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Energy Feedback enabled by Load Disaggregation

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1. Comparison with that of the previous month or year => 100%
2. Comparison with other households => 50%
3. Monthly consumption => 65%
4. Daily or weekly consumption => 25%.
5. Appliance-specific use => 70%
Load Disaggregation via Non-intrusive Appliance Load Monitoring (NILM) for smart-meter aggregate load data

- **Supervised NILM methods**\(^1,2\) — relatively simple, robust, and require short training periods
- **Unsupervised method**\(^1,3\) — does not require a labelled set of appliances for training
- **Training-less method**\(^4\) — does not require any prior knowledge of appliances or a training period

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Smart electricity meters and IHDs tell us about real-time household electricity use, but they don’t tell us which appliances were running, nor **what to do about it**.

Energy disaggregation tells us **when**, **how long** an appliance was used and **how much energy** it consumed, but nothing about **why** it was used.

**Beyond NILM**

**Enhanced feedback on electricity consumption**
- advice on non-efficient usage of an appliance
- inform appliance upgrades
- opportunities for (appliance) load shifting
- predict appliance electricity demand
- relating energy consumption to activities in the home, such as cooking or laundering
Appliance Modelling & Informing Energy Savings

- **Kettle**: Model inferring the volume of water used purely from disaggregated electricity consumption
- **Estimating best usage scenarios to reduce waste**

<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>
<td>126.76</td>
<td>15.32</td>
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<td>3</td>
<td>20</td>
<td>251.16</td>
<td>550</td>
<td>171.06</td>
<td>28.85</td>
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<tr>
<td>5</td>
<td>21</td>
<td>314.66</td>
<td>825</td>
<td>148.85</td>
<td>17.32</td>
</tr>
<tr>
<td>6</td>
<td>19</td>
<td>273.6</td>
<td>550</td>
<td>122.75</td>
<td>16.67</td>
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<td>8</td>
<td>18</td>
<td>245.68</td>
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<td>23.41</td>
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<tr>
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<td>271.31</td>
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<tr>
<td>11</td>
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<td>500</td>
<td>83.78</td>
<td>29.99</td>
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<tr>
<td>12</td>
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<td>163.92</td>
<td>825</td>
<td>105.54</td>
<td>20.98</td>
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<td>15</td>
<td>183.63</td>
<td>550</td>
<td>98.98</td>
<td>16.99</td>
</tr>
</tbody>
</table>

Informing Appliance Upgrade
Case study of a household upgrading from a standard kettle to a vacuum kettle

- Reduction in the number of re-heats
- ~5% reduction per use
- ~14% total reduction
- Continued economical usage style

<table>
<thead>
<tr>
<th>Year</th>
<th>Uses</th>
<th>Consumption (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dec 2013 – Standard</td>
<td>238</td>
<td>17.2</td>
</tr>
<tr>
<td>Dec 2014 – Vacuum</td>
<td>217</td>
<td>14.8</td>
</tr>
</tbody>
</table>
Load Shifting

65% of REFIT households would consider adjusting the timing of their appliance use to benefit from a better tariff.

- dishwasher, washing machine and tumble dryer, hobbies, charging devices, bread-maker, computing, and charging their car.

Non Off-Peak uses: 344
Total load that can be shifted: 99.77 kWh
Day Price: £13.05
Night Price: £7.54
Possible Savings: ~ £5.10
Temporal Patterns of Appliance Use

House 12 (Working)

House 12 - Kettle
Consumption by Hour (kWh)
Working Household

House 11 (Retired)

House 11 - Kettle
Consumption by Hour (kWh)
Retired Household

Kettle Demand Prediction

Deeper understanding and more accurate prediction of appliances will enable more accurate load simulation.

Meaningful & salient feedback

Feedback is important “in making energy more visible and more amenable to understanding and control”.

Moving away from ‘energy-centric’ approach in which information feedback directly concerns energy consumption.

To an ‘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.
Understanding the linkages between appliance use and common activities in the house by integrating **quantitative smart home data** with **qualitative household ethnography** to identify activities at home.

Develop, test, and validate a multi-step methodology for making robust activity-based inferences in households.

Demonstrate how smart energy meter data can be used to feed back information to households on the time profile of everyday activities in the home and their energy-using consequences.
Linkages between Time-use (Activities) and Energy

Electricity use by activity over the course of a day: average weekday (Oct 2014), % of total electricity use

explained but not linked to activities
In this household, detected activities can account for almost 50% of the monthly total electricity consumption, with cooking and laundering playing a significant part.
- The total electricity use explained by activity inferences is 33%. The rest is accounted for by lighting, cold appliances, base load, and heating.
NILM-facilitated Energy Feedback

- Using disaggregated information about the when, duration and energy consumption of each appliance use:
  - Time use statistics to quantify, predict and inform (efficient) appliance use and upgrade
  - Identify opportunities for load shifting of particular appliances & quantify energy savings due to shifting appliance use
  - Understanding electricity demand through the lens of activities by integrating **quantitative smart home data** with **qualitative household ethnography** to identify activities at home