

# Price Responsive Loads – Simulation Results

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# Presentation Overview

- Motivation
- Simulation Overview
- Controls Background
- Local Control
- Systemic Control
- Conclusion
- Future Work

# Research Motivation and Goals

## Load Management

- Reasons to use
  - ▶ Avoid blackouts
  - ▶ Avoid peaker plants
- Examples Technologies
  - ▶ Load Switches
  - ▶ Thermostat Set-Point Adjustment
  - ▶ Grid Friendly Appliances

## Goal: Explore Residential Load Management Controls Issues

- Local Control – individual unit response
- Systemic Control – aggregate response
- Customer Effects – comfort, cost, etc.

# Simulation Motivation

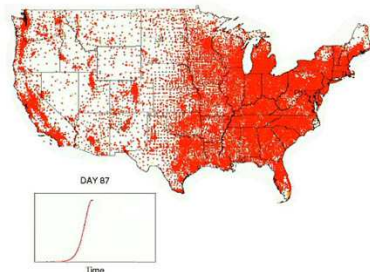
**Problem:** Difficult to safely vet algorithms

- Equipment is *costly*
- Experiments take *time*
- Failure could be *catastrophic*

**Solution:** Simulation makes life easy

- *Cheap*
- *Quick*
- *Safe*
- *Repeatable*

Avian Flu Pandemic (Milner, 2006)



(Thankfully, just a simulation)

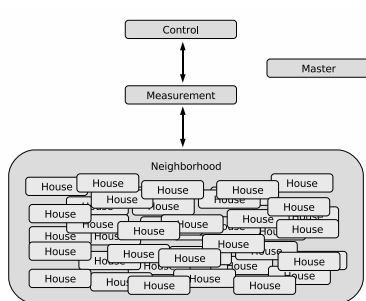
# Simulation Overview

Constructed using TranRunC

- Object Oriented style
- Task/State Architecture

Consists of three *main* tasks

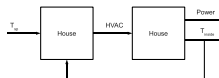
- Neighborhood Task
  - ▶ Array of independent houses
  - ▶ Coordinates timing and communications
- Measurement Task
  - ▶ Feeder station
  - ▶ Aggregates HVAC power
- Control Task
  - ▶ Sends DR messages
  - ▶ Flexible



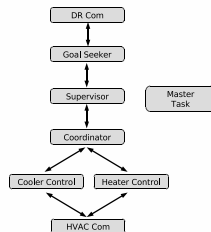
# Simulation – House Object

- Reduced Complexity Model
  - ▶ 5 state dynamic model
  - ▶ Modifiable state parameters  
Randomly generated
- PCT Controlled
  - ▶ Strict Task/State Architecture  
8 Tasks per house
  - ▶ Temperature Control
  - ▶ Set-point tables  
Randomly generated
  - ▶ DR Communications

House Block Diagram



PCT Task Diagram



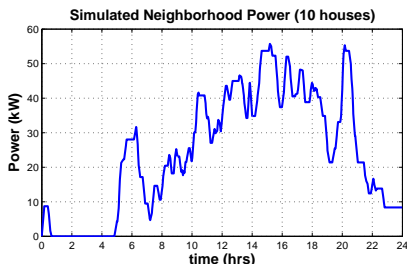
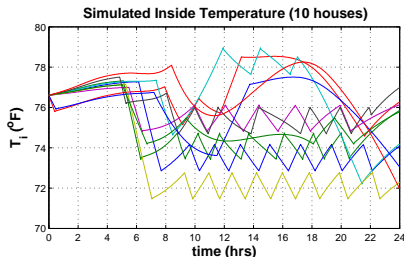
# Simulation – Example Response

## 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         |              |

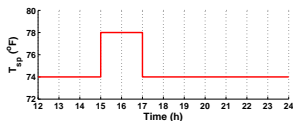


# Controls Background – Motivation

## Setback Events

- 4°F Setback for 2 hours
- Each house responds simultaneously

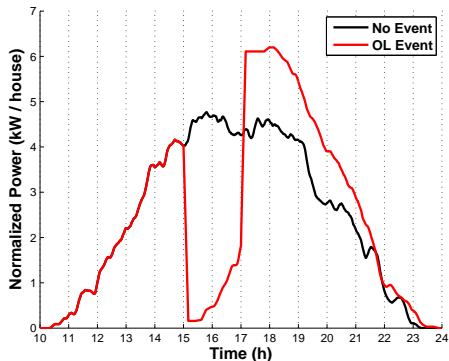
Simple Event Set-point Profile



## Problem – Not Robust

- Not scalable
- Large discontinuities
- Large payback
- Not equitable

Simple Event Response



# Controls Background – Temperature Control Problem

## Traditional Hysteresis Control

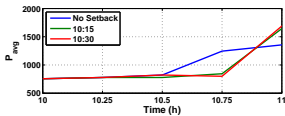
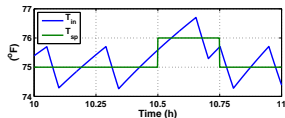
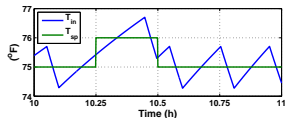
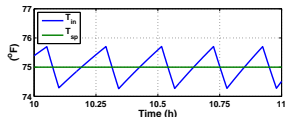
- Robust simple design
- Non-linear
- Difficult to modulate power

## Unreliable Setback Power Response

- Difficult to predict output
- Not same for different houses

## Unreliable Setback Example

- Three simulations with identical houses
- First – no setback
- Second –  $1^{\circ}F$  at 10:15
- Third –  $1^{\circ}F$  at 10:30
- Second and third have similar power!



# Controls Background – Overview

## Open-Loop Control Is Coarse

- Set-point is *not* the same as power
- Not equitable – each house responds differently
- Payback hard to control

## Intelligent Control Can Help

- Systemic control
  - ▶ Choose meaningful control variable, e.g. price
  - ▶ Use feedback (communications or measurements) to gain robustness
  - ▶ Apply different techniques – feedback controls, real-time auctions, etc
- Local control
  - ▶ Each house responds independently
  - ▶ Individual comfort/cost optimization

# Systemic Control – Real-Time Auction

## Use Auction Mechanism

- 1 *Bid Call*: At predefined time before, the units submit bids, bids = {expected consumption, price willing to pay}.
- 2 *Clearing*: Compute clearing price
- 3 *Auction Period*: Units charged the clearing price for their consumption

## Assumptions

- Normalized Price
  - ▶  $Price\ ratio = \frac{current\ price}{normal\ price}$
  - ▶ Price = 4 means: electricity cost 4 *times* “normal” price
- Market Operation: 15 Minute Period
  - ▶ Normal Period – price is a predefined value, i.e. 1
  - ▶ Control Period – price is time varying
- Resource is scarce, i.e. agents want more than exists

# Systemic Control – Soft Cost Constraints

## Possibly Conflicting Goals

- Maintain comfort
- Reduct cost

## Cost Limiting Demand Function

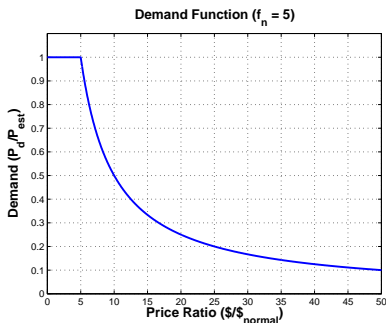
$$P_d = \min \left\{ \frac{P_{est} f_n}{p_r}, P_{est} \right\} \quad (1)$$

Cost limited demand –  $P_d$

Estimated power –  $P_{est}$

User input neutral factor –  $f_n$

Energy price ratio –  $p_r$



# Systemic Control – Clearing Mechanism

## Soft Budget Constrained Mechanism

- 1 Order the bids in ascending order
- 2 Iterate on a “function” until the clearing price is between two bids.
- 3 Compute the allocations

## Theorem

*The Soft Budget Constraint Mechanism is policy-consistent when the bidders have soft budget constraints.*

## Benefits

- Game Proof!
- Fast – Computable in polynomial time
- Communication Efficient – only one message per bidder

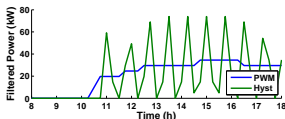
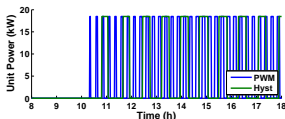
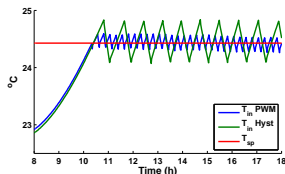
# Local Control – PWM Synchronization and Control

## Low-Frequency PWM

- On/off HVAC operated proportionally
- Use any control method (PI for example)
- *Simple power modulation using tunable saturation*

## PWM Synchronization

- Synchronize PWM period with auction
- Prediction much easier (1 step look-ahead)
- Force load diversity – random start times



# Local Control – PWM and Power Control

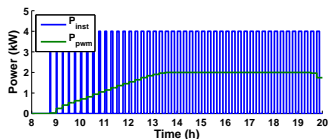
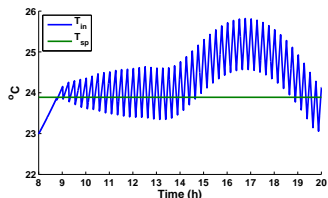
## Control with Low-Freq PWM

- Controller directly modulates power
- Controllable saturation limits

## Direct Load Control (DLC)

- Radio operated switch
- Cuts power from compressor for specified time
- Variable effect on power
- Adaptive switches

## PWM Control with Tunable Saturation



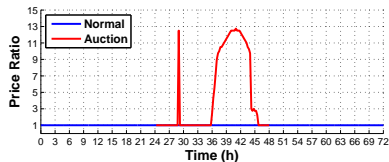
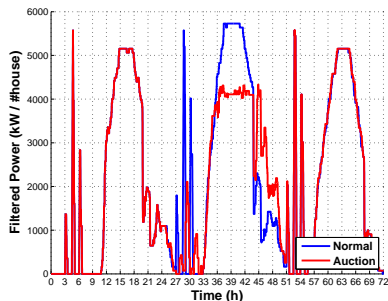
# Results – Aggregate Power

## 3 House Simulation

- Plotting 3 days for visualization purposes
- 7 days to ID house
- Day 8, control begins
- Day 9, no control
- Goal: keep average power below 4kW

## Aggregate Power Response

- Price increase at hour 36
- Average power follows 4kW
  - ▶ Mismatch due to poor local power estimate



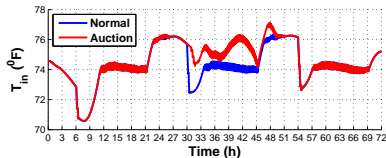
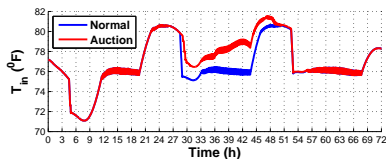
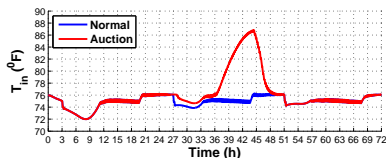
# Results – Inside Temperature

## 3 House Simulation Results

- Same simulation as previous
- Each figure shows inside temperature for one house
- Comparison with and without auction

## Inside Temperature Comparison

- Different responses due to different neutral factor
- Inside temperature deviates before price change
  - ▶ Mainly due to inaccurate power estimate



# Conclusion

## Systemic Control Results

- Cost limiting demand curve enables price response
- Cost Constraint Mechanism is fast, efficient, and game proof

## Local Control Results

- Low-Frequency PWM simplifies power control
- Synchronization allows for systemic control

## Future Work

- Vehicle-to-Grid
- Decentralized Control
- Micro-Grids with Responsive Loads
- Electricity Hedging for “Real” Real-Time Pricing

# For More Information

## **Project**

<http://response.berkeley.edu>

## **William Burke**

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# Bibliography

Milner, J. (2006). *Avian flu pandemic simulation*.

(<http://jeffmilner.com/index.php/2006/04/08/avian-flu-pandemic-simulation/>)