Retail and Wholesale Power Market Operations under Increased Penetration of Price-Responsive Demand

PSERC Webinar

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Presentation Outline

- Business case needed for demand response (DR)
- Use of ***IRW Test Bed*** to explore DR business case

  Integrated ***R***etail & ***W***holesale (***IRW***) Power System Test Bed

  http://www.econ.iastate.edu/tesfatsi/irwprojecthome.htm
- Illustration: Price-responsive residential A/C loads

Demand Response (DR)

- DR has been used for three distinct concepts:
  - ISO up/down management of demand
  - Automated demand dispatch
  - Bottom-up retail customer price response

- Main barrier to DR implementation to date has been the lack of a compelling business model

(Oren, PSERC Webinar, 1 Feb 2011; Xie et al., PSERC Report 13-41, 2013)

Compelling Business Model for DR

- For Market Participants:
  - Provides economic incentives that sustain voluntary participation
- For ISO:
  - Sustains/improves reliability of operations
- For Society:
  - Encourages more efficient energy usage (less wastage of resources)
  - Reduces environmental pollution

Testing of Business Models for DR

- Must cross “valley of death” between theory & commerce
- Valley of Death ⇒ DOE Technology Readiness Levels 4–6
  https://www.directives.doe.gov/directives/0413.3-EGuide-04a/view

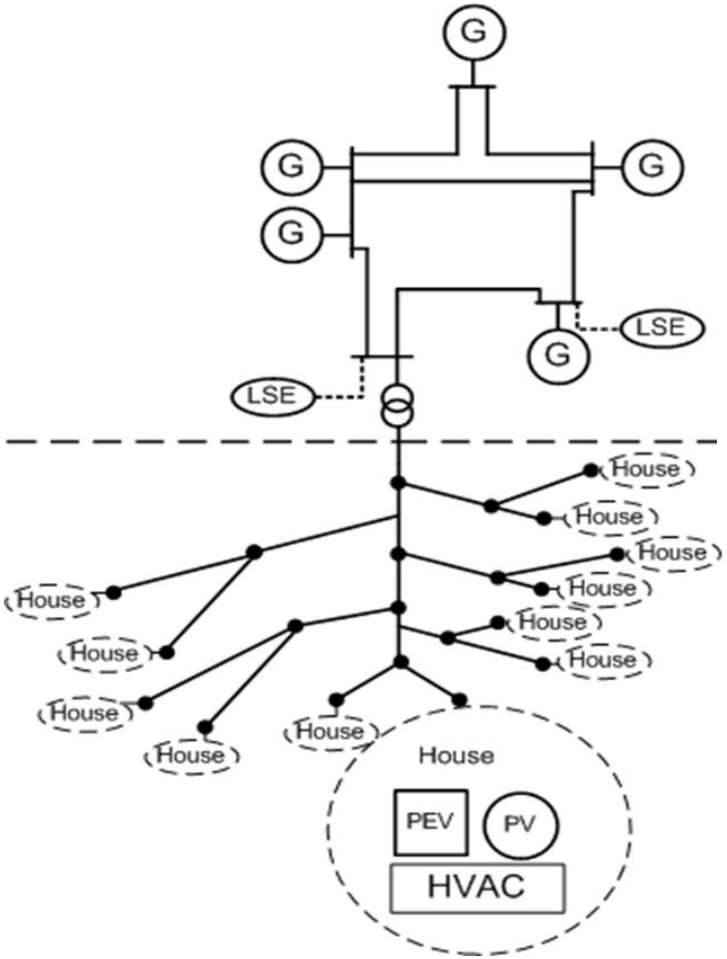
– **TRL 4:** Analytical/lab demonstration that basic technological components work together as a system

– **TRL 5:** System tested in reasonably realistic simulation

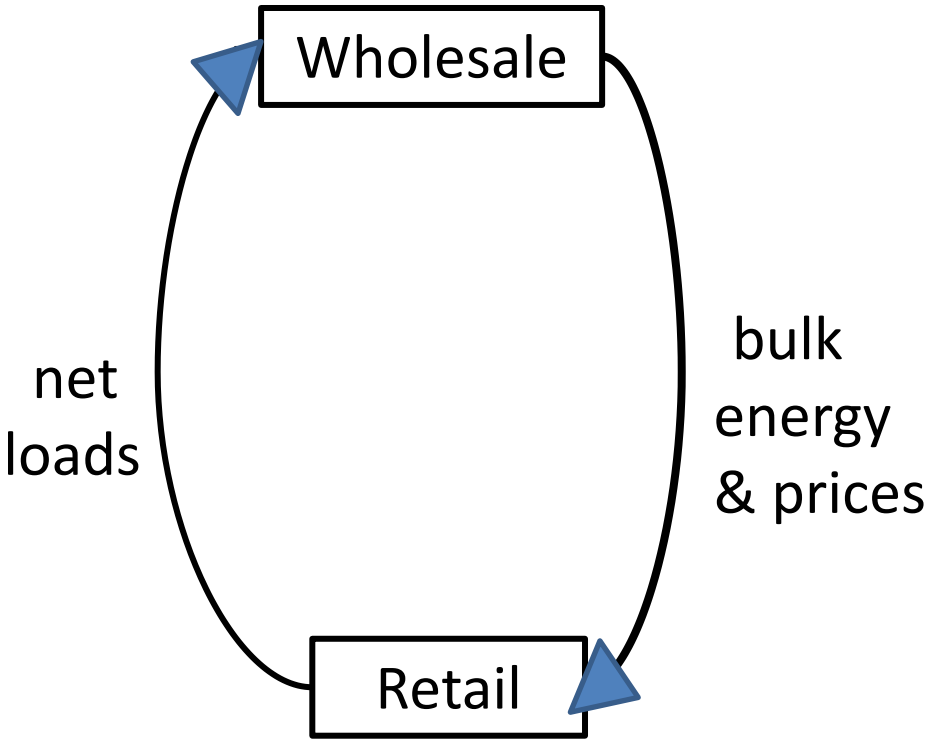
– **TRL 6:** System tested in high-fidelity lab or simulated operational environment

IRW Test Bed: TRL 5

5-Bus 1-Feeder Example



AMES Test Bed

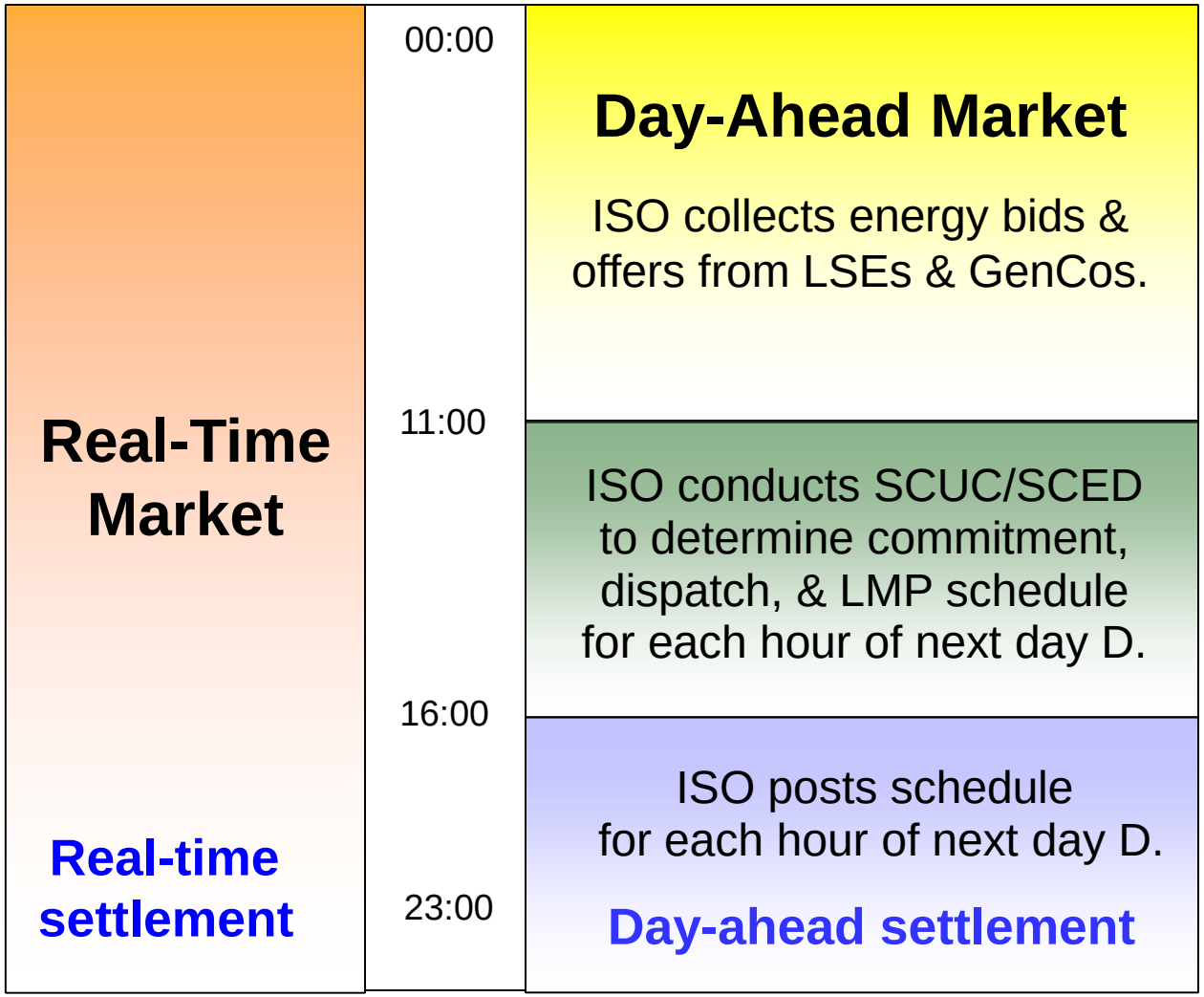


Distribution Test Feeders

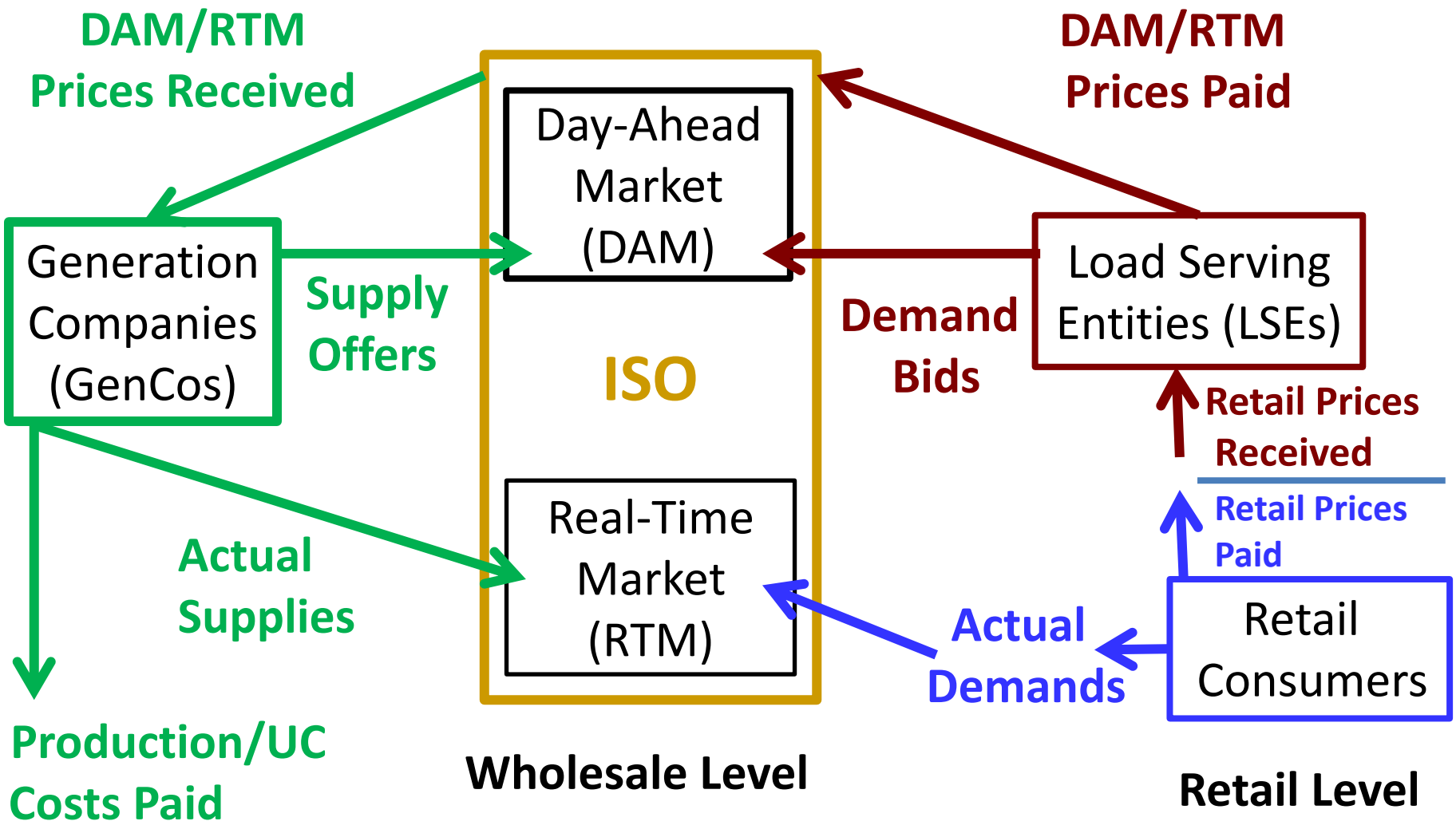
AMES Wholesale Power Market Test Bed

- ***AMES*** = ***A***gent-based ***M***odeling of ***E***lectricity ***S***ystems
- AMES(V2.06) released as open-source software under GPL
  www.econ.iastate.edu/tesfatsi/AMESMarketHome.htm
- Agent-based platform (Java/Python/Pyomo)
- Simulates ISO-managed wholesale power market over AC grid
- Agents include
  - **Decision-making entities** (ISO, GenCos, LSEs,…)
  - **Institutions** (day-ahead market, real-time market, regulations, …)
  - **Physical structures** (AC transmission grid, loads, …)
- Events driven by agent interactions, starting from initial conditions

Activities of AMES ISO during a typical day D-1



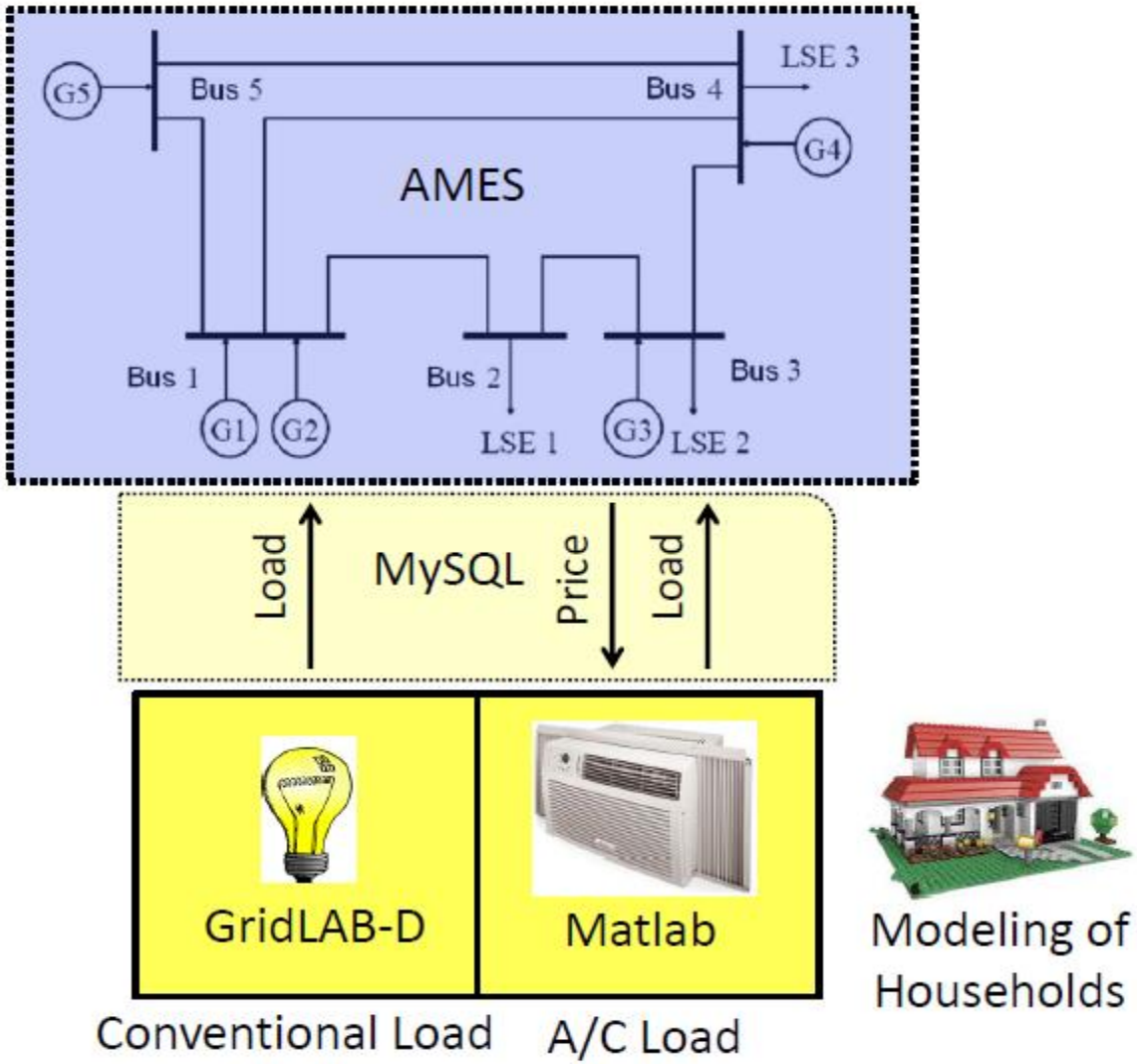
Economic Incentives for GenCos, LSEs, & Consumers



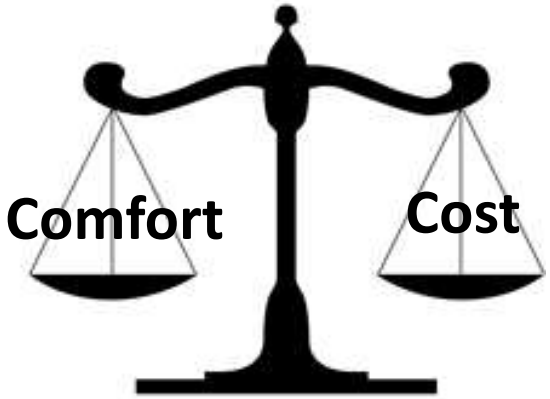
Illustrative Application:
IRW Case Study with Intelligent A/C Systems

- An intelligent A/C system controller for households has been developed
- Solves for optimal 24-hour comfort/cost tradeoffs, given anticipated prices & environmental conditions
- IRW Test Bed is being used to study IRW effects when some households have intelligent A/C system controllers

IRW Test Bed Implementation of Case Study



Intelligent A/C Controller



Prices

Household Preferences

House Thermal Dynamics (ETP model)

Environmental conditions

(to A/C motor)

On/Off

Air Temp.

Forecast of environmental conditions

Retail price sequence

Scheduling (on remote or local server)

Control Map

Estimator for Mass Temp.

Wall Control Unit

User-defined preferences (entered via a user-friendly graphical interface)

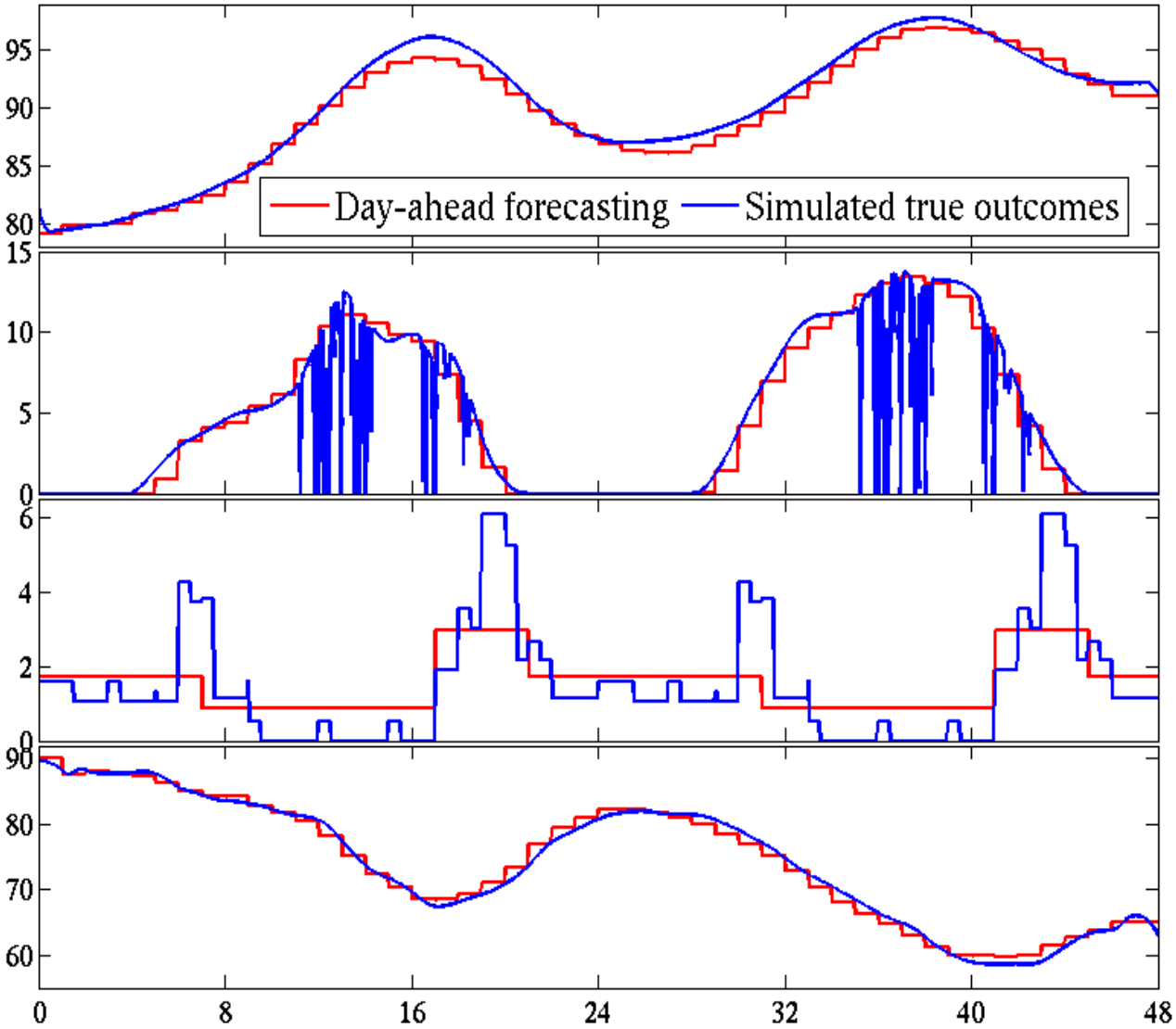
Environmental Forcing Terms

Outside Temperature (^{o}F)

Solar Heat Flow Rate ($^{kBTU}/_{h}$)

Internal Heat Flow Rate ($^{kBTU}/_{h}$)

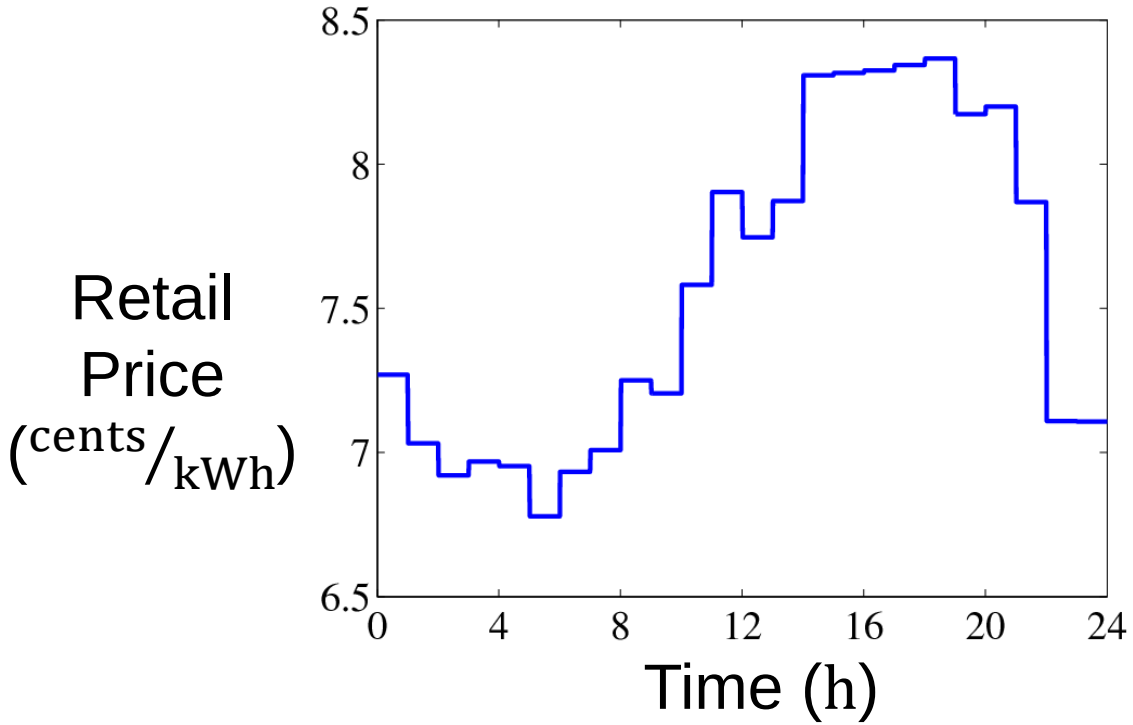
Relative Humidity (%)



Time (h)

Wholesale Prices Passed Thru to Households

- Retail prices charged to retail energy customers on day D given by DAM LMPs plus profit mark-up determined on D-1
- Retail prices for day D conveyed by LSEs to households by evening of day D-1

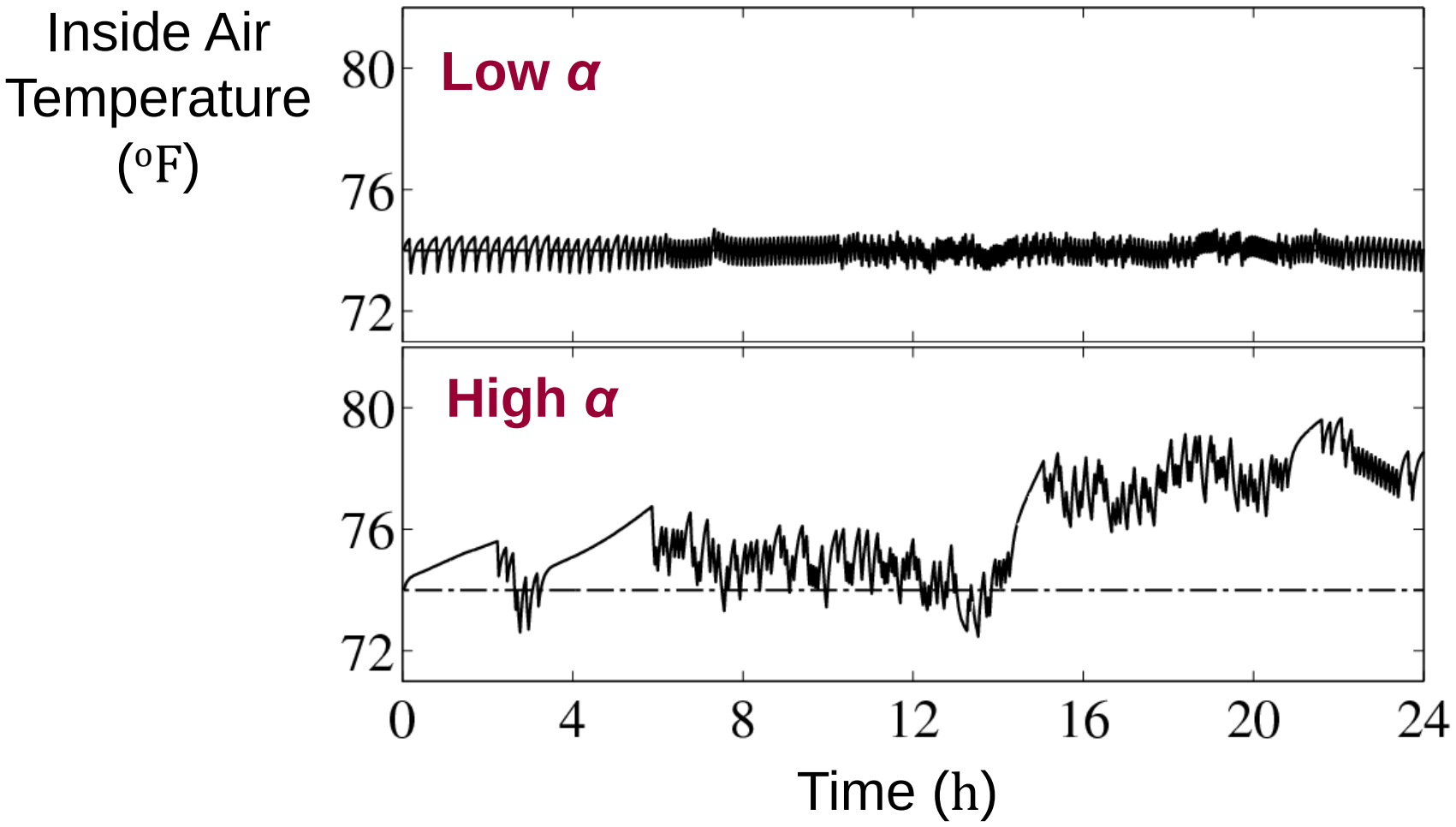


Attributes of Household Residents

- Comfort function (utils) measuring household resident's comfort level as a function of inside air temperature
- Bliss temperature = Inside air temperature providing highest comfort to the at-home resident
- α = Parameter (utils/$) measuring resident's trade-off between thermal comfort and electricity cost (higher α ⇒ higher concern for cost relative to comfort)
- Home-occupancy times of the household resident

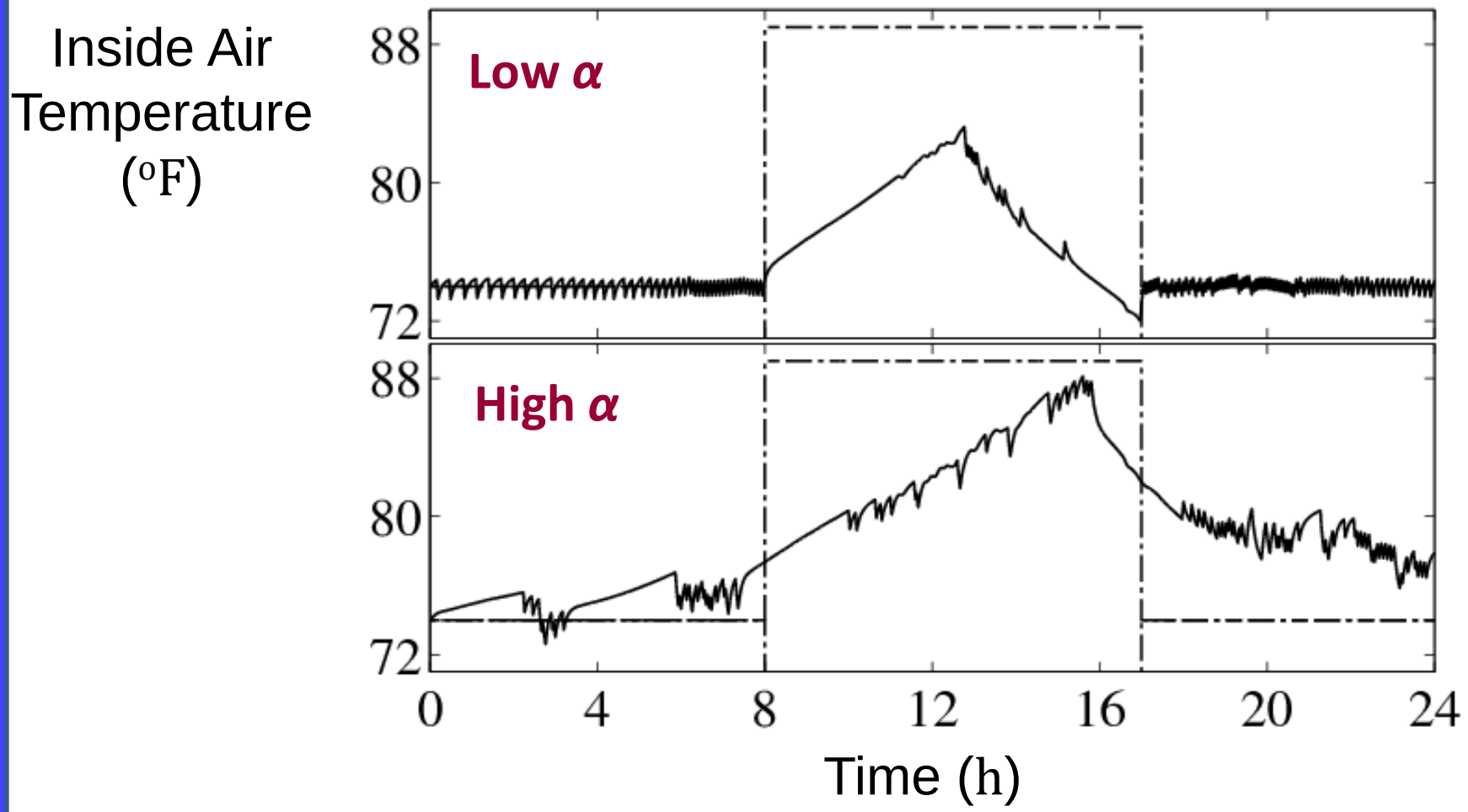
Illustrative Results: Resident always home

Higher α = Higher concern for cost; Bliss temp = 74ºF



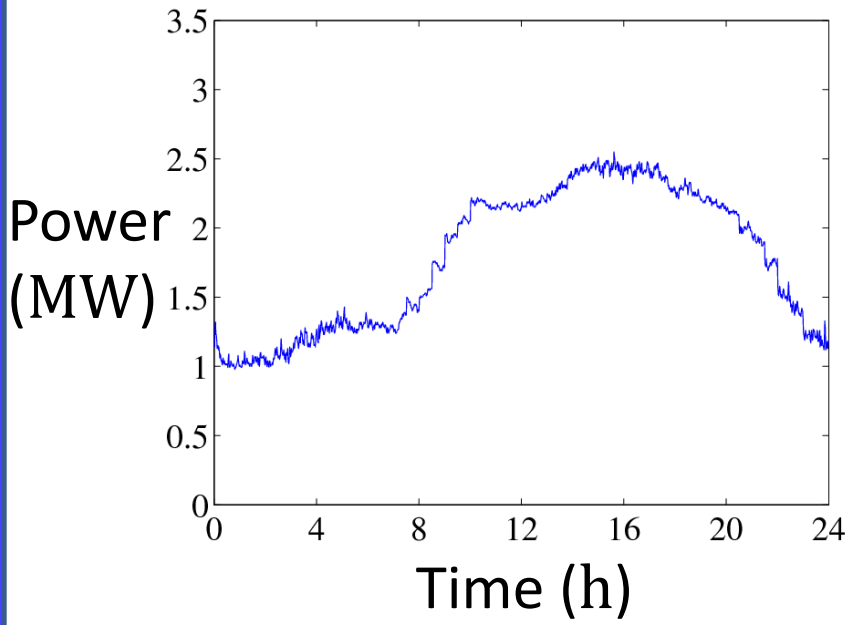
Resident away from home 8am - 5pm

Higher α = Higher concern for cost; Bliss temp = 74ºF

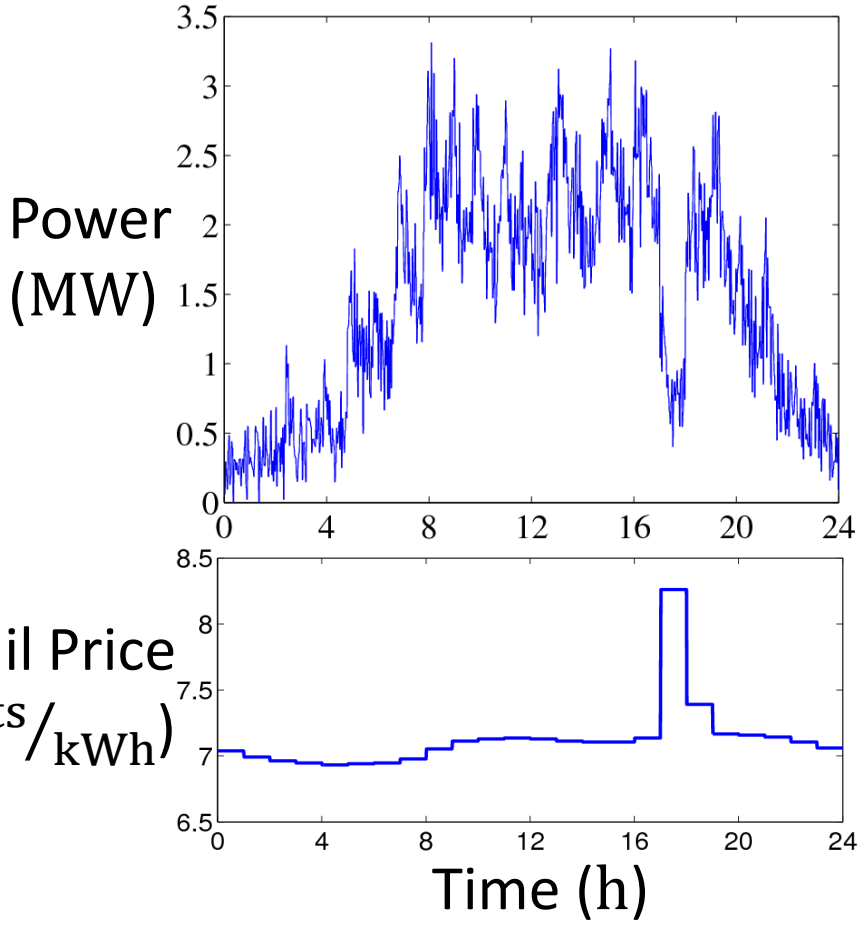


From single-household load to aggregated bus load

Non-Price-Responsive Load

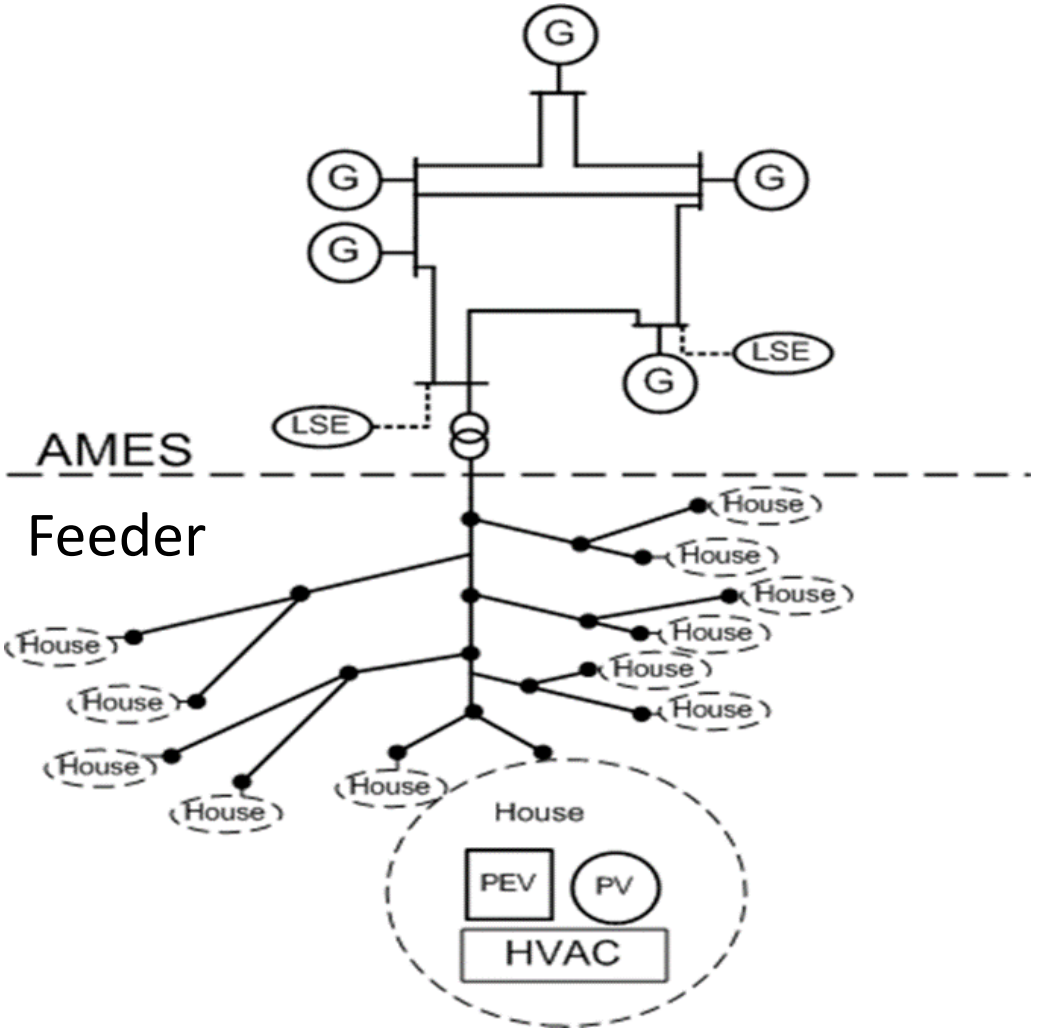


Intelligent A/C Load



IRW Case Study Specifications

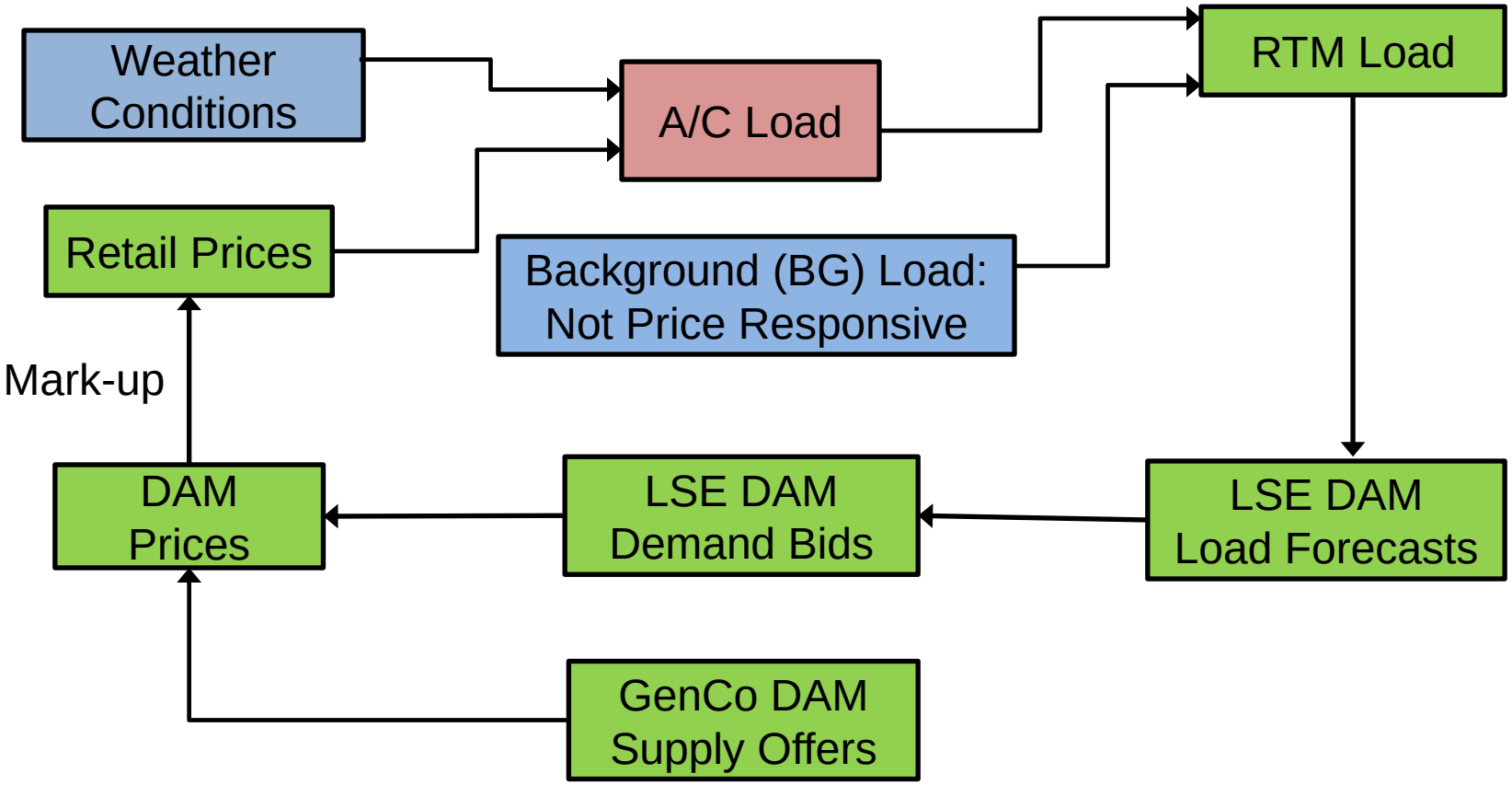
- Wholesale Power System (AMES)
  - 5 buses and 6 lines
  - 2 LSEs serving only conventional loads (no price sensitivity)
  - 1 LSE serving feeder of price-sensitive and conventional loads
  - 5 GenCos
- Distribution Feeder
  - Many types of houses
  - Many types of household residents (differing α values)



IRW Case Study Specifications…Continued

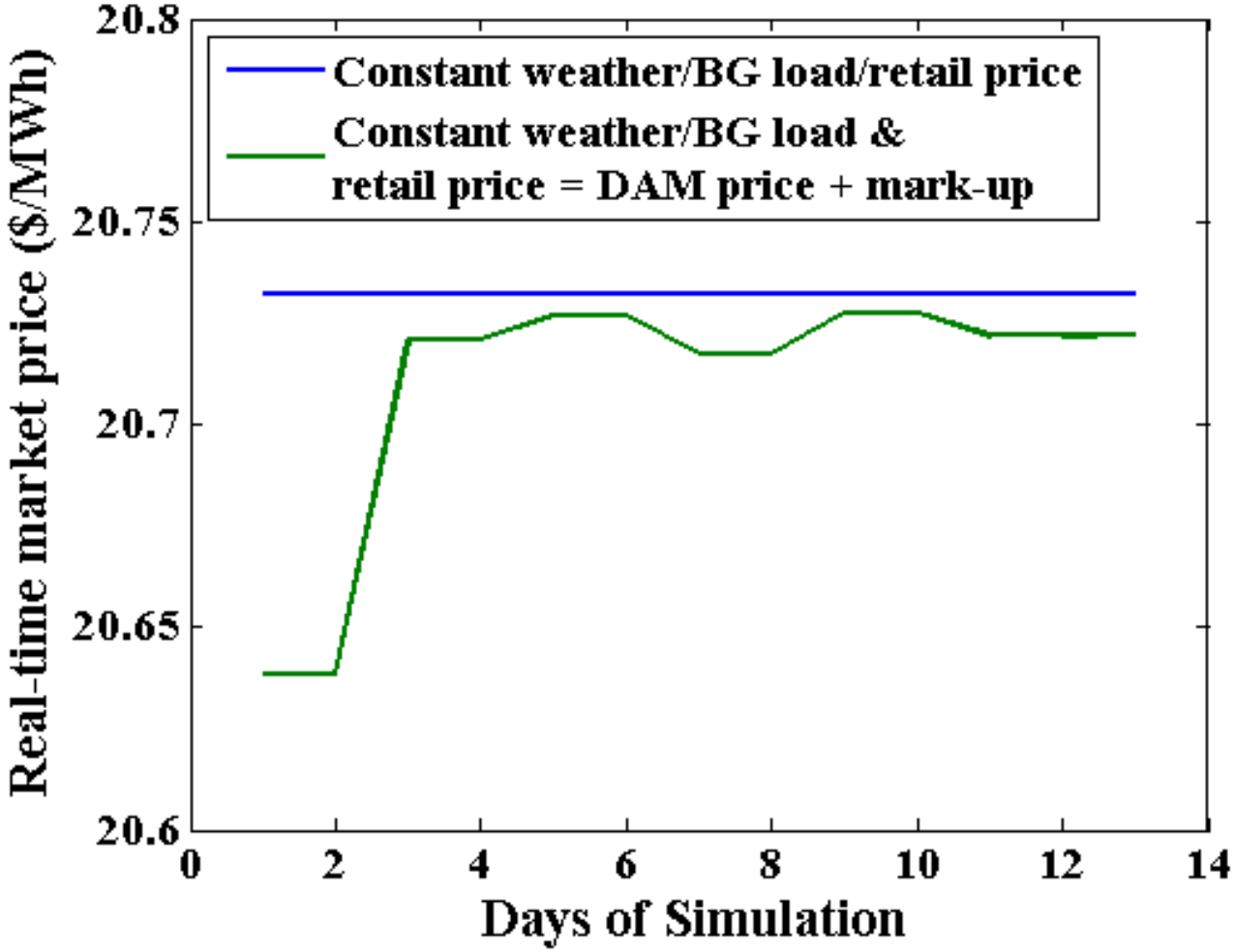
- Exogenously given state vector for each day
  - Weather conditions
    - Outside temperature profile
    - Profiles for other environmental forcing terms
  - Background (BG) conventional load profile (not responsive to price changes)
- LSE DAM demand bid method
  - Day D-1 actual load ⟹ Day-D demand bid
- Household comfort/cost preference parameters α
  - Set at random (uniformly distributed) values unless otherwise indicated.

IRW Feedback Loop Illustration

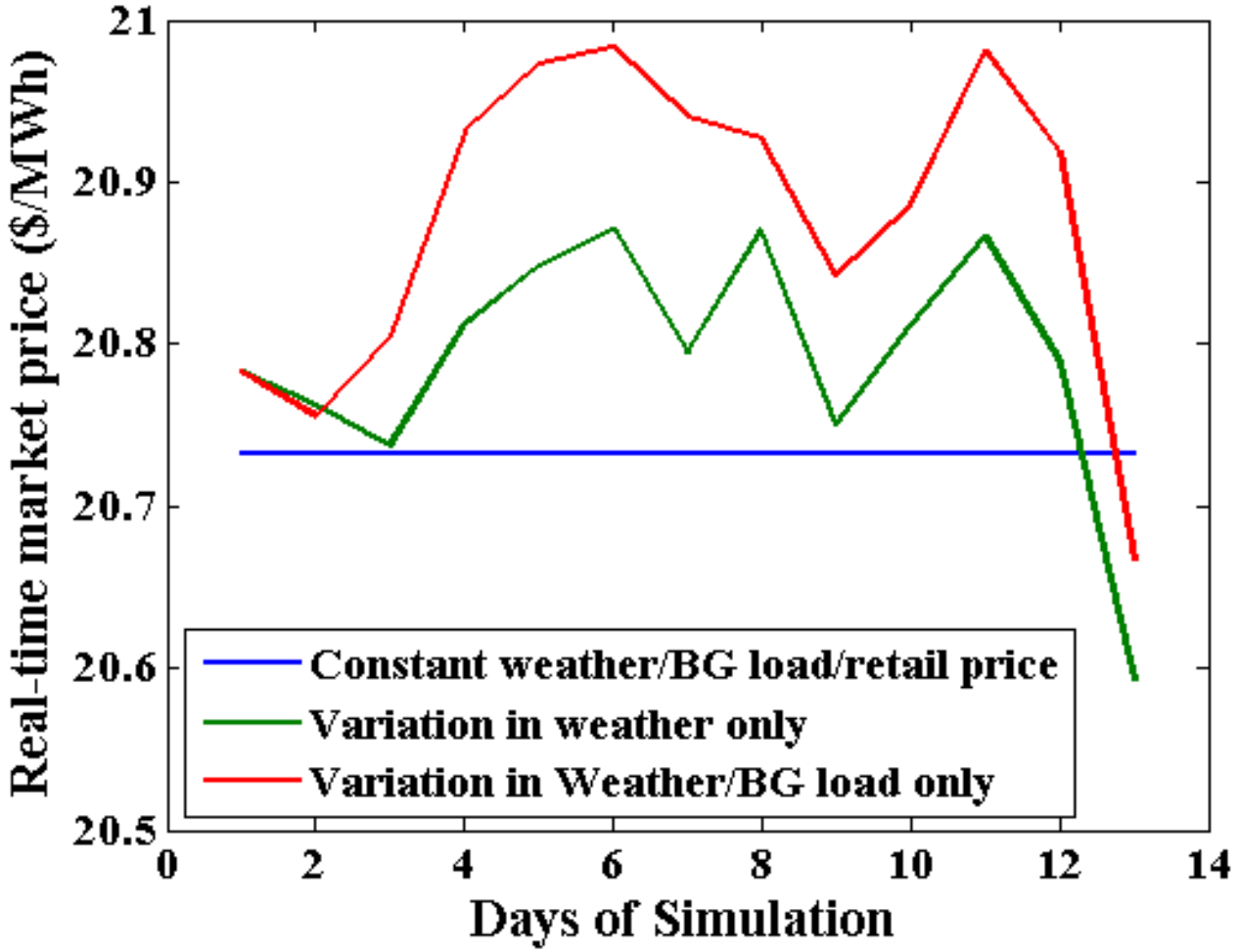


Illustrative Results:

RTM price at feeder bus (peak hour 18) under varied forcing-term and retail-price conditions



RTM price at feeder bus (peak hour 18)



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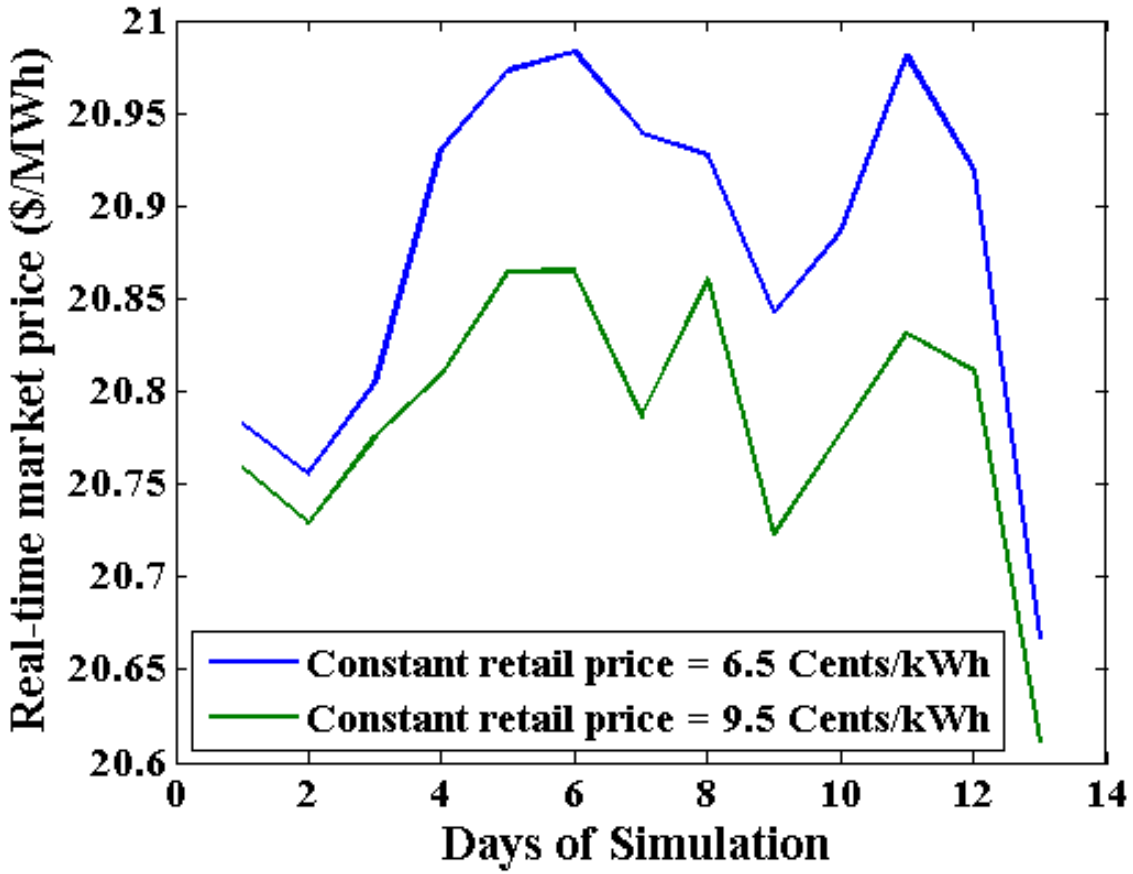
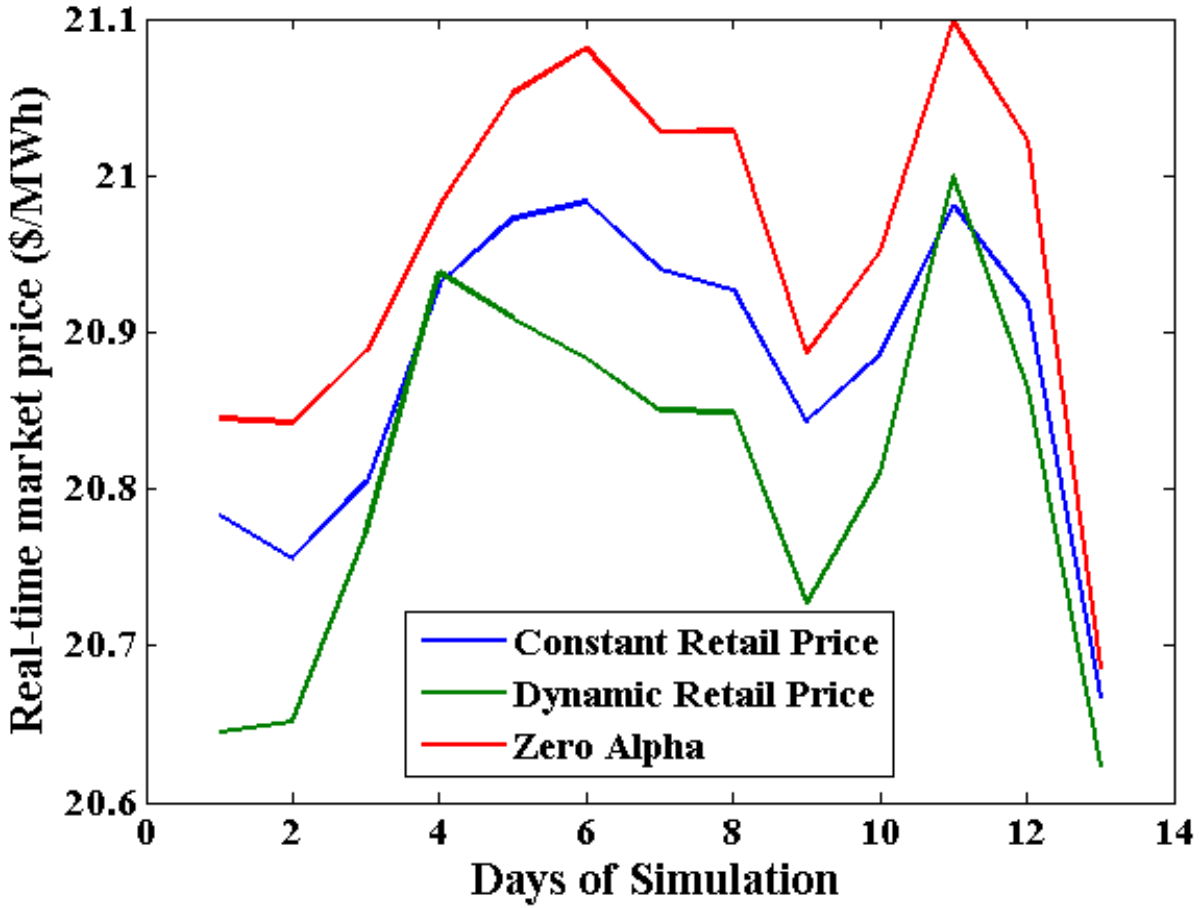


* Variation in weather and BG load

RTM price at feeder bus (peak hour 18)



* Variation in weather and BG load

Ongoing Research

- Additional intelligent A/C sensitivity testing of
  - resident attributes (α values, k values, …)
  - environmental attributes (weather,…)
  - house attributes (insulation levels, sizes,…)
- Performance metrics for the DR business case
- Newly installed High Performance Computing (HPC) cluster will permit
  - inclusion of distribution feeders at multiple buses
  - studies of multiple forms of DR
  - parallel processing implementation

DR business-case metrics that the IRW Test Bed can calculate

- Price volatility
- GenCo profits (LMP payments – production/UC costs)
- LSE profits (retail payment receipts – LMP costs)
- Household resident net benefit from comfort/cost tradeoffs
- ISO congestion rent (LMPs received – LMPs paid out)
- Energy usage levels
- Reliability of operations (e.g., need for reserve)

IRW Project Publications

- Auswin George Thomas, Pedram Jahangiri, Di Wu, Chengri Cai, Huan Zhao, Dionysios C. Aliprantis, and Leigh Tesfatsion, “Intelligent Residential Air-Conditioning System with Smart-Grid Functionality,” ***IEEE Transactions on Smart Grid***, Vol. 3, No. 4, December 2012, 2240-2251.
- Auswin George Thomas, Chengrui Cai, Dionysios C. Aliprantis, and Leigh Tesfatsion, “Effects of Price-Responsive Residential Demand on Retail and Wholesale Power Market Operations”, ***Proceedings of the IEEE Power and Energy Society General Meeting***, San Diego, CA, July 22-26, 2012
- Chengrui Cai, Pedram Jahangiri, Auswin George Thomas, Huan Zhao, Dionysios C. Aliprantis, and Leigh Tesfatsion, “Agent-Based Simulation of Distribution Systems with High Penetration of Photovoltaic Generation”, ***Proceedings of the IEEE Power and Energy Society General Meeting***, Detroit, MI, 2011
- Huan Zhao, Auswin George Thomas, Pedram Jahangiri, Chengrui Cai, Leigh Tesfatsion, and Dionysios C. Aliprantis, “Two Settlement Electric Power Markets with Dynamic-Price Customers,” ***Proceedings of the IEEE Power and Energy Society General Meeting***, Detroit, MI, 2011
- Auswin George Thomas, “Residential air-conditioning system with smart-grid functionality,” ***M.S. Thesis***, Iowa State U., 2012

On-Line Resources

- **IRW Project Homepage**

  www.econ.iastate.edu/tesfatsi/IRWProjectHome.htm

- **AMES Test Bed Homepage (Code/Manuals/Publications)**

  www.econ.iastate.edu/tesfatsi/AMESMarketHome.htm

- **Agent-Based Electricity Market Research**

  www.econ.iastate.edu/tesfatsi/aelect.htm

- **Open Source Software for Electricity Market Research, Teaching, and Training**

  www.econ.iastate.edu/tesfatsi/electricoss.htm