System Reliability and Price Responsiveness of Residential Loads

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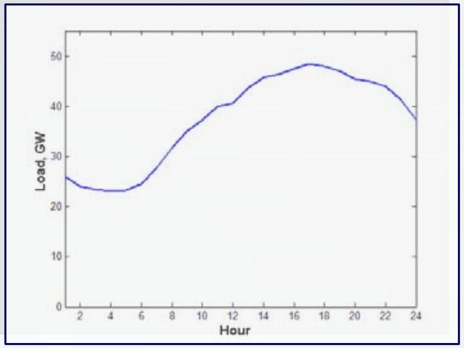
Outline of Talk

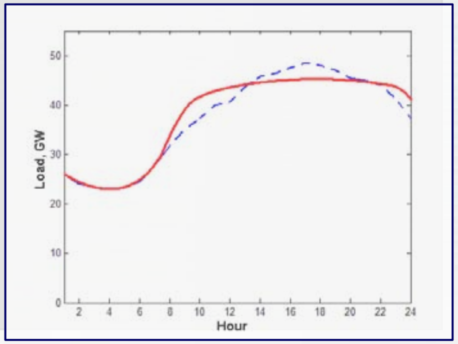
I. Computer-Aided Home Energy Management System (CAHEM)
   A. CAHEM Design
   B. Simulations of its Effects on Load

II. Market and System Effects of Residential Sector Price-Responsiveness
   A. Effect if Supplier Behavior is Unchanged
   B. Effect of PRRL on Behavior of Suppliers
   C. Multi-Agent Simulation of Market
   D. Assessment of Net Effects on Market:
      1. Price Levels
      2. Reserve Margin

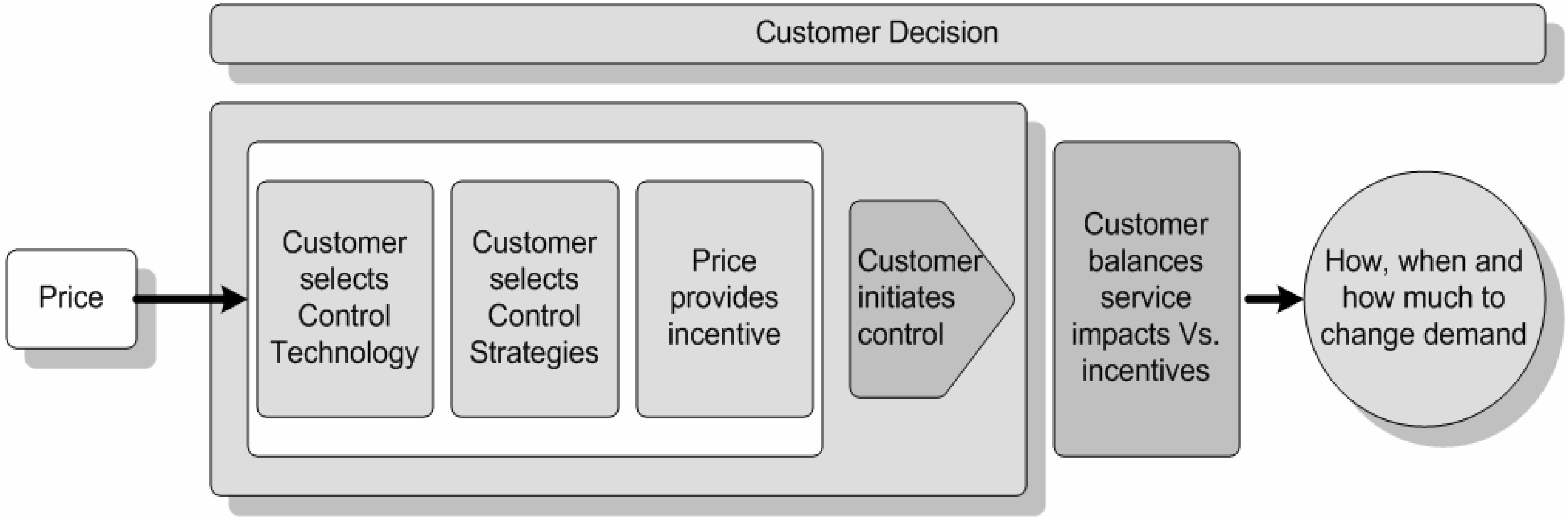
Computer Aided Home Energy Management



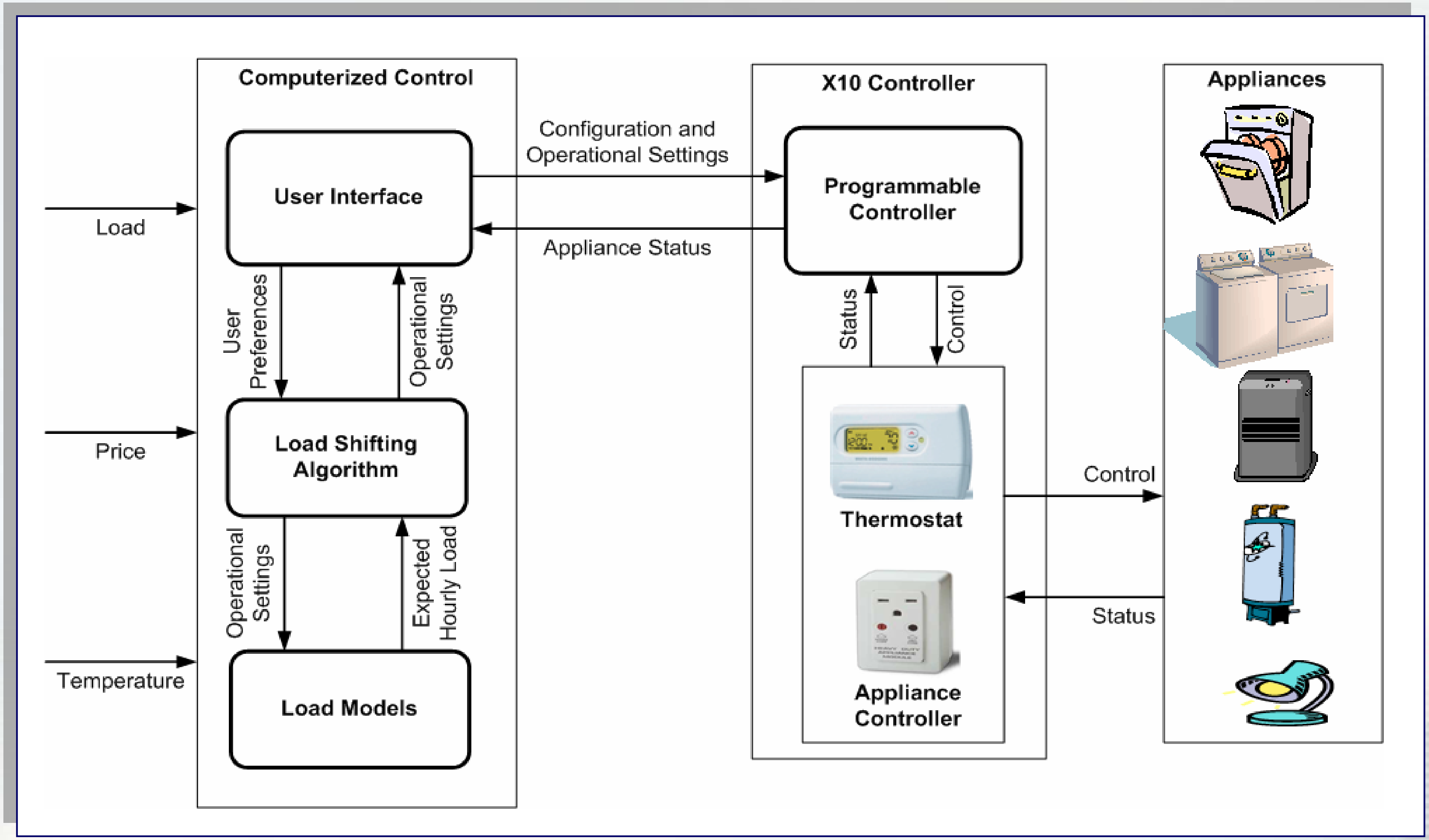
CAHEM



Increased Customer Choice



CAHEM Block Diagram



Load Models – Air Conditioner

‘**Cooling Load**’ is the thermal energy that must be removed from the interior of a house in order to maintain desired comfort conditions, specified by interior dry-bulb temperature.

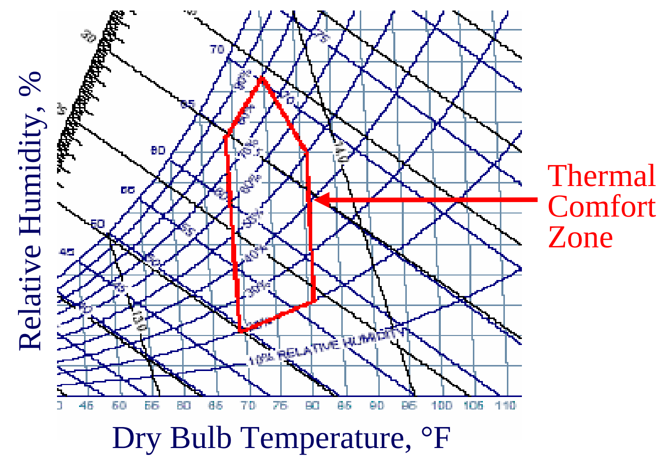
- **Dynamic cooling load calculations** to characterize the effects of thermostat setback/setup
- **Hourly** cooling load calculations

Assumptions:

- **Single-family detached house with single cooling zone** with uniform room temperature
- **No humidity control**
- Each component of a house envelope (including **walls, roof, and windows**) is **uniform**
- **No independent thermal storage**

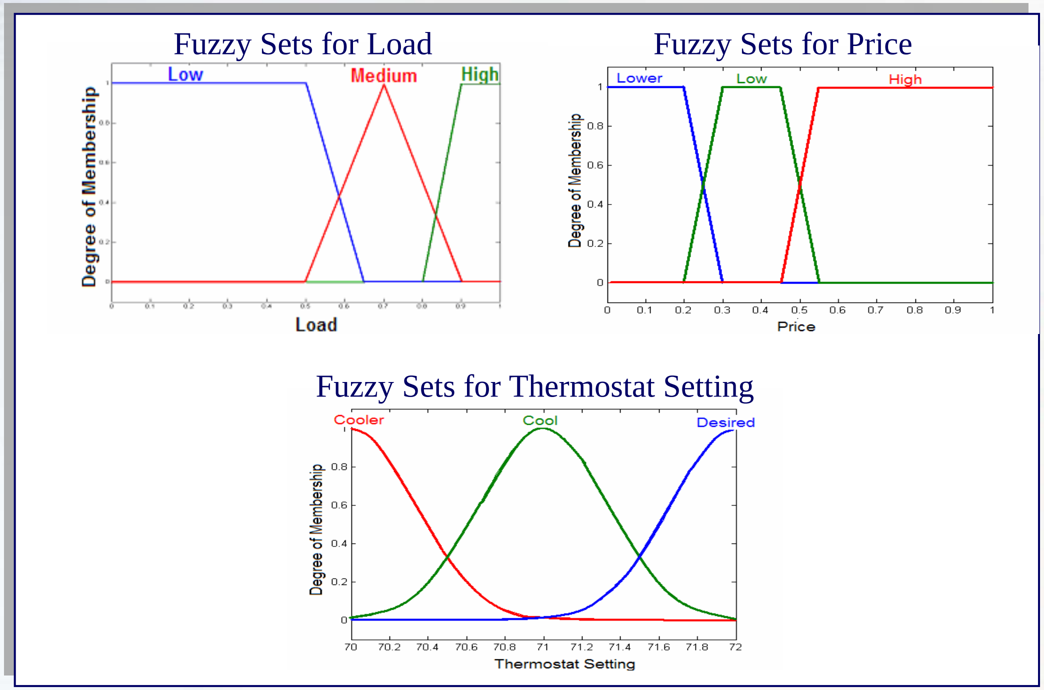
Thermal Comfort*

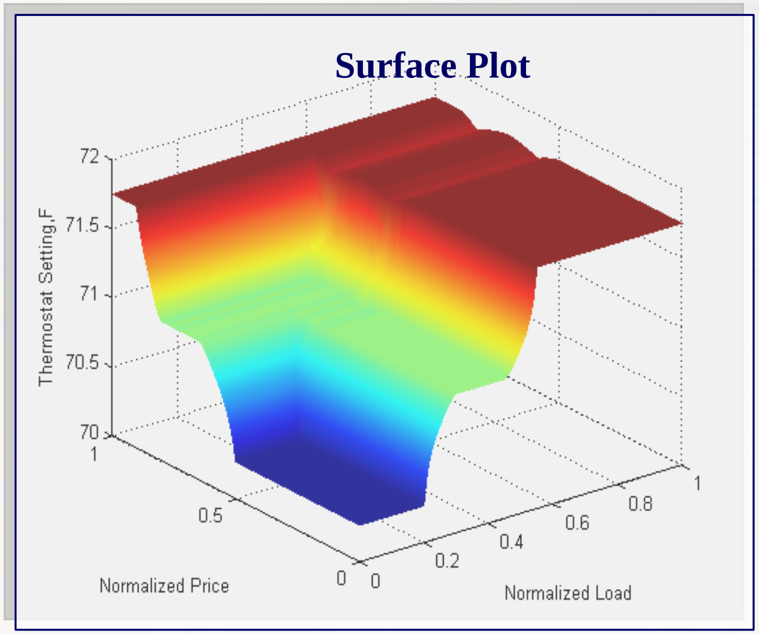
Psychometric Chart



* Specified by American Society for Heating Refrigerating and Air-Conditioning Engineers (ASHRAE)

Fuzzy Logic Load Control





Fuzzy Rules

1. If *load* is *high*, then the *thermostat setting* is at *desired*.
2. If *load* is *medium* and *price* is *high*, then the *thermostat setting* is at *desired*.
3. If *load* is *low* and *price* is *high*, then the *thermostat setting* is at *desired*.
4. If *load* is *medium* and *price* is *not high*, then the *thermostat setting* is *cool*.
5. If *load* is *low* and *price* is *low*, then the *thermostat setting* is *cool*.
6. If *load* is *low* and *price* is *lower*, then the *thermostat setting* is *cooler*.

Simulation Data

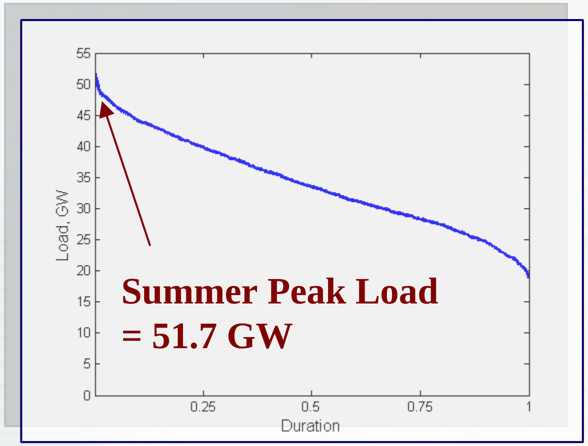
Pennsylvania-New Jersey-Maryland (PJM) Market

Simulation Duration:

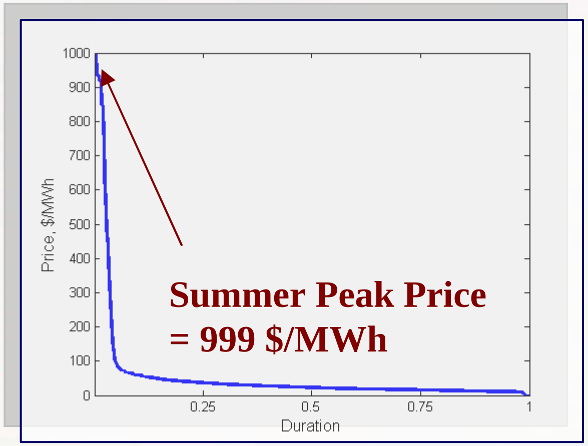
June 1,1999 – August 31, 1999

Generation Capacity: 55 GW

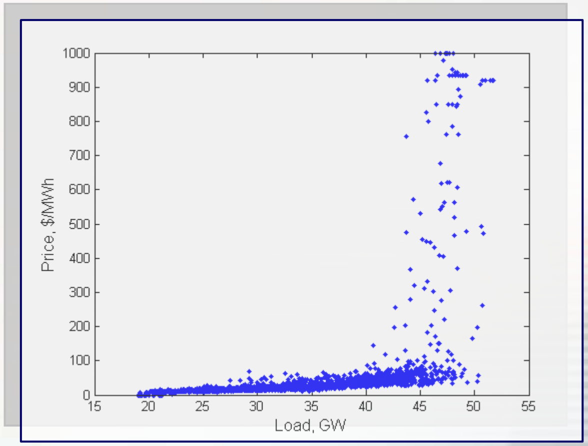
Load Duration Curve



Price Duration Curve

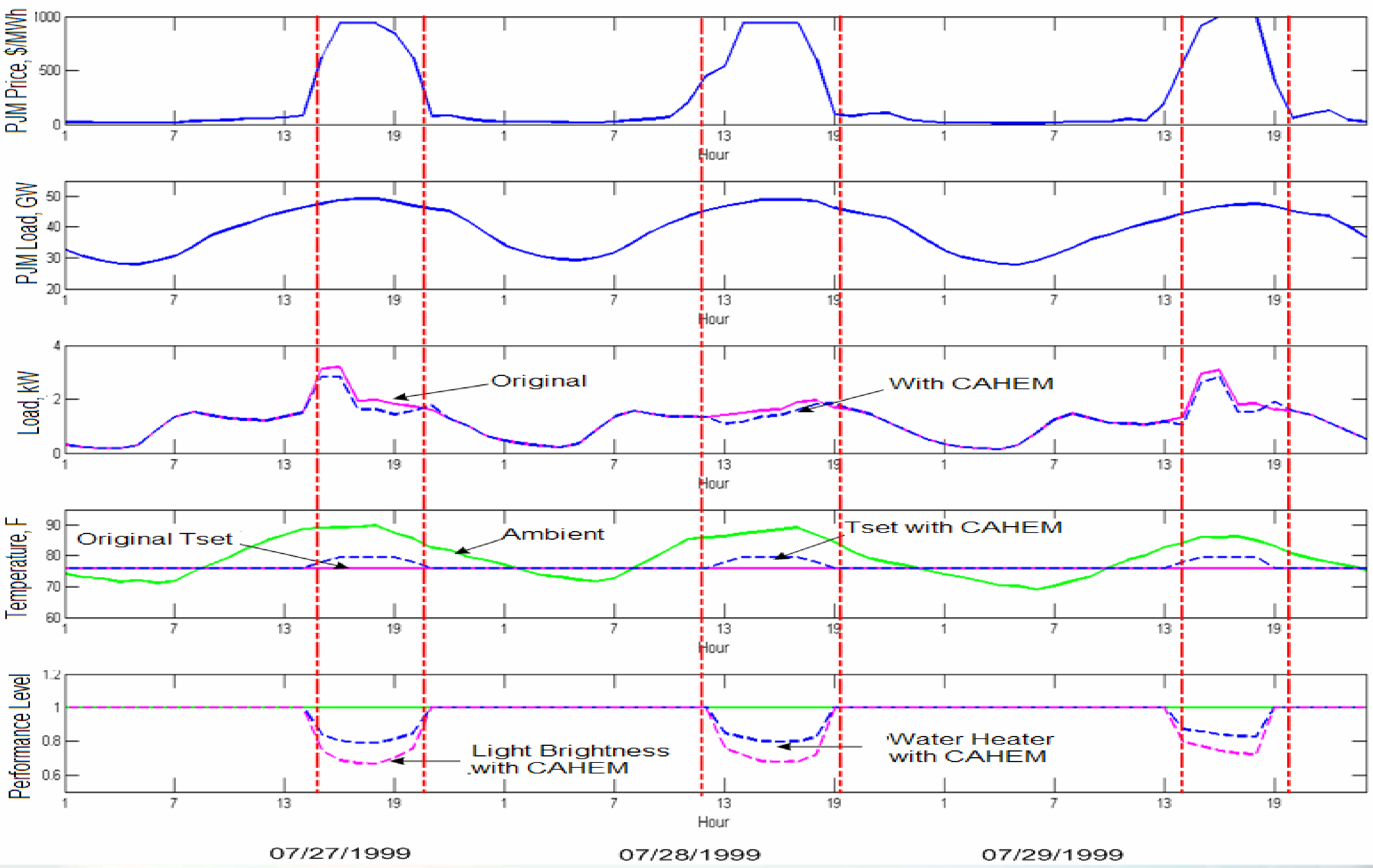


Offer Curve

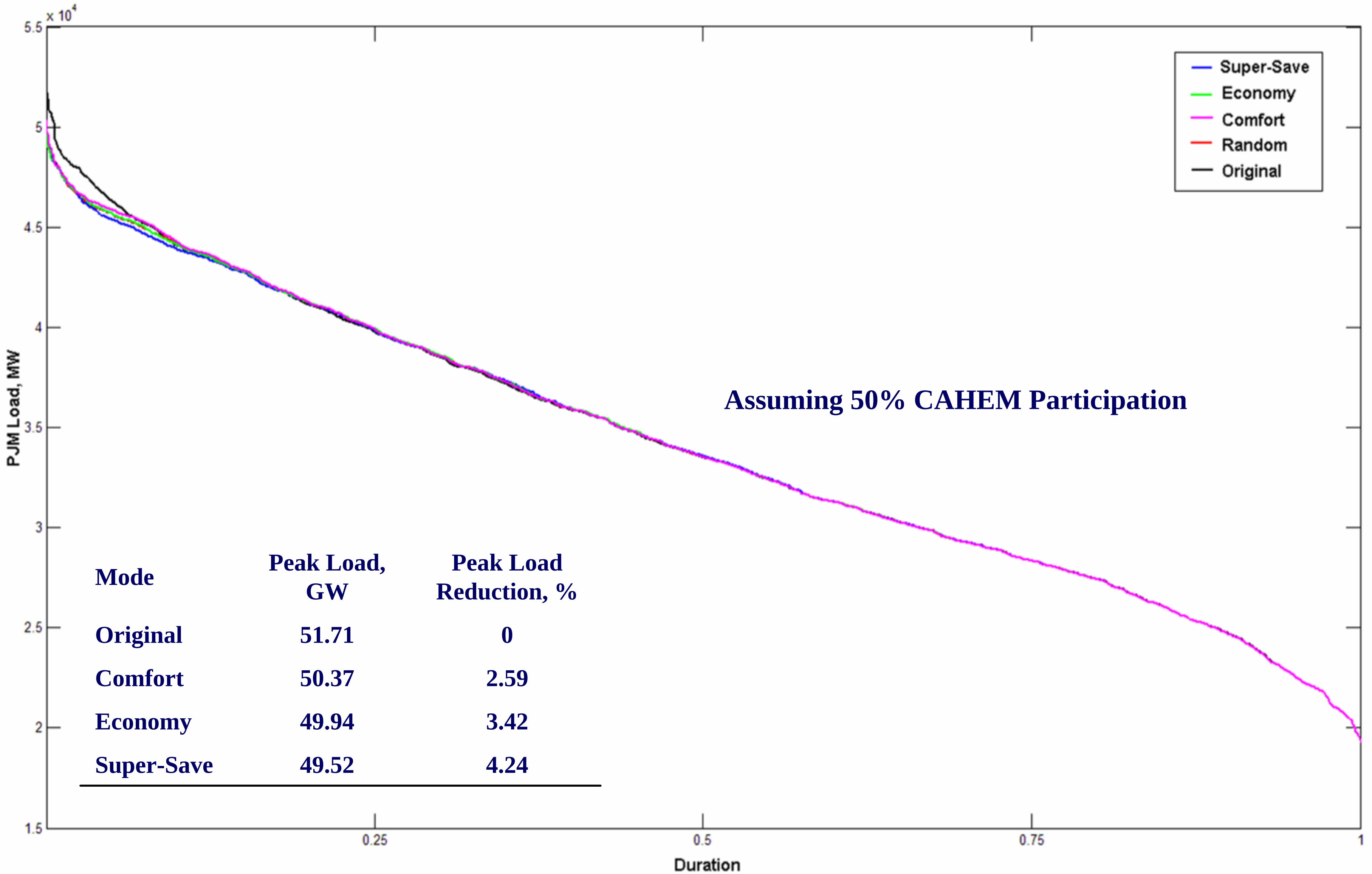


Individual House-Level Results

Hour-Ahead Notification



Peak Load Reduction



Mode	Peak Load, GW	Peak Load Reduction, %
Original	51.71	0
Comfort	50.37	2.59
Economy	49.94	3.42
Super-Save	49.52	4.24

Impact of PRL on Supplier Offer Strategy

$$\underset{P}{Max}\ P \cdot [D(P,e) - S^j(P)] - C(D(P,e) - S^j(P))$$

Optimum Offer : $P = C'(\cdot) + \dfrac{Q_i}{S'^j(P) - D'(P,e)}$,where $D'(P) \leq 0$

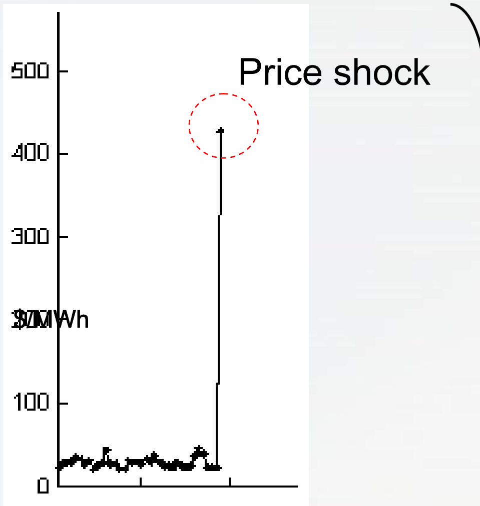
PRL ➔ *D'(P)* < 0 ➔ optimum offer Price decreases.
So, PRL mitigates suppliers' mark-up pricing behavior

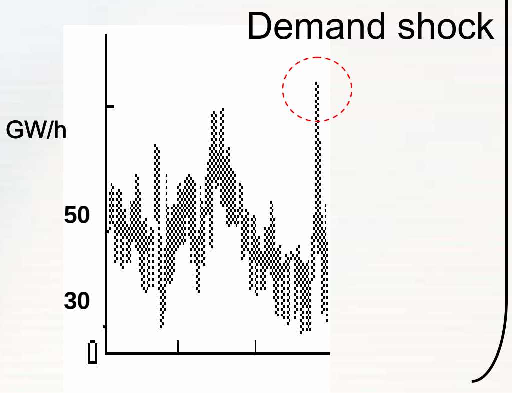
How Does PRL Affect Capacity Withholding Behavior? –
1) Reduces Market Power → Less Price Manipulation
2) PRL Decreases Price Spikes (and Expected Revenues)
→ More Generation Withheld due to Standby Costs.

Multi-Agent Simulation

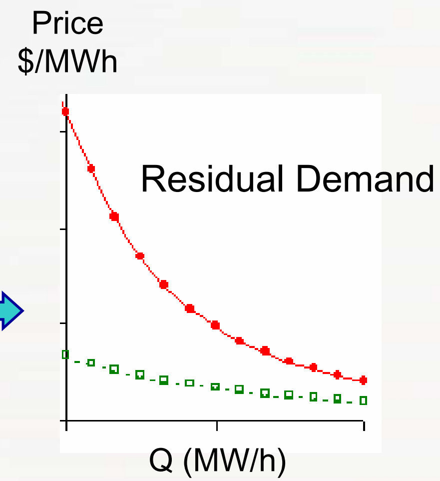
Supplier Agent Learning and Decision Algorithms

Last market outcome





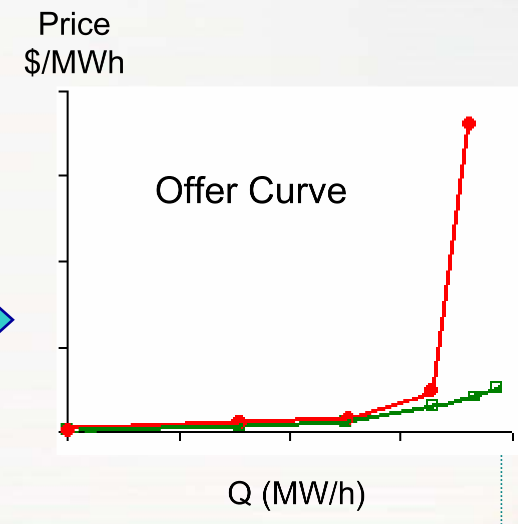
Update the residual demand curve



$$P_t = f(Q_t \mid \beta_t, D_t)$$

By Kalman Adaptive Learning

Determine the optimum offers

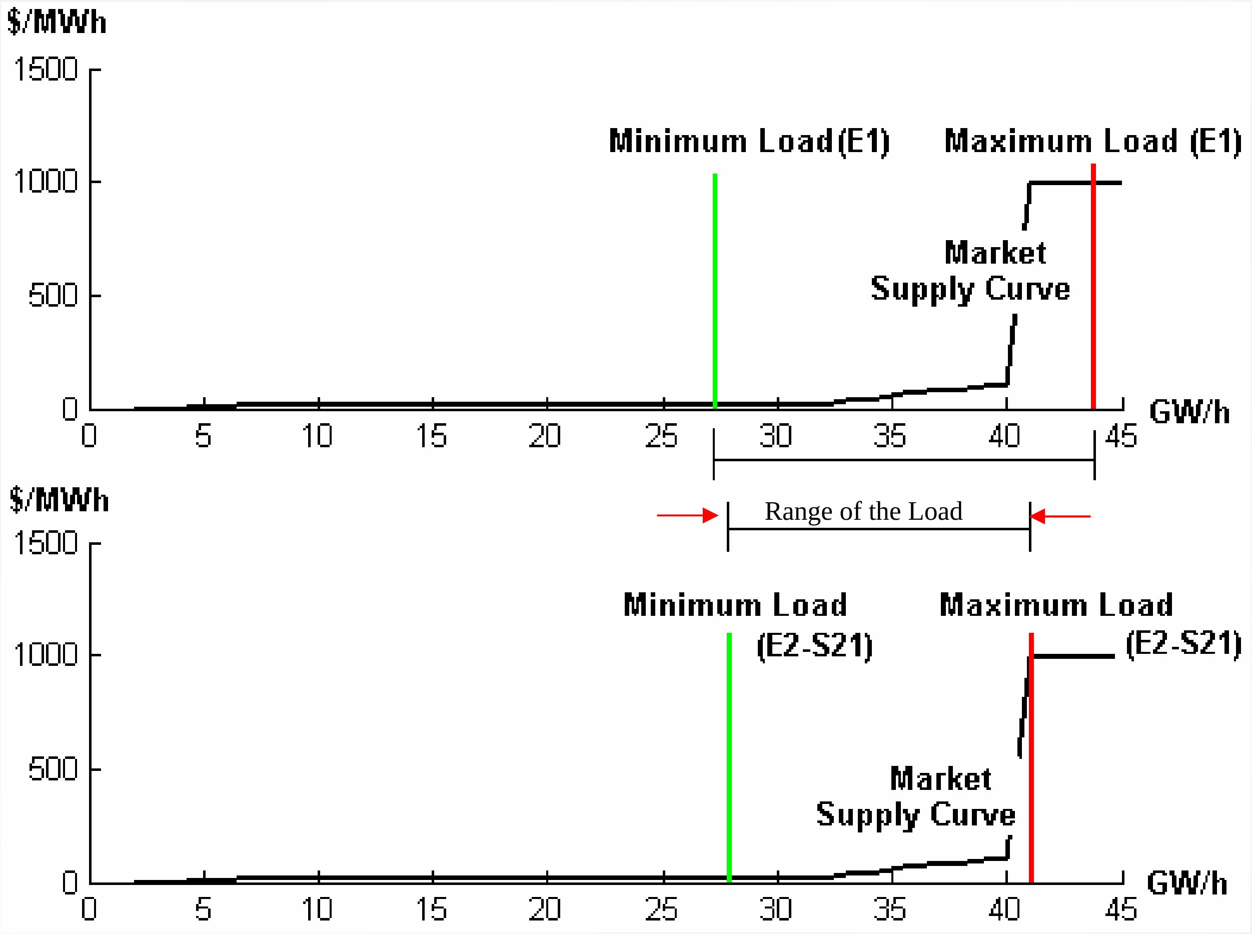


By Maximizing E[Profits]

Multi-Agent Market Simulation Scenarios

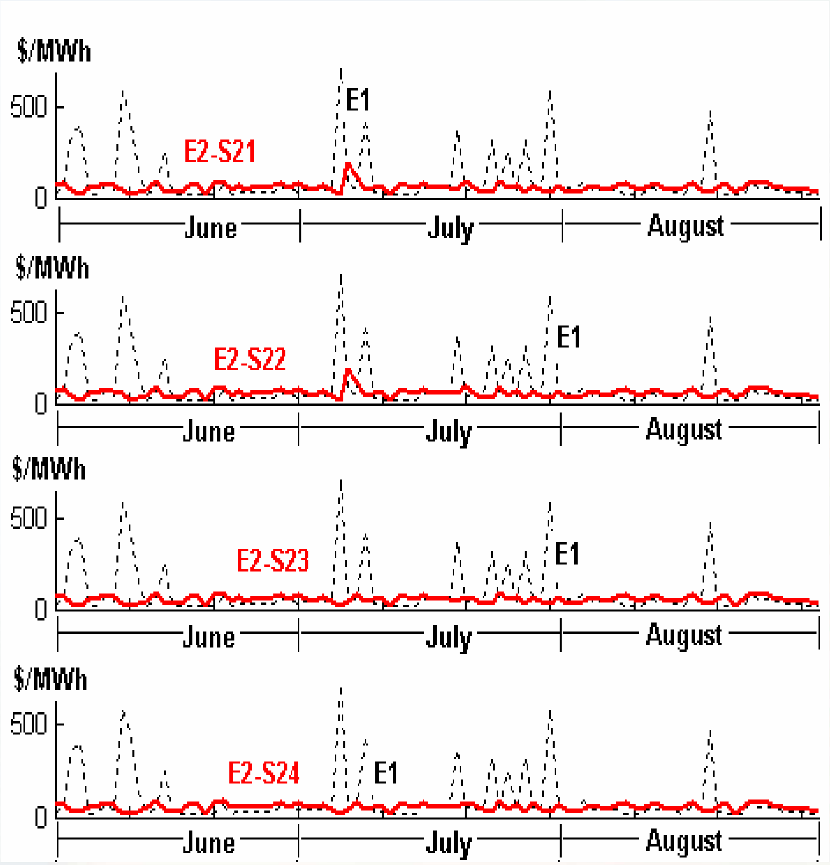
Base Scenarios	**E0: Perfectly Competitive Market**			
	E1: Oligopolistic Base Scenario			
PRL Scenarios	**E2: Naive Suppliers**		**E3: Strategic Suppliers**	
	$500 Threshold Price	**$300 Threshold Price**	**$500 Threshold Price**	**$300 Threshold Price**
Low PRL Penetration (20%)	S21	S22	S31	S32
High PRL Penetration (40%)	S23	S24	S33	S34

Simulation: PRL Management Reduces Load

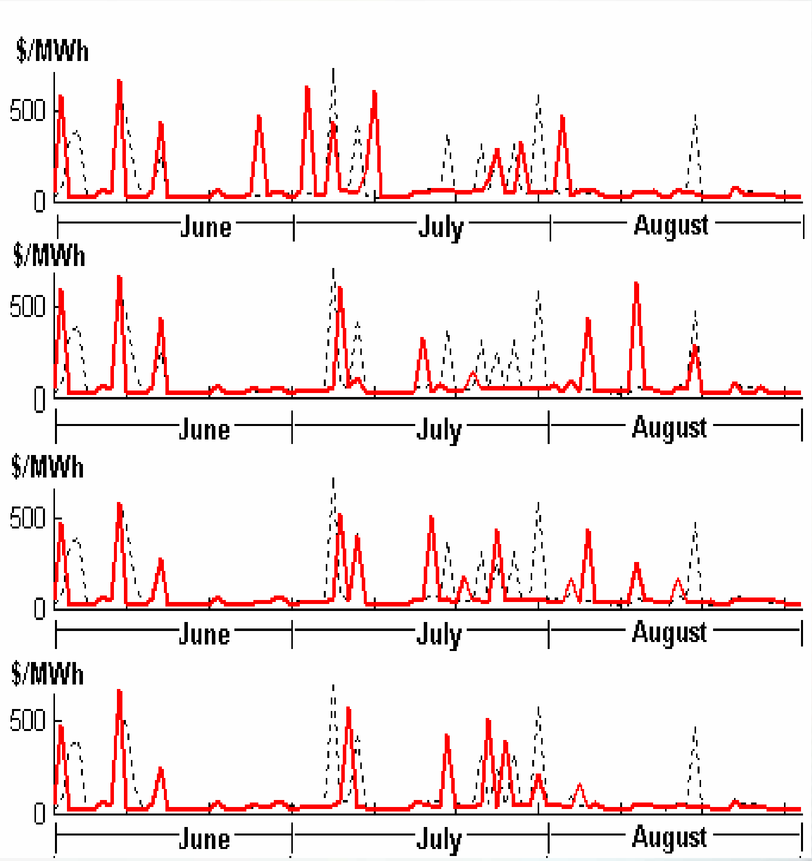


Simulation Results: Effect of PRL on Price Spikes

Naive Suppliers (E2)

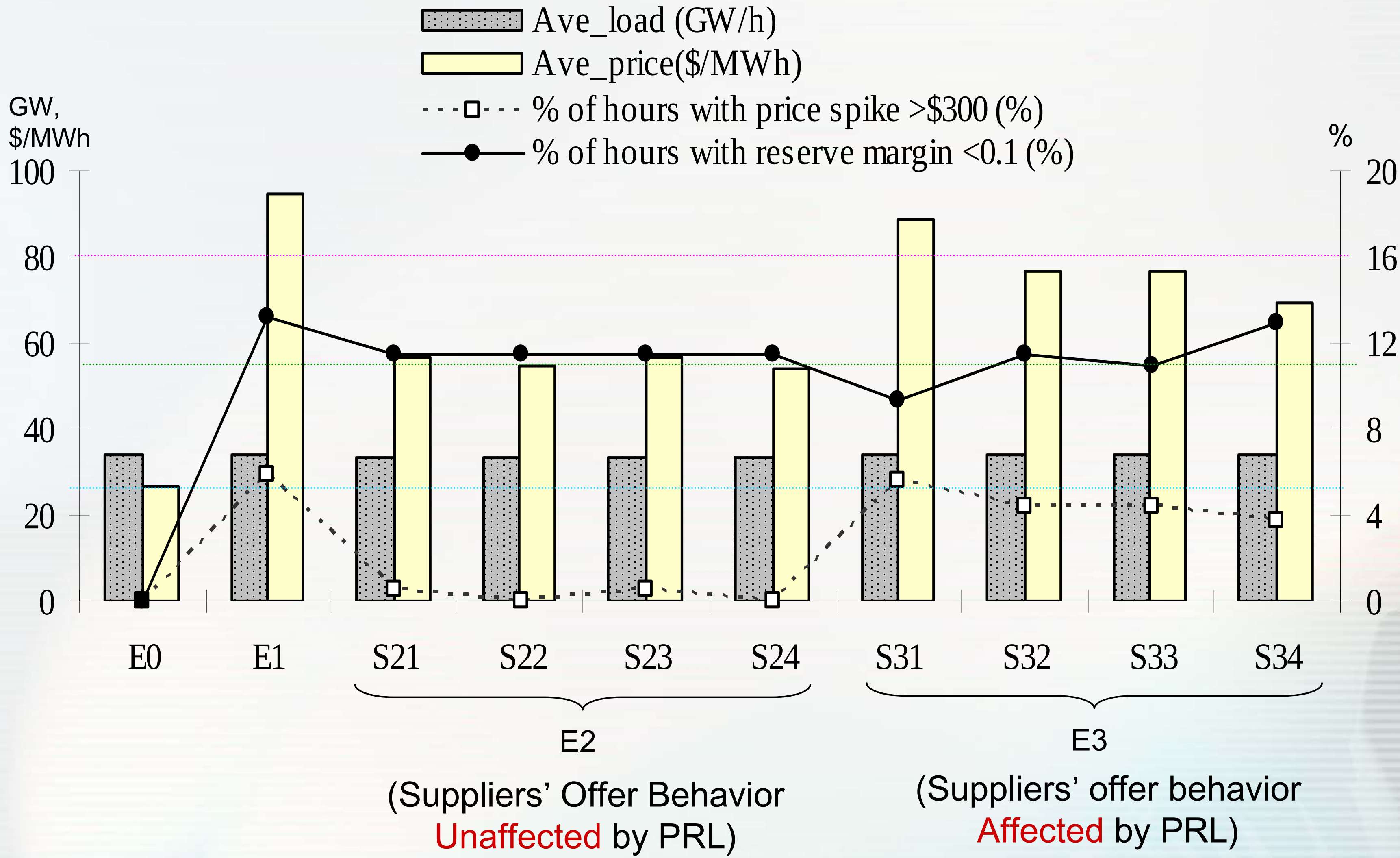


Strategic Suppliers (E3)



Simulation Results

Prices, Spikes, and Reserve Margins



Summary and Conclusions

- A Residential PRL System Can:
  - Reduce price spikes
  - Reduce Average Prices
  - Improve Reliability

But . . .

- Rational Sellers Will React to PRL by Reducing Generation Capacity Availability
  - Strategic Response Reduces Benefits of PRL Program
  - Price spikes, low capacity margins return (though weaker)
- Penetration Rates and Aggressiveness of Price Responsiveness Affect this Tradeoff
- Decline in Local Generation Capacity Availability May Increase Stress on Transmission System, Despite Lower Overall Loads

Policy Conclusions

- Initiate Price-Responsive Reactions at Relatively Low Prices.
- Carefully Monitor Aggressive PRL Programs for Seller Response.
- Sellers May Respond to PRL by Reducing Capacity Offers (Decline in Local Supply).
- Decline in Local Supply May Increase Stress on Transmission System, Despite Lower Overall Loads.
- Current Real-World PRL programs are unlikely to do much harm (or good) because of low penetration rates.

Preliminary MAS Simulation Results

		Ave_Load (GW)	Ave_Price ($/MWh)	% of time w/ Price Spikes >$300/MWh	% of time w/ Reserve Margin <10%	Avg_Cost $million (** compared to E1)
Actual		34.0	53.7	3.5	N.A.	4,031
E0 (Efficient case:No PRL)		34.0	26.6	0.0	0.0	1,997
E1 (Base case:No PRL)		34.0	94.7	5.9	13.1	7,109
E2: PRL, Naïve Sellers	S21 (0.2, $500) Low-Pen, Modest	33.5 (-1.5%)**	57.0 (-39.8%)**	0.5 (-90.8%)**	11.5 (-12.8%)**	4,216 (-40.7)**
	S22 (0.2, $300) Low-Pen, Aggressive	33.5 (-1.5%)**	54.5 (-39.8%)**	0.0 (-100%)**	11.5 (-12.4%)**	4,031 (-43.3%)**
	S23 (0.4, $500) Hi-Pen, Modest	33.4 (-1.8%)**	57.0 (-42.5%)**	0.5 (-90.8%)**	11.5 (-12.8%)**	4,204 (-40.9%)**
	S24 (0.4, $300) Hi-Pen, Aggressive	33.4 (-1.8%)**	54.3 (-42.7%)**	0.0 (-100%)**	11.5 (-12.4%)**	4,004 (-43.7%)**
E3: PRL, Strategic Sellers	S31 (0.2, $500) Low-Pen, Modest	33.9 (-0.3%)**	88.4 (-6.7%)**	5.6 (-6.1%)**	9.4 (-28.6)**	6,617 (-6.9%)**
	S32 (0.2, $300) Low-Pen, Aggressive	34.0 (0%)**	77.0 (-18.7%)**	4.4 (-25.2%)**	11.5 (-12.8%)**	5,781 (-18.7%)**
	S33 (0.4, $500) Hi-Pen, Modest	33.9 (-0.3%)**	76.8 (-%)**	4.3 (-26.7%)**	10.9 (-17.2%)**	5,749 (-19.1%)**
	S34 (0.4, $300) Hi-Pen, Aggressive	33.9 (-0.3%)**	69.2 (-%)**	3.8 (-36.6%)**	13.0 (-1.4%)**	5,180 (-27.1%)**