Analytical Tools for Understanding Appliance Usage Patterns and the Potential for Energy Savings

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• REFIT Load Measurements Dataset
• Appliance modelling,
  – Non-intrusive appliance disaggregation from smart meter data
  – Prediction of energy demand from households and appliances
  – Opportunities for load shifting
  – Assessing tariff suitability
  – Understanding household routines through time use and energy consumption studies of daily activities in the home, such as cooking or laundering
• Patterns of appliance use
• Energy feedback generation
• Innovative analytical tools for understanding energy end-use
Data Collection Platform

- Data collection platform recorded data at 6-8 second intervals for a period of 2 years across 20 houses.
- Aggregate + 9 Individual Appliance Monitors
- Environmental Sensors (Light, Movement, Temperature)

Paper: https://goo.gl/Mhj4XQ
Dataset: https://goo.gl/QvQU4a
Signature Dataset

• Crowd Sourced
  – Open Access
• Designed to enable:
  – On the fly load disaggregation
  – Realistic load profiling
  – Appliance benchmarking
  – ...
Load Disaggregation via Non-intrusive Appliance Load Monitoring (NILM)

Why use NILM:
• Energy accountability
• Itemised billing
• Inform appliance upgrade decisions
• Predict demand from appliances and households
• Inform load shifting
• Understand households’ daily routines
Our Designed NILM Methods

• **Supervised NILM methods**— relatively simple, robust, and require short training periods, based on Decision Tree (DT) and Support Vector Machine (SVM)\(^1,2,3\)

• **Unsupervised method**—does not require a labelled set of appliances for training, but the complexity is affected by the number of appliance signatures in the database, based on Dynamic Time Warping (DTW)\(^1,2,4\)

• **Training-less method**—does not require any prior knowledge of appliances, based on Graph-based signal processing (GSP)\(^5,6\)

1. [https://goo.gl/SnTWVB](https://goo.gl/SnTWVB)
2. [https://goo.gl/eSN6q0](https://goo.gl/eSN6q0)
3. [https://goo.gl/bpXK6u](https://goo.gl/bpXK6u)
4. [https://goo.gl/hE9XhK](https://goo.gl/hE9XhK)
5. [https://goo.gl/0wmB08](https://goo.gl/0wmB08)
NILM: Accuracy Comparison

Comparison of disaggregation accuracy among three different methods. Our benchmark is Hidden Markov Model (HMM) based NILM.

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Graph showing the comparison of Precision, Recall, and F-Measure for supervised DT, unsupervised DTW, training less GSP, and benchmark HMM.
NILM for Energy Feedback

- Percentage of power usage attributed to each kind of appliance via NILM.
- Unknown accounts for lights, chargers and other low powered equipment (<50 Watts)
Households tend to exhibit similar peak times, morning & evening.
Appliances like the television can follow distinct load patterns, with many houses having a higher evening demand due to top-rated shows being shown during the 8-9pm prime time slot.
Demand Profile

The kettle - an appliance present in each household with a very distinct pattern of usage.

Working households have peaks based around daily schedule; before work and after work consumption times are immediately visible.
Load Shifting

In the UK load shifting would best be applied to households with an Economy7 tariff (cheaper electricity between 12am-7am).

Large white appliances such as Tumble Dryers and Washing Machines are ideal as they can be turned on and left.
Day/Night Tariffs

- We can analyse the amount of power used in each household and identify the most suitable tariff
- We can advise if people should shift back based on lack of usage on Economy7.

<table>
<thead>
<tr>
<th>Month</th>
<th>Consumption (kWh)</th>
<th>Day</th>
<th>Night</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>July</td>
<td>202.87</td>
<td>52.59</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>Aug</td>
<td>211.11</td>
<td>45.73</td>
<td>18</td>
<td></td>
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<tr>
<td>Sept</td>
<td>270.94</td>
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<tr>
<td>Oct</td>
<td>236.83</td>
<td>48.71</td>
<td>17</td>
<td></td>
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<tr>
<td>Nov</td>
<td>248.56</td>
<td>45.70</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Dec</td>
<td>256.91</td>
<td>48.14</td>
<td>16</td>
<td></td>
</tr>
</tbody>
</table>

### About Online Fixed Saver December 2017 electricity tariff

- **Supplier**: ScottishPower
- **Tariff name**: Online Fixed Saver December 2017
- **Tariff type**: Fixed Price
- **Payment method**: Monthly Direct Debit
- **Standing Charge**: 27.39p per day
- **Unit rate - All/Day**: 14.557p per kWh
- **Unit rate - Night**: 6.749p per kWh
- **Tariff ends on**: 31/12/2017
- **Price guaranteed until**: 31/12/2017
- **Exit Fee (if you switch supplier more than 49 days before the tariff end date)**: £30.00
- **Discounts and additional charges**: Annual Online discount £5.25, Annual Dual Fuel discount £5.25
- **Additional products or services included**: Not Applicable
Demand Prediction

Prediction of kettle usage, over the month of January using ANFIS, deeper understanding and more accurate prediction of appliances will enable more accurate load simulation.
Estimating best usage scenarios, we can advise on changes which will help the consumer save money. In many cases a small change but which will help reduce waste and save money.

<table>
<thead>
<tr>
<th>House</th>
<th>Months Recorded</th>
<th>Total Consumption (kWh)</th>
<th>Optimal Volume (mL)</th>
<th>Consumption Above Optimal (kWh)</th>
<th>Savings per Year (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>20</td>
<td>255.32</td>
<td>825</td>
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<td>126.76</td>
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<tr>
<td>3</td>
<td>20</td>
<td>251.16</td>
<td>550</td>
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<td>171.06</td>
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<td>20</td>
<td>135.86</td>
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<td>45.02</td>
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<td>5</td>
<td>21</td>
<td>314.66</td>
<td>825</td>
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<td>550</td>
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<td>20</td>
<td>15</td>
<td>136.11</td>
<td>825</td>
<td></td>
<td>19.66</td>
</tr>
</tbody>
</table>

Long term usage habits emerge for each household. Kettle usage is shown below and shows two distinct household types, working and retired.
Linkages between Time-use (Activities) and Energy

- Mapping of smart energy meter data (and other sensors) to infer everyday activities, as an indication to how we live our life, and quality of life.
- Activity-centric approach, where the emphasis shifts from energy use to households’ lived experience, i.e., routines, habits and activities that constitute the majority of life at home.

**Electricity use by activity over the course of a day:**

*average weekday (Oct 2014), % of total electricity use*
At least a quarter of the total electricity consumption of a household can be accounted for by activities, where cooking contributes to a major chunk. Only 18% of the total load is not inferred, and this includes lighting predominantly.
Activities can account for almost 50% of the monthly total electricity consumption, with cooking and laundering playing a significant part. This is to be expected for a family with two teenage children.
### Energy Feedback Generation

**REFIT**

#### Energy Consumption Report V2

**REFIT House 01**

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Energy Use (kWh)</th>
<th>Cost (£)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Your House</td>
<td>16,547 kWh</td>
<td>£1,159.84</td>
</tr>
<tr>
<td>Average 4 Bed Detached House</td>
<td>25,500 kWh</td>
<td>£1,754.25</td>
</tr>
<tr>
<td>REFIT Comparison Household</td>
<td>22,402 kWh</td>
<td>£1,420.42</td>
</tr>
</tbody>
</table>

#### Your Appliance Use & Costs (February 2015)

- **Base Load**: £7.96
- **Electric Heater (2)**: £7.39
- **Unknown**: £6.50
- **Electric Heater (1)**: £5.16
- **Kettle & Oven**: £3.08
- **Electric Hob**: £3.02
- **Electric Shower**: £2.16
- **Freezer (2)**: £2.02
- **Washing Machine**: £1.78
- **Fridge**: £1.29
- **Cookware**: £1.19
- **Freezer (1)**: £0.91
- **Dishwasher**: £0.78
- **Television Site**: £0.53
- **Computer**: £0.51
- **Washer/Dryer**: £0.49

**Total**: £49.88

#### Your Appliance Use & Costs (July 2014)

- **Base Load**: £7.31
- **Electric Shower**: £7.75
- **Freezer (2)**: £7.87
- **Unknown**: £2.64
- **Fridge**: £1.86
- **Electric Heater (1)**: £1.80
- **Kettle & Oven**: £1.68
- **Electric Hob**: £1.37
- **Cookware**: £1.29
- **Dishwasher**: £0.94
- **Television Site**: £0.90
- **Computer**: £0.90
- **Washing Machine**: £0.81
- **Television Site**: £0.53
- **Washer/Dryer**: £0.51
- **Total**: £27.17
Conclusion
What can we do with smart meter data?

- NILM
- Time Use Statistics
- Load Estimation and Simulation
- Appliance Benchmarking
- Energy Feedback & Advice
- ...
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