Report on Theme-2: Project-3 Demand Response Technologies and Strategies- Energy Management & Metering

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Overview of the Presentation

- Research team members and topics
- Research objectives
- Impact of pricing on demand response
- Indoor Ice Rinks:
  - System description, mathematical model, inputs
  - Brief discussion of results
- Multi-unit residential buildings:
  - system description, mathematical model, inputs
  - Brief discussion of results
- System impact of price responsive demand:
  - System description, mathematical model, inputs
  - Brief discussion of results
- Conclusions
- Next steps

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Research Team

- Rupali Jain, MASc Student
- Rajib Kundu, MASc Student
- Felipe Ramos Gaete, MASc Student
- Professor Claudio Cañizares
- Professor Kankar Bhattacharya
- Collaborators
  - Dr. Steve Wong, NRCAN
  - David Curtis, Ravi Seethapathy, Bob Singh, Hydro One
  - Gord Elis, Energent Inc.

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Research Problems

- Impact of pricing on demand response:
  - Rupali Jain
  - Rajib Kundu
- Optimal operation of climate control systems of indoor ice rinks:
  - Rupali Jain
- Optimal operation of centralized temperature control system in multi-unit residential buildings:
  - Rajib Kundu
- Effect of price-responsive demand on dispatch and prices:
  - Felipe Ramos Gaete

Research Objectives

- Study the effect of various types of prices on the demand of price-responsive loads.
- Develop a comprehensive mathematical model for optimal energy management in indoor ice rinks:
- Develop a mathematical model of centralized indoor temperature control system for multi-unit residential buildings to minimize electricity cost and energy consumption.
- Study effects of demand elasticity on market price and dispatch levels in power grids.

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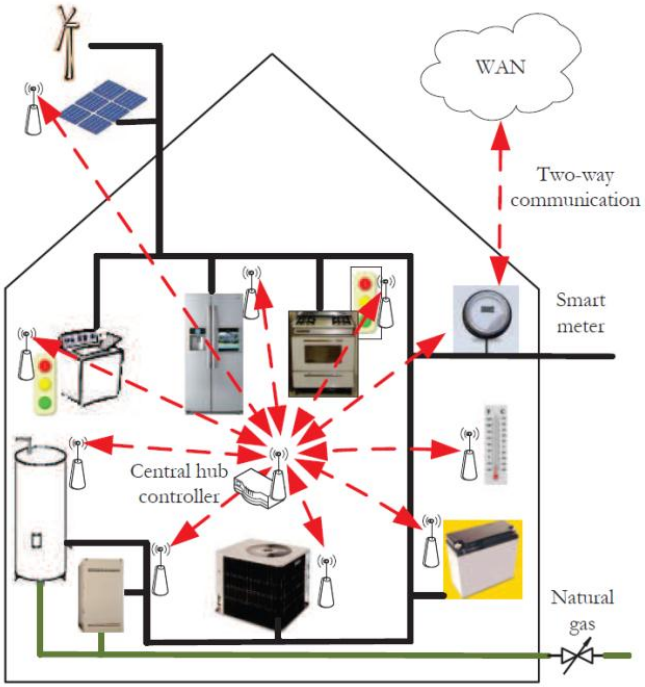
Price-responsive Load Model

- Objective:
  - Minimize energy costs
- Modeled devices:
  - PV array
  - Energy storage system
  - AC and heating system
  - Water heater



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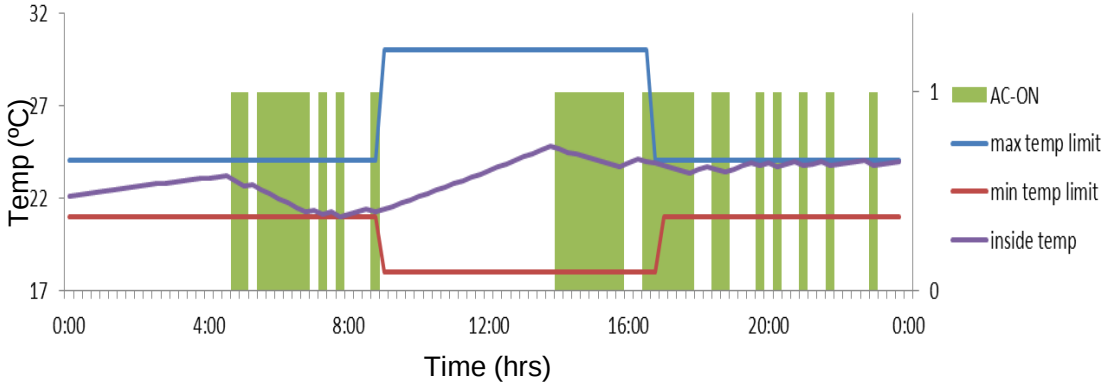
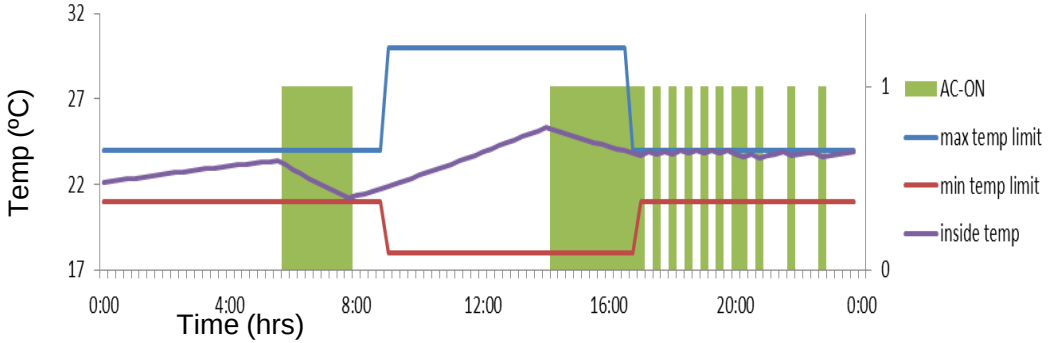
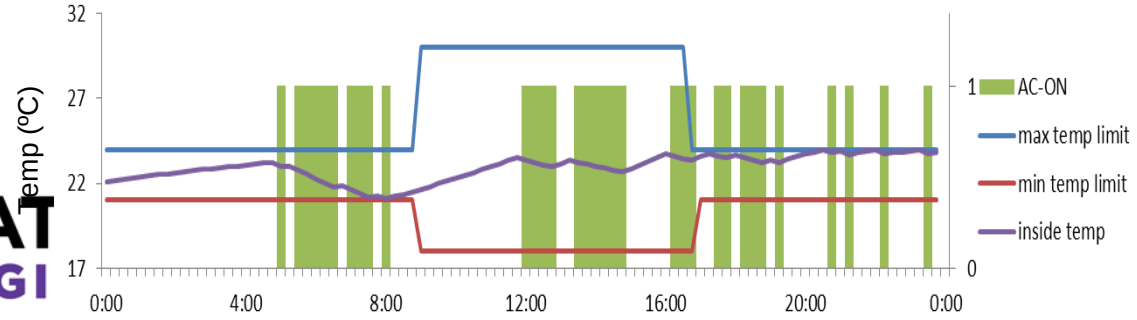
Optimal Operation of AC



RTP

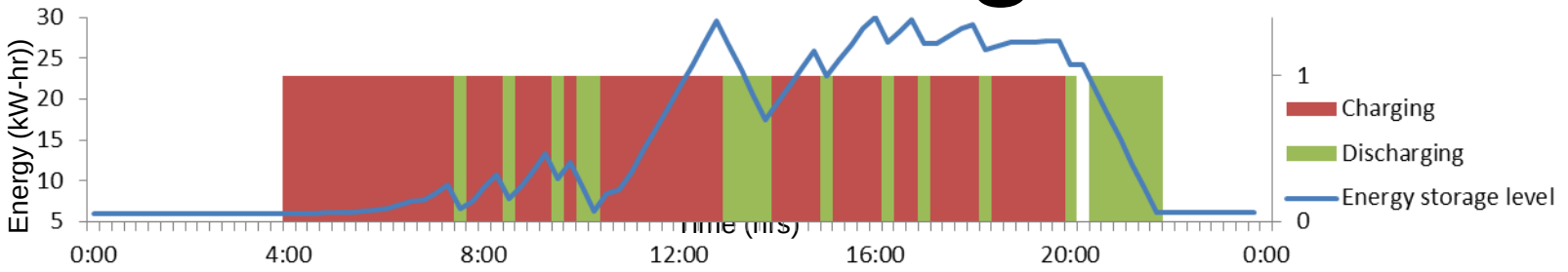


TOU



LMP

Optimal Operation of Energy Storage



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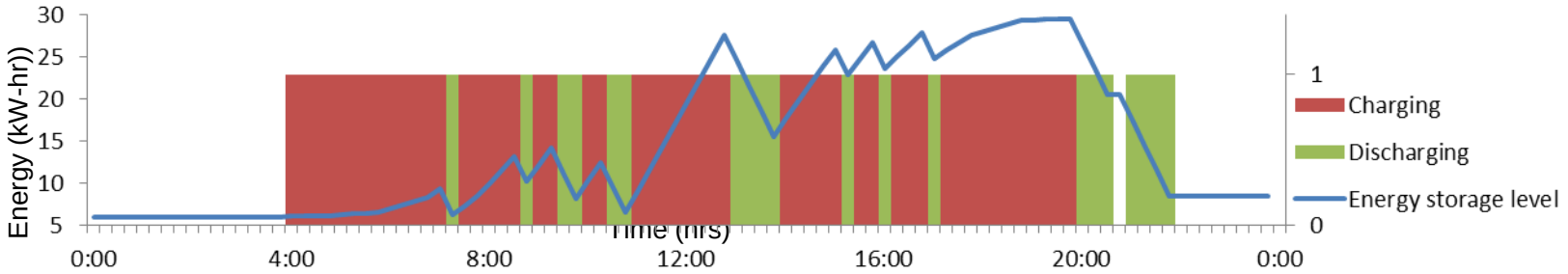

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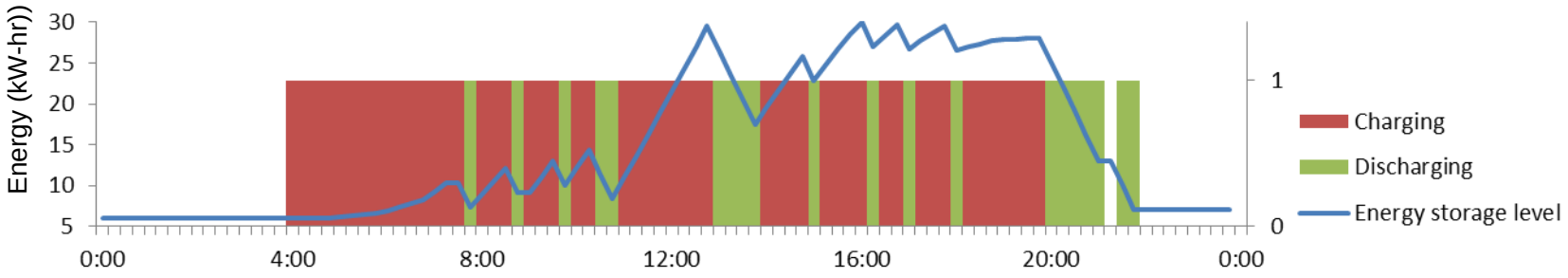
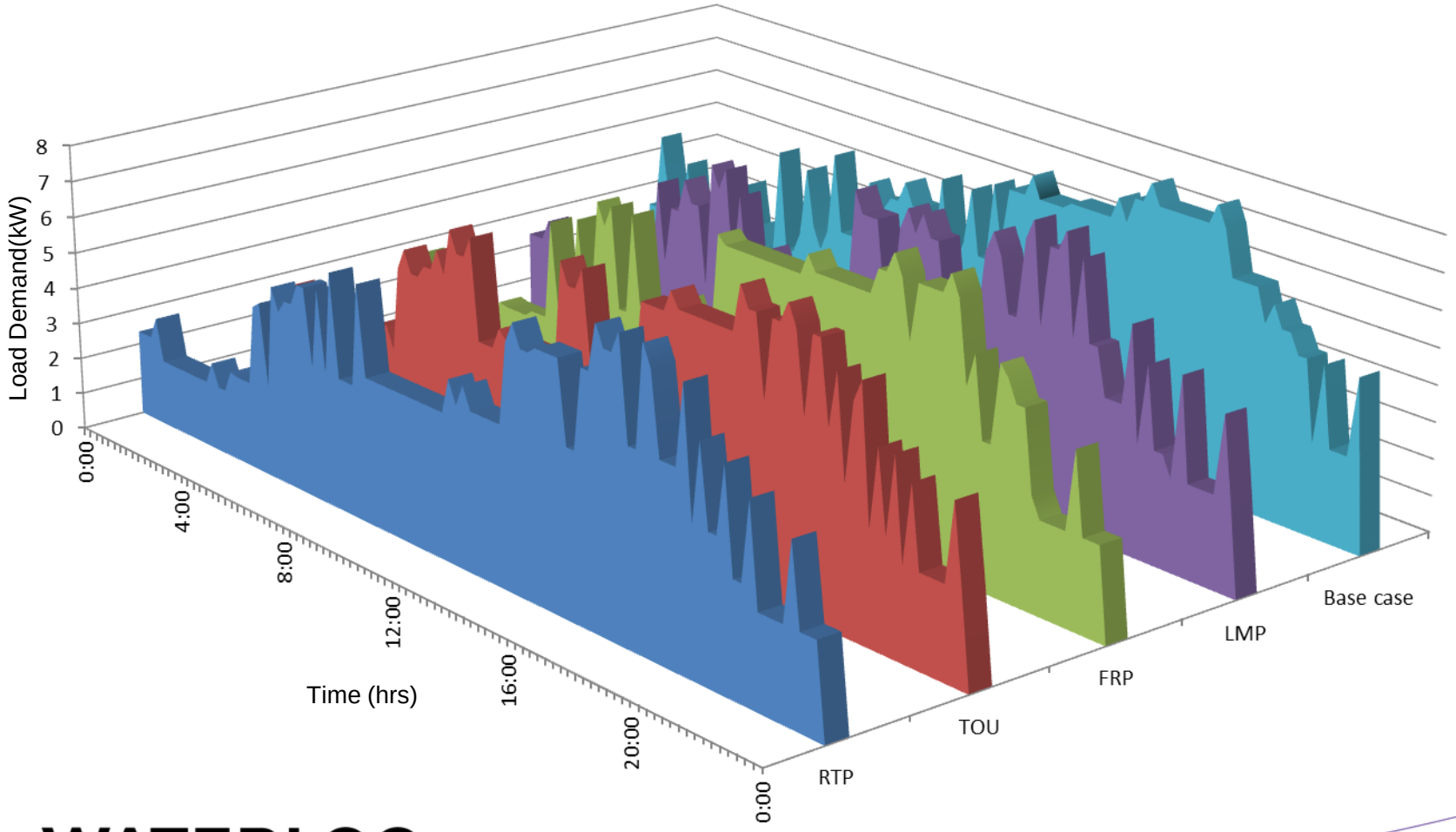


LMP

Comparison of Summer Load Profiles



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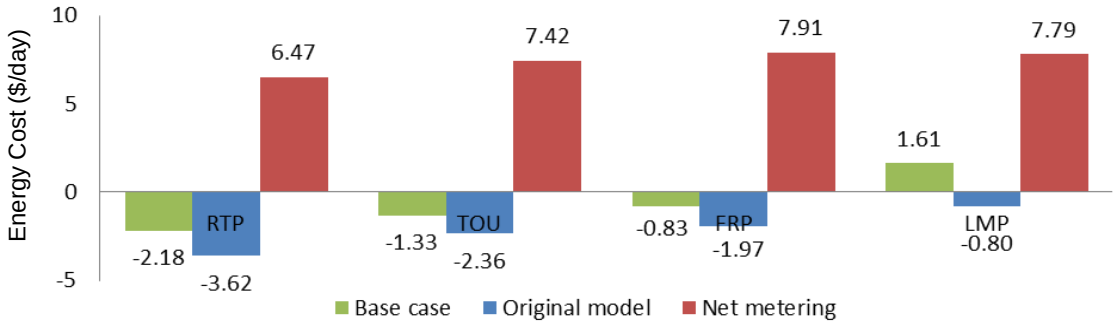
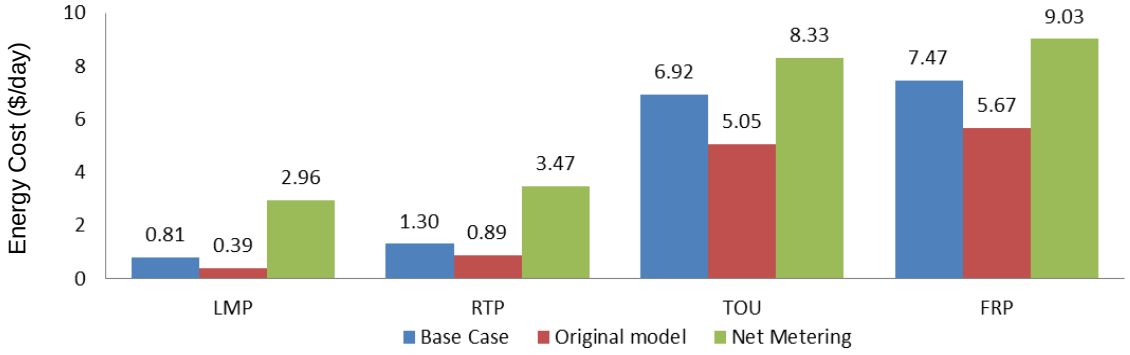
Comparisons

- Aggregated residential electrical energy cost:
  - Summer:



  - Winter :



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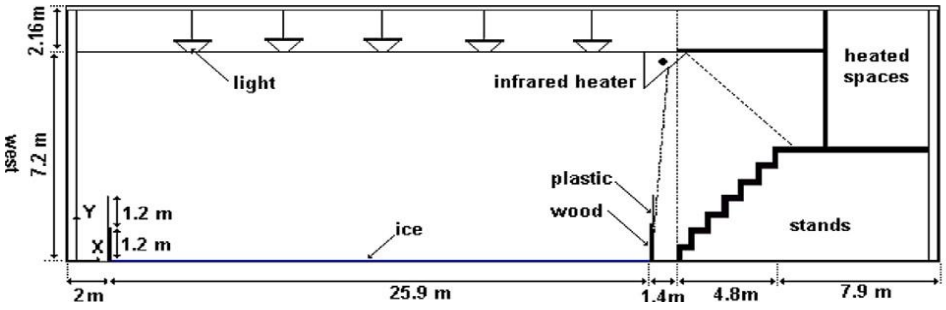
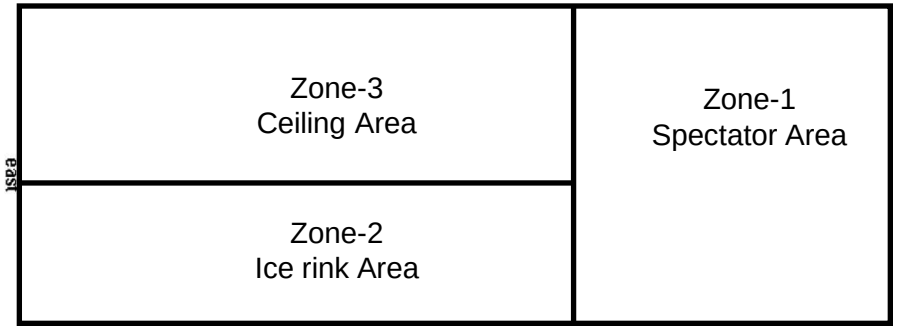
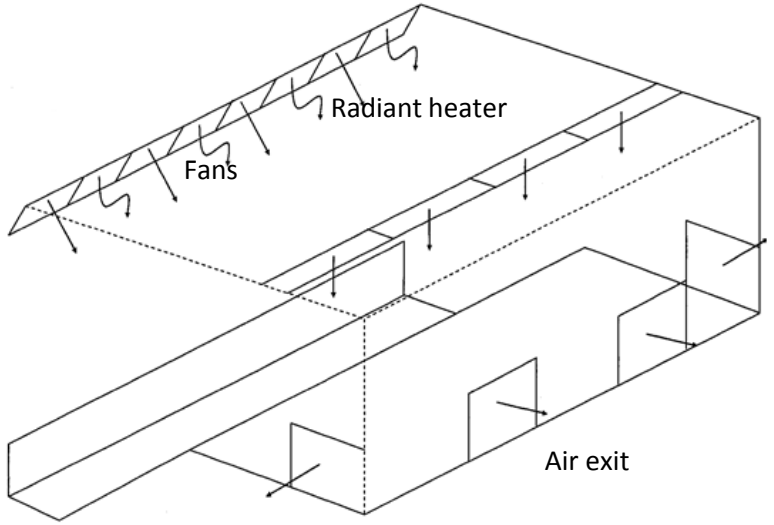
Indoor Ice Rink Schematics





Source: Daoud *et.al* [3]

- Ventilation system
- Radiant heating
- Dehumidifier



Source: Daoud *et.al* [3]

Inlet, outlet and radiant heating conditions in the spectator area

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Mathematical Model

- Objectives:
  - Minimization of temperature and humidity deviations (base case)
  - Minimization of electrical energy cost
- Constraints:
  - Indoor humidity constraint
  - Indoor moisture balance
  - Indoor temperature constraint
  - Temperature and humidity limits
  - Binary decision variables

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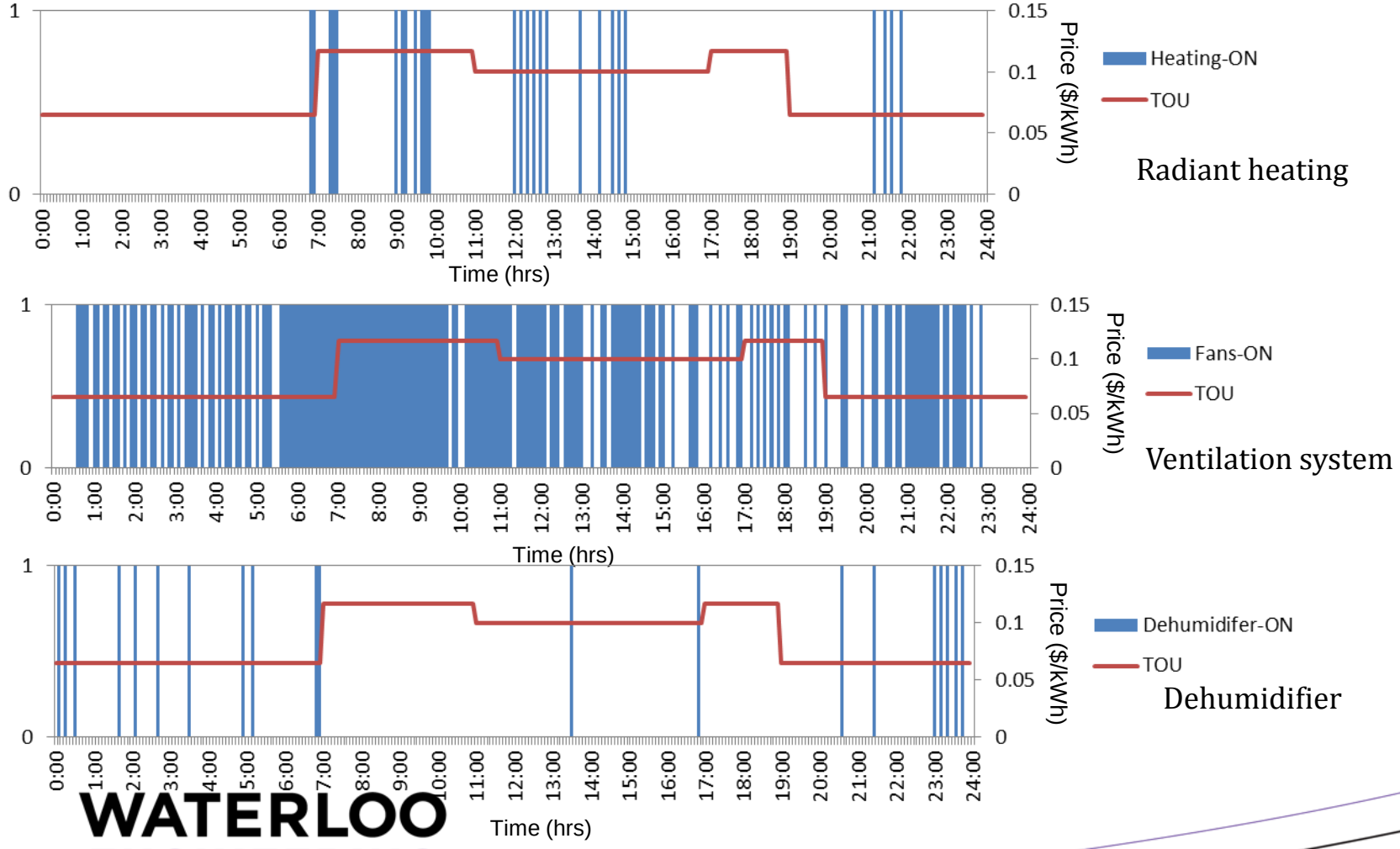
Optimal Operational Schedules with TOU



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Comparisons

- Device specific electrical energy cost:

Device	HOEP			TOU		
	Base Case ($/day)	Minimizing cost ($/day)	Savings (%)	Base Case ($/day)	Minimizing cost ($/day)	Savings (%)
Radiant Heating	30.144	11.727	61.096	114.623	49.073	57.188
Ventilation Fans	19.968	20.199	-1.160	58.247	62.906	-7.998
Dehumidifier	3.168	1.123	64.558	6.010	2.925	51.333
Total	53.280	33.049	37.970	178.880	114.903	35.765

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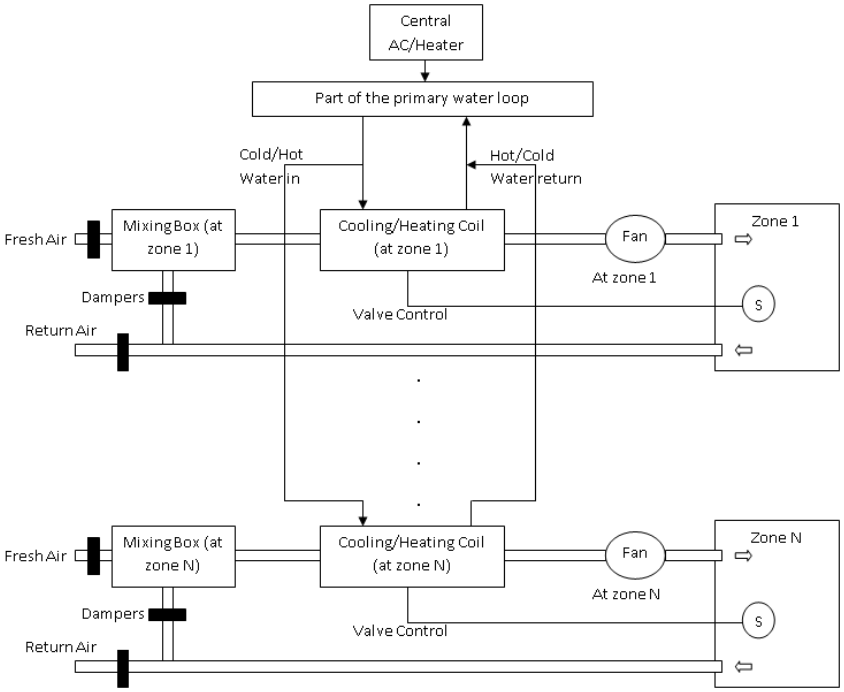
Multi-unit Residential Building



- Multi-unit residential building
  - 3 floors (zone), each 130 m2
  - All walls, floors and roofs have same thermal properties.
- Modeled device: Centralized AC
  - Primary system comprises air-cooled water chiller and two water circulation pumps.
  - Secondary system- mixing box, cooling/heating coil and supply fan for each floor.

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Mathematical Model

- Objectives:
  - Minimization of temperature deviation (base case)
  - Minimization of energy cost
  - Minimization of energy consumption
- Constraints:
  - Primary system heat balance constraint
  - Secondary system indoor temperature dynamics
  - Indoor temperature constraint
  - Binary decision coordination constraints

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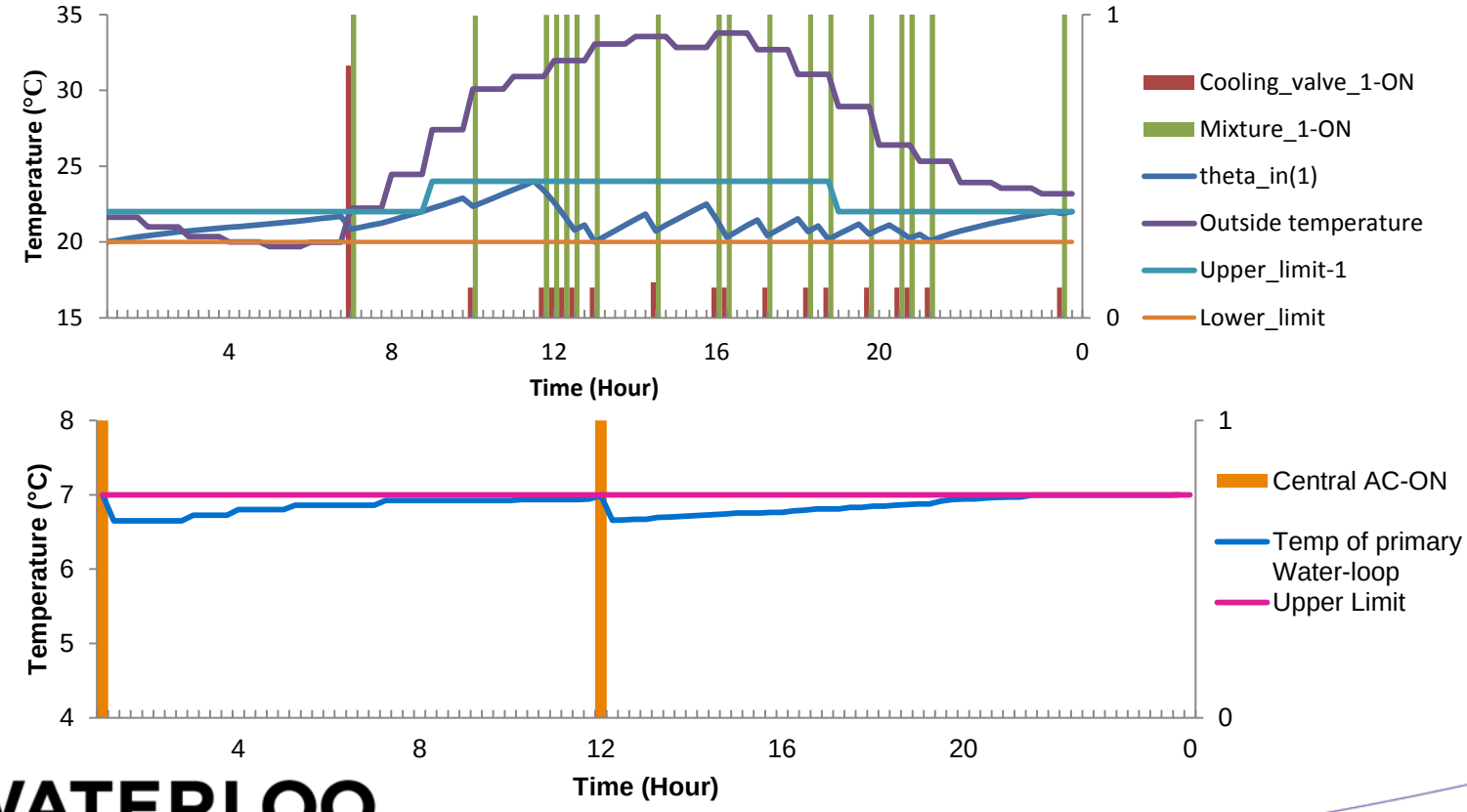
Optimal Operation with TOU



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Comparisons

	Pricing Scheme	Zonal Cost			Total		Total Saving w.r.t base case (%)	
		Zone 1	Zone 2	Zone 3	Cost ($)	Energy Consumption (kWh)	In Cost	In Energy Consumption
Case 0 (Base Case)	HOEP	6.426	6.93	5.952	19.308	572.541	-	-
	TOU Ontario	9.162	14.353	12.251	35.766	572.168		
Case 1	HOEP	4.34	3.654	2.853	10.871	287.762	43.696	49.739
	TOU Ontario	4.145	7.73	4.849	16.724	195.694	53.24	65.8
Case 2	HOEP	2.592	2.559	1.545	6.696	196.999	65.32	65.57
	TOU Ontario	4.851	4.788	2.891	12.529	196.999	64.97	65.57

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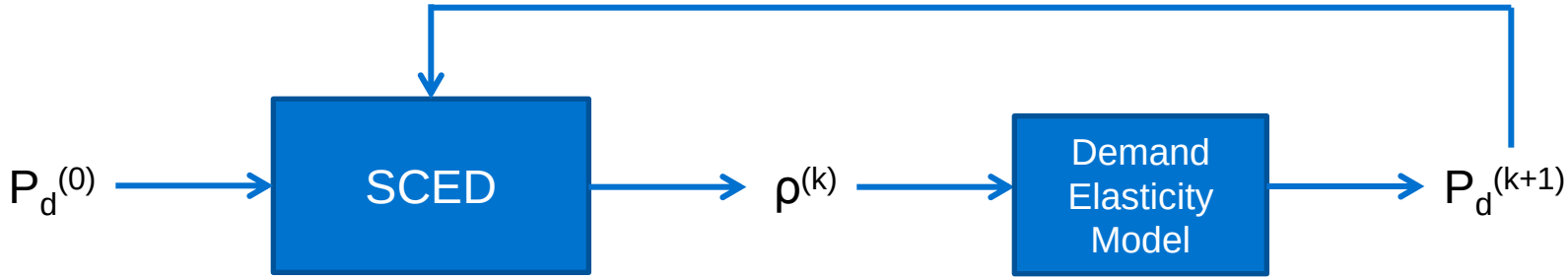
System Impact of Price Responsive Demand

- Nodal prices are obtained from a security constrained economic dispatch (SCED).
- These are used as input to the demand elasticity model
  - The price-responsive demand for the next iteration is obtained, assuming that the load schedule is defined a day ahead.



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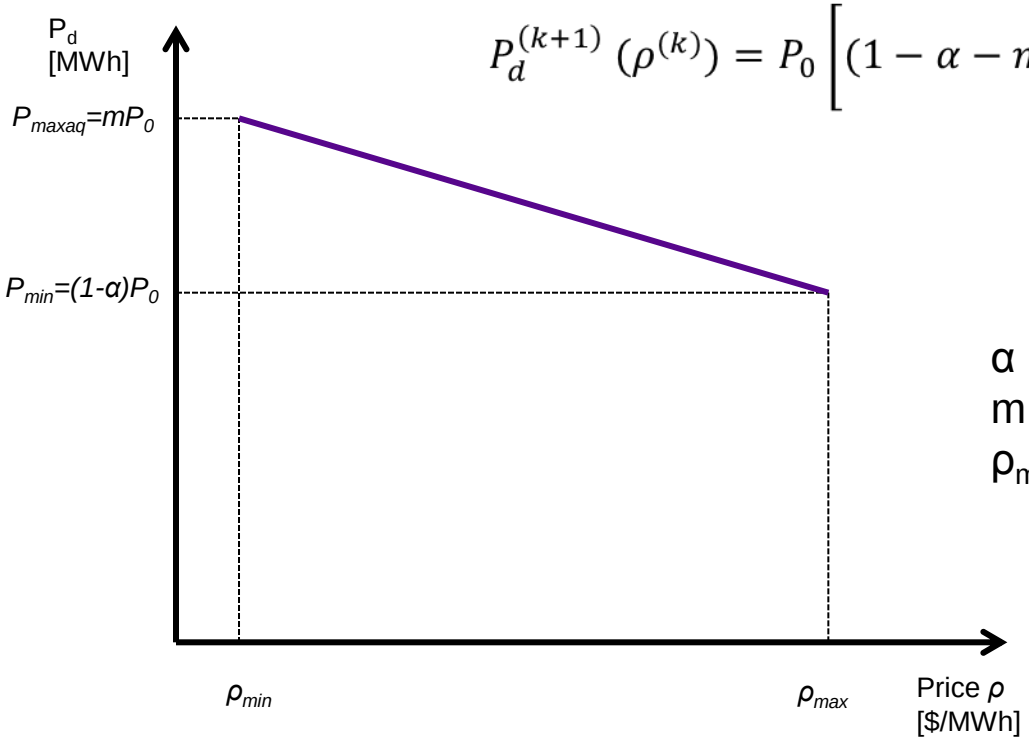
Linear Load Elasticity Model



$$P_d^{(k+1)}\left(\rho^{(k)}\right) = P_0\left[(1-\alpha-m)\frac{\rho^{(k)}-\rho_{min}}{\rho_{max}-\rho_{min}}+\mathrm{m}\right]$$

α : Percentage of elastic load

m : Maximum power purchasable by customers (pu)

ρ_{max} : Maximum price acceptable for customers

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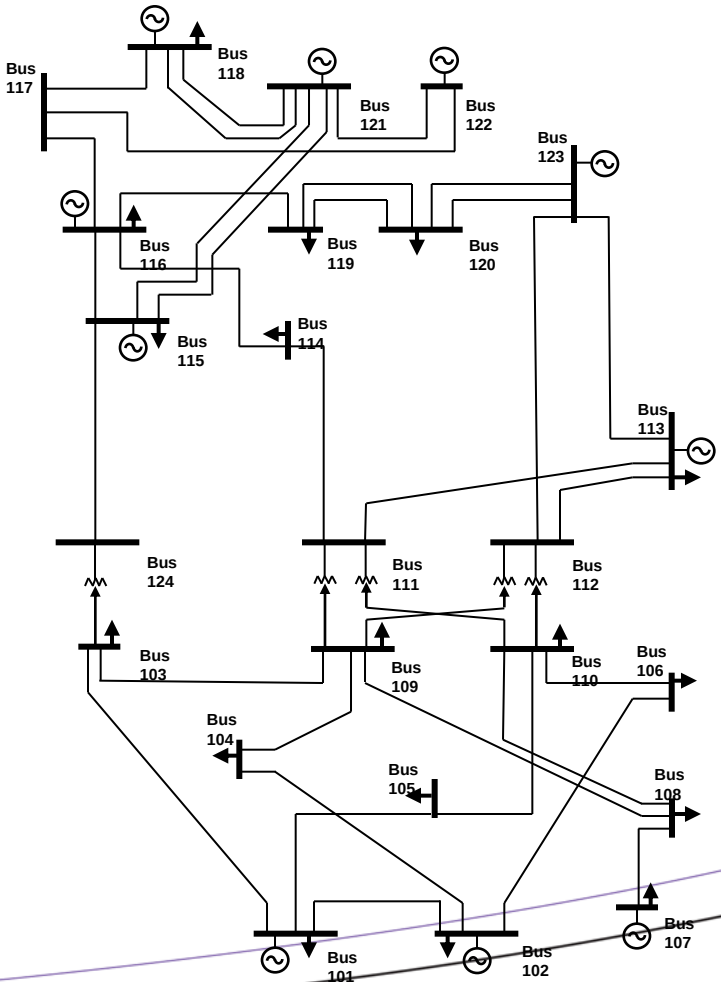
Mathematical Model and System

- Objective:
  - Minimization of generation cost
- Constraints:
  - Energy balance (dc power flow)
  - Line flow limits
  - Generator limits

IEEE RTS 24 Bus System (Modified)



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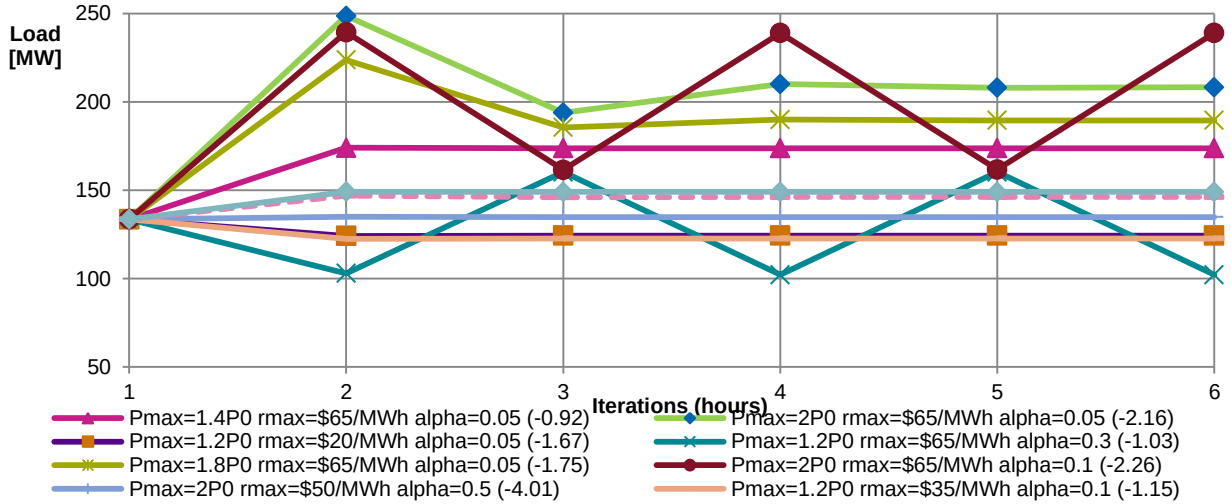
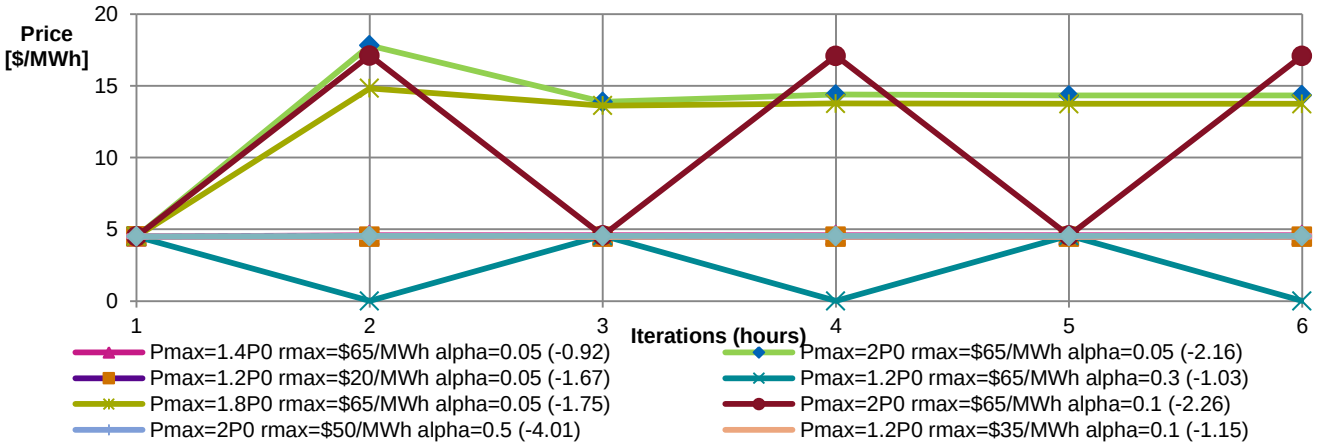
Results

- Demand and nodal price at Bus 113:





Conclusions

- Effect of pricing on demand:
  - There is significant reduction in energy cost with the original model for all pricing signals; this is due to the device optimized schedules.
  - The energy cost for individual devices is also reduced considerably, with the AC having the most significant reduction of 50% in its electrical energy cost for LMP and RTP.
  - The schedules for charging and discharging of the energy storage device change slightly for different pricing signals, because of multiple local solutions, but the total number of charging and discharging events, and hence revenue from solar PV remain the same.
- Mathematical model for real-time DR of ice rinks:
  - Incorporates weather forecast, electricity price information and end-user preferences to optimally operate the climate control system to minimize energy cost.
  - Significant reduction in energy cost is achieved (around 35% and devices' costs up to 50%).
- Mathematical model for real-time temperature control of multi-unit residential buildings:
  - Optimal operational schedules of centralized ac system is obtained to minimize electricity costs and consumption.
  - Over 40% savings in electricity costs and consumption are observed.
- Effect of load price-elasticity in market prices and dispatch for a linear price-elasticity demand model:
  - System prices and loads were observed to stabilize quickly to steady state values or oscillate between two price bands, depending on load elasticity levels.

Next Steps

- Ice rinks:
  - Estimate annual energy savings for operation of climate control systems.
  - Estimate the difference in electrical energy cost during weekdays and weekends.
  - Journal paper in preparation.
  - To be presented at CanmetENERGY Workshop, 27th Sept 2012.
- Residential units:
  - Consider customers in different zones have different priorities and objectives.
  - Consider several sub-zones requiring development of an intra-zonal heat flow model.
  - A humidifier model in cooling/heating coil can also be incorporated.
  - Journal paper in preparation.
  - To be presented at CanmetENERGY Workshop, 27th Sept 2012.
- Price elasticity:
  - Increase model complexity considering 24-hour operations, ramp-up and down constraints, spinning reserve constraint, unit commitment constraints.
  - Include other elasticity models.
  - To be presented at CanmetENERGY Workshop, 27th Sept 2012.
- Integration of the above models into a micro-grid dispatch model.

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Possible Areas for Collaboration

- Project 1.4: To examine where a microgrid may have a high penetration of renewables and available storage considering various strategic aspects.
- Project 2.1: To examine a microgrid cost-benefit framework where an EMS seeks to maximize stakeholder benefit.
- **Project 2.2:** To examine supply security and interaction aspects between the microgrid and larger grid, for sharing information so that DR interactions can be modelled appropriately.
- Projects 3.1 and 3.2: Communication aspects between one (operator) to many (loads) pertaining to EMS in microgrids.
- Project 3.4: Regarding data communication needs pertaining to microgrid EMS and understand any limitations to be imposed on any algorithms.