A Scalable Low-Cost Solution to Provide Personalised Home Heating Advice

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Problem

Space and hot water accounts for approximately 70% of household energy bills, but households poorly understand their heating systems and operate them inefficiently.

Aim

Provide personalised home heating advise to households at scale and minimal marginal cost, and generate reusable data set on typical home heating practises:

- Minimal number of reusable sensors
- No hardware installation
- No software installation

Solution

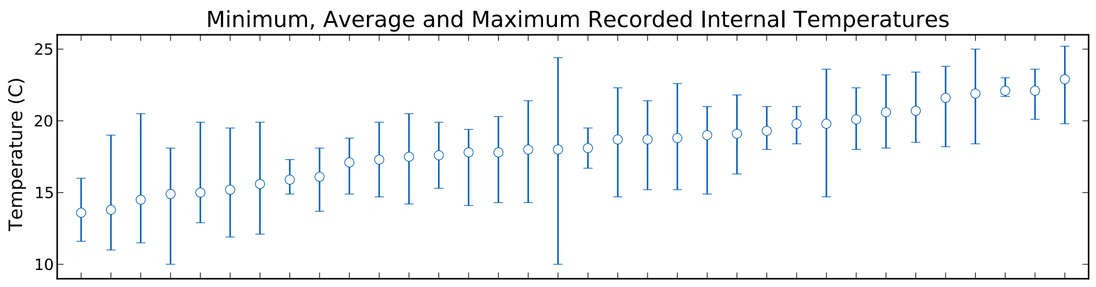
Three part solution using low-cost USB temperature loggers delivered by post to homes, and web-based data upload and analysis:

- Easy to use USB temperature logger
- Website to request logger, upload data, and receive feedback
- Analysis algorithms that perform robust thermal modelling of the home and perform comparison against peers

Initial Trial Data Collection

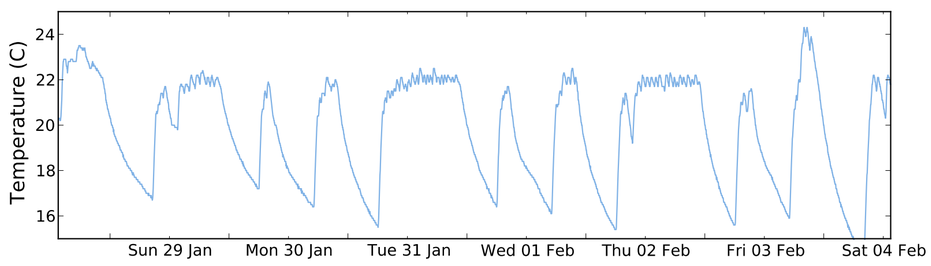
Approach verified in initial trial using COTS temperature loggers:

- 30 homes from ECS students and staff
- 30 homes from Energy and Communities (ESRC) project

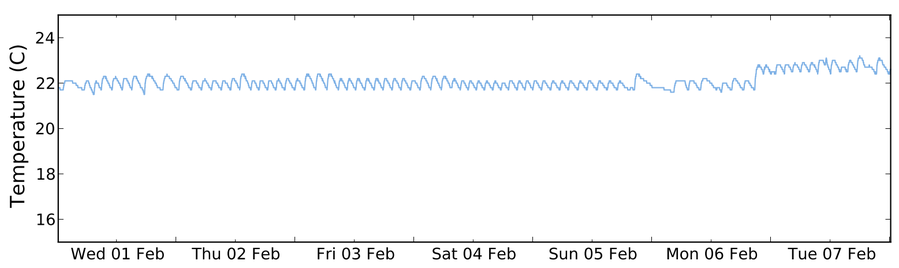


Example datasets from initial trial all showing thermostats operating with a 22° C set-point:

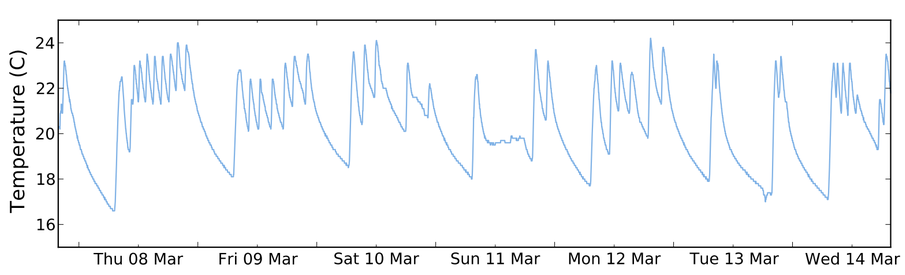
Timed heating periods with an electronic proportional control thermostat and timed on-off periods.



Constant heating with electronic proportional control thermostat

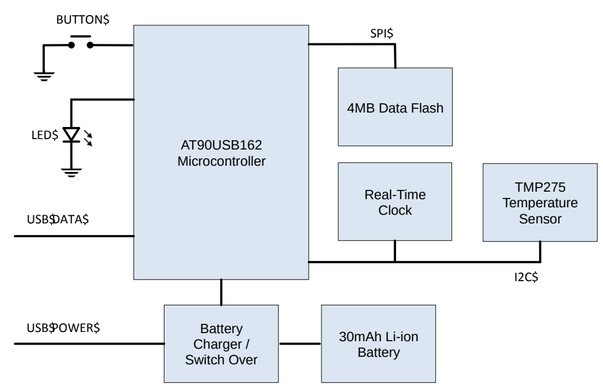


Timed heating periods with a mechanical thermostat

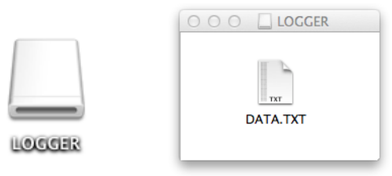


USB Temperature Logger

- Embedded microcontroller
- USB interface in firmware
  - HID for configuring
  - Mass storage for user
- No driver required
- Minimal user interface (one button and one LED)



- Logger records 2 min temperature measurements (+/- 0.2° C) for 7 days
- Appears as flash drive when plugged into USB port



- Logger placed on thermostat (control point of heating system)

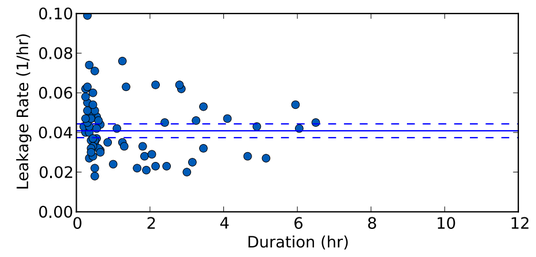
Thermal Modelling and Analysis

Build thermal model of home using discrete stochastic differential equation

$$T_{in}^{t+1} = T_{in}^{t} + \left[r_h^t - \phi\left(T_{in}^t - T_{ext}^t\right)\right]\Delta t + \varepsilon^t$$

Heater output (C/hr) — Leakage rate (1/hr)

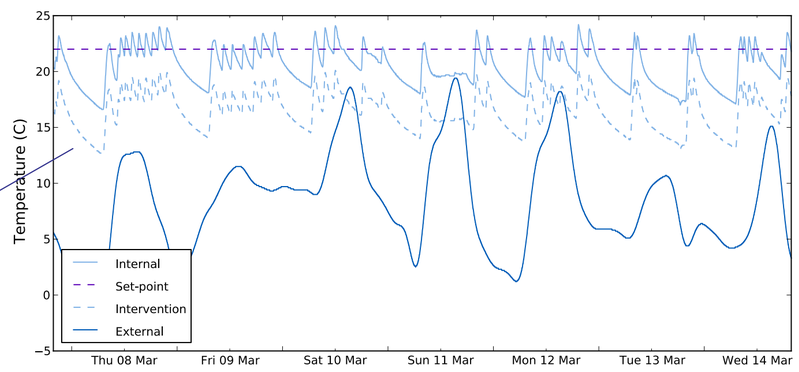
Embed dynamics in a state space model and use Kalman filter to estimate leakage rate over intervals of decreasing temperature.



Estimating total energy input by summing over temperature profile, allows percentage energy saving of interventions to be modelled.

$$E \propto \sum_{t=1}^{N} r_h^t = \phi \sum_{t=1}^{N} \left(T_{in}^t - T_{ext}^t\right) + \frac{T_{in}^{N+1} - T_{in}^1}{\Delta t}$$

Internal temperature shifted by 4° C to simulate reduction of set-point temperature from 22° C to average of 18° C.



Future Work

- Robust thermal modelling algorithms informed by new dataset
- Heating timer identification and feedback
- Encourage reflection through interactive controls simulation