TECHNICAL PAPER 34

ENERGY CONSUMPTION AND BEHAVIOUR PROFILES FOR EIGHT TRADITIONALLY BUILT DWELLINGS

HISTORIC ENVIRONMENT SCOTLAND | ÀRAINNEACHD EACHDRAIDHEIL ALBA

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ABOUT THE RESEARCH TEAM

Founded in 1984, The Scottish Energy Centre is a portal for research, knowledge transfer and expert services within the energy sector, and it is based within Edinburgh Napier University's School of Engineering and the Built Environment. The research team have established expertise in the scientific fields of building physics, building performance evaluation and occupant user-experience assessments. They have produced over 30 peer-reviewed academic papers, industry technical papers, case-studies etc. on the topic of thermal refurbishment to Scottish dwellings and many of these have focused upon retrofit solutions for historical domestic dwellings. The centre is a founding member of RetrofitScotland.org.

Jon Stinson worked as a research fellow at the Scottish Energy Centre. He contributed to and led on various research projects in the fields of humanistic architecture and energy reduction strategies. Jon's research focus included human behaviour & energy use in the built environment and hygrothermal building performance. He holds an honours degree in Architectural Technology and a Ph.D. on energy ergonomics and human factors.

Julio Bros Williamson is an energy and building consultant with the Scottish Energy Centre. He has been educated as an architect at the Marista University in Mexico City and has an MSc in Energy Efficient Building from Oxford Brookes University. He has been a chartered architect in Mexico since 2003. At the Scottish Energy Centre, Julio has been a firm contributor to the renewable, energy efficiency and the sustainability sector, and involved in post-occupancy evaluation of domestic buildings. Julio is also a Director at the Scottish Ecological Design Association and the Scotland 2020 Climate Group as an advisor to the Scottish Government.

Céline Garnier had been a Reader in Energy, Environment and Sustainability at Edinburgh Napier University since 2008. She was also an Energy and Building consultant, and researcher within the Scottish Energy Centre with a track record in research in solar thermal technologies and building performance. She was involved in the development of energy systems, energy efficiency assessment, modelling and application of low energy design solutions for buildings. Céline brought a range of technical and analytical skills to the Centre, including modelling and simulation techniques, supported by a range of empirical testing methods and experience of field-testing energy systems.

John Currie is Director of the Scottish Energy Centre and Fellow and Chairman of the Energy Institute in Scotland. A chartered engineer with over 30 years' experience in teaching, research and practice, John was formerly Chief Engineer at a brewery. Widely published, his research interests currently include improving building energy and environmental performance, monitoring and modelling pollution in the urban environment, and the development of novel renewable energy technologies. He was co-chairman of Scotland's 2020 Climate Group, founder of 'Retrofit Scotland' and sits on the Engineering Accreditation Board of the Engineering Council.

PREFACE

Over the last decade, there has been an increased awareness of the need to improve the energy efficiency and sustainability of Scotland's building stock and to fulfil obligations under the Climate Change (Scotland) Act 2009. Since approximately 20% of buildings in Scotland are traditionally constructed, accurate representation of the energy consumption of this group is very important to consider in the ongoing battle. However, most baseline studies about energy consumption and room comfort have been conducted with modern buildings in mind. The purpose of the study is to provide baseline results for these values for traditional buildings, in order to better understand how this group of buildings behave, and at the very least get an appreciation of energy consumption per square meter per year in the traditional housing stock.

This study is looking at the energy consumption, humidity and room temperature of several traditionally constructed dwellings. The buildings are all traditional solid wall construction of stone and brick and were built before 1919. Often, they also include other traditional features such as higher ceilings, ventilation through chimneys, windows and sub-floor vents. Included are flats, as well as terraced and detached dwellings, with various levels of insulation. Part of the study is the assessment of perceived comfort level of the occupants in the various properties as a subjective measure necessary to complete the picture of the baseline study.

The results show, as might be expected, that the occupation pattern and number of inhabitants had a great influence on the energy. The energy used was on average 156 kWh/m2/year in 2013 and 192 kWh/m2/year in 2014. The measured values were also compared to the calculated gas and electricity usage as simulated by the reduced data SAP calculations, used for EPC certificates. This can be used to help provide a better understanding of the accuracy of the SAP models for use on older properties. It can also provide an assessment of confidence in energy consumption predictions. It is acknowledged that the sample size is too small to draw enough information from to create a baseline, and the variances in occupation and circumstances make direct comparisons difficult. However, it is a start and an establishment of a methodology to appreciate energy performance in traditional properties. It is hoped that this programme can be progressed with more study buildings in due course.

This study supports the on-going research by Historic Environment Scotland into energy efficiency improvements in traditional buildings that has been running since 2008. This paper should be read in conjunction with other Historic Environment Scotland publications on the subject such as the Refurbishment Case Studies and *Short Guide 1: Fabric Improvements for Energy Efficiency.*

ACKNOWLEDGEMENTS

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NOMENCLATURE

EEBS	Energy Efficiency Behaviour Score
kWh	KiloWatt Hour
M	Mean (or average)
n	Number of participants in a sample or group
OP	Occupancy Profile
p	Calculated Probability
SAP	Standard Assessment Procedure
SD	Standard Deviation
SE	Standard Error
t	t statistic

SUMMARY OF RESULTS

		E1 East Claremont	E2 Fettes Row	E3 Roxburgh Str.	E4 Drummond Str.	E5 Morrison Str.	E6 Pleasance Str.	E7 Newtongrange Main Str.	E8 Newtongrange Main Str.
Picture									
Dwelling type		Mid floor flat	Mid floor flat	Top floor flat	Basement flat	Top floor flat	Top floor flat	Two-storey mid terrace cottage	Two-storey mid terrace cottage
Floor area (m^2)		127	182	84	65	110	76	95	95
Monitored electricity consumption (kWh/Year)		3,430	4,570	3,020	2,000	2,140	2,470	4,580	4,200
Monitored gas consumption (kWh/Year)		7,980	19,450	15,730	16,030	19,250	15,390	19,860	10,730
Electricity consumption ($kWh/m^2/year$)		27	25	36	31	22	32	48	44
Gas consumption ($kWh/m^2/year$)		63	107	187	247	194	202	209	113
Predicted gas demand, (SAP) ($kWh/m^2/year$)		142	149	132	191	143	178	191	191
Occupancy	No. of occupants	4	4	2	3	3	2	2	4
	Occpancy Profile	2	2	1	1	1	1	1	2

Notes: For clarity, all values are rounded up to 0dp and the monitored values (kWh/year) are rounded up to nearest multiple of 10.
Monitored energy consumption results relate to the mean values for 24 months between January 2013 and December 2013, with the exception of E4, E5 and E8.

1 INTRODUCTION

This technical paper presents the findings from a four-year project, the objectives of which were to gather, analyse and present the energy consumption profiles for eight dwellings in Edinburgh and Midlothian, designed and built prior to 1919. The data collection period lasted for two years, during which time, hourly electricity and gas consumption levels were recorded along with internal and external air temperatures. The energy and temperature profiles are complemented with the analysis of qualitative data sets. These sets have focused on profiling the occupants' behaviour, internal thermal and environmental comfort and the calculation of their energy efficiency behaviour score.

The eight dwellings selected for this study contained a mix of owner-occupier participants who volunteered via Edinburgh World Heritage and social housing tenants who volunteered to participate via Castle Rock Edinvar Housing Association. Both organisations were coordinated by the Conservation Directorate at Historic Environment Scotland. The eight dwellings are common in that they all possess the base elements of traditional architecture. The sample of eight includes urban tenement flats containing a mix of solid sandstone, lath & plaster wall construction (finished as rubble or ashlar), and red bricked cavity-walled bungalows with two living levels and situated in a rural village environment. The construction types within the sample possess a range of different levels of retrofitted thermal insulation, including wall insulation, secondary glazing and ceiling insulation.

This study began after the successful completion of over 20 Technical Papers funded by Historic Environment Scotland and completed by various academic and industry authors on the topic of "sympathetic and effective retrofitting strategies and techniques for dwellings and buildings considered to be of historical and/or architectural significance". Through a series of demonstration sites, simulated modelling information and in-situ monitoring projects, those papers have provided a considerable knowledge base for designers, specifiers, builders, authorities and owners of these types of building who wish to understand the retrofit process and energy performance when enhancing the energy efficiency of historical archetypes. The accumulation of this combined knowledge in the conservation and retrofit field has led to the development of the Retrofit Scotland website.

Historic Environment Scotland and the Scottish Energy Centre have identified the growing need to generate a better understanding of how much electricity and heating fuel (typically mains gas) is being used by occupants living in homes of historical and architectural value. This technical paper was written to launch the systematic cataloguing of domestic energy use in traditionally constructed dwellings and the research was conducted to supplement the growing knowledge base of energy performance information for these buildings. The results provide the beginning of such a database which takes account of dependent variables such as building fabric, occupant energy use behaviour, occupancy profiles and thermal comfort.

The methods and results presented here also aim to inform stakeholders of the relationship between the occupants' energy behaviours, occupancy profiles and levels of energy consumption. The energy profiles defined here will provide necessary and detailed energy benchmarks for these types of dwellings, as well as a greater accuracy to energy consumption prediction models/software. The objective of this research is to inform the development of retrofit strategies, modelling and monitored refurbishment programmes.

The paper also details the methods, tools and procedures used to capture and analyse the data sets (Chapters 2 and 3). The findings are presented in a case study format, referred to as Energy Summary

1 to 8, where the energy consumption data, building and occupant characteristics are displayed over a single page for each of the eight households involved with this project. The end of this report combines the energy, temperature and occupant feedback data to create a comparative presentation of results describing the similarities and differences in greater detail.

2 METHODOLOGY

The aim of this work is to present and catalogue the energy consumption and behaviour profiles for eight dwellings built to traditional construction standards. To more accurately present the energy demand profile for any building, it is imperative that variables which influence the consumption of energy are considered. This paper investigates these variables along with the electricity and gas consumption. The energy consumption was recorded using the technology and logging schedules described below. The variables which energy consumption is dependent upon, and which were recorded for each participating household, are as follows and described in more detail in the sub-section below:

- Internal and external temperatures
- Building characteristics (used to construct numerical models to simulate heating requirements)
- Occupancy profile
- Thermal and internal comfort levels
- Energy efficiency behaviour

2.1 PROCEDURE

Historic Environment Scotland facilitated the recruitment of volunteer participants (owners/occupiers) to this project through their contacts with Castle Rock Edinvar and Edinburgh World Heritage. An initial meeting between the occupants and researcher was setup in 2012 before the monitoring began. Research projects of this nature can present challenges due to occupants moving home and withdrawing from the research. Therefore, it was paramount that during this initial visit, a visiting schedule suitable for each participant and a code of conduct between the researcher and the occupants were established. During the initial meetings with the occupants a rapport was developed, the frequency and length of visits to the household were closely regulated, as was the wording and phrasing of the researcher when interacting with the occupants at each visit.

The monitoring officially began at the start of 2013 with eight households participating. In the summer of 2013, one participant wished to be removed from the project, while another moved out of their rented accommodation. During autumn/winter 2013, two replacement households were recruited. Monitoring officially commenced in those households at the start of 2014.

Each household was visited by the research team a total of six times during the project, with the exception of the two replacement households that were visited on five different occasions. The number of visits was dictated by the requirement to measure the occupants' opinion of thermal comfort and energy efficiency behaviours during the warmest and coldest periods of each year that they were being monitored.

Due to the social science investigative methods employed to complete this research, the 'Hawthorne effect' (Draper 2014, Stinson 2015a), often referred to as the 'observer effect' was considered. The term refers to the change in the participant's behaviour due to the presence of an experimenter in their environment (Mayo 1933, Roethlisberger & Dickson 1941, French 1953). This commonly manifests itself when the project participant manipulates their behaviour in a way that they presume that the researcher wants to document/observe. This undesired effect tends to be temporary but may affect project participants in different ways.

The impracticality of completely eliminating all of the undesired effects that a researcher could have on a participant's behaviour is well recognised amongst social scientists. However, procedures can be set in place to mitigate, as far as reasonably practicable, potential indirect influence on those whom we observe.

It is for such considerations that a second year of monitoring to include all 8 households was added in the research.

2.2 TOOLS: ENERGY AND TEMPERATURE COLLECTION

Energy logger and data

The Ewgeco energy monitor was selected as the preferred data logger to record each dwelling's electricity and gas consumption. The Ewgeco logger used a current transducer (CT) clip connected around the main live power cable to collect the data for the electricity consumption. It collected gas consumption data by recording the number of pulses or revolutions made by the numerical dial, which was achieved via a pulse block or optical reader connected to the face plate of the gas meter, see Figure 2.1.

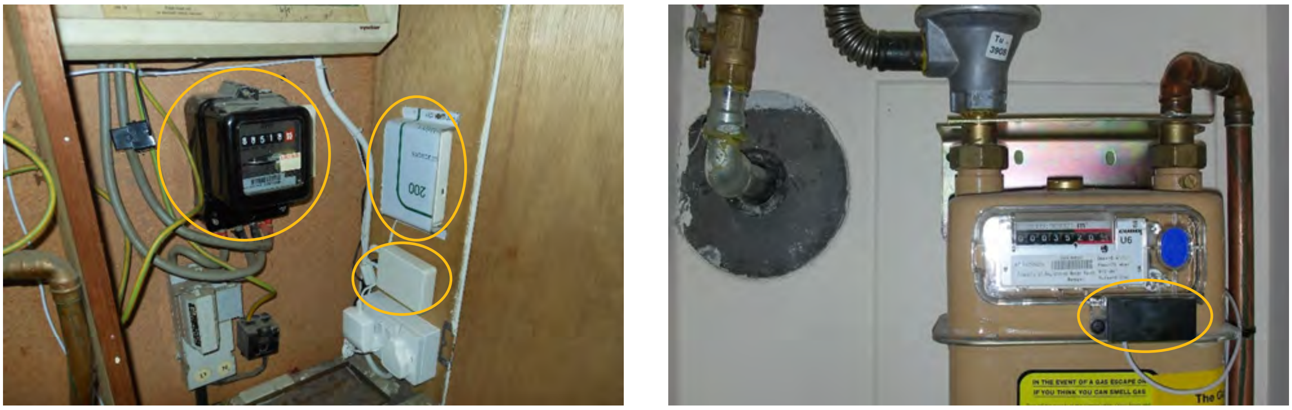


Figure 2.1 - The Ewgeco energy logger connected to electricity (left) and gas (right) meters. Logging equipment circled.

The Ewgeco logger can connect to most dwelling's electricity infrastructure regardless of the type of electricity meter. However, the logger can only collect data from pulsed-enabled gas meters. Therefore, during the initial visit, the dwelling's metering infrastructure was evaluated for compatibility to the selected Ewgeco energy monitor. For those dwellings with incompatible gas meters, and with the permission of the occupants, the gas meter was swapped for a compatible one.

The Ewgeco energy monitors were installed as close to the meters as practical and recorded the total electricity and gas consumption every hour. The data stored by the logger was downloaded during each visit. Meter readings were taken during each visit to validate the data recorded by the logger. The energy data was converted to kilowatt hours (kWh) and presented per month and year and used to describe the energy profile of each household in the Energy Summaries and comparison Sections.

Temperature logger and data

Gemini Tinytag view 2 temperature loggers were used to measure internal and external ambient temperatures. External temperature loggers were placed inside solar radiation shields and the internal loggers were placed within the main living area of each dwelling, see Figure 2.2. The participating households were clustered into four locations that best represented the location of all eight households (see Section 3) and one external temperature logger was placed in each of the four locations. The temperature loggers recorded the mean temperature at hourly intervals to match the sampling rate of the energy loggers.

Figure 2.2 - The TinyTag temperature logger inside radiation shield (left) and dwelling (right).

The temperature difference between the internal and external temperatures was calculated per month and presented along with the gas consumption data in each of the Energy Summaries. Section 4 presents the statistical relationship between the monthly total gas data and monthly average temperature differences.

2.3 TOOLS: BUILDING CHARACTERISTICS

During the initial pre-project meeting with the occupants, the researcher collected information about each dwelling's characteristics. This related to the composition of the dwelling's thermal envelope, dimensions and heating system. This information, which was checked at the end of the study, was used to construct SAP numerical building models to simulate the dwellings predicted heating requirement.

The Standard Assessment Procedure (SAP) remains to be the UK Government's preferred methodology for calculating the energy rating of domestic dwellings. The output of SAP modelling is an Energy Performance Certificate (EPC), which is used to provide an indication of the dwelling's energy efficiency. An EPC is produced for new homes and those buildings sold or rented to demonstrate compliance with Scottish Building Regulations (and those of England, Wales and Northern Ireland). The output of the SAP modelling also provides an indication of the proportion of energy gains and losses within each dwelling due to its construction, size and orientation etc. and the energy input required to maintain certain temperature levels. In this case, the Stroma FSAP 2009 software was used to calculate each dwelling's required heat energy (Figure 2.3).

The key characteristics recorded for each dwelling is presented in the Energy Summaries Section along with the calculated SAP gas requirement and temperature profile. These figures are presented in Section 4, along with the monitored gas consumption figures, where a comparison between the two is provided.

A comparison between the measured energy consumption and that estimated by the SAP is presented and discussed below. For the analysis, the term "heat score" is used. A household's heat score is derived by dividing the measured gas consumption by the calculated gas consumption as provided by the SAP. The units for this heat score are kWhmes/kWhSAP. (For more on the results of the comparison, see Section 4.6).

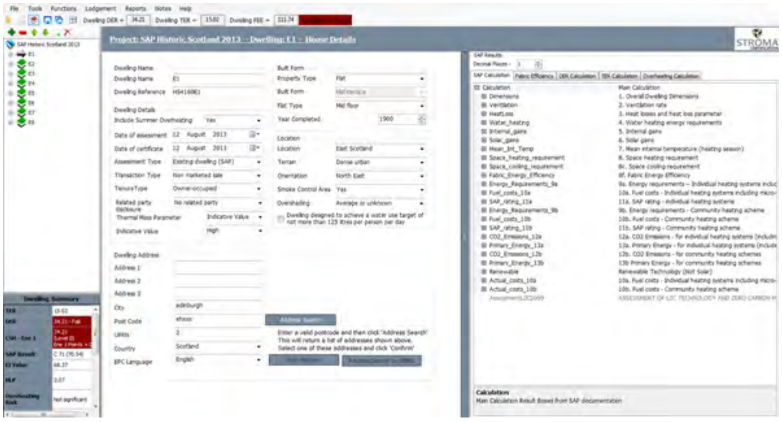
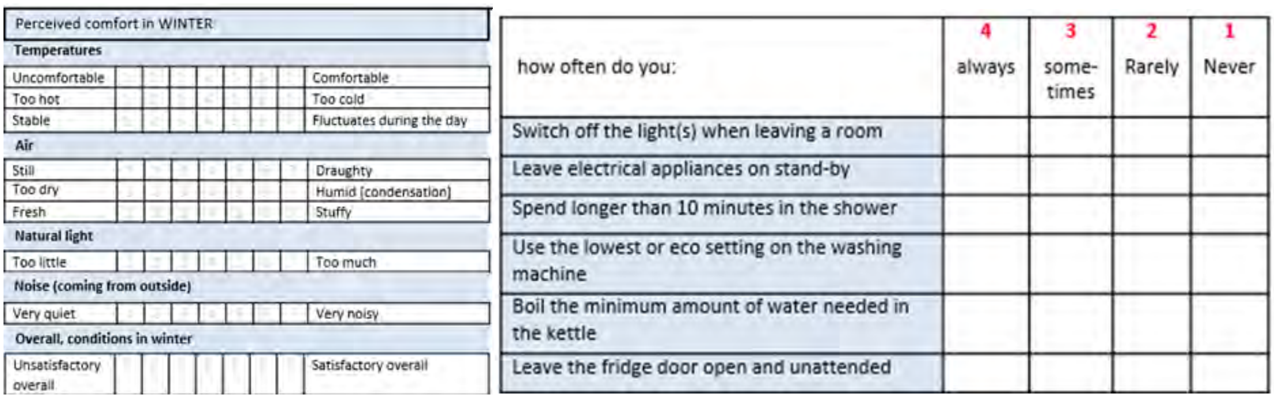


Figure 2.3 - Screenshot of Stroma FSAP 2009 software interface.

2.4 TOOLS: OCCUPANT PROFILING

A survey defined by ENU researchers during previous domestic energy use research was adapted to capture information pertaining to the occupancy profile, the occupants' opinion of their thermal comfort and perception about their energy use behaviour.

A questionnaire was used as part of a semi-structured guided survey between the occupants and a member of the research team (Stinson et al 2015b). The survey consisted of three main parts and was used to develop an understanding of the occupants' experience of living in the dwelling (Figure 2.4). Part 1 of the user experience survey asked the occupant about the members living in the dwelling and their daily occupancy pattern. This part was undertaken at the start and repeated at the end of the study. Part 2 asked the occupant specific questions to their level of thermal comfort within the dwelling over the winter and summer periods. Part 3 was used to develop an understanding of the frequency by which the occupants undertook certain activities to reduce household energy consumption; this is referred to as the energy efficiency behaviour score (EEBS) (Stinson 2015a, Stinson et al 2016).



Perceived comfort in WINTER		
Temperatures		
Uncomfortable		Comfortable
Too hot		Too cold
Stable		Fluctuates during the day
Air		
Still		Draughty
Too dry		Humid (condensation)
Fresh		Stuffy
Natural light		
Too little		Too much
Noise (coming from outside)		
Very quiet		Very noisy
Overall, conditions in winter		
Unsatisfactory overall		Satisfactory overall

how often do you:	4 always	3 some-times	2 Rarely	1 Never
Switch off the light(s) when leaving a room				
Leave electrical appliances on stand-by				
Spend longer than 10 minutes in the shower				
Use the lowest or eco setting on the washing machine				
Boil the minimum amount of water needed in the kettle				
Leave the fridge door open and unattended				

Figure 2.4 - Samples of part 2 (left) and part 3 (right) of the user experience survey.

These surveys were conducted with the same occupant on four separate occasions during the project. The visits to each dwelling were scheduled to satisfy the thermal comfort aspect of the survey, meaning the visit typically occurred in February and September to capture the occupants' responses for summer and winter. The visit plan and elements of the survey applied are listed below:

1. Autumn 2012 or Autumn 2013* - Logger installed and Part 1 of survey completed
2. Summer 2013 - Part 2 and Part 3 of survey completed
3. Winter 2013/2014 - Part 2 and Part 3 of survey completed
4. Summer 2014 - Part 2 and Part 3 of survey completed
5. Winter 2014/2015 - Part 2 and Part 3 of survey completed
6. Spring/summer 2015 - Loggers removed. Part 1 of survey completed to identify any changes

*When replacement participants entered the project

Part 2 of the survey consisted of semantic differential scales ranging from 1 to 7, implemented to score the occupant's perception of their thermal comfort whilst inside the dwelling during summer and winter (temperature, air quality, natural and artificial light). These were supplemented by open-ended and conversational style questions used to verify the responses.

The semantic differential scale technique attributed to Osgood et al (1957) and adopted by Leaman, Bordman, and Stevenson for their version of the non-domestic Building User Survey BUS (1993, 2010), is an established psychological technique to directly measure attitudes towards a theme using adjectives on a bipolar scale. The 5-point version is also the basis of the 1986 System Usability Scale - SUS (Brooke 2013) designed to allow for the evaluation of a wide variety of products and services, including hardware, software, mobile devices, websites and applications.

Part 3 uses the Likert scale method (Likert 1932). The responses are captured on a one to four scoring system where the responder can choose from "never", "rarely", "sometimes", "always" (alternative wording used "as frequently as possible") to directly measure the occurrence of 14 activities by the occupants to reducing household energy consumption. The list of activities relates to the use of electricity, space and water heating appliances common to a large majority of homes. The activities relating to electricity consumption specifically focuses on appliances which typically contribute the most to a domestic energy profile, i.e. showering, lighting, cooking and white goods. The gas related activities centred on the use of the three most common domestic heating controls, window and individual thermal layering.

The set of energy use questions were posed to the occupants on four occasions over the two-year monitoring period, twice for summer and twice for winter. The answers were quantified one to four for each activity and averaged based on the utility they affect (electricity and gas). The result of which is being referred to as the energy efficiency behaviour score (EEBS). The seasonal EEBS is calculated by averaging the scores from the two summers' and two winters' surveys; the results are displayed at the end of each household's energy summary in the main section of this paper. The total EEBS is calculated by adding the summer and winter EEBS together, the results are presented and discussed in Section 4.8.

3 SAMPLE DESCRIPTION AND SUMMARY

3.1 SAMPLE SIZE AND GEOGRAPHICAL LOCATION

The sample was made up of two cottages, two mid-floor flats, one basement flat and three top floor flats. The eight dwellings are known to be of traditional design and construction, each with large timber frame sash & case windows, six constructed with sandstone and two with redbrick walls. Photographs of the front elevation of each of the participating dwellings are presented in Figure 3.1 to 3.8.

The occupants who volunteered to contribute to this project were granted anonymity in accordance with a standard code of ethics for such research. The participating households are thus referred to as E1, 2, 3, 4, 5, 6, 7 and 8.

The dwellings were grouped over four locations. Six were located around the centre of the City of Edinburgh and within 1.9km of Edinburgh Castle, while two were in the Midlothian Village of Newtongrange, 13km from Edinburgh Castle. More specifically: Dwellings E1 and E2 situated 800m apart in Edinburgh's New Town; Dwellings E3, E4 and E6 located in Edinburgh's Old Town within 200m of each other; Dwelling E5 situated 800m west of the Castle in Edinburgh's West End; And dwellings E7 and E8 located within 50m of each other in the Midlothian village of Newtongrange.


E1


E2


E3


E4


E5


E6


E7


E8

Figure 3.1 to 3.8 - Photographs of the front elevation of each participating dwelling

3.2 OCCUPANCY PROFILE

Occupancy Profiles (OPs) were defined through a combination of self-reported occupant feedback and analysis of the household's weekly energy consumption profile. The OP has two classifications which are defined as:

OP1: Majority of the occupants are in the house the majority of the time during a typical week.
OP2: Majority of the occupants are out of the house the majority of the time during a typical week.

Here, a 'typical week' means a non-holiday week, excluding bank and seasonal holidays. In this case the term 'majority of occupants' means more than half the people living in the home, and 'majority of the week' relates to the amount of time the occupants spend inside or outside the home whilst awake. Figure 3.9 and 3.10 shows the typical daily energy consumption profile for households classified as OP1 and OP2. These data cover the same day in February.

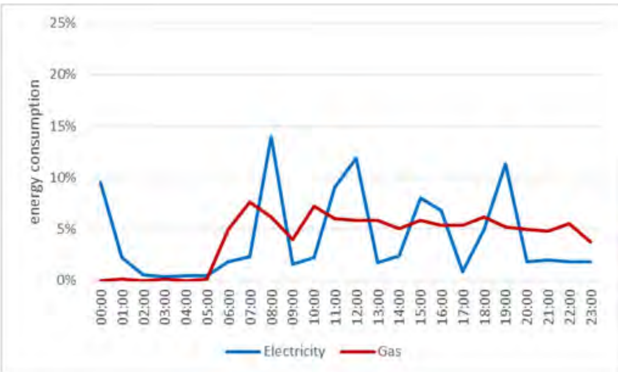


Figure 3.9 - Energy profile for occupancy profile 1.

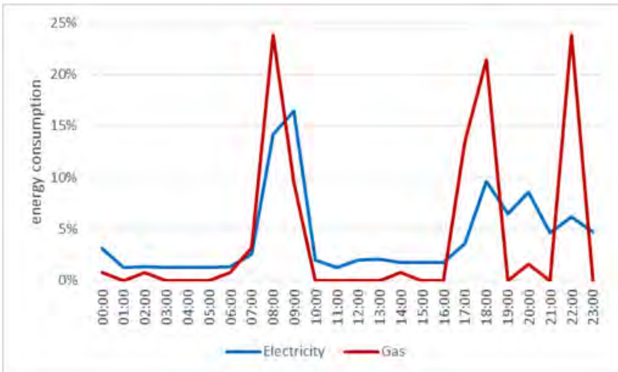


Figure 3.10 - Energy profile for occupancy profile 2.

Figure 3.11 Displays the percentage split of the sample's demographic based on employment and daily activity. These are shown for each year of the monitoring and the percentage of the households that were classified as OP1 and OP2.

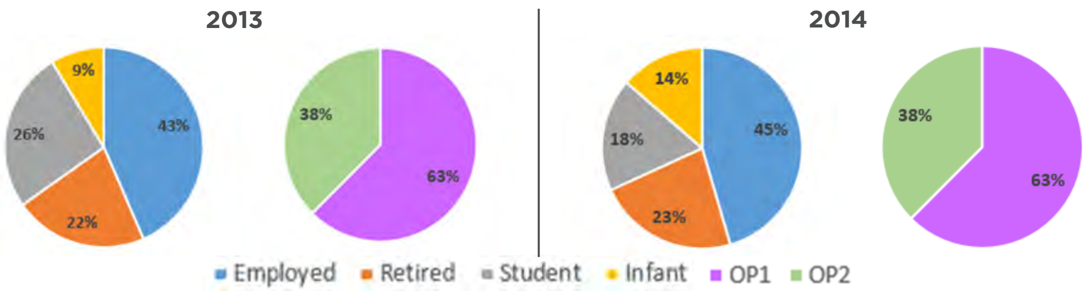


Figure 3.11 - Percentage breakdown of occupants and occupancy profile.

The project aimed to record two full years of the energy consumption and temperature data for 2013 and 2014. During the first year of monitoring (2013) the original households coded E5 and E8 withdrew from the project. Replacement households were recruited in late 2013, only 2014 consumption data for E5 and E8 are presented and discussed in this report. One energy logger malfunctioned resulting in loss of data for household E4, thus monthly energy consumption data for 2014 is not presented for this household; its yearly data is used instead.

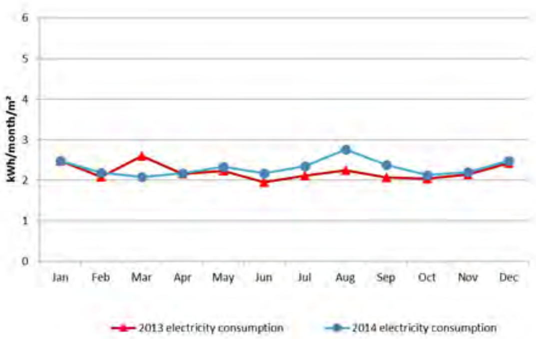
ENERGY SUMMARY I

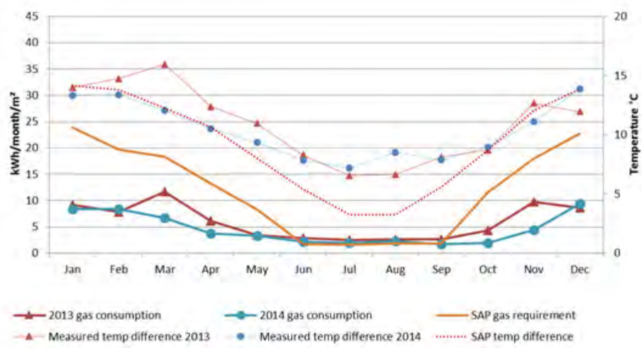
Edinburgh - East Claremont - Mid floor flat (owner occupier)

YEARLY ENERGY CONSUMPTION

	2013	2014	SAP
Electricity (kWh/m²/year)	27	28	n/a
Gas (kWh/m²/year)	72	54	142

MONTHLY ENERGY CONSUMPTION





BUILDING CHARACTERISTICS

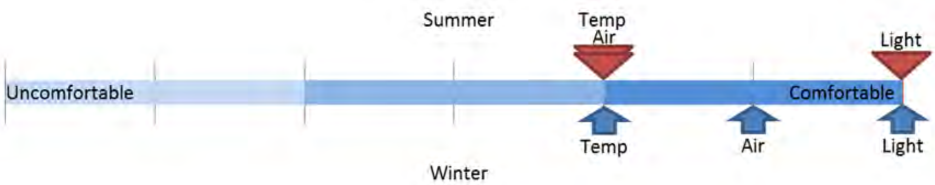
Details		Construction	
Floor area	127m²	**Ceiling**	Timber, lath & plaster (dwelling above)
Window orientation	North west/South east	**Wall**	Sandstone, lath and plaster (no insulation)
Age of building	1830-1850	**Floor**	Timber (dwelling below)
Heating system	Heating fuel: mains gas Heating system: Combi boiler Heating distribution: radiators	**Window**	Double glazing (timber frame)

OCCUPANTS CHARACTERISTICS

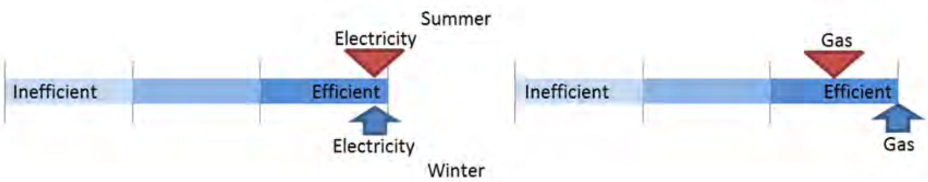
Daily activity profile

	2013	2014
Occupancy profile	2 - Majority of occupants are out of the home for the majority of the week.	2 - Majority of occupants are out of the home for the majority of the week.
Number of people	4	3
	1 x full-time employed 1 x full-time employed (working at home) 2 x under 18 years old, students	1 x full-time employed 1 x full-time employed (working at home) 1 x under 18 years old, student

Self-reported comfort scores



Self-reported energy efficiency behaviour scores



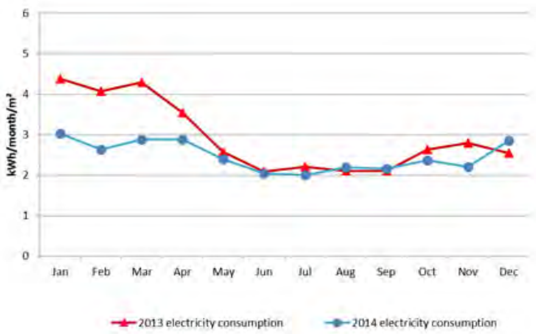
ENERGY SUMMARY 2

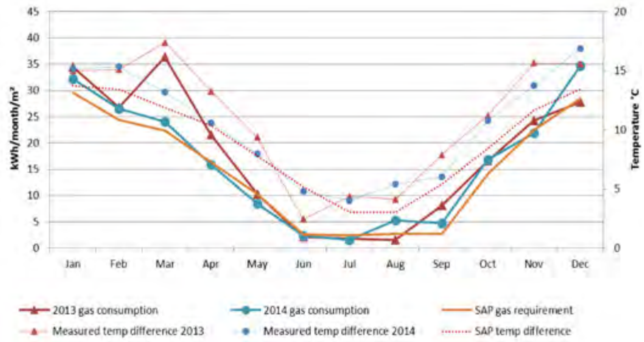
Edinburgh – Fettes Row - Mid floor flat (owner occupier)

YEARLY ENERGY CONSUMPTION

	2013	2014	SAP
Electricity (kWh/m²/year)	35	30	n/a
Gas (kWh/m²/year)	212	194	178

MONTHLY ENERGY CONSUMPTION





BUILDING CHARACTERISTICS

Details		Construction	
Floor area	76m²	**Ceiling**	Timber, lath & plaster (insulation, 250-270mm sheep's wool, cold attic)
Window orientation	West/East	**Wall**	Sandstone, lath and plaster (no insulation)
Age of building	1800-1830	**Floor**	Timber (dwelling below)
Heating system	Heating fuel: mains gas Heating system: Combi boiler Heating distribution: radiators	**Window**	Single glazing (timber frame) (Aluminium secondary single glazing)

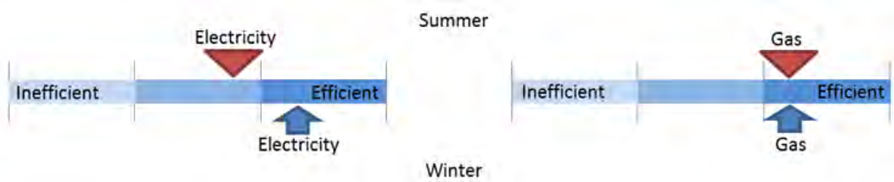
OCCUPANTS CHARACTERISTICS

Daily activity profile

	2013	2014
Occupancy profile	1 - Majority of occupants are in the home for the majority of the week.	1 - Majority of occupants are in the home for the majority of the week.
Number of people	3	2
	1 x unemployed 1 x full-time employed (residing periodically) 1 x under 18 year old, student	1 x unemployed 1 x full-time employed (residing periodically)

Self-reported comfort scores

Self-reported energy efficiency behaviour scores



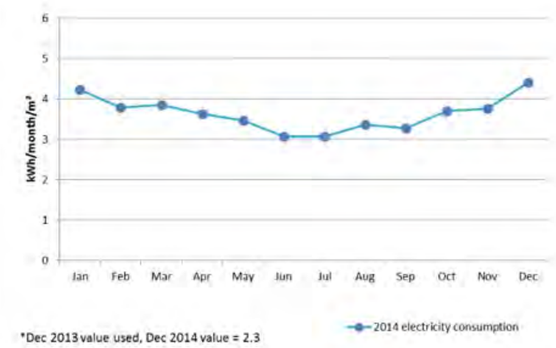
ENERGY SUMMARY 3

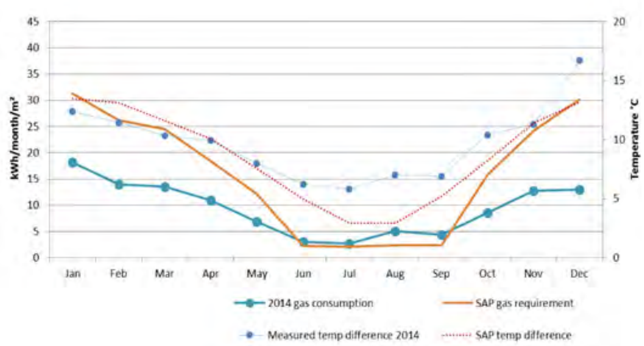
Edinburgh – Roxburgh Street - Top floor flat (social rented)

YEARLY ENERGY CONSUMPTION

	2013	2014	SAP
Electricity (kWh/m²/year)	x	44*	n/a
Gas (kWh/m²/year)	x	113	191

MONTHLY ENERGY CONSUMPTION





BUILDING CHARACTERISTICS

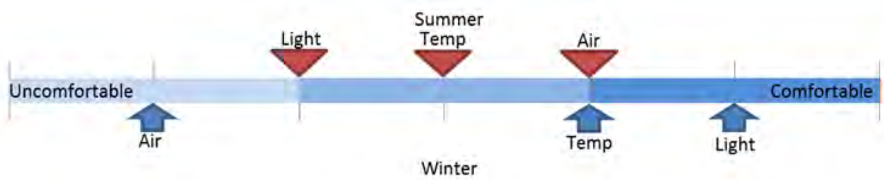
Details		Construction	
Floor area	95m²	**Ceiling**	Timber, lath & plaster (insulation, 250-270mm sheep's wool, cold attic)
Window orientation	West/East	**Wall**	Redbrick, lath and plaster (full fill cavity insulation, 50mm mineral wool)
Age of building	Pre-1860	**Floor**	Suspended timber and solid stone (no insulation)
Heating system	Heating fuel: mains gas Heating system: Combi boiler Heating distribution: radiators	**Window**	Single glazed (timber frame), (Roof light double glazed)

OCCUPANTS CHARACTERISTICS

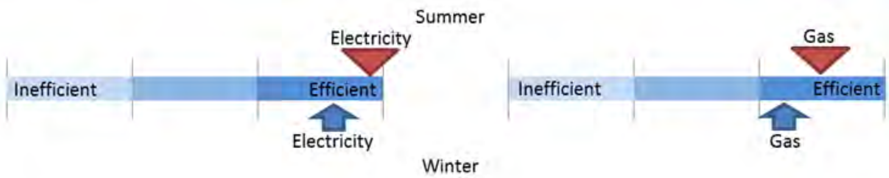
Daily activity profile

	2013	2014
Occupancy profile	2 - Majority of occupants are out the home for the majority of the week.	2 - Majority of occupants are out the home for the majority of the week.
Number of people	4	4
	1 x full-time employed 1 x part-time employed 2 x children under 5 years old	1 x full-time employed 1 x part-time employed 2 x children under 5 years old

Self-reported comfort scores



Self-reported energy efficiency behaviour scores



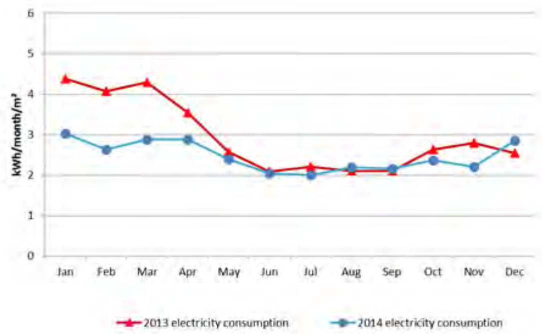
ENERGY SUMMARY 4

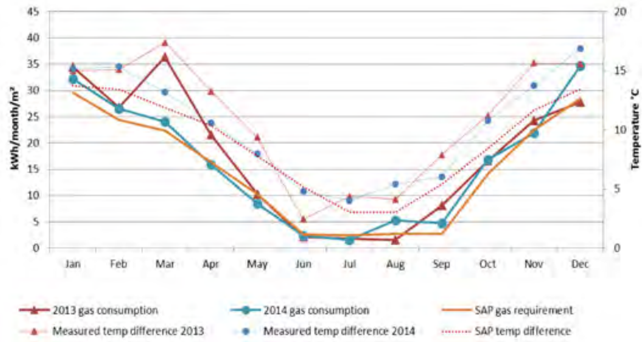
Edinburgh – Drummond Street - Basement flat (social rented)

YEARLY ENERGY CONSUMPTION

	2013	2014	SAP
Electricity (kWh/m²/year)	35	30	n/a
Gas (kWh/m²/year)	212	194	178

MONTHLY ENERGY CONSUMPTION





BUILDING CHARACTERISTICS

Details		Construction	
Floor area	76m²	**Ceiling**	Timber, lath & plaster (insulation, 250-270mm sheep's wool, cold attic)
Window orientation	West/East	**Wall**	Sandstone, lath and plaster (no insulation)
Age of building	1800-1830	**Floor**	Timber (dwelling below)
Heating system	Heating fuel: mains gas Heating system: Combi boiler Heating distribution: radiators	**Window**	Single glazing (timber frame) (Aluminium secondary single glazing)

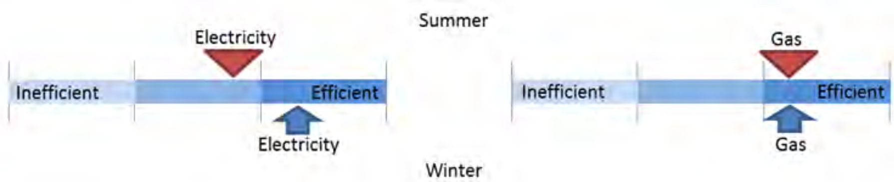
OCCUPANTS CHARACTERISTICS

Daily activity profile

	2013	2014
Occupancy profile	1 - Majority of occupants are in the home for the majority of the week.	1 - Majority of occupants are in the home for the majority of the week.
Number of people	3	2
	1 x unemployed 1 x full-time employed (residing periodically) 1 x under 18 year old, student	1 x unemployed 1 x full-time employed (residing periodically)

Self-reported comfort scores

Self-reported energy efficiency behaviour scores



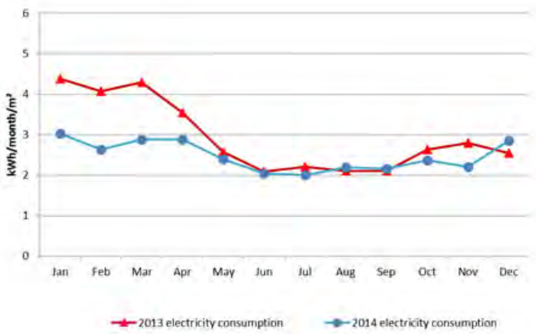
ENERGY SUMMARY 5

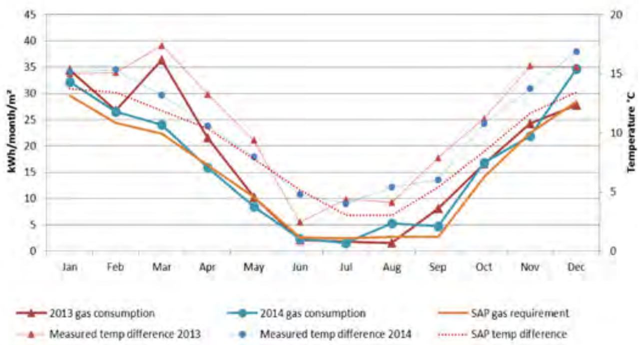
Edinburgh – Morrison Street - Top floor flat (owner occupier)

YEARLY ENERGY CONSUMPTION

	2013	2014	SAP
Electricity (kWh/m²/year)	35	30	n/a
Gas (kWh/m²/year)	212	194	178

MONTHLY ENERGY CONSUMPTION





BUILDING CHARACTERISTICS

Details		Construction	
Floor area	76m²	**Ceiling**	Timber, lath & plaster (insulation, 250-270mm sheep's wool, cold attic)
Window orientation	West/East	**Wall**	Sandstone, lath and plaster (no insulation)
Age of building	1800-1830	**Floor**	Timber (dwelling below)
Heating system	Heating fuel: mains gas Heating system: Combi boiler Heating distribution: radiators	**Window**	Single glazing (timber frame) (Aluminium secondary single glazing)

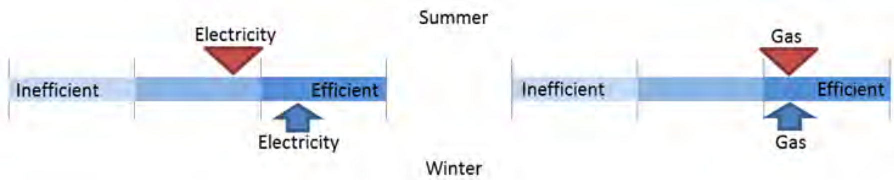
OCCUPANTS CHARACTERISTICS

Daily activity profile

	2013	2014
Occupancy profile	1 - Majority of occupants are in the home for the majority of the week.	1 - Majority of occupants are in the home for the majority of the week.
Number of people	3	2
	1 x unemployed 1 x full-time employed (residing periodically) 1 x under 18 year old, student	1 x unemployed 1 x full-time employed (residing periodically)

Self-reported comfort scores

Self-reported energy efficiency behaviour scores



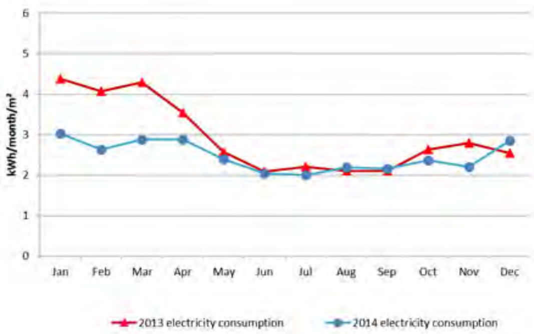
ENERGY SUMMARY 6

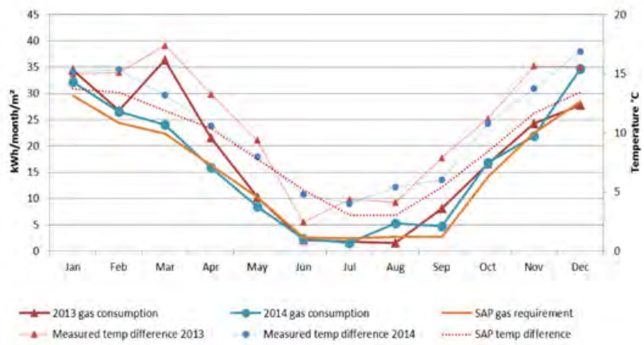
Edinburgh - Pleasance - Top floor flat (social rented)

YEARLY ENERGY CONSUMPTION

	2013	2014	SAP
Electricity (kWh/m²/year)	35	30	n/a
Gas (kWh/m²/year)	212	194	178

MONTHLY ENERGY CONSUMPTION





BUILDING CHARACTERISTICS

Details		Construction	
Floor area	76m²	**Ceiling**	Timber, lath & plaster (insulation, 250-270mm sheep's wool, cold attic)
Window orientation	West/East	**Wall**	Sandstone, lath and plaster (no insulation)
Age of building	1800-1830	**Floor**	Timber (dwelling below)
Heating system	Heating fuel: mains gas Heating system: Combi boiler Heating distribution: radiators	**Window**	Single glazing (timber frame) (Aluminium secondary single glazing)

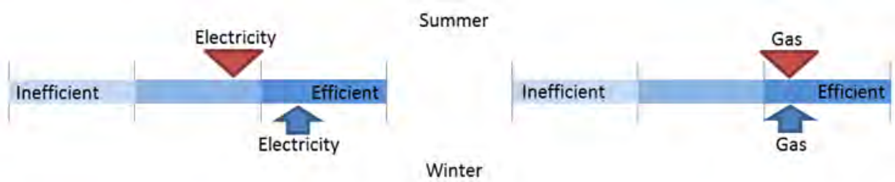
OCCUPANTS CHARACTERISTICS

Daily activity profile

	2013	2014
Occupancy profile	1 - Majority of occupants are in the home for the majority of the week.	1 - Majority of occupants are in the home for the majority of the week.
Number of people	3	2
	1 x unemployed 1 x full-time employed (residing periodically) 1 x under 18 year old, student	1 x unemployed 1 x full-time employed (residing periodically)

Self-reported comfort scores

Self-reported energy efficiency behaviour scores



ENERGY SUMMARY 7

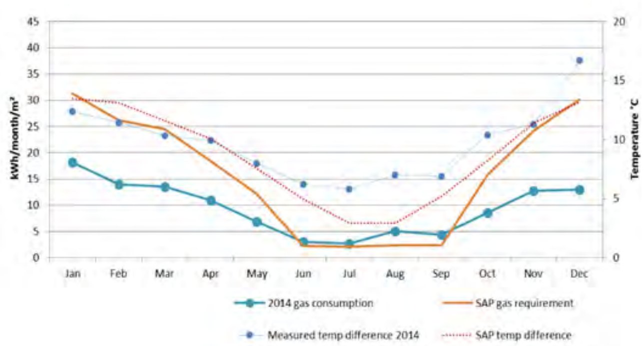
Midlothian – Newtongrange – Two floor mid-terrace cottage (social rented)

YEARLY ENERGY CONSUMPTION

	2013	2014	SAP
Electricity (kWh/m²/year)	x	44*	n/a
Gas (kWh/m²/year)	x	113	191

MONTHLY ENERGY CONSUMPTION

*Dec 2013 value used, Dec 2014 value = 2.3



BUILDING CHARACTERISTICS

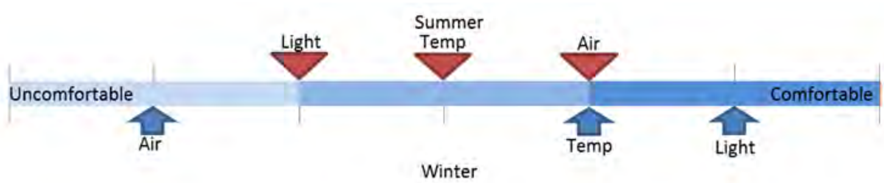
Details			Construction
Floor area	95m²	**Ceiling**	Timber, lath & plaster (insulation, 250-270mm sheep's wool, cold attic)
Window orientation	West/East	**Wall**	Redbrick, lath and plaster (full fill cavity insulation, 50mm mineral wool)
Age of building	Pre-1860	**Floor**	Suspended timber and solid stone (no insulation)
Heating system	Heating fuel: mains gas Heating system: Combi boiler Heating distribution: radiators	**Window**	Single glazed (timber frame), (Roof light double glazed)

OCCUPANTS CHARACTERISTICS

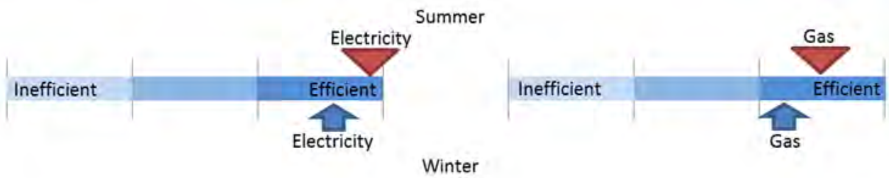
Daily activity profile

	2013	2014
Occupancy profile	2 - Majority of occupants are out the home for the majority of the week.	2 - Majority of occupants are out the home for the majority of the week.
Number of people	4	4
	1 x full-time employed 1 x part-time employed 2 x children under 5 years old	1 x full-time employed 1 x part-time employed 2 x children under 5 years old

Self-reported comfort scores



Self-reported energy efficiency behaviour scores



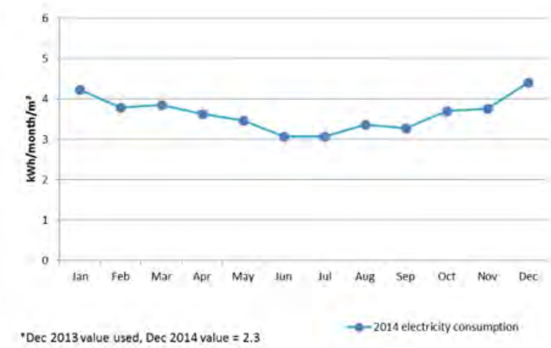
ENERGY SUMMARY 8

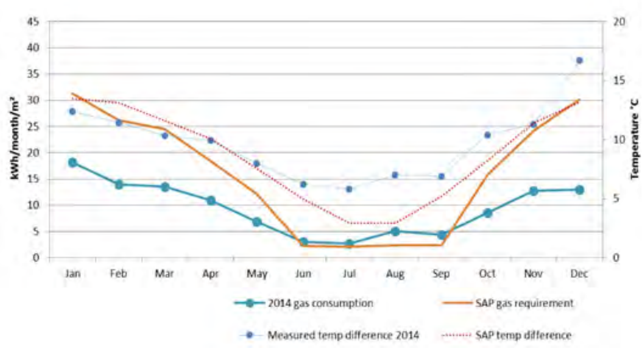
Midlothian – Newtongrange – Two floor mid-terrace cottage (social rented)

YEARLY ENERGY CONSUMPTION

	2013	2014	SAP
Electricity (kWh/m²/year)	x	44*	n/a
Gas (kWh/m²/year)	x	113	191

MONTHLY ENERGY CONSUMPTION





BUILDING CHARACTERISTICS

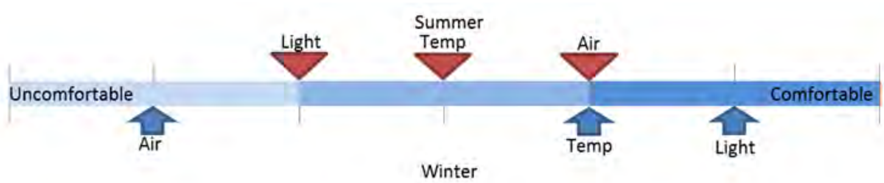
Details		Construction	
Floor area	95m²	**Ceiling**	Timber, lath & plaster (insulation, 250-270mm sheep's wool, cold attic)
Window orientation	West/East	**Wall**	Redbrick, lath and plaster (full fill cavity insulation, 50mm mineral wool)
Age of building	Pre-1860	**Floor**	Suspended timber and solid stone (no insulation)
Heating system	Heating fuel: mains gas Heating system: Combi boiler Heating distribution: radiators	**Window**	Single glazed (timber frame), (Roof light double glazed)

OCCUPANTS CHARACTERISTICS

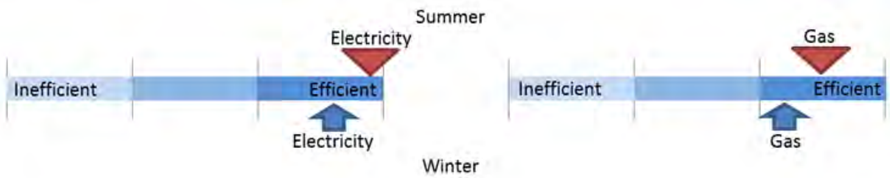
Daily activity profile

	2013	2014
Occupancy profile	2 - Majority of occupants are out the home for the majority of the week.	2 - Majority of occupants are out the home for the majority of the week.
Number of people	4	4
	1 x full-time employed 1 x part-time employed 2 x children under 5 years old	1 x full-time employed 1 x part-time employed 2 x children under 5 years old

Self-reported comfort scores



Self-reported energy efficiency behaviour scores



4 COMPARATIVE SUMMARY

4.1 ANNUAL ENERGY CONSUMPTION SPLIT: BETWEEN HOUSEHOLDS

The total annual energy consumption (kWh/m²/year) for each household is presented in Figure 4.1. The mean (average) energy consumption for the sample in 2013 was 156 kWh/m²/year with a standard deviation (SD) of 100.6. The mean energy consumption during 2014 was 192 kWh/m²/year [SD=58.3]. Using the 2014 annual gas consumption data, the gas consumption of this sample appears to fall broadly into two gas consumption groups; one with an average consumption of 200 kWh/m²/year [SD=20] [n=5] and the other with an average consumption of 88 kWh/m²/year [SD=25] [n=3]. These two groups contain the same households as the grouping by Occupancy Profile (OP). Gas consumption group one consisting of E3, 4, 5, 6, 7 being classified as OP1, and gas consumption group two consisting of E1, 2, 8 classified as OP2.

Household E1 had consecutively consumed the least amount of gas within the sample, consuming 72 kWh/m²/year in 2013 and 54 kWh/m²/year in 2014. Higher internal-external temperature differences calculated for E1 in the first five months of 2013 compared to 2014 will contribute significantly to the extra 18 kWh/m²/year of gas use. During the user experience survey, the interviewee explained how diligent the family were to avoid misusing energy and detailed the activities that the family did to reduce unnecessary gas consumption for space heating. The self-reported energy efficiency behaviour scores (EEBS) calculated for E1 for gas use in the winter and summer was the highest (most efficient) among the sample.

Furthermore, E1 was one of two dwellings in this sample that had the large single-glazed sash and case windows replaced with slim-profile double glazed sash and case windows. Previous research studies have shown that upgrading single glazed windows to double glazing or secondary double glazing can improve the heat reduction by over 50% (Baker 2006, Currie et al 2013, and Stinson et al 2015c). Furthermore, E1 had an occupancy profile of 2, meaning that the majority of the occupants were out of the home for the majority of the week.

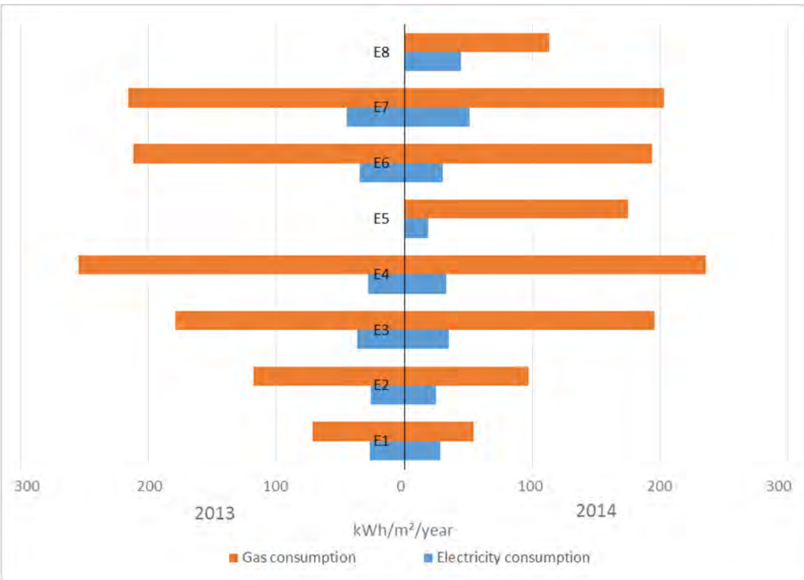


Figure 4.1 - Annual electricity and gas consumption values for 2013 and 2014.

Household E4 had the highest gas consumption for both 2013 and 2014. This household differs somewhat from the sample as it was the only basement dwelling. E4 was one of three dwellings that had secondary glazing and internal wall insulation, however, the interviewee for E4 highlighted that the orientation and below-street level placement of the windows meant that the dwelling received 'very little' amounts of solar heat gain. This was highlighted by the interviewee during the both the winter and summers surveys. The interview section of the survey noted that the occupants have had the sensation of 'feeling cold from the exposed flagstone floor'. The monthly gas consumption profile for E4 shows that, unlike the other seven households in the sample, E4 consumed considerably more gas during the summer months (June – September) for both 2013 and 2014. The internal temperature and temperature difference profile for E4 shows little difference when compared to the temperature profiles of the other seven households. During the user experience surveys, the occupants admitted to using the gas-powered space heating during the summer months to maintain a reasonable level of comfort.

4.2 ANNUAL ENERGY CONSUMPTION AND OCCUPANCY PROFILE

The energy consumption data from 2014 was used to statistically test for differences in energy consumption between the households assigned to the two different Occupancy Profiles (OP). The number of occupants in the home and the presence of children were used as variables to test for significant differences within the sample.

A Shapiro-Wilk test showed that the 2014 annual electricity and gas consumption values were approximately normally distributed for both occupancy profiles ($p > .05$). Analysing the data skewness and kurtosis values also showed that the data are normally distributed. These results suggest that the parametric test known as the T-Test was suitable to test the differences in 2014 annual gas and electricity consumption between the groups based on those variables. The Pearson's product-moment correlation coefficient (Pearson's r-test) was also selected to test the strength of the relationship between the variables.

The results from the two-tailed independent T-Test show that households E3,4,5,6 and 7, classified as Occupancy Profile 1 in 2014 (M = 200.8, SE = 9.95), consumed significantly more gas (128%) than the households classified as Occupancy Profile 2 (M = 88, SE = 17.62), ($t(6)=6.11$, $p = .001$). The same was not found for the 2014 electricity consumption; Households classified as Occupancy Profile 1 (M = 33.6, SE = 5.154) consumed only 4% more electricity than those in Occupancy Profile 2 (M = 32.3, SE = 5.897). This difference was not statistically significant, ($t(6)=0.166$, $p = .88$), whereas the relationship between the 2014 gas consumption and occupancy profile was measured as strong at $r=-.93$ and statistically significant ($p = .001$), suggesting a strong negative correlation between the amount of gas consumed in 2014 and the dwelling's occupancy profile. This difference between gas and electricity consumption, however, is to be expected as electricity consumption (with the type and number of appliances that are on all day, generally being very similar across the households) is based on a different set of variables to gas consumption (Fig. 4.2).

Further results show that those households without children (E3,4,6 and 7) (M = 207.3, SE = 9.78) and therefore lower occupancy (which is true for this sample) consumed 89% more gas than the households with more people and children at home (M = 109.8, SE = 25.07). This difference in gas consumption was statistically significant ($t(6)=3.624$, $p = .011$) and could be linked to a number of things, including difference in occupancy behaviours and/or more socially active lifestyles. The results for electricity consumption show a similar trend, where the households without children and therefore a lower occupancy (M = 37.3, SE = 4.70) consumed 28% more electricity than those households with children (M = 29.0, SE = 5.34). However, this difference was not statistically significant ($t(6)=1.16$, $p = .29$).

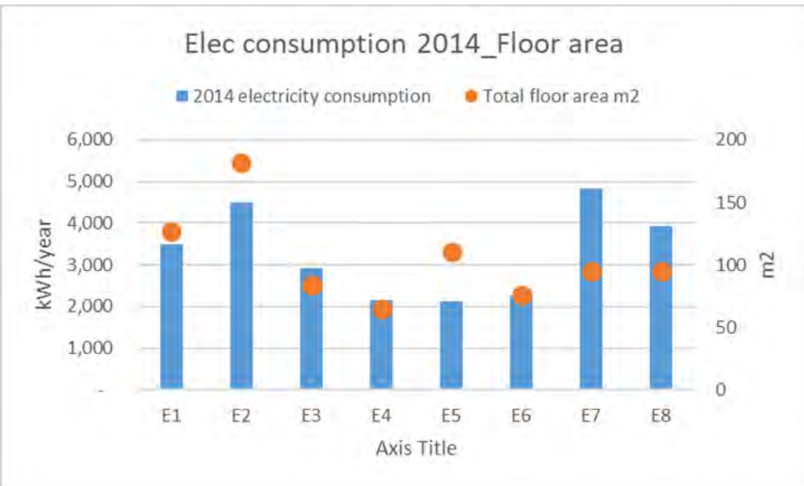


Figure 4.2 - Electricity consumption for 2014 against each household's total floor area.

It should be noted here, that the households without children and with lower occupancy (n=4) were all classified as Occupancy Profile 1, (OP1: the majority of the occupants are at home for the majority of the week). While this supports the use of the Occupancy Profile classification to group households for their gas consumption, it does not apply so strongly to electricity consumption. Figure 4.3 shows the relationship between the three occupancy variables (number of occupants, presence of children and occupancy profile) compared to levels of gas consumption (kWh/m²/year). In this figure, the households have been arranged by the amount of gas consumed during 2014.

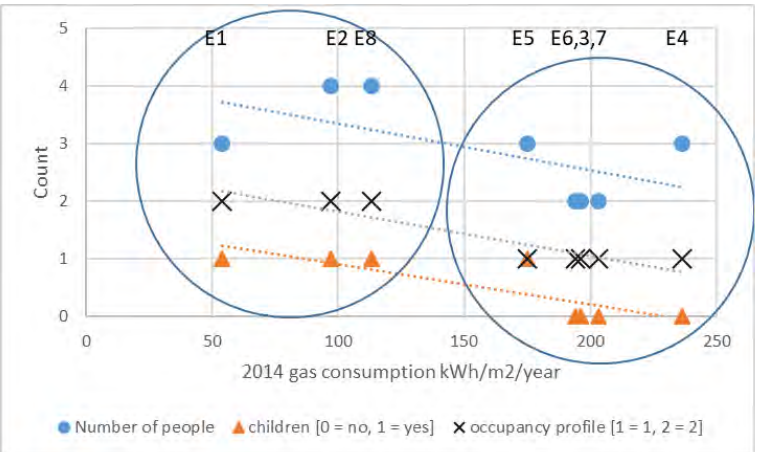


Figure 4.3 - Correlation between gas consumption, number of occupants, presence of children and occupancy profile.

The mean electricity consumption calculated from the total yearly electricity consumption during 2014 was 33 kWh/m²/year [SD=9.1]. Out of the eight households E7 and E8 (M = 47.5, SE = 3.5) both consumed more electricity than the others (M = 28.3, SE = 2.36). From the building information gathered during the monitoring period, E7 and E8 are distinct from the other dwellings because they are suburban two-storey cottages, whereas the other six households are urban tenement dwellings. Figure 4.4 shows the households arranged in order of the amount of electricity consumption, occupancy information (number of people, presence of children and occupancy profile) are also displayed for each household. Unlike the gas consumption results there is no clear relationship between the amount of electricity consumed during 2014 and the households' occupancy information. E2 and E8 have the same occupancy information but they are on different ends of the electricity consumption spectrum. More information about the number, type and frequency of use of the electrical appliances in the home may be required before a clearer correlation can be discovered.

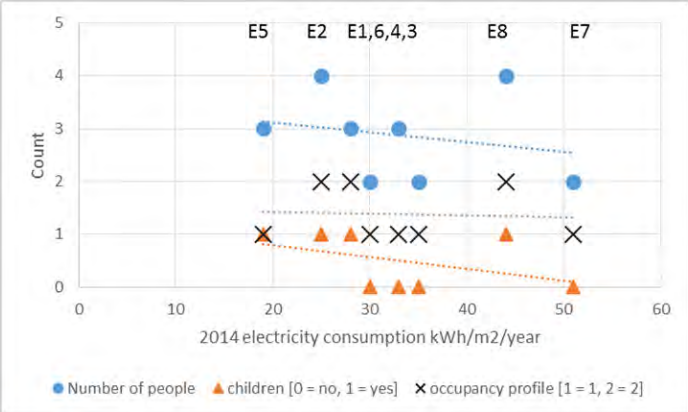


Figure 4.4 - Correlation between electricity consumption, number of occupants, presence of children and occupancy profile.

4.3 ANNUAL ENERGY CONSUMPTION SPLIT: BETWEEN YEARS

The annual energy consumption from each household is very similar between the two monitored years. Gas consumption differs between 13 and 21 kWh/m²/year between 2013 and 2014, with the majority of the households consuming more in 2013 relative to 2014. Household E3 is the exception to this (Figure 4.5). Colder external temperatures during February, March and November 2013 resulted in higher temperature differences and may be the cause for considerably more gas being consumed during those months. The gas consumption from household E3 displayed the same monthly profile for February, March and November as the rest of the sample, however, E3 consumed significantly more gas in the last month of

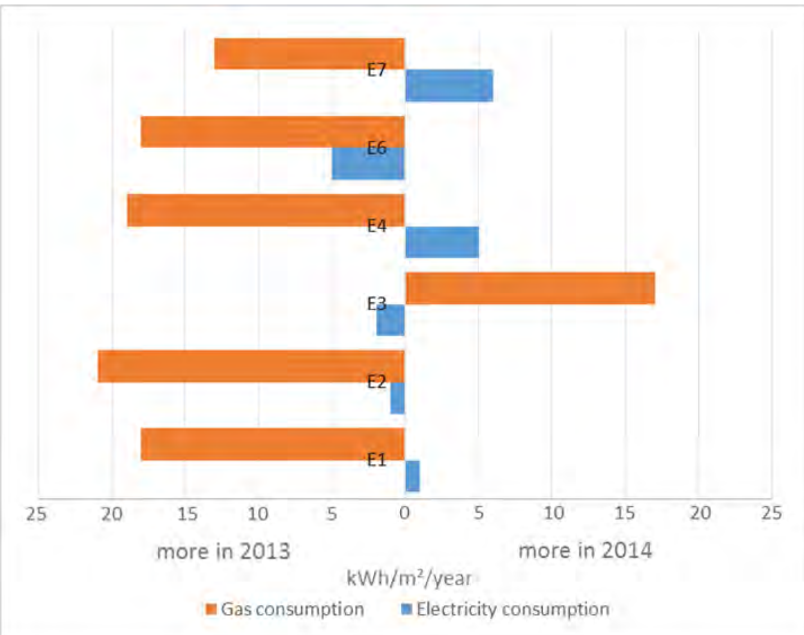


Figure 4.5 - Energy consumption difference between 2013 and 2014.

2014 than 2013. This has been attributed to a temporary increase in the number of residing occupants during that month.

For the whole sample, the differences in electricity consumption between the two years varied between 1 kWh/m²/year and 6 kWh/m²/year. Changes in occupancy profiles and frequency of guests was recorded as the major influencing factor in those differences for electricity consumption between the years. Households E6 and E4 provide examples of this.

4.4 PERCENTAGE BREAKDOWN OF ENERGY CONSUMED

The total energy consumed by the eight households during the 24-month research project has been calculated as a percentage split and is presented graphically in Figure 4.6 and Tables 4.1 and 4.2.

The results show that the occupants have consumed considerably more gas than electricity each year. For households where the heating is powered by gas, many other energy consumption statistics report the same level of gas to electricity split. The Office For Gas and Electricity Markets' (OFGEM) Typical Domestic Consumption Values (TDCV) indicate an 81% gas and 19% electricity split for a 'medium' energy user in Britain. With high consumers (79%/21%) and low consumers (82%/18%) calculated to have a similar percentage split (OFGEM 2013). However, the energy percentage split in highly insulated dwellings can be 50/50 electricity and gas; these are typically homes constructed after 2010 with lower levels of air permeability (Bros-Williamson et al 2015, Stinson 2015a).

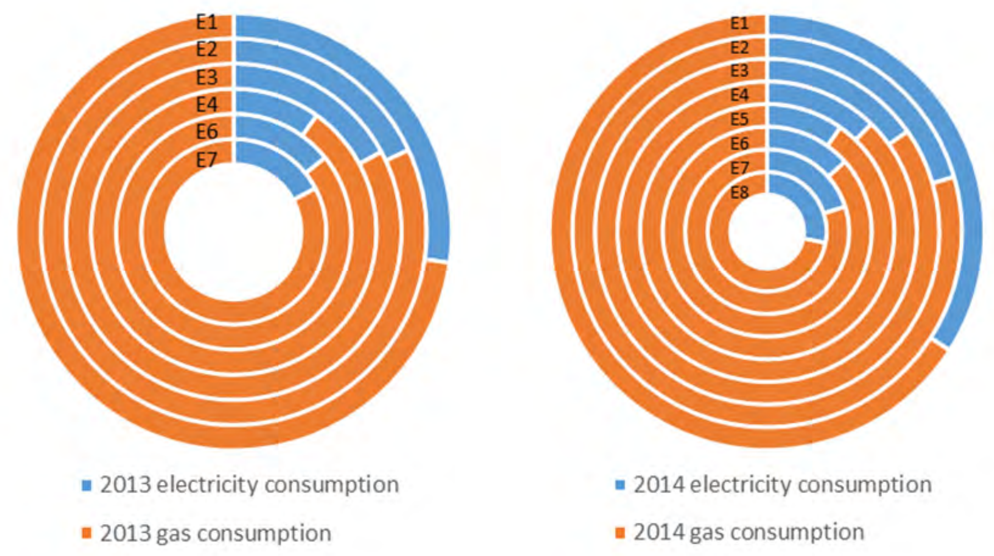


Figure 4.6 - Percentage split of electricity and gas consumption (kWh/m²/year) per household.

Table 4.1 - Percentage split of electricity and gas consumption (kWh/m²/year) per household.

	E1	E2	E3	E4	E5	E6	E7	E8
2013 electricity consumption	27%	18%	17%	10%		14%	17%	
2013 gas consumption	73%	82%	83%	90%		86%	83%	
2014 electricity consumption	34%	20%	15%	12%	10%	13%	20%	28%
2014 gas consumption	66%	80%	85%	88%	90%	87%	80%	72%

Table 4.2 - Statistical analysis on percentage split of electricity and gas consumption (kWh/m²/year) for all households per year.

	Maximum recorded value	Mean calculated value	Minimum recorded value	Standard deviation
2013 electricity consumption	27%	17%	10%	5%
2013 gas consumption	90%	83%	73%	5%
2014 electricity consumption	34%	19%	10%	8%
2014 gas consumption	90%	81%	66%	8%

4.5 RECORDED TEMPERATURES AND SAP TEMPERATURES

Differences or similarities in gas consumption between the two years of monitoring may be associated with external and/or internal temperatures. The temperature data recorded have been examined and considered for differences between location, household and year.

The differences between the recorded temperatures and those calculated by SAP have also been considered. This was done to better inform the comparative analysis with the energy calculations derived from SAP in Section 4.6.

4.5.1 Monthly external temperatures

The mean monthly external temperatures have been calculated using the two years of data collected from each location. The same data has been used to calculate the maximum and minimum monthly temperatures along with the standard deviation of the recorded means. The monthly external temperature generated by the UK domestic building carbon/energy regulation compliance tool known as SAP 2009 (Standard Assessment Procedure) have been overlaid. These are plotted in Figure 4.7.

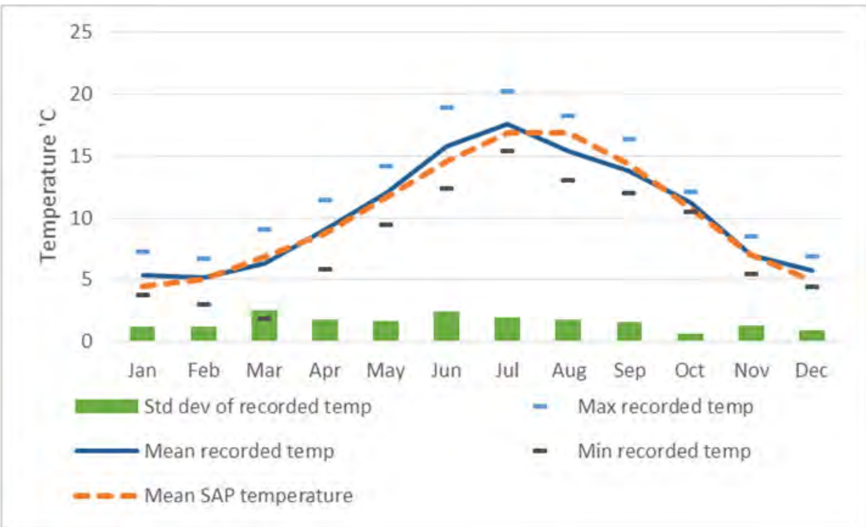


Figure 4.7 - External temperatures.

The data shows that the recorded average monthly temperature profile is very similar to that used by SAP (R^2=0.98, Y=0.9559x+0.6281). The standard deviation calculated from the eight data sets (four locations over two years) are relatively low with maximum and minimum temperatures on average +/-2°C from the mean. Larger differences between the two years of data recorded at the four locations are seen in March and June. The temperatures recorded in March 2013 by the inner-city loggers were up to 7°C lower than those recorded in the rural location. External temperature recorded in March 2013 and 2014 where some of the coldest temperatures recorded over the monitoring period. The lowest temperatures in March were up to 6°C lower than SAP. The June temperatures for 2013 and 2014 where 4 to 5°C higher in the Old Town of Edinburgh when compared to the new town of Edinburgh or at the rural location. Many of the households located in the urban environment reported uncomfortable internal conditions during the summer due to overheating. Moreover, it is assumed by SAP that the space heating is not used during the summer months which, in reality, may not always be the case, as there are also other factors that affect our perception of thermal comfort (e.g. more extreme day/night temperature fluctuations, limited solar heat gain, wind speed etc.).

4.5.2 Monthly internal temperatures

The internal temperatures were recorded for each of the eight households in this study. The data was collected at hourly intervals for each month during 2013 and 2014. The temperature logger was placed in the hallway of the dwelling and positioned in a location as central as reasonably practicable. The hourly data was used to generate monthly averages.

Within the sample, the monthly mean internal temperature for each household varied little between months and years. The yearly average internal temperature for the whole sample for both years was 20°C, standard deviation of 1.9°C, with an average high in July of 23°C and average low of 19°C in January and February.

Figure 4.8 shows the monthly mean, maximum, minimum and standard deviation calculated for the monthly internal temperatures for the sample. Largest temperature differences between the households were observed during the winter months, December to February. During these months the social rented households E3 and E6 with older and retired occupants had an internal temperature 4°C to 5°C higher than the other households in this study.

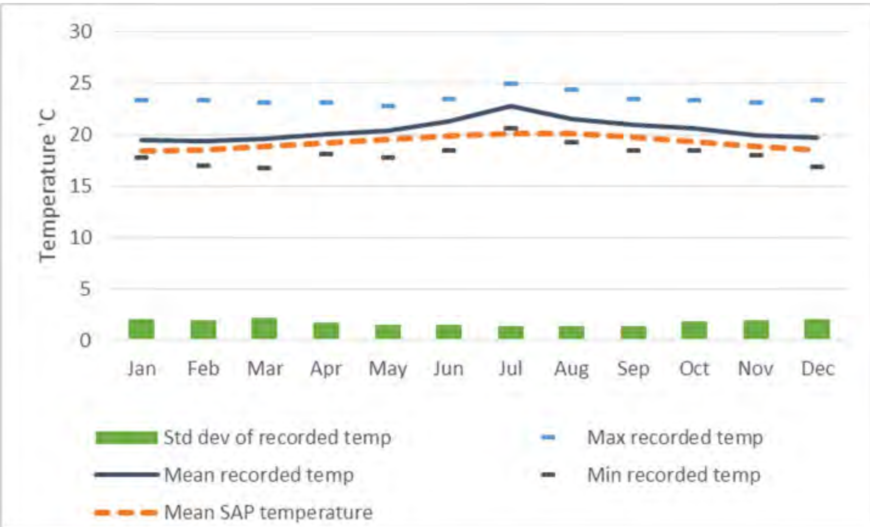


Figure 4.8 - Internal temperatures.

The standard deviation of the mean internal temperatures was less during the summer months. The summer months (May to September) are times when the occupants had less influence on the internal temperature via the gas-powered space heating. During this time, the internal temperatures are typically governed by the external weather conditions, of which the occupants have little control on how they affect the internal temperatures. Furthermore, it was observed that the internal temperatures are more dependent on solar heat gain and, therefore, the orientation of windows.

SAP also produces an internal temperature profile for each dwelling using a target of 21°C in the living area and 18°C in the rest of the dwelling. These target temperatures are then used with an estimate weekday and weekend heating schedule and the calculated heat losses and heat gains based on the building fabric to generate monthly mean internal temperatures for the whole dwelling. The monthly internal temperatures generated by SAP have been averaged together from the eight dwellings and plotted with the recorded temperatures in Figure 4.8. The average internal temperature from SAP for all dwellings was 19°C, with very small variation between dwellings (<1°C) or months (<1.6°C), and a standard deviation 0.7°C.

The comparison between the monthly recorded average internal temperature data and the equivalent SAP generated data shows that the difference between the two is relatively small (R^2=0.82, Y=1.4723 x+7.823), where the recorded average temperature is on average 1.2°C higher than the SAP data set. The largest difference between the two data sets was calculated for July, with a difference of 3°C.

4.6 HEAT CONSUMPTION COMPARED TO SAP PREDICTION

The Standard Assessment Procedure (SAP) heating requirement results have been used to normalise the measured heat. This was done for each dwelling. The result is being referred to as the household's heat score, with units of kWhmes/kWhSAP. The monthly heating score results are presented in Figure 4.9. The difference between the annual measured heat consumption and SAP heat consumption is presented as percentages in Figure 4.10.

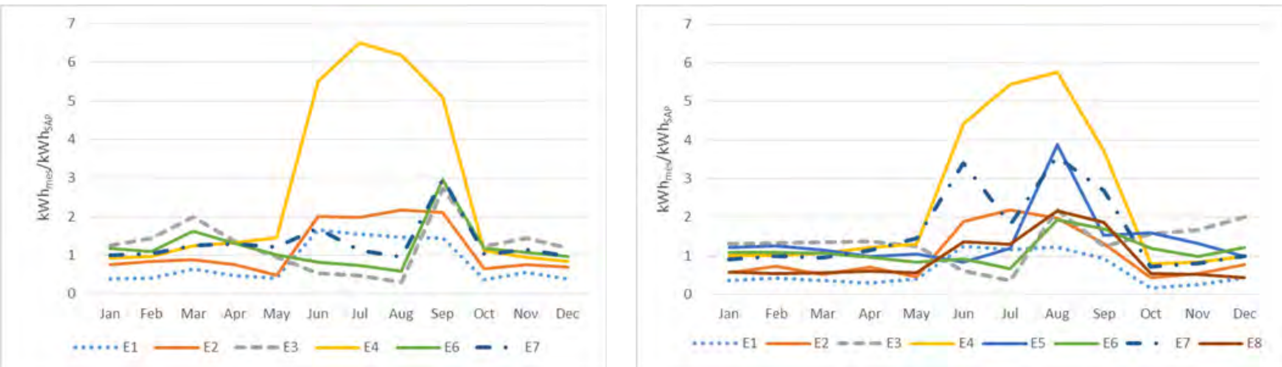


Figure 4.9 - Monthly heat score for all households with available data [left] for 2013 (n=6), [right] for 2014 (n=8).

Normalising the measured heat consumption by the SAP heat requirement values takes into account the energy required in the dwellings over an annual cycle based on orientation, heat losses and gains, fabric efficiency, floor area etc. It thus allows for a comparison of energy use across dwellings and removes the bias of energy consumption based on fabric, orientation, technology performance, internal and external temperature differences.

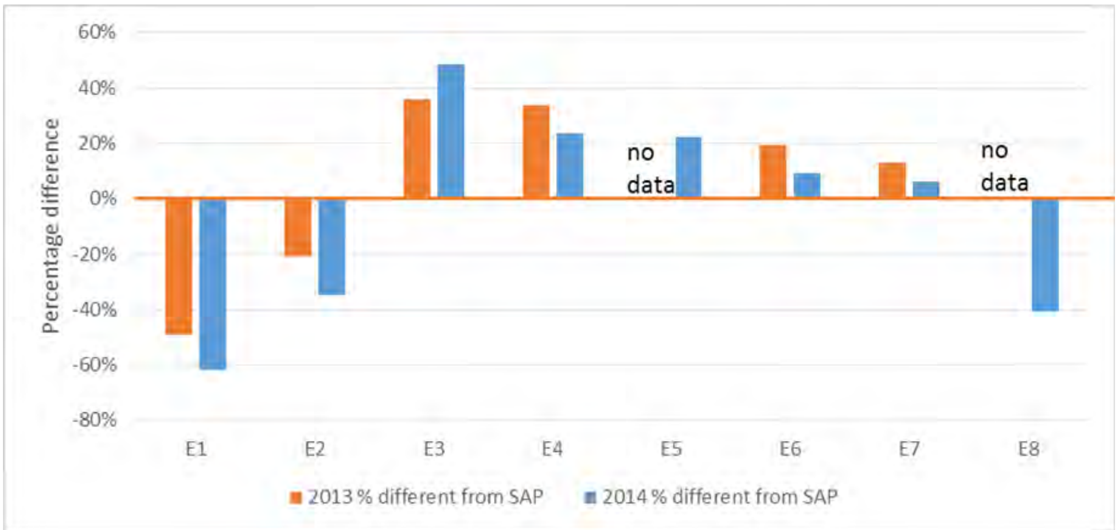


Figure 4.10 - Difference between annual measured heat consumption and calculated annual heat consumption from the SAP.

A household with a heat score of 1 signifies that the recorded gas consumption is equal to that calculated by the SAP. A heat score greater than 1 (>1) means that the measured heat consumption is higher than that calculated by the SAP. A heat scores below 1 (<1) signifies that the household's heat consumption is lower than the SAP calculated value.

The monthly heat score profile for the eight households show that largest differences between the measured and calculated values occurs during the summer months (June, July, Aug, Sept) of 2013 and 2014.

Outside of the summer months, the heat scores for household E1, E2 and E8 are typically lower than 1 (the SAP baseline). Households E3 and E6 have summer heat scores below 1. Household E4's (basement household) heat scores shows the largest variation from SAP during the summer months. These summer results may be related to the assumptions within the SAP methodology that state a household will consume zero gas for space heating during the summer months, whereas most of the households in this sample appear to have consumed some gas for space heating during these months. This may also relate to inaccuracies with water heating consumption where the SAP methodology links the amount of water heating to the number of people which in turn is linked to a calculation of the number of people per floor area (m^2).

On average, excluding the four summer months, most of the households in this sample had monthly heat scores for 2013 and 2014 close to 1. Figure 4.11 shows the mean (average) monthly heat scores and the standard deviation for all households, considering both years of monitoring. Also presented in Figure 4.11 is the sample's monthly mean without household E4. Overall, the annual percentage differences between the measured and consumed heat shows that E1 and E2 consumed less heat during the two years, E8 also consumed less during 2014. Households E3, 4, 5, 6 and 7 consumed varying amounts more than the SAP calculated heat requirement during both years.

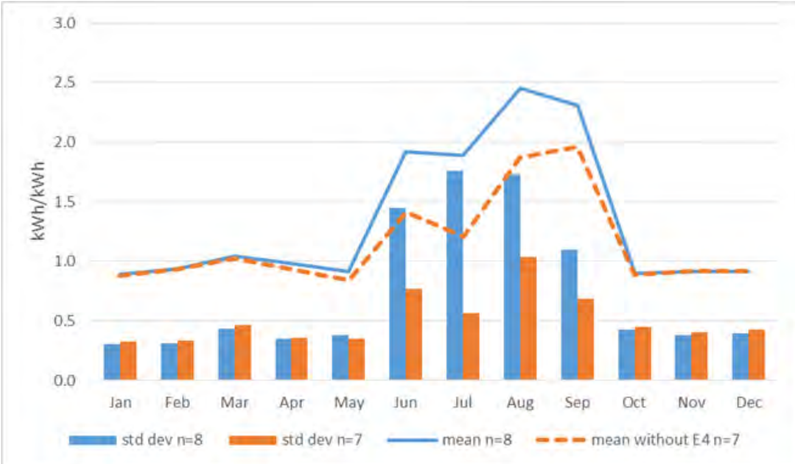


Table 4.11 - Sample's mean monthly heat scores with standard deviation.

4.7 CORRELATION BETWEEN HEAT CONSUMPTION AND TEMPERATURE DIFFERENCES

It was not feasible to sub-monitor the gas consumed for space and water heating, therefore, recorded heat consumption is reported here to include the amount of gas to heat both the water and the space heating. This monthly heat consumption data is analysed for its relationship to the monthly external temperature recorded around the sample of households. The temperature analysis (see Section 4.5) has shown some, but marginal, difference between SAP calculated temperatures and those recorded within and outside the dwellings.

The water heating requirement calculated by the SAP is dependent on the number of people within the household and this value cannot be changed within the market-available SAP software. The number of people is dependent on floor area. From the SAP results for these eight dwellings, the calculated number of people per dwelling ranged between 2.12 to 2.98.

It is important to be aware that heated water use behaviour was not monitored or calculated for this sample, therefore, caution should be exercised when interpreting the results in this Section.

The Pearson's product-moment correlation coefficient was calculated for each household and for each year. The data used to generate these results were the monthly heat consumption data and monthly temperature difference data. This result was then squared to calculate the coefficient of determination (R^2). The results represent the proportion of the variance between the monthly temperature difference (internal – external temperature) and measured heat consumption in kWh/month with a range of 0 (0%) and 1 (100%).

Fourteen correlations tests were conducted, one for each household for each year of available temperature and heat consumption data. The results show that for the 64% in this sample, over 90% (0.9) of the variance in the monthly heat consumption can be explained by the internal-external temperature difference. For the majority (92%) in this sample, over 76% (0.76) of the variance in heat consumption can be linked to the internal-external temperature difference. For the households with lower R^2 values the temperature difference explains less of the variance in gas consumption. For E8, this relates to the month of December where the gas consumption is considerably lower than expected for the temperature difference. Removing December's data from E8 changed the coefficient of determination from 0.76 (76%) to 0.93 (93%). For the sets where the coefficient of determination is between 0.75 (75%) and 0.90 (90%), less of the variance in heat consumption data can be explained by water heating demand and enigmatic nature of occupancy profile.

Overall, when the heat consumption was high, so too was the difference between internal and external temperatures. This suggest a strong linear relationship between the external temperature becoming colder and the occupants using more gas for space heating to maintain comfortable internal temperatures. Figure 4.12 shows the R^2 results for each household for each year of monitoring.

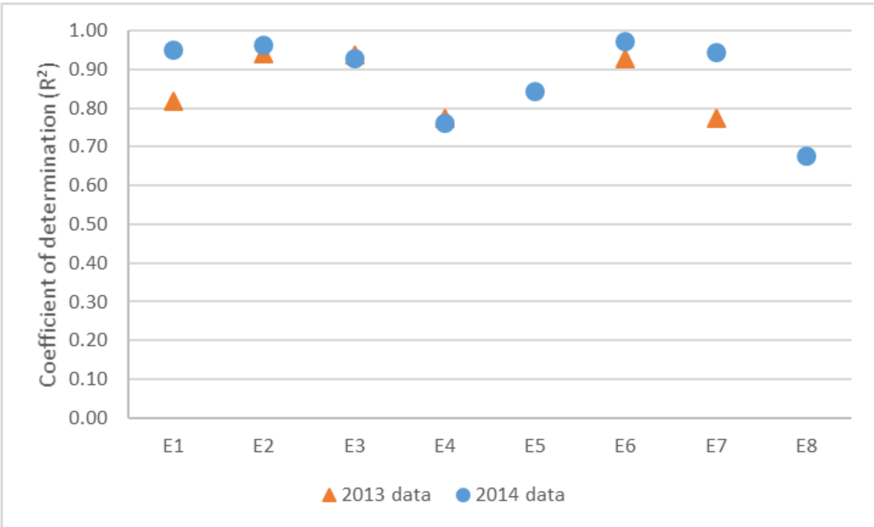


Figure 4.12 - Results from Pearson's correlation (r) test for each household's monthly data for each year.

4.8 ENERGY CONSUMPTION COMPARE TO SUB-NATIONAL ENERGY STATISTIC

This section compares the electricity and gas consumption (kWh/year) from this project's sample to the Typical Domestic Consumption Values (TDCVs) published by OFGEM (2013) and the national and sub-national energy consumption statistics as published by the Department for Business, Energy & Industrial Strategy (BEIS, 2015).

The OFGEM and the BEIS statistics are not normalised by dwelling age, tenure, archetype or floor size and the TDCVs are not specific to the pre-1919 constructed dwellings. OFGEM calculate typical low, medium and high TDCVs for gas and electricity by averaging the two most recent values for the lower quartile, median and upper quartile of the consumption data. The TDCVs figures published in 2013 have been chosen as they represent the national figures at the time when the data was recorded from this sample. The BEIS present the average energy consumption values by median per year by local authority. The recorded energy consumption values for this sample are presented here in kWh/year, so they are comparable to the values offered by the BEIS and OFGEM.

The TDCVs for gas are calculated from temperature corrected (weather-desensitisation) data. These are published to allow consumers to compare energy consumption levels. The BEIS statistics are also calculated from temperature corrected data. Other online accessible databases with energy consumption for local authorities such as www.statistics.gov.scot are based on the BEIS's temperature corrected data.

The OFGEM and the BEIS statistics have been presented with the recorded energy data from this test sample and are presented in Figure 4.13 for gas consumption and Figure 4.14 for electricity consumption. Figure 4.13 also displays the calculated SAP values for each household and shows that the majority (n=6) of the sample fell between the medium and high levels of typical domestic consumption for gas. The median gas consumption for Great Britain, Scotland and Edinburgh is presented in Table 4.3.

Distribution of gas consumption per number of households in the UK is positively skewed, meaning the median average is lower than the mean average. The gas distribution for 2013 shows that the majority of households consumed between 8,000 and 14,000 kWh/year (NEED 2013). Those figures are also temperature corrected. The median consumption has been quoted from the BEIS figures as it is a more appropriate measure of typical consumption than the mean.

Comparing the values in Table 4.3 and Figure 4.13 shows that the gas consumption values for Edinburgh are less than that for Scotland (13% less) and GB (10% less). Edinburgh was one of the local authorities with the lowest annual gas consumption for 2013 and 2014. This is not represented from the test sample's gas consumption data. Six of the test samples have consumed considerably more gas than the BEIS statistics median values.

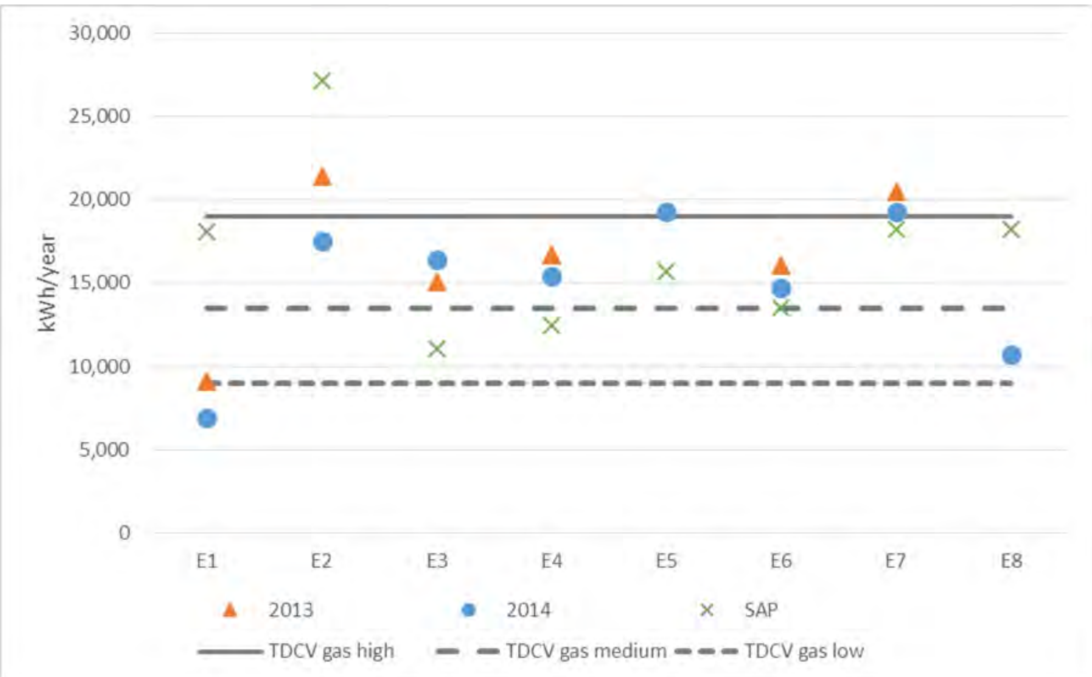


Figure 4.13 - Annual gas consumption data per household for 2013 and 2014, including SAP data and TDCVs.

The OFGEM and the BEIS electricity consumption data are not temperature corrected and offer a direct comparison to the electricity consumption data recorded from the households in this study. Three of the test samples consumed levels of electricity close to the low levels of TDCV. Three consumed electricity levels close to the TDCV medium level, while the remaining two had consumed electricity close to, but not above, the TDCV for high consumption.

Comparing the electricity consumption values in Table 4.3 and Figure 4.14 shows that, similar to the gas consumption, Edinburgh's electricity consumption is lower that the median for Scotland (10% less) and GB (11% less). Again, Edinburgh's median electricity consumption is one of the lowest among other local authorities in Scotland. Over half (n=5), consumed electricity levels close to the BEIS median consumption values, with three households consuming less than the BEIS annual median electricity consumption for Edinburgh.

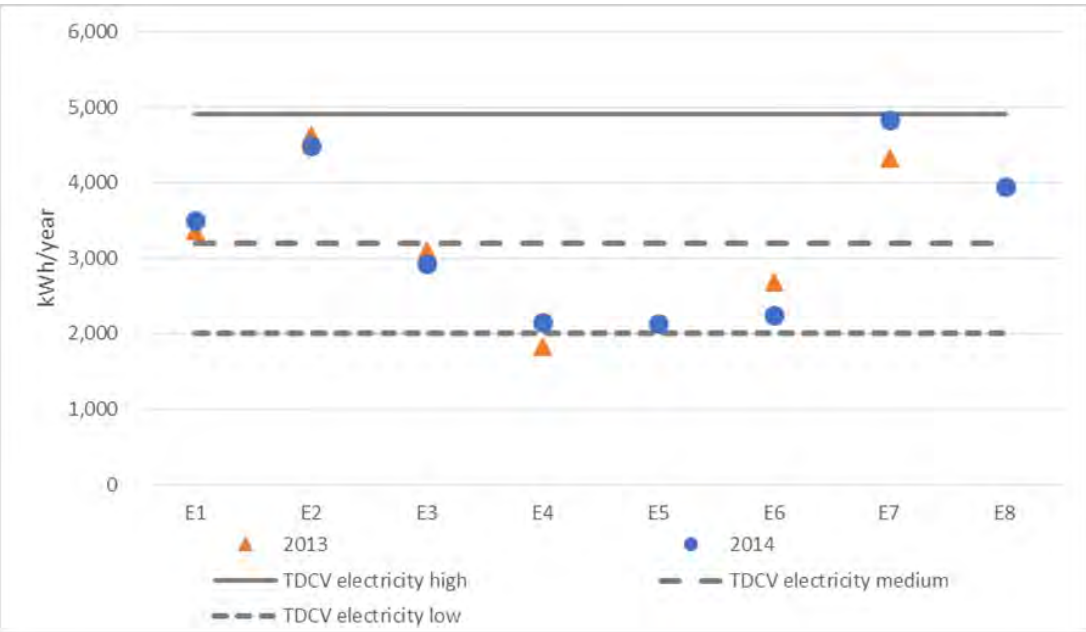


Figure 4.14 - Annual electricity consumption data per household for 2013 and 2014 including SAP data and TDCVs.

The national and sub-national data gas consumption data are temperature corrected and not directly comparable to the values recorded from the test sample. However, analysis undertaken by the authors of the sub-national gas consumption values have shown that the difference between corrected and actual average annual gas consumption is between 500 and 1000 kWh of the total GB gas consumption during 2013 and 2014.

Table 4.3 - Median gas and electricity consumption data from the BEIS sub-national statistics.

	Great Britain	Scotland	Edinburgh
2013 electricity consumption	3,080	3,033	2,715
2013 gas consumption	12,218	12,711	10,989
2014 electricity consumption	3,072	3,043	2,731
2014 gas consumption	11,788	12,268	10,613

4.9 COMPARISON TO OTHER AGES AND ARCHETYPES

This section compares the energy consumption from the historically built dwellings to that from 60 dwellings built between 2012 and 2017. These 60 dwellings have been separated into 2 samples:

1. 43 electrically heated dwellings; constructed using closed panel timber framing; with mechanical ventilation and heat recovery; built to Scottish Building Standards 2015; occupied in 2017.
2. 17 gas heated dwellings; constructed using timber or steel frame systems; with mechanical ventilation and heat recovery; built to Scottish Building Standards 2010; occupied in 2012.

The energy data used for this comparison includes both regulated (space and water heating) and unregulated (all other, including lights and domestic electronics) energy consumption. For the households in this study (pre-1919 gas heated) the 2014 energy consumption is used.

The range of energy consumption from the homes in each sample is evidenced by the length of the box plot in Figure 4.15. The box plot shows the average (median) energy consumption for each of the respective samples – this is indicated as a horizontal line with an X inside the coloured boxes. The top and bottom of the coloured boxes represent the 3rd and 1st quartiles of the measured data. Whilst the top and bottom of the vertical lines represent the maximum and minimum measured values within each sample. The large ranges seen in Figure 4.15 are a common occurrence observed in the field of energy monitoring, evidenced by the length of box plot for the households in each sample.

The three box plots for the three samples overlap considerably, however, if only averages are quoted (mean), then on average, the households in this study (pre-1919 gas heated) (18,287 kWh) consumed 51% more energy than the comparators from the new-build (2012) gas heated sample site (12,149 kWh). Although this is ill-advised due to a change in the heating fuel time, the direct energy difference to the electrically heated sample is also reported – for completeness. On average, the households in this study (18,287 kWh) consumed 178% more energy than the households in the new-build (2017) electric heated site (6576, kWh).

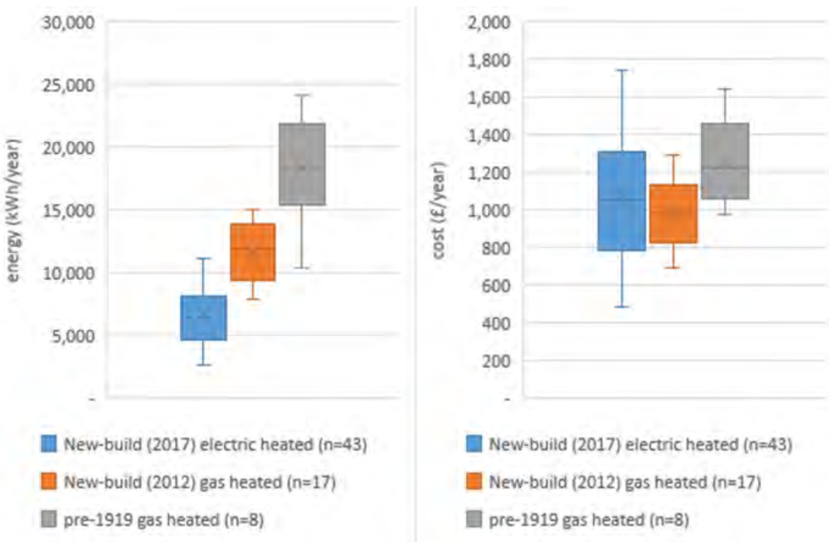


Figure 4.15 - Annual electricity consumption and energy cost with 2 comparators.

The energy data from the 3 samples have been converted into costs using a common 2016 tariff structure. This being 27.39p per day standing charge; 15p/kWh for electricity consumption and 3.839p/kWh for gas consumption. This allows for a more logical comparison between the households' energy consumption. The considerable difference between the unit cost of electricity and gas is made evident by the substantial change in the scale of the box plots.

On average (mean), the households in this study (pre-1919 gas heated) consumed 28% more energy (£1,249) than the comparators from the new-build (2012) gas heated sample site (£979); and 17% more energy than the households in the new-build (2017) electric heated site (£1,072).

The comparison results returned values which are in keeping with the general consensus; older archetypes consume more energy than newer dwellings. Most of which is predicated on the dwellings' thermal envelope (U-values), internal dimensions (volumes) and ventilation strategies. However, occupant energy efficiency behaviour, perceived levels of thermal comfort and other socio-economic factors (fuel poverty, demographics, occupancy profile) can have a considerable influence on annual energy consumption, perhaps evidenced by the overlapping pattern from the 3 datasets. To this effect, an occupants' level of energy efficiency and perceived thermal comfort, linked to appropriate levels of fabric efficiency retrofits, can achieve similar levels of gas consumption and heating bills as those in new-build dwellings.

4.10 BEHAVIOUR COMPARISON – COMFORT AND ENERGY EFFICIENCY

During the monitoring period, the occupants from each household completed a survey administered by the researcher. The surveys were completed on four occasions and conducted towards the end of two summer periods and two winter periods. The surveys inquired about the occupant's perception on their thermal comfort and the frequency of conducting energy saving activities in the dwelling (for more detail see Section 2.4).

4.10.1 Thermal comfort

The thermal comfort questions were split into three aspects; temperature, air movement and lighting, each aspect had two or three criteria. These criteria were used to construct the questions for the semantic differential scales. To evaluate the occupants' perceptions towards internal levels of comfort the following aspects and criteria were used. The same aspects and criteria were used to score levels of internal comfort for both the winter and summer seasons:

- **Temperature**
  - Comfort
  - Extremes of hot or cold
  - Variations in temperature
- **Air movement**
  - Unwanted ventilation (around doors, windows etc.)
  - Levels of condensation
  - Quality of air, sensations of freshness or stale air
- **Lighting**
  - Amount of natural need to feel comfortable
  - Amount of artificial need to feel comfortable

The results collected after summer and winter 2013 were compared to the results collected after summer and winter 2014. Very marginal differences were measured between the years for both seasons. This difference was in the range of +/-1 on the 7-point semantic differential scale. This finding shows consistency in the responses of the occupants and supports the use of this evaluation method.

The scores for the individual criteria were averaged to create a score for the overall aspect of thermal comfort. Figure 4.16 shows the qualitative scores for each household as calculated for each aspect and each season. The outer and inner rings of the radar charts have been coloured green and red to denote comfort and discomfort. Scores within those bands indicate that, on average, the occupant scored the criteria within each comfort aspect as very comfortable (green) or very uncomfortable (red).

The occupants typically scored the lighting as very comfortable. Interviews found that those in this sample preferred the use of natural light over artificial light. Furthermore, the large windows and >2m room heights which are typical of the archetype had allowed for natural light to be the primary source of task lighting for most of the day and year.

50% of the occupants in this sample scored the air movement criteria as very uncomfortable, and more so during the surveys conducted for the winter season. Interviews identified condensation and cold air infiltration as the primary reasons for the low winter scores. Some occupants commented on the lack of air movement in the dwelling during the summer months. This was a leading cause of discomfort which was related to long episodes of overheating and feeling that the air was too dry - 'stuffy'.

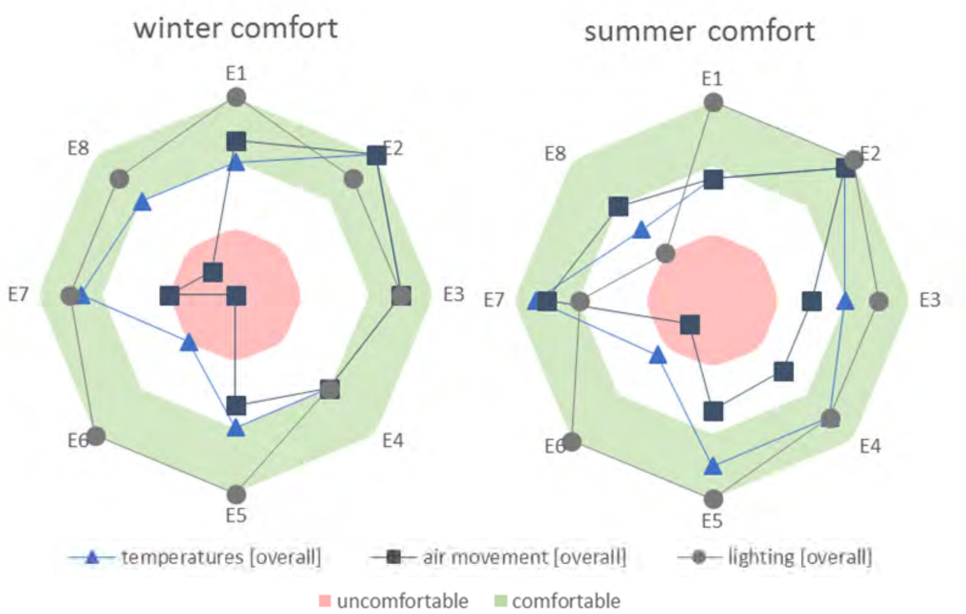


Figure 4.16 - Thermal comfort scores for all criteria in each aspect for both seasons.

The overall comfort scores for temperature, air movement and lighting have been compared using correlation coefficient analysis. This was done to measure the relationship between the occupants' score for each aspect of comfort. The results show a strong positive correlation between the occupants' comfort score for summer internal temperature and the comfort scores for summer air movement ($r = 0.7$), and a slightly stronger correlation coefficient was returned for the relationship between the comfort scores for winter internal temperature and air movement ($r = 0.8$). No significant correlation relationship was found between temperature and lighting, or air movement and lighting for either winter or summer. This result demonstrates the sensitivity between temperature and air movement on the occupants' comfort levels.

The total thermal comfort scores for each household has been calculated by summing the scores calculated for the three aspects: temperature, air movement and lighting. This has been done for the comfort scores calculated for summer and winter and are presented in Figure 4.17. The results show that the majority of the occupants scored their perception of the internal environment as "comfortable" with none of the occupants scoring their environment as totally uncomfortable.

The majority ($n=5$) scored their comfort levels during the summer higher than their comfort levels during the winter. These differences where marginal and not statistically significant, $t(7)=-.197$, $p>.05$ $r=0.8$ (which may be linked to the small sample size). Feedback from the occupants, collected during the interviews, revealed that overheating in the summer and condensation and draughts in the winter were the most common conditions that negatively affected their overall thermal comfort scores.

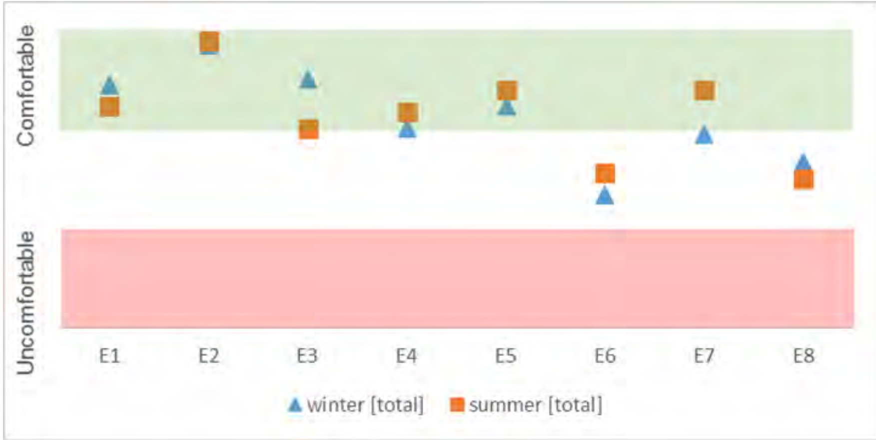


Figure 4.17 - Total thermal comfort scores for both seasons.

A comparison of results between seasons (summer to winter) has shown a strong correlation between the comfort scores. When occupants scored one aspect (e.g. temperature) high or low in the summer, they also scored the same aspect in a similar way (+/-1) for the winter version. The exception to this is observed in households E7 and E8. These dwellings have very similar characteristics, archetype, room layout, and SAP scores. The variation between seasons for these dwellings was in their perception of the "air movement" aspect, which contained questions relating to undesirable ventilation, condensation and sensation of freshness in the dwelling. The occupants of E7 and E8 scored their comfort in terms of air movement lower in the winter and higher in the summer. Responses collected during the interviews identified that occupants in both dwellings highlighted cold draughts and surface condensation as factors which significantly affected their comfort in the winter seasons.

Summing the summer and winter thermal comfort scores together returns the total thermal comfort score for each household for the year. Figure 4.18 shows these scores ranked from highest to lowest. The chart also shows the calculated average thermal comfort score for this sample.

Figure 4.18 - Total comfort score for year with average comfort score from the sample group.

Based on tenure type, the sample can be divided into two groups. The occupants from three dwellings were owner/occupiers and the remaining five participants lived in social rented dwellings. There is a trend in the results that shows those who are owner/occupiers scored their thermal comfort higher than those in social rented dwellings. Numerous variables affect these results. During the interviews, concepts of ownership of the dwelling in terms of ability/permission to enhance the dwelling; beliefs on investing time and/or money to improve the dwelling; and disposable income were the factors which were raised by the occupants to support their description of the dwelling in relation their levels of thermal comfort.

4.10.2 Energy Efficiency Behaviour Score (EEBS)

All of the households in this sample used electricity to power entertainment, kitchen and bathroom appliances including ovens, fans, and showers. The space and water heating for all of the dwellings was provided by a gas combi-boiler. During the interviews, the occupants were presented with a list of 14 activities relating to electricity and gas use in the dwelling. The list of activities consisted of six activities relating to gas consumption and eight relating to electricity consumption. The occupants were asked to comment on the frequency by which they conducted each of these activities. The occupants' feedback has been analysed per households; the results are referred to as Energy Efficiency Behaviour Scores (EEBSs).

An occupant's energy use behaviour was classified as "efficient" if they stated that they "always" (alternative wording "as frequently as possible") undertook an energy saving activity. On the same scale, the occupant's behaviour was scored as "inefficient" if they stated that they "never" undertook the energy saving activity. During the monitoring period, the EEBSs were collected after the summer and winter seasons, and these responses for each utility were averaged respectively.

Very little variation was detected between the mean EEBSs based on seasons or utilities. The occupants scored their summer electricity consumption behaviour and winter gas consumption behaviour as being the most efficient, with the least amount of variation. [Electricity_summer_EEBS $M = 3.3$, $SE = 0.17$; gas_summer_EEBS $M = 3.2$, $SE = 0.12$. Electricity_winter_EEBS $M = 3.2$, $SE = 0.47$; gas_winter_EEBS $M = 3.3$, $SE = 0.48$]. The differences between summer and winter scores were not statistically significant for both the electricity ($t(7) = 0.68$, $p > .05$) and gas ($t(7) = -0.80$, $p > .05$) EEBSs. Also, the differences between electricity and gas scores were not statistically significant for summer ($t(7) = -0.62$, $p > .05$) or winter ($t(7) = 0.29$, $p > .05$).

Figure 4.19 shows the EEBSs for each utility, for each household. The EEBSs in Figure 4.19 are the combined scores for both averaged summer and averaged winter scores. Six households (E1, E2, E4, E6, E7, E8) scored in the upper "efficient" third of the energy efficient behaviour scale for at least one utility. Households who declared regularly conducting energy saving activities for one utility did not always report the same level of regularity for the other utility. Of the six households with different electricity and gas behaviour scores, four had noticeable differences in the frequency of energy efficient behaviour for the two utilities. There was no clear preference towards increased frequency of energy saving behaviour based on utility type. Four households had higher electricity EEBSs, while three households had higher gas EEBSs.

A strong negative relationship ($r = -.87$) was calculated when comparing the EEBSs for gas consumption behaviour to the results from the SAP normalised gas consumption (gas score) data. A scatter plot chart presents these results in Figure 4.20. The EEBSs of the eight households are plotted along the x-axis; this is an absolute range as EEBS scores cannot be higher or lower than the range presented in the chart. The y-axis is the range for SAP normalised gas consumption (heat score). This ranges from 0 to 2. It is possible that a household could be consuming gas at more than twice that calculated by SAP, but it is impossible for a household's gas score to be 0 or lower.

Figure 4.19 - Occupants' total yearly EEBSs for electricity and gas use.

The chart also displays the SAP line. Data points plotted above this line represent households whose actual gas consumption was higher than that calculated by the SAP. Data points below the line represent households who consumed less gas than that calculated by the SAP.

The inference made from these data is that a household with a higher EEBS has lower heat score. The R^2 value (coefficient of determination) is used here to show that the households' EEBSs share 75% of the variability in the households' heat scores. This leaves 25% of the variability still to be accounted for by other variables.

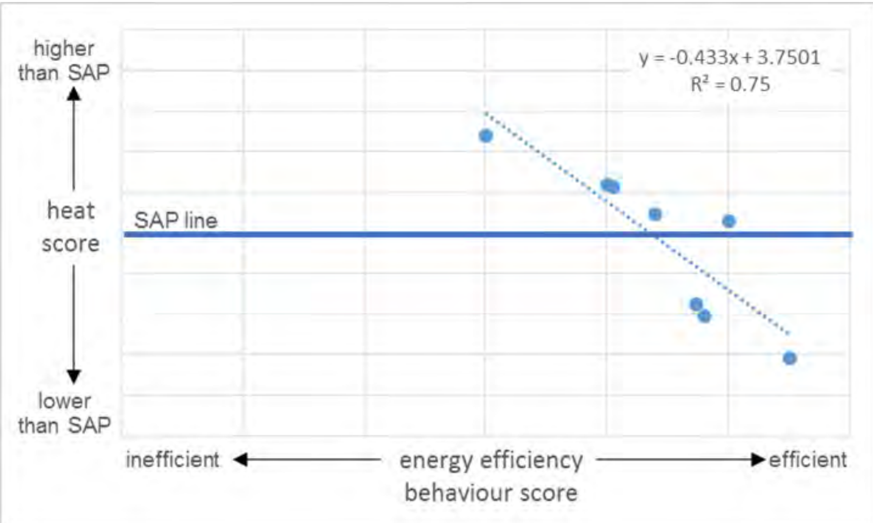


Figure 4.20 - Occupants' total yearly EEBSs for electricity and gas use.

The results presented here are based on limited (eight households) datasets. Although the data provides results to support the hypothesis that a large EEBS relates to low gas consumption ($r = -.87$, $p = .001$ [one-tailed]), more data is needed to fully test this model. It may be that different models are needed for different archetypes or age of household. For example, the linear regression shown in Figure 4.20 may only be applicable to pre-1919 dwellings. This may explain why the SAP line intersects the regression line in the upper range of EEBS. Different theories could explain this; perhaps the SAP calculated energy consumption is not appropriate for historical dwellings and/or perhaps the energy use behaviours of occupants who live in historical dwelling are much more efficient, due to the experience or perception that older dwellings are more expensive to heat which may affect their energy use behaviour.

5 CONCLUSION AND FURTHER RESEARCH

This paper was produced from research conducted with eight households located in Edinburgh and Midlothian between 2012 and 2015. The data analysis, statistics and results were produced to provide greater insight into the levels and type of energy consumption between occupants and dwellings. The aim of publishing this work is to establish energy benchmark data to assist further research and development of tools and strategies for the continual protection of these dwellings into an energy efficient future.

This research and presentation of results has contributed to the substantial body of knowledge being funded and collated by Historic Environment Scotland. This report marked the beginning of longer-term research project with the vision of monitoring and reporting on several years' worth of energy consumption and user behaviour data for different styles of historical dwellings.

In 2015, the energy and temperature loggers were removed from the eight households listed in this report. These loggers will be installed into differently styled but similarly aged dwellings with the objective of running the same methodology and adding the new data sets to the growing www.retrofitscotland.org data base.

5.1 REVIEW OF RESULTS

The energy consumption and energy use behaviour data were collected for 24 months, from January 2013 to December 2014. The statistics here divide the energy data into two years, 2013 and 2014.

Table 5.1 - Energy and gas consumption per year.

All units are in kWh/m²/year	**Mean (Average)**	**Standard Deviation**	**Range – minimum**	**Range – maximum**
2013 total consumption (electricity and gas)	208	100.6		
2014 total consumption (electricity and gas)	192	58.3		
2013 gas consumption	175	57.7	72	255
2014 gas consumption	159	55.5	54	236
2013 electricity consumption	33	6.3	26	45
2014 electricity consumption	33	9.1	19	51

Using the 2014 annual gas consumption data, the gas consumption of this sample fell broadly into two groups; one with an average consumption of 200 kWh/m²/year [SD=20] [n=5] and the other with an average consumption of 88 kWh/m²/year [SD=25] [n=3].

Gas consumption differs between 13 kWh/m²/year and 21 kWh/m²/year between 2013 and 2014 with the majority of the households consuming more in 2013 relative to 2014. Colder external temperatures during February, March and November 2013 may have resulted in higher temperature differences and considerably more gas being consumed during those months.

The differences in electricity consumption between the two varied between 1 kWh/m²/year and 6 kWh/m²/year, with occupancy rate and frequency of family visits being the primary reason as the influencing factor.

5.2 ENERGY CONSUMPTION AND OCCUPANCY PROFILE

The research introduced the Occupancy Profiles (OP), which was used to classify the households into two categories - OP1 and OP2 – depending on how long the occupants stayed in the house during a typical week (section 3.2). This derived from the information that they provided during the user experience surveys. The households' energy consumption data recorded at hourly intervals were reviewed to corroborate the OP selection. Those classified as OP1 consumed 128% more gas than the households classified as OP2. Households classified as OP1 consumed 4% more electricity than those in OP2. The relationship between the gas consumption and OP was measured as strong at r=-.93 and statistically significant (p = .001), indicating that the gas consumption in these dwellings was significantly influenced by the Occupancy Profile.

5.3 ENERGY CONSUMPTION AND NUMBER OF OCCUPANTS

The energy consumption of households without children and therefore lower occupancy (true for this sample) was compared to households with more people and having children in the home. The results showed that households without children and lower occupancy consumed:

- 89% more gas
- 28% more electricity

It should be noted here that the households without children and those with lower occupancy (n=4) were all classified as Occupancy Profile 1, where the majority of the occupants are at home for the majority of the week.

5.4 MEASURED GAS CONSUMPTION COMPARED TO CALCULATED GAS CONSUMPTION

The Standard Assessment Procedure (SAP) heating requirement results have been used to normalise the measured heat; this was done for each dwelling. The result is being referred to as the household's heat score, with units of kWhmes/kWhSAP. A household with a heat score above 1 means that the measured heat consumption is higher than that calculated by the SAP and vice versa. The monthly heat score profile for the eight households' show that largest differences between the measured and calculated values occurred during the summer months (June, July, Aug, Sept) of 2013 and 2014.

On average, excluding summer months, most of the households in this sample had monthly heat scores for 2013 and 2014 close to 1. Overall, the annual percentage differences between the measured and consumed heat show that three households consumed less heat than that calculated, while five households consumed varying amounts more than the SAP calculated heat requirement during both years. The temperature analysis has shown some marginal difference between SAP calculated temperatures and those recorded within and outside the dwellings.

5.5 USER EXPERIENCE AND ENERGY EFFICIENCY BEHAVIOUR

By implementing user experience data capture methods, this research introduces a statistical relationship between the occupant's energy use behaviour and measured levels of energy consumption. These documented insights into the Occupancy Profiles and the energy efficiency behaviour score (EEBS) have been included to continue the research into understanding and predicting occupant impact on consumption for data modelling and retrofit programmes.

The occupants typically scored the dwelling's lighting as very comfortable, the large windows and >2m room heights which are typical of the archetype had allowed for natural light to be the primary source of task lighting for most of the day and year. Half of the occupants in this sample scored the air movement criteria as very uncomfortable, and more so during the winter season. Interviews identified condensation and cold air infiltration as the primary reasons for the low winter scores. Remarks were made around air movement discomfort during the summer; these related to episodes of overheating and feeling that the air was too dry and 'stuffy'. These were associated with not enough natural ventilation.

Very little variation was detected between the mean EEBSs based on seasons or utilities, with the occupants' summer electricity and winter gas energy efficiency behaviour being slightly higher than the rest. The differences between summer and winter scores were not statistically significant for both the electricity and gas EEBSs. Also, the differences between electricity and gas scores were not statistically significant for summer.

Six households scored in the upper 'efficient' third of the energy efficient behaviour scale for at least one utility. Households who declared regularly conducting energy saving activities for one utility did not always report the same level of regularity for the other utility. Of the six households with different electricity and gas behaviour scores, four had noticeable differences in the frequency of energy efficient behaviour for the two utilities. There was no clear preference towards increased frequency of energy saving behaviour based on utility type. Four households had higher electricity EEBSs, while three households had higher gas EEBSs and one household scored the same for both utilities. A high EEBS of occupants in historical dwellings may be due to their experience or perception that older dwellings are more expensive to heat which may positively affect their energy use behaviour.

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ANNEX I: STATISTICAL TESTS

The following statistical tests were selected for the comparison of energy consumption profiles as presented in Section 4. The IBM computer program SPSS and Microsoft's Excel program were used to calculate the results of the tests.

Alpha (.05): also referred to as the significance level and often denoted as α. The alpha is used to denote the probability for hypothesis testing. Commonly, three alpha values exist in statistics for hypothesis testing, these are 0.01, 0.05 and 0.10. Each alpha value has a related confidence interval which can be described as a percentage (1 – α), these are 0.01 = 99%, 0.05 = 95% and 0.10 = 90%. The confidence interval are limits constructed to express the degree of uncertainty associated with a sample's statistic, for example for an alpha of 0.05 you can be 95% confident that the sample will have a score or value between the lower and upper interval values. In this report the alpha of 0.05 therefore a confidence interval of 95% is selected. The smaller the alpha and larger the confidence interval means that the test to detect statistical significance is more stringent.

The alpha is also associated with critical values which are used as thresholds for the test statistic to pass in order for the sample's data to be deemed as statistically significant, these are 0.01 = 2.58; 0.05 = 1.96; 0.10 = 1.64.

Coefficient of determination: see **R^2 value**

Correlation coefficient: see **r-value**

Energy Efficiency Behaviour Score (EEBS): Here, the frequency by which a person undertakes an activity that can reduce the amount of energy being consumed is deemed as energy efficient behaviour. The participant is presented with a list of 14 activities relating to electricity and gas use in the dwelling. Depending on the fuel type the list of activities typically consisted of six activities relating to thermal fuel consumption and eight relating to electricity consumption. The occupants were asked to comment on the frequency by which they conducted each of these activities. The results are returned on a scale of 0 to 4 - where 0 is very inefficient and 4 is very efficient behaviour.

Kurtosis: Is another form of testing the data against normal distribution. The quintessential bell-curve (normal curve) is overlaid to measure the combined weight of the data sets tails relative to the rest of the distribution, often called tailedness. Some authors explain that the level of kurtosis describes the shape of the peak in the data set, often called peakedness. Either way, the kurtosis value describes the shape of the frequency of data along the vertical axes.

If the data are positively kurtotic (leptokurtic) then the scores of the sample are clustered more too together over a small group of scores. The opposite is observed for negatively kurtotic data (platykurtic) where the data are more spread out along the measured scores. Descriptive statistics are used to discover if the data are too heavily kurtotic. This is achieved by dividing the kurtosis value by its standard error. If the result is smaller than +/-1.96 then the data are deemed to be within acceptable levels of normal distribution. This value is typically examined with the Skewness value.

P-value: is the probability value. The **alpha** sets the threshold by which the data must pass before the difference in the sample's mean is statistically significant. Then the p-value is the result of a statistical test and is compared to the **alpha** to determine if the sample's data are statistically significant.

r-value: The Pearson's product-moment correlation coefficient (Pearson's r-test) is a measure of the strength or association or relationship between two variables. Pearson's correlation coefficient is one method for measuring this strength. The result is between 0 and 1. Result of 0 means there is no relationship, a result of 1 means there is a perfect relationship. The higher the result the stronger the relationship between the variables. Positive results show a correlation with a positive orientation (when 1 variable is high so too is the other), a negative result shows the opposite.

R^2 value: the coefficient of determination shows the proportion of variance in one variable explained by a second variable. The result is between 0 and 1 and denotes the strength of the linear association between the two variables.

Shapiro-Wilk test: also referred to as the W test, is a non-graphical procedure for testing a data sets fit to the normal distribution. The test was designed to test normality by comparing a sample's data set to a normal distribution with the same mean and standard deviation of the samples. If the test is not significant then the data are normal. For this test the probability of .05 (95%) is used as the threshold to signify statistical significance (see **Statistical significance** and **P value**)

More information can be found from this article Shapiro, S.S. Wilk, M. B. (1965). An analysis of variance test for normality. Biometrika Trust. Vol 52. Pp. 591–611.

Skewness: Is another form of testing the data against normal distribution. The quintessential bell-curve (normal curve) is used and the symmetry of the data is examined. The skewness value describes the shape of the frequency of data along the horizontal axes.

If the data are positively skewed then the scores of the sample are clustered more to the left (lower scores) of the bell-curve, then the opposite is observed for negatively skewed data. Descriptive statistics are used to discover if the data are too heavily skewed. This is achieved by dividing the skew value by its standard error. If the result is smaller than +/-1.96 then the data are deemed to be within acceptable levels of normal distribution. This value is typically examined with the Kurtosis value.

Statistical significance: is statistical terminology and means that the result is unlikely to have happened by chance. A result that is 'statistically significant' is predicated on the threshold by which we accept for the amount of chance, this is the **alpha**. A significance level of 0.05 indicates a 5% probability of concluding that a difference exists when there is no actual difference.

T-test: The outputs of a t-test are reported as in this example: (M = 88, SE = 17.62), (t(6)=6.11, p = .001). Where (M) is the Mean (or average) score of the sample. (SE) is the Standard Error from within the sample's score. (t) is the test statistic calculated for the t-test. The test statistics is measured against the critical values of the t-distribution as a threshold of **statistical significance** based upon the degrees of freedom and **alpha** value. The value between the parentheses is the degrees of freedom. The degrees of freedom are calculated as the number of participants in the sample -1 for each variable. P is the p-value result of probability, it is expressed as decimal value between 0 and 1. This value is compared to the selected **alpha**. If the value is less than the declared alpha then the result is accepted as being **statistically significant**.

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