A Flexible Aggregator Concept for Demand Response from Supermarket Refrigeration

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Agenda

- Why supermarkets?
- Refrigeration system model
- Complexities of demand response
- Participation in a market
- Conclusions

Why Supermarkets?

What makes a good DR resource?

What do supermarkets have?

Ability

Thermal mass in refrigeration system for energy storage enables shifting of electricity in time.

Scale

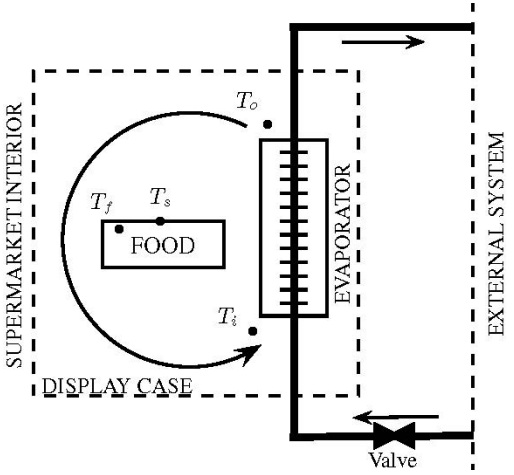
- ✓ 550GWh in Denmark (2% total annual electricity consumption)
- ✓ 50% of which is refrigeration
- ✓ Equivalent to 20% of energy imbalance from wind in 2011.

Incentive

- ✓ Energy costs are only 1% of operating costs
- ✓ But – profit margin is only 3%!
- ✓ Cost efficiency in energy translates to revenue!!

Refrigeration System Model

- Danfoss Refrigeration Test Centre (Nordborg, Denmark)
- DR experiments – changing reference temperature
- Datasets
  - Total power consumption
  - Temperature sensors at various locations
  - Condensed to two smoothed power signals and two representative temperature signals (MT and LT)



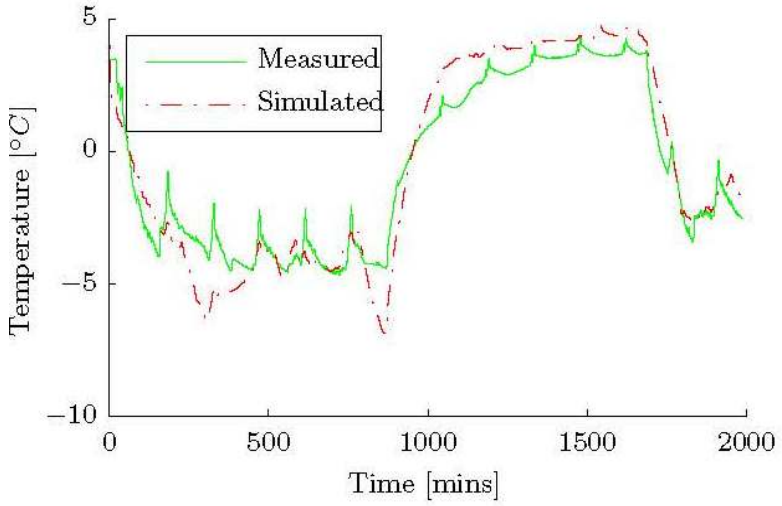
MT

LT

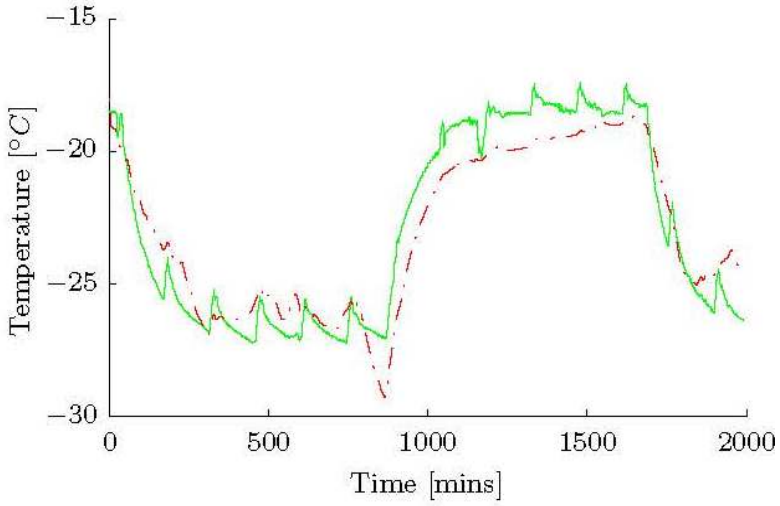
- ARMAX Simulation Model
  - Model intended for high level demand response analysis
  - Single input (power consumption),
  - Two output (representative temperature signals)
  - **Time constants: 10 hours, 7 minutes**

Refrigeration System Model

- Current models are quite generic–lack of data on external temperature and impact of opening/closing hours precludes the use of the model for longer term studies
- Gives impression of general capabilities, and methods to be applied when data is available.



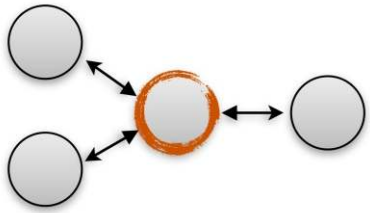
(c) Simulation, Medium Temperature

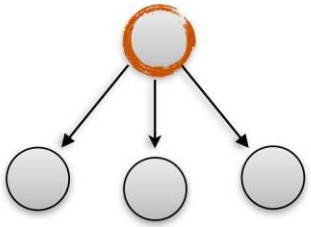


(d) Simulation, Low Temperature

Demand Response Simulations

- Model suitable for implementation within a range of control environments
- Model Predictive Controllers for individual Supermarkets
  - Direct Control: Power & Temperature Tracking
  - Indirect Control: EMPC





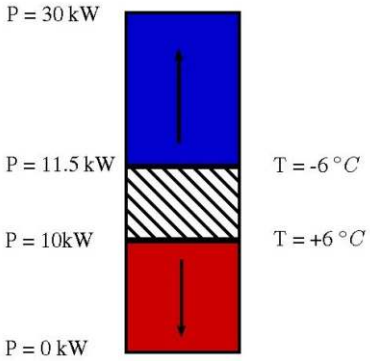
Optimised Control can achieve wonderful things in theory

Complexities

Need to be able to communicate the capabilities of the resource to the market in a **understandable** and **reliable** manner

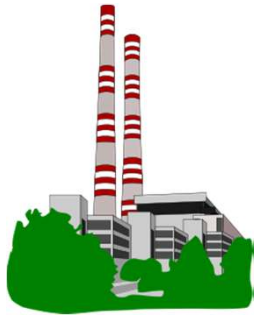
- Response highly dependent on control parameters, some of which are “personal”

- Asymmetric response capabilities

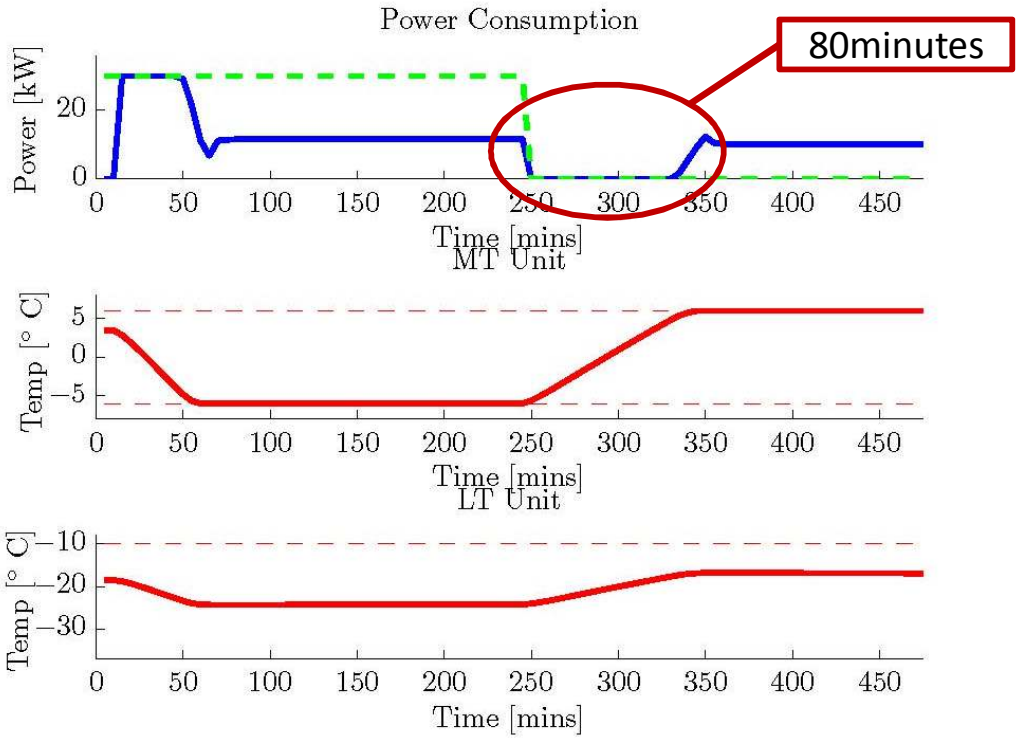


- **More like this:**

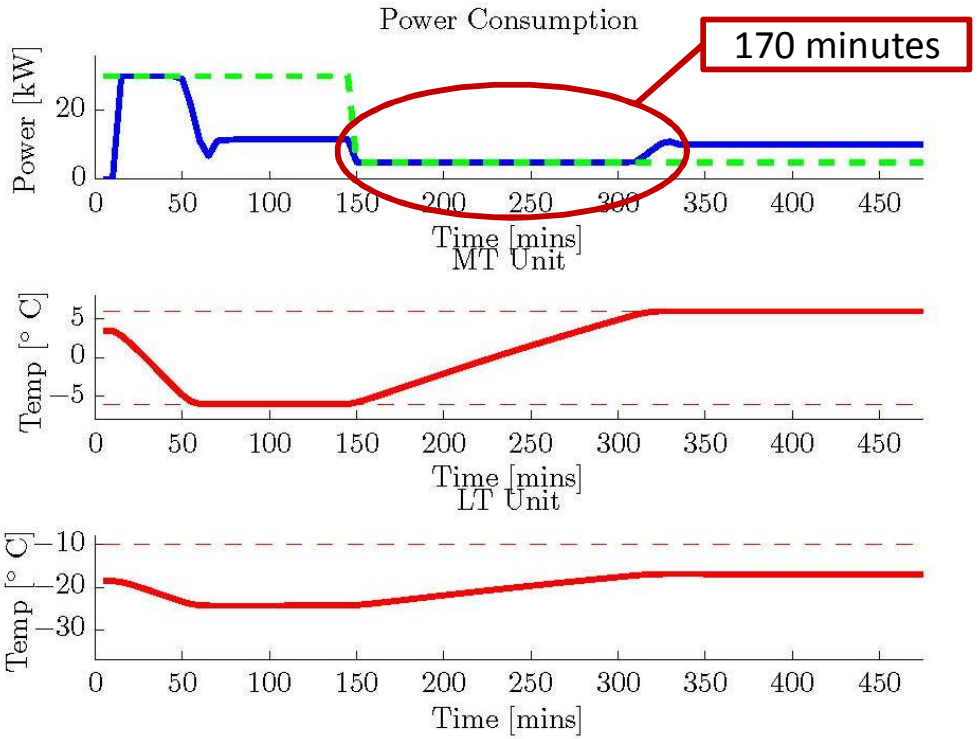
than this:



Saturation of Response



Pref: 0 kW



Pref: 5kW

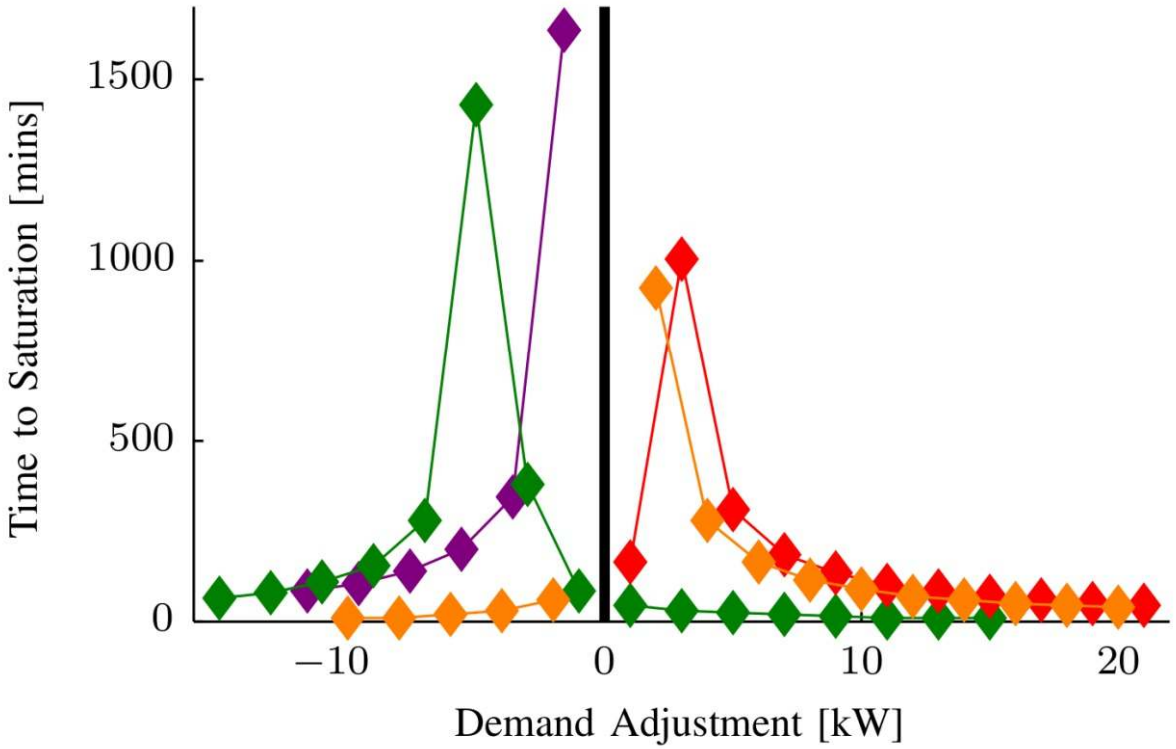
Participating in the Regulating Power Market

- Necessary to inform system/market operator of the ability of the DR resource to provide up/down regulation.
  - Bids typically submitted up to e.g. 45 minutes prior to operating hour[1]
  - Activated any time during the hour
  - Must be able to fully respond within 15 minutes.

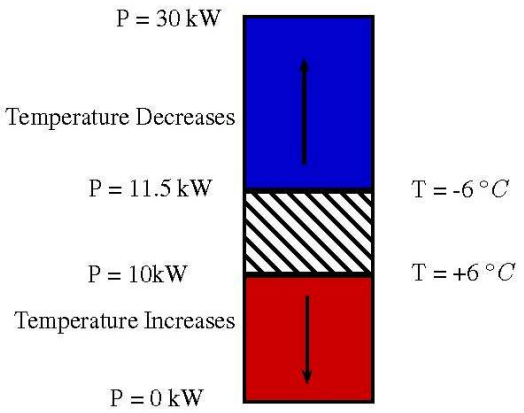
- Supermarket Refrigeration and Response Saturation:
  - Important know when bidding in balancing/regulation market: e.g. how long can a curtailment of X kW be maintained?
  - Function of:
    - Initial Conditions: Power Consumption and Temperature(s)
    - Consumption reference during regulation period
    - Upper/Lower temperature limits
    - Forecast extent

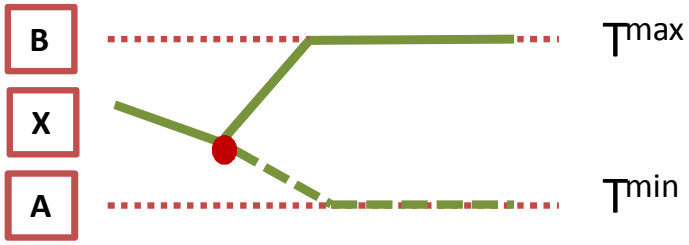
[1] Nordic Regulating Power Market

Saturation of Response

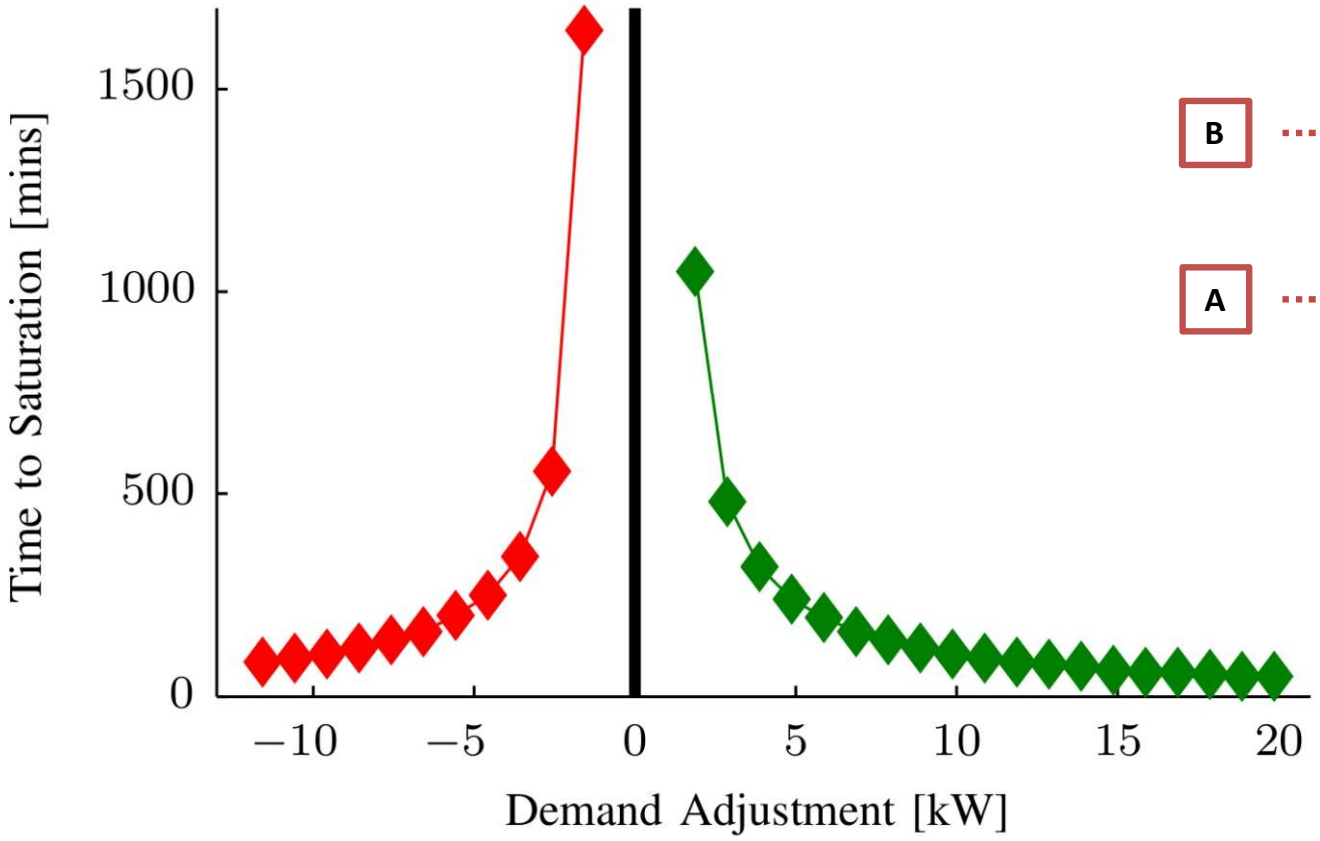


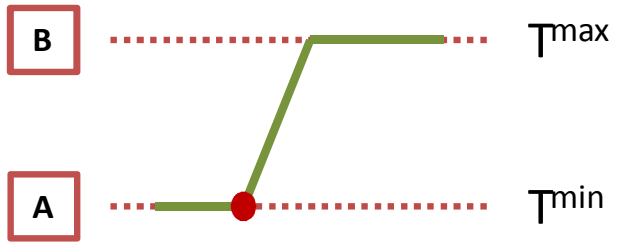
		[kW]
Purple	-6	11.5
Green	-3.1	15
Orange	5	11
Red	4	10





Simplified Saturation of Response

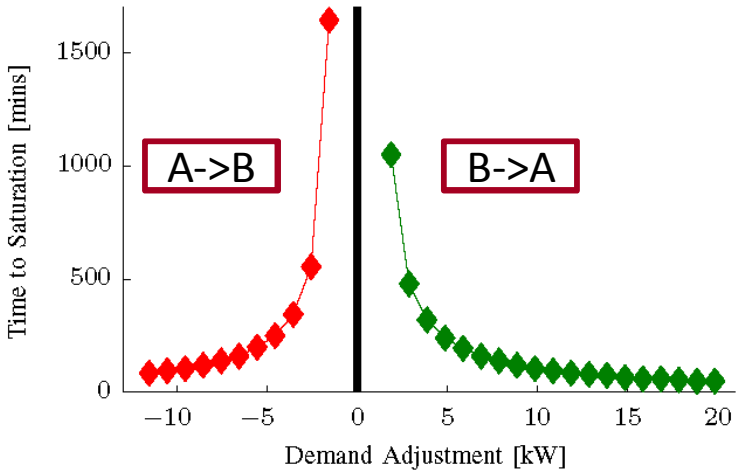


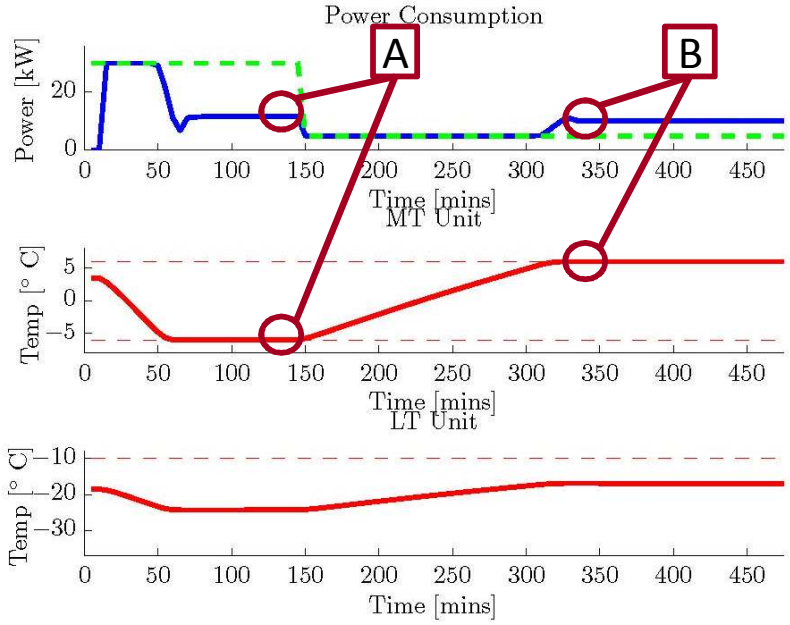


Regulating Power Market and Forecasts

- Knowledge of saturation time allows aggregator to communicate the DR capabilities in a *simple* manner that is understandable to the market operator and can be incorporated into existing market structures and clearing processes.

- Forecast of imbalance on the system a key requirements for the aggregator when planning operation on a 24 hour horizon
  - Thermal systems for DR experience **rebound**
  - **Should I stay or should I go?**





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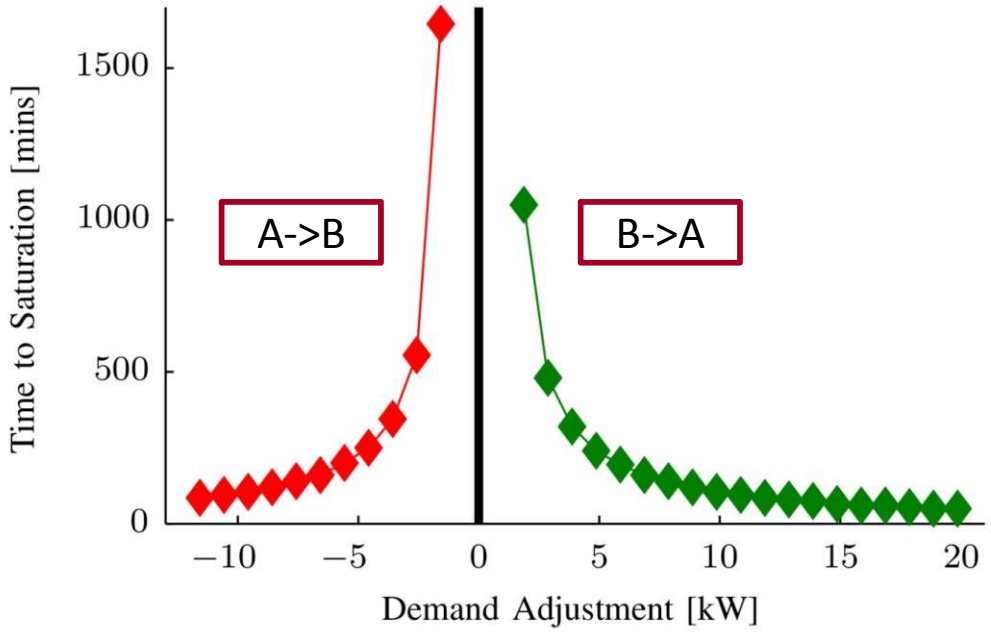

Conclusions

- Optimised performance of DR from supermarket refrigeration systems too complex to communicate to system/market operator – too many possibilities and possible complications
- Need a pragmatic approach – gives a realistic view of DR capabilities
  - Evaluate the benefit of DR to the *system*
  - Develop business cases for the *aggregator* or *supermarket chain operator* (e.g. Coop/Tesco)

- This work focusses on the ***regulating power market*** and a ***single*** supermarket
  - Applications in other markets
  - Greater possibilities with a population of supermarkets – e.g. optimised ramping rates
  - Necessary to evaluate the reliability of this resource

Thank you!

Any Questions?