Modular and Extensible Systemic Simulation of Demand Response Networks

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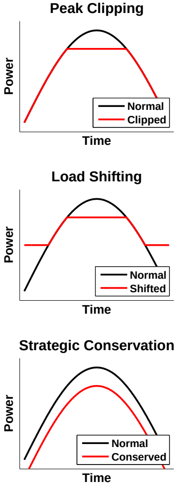
Demand Response Background

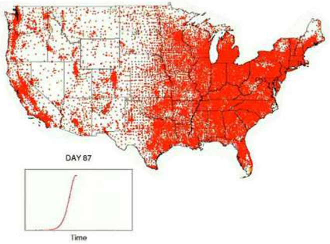
- DR Goal:
  - Manipulate power demand on the electrical distribution and generation system.
- DR Types [Bellarmine, 2000]:
  - Peak Clipping
  - Load Shifting
  - Strategic Conservation
- Reasons to use DR:
  - Avoid blackouts
  - Avoid peaker plants
- Examples Technologies:
  - Load Switches
  - Grid Friendly Appliances [Lu and Nguyen, 2006].
  - AutoDR [Watson et al., 2004].



Simulation Motivation

- **Goal:** Explore main DR controls issues
  - Systemic Control
  - Local Control
  - Disturbances
  - Customer Effects
- **Problem:** Difficult to safely vet algorithms
  - Equipment is *costly*
  - Experiments take *time*
  - Failure could be *catastrophic*
- **Solution:** Simulations make life easy
  - *Cheap*
  - *Quick*
  - *Safe*

Avian Flu Pandemic [Milner, 2006]



(Thankfully, just a simulation)

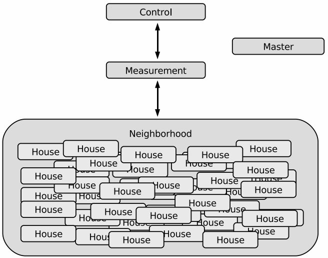
Simulation Approach

- Restricted scope
  - Residential HVAC (Easily Expanded)
  - Inexpensive Equipment (PCT)
- Approach
  1. Thermal Simulation of Individual Houses
  2. Simulate PCT in Each House
  3. Randomize House/PCT Parameters
  4. Examine Aggregate Response
- Major Contribution – Extensibile Throughout
  - Thermal Simulation: random houses easy to create
  - Thermostat: easy to change local control
  - Systemic Control: try different global control algorithms

Systemic Simulation Overview

- Uses Strict Task/State Architecture
- Constructed using TranRunC
- Consists of three *main* tasks
  - Neighborhood Task
    - Array of independent houses
    - Coordinates timing and communications
  - Measurement Task
    - Feeder station
    - Aggregates HVAC power
  - Control Task
    - Sends DR messages
    - Flexible

Simulation Task Diagram



Systemic Simulation – House Object

- Reduced Complexity Model
  - 5 state dynamic model
  - Modifiable state parameters

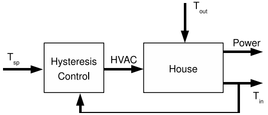
    Randomly generated
- PCT Controlled
  - Strict Task/State Architecture

    8 Tasks per house
  - Hysteresis Control

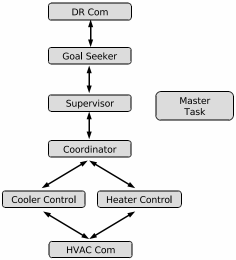
    ```
    e = T_s - T_air
    if u_{AC} == TRUE and e >= C_c - C_a
       then u_AC = FALSE
    if u_{AC} == FALSE and e <= -C_h
       then u_AC = TRUE
    ```
  - Set-point tables

    Randomly generated
  - DR Communications

House Block Diagram



PCT Task Diagram



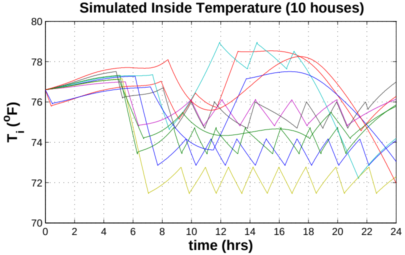
Systemic Simulation – Example Response

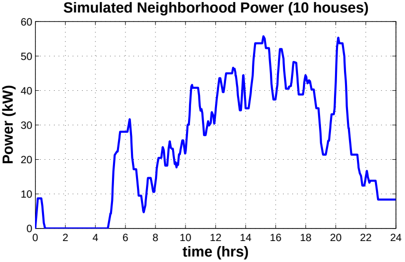
Simulation Construction

- 10 Houses
- Randomly generated parameters
- Randomly generated set-point tables

House Parameter Range

Parameter	Range	Scale
House Size (ft^2)	1661 - 3222	1x - 2x
AC Size (ton)	2 - 10	0.5x - 1.25x
Slab Construction	Y/N	





Individual House Demand Response

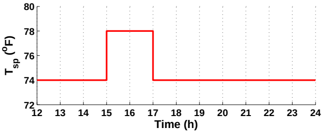
- Different local control strategies easily tested
  - Each house has independent control
  - Local Control Task extensible
- Example control strategies
  - Setback DR
    - DR command states thermostat setback
    - Allows temporally different setbacks – ramps, random times, etc
  - Cost Ratio DR
    - Learn past duty cycle/cost
    - Limit current power
    - DR Signal = price ratio
      e.g., ‘4.5’ means ‘Power costs 4.5 x normal price.’
    - Each house has a price tolerance
      e.g., ‘1.5’ means ‘I will tolerate 1.5 x normal cost.’

Set-point DR – Simple Event

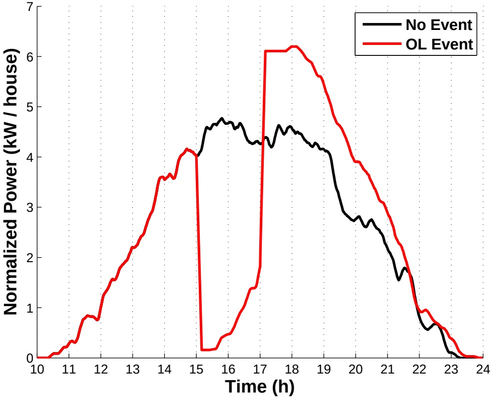
Event Description

- $4^o F$ Setback for 2 hours
- Each house responds simultaneously

Simple Event Set-point Profile



Simple Event Response



Notice

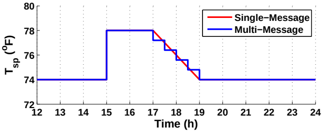
- Large discontinuities
- Large payback

Set-point DR – Payback Mitigation

Ramp Types

- Multi-message ramp
- Single-message ramp

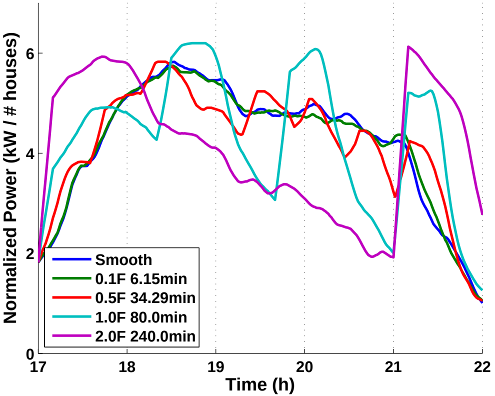
Ramped Event Set-point Profile



Notice

- Large spikes with multi-message
- Single Message better

Ramped Event Response



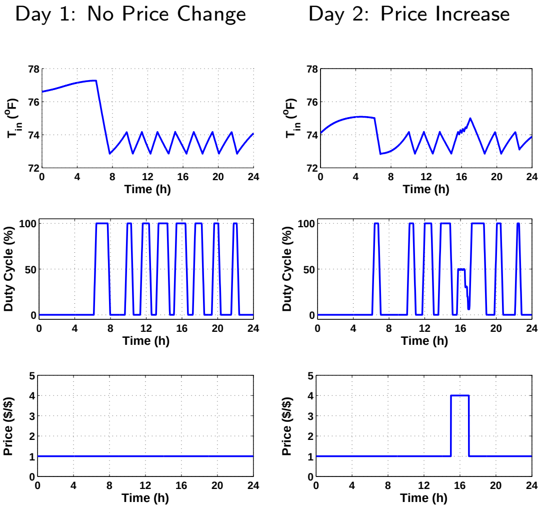
Cost Ratio DR – 2 Day Example

Simulation Parameters

- Neutral Factor: 2
- DR Event
  - Price Ratio 4
  - From 3-5pm

Notice

- Lower AC duty cycle during price increase
- Increased T_{in} during price increase



Cost Ratio DR – Systemic Response

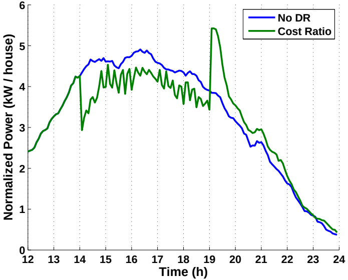
California CPP Event

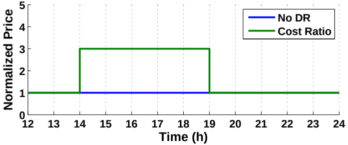
- Price increase of 3x
- from 2-7pm

Notice

- Houses have random cost preferences
- Response still follows T_{out}
- Basis for closed loop control

Response to CPP Rate





Conclusions

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- Demonstrated Systemic Simulation
  - Flexible
  - Extensible
- Demonstrated Different Control Strategies
  - Simple DR Events
  - Rebound Mitigation Techniques
  - Cost Ratio DR

Future Work

- Add residents to the model
  - Use stochastic state machine to model resident actions
  - Use the same random property assignment as used for physical properties
- Refine Cost Ratio DR Predictions
- Systemic Control
  - Closed Loop Control Strategies
  - Estimation methods for HVAC energy usage

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