Improved Energy Services Provision through the Intelligent Control of Distributed Energy Resources

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Presentation Outline

- Introduction: Distributed Energy Resources and Energy Services
- Modeling of Energy Services
- Simulation Platform: Scheduling of DER Operation
- Particle Swarm Optimization
- Case Study
  - Description
  - Simulation Results
- Conclusions

Distributed Energy Resources

- Fine-grained equipment and practices
- Co-located or near the consumer
- Support the utility in delivering energy services
- Types*
  - Generation resources: embedded generation (fossil fuel -fired or renewable)
  - Grid resources: grid-sited storage, reduced grid losses, improved power factor
  - Demand-side resources: efficient end-use equipment, motor controls, shiftable loads, consumer-sited storage

* Lovins, A. B., *Small is Profitable: The hidden economic benefits of making electrical resources the right size,* Colorado, USA: Rocky Mountain Institute, 2002.

Energy Services

- Energy forms, processes and products from where users derive the value of raw energy carriers
- Examples:
  - Direct energy services*: illumination, space conditioning, mobility, water heating, cooking, etc.
  - Indirect energy services*: information processing, entertainment, commercial goods, etc.
- Demand and value of services change with time

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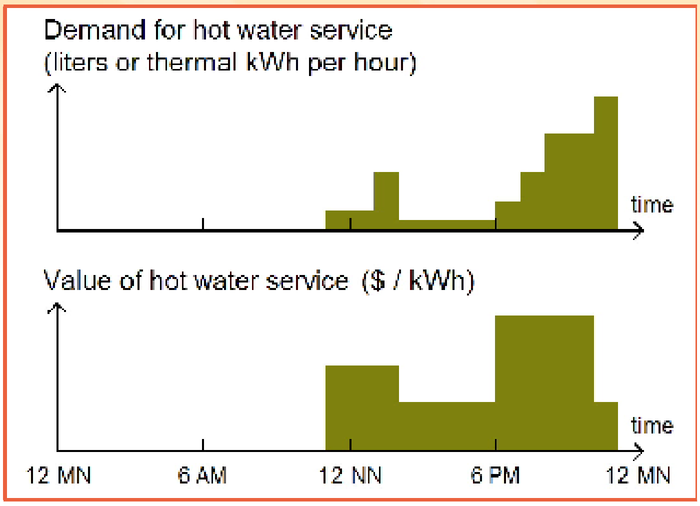
* Haas, R., etal, "Towards sustainability of energy systems: A primer on how to apply the concept of energy services to identify necessary trends and policies," *Energy Policy*, 38 (2008) 4012-4021.

Modeling Energy Services

- Temporal variation of demand
- Temporal variation of value
  - Value is assigned to the "energy equivalent" of the energy service
- Relationship between "energy equivalent of energy service" and actual energy consumption of end-use equipment.



Modeling the demand and value of water heating service in a restaurant.

DER Scheduler

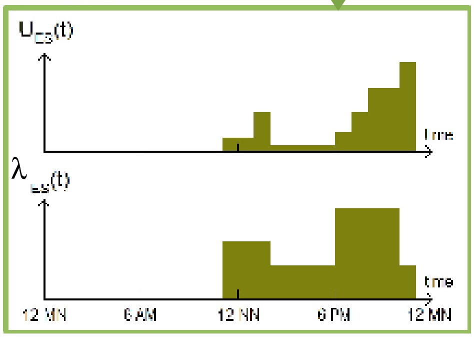
- Schedule the operation of DER to maximize the net benefit of energy services
- Net benefit = “benefit derived from availability of service” – “cost of provision”
- Scheduling takes advantage of
  - Temporal variation of cost of electricity
  - Flexible delivery of some services
  - Temporal mismatch between demand and electricity consumption
  - Availability of active storage options

Scheduler Mathematical Formulation

Maximize

$$\sum^{time}\left(\left(\sum^{services}\text{value derived from energy services}\right)-\text{cost of electricity}\right)$$

$$=\sum_{t=1}^{T}\left(\left(\sum_{i=1}^{S}\lambda_{ES,i}(t)\,U_{ES,i}(t,\boldsymbol{x})\right)-\lambda_{e}(t)\,P_{e}(t,\boldsymbol{x})\right)$$

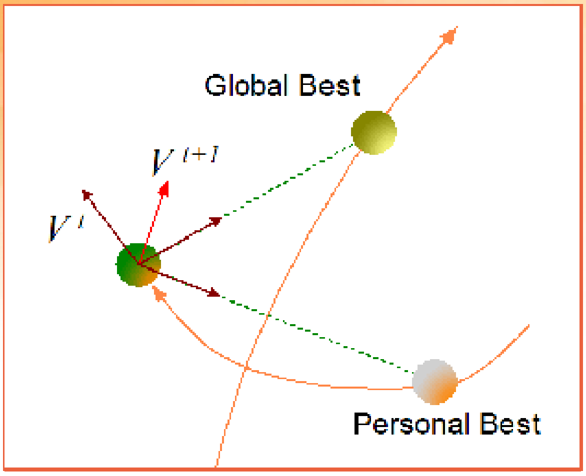


Hourly energy consumption

Hourly cost of electricity

$\boldsymbol{x}$ = DER operation schedule

Particle Swarm Optimization



- Population-based search technique
- Particle positions and speeds are updated by

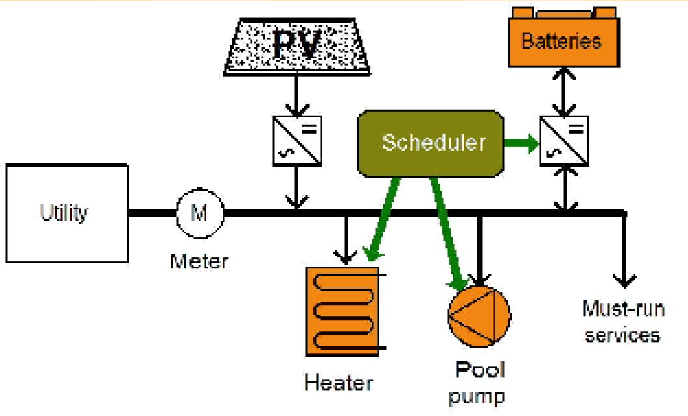
$$v_i^{t+1} = \omega \cdot v_i^t + c_1 \cdot rand() \cdot \left(p_{Gbest,i}^t - p_i^t \right) + c_2 \cdot rand() \cdot \left(p_{Pbest,i}^t - p_i^t \right)$$

$$p_i^{t+1} = p_i^t + v_i^{t+1}$$

- Robust, simple implementation, can generate solutions to complex optimization problems
- Binary PSO: p_i is either 1 or 0

Case Study: Description

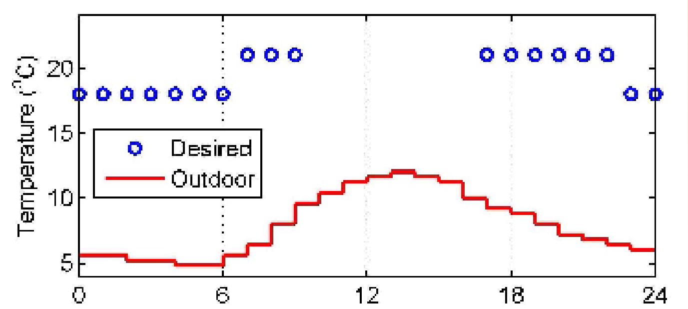
- Residential premises
- Services to provide
  - Space heating
  - Pool pumping
  - Others
- DER
  - Space heater
  - Pool pump
  - Battery
  - PV



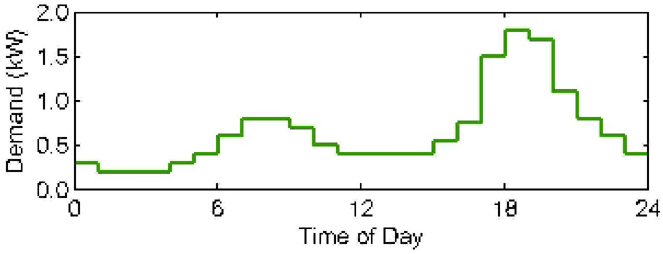
Time of Use	Cost, λ_c (\$/kWh)
Peak (2-8 PM)	0.3025
Shoulder (7AM-2PM, 8-10PM)	0.1089
Off-peak (10PM-7AM)	0.0605

Case Study: Services demand and value

Demand for space heating:



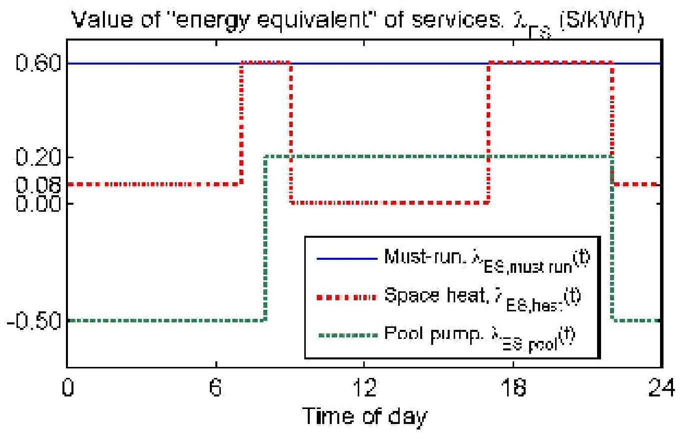
Demand for must-run services:



Demand for pool pump service:

pump should run at most 6 hours/day, anytime between 8am and 10pm

Perceived value of services:

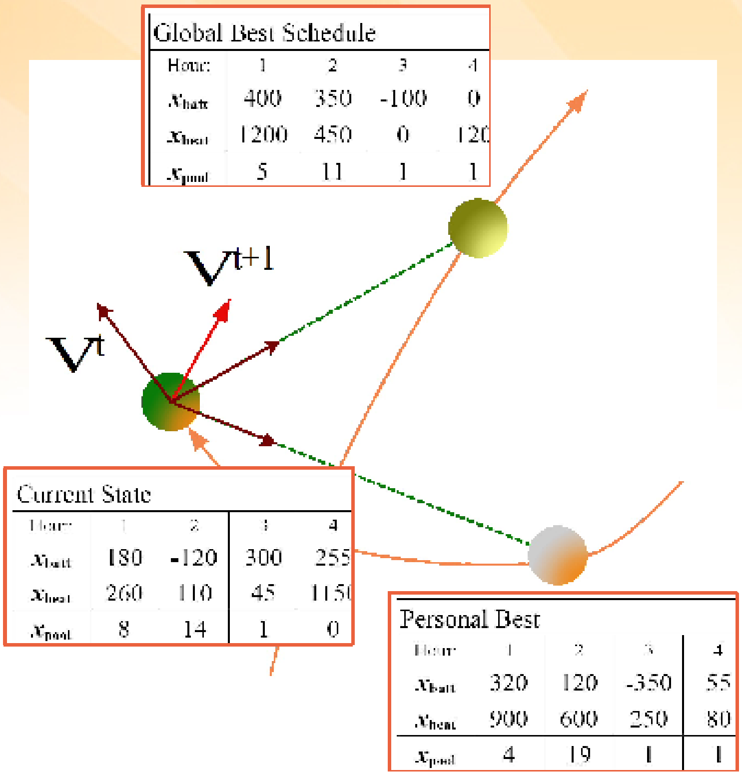


Case Study: Variables to optimize

Hourly heating power of space heater, x_{heat}

Hourly battery charging and discharging rate, x_{batt}

Pumping periods, $x_{pool} = [x_{start1} \quad x_{start2} \quad x_{state1} \quad x_{state2}]$



Global Best Schedule

Hour:	1	2	3	4
x_{batt}	400	350	-100	0
x_{heat}	1200	450	0	120
x_{pool}	5	11	1	1

Current State

Hour:	1	2	3	4
x_{batt}	180	-120	300	255
x_{heat}	260	110	45	115
x_{pool}	8	14	1	0

Personal Best

Hour:	1	2	3	4
x_{batt}	320	120	-350	55
x_{heat}	900	600	250	80
x_{pool}	4	19	1	1

Case Study: Mathematical formulation

$$\mathit{Maximize}$$

$$\sum_{t=1}^{T}\begin{pmatrix}\lambda_{ES,\,must\,run}(t)\,U_{ES,\,must\,run}(t)\\+\lambda_{ES,\,heat}(t)\,U_{ES,\,heat}(t,\boldsymbol{x}_{heat})\\+\lambda_{ES,\,pool}(t)\,U_{ES,\,pool}(t,\boldsymbol{x}_{pool})\end{pmatrix}-\lambda_e(t)\,P_e(t,\boldsymbol{x})$$

Expressions for the “energy equivalent” of the services:

- $U_{ES,\,must\,run}(t)=P_{e,\,must\,run}(t)$
  = energy consumption of must-run services
- $U_{ES,\,pool}(t)=P_{e,\,pool}(t)=$energy consumption of pump
- $U_{ES,\,heat}(t)=\frac{1}{R}\left(\theta(t)-\theta_{out}(t)\right)=$heating load

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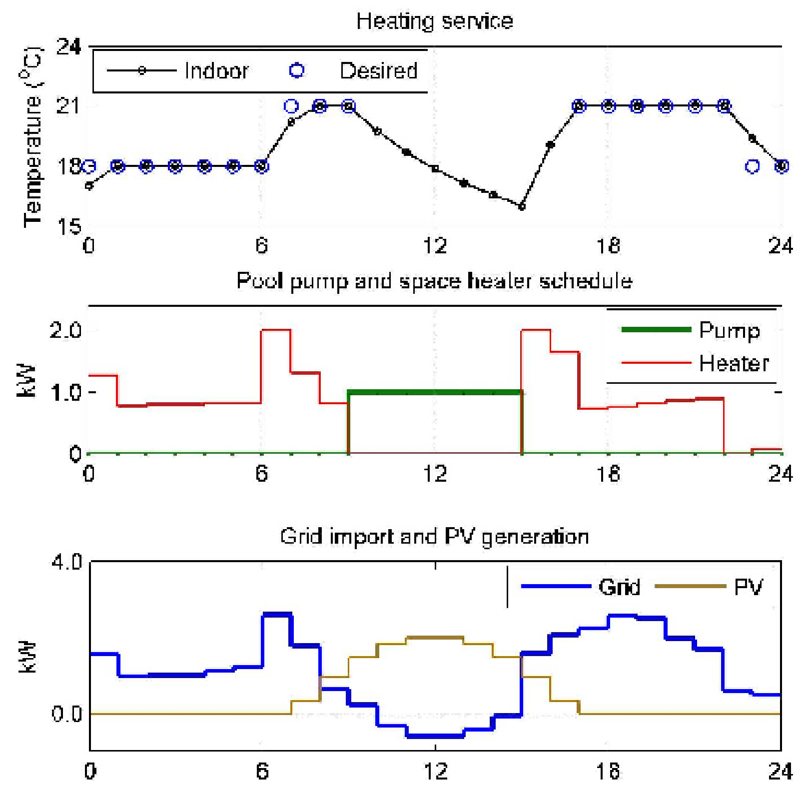
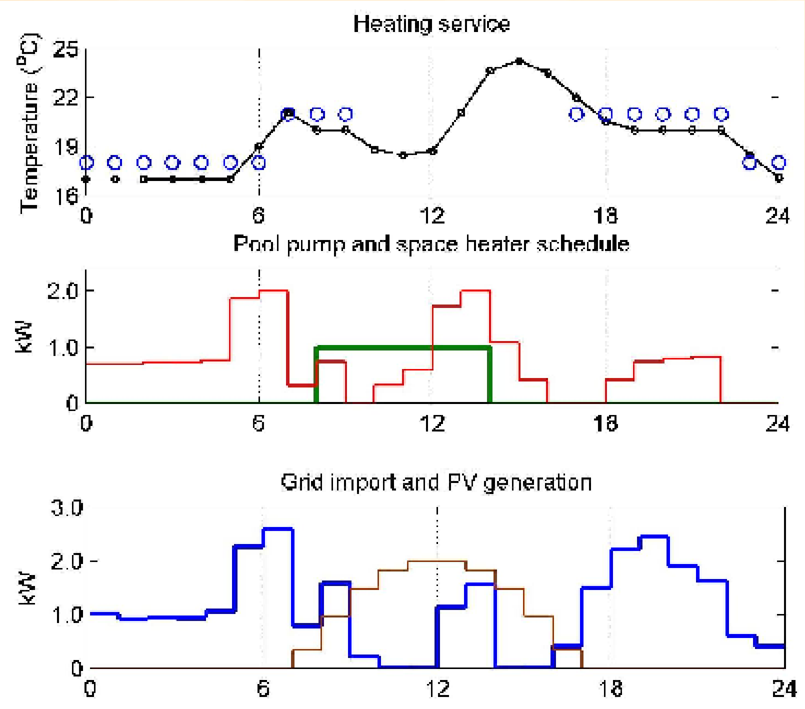
Case 1:
Baseline Case

- DER are manually controlled
- No battery storage
- Cost: $4.40
- Net import: 25.8 kWh
- Export: 2.0 kWh
- Peak: 2.6 kW



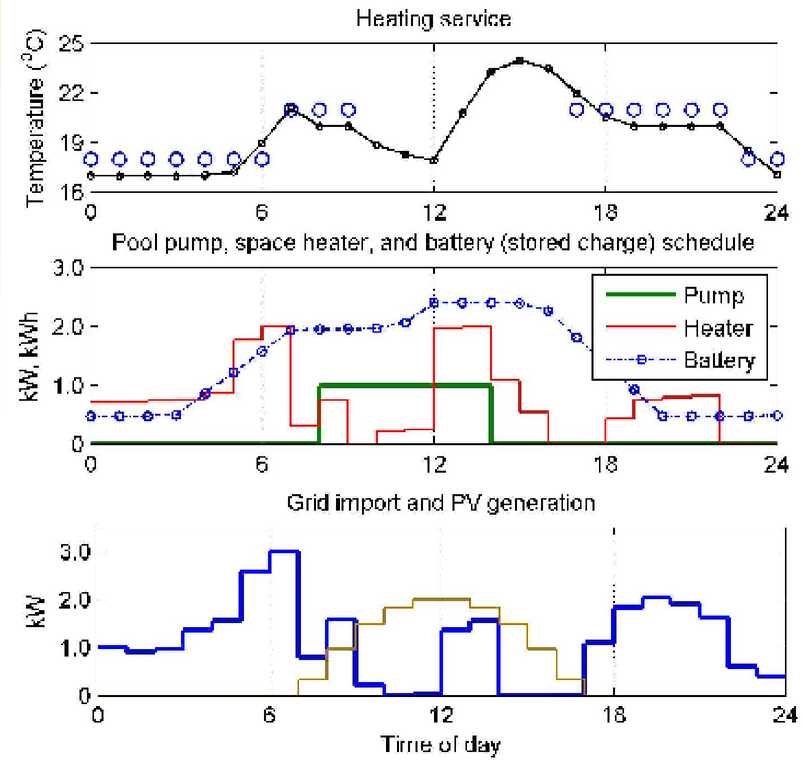
Case 2

- No battery storage
- Cost: $3.60
- Net import: 26.1 kWh
- Export: 0.0 kWh
- Peak: 2.6 kW



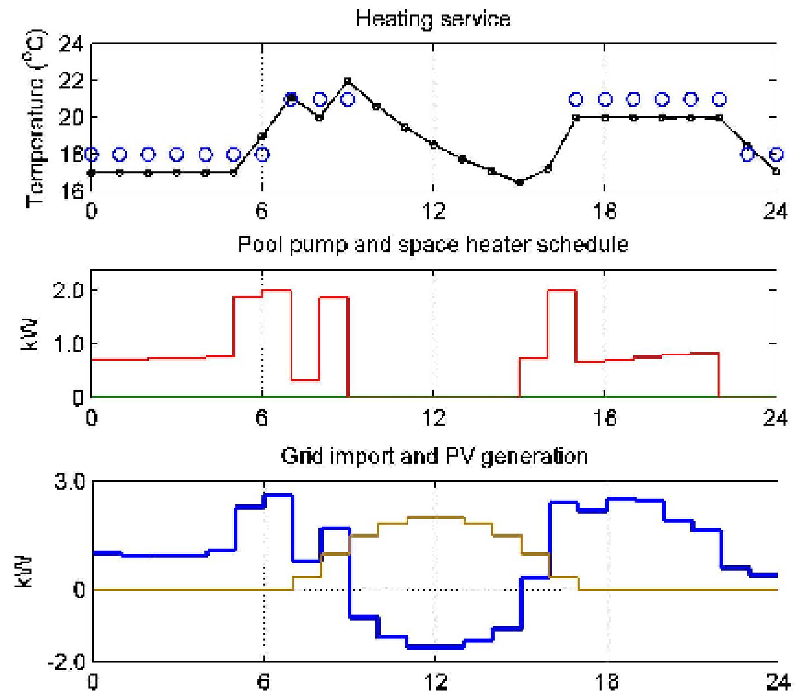
Case 3

- Battery storage available
- Cost: $3.25
- Net import: 26.5 kWh
- Export: 0 kWh
- Peak: 3.0 kW



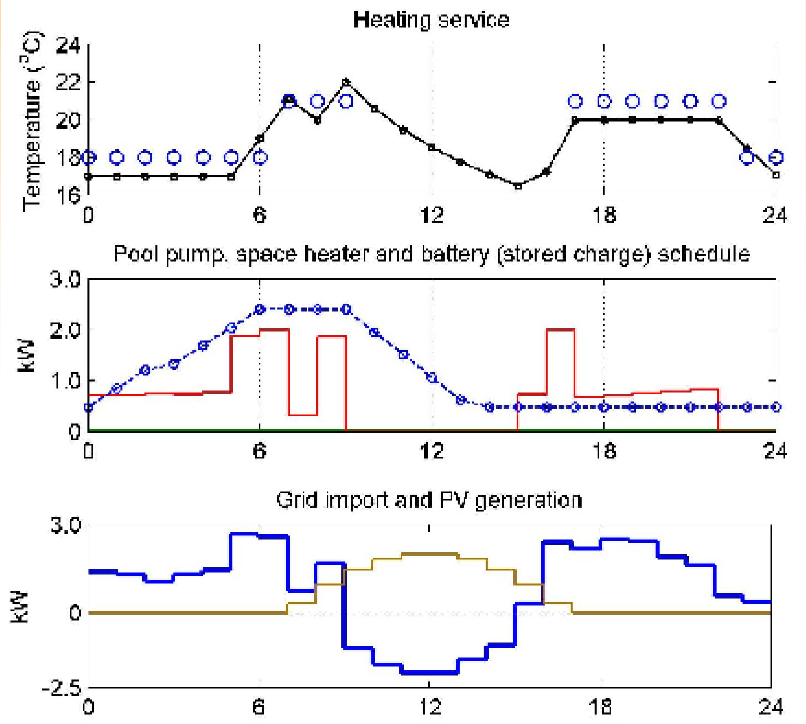
Case 4

- No battery storage
- Net feed-in rate: $0.44 / kWh
- Cost: $0.84
- Net import: 18.8 kWh
- Export: 7.8 kWh
- Peak: 2.6 kW
- Pool pump not operated



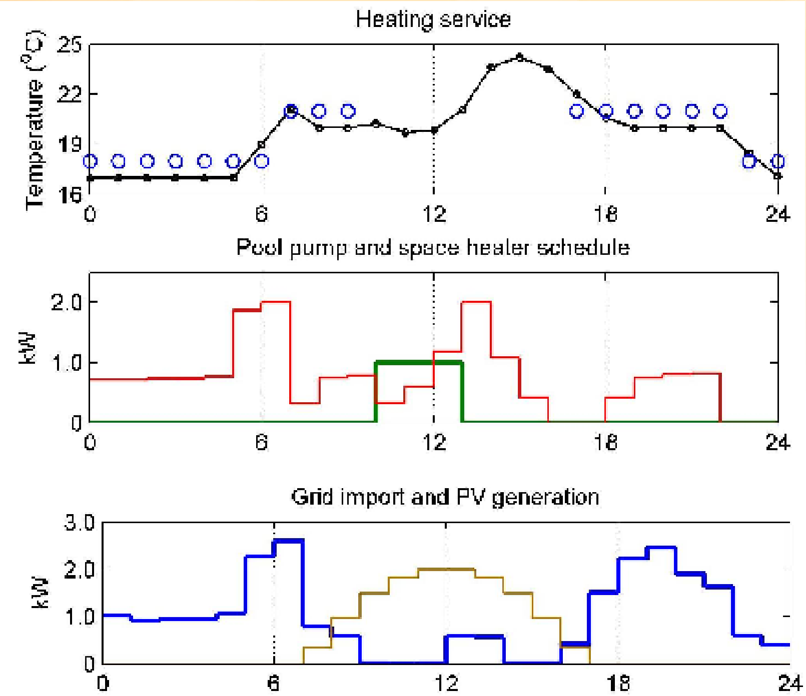
Case 5

- Battery storage available
- Net feed-in rate: $0.44 / kWh
- Cost: $0.21
- Net import: 19.2 kWh
- Export: 9.5 kWh
- Peak: 2.7 kW
- Pump not operated



Case 6

- Value of pool pumping service reduced from *medium* to *low*
- Battery not available
- Cost: $3.30
- Net import: 23.4 kWh
- Export: 0.0 kWh
- Peak: 2.6 kW
- Pump operated only for 3 hours



Current Research Developments

- Added a 4th controllable DER: storage water heater
- Plug-in hybrid used as energy storage option
- Use co-evolutionary PSO
- Scheduling under uncertainty
- Future: aggregation of DER schedules to effect large-scale response

Conclusions

- The provision of energy service may be improved by recognizing that consumers put different levels of benefit to different services.
- The energy service modeling technique enables users to assign benefit to services, and differentiates the energy that realizes the service from actual electric energy consumption.
- The scheduler was able to optimize the provision of services by controlling the operation of available DER.
- PSO was able to produce efficient schedules in brief computation times.

Thank you,
and
Questions?

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