Integrated Transmission and Distribution Effects of Demand-Side Participation

Auswin Thomas[a] and Leigh Tesfatsion[a,b]
Electrical & Computer Engineering[a] and Economics[b]
Iowa State University
{agthomas,tesfatsi}@iastate.edu

Panel Session: Wholesale and Retail Market Interaction Requirements for Effective Demand-side Participation

IEEE PES GM 2015, Denver, CO
30th July 2015

Presentation Outline

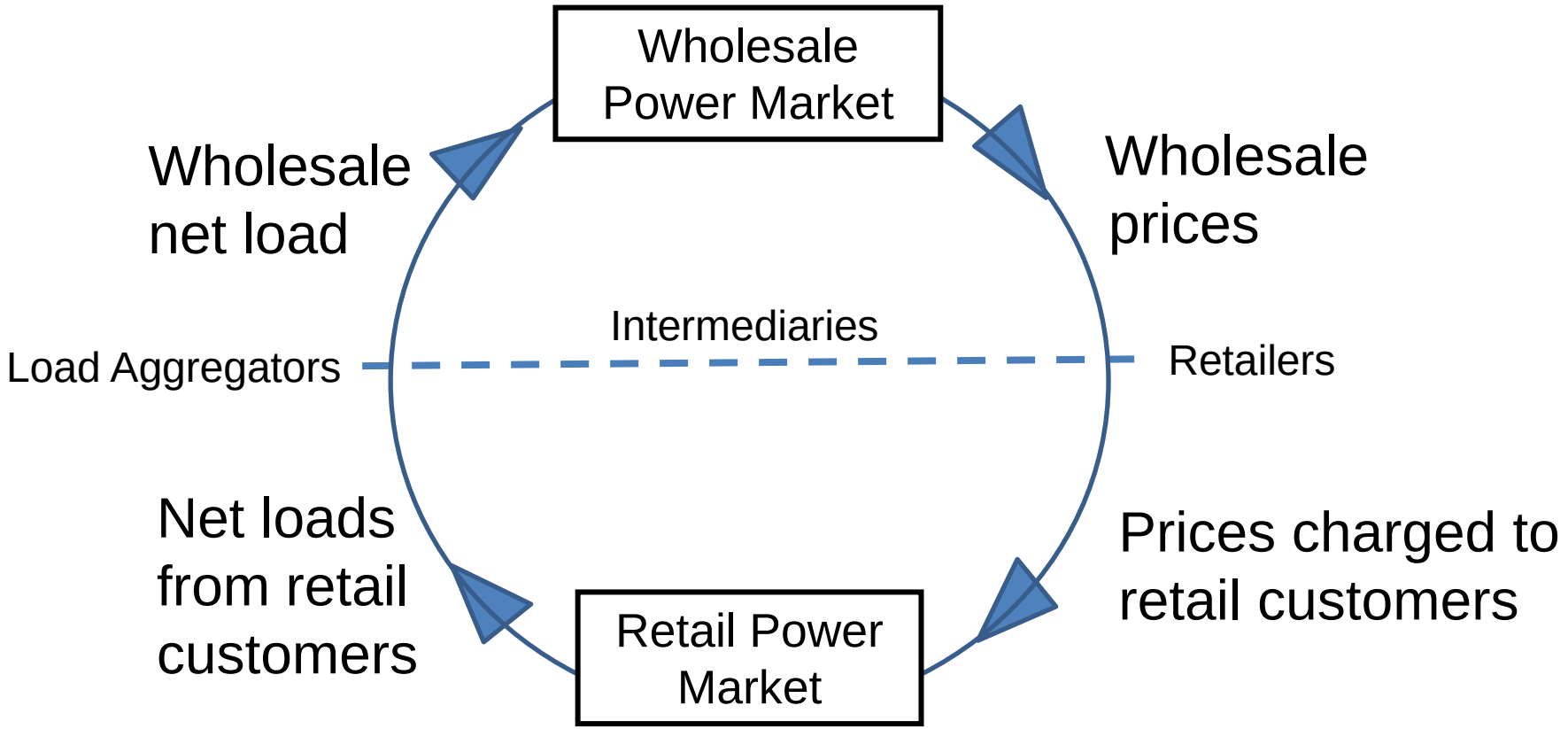
- Why an ***Integrated Retail and Wholesale (IRW)*** scope for ***Transactive Energy (TE)*** studies?
- An agent-based IRW platform suitable for TE studies

  IRW Test Bed: Homepage

  http://www2.econ.iastate.edu/tesfatsi/IRWProjectHome.htm
- The IRW Test Bed permits:
  - Agent-based modeling of complex IRW interactions among physical devices, transaction rules/regulations, & human participants
  - Testing for efficient and reliable IRW system operations
  - Testing for unintended adverse consequences (e.g., gaming opportunities, dynamic instabilities from IRW feedback loop effects)
- Illustrative IRW-TE test case: Demand response

Why an IRW Scope for TE Studies?

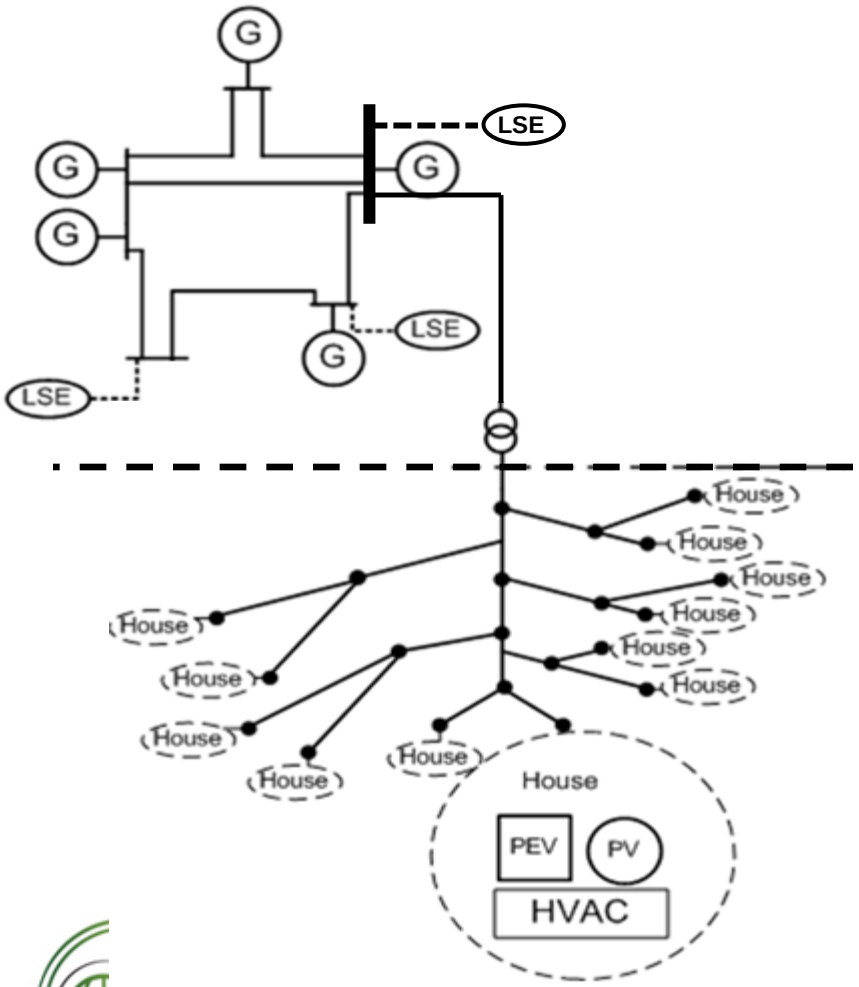
Energy transactions typically form an IRW Feedback Loop:



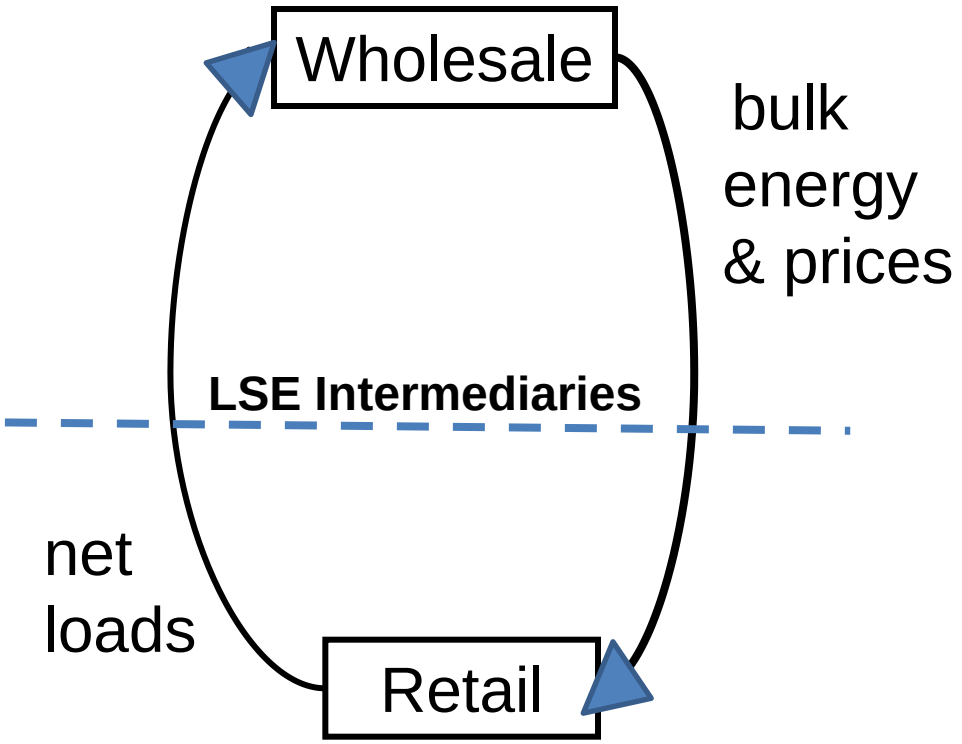
IRW Test Bed = AMES + Distribution Feeders

http://www2.econ.iastate.edu/tesfatsi/IRWProjectHome.htm

5-Bus 1-Feeder Example

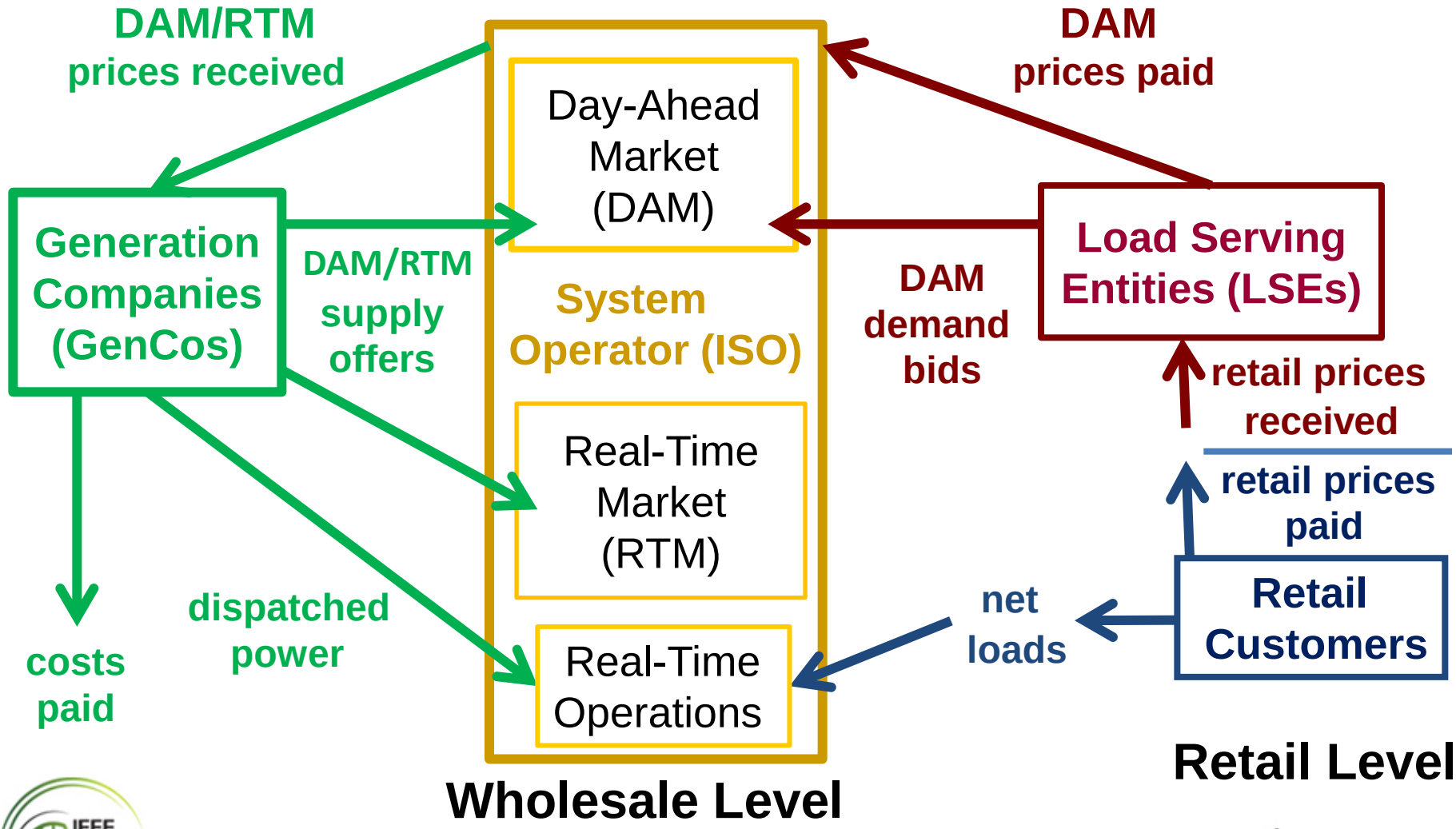


AMES Test Bed



Distribution Feeders

IRW Test Bed records transaction histories for each transacting agent (ISO, GenCo, LSE, Retail Customer)



IRW-TE Test Case: Effects of Demand Response (DR)

- DR has been used for three distinct concepts:
  - Central down/up management of demand
  - Automated down/up demand dispatch
  - Price-responsive retail customer demand
- Main barriers to DR implementation to date
  - Lack of a supporting regulatory framework
  - Lack of a compelling DR business model that covers all system participants

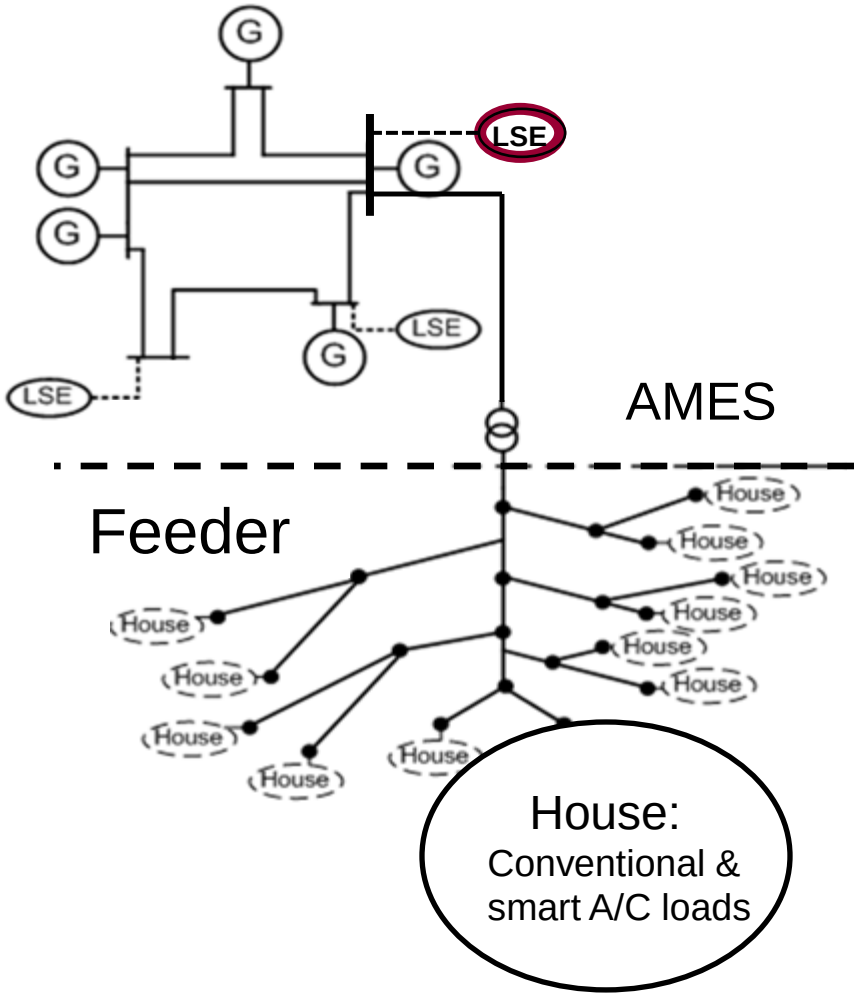
Compelling DR Business Model Requires IRW Scope

- For non-operator participants:
  - Should provide economic incentives that sustain voluntary participation
- For transmission & distribution system operators:
  - Should sustain/improve reliability of operations
- For society:
  - Should encourage efficient energy usage (non-wastage of resources)
  - Should reduce environmental pollution

IRW-TE Test Case: Basic Specifications

Wholesale Power System (AMES)

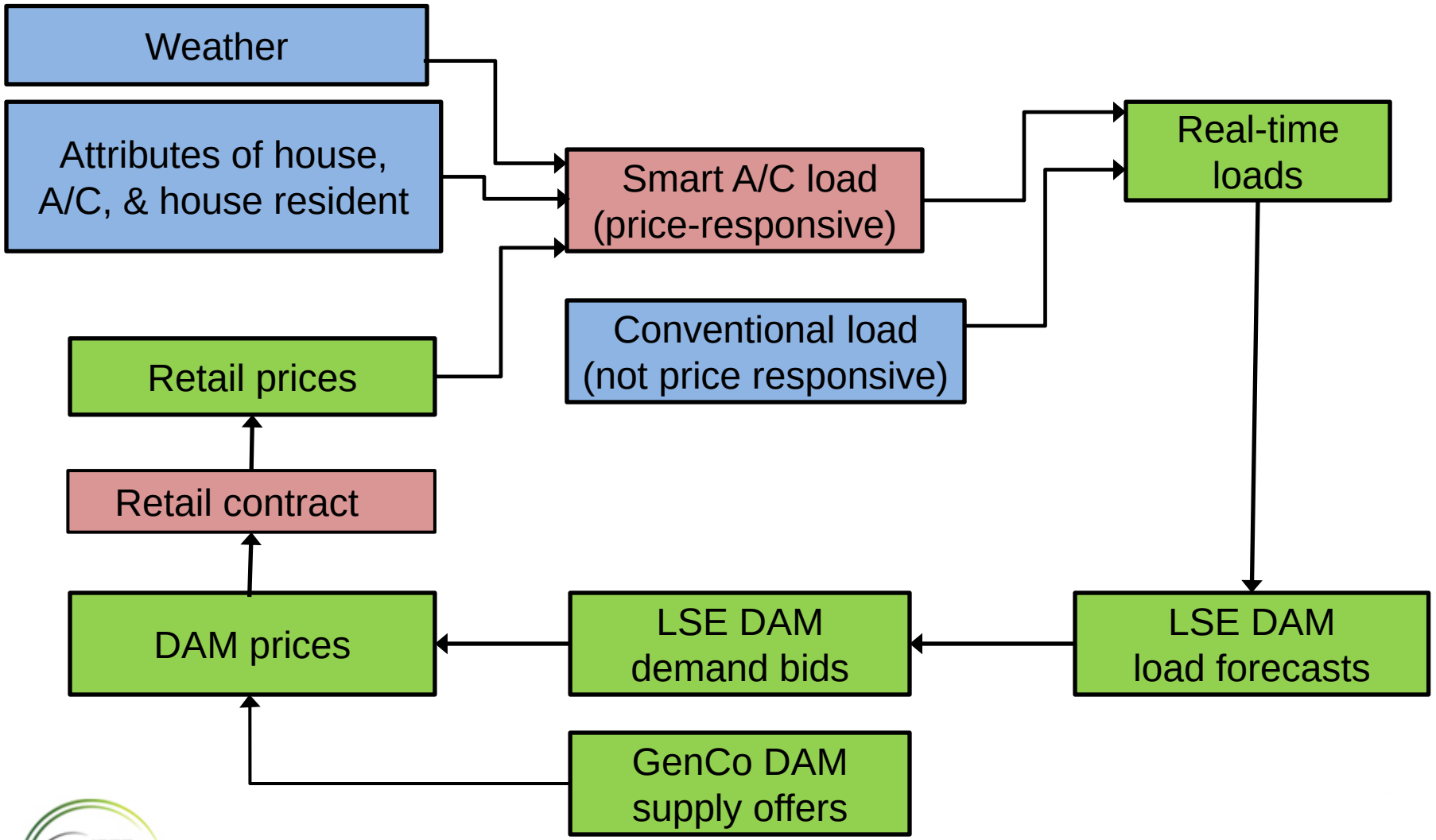
- Meshed 5-bus transmission grid
- 5 GenCos
- 2 LSEs servicing conventional loads only (no price sensitivity)
- 1 LSE servicing a feeder with conventional loads & smart (price-sensitive) A/C loads



Distribution Feeder

- Radial distribution grid
- 500 houses
- Multiple types of houses
- Multiple types of house residents

IRW Feedback Loop for Test Case: Open-Ended Dynamics



Attributes of a House-Resident Agent

- Comfort function measuring house-resident's comfort (in utils) as a function of inside air temperature
- Bliss temperature = Inside air temperature providing highest comfort to the at-home resident
- α = Non-negative scalar parameter (utils/$) giving a resident's trade-off between comfort and electricity cost (higher α ⟹ higher concern for cost relative to comfort)
- **k** = Parameter vector indicating hours that a resident is away from home each day (**k** = 0 ⟹ always at home)

Smart A/C Controller for Households

A. Thomas, P. Jahangiri, D. Wu, C. Cai, H. Zhao, D. Aliprantis, and L. Tesfatsion, *IEEE Trans. Smart Grid*, Vol. 3, No. 4, 2012, 2240-2251

Alpha α

Low → **High**

Comfort

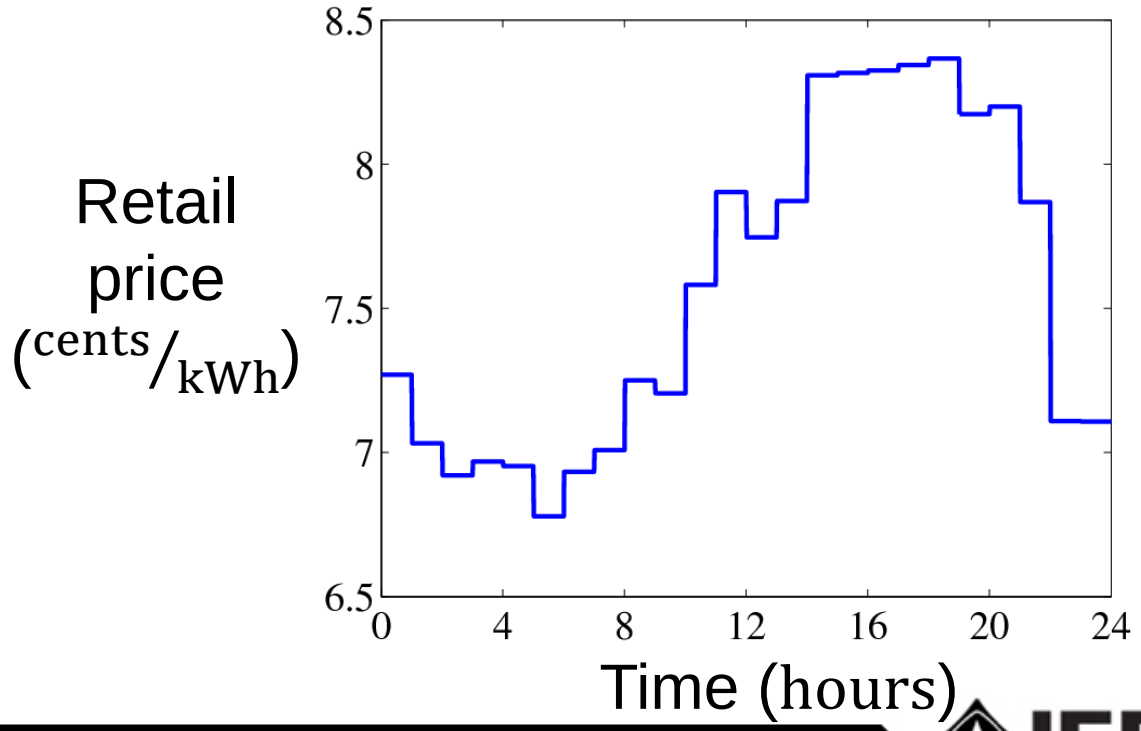
Cost

Retail Price DAM Price + Markup **Weather** Temp, humidity, solar radiation,…	**House-Resident Attributes** α setting, bliss temp, k values for away hours, … **House and A/C Structural Attributes** Btu ratings, dimensions, COP (Coefficient of Performance),…

Demand-Response Retail Contracts:

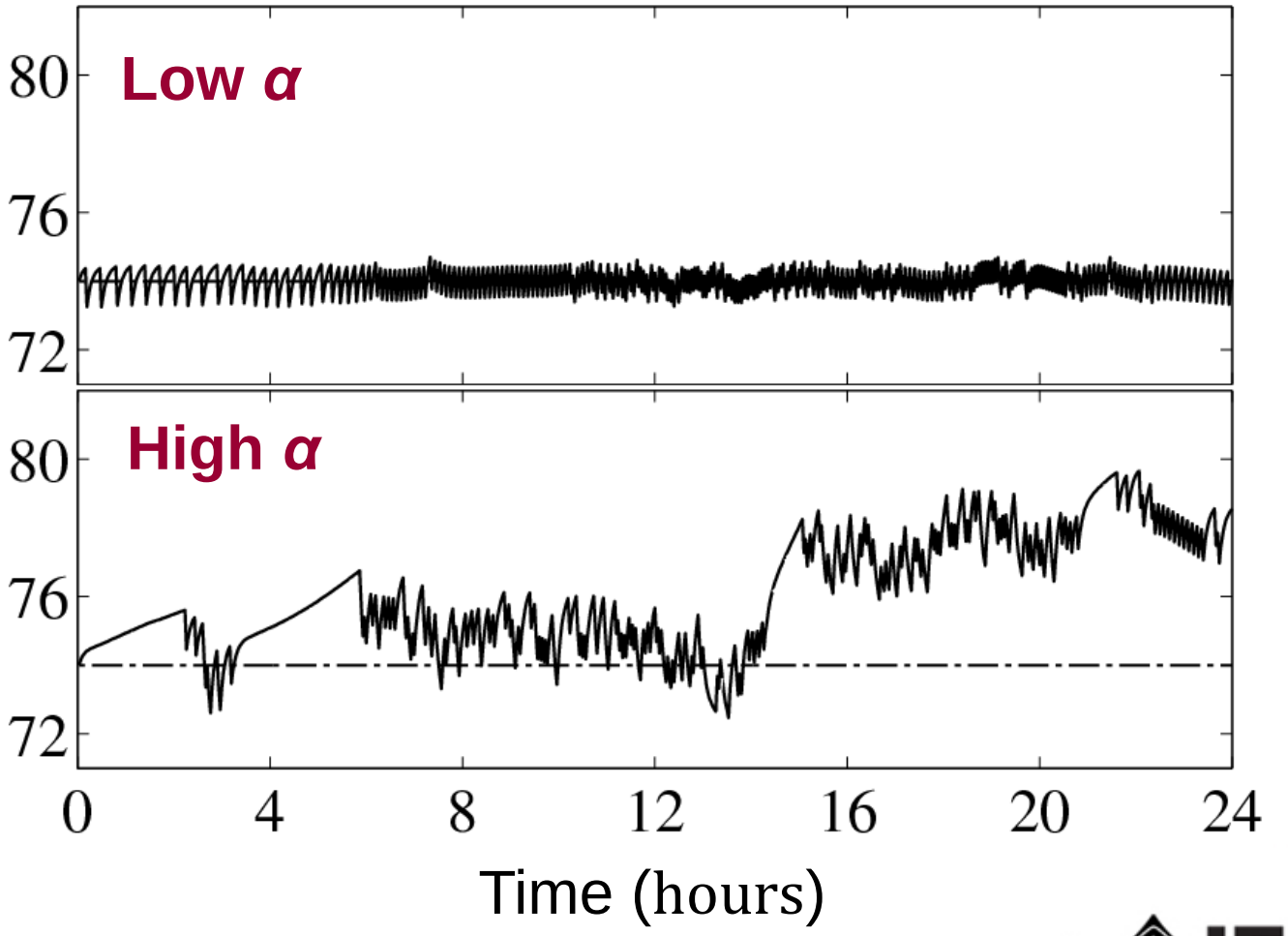
Wholesale prices are passed thru to households

- Retail prices charged to households for their day-D energy usage are the DAM LMPs from day D-1 with a profit mark-up
- Retail prices for day-D energy usage are conveyed by LSEs to households by evening of day D-1



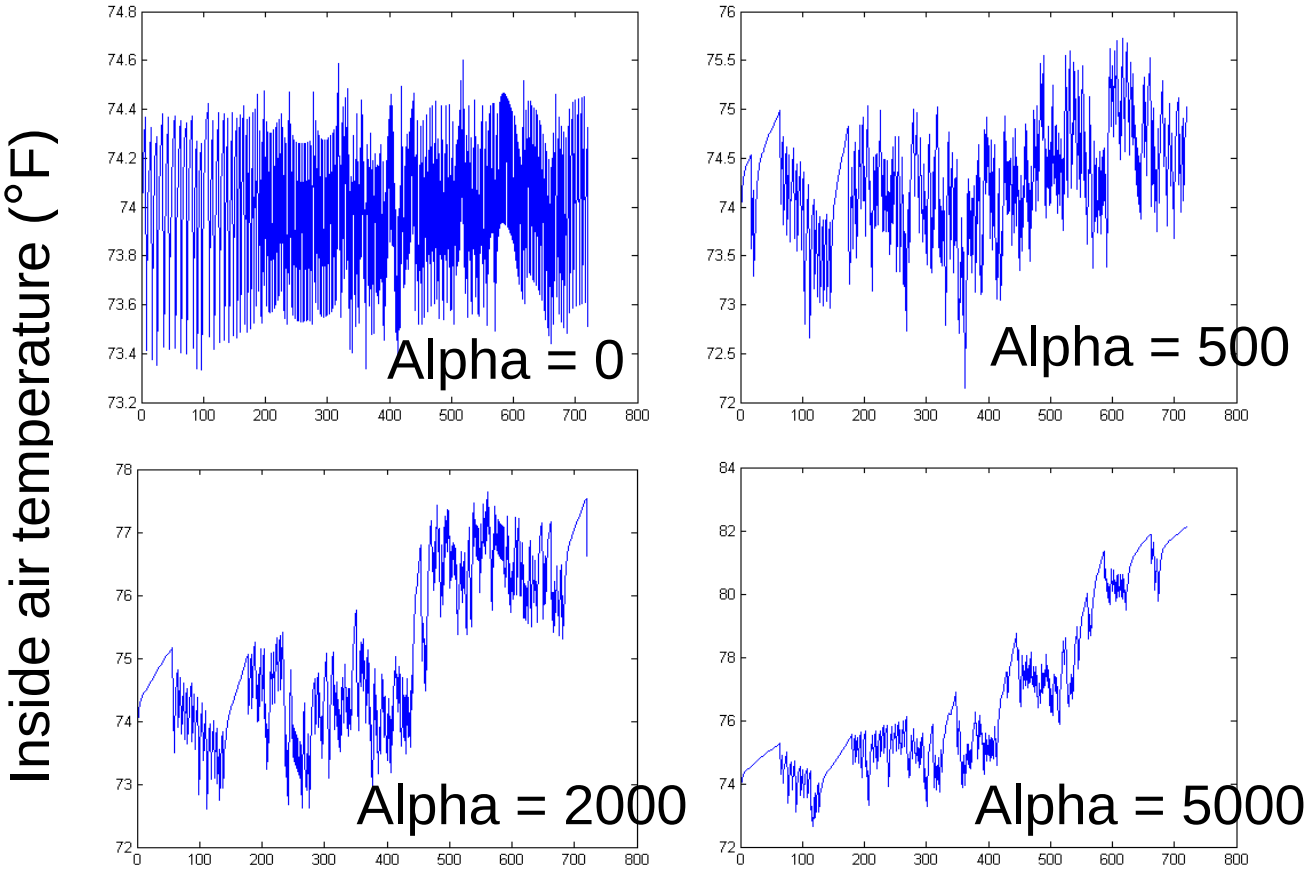
Illustrative A/C results for a single resident, always home
Higher α = higher concern for cost; Bliss temp = 74ºF

Inside air temp (ºF)



Illustrative A/C Results… Continued

High insulation; Bliss temp = 74ºF; Resident always home

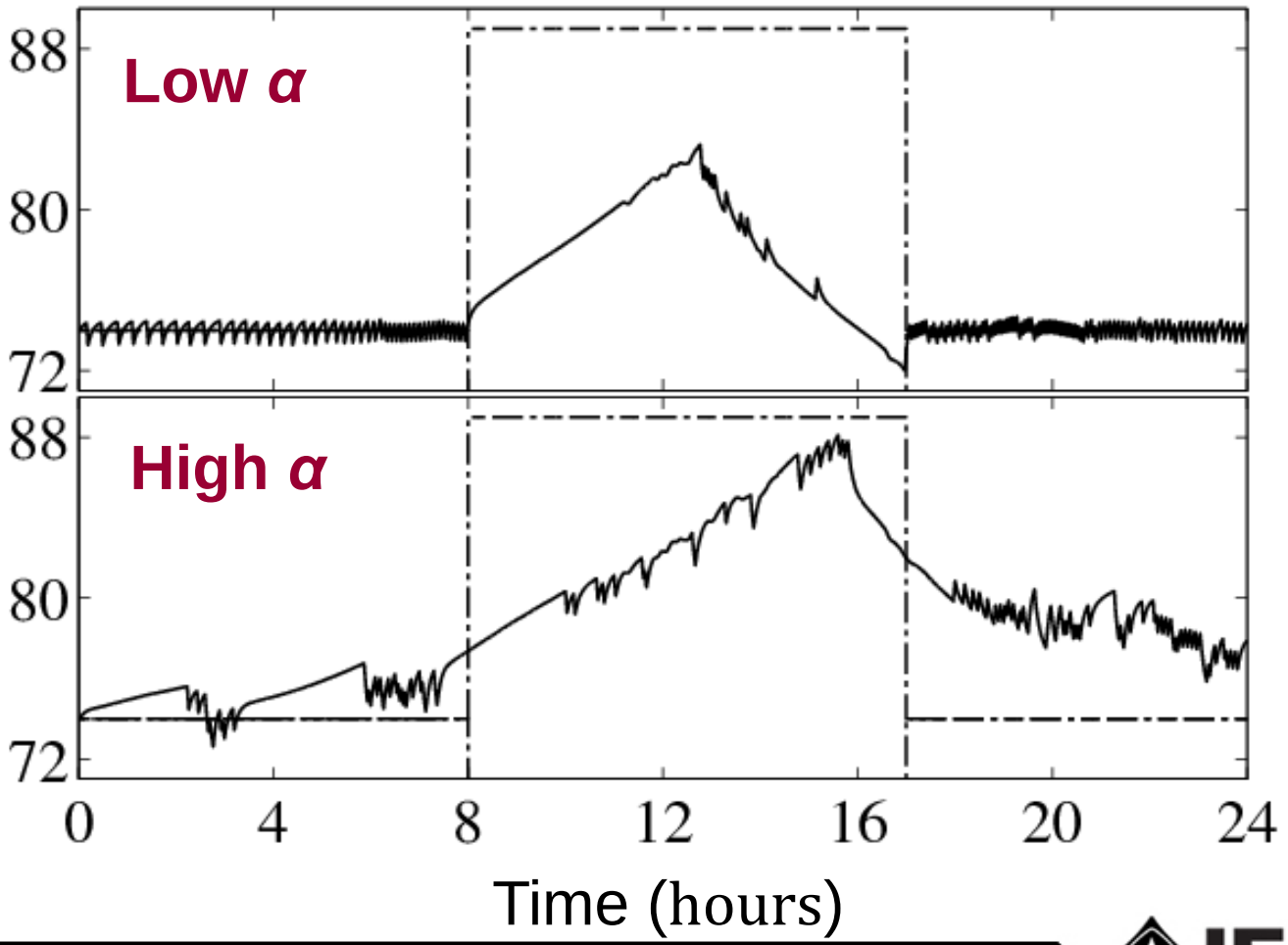


Alpha	Daily Energy Cost ($)
0	2.04
500	1.98
2000	1.79
5000	1.40

Time period = One day (720 minutes)

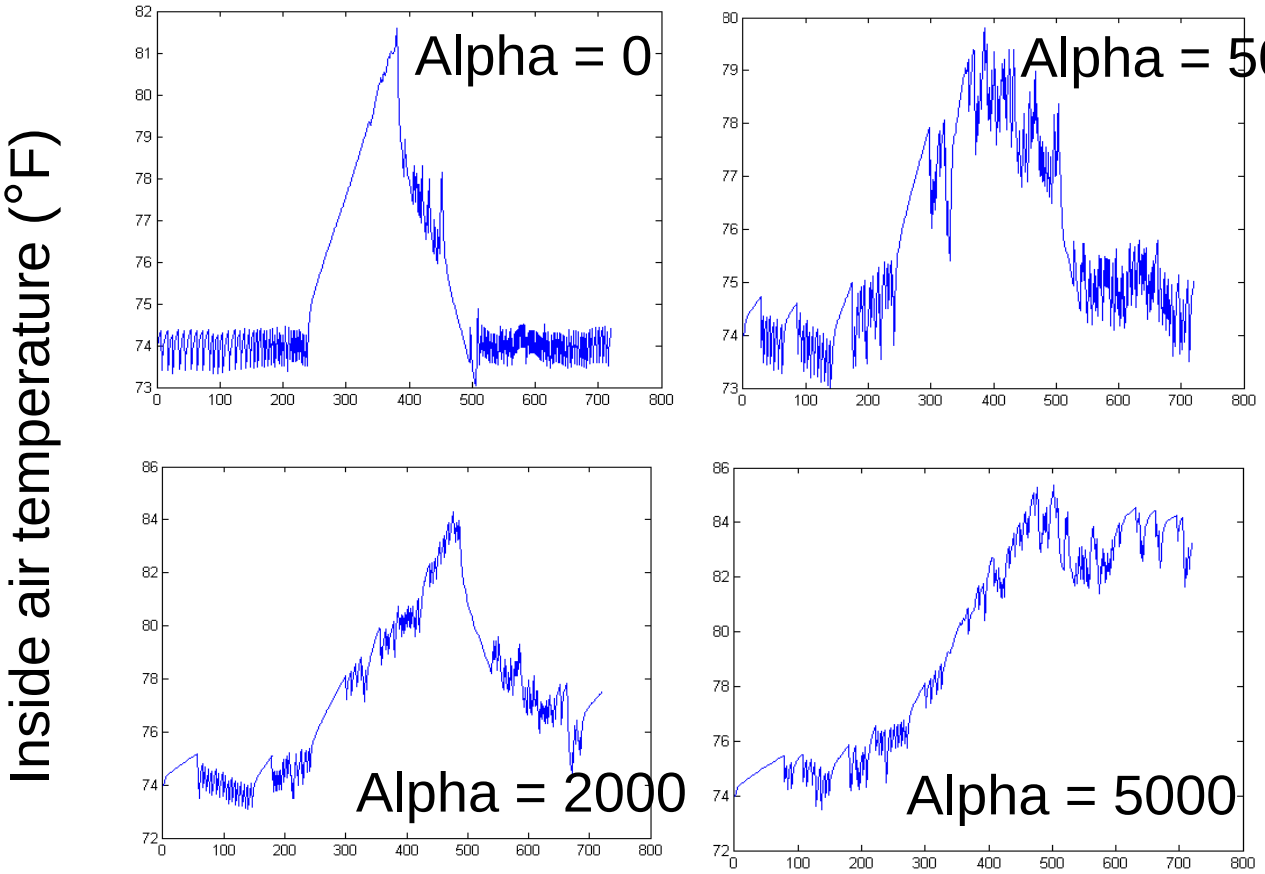
Illustrative A/C results for a single resident, away 8am-5pm
Higher α = higher concern for cost; Bliss temp = 74ºF

Inside air temp (ºF)



Illustrative A/C Results … Continued

High insulation; Bliss temp = 74ºF; Resident away 8am-5pm

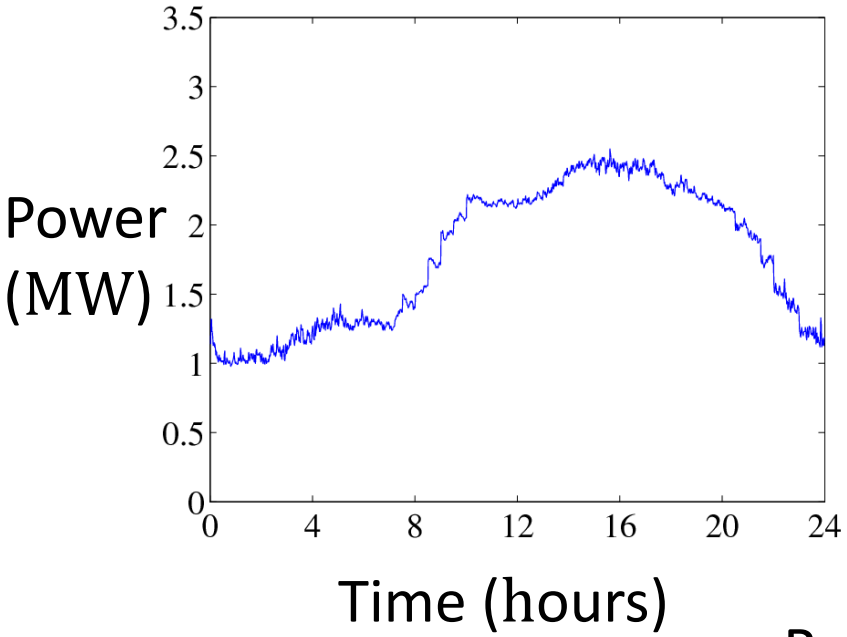


Alpha	Daily Energy Cost ($)
0	2.01
500	1.92
2000	1.66
5000	1.13

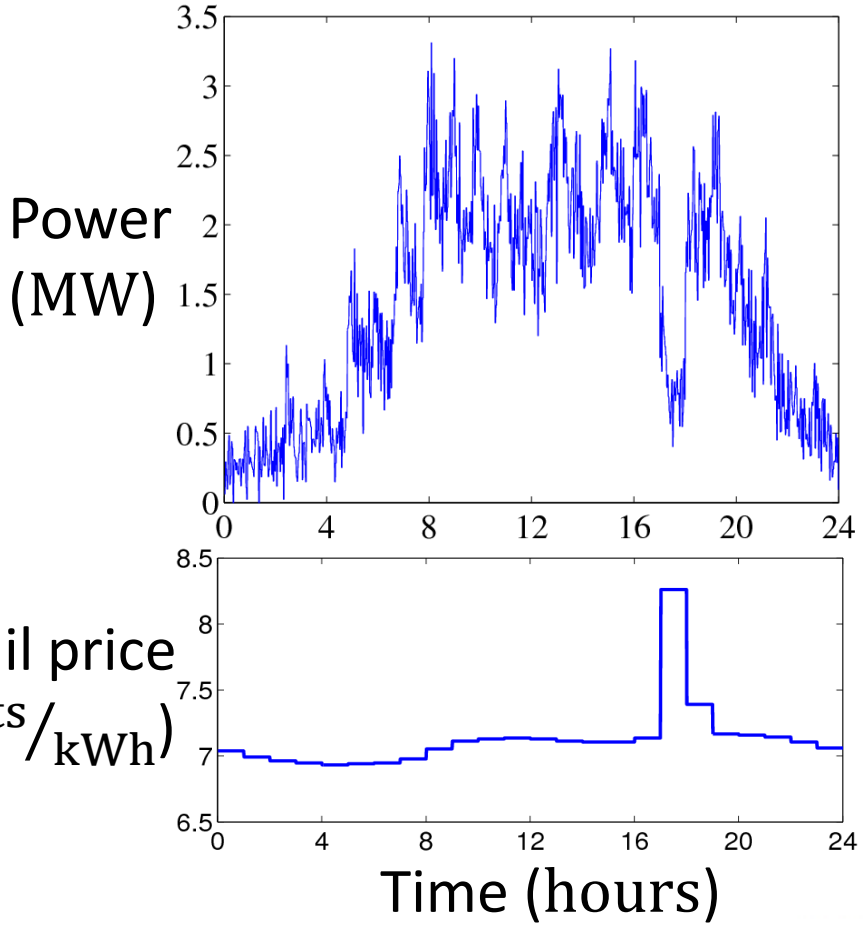
Time period = One day (720 minutes)

From single-household load to aggregated feeder load

Non-Price-Responsive Load

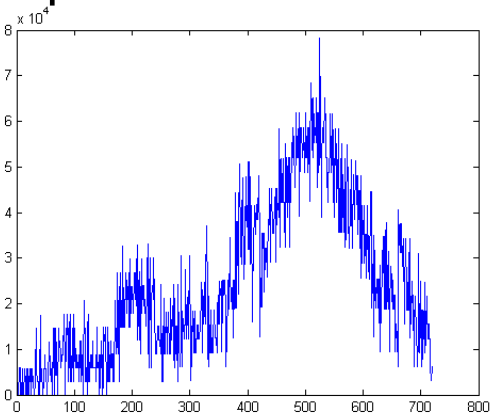


Smart A/C Load

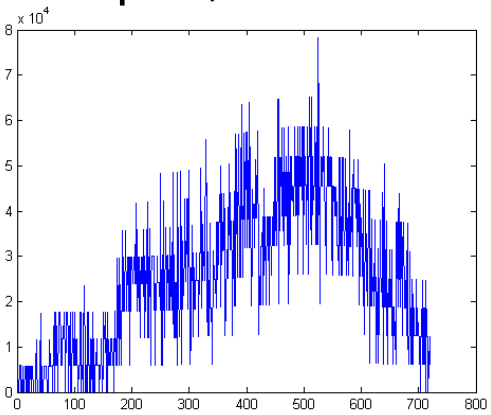


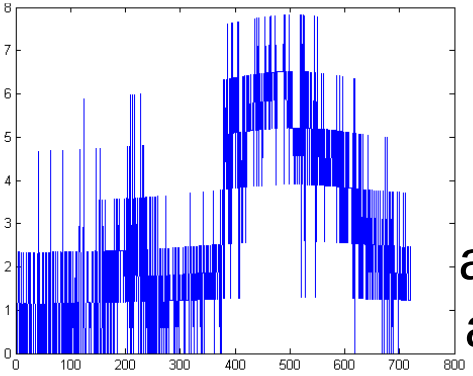
Aggregated feeder load illustration … Continued

Uniformly distributed alpha and k values



Uniformly distributed alpha, and **k**=0





alpha=0 and **k**=0

Type	Power (kW)
Uniform alpha & k values	24.15
Uniform alpha, **k**=0	25.42
alpha=0, **k**=0	27.59

Note:

k ≥ 0 determines hours when a resident is away from home

k=0 implies always home

Time period = One day (720 minutes)

IRW-TE Test Case Specifications …Continued

- Exogenously given state vector for each day
  - Weather conditions
    - Outside air temperature
    - Other environmental forcing terms
  - Background (BG) conventional load profile (i.e., load not responsive to price changes)
- 500 houses with conventional & smart A/C loads
- LSE DAM forecasting (demand bid) method
  - Day D-1 actual load ⟹ Day-D load forecast (demand bid)
- House-resident comfort/cost preference parameters α
  - Simulation treatment factors, not empirically derived
  - Set at uniformly-distributed random values unless otherwise indicated

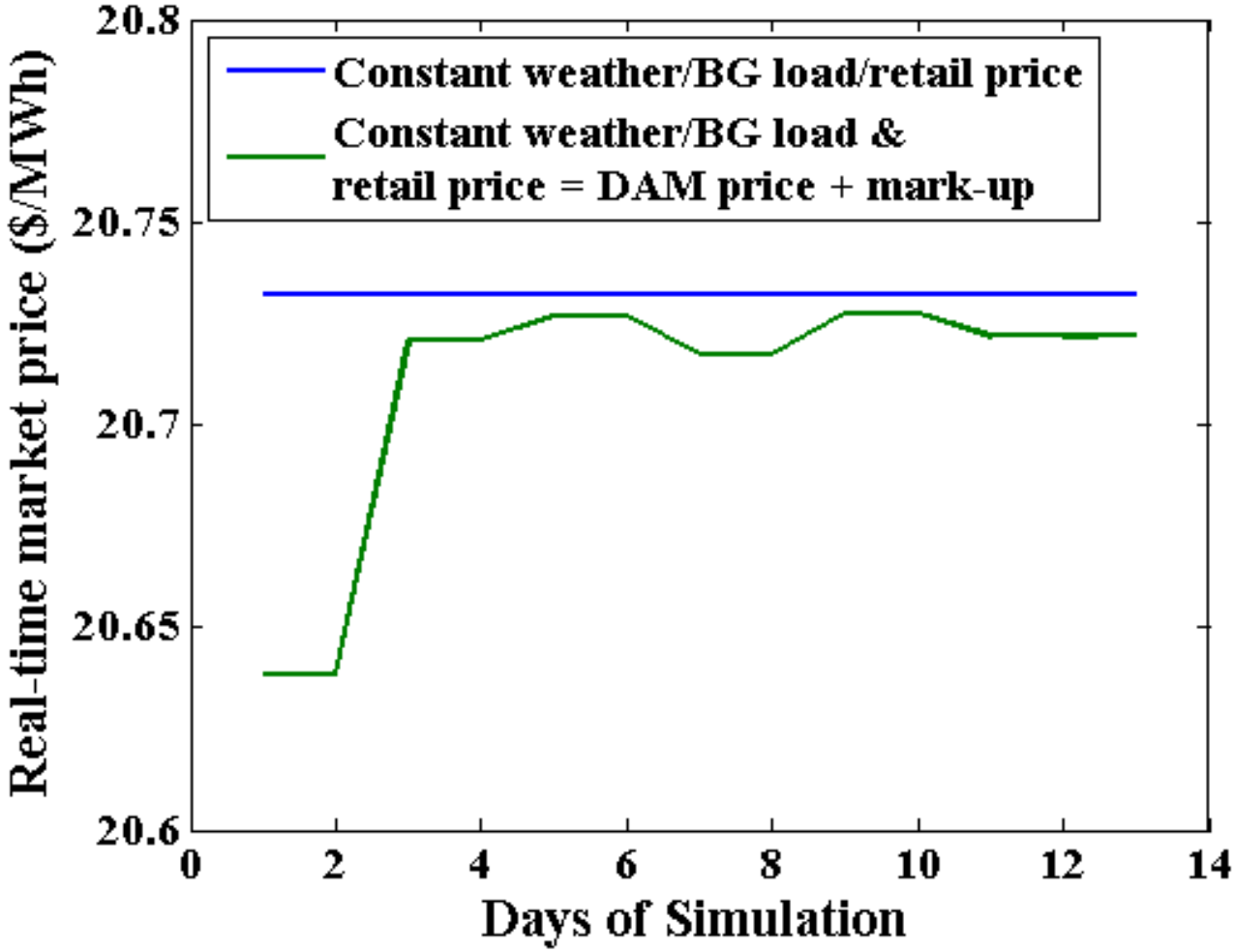
Illustrative Findings for IRW Feedback Loop

Fluctuations in *Real-Time Market (RTM) price* at feeder bus (peak hour 18) under varied forcing-term and retail-price contracts

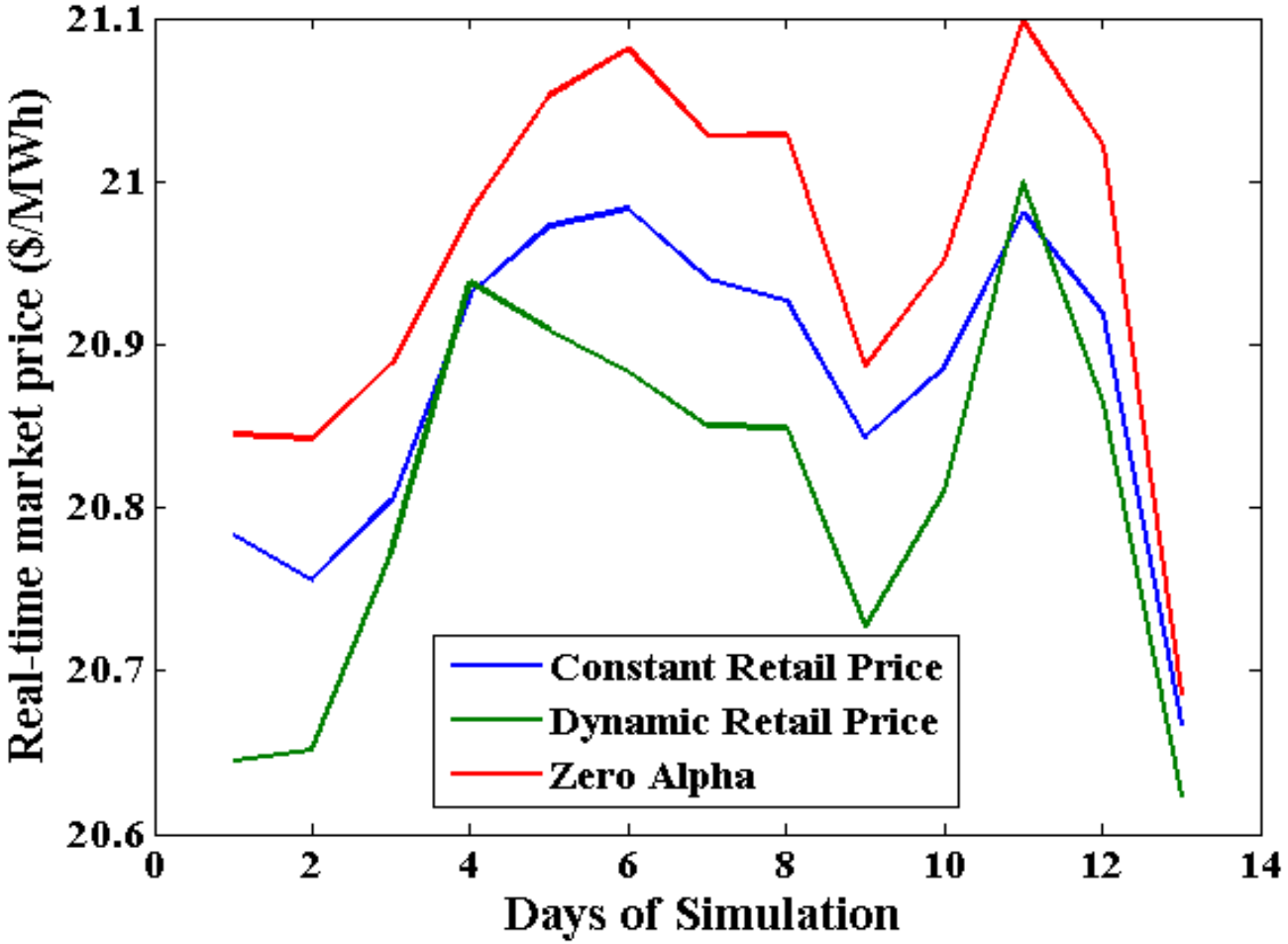
Note:

RTM price = wholesale price charged for imbalance energy

Retail price = price charged by LSE to household energy users



Illustrative Findings for IRW Feedback Loop … Continued



Note: **Variation in weather and background load**

Ongoing IRW-TE Research

- Systematic investigation of IRW feedback loop & potentially adverse cobweb price effects under alternative retail-contract designs

- Improved test-case implementation
  - Fully online simulation

- More realistic test-case specifications
  - Multiple distribution feeders linked to multiple buses
  - Improved LSE forecasting methods

Additional IRW Test Bed Capabilities for TE Studies

- IRW Test Bed can model human participants as ***strategic agents with learning capabilities***
  - Can learn over time how to submit profitable bids & offers
  - Can learn over time how to better forecast prices & loads
- IRW Test Bed can test the ***robustness of operational rules*** against adverse unintended consequences
  - Gaming of IRW market rules by strategic market participants
  - IRW system unreliability resulting from local retail contracting

On-Line Resources for IRW-TE Research

- IRW Project Homepage
  http://www2.econ.iastate.edu/tesfatsi/IRWProjectHome.htm

- AMES Test Bed Homepage (Code/Manuals/Publications)
  http://www2.econ.iastate.edu/tesfatsi/AMESMarketHome.htm

- Agent-Based Electricity Market Research
  http://www2.econ.iastate.edu/tesfatsi/aelect.htm

- Agent-Based Computational Economics (ACE)
  http://www2.econ.iastate.edu/tesfatsi/ace.htm

- Auswin Thomas Homepage
  http://www.auswingeorgethomas.com/

- Leigh Tesfatsion Homepage
  http://www2.econ.iastate.edu/tesfatsi/