PCT Systemic Control

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7/17/2007

Systemic Control?

- Motivation
  - System is very complicated.
    - Power generation
    - Substations
    - Industry
    - Residential
  - Critical to modern life
  - SNAFU very bad

    Unhappy voters!
- How do you decide about events?
  - PCT load group simulation
  - Characterize open loop system
  - Stability analysis
  - Design feedback controllers

Outline

- Simulation Overview
- Simulation Uses
- Summary and Future Work

Acknowledgements

PI's

- David Auslander (Research Advisor)
- Paul Wright
- Dick White

PCT Team

- Alex Do
- Charles Glorioso

Special Thanks

- Charlie Huizenga

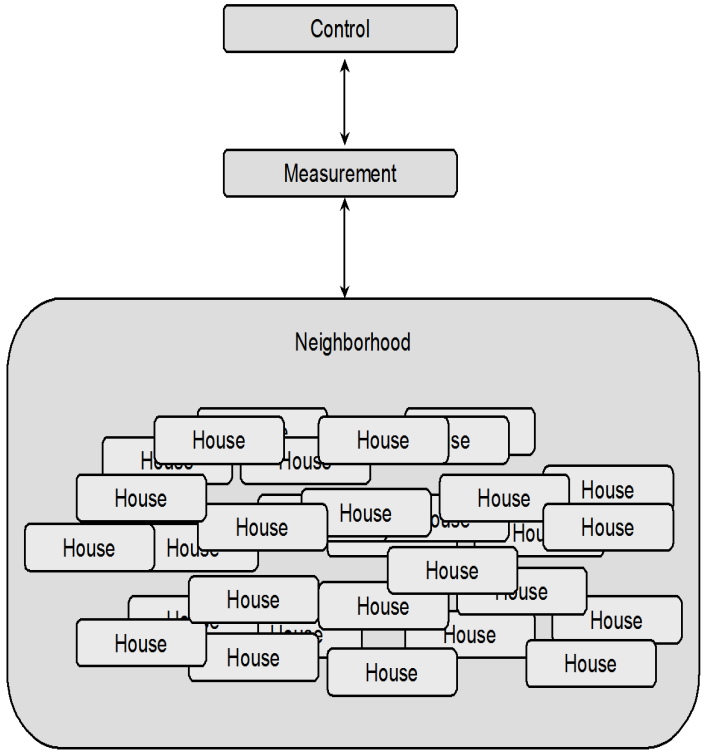
Big Dogs

- Ron Hofmann
- Gaymond Yee

California Energy Commission

Simulation Overview

- Neighborhood Task
  - Made up of an array of **house objects**.
  - Each house has individual parameters.
    - Random thermal parameters
    - Random setpoints
    - Random efficiencies
  - Each house has a PCT
- Measurement Task
  - Aggregates power
    (HVAC power only)
- Control Task
  - Sends DR messages
  - *The interesting part!*

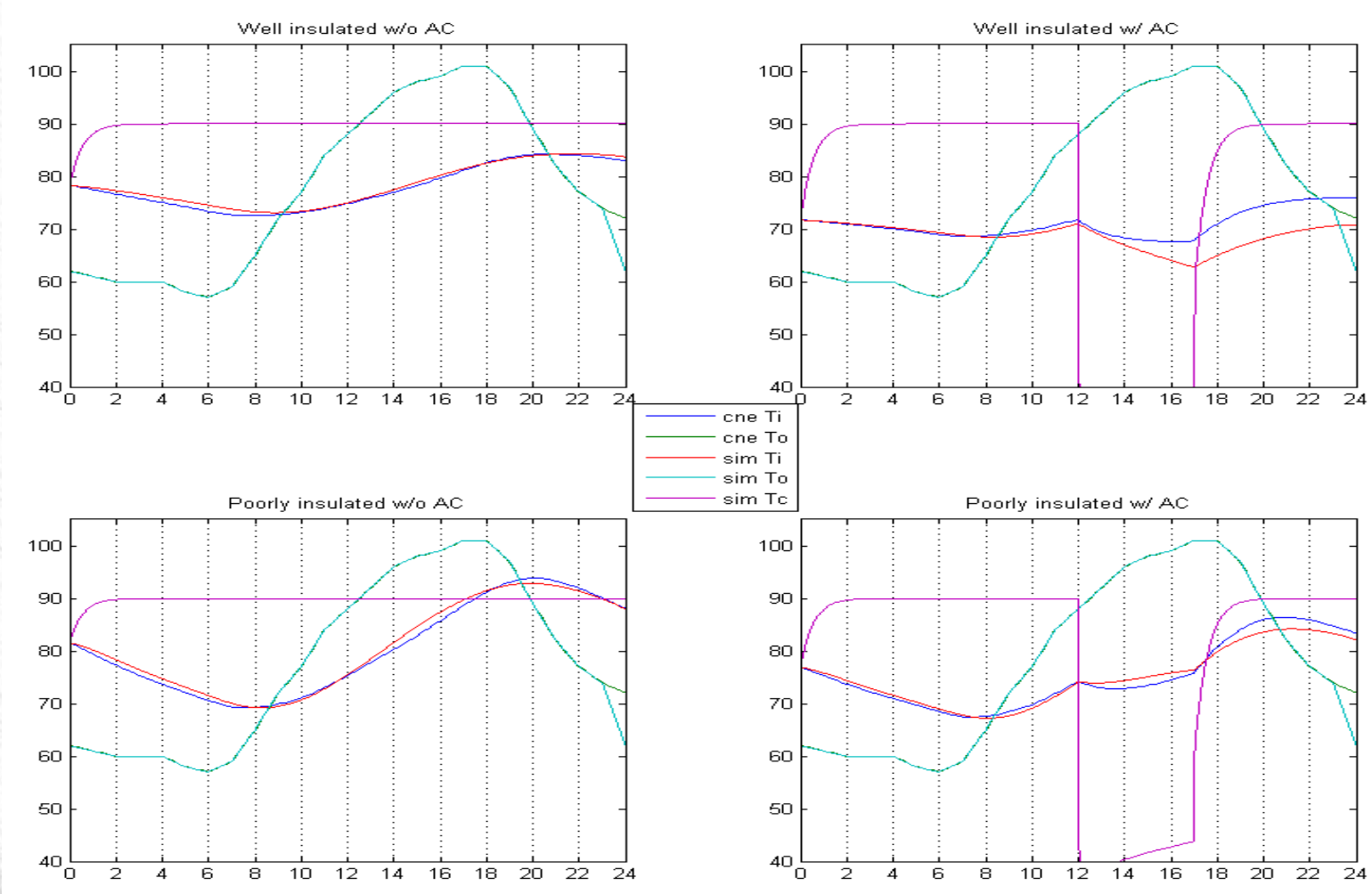


Simulation – House Object

- House Construction
  - Reduced Complexity Model
    - 5 state dynamic model
      Air, Internal Walls, External Walls, Heater, Cooler
    - Modifiable state parameter variables.
  - PCT Controlled
    - Hysteresis Control
    - Setpoint tables
    - DR Communication
- Tuning Methodology
  - Match MZEST (CALRES) simulation
  - Define and test min and max
  - Determine population size

House – Baseline Parameters

Open Loop Simulation



House – Parameter Range

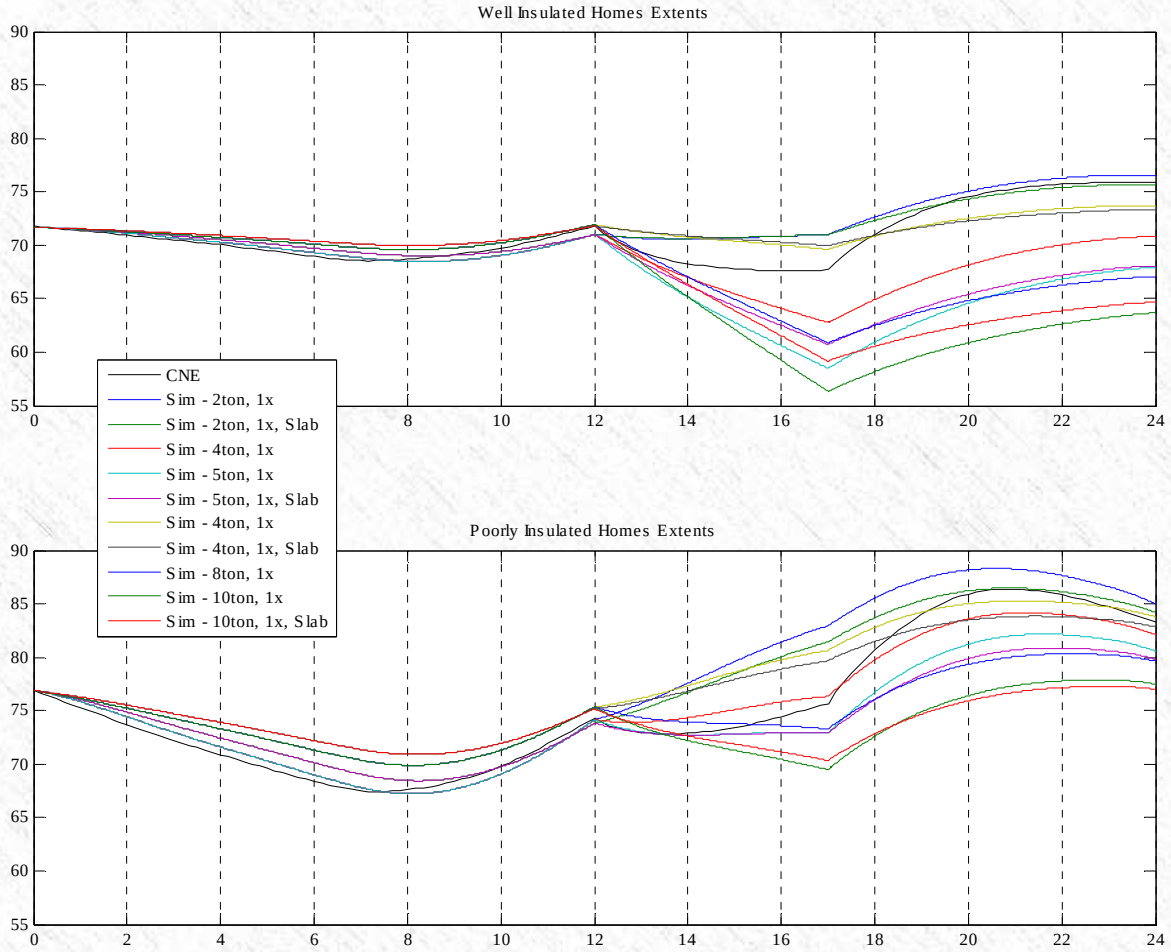
Reduced Degrees of Freedom to 4

- House Size – air, walls, window, AC, infiltration
- Insulation Level – walls, windows, infiltration
- AC Size – applied after house size scaling
- Slab Construction – true or false

Test Performed with and without Title 24 Insulaiton Levels											
	1	2	3	4	5	6	7	8	9	10	Range
House Size (ft^2)	1661	1661	1661	1661	1661	3322	3322	3322	3322	3322	2x
AC Size (ton)	4	2	2	5	5	8	4	4	10	10	0.5 to 1.25
Slab Construction	N	N	Y	N	Y	N	N	Y	N	Y	Y/N

House – Simulation Extents

Open Loop Simulation

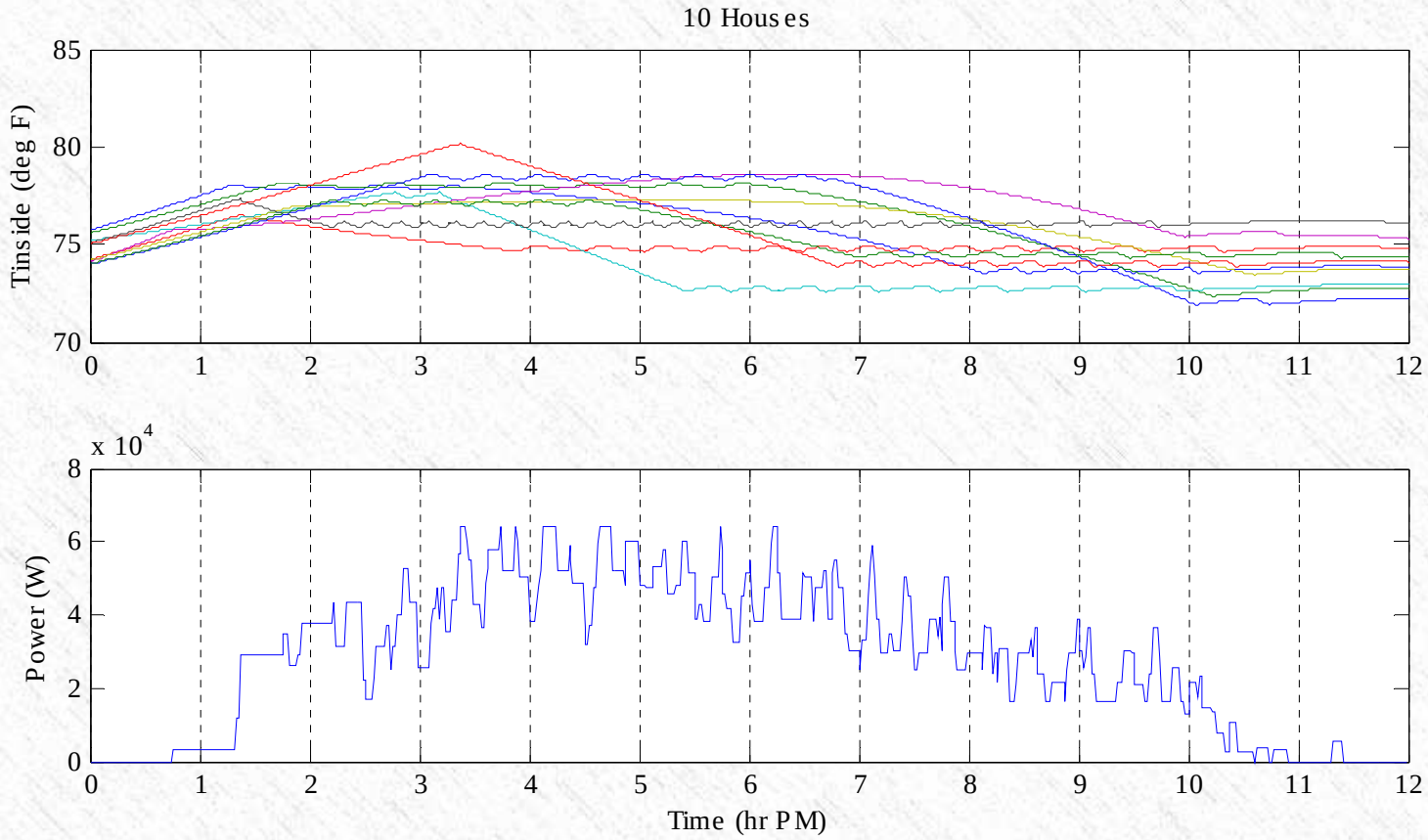


“Neighborhood” Size

- Importance
  - Smoothes power curve
  - Computational expense
- Goal
  - Find minimum number of houses in a neighborhood
- Methodology
  - Choose parameters from inside range.
  - Simulate different size neighborhoods

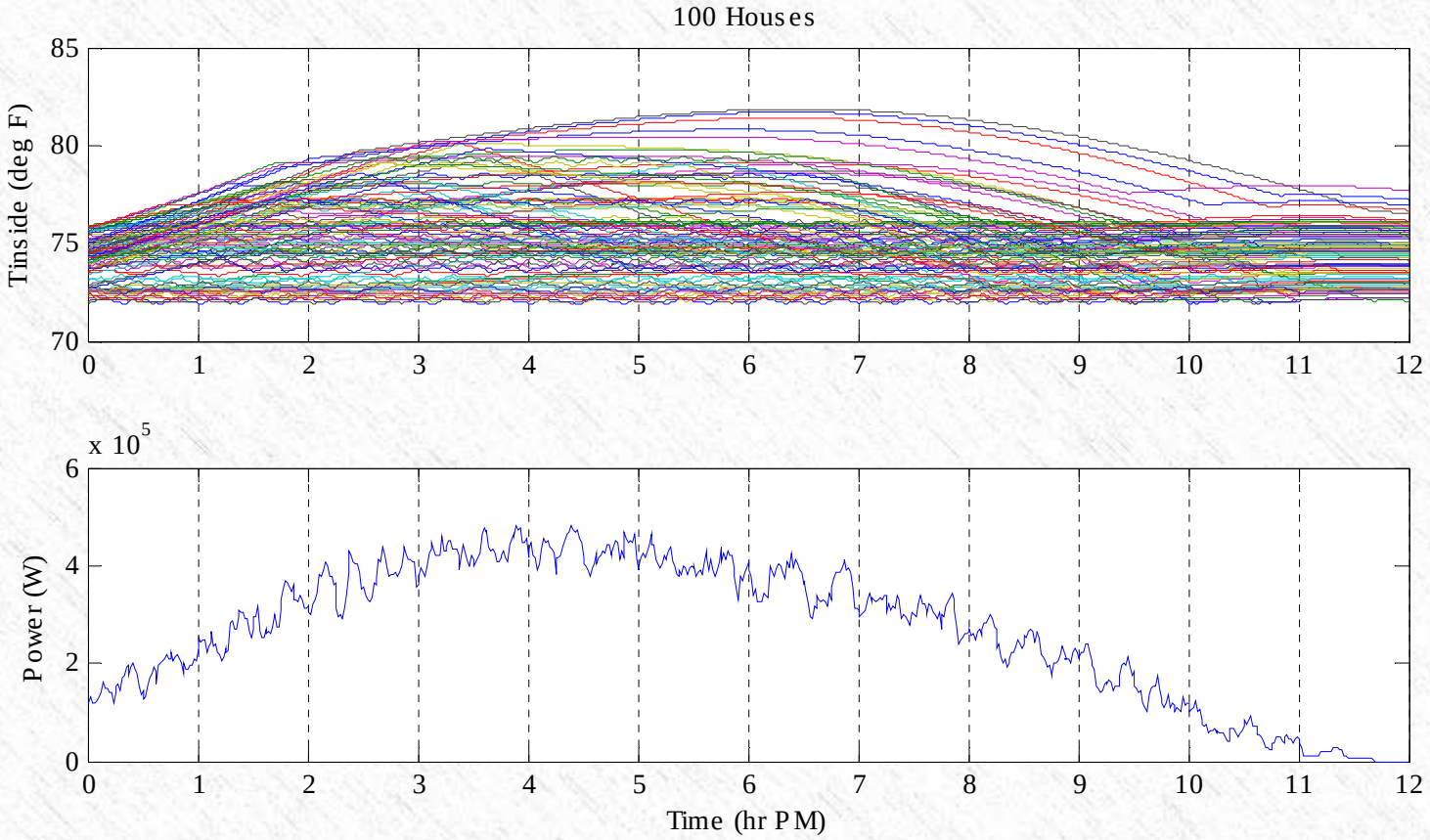
“Neighborhood” Size Simulation

10 Houses; Sacramento 101ºF Peak



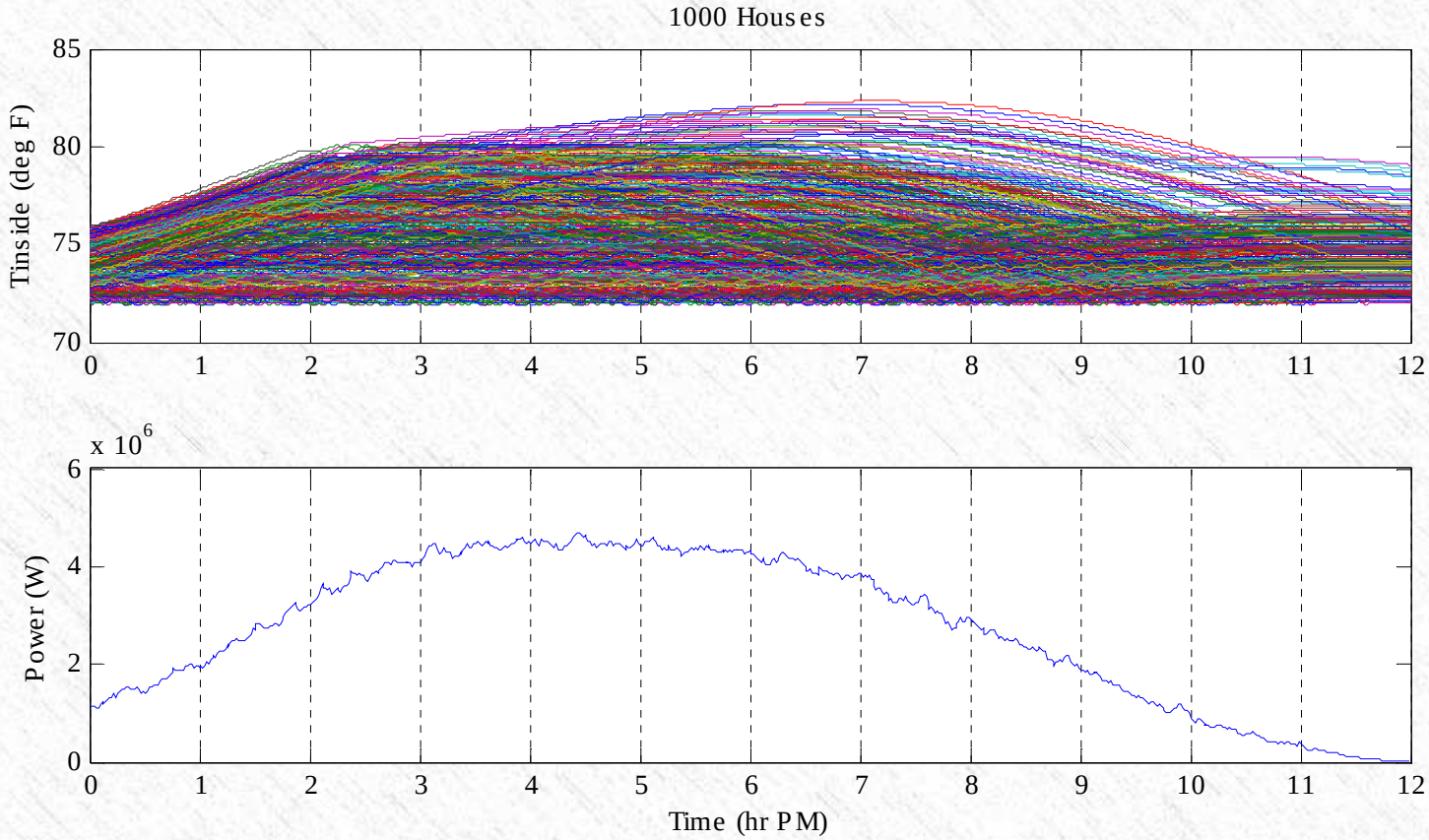
“Neighborhood” Size Simulation

100 Houses; Sacramento 101ºF Peak



“Neighborhood” Size Simulation

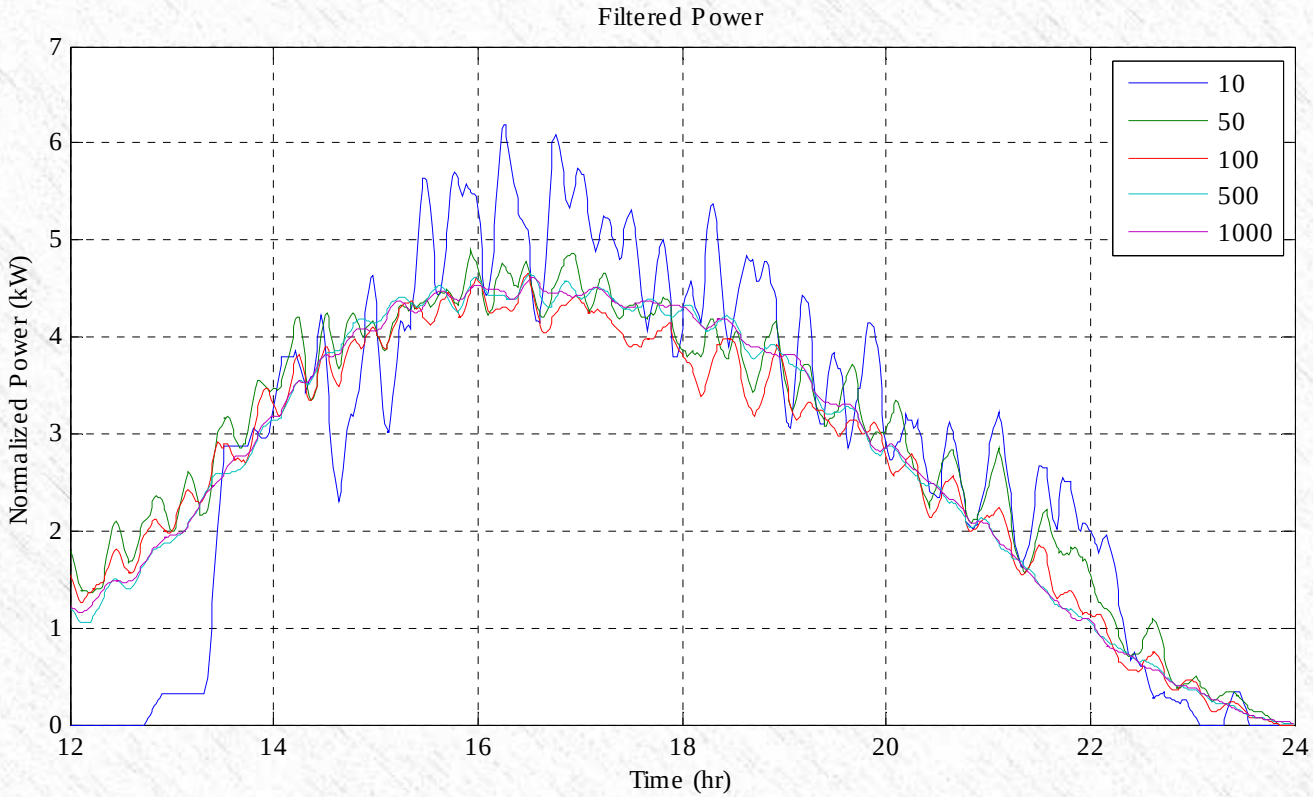
1000 Houses; Sacramento 101ºF Peak



Neighborhood Size Simulation

Data Range – All, Smoothed

100 houses is good enough



Simulation Uses

- Demonstration
  - Basic DR event.
  - Exit strategies.
  - Complex thermostats.
    - Cost Neutral DR
- Future possibilities
  - Entrance strategies
  - **Close loop control**
  - **Intelligent Agents**

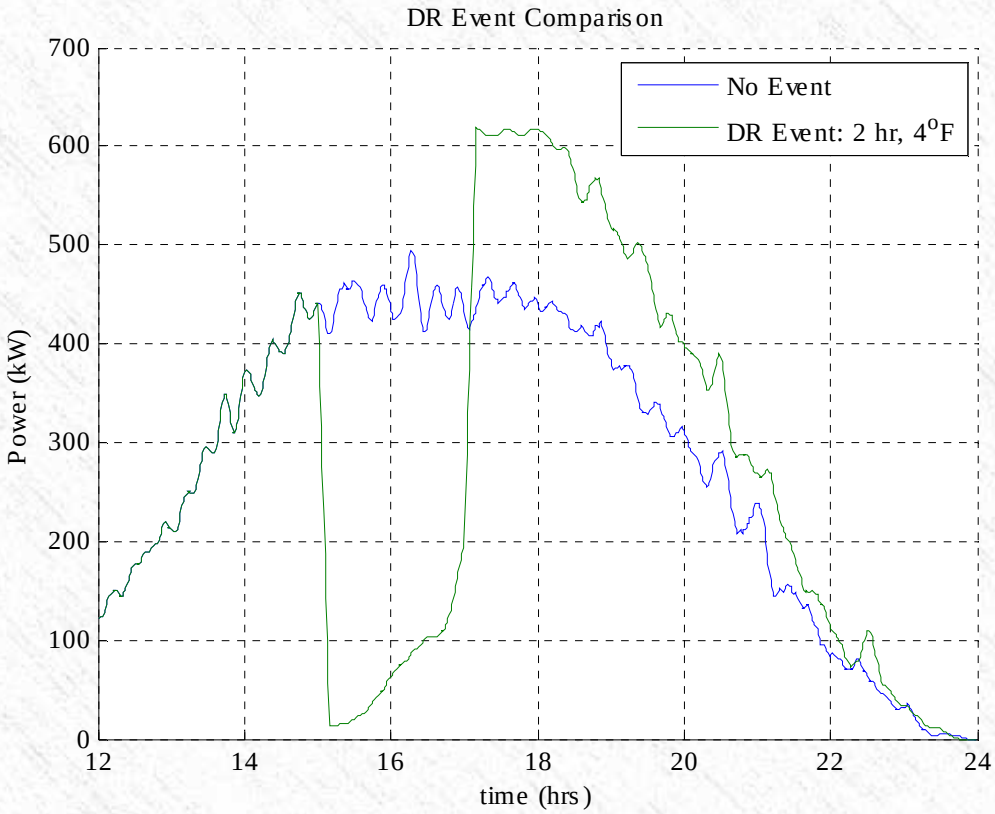
Simple DR Event Results

Comparison:

- DR Event
  - 3:00-5:00 pm
  - 4°F Setback
- No Event

Problems:

- Payback Power
- Discontinuities

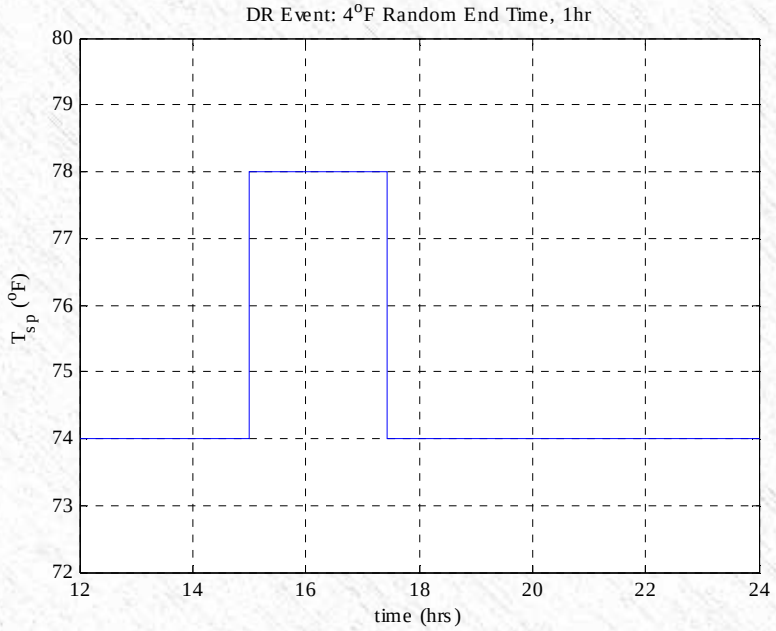


DR Exit Strategies

- Why?
  - Reduce payback peak.
  - Smooth exit discontinuity.
- Possible Strategies
  - Random end time
  - Linearly ramped exit
  - *Many other possibilities*
- Easily extend to beginning discontinuity.
  - Ramped beginning
  - Etc.

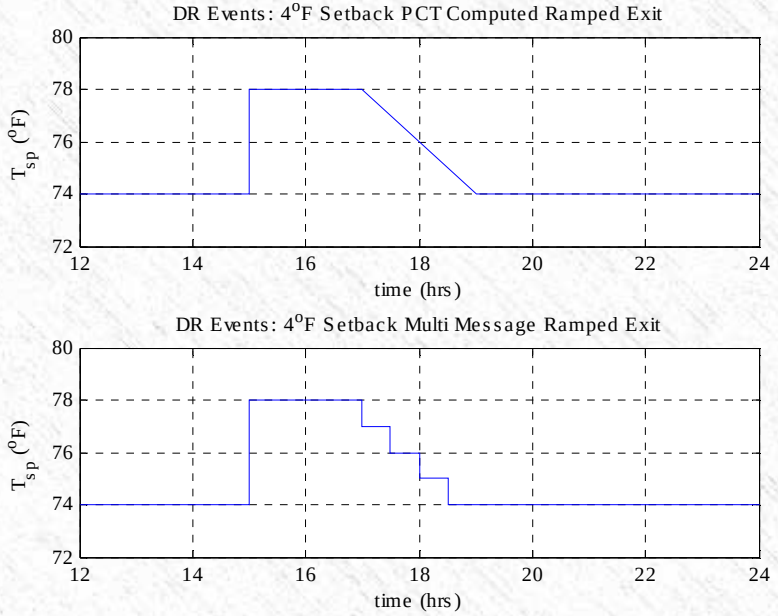
Exit Strategy – Random End

- How it works:
  - End at different random times.
- Effect:
  - Slowly bring load back online.
- Issues:
  - Every home ***not at*** desired temperature at end of window.
  - ***Not equitable.***



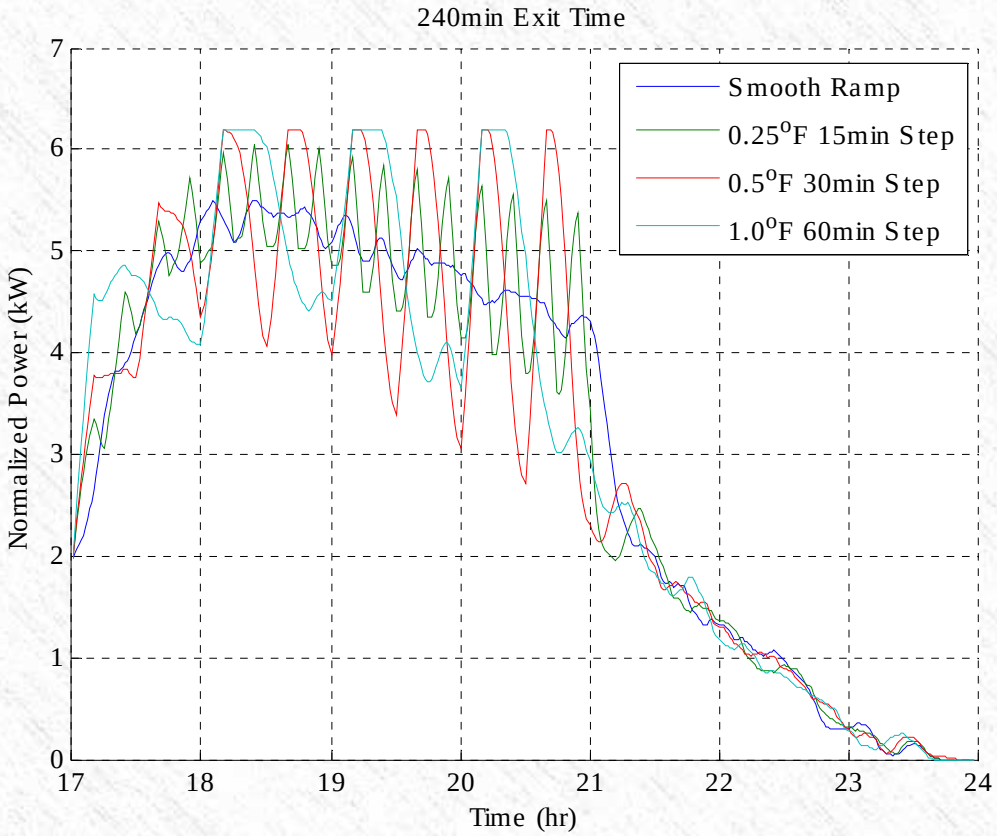
Exit Strategy – Ramped End

- How it works:
  - Slowly ramp setpoint back to desired.
  - Two types
    - PCT calculated
    - Multi Message
- Effect:
  - Slowly bring load back online.
- Issues:
  - Every home ***at*** desired temperature at end of window.
  - ***Equitable***!



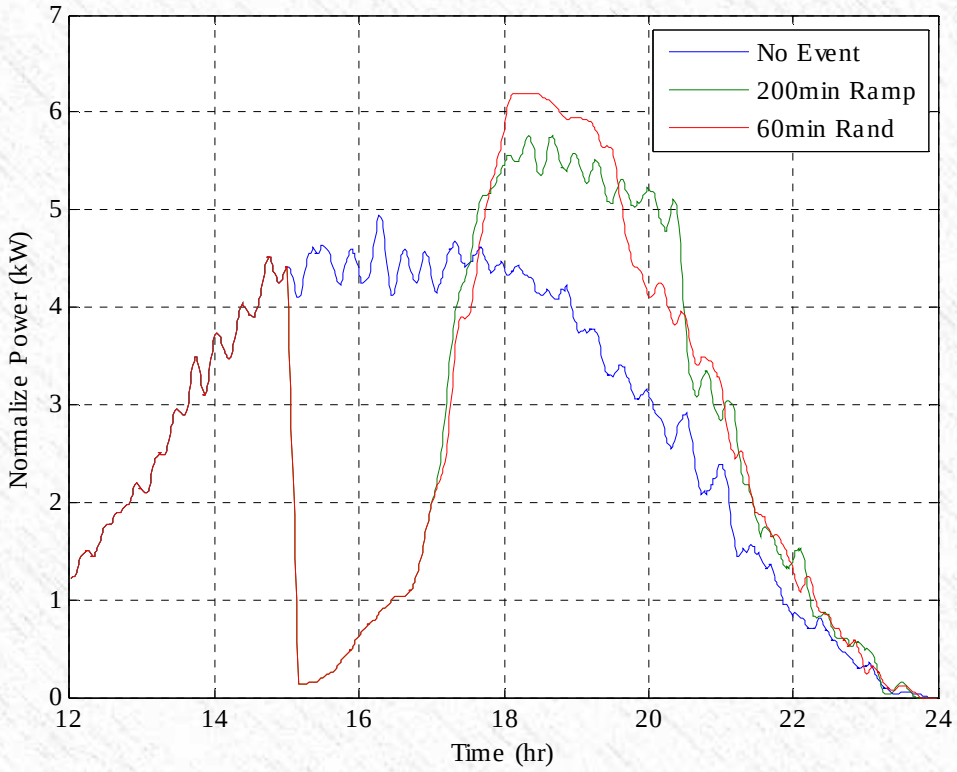
Exit Strategy Ramp Type

- 240min Ramp
  - PCT Computed
  - Multi Message
- Multi Message Issues:
  - Discontinuities
  - Saturation
  - Loss of diversity
- PCT Computed much better.



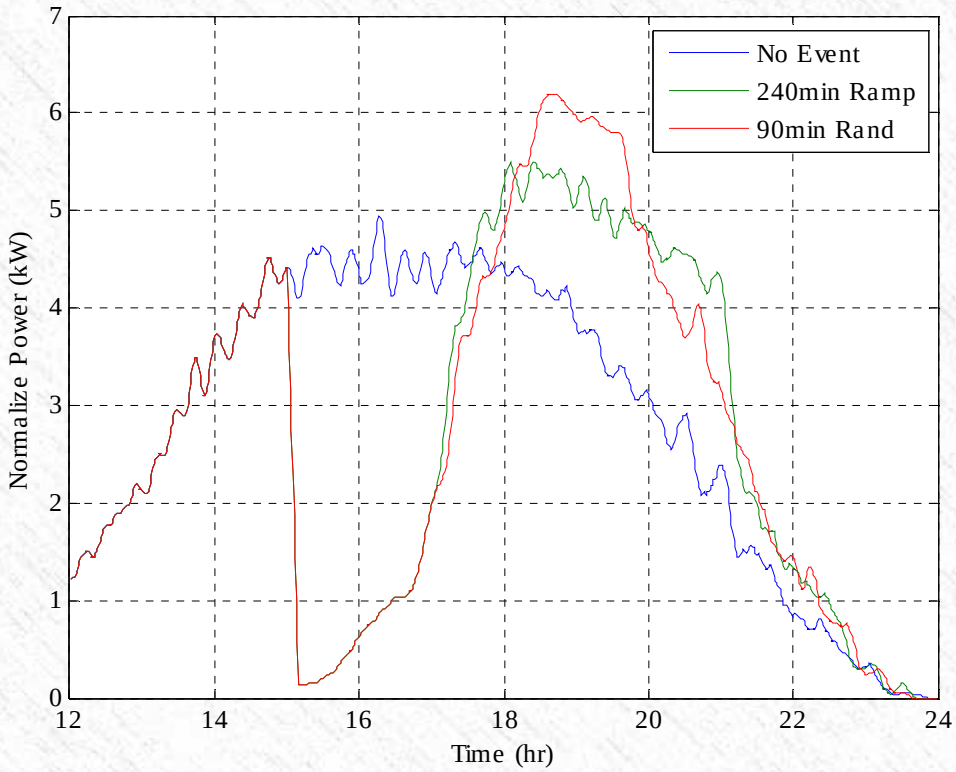
Exit Strategy Ramp v Rand

- 200min Ramp
  - ΔE_n = -1.97 kWh
  - ΔP_n = 0.63 kW
- 60min Random
  - ΔE_n = -1.96 kWh
  - ΔP_n = 0.93 kW



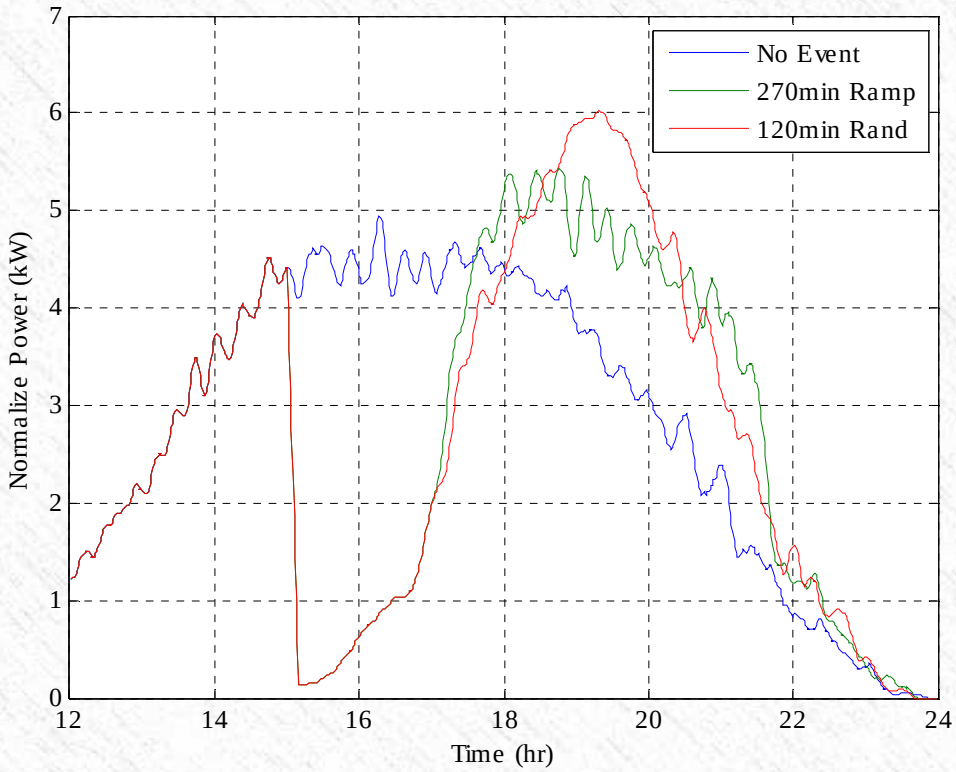
Exit Strategy Ramp v Rand

- 240min Ramp
  - ΔE_n = -2.11 kWh
  - ΔP_n = 0.52 kW
- 90min Random
  - ΔE_n = -2.11 kWh
  - ΔP_n = 0.93 kW



Exit Strategy Ramp v Rand

- 270min Ramp
  - ΔE_n = -2.23 kWh
  - ΔP_n = 0.51 kW
- 120min Random
  - ΔE_n = -2.25 kWh
  - ΔP_n = 0.87 kW



Exit Strategy Summary

- Ramps better than Rands.
  - Maintain better diversity
  - Lower peak load.
  - More Equitable.
- PCT should compute ramp.
  - Lower bandwidth requirement
  - Better performance

Exit Type	Length (min)	Normalize Day Pmax (kW)	Normalized Day Energy (kWh)
ramp	60	0.93	-1.69
rand	15	0.93	-1.68
ramp	80	0.93	-1.74
rand	30	0.93	-1.76
ramp	160	0.93	-1.86
rand	45	0.93	-1.86
ramp	200	0.63	-1.97
rand	60	0.93	-1.96
ramp	240	0.52	-2.11
rand	90	0.93	-2.11
ramp	270	0.51	-2.23
rand	120	0.87	-2.25

Cost Neutral DR

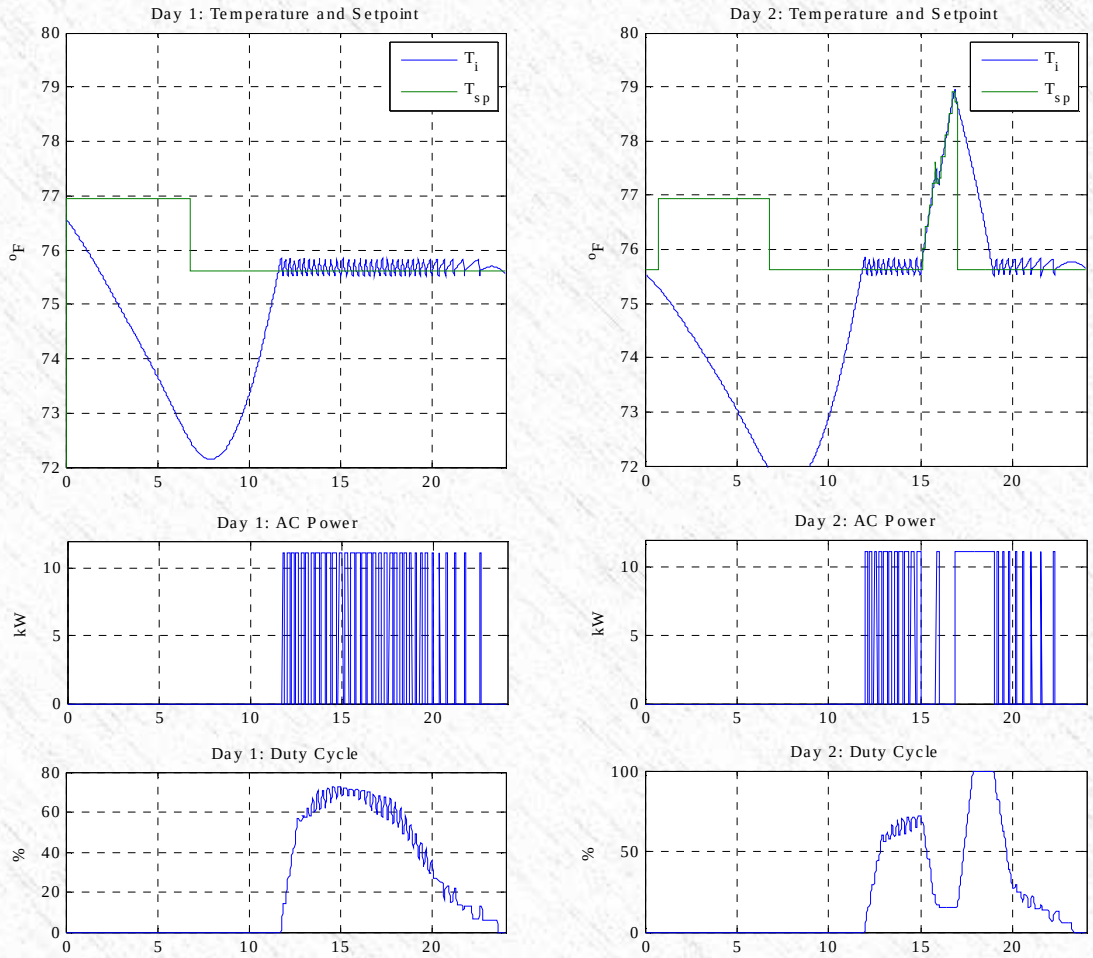
- Big Idea:
  - Remember past duty cycle.
  - Use history to limit power consumption.
- Assumptions:
  - DR Signal = price ratio.

    e.g., ‘4.5’ means “Power costs 4.5 x normal price.”
  - Homeowner chooses price tolerance.

    e.g., ‘1.5’ means “I will tolerate 1.5 x normal cost.”

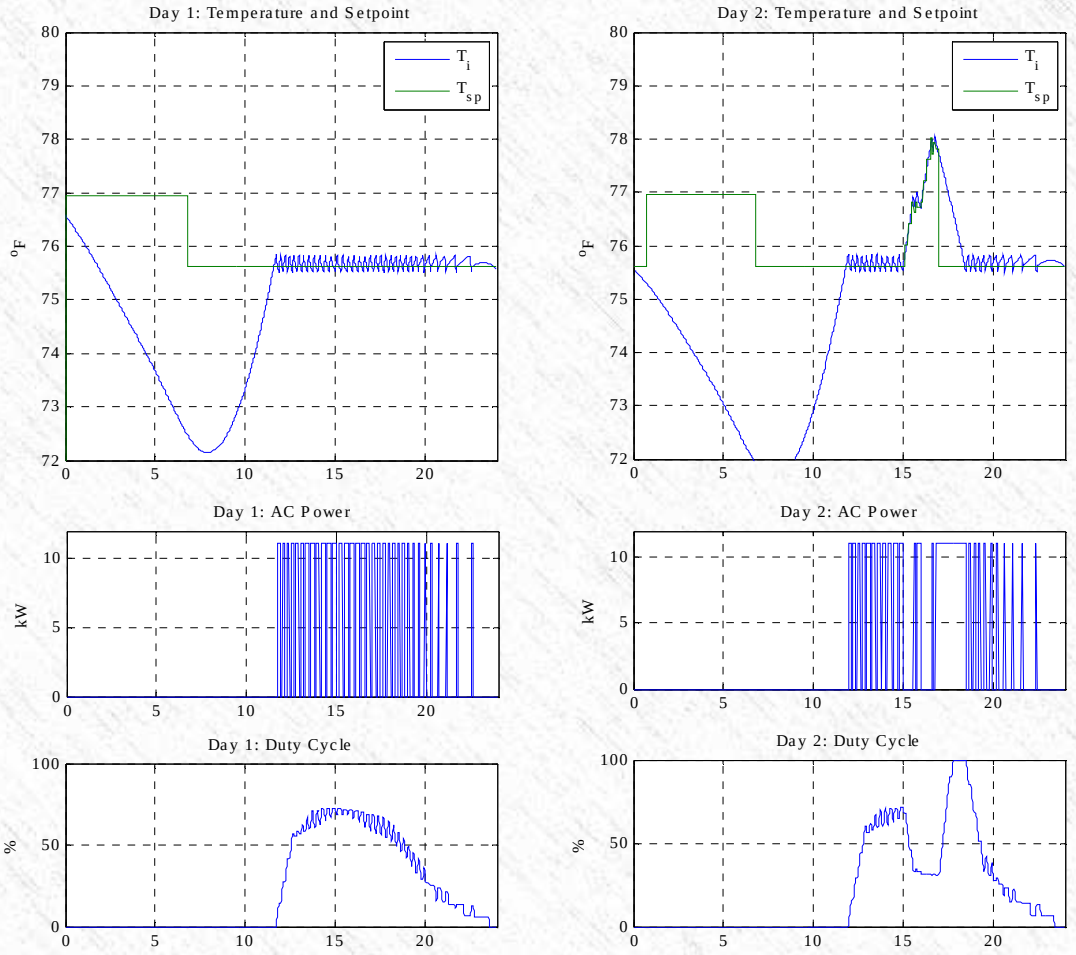
Cost Neutral DR Single House

- 2 Day Simulation
- Neutral Factor: 1
- DR Event:
  - Price Ratio: 4
  - 3-5pm



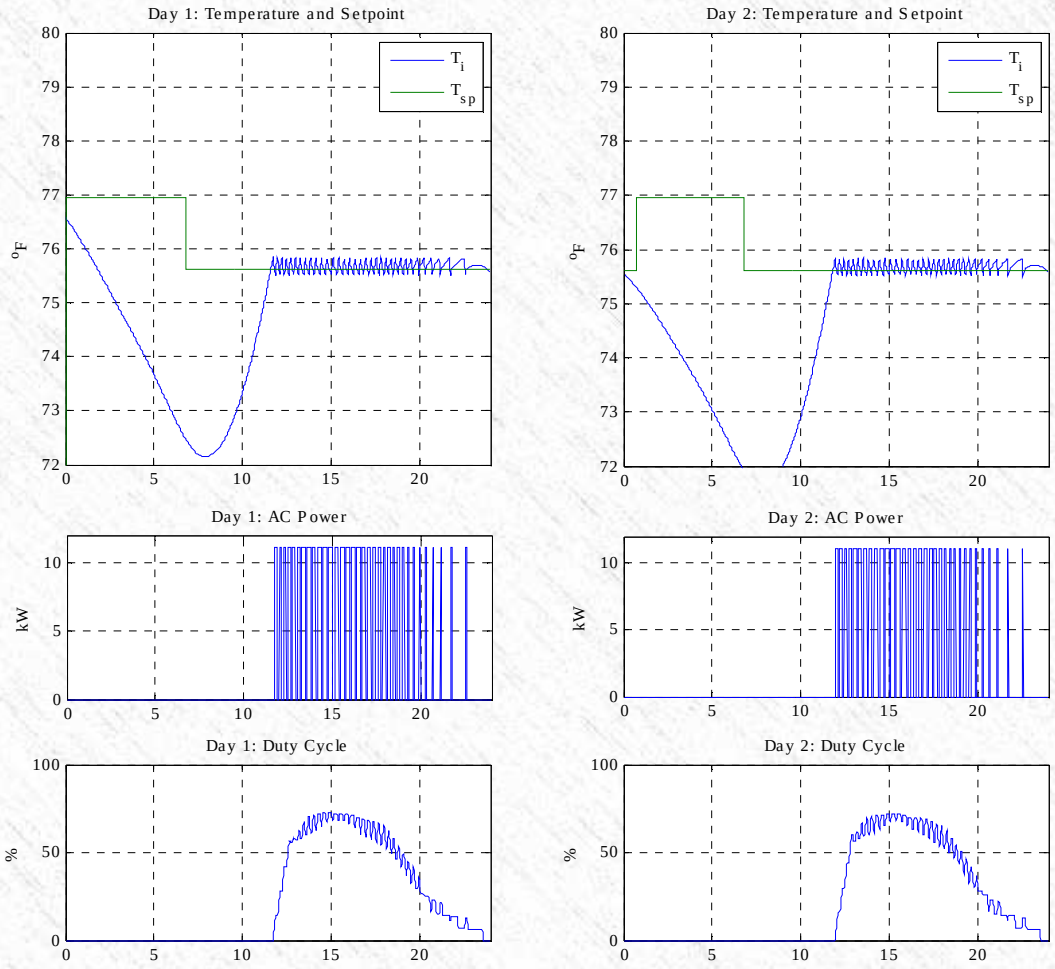
Cost Neutral DR Single House

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



Cost Neutral DR Single House

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



Summary

Simulation demonstration successful!

- Basic event tested.
- Examined different exit strategies.
  - Ramped is superior to random.
  - PCT should compute its own ramp (single message).
- Began Cost Neutral study
  - Viable option for DR and *real time pricing.*

Future Work

- Interests
  - Close the loop!
    - Linear Quadratic optimal control.
    - Adaptive system ID.
    - Model Predictive control.
  - Simulate intelligent agent thermostat network.
- Suggestions?

Questions / Comments