Hardware Development & Network Test

Real House Test Platform

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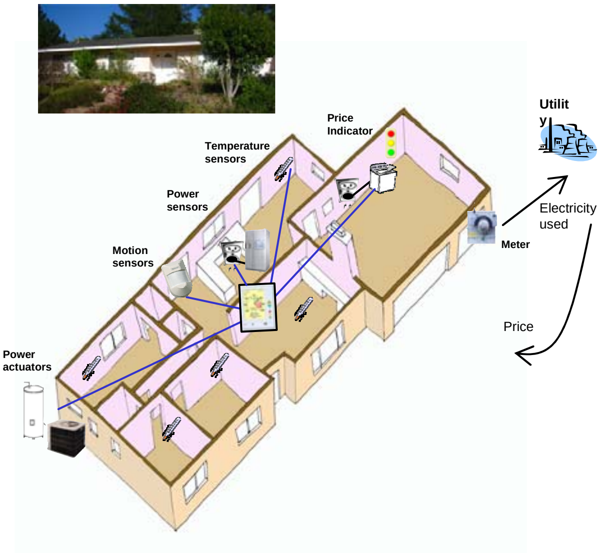
Vision

Over the course of the year in California, 20% of the entire electrical demand (approximately 10 gigawatts of power) is needed for only about 5% of the year. Almost half this amount (4 GW, the equivalent of eight 500 MW power plants) is needed for only 1% of the year (CEC 2002). This peak electrical demand usually occurs in the summer months corresponding to air conditioning use. One method to reduce peak electrical use is to increase the price of electricity when demand is high.

Our vision is to develop a control system that responds to price signals from the utility, implementing a wireless network of sensors and actuators to reduce costs and allow flexibility of system design. This system, named the Demand Response Electrical Appliance Manager (DREAM), automatically responds to price signals and informs the occupant of energy consumption. The first step towards development of the system was to develop the hardware components and install them in an occupied house.

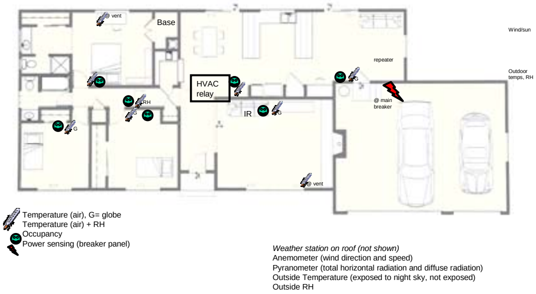


Research

Questions

Field research in an occupied house is more complex than research conducted in a laboratory, and can bring up a number of issues not found in the lab. The issues include how to package the motes, how to physically affix them in the space, where to locate the motes, the reliability the network, and the types of hardware needed to adequately sense and control the house.

The climate data was needed to calibrate the energy simulation tool, and realistic occupancy data was needed to develop learning algorithms for the control code.



Plan of the house, showing location and types of sensors.

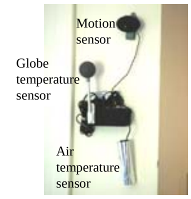
Methods

We developed sensors and actuators for the T-mote Sky wireless motes as well as a repeater mote for deployment in a house. The motes have a small radio and antenna powered by two AA batteries in series. Several analog/digital pins allow connection to various sensors and actuators. The motes communicate with a base mote attached to a laptop computer in a "star" type network. Control software written in Java administers messages from the sensor motes and to the actuator motes. Data from the motes are stored in a database locally on the laptop and sent via the internet to a remote database on a server at UC Berkeley.

Moteiv T-mote Sky mote.

Sensors

A generic sensor platform provided universal input jacks for up to four analog/digital sensors. These sensors included air and globe temperatures and an Infrared motion sensor, along with an onboard relative humidity sensor. Air and globe temperature and relative humidity are used to estimate thermal comfort. The motion sensor indicates occupancy of rooms in the house and is used to control the HVAC system.



Generic sensor mote.

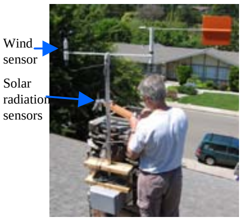
All motes recorded battery voltage since the radio required a minimum voltage to work.

We obtained power consumption via two types of current sensing motes. One mote used the commercially available Veris transducers to measure current, voltage, and power at the main circuit breaker panel in the house. This sensor can provide power factor information as well. Another mote used current transducers to measure current at individual circuit breakers. This mote could also be used to measure current for single appliances at the outlet level.

Power sensing at mains level

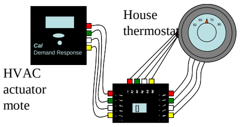
Current sensing at breaker level

Outside weather data was collected and used to calibrate the energy simulation model for the house. One mote had an onboard relative humidity sensor and two temperature sensors, one exposed to the sky and the other under the eave of the roof. A single mote collected solar radiation and wind data on top of the house. One pyranometer measured global solar radiation; the other was shielded from direct solar radiation and thus measured diffuse radiation. An anemometer measured wind speed and indicated wind direction.



Since the base mote was located at one end of the house, a repeater mote was added to the network to relay the message from the motes farthest away from the base mote.

For safety purposes, a switch was developed to allow the user to switch control between the household thermostat and the wireless HVAC actuator.



Thermostat-thermostat switch

Actuators

In order to replace the thermostat in the house, an HVAC actuator mote was developed. This actuator mote contains three relays: one for the air conditioning compressor, one for the blower fan, and one for the furnace. These relays connect at the point of the existing thermostat and uses the existing wiring. Since most people are accustomed to looking at the thermostat to find out temperature, an LCD screen and temperature sensor will added to this device to display current temperature. In addition, the current price level will be indicated by four LEDs: blue for critical price, red for high, yellow for medium, and green for low price.

HVAC actuator

We developed a price indicator mote to place on high energy consuming appliances, such as clothes dryers, clothes washers, and dishwashers. This mote receives a price signal from the controller and displays the appropriate color light to indicate the current price. One future addition to this device will be sound to indicate the changes in price. In addition, this mote will have an LCD screen that will display cost information to the customer specific to the appliance in question, using past information from the current sensor mote on the appliance.

Price indicator

Findings

Our simple star network deployment was successful in that we were able to achieve a functional wireless sensing and actuation system in an occupied house. We discovered that you can make a star network work, but it required a bit of trial and error because of the distance and location of the motes. Solutions include high sensitivity and/or a high power repeater in a star network, or establishing a denser configuration in a mesh network.

The data we collected over the four month experiment was used to fine tune the MZEST simulation tool to represent the occupied house. The simulated energy performance of the house closely matches the actual data.

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Demand Response Enabling Technology Development