# Demand Response as a Substitute for Electric Power System Infrastructure Investments

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# Agenda

- Overview
- Potential for Residential Demand Response
- Thermal Storage Example
- Substitution for Capacity Investments
  - Generation Capacity Example
  - Simple 3-node Transmission Example
- Future Research

# Potential for DR

- Electricity Demand is Indirect
- Current System designed for Exogenous Demand
- Three Types of Demand -
  - Power: immediate/no delay (lights, TVs, etc)
  - Deferrable Power: Can be delayed for short time periods
  - Energy/Thermal: Indifferent to time of consumption

# Potential for Residential DR

- Thermal Demand (>50% of household demand)
  - AC (>20%)
    - >30% of total peak demand (including commercial AC)
  - Hot Water (~20%)
  - Refrigeration (~10%)
- Deferrable Demand (> 5%)
  - Washer
  - Dryer
  - Dishwasher

# Thermal Storage

- Use Temperature to “store” electricity
  - Controlled cycling of thermal loads
  - Pre-heat or pre-cool
  - Maintain consumer comfort
  - Reduce peak loads
  - Minimize costs

# Thermal Storage Example

- AC control
- Assumes RTP
- Uses PJM Data (Price, Load, Supply, Temp)
- Assumes 2 °F temperature deviations from set point with no loss of comfort (ASHRAE)

# Thermal Storage Example

$$Min_e C_{ac} = \sum_i P_i * q_i$$

**s.t.**

$$0 \le q_i \le q^{\max}$$

$$T^{\min} \le T_i \le T^{\max}$$

Where:

$T^{min} = T^{ideal} - d$, $T^{max} = T^{ideal} + d$

d = Acceptable temperature deviation

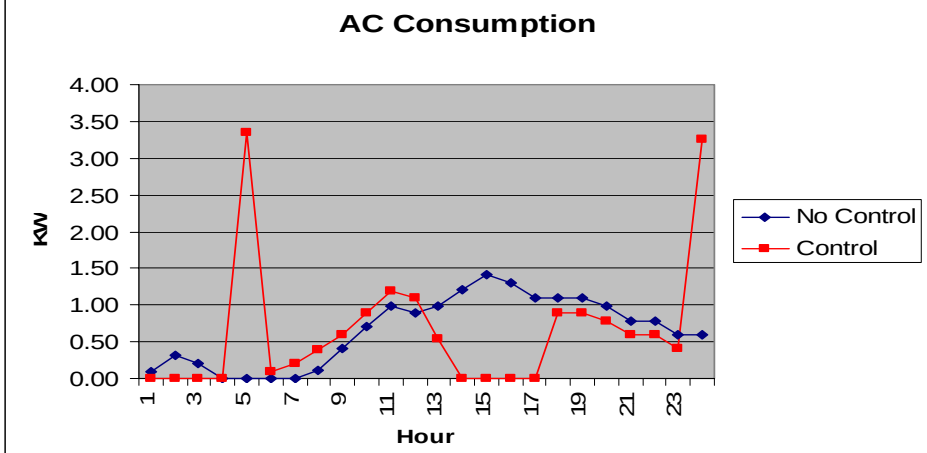
$q_i$ - energy (kWh) consumed in hour i.

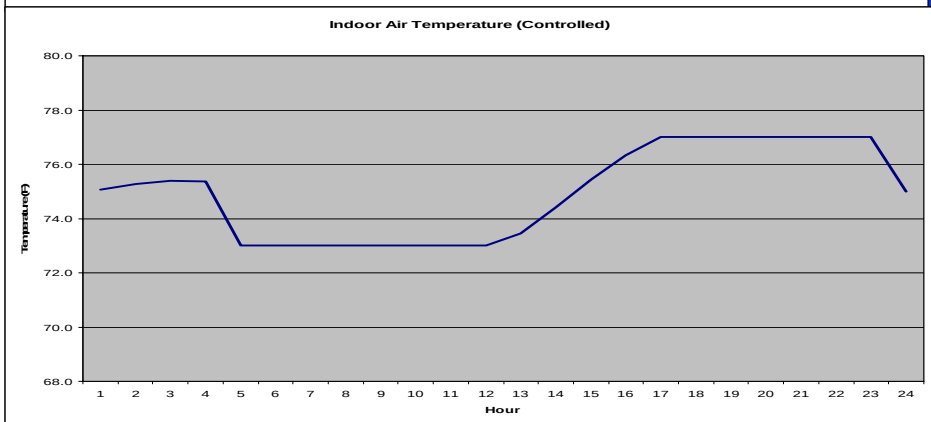
$P_i$ - price of electricity ($/kWh) in hour i.

$$T_{i+1} = \varepsilon T_i + (1- \varepsilon)(T^o - \eta * q_i / A)$$

# Thermal Storage Example

| Date | 8-Jul-03 | | Normal Cycling | | | Load Control | | |
|---|---|---|---|---|---|---|---|---|
| Hr | Price ($/MWh) | Temp (outside) | Temp (inside) | Output (KWh) | Cost (mils) | Temp (inside) | Output (KWh) | Cost (mils) |
| 1 | $ 32.43 | 76 | 75.0 | 0.09 | 2.92 | 75.1 | 0.00 | 0.00 |
| 2 | $ 24.23 | 78 | 75.0 | 0.31 | 7.51 | 75.3 | 0.00 | 0.00 |
| 3 | $ 22.34 | 77 | 75.0 | 0.20 | 4.47 | 75.4 | 0.00 | 0.00 |
| 4 | $ 21.43 | 75 | 75.0 | 0.00 | 0.00 | 75.4 | 0.00 | 0.00 |
| 5 | $ 21.41 | 75 | 75.0 | 0.00 | 0.00 | 73.0 | 3.35 | 71.65 |
| 6 | $ 23.45 | 74 | 74.9 | 0.00 | 0.00 | 73.0 | 0.09 | 2.11 |
| 7 | $ 30.55 | 75 | 74.9 | 0.00 | 0.00 | 73.0 | 0.20 | 6.11 |
| 8 | $ 39.65 | 77 | 75.0 | 0.10 | 4.16 | 73.0 | 0.40 | 15.86 |
| 9 | $ 49.66 | 79 | 75.0 | 0.40 | 19.86 | 73.0 | 0.60 | 29.80 |
| 10 | $ 58.45 | 82 | 75.0 | 0.70 | 40.92 | 73.0 | 0.90 | 52.61 |
| 11 | $ 68.55 | 85 | 75.0 | 0.99 | 67.86 | 73.0 | 1.19 | 81.57 |
| 12 | $ 82.31 | 84 | 75.0 | 0.90 | 74.08 | 73.0 | 1.10 | 90.55 |
| 13 | $ 92.16 | 85 | 75.0 | 0.99 | 91.24 | 73.5 | 0.53 | 48.98 |
| 14 | $ 105.32 | 87 | 75.0 | 1.21 | 127.44 | 74.4 | 0.00 | 0.00 |
| 15 | $ 113.13 | 89 | 75.0 | 1.41 | 159.51 | 75.4 | 0.00 | 0.00 |
| 16 | $ 118.23 | 88 | 75.0 | 1.30 | 153.70 | 76.3 | 0.00 | 0.00 |
| 17 | $ 126.77 | 86 | 75.0 | 1.10 | 139.44 | 77.0 | 0.00 | 0.00 |
| 18 | $ 118.94 | 86 | 75.0 | 1.10 | 130.84 | 77.0 | 0.90 | 107.05 |
| 19 | $ 93.85 | 86 | 75.0 | 1.10 | 103.23 | 77.0 | 0.90 | 84.46 |
| 20 | $ 83.79 | 85 | 75.0 | 0.99 | 82.95 | 77.0 | 0.79 | 66.19 |
| 21 | $ 79.89 | 83 | 75.0 | 0.79 | 63.11 | 77.0 | 0.59 | 47.13 |
| 22 | $ 69.03 | 83 | 75.0 | 0.79 | 54.53 | 77.0 | 0.59 | 40.73 |
| 23 | $ 48.95 | 81 | 75.0 | 0.60 | 29.37 | 77.0 | 0.40 | 19.58 |
| 24 | $ 43.72 | 81 | 75.0 | 0.60 | 26.23 | 75.0 | 3.26 | 142.39 |
| Totals - | | | | 15.67 | 1,383.38 | | 15.79 | 906.77 |



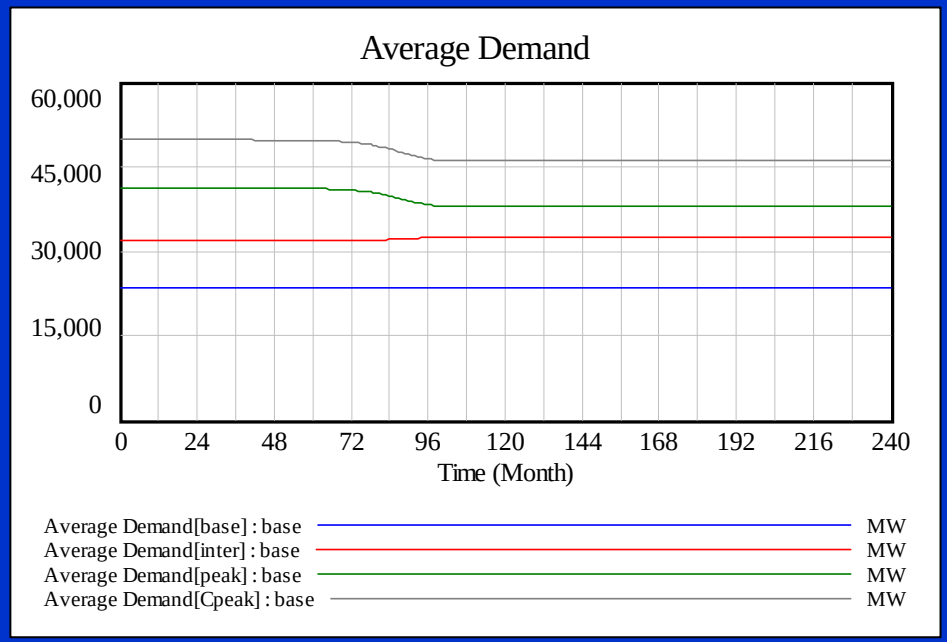



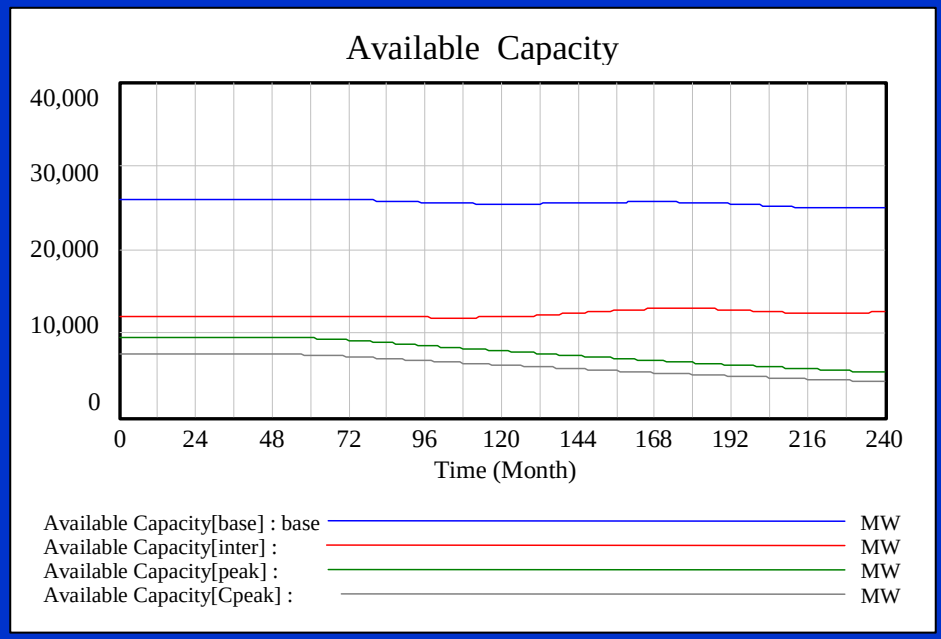

**88% reduction in Peak Demand, 33% reduction in Costs**

# Substitution for Capacity Investments

- Evaluation of DR potential should include Reductions in:
  - Generation Capacity
  - Reserves/Ancillary Services
  - LMP
  - Transmission and Distribution Investments

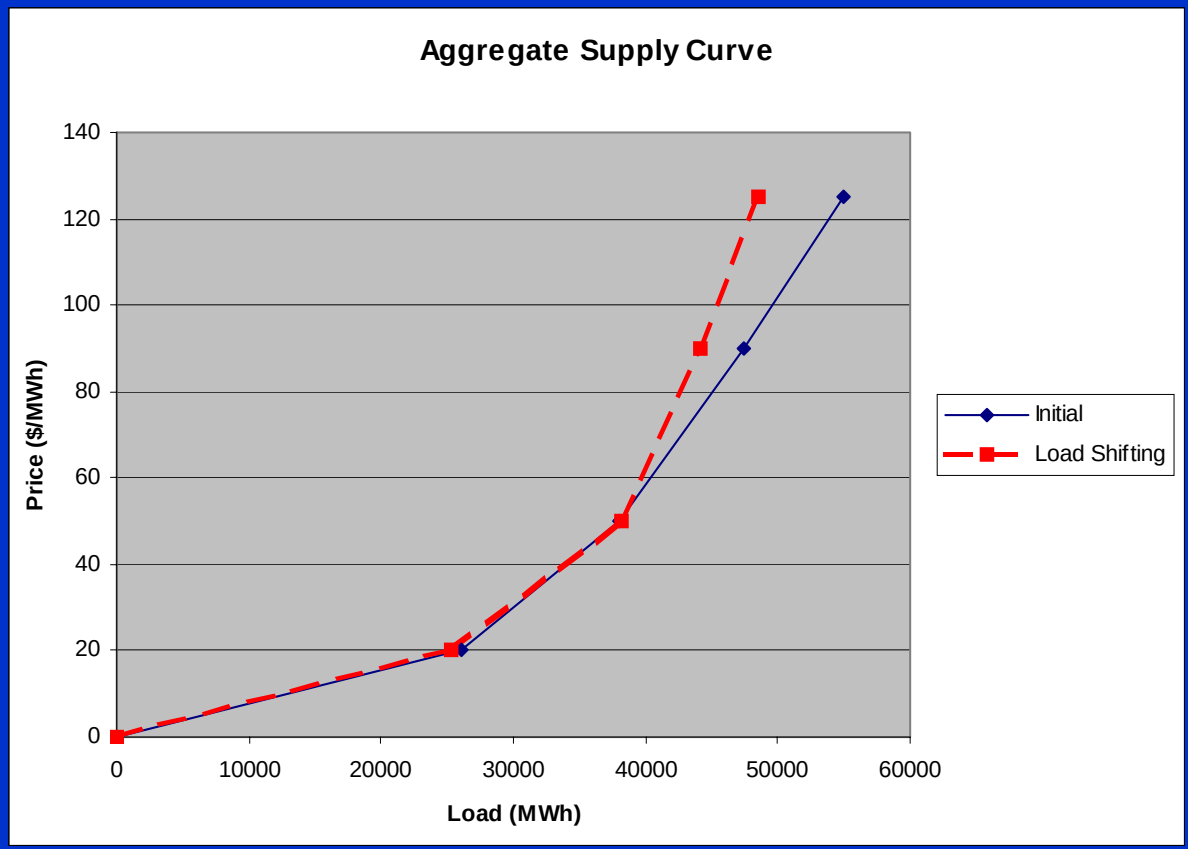
# Generation Capacity Example



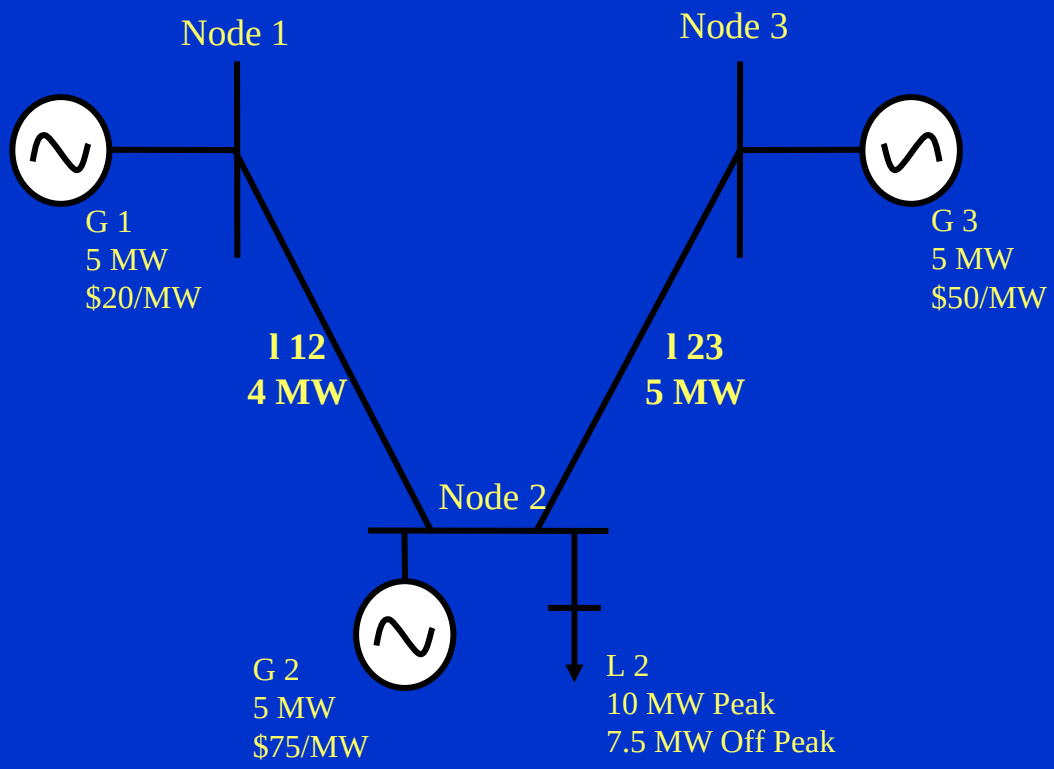




- Preliminary Results:
  - –Adoption by 25% of households yields:
  - –8% reduction in peak demand
  - –12% reduction in System Gen Capacity

# Generation Capacity Example



# 3 Node Transmission Example




No DR:
Peak Price $75/MWh
N-1 Violated: 1MW capacity needed

With DR (10%):
Price $50/MWh
N-1 satisfied

# Future Research (Engineering)

- Transient Stability
- Effects on Efficiency from Controlled Cycling
- Development of Control Schemes
  - Cost Effect, Acceptable, Ease of Use
- Integration of DR into Ancillary Services
- Integration of DR into Protection Schemes
- Effects on Losses

# Future Research (Economics)

- Market Stability
- Potential for Needle Peaks
- Real Options value of DR
- Effects on Market Power
- Potential for Stranded Assets
- Determination of Rebound Effect
- Market Design and Incentives (Coordinated vs. Decentralized)

# Future Research (Policy)

- Status Quo Bias
- Effects of Subsidies and Information Programs
- Effects on Stakeholders
- Regulatory Capture
- Potential for Coalitions

# Conclusion

- Large Potential for DR
- Analysis should include dynamic effects on T&D, ancillary services, reliability, etc
- Further Research Necessary

# Questions??

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# Additional Slides

# ASHRAE Comfort Graph

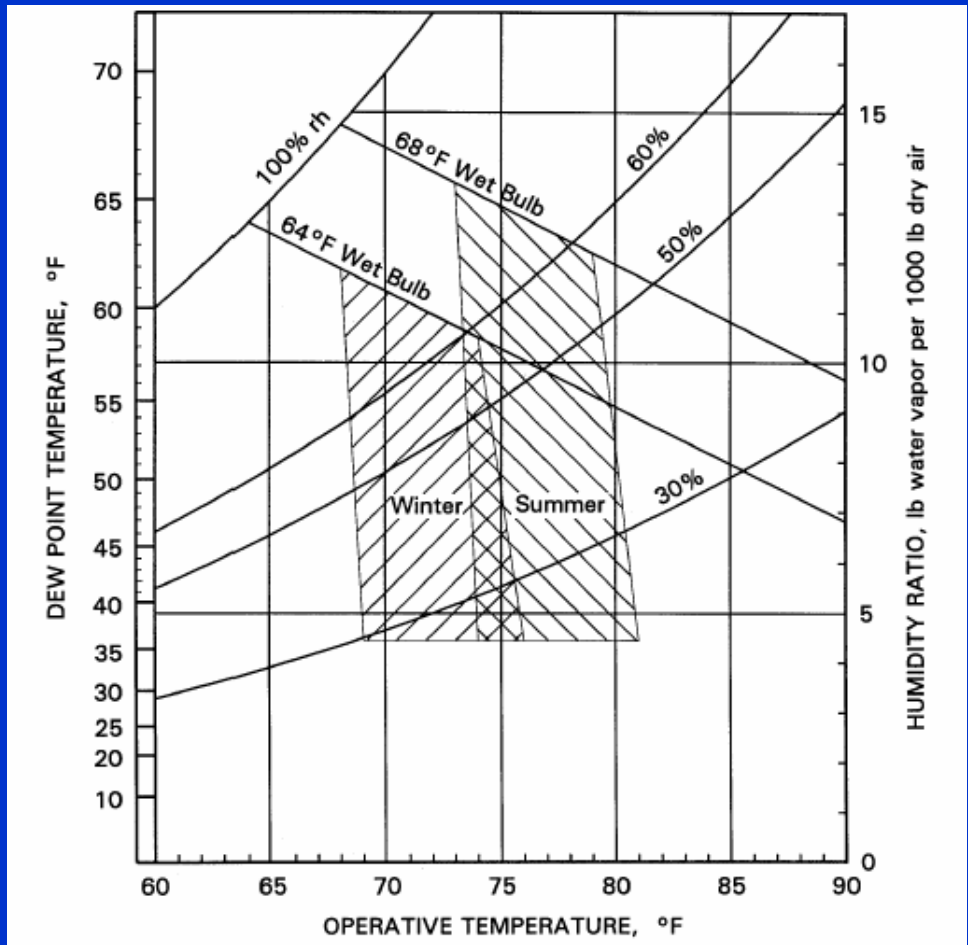


**Fig. 5 ASHRAE Summer and Winter Comfort Zones**
(Acceptable ranges of operative temperature and humidity for people in typical summer and winter clothing during primarily sedentary activity.)

# Generation Capacity Example

- Dynamic Model of aggregate affects on MCP and Generation Mix
- Preliminary Results:
  - Adoption by 25% of households yields:
  - 8% reduction in peak demand
  - 12% reduction in System Gen Capacity