Contents

ESCOLA TÈCNICA SUPERIOR ENGINYERIA D'EDIFICACIÓ UNIVERSITAT POLITÈCNICA DE VALÈNCIA

Abstract

Knowing more about the energy consumption in dwellings is one issue in the development of further interventions that will help to decrease the energy consumption and consequently the CO_2 footprint per household.

The energy consumption used in a dwelling depends widely on the characteristics of the house and installations, and on the householder's behaviour.

Based on the aim of looking at how energy is used within the house, we installed a set of equipment in 20 sample dwellings. The equipment monitors the electricity and gas consumption as well as the hot water flow.

For the analysis in this report, the data from the electric monitoring devices will be used.

The purpose of this analysis is to obtain new insights into the reduction of energy use in some sample houses through looking at the characteristics and appliances within the house coupled with the householder's behaviour.

Aims and objectives:

- To study the trends in energy consumption by fuel type, by appliance consumption and by activity in the house.
- To look at energy disaggregation by appliances across houses.
- To study the link between house characteristics and householders behaviour.
- To study the electricity consumption by occupancy.
- To understand the data system and the monitoring installation of electric devices and to analyse data from the monitored equipment in the dwellings.
- To review previous researches linked to the use of energy in residential buildings.
- To analyse in detail current domestic consumption, identifying opportunities for reducing energy consumption.
- To look at digital media, use at home and potential demand reduction.
- To study the Iterative innovation and development processes involving householders, energy providers and UK business to fully explore householder requirements, desires and motivating factors.
- To get new insights in how to reduce energy consumption for sample dwellings.

Introduction

Energy

The Energy

Most of the world's energy resources are from the conversion of the sun's rays to other energy forms after being incident upon the planet. Some of that energy has been preserved as fossil energy; some is directly or indirectly usable; for example, via wind, hydro- or wave power.

Fossil fuels are fuels formed by natural processes such as anaerobic decomposition of buried dead organisms. The age of the organisms and their resulting fossil fuels is typically millions of years, and sometimes exceeds 650 million years. Fossil fuels contain high percentages of carbon and include coal, petroleum, and natural gas.

Main Energy sources:

It was estimated by the Energy Information Administration that in 2007 primary sources of energy consisted of petroleum 36.0%, coal 27.4%, natural gas 23.0%, amounting to an 86.4% share for fossil fuels in primary energy consumption in the world.[4] Non-fossil sources in 2006 included hydroelectric 6.3%, nuclear 8.5%, and others (geothermal, solar, tide, wind, wood, waste) amounting to 0.9%.

The Energy Information Administration (2007) estimated as well that the world energy consumption was growing about 2.3% per year.

Fossil fuel into energy:

The burning of fossil fuels produces around 21.3 billion tonnes (21.3 gigatonnes) of carbon dioxide (CO2) per year, but it is estimated that natural processes can only absorb about half of that amount, so there is a net increase of 10.65 billion tonnes of atmospheric carbon dioxide per year (one tonne of atmospheric carbon is equivalent to 44/12 or 3.7 tonnes of carbon dioxide). Carbon dioxide is one of the greenhouse gases that enhances irradiative forcing and contributes to global warming, causing the average surface temperature of the Earth to rise in response, which the vast majority of climate scientists agree will cause major adverse effects.

Energy in UK

Energy use in the United Kingdom stood at 3,894.6 kilogrammes of oil equivalent per capita in 2005 compared to a world average of 1,778.0. In 2008, total energy consumed was 9.85 exajoules (EJ) - around 2% of the estimated 474 EJ worldwide total (while the UK accounts for less than 1% of global population)

The Low Carbon Transition Plan launched by the British government in July 2009 aims at 30% of renewable and of 40% of low CO_2-content fuels in electricity generation by 2020.

Research in the area of energy is carried out by a number of public and private sector bodies:

The Engineering and Physical Sciences Research Council funds an energy programme spanning energy and climate change research. It aims to develop, embrace and exploit sustainable, low carbon and/or energy efficient technologies and systems to enable the UK to meet the Government's energy and environmental targets by 2020. Its research includes renewable, conventional, nuclear and fusion electricity supply as well as energy efficiency, fuel poverty and other topics.

Since being established in 2004, the UK Energy Research Centre carries out research into demand reduction, future sources of energy, infrastructure and supply, energy systems, sustainability and materials for advanced energy systems.

The Energy Technologies Institute, expected to begin operating in 2008, is to 'accelerate the development of secure, reliable and cost-effective low-carbon energy technologies towards commercial deployment'.

In relation to buildings, the Building Research Establishment carries out some research into energy conservation.

Towards Energy Efficiency

The UK government has instituted several policies designed to increase energy efficiency. These include the roll out of smart meters, the Green Deal, The CRC Energy Efficiency Scheme and Climate Change Agreements.

2050 UK Target

New policies

Based on the need of reducing carbon emissions on the whole world, the UK government emitted the energy white paper in 2007.
The main commitments to get before 2050 for the country are:

Figure 0-1 CARBON EMISSIONS REDUCTION TARGET

✓ REDUCE ENERGY FROM:
- BUSINESS
- HOUSEHOLD
- TRANSPORTS
- PUBLIC SECTOR

✓ MOVE TOWARDS CLEANER ENERGY SUPPLIES:
- HEAT
- ELECTRICITY
- TRANSPORT FUELS

✓ SECURE RELIABLE ENERGY SUPPLIES AT PRICES SET IN COMPETITIVE MARKETS.

What about residential buildings?

The UK energy research centre emitted the next statistics:

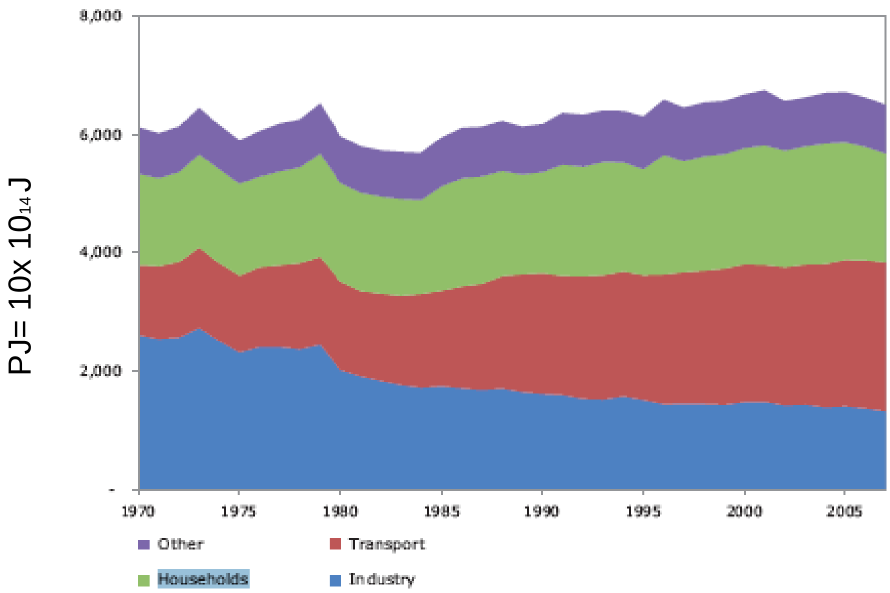


Figure 0-2 Source: Final energy demand by sector.

Household energy demand was being increasing by 20% from 1970 to 2005 in UK. Transport and households are the main points front the drop of the energy demand, (Data from UKERC Tarjet 2050)

BERR (Department for Business, Enterprise and Regulatory Reform), 2008

The UK commitment brought new needs related with energy consumption and a huge part of them focus on dwellings and their facilities.

Its need to achieve:

- Buildings zero carbon.
- Energy efficiency of existing homes.
- Double effort on current energy suppliers.
- Duck-out of light bulbs. Replace it by compact fluorescent lamps (CFLs), and low-cost Light Emitting Diodes (LEDs). Lighting energy use by 90% off by 2030.
- Consumers informed about how everyday activities contribute to emissions.
- Clearer bills and advice about energy efficiency.
- Achieve smart meters and real time displays which enable people to track their energy use conveniently in their homes.
- Energy Performance Certificates for new and existing homes.
- Micro generators.
- Cleaner energy supplies*.

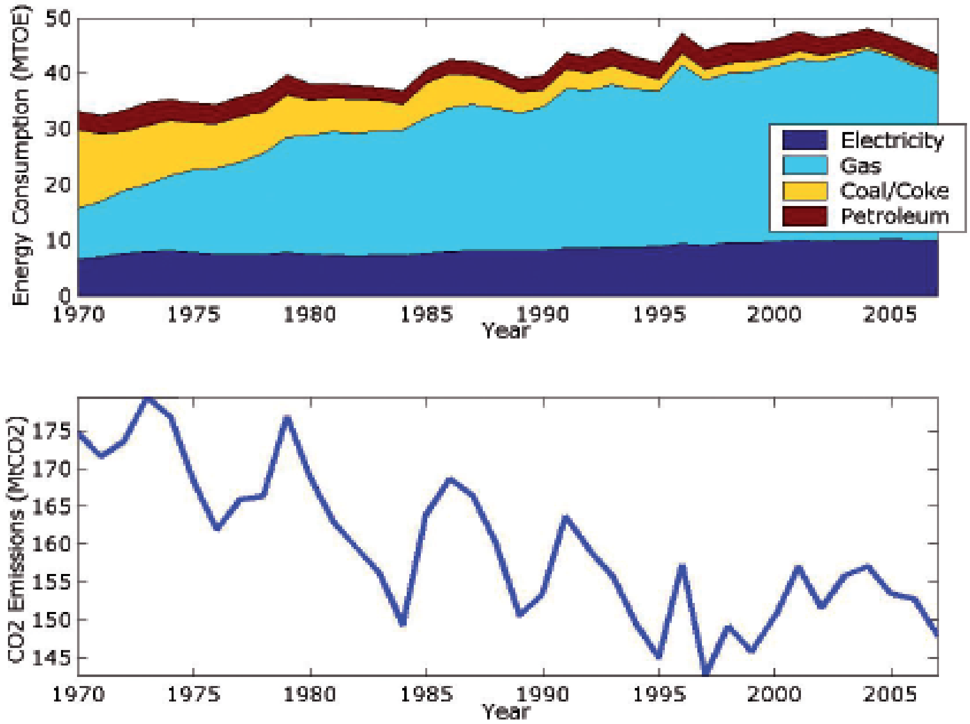


Figure 0-3 Trends in energy consumption, fuel mix, and CO2 emissions for the UK residential sector.

Household energy demand in the Lifestyle Reference scenario:
The dominant heating technologies must change radically.
The graphic shows different trends depending on the lifestyle studied.
The predominance of the gas boiler is challenged by several alternatives: Biomass, CHP (Combine Heat and Power) and heat pumps (ground source and air source).
Solar water heating becomes an accepted part of the built environment providing 50% of water heating demand by 2050.
The decline of incandescent lighting replaced by (CFLs) and (LEDs) it's going to suppose savings of 90% of energy lighting and so in Electricity.

The combined effects of substantial improvements in building fabric (insulation and glazing) coupled with widely lower internal temperatures, it's expected to have a significant effect on the demand for space heating.

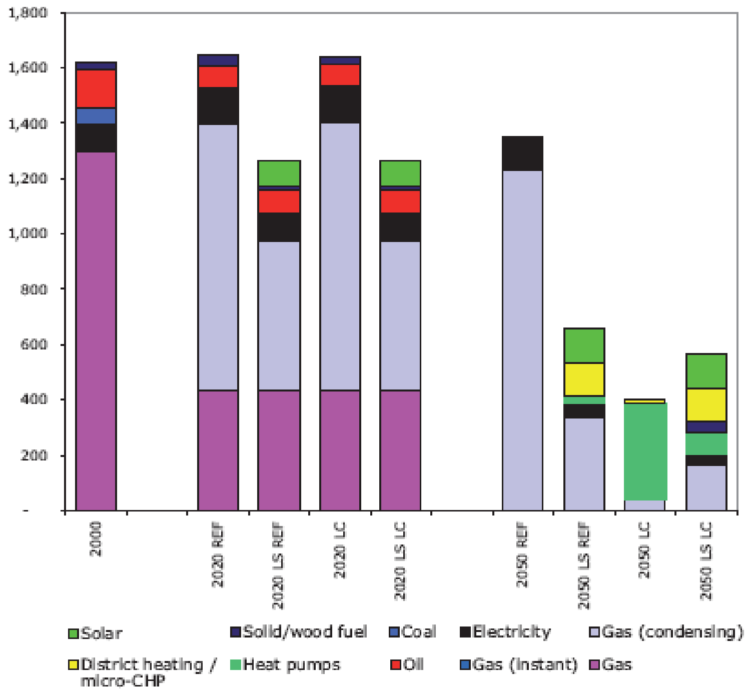


Figure 0-4 Residential heating by fuel type, different scenarios

UKERC

House Stock

The complexity of the UK domestic built environment arises from variations in its physical form, the climatic conditions it is subjected to, and the behaviour of the building occupants.

There are over 20 million dwellings in the UK and there is a great variation in the size, shape and construction of these buildings.

The UK housing stock has been constructed over a long period of time and there are many different building materials and techniques used, from stone and solid brick walls to highly-insulated cavity wall construction.

Within the homes the space and water heating provision can vary widely in terms of types of systems, fuels used and efficiency.

Each of these buildings is subjected to climatic conditions, including ambient air temperature and solar irradiation, which can vary spatially as well as containing short-term fluctuations and long-term trends. In particular the local micro-climate can vary considerably across the housing stock from highly exposed rural locations to city centres affected by the urban heat island effect.

The behaviour of the occupants in the homes is a further complexity and is dependent on the number of people in the household, their ages, the occupancy patterns and many other social factors.

The space and hot water heating demand, and the usage of electrical appliances, is largely determined by building occupant behaviour.

Even if the UK housing stock was fully insulated, the electricity generation and supply, appliances and heat generation equipment was as efficient as possible and renewable energy devices installed, further reductions in energy consumption and CO2 production can only be achieved by the consumer changing their behaviour, which must be pursued in parallel if energy reduction targets are to be met.

In order for this to occur, the consumer needs feedback that relates domestic practice to consumption; a particular issue with the current quarterly billing and payment by direct debt system in the UK means that energy consumption is almost invisible to the householders.

Domestic energy metering:

Energy meters record the amount of fuel supplied. In the simple houses, it can be gas (cubic feet or m3) and electricity (KW).

Energy use is often estimated by the supply companies because of the impossibility of regularly human readings.

These meters have no potential to record energy export from Solar Panels.

Introduction to Smart Meters

The smart meters installed, record electric consumption every minute. It communicates that information daily to the utility for monitoring purposes. Smart meters enable two-way communication between the meter and the central system. Unlike home energy monitors, smart meters can gather data for remote reporting. Such an advanced metering infrastructure (AMI) differs from traditional automatic meter reading (AMR) in that it enables two-way communications with the meter.

Use of the smart meters

Traditional electrical and gas meters only measure total consumption.

Smart meters provide information of when and where the energy was consumed. Smart meters provide an economical way of measuring this information, allowing price setting agencies to introduce different prices for consumption based on the time of day and the season.

From a consumer perspective, smart metering offers a number of potential benefits to householders. These include:

a) To have the control of the energy consumption, being aware of the amount of money spent in energy whenever they want to know. The traditional estimated bill are one of the major source of complaints for many customers.

b) A tool to help consumers better manage their energy use - smart meters with a display can provide up to date information on gas and electricity consumption in the currency of that country and in doing so help people to better manage their energy use and reduce their energy bills and carbon emissions.

Electricity pricing usually peaks at certain predictable times of the day and the season. In particular, if generation is constrained, prices can rise from other jurisdictions or more costly generation is brought online. To encourage customers to adjust their consumption habits to be more responsive to market prices is one of the ideas to avoid peaks consumption. Regulatory and market design agencies hope these "price signals" will delay the construction of additional generation or at least the purchase of energy from higher priced sources, thereby controlling the steady and rapid increase of electricity prices.

Technology

Of all smart meter technologies, one critical technological problem is communication. Each meter must be able to reliably and securely communicate the information collected to some central location. Considering the varying environments and locations where meters are found, that problem can be daunting. Among the solutions proposed are: the use of cell/pager networks, satellite, licensed radio, combination licensed and unlicensed radio, power line communication. Not only the medium used for communication purposes but the type of network used is also critical. As such one would find: fixed wireless, mesh network or a combination of the two. There are several other potential network configurations possible, including the use of Wi-Fi and other internet related networks. To date no one solution seems to be optimal for all applications. Rural utilities have very different communication problems from urban utilities or utilities located in difficult locations such as mountainous regions or areas ill-served by wireless and internet companies.

Smart Meters in Spain

Information gathered from "SmartRegions" program.Summary of the European Smartmettering deployment.

Regulation existing in Spain related to smart meters implementation:

– RD 1634/2006: Order to the Regulator (Comisión Nacional de Energía, CNE) about Substitution Plan including the Substitution plan for all Spanish residential meter, criteria for the substitution and number of meter to install every year: percentage of the total equipment.

– ORDEN ITC/3860/2007: Publication of the criteria for the Substitution plan, including that every distributor has to present its own plan and AMM system design.
– Based on the Royal Decrees a meter substitution plan was established with an obligation to install smart meters for all consumers under 15 kW by 2018. By 31 December 2010, 30% of the contracts from each distribution company below 15 kW should have the smart meter installed. Distribution companies are responsible for the installation of the meters.

The Smart Metering obligations were established in December 2007 with the national meter substitution plan for end-users up to 15 kW. The aim is to support remote energy management systems. The plan is managed by the Ministry of Industry, with a deadline for the completion of the plan by 31 December 2018. All DSOs had to submit their substitution plans to the regional governments. A binding target of 30% of all customers was set for 2010. However, this initial target could not be reached by any of the DSOs due to a late approval of the substitution plan (in May 2009), technological uncertainties in terms of system communication, alleged supply problems of certified meters that were available only in June 2010 and on-going negotiations with the regulators about the level of cost acceptance.

LEEDR project

Low Effort Energy Reduction (LEEDR) is the research group that is running from 2010 in Loughborough University, (United Kingdom).

The team who is working in LEEDR project is a multidisciplinary team financed by the English government in its aim to increase Energy Efficiency in dwellings before 2020. It is founded along with other private business (Figure 5).

The idea is to look at how, when and what for is used the energy at sample households. What percentage is caused by the heating? What is caused by the lighting? Is there any trend followed by the dwelling? Are there across houses? What is causing it? Is it possible to solve it? How?

Figure 0-1 LEEDR Partners

Getting into their day-to-day routines and analysing from different aspects these questions will give new insights to help households to reduce energy consumption.

LEEDR is looking at twenty sample households within Loughborough.

Loughborough is a medium sized town within the Charnwood borough of Leicestershire, in the midlands of England. The town has a population of approximately 60,000, about 14,000 of which are students based at Loughborough University. Loughborough is the largest settlement in Leicestershire outside the city of Leicester.

The aim for that multi-disciplinarily approach is to reveals some new insights about energy behaviour, causes and trends.

Which social aspects are driving their energy behaviour? Which house characteristics are increasing the use of energy within the dwelling? Which appliances are the most important ones when focusing in energy consumption?

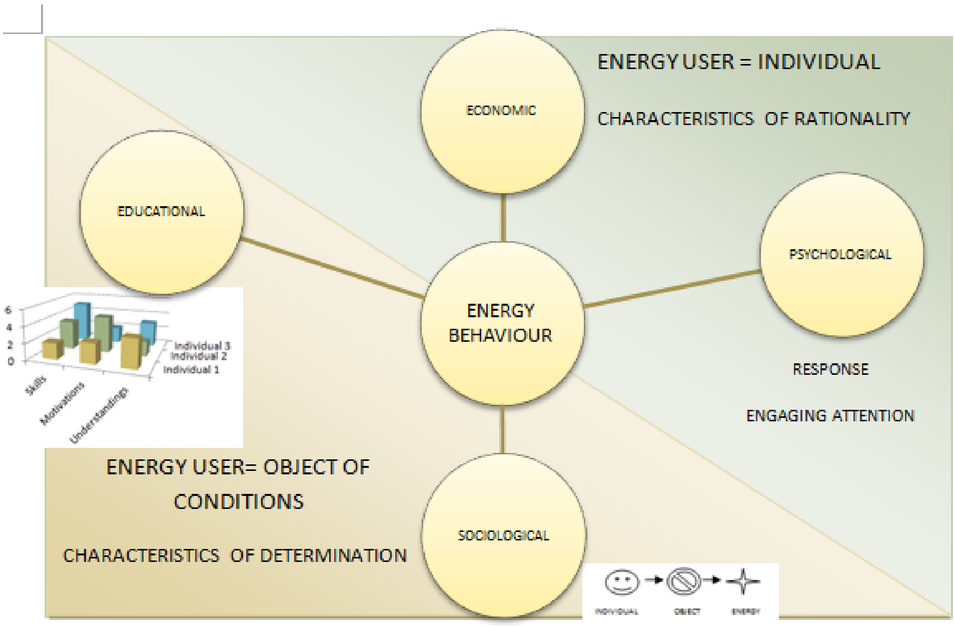


Figure 6 Energy user determinations: Map mind

On the other hand, understanding more about “Media” at home.

Media is becoming one of the main power consumers at home. The use of TV, Computers, mobile phones and video consoles is changing very quickly from the last few years. It’s needed to understand how Media is being used and why.

LEEDR works across disciplines: Social Sciences, Civil and Building Engineering, Design, Systems Engineering, Electronic & Electrical Engineering and Computer Sciences.

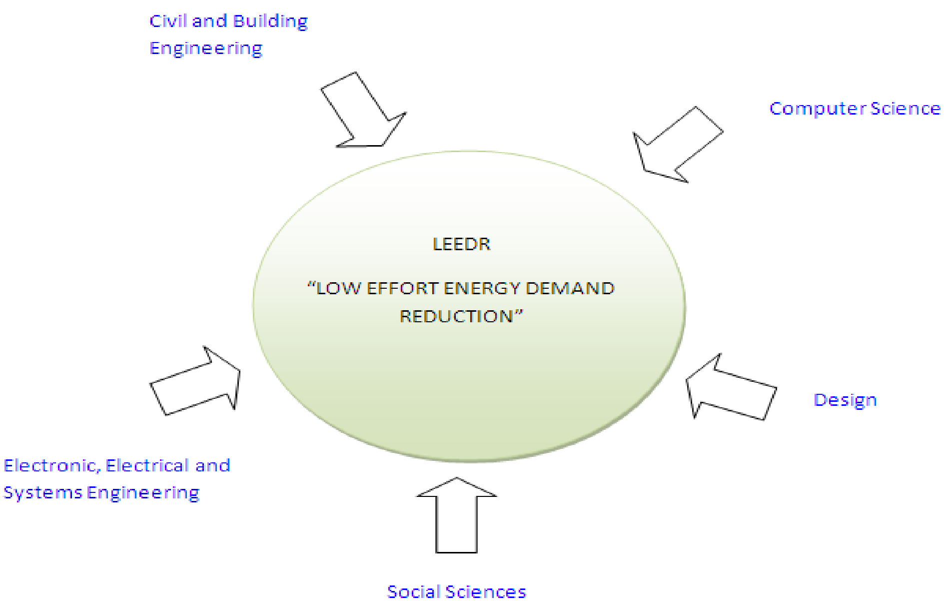


Figure 7 Multi-disciplinary work

The study involves two stages:

- Stage one involves data collection and interpretation.
    - Energy use and human behaviour;
    - Interaction of the participants with digital media.
    - Use of the appliances at home.
- The stage two will be the interventions in the dwellings.

The interventions are dependent on the results of the stage one.

The data analysis and evaluation from stage one will be the base for the interventions and iterative processes on stage two.

LEEDR within 2050 UK target

The need for the reduction of the demand for energy is a global issue and the UK Government has committed the UK to an 80% CO2 reduction target for 2050.

Of the total demand, energy use in dwellings in 2008 accounted for nearly 30% of energy use in the UK.

At present, metered energy data currently only translates total domestic electrical loads into a time averaged kWh data, plotted against time, explaining nothing about where, how or why the energy is used.

There have been many energy consumption studies over the last few decades in UK, although intervention studies in the UK have been limited.

The focus of these studies has been on the end, the usage of energy in the buildings, but without connecting it with domestic practice, even, when was shown that the house characteristics don't determine the use of energy because of the importance of the householders behaviour.

Understanding this practice and how householders interface with technology and energy information is key to develop effective strategies and interventions.

Understanding how householders use digital media and their main aspirations is critical to create user-led 'low effort' interventions to enable strategies for energy demand reduction to be built into everyday media practices that are already embedded in the householders' life.

LEEDR as a multidisciplinary team

Way of work:

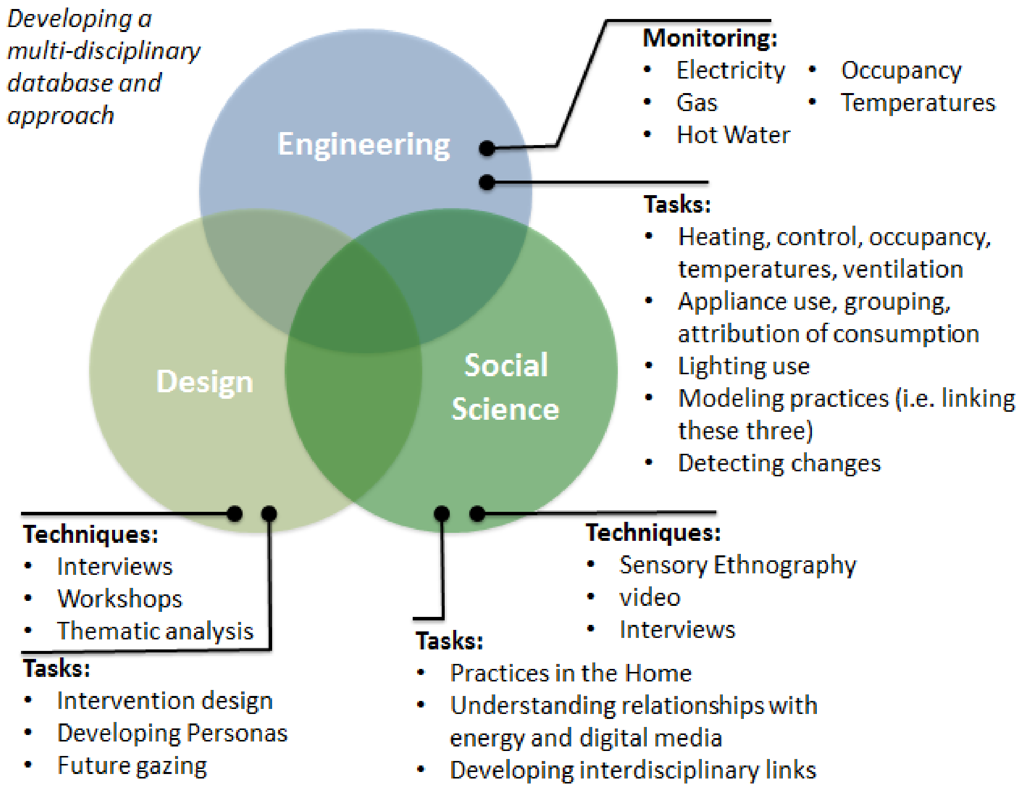


Figure 8 Team work approach (LEEDR Team, Loughborough University)

The mixture of professionals in the team encloses six specialities: Design, Computer Sciences, CREST (Renewable science), Civil and Building, Systems Engineering and Social Science.
These specialities are divided in three different blocks characterized by the technics and tasks in common, as shows Figure 9.
The team works around the University campus.

Figure 9 LEEDR group (LEEDR Team, Loughborough University)

Communication

One of the challenges of working in a multidisciplinary project is to work all together without losing the connection between members and disciplines. The communication between the team members is critical to get the best possible results.
To achieve the communication within the group, several protocols and technics are used:.

- Use of Network drivers.

- Use of a share calendars.

Figure 10 Sample Calendar

- Following several regular meetings along the year.

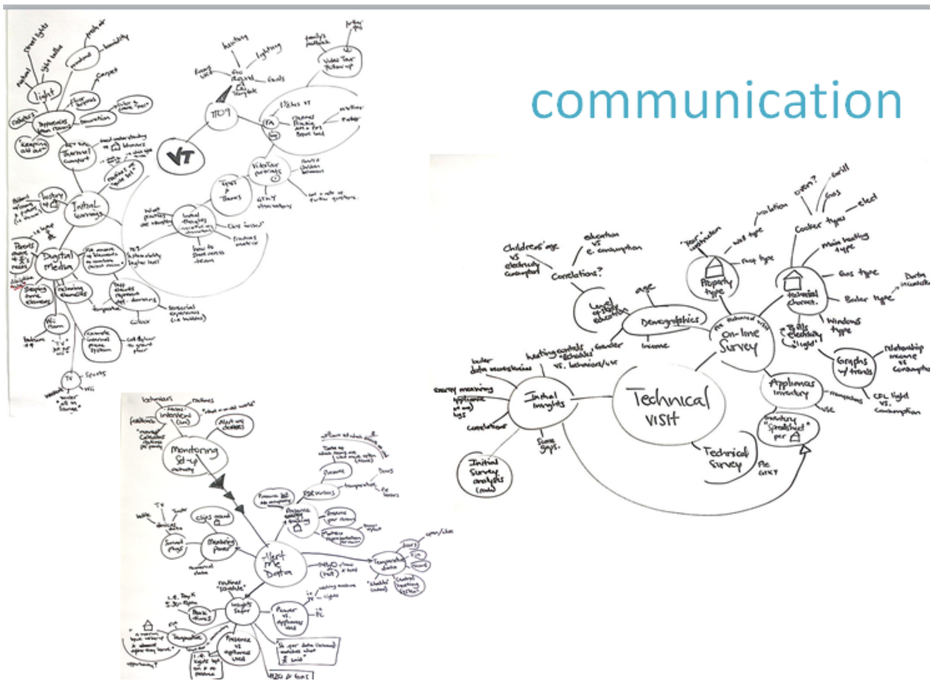


Figure 11 Map mind from data meeting (LEEDR Design Team, Loughborough Design School, Loughborough University)

- Preparing presentations.

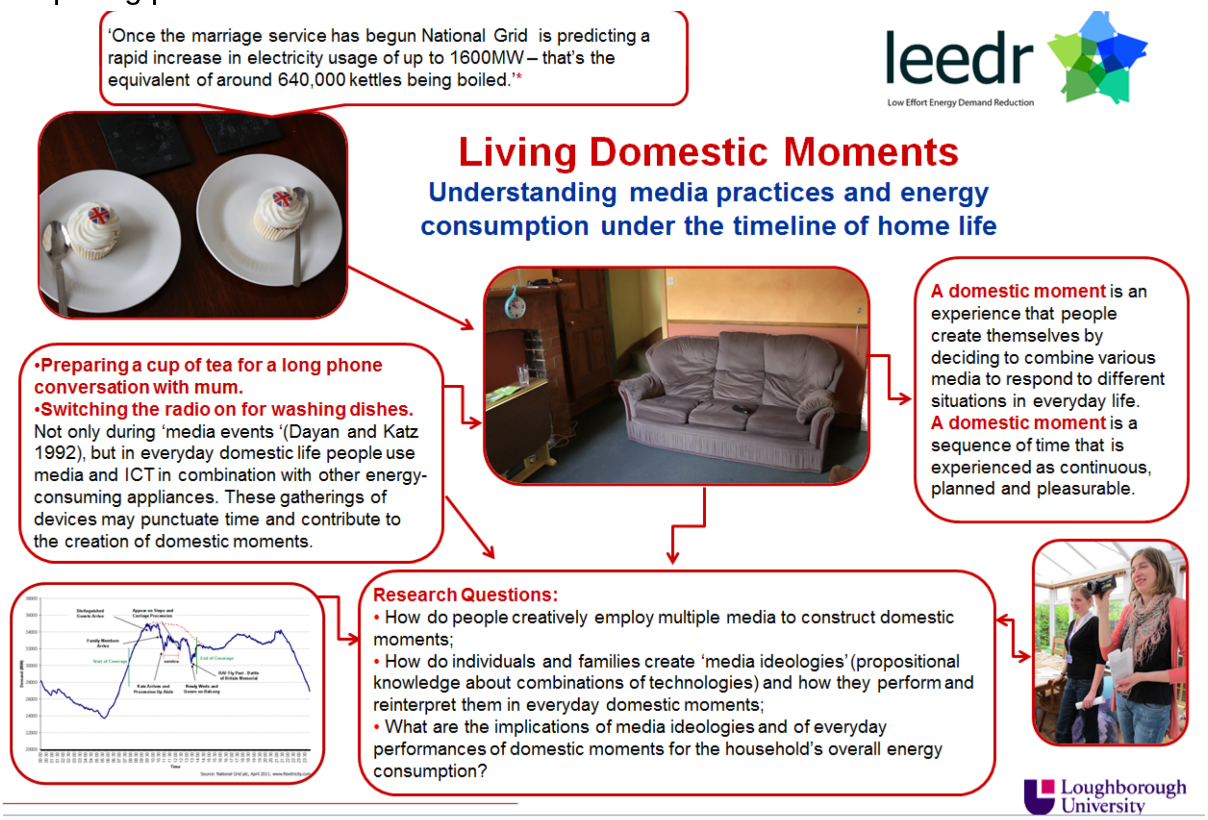


Figure 12 LEEDR Poster (LEEDR Social Science Team, Loughborough Social Science School, Loughborough University)

Participants

Recruitment

The participant recruitment was one of the first steps in the project.

The selection of the participant followed the criteria shown in the Figure 13.

It was really important to be known by as many people as possible, this was the only way to select the suitable participants for the research.

For the recruitment, the following methods were employed:

•Posters in and around public places in Loughborough: Library, community centre and shops.

•Loughborough University Notice Boards either electronic or paper.

•Advertisements' in Local papers: Loughborough Echo, Leicester Mercury.

•Public Email Forums and Mailing lists.

•Word of mouth.

•Local Radio Leicester.

The criteria used for the recruitment is:

•The house must be smaller than five bedrooms.

•The location must be within 10 mile of Loughborough University –practical reasons.

•All household participants must be willing to take part in the project otherwise the household would be excluded as it's not possible to segregate one person's energy usage from another.

	Criteria									
	Family characteristics				Situation		House characteristics		Technical considerations	
	Interest in participate	Energy conscience	Age of children	Number of Children	Future occupancy	Ownership	Location	House size	Hot water	Central heating
Ideal	Willing to give a lot of time	Mixed of people	Babies, young children and teenagers mix.	1 to 3	Not planning to move in the next 3 years	Home owners	Loughborough	3 bedroom	Combi boiler	Gas
Other							Nearby (max.10 miles)	Extremes: 2 -5 bedroom	Tank system	No coal

Figure 13 Selection Criteria

Forty six houses were interested in being part of the project, twenty were chosen for the study.

They are all in the same geographical location (Loughborough), just three of them are in nearby villages, but patterns can be considered to be very similar for majority of the time.

Ethics: Appendix 3

Collection of data

Household general information

- Main personal details.
- Mean dwelling characteristics.
- Floor house plan.
- Demographic information.
- Attitude related with Energy consumption; semi-structured interview.
- Electricity installation characteristics.
- List of electrical circuits and appliances.
- Gas installation characteristics.
- Gas and electricity measurements at Meter point taken manually monthly.

Data needed for further analysis and interventions

- Location of electrical and gas appliances on floor plans – to include photographic and/or video tour of appliances in situ.
- Appliance use information – how the householder perceives current usage.
- Appliance ‘ownership’ – Who is the owner of each appliance and the way is shared.
- Continuous energy consumption for targeted household appliances.
- Continuous hot water flow measurements.
- Continuous gas usage measurements.
- Semi - structured interview to include:
- Attitudes to energy use/reduction
- Use of everyday technologies
- Descriptions of daily tasks and activities
- Use of digital media inside and outside the household
- Observation of householders carrying out specific household tasks.
- Observation and audio recording
- Observation and video recording
- Participant audio diaries
- Participant video diaries

•Occupancy patterns inside and outside of house, included location.(Continuous or done for short periods of time).

•Calendar record through Workshop with participants. (Recompilation of their daily activities in a calendar in terms of going to work, children at school, children at afterschool activities, hobbies out of the home).

Data collection

Visit procedures and protocols: Appendix 1.Technical Survey

Electricity installation characteristics:

- Location: Meter and consumer unit.
- Main clip and additional clips.
- Acceptability with the monitoring equipment.
- Electric Circuits: Amperage.

Figure 14 Electric Circuits and Meter

Hot water installation:

- System type: Tank or combination (Appendix 1).

- Location
- Flow sensor location.
- Pipe size (mm)
- Acceptability.
- Power availability for the flow sensor installation.

Gas installation:

- Type.
- Meter Location.
- Units (m^3 or ft^3)

Figure 15 Gas Meter

Figure 16 Boiler

Broadband Characteristics

Appliances within the house:

- Power demand
- Brand
- Location
- Usage trend along the week
- Photos

BOS Survey

Building fabric

- Layout and type of building
  - House
  - Bungalow
  - Flat
  - Apartment
  - Maisonette
- Style
  - Semi-Detached
  - Mid-terrace
  - End-terrace

The dwellings of study are Houses. About half are detached and semi-detached and just one of them is Mid-terrace.

- Age of the buildings
  - Before 1900
  - 1900-1929
  - 1930-1949
  - 1950-1965
  - 1966-1974
  - 1975-1981
  - 1982-1990
  - 1991-1995
  - 1996-2002
  - 2003-2006
  - After 2006

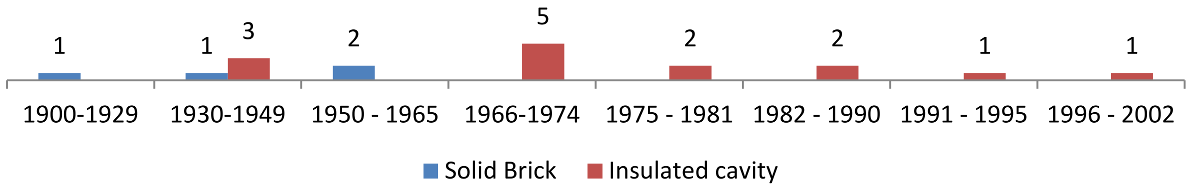


Figure 10-1 Year of construction

- Construction
- Insulation levels
    - Timber frame
    - Un insulated cavity
    - Insulated cavity
    - Solid brick
    - Stone

The 20 participant households are built between thirties and seventies; all but one which was built around 1900 and another a new one built around 2000.

All the houses but three have two storeys. That three have three storeys.

Most of the houses (fifteen) have been extended. All of them but three have a garage and three of the houses have a conservatory.

All the samples built from the sixties have insulated cavity. The other four, all built before, are solid brick.

The information about loft insulation is not clear because five of the twenty participants don't know about it and the other answers show very different values for the insulation thickness in the loft.

- Double glazing

Sixteen of the houses have double glass windows in the whole house and the rest have still some original windows but some double glazing.

- Draft proofing

Most of the houses have full draft proof windows and doors; three of the answers contradict because they say they have full double glazing but not draft proofing.

Other two samples are not sure about the answer.

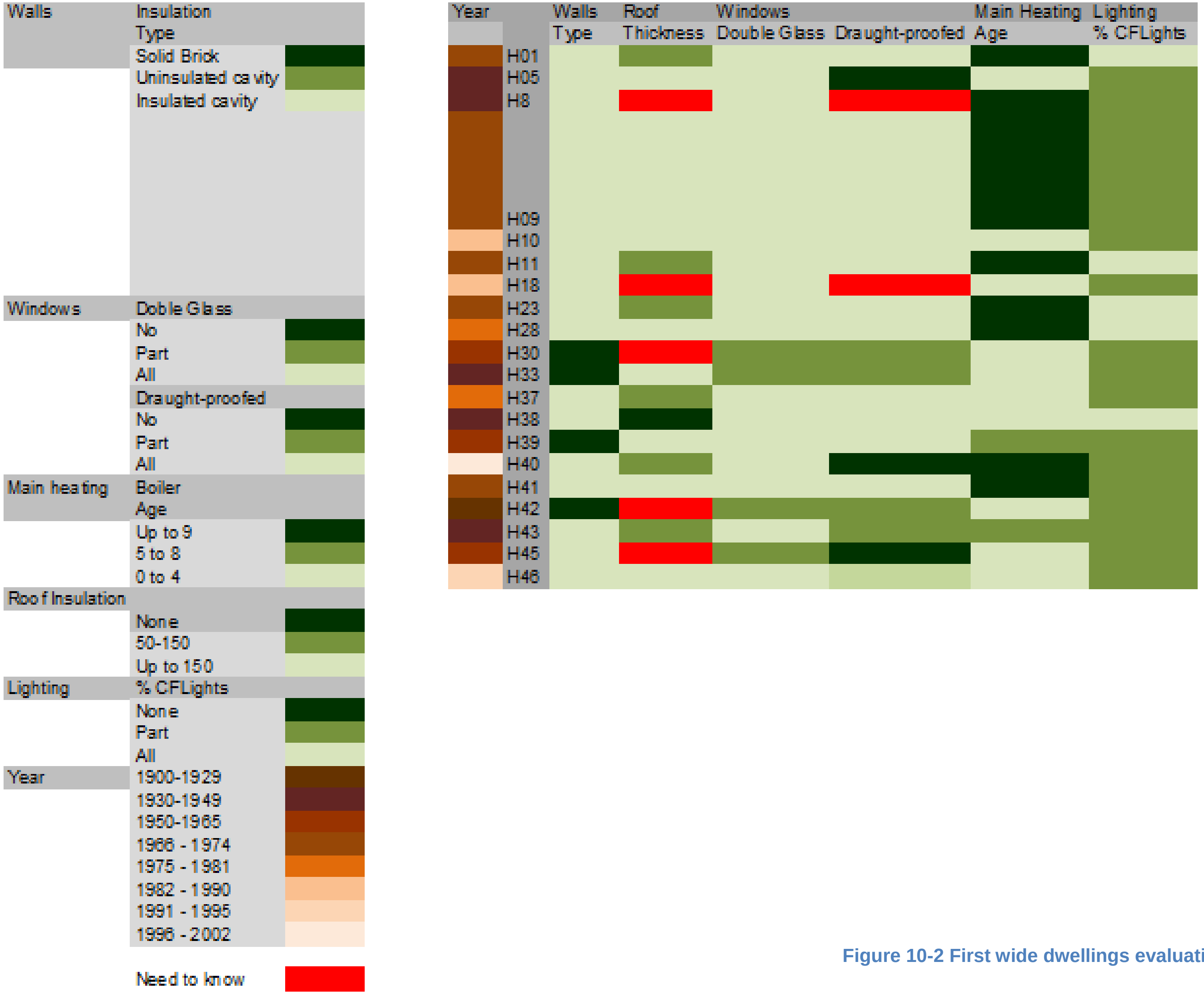


Figure 10-2 First wide dwellings evaluation

Building Systems

- Type of hot water system

All the participants use the main heating system to hot water for washing and personal showers. Half of the houses have electric showers in all or some showers at home.

- Number and type of lighting

All the houses have some of the lights CFL bulbs but just five of them are full installed with low energy lights.

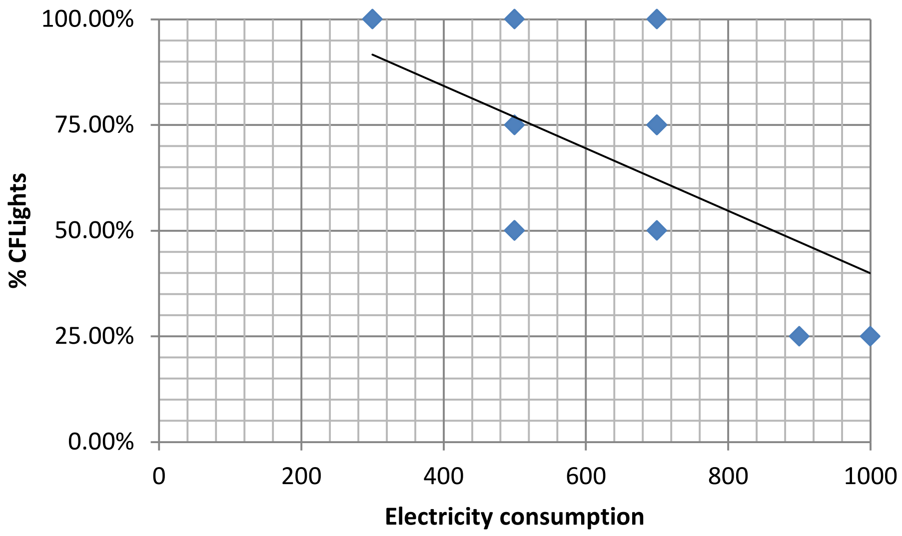


Figure 10-3 Total Electricity consumption (£)

- Boiler type and age (Appendix 1)

The main heating system in all the houses is a boiler supplying radiators. All the houses but six have combination boiler.

- Heating system age, presence of TRVs

The age of the heating system in half of the house is less than four. Other two samples are between five and eight years old, but still eight houses have boilers up to nine years old.

All the heating systems have TRVs, half in some of the radiators and half in all of them.

- Installation of photovoltaic systems (2 homes)

Two houses have installed photovoltaic systems. One of them, H01, installed it after becoming part of the project.

- Extent and type of heating system controls (probably don’t have this yet)

The control of the heating system is by using the TRVs and in some of the examples programming the temperature with a simple time clock, manually or by using the room thermostat.

Occupants

- Household income

They were asked about their household annual net income and just three of the samples prefer not to answer this question or were not sure about it. Eight of the samples have incomes over £50000 and just two examples have incomes between £20000 and £30000.

- Families

Most of the families are constituted by both parents and their respective children. In the dwellings live from two to six people.

Thirteen of the samples are families with four members. There are exceptions, like one of the houses where just live mother and daughter and other where an elder person lives in.

Most of the families have two children. There's one family with four children, four with just one and three whit three children.

- Children ages

Fourteen families have children in the range of 7 to 12 years old and just two examples have babies at home.

- Adults, number and ages

The age of the adults in most of the families is from thirties to forties. The parents with very young children are in most cases in their twenties-thirties.

- Education level

Most of the parents have a high education level, just nine of the adults have undergraduate studies.

Legend Studies	Level
University of life	1
Lifetime of experience	1
A level	2
Certificate of He	2
NVQ	2
GCSE/GCE	3
Degree	4
HND	4
Higher degree	5
Chartered Accountant	5
PGCE	5

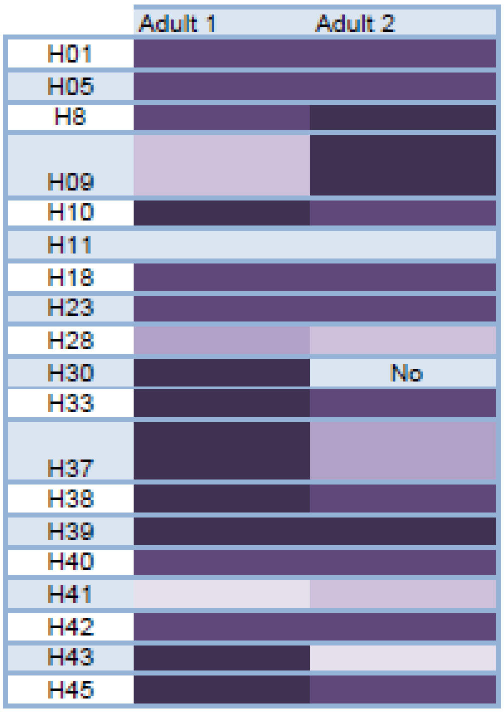


Figure 0-4 Householders studies level

ESCOLA TÈCNICA SUPERIOR ENGINYERIA D'EDIFICACIÓ UNIVERSITAT POLITÈCNICA DE VALÈNCIA

Childrens			Adult 1				Adult 2					Adult 3				Total	
	Ages	Total	26 - 35	36 - 45	46 - 55	(blank)	26 - 35	36 - 45	46 - 55	No adult	(blank)	20 - 25	56 - 65	No	(blank)	Adults	
H23	1 4	2		1			1							1		2	4
H10	2 4	2		1			1							1		2	4
H18	3 & 3	1		1			1								1	2	3
H38	3	1		1			1							1		2	3
H42	3 5	2		1			1							1		2	4
H46	3 5 7	3	1				1						1			3	6
H11	4 10	2				1					1				1	2	4
H33	5 7	2			1			1						1		2	4
H37	6 9	2		1				1							1	2	4
H09	7 10	2		1				1						1		2	4
H39	7 11	2			1			1						1		2	4
H40	7 10	2			1				1					1		2	4
H01	10 17 19	3			1				1					1		2	5
H30	10	1			1					1					1	1	2
H41	10 15 19	3			1			1				1				3	6
H43	10 12	2		1				1						1		2	4
H8	11 14	2			1			1							1	2	4
H45	11	1			1			1							1	2	3
H05	12 19	2			1				1					1		2	4
H28	14 16	2			1			1						1		2	4

Figure 21 Occupancy table

Getting to know you

This activity was designed by the LEEDR Design team (Design School) to get data about the family and their behaviour regarding energy use at home.

Objectives:

•To learn about their general attitude and behaviour towards energy, sustainability and vision about the future.

•To understand the way they interact as a family: Their awareness about the energy consumption, their vision about their home, rooms and spaces.

The activity was designed for creating a relaxed and comfortable setting.

For that reason the activity included the next formalities:

–A Take-away meal paid by the project.

–Presence of all the family members.

–Flexible and friendly Attitude.

At the beginning of the activity we took a few minutes to answer any concerns the family may have had about the project.

The process followed during the activity is shown in the next figures.

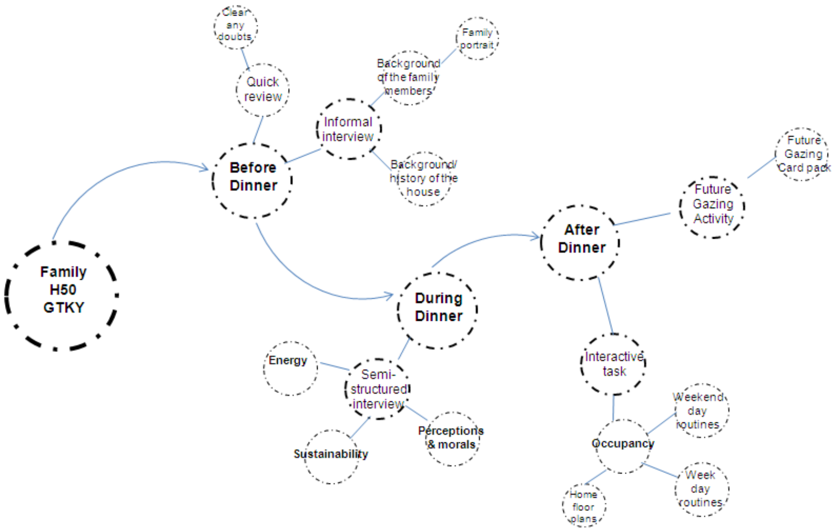


Figure 22 . GTKY process (LEEDR Design Team, Loughborough Design School, Loughborough University)

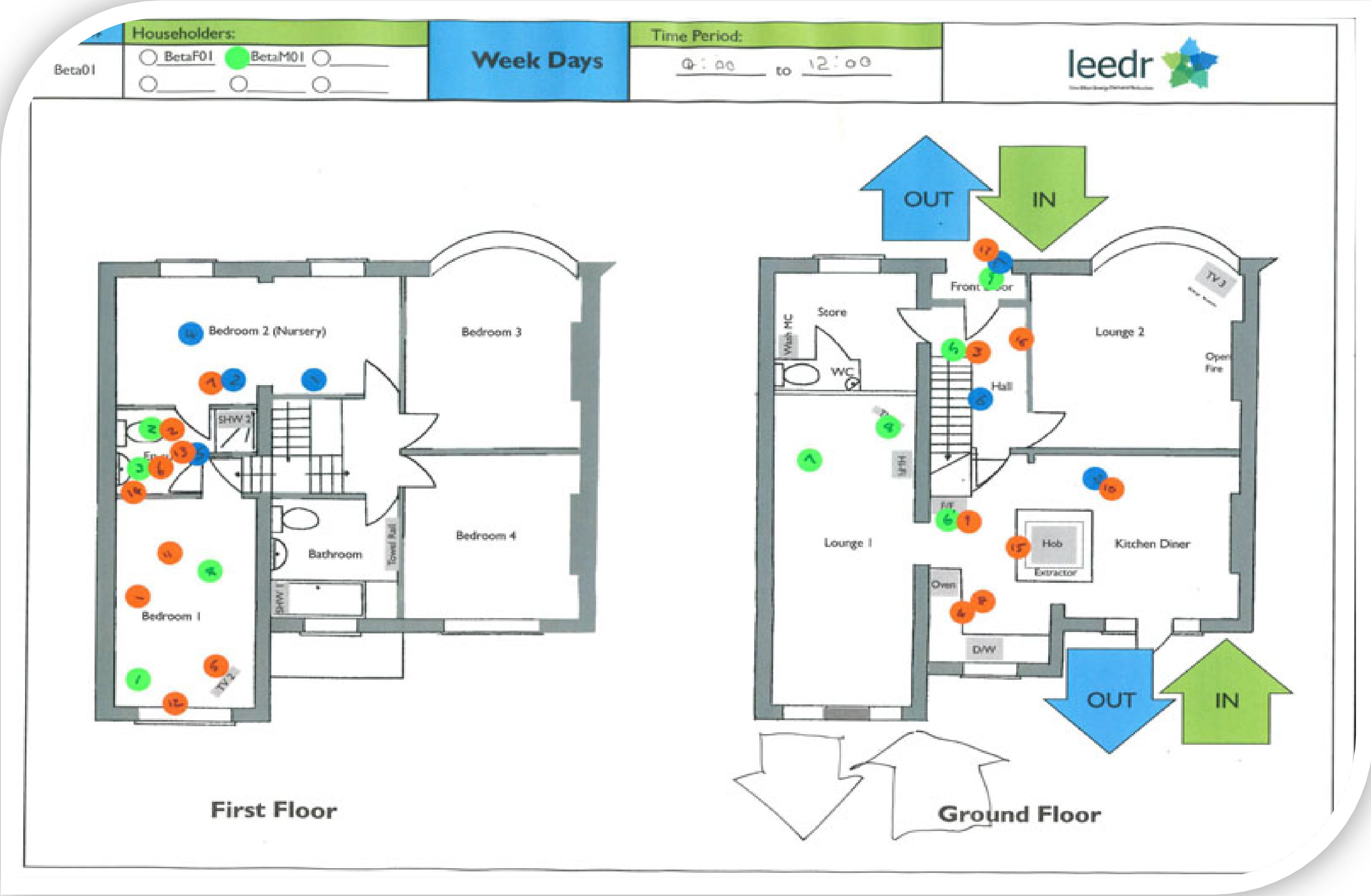


Figure 23 Sample of GTKY Activity Floor Plan (LEEDR Design Team, Loughborough Design School, Loughborough University)

Monitoring equipment

Equipment

Gas Cam Equipment:

The gas meter camera records the meter readings several times per minute in order to measure the gas usage.

For the correct function of the camera is needed to have all the operating lights working. For that reason the participants must be advised to contact the team if any light is not illuminated or if the camera switched off. T

he data from the Gas cam is not used in the analysis because of the lack of readable data on the system at the moment.

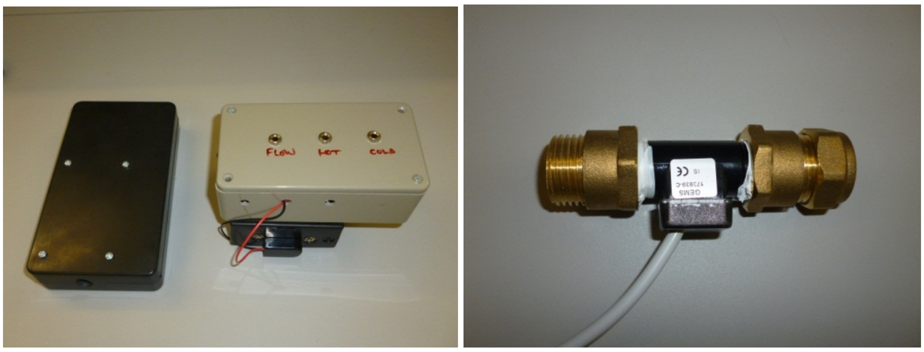


Figure 24 Hot water flow meter

Hot water flow meter:

The flow meter is installed in the cold water feed to either a combination boiler or hot water tank, depending on the hot water system.

•Low voltage signal cables connect the flow meter to the “IndeedNet” hub.

•The hub is plugged into a 13A socket.

•The hub must be switched on at all times.

The participants must be alerted about the importance of contact a member of the team if they notice any water leakage problems with the flow meter.

The data from the water flow meter is not going to be used in the analysis because of the lack of data.

Alert Me equipment:

The monitoring equipment installed in the dwellings of study, is a set of equipment from Alert-me, one of the partners of the project, and a company which provide electricity monitoring services for dwellings and enterprises.

This is a UK company that provides energy and home monitoring hardware and services. AlertMe produces hardware and software to enable users to monitor and control their home energy use.

AlertMe uses Non Intrusive Load Monitoring (is a process which analyse changes in the voltage and current) to extrapolate trends from customer data, which is then used to estimate electricity consumption.

The core of the AlertMe system is a hub which creates a home area network using the Zigbee wireless standard. Devices connect to the hub over Zigbee, and the hub sends their data to AlertMe servers over the internet.

Hardware accessories include:

•Meter Readers, which connect to electricity meters to measure household energy use;

•Smartplugs, which allow monitoring of specific devices.

•Presence and temperature detectors, which allow seeing the occupancy within the house, the movements of main doors and windows and the temperature for each room in the house.

The AlertMe Energy service allows seeing home’s energy use in real time. It can be shown by an in home display, web interface, or even by a mobile phone.

The data for the analysis was extracted from the AlertMe website. For that analysis was used the data from Meter readers and smart plugs.

1. Window/Door opening sensors (DOR):

It detects the movement and gives back signal. Every two minute it records the temperature in degrees.

Figure 25 DOR sensor

Room	DOR-D	DOR-W	PIR
Hall	400		801
kitchen	401		
kitchen		404	800
kitchen		405	
Lounge		402	802
Lounge		403	803
Bed 2		406	806
Bath		407	807
Bath		408	
Bedroom 1		409	805
Bedroom 1 side w		414	
Bedroom window		410	
Hall upstairs		411	804

Figure 26 Sample PIR and DOR situation

The data record from the DOR about the temperature within the houses is not used for the analysis in this report.

For further analysis, the information about the temperature in each dwelling is used to look at different points about the energy use at home:

•Temperature outside and inside. Mean difference.

•Temperature for each room. How it varies depending on the occupancy and the activity in the house.

•Relation between temperature and proximity in different spaces.

•Temperature for a specific location before and after ventilating by natural processes (open/close windows and doors).

•Comfort temperature for the householders.

•Hottest moment in the day and coldest time.

•Orientation of the room and temperature.

To understand widely, what kind of analysis can be made from the data record by the DOR, the next plot is commented.

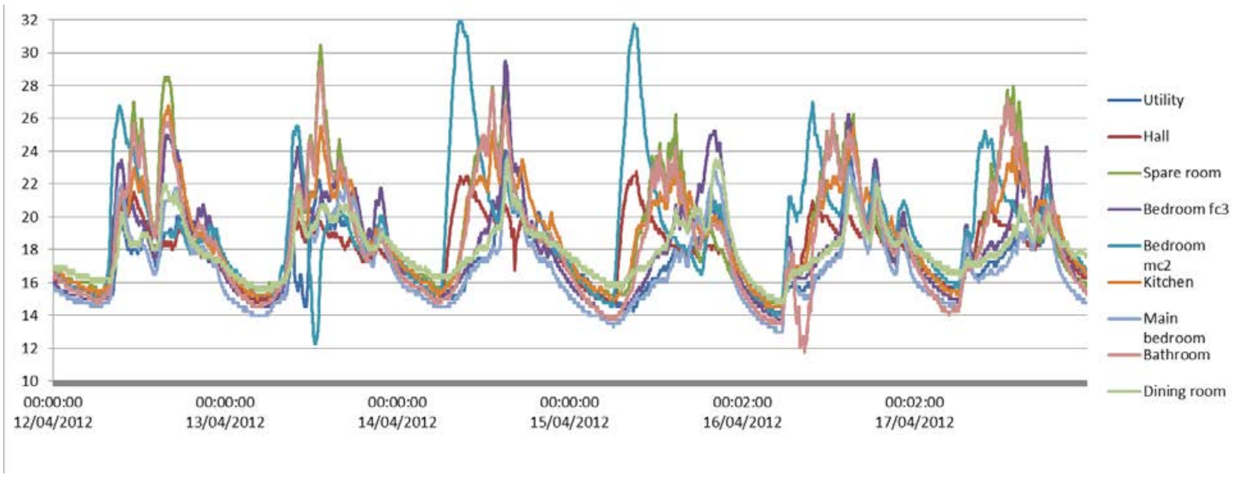


Figure 26 Temperature in Degrees for a sample house along a sample week

The plot shows a piece of information for one of the houses for a period of time of six days.

The Y axis shows the temperature in Degrees, the X axis shows the date.

The temperature varies keeping the same wide trend in the house. However, there are some peaks in the temperature for the different spaces. The mc2 bedroom has a higher temperature than the rest in two consecutive noons. It can be caused by the effect of the sun radiation or by the use of the heating in that bedroom.

The spare room is the most regular room in terms of temperature, besides the bathroom, which appears to be very different along the day.

2. Occupancy PIR sensors:

It detects presence and gives back signal.

Figure 27 PIR sensor

The next graph is a piece of PIR data extracted from one of the houses of study for two days. The labels indicate the PIR code to find the devices in the related floor plan.

Each line shows movement detected by a specific device for a specific instant.

Thereby, it is possible to know if the room monitored is actively occupied.

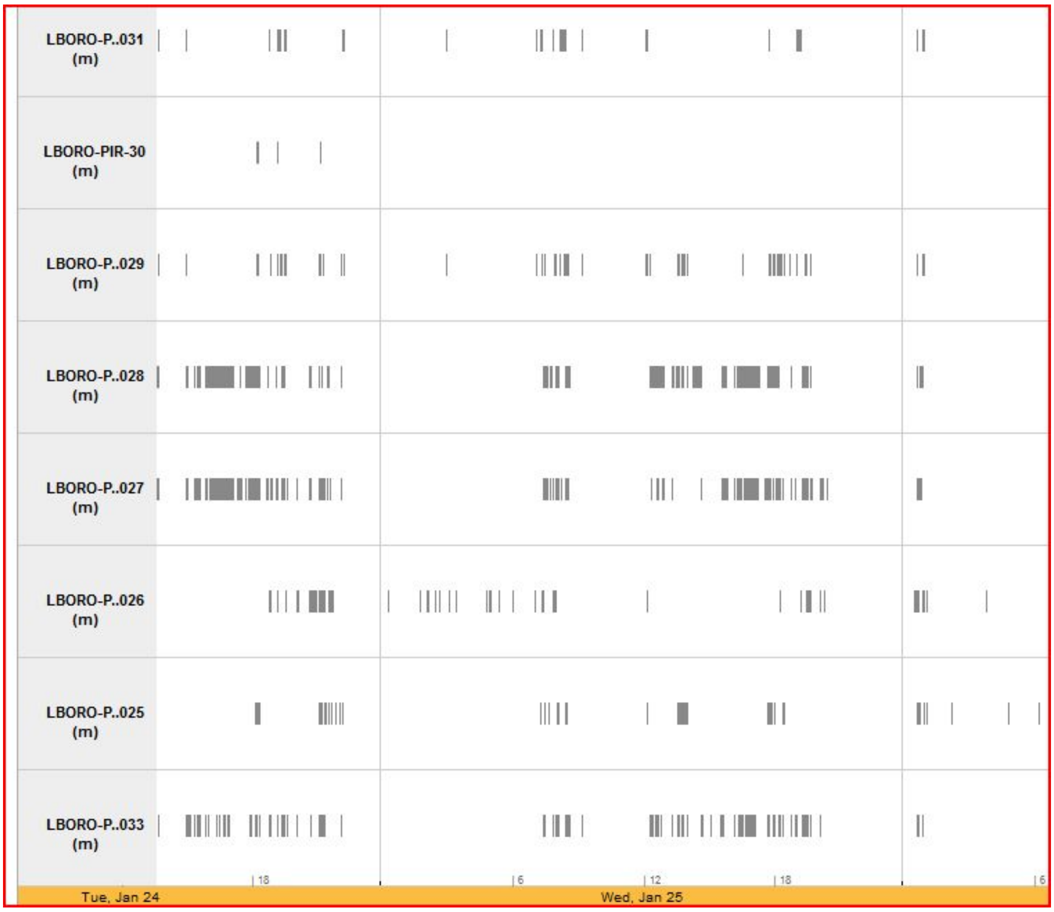


Figure 28 Sample Presence Graph

3. AlertMe Smart-plugs:

The Smart-plugs are installed between the appliance plug and the wall socket to measure the power average every minute (W).

Figure 29Smart-plug

4. Meter readers:

Figure 30 Meter reader

The CT clip part of the meter reader is installed by professional electricians on each electrical circuit inside the distribution board (fuse box). Each lead emerging from the distribution board is connected to a battery pack that measures the power being consumed by that circuit and transmits the data wirelessly to the AlertMe hub installed in the home.

Figure 31 Electric Circuits Control

5. Communication hub:

It monitors all the devices on the system and communicates with the service securely and continuously. Then feedback the information to the website where it's shown the energy consumption by plots. (Figure 11)

The Hub runs on mains power and via broadband connection. However a battery and GPRS back up means your system will continue to work even in the event of a power outage.

Figure 32 Communication hub

The power used constantly by a Hub is 3W.

For the analysis of the electricity use in this report, data from smart plugs and meter readers will be used.

Methodology

The analysis in this report aims to identify trends in the electricity consumption for three sample houses.

The analysis will have two different stages:

- The first stage looks at electricity consumption house by house.
- The second stage looks across houses to compare different trends in the electricity demand.

The analysis is based on the social surface and the technical field.

The social and demographic data is extracted from the interviews and surveys done by the design and social school within LEEDR project. The surveys were defined in “Data collection: BOS survey and Getting to know you”. Moreover the interviews were done during the Initial Visit and the activity/interview “My ideal world”.

For the technical data, it might be divided by the data from the monitoring equipment and the data from “BOS Survey” and the “Technical Visit”, both defined in “Data collection”

Two blocks of data were extrapolated from the monitoring equipment by using the AlertMe web interface.

The data was extracted from two consecutive weeks.

- First week (24th of April to1st of May)
- Second week (1st of May to 8th of May)

The two weeks’ of data are used as a model of behaviour for each house to estimate the total electricity consumption.

The values for the cost per month, year and person, are based on the amounts of energy used in those two weeks.

For the cost analysis, the price is based on the electric British company “British Gas”. The cost is the standard for the region (Loughborough) per KWh.

This analysis aims to identify trends in the electricity consumption to study possible interventions which cut down the electricity consumption by looking to specific activities within the house.

Analysis house by house

H01

House Characteristics

H01 is a two storey detached house (figure 1-1) built in the 60s-70s.

The envelope walls are insulated. The loft insulation thickness is between 100 and 150mm.

All the doors and windows are draught-proofed and double glazed.

The main heating system is a boiler supplying radiators. The age of the system is 9 to 12 years old. The fuel is gas.

The boiler is a conventional, non-condensing boiler.

The system is controlled directly by the householder by using the Thermal Radiator Valves (TRVs) on the radiators and indirectly by the programmer with simple time clock and room thermostat on the wall

The shower hot water is supplied by an electric shower.

The lighting is equipped with high efficient bulbs (CFL) in the first floor and part of the grand floor but still with some incandescent bulbs in the ground floor.

1-0-1 Frontal view

Householders: Demographic characteristics and main motivations

H01 is occupied by a family which is composed of five members; three children: FC1 who is nineteen, mc2 seventeen and fc3 ten years old and their respective parents, FA who is forty eight and MA who is fifty three.

As part of the initial visit, they were asked about motivations to become part of the project. They show three main arguments:

- Curiosity. “What can families do to reduce energy consumptions besides insulation and double glazing?” (H01MA)

- Lower energy bills.

- They have considered putting solar panels as an energy income, but they are uncomfortable with the idea of committing to a 25 years lease.

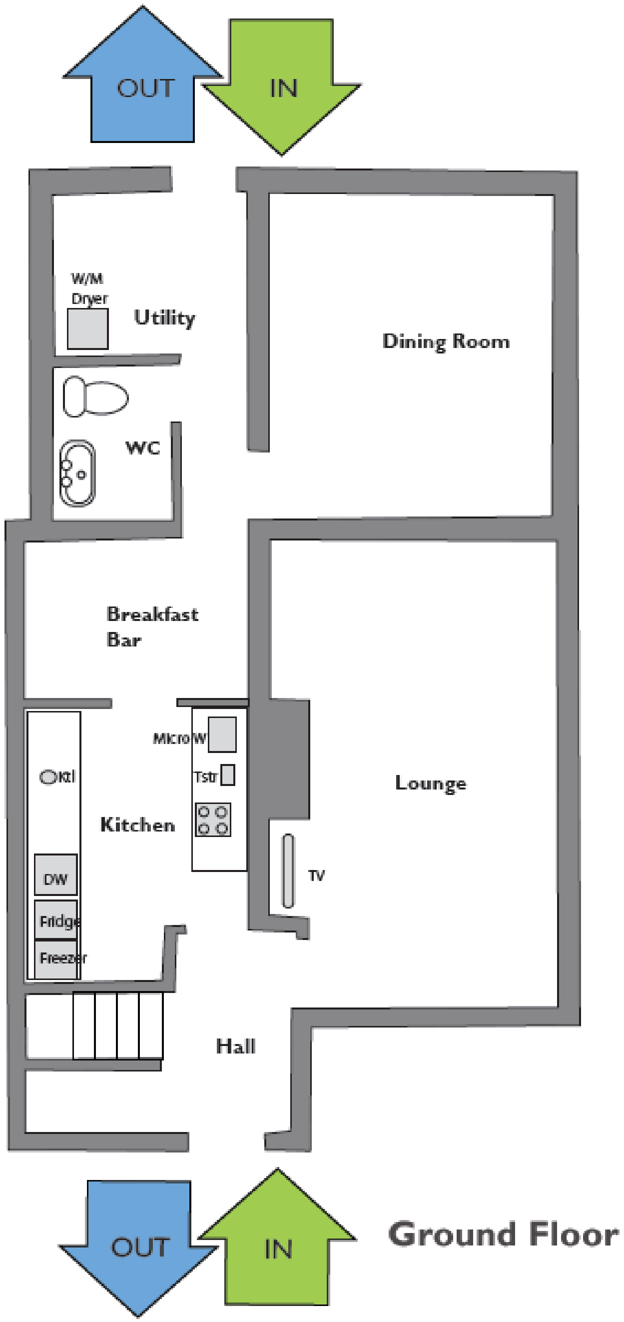
Later on, (2nd November 2011), they were asked about their ideal world in terms of energy consumption. They spoke about their intention to change their old appliances to more efficient ones but just at the right time, to achieve as high reduction as possible.

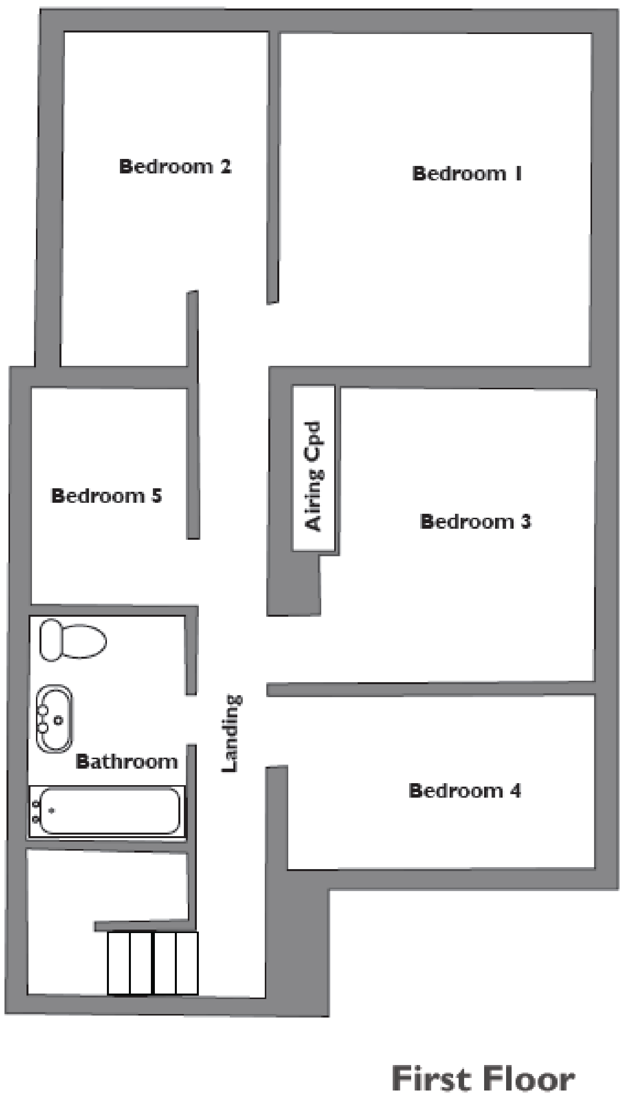
It is important for them to be motivated when changing their appliances by strong energy reductions. They expressed the desire to understand more about appliances energy efficiency.

They were astonished to learn that leaving standby lights on, their appliances were wasting energy. They asked why designers create appliances with this light on.

Regarding the heating system, they said that they would like to control it from a digital device with touch screen and be able to specify very accurately the temperature and the time to set up the system.

From the initial visit (15th of July 2011), H01 householders has installed a solar panel which is monitored by a meter reader.



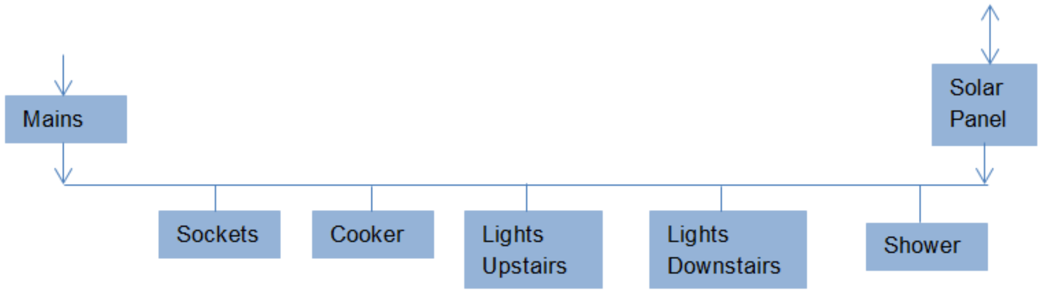


1-0-2 Floor Plan

Data: Understanding and reliability

In H01 monitoring devices were installed for the main electric circuits and for twenty one appliances.

Electric circuits Structure:



0-3 Electric Circuit Scheme

The scheme shows how the different circuits are supplied by the incoming electricity to the house (mains and solar panel).

The mains accounts for the total electricity consumption supplied by the electricity enterprise.

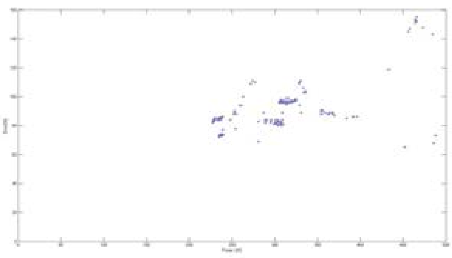
The solar panel generates an amount of energy monitored by a CT. This energy is used at home or exported to the national grid. The energy exported from the solar panel is not monitored.

Mains + SolarPanel = Sockets + Cooker + Lights (Up and downstairs) + Shower

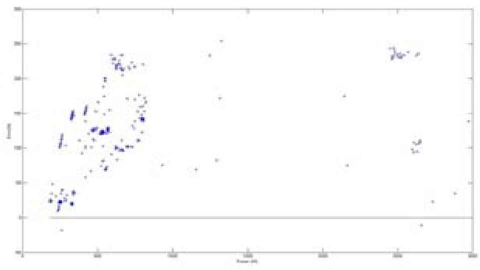
Only if exported energy from the solar panel=0 in other words, all the solar energy is consumed within the house.

To calculate the error, we will take periods of time when there's no sunlight. This is because the amount of energy that is produced by the solar panel and sent back to the supplier is not monitored. To calculate the error we will total all the sub circuits and they must be equals to the mains.

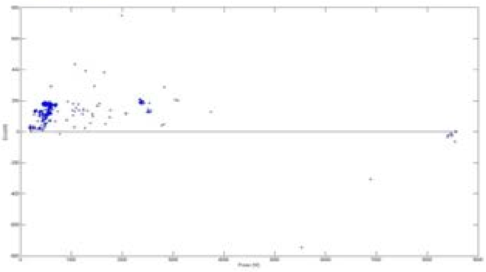
No light (period 1)



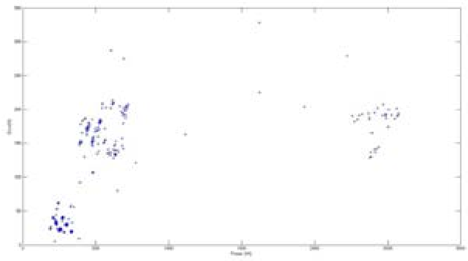
No light (period 2)



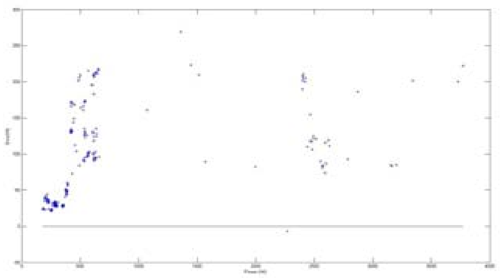
No light (period 3)



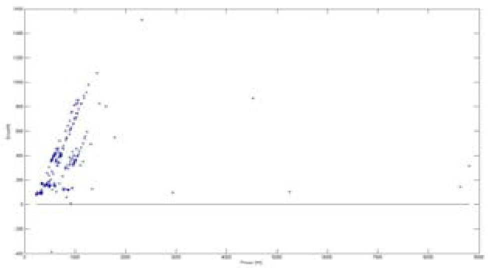
No light (period 4)



No light (period 5)



No light (period 6)



0-4 Relative Error

Y axis -> Error=mains+solarP-sumCT (W)

X axis -> Power= mains+solarP (W)

solarP=0 (No sunlight periods)

e=mains+0-sumCT

e-> 0

The plot, graphs the relative error for the total power.

Part of the error is explained by the limits of the monitoring devices. These devices account for over 60 W of power measured in the circuit. If the power supplied by the circuit is less than 60 W, the device will not account for it.

The mains will be more accurately because will supply more than 60 W in the majority of the cases.

Data analysis

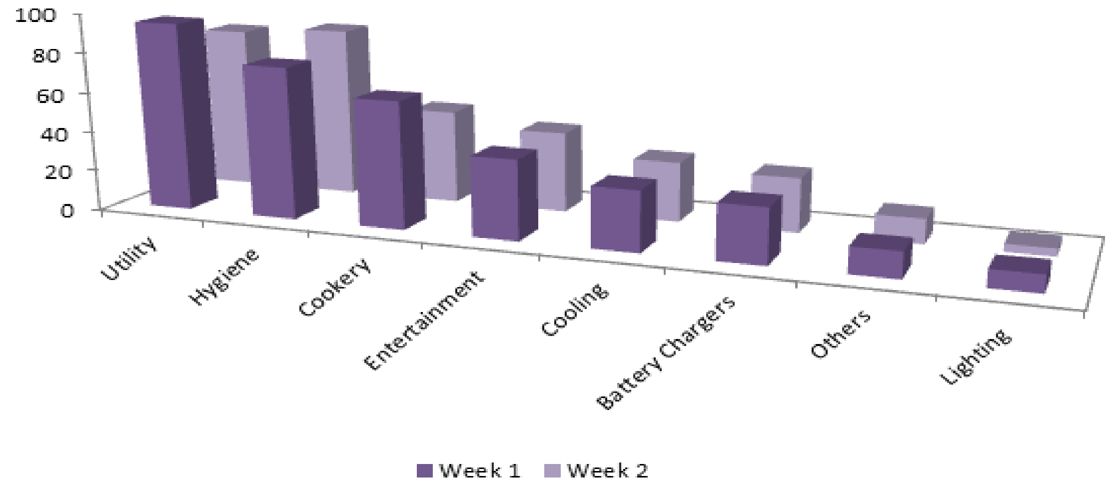
The electricity consumption within the house is categorized according to the activity that it is related to:

- Utility: Dishwasher, Washing machine, Dryer and vacuum cleaner.
- Cookery: Cooker, microwaves, kettle, sandwich maker and toaster.
- Cooling: Fridge and freezer.
- Entertainment: TV, Wii video record, CD player.
- Battery chargers: Laptops and computers.
- Personal hygiene: Electric Shower and hair dryers.
- Lighting: Lights and lamps.
- Others: Aquarium.

The total consumption for the first week was 432.3 MJ.

The total consumption for the second week was 401.6MJ.

1-0-5 Appliances H01



1-0-6 Electric consumption by categories

	Device	Frequence of use	Use Regularity	% Total	Duration of use
Utility				22	
	Dishwasher	7	Dayly	7	Around 1 hour
	Washing Machine	7	Weekly	4	Around 1 hour
	Dryer	7	Weekly	11	Around 1 hour
Cookery				15	
	Cooker	9 to 12	Dayly	9	Irregular
	Microwave	7 to 8	Weekly	1	Irregular
	Kettle	43 to 56	Dayly	5	2 to 4 minutes
	Toaster	10 to 12	Dayly	1	Around 1 minute
	Sandwich	2 to 3	Weekly	-	Irregular
Cooling				8	
	Fridge	Constant	Constant	2	Constant
	Freezer	Constant	Constant	5	Constant
Entertainment	TV lounge & dining room	Dayly	Dayly	11	Irregular
Computer and mobile				6	
Personal Hygiene				18	
	Shower			17	
	Hair Dryer			1	
Lighting				2	
	Downstairs	Dayly		2	Irregular
	Upstairs	Dayly		-	Irregular
	LampFC1	Dayly		-	Few minutes
	LampMC2	Rarely		-	Few minutes
Others				3	
	Aquarium	Constant	Constant	3	Constant
	Garage Battery	Constant	Constant	-	Constant

0-7 Usage Table H01

Utility:

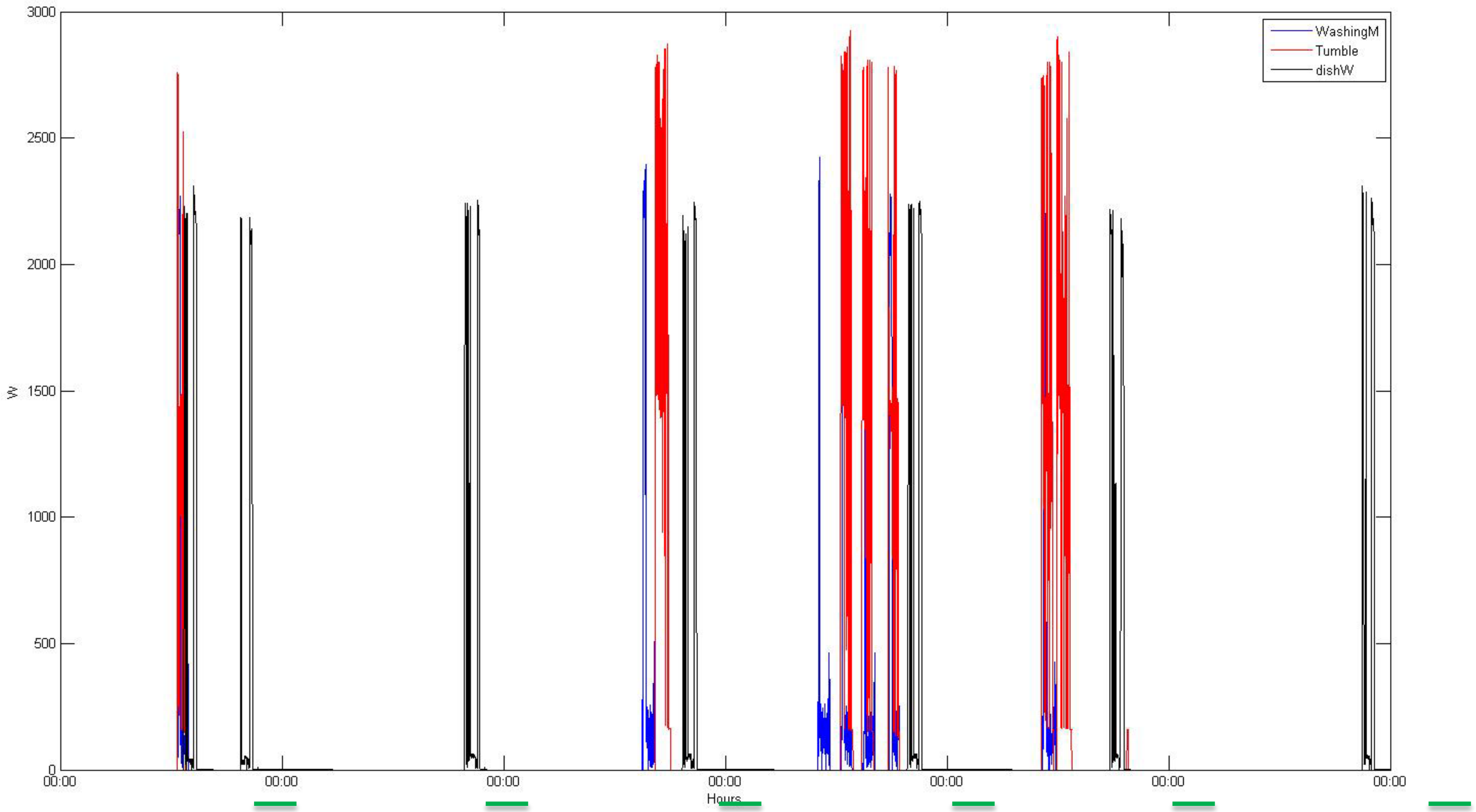
The utility accounts for more than the 20% of the energy consumption.

The washing machine was used seven times during the week; three of them, occurring on Saturday afternoon. The amount of energy used for the washing machine was 15.9 MJ, 4% of total electricity consumption.

For each washing cycle, the tumble dryer was used.

The tumble dryer is the highest user of electricity in the house, accounting for the 11% of the total for that week.

The dishwasher follows a clear trend along the week. It was used once a day every day but one that was used twice. The time of use doesn't change, being at the end of each day. It assumes 7% of the total electricity consumption.



0-8 Utility Week 1

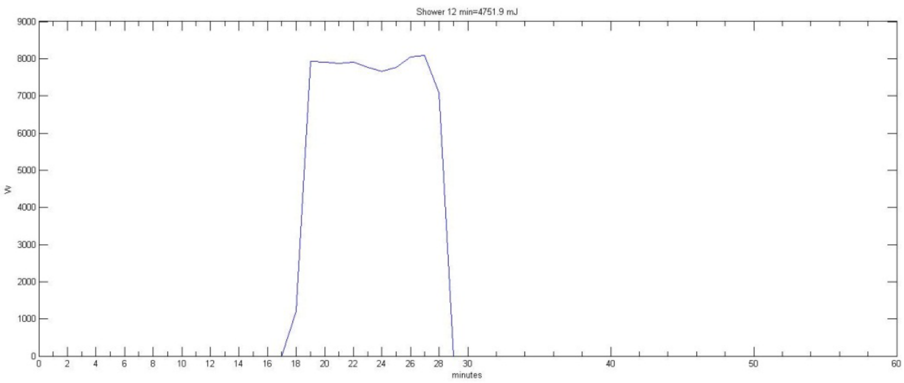
*The green line has the same length to easily compare the time difference between usages.

Personal Hygiene:

The personal hygiene is the third top energy consumer. It accounts for 18% of the total electricity consumption.

The electric shower was used fourteen times within the six days. It accounts for the 17% of the total. The hair dryer accounts for 1%. The shower was used at least once a day and up to four times a day.

The next graph shows a typical morning weekday shower usage. The shower lasts 12 minutes and spends about 4.7MJ. The length of the shower varies from 5 to 15 minutes but it doesn't seem to have a specific trend regarding to the time of day or day in the week.



1-0-9 Typical Morning shower

Cookery:

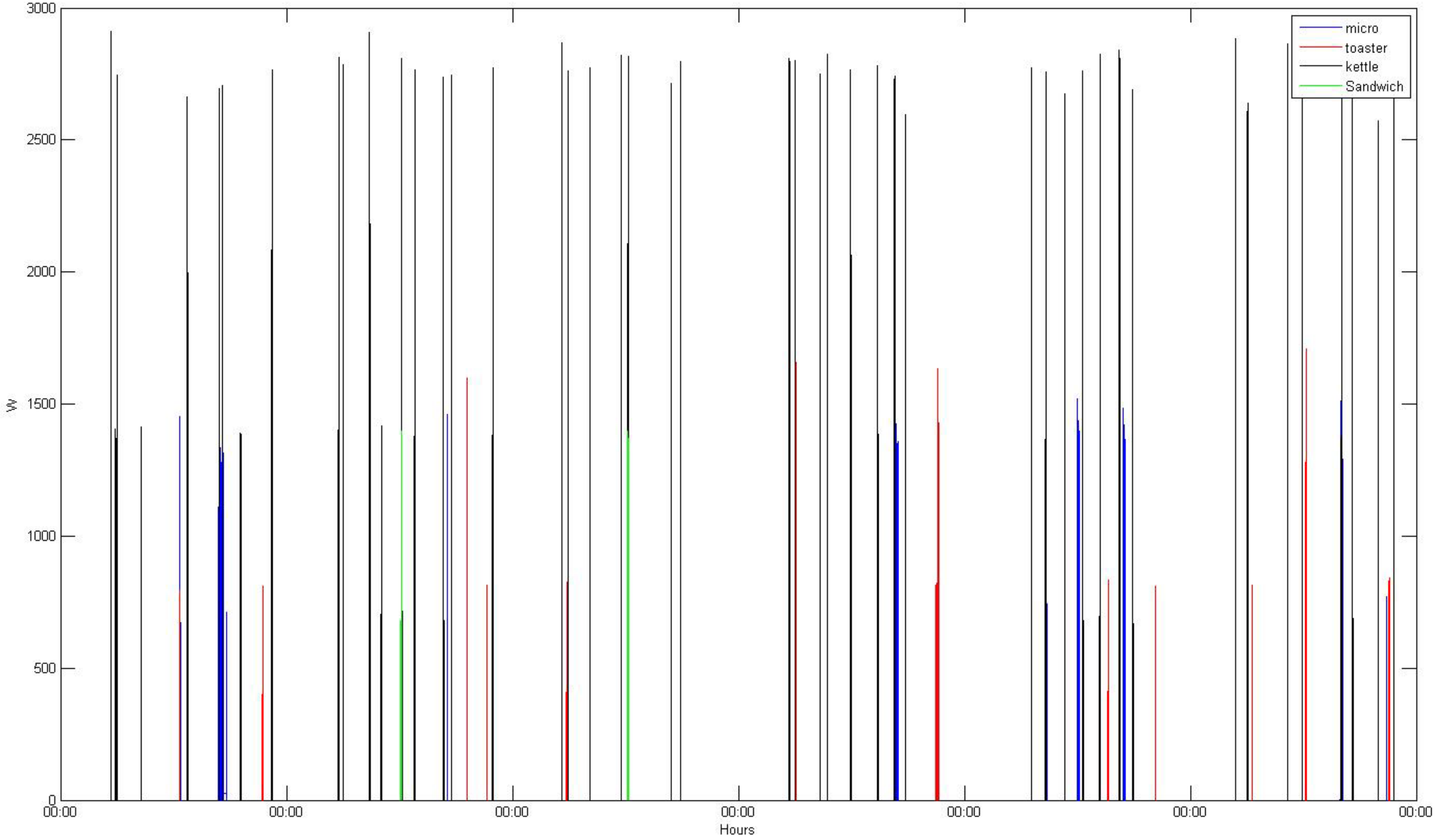
Regarding cooking activities, this accounts for 15% of the electricity consumption. The cooker accounts for 9%. It was used at dinner time every day and was used twice and three times a day on the weekend.

The cooker includes hob and oven and as shown in the picture is quite old. The maximum power specified for that device is 9KW.

The kettle, however, was used very often. The first use of the kettle is at the same time every day but on Sunday when it's usage was later. The kettle is being used very regularly during the day, from six times to eight times, and at very similar times. The kettle is a relevant appliance regarding to energy consumption, as it accounts for 4% of the electricity.

The sandwich maker was used at noon on consecutive days but not use again so it doesn't seem to follow a trend and the amount of energy used is insignificant.

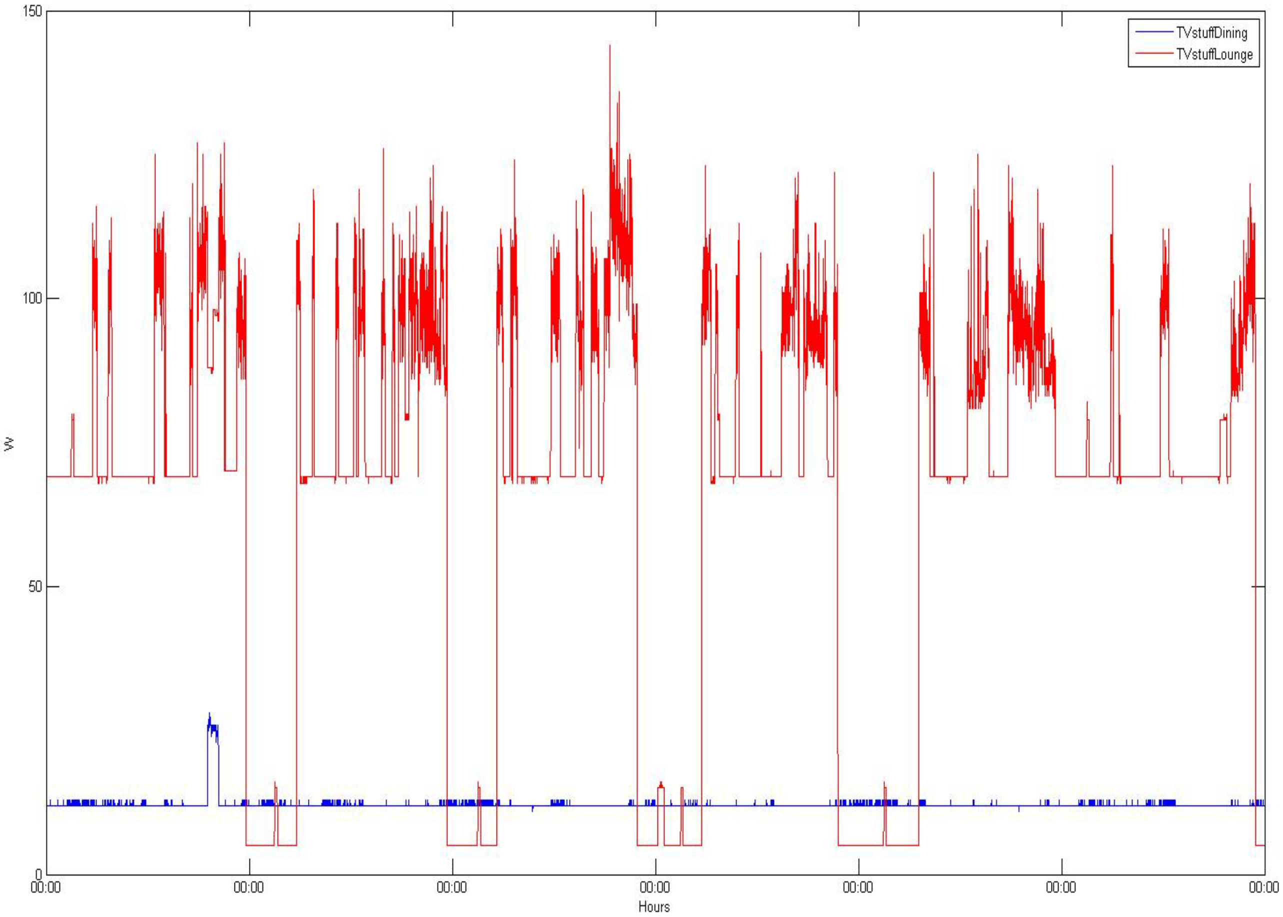
The toaster was used at least once a day and usually twice a day at breakfast time coupled with the kettle and/or at night time. It accounts for just 1% of the total as does the microwave.



1-0-10 Kitchen devices Week 1

Entertainment:

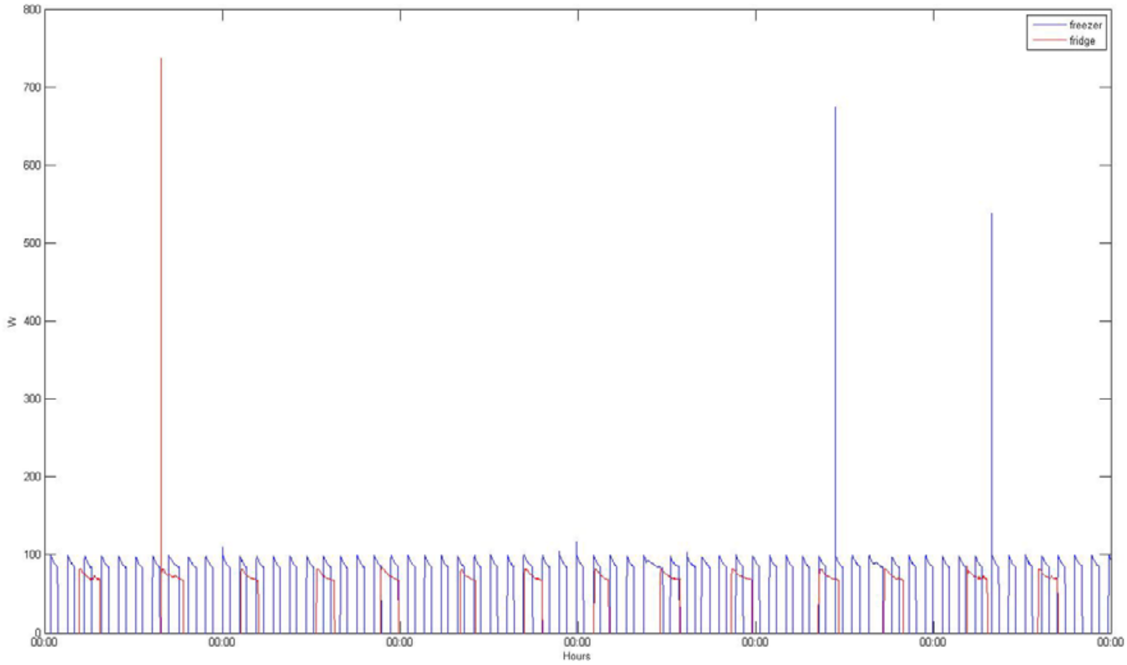
It accounts for the 11% of the electricity consumption. The use of the TV is mainly in the dining room. It was used in the lounge just once for those days. The TV in the lounge spends much less energy than the TV in the living room. The sparks in the power of the dining TV are caused by the use of the stereo simultaneously. The stand by status for the TV in the lounge is nearly three times that in the dining TV. Clearly the TV in the dining room is switch off every night until the next day when is used for the first time at the same hour every day and for the same period of time. The TV is switched on six times a day, the longest period of time in the evening. During the day, when is not being used it is on standby.



1-0-11 TVs Week 1

Cooling:

The food cooling in the house is obtained by an independent fridge and freezer. The freezer is using 5%of the electricity, 3 % more than the fridge.



0-12 Fridge and Freezer Cycles

Battery chargers and computers:

The computer power use and the battery chargers for the laptops account for 6% of the electricity, even having in use four laptops and one computer. The computer equipment use a constant power of 24W (standby position) and in use consumes nearly 100 W more that the higher consumer laptop. The power for the most efficient laptop is around the power than is being use by the computer on standby.

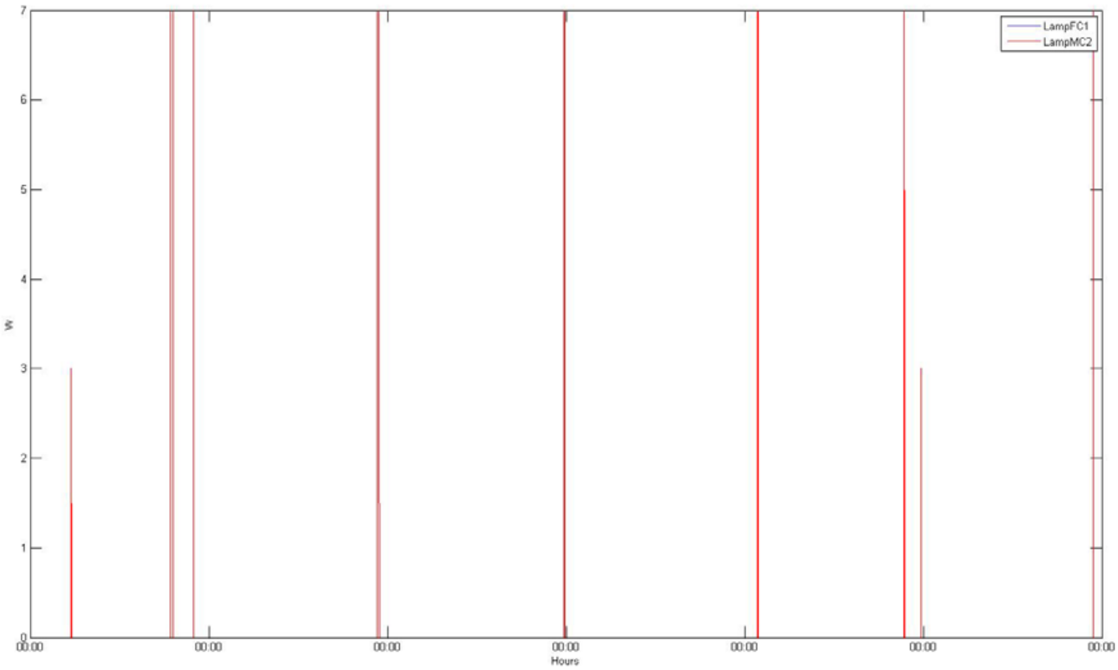
Others:

The fact of having an aquarium in that house means a constant consumption along the year of 12.4 MJ per week, 3% of the total consumption based on that week data.

Lighting:

The lighting accounts per the 2% of the total. It might be slightly higher but because of the limitation in the monitoring devices it is not possible to account for the upstairs lighting.

The lamp in fc1 bedroom shows clearly the bed time. Every day it is used for a few of minutes around midnight.

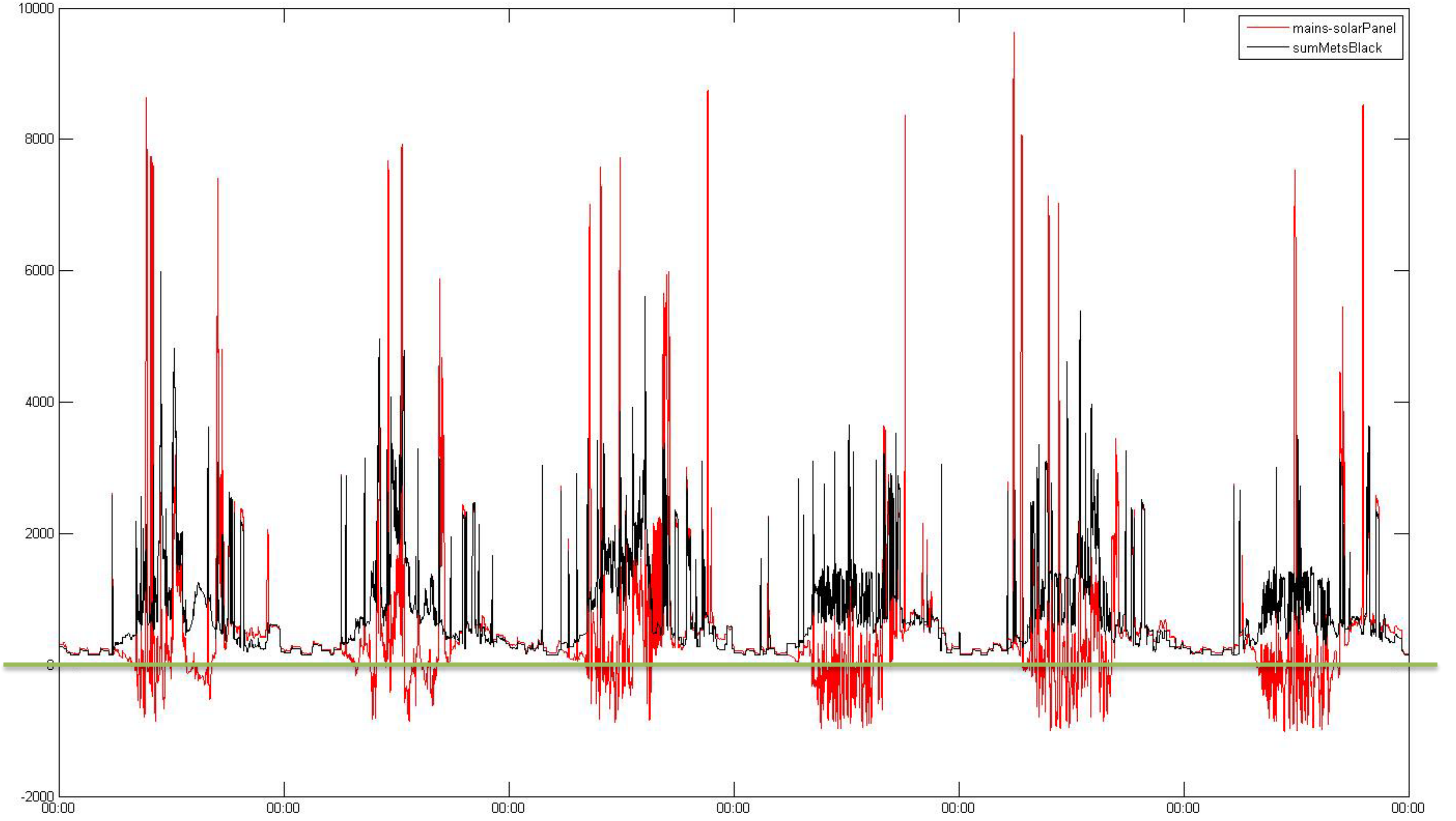


0-13 Bedroom Lamps Week 1

Solar Panel:

The solar panel makes a clear difference in the energy demand decreasing the amount of energy asked to the general grid. During this week, the solar panel generated 74.3 MJ, 17% of the total electricity consumption.

The next plot shows the difference between the energy consumption (mains) and the energy production (solar panel). When the solar panel is producing more energy than the energy used within the house, the red line appears to be negative (Energy produced by the solar panel higher than energy used within the house. The black line shows the energy used by the being sockets.



W T F Saturday Sunday

The week presents two different scenarios. During the week days, most of the appliances are used steadily: The cooker before dinner time, the dishwasher after dinner time, the shower on waking, the downstairs lights in the evening or the fc3 lamp around twelve p.m., bed time.

The week days have two clear busy moments for electricity demand. The first peak is in the morning and is caused by the activity in the shower, the kitchen (toaster, kettle…) and the TV in the dining room.

The second peak is during the evening. This peak is much more complex. Lights downstairs, kitchen, washing machine, dryer… Most of the energy consumption for the day is concentrated in the evening time, when presumably, the family is at home.

During the weekends the activity in the kitchen is higher, the cooker was used both for lunch and dinner instead of being used just for the dinner. The shower was used five and four times at the weekend, instead of once or twice as in the week days.

Saturday afternoon appears to be the official washing day, with the washing machine and dryer working all the afternoon.

The average of electricity consumption during a weekend day is 2/3 more than during the week.

For the second week the total consumption was 371mega Joules, 14% less than the first week.

The main difference is in the day light during the week. The solar panel produce for that week 12% more energy than the last one. The use of the lights within the week decreased a 55%.

The percentage with regard to the last week remain constant or very similar but for the personal hygiene, which is the top one for that week (23% of the total consumption) followed by the Utility, totalling 22%, then cooking (13%) and entertainment (11%), cooling (8%, same energy consumption), battery chargers (7% same energy consumption) finally “others” (2%, same energy consumption) and lighting (1%).

The trend remained constant during the second week.

The main differences are in the use of the shower, which is considerably more often than the first week, and the cooker which was used four of the six days at lunch and dinner time.

Laundry assumes a specific evening each week and is during the weekend.

Estimating the energy consumption for that house, if the occupants behaviour remain constant through the year, the electricity cost for that year will be 401.605 mega

Joules. At the standard price of £0.24 per KWh (British gas, electricity, Loughborough, rate1), it will signify £1628 per year, about £135 per month.

However this cost isn't the actual cost because it is not taking into account the discounts offered by the enterprise for different intervals of consumption.

To decrease the energy consumption in that dwelling, changes will need to be made in either the householders' behaviour or on the appliances. The appliances characteristics are relevant to the energy demand for each device and crucial for some of the appliances.

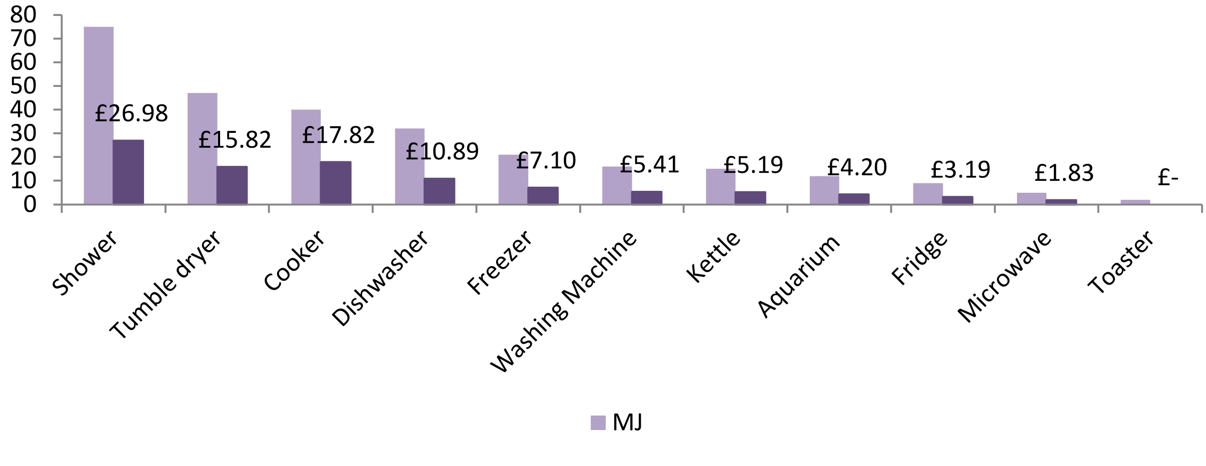
Focussing on the energy efficiency of the appliances within the house and how much they are spending, will be a first step to categorise the top consumer appliances.

The highest consumer is the electric shower. It accounts for 20% of the electricity consumption within the house. It means about £8 a months, £90 per year.

The tumble dryer accounts for 10%. This device is generally known as a huge power-consuming appliance in the dwellings. The cost for this appliance is about £50 per year, £4 per month.

Ten top devices:

The next graph shows the cost per month for the top ten appliances within the house and the related consumption in MJ.



1-0-14 Ten Top devices H01

H30

House Characteristics

0-1 Frontal View

H30 is a two storey detached house (figure 2-1) built on the fifties-sixties.

The main wall type is solid brick. This kind of walls is normally found on houses built before 30s.Some dwellings, as this house, built in the 50s, have solid masonry walls. Heat loss through the external walls is on average 35%.

Part of the doors and windows are draught-proofed and double glazed.

The house has two bathrooms: one downstairs (Access from the kitchen) and other upstairs. There are three bedrooms in the house, one of them is a spare room used as a cover.

The living room has two different spaces: the dining area and the “sofa and TV corner”, the lounge.

The kitchen has different spaces as well. There’s a separate bar with the kettle, the toaster and the washing machine. This bar is specifically illumined by under cup board lights.

There’s a food store room in the kitchen just in front of the oven.

The main heating system is a boiler supplying radiators. The age of the system is about four years old. The fuel is gas.

The boiler is a combination, condensing boiler.

The system is controlled directly by the householder by using the TRVs on the radiators and indirectly by programmer with simple time clock and moveable room thermostat. The programme is set to have different time periods and temperatures for the weekdays and weekends. The TRVs are on in every room. The radiator in the spare room is on but at lower level than in the rest of the house. The reason for having all the radiators on service, was the miss known consequence in terms of being the house warm.

The hot water for showering is supply by the main heating system.

The electric shower is a powerful device which supposes a high percentage in the electricity consumption.

The lighting is equipped with some incandescent lights with some exceptions.

The percentage of CFL is very low.

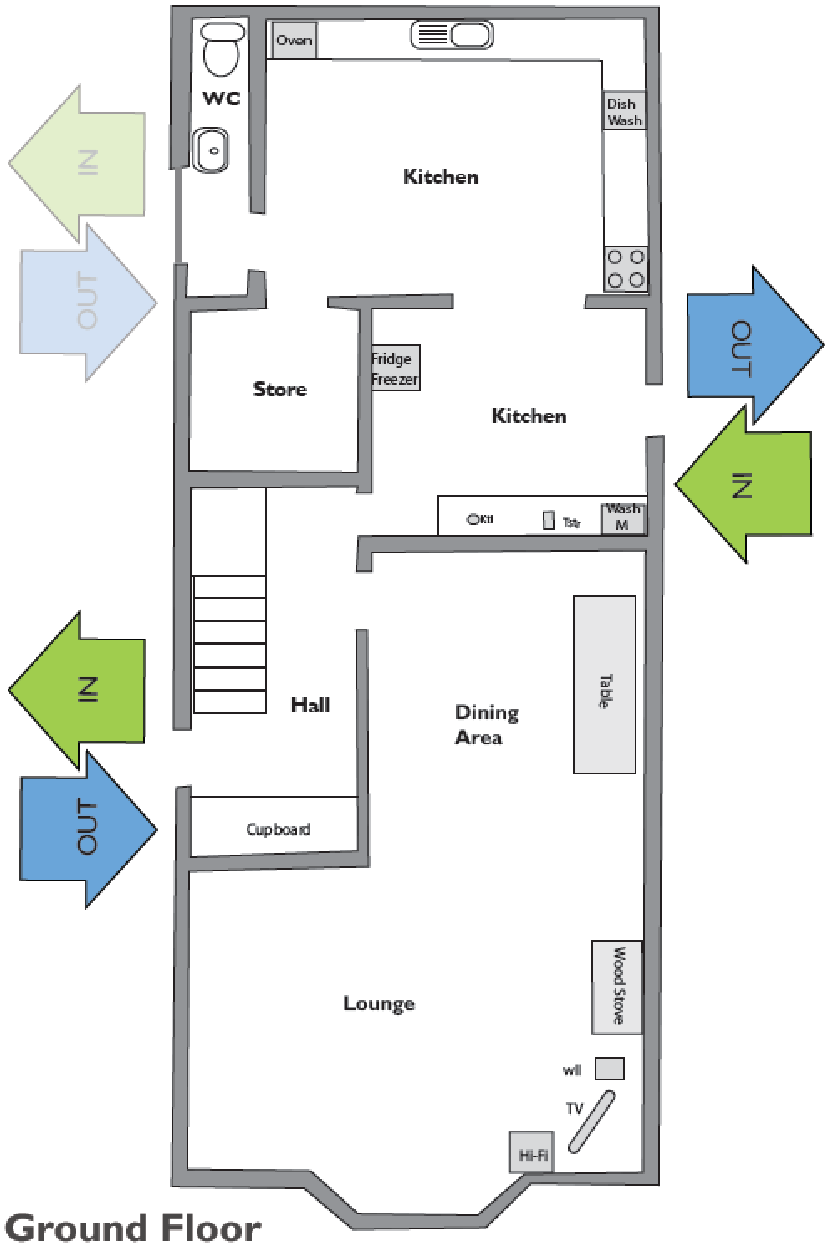
Householders: Demographic characteristics and main motivations

H30 is occupied by a family which is composed by two members: H30FA who is forty-seven and fc that is eleven years old.

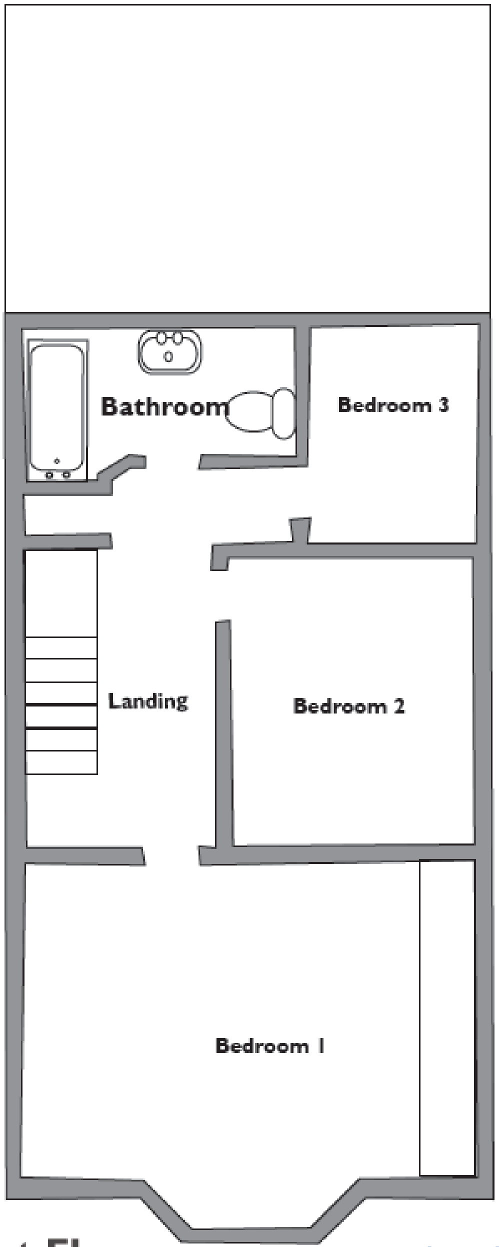
FA is not working, which is a main factor to consider when analysing trends in energy consumption within the house.

During the initial visit (8th September 2011) they were ask about their motivations to join the project:

The FA answer was that they were interested in helping friends, to perhaps in the future, being able to reduce bills. They consider themselves to be "not very good with energy".



Ground Floor



First Floor

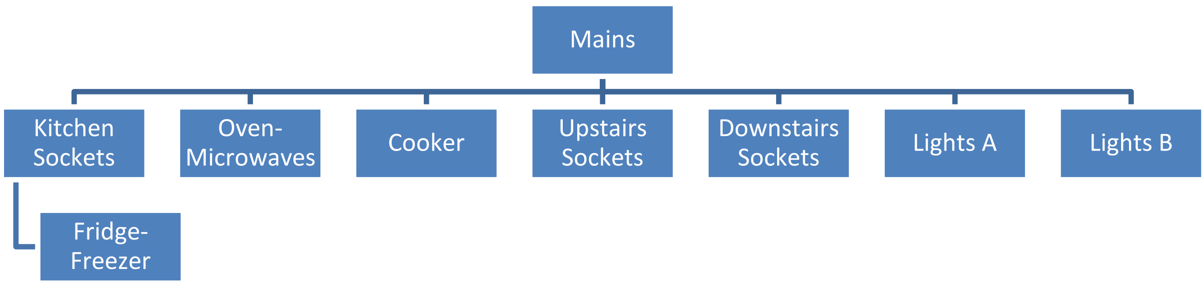
0-2 Floor Plan H30

Data: Understanding and reliability

In H30 were installed nine meter readers for the main electric circuits. The fridge is monitored with a meter reader instead of with a smart.

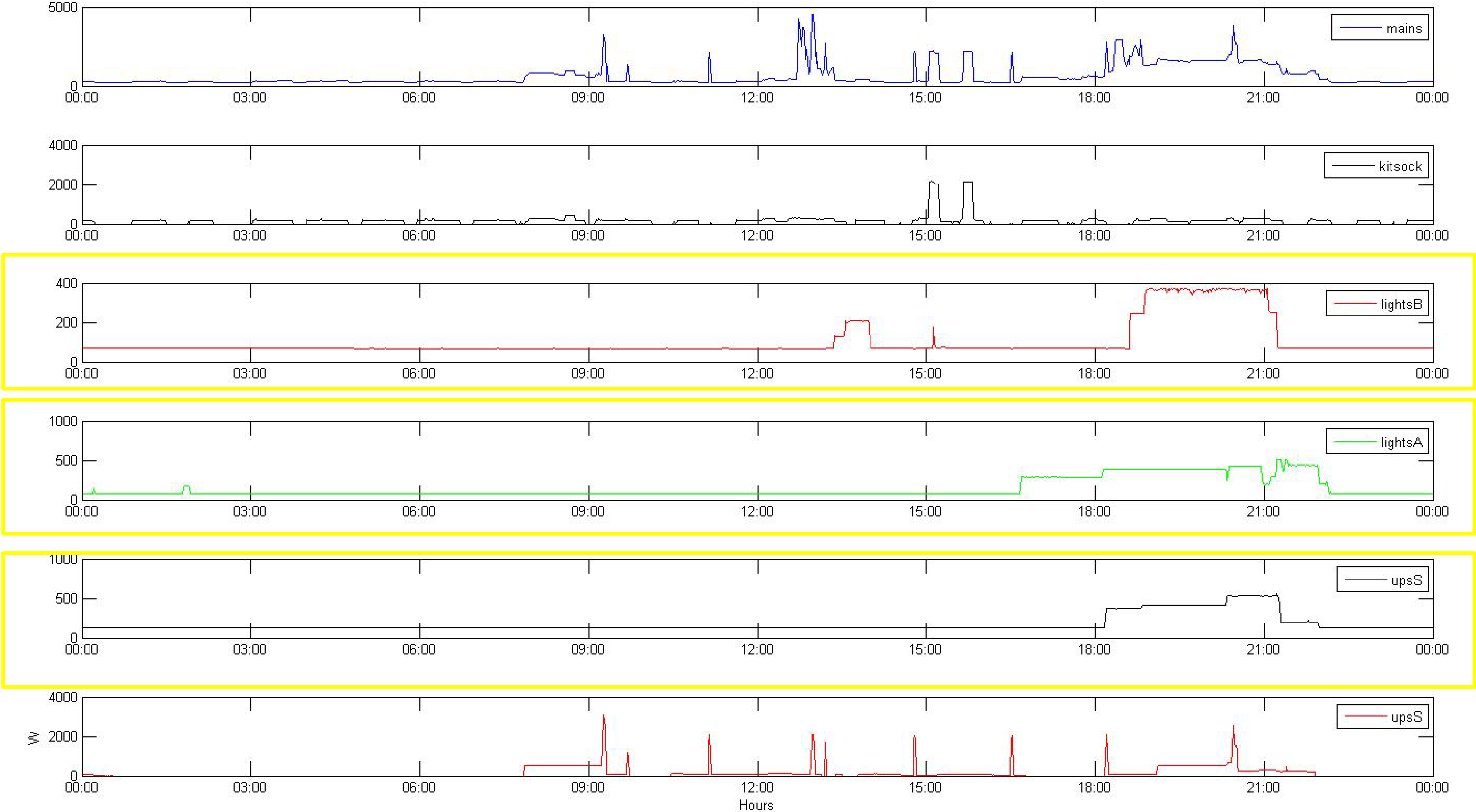
Twenty devices are monitored within the house.

Electric circuits Structure:



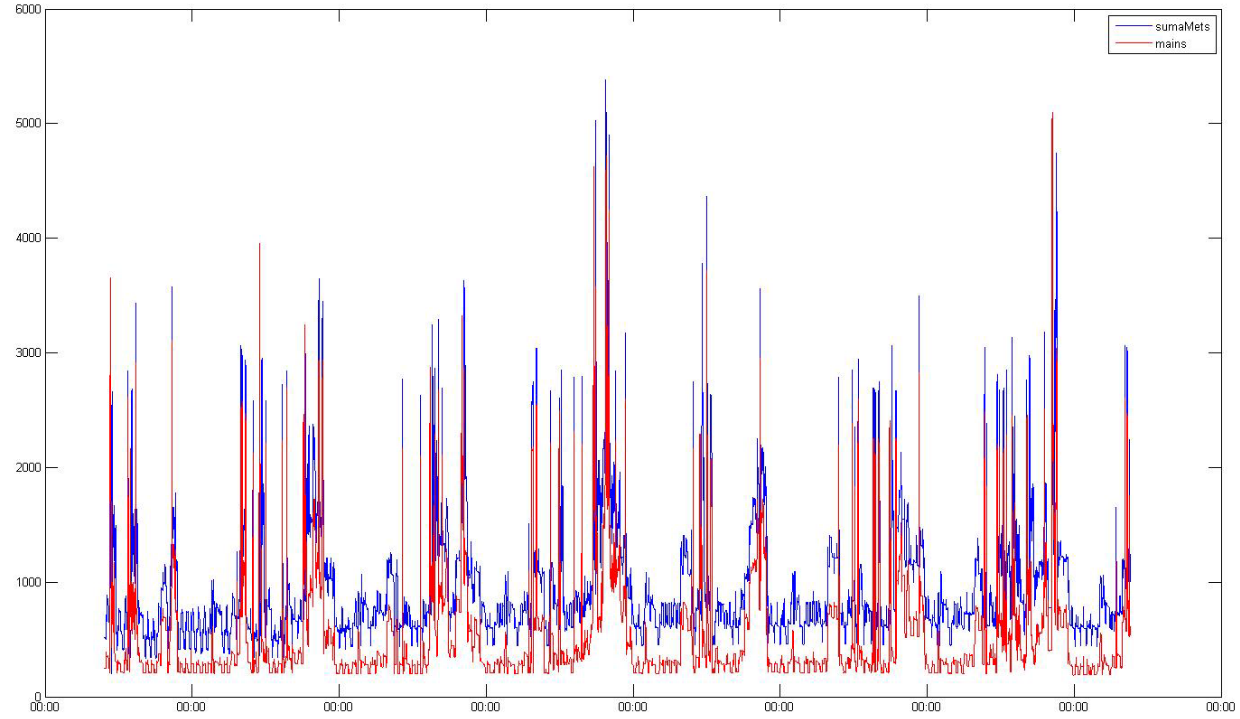
0-3 Electric Circuits Scheme

The devices on each circuit read power over 60 W. The ideal figure is that the sum of the mains equals the sum of the circuits. The data from the first installation was giving a significant error, the mains were measuring less power than the sum of the circuits. That was caused by three of the devices in three of the circuits. Those devices were reading a constant amount of energy summed to the real one being used. The first graphs, the ones with the faulty circuits, are shown in the figure 2-3.



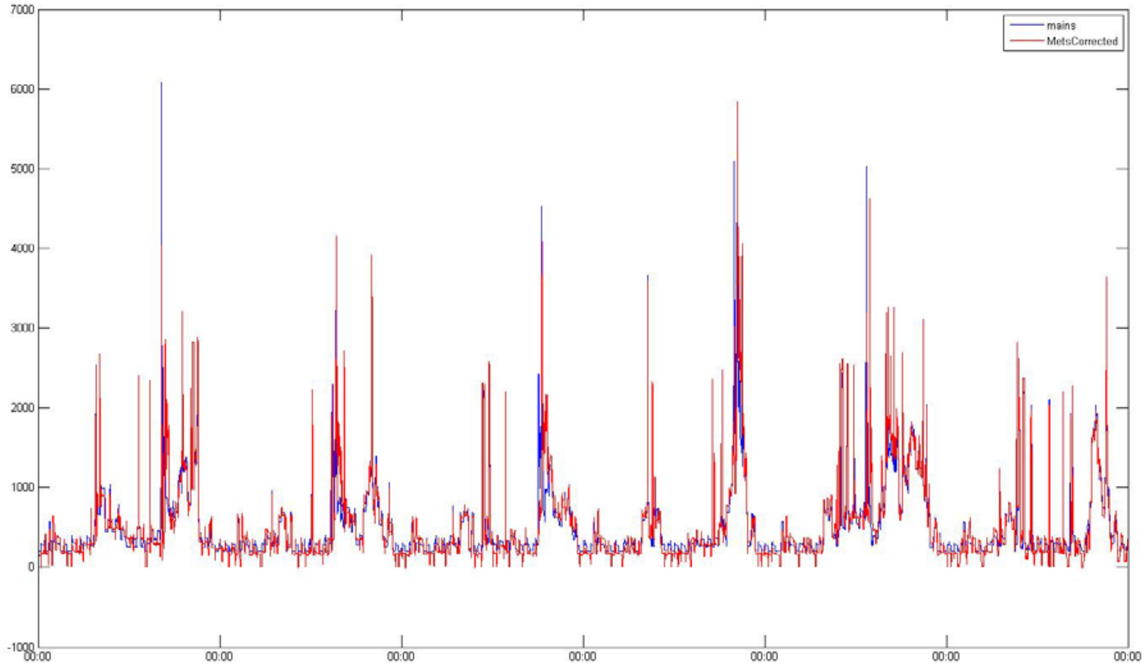
*The highlight circuits show a constant value when there's no activity in the circuit.

The error accounting the faulty circuits was corrected by resting the constant value for each circuit and comparing with the mains.



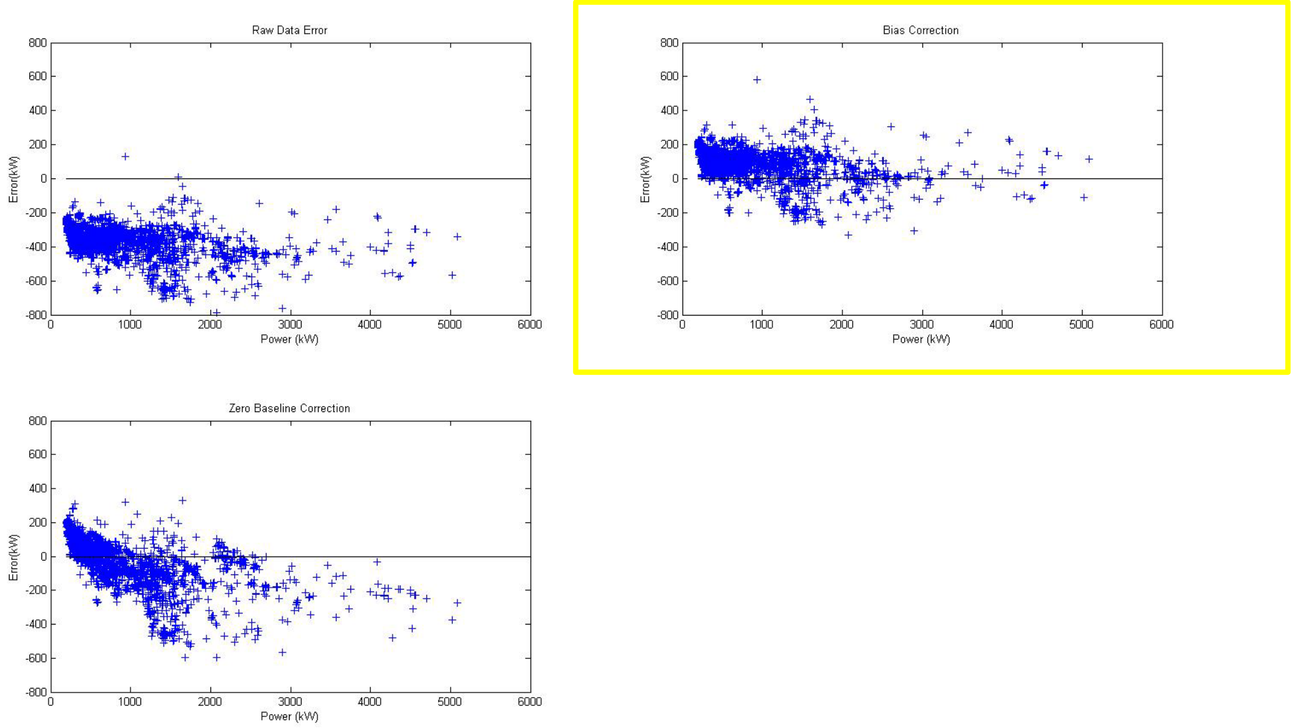
0-5 Faulty Power (W)

The difference between the data shown by the mains and the sum of the circuits was reduced significantly. The adjustment is shown in the figure 2-6



2-6 Correct Power (W)

To determine the problem with the circuits was calculated the relative error for the circuits if the error appears just under low power loads and if it appears without connection with the power load.



0-6 Relative Error

The most accurate correction is the “Bas Correction”, the constant value sum to the real power load in those specific circuits.

The data was corrected and used for the data analysis.

Data analysis

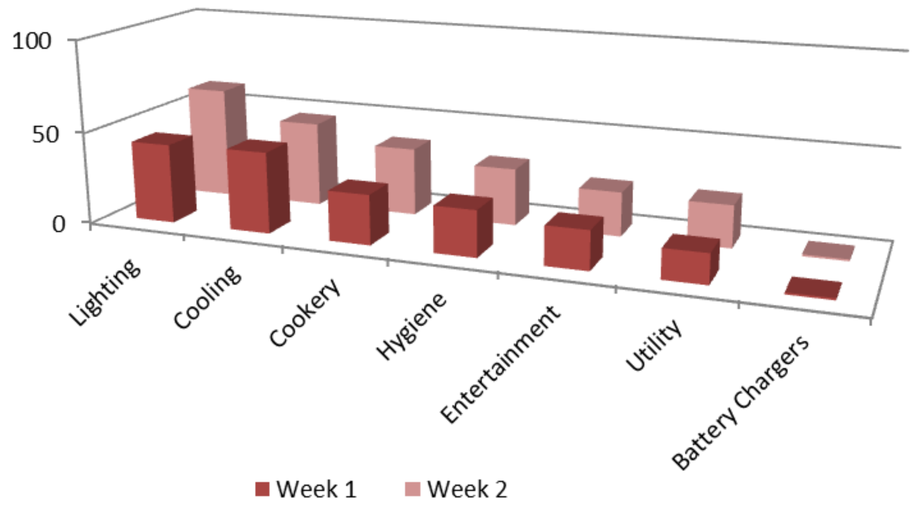
The electricity consumption within the house is categorized attending to the activity that is related to:

- •Utility: Dishwasher, Washing machine and vacuum cleaner.
- •Cookery: Cooker, kettle, microwave and toaster.
- •Cooling: Fridge.
- •Entertainment: TV, Wii video record, CD player, iPod Dock.
- •Battery chargers: Laptops, computers and mobiles.
- •Lighting: Lights and lamps.
- •Personal Hygiene-Bathroom enabling: Under floor heating and extractor fan in the bathroom,

The total consumption for the first week was 273.3 MJ.

The total consumption for the second week was 282.39MJ.

0-7 Appliances H30



0-8 Consumption in MJ by category

	Device	Frequence of use	Use Regularity	% Total	Duration of use
Utility				7	
	Dishwasher	4 to 6	Weekly	6	Around 1 hour
	Washing Machine	4	Weekly	1	Around 1 hour
Cookery				12	
	Cooker	5 to 8	Weekly	7	Irregular
	Microwave	8 to 11	Weekly	1	Irregular
	Kettle	30 to 36	Dayly	4	1 to 4 minutes
	Toaster	7 to 12	Dayly	-	1 to 2 minutes
Cooling	Fridge-freezer	Constant	Constant	10	Constant
Entertainment	TV & gamer lounge	Dayly	Dayly	8	Irregular
Battery Chargers	Computer and mobile	7 to 14	Dayly	1	Irregular
Personal Hygiene	Under Floor Heating	14	Twice a day	10	Arround 1 hour
Lighting				18	
	Kitchen Undercover light	6 to 10	Dayly	-	Irregular
	Lounge lamp	6 to 9	Dayly	2	Irregular
	LampFA2	Dayly	Dayly	-	Irregular
	Lighting	Dayly	Dayly	15	Irregular

2-0-9 Usage Table

Cooling:

H30 has a fridge-freezer as only appliance for cooling.

This fridge is the top consumer device within the house. It accounts for 16% of the total consumption. It consumes more energy than separate fridge and freezer in H01, 33% more than the total of both appliances. The fridge is a high quality device, further it is younger than the cooling devices in H01. It is shown in the figure.

Cookery:

The electricity consumption related with cooking activities supposes 19% the total electricity consumption.

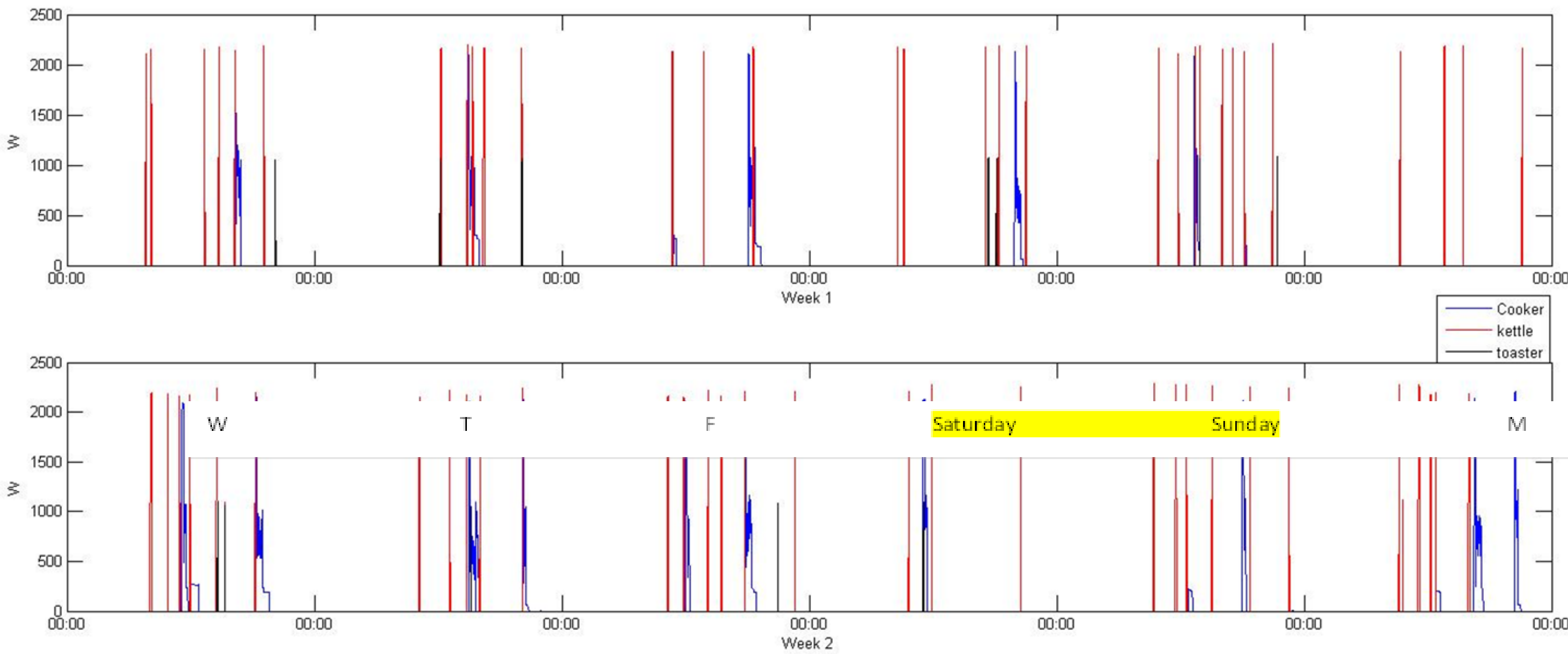
The cooking equipment measured in the house is the cooker, which is the fourth top appliance in the house, the kettle, toaster and the microwave.

The cooker is the 8% of the consumption, followed by the kettle which is the 4%, the microwave, which is the 2% and the toaster which is less than 1%.

Lunch and dinner time is clearly shown in the graphs. The cooker is used almost every day at dinner time or and lunch time. The toaster is not used every day.

The patrons in the kitchen are very similar each day for both weeks. The use of the kettle is very regular. Every day is switched on six to eight times a day.

It is used from first time in the morning (breakfast time) until last time in the evening. In the figure is shown how is used the kettle, toaster and the under cupboard lights for one day. The under cupboard lights are used when using the kettle and toaster from six p.m, when there's lack of light.

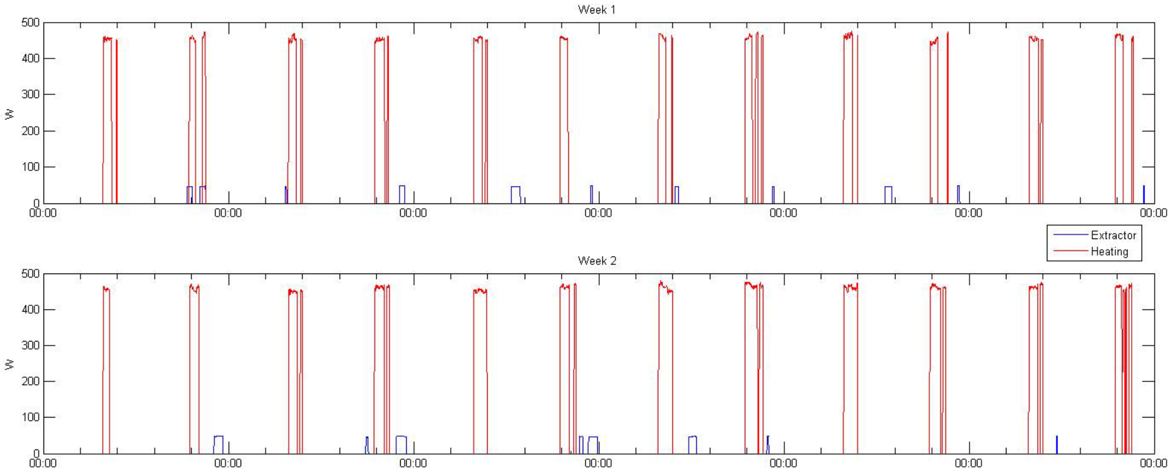


2-0-10 Kitchen devices Week 1 and 2

Personal Hygiene-Bathroom Enabling:

Another important electricity consumer in the house, is the under floor heating in the upstairs bathroom. It accounts for 12%. It is categorised as hygiene device as it is the electric fan in the bathroom.

The under floor heating is programmed to be used every day at the same time as it shown the graph.

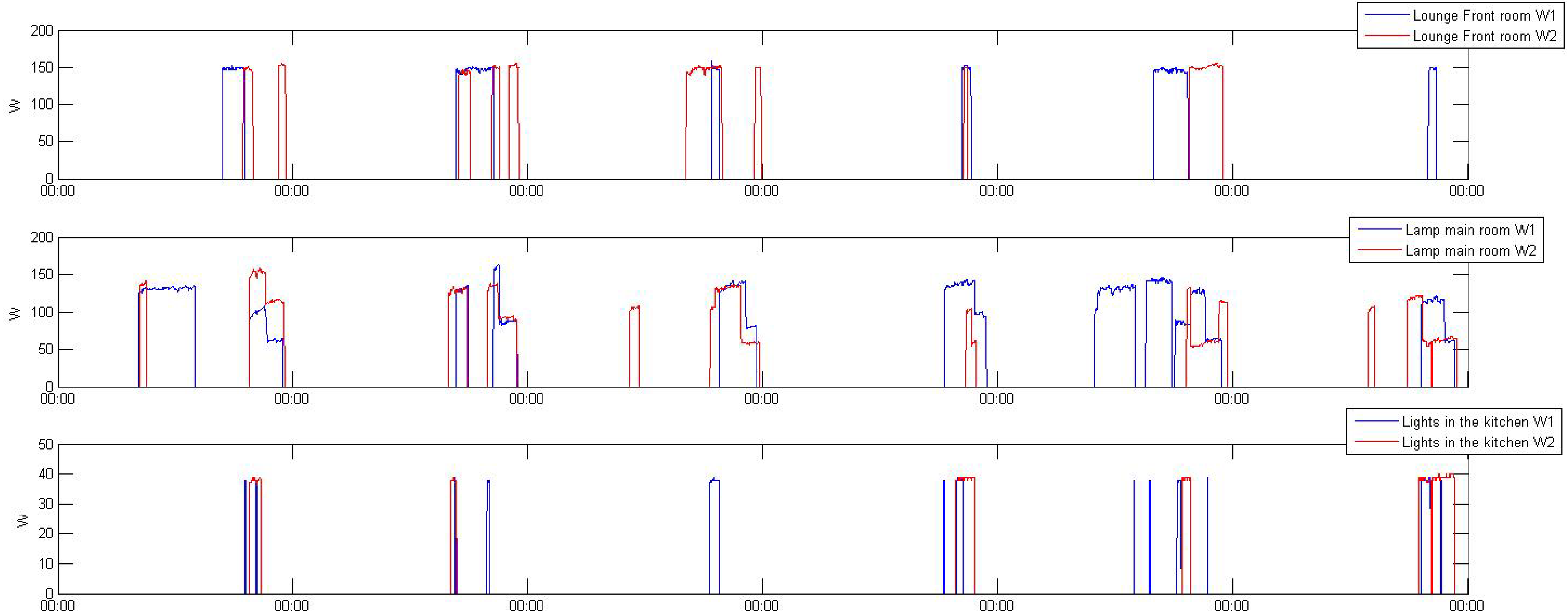


0-11 Bathroom Enabling

Lighting:

The lighting in the house supposes a high % of the total consumption comparing with H01. It is about five times the lighting for H01 even living at home five people instead of two.

The activity for the lighting was shown mainly in the lounge, kitchen and in the main room. For both weeks the trend remains constant regarding to time and periods.

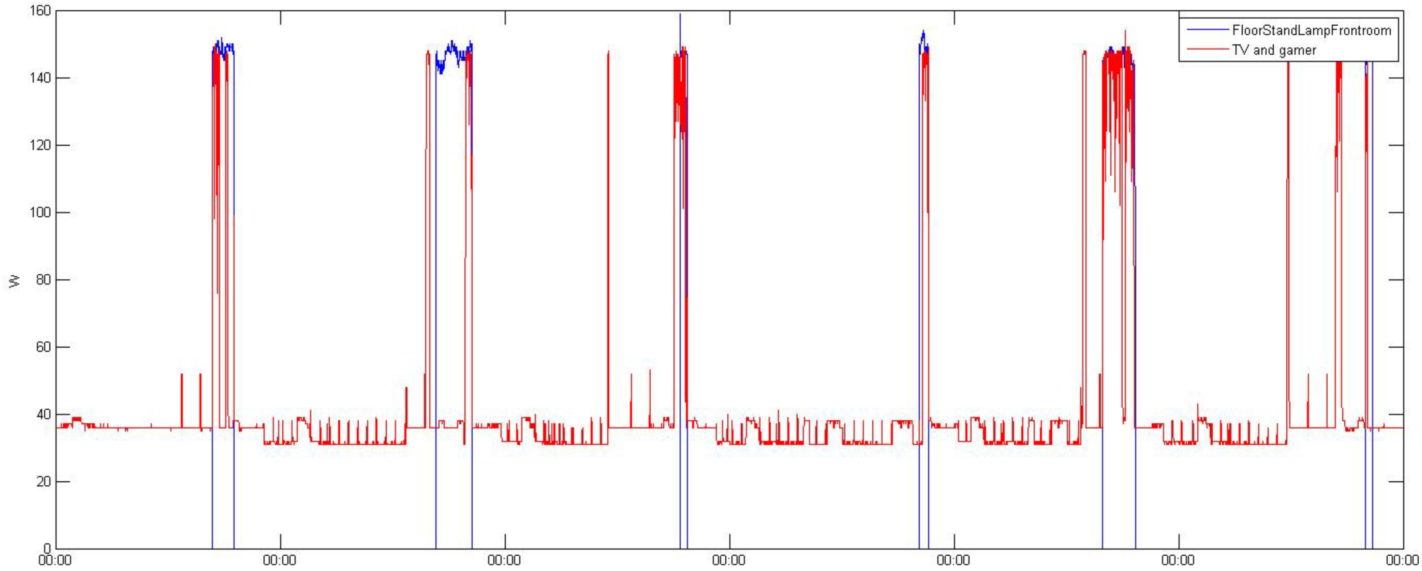


2-0-12 Lighting Week 1 and 2

W T F Saturday Sunday M

Entertainment:

The activity in the lounge is quite regular during the week. The TV, the audio/video receiver and the Wii are in stand by position along the day. The stand by consume varies from 30 W to near 40 W depending on what it is switch off and what it is in standby. The main activity in the lounge appears every day about six o'clock. It varies in terms of duration. The lamp in the lounge is used most of the times when the TV but depending on the light is used from six p.m. or later on.



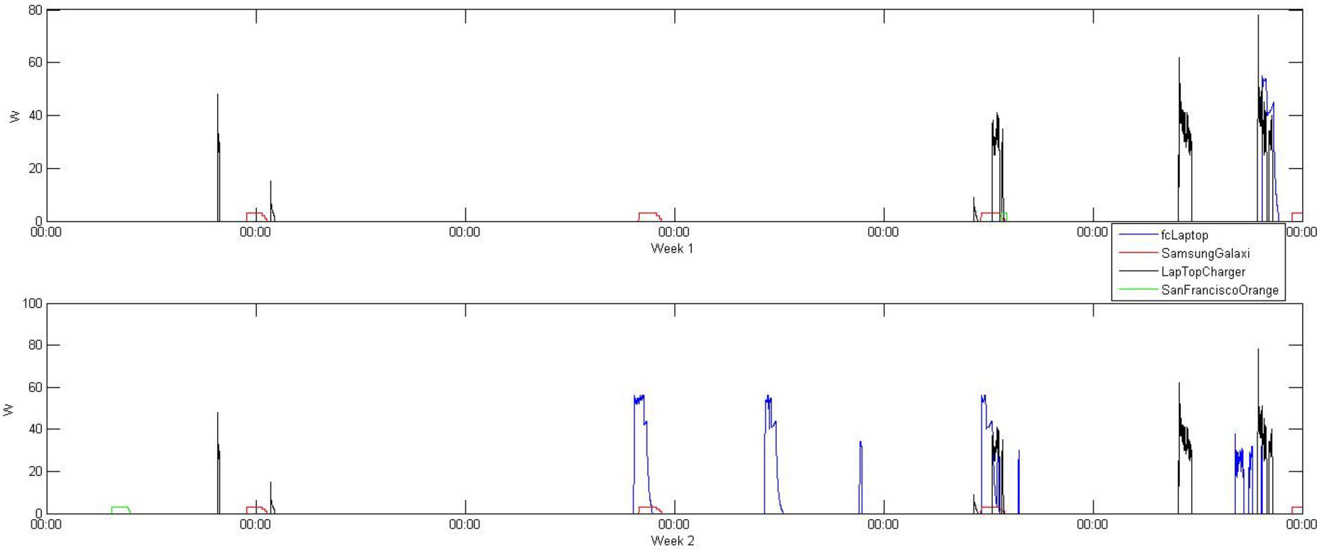
2-0-13 Lounge activity Week 1

Battery Chargers and Computers:

In terms of mobile phones and computer use, the energy spent is minim. Both people in the house have a personal mobile and a personal laptop. The use of the laptop is not showing any trend for these two weeks. The child is charging it most of the days in one of the weeks but not in the other. The daughters' mobile phone is charged in different days and times in both weeks.

On the other hand, the H30FAs' laptop is being used following the same trend both weeks and so the mobile chargers as it shown in the figure.

The data shows that the H30FA has a regular habit with her media devices but not fc1.



0-14 Computer equipment Week 1 and 2

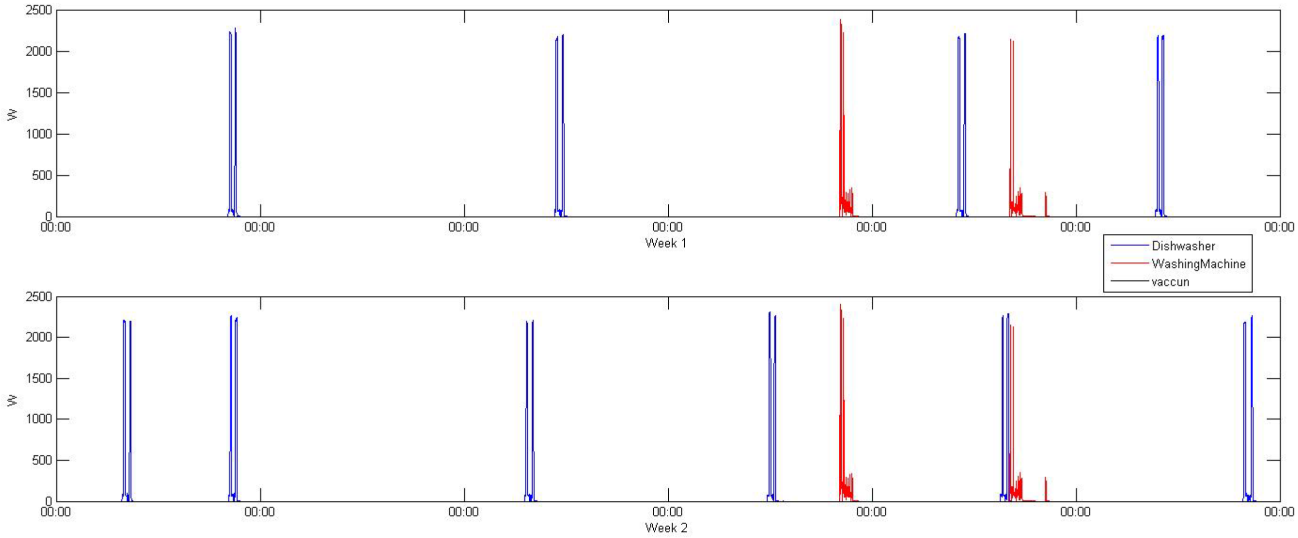
Utility:

Looking at laundry practices, this house doesn't use any tumble dryer, which is an important saving in the electricity consumption. The utility accounts for 7% the total electricity consumption.

The dishwasher is the main device for this category, it accounts for 6%, while the washing machine accounts for 1%.

The washing machine, as shown in the graph, is used twice a week, both times during the weekend. The washing practices have a clear routine.

The vacuum cleaner might not be used every week because doesn't show any activity for those weeks.



0-15 Utility Week 1 and 2

H30 is a detached house which is not insulated. This house is occupied by two people, which is a key fact for the energy use by person within the house. The energy used for conditioning the house in many of the facts is basically the same for two people as it is for three or four people.

Looking at the fridge, it is a big device able to supply more than two people. In fact, this device uses more energy than the other cool appliances in the other houses of the analysis.

The heating for the bathroom is another conditioning device which makes no difference with the number of people who is living at home. It is programed to work the same number of hours not without taking account of the use in the bathroom.

The under floor heating is an important fact within the electricity consumption.

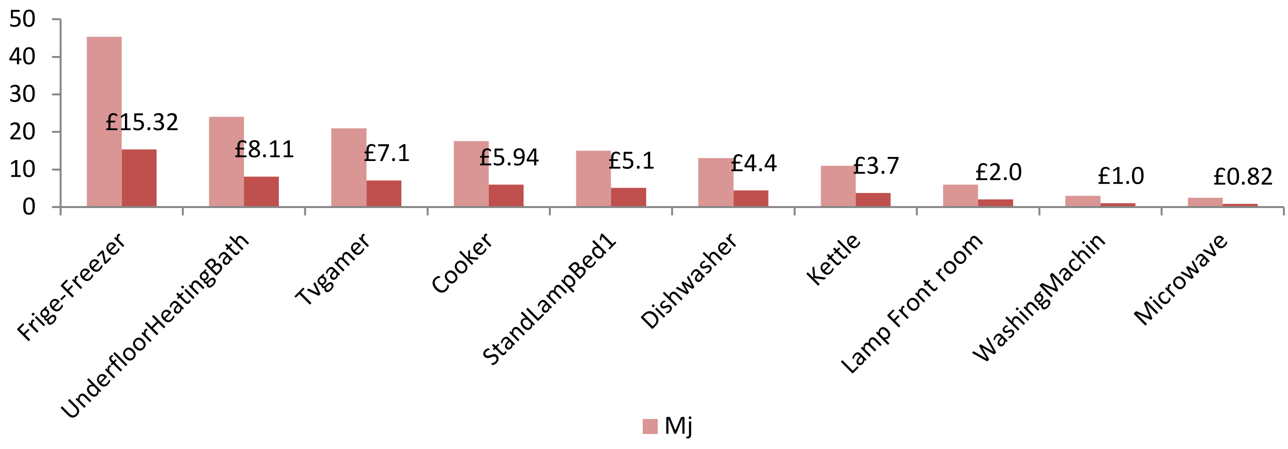
To program the under floor heating might be a disadvantage when trying to cut down the electricity consumption. It is costing £100 a year to heat the bathroom for two people. It is need to check the gas consumption and evaluate the cost of the heating for the whole house to better determine another more efficient way to heat it.

The lights, on the other hand are used in even three rooms at the same time and several times in the two weeks of data.

In most of the time, they are switched on in more than one room.

Ten top devices:

The graph shows the ten top consumer appliances within the house.The cost per month in £and the consumption in MJ.



0-16 Ten Top devices H30

H43

House Characteristics

H43 is a two storey detached house (figure 3-1) built on the sixties-seventies.

The main wall type is insulated cavity. The loft insulation thickness is up to 50mm.

Part of the doors and windows are draught-proofed and double glazed.

The house has a fully integrated garage and a double door in the entrance.

There's a studio in the garden, which is used by the H43FA, who is a painter. It is monitored as active part of the house, which it is.

3-0-1Frontal View

The kitchen is one of the most used spaces in the house. It is used, as a kitchen, as a lounge as a way out to the garden and as a studio by FA.

In addition to the kitchen, in the ground floor there's a study, a playing room, a living room, a lounge and a toilet. Figure 3-2

The main heating system is a boiler supplying radiators. The age of the system is five to eight years old. The fuel is gas.

The boiler is a combination, condensing boiler.

The system is controlled directly by the householder by using the programmer with simple time clock and room thermostat on the walls.

The hot water for showering is supply by the main heating system.

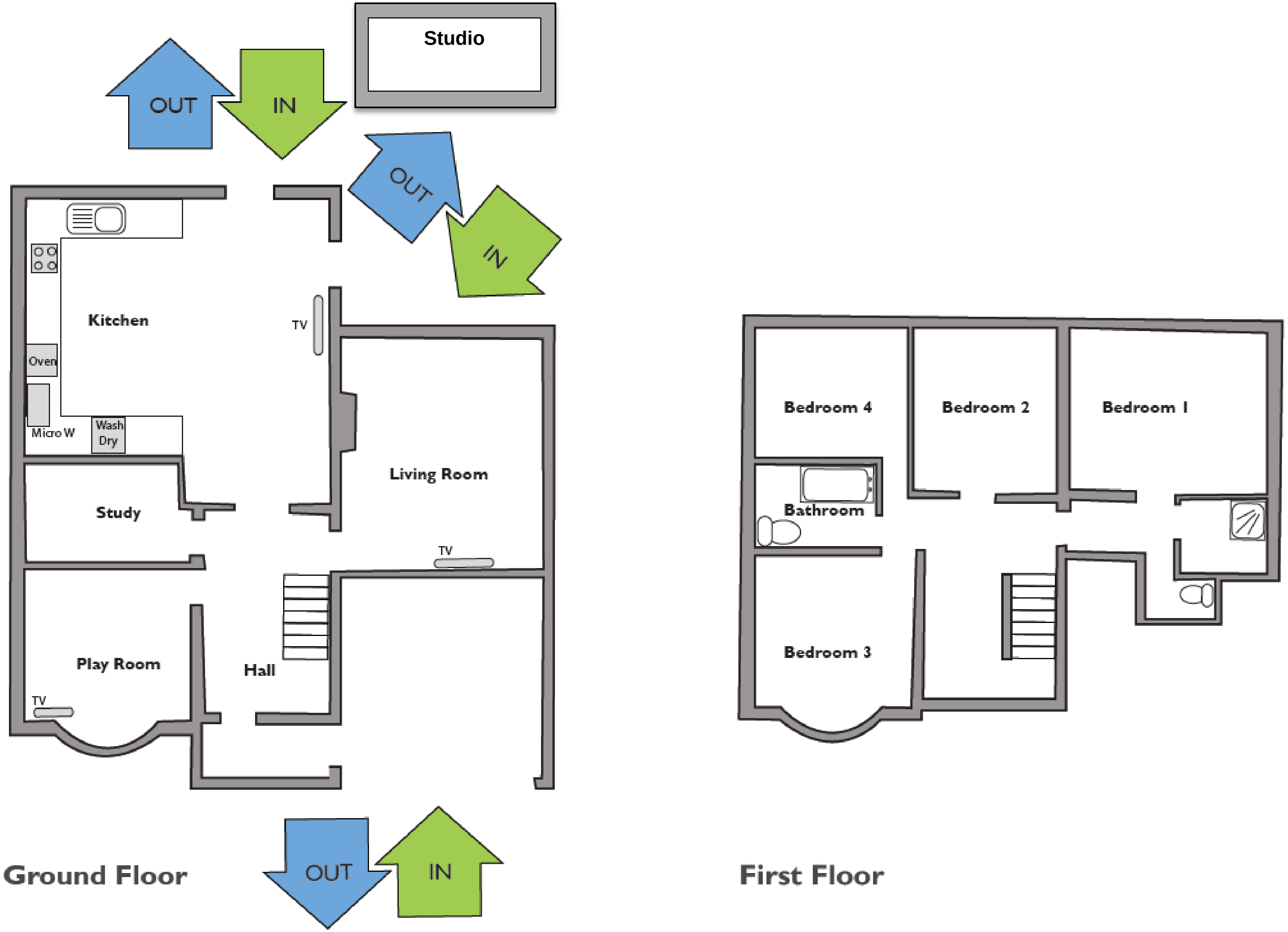
The lighting is equipped with some incandescent lights with some exceptions. The percentage of CFL is very low.

Householders: Demographic characteristics and main motivations

H43 is occupied by a family which is composed by four members: two teenagers of ten and twelve years old and their respective parents. H43FA and H43MA are in their young forties.

H43FA works at home. FA is a painter. She has a studio in the rear, it is an independent space conditioned for painting purposes. She paints in the kitchen/dining room very often.

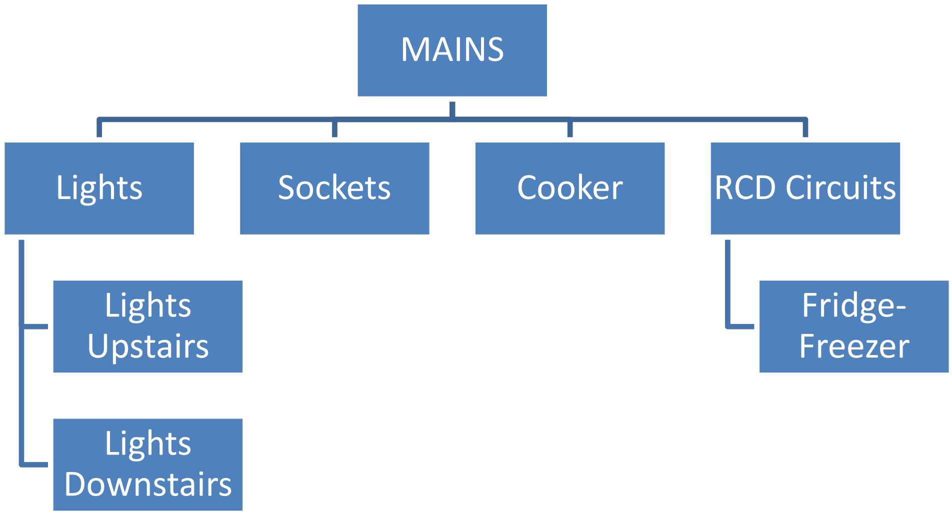
During the initial visit, they were asked about main motivations to join the project. They show their willing of learning about their habits and how they use or waste energy. The consider themselves to be "a very wasteful family", and "energy hungry". Children were excited about the project and commented that it sounded like "a lot of fun". Parents are interested in helping to reduce the C02 emissions, believe in science (research), and want to help people out when they can.



0-2 Floor Plan

Data: Understanding and reliability

The electric circuits in the house follow the next scheme:



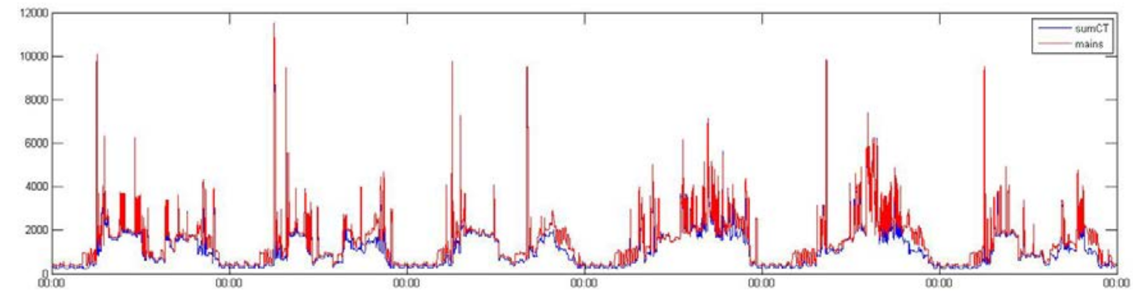
3-0-3 Electric Circuits Scheme

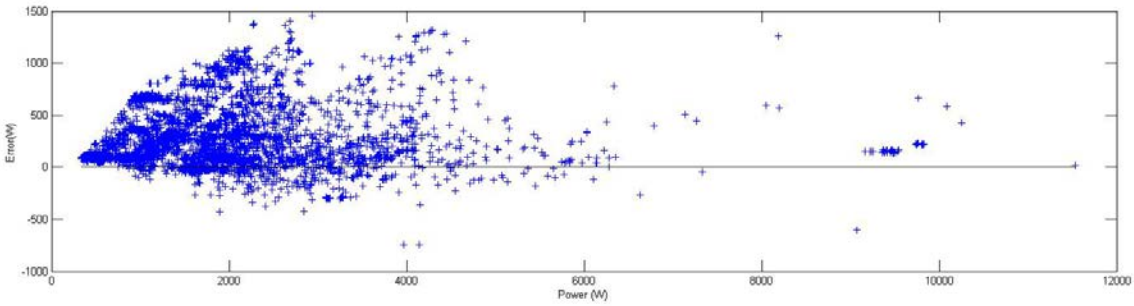
In terms of reliability on the monitoring devices, this is one of the most reliable houses.

The error from the devices in the circuits is lower than in the other two houses.

The graph show how match the main circuit with the sum of the sub circuits.

The second graph shows the relative error.



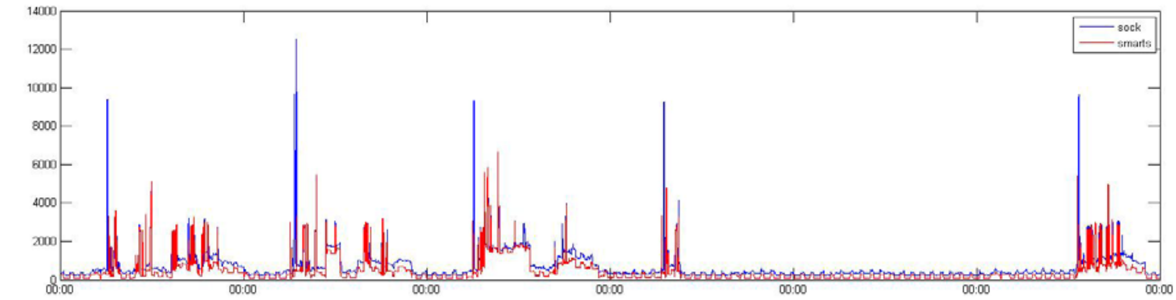


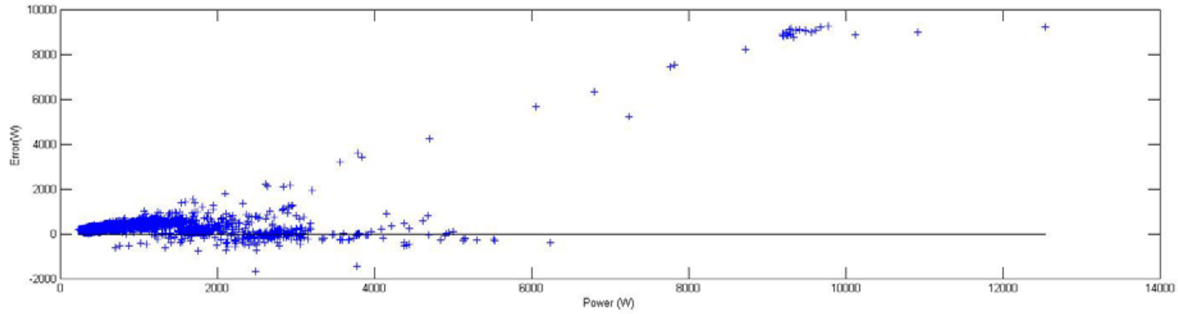
3-0-4 Power (W)

3-5 Relative Error

The data from the appliances is showing what is measured by the monitoring equipment. To have an idea about how much of the energy is being measured, it is compared the electricity used by the sockets in the house, and the sum of all the appliances measured at home.

As it's shown in the figure there's some device that are not being measured so the data analysis will be accounting with that limitation.





3-6 Sockets Power (W)

3-7 Sockets Relative Error

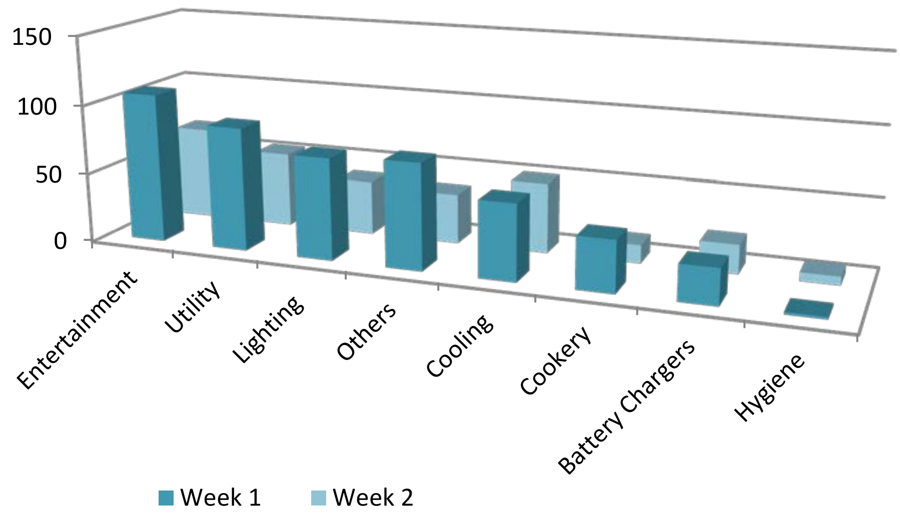
Data analysis

The electricity consumption within the house is categorized following the next division:

- Utility: Dishwasher, Washing machine and Dryer.
- Cookery: Cooker, microwave, kettle and toaster, coffee maker, sandwich and mixer.
- Cooling: Fridge and freezer.
- Entertainment: TV, Wii, video record, CD player and gamer.
- Battery chargers: Laptops and computers.
- Personal hygiene: Hair dryers.
- Lighting: Lamp.
- Others: Fan, heating in the studio, dehumidifier, electric tool and electric door in the garage.

The total consumption for the first week was 758 MJ.

The total consumption for the second week was 543 MJ.



3-8 Electricity Consumption by Category

For that house is critical to take into account the fact of being used as a studio during the week. It will determine the trends in the electricity consumption.

	Device	Frequence of use	Use Regularity	% Total	Duration of use
Utility				11	
	Dishwasher	4 to 6	Weekly	4	Around 1 hour
	Washing Machine	6 to 9	Weekly	2	Around 1 hour
	Dryer	8 to 9	Weekly	5	Around 1 hour
Cookery				4	
	Cooker	2 to 6	Weekly	2	Irregular
	Microwave	10 to 14	Dayly	-	Irregular
	Kettle	14 to 25	Dayly	1	1 to 4 minues
	Toaster	8 to 12	Dayly	-	Few minutes
	Cofee Maker	6 to 7	Dayly	-	Few minutes
	Mixer	1 to 4	Weekly	-	Few minutes
Cooling	Fridge-freezer	Constant	Constant	8	Constant
Entertainment				13	
	TV & gamer lounge	7 to 8	Weekly	6	Irregular
	TV Dining room	12 to 18	Dayly	4	Irregular
	TV & gamer playroom	6 to 13	Dayly	-	Irregular
	TV main bedroom	5 to 10	Dayly	-	1/2 to 1 hour
	Studio TV	3 to 6	Weekly	-	Irregular
Battery Chargers				4	
	Computer equipment	5 to 11	Dayly	4	Irregular
	Laptop Playroom	1 to 4	Weekly	-	Irregular
Personal Hygiene				-	
Lighting		-	Dayly	8	Irregular
Others					
	Studio Heating	2 to 4	Weekly	8	Irregular

3-9 Usage Table

Entertainment:

The use of the TV and gamer in that house is very significant, it is almost constant during the week. It accounts for 13% of the total electricity consumption.

From first time in the morning until bed time there’s activity in some of the TVs in the house.

The next graph shows the activity for all the TVs in the house for both weeks. The blue line matches the activity in different parts of the house for one day in during the first week. The red line matches the activity for one day in the second week. Those lines try to define clearly the constant activity of the TV during the day in the house.

The TV in FA and MA bedroom has activity at first time in the morning and last time in the evening most of the days.

The activity of the TV in the studio and the dining room gives an idea about where is working H43FA.The first week the studio is used every day but on weekend, whereas the second week the studio is just used two days.

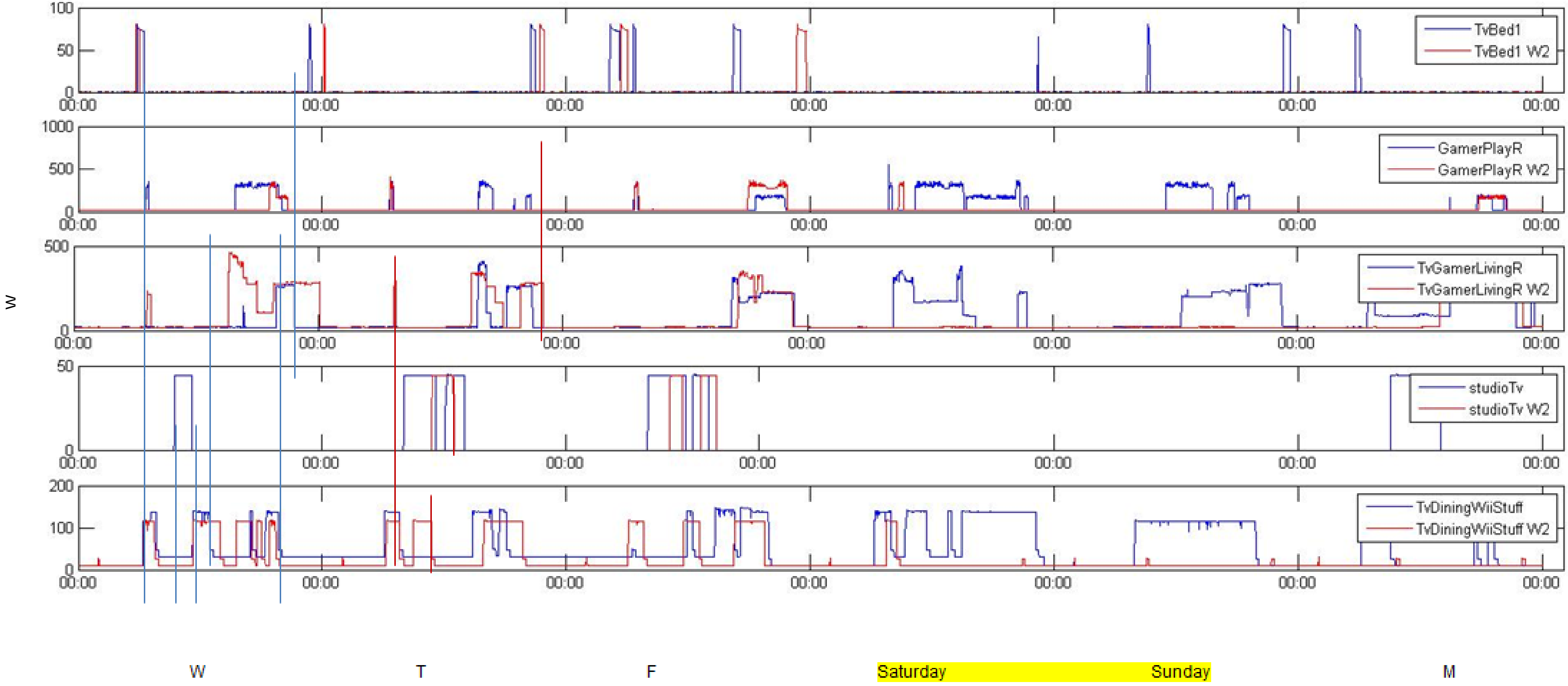
The dining room is the most used room during the day as it shown by the activity in the TV and gamer. The standby consumption varies depending on the devices in standby for each moment. It’s clearly shown in the figure as the first week the standby status is spending more electricity until the fourth day, when after being use the TV devices, one of them (Wii or video recorder) is switched off. Then, the standby position remains spending less energy until the end of the second week.

The difference between TV s regarding to power consumption is very high.

TV in bedroom 1 and TV in the studio spend around 50 W when showing activity.

The TVs in the living room (Lounge), playroom and dining room are equipped with gamer devices. The activity for them is five to ten times 50W.

The entertainment devices in the living room account for 6% the total consumption, however, the ones in the dining room account for 4% the total consumption even having higher activity during the week. The reason for that is the power used by the TV devices in the living room. It is near the double comparing with the dining room.



0-5 TV activity Week 1 and 2

Utility:

The utility accounts for 11% of the electricity.

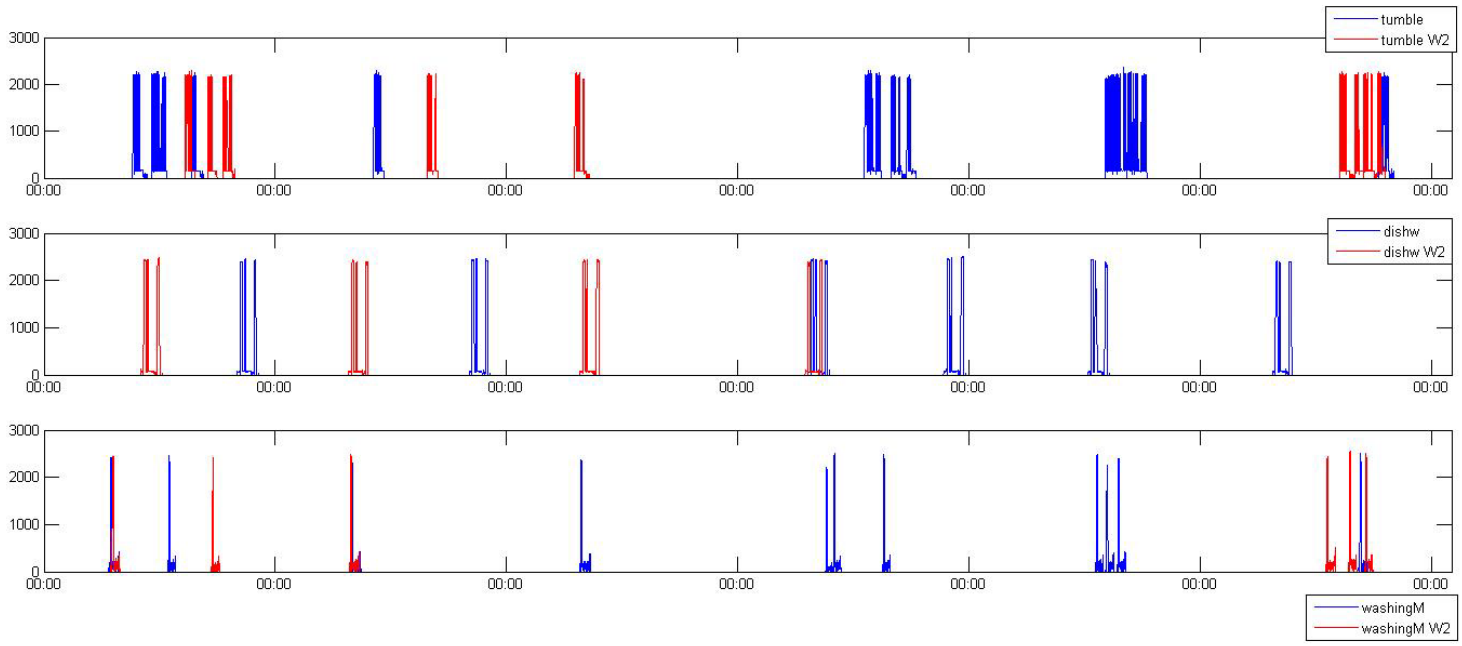
The dishwasher is an important device within the house, it accounts for 4% the total. There's not a clear trend in the use of the dishwasher in terms of times a day and number of times a week but as shown in the figure 3-6 it's used almost daily.

The dishwasher is the sixth top device in the electricity consumption for that house. It cost, following the trend from these two weeks, about £11a month.

The laundry activities in the house are spread along the week. There's not a particular day or time where it's being done but what it is interesting is that most of the times, the tumble dryer is used twice per one washing machine use.

The tumble dryer is the third top consumer device. It accounts for 5% the electricity consumption and costs about £14 a month.

The washing machine is the tenth top, about 2% the electricity consumption and it costs about £5.



0-6 Utility Week 1 and 2

Others:

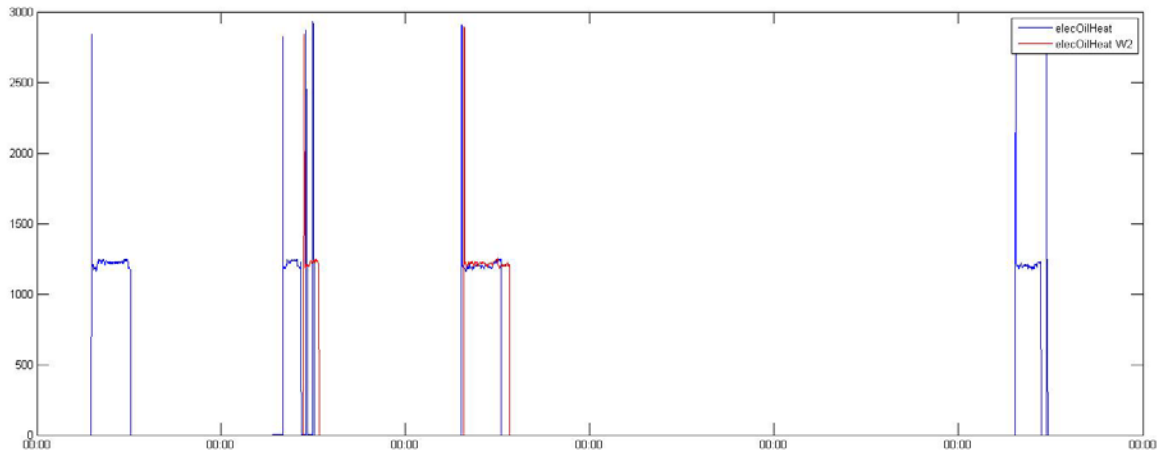
For that house the use of some devices not use in the other houses of study, make the “others” category very significant. It accounts for 8%

The electric door in the garage, the dehumidifier, the fan in H43fc bedroom, the circular saw and the electric heating oil in the studio are the devices accounted in that category. The studio heating is the device that shows an important consumption use, being most of the % of the “others” consumption.

The use of the electric oil heating in the studio accounts for near 8% the electricity consumption. It is near £26 a month.

The need of warming up the studio has an important reflection in the electricity cost.

The power of that device is about 3KW, it is used for long periods of time during the week. The graph shows the trend for the two weeks of study.

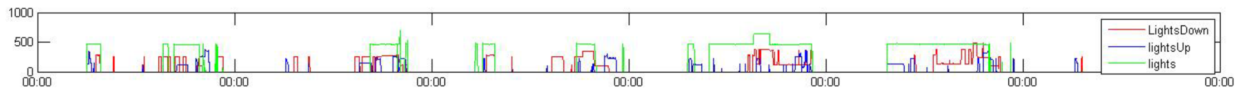


W T F Saturday Sunday M

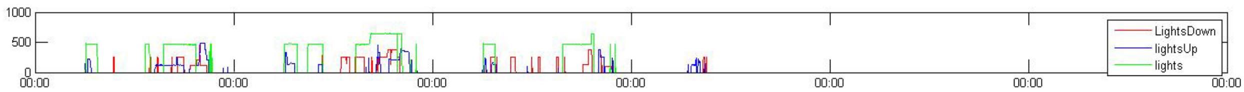
3-0-7 Studio Heating

Lighting:

The lighting in the house has an impact of near 9% of the electricity consumption. On peak times (evening), it is using more than 500 W.



0-8 Lighting Week 1 (W)



3-9 Lighting Week 2 (W)

Cooling:

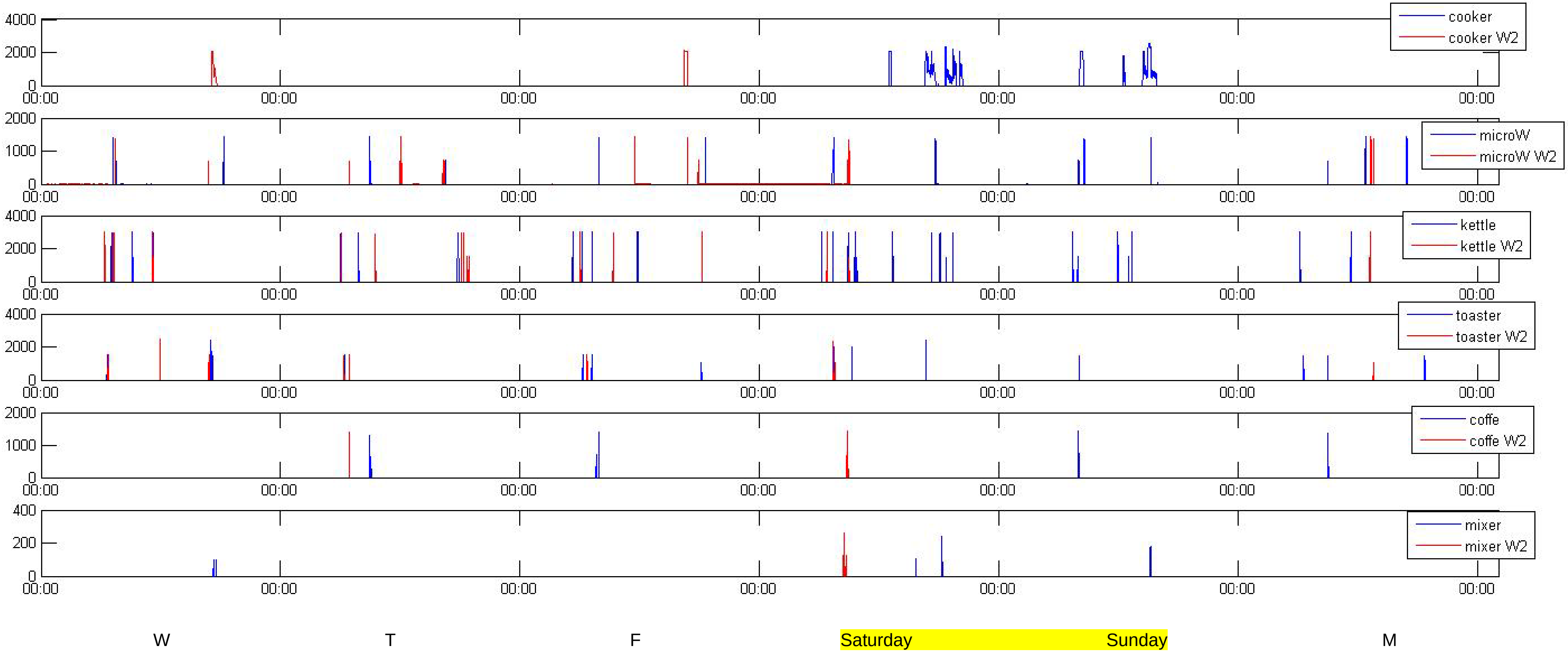
In terms of cooling devices, the fridge freezer used in the house is a high consumer device which accounts for 8% of the electricity consumption. It costs about £18 per month.

Cookery:

The kitchen is a key space in the house but not the cookery activity. It accounts about 4% in the electricity consumption. There are more devices being used than in the rest of the houses (mixer, coffee and sandwich maker).

The device with more activity in the kitchen is the kettle followed by the microwave. They are used several times a day. The coffee maker is used almost every day, once a day. The cooker doesn't show much activity and the main activity shown is during one of the weekends. It accounts for 1%. It costs near £7 a month.

The activity in terms of cookery in the kitchen is shown in the graph 3-9.

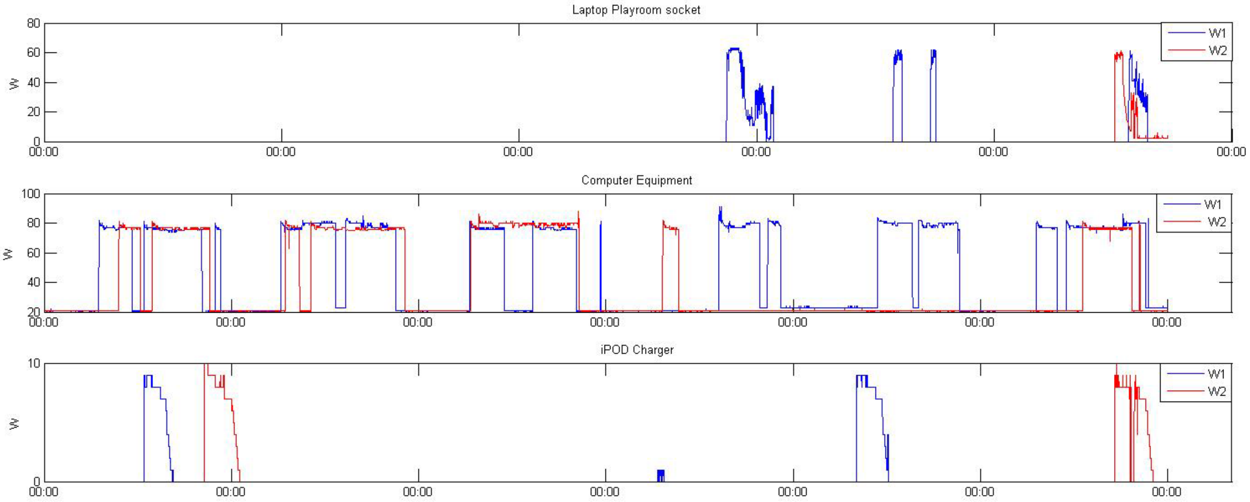


0-9 Kitchen activity Week 1 and 2

Computer and Battery chargers:

Regarding to computer practices, the main activity is in the study, in the main computer. The cost for the use of the computer is £8 a month. It is higher than the cost of the cooker. The use of the laptop in the playroom appears mainly during the weekends. It accounts for 4% of the electricity, most of it because of the computer in the study.

The iPod charger has a very low power, about 10W. It is used twice a week.



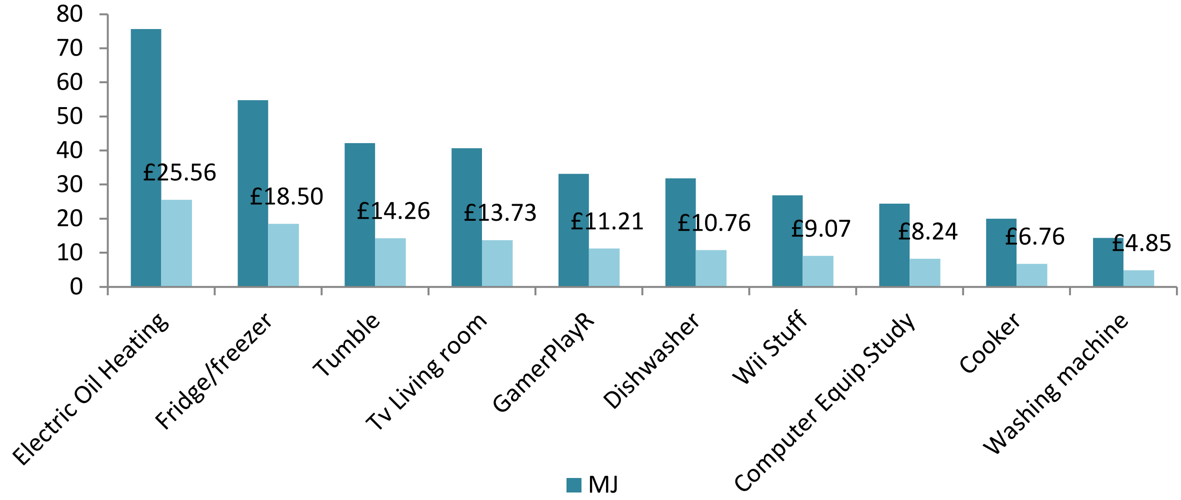
0-10 Battery Chargers Week 1 and 2

Personal hygiene:

For this category, it is taking into account the FA hair dryer in the main room and the fc hair dryer. It accounts for less than 1% of the electricity consumption.

Ten top devices:

The next graph shows the cost per month for the top ten appliances within the house and the related consumption in MJ.



0-11 Ten Top devices H43

Analysis across houses:

The houses of study are situated in the same English town: Loughborough. The weather and urban conditions are considered equals for the scope of this study.

The three houses were built between the 50s and 70s.

They are similar in terms of dwelling characteristics.

They all are detached two storey houses. They have three to four bedrooms and they all have insulation cavity walls but H30, which walls are solid walls.

For the conclusions in this analysis, the dwellings are considered homogeneous. The main differences between dwellings will impact widely on the gas consumption.

The energy needed for the heating varies significantly with the insulation conditions of the dwelling, but cause of the fact that all of the houses have a boiler as a main system for heating, these differences will not affect significantly in the electricity consumption.

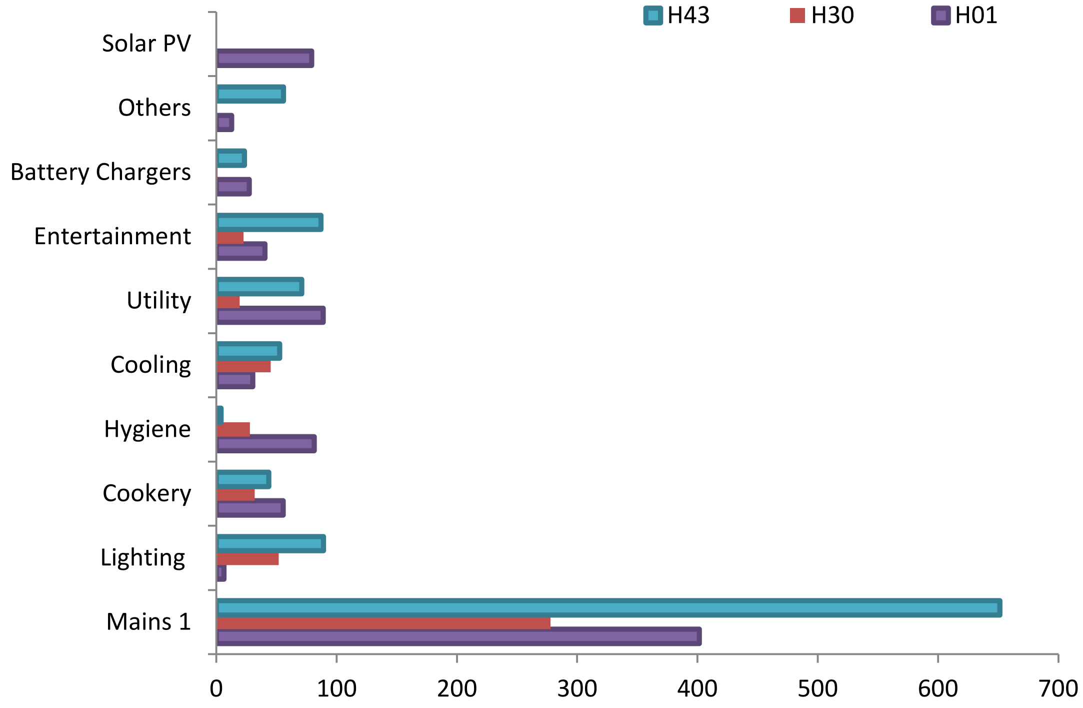
An important fact for the evaluation of the electricity demand across houses is the use of an electric shower, as it is in H01, and the fact of having a solar panel producing electricity.

The families are different in size, occupancy and ages. More study need to be made to understand the social interface related with energy consumption.

For this study, it is analysed the energy consumption across houses by using the categories used in each house analysis.

To get a clear idea about the relation between number of people within the house and energy consumption, some of the analysis is done attending to personal consumption.

The top consumer house is H43. H30 is the lowest one (graph 4-1). The scenario changes radically when accounting the occupancy differences across houses.



0-1 Consumption across houses

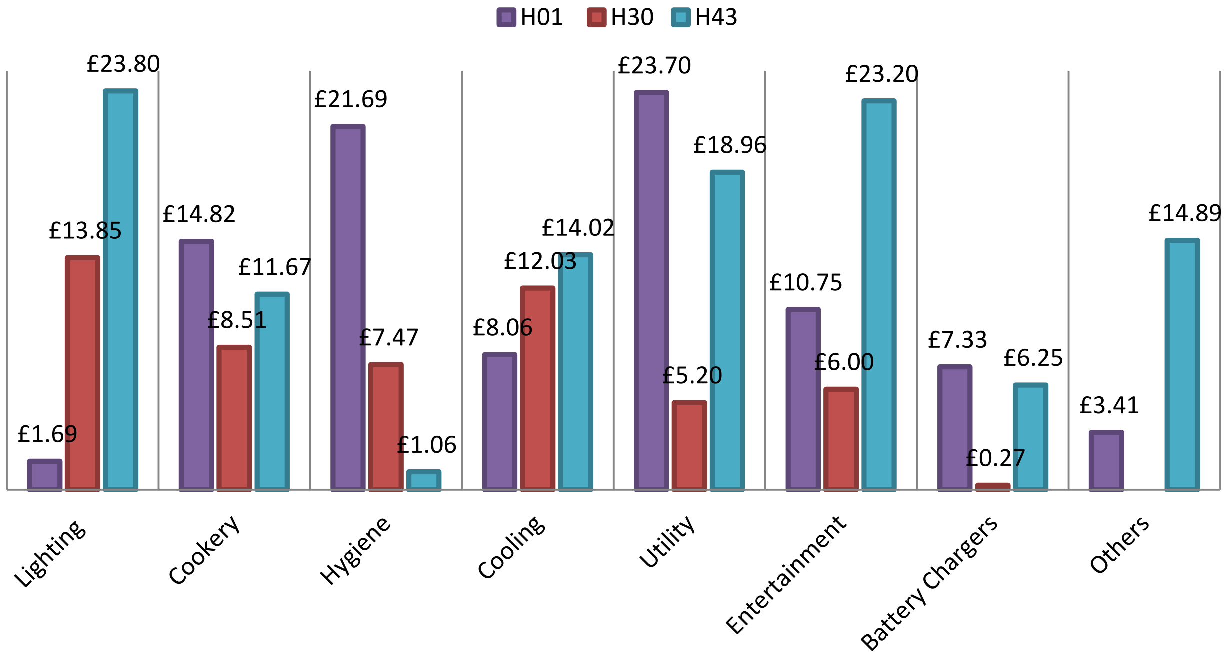
Looking at the cost per category and house there are savings that can be achieve by punctual changes in each house and category (graph 4-2)

Regarding to lighting, H01 is spending about 1/10 of the electricity demand for lighting in H30 and H43.

H01 is the only house which is equipped with a considerable number of CFL.

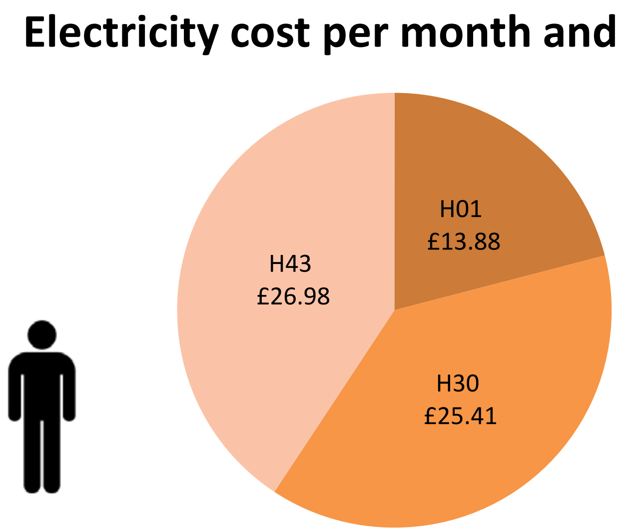
Other clear differences appear in the use of electricity in entertainment, battery chargers and hygiene.

The cooling followed by the cookery are the most regular classification when looking to the house overall but not when looking at personal consumption.



0-2 Consumption across houses by category

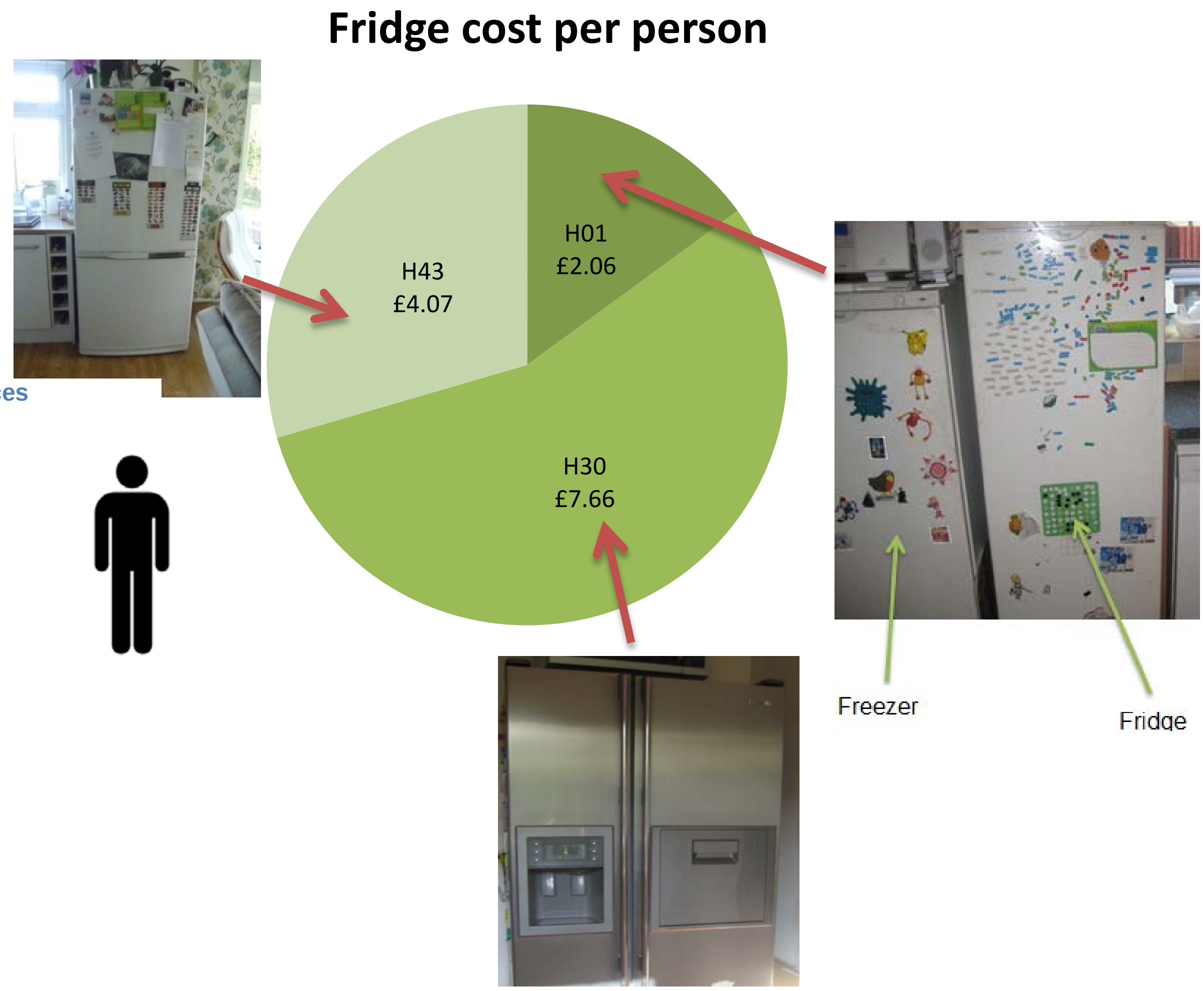
The estimated monthly electricity cost per person in H01is half the cost per person in H43. H30 is as high as it is in H43.



0-3 Total consumption across Houses

Looking at the main differences between H01 and H43 and H30, H01, as specified before, have installed CFL lights in the first floor which is making a huge difference with the other houses as it is shown in the graph 3-3.

H01 also, is generating electricity from the solar panels. It accounts for 20% of the consumption.



0-4 Cooling devices

On the other hand, H01 is using an electric shower for showering which is accounting for 20% of their electricity usage.

The cooling device is making an important difference between H01 and H30 and H43.

H01 is spending much less electricity than the other two houses, even using and independent fridge and freezer, both older devices than in the other houses (graph 4-4)

Looking at the use of specific appliances in each house, it is categorised the ten top consumer ones in the next table:

Top ten consumer appliances					
H01		H30		H43	
Shower	£ 5.40	Frige-Freezer	£ 7.66	Electric Oil Heating	£ 4.87
Cooker	£ 3.56	UnderfloorHeatingBath	£ 4.06	Fridge/freezer	£ 4.07
Tumble dryer	£ 3.16	Tvgamer	£ 3.55	Tumble	£ 3.57
Dishwasher	£ 2.18	Cooker	£ 2.97	TV Living room	£ 3.43
Freezer	£ 1.42	StandLampBed1	£ 2.53	GamerPlayR	£ 2.80
Washing mach	£ 1.08	Dishwasher	£ 2.20	Dishwasher	£ 2.69
Kettle	£ 1.04	Kettle	£ 1.86	Wii Stuff	£ 2.27
Aquarium	£ 0.84	Lamp Front room	£ 1.01	Computer Equip.Study	£ 2.06
Fridge	£ 0.64	WashingMachin	£ 0.51	Cooker	£ 1.69
Microwave	£ 0.37	Microwave	£ 0.41	Washing machine	£ 1.21

4-5 Appliances £ per person

For H01, the lowest energy consumer house, the key consumer appliance is the electric shower. It cannot be compared with the other houses because of the lack of data from the gas consumption.

For H30, the under floor heating is a key element in the house.

It is programmed to be used every day for two long periods of time. It is need to look at the temperature in the bathroom for a typical day and see if it can be re set up with shorter periods of time and if it is worth to have the heating on twice a day for the purpose they have it.

On the other hand, the TV equipment is using near 40 W constantly when not being used. This is because it is in standby position when not being used. For that reason they can be paying about £5 a month.

For H43, the electric oil heating in the studio is the top consumer device.

The studio is the work place for H43FA, which is very significant looking at electricity consumption because of the need of warming it up.

Conclusions

Cutting down energy consumption is currently a priority for most of the developed countries.

The CO_2 emitted because of the use of fossil fuel energy is not sustainable anymore.

One of the huge causes of the CO_2 production is the electricity generation and relative consumption.

Households' electricity demand is an important % of the total electricity claim.

Knowing more about the reasons of the electricity consumption within the house and investing and promoting energy efficiency in dwellings are two key facts for further electricity reductions.

The monitoring equipment can be a tool to analyse the consumption but at the same time useful feedback for the householder.

For the scope in this analysis, the fact of being estimation on two weeks of data is not accurate enough to determine any definitive trend in the sample houses.

Looking at the data, each house has a different trend regarding to energy consumption. Looking at specific demographic characteristics and focusing in the installations and appliances within the house, it is possible to pre-determine the main savings that can be done for a specific family and house.

In my point of view, feedback by monitoring electric circuits and appliances in sample houses, can lead to design educational and political interventions.

For that purpose is need to understand what is happening in real houses, which behaviours and lifestyles can drive to get a sustainable future and how to create a global conscience with the energy use.

Educational and political interventions might lead to our society to consume fair and might lead to enterprises to design to last and not to consume.

In my opinion it's need a balance between the cost of the energy and the need that it covers. The fact of warming water can be a need or a luxe depending on what it is for. The difference between a shower and a luxury shower is not highlighted on the cost so the user relay on his behaviour and attitudes which is difficult to control.

Further studies are needed to make to better understand which interventions can help to reduce energy consumption within dwellings.

Transferable skills

Loughborough University offered me several options to develop different professional skills.

During six months of dissertation I attended courses and conferences such as:

- Excel advance (4 hours)
- Word advance (6 hours)
- Project Management in the real world (6 hours)
- Conference 'Research that matters' (8 hours)
- Conference 'Climate change' (2 hours)
- Conference 'Recent Sociotechnical Research on National Energy Demand'

Furthermore, I received continuous supervision from Richard Buswell. He gave me several tutorials to drive Matlab and MySquirol Database.

Acknowledgements

The "Erasmus Practicas" Program has been funded by the Universidad Politecnica de Valencia along with the Education and Science Minister of which I am grateful. The opportunity that this program offers to the university students to get integrated in another's country professional field is of uncountable value.

Notable thanks go to my supervisor Dr Isabel Tort whose invaluable help and guidance through the year has been paramount. Isabel never lacked in enthusiasm which helped keep me motivated and was always willing to make time to help me.

Thanks to Dr Richard Buswell, my supervisor in Loughborough University for relying on me and allowing me as part of the LEEDR PROJECT. Richard offered me several tools to develop my dissertation and supervise me with dedication.

I would like to give thanks to Dr Lynda Webb who treat me as a trainer and teach me lots of work techniques.

Ultimately, I would like to thank my family for their infinite love and support, and my husband Carlos to make a special day of each day in England.

"The patience is the mother of the science"

Appendix

Appendix 1 Visit procedures and protocols

The following guidelines and procedures for LEEDR researchers visiting participant households function in addition to and accordance with individual departments' risk assessments".

General Guidelines

Even dealing with lower-risk procedures, it's needed to keep safety in mind during the installation process:

•Participant recruitment process.

• Initial technical visit.

•Installation of monitoring equipment.

Incidents need to be recorded in household calendars and registered with one of the supervisors. Team members are also asked to record any odd or worrying behaviour in household calendars, even if no specific incident has occurred. It is important that all members of the team know they can voice concerns.

While working, each team member must:

1. Aim to work during reasonable daylight hours (avoid working after dark when possible)

2. Confirm dates and times with households before each visit, as specified by householder.

3. Ask who will be at home; if uncomfortable with this person and/or depending on gender set-up, consider taking a colleague.

4. Nominate a safety person (this is the partner in paired visits or another reachable colleague during lone working trips)

5.Share a hardcopy of participant address details (including landline) and the researcher's active (project) mobile number with nominated safety person prior to visit (lone working)

6. Specify times and procedures for safety calls (different procedures apply, depending on lone or paired work, see below)

7. Make the first safety call (arrival) in the presence of the householder (this will have been explained to householders; if necessary, remind them this is common procedure)

8. Ensure shared household calendars are up to date before starting work, on completion of a visit, and in case of a change of plan. -- Calendar entries should include:

•Researcher initials

•Household code

•Expected time and duration of visit

•Name of nominated safety person (lone working)

•Number of active project mobile (lone working)

9. Be in reach via mobile phone at all times (try carrying it on the body) – ensure the mobile is charged and has credit; organise other means of contact if out of reception area.

10. Carry and present a university ID card.

11. Carry change for emergency phone calls.

12. Draw on departmental taxi account if in urgent need of a taxi (payment is automated)

13. Keep (car/bike) keys on them when in the house.

14. Determine an exit strategy (identify possible points of refuge) before visiting a house for the first time.

15. Avoid research activities in kitchens/bedrooms, though this may not always be possible.

16. Aim to sit close to doors; ensure no person can get in the way of the nearest exit.

17. Be relaxed around householders but remain vigilant; walk away from situations that give any cause for alarm.

18. Politely refuse to enter a house where the occupier appears aggressive or intoxicated.

19. Avoid dealing with children on their own, always ask for an adult to be present or nearby before entering a house (leave doors open and maintain contact with adults in the house if having to deal with children on a one-to-one basis).

Lone Working

Researchers should be free to work on their own, if necessary. If in doubt, it is important researchers feel able to ask a colleague to accompany them to participant households.

Researchers choosing to work on their own must:

1. Nominate a safety person prior to their visit and agree on relevant information and procedures with them (see below)

2. Carry a charged project mobile with credit; preferably carry their private phone also.

3. Carry a hardcopy of the safety person's phone number, plus that of accredited taxi firm (01509 260000).

It would be advisable to have the safety person's phone number on speed dial, for easy access. Lone working procedures require a minimum of two phone calls between researcher and nominated safety person, one on arrival at participant households (and in the presence of the participant), and one on departure (when having left the house). It is advised that, for added safety, researchers and safety persons set automated reminders on their phones prior to visits, so the risk of forgetting a phone call is minimised. If a research visit takes longer than expected, an additional phone call needs to be made to inform the safety person of this change in procedures, and a new time for the departure phone call needs to be arranged.

Safety persons and researchers need to update each other about any change of circumstances before proceeding with a task. To do so, they need to speak to each other in person – e-mails or text messages are not enough, unless changes occur sometime before the visit and there is opportunity to confirm them with each other.

A nominated safety person must:

- Be in a position to respond to and make phone calls.
- Have a copy of the emergency protocol to hand when on call (see below) Know a given participant household address and phone number.
- Know the number of the active project mobile.
- Know expected times of contact.

Working in Pairs

In particular, paired researchers must:

- Exchange mobile phone numbers.

- Identify the safest and most reliable form of transport to a house; if possible, aim to travel to and from participant households together.
- Agree on a safety procedure prior to leaving the participant household; if travelling on their own at night (or whenever required) inform each other of the safe arrival at a predetermined location (e.g. home) at a prearranged time after the research visit.

The latter is as significant in pairs as it is in the case of lone working. If out of mobile reach, researches need to ensure other reliable means of communicating with the colleague.

Paired researchers can choose to follow a lone-working safety procedure (i.e. nominate an additional safety person), if they so wish. This may be especially relevant to female researchers working in pairs and outside office hours.

Travelling to and from Households

Consideration should be given to the safest and most reliable form of transport to, and from households.

If travelling by bike, it is good practice to wear visible clothes and a helmet, and to have lights (this is the law after dark). In any case, all travelling equipment needs to be ‘roadworthy’ (and insured for purpose).

If visiting a household during the evening (and particularly during lone working), it is advised to travel by car or pre-book a taxi. Researchers need to make use of a university- and LEEDR-approved taxi firm.

Emergency Protocol – Lone Working

A researcher is in a difficult situation which they cannot get out of, but they find a way to call:

Researcher to inform safety person of the situation and level of perceived danger. If there is scope for the safety person and an additional colleague to resolve a situation, this option can be considered. If there is acute danger and the researcher cannot walk away, the safety person needs to call 999 and provide the police with all necessary information about the researcher’s context and whereabouts.

A researcher calls safety person but cannot talk:

Safety person to call researcher’s private mobile and, if necessary, participant household. If no response or there seems to be a problem, call 999.

A researcher does not call at pre-arranged time:

Safety person to call researcher 10 minutes after expected time of arrival or departure

-No answer: Call household to check if the researcher has arrived/left.

-No answer from household: Try calling researcher's private mobile and project mobiles for another 10 minutes. If no answer, call 999.

Researcher is there: Ask to speak to the researcher, clarify the situation.

Researcher can speak, and all is well: Researcher explains situation

Researcher can speak, but there is a problem: Safety person to call 999

Researcher is there but cannot come to the phone: Ask to be called back within 10 minutes. If no answer: call 999.

Researcher does not appear to be there: Try calling researcher's private and project phones for a period of 10 minutes. If no contact, call 999.

Emergency Protocol – Working in Pairs

A colleague has not arrived at the participant address:

1. Try calling colleague straight away – your colleague should have notified you of any delay, the participant is waiting, and you have agreed to enter the house together.*

2. If there is no answer, wait 10 minutes, then call again.

3. If there is still no answer, try calling other known phone numbers (office, colleagues, etc.).

4. If, after 1 hour, there has not been a response, call 999 and provide them with any information you have.

* For your own safety or comfort, do not enter the participant household unless you have informed an additional colleague of the situation. If you cannot get hold of another colleague, reschedule your visit.

A colleague fails to send their notification of safe arrival post-visit:

1. Give your colleague 10 minutes to respond.

2. Call their mobile – repeatedly, if necessary. If they respond, good: check what the problem was, establish how they could have gotten in touch.

3. If there is no response, call any other related numbers (e.g. landline, friends, colleagues)

4. If 1 hour has passed and there has not been a response, call 999.

When calling 999 in an emergency, make reference to the team safety protocol and explain that there is reason to be concerned for the safety of the colleague.

Appendix 2: Data protection and Risk assessment

The practices and policies noted below must be followed by all the team at any time for managing information securely. These practices follow the appropriate standards and legislation.

Security is considered to cover durability, authorization and authentication, which are managed through physical, administrative and technical controls. A risk management approach is adopted based on the ISO 27001 standard for information security.

Risk Assessment

Value	Classification	Description
0	Public	Non-sensitive information, resources and processes available to the public.
1	In Confidence	Sensitive information, resources and processes restricted to the LEEDR project.
2	Personal in Confidence	Personal information and resources available on a *need-to-know* basis only to selected members of the project.
3	Sensitive Data	Sensitive data is information that a person may consider secret or confidential. For example beliefs, health and criminal activities. These resources are available only on a *need-to-know* basis and carry legal and financial penalties for unauthorized disclosure.

Table 1 - Confidentiality classification

Value	Classification	Description
0	Low integrity / criticality	The unauthorized damage or modification of information has very low impact on the project. For example, loss of temporary files.
1	Medium integrity / criticality	The unauthorized damage or modification of information is not critical, but may impact on the project. For example loss of derived information that may take considerable time to recover or temporary loss of sensor information.
2	High integrity / criticality	The unauthorized damage or modification of information, which cannot be recovered. This covers primary data, such as long term / large-scale loss of sensor data.

Table 2 - Integrity classification

Value	Classification	Description
0	Low availability	Information that is retrievable within 1-2 days.
1	Medium	Access to information must be available on campus

	availability	24/7 upon request.
2	Very high availability	Immediate access is required, such as working documents.

Table 3 - Availability classification

Asset Classification

ISO27001 classifies information assets according to confidentiality, integrity and availability. Tables 1-3 define each classifications for the purposes of the LEEDR project.

Classification is based on the Loughborough University Data Protection Policy, which outlines definitions of confidentiality and provides requirements on data integrity.

Asset Identification

The LEEDR project aims to contextualise home energy consumption by family households and subsequently use this insight to explore low effort interventions for reducing energy use. The project observes a representative set of family households for a period of three years. These observations involve disaggregation of energy use within the home as well as behavioural observations through sensors and ethnographic techniques. That generates a set of data representing many aspects of family life.

The following sections outline the types of information that are collected.

Personal Details

To provide demographic and location information. This information is used to select suitable homes from the recruitment.

Energy consumption

Energy use by each household is monitored through monitors on the gas and electricity consumer units. This information is disaggregated through individual sensors attached to selected electricity appliances.

Behaviour monitoring

Additional sensors provide behaviour monitoring. For example thermal status will be monitored through window sensors, humidity and temperature sensors. A sub set of households may be involved in additional monitoring such as movement within homes. Unlike energy monitoring, behaviour monitoring is likely to be viewed as sensitive data by volunteers.

Audio interviews

Interviews with households are recorded. Transcripts of each interview will be taken.

Video studies

Select activities conducted by researchers and households require video records, which can provide rich contextual information.

Ethnographic narratives

The behaviours and patterns of each household may be captured through ethnographic narratives. These narratives provide a rich context to energy usage within a household; as such they may contain information that is classified as sensitive.

Documents

Throughout the project documents and reports are produced. This information include primary sources such as questionnaires and surveys of the households or derived information that is obtained through analysis of primary data sources.

ID	**Description**	**Source**	**Confidentiality**	**Integrity**	**Availability**
1. Personal Details					
1.1	Location information	Primary	Personal	High	Low
1.2	Demographic information	Primary	Sensitive	High	Low
2. Energy Consumption					
2.1	AlertME Sensor data	Primary	In Confidence	High	High
2.2	IndeedNet Sensor data	Primary	In Confidence	High	High
2.3 Gas Measurement					
2.3.1	Gas Meter Images	Primary	In Confidence	High	High
2.3.2	OCR Meter Values	Secondary	In Confidence	Medium	High
3. Behaviour monitoring					
3.1	Thermal comfort monitoring	Primary	In Confidence	High	High
3.2	Movement monitoring	Primary	Personal	High	High
4. Audio Interviews					
4.1	Audio recording	Primary	Personal	High	Medium
4.2	Transcripts	Secondary	Personal	Medium	High
5. Video studies					
5.1	Video Tour	Primary	Personal/ Sensitive	High	Medium

5.2	Other primary video	Primary	Personal	High	Medium
5.3	Derived video collections	Secondary	Personal	Medium	High
6. Ethnographic Narratives					
6.1	Activity Stories		Sensitive	High	High
7. Questionnaires					
7.1	Technical Suitability Survey	Primary	In Confidence	High	Low
8. Documents					
8.1	Getting to know you	Primary	Personal	High	Low
8.2	Analysis and Reports	Secondary	Public / In Confidence	High	Medium

Table 4 - Asset Register

Asset Register

Each type of information may contain a number of assets with differing risk classifications. The register is reviewed and amended periodically throughout the LEEDR project as the requirements of the project develop.

Threat Identification and Assessment

Table 5 defines a risk register for various threats that may occur to the assets identified in the asset register. The table is priority ordered with the most likely threats listed first.

ID	Threat	Example	Likelihood	Risk
1.	Storage Device failure	Hard disk crash	High	Loss of integrity
2.	Software failure	Application crash	High	Loss of integrity
3.	Physical media loss	Loss of flash memory devices.	High	Loss of integrity, theft, unauthorized access, disclosure of personal data
4.	Virus / Trojan	Windows virus	High/Medium	Loss of integrity, unauthorized access, unauthorized monitoring, disclosure of personal data
5.	Accidental operations (authorised)	Accidental file deletion or alterations.	Medium	Loss of integrity.

6.	Authorized users	Many simultaneous users	Medium	Delayed access, denial of service, loss of integrity,
7.	Physical loss (malicious)	Theft of laptop	Low	Loss of integrity, unauthorized access, disclosure of personal data
8.	Unauthorized user (curious)	Unanticipated access through Google search	Low	unauthorized access, unauthorized monitoring, disclosure of personal data
9.	Unauthorized user (malicious)	Deliberate attack on services	Low	Loss of integrity, unauthorized access, unauthorized monitoring, disclosure of personal data
10.	Natural disaster	Building fire	Very Low	Large scale loss of data

Table 5 – Risk Register

Risk Treatment

Risk treatment helps guide solutions to reduce, transfer or avoid the next. Recommendations must balance the cost of treatments against the likelihood of potential threats. The threats identified in section 3.4 can be broadly grouped as resulting in loss of data integrity and/or unauthorised access and disclosure, which are addressed separately by sections 4.1 and 4.2 below.

Solution	**Threat mitigated**	**Availability**	**Cost**
Duplicate disk partitions.	Software failure	Medium, manual backup and recovery.	Low
Duplicate physical disks	Software failure, Physical failure	Medium, manual backup and recovery.	Low, additional commodity disks
RAID Storage	Software failure, Physical failure	High, transparent data backup and recovery. Does not protect authorised deletion.	Medium, additional software or hardware required.
Duplicate systems	Software failure, physical, denial of service.	High, transparent data backup and recovery. Does not protect authorised deletion.	High, duplicate physical resources required.
Periodic off-line storage (physical access controls)	Software failure, Physical failure, Accidental	Low, data must be physically retrieved through administration controls.	Low, additional commodity disks required.

	commands. Natural		
Periodic off-line storage (encrypted access)	Software failure, Physical failure, Accidental commands, Natural, Theft, Accidental loss.	Low, data must be physically retrieved through administration controls.	Medium, additional disks with appropriate software or hardware encryption.

Table 6 - Data duplication solutions

Data integrity

Assurance of data integrity is critical to achieving verifiable research outputs from the LEEDR project. The project is also obligated to maintain accurate information on volunteers as outlined by the Data Protection Act.

Data integrity can be managed through appropriate detection and recovery from loss of data (risk reduction). The most likely scenarios resulting in loss of data integrity are system failures resulting in data corruption. These losses are detectable through file system integrity checks and physical self-tests. The threat of accidental operations might be reduced through the use of data versioning, write access protection and off-line storage. Detection issues arising from the deliberate and malicious alteration of data are not easily mitigated through detection mechanisms that would be proportionate to the likelihood of occurrence. Risk treatment should instead focus on prevention of unauthorised access.

Recovery from detected data loss can be achieved through duplication of data across devices or systems that are not subject to the same simultaneous risk.

The LEEDR project is classified as a *longitudinal study* under the university data collection guidelines due to the three year duration of the project. As a result, collected data must be retained for 10 years after completion of the study. An archive off-line solution is appropriate for long-term storage, as the guidelines do not require a particular level of availability.

Unauthorized access

Preventing unauthorized access to information assets is essential for compliance with the Data Protection Act. A lack of appropriate controls resulting in unauthorized disclosure of data would constitute a breach of the act and severely impact the reputation of the project. The Data Protection Act limits authorization to that granted by volunteers upon consenting to the LEEDR project, therefore for consent forms must include “use by members of the LEEDR project”.

Impact reduction

The impact of unauthorized data disclosure must be reduced. In the project, it is achieved through de-identication of data at the point of collection.

De-identification must be reversible through a coded system, such that when required all data associated with a volunteer, can be retrieved. This is to allow volunteers to leave the project at any time, as defined in Loughborough University’s Data Collection and Storage policy.

Reversible de-identification is achieved through a coded lookup table, which match each volunteer and household to a unique and unrelated code. This code is applied to energy, behaviour monitoring, documents, notes and narrative assets.

Use of codes:

A suitable coding format MUST be derived in part using a randomly assigned number and a shorthand term to classify the entity. For example:

- Houses can described using H01, H13, H28.
- Adults in the house can be described as AF01, AM14, an female adult and adult male respectively.
- Children in a house can be described as CF23, CF14, a female child, and male child respectively.

The coding format MUST NOT be derived from identifiable information associated with the entity, for example the household postcode.

The coding format for persons within a house MUST NOT contain explicit links between members of the household. For example:

- H01AF01, H02AM02, H01CM01.

The coding format should also avoid being sequential or predictable. For example:

- H01, AF01, AM01, CF01.
- H02, AF02, AM02, CM02.

Sequential numbering such as this infers links between all entities within a household.

A map translating coded forms to real identities is stored as a secure lookup table.

The lookup table that associates name and addresses with individual codes MUST be:

- Stored in paper form ONLY.
- Kept in a locked cabinet in a room on campus, which is restricted to University staff (including postgraduates).

The lookup table MUST NOT be:

- Photographed except for the purpose of a photocopy.
- Digitised or stored on a computer.
- Removed from the room in which it is stored.
- Taken off campus.

Duplication of the lookup table is permissible. Each new copy must be stored according to the above guidelines. Unwanted copies must be destroyed using a cross-cutting shredder before being recycled.

Personally identifiable information such as location information, audio and video cannot be reduced in confidentiality through a coded system. Therefore, it is critical that these assets (in particular the coded lookup table itself) are not stored along side anonymised data. Where this is not practical, all assets must be assumed to have a sensitive confidentiality level and appropriate control mechanisms implemented.

Risk avoidance

The risk of unauthorized access is being avoided by giving careful consideration to the collection of personal and sensitive data.

Prevention

The likelihood of unauthorised access is being reduced through administrative and technical controls as outlined in Table 7. A suitable prevention treatment will involve a set of these controls.

Primary data storage use both encryption and physical controls to prevent unauthorized access and loss.

When working with data that has confidentiality classification of higher the computer system implement a form of secure asset storage, (whole disk encryption), and have system integrity maintenance. Data that has been de-identified does not require a computer system with secure storage.

Solution	Threat mitigated	Cost

Secured asset storage (encryption)	Accidental loss, unauthorized access (curious and malicious)	Medium, additional disks with appropriate software or hardware encryption.
Secure asset storage (encryption and physical controls)	Loss (accidental, theft), unauthorized access (curious and malicious)	Medium, additional disks with appropriate software or hardware encryption.
System integrity maintenance (Anti-virus and operating system updates)	Virus/ Trojan, unauthorized access (malicious)	Low
Management of credentials	Unauthorized access (malicious)	Low
Encrypted data transfer (SSL)	Unauthorized access (malicious)	Low (requires signed certificates).

Table 7 - Unauthorized access solutions

Implementation of risk treatment

This section outlines the policies and procedures that must be followed to correctly implement the risk treatments.

Centralised data repository:

A centralised repository is utilised to provide high-availability of primary information assets. The repository maintains data integrity whilst restricting data access to authenticated project members.

The central repository must authenticate LEEDR project members through a username and password combination, which meets the credential requirements outlined in section 5.3 below. The repository must attempt to detect authentication misuse by detecting duplicate access from separate locations.

Individual information assets access permissions within the repository to prevent accidental alteration or viewing of assets. These access permissions describe:

- Users that are permitted to delete or edit an information asset.
- Users that are permitted to view an information asset.

Data storage

Data storage implements a transparent backup and recovery system such as RAID or duplicates system resources. The storage solution is durable to recover from a physical or software incident affecting up to 50% of the underlying storage devices.

The storage system include periodic off-line backup of all information assets to protect against accidental loss of data, theft and natural disaster. The off-line backup must be stored securely in a locked cabinet at separate location.

Communication

Remote access to the repository is restricted to the university computer network, including secure off-campus access through the VPN. Where possible all communication with the repository utilise a secure-socket layer (SSL).

Credential types

There are two distinct types of credentials used within the LEEDR Project:

- Shared authorization credentials such as when transferring secure documents or archives. For example an encrypted external USB drive.
- Authentication credentials – which are used to identify as well as authorise a team member and must not be shared with anyone. One example is the University username and password.

Password Structure

Passwords used to obtain access to LEEDR information assets must meet the requirements that Loughborough IT Services recommend[1].

Incident Reporting

Asset loss independent of recovery must be recorded in a register. This allows appropriate action to be taken according to the risks established in this document. The register will also inform further reviews of this document in the future and inform the development administrative and software procedures.

Documents and Standards

Publications

- *Social Research: Data Security Review – The Scottish Government*
- *Guidance Notes for Investigators - Data Collection and Storage – Loughborough University (http://www.lboro.ac.uk/admin/committees/ethical/gn/dcas.htm)*
- *Loughborough University Data Protection Policy (http://www.lboro.ac.uk/admin/ar/policy/dpact/ludpp/)*

Legislation

- *Data Protection Act 1998*
- *Computer Misuse Act 1990*

Standards

- *ISO/IEC 27001:2005 - Information security risk management*
  Designed to ensure the selection of adequate and proportionate security controls that protect information assets and give confidence to interested parties.

[1] http://www.lboro.ac.uk/it/doc/guidance.html

- *ISO/IEC 27002:2005 - Code of practice for information security management Establishes guidelines and general principles for initiating, implementing, maintaining, and improving information security management in an organization.*

- *ISO/IEC 27003:2010 - Information security management system implementation guidance*
  Focuses on the critical aspects needed for successful design and implementation of an Information Security Management System (ISMS).

- *FIPS_140-2 - Security Requirements for Cryptographic Modules*
  A U.S Government standard for the certification of cryptographic techniques. It requires accreditation of storage devices by an independent approved lab (compliant with ISO 17025). This standard is recommended for all research directly contracted by the UK Government.

Appendix 3 : Ethics

The participants need to declare the next statements

•The purpose and details of the study have been explained.

•It's understood that this study is designed to further scientific knowledge and that all procedures have been approved by the Loughborough University Ethical Advisory Committee.

•The information sheets and the consent form it's read and understood.

They are asked to confirm that:

•They had the opportunity to ask questions about their participation.

•They understand that there's no obligation to take part in the study.

•They understand that they have the right to withdraw from this study at any stage for any reason, and that they will not be required to explain their reasons for withdrawing.

The children within the houses are active part of the project. They need to fill the form showed in the next figure by confirming:

•The LEEDR study was explained to me.

•They understand that it is their choice to take part.

•They understand that the amount of electricity, gas and water used in the house will be monitored.

•They understand they can choose whether or not to be part of any photos, audio or video recordings.

Consent Form

(to be completed after the Booklet and Information Sheets have been read)

The purpose and details of this study have been explained to me. I understand that this study is designed to further scientific knowledge and that all procedures have been approved by the Loughborough University Ethical Advisory Committee.

I have read and understood the information sheets and this consent form.

I confirm that:

I have had an opportunity to ask questions about my participation.

I understand that I am under no obligation to take part in the study.

I understand that I have the right to withdraw from this study at any stage for any reason, and that I will not be required to explain my reasons for withdrawing.

I agree to participate in this study and I also agree to (please tick yes or no):

Monitoring gas and electrical consumption at the meters and some appliances continually for three years	Yes ☐	No ☐
Monitoring hot water usage continually for three years. I understand this will require professional fitting of one water flow meter into my existing pipe work.	Yes ☐	No ☐
Being interviewed and audio recorded as part of this study	Yes ☐	No ☐
Being photographed as part of this study	Yes ☐	No ☐
Being video recorded as part of this study	Yes ☐	No ☐
Photographic materials in which I am shown being included in the publications arising from this research	Yes ☐	No ☐
Video materials in which I am shown being published on-line (I will be able to review all video material before it is published and agree on methods of anonymizing materials if I chose).	Yes ☐	No ☐
I would like to remain anonymous in all publications including videos and images.	Yes ☐	No ☐

I understand that any images and texts made during the research and that are given to me will remain in the ownership and the copyright of the LEEDR project.

Your name: ______________________ (Please print)

Your signature: ______________________ Date: ..../......./........

Researcher's name: ______________________ (Please print)

Researcher's signature ______________________ Date: ..../......./........

LEEDR Willingness to Take Part Form Participant Copy ☐
Project Copy ☐

Willingness to Take Part Form

- I have had the LEEDR study explained to me.
- I understand that it is my choice to take part.
- I understand that the amount of electricity, gas and water used in the house will be monitored.
- I understand I can choose whether or not to be part of any photos, audio or video recordings.

Your name: ______________________ (Please print)

Your signature: ______________________ Date: ..../......./........

Researcher's name: ______________________ (Please print)

Researcher's signature ______________________ Date: ..../......./........

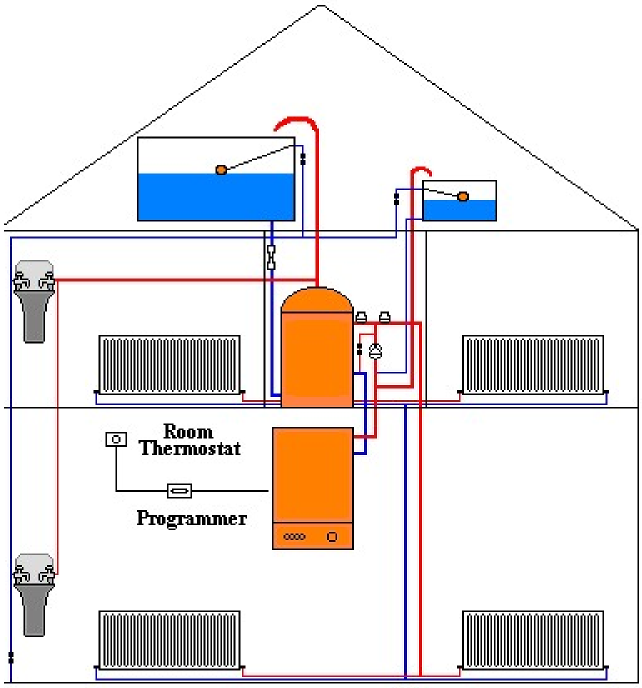
Appendix 4: Heating systems:

System with a boiler:

1. Conventional: These boilers are only a heat source, and require a pump & control valves to be fitted separately, as well as a header tank, or sealed **(1)** system kit.

Up until the early 80s the majority of heating systems installed were conventional (traditional type).

This requires a hot water storage cylinder and 2 cold water storage cisterns within the roof space - one for feeding the hot water cylinder and one for feeding the central heating system. This makes maintenance very difficult as the tanks often suffered from frost related problems in the roof space.



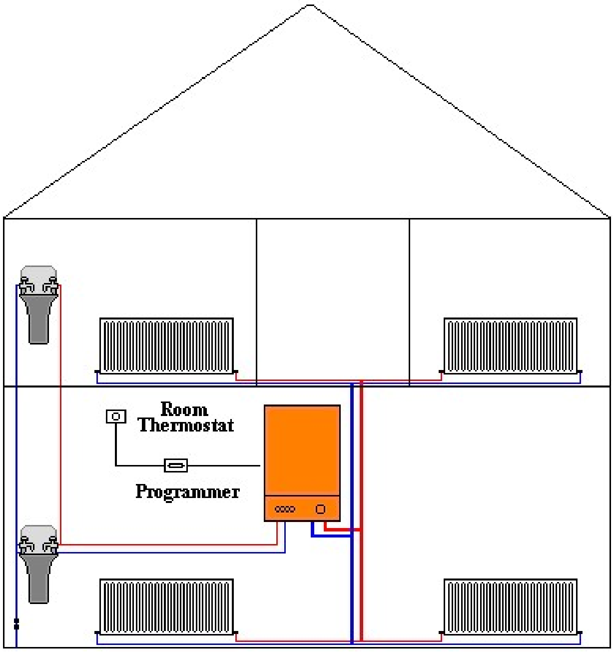
(1) To enable the boiler/system to work correctly, a sealed system, will include a pressure vessel, pressure gauge, pressure relief valve, and a fill loop, these item may be incorporated within the boiler, or fitted separately.

2. Combination (Combi): Combination boilers include a pump & a changeover valve to switch between instantaneous hot water, and heat to the radiators. They are usually on a sealed system, but some early ones where suitable for an open system with a header tank.

Combi boilers, as they are known, are the most popular choice for homes today.

These boilers heat domestic hot water instantly and have no storage tanks in the loft space.

Combi's have everything under one cover including the pump and often come with integrated time clock and temperature control.



3. System: System boilers are boilers which supply heat to a heating system, and usually a cylinder. Within the casing they contain a pump & sealed system kit. They will require a separate control valve to switch between cylinder and/or radiator supply.

All three types can be found to be either **condensing or non condensing**. Since 2005, England, required all newly installed domestic boilers, (with a very small number of exemptions) to be energy rated A or B, to achieve this they are condensing boilers.

Condensing boilers remove more heat from the gases given off by the burner, and some of the fumes condense into water within the boiler, which is drained from the bottom of the boiler.

Each boiler may be suitable for either an open **system or a sealed system**.

Generally the older boilers will only be suitable for a open sytem, with a header tank, at a high level such as the loft. Newer boilers may be suitable for either an open system or a sealed system, or only a sealed system.

A Sealed system means that the system is charged with a temporary connection to the cold mains, to a pressure of around 1.3 bar (typically a third of mains pressure).

- Heat exchangers:
  - Radiators.
  - Under floor heating.

- Heating controls:
  - Room thermostat
    - Fix to wall
    - Moveable
  - Programmer with simple time-clock.
  - Programmer with multiple temperature/time settings.
  - (In radiators) Thermostatic control valves.

Electric System

Electrical energy is converted to heat. An electric heater is an electrical appliance that converts electrical energy into heat. The heating element inside every electric heater is simply an electrical resistor, and works on the principle of Joule heating: an electric current through a resistor converts electrical energy into heat energy.

The next graphic shows the different system used depending on the year of construction of the house.

- Heat exchangers:
  - Storage heaters.
  - Warm air.
  - Electric fire
  - Radiative heaters
  - Convection heaters
  - Fan heaters
  - Domestic electrical underfloor heating
  - Heat pumps

Other systems:

- Open fire.

Appendix 5: Hot water systems

- Main Heating system. (The fuel used is Gas)
- Electric immersion heater.

The heater contains an insulated electric resistance heater and a temperature sensor. Domestic immersion heaters (usually rated at 3 kilowatts in the UK) run on the normal domestic electricity supply.

Instant (in-line) shower

(These water heaters instantly heat water as it flows through the device, and do not retain any water internally except for what is in the heat exchanger coil).


Thankless heaters are often installed throughout a household at more than one point-of-use (POU), far from the central water heater, or larger models may still be used to provide all the hot water requirements for an entire house. The main advantages of tankless water heaters are a continuous flow of hot water and energy savings (as compared to a limited flow of continuously heating hot water from conventional tank water heaters).

- Range.

Appendix 6: Tables and graphs used for the analysis:

	Week		Mains 1	Lighting	Cookery	Hygiene	Cooling	Utility	Entertainment	Battery Chargers	Others	Solar PV
	W1	mJ	432.209	8.76742	63.905	76.634	30.261	94.996	40.037	27.676	13.025	74.257
H01		%	100%	2%	15%	18%	7%	22%	9%	6%	3%	17%
	W2	mJ	371	3.925	47.273	86.004	30.186	82.752	40.576	27.286	12.578	84.4
		%	100%	1%	13%	23%	8%	22%	11%	7%	3%	23%
	W1	MJ	273	43	27	25	44	16	21	1		
		%	100%	16%	10%	9%	16%	6%	8%	0%		
	W2	MJ	282.39	60.85	36.82	31	46.21	23	24	1		
H30		%	100%	22%	13%	11%	16%	8%	9%	0%		
	W1	mJ	758	73	37	2	55	88	107	26	76	
		%	100%	10%	5%	0%	7%	12%	14%	3%	10%	
	W2	MJ	545	39	13	6	50	54	67	21	36	
H43		%	100%	7%	2%	1%	9%	10%	12%	4%	7%	

1 Consumtion per categories for each week

	Units	Mains 1	Lighting	Cookery	Hygiene	Cooling	Utility	Entertainment	Battery Chargers	Others	Solar PV
H01	MJ	401.6045	6.34621	55.589	81.319	30.2235	88.874	40.3065	27.481	12.8015	79.3285
	MJ per person	80.3209	1.269242	11.1178	16.2638	6.0447	17.7748	8.0613	5.4962	2.5603	15.8657
H30	MJ	277.695	51.925	31.91	28	45.105	19.5	22.5	1		
	MJ per person	138.8475	25.9625	15.955	14	22.5525	9.75	11.25	0.5		
H43	MJ	651.5336	89.25994	43.7495	3.9722	52.5728	71.0915	87.0095	23.4515	55.832	
	MJ per person	162.8834	22.314985	10.93738	0.99305	13.1432	17.77288	21.752375	5.862875	13.958	

2 Media of consumption by categories

House	Unit	Week	Mains 1	Small Power Down	Kitchen sockets	Small Power Up	Lighting Down	Lighting Up	Lights	Cooker	Shower	Freezer	Fridge Freezer	Freezer and Fridge Freezer	Extension Lights	Water Heater	Sockets 1	Kitchen Sockets	Microwave	RCD circuit	Solar PV
H01	mJ	Week 1	432				8.743	0		39.833	75.063						266.662				74
	%		100%				2%	0%		9%	17%						62%				0
	mJ	Week 2	371				4	0		26	85						250				84
	%		100%				1%	0%		7%	23%						67%				0
	Media		401.60				6.32	0.00	0.00	32.82	79.83						258.33				79.33
H30	mJ	Week 1	273.24606	44	73	68.28	14	29		12			44						3		
	%		100%	16%	27%	25%	5%	11%		5%			16%						1%		
	MJ	Week 2	282.39	49.98	80.18	72.94	20.00	23.87		22.83			46.21						1.72		
	%		100%	18%	28%	26%	7%	8%		8%			16%						1%		
	mJ		277.8	46.8	76.8	70.6	17.0	26.6		17.6			45.3						2.4		
H43	mJ	Week 1	758				28	14	72	20			55				40			503	
	%		1				4%	2%	9%	3%			7%				5%			66%	
	mj	Week 2	545				13	13	38	4			50				12			374	
	%		100%				2%	2%	7%	1%			9%				2%			69%	
	mJ		652				20	13	55	12			53				26			438	

3 Consumption by Electric Circuit

	Devices	Media consumption MJ	Year consumption MJ	Total Consumption/year KW h	£	£ Monthly No discount	KW h	£ monthly	£ m/per perso
H01	total	401.6045	24430.94042	6786.372338	1628.73	135.7274468	565.531	69.4	13.88
	Tumble dryer	46.8	2848.216667	791.1712963	189.881	15.82342593	65.9309	15.82343	3.164685185
	shower	79.8315	4856.41625	1349.004514	323.761	26.98009028	112.417	20.12	5.396018056
	dishwasher	32.233	1960.840833	544.6780093	130.723	10.89356019	45.3898	10.89356	2.178712037
	cooker	53	3207.924167	891.0900463	213.862	17.82180093	74.2575	15.94	3.564360185
	freezer	21	1277.5	354.8611111	85.1667	7.097222222	29.5718	7.097222	1.419444444
	washing mach	16	973.3333333	270.3703704	64.8889	5.407407407	22.5309	5.407407	1.081481481
	kettle	15	934.50585	259.5849583	62.3004	5.191699167	21.6321	5.191699	1.038339833
	Aquarium	12	756.1583333	210.0439815	50.4106	4.20087963	17.5037	4.20088	0.840175926
	Fridge	9	574.5039167	159.5844213	38.3003	3.191688426	13.2987	3.191688	0.638337685
	Microwave	5	329.8067	91.61297222	21.9871	1.832259444	7.63441	1.832259	0.366451889
H30	total	278	16900.59683	4694.610229	1126.71	93.89220458	391.218	50.81	25.405
	Frige-Freezer	45.32333	2757.169242	765.8803449	183.811	15.3176069	63.8234	15.31761	7.658803449
	UnderfloorHeatingBa	24	1460	405.5555556	97.3333	8.111111111	33.7963	8.111111	4.055555556
	Tvgamer	21	1277.5	354.8611111	85.1667	7.097222222	29.5718	7.097222	3.548611111
	Cooker	17.58641	1069.839942	297.1777616	71.3227	5.943555231	24.7648	5.943555	2.971777616
	StandLampBed1	15	912.5	253.4722222	60.8333	5.069444444	21.1227	5.069444	2.534722222
	Dishwasher	13	790.8333333	219.6759259	52.7222	4.393518519	18.3063	4.393519	2.196759259
	Kettle	11	669.1666667	185.8796296	44.6111	3.717592593	15.49	3.717593	1.858796296
	Lamp Front room	6	365	101.3888889	24.3333	2.027777778	8.44907	2.027778	1.013888889
	WashingMachin	3	182.5	50.69444444	12.1667	1.013888889	4.22454	1.013889	0.506944444
	Microwave	2.43425	148.0835417	41.13431713	9.87224	0.822686343	3.42786	0.822686	0.411343171
	Toaster	1	60.83333333	16.89814815	4.05556	0.337962963	1.40818	0.337963	0.168981481
	Extractor Fan Bath	1	60.83333333	16.89814815	4.05556	0.337962963	1.40818	0.337963	0.168981481
	UnderCupBoardLight	1	60.83333333	16.89814815	4.05556	0.337962963	1.40818	0.337963	0.168981481
H43	Total	652	39634.95763	11009.71045	2642.33	220.194209	917.476	107.9	26.975
	Electric Oil Heating	75.6215	4600.307917	1277.86331	306.687	25.5572662	106.489	19.46	4.865
	Fridge/freezer	54.746	3330.381667	925.1060185	222.025	18.50212037	77.0922	16.27	4.0675
	Tumble	42.1985	2567.075417	713.0765046	171.138	14.26153009	59.423	14.26153	3.565382523
	Tv Living room	40.6264	2471.439333	686.5109259	164.763	13.73021852	57.2092	13.73022	3.43255463
	GamerPlayR	33.1572	2017.063	560.2952778	134.471	11.20590556	46.6913	11.20591	2.801476389
	Dishwasher	31.8235	1935.929583	537.7582176	129.062	10.75516435	44.8132	10.75516	2.688791088
	Wii Stuff	26.8345	1632.432083	453.4533565	108.829	9.06906713	37.7878	9.069067	2.267266782
	Computer Equip.Stud	24.3944	1483.992667	412.2201852	98.9328	8.244403704	34.3517	8.244404	2.061100926
	Cooker	20	1216.666667	337.962963	81.1111	6.759259259	28.1636	6.759259	1.689814815
	Washing machine	14.3623	873.7065833	242.6962731	58.2471	4.853925463	20.2247	4.853925	1.213481366
	Kettle	10.55	641.7916667	178.275463	42.7861	3.565509259	14.8563	3.565509	0.891377315
	Toaster	3.2045	194.9404167	54.15011574	12.996	1.083002315	4.51251	1.083002	0.270750579
	StudioTv	2.7021	164.37775	45.66048611	10.9585	0.913209722	3.80504	0.91321	0.228302431
	Microwave	2.4304	147.8493333	41.06925926	9.85662	0.821385185	3.42244	0.821385	0.205346296
	Gamer LivingRoom	2.4176	147.0706667	40.85296296	9.80471	0.817059259	3.40441	0.817059	0.204264815
	Hair Style fc	1.505	91.55416667	25.43171296	6.10361	0.508634259	2.11931	0.508634	0.127158565

4 Costs and Consumption Table

Bibliography and references:

1. *Abrahamse, W. et al., 2005. A review of intervention studies aimed at household energy conservation. Journal of Environmental Psychology, 25(3), pp.273-291.*
2. *Alahmad, M.A. et al., 2012. A Comparative Study of Three Feedback Devices for Residential Real-Time Energy Monitoring. Network, 59(4), pp.2002-2013.*
3. *Aydinalp, M., Ismet Ugursal, V. & Fung, A.S., 2004. Modeling of the space and domestic hot-water heating energy-consumption in the residential sector using neural networks. Applied Energy, 79(2), pp.159-178.*
4. *Bin, S. & Dowlatabadi, H., 2005. Consumer lifestyle approach to US energy use and the related CO< sub> 2</sub> emissions. Energy Policy, 33(2), pp.197-208.*
5. *Bourgeois, D., Reinhart, C. & Macdonald, I., 2006. Adding advanced behavioural models in whole building energy simulation: a study on the total energy impact of manual and automated lighting control. Energy and Buildings, 38(7), pp.814-823.*
6. *Brohus, H. et al., 2009. Uncertainty of energy consumption assessment of domestic buildings. In Proceedings of the 11th International Building Performance Simulation Association (IBPSA) Conference, Glasgow, UK. Citeseer, pp. 27-30.*
7. *Guerra Santin, O., 2011. Behavioural Patterns and User Profiles related to energy consumption for heating. Energy & Buildings, 43(10), pp.2662-2672.*
8. *Guerra Santin, O., Itard, L. & Visscher, H., 2009. The effect of occupancy and building characteristics on energy use for space and water heating in Dutch residential stock. Energy and Buildings, 41(11), pp.1223-1232.*
9. *Guerra, A.-I. & Sancho, F., 2010. Measuring energy linkages with the hypothetical extraction method: An application to Spain. Energy Economics, 32(4), pp.831-837. Available at: http://linkinghub.elsevier.com/retrieve/pii/S014098830900200X [Accessed February 22, 2012].*
10. *Lang, S., 2004. Progress in energy-efficiency standards for residential buildings in China. Energy and Buildings, 36(12), pp.1191-1196.*
11. *Leon-garcia, A., 2010. Price Prediction in Real-Time Electricity. , 1(2), pp.120-133.*
12. *Meyers, R.J., Williams, E.D. & Matthews, H.S., 2010. Scoping the potential of monitoring and control technologies to reduce energy use in homes. Energy and Buildings, 42(5), pp.563-569.*
13. *Pierce, J., Schiano, D.J. & Paulos, E., 2010. Home , Habits , and Energy : Examining Domestic Interactions and Energy Consumption. Human Factors, pp.1985-1994.*
14. *Richardson, I., Thomson, M. & Infield, D., 2008. A high-resolution domestic building occupancy model for energy demand simulations. Energy and Buildings, 40(8), pp.1560-1566.*
15. *Richardson, I. et al., 2010. Domestic electricity use: A high-resolution energy demand model. Energy and Buildings, 42(10), pp.1878-1887.*
16. *Rodgers, J. & Bartram, L., 2011. Exploring ambient and artistic visualization for residential energy use feedback. IEEE transactions on visualization and*

computer graphics, 17(12), pp.2489-97. Available at: http://www.ncbi.nlm.nih.gov/pubmed/22034370.

17. *Saelens, D., Parys, W. & Baetens, R., 2011. Energy and comfort performance of thermally activated building systems including occupant behavior. Building and Environment, 46(4), pp.835-848.*
18. *Standard, A.H.N., 2010. Standards & Emerging Technologies Echonet : A Home Network Standard. Sensors (Peterborough, NH), pp.88-92.*
19. *The Mendeley Support Team, 2011. Getting Started with Mendeley. Mendeley Desktop, pp.1-16. Available at: http://www.mendeley.com.*
20. *Thollander, P., Rohdin, P. & Moshfegh, B., 2011. On the formation of energy policies towards 2020: Challenges in the Swedish industrial and building sectors. Energy Policy, 42, pp.461-467. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0301421511010044 [Accessed January 4, 2012].*
21. *Weiss, M. et al., 2 Information Provisioning on Mobile Phones. Energy.*
22. *Westergren, K.E., Hogberg, H. & Norlén, U., 1999. Monitoring energy consumption in single-family houses. Energy and Buildings, 29(3), pp.247-257.*
23. *Yun, G.Y., Tuohy, P. & Steemers, K., 2009. Thermal performance of a naturally ventilated building using a combined algorithm of probabilistic occupant behaviour and deterministic heat and mass balance models. Energy and Buildings, 41(5), pp.489-499.*