

Engineering and Physical Sciences Research Council



REFIT: Smart Homes & Energy Demand Reduction

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

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# Contents

- 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 enduse



2

# **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



1.426444

1.426445

- Crowd Sourced
  Open Access
- Designed to enable: ...
  - On the fly load disaggregation
  - Realistic load profiling
  - Appliance benchmarking

1.42644

1.426441

1.426442

1.426443

2000

1500

500

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



- <u>Supervised NILM methods</u>— relatively simple, robust, and require short training periods, based on Decision Tree (DT) and Support Vector Machine (SVM)<sup>1,2,3</sup>
- <u>Unsupervised method</u>—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)<sup>1,2,4</sup>
- <u>Training-less method</u>—does not require any prior knowledge of appliances, based on Graph-based signal processing (GSP)<sup>5,6</sup>
- 1. https://goo.gl/SnTWVB 4. https://goo.gl/hE9XhK

https://goo.gl/eSN6q0
https://goo.gl/0wmB08

https://goo.gl/bpXK6u
https://goo.gl/jJFBZp

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#### **NILM: Accuracy Comparison**



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



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#### NILM for Energy Feedback



#### Winter month-February

- Percentage of power usage attributed to each kind of appliance via NILM.
- Unknown accounts for lights, chargers and other low powered equipment (<50 Watts)</li>



# Load Profile



# Households tend to exhibit similar peak times, morning & evening.



# **Demand Profile**

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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

House 1 - Economy7 Washing Machine Hourly Load

10pm

2pm

8pm

12am 25

20 15 10 5 6am

10am



In the UK load shifting would best <sup>6pm</sup> be applied to households with an <sup>4pm</sup> 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.



12pm

# 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.

	Consum		
Month	Day	Night	%
July	202.87	52.59	21
Aug	211.11	45.73	18
Sept	270.94	44.73	14
Oct	236.83	48.71	17
Nov	248.56	45.70	16
Dec	256.91	48.14	16

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				
<b>Exit Fee</b> (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				

16 Dec 2015

# **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.



Hourly Consumption & ANFIS Prediction

# **Energy Savings**



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.

					Savings per Year
House	Months Recorded	Total Consumption (kWh)	Optimal Volume (mL)	Consumption Above Optimal (kWh)	(kWh)
2	20	255.32	825	126.76	15.32
3	20	251.16	550	171.06	28.85
4	20	135.86	550	45.02	6.29
5	5 21	314.66	825	148.85	17.32
6	5 19	273.6	550	122.75	16.67
7	20	109.84	825	42.21	5.17
8	3 18	245.68	550	171.83	23.41
ç	18	312.36	550	271.31	73.71
11	. 12	182.02	500	83.78	29.99
12	15	163.92	825	105.54	20.98
13	16	103.24	825	62.32	7.37
17	, 15	183.63	550	98.98	16.99
19	15	108.27	825	26.64	3.56
20	) 15	136.11	825	19.66	1.64

## **Time Use Statistics**



#### 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* 



# Understanding Energy Demand through Activities I



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.



# Understanding Energy Demand through Activities II



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**

Energy Consumption Report V2

**REFIT House 01** 



This shows how much energy you use and how much it costs in comparison to an average house like yours. and a similar household in the REFIT project. The comparative criteria are shown in the table below

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How You Compare to Others



Floor Area (som)

108

Unknown

129

**Property Build Age** 

1975 - 1980

1005.11002

1005-1074

verage Ai

E800 E1,000 E1,200 E1,400 E1,600 E1,800 E2,000

REFIT Household

Property Type

4 Bedroom Detached

4 Bedroom Detached

# Dedcom Detached

Number of Occupants

2 Adults

Unknow

2.80.89

£600

House

Your House

Average House

**REFIT Household** 

£200

£400

Total Cost:



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

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Your Appliance Use & Costs (February 2015)



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#### 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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