Impacts of Residential A/C Demand Response on Wholesale Power Markets

Technical Committee on Power System Operations

Smart Dispatch with Demand Response and Distributed Energy Resources: Business Models, Methodology, and Incentives

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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

- Illustrative findings: Price-responsive residential A/C

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 lack of compelling business model (Oren, PSERC, 2011)

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

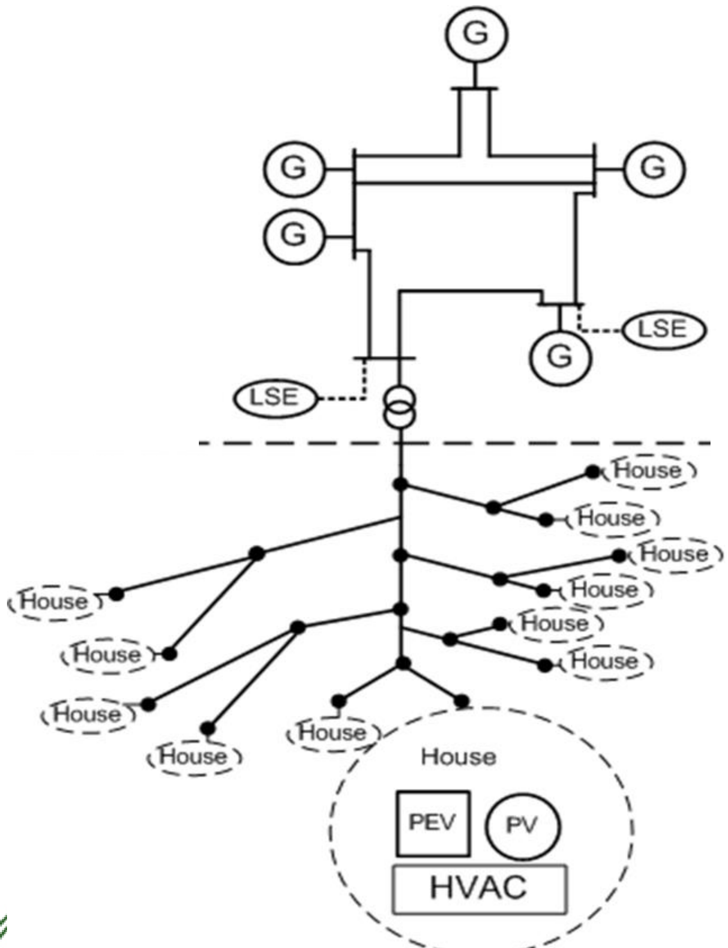
– **TRL 4:** Analytical/lab demonstration that basic technological components work together as a system

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

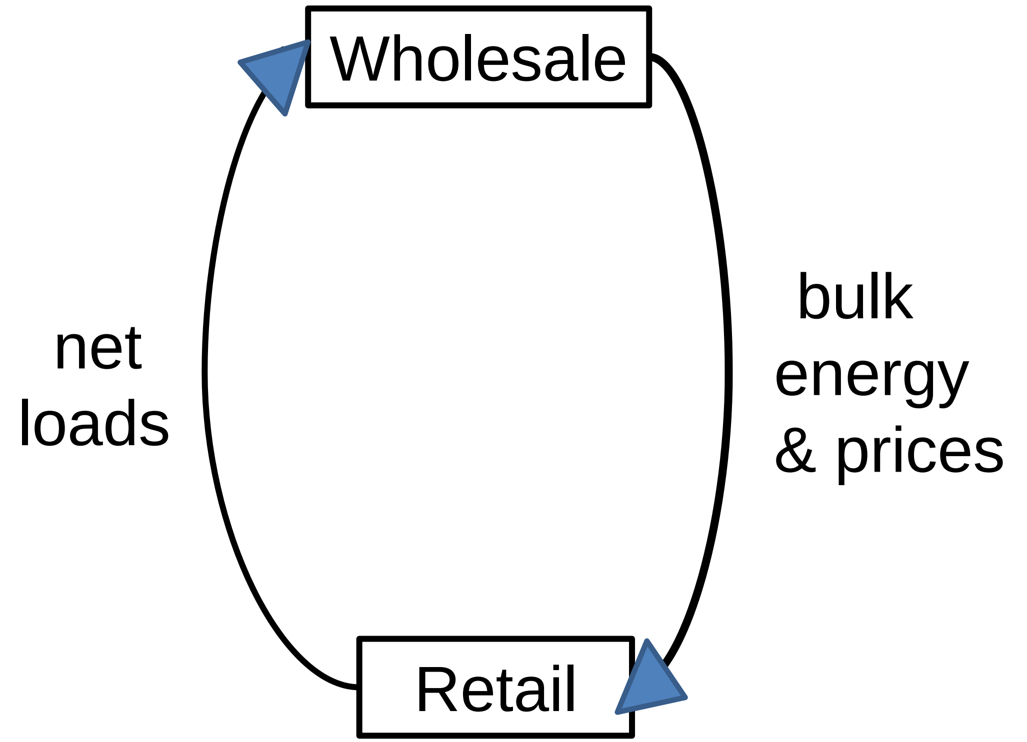
– **TRL 6:** System tested in high-fidelity lab or simulated operational environment

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

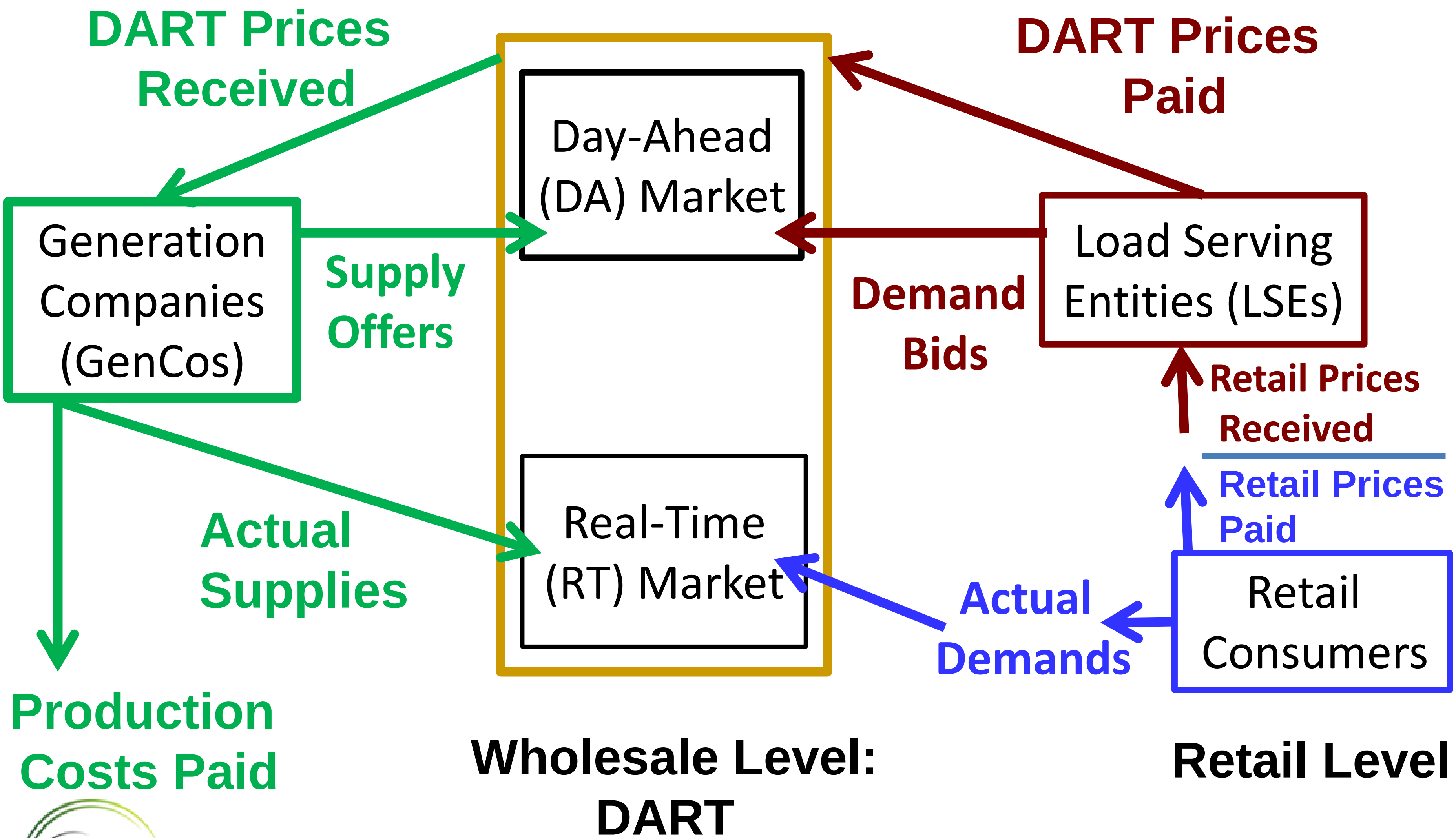
Activities of AMES ISO during a typical day D-1

Real-Time Market

Real-time settlement

Time	Day-Ahead Market
00:00	ISO collects energy bids & offers from LSEs & GenCos.
11:00	ISO conducts SCUC/SCED to determine commitment, dispatch, & LMP schedule for each hour of next day D.
16:00	ISO posts schedule for each hour of next day D.
23:00	**Day-ahead settlement**

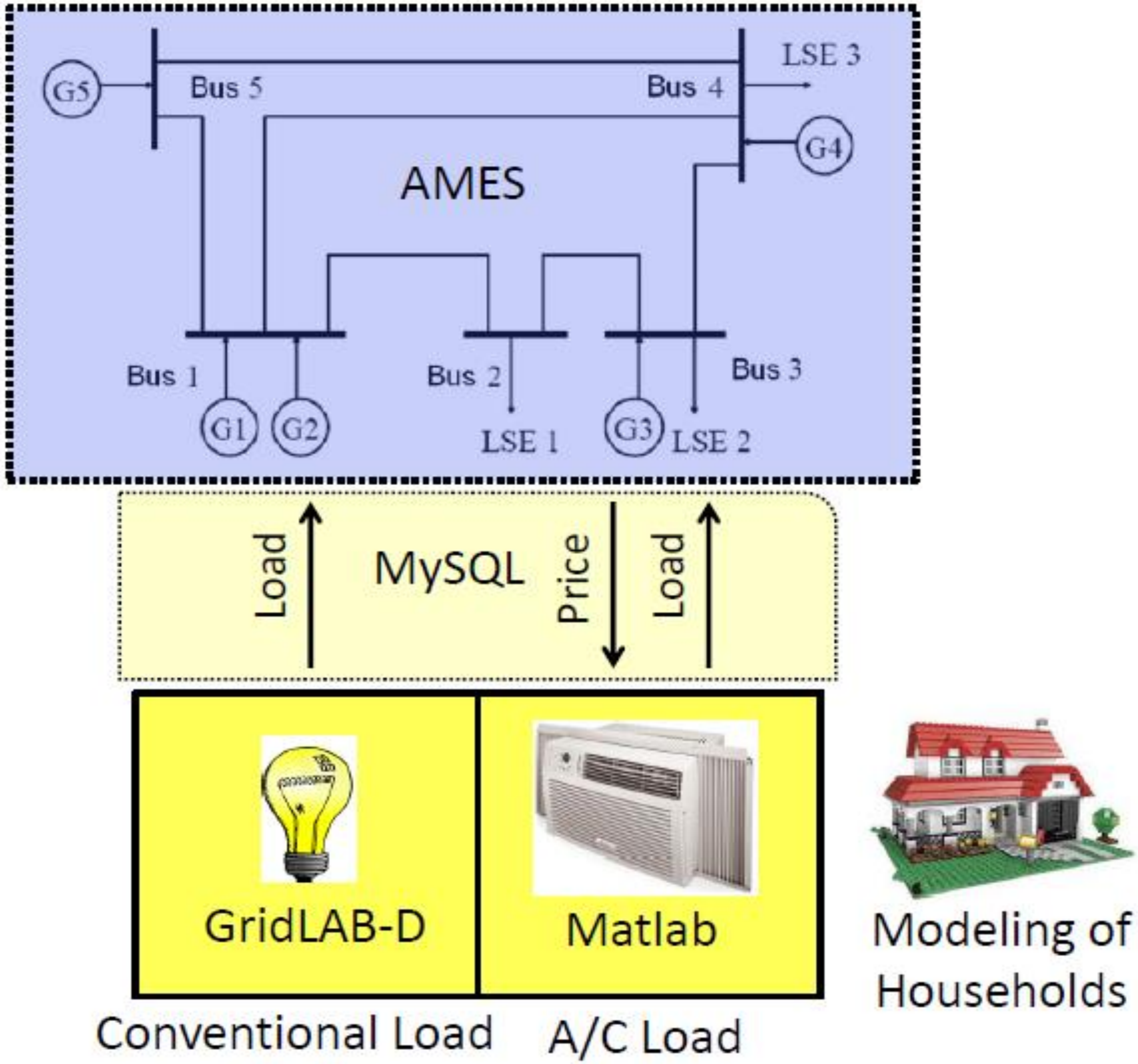
Economic Incentives for GenCos, LSEs, & Consumers



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



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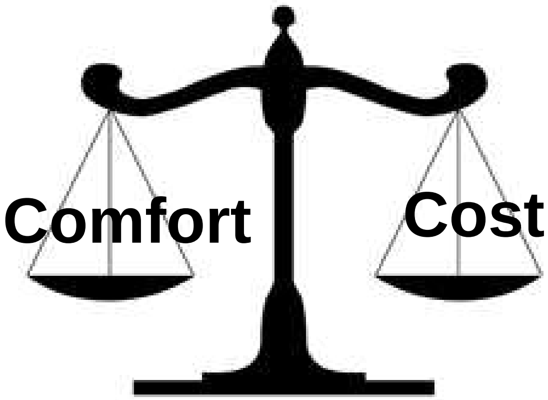
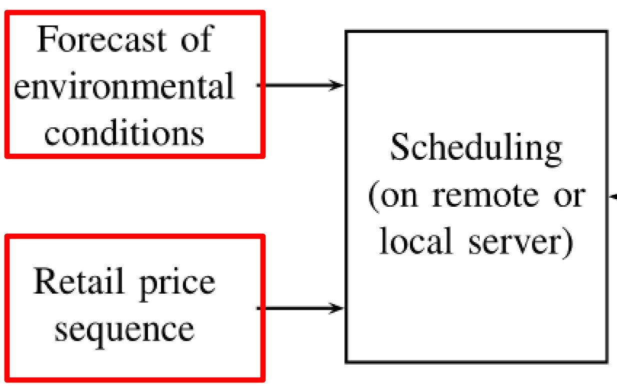
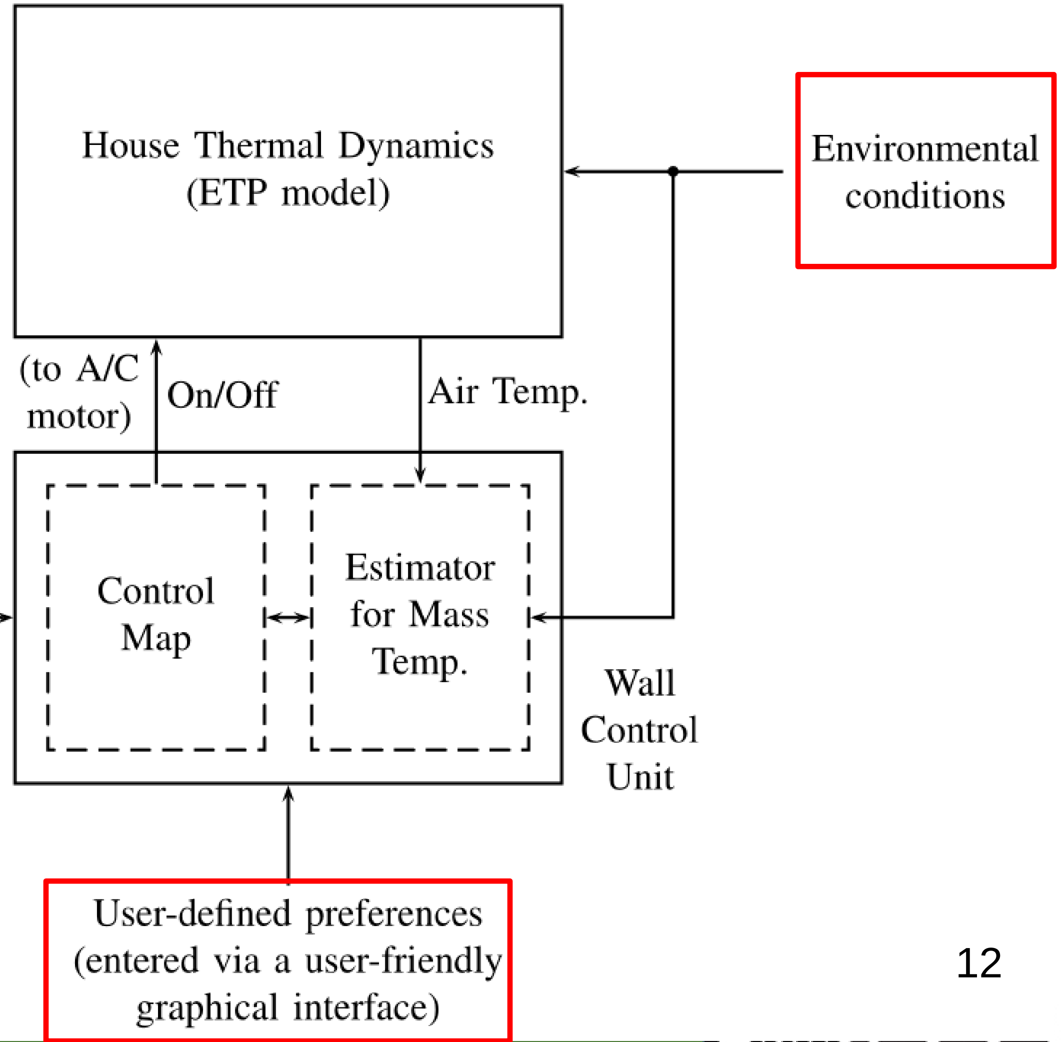
Intelligent A/C Controller



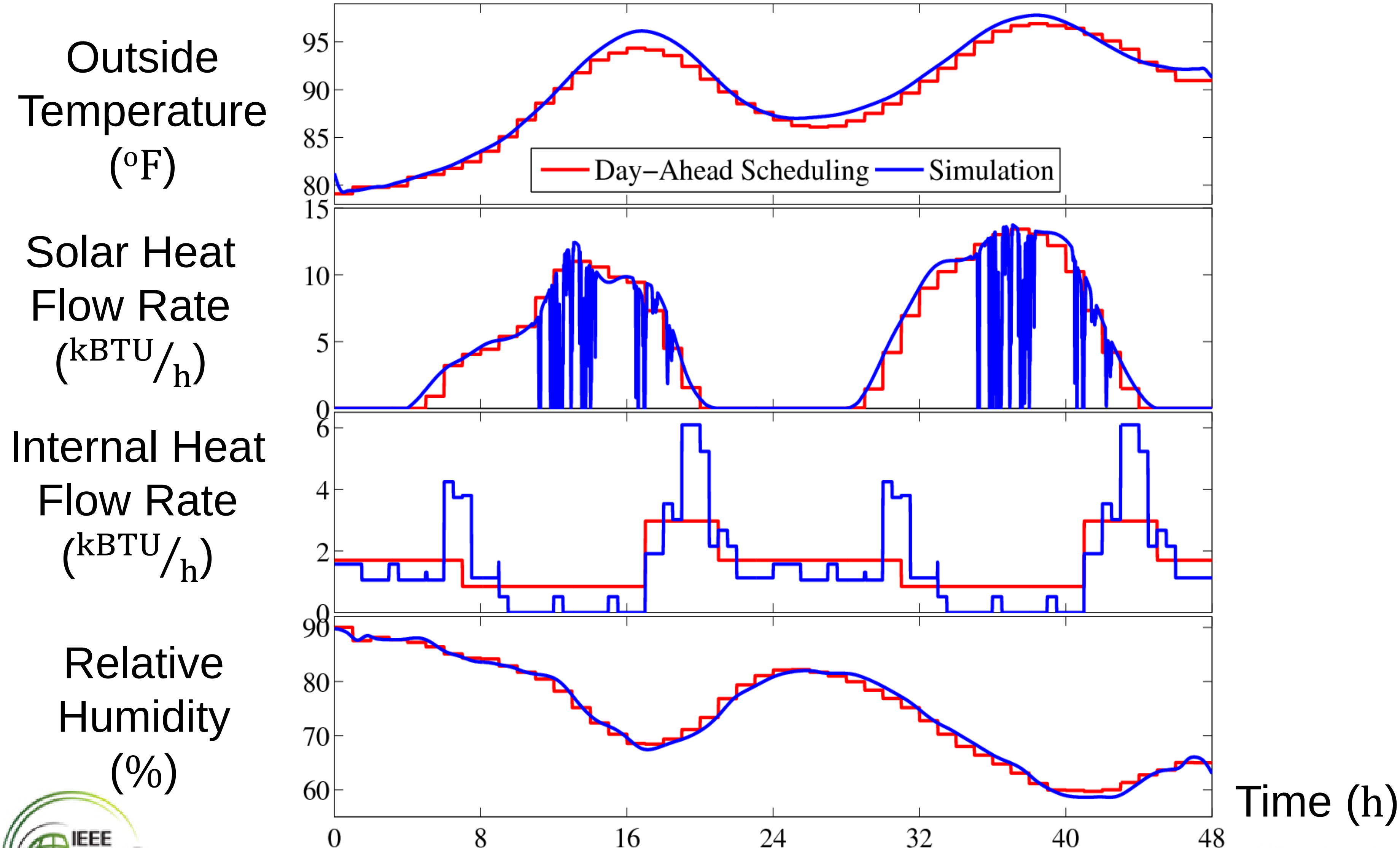
Prices

Household Preferences



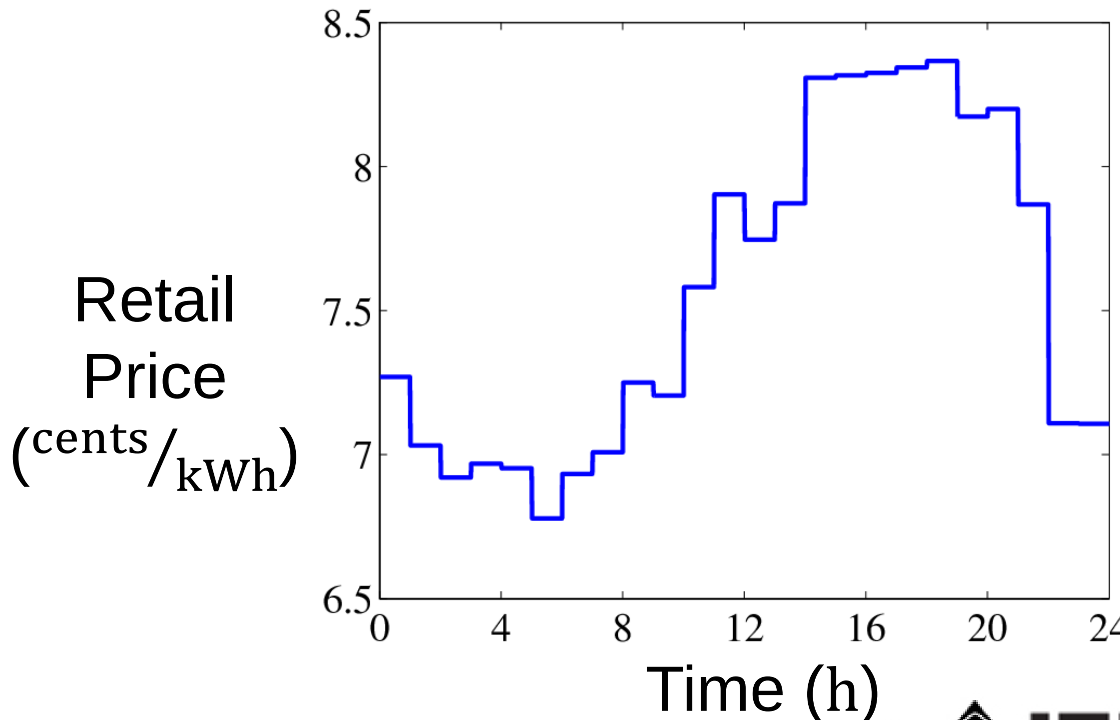


Environmental Forcing Terms



Wholesale Prices Passed Thru to Households

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

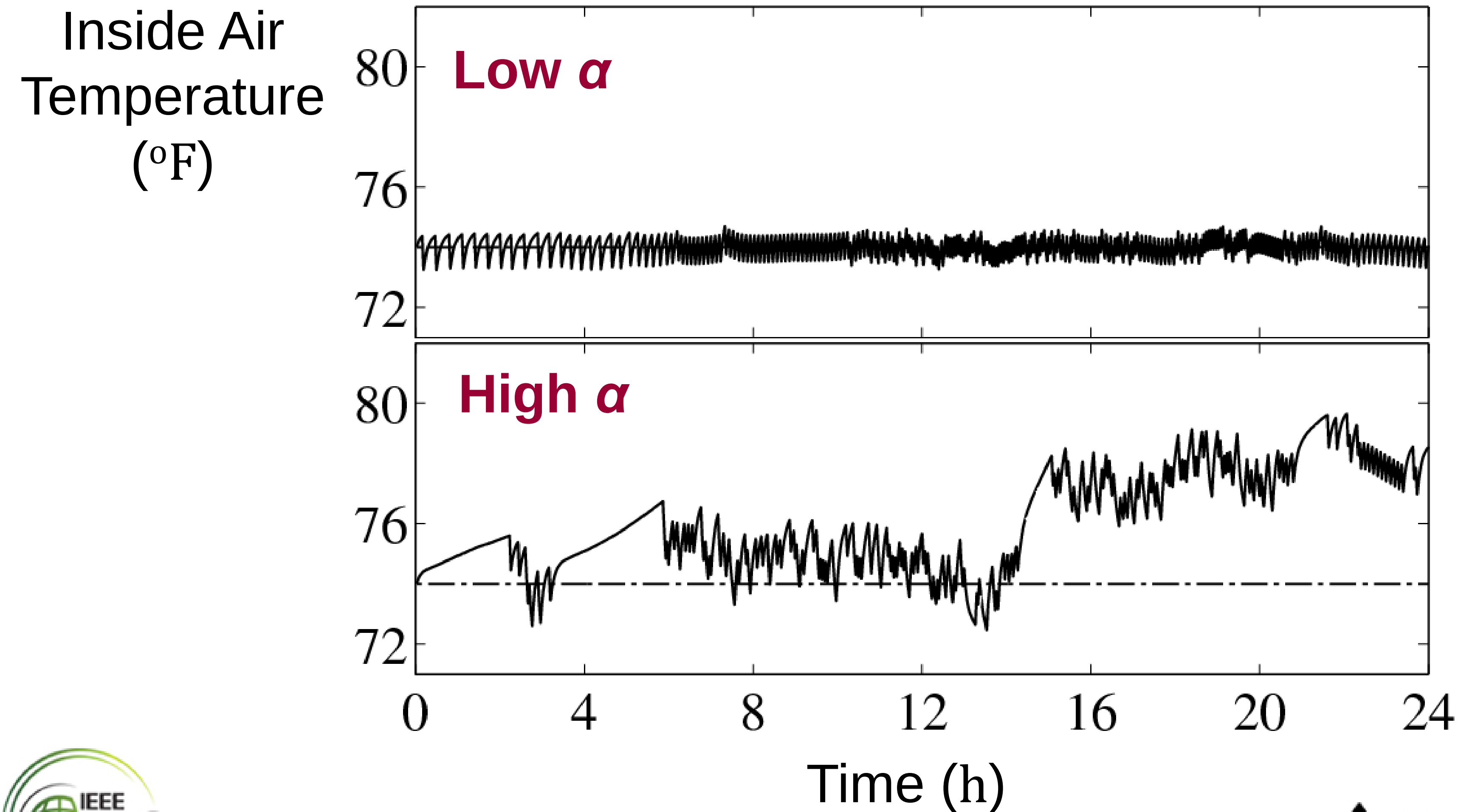


Attributes of Household Residents

- 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



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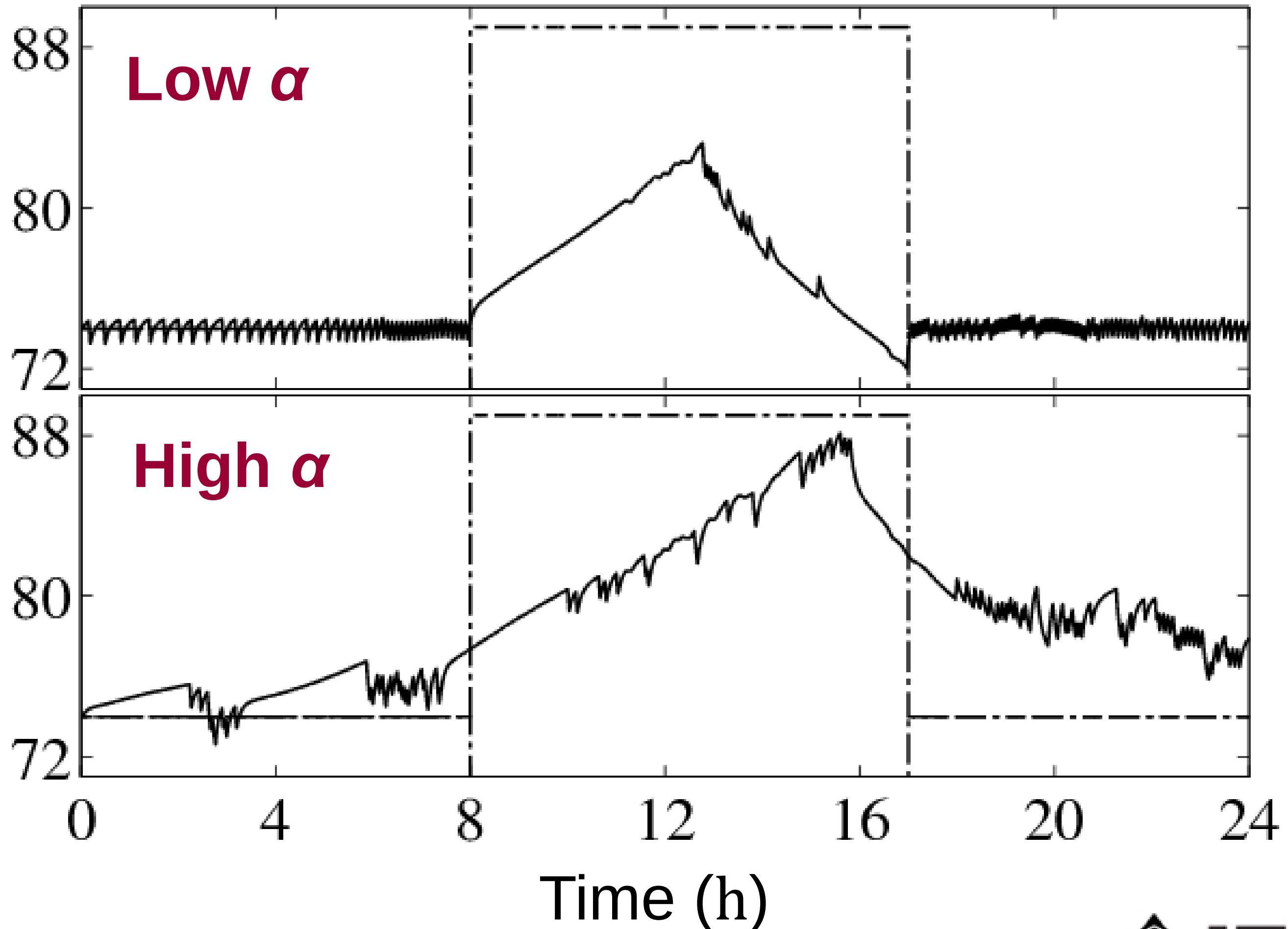
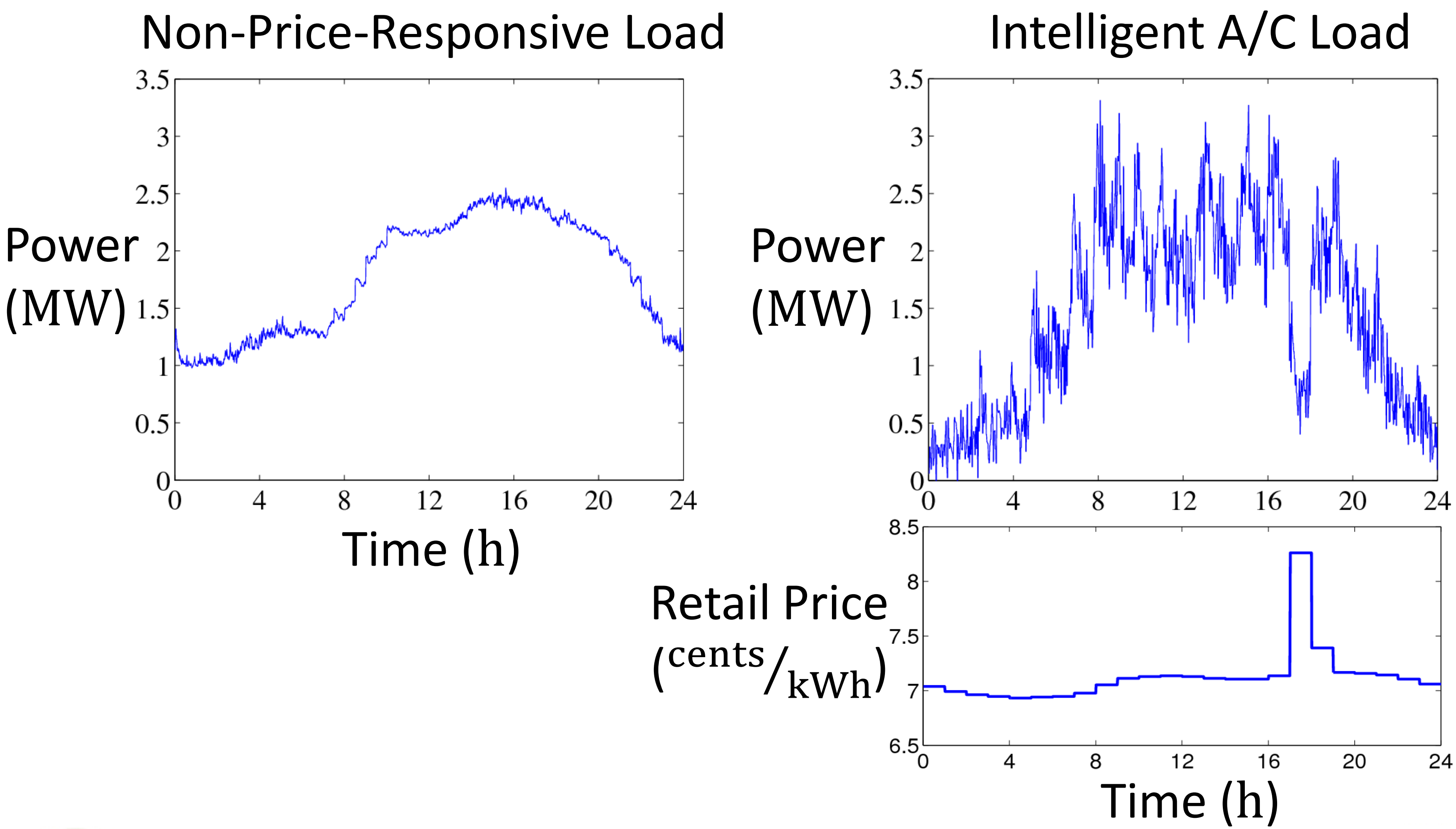
Resident away from home 8am - 5pm

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

Inside Air Temperature (ºF)



From single-household load to aggregated bus load



IRW Case Study Specifications

- Single Distribution Feeder
  - Many types of houses
  - Many types of household residents (differing α values)

- Wholesale Power System
  - 5 buses and 6 lines
  - 3 LSEs with conventional loads (no price sensitivity)
  - 1 LSE with price-sensitive-load customers
  - 5 GenCos

IRW Case Study Specifications…Continued

- Exogenously given state vector for each day
  - Temperature profile
  - Conventional load profiles
  - Other forcing terms

- LSE DAM demand bid method
  - Day D-1 actual load ⟹ Day-D demand bid

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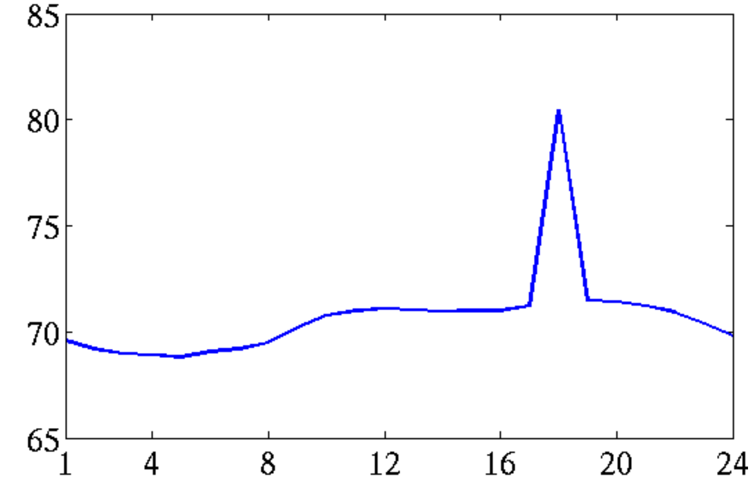
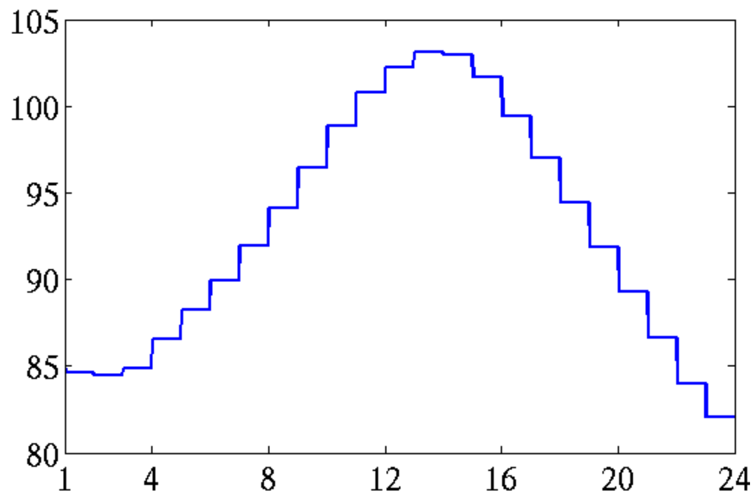
Illustrative Results for a Single Day
Retail Prices/Temp ➡ Retail Total Load Profile

Retail Price

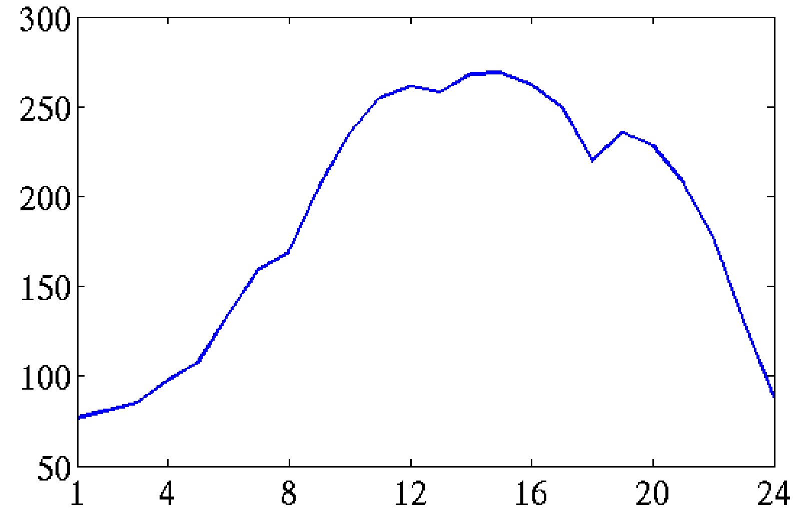


Outside Temp



Time (hrs)

Retail Total Load



Time (hrs)

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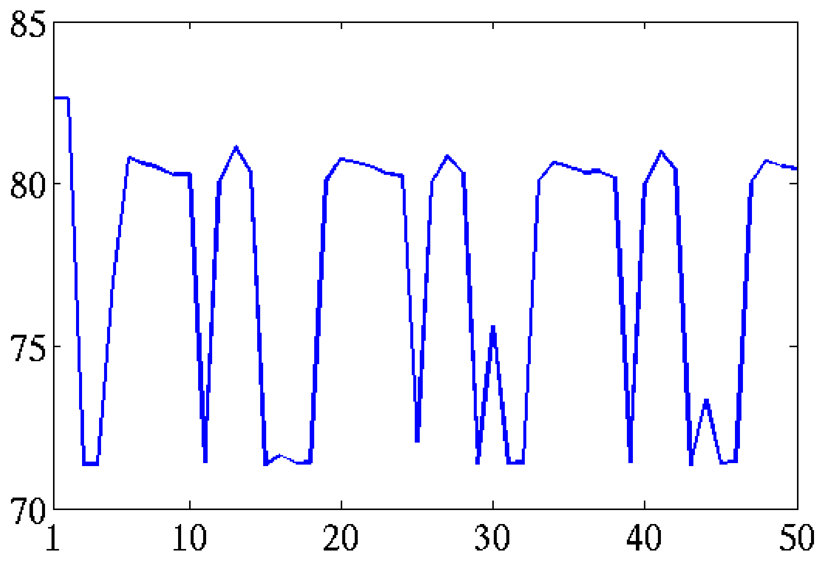
Illustrative results for 50 Days (Peak Hour 18)

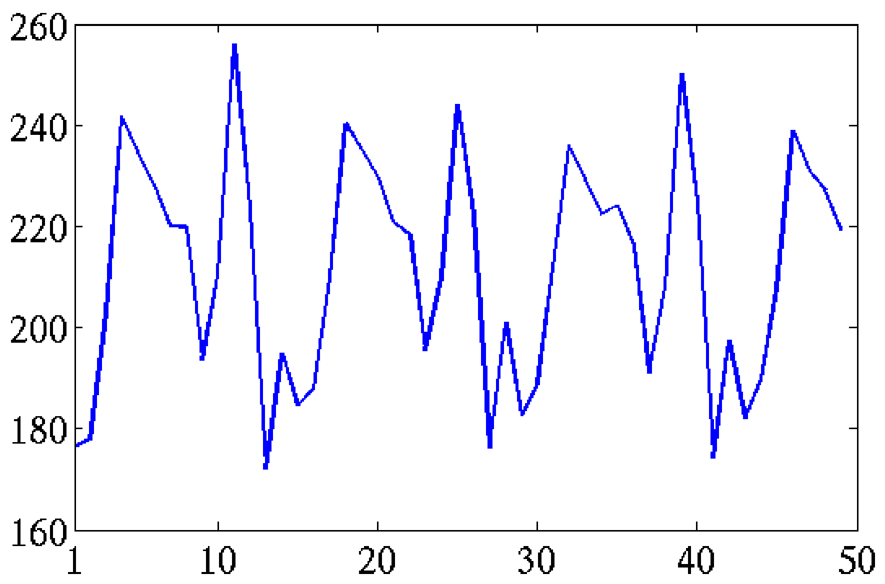
Retail Price ⟶ Retail Total Load

Retail Price



Days

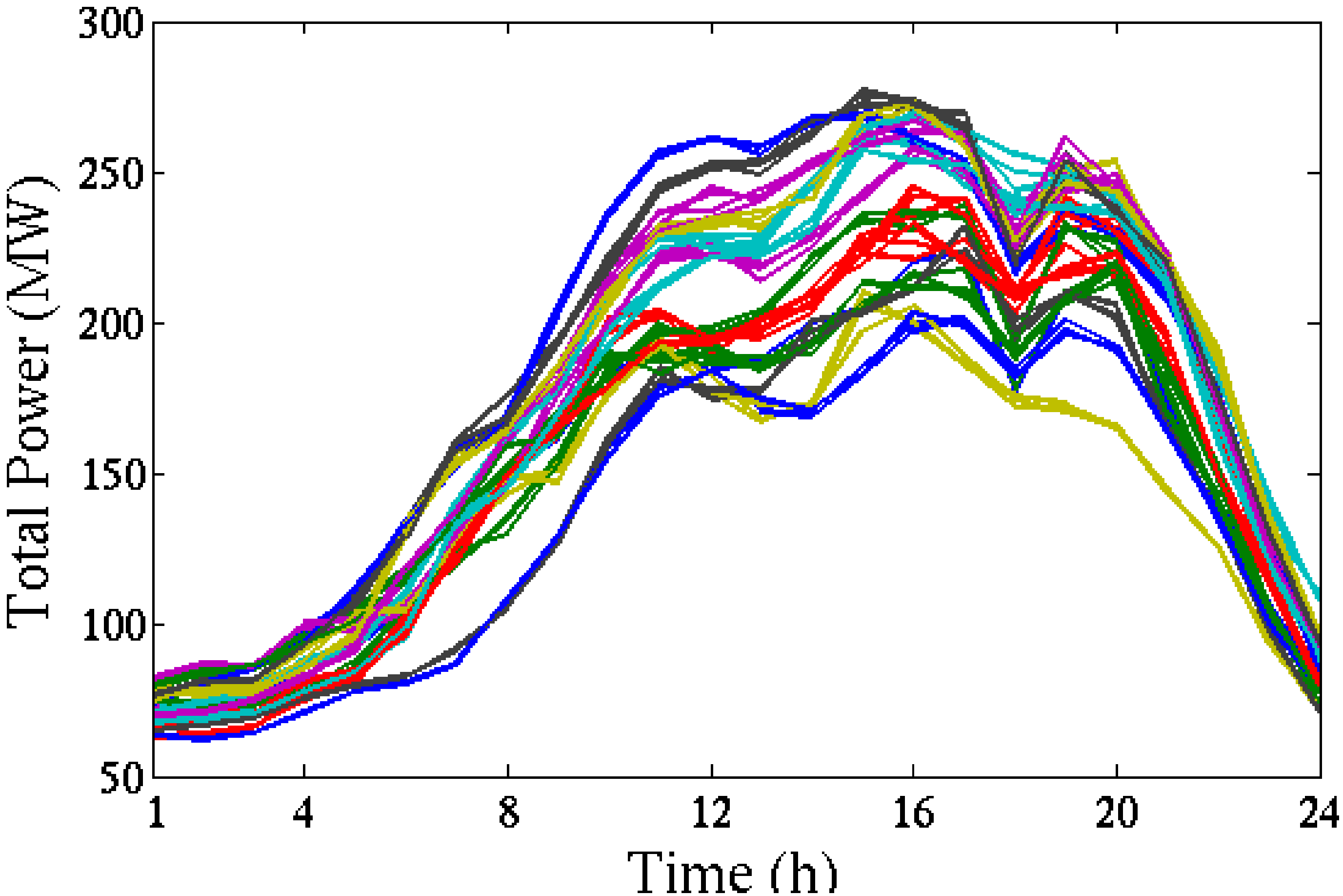
Retail Total Load



Days

Illustrative Results for 50 Days

Superimposed retail total load profiles



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

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

- GenCo net earnings (LMP payments – production costs)
- LSE net earnings (retail payment receipts – LMP costs)
- Residential household comfort/cost tradeoffs
- ISO congestion rent (LMPs received – LMPs paid out)
- Energy usage levels
- Price volatility
- 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