Automated Energy Usage Optimization for the Residential Sector: Impact of Price Tariffs

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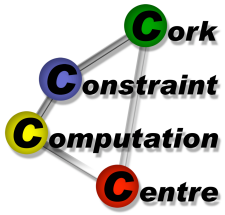


Motivation

- Energy consumption in residential sector accounts for significant proportion of national usage.

- Ireland (2008):
  - 32% of total energy usage
  - 44% of thermal energy usage

- Influx of electric vehicles will increase consumption in residential sector.

Motivation

- Utilities can influence user behavior.
- Time-variable pricing tariffs to reduce peak demand.
  - Time-of-use Pricing (*TOUP*)
  - Real-time Pricing (*RTP*)
- Problem: User often unable to react to price changes.

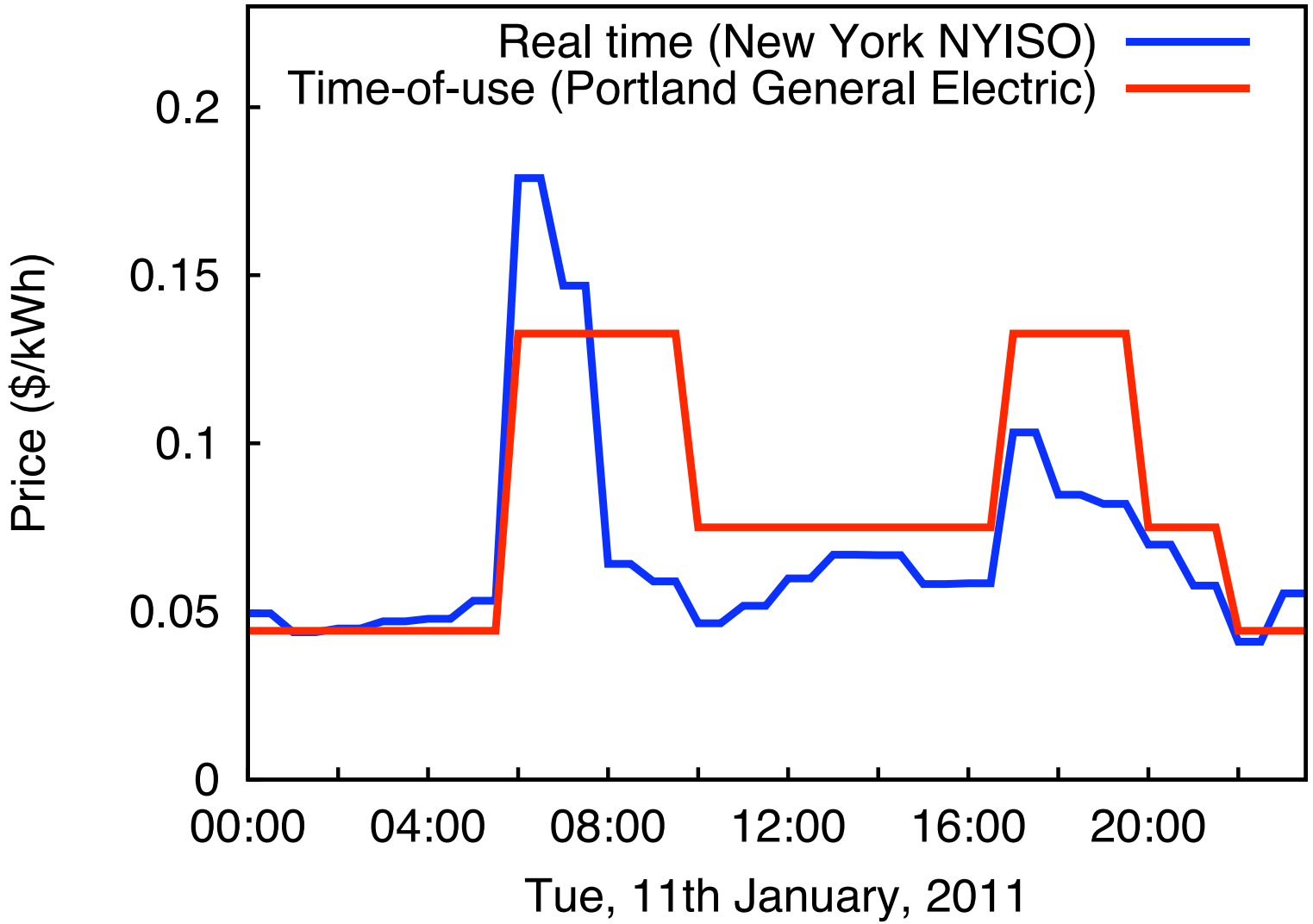
Motivation

- Home Energy Management System (*HEMS*)
  - Automate usage of flexible energy consumption appliances in the home.
  - Optimize scheduling w.r.t. cost and user comfort.
- Benefits:
  - **User** – Reduction in electricity costs, contribution to environment.
  - **Utility** – Reduction in peak energy usage; more balanced demand.
  - **Environment** – Large-scale, carbon-intensive, generators required less.

Time-Variable Pricing Tariffs

- Time-of-use Pricing
  - Fixed for duration of contract => customer aware.
  - Price based on season, day of week, and time of day.
  - Day divided into blocks: On-peak, off-peak, shoulder.
- Real-time Pricing
  - "Pay what it costs."
  - Price based on actual price of electricity in the market at the time point.
  - User does not have advance knowledge of costs, but maximum price charged may be capped.

Time-Variable Pricing Tariffs



Home Energy Management System

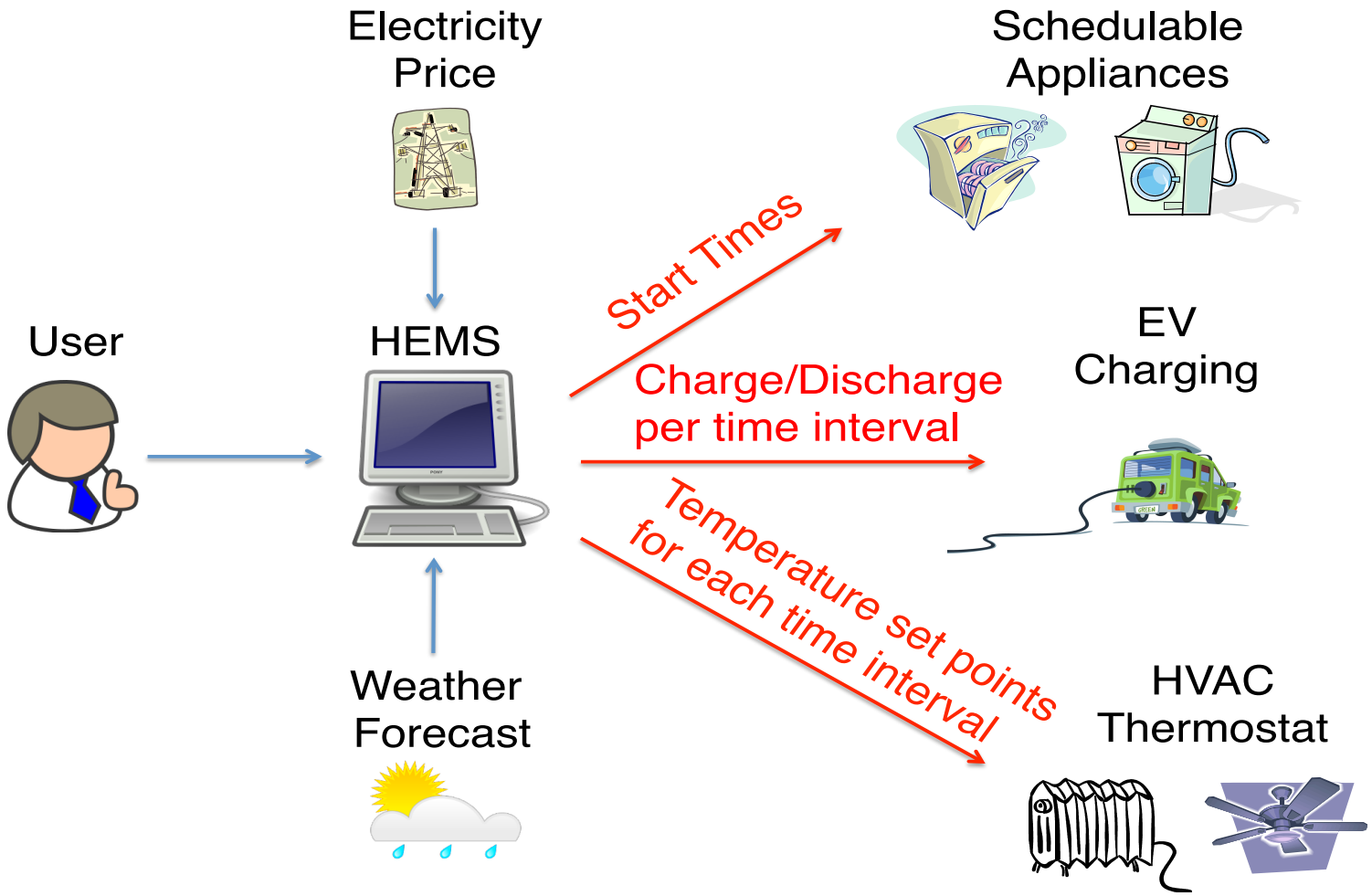
- Fixed horizon discretized into *n* time intervals (e.g. 24 hour horizon, 30 min time slots).

- Flexible home energy consumers:
  - Electric Vehicle (with vehicle-to-grid capability).
  - HVAC.
  - Schedulable appliances, e.g. dishwasher, washing machine.

Home Energy Management System

- User requests (can be learnt over time):
  - EV - Departure time and required state-of-charge.
  - HVAC - Temperature set points for certain time periods.
  - Schedulable Appliances – Time windows, preferred start time.

Home Energy Management System



Home Energy Management System

- Schedulable appliances: Start time
- For each time interval
  - EV: Charge/discharge power → battery state
  - HVAC: Heating/cooling power → temperature

Home Energy Management System

- User comfort:
  - Difference between requested and actual indoor temperature for time periods.
  - Difference between requested and actual start time of schedulable appliances.

- Penalty function of the form:

$$\sum_i a * Max(0, x_{i,user} - x_{i,actual}) + b * Max(0, x_{i,actual} - x_{i,user})$$

Home Energy Management System

- Multi-objective optimization:

  Minimize energy cost over the fixed horizon, while maximizing user comfort.

- Modeled using Mixed Integer Programming.

- CPLEX solver.

Real-time price data

- Markets:
  - Ireland (www.sem-o.com)
  - Germany (www.epexspot.com)
  - Sweden (www.nordpoolspot.com)
  - New York (www.nyiso.com)
  - Ontario (www.ieso.ca)
- 4 weekdays from winter 2011 (10/01/11–14/01/11, midday – midday)

- Weather data for city, in each country for national markets (www.wunderground.com)

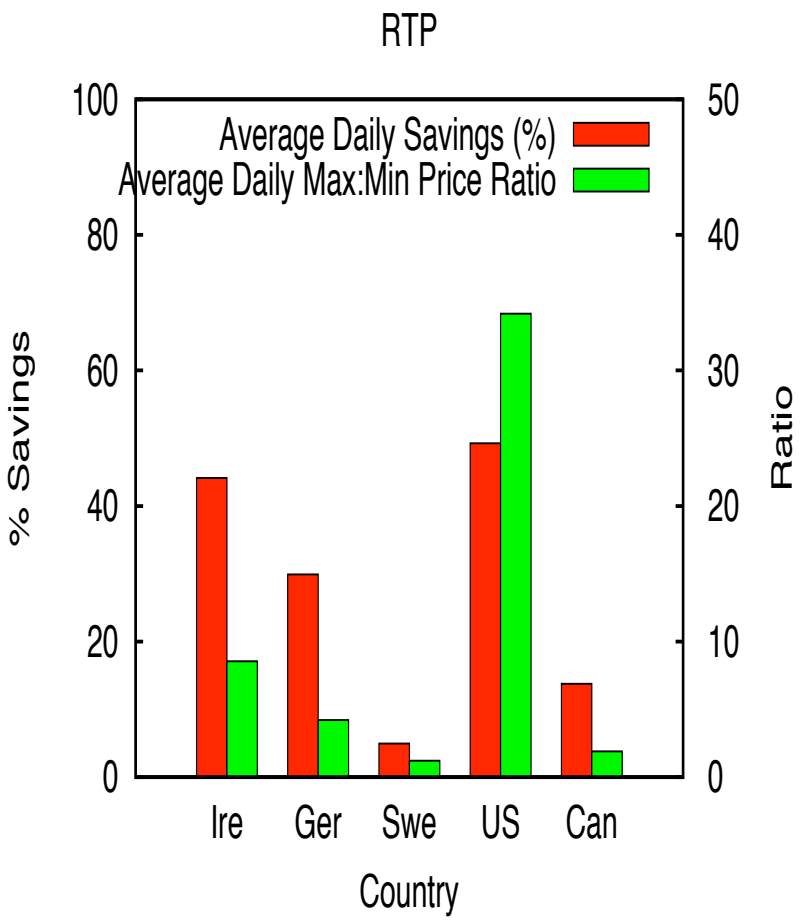
Time-of-use pricing tariffs

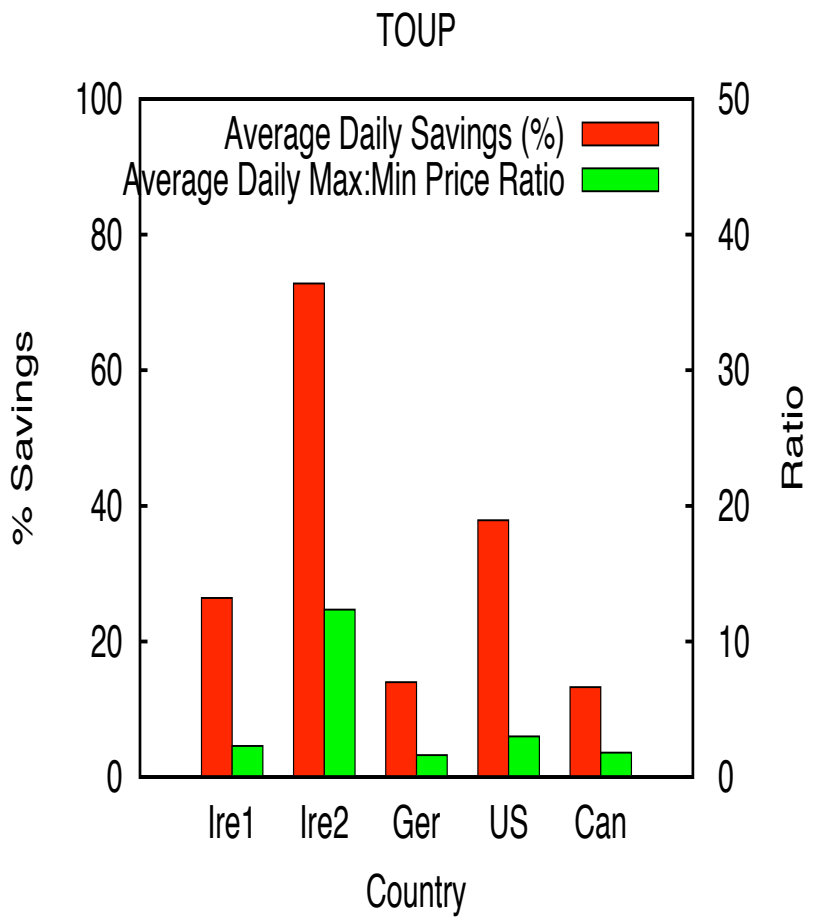
- Tariffs:
  - Ireland, two tariffs proposed in ESB white paper
  - Bielefeld, Germany (www.stadtwerke-bielefeld.de)
  - Portland General Electric (www.portlandgeneral.com)
  - Ontario-Hydro (www.ontario-hydro.com)

- Winter weekday

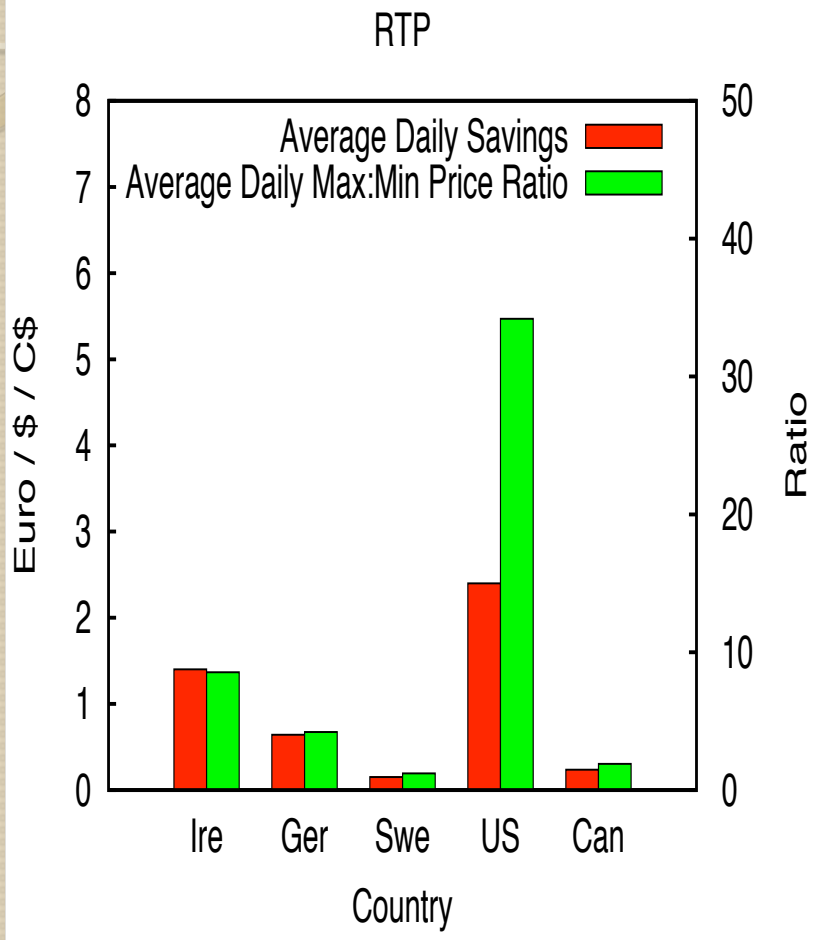
- Compared in terms of possible savings over non-optimized algorithm (where no price information is taken into account).

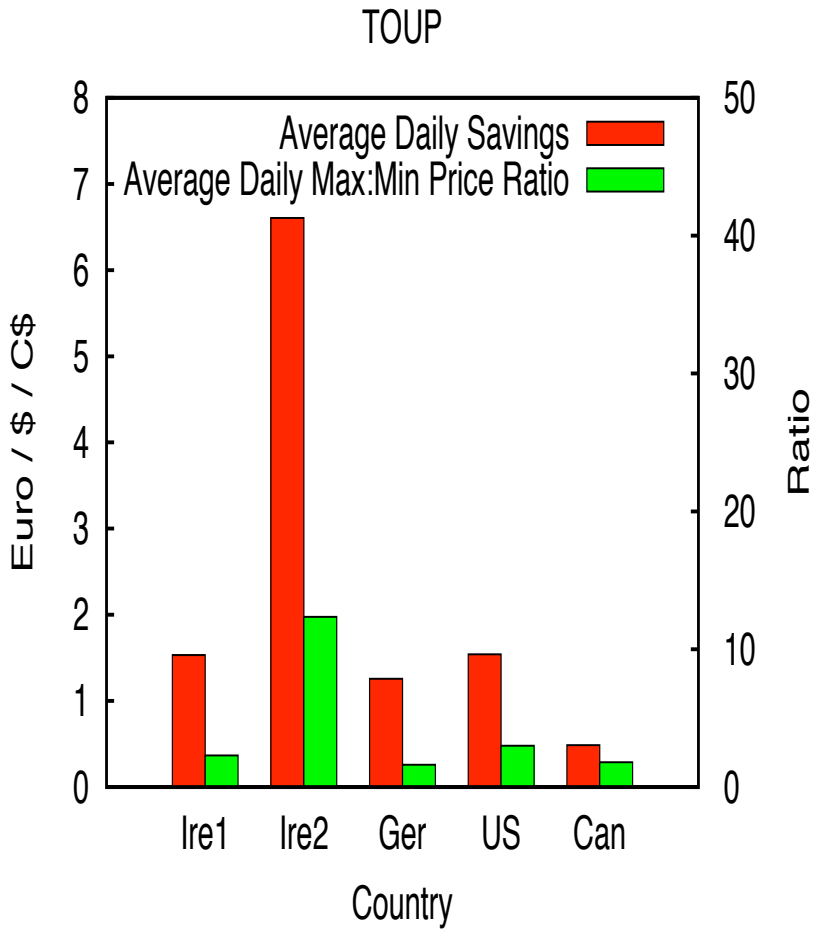
Percentage Savings





Monetary Savings





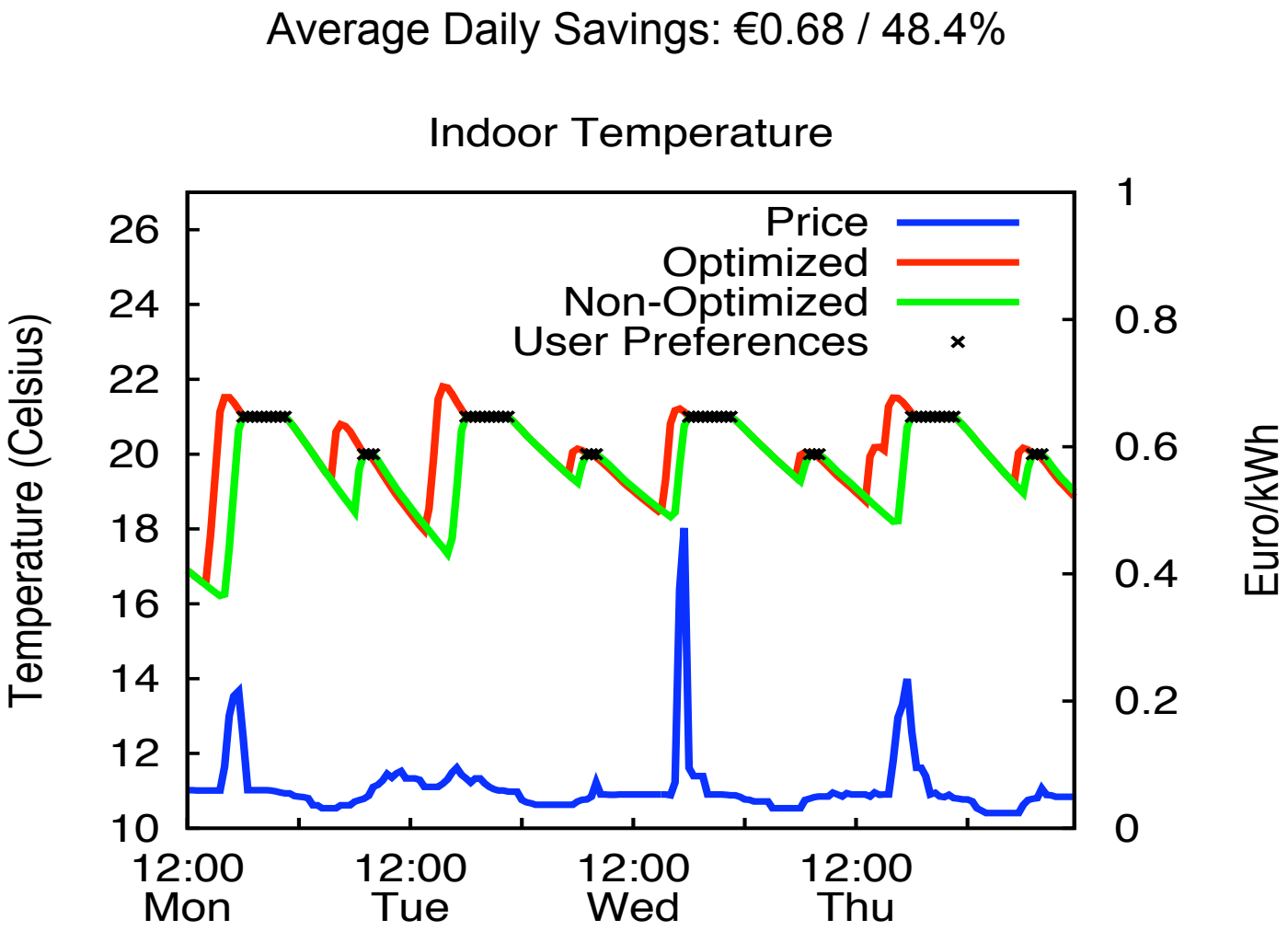
Summary

- Significant savings can be made with both.
- TOUP tariffs more consistent in savings achievable.
- High correlation between daily Max:Min price ratio and savings.

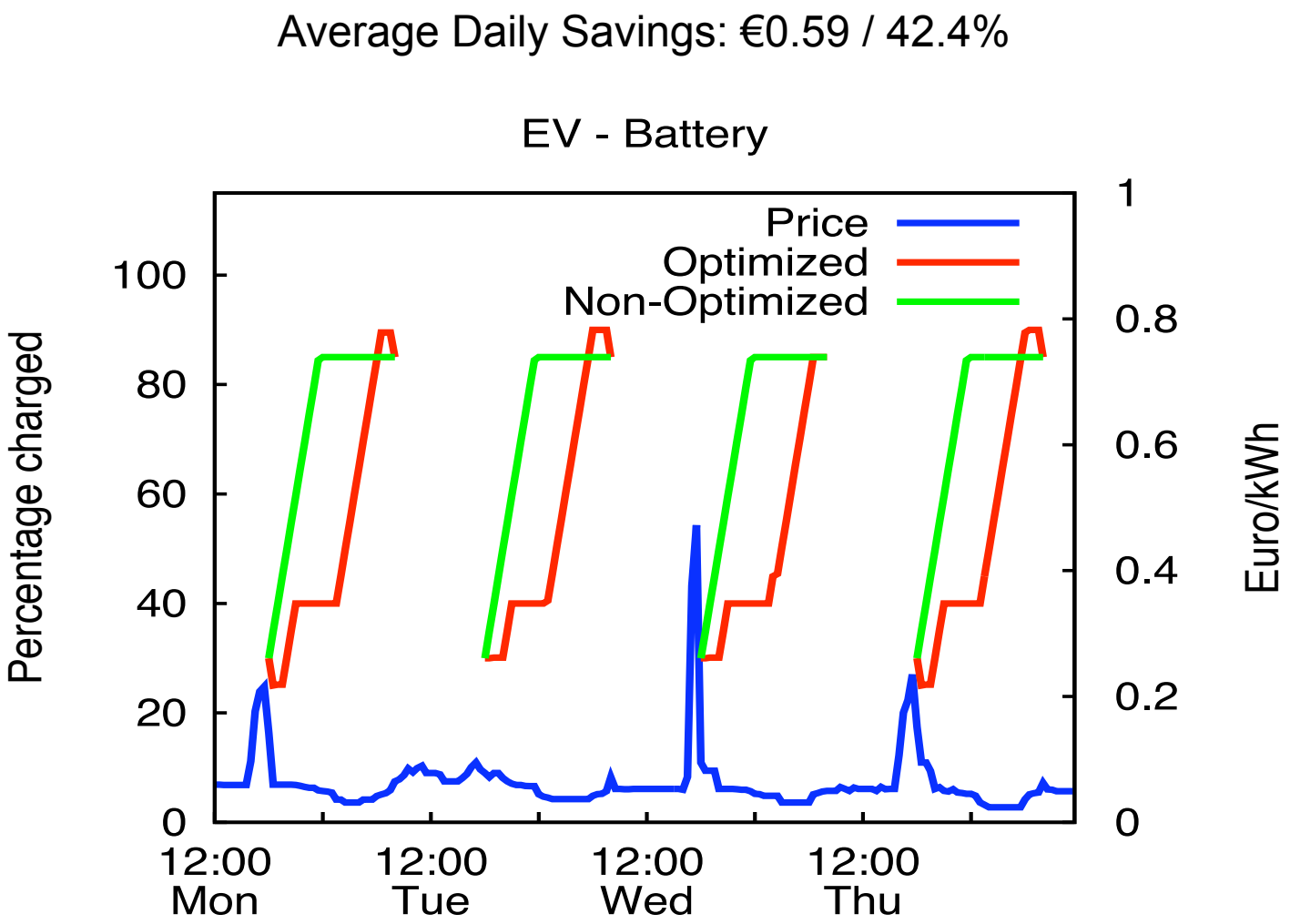
Price Distribution

- Sufficient deviation in price is required to overcome losses:
  - HVAC: preheating will require more energy to account for heat losses.
  - EV: vehicle-to-grid will incur energy losses due to inefficiencies in charging and discharging the battery.

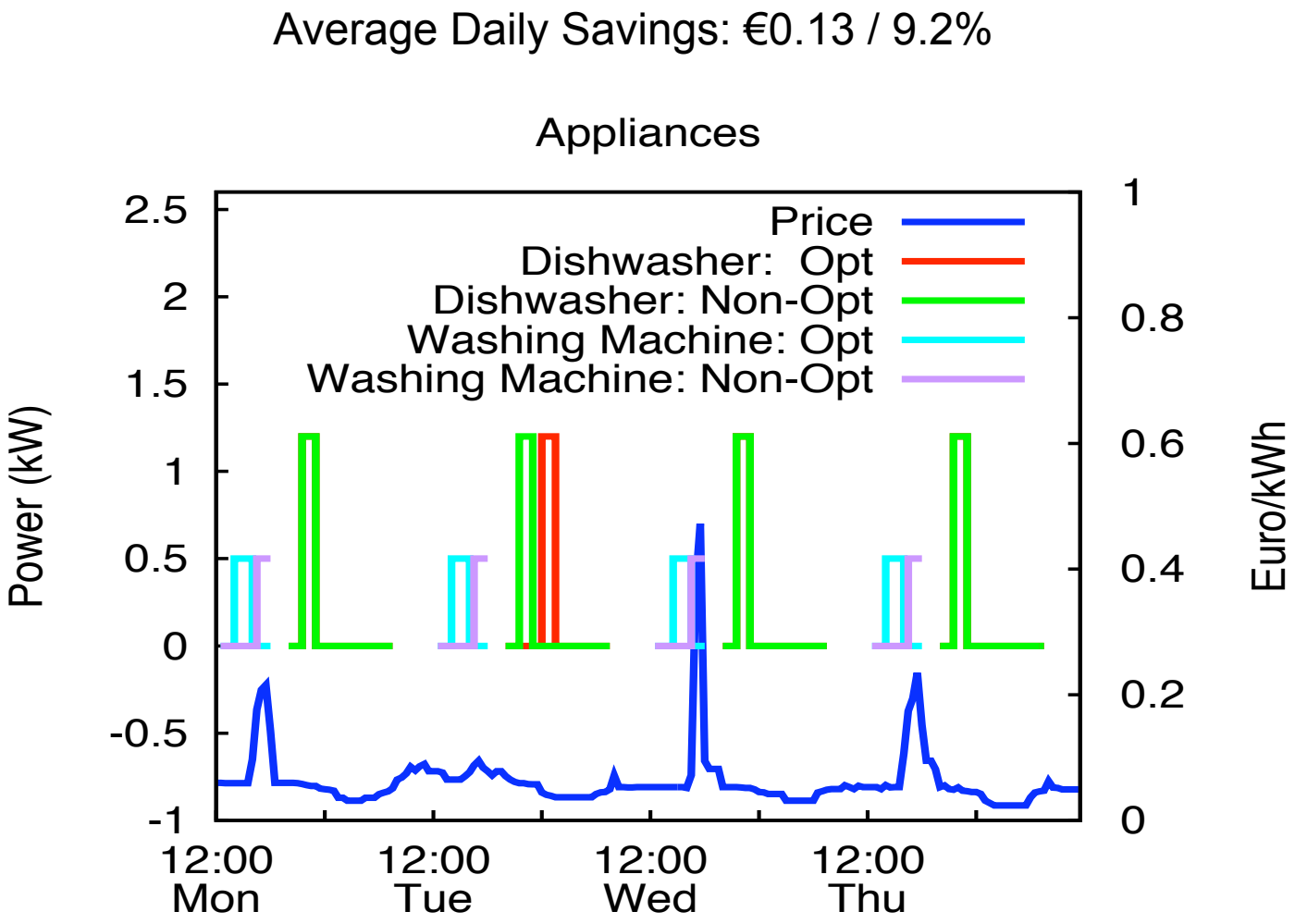
Preheating (Ireland)



EV Charging (Ireland)



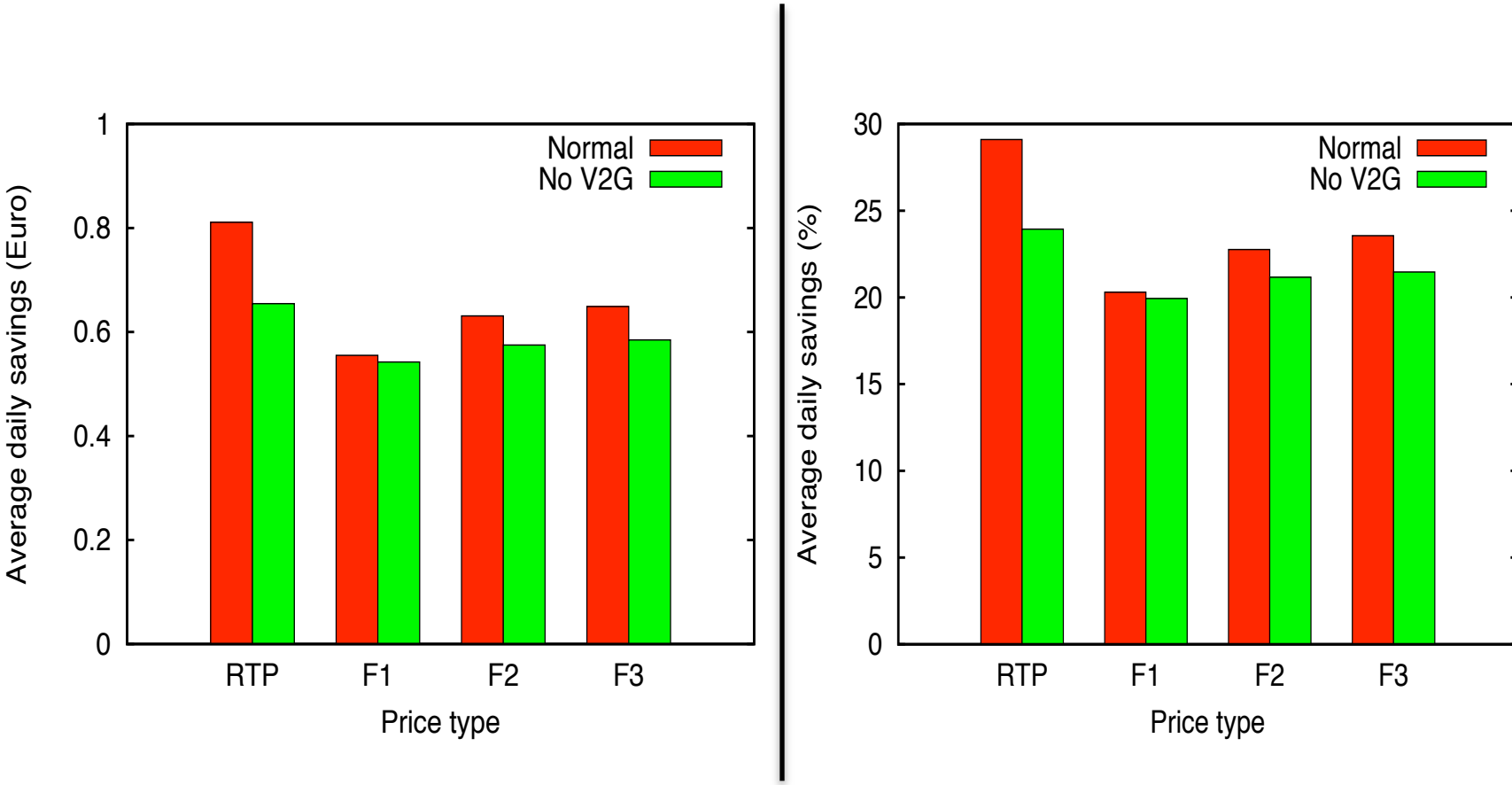
Appliance Scheduling (Ireland)



Price Forecasts

- Tested three forecasts.
- 40 weekdays of RTP and forecast for Irish market.
- Also assessed the impact of vehicle-to-grid discharging of EV.

Impact of price forecasts and V2G



Conclusions

- Time-variable pricing + HEMS = savings for user, reduction in peak demand.
- Sufficient deviation in price across horizon necessary.
- Savings primarily due to intelligent EV charging and preheating.
- Forecasts of market price don't need 100% accuracy.
- Vehicle-to-grid can give additional savings, when price peaks are correctly predicted.