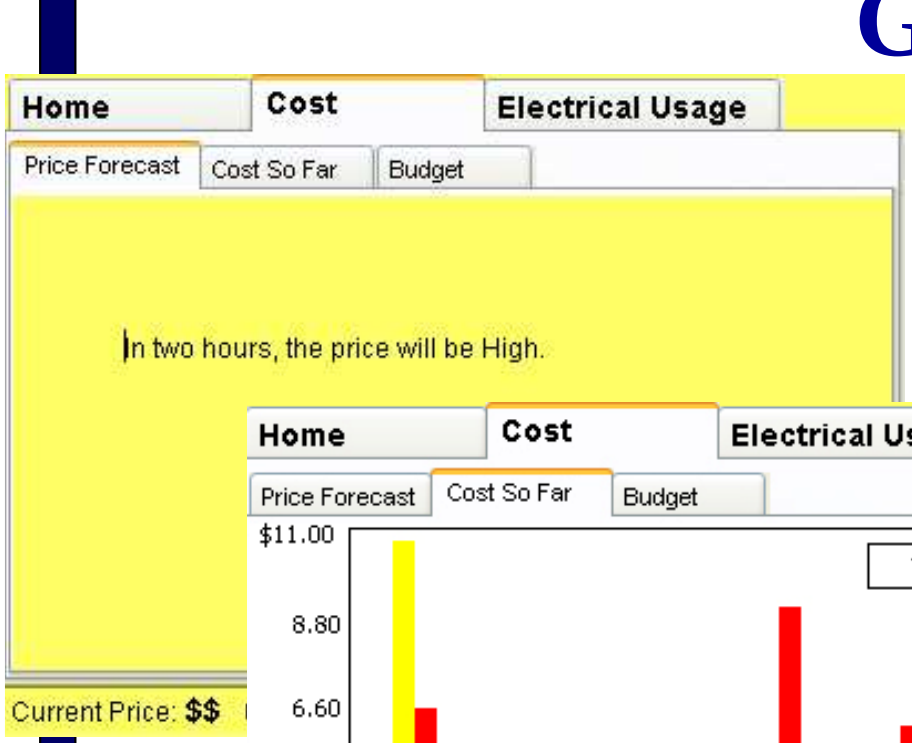
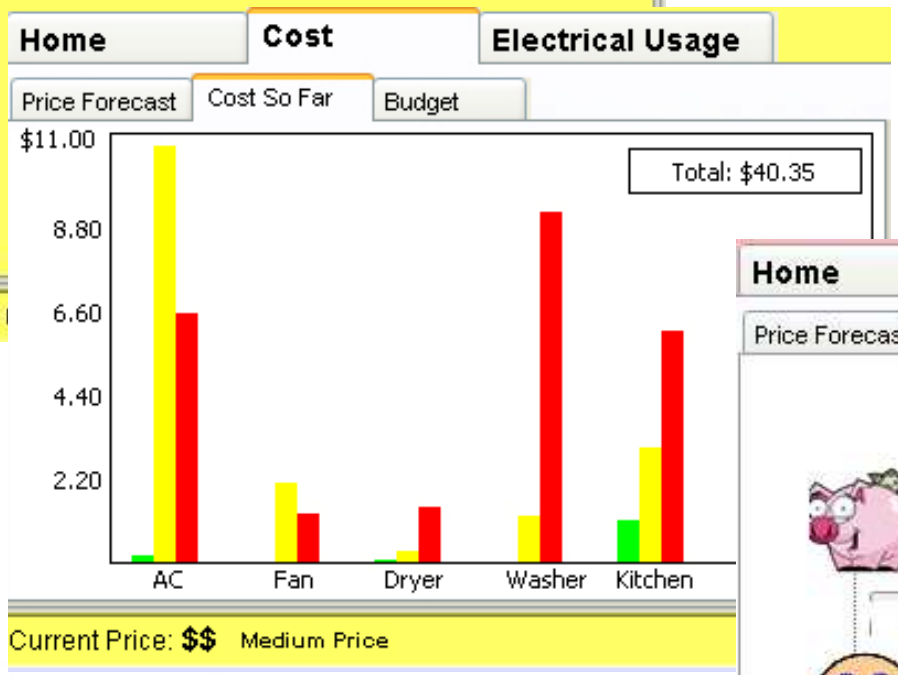
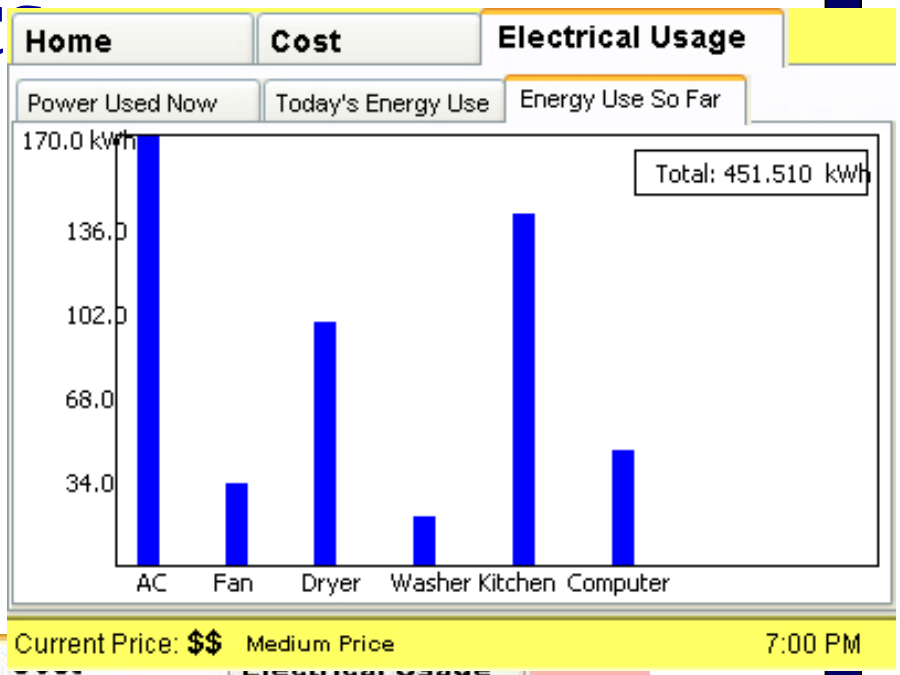
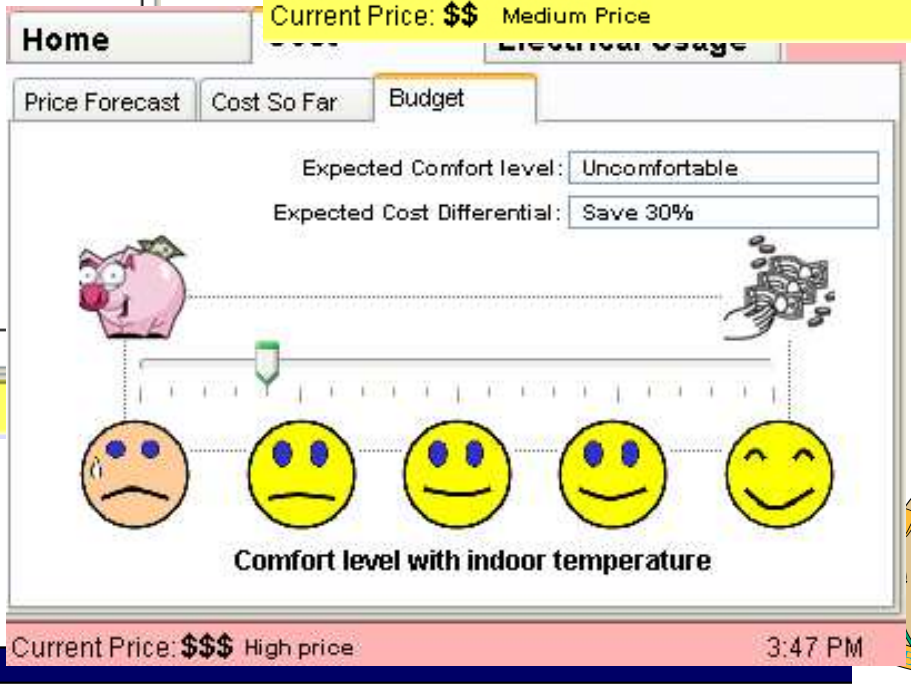
User Interface Cost and Energy Graphics









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Summary of Results

- Sensors useful for fault detection
- Optimization of cost/comfort effective
- Precooling only worked for house with adequately sized HVAC
- “Learning” about house worked
- Learning occupant’s schedule did not…

Behaviors that enable residential demand response?

- **Accommodate existing behavior that probably won't change**
  - Leaving windows open when AC is on
    - Air-to-air heat exchangers?
  - Variable schedules
    - Better/easier means of programming schedule?
    - Use occupancy sensors to control HVAC system?
  - Automatic 4F degree change: not with undersized HVAC units
    - "Learn" house parameters

- **Reinforce desired behaviors**
  - Opening windows at night, "precooling"
    - Provide outdoor temperature info
  - Personal control
    - Provide customer choice over how much/what appliance to reduce energy

Behaviors that enable residential demand response?

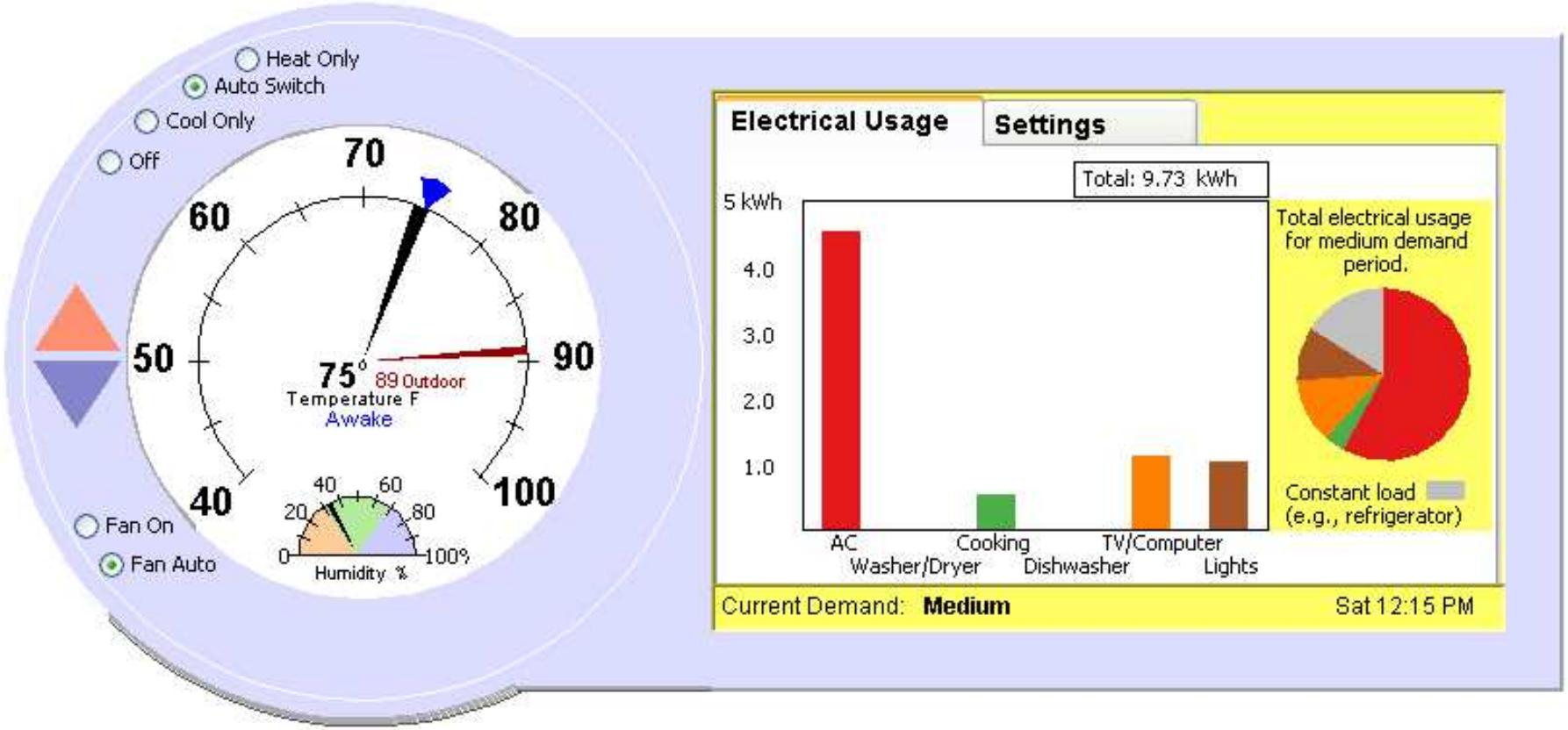
- **Create behavior change (if possible)**
  - Increase tolerance for higher temperatures on very hot days
    - Provide variable temperature setpoints?
  - Thermostat setback/setup when away or peak times
  - Decrease use of appliances during peak times
    - Education/increase awareness
    - Feedback
      - –Consumption, cost, carbon, compare to goal/neighbor
      - –Better and simpler graphics needed
      - –“Cost of comfort”: dollars per degree change

Work beyond DRETD

- **Spring 2008**
  - Work with EcoFactor on Dynamic Signature Learning and Control Strategies
  - Developed and tested new user interface graphics/DR questionnaire
- **Current**
  - Develop residential energy simulation model including people's behavior

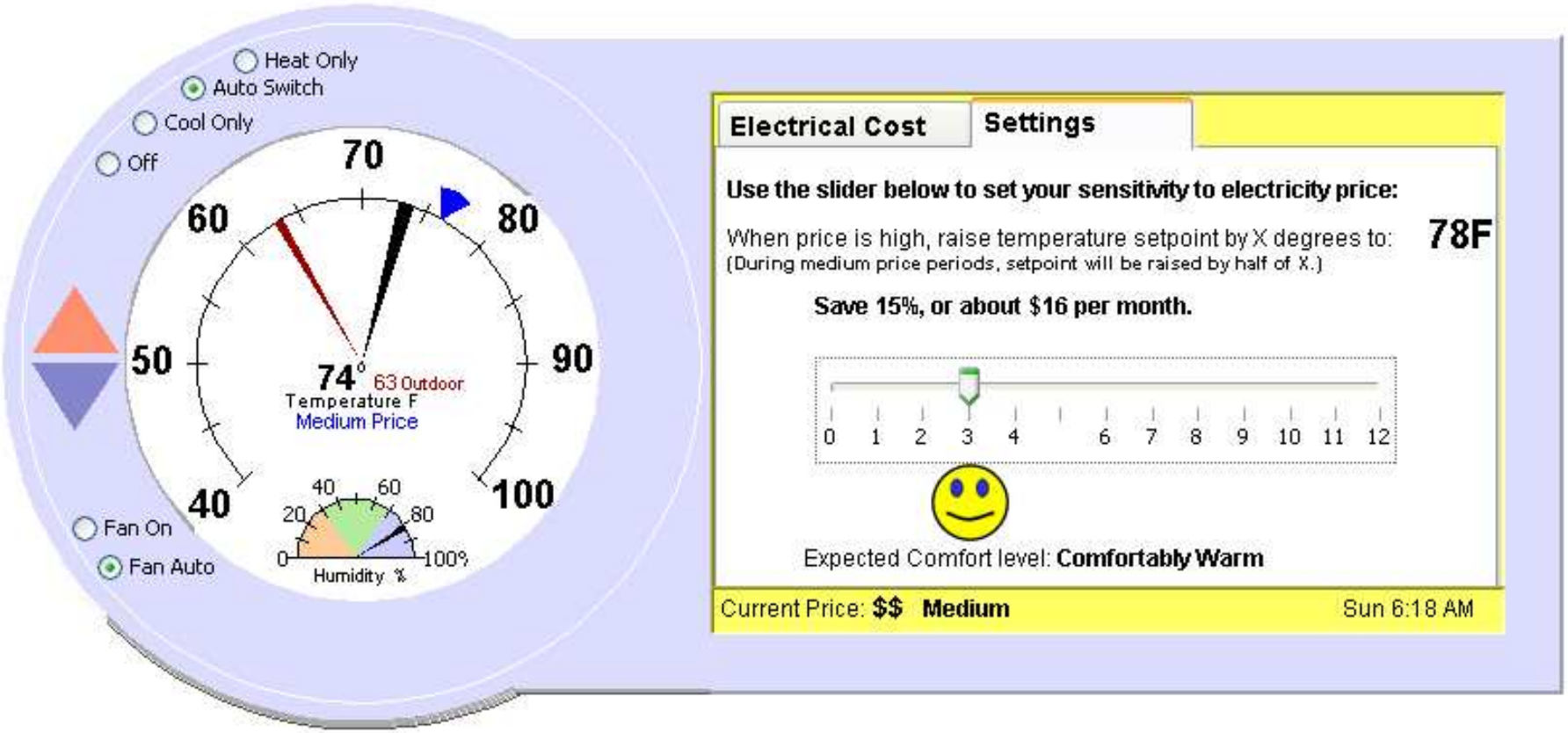
User Interface Testing

- Questionnaire
- Simulation: Energy or Price information
- Questionnaire



User Interface Testing

- **Asked to change temperature offset for high price/demand**



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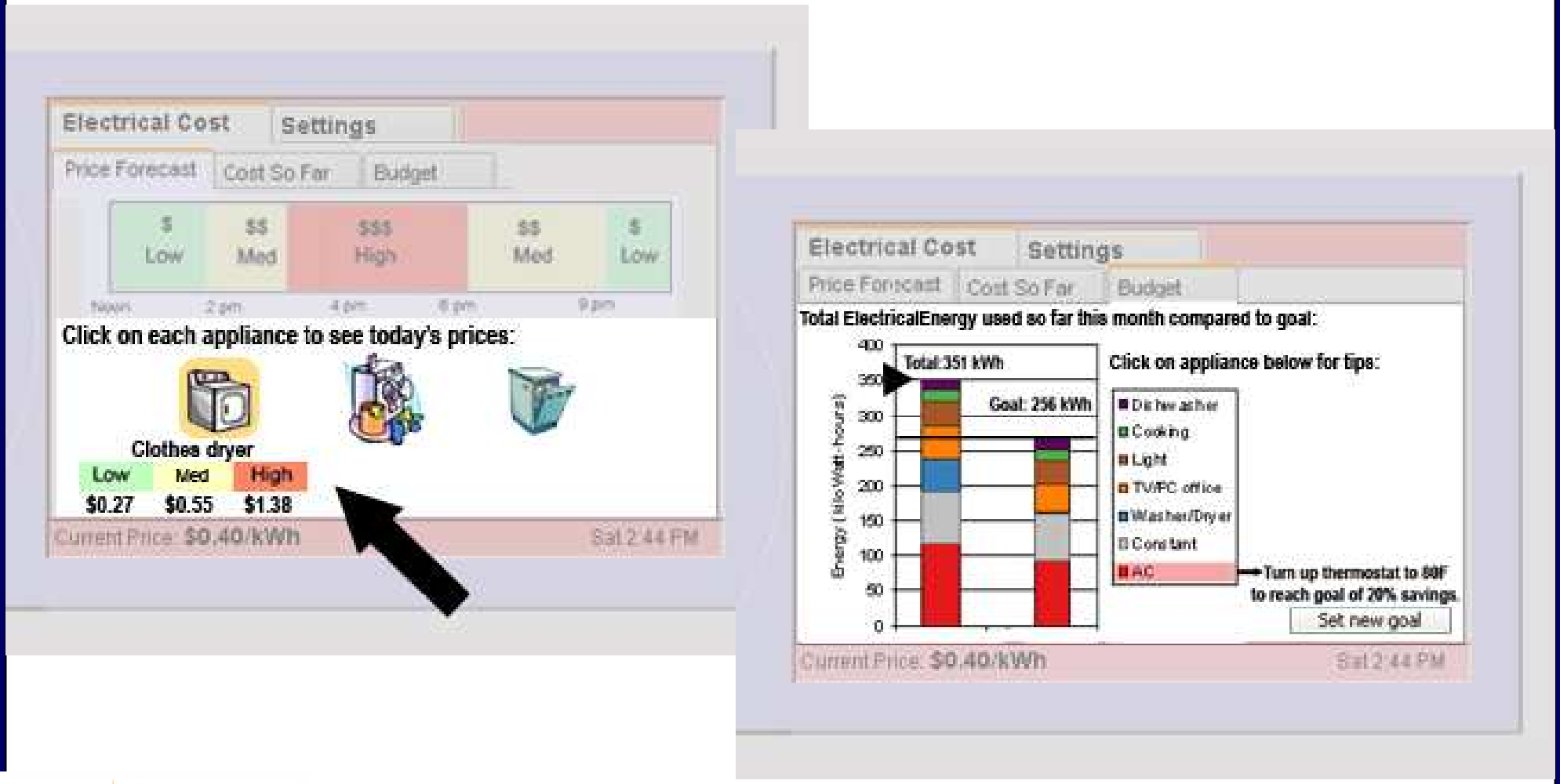
Feedback on graphics



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Questions?

- **therese.peffer@gmail.com**
- **Conference presentations:**
  - Chen et al and Peffer et al at 2008 ACEEE Summer Study for Energy Efficiency in Buildings
- **Reports to PIER**
  - http://www.cbe.berkeley.edu/research/pdf_files/DRThermostatPhase_II.pdf
  - http://www.cbe.berkeley.edu/research/pdf_files/DR-Phase1Report_April24-2006.pdf
- **Posters and presentations**
  - http://dr.berkeley.edu/dream/index.htm
- **Development of the user interface**
  - http://www2.sims.berkeley.edu/academics/courses/is213/s05/projects/thermostat/index.php