Using Fridges to Balance the Electricity Grid

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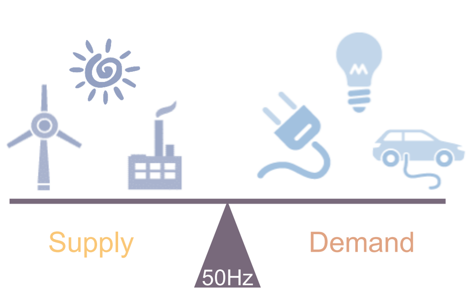
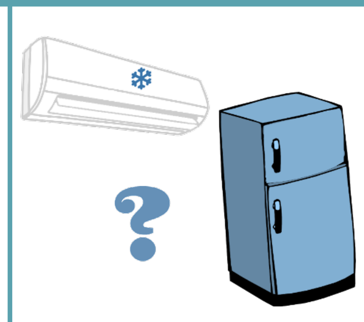
Background



The electricity system needs to remain balanced at all times

Currently use flexible generation such as gas

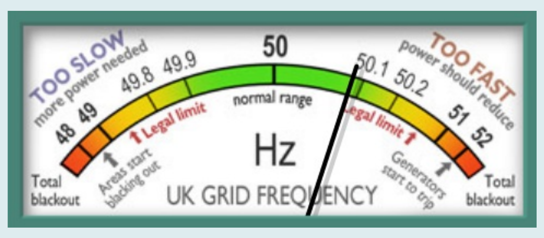
More renewables makes this more difficult



Could household appliances play a role?

Grid frequency and system balancing

- Frequency increases ↑ when supply > demand
- Frequency decreases ↓ when supply < demand

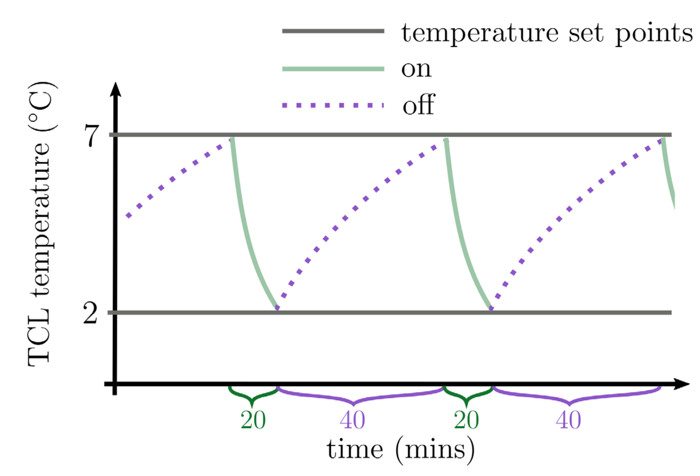


How can fridges help?

Fridges operate between two temperature set points.

They switch on when they get too hot and remain on until sufficiently cool when they turn off.

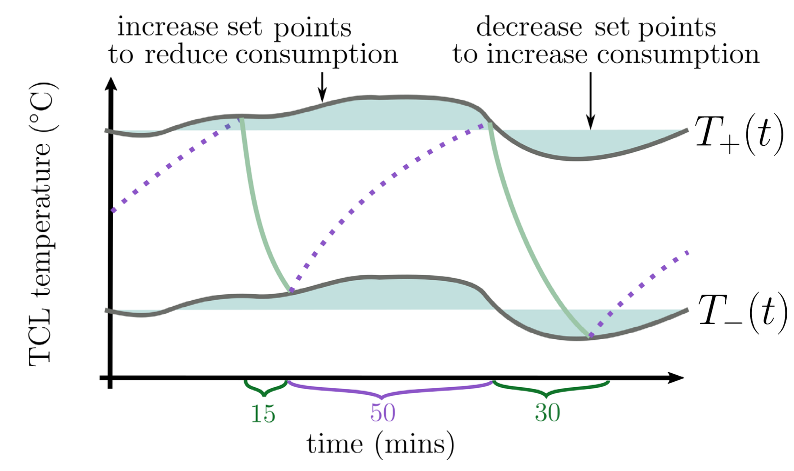
Users don't care the exact on/off times so long as food stays fresh.



If we make the set points depend on system frequency then a population of fridges can act as a frequency response provider.

They delay or advance consumption by staying on/off for longer/shorter as needed. We use simple deterministic control:

$$T_\pm(t) = T^0_\pm - \beta f(t)$$



Research overview

Challenge

An identical population of fridges responding to the frequency in this way will eventually synchronise their heating/cooling cycles and cause big frequency disturbances – causing more harm than good. To communicate with each fridge directly to desynchronise them would require huge infrastructure investment and be open to hacking. Adding stochasticity to the control could be a solution but we believe that isn't necessary.

Research questions

- Does the natural heterogeneity present in a fridge population (differing room temperatures, cooling efficiencies, temperature set point preferences etc.) prevent the synchronisation issues of an identical population?
- How much heterogeneity would be required for fridges to provide electricity grid balancing with only simple deterministic control based on the grid frequency?

Method

- Use (1 year of) electricity system data from the GB system operator National Grid and adapt their model (in R) for grid operation and system balancing
- Simulate fridges responding to the frequency alongside other existing `frequency response providers' and assess:
  - Do the fridges synchronise?
  - Do they get too hot or too cold?
  - Do the fridges reduce the response needed from other providers?
  - How much response are they able to displace?

Simulations

Historic system data: national demand, frequency, system inertia, response holdings

Fridge model

$$T_\pm(t) = T^0_\pm - \beta f(t)$$
$$\dot{T}(t) = \alpha(T_{\text{ON/OFF}} - T(t))$$

Original response providers model

$$\text{generation} = g(f(t))$$

Simulate

Simulate new frequency, fridge operation, actions of other providers

Up to 10M fridges (simulate 10k individual groups of 25-1000 each)

Update every second for 10 days

36 runs covering 1 year of input data

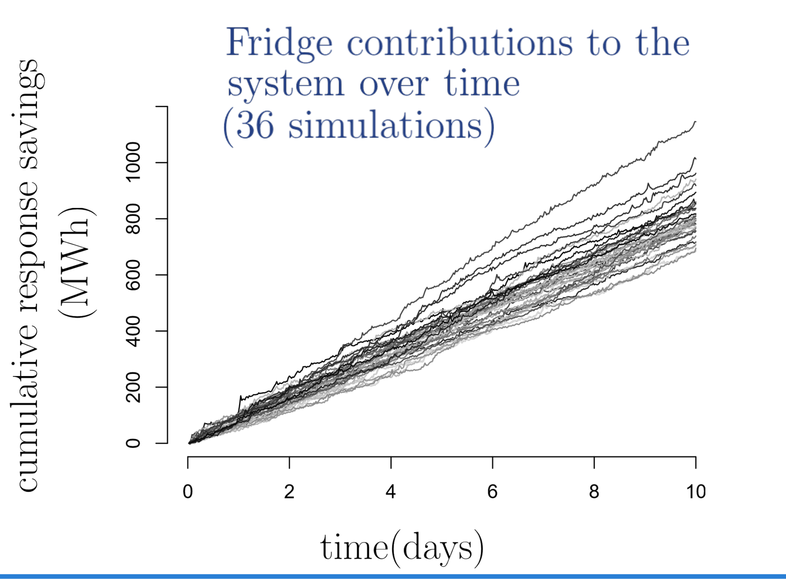
Use parallel processing to reduce computation time

Outputs:
- Fridge states and temperatures
- Fridge response
- Response provision from other providers
- Fridge response contribution: displaced (or extra required) response

Results

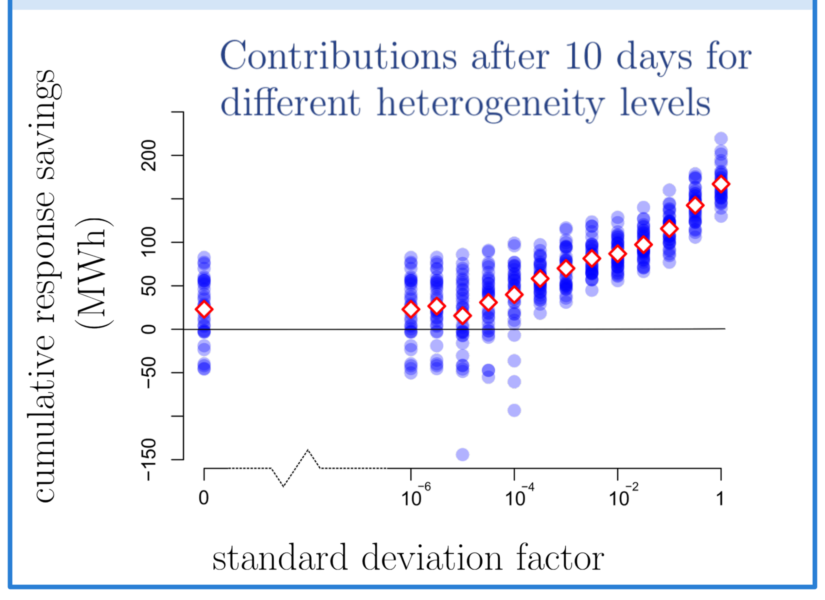
Adding parameter heterogeneity leads to a positive contribution that continues over time.

Note that if the population were identical then this graph would become negative (i.e. more harm caused than good) due to synchronisation issues.



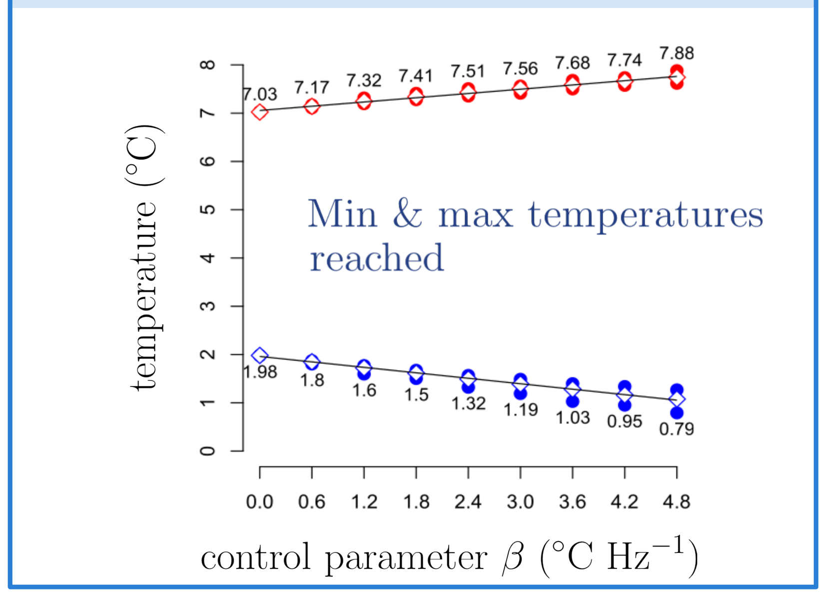
By introducing a 'standard deviation factor' we can increase the heterogeneity of multiple parameters simultaneously on different scales.

Very little heterogeneity is required to prevent negative 'savings'. For example, 10^{-2} gives 99.7% of room temperatures all within ± 0.04°C of the mean.



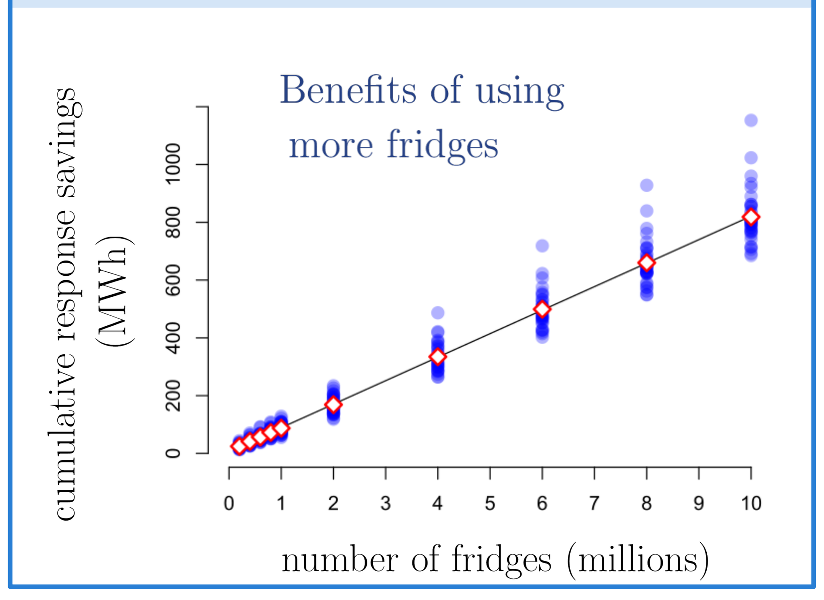
By varying the sensitivity of the fridges to the frequency (control parameter β), we can change the amount of response the fridges can provide.

This plot shows the impact on fridge temperature range of varying β. Up to 3°C/Hz variation gives a very reasonable temperature range.



By scaling up the power consumption of each of the 10k groups of fridges we can simulate larger populations.

We see that benefits increase proportionally with more participating fridges in the population.



Summary

- **First simulation** of a population of **fridges** providing response **alongside existing response providers**
- **Fridges can provide useful** frequency **response** with simple deterministic autonomous control
- There is a **linear** relationship between the **number of fridges** providing response and the system **benefits**
- A **suitable range** for the **control parameter** β has been determined and **could be used in practice**

Find out more

Webborn, E. Natural heterogeneity prevents synchronisation of fridges with deterministic frequency control. *IEEE Access* 2019

Webborn, E. The dynamics of thermostatically controlled loads for power system frequency control. *PhD Thesis, University of Warwick*, 2018

Webborn, E; MacKay, RS. A Stability Analysis of Thermostatically Controlled Loads for Power System Frequency Control. *Energy and Complexity*, 2017

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