AN INVESTIGATION INTO THE RELATIONSHIP BETWEEN POST OCCUPANCY BEHAVIOUR AND ENERGY EFFICIENCY IN RESIDENTIAL BUILDINGS

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ABSTRACT

Currently scientists remain concerned regarding the earth's temperature and forecast that the earth's temperature will rise due to global warming by 2050. The earth has reached its hottest in nearly 3 million years. This has had a major effect on climate conditions, causing extreme weather fronts, flooding and storms the strength of which have never been encountered before. Taking all these events into account, global warming, weather conditions, CO_2 emissions and energy usage, Government agencies, Engineers and Designers need not only to set targets, offer incentives, design and construct new buildings and improve the existing housing stock with energy saving technologies in mind, but consider the end user and how each one of these will perceive the technologies.

Occupants remain unique in their behaviour, understanding and beliefs relating to energy conservation. Therefore, this project analysed the relationship between occupancy behaviour and energy efficient technologies. The assessment of behaviour and energy usage was achieved by investigating innovative technologies that had been installed in an energy efficient retrofitting pilot case study. These technologies included Balco glazing system, air source heat pumps, voltage optimisation units, phase change material, thermodynamics, passivents, energy efficient boilers, solar panels and external structural insulation.

This pilot study consisted of 51 dwellings, based on 5 property types including a mixture of semi-detached houses British Iron and Steel Federation (BISF), semi-detached and mid terraced bungalows and flats, all constructed in the south east of the UK between 1950 -1970.

Behaviour traits of occupants along with energy usage were collected over a period of 2 years. Data was collected through questionnaires, before and after the energy efficient retrofitting works had been carried out, supported by interviews and random observations.

The analyses concluded that the properties with the most significant reduction in gas usage (20.62%) were the BISF properties. These properties were

characterised by structural insulation, boilers and solar panels. Furthermore, all the occupants living in this type of retrofitted properties were employed. They were conversant with maintenance manuals and the use of the internet, familiar with the types of energy efficient technologies that had been fitted and they paid their energy bills by pre-payment card.

The outcomes of this investigation could further advance the research in the area of the energy retrofitted residential housing in order to maximise their energy efficiency based on occupants' behaviour, matched against user-friendly technologies, thus supporting designers, management agents, manufactures as well as responding to the occupants' needs.

Keywords: Sustainability, Energy efficiency, Occupant behaviour, Energy retrofitting of residential buildings, Innovative energy efficiency technologies.

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LIST OF ABBREVIATIONS

BISF	British Iron and Steel Federation
BRE	British Research Establishment
BREEAM	Building Research Establishment Environmental Assessment Method
CAT	Centre of Alternative Technology
CERT	Carbon Emission Reduction Target
CFTs	Compact Fluorescent Lamps
CO_2	Carbon Dioxide
CIOB	Chartered Institute of Building
DECC	Department of Energy and Climate Change
ERDF	European Regional Development Fund
GHE	Greenhouse gas emission
HER	Home Energy Report
HIP	Home information Pack
LED	Light – Emitting Diode
NB	N Build
PCA	Principal Component Analyses
PVC	Polyvinyl Chloride
R	A language and environment for statistical computing and graphics
SC	Southend Council
SEH	South Essex Homes

SPSS Statistical Package Social Sciences

UBT Usable Building Trust

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‘Skyline pigeon’

Chapter 1

INTRODUCTION

Along with the expansion of the construction industry, the perception of modern day techniques has been continually changing. The simplest example is concrete, the patent for the manufacture of the first Portland cement in 1824 changed the building industry radically (Crook and Day, 2008). Engineers were overwhelmed with the almost boundless possibilities for the use of concrete. They could build bigger, longer, taller - greater and faster than ever before. The main concern of the time was to build safe concrete-structures. Later, next to the safety, the economical aspect of the construction appeared. Nowadays, engineers, clients and the end users are looking not only for safe, economical structures but also for those structures to be sustainable and user friendly.

To fulfil the criteria for the sustainable buildings like The Code of Sustainable Homes and BREEAM standard rules, engineers have to look into the performance of the building in terms of the energy, management, health and well-being, to name but a few (BRE Global Ltd, 2011). Although the designers and builders tick all the boxes for safety, economy and sustainability, the post-completion performance of many buildings continues to disappoint. It often happens that the building results in higher-than-modelled energy consumption and emissions, as well as operational problems for occupants (Usable Buildings Trust, 2014).

A concept developed by Way (2005) looked at how buildings were monitored after completion, the missing element in the building construction puzzle is a concept called Soft Landings. Soft Landings is a new approach to the building construction process and considers the lifecycle of the project involving constructors and designers beyond practical completion. This allows for the observations and learning from the buildings and their performance. Collecting valuable information by energy managers regarding building usage and performance that can be used in the future.

Looking beyond the actual performance of the building and the expectations set out by designers the bigger picture includes climate conditions. Scientists remain sceptical regarding the earth's temperature and forecast that the earth's temperature will rise due to global warming by 2050. (Fig 1) The earth has reached its hottest in nearly 3 million years. This has had a major effect on climate conditions, causing extreme weather fronts, flooding and storms the strength of which have never been encountered before.

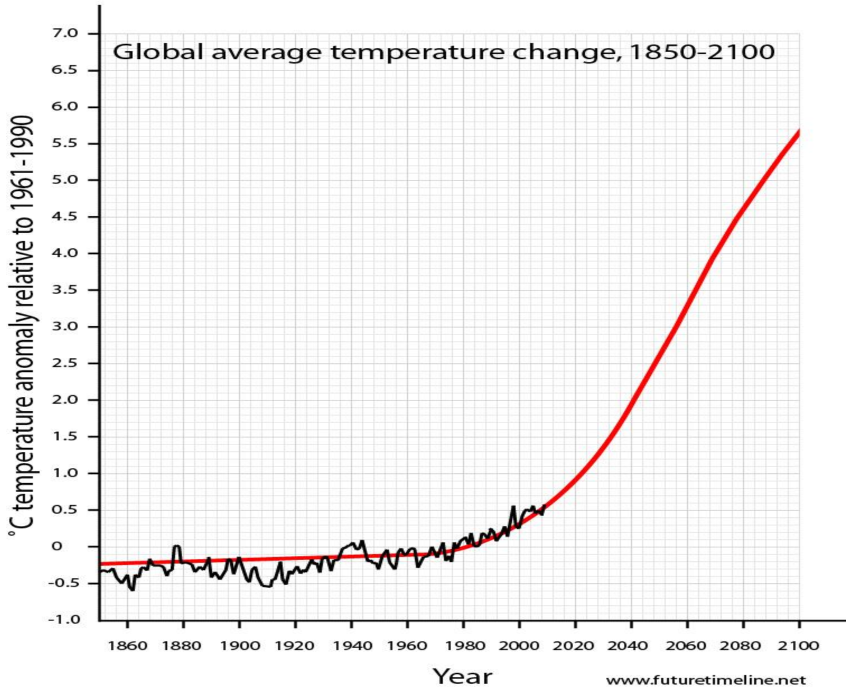

Fig. 1.1 Global average temperature change, 1850-2100

Global average temperature change, 1850-2100 ('2050 Demographics Projections | Prediction | Future | Technology | Timeline | Trend | 2050 Space Travel | 2050 Global Warming Timeline | 2050 Climate Change,' 2012)   (Fox, 2016)

Increased concentrations of greenhouse gases (Dakwale, Ralegaonkar, and Mandavgane, 2011), which include carbon dioxide, methane, CFCs, halons, nitrous oxide, ozone and peroxyacetyl nitrate in the atmosphere raise the earth's temperature by trapping heat that has subsequently been radiated by the earth's surface.

Therefore Building Engineers face a huge task in delivering dwellings that not only address global warming but provide acceptable internal conditions while also considering the external impact and environmental conditions that ultimately affect the amount of energy used in the building (Malmqvist, and Glaumann, 2009).

To further add to these problems, estimations have found that the temperature of the planet has risen by 0.74 degrees Celsius since 1900. Rainfall in England has risen since rain records began in 1766, whilst heavy rain was experienced during the summer of 2012 and as recently as January 2014. (Met Office Hadley Centre, 2016). Subsequently this has led to heavy flooding in Cumbria 2009, and Somerset in January 2014. Somerset encountered some of the worst flooding ever recorded with properties staying underwater for weeks, with many power lines out of commission due to the extreme weather conditions. To add to this, further floods hit Cumbria (figure 1.2) for a third time in December 2015 some of the worst ever encountered.

In figure 1.2 floods hit Cumbria due to extreme weather conditions.

Figure 1.2 Flood to Cumbria 2015. Macleod, J (2015)

Prior to these events, in 1997 in Kyoto, Japan, the United Nations Framework Convention on Climate Change (UNFCCC) came together to discuss measures that would reduce greenhouse gases in the ensuing years. During this first conference, it was agreed by the UNFCCC delegates that greenhouse gases (or GHG) were likely as a result of developed countries’ industrial activities spanning over the past 150 years (UNFCCC, 2012b).

The Kyoto agreement, drafted on 11th December 1997, stated that the objective of the UNCCC and the resultant Kyoto Protocol is the "stabilization and reconstruction of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system” (UNFCCC, 2012a).

On 11 December 1997, 35 countries committed their allegiance to the Protocol, all with the common aim to reduce high levels of GHG. Subsequently, the policy was adopted and entered into force on 16th February 2005. When the Kyoto Protocol came into force, it was estimated that the 141 countries ratified the treaty accounted for nearly 55% of global greenhouse emissions. The signers of the Protocol pledged to reduce emissions by over 5% by 2012 ('Kyoto Protocol comes into force,' 2005).

To meet the targets set down by the Kyoto Protocol, energy policies subsequently enacted have required that buildings improve their energy efficiency; occupants will need to understand new technologies to enable energy consumption to be reduced. Currently, approximately one third of our energy requirements are used by the building sector (Gonzalez *et al.,* 2011). .

Natural resources such as oil and natural gas can been seen as being responsible for greenhouse gases due to the growing worldwide demand .(Gonzalez *et al,* 2011)

Taking all these events into account, global warming, weather conditions, CO_2 emissions and energy usage, Government agencies, Engineers and Designers need not only to set targets, offer incentives, design and construct new buildings and improve the existing housing stock with energy saving technologies in mind, but consider the end user and how each one of these will perceive the technologies.

Occupants remain unique in their behaviour, understanding and beliefs relating to energy conservation. This project will analyse whether a relationship exists between occupancy behaviour and energy technologies.

1.1 PROBLEM STATEMENT

One of the most significant challenges based on the literature review in addressing energy conservation in domestic buildings is not only understanding the building design and how it performs but the end user- the occupant. Understanding how occupants behave when assessing energy consumption can be an extensive process. In a textbook environment, investigations on large samples provide a cross sectional view of the occupant, behaviour patterns and energy usage. What can be reasoned is the level of accuracy from the data received from them, many contributing factors such as timing, interpretation and accuracy of responses may influence the results? Additionally, undertaking studies on small populations can allow an informal relationship and trust to be built up by the researcher providing clearer explanations leading to improved results.

Further in-depth studies into occupants understanding of new technologies will also be investigated, along with their understanding of government agency's policies and targets encouraging a greener future for all. New technologies with little or no history will be included within the pilot scheme and will contribute toward the investigation.

The results from this study may not always be transferable to other geographical locations, inferences such as education, behaviour, types of buildings, disposable income and location may affect the results.

The study further contributes toward meeting government targets to reduce CO_2 emissions and energy consumption by 2050.

Finally, this research covers a significant gap in knowledge investigating occupant's behaviour, comparing these traits with energy efficiency and new technologies. This was undertaken based on a unique data set collected through questionnaires, interviews and observations.

Based on the problem statement the research question set out in section 1.2 were designed.

1.2 AIM AND OBJECTIVES OF THE RESEARCH

The main aim of this research is to critically assess, the new technologies government agencies have introduced to reduce carbon emissions in the sustainable built environment and to investigate the relationship between post occupancy behaviour in buildings and energy efficiency.

In line with the aforementioned aim of the research, the following objectives of the present study were identified:

1. *Analyse data taken from the retro fit (refurbishment) project through interviews, questionnaires, random observations and systematically data analyses. The study will investigate a mixture of flats, semi-detached bungalows, terraced bungalows and semi-detached BISF houses built between, 1950-1970.*

2. *Investigate new technologies and the way occupants adapt to them. To obtain energy efficiency, occupants will need an understanding of modern day technology and have the ability to use it effectively.*

1.3 CONTRIBUTIONS

Table 1.1 maps the objectives to the specific research questions, case studies, main contributions, and chapter references.

Table 1.1 Mapping objectives to specific research questions and contributions.

Objective	Research questions	Case studies	Contributions	Chapter
Analyse data taken from the retro fit (refurbishment) project through interviews, questionnaires, random observations and systematically data analyses. The study will investigate a mixture of flats, semi-detached bungalows, terraced bungalows and semi-detached BIS houses built between 1950-1970**.**	An investigation into the relationship between post occupancy behavior and energy efficiency in residential buildings Assess new Technologies Government Agencies have introduced to reduce carbon emissions in the sustainable built environment	Government agency policies. Very Smart House Project based on questionnaires, interviews & observations	Evaluation of occupants' behaviour with new technologies & energy efficiency	5

Continued on next page

Table 1.2 Mapping objectives to specific research questions and contributions (continued from previous page).

Objective	Research questions	Case studies	Contributions	Chapter
Investigate new technologies and the way occupants adapt to them. To obtain energy efficiency, occupants will need an understanding of modern day technology and have the ability to use it effectively.	Investigate the relationship between post occupancy behavior in buildings and energy efficiency.	Case study Really Smart House R & WC properties.	Identification and selection of new energy efficient technologies.	**6**

1.4 DEVELOPMENT EFFORT

The investigation into occupant's behaviour required data from questionnaires to be analysed. Different procedures were considered within the investigation process, these included inferential data analyses, observations and statistical analyses.

To meet government targets to improve energy consumption, reduce CO_2 emissions, and introduce new technologies a greater understanding of occupant's behaviour would be required.

The research has been carried out within the limits of the specific boundaries of research. Each study was subjected to the constraint of time, instruments, opportunities, and location.

1.5 STRUCTURE OF THE THESIS

The thesis contains nine chapters, the content of which are as follows:

Chapter One includes the background, aim and research questions, the boundaries of the research and the brief description of the contribution to knowledge as an outcome of this research.

Chapter Two presents the review of literature underpinning the study. It also provides context for the research, knowledge, presenting state-of-art in technologies investigated within the study. It critically reviews the current literature available relating to government agency policy's and occupant's behaviour. Subsequently, the gaps in the present knowledge related to the new technologies government agencies have introduced to reduce carbon emissions in the sustainable built environment. The relationship between post occupancy behaviour in buildings and energy efficiency are identified within the review.

Chapter Three provides an outline of the methods used in this thesis to assess the relationship between technologies used and energy efficiency of the buildings as well as occupant's behaviour and energy efficiency of the buildings they live in. Both quantitative and qualitative types of methodologies were employed in this research. The research methods used for data collection and analysis are described in section 3.7, and provide a brief description to support the methods chosen.

Chapter Four will look at the questionnaires, the design of the questions and reflect on several of the key responses received from occupants that extended beyond the scope of the questionnaires. Two questionnaire methods were considered at inception; self-administered and Interviewer administered, these will be discussed further within this section

Chapter Five focuses on the types of property's that formed part of this research project, the technology's that were chosen by the design team, SEH and Southend Council including the funding method used to finance the scheme. The study investigated a mixture of flats, semi-detached bungalows, terraced bungalows all brick built and semi-detached BIS houses built between,, (1950 - 1970).

The chapter will summarise results obtained using cluster analyses to group properties and technologies together that encountered some form of similarities or relationship between each other.

Chapter Six investigates the characteristics of the occupants, their behaviour patterns that formed part of the research questions, Information extrapolated from questionnaires will be analysed using Inferential Analyses, Bivariate Statistics, (PCA) Principle Component Analyses and Cluster Analyses.

As in any refurbishment project, it is very important to understand how occupants behave (the end users) and can the technology be fully understood and utilised by the occupant.

Chapter Seven presents the energy efficiency of residential building in relation to technologies fitted and occupants' behaviour. Results from previous cluster analyses investigations were taken from the technology and occupant's groups from chapters 5 & 6 and compared.

Chapter Eight presents the discussion of the investigation, this will be undertaken by breaking the results down from chapters 5,6 & 7 and carrying out an in depth post - mortem on the results.

Chapter Nine presents the overall conclusions of the study, the contribution to knowledge and the suggestions for future research. The aim of this research study was to critically assess, the new technologies government agencies introduced to reduce carbon emissions in the sustainable built environment and to investigate the relationship between post occupancy behaviour in buildings and energy efficiency.

Chapter 2

LITERATURE REVIEW

The Literature Review will explore the topics outlined in section 1.2. It will discuss emerging green technologies and their introduction into the UK housing stock. The literature review will also discuss past and current handover procedures, and introduce the concept of post-handover monitoring from a viewpoint of sustainability and user behaviour. Energy efficient schemes set forth by the government will be introduced and reviewed. Design, implementation, construction and retrofitting of UK homes will be overviewed. Finally, occupant behaviour and its effect on energy efficiency will be discussed.

2.1 SCOPE

This Literature Review comprises of a brief background into energy efficient and green technologies that have been developed in response to government policy and environmental awareness. Past and present government policy regarding the promotion of energy efficiency and reduction of carbon emissions will be investigated. A critical assessment of the literature will be undertaken, examining design, building retrofits, building performance and post-handover support. An introduction of occupant behaviour, occupant demographic and building performance, along with the background information for any assumptions regarding the data will be assessed.

2.2 Government policy

Legislation, particularly in the United Kingdom, has been a major force in driving forward green innovation and technological advances in construction. Stemming from the Kyoto accords, government policies has led the way to the construction of greener homes across Britain through strategies such as home information pack (HIP), warm front scheme, green deal and energy performance schemes. In addition, addressing the issue of unsuitable and costly housing for low-income earners has been a high priority among several different government departments.

2.2.1 Energy efficiency of the residential buildings

Changes in UK building regulations have addressed issues such as energy conservation through such policies as requiring a minimum amount of cavity and loft insulation. Between 1930 and the 1990's, significant reductions in space heating costs were reduced by 70% through energy conservation policies. This reduction in energy costs was spurred on by on-going scientific discussions regarding climate change and energy consumption (Gaterell and McEvoy, 2005).

Currently, many dwellings in the UK have low levels of energy efficiency. Of the 27 million low efficiency homes, more than 4 million were built prior to 1919 and 8 million predate 1945. A significant number, about 4.8 million, are in the social housing sector, split evenly between housing associations and local authorities (Radian, 2011). Improving the energy efficiency and heating in these homes is a critical component of government policy.

Securing energy for the future remains at the top of the British agenda. Newly introduced policies and legislation provide measures to ensure that energy usage is managed efficiently to preserve future supplies. Government bodies, stakeholders and occupants must understand how buildings behave and how energy efficient measures influence that behaviour. In order to achieve the desired long-term success in building energy performance, the benefit to energy conservation and impact of the energy efficient measures must be understood from the early design stages (Heeren *et al*., 2013).

In the 1990's, when world energy consumption came to the forefront of the public consciousness, Western European countries such as Denmark and Belgium typically used 30% of their total energy consumption on domestic use. In 2006, energy labelling of homes in Denmark became compulsory, causing a debate as to how Danish occupants viewed potential home purchases (Gram-Hanssen *et al.*, 2007). Gram-Hanssen *et al*. found that energy labels did not control what Danes purchased but did influence how they approached energy efficient home improvements once they acquired the property. While the Danish government labelled a property's efficiency, the UK government went one-step further by recommending the building of carbon neutral homes in new builds.

From BREEAM and the Home Information Pack through to the Green Deal, the UK government has pursued legislation that would make existing housing stock more energy efficient and encourage the building of zero carbon new homes.

2.2.2 BREEAM

One of the most well-known procedures for assessing sustainability is BREEAM, or the Building Research Establishment Environmental Assessment Method. In

1990, in order to further support UK sustainability initiatives, the then-executive agency Building Research Establishment (BRE) developed this new environmental assessment system in order to appraise and evaluate the efficiency of sustainable construction technology.

Subsequently recognised as the internationally leading environmental assessment for buildings points are awarded through a credit rating system based on the environmental performance of a building. Additionally further aims include the mitigation of the building lifecycle impacts on the environment and enabling buildings to be recognised according to their environmental benefits. Lastly, the assessment aims to provide a credible environmental label for buildings and to stimulate demand for sustainable homes (BREEAM, 2012).

Additionally, strategies are used to reduce carbon emissions and a method for educating the population regarding the importance of living in, or owning, environmentally sustainable buildings and homes. It aims to provide market recognition of buildings with low environmental impact and to ensure that environmental best practice is incorporated in building planning, design, construction and operation. By raising awareness among building users and construction industry members it reduces the life cycle impact on the environment and allowing organisations to demonstrate progress towards corporate environmental objectives (BREEAM, 2012).

Several Soft Landing philosophies are also supported through the process, including the incorporation of post-handover monitoring of the end product. Long-term aftercare forms part of the criteria set down within the BREEAM technical manual, and credits are awarded according to the level of aftercare that is provided upon the completion of a project. While the manual describes interviews or telephone surveys with occupants during the first 3 months of occupation up to a 12-month period, there are requirements for longer periods of support.

The standards can be applied to any type of building – new build, retrofit, commercial, residential, large project or small. It is the accumulation of best practice standards in sustainable design and construction. Minimum standards include: sustainable procurement, responsible construction practices, stakeholder participation, visual comfort, water quality and monitoring, low water consumption, reduction of CO_2 emissions, energy monitoring, incorporation of low carbon or zero carbon technologies, responsible materials sourcing, reduction and management of construction and operational waste, and mitigation on any ecological impact. Completed buildings are ranked according to weighted success of those standards, from Outstanding (less than 1% of UK buildings, an innovator) to Pass (top 75%, standard good practice) (BREEAM, 2011).

While BREEAM was originally developed by the government as a means to measure and reward innovation in sustainable building practices, most government programmes have focussed on identifying improvements and incentivising homeowners and builders to install energy efficient appliances and insulation.

2.2.3 HOME INFORMATION PACK AND HOME ENERGY REPORT

In 1999, the Home Information Pack (HIP) or Home Energy Report (HER) was proposed by the government to streamline the buying and selling process of properties in England and Wales (Parnell *et al.*, 2005). One intention of the HIP was to raise public awareness of building energy performance and how energy-saving improvements could be made to homes. Homebuyers were provided with reports detailing energy efficient improvement recommendations. The most common recommendations in these reports included the changing of light bulbs to more energy efficient ones, installation of loft and cavity insulation and draught proofing. A survey carried out into the effectiveness of this report indicated that 27.1% of homebuyers and occupants took this advice seriously. At the same time, the low rate of implementation of these recommendations revealed by the same survey indicated that the scheme needed improvement in order to be effective (Parnell *et al.*, 2005). Parnell *et al.* (2005) concluded that the overall significance of HIP recommendations was unclear to home buyers and thus the report never obtained the envisaged momentum of improving home efficiency. Indeed, it was inferred that only a minority of homeowners were committed to a plan to reduce their carbon footprint and improve home energy efficiency as a result of this programme.

2.2.4 Warm Front Scheme

To increase insulation measures, various government schemes were made available over the years to encourage occupants to improve the performance of their dwellings. Building regulations have changed at such a rate that insulation installed in the 1970’s does not meet current regulations and needs either replacement or additional insulation installation. These schemes have proven quite popular; Shorrock (1999) suggested that there is a correlation between available grants and the amount of loft insulation installed. Improvements in energy efficiency and the installation of new boilers and cavity insulation have also produced positive benefits in this regard (Tovar, 2012).

Introduced in 2000, the Warm Front Scheme was developed by the Department of Energy and Climate Change (DECC) to aid funding and enable dwellings to become more energy efficient. Households who spent 10% or more of their income on fuel in order to sustain a temperature of 21°C were classified as the fuel poverty bracket and eligible for funding. Improvements to properties promoted under this scheme included: the addition of loft and cavity wall insulation, draught proofing, installation of insulating tanks, gas room heaters with thermostatic controls and central heating, as well as the conversion of solid fuel open fires to glass-front fires. Critics of the scheme claimed that funds made available were grossly underspent in vulnerable areas, it was shown that retrofitted properties were warmer, more energy efficient and healthier (Department of Energy & Climate Change, 2012).

In addition to those classified as in fuel poverty, the scheme targeted other vulnerable populations in the UK. It also allowed grants to those with disability aid in order to tackle fuel poverty. Studies carried out by Hong et al. (2006) found that improvement in bedroom and living room temperatures aided the thermal comfort and contentment of occupants. Additionally, Oreszczyn et al. (2006) found that properties with Warm Front Scheme interventions such as heating and insulation improvements had living room temperatures increased by 1.6°C and bedroom temperatures by 2.8°C. Significant improvements in bedroom temperatures indicated that further living space was available at night, encouraging occupants to use these rooms to watch TV, study or relax. Both studies concluded loft space insulation provided the most significant reduction in heat loss under the scheme.

While the Warm Front Scheme solely tackled fuel poverty through home improvement schemes, other schemes, such as the Green Deal and Carbon

Emission Reduction Target (CERT) integrated reduction in carbon emissions with energy efficient home improvement schemes. The Warm Front Scheme ran until 2013, but was partially superseded in 2008 with the introduction of CERT followed by the Green Deal in 2012.

2.2.5 LONDON PLAN

To further support energy efficiency initiatives set out by the government, London was the first city to address carbon emissions, which it did by introducing the London Plan. In 2004, the Mayor of London outlined intentions to cut carbon emissions in the capital by 10% through the introduction of new technologies into building applications. Many London boroughs followed suit and included similar policies within their strategy and development plans. As a result, developers have had a duty at the planning stages to incorporate energy policies that would demonstrate carbon emission reductions in excess of 10%. Developers now have to submit a detailed energy plan demonstrating the benefits of the proposed energy saving technologies through the savings in CO_2 emissions (Day et al., 2009). New energy efficient measures proposed by homebuilders is found in table 2.1.

The plan was the first set of building requirements set by a city government in order to reduce carbon emissions and to compel energy efficient building planning. This was a natural progression from requirements for already built homes such as the Home Information Pack / Home Energy Report as well as extending the CO_2 reduction of energy efficiency schemes such as CERT to new builds regardless of income bracket. Additionally, its introduction of worked as a way to incorporate BREEAM into mandate.

Table 2.1 London Plan Proposed Energy Efficient Measures

Automatic Controls	Condensing boilers
A-rated appliances	Airtight building design
Energy efficient lighting controls	Building Energy Management Systems (BEMS)
Enhanced insulation	High performance glazing
Passive solar design	Water efficient fittings
Variable speed pumps and fans	District community heating systems
Mechanical ventilation with heat recovery	Solar shading
Chilled ceilings (where cooling cannot be avoided)	Variable refrigerant flow systems (where cooling cannot be avoided)

2.2.6 Code for Sustainable Homes

The UK government committed to targets set out in the Kyoto accord to reduce greenhouse gases by reducing carbon emissions. Initiatives introduced in December 2006 proposed that all new properties built after 2016 should be built to zero carbon standards, otherwise referred to as carbon neutral (McManus et al., 2010). Known as the Code for Sustainable Homes, the aim of these initiatives is to reduce the amount of embedded carbon, reducing pollution, and increasing energy efficiency in new build homes.

After defining the terms “carbon neutral” and “zero carbon” and their criteria for assessment, the CSH challenged home builders to alter construction methods, allowing energy systems to be integrated into new designs in order to meet new building regulation targets for zero carbon homes by 2016 (NHBC Foundation, 2009). In order to achieve the reductions, the CSH configured levels for carbon reduction and set out a timeline by which to achieve these levels as shown in Table 2.2.

Table 2.2 - Code for Sustainable Homes Carbon Reduction Schedule

Level		Percentage Carbon Reduction	Deadline
Level 1	♦	10%	2007
Level 2	♦♦	18%	2008
Level 3	♦♦♦	25%	2010
Level 4	♦♦♦♦	44%	2013
Level 5	♦♦♦♦♦	100%	2016
Level 6	♦♦♦♦♦♦	Zero Carbon (including appliances)	

Under the new codes, houses are required to be designed and built to the higher environmental standard and measured by the carbon reduction outlined above. In all, nine key areas are monitored, including: energy and CO_2 emissions, water, materials, surface water runoff, waste, pollution, health and wellbeing, management and ecology. All newly constructed homes are rated in each of these categories, ensuring that the objective of the designer and constructor is to provide zero carbon properties under the measured criteria. By 2010, the carbon reduction was to be a mandatory 25% (level 3) and raised to 44% (level 4) by 2013. By 2016, all homes must be built to the “zero carbon” (Level 6) level (The Guardian, 2005).

Osmani and Riley (2009) described much debate among fellow researchers regarding the achievability of this target and concluded that the 2016 deadline was unrealistic, suggesting instead a deadline of 2023. In order to achieve a carbon neutral project, contractors and designers need to know what such a project entails and what practical issues arise from these projects.

2.2.6.1 Cessation for the Code of Sustainable Homes

In 2014 the government announced plans that the CSH was to be withdrawn by March 2015 and integrated into building regulations where possible, this meant that local authorities could no longer stipulate compliance with code levels. This step down by the government caused much debate amongst professionals and the green building industry; constructors would now only be working closer to code 4 requirements. Critics were worried that the step down would have a detrimental effect on achieving carbon targets set down 'Under the Climate Change Act' by 2050. (Ares, 2016).

2.2.7 European Regional Development Fund

The European Regional Development Fund (ERDF) was set up by the European Union to support municipal and rural developments through investment in economic growth. In 2007, the scheme was altered slightly to promote sustainable and energy efficient development in areas that needed an economic boost. The scheme created sustainable employment opportunities for Small-Medium Sized Enterprises (SMEs) and supported regional and local growth. Some of the approved projects have included properties that experienced, or were threatened by physical deterioration. Applicants applying for funding would have to demonstrate that their project will provide sustainable economic development, community rejuvenation and without ERDF support would not likely occur. Most projects are given grants between 50-75% of the project cost.

Applicant SMEs are encouraged to support new projects by providing new technologies and using innovative ideas (European Union, 2011). This project was jointly funded between SC and ERDF as discussed in later chapters.

2.2.8 Feed-In Tariffs and Renewable Incentives

Using incentives, the UK government encouraged energy users to produce electricity from renewable sources and sell the surplus back into the UK energy grid. This renewable incentive allows consumers to both reduce their carbon footprint and energy bills. Proposed feed-in tariffs would allow the consumer the opportunity to receive payments for the energy they generated. These tariffs would assist in achieving the government's own renewable energy targets, set at 15% by 2020 (Couture and Gagnon, 2010).

Feed-in tariffs produce three financial benefits. First, there is a payment for all renewable electricity that is produced, even if it is used by the consumer. Secondly, there is a reduction in electricity bills, as consumers will use most if not all the electricity they generate. Lastly, there is a bonus for any surplus energy exported back onto the grid (Couture and Gagnon, 2010).

Domestic householders would have the added gratuity of not having to pay income tax on earnings generated from renewable electrical production, providing it is for the private use by domestic consumers (Couture and Gagnon, 2010).

2.2.9 Stamp Duty Relief

Like feed-in tariffs, stamp duty relief was introduced as a way to promote the government's environmental goals in domestic housing. To further incentivise energy efficiency, the government introduced a stamp duty reduction on zero carbon homes in 2007, providing relief on all homes up to £500,000 until the end of September 2012 (Sayce *et al.,* 2007).

However, government proposals did not make clear what actually constituted a 'zero carbon' home. Developed by former Chancellor Gordon Brown, these ambitious plans followed the possibly miscalculated Code for Sustainable Homes, which stated that all homes built after 2016 must be carbon neutral. In introducing the stamp duty relief, Brown defied critics, stating that Britain would be the first country in the world where every newly built property in the following decade would be zero carbon (UK scraps zero carbon homes plan, 2015). Unfortunately as discussed earlier, in this chapter the pathway for the Code of Sustainable Homes took a huge U-turn in 2015 changing the direction and reducing the potential to save on CO_2.

2.2.10 Carbon Emission Reduction Target

Following on from the guidelines put forward by the Kyoto Accord, the government set targets such as the Carbon Emission Reduction Target (CERT) to further reduce carbon emissions by the domestic sector. The Carbon Emission Reduction Target ran from 2008 to 2012, and was developed as a way to both contribute to the government's on-going fuel poverty strategy and achieve a reduction in carbon emissions generated by the domestic sector.

Managed by the gas and electricity market regulator Ofgem, CERT targeted low-income and elderly domestic consumers and occupants as a priority group. A further 'super priority group' was made up of those claiming specific credits, benefits, or had parental custody of a child under the age of 5. Qualifying credits and benefits included income-related Employment and Support Allowance, income-based Job Seeker's allowance, income support and state pension credit (Ofgem, 2012).

Suppliers that individually, or within a group of companies under the same ownership, had over 250,000 domestic customers were required to comply with CERT. Under CERT legislation, these energy suppliers were obligated to achieve certain energy targets. These included a carbon emissions reduction of 293 million lifetime tonnes of CO_2. Additionally, suppliers were compelled to improve the affordability of a warm home in priority groups through actions such as the replacement or repair of a boiler to make it more energy efficient. Insulation targets were introduced, aiming to save 73.4 lifetime tonnes of CO_2 through professionally installed domestic cavity wall and loft insulation (Ofgem, 2012).

As of 2013, CERT was superseded by the Energy Company Obligation (ECO) which has largely the same targets as its predecessor, such as carbon emissions reduction, carbon saving community obligation and home heating cost reduction (Ofgem, 2015).

2.2.11 Energy Performance Certificate (EPC)

Nearly twenty years after the Home Information Pack / Home Energy Report was rolled out for private homebuyers, landlords became obligated to provide an Energy Performance Certificate (EPC) to new tenants. The certificate is supplied to prospective tenants before a property is let or sold. It consists of a detailed assessment of a dwelling, analysing the energy efficiency and building performance. In the EPC, a rating is given on a scale from A to G, with A being the highest and most efficient rating. The majority of properties fall into the D and E categories. The type of building, size, orientation, type of heating, window glazing, lighting, amount and type of insulation all influence this rating. Older buildings with single glazing, solid brick walls and limited insulation will underperform and receive a low rating (Watson, 2010).

Information provided allows the occupant to evaluate the energy performance of a building and consider future running costs. In addition, recommendations are provided to the occupants as to how to improve energy efficiency and details possible opportunities to obtain financial assistance from government departments for further energy efficient domestic interventions.

However, in addition, whether or not the rating influences behaviour and approach to energy efficiency or whether occupants understand the significance of a rating system remains to be seen.

The certification is based on a number of assumptions such as standardised heating patterns; number of occupants, hot water usage. These factors may vary between different households because the system is calculated based on standard occupancy rather than how the individual uses the property and the appliances within their homes; such as cooking or electrical products are not accounted for the energy used for heating.

Even if the property is maintained to a high standard but the results issued reflects a rating, which should be higher than the calculation, this may be due to the energy assessment performed in part because they are non-intrusive in practice when carried out. To tackle this problem a household must provide evidence, either visually or documentary, specific to works relating to the property being assessed for the energy assessor to observe for it to be included as part of his/

her assessment criteria when addressing the household's elements such as thermal insulation in dwellings. This is not always possible, as the occupant would not have been notified prior to the visit, which then brings in the case of assumptions.

Unfortunately, this assessment does not take into account the physical condition or quality of the element, but rather the energy efficiency of a dwelling's performance in part relating to each element such as walls, heating systems and roofs for an approved rating and not the appearance in summary to the extent to which the element contributes to the fuel costs. (Department for Communities and Local Government, 2016)

2.2.12 GREEN DEAL

The Government's commitment to the emission reduction was further reinforced in 2011, when the coalition prompted a plan to reduce greenhouse gases (GHG) by half by 2020 based on the 1990 Kyoto Accord baseline. Further, they revealed an aim to reduce GHG emissions by a further 80% by 2050. With these new targets, the government projects that by 2030, half of the heat used in buildings will come from low-carbon technologies. To reinforce these new policies, launched in 2012, the Green Deal supported the consumer in the pursuit of energy efficiency (Department of Energy and Climate Change, 2011). Under the scheme, government targets included insulation of all new-build cavity walls and advancing the technology used in condensing boilers. Under obligations placed on energy companies to reduce greenhouse gas emissions , energy-monitoring devices such as smart metering would become mandatory. Fuel poverty would be managed by the installation of new, more energy efficient boilers and the addition of cavity wall and loft space insulation. This in turn would lead to a reduction in use of fossil fuels and high cost suppliers (Department of Energy and Climate Change, 2011).

By signing up for the deal, households were offered the chance to lower their bills by using less energy. For those that qualified, energy providers would provide loans for the installation of new energy efficient technologies. The loans were paid back by occupants, offsetting the lower bills due to energy savings.

From the Warm Front Scheme to the Green Deal, the UK government has provided many incentives for UK homeowners and tenants to retrofit their properties with more energy efficient appliances and energy saving insulation. Through programmes like BREEAM certification, the Home Information Pack, London Plan and Code for Sustainable Homes, constructors and users alike have been encouraged to build or purchase a zero or low carbon home. Despite all of these programmes, it remains to be seen how knowledgeable end users are when it comes to operating these green technologies and buildings. A gap between the expected energy savings and actual saving may be quite significant, should occupants not fully understand the purpose and best methods to use the energy efficient tools at their disposal.

Government programmes have driven forward the need for more energy efficient interventions in the domestic market. Despite this, the housing stock in the UK remains dated and inefficient. Many families still live in cold and draughty homes. In some cases, building performance can only be attained by either improved design of new homes and replacement of inefficient housing stock or through intensive retrofitting.

2.2.13 Summary of Government Policies

This section has summarized government policies over the last decade, this has included, incentive schemes, targets, procedures and methods to reduce energy usage along with improving the carbon footprint. Government agencies have worked to address these issues in pursuing a common goal in conserving depleting energy sources, reduce usage and address affordability to the less fortunate. It is evident from this overview that a large number of schemes are available Also, whether the end user fully understands the benefits these may represent and subsequently are not confused by choice or jargon.

However, occupants that carry the green batten will appreciate the efforts being made but to the majority the ideas and procedures, have little or no impact and may be seen as achieving very little here.

2.3 THE INFLUENCE OF THE OCCUPANTS' BEHAVIOUR ON ENERGY EFFICIENCY

Solving energy issues for the environment requires integrated solutions considering not only the building but also the end user. Encouraging occupant's awareness and participation in the future of a sustainable energy world will involve such things as the use of electricity and gas. Current energy policies will have a lasting impact on human and ecological systems leaving alternative solutions as the only answer (Klein and Coffey, 2016). The market is keen to encourage early adopters the opportunity to pursue new greener technologies, but a balance must be struck between affordability and use ability. What does this mean; the technology must have the capability to be understood by the user with clear concise manuals provided along with one to one support if required for the system to function efficiently. Furthermore, everyone has different priorities in life, behaviour patterns very dependent on the type of occupant, age and social background.

2.3.1 AGE

Further to this, challenges will also include the average age of occupants and their projected increase; this currently stands at 10 million people over the age of 65 years old. Government projections (Parliament UK, 2015) have revealed that this will increase by 5.5 million in the next 20 years and reach nearly 19 million by 2050. Figures also show that currently one in six people are aged over 65 and this is anticipated to rise to one in four by 2050. By this massive shift in longevity in the coming years, more and more occupants will be reliant upon heating and energy resources supporting them in their habitats. Obtaining a balance between the increase of population and energy usage, therefore, becomes a very important issue. Each occupant's needs may vary due to their ability to pay, social upbringing or commitment to green issues. Further predictions show that by 2033 the ratio between the working populations to that of people of a pensionable age will fall from 3.2 to 2.8 per person based on 2008 calculations. (Parliament.uk 2011). Whilst the increase in age is set to rise this will not be seen proportional to good healthy life which will put additional strains on the NHS to support occupants in not only health conditions but in their living environment. Elderly people suffer more from weather conditions especially the cold and this added to their health will also add further demands to their energy usage.

For older people, health is widely known as a barrier towards the ageing process. It was discovered by 'The Royal Commission on Long-term Care 1999' that retaining appropriate living conditions within the environment should be considered crucial to maintaining and enhancing independent living and quality of life in particular for the elderly. (Dalley, 2000).

Consideration must be given to the UK system regarding the provision of long-term care in light of changes in health amongst people living longer, along with the current housing stock availability and shortfall that needs to be made up addressing there needs (Karlsson et al., 2015). Building regulations have addressed several of these issues for the ageing population including easy access to buildings via ramps and larger door openings to ground floors to allow for wheel chair access. New buildings design also take these design elements on board and deal with wet rooms and ground floor cloakrooms along with easy access to spare bedrooms.

2.3.2 LIFESTYLE

Early findings by the Centre of Alternative Technology (CAT) in 2009 supporting energy usage revealed that *(figure 2.1)* 57% of energy was consumed in domestic households by space heating, 24% by hot water systems, 16% from lighting and 3% by cooking and catering. This confirmed the fact that large proportions of energy are currently being used to provide simple everyday needs such as heating affecting many occupant's ability to pay, subsequently categorising them into the fuel poverty bracket once 10% or more is used on fuel bills every year.

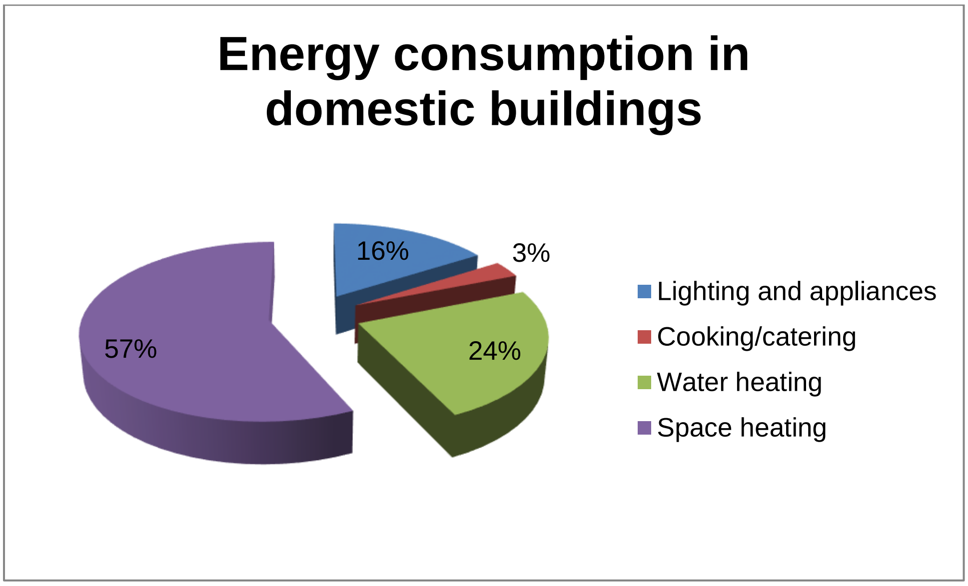

Figure 2.1 Average Energy Consumption of a domestic building 2009.

(Source; Centre for Alternative Technology (2010, p.88)

However, since 2010 the drive towards more efficient technologies has remained at the forefront of government initiatives. Companies are now developing more efficient combination boilers proving not only an economical heating system but also hot water that is only paid for on demand. More advanced boilers include CHP (Combined Heat and Power), providing not only heat and hot water but electricity as well. The problem is affordability; until the costs are reduced, the general consumer will not invest. Lighting systems over the last 7 years have changed dramatically; the phasing out of high wattage standard bulbs to energy saving bulbs, LED's and low voltage systems, have paved the way for consumers to reduce their energy consumption by using these commodities.

What remains to be seen is the lifestyle, the type of occupant and their views on government initiatives along with green issues. The challenges that lay ahead include lifestyle changes when purchasing such things as boilers, double-glazing, insulation and even light bulbs. The question that needs to be asked here is does the payback period off-set the additional cost, will the occupant look for early savings or long-term investment.

As buildings become more energy efficient and automated, the role of occupants becomes more significant to assist buildings to reach their full potential. Bringing forward the behaviour of energy consumptions for the occupant has been identified with building management system operations. The case of individual energy profiles has now more than ever been on the increase, to improve the effectiveness of energy efficiency methods to assess supportive means in order to better predict control for the occupant in the short and long term (Khosrowpour, Gulbinas, and Taylor, 2016).

2.3.3 Behaviour Change

The key to improving behaviour and reducing energy usage must come from training, advertising, general media discussions, documentaries reinforcing the basic understanding of energy saving measures. This could include turning off the stand-by lights to appliances, switching off lights when leaving a room, heating up rooms only when required, using energy saving appliances.

A study undertaken by the *Bio Regional group 2012* found that on a pair of semi-detached houses significant reductions in CO_2 emissions were obtained when occupants were fully conversant with energy saving measures. *(Table 2.3)* outlines these benefits and concludes that an overall saving of 12.9% was achieved once a change of habits was implemented. The biggest saving was found to be when the thermostat was turned down; 1 degree produced a saving of 2.7% and by further reducing the temperature 2 degrees this produced an overall energy saving of 5%. Using the tumble drier unnecessarily ranked third with a reduction of 1.8%, this simple exercise demonstrated that it is possible to change behavioural patterns. However, what is missing is the type of occupant being considered, their age, gender and employment status.

Table 2.3 Percentage of CO_2 emissions reduced from behavioural changes using pair semi-detached houses as a case study. Bio Regional (2012)

Behaviour change measures	Percentage reduction in CO2e emissions
Behaviour change measures to reduce heating and hot water demand	
Turn down thermostat by 1 degree	2,70%
Turn thermostat down by 2 degrees	5,00%
Behaviour change measures to reduce electricity demand	
Washing machine only use at 30 degrees	0,80%
Eco-kettle	0,50%
Turn off lights when leaving a room	0,20%
Only boil as much water as you need in the kettle	0,40%
Turn appliances off and avoid standby	1,40%
Don't use the tumble drier	1,80%
Total	**12,90%**

2.3.4 Occupants Habits

Moving on from behaviour change occupants are generally set in their ways, changing habits, purchasing new brand products can cause unease especially with the older generation. Energy providers monitor energy usage in the form of

Kilowatt hour (KW/h), this unit of measurement is very important to the supplier but irrelevant to the consumer (Kempton & Layne, 1994).

The decision making process can be a daunting subject to some, making crucial decisions when purchasing products will include cost, specification and fit for the purpose. The last two later points are generally overlooked here. An example could be the installation of new windows, this may be seen as a problem for many people. What considerations were given to the process-

1. Type of window wood or UVPC
2. No openings fixed – casement - fanlights
3. Cost inexpensive – expensive
4. Life expectancy short life - long life
5. Type glass Single glazed - double glazed – triple glazed
6. Performance U value – energy loss
7. Maintenance Coating – General clean

Whilst the list could be exhaustive, the average person will not consider beyond the point that the window needs to be not only fit for the purpose, aesthetically pleasing to the eye, watertight but affordable. In addition, maintenance factors, life expectancy and energy usage will collectively improve the buildings performance. The second issue that needs to be considered is ownership of the building; does the occupant own the building or are they tenants with little or no involvement in the decision making process when the windows are chosen, designed, ordered and finally fitted.

Whilst self – concept is seen as how occupants may perceive themselves, their identity, image, how they may behave, are they seen as a good people, if they save energy how are they placed in society. Chatterton, (2011) believes that promoting certain behaviours such as low carbon activities to save energy or reduce the carbon footprint , recycling or walking instead of using some form of mechanical transport may be seen differently if in promoting the low carbon activity whereby the only saving is financial. As age increases people tend to become more organised, life slows down and these important issues may be recognised and consequently become more important.

Considering new technologies, personal gains, avoiding waste and obtaining a better quality of life and wellbeing underlines the benefits that can be realised by the occupants. The manner in which the information is provided, timing, accuracy, easy to follow will all have a significant impact on the results. (Parnell & Popovic Larsen, 2005). Unfortunately, this is not always possible as occupants have different levels of understanding and perception of information and technical advice, each one will perceive these factors from different perspectives.

Changes in government legislation mean that all households will soon have "Smart Meters" installed in the home encouraging them to monitor their energy usage. This is discussed later in the literature review and could have two consequences, positive and negative. The benefit would see the occupants monitoring their usage and making changes to their lifestyle. This could include the amount of time the heating was used, the amount and times various appliances would be used. The problems that could be encountered would include occupants that were either in the fuel poverty bracket or careful with their income switching off vital appliances such as heating when usage needed to be higher than normal possibly due to colder weather conditions.

2.3.4.1 Fuel Poverty

Fuel poverty is the most commonly accepted term that describes a household's inability to afford basic standards of power, heat and light. If their outgoings on energy bills represent 10% of their income then they are classified as being fuel poverty. Since 1991, the concept has gained widespread acceptance with publications of the UK Fuel Poverty Strategy in 2001, in setting a more informed approach for future targets (Liddell et al., 2012).

Since 1996, notable progress has been seen towards a reduction in occupants falling within this category from 6½ million households in the UK to around 2 million households in 2004. Although there has been an increase in overall costs increase with fuel and light during the period of 2004 to 2006 by 35% as well as gas prices increase by 45% and electricity prices by 29% in real terms indicating a problem with challenges concerning fuel targets in these areas (Department of Trade and Industry, 2007). Information provided in Figure 2.2 predict substantial reductions by 2016. However spiralling energy cost seen in mid-2017 may have a detrimental effect on these figures.

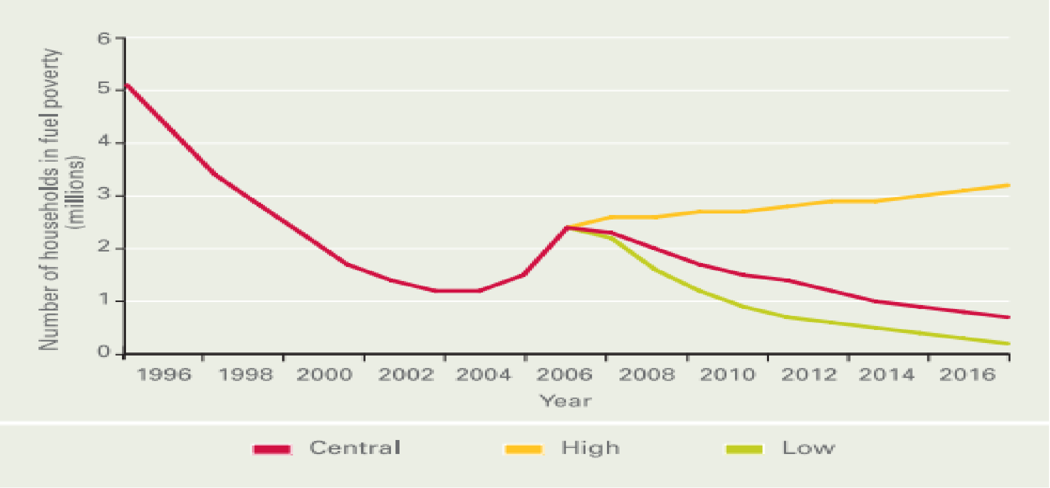

Figure 2.2 Historical projected numbers of households in fuel poverty in England 1996 to 2016 *(Department of Trade and Industry, 2007)*

Older dwellings tend to be poorly insulated and subsequently have a higher number of occupants in fuel poverty, *Department Energy Climate Change (2016).* It was also found by DECC that properties with gas heating had a lower rate of fuel poverty than properties using alternative energy sources, this may have been down to the cheaper fuel. The problem was also seen to be higher in the private rented sector which could have been contributed to by the higher rents being charged and disposable income available.

To meet the challenges and reduce the effect of fuel poverty can only be achieved by installing not only energy efficiency technologies supported by government incentives but holding down energy prices in line with the current economic climate.

2.3.4.2 WELL BEING

With the growing concern about methods that allow the ageing population to maintain their health and well-being while living in their homes with modern technologies and the readiness amongst older people's ability to use them, is a complex issue. The term Smart Homes and health monitoring technologies have since been introduced into the industry to combat the daily living activities to address such issues. This technological advancement remains a problem that needs a greater understanding for ageing occupants with complex needs (Liu et al., 2016)

Furthermore, the quality of the internal environment and its effect on occupant well- being and comfort can be related to a range of issues such as sick building syndrome, indoor air quality, visual comfort to mention a few. It is the design of buildings that come into question and have the needs of the occupant been considered within the design parameters at inception. Researchers have acknowledged that the relationships between the built environment and the occupant can play a significant factor leading to matters of concern, causing technical flaws in the building system. Since people can spend as much as 80% of the time indoors studies have indicated that a range of comfort and health-related issues are linked to the characteristics of the building and the design. Al horr et al. (2016) suggest that a few symptoms of discomfort can lead to further discomfort and affect the work performance of occupants. To further add to these problems factors such as dust, mould and airborne fungi can effect occupants with asthma primarily due to poor ventilation. Additional issues such as leaking pipes and dampness can be avoided if care monitoring of the buildings are carried out frequently (Redd, 2002).

2.3.4.3 HOUSEHOLD SIZE

Energy usage within homes can be related to the size of the property, the larger the property the higher the energy usage. Considering these factors, heating, hot water, lighting and power applications, households larger in structure tend to generally use more energy. This relationship between the amount of energy used for these tasks as well as the size and location can have an impact on the occupant's affordability (Right, 2008).

A traditional model used in heating such as Standard Assessment Procedure (SAP) determine standard occupancy pattern of a well-heated living room at say 21°C , while the rest of the house is at 18°C during occupancy. However, the model only reflects the cost normalised by the total floor area and carbon emission factors. This includes thermal transmission of exposed elements; air infiltration rate, energy systems, and types of fuels related to the age of a building and built form. However, studies have shown that SAP is actually a poor indicator for individual dwellings, mainly because of improvements in household's efficiencies in recent decades and new homes are now built in different ways whereby energy factors cannot be just related to the built form (Right, 2008). Furthermore with bedrooms in particular becoming more comfortable, and used for occupancy inclusion within their homes as remedial office space and liveable, means they are increasing their living space. Additionally, conservatories for example, with passive solar design to preheat incoming air are growing more common and are subsequently expanding the occupancy comfort space further (Right, 2008).

2.3.4.4 TYPE OF RESIDENT (OWNER /TENNANT)

Evaluating the type of residents can be considered almost impossible, how do they perceive certain factors such as energy efficiency green issues. Does the household owner / tenant want to have an understanding on energy awareness? The end users relationship with technical features in appliances fitted to new or retrofitted projects may be complex, has the technical data been written in such a way that this is fully understood by the recipient (Podgornik, Sucic, and Blazic, 2016).

According to Vassileva, Wallin, and Dahlquist (2012) results carried out through a series of questionnaires revealed residents with higher household incomes accounted for greater energy usage as well as the behaviours determining greater electricity consumption. The questions were formed by three characteristics, type of resident, usage of electrical appliances and attitudes towards energy consumption.

Understanding the individual primarily could determine in this instance the type of resident that is more likely to use up energy usage just because they can afford to without little consideration of expense. Therefore, the argument may have some backing towards actively seeking why energy use of electricity is higher with those with better incomes.

The UK housing stock mainly consists of three tenure types Ownership- occupies 65% of housing stock whilst social renters and private account for 17% and 18%.

Hope and Booth (2014) discuss the major challenges required to improve the housing stock and how this needs to be addressed; this will include the private sector landlord's attitudes towards improving the energy efficiency of their tenanted homes, providing detailed information of this to tenants is all too often omitted.

Elderly homeowners with low incomes have deepening concerns about their housing situation; this includes energy consumption, shelter quality, accessibility and mobility, as well as burden of homeownership and social support networks. (Leung, 1987)

For older people health is widely known as a barrier towards the ageing process it was discovered by 'The Royal Commission on Long-term Care 1999' retaining appropriate living conditions for the environment should be considered crucial to maintaining and enhance independent living and quality of life in particular for the elderly (Dalley, 2000).

2.3.5 Occupancy and Design

Whilst not considered in building design stage until recently, undertaking a study of the end-user occupant and involving them in the design process has a lasting effect on the success of a project. In regards to energy efficient design concepts particularly, instructing the end user on use and theory is likely to have a positive effect on building performance.

When incorporating new and energy efficient technologies, information regarding its use and purpose needs to be transferred between the installer, the client and the occupant in a more in-depth manner than a basic user manual. Such instruction would need to include relaying the basic design concepts to the end user (Elecnik *et al.*, 2012). Communication barriers could be overcome by performing a post occupancy evaluation (POE), which would maximise both the understanding of the installed technology by tenants and the economic benefits that would result from correct usage and implementation (Way, 2005). Inclusion and engagement of current occupants prior to refurbishment also provides positive benefits (Gupta *et al.*, 2010). While building occupiers and owners are primarily concerned about the rising cost of energy, building designers have a duty to consider energy saving technologies. These two aims are not mutually exclusive and if all parties are considered in the design stages, those objectives can be met (Dickinson *et al.*, 2009).

Monitoring the way in which occupants understand how buildings and energy efficient technologies perform can be undertaken by various methods, from questionnaires and occupant satisfaction surveys to interviews, forensic walkthroughs, data analysis and Way's (2005) Soft Landings post occupancy survey. These methods should be able to identify which occupant factors, if any, limit the understanding of either proposed energy efficient technology or one that has already been fitted. One of the most important questions to consider is do the occupants either understand and take government targets seriously or are they really concerned.

2.3.6 TIME CONSTRAINTS

One of the problems with collecting data from occupants before the refurbishment stage is that of time constraint. Often in a refurbishment project, a client commissions a team of specialist advisors to put forth construction and budget proposals. Currently, they are only involved at the early design stage in limited numbers, which can lead to issues in implementation and uptake of any retrofitted technologies. Generally, the timeframe between deciding to undertake a refurbishment and project commencement is very short, with little to no dialogue with the end user. This means they have no feedback to any planned installations or input into the design (Gupta and Chandiwala, 2010). Engagement with these people in the conceptual stage of a retrofit project can result in increased energy efficiency and less wastage. In addition, ensuring that they have a general understanding of the technologies involved in the retrofit enhances that result. If possible, occupants should be engaged starting at the conceptual stage so that any retrofit projects are cost effective and result in low wastage and high-energy efficiency.

A case study was carried out in post occupancy evaluation (POE) assessment for retrofitting commercial office buildings in Malaysia. To address measures to determine the occupants' satisfaction level, through the use of questionnaires they found that communication played a large part in identifying functions and trends. It was found to obtain better building performance in the area of sustainable development. (Shika et al., 2012). This approach led to the economic and social aspects being included in the plan, which resulted in the building user fully understanding the new technologies along with the feedback mechanism that supported the process.

Occupant’s behaviour is an essential factor relating to the energy consumption of a building. Research studies predict that their role requires further evaluation for better-informed decisions for post interactions between them and building energy performance. The problem of behaviour and the patterns to predict improved efficiency need to schedule ongoing activities with them and the way in which information is communicated. The presence of sustainable choices needs to reflect the individual’s needs and requirements, in the long term this could improve the performance of the building.

One method that could achieve this is by implementing a system that requires the practical means to improve operations by the use of data. (Liang, Hong and Shen, 2016). User-friendly systems will obtain the most practical results, hard to understand manuals and technologies will not obtain the results that were originally predicted along with the cost benefits from the interventions.

2.3.7 Financial Objectives

Considering energy efficient technologies should include not only the financial objectives and net end gain, but also an affordable solution that is both user friendly and sustainable. In addition, government incentives and expectations for homeowners towards refurbishment and new technologies, requires an ability to analyse the degree to which these promote or hamper the implementation of energy efficient refurbishment.

Investment into cost effective design requires further understanding, reaching out to occupants and explaining the benefits of improving existing energy systems needs to be clearly presented. (Stieß and Dunkelberg, 2013)

Clear methods of saving money and reducing energy consumption should be user friendly and easy to follow. As discussed earlier incentives such as the

Green Deal encouraged the occupant to borrow money from the energy provider, invest this into some kind of energy efficient technology and repay the loan back form the savings obtained from the reduction in energy consumption. In essence, the scheme was practical but not fully taken up by the population.

If occupants could clearly see the benefits and monitor how much energy is being used on a daily basis, this may make them feel more conscious about the cost. An example could have illustrated the cost of a new boiler £1,500.00, being eco-friendly this could account for a reduction in energy bills by up to 30% per annum. The cost of the new boiler would have been offset by the reduction in the energy usage over a payback period before the benefit is fully recognised.

2.3.8 LANDLORD'S OBLIGATION

Factors, which affect the housing market relate to not only interest rates, but also economic growth, population, state of the mortgage industry and demographic trends. (Economicshelp.org, 2015). Due to the increase in property prices (figure 2.3), the market has seen a massive uptake in the rental sector, high property costs and ability to pay has now placed a massive burden within this area.

In figure 2.3 Average UK house prices between 1992 – 2015.

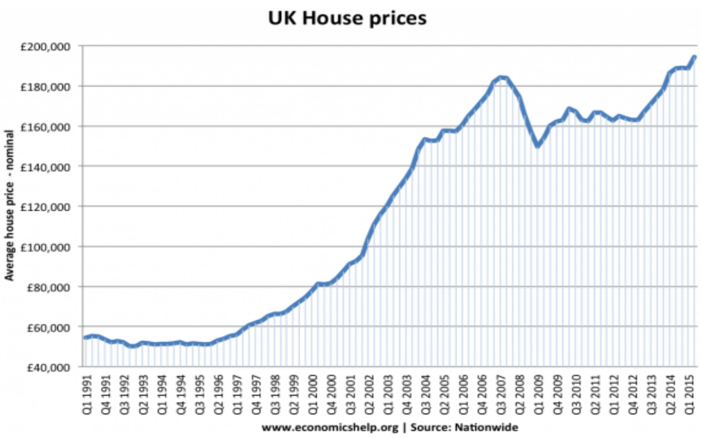

Figure 2.3 Average house price from 1991 to 2015 (Economicshelp.org, 2015)

The current trend shows a steep increase in property prices forcing people into the rental sector who have not the financial capacity to purchase. A dip in 2009 indicated the state of the economy at the time and subsequent austerity measures were introduced. Whilst the interest rates were seen to be stable the criteria to obtain finance and a mortgage was highly scrutinised leading to renting this led to ineffable buildings not always being fit for the purpose. Properties would be damp, poorly maintained and the most important thing the landlord difficult to find when problems arose. However, it is not always the landlord that is at fault, unscrupulous tenants failing to pay their rent on time and in several cases, buildings stripped bare when the tenant leaves.

Social housing landlords face the biggest dilemma in providing dwellings that are not only fit for purpose but meet the occupants' needs. Not only are occupants living longer now and many with some form of disability there's a responsibility to provide easy access not only to the building but internally as well.

Legislation in the UK finally has been changing in favour of the occupant, landlords must provide buildings that are not only safe, comfortable to live in but also energy efficient and well maintained. Taking receipt of a rented building now provides the occupant with an energy performance certificate EPC, the gas and electric services must be certified. The tenancy agreement should be clearly set down and comply with UK law.Gov Uk (2016.)

2.3.9 Summary

Ownership of post-occupancy problems can originate from parties including the client, design team, contractor and even the installed technology. Problems may not be readily apparent at the early stages of a project; matching the design and technology to a dwelling or occupant requires careful thought and deliberation. The type of occupant: their age, level of IT awareness, energy awareness and ability to afford running costs all affects the success of a refit.

The inclusion of temperature controls, improving indoor air quality and comfort for occupants, are perceived productive for health and also improve energy efficient systems. The positive result can be achieved by careful planning and the reduction in operational energy with carbon demonstrates the potential to future proofing buildings with design in the context of climate change.

However, if not implemented in the early stages of design this could have a negative effect and complicate results for the benefits of long-term sustainability. Efforts to improve retrofitting therefore should be responsive in its approach with feedback systems in place at early design stages.

The role of ownership therefore should reflect a process of implementing the requirement of the occupant and the building, which represents the views and interests of all the parties, involved. (Thomas, 2010)

2.4 BUILDINGS

2.4.1 HOUSING STOCK

Moving on from occupants' behaviour and the type of environment they live in the housing stock in the UK has become increasingly tired and worn out. While no set directives have been put in place to replace these worn out homes, measures to retrofit the existing stock is an increasingly attractive alternative solution. If the energy efficiency of a property underperforms, the residual value will suffer. Properties with a higher energy rating can be seen to be sustainable and technically obtain an edge in the marketplace. Unfortunately that's not always the case the desire to either own or live in a property will out- weigh the benefits that the property may offer.

Purchasing a property that requires refurbishment can also come with a certain amount of problems. Marszal *et al*. (2011) explained that renovation work remains more complex than newly constructed buildings, making it difficult to meet all criteria that current building regulations require. Maver and McElroy (1999) argue the UK can spend about one billion pounds per annum on repair of building defects. However, the design of new buildings and the use of the correct interventions to the existing housing stock could significantly reduce these costs. Researchers estimated that by the time we passed 2016, an additional 500,000 households would have been renting, putting pressure on local authorities and government agencies to release land banks for future development. From this data, approximately 42,000 additional homes would have needed to be constructed each year to support these new tenants.

2.4.2 Listed Buildings

Listed buildings add to the problems surrounding energy efficiency and retrofitting; the age will denote the form of construction synonymous with a particular era. Older buildings are less energy efficient and may fall under heritage policies that restrict any change to the fabric of the building. This in turn may restrict the extent of refurbishment that can be undertaken to improve the energy performance in housing stock that is notorious for poor levels of insulation, glazing, heating and high levels of infiltration (Moran *et al*., 2012).

Most buildings dating back to the nineteenth century consisted of solid wall construction that was typically one brick thick for a standard home. In London, terraced houses were slightly different, with a basement party wall as thick as two bricks, reduced each floor by half a brick. These thin walls with no insulation allow for high levels of infiltration and for heat to quickly escape, leading to drafts in homes. Lack of proper glazing on the windows of these older homes also adds to the loss of heat energy and warmth.

2.4.3 Demolition

Addressing problems such as our tired housing stock and listed buildings, extensive debates have taken place in the past regarding whether to demolish or renovate dated housing stock in poor condition. Older buildings such as unsanitary slums were pulled down in the last century, prior to any consideration being given to sustainability and the possibility of retrofitting. In the 1960's, debate arose over proposed extensive demolition plans. To this day, many see this as a quick fix to the landscape of outmoded inefficient and damp properties that are no longer fit for purpose.

Predicted figures indicate that nearly two million properties will need to be demolished by 2050 in order to meet the stringent energy targets set by the government (Power, 2008). Realistically, only 10% of existing housing stock will have been by that date; many professionals argue that refitting will provide just as many benefits. The current rate within the UK remains at 20,000 units per annum, which accounts for less than 0.15% of the UK's housing stock (Boardman, 2005). From these figures, the current housing stock should last for at least a thousand years, which is unlikely. Even if the current rate were increased fourfold to 80,000 dwellings per annum by 2050, only 3.2 million homes would have been pulled down and rebuilt. This still only accounts for 13% of the current housing stock. Lastly, these rates remain very low, with the constant construction of new dwellings adding to the housing stock rather than renewing and replacing it (Bell and Lowe, 2000).

There is much debate not just about the carbon footprint of demolition but also regarding what happens to the occupants of would-be demolished properties. Many have lived in the same house and the same communities throughout their lives. The mere thought of their home being demolished causes unnecessary stress. Many hold onto memories and feel safe within the boundaries of the environment that they have known for so long. For this reason, greater weight should be placed on retrofitting existing homes or placing tenants back into the same neighbourhoods in order to maintain social bonds.

2.4.4 Retrofitting Buildings

Demolition can cut apart the fabric of a neighbourhood, severing ties between lifetime neighbours and family members in the name of improved housing. In many areas, this can act as a catalyst to break neighbourhoods apart, leaving the new housing in a sterile environment without any developed ties between occupants. Occupants often prefer to live in substandard older housing in order to maintain the ties that they have developed over time. Because of this, retrofitting is viewed as a more socially acceptable and sensitive way to improve housing stock. Refurbishment, however, is not without its issues, in that any measures have to be adapted to the existing framework and fabric of the house.

Retaining the existing housing stock reduces unnecessary transport costs, emissions and landfill waste while allowing for the reuse of existing building materials and maintaining community networks. Renovating properties also allows families to stay in the same areas, strengthening family relationships and providing support for the elderly (Power, 2008).

Challenges currently surround housing professionals in how to retrofit Britain's existing housing stock and bring it in line with the government's energy efficiency targets. Many buildings will be complex projects due to their outmoded design. For example, Victorian housing normally has sliding sash windows and solid brick construction. This means that both windows and wall insulation would be difficult to replace to the property (Mallaband, Haines, and Mitchell, 2013).

The existence of many listed and older buildings makes the quest for energy efficiency difficult to achieve. Buildings built in the early 1950's, similar to the stock being investigated within this study, were constructed with a steel frame, timber infill and very little insulation (BRE, 1986). This type of dwelling was quickly constructed as a reduced lifespan building that addressed the shortage in social housing that arose from WWII bombing. These buildings were designed and then replaced before the end of their serviceable lifespan, but many local authorities' budgets did not allow for demolishing and rebuilding such a considerable amount of social housing stock. This meant that the only option left was to refit existing housing stock, subject to grants and available funding (Mallaband, Haines, and Mitchell, 2013).

In Germany a survey was carried out via phone interview with end user occupants, the study recorded if any retrofitting measures had been carried out on their property in the last four years. Residents were categorised between those who had just carried out basic improvement measures and those who included energy saving measures. The study revealed that many homeowners were hesitant to take out additional funds to pay for these works. Those that carried out energy efficient works had an interest in reducing energy consumption and often had advisors guiding them through the refitting process. The study concluded that the German government would more likely meet future carbon reducing targets if it provided additional incentives to promote installation of new energy efficient technologies (Steiss and Dunkelberg, 2012).

There are many benefits in choosing retrofitting instead of demolition and rebuilding. This route can provide a steady stream of work for small building companies, as well as building community relations and cutting the carbon footprint (Mallaband, Haines, and Mitchell, 2013).

However, this type of work does come at a cost, Stafford *et al*. (2011) examined the costly effect of retrofitting and the need for a project to be correctly researched prior to the start of a build in order to foster a 'get it right the first time' environment. Insufficient understanding of the building fabric, process and systems has led to a performance gap between predicted and actual energy performance. When undertaking such a project, selecting the most appropriate technology to enable the reduction in energy use provides a challenging task. Modelling the use of energy within the building can show significant benefits in attaining energy savings. Lastly, the extent of up grading our housing stock must be significantly balanced to the savings that will be achieved, offsetting the amount of investment by the return and repayment period (Mata *et al*., 2013).

High-rise flats have been overlooked in the past, limited information is currently available regarding the ease, efficacy and success of retrofitting these types of buildings with energy efficient technologies. Earlier research studies have found that the higher floors of a retrofitted building attained the most significant benefits due to the decrease in wind and cold weather infiltration. Gorgolewski *et al*. (1996). By installing basic measures such as draught proofing measures to these units' energy savings of twenty-five percent were achieved. However, this installation did not take into account or monitor any change to the occupants' behaviour as a result of the works.

2.4.5 Building Fabric

Designers, constructors and engineers face many challenges when selecting appropriate building materials when upgrading buildings. The material behaviour, environmental performance and reuse values all must be considered. With a current emphasis placed on green initiatives and technologies, future design and end of life values will place a premium on low embodied energy values and the future recycling potential (Saghafi *et al*., 2011).

New build projects have the ability to insulate to a high standard the complete fabric of a building during the construction process. This is not always the case when upgrading older buildings, as Heeren *et al*. (2013) found that there was only a 10-17% energy saving. This is not as good a savings as predicted, due to an inability to insulate all walls and roofs. In addition, sacrificing space is an issue, as it is easier to insulate internal walls instead of external.

2.4.6 OVERHEATING

One of the issues that must be considered when upgrading an older building is the comfort of occupants and the hazard of overheating. As temperatures rise, the comfort of occupants in certain types of buildings may become compromised, causing discomfort to the elderly and vulnerable (Porritt *et al*, 2012).

Using dynamic simulation modelling software, predicted future weather patterns and four housing types common to the UK, Gupta and Gregg (2012) identified future concerns relating to overheating. Gaterell and McEvoy (2005) concluded that insufficiently insulated dwellings would see temperatures rise well above the comfort zone by the 2080's during the summer months.

Studies have also shown that this syndrome is more likely to hit the elderly and vulnerable people, as these populations tend to remain indoors on the hottest days of the year and are not necessarily able to remove themselves from overheated rooms (Porritt *et al*., 2012). The heat island of London and the southeast will see some of the worst cases of overheating. In order to reduce the severity of these issues, occupants at risk, including the vulnerable and the elderly, need to be prioritised to receive insulation and other relief.

2.5 THE EFFECT OF THE GREEN TECHNOLOGIES ON ENERGY EFFICIENCY

Driven by market demand and Government mandates, to support either our new generation of buildings or the existing housing stock energy, efficient and green technologies have surged to the forefront of the marketplace in recent years. An emphasis has been placed on renewable energy systems. Additionally, from smart monitoring systems to improved insulation, water heaters and efficient light bulbs, existing homes and commercial buildings have an opportunity to become increasingly green and economical to run and maintain.

2.5.1 RENEWABLE ENERGY SYSTEMS

Market demand for renewable energy systems are expanding at an incredible rate. Fossil fuels are declining at a disturbing rate; sooner rather than later, these energy sources will be wiped out. Alternative solutions need to be considered, tried, tested and implemented long before this eventuality arrives. Increasing costs of natural resources such as gas and oil are the main drivers into sustainable technologies. Global warming and the desire to reduce greenhouse gas emissions also prompted the acceleration into the renewable sector (Hoffert *et al.*, 2002).

Renewables aim to bridge the shortfall in energy by using natural resources such as sun, wind and water. Plants will be able to support biomass technologies including the production of fuels for transport. Energy can be produced by wind turbines driven by climate conditions; rivers and streams can be harnessed for hydroelectric power. Organic compounds can produce electricity by mixing hydrogen with other elements (Hoffert *et al.*, 2002).

Moving into the renewables sector will not only reduce the use of fossil fuels and safeguard our energy stocks, but will promote commercial growth. Technologies such as on-off shore wind farms, which have risen dramatically in the last five years (Zitrou *et al*, 2013).

The most commonly supported renewable systems include: solar power (either stand-alone or roof mounted photovoltaic cells), wind turbines (free standing or building mounted), hydroelectricity, anaerobic digestion for electricity generation, and micro combined heat and power (MCHP) for electricity generation (Willmott Dixon, 2010).

Like the push into renewables, smart monitoring systems in homes and commercial buildings are being rolled out across the UK as a means to conserve energy and reduce greenhouse gas emissions.

2.5.2 IMPROVEMENTS TO ENERGY PERFORMANCE

Currently the performance of buildings is a requirement for all EU member states to develop and improve their energy use by implementing consumption certification schemes for buildings such as Concerted Action by eliminating wastage found in the existing building stock. This has been backed by legislation to ensure that both new and existing buildings consume less energy (Carutasiu et al., 2015).

Emerging technologies such as photovoltaic panel systems connected to the grid can also be used for a domesticated house; when utilized can save part of the energy consumed for operating a house (Carutasiu et al., 2015).

2.5.2.1 Household Energy Consumption

Since the drive towards new energy initiatives, technologies are frequently entering the market place. The main aim of smart metering is to encourage consumers to use less electricity through being better informed about their energy consumption patterns.

The system is used to monitor electricity consumption within domestic houses and include technical measures designed to influence the occupants' behaviour by way of use with energy lighting and energy labelling functionality. The main aim of smart metering is to encourage consumers to use less electricity through being better informed about their energy consumption patterns.

The English House Condition Survey (EHCS) provided by the National Statistics within the UK delivers energy statistics and shows the average English household consumption. These figures include hot water usage and space heating as well as energy consumption. However, they do not support how to improve effective measures on how to better understand or replace household appliances to influence change or behavioural competencies within the domestic dwellings. What is missing is a breakdown on how best we can make changes to determine the usage of electricity consumption consumed by each appliance. Also identifying electrical equipment such as televisions and fridges that drawdown on the continuous usage of power (Firth et al., 2008).

2.5.2.2 Emerging Technologies

Currently key objectives' for our present government include decarbonising the UK by sustainable supplies and increase the productivity of businesses by reducing bills for both domestic and business customers. This is achieved by turning off appliances that are not in use as well as buying products that are more energy efficient.

Once the technology enters the market and has been tried and tested, demand for it increases providing it has proved to be successful. This rise in popularity has a knock on effect, which in turn promotes competition between the manufacturers thus making the product more affordable.

What remains to be seen here is that the product does what it says, is it user friendly, if not, will adequate support be provided to the customer to fully understand how it works to maximum efficiency.

2.5.2.3 COST EFFECTIVENESS OF NEW TECHNOLOGIES

Unlike innovative technologies like renewable energy systems and smart monitoring systems, standard efficiency technologies such as insulation have been tasked with increasing importance in order to reduce heat and energy loss. The benefits of these types of technologies include a reduction in maintenance and aftercare. Constructors tend to prefer this type of intervention, which is easy to install and maintain, aftercare costs are greatly reduced along with the performance of the system providing it has been correctly fitted. The next step on from this intervention is to control the energy usage; this could be achieved by the use of smart metering as discussed in section 2.5.3.

2.5.3 SMART MONITORING SYSTEMS

The British Government had made a commitment to a low carbon economy in order to achieve sustainable and affordable energy in the domestic sector. The use of smart metering systems is one method used to support these initiatives. It is intended that these systems will be rolled out through pilot programmes and eventually installed into every UK home as a means for allowing occupants to monitor their energy usage and costs (LeBlond, Holt, and White, 2012).

The transition period for installing new metering systems will come into effect between 2014 and 2019. During that time, over 53 million combined gas and electricity meters will be converted, consisting of over 30 million visits to domestic homes and small businesses (Department of Energy and Climate Change, 2012). It is anticipated that smart metering will encourage consumers to monitor their energy usage without being reliant on their energy supplier's estimated bill. This will also allow occupants the opportunity to manage their energy usage more efficiently in real time and understand which appliances consume the most energy over a set period of time (Gungor, 2011).

Due to the greater efficiency of the system, suppliers should be able to improve customer service and reduce costs. Less emphasis will be placed on call-out service, which should allow savings to be passed onto the consumer (Darby., 2010 and Faruqui *et al.*, 2010). As a result of this, occupants may consider using more sustainable hot water heaters and appliances. The key factor that will drive forward the use of energy efficient appliances is the awareness of cost savings that may be found.

However, one downside is that consumers may believe suppliers hold too much personal information in this 'real-time' data – including a household's consumption habits and the times of day their residence is occupied. The upside of this could be the possibility that peak usage tariffs could be introduced to serve personalised household needs (Faruqui *et al.*, 2010)

Occupant habits are dependent upon the time of day and even the season. Light usage dramatically reduces in the summer due to longer days, and cooking habits similarly change with occupants less likely to be in the kitchen during times of hot weather. Water heating costs are also reduced during the summer months, as people are more likely to take a shower than a bath, which saves water (Hong *et al.*, 2006).

As a natural progression from smart monitoring systems, intelligent buildings will become the next technology to emerge. Investigations into commercial buildings found that 'smart' systems could understand behaviour and respond to requests. Simply put, buildings can be programmed to react to occupant behaviour (Yang *et al.*, 2013). What seems to be apparent here is that whilst commercial buildings are being investigated monitoring domestic buildings further needs to rank higher in this area.

While smart monitoring systems allow users to monitor their energy usage through the day and change their usage accordingly in order to save energy and money, smart thermostat systems work with already established behaviour patterns in order to heat homes efficiently.

2.5.4 Smart Thermostat Systems

One-step beyond smart monitoring systems is other smart home systems, in particular, smart thermostat systems. Several of these have come to the market in recent years, such as the Nest system, which have been heavily promoted by energy providers as a component of energy efficient heating systems. These control systems work primarily through either sensing movement in the house or remotely controlling the thermostat, so that the house is not heated when unoccupied (Meyers, Williams and Matthews, 2010). The problem that must be considered here is that if the building is poorly insulated then the rooms not heated may absorb the heat through the walls from the ones that are.

Remotely controlled thermostats allow home occupants to turn off or down their heating system remotely, usually via a smartphone app. This also means that a user can set a minimum temperature to the home that is lower in the winter months than they might have previously set due to fear of freezing pipes. If colder weather is expected, the occupant can simply raise this in the home high enough to avoid any pipe freezing or other cold weather damage. Likewise, an occupant can warm the house prior to coming home to allow for comfortable living quarters, also it allows for a comfortable awakening early in the morning. (Meyers, Williams and Matthews, 2010).

2.5.4.1 SECURITY- SMART SYSTEMS

One possible shortcoming to smart home systems and smart thermostats in particular, is their security features. If these systems were easily hacked, a would-be burglar or other possible criminal element could monitor a residence to see when the occupant was home – and when they were not. According to Burrough and Gill (2015), most tested systems appear to be aware that security is incredibly important. For example, Nest's security features and coding ensure that hacks such as reverse engineering and man-in-the-middle attacks cannot occur. Other systems have been more vulnerable in the past, but updated software has reduced the chance of being hacked through lack of encryption and other means.

2.5.4.2 Cost saving

According to Nguyen and Aiello (2013), smart monitoring and thermostat systems can save up to 1/3 of the energy usage and costs associated with residential use. Implementation and installation of these systems have been promoted by energy companies, further adding to the cost-savings passed onto the consumer. For the energy supplier, these systems are cost-effective, in that they save the supplier from having to produce as much energy or buying it from other suppliers who have surplus (Faruqui *et al.*, 2007). Other ways of reducing domestic usage could include replacing out of date domestic boilers.

2.5.5 Heating appliances

Following on from smart meters the next consideration must be the type of heating that will be adopted by the occupant. According to the Shorrock and Utley (2003) and Singh, Muetze and Eames (2010), there are two types of boilers that provide space and water heating in UK homes: conventional immersion boilers with hot water tanks and instantaneous (or combi) boilers. Currently, conventional boilers with hot water tanks are seen to be more popular, the addition of insulation to the pipes and hot water cylinder jackets does assist in reducing the heat loss to a certain degree.

However, despite this additional insulation, conventional boilers with hot water tanks are notoriously inefficient. This inefficiency stems from the fact that boilers heat the water then the water stays in a tank until it is used for either space or water heating. Much energy is lost via heat loss and that the water must be frequently reheated in order to be used. While insulation and hot water cylinder jackets have reduced this heat loss, the combi boiler has played an increasingly important role in the UK domestic market.

A combination boiler works by instantaneously providing hot water for space heating or water usage. It heats the water on demand, which means that the heat loss experienced by water tanks is eliminated. Additionally, combi boilers are attractive as space-savers for occupants of small British homes due to this water tank elimination. No pump is needed and water is supplied at mains pressure, which also saves energy. Lastly, installation costs can be up to half the cost of a conventional boiler, due to the simplified plumbing and smaller units. Combi boilers are far more efficient than conventional boilers, being twice as efficient and reducing over twice the amount of carbon emissions depending on occupancy rates (Boait *et al.*, 2012).

Due to decreased installation costs, decreased running costs and energy savings, combination boilers are very popular and successful with both energy providers and domestic customers alike. Some manufacturers now offer as much as a seven-year guarantee on the boiler provided they have been fitted by an approved contractor and regularly serviced.

2.5.6 INSULATION

A large amount of emphasis has been placed by the government on properly insulating existing and newly constructed buildings.

One of the main pushes has been to make existing housing stock more efficient through retrofitting insulation. Dowson *et al*. (2012) demonstrated that millions of existing UK housing stock could be classed as ‘hard to treat’, with solid walls, no gas mains and little ability to insulate in the loft. Other methods, such as external insulation would make such homes much more energy efficient but this method can run into barriers with building regulations and council planning permission.

Homes that qualify for conventional insulation retrofits can be easily and cheaply upgraded using loft insulation and cavity insulation if they do not have solid walls. That said, certain upgrades, such as double-glazing, have a long financial payback period and high amounts of embodied energy that must be evaluated prior to implementation. This embodied energy may be so high that the increased efficiency of the house to run may not offset the energy costs involved (Dowson *et al*., 2012). Bernier *et al*. (2010) devised a rating system to evaluate the sustainability advantages of a home retrofit and its possibility of success. This system takes into account things like embodied energy, cost, government regulations and incentives, and is able to project the likelihood of achieving energy efficiency goals.

Improvements have also been made in terms of the sustainability of the insulation itself. From improvements in woodchip insulation to wool, old methods of insulation are being re-evaluated and improved. Griffiths and Goodhew (2012) examined lime hemp external solid wall insulation in a Victorian retrofit context and found that the improvements in energy efficiency brought a ‘hard to treat’ home to energy efficiency standards that exceeded current UK regulations.

As shown above, insulation is an easy way to increase the energy efficiency of a home and is important in order to keep households out of fuel poverty. The addition of loft or cavity insulation makes a home cheaper and easier to heat adequately – and enables occupants to maintain warmth in their homes. Natural light

Kumar, Soori and Vishwasb, (2013) briefly discuss energy saving methods relating to occupant behaviour in buildings, its apparent that designing natural light sources should be considered in depth to allow the occupant to either work or live in a natural environment.. The orientation of the building, position of windows and external obstacles play a big part in occupant's comfort and in some cases can affect their well-being.

2.5.6.1 WINDOWS

Bell and Lowe (2000) examined how changing windows improved the energy efficiency of a home. In the study, some homes had their original windows replaced with more energy efficient windows. This replacement decreased the running energy costs of the home by 25 to 30% in comparison to houses that did not have this intervention. Gas-filled windows, using gasses such as argon and xenon were found to be more efficient and allow less heat transfer than traditional air-filled windows, allowing 30% greater efficiency but with added embodied energy (Weir and Muneer, 1998).

According to the (Energy saving Trust 2016) double-glazing a complete property can produce benefits as out- lined in (*table 2.4)*, It can be seen that the A rated glass produced slightly better results in almost all property types. Currently glass is rated on a scale from G being the lowest to A+ being the most efficient.

Table 2.4 Glass ratings for-England, Scotland and Wales

Energy rating	Detached	Semi detached	Mid terrace	Bungalow	Flat
A rated	£120 - £160	£85 - £110	£65 - £90	£55 - £75	£40 - £60
B rated	£110 - £145	£75 - £100	£60 - £80	£50 - £70	£40 - £55

Energy rating	Detached	Semi detached	Mid terrace	Bungalow	Flat
C rated	£110 - £135	£75 - £95	£60 - £75	£50 - £65	£40 - £

Energy saving trust (2016)

Despite this decrease in energy running costs, windows are not a popular improvement due to the cost of installation. Simple draught proofing around windows and doors can run around £200 as a temporary measure but window installation can run into thousands of pounds. Additionally, windows have a high-embedded energy, during their production, which means that the energy efficiency really can only be calculated after the energy used to create the window has been balanced against the saved heat (Weir and Muneer, 1998).

2.5.7 PASSIVE HEATING AND COOLING

In addition to the smart metering and thermostat systems, improvements in insulation and windows, some houses have gone a step further and adopted what is called the Passivhaus standard (figure 2.4). This standard uses a high level of insulation, air tightness and efficient heating and energy usage to ensure a warm and cost-effective home.

In figure 2.4 the Passipedia passive house technologies are shown.

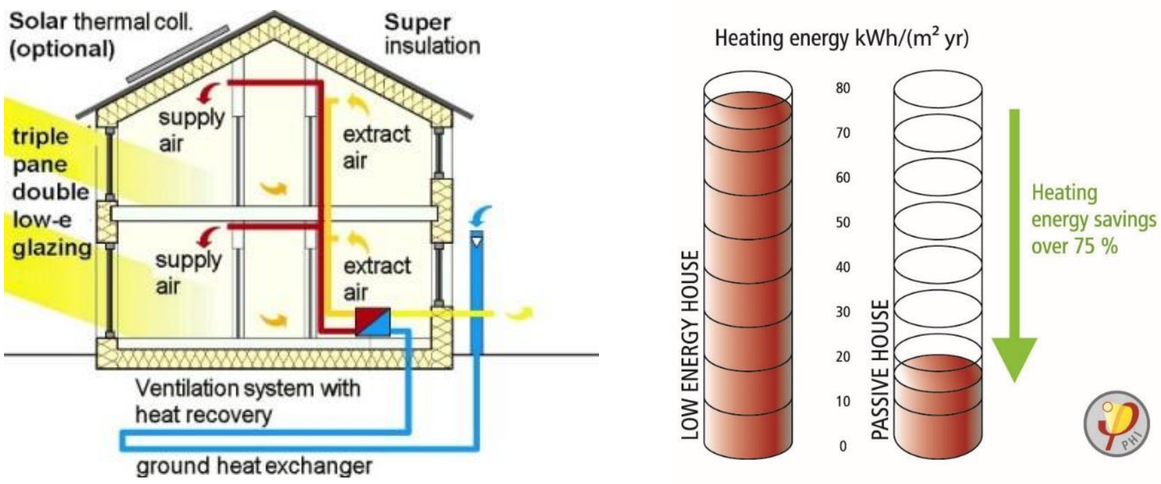

Figure 2.4 Passipedia-The passive house resource Francis Bosenick (2015).

Schiano-Phan *et al.* (2012) examined the feasibility of importing the Passivhaus standard from Germany to the UK. The current standard for low energy homes contains criterion for heating, primary energy demand, air tightness, winter comfort temperature, and total energy demand. Further to that, the Passivhaus standard includes a cooling criterion for summer months, a stricter air tightness standard, and a comfort criterion room temperature in summer. In their study of a BASF new build, the house met the 15kWh/m^2 Passivhaus standard without even implementing the whole house mechanical ventilation heat recovery system. From this, Schiano-Phan *et al*. (2012) recommended that while the Passivhaus standard from Central Europe is suitable to be adapted to the warming climate of the UK, the standard is best used as an adapted measurement of building performance rather than prescriptive standard. Furthermore, it was proposed that the Passivhaus standard be adapted to the British context regarding differences in lifestyle, climate, construction standards, technology and economics.

In another study, following on the recommendations regarding the importation of Passivhaus standards from Germany from Bell and Lowe (2008) and Lowe and Oreszczyn (2008), the first UK Passivhaus retrofit was completed in 2011 on a mid-terrace home in a West London conservation area. Due to the restrictions in external insulation, the Passivhaus standard was achieved using solid internal insulation and triple glazing. An energy saving of up to 89% was projected (Dowson *et al*., 2012).

Thus, it can be shown that passive heating and cooling standards such as Passivhaus can be adapted to both new builds and retrofits in the UK environment to a good result. While the studies concentrated on energy use and meeting standards, they did not examine how the occupant adapted to the change or the occupants behaviour.

In fact, it appears that while there have been huge strides in emerging energy efficient technologies; the limiting factor to that very efficiency is how users employ those very technologies. Like automobile emissions testing, energy efficient technologies are measured under ideal conditions. These ideal conditions are difficult to translate to real life situations with similar results. It remains to be seen how the population at large will use these new tools, and if they will take advantage of the energy efficiency or if it will be lost due to a lack of knowledge transfer.

2.5.7.1 EU Commitment

Prior to Brexit the European commission proposed to ensure a better chance of success with policies that reflect a regulatory framework of governance based on competitive plans to secure and sustain energy efficiency. This came down to the responsibility of the EU member countries through iterative process to meet the energy and environmental EU objectives. A clear and definitive approach with plans from the National Renewable Energy Action Plans (NREAPs) represents the importance of the Renewable Energy Directive to reduce these impacts by 2030 (Bigerna, Bollino and Micheli, 2016) What remains to be seen here is how these policies will affect the UK once they have left the EU.

2.6 After Care

2.6.1 Post-Handover Monitoring

Up until recently, any post-handover monitoring of a building was largely measured in terms of quality and cost of repairs. Basu (2015) demonstrates this emphasis on quality, solely examining the success of a project by comparing the cost of quality to the cost of failure in a traditional model while incorporating certain aspects of Six Sigma and other methodologies for eliminating defects. While this approach works in manufacturing and certain large-scale construction aspects, this monitoring does not reveal the long-term usability and viability of a project from a user and occupier standpoint.

Alternatively, Dainty *et al.* (2013) recognise the importance of a collaborative approach to sustainable design and following that collaboration through to post-handover. In their research presentation, as-built performance evaluation of implemented sustainable technologies is part of the post-handover monitoring. This will allow for the appraisal of energy efficient technologies, to find how they are used in practice. From this appraisal, the incorporation of the technology into future projects can be assessed. In addition, occupant behavioural monitoring will make up a large part of the post-handover evaluation. This evaluation will characterise performance so that deficits and gaps in design and process can be identified. At the same time, the process devised by Dainty *et al.(2013)* does not identify educating the end user regarding use of sustainable technologies in order to obtain the desired energy savings.

Current industry best practice at the handover of a commercial project involves handing over both health and safety files and operation and maintenance manuals. These together are meant to explain to any user or future contractor on a building how the building was constructed, designed to be used and how to maintain it. This method falls short in domestic dwellings leaving the owner/occupier with limited information.

Specifically, the health and safety file sets out how the building was constructed, what materials were used, and how the building was designed. This includes listing and explaining any residual risks inherent in the build. However, the information used to make decisions in the management of complex projects has moved to entering an era of Big Data with the expansion of asset information as a project deliverable. This information is set to achieve not only a sustainable building but allow the performance of systems to be monitored through the life cycle of building.

Construction owners and clients now seek information to describe maintenance scheduling, design rationale determining the building's functionality and post occupancy usage. Providing occupants with support during and after this period can not only address any commissioning or running issues but also provide historical data for future projects to learn from. This can only be successful if the monitoring period is extended past the post completion date.

The very basis of building information as a leading process therefore presents itself with big challenges, bringing parties together and sharing information that eventually contributes to the process of handover and review. Reducing waste, construction time and improving not only the efficiency of the building but also the aftercare and maintenance remain at the forefront of new policies. (BIM)

As well as Building Information Modelling (BIM) data initiatives now backed by the UK Government implementation as part of its strategy in essence will determine the managing of infrastructures with big data as part of the future and building blocks of Digital built Britain. (Whyte, Stasis and Lindkvist, 2016)

2.6.2 CURRENT BEST PRACTICE

The importance of post occupancy evaluation consists of a variety of methods concerning monitoring the performance of buildings; these require not only expert knowledge, which in many cases can be difficult in practice to obtain, but an understanding of how the occupants perceive the technology. Installing technologies with user manuals that are difficult to follow and no back up support from engineers is a recipe for disaster from the offset.

Ultimately, there are various methods to reduce the carbon footprint in building design and sustainability, improving energy efficiency within the building. One of the leading research schemes that consider this method of practice is called ‘Soft Landings’ which has rolled out a framework to categorise the process of building energy efficiency and building performance with techniques that are documented with specific tools for the purpose of energy efficient evaluation and the performance of the building. (Olivia and Christopher, 2015). The system also monitors in depth the occupant along with the aftercare support.

2.6.3 Soft Landings

As a method of monitoring properties post-handover, Way (2005) developed Soft Landings. A new approach in the building construction process, the process considers the whole life cycle of a project, involving constructors with buildings beyond the practical completion of the project. This tactic allows for the observation and collection of data to analyse the performance of in-use buildings. This analysis can, in turn, be used to implement best practice on future projects.

Way (2005) found the inspiration came in the 1990's while observing an innovative building designed for a major pharmaceutical company in use. Noticing that many of the building's features that had been intended to enhance building performance were not used or their function understood by the occupants, he surmised that the post-handover care was insufficient. Specifically, he hypothesised that knowledge of how a building is practically used is essential to improving building design, construction and end-user performance. After the methods and approaches that would result in buildings delivering their full potential, Way worked to develop a standard procedure.

Teaming with Bill Bordass of the UBT (Usable Buildings Trust) and Roderick Bunn of BSRIA (Building Services Research and Information Association) and the post-occupancy evaluation programme PROBE, Way developed the Soft Landings Framework using open-source documentation (Bunn, 2011; McGowan, 2010). Described as "a method for helping design and building teams improve building performance on live projects" and a "way of working rather than a tick-box assessment process run for profit", the Soft Landings Framework was included in BREEAM in 2011 (Usable Building Trust, 2011; McGowan, 2010).

In an early publication of his research results, Way described Soft Landings as:

> "…[an] approach [that] increases designer and constructor involvement during and after handover of the buildings to help clients get the best out of their new building and to reduce the tensions and frustrations that so often occur during initial occupancy" (Way, 2005).

The approach involves a new professionalism and a change in the way buildings are monitored during and after completion, it can be employed on a variety of different construction types including new constructions, retrofitting and alterations. Additionally, it can be employed on a wide range of procurement routes.

The purpose was not to duplicate procedures but to complement existing procedures by filling in the gaps. It covers the entire procurement process, starting from the early feasibility and briefing stages through to design, construction and commissioning. It makes a building's performance the key criterion by which to measure the end product. It extends and emphasises the importance of aftercare as a phase that allows occupants to understand a building's features in order to make the most use of them. In turn, this allows designers and builders to observe in-use buildings and implement changes based on that knowledge to improve future projects (Way, 2005; Way and Bordass, 2009). For designers and contractors, the biggest advantage is the knowledge gained through the procurement process, particularly at the final stage of post-handover care. Quite simply, Soft Landings demonstrates that "better feedback improves the product" (Way, 2005).

In addition to providing a way for designers and contractors to gain knowledge from existing buildings to improve future designs, it is also a tool used for energy monitoring, conducting occupant satisfaction surveys and benchmarking (McGowan, 2010).

What remains unclear is the way of monitoring the change in efficiency of a technology between its expected energy usage and actual usage due to occupant behaviour. This will have to be further assessed and developed as post-handover monitoring evolves as a process. Although use of energy efficient technologies and monitoring implementation in the post-handover phase is important, these developments would not occur without regulations and government incentives for developers and homeowners.

2.7 BUILDING PERFORMANCE AND DESIGN

From the initiatives described in the previous section, it is apparent that building performance ranks at the forefront of government policies in the UK. Energy efficient technologies improve the subsequent performance of a building (Dakwale *et al.*, 2011). However, this improved performance can only be achieved if all of those involved in the building process engage early at the design stage and support the development up to and after practical completion. Increasing the use of energy efficient technologies in design will significantly decrease global CO_2 emissions (Levine *et al*., 2012). These decreases can only be accomplished through continued assertive design changes and a comprehensive understanding of the end user and their behaviour. Way (2005) realised that understanding the occupant and supporting the aftercare formed a major part in how the building would finally perform.

Understanding energy consumption by end users can only be achieved by guidance and awareness of behaviour. In the future, existing inefficient technologies will have to be reconsidered and if found to be dated, replaced by more appropriate systems (Dakwale *et al*., 2011). Improving energy efficiency is required to reduce energy demands in buildings. In turn, this efficiency will save natural resources and reduce carbon emissions (Dakwale *et al*., 2011). Carefully designed technologies, tailored to suit specific buildings and uses, will produce long-term gains. Implementing a strategic plan alongside an environmental policy could pave the way forward for actively monitoring energy performance and improving systems from the implementation stage. However, these factors are all reliant upon the end user – the occupant – and their perception and understanding of energy savings.

In order to enable buildings to function efficiently, building designers, structural engineers and other industry members now face further challenges such as intricacy in design and balancing energy performance with production cost. To better enable buildings to run continually at low or no cost, emphasis needs to be placed on additional measures such as solar shading and innovative ventilation systems (Hong *et al*., 2006).

Understanding the relationships between a functional building, sustainability and comfort remains an on-going task. Architects and designers have different opinions on how to rank these variables. Menzies and Wherrett (2005) found that in an office environment, architects place building layout as most important followed by heating and glazing. Akadiri *et al*. (2012) place emphasis on three sustainability objectives in design: resource conservation, cost efficiency and design for human adaptation. Resource and energy conservation is made up of several concepts from the design stages that follow a building through its lifecycle: correct choice in construction material and method, insulating the building envelope, and designing for energy efficient building deconstruction and material recycling.

According to Rogers (2005), using the right design team influences the success of an outcome. Designers need to understand their client's demands but also an end user's needs and ability to understand green technology. The main drivers behind green design modification include awareness of occupants, financial incentives and development in technologies. Meeting government targets and designing in green schemes can satisfy the requirements but maximising the efficiency of a new technology can only be realised if the occupant is cooperative and engaged. Realising this balance is difficult as many end users are resistant to change (Rogers, 2005).

2.8 THE BENEFITS OF DELIVERING GREEN TECHNOLOGIES

The rising costs and burden on the industry to deliver green technologies under the current government policies to uphold and reduce the demand for energy costs has been a discussion by the International Energy Agency in support of the G8 Gleneagles Plan of Action for Climate Change. Making energy efficiency an infrastructure priority is now the most widely supported challenge in the UK with support from the 'Energy Bill Revolution' to warm homes and lower bills.

The opportunity to rethink and reprioritise delivery of the best value investments for renewing the energy system demands the current process to broaden and review policies allowing the most pragmatic solution to deliver long term objectives of greenhouse gas emissions (GHE) reduction. By investing in the renewable energy sector this will in turn reduce our primary demand on existing resources and in the long term reduce CO_2 complying with government targets. Understanding the correct pathway when selecting the correct renewables will require a team that not only understand how the building works but also the type of occupant that will adopt the technology and maximise its potential.

However much discussion is needed in the way of an affordable answer to help consumers manage the impact of rising electricity costs with the momentum to generate savings on energy bills against the rising cost of electricity has put significant pressure on the household.

As occupants are forced to allocate an even bigger proportion of their income to energy bills in residential buildings much investment is needed to improve the out dated building façade, whereby a large proportion of the population are unable to afford to adequately heat their homes. The current focus on electricity ignores the social impact, rising costs of electricity in the UK, this far falls short in addressing fuel poverty issues whereby the energy prices affects the poorest members of society most.

In the UK the Department of Energy and Climate Change (DECC) evaluation of demand response trials targeted at domestic consumers said that clear and definitive benefits could save occupants between 7% - 10% on electricity bills.

However, one of the biggest challenges set out here is how to increase retrofitting of older properties in terms of programmes aimed at driving the uptake of energy efficiency. In this case, the key factor to improve the standard of heat produced in our homes for the UK housing stock needs refurbishment. Improving living standards must not only consider training and how to manage energy usage to reduce household bills but further investigation into disposable income may be useful. (Scholz et al., 2014)

The process of retrofitting can be a complex procedure, in social housing occupants resist change. Understanding new complex systems can be not only confusing but also lead to anxiety for some people. Looking at the private sector occupants that already carry the green baton already are advantaged, they are either interested or committed to the process before it actually starts.

2.9 SUMMARY

The literature review has explored the current practices in government policies, technologies, energy usage and behaviour patterns in occupants.

2.9.1 GAP IN KNOWLEDGE

According to the background literature, there is a gap in our understanding of how the most important fundamental factors will influence the findings of this investigation. As discussed earlier in section 2.3, understanding the type of occupant, gender, age, education and lifestyles could influence these findings.

Building performance ranks at the forefront of government policies in the UK. Energy efficient technologies improve the subsequent performance of a building (Dakwale *et al.*, 2011). However, this improved performance can only be achieved if all of those involved in the building process engage early at the design stage and support the development up to and after practical completion

The problem that needs to be thoroughly investigated is that all occupants have different mannerisms; their perception and understanding of new technologies vary dependent upon their education and social interests.

The important facets studied within this report, include:

1. Government targets
2. Occupants behaviour
3. Buildings
4. Technologies/Energy
5. Aftercare/soft landings

Targets set down by government agencies are seen to be tenable, new technologies are user- friendly and lastly occupants not only are aware of reducing CO_2 emissions but also conversant with the new technologies.

The unanswered question that will be fully investigated within this study is, does 'A Relationship between Post Occupancy Behaviour and Energy Efficiency in Residential Buildings' exist?

Chapter 3

METHODOLOGY

3.1 INTRODUCTION

This chapter provides an outline of the methods used in this thesis to assess the relationship between technologies used and energy efficiency of the buildings as well as occupants' behaviour and energy efficiency of the buildings they live in. Both quantitative and qualitative types of methodologies were employed in this research. The research methods used for data collection and analysis are described in section 3.7 and provide a brief description to support the methods chosen.

3.2 CHARACTERISTICS OF THE RESIDENTIAL BUILDINGS

The project is called 'The Very Smart House' several of the technologies are in their infancy stage and this project will act as a pilot scheme; the population consisted of 41 dwellings. The majority of these properties are owned by Southend Council and managed by SEH. Several properties are privately owned. The retrofit consists of 5 main interventions with several secondary technologies' being incorporated within the design. Occupants from a select area were invited to participate within the project; they were also represented and supported by their occupant local liaison officers. These officers were also residents and took part in the project.

Funding was jointly sponsored between the local authority and the ERDF (European Regional Development Fund) on a 54%- 46% split.

The project commenced in August 2012 after lengthy meetings and negotiations by all the parties to the contract, the project architect providing not only the design but also entered as lead project managers.

The study was based on a mixture of semi-detached houses (BISF-British Iron and Steel Federation) built in the 1950s, semi-detached bungalows, mid terraced bungalows and flats managed by (SEH). The majority of the properties are poorly insulated. The population age and gender of the occupants are mixed.

A further ten BISF properties received similar interventions to C1-C6 & WC1-WC4 but did not form part of the original smart house project, these were managed by SEH and works carried out by N Build, the lead contractor responsible for carrying out the construction works. To increase the sample these properties were included into the research study.

3.3 OUTLINE OF THE RESEARCH METHODS

The objectives of the research are to determine the efficiency of the installations retrofitted in residential buildings and to investigate occupants' behaviour and their perception and understanding of technologies. By achieving these objectives, the relationship between energy efficiency of the buildings, interventions and occupancy behaviour can be considered.

The methodological approach to the present research is a mixture of quantitative and qualitative. The research methods used to obtain data were through questionnaires and interviews.

The energy usage in residential buildings can be influenced by technologies installed but also by behaviour patterns in occupants. Hence, the assessments of energy efficiency was divided into three studies:

i. Technology Study

ii. Occupants Study

iii. Energy Study

Technology study: interviews with SEH and the project architects were carried out to establish the type and nature of the interventions that were chosen. The properties were grouped as per their geographical location and then allocated their set of interventions; each groups lead intervention was unique to that group.

Occupants study: qualitative and quantitative data was collected through questionnaires (appendix 1) and interviews with the occupants within the study of residential buildings. Behaviour was also considered within the context of this research, including needs and benefits. Understanding new technologies, changing habits and levels of expectations were also examined within the study.

The data gave insight into behaviour patterns, perception and understanding of technologies along with the characteristics of the occupants.

Energy study: the energy usage data was collected through questionnaires and energy bills provided by occupants. From the information provided, it was possible assess the occupants' energy usage and examine whether any reductions were evident after the interventions had been installed.

The methods for each study are described in detail in the sections 5.2 and 6.2-6.4

3.4 TECHNOLOGY STUDY I.

One of the biggest challenges was how to increase retrofitting of older properties driving the uptake of energy efficiency. Driven by market demand and government mandate, energy efficient and green technologies were looked into as best suited solutions. An emphasis was been placed on renewable energy systems such as smart monitoring systems, improved insulation, water heaters and efficient light bulbs. The final list of the technologies installed (also called interventions) are listed in the [*Table 5.7 coding of intervention*]. These new energy saving technologies were introduced; the occupants were surveyed to analyse their understanding of the systems. Data from the investigation was analysed to identify if a relationship between occupants behaviour and energy usage (electricity and gas) existed.

Table 3.1 Interventions (cont.) The highlighted interventions were not fully commissioned at the end of the data collection period.

Intervention
Structural Insulation
EWI –Insulation
VIP - Vacuum Insulated panels
PSHC-Passive Solar Heat Collector
Micro-CHP (System was never commissioned)
Ceramic Fuel Cell (System was never commissioned)
ASHP -Air Source heat Pump
SHRV- Single Heat Recovery Ventilation
PCM -Phase Change Material
Passivents
MVHR -Mechanical Ventilation with Heat Recovery
PVHR- Passive ventilation with Heat Recovery (Removed by George)
PV- Photovoltaics
PVT- Photovoltaics Thermal (Never went in at Lorne's)
Thermodynamics
LEDs Lights
VOU Voltage Optimization Units
DC Circuits
Boiler
Solar Panels-Hot water

3.5 OCCUPANTS STUDY

This section will describe the approach used in conducting the research i.e. type of the methods being used to support the methodology.

Data will be collected through Questionnaires

Interviews (Selected residents)

Random Observations

Energy systems analyses

Eco Clinics

3.5.1 QUESTIONNAIRES'-

A longitudinal approach was considered within the design of the questionnaires; the same population was interviewed on several occasions over a given period. Questions were carefully designed, several being of a similar nature placed in different sections to measure consistency of results. Ambiguities' were considered at an early stage by a pilot group, which allowed changes to be made. Two questionnaire methods were considered at inception; self-administered and interviewer administered. Early information derived from the Eco clinics revealed that many occupants preferred verbal explanations rather than form filling exercises Due to these observations it was decided to use 'Interview administered methods' where clear explanation were presented and further information provided regarding any unclear questions.

The following information was considered within the design of the questionnaire.

- User friendly document

- Confidence of population
- Impersonal
- Pilot scheme on colleagues
- Easy to use language
- Discovery of information
- Dissemination of information
- Qualitative and Quantitative data
- Scale of measurement
- Data Collection -Questionnaires

The aim of this section was the collection of data through questionnaires provided by the occupants covering a variety of questions establishing their habits and understanding of new technologies.

Residents were visited and presented with the questionnaire along with a clear explanation; any unclear questions were also discussed. This process was repeated for the second questionnaire where additionally the aftercare section was included.

Occupants from 51 mixed dwellings consisting of a variety of ages and gender above 18 years of age formed the basis of this research project.

Delivery

1st set Questionnaires September /October 2013

2nd set Questionnaires November/January 2014/15

R & WC Properties

1st set Questionnaires December 2014

2nd set Questionnaires July 2015

3.5.2 INTERVIEWS

Interviewing techniques can be traced back for centuries, such techniques used included population monitoring along with various evaluation techniques. The main aim of an interview is a fact-finding expedition, finding information out in a non-intrusive manner. The interview will enable information and corroboration of information gathered elsewhere i.e. by questionnaires to be carefully analysed.

Many different interview techniques are available these can include the following;

Face to face- interviews will consist of the interviewer and the interviewee this technique is not always possible due to the geographical location of the occupants. The advantages to this method include a spontaneous response from the interviewee but also lend itself to designing further questions around the response. Modulation of the voice from interviewer can mislead or prompt the interviewee on their response here. Other benefits can include security for the interviewee, location and the way in which the event is carried out. Disadvantages would include location, distance, availability and health to the interviewer.

3.5.3 ECO CLINICS

At the commencement of the project, a sustainable timber framed building was constructed on site. The construction of the building had two main themes the first for bi monthly site meetings by all the main parties and secondly a place for occupants to meet with professional members of the team to discuss any issues they may have.

The Eco clinic drop in centre was built to create an informal environment where the occupants provided feedback on the retrofitting process, the installation of the new technologies and their use. Staff from the project architects and SEH where available every Wednesday to answer any questions occupants may have had. During the eco clinic drop in sessions, a rapport was built up with all occupants in order to obtain their support with the proposed research.

The Eco Hut was also available throughout the working week for residents' to relax in if construction works were too raucous.

3.6 ENERGY STUDY III

The main aim of this section was to undertake in depth analyses to investigate the new technologies and how the occupants understood them. In addition, consider whether any benefits may have been achieved through their energy usage.

A remote diagnostic system was to be used 'Moixa' which monitors real time energy usage including lighting and electrical components. Unfortunately this system was never fully commissioned during the research period, to compromise this situation the energy usage was calculated on annual basis for the year from information supplied from the occupants and suppliers.

Energy usage data for both gas and electricity was taken before and after the interventions had been fitted 2013 and 2015.This information was documented in excel and used within the SPSS data analysis process. (Ref appendix 4&5)

3.7 DATA ANALYSIS METHODS

3.7.1 GROUNDED THEORY APPROACH.

At the beginning of the project a Grounded Theory was considered within the study, this can be conceived as a qualitative research technique where instead of starting with a theory, the researcher starts with the data and uses the data to generate a theory. Starting with the data first rather than the theory can be considered as a reversed engineered hypothesis. Glaser *et al.(*1967) The theory is not created from analysing research literature, but from systematically analysing the data through both inductive and deductive reasoning.

Data was collected through, Eco clinics, Questionnaires, Interviews and Visual Observations.

The data was analysed using SPSS and excel to investigate whether any relationships between occupants' behaviour to new technology and energy efficiency existed.

This included mixed methods- Quantitative and qualitative analysis:

Statistical analysis e.g. exploratory data analysis, Correlation of variables, factor analysis, association of categorical variables, etc.

3.7.2 DESCRIPTIVE STATISTICS

After selecting, the software (SPSS) to analyse the data it was important not to seek any correlation (or relationship) between the variables, but to analyse, first, the characteristic of each variable. In other words, it is important to identify some tendencies within the data, such as frequency tables and distribution graphs – in this case, to try to identify the distribution type of each variable, which could be normal or not normal. In this section, the process named *'Descriptive Statistics'* is present. The SPSS Software were used to produce any table and graph.

Generally, the following analysis will be considered for suitable variables present in this research:

- Frequency Graphs - Pie Chart and Histograms
- Means, Median, Standard Deviations, Mode, Maximum, Minimum, etc.,
- Box plot

These 'tests' listed above may recognize the type of the variable in regard of its distribution: normal/parametric or no-normal/nonparametric.

This information will be quite useful in the final stage of this research, because it may determinate what correlation's test might be apply between the variables.

Further analyses would also include:

- Hierarchy clustering
- PCA (Principal Component Analyse

Data was analysed using excel and SPSS to investigate past and present energy usage, from this- information was correlated between questionnaires and interviews to investigate if any relationships existed between them.

3.7.3 CLUSTER ANALYSES

Cluster analyses has been chosen in this section as a statistical tool to analyse data into groups, it has the ability to define which groups certain data should belong to. Sharing comparable values clustering is a multivariate procedure that can group rows together that share similar values. Similarities are considered and this forms the basis of which group the information is categorised into, the procedure is very well suited for early exploratory data analyses and allows similar data to be grouped together. Using SPSS, Hierarchical Cluster methods were adopted, a widely used method allowing nominal, and ordinal and scale data to be investigated. This method best suits a small sample.

The first step was to look at all the interventions that were installed within this research project and group them according to the property type they. By changing the amount of clusters being investigated, this affected the grouping characteristics of the data along with the final results. Increasing the amount of clusters changed the grouping matrix and likewise for reducing it, identifying the correct amount of clusters and the characteristics allowed an interpretable solution to be considered.

3.8 DATA PREPARATION

3.8.1 QUESTIONNAIRES' ANALYSIS AND CLASSIFICATION OF THE VARIABLES

The first step within the Project development was to design a new standard layout (sheet) on Excel to present the data collected from the Questionnaires Phase I and II. The Excel sheet designed is attached in the Appendix 03. It contains the description of each dwelling studied during the research with all the relevant information and classifications of each question.

3.8.2 STATISTICS ANALYSIS USING THE SPSS SOFTWARE

After the data's organization on Excel, coding the results to allow software analyses was required i.e. 1 yes and 2 No, or alternatively using a Likert scale 1-10. This can be found in Appendix: table A3 2-4

Finally, each question was coded in SPSS highlighting the variable associated with it, i.e. which category did that question belong to Nominal, Ordinal or Scale.

This can be found in Appendix: table A3.1

Classifying the different variables correctly would avoid inconclusive or incorrect results. The key point of classification and a good understanding of the variables may be seen as choosing the correct statistics method with each variable. It was important to understand that some variables should be studied with some particular methods and any wrong methods applied may result in wrong outputs and conclusion as well. From here, the data was inserted onto the *Variable View* Window with all the relevant information, such as Name, Type, Label, Values and Measure.

Some questions in the Questionnaires may bring multiple options of answers. Therefore, for these questions, considering that the SPSS is able to process only numbers (not names), it was necessary to reference the results with numbers; this is clearly shown in the Appendix table 3.2.-3.4.

3.8.3 PRINCIPLE COMPONENT ANALYSES

PCA has been selected for this research as a tool to investigate and reduce the number variables to a smaller defined set. By rationalizing or reducing the number of variables this identifies a smaller data set identifying the relationship between the variables and allowing the information to be grouped.

The key areas that will form this part of the analyses will include-

- Energy usage
- Motivation
- Energy saving behaviour
- Knowledge of technology's
- Technology installation
- Internet usage
- Technology guides
- Eco clinic

The process used will be further examined and discussed in the Occupancy chapter.

3.9 ETHICS

The research was conducted to strict ethical guidelines set down by the University of East London; all personal information collected remains totally anonymised.

All occupants that filled in questionnaires and attended interviews were informed about confidentiality and anonymity, and that taking part in research is purely voluntary.

Occupants were presented with the following information;-

- Consent Form
- The Interview structure
- Participation Sheet

3.10 SUMMARY

The proposed research will strengthen the understanding of future demands to save fuel and consequently allow us to analyse new techniques to pursue energy efficiency systems. An understanding from not only the Designers and Engineers will be considered but how the occupant understood the technology, whether a relationship between post occupancy behaviour and energy efficiency can be determined.

3.10.1 Contribution to the field of Sustainable Development.

The research will provide a significant contribution to the field of sustainable development where little or brief information is currently known within these areas. Customer needs, expectations and understanding will be investigated within the project.

Future long-term Energy standards in building regulations will need to be enhanced, as changing government targets set out deadlines to not only improve the efficiency of residential buildings but also reduce the carbon footprint. Monahan *et al. (*2011a) states that low energy low carbon affordable homes require an immense understanding.

Chapter 4

QUESTIONNAIRE STUDY

This section will look at the questionnaires, the design of the questions and reflect on some of the responses from occupants that extended beyond the information required within the questionnaires. As discussed in the methodology two questionnaire methods were considered at inception; self-administered and Interviewer administered.

Early information derived from the Eco clinics revealed that many occupants preferred verbal explanations rather than form filling exercises Due to these observations it was decided to use 'Interview administered methods' where clear explanation were presented and further information provided regarding any unclear questions, additional notes were also taken where occupants felt that their concerns needed to be raised.

4.1 INTRODUCTION TO OCCUPANTS

At the commencement of the retrofit project, occupants met with the design team where explanations were provided regarding the retrofit. The occupants were also written to by the housing association explaining that the project would be monitored in terms of energy efficiency and occupants' behaviour. Within the letter there was also details regarding the questionnaire and the research being undertaken along with the researcher's identification (ID Photo).

Occupants signed up to the project on a voluntary basis and were grouped into their property types accordingly.

4.2 PRESENTATION EVENING

A presentation evening was arranged at a local community hall to allow occupants to meet with SBC, SEH, design team, works contractor and technologist to discuss the project. This was well represented by the residents along with some challenging questions to the technologist and local authority. Two resident liaison officers were also present at the meeting and provided several questions on behalf of the residents that were absent to the design team.

4.3 THE QUESTIONNAIRE

The questionnaire comprised of two sections in phase 1 and three sections in phase 2. (Please refer to Appendix 1).

Section 1- Occupants. Twenty-eight questions were designed to cover this section, questions focused on age, gender, type of property, energy usage/ payment methods and internet usage.

Section 2- The installation. Twenty-five questions were designed to cover this section, questions focused on the type of technologies used, monitoring energy usage, government policies and installation.

Section 3- The Aftercare. Twenty-six questions were designed to cover this section; questions focused on temperature settings, comfort and energy suppliers.

Phase 1 of the questionnaires was completed during the commencement of the works; this provided an overview of the occupants' behaviour and habits. Whilst the initial sample comprised of 41 dwellings the process was challenging to make contact in weekdays with them. To overcome these problems the occupants were contacted and suitable appointments were arranged around there schedule. The process was similar for the additional ten properties that would be included later.

Phase 2 was completed approximately one year after the works had commenced an additional section was included here 'The Aftercare'. This section covered mainly comfort and energy usage within this section, several questions were also included being of a similar nature to earlier question used in section one and two. This would allow comparisons to be made regarding the occupants' responses and validity of information provided.

4.4 C Properties

C1 - C7 Semi- Detached Houses. (BISF) British Iron and Steel Federation.

Phase 1

Within this group, seven occupants took part in the study, three of which were retired and over the age of 60. Two of the properties were privately owned and agreed to participate in the project, only external works were carried out on these. Questions and concerns raised within this group outside the scope of the questionnaire included the following points.

- Energy light bulbs were not provided to all rooms to three properties.
- Workman used occupants' electricity and this had not been compensated for.

- A voucher was provided to several occupants to reinstate some flowers that were damaged, occupants were unhappy with the value.
- One occupant was concerned that they had signed up for solar panels but this was omitted from the works.

This phase of the works was set up as rolling programme by the contract administrators, basically moving along property by property carrying out the works on a pair by pair of houses basis. The nature of the works were at their infancy stage and gradually the momentum built up as the works progressed. One family within the group had a child with special needs, extra support and careful logistical planning of the works were undertaken here to minimise any disruption in their daily life's and routine.

Phase 2

In phase two after completion of the works there was more comments made by occupants during and after filling in the questionnaire.

- The scaffolding was up for too long period raising concerns of security.
- Workman used occupants' electricity and this had not been compensated for.
- Hallways were still very cold; several occupants did say an improvement was noted by her though.
- Several occupants stated that they no longer require heating upstairs due to the improvements with one reducing the daily temperature from 25 to 21deg
- Energy light bulbs were still not provided to all rooms to several properties.

Summary

One occupant stated in the questionnaire 1.7 they did not know their monthly energy expenditure but felt a reduction had been obtained but stated in qu. 2.4 that they knew their energy expenditure?

Another occupant commented that they could see improvements in their energy bills but felt the lounge was now colder?

Interesting that one household with a reasonably high-energy usage stated they do not like using the heating.

4.5 L PROPERTIES

Phase 1

L1- L8 Mid-Terraced Houses, ground floor flats (GF) and first floor flats (FF). Brick built with flat roofs.

Within this group eight occupants took part in the study, three of which were retired and over the age of 65, unfortunately only several technologies were used here, Solar panels originally scheduled to be fitted, these were later cancelled due to strengthening of roof works needed to be undertaken which in turn increased the budget. Questions and concerns raised within this group outside the scope of the questionnaire included the following points.

- Several occupants did not fully understand which technologies were being fitted and were not informed regarding the changes.
- One occupant was not aware of the Eco Clinic.

- Noisy fans

Phase 2

- Several occupants stated Moixa system was never commissioned
- The schedule of works could have been clearer.

Summary

One occupant commented that since some double-glazing works had been carried out here energy bills had reduced and the house felt warmer, these improvements however were not part of the works.

4.6 P PROPERTIES

P1- P14 Terraced Bungalows, ground floor flats (GF) and first floor flats (FF) Brick built, pitched roofs.

Phase 1

Within this group, 14 occupants took part in the study; this was reduced to 13 before works commenced as one resident left the scheme. A large proportion of the residents were retired and of mixed ages. Questions and concerns raised within this group outside the scope of the questionnaire included the following points.

- One occupant was concerned that his smart monitoring energy system would cost him more money to run.
- Several occupants didn't really understand anything about the technologies being fitted

- Several rooms on the rear elevation where compromised by the works to the balcony walls and rear passageways reducing light to their kitchens.
- Unclear how energy bills would be paid for.
- The occupants liaison officer provided good support and information to the occupants
- Access to the heating system fitted in the loft was in an occupant flat; this clearly caused concern to him.

Phase 2

- Heat recovery pumps were switched off by several occupants due to the noise and they believed it would save on their energy bills.
- Many occupants raised concerns that the energy monitoring system had not been commissioned.
- Energy bulbs were not complete in one flat.

4.6.1 SUMMARY

This was predominantly a group of residents that were mainly retired through mixed reasons. Several were very worried that the traffic light led system, which was installed to display how much energy was being used was actually costing them money. Subsequently several of them switched the systems off here believing they would reduce energy costs.

One occupant now had to leave the kitchen light on all the time as the balcony glazing system had compromised the natural light entering the kitchen. Scaffolding and the length of time it was up was also a concern for many occupants, some just did not understand which technologies were being fitted and how they worked. Many individual concerns were raised regarding the rear balcony glazing system not working effectively.

4.7 PA PROPERTIES

PA1-PA3 Mid-Terraced and End - Terraced Bungalows.

Within this group 3 occupants took part in the study. All three occupants were retired with mixed ages. Questions and concerns raised within this group outside the scope of the questionnaire included the following points.

Air source heat pumps were fitted to all three, which meant there was little or no gas usage now by all three properties.

Phase 1

- *(No comments available)*

Phase 2

- Some minor making good was incomplete
- Reduction in garden space

4.7.1 SUMMARY

One occupant noted that their combined gas and electricity bill had been reduced. Another occupant noted that the thermostat had been located from the lounge to the hall and subsequently had to be turned up, they also stated they preferred gas. Two occupants stated that the system seemed complicated to them.

4.8 PB PROPERTIES

PB1-PB10 Mid-Terraced and End - Terraced Bungalows.

Within this group, 10 occupants took part in the study. Eight were retired and over the age of 60. Questions and concerns raised within this group outside the scope of the questionnaire included the following points.

Phase 1

- System was complicated to understand
- Gable wall wasn't insulated and there was damp in the bedroom

Phase 2

- One occupant was confused how to use room stat.
- Three commented that the heat recovery fans were not reliable and noisy.
- Wiring problems that never got resolved.
- Energy light bulbs missing

- Bungalow is now warmer.
- Fan turned off at night in bathroom.

4.8.1 Summary

Excessive heating bills was noted by several tenants, housing association reverted to standard boiler system in that set of properties. Occupants were not being compensated for power sold back to the grid correctly. Several occupants raised concerns regarding draughts but these issues did not form part of the works. It was made clear by several occupants that the aftercare needed to be considered further, several technologists had not visited properties after the works were completed to assess the reliability of their product and whether the occupants were getting the most from it

4.9 R & WC Properties

R1-R6 & WC1-WC4 Semi- Detached Houses. (BISF) British Iron and Steel Federation.

These ten properties were included within the study ten months after the completion of the original project; technologies were very similar in nature along with the type of buildings. What did change was the management of the works this was undertaken by ‘N Build’ who were also insulation specialist. They also managed the subcontracting works long with all the associated works on site including the boiler replacement and solar panels.

SEH oversaw the works following a standard form contract and programme of works. Site offices were set up within the close proximity of the works where daily site meeting took place.

Within this group, 10 occupants took part in the study. Two were retired and over the age of 60. Questions and concerns raised within this group outside the scope of the questionnaire included the following points

Phase 1

- Hall is cold all the time.

Phase 2

- Prior to start one occupant was not fully aware of what was happening but during the works he was made fully aware of the project.
- Solar system kept breaking down, difficult to access as switching system was in the loft space
- Hall still remained cold for several residents

4.9.1 Summary

A family of six living within this group of properties felt there was a vast improvement in comfort and a reduction in energy usage. The electricity usage had increased in one property and it became known that the occupants had since purchased several reptile tanks powered by electricity. Several occupants felt that their electricity usage had increased due to the solar panels tripping out in the loft area. Due to access issues to the loft, emersions heaters were switched on to provide hot water. One retired resident felt their energy bills had increased due to health issues and subsequently the heating was on for long periods. The works were completed in approximately three months.

4.10 Eco Clinic

As discussed earlier, the Eco Clinic provided a warm friendly environment where occupants could come and meet the team or spend time in it when works were going on in their properties. Bi monthly meetings were held by the design team and main parties to discuss progress and any issues that had arisen.

Similar issues were brought to the clinic by the resident's, humidistat fans raised many concerns regarding noise and cost to run, several residents, set in their ways refused to accept advice given to them and simply switched them off. A simply activity such as switching the kettle on would automatically switch the fan on once it sensed some kind of humidity change in the room. The older occupants however did appear to raise more concerns here regarding noise, possibly because they were home longer periods and were more conscious about their outgoings. The issue was addressed several times by engineers who patiently reset the fans so they would not react to such a sensitive environment.

Long life energy light bulbs also posed several issue through blowing and becoming dysfunctional. One occupant reported that he had removed the energy light bulbs disposed of them and then replaced bulbs with the existing ones. He had no concept to report the problem or about the cost this had incurred.

What did become evident at these clinics with several occupants was the fact that information discussed with them did not reflect the same view when the questionnaires were filled. Examples here would include- 'How were the works progressing did they have any issues with anything generally', occupant 'A' stated no areas were causing concern here. However, when the questionnaires were compared with these interviews on several occasions the results were different. Occupant 'B' was asked if they were happy with the visits from SEH, their response - very happy. The results in the questionnaire however stated they had not seen them very often. This change in attitude reflects Ferstingers (1957) theory of cognitive dissonance, allowing conflicting believes to impact on the decision making process. Occupants would state one thing at a one to one interview, compromising later accounts; this could be seen, as conflict of their true believes.

Whilst there is no clear, evidence as to why interviews and questionnaires may receive different results it could be perceived that cognitive dissonance effected the decision making process, occupants were more comfortable in providing the correct information for the questionnaire possibly because their identity could be masked.

Chapter 5

ENERGY EFFICIENCY OF THE RESIDENTIAL BUILDINGS IN RELATION TO INTERVENTIONS

This chapter focuses on the types of property's that formed part of this research project, the technology's that were chosen by the design team , SEH and SBC. How the project was funded, managed and completed will also be considered. As in any refurbishment project, it is very important to understand how the building performs, who are the end users and can the technology be fully utilised by the occupant.   This chapter will also address the following aim:-

The aim of the research was to assess new technologies introduced by government agencies in relation to energy efficiency in the sustainable built environment.

The study investigated a mixture of flats, semi-detached bungalows, terraced bungalows all brick built and semi-detached BISF houses built between, 1950-1970. This chapter presents the properties types used within this study, the proposed technologies along with an overview of the installation process. This chapter summarises the results obtained by using cluster analyses to group the properties and technologies together that encountered some form of similarities or relationship between each other.

5.1 The Project

Overview of the 'Very Smart House '

The Project Architects along with SBC secured a match funding from the ERDF (European Regional Development Fund) with a 46 % – 54 % split (46% ERDF, SBC and SEH shared 54%) 1.3million pound.

41 mixed properties originally were selected; this process consisted of choosing a variety of properties owned by (SBC). The consent was obtained through (SEH), (SBC) writing to the occupants, providing a clear explanation about the works, several workshops were also provided to enable a greater understanding of the project.

Five property types formed the basis of the project; managed by (SEH), these consisted of semi-detached houses, terraced houses, flats, bungalows and end terraced properties. The majority of the properties were owned by SBC, several of them however were privately owned. Privately owned property owners were encouraged to buy into the scheme several of these took up the offer and formed part of the project.

Consideration was placed on the type of property chosen, orientation and design; these would be important factors to the project architect, when selecting the appropriate intervention. The existing thermal performance of the buildings chosen would form the basis of the selected technologies in reducing CO_2 emissions and improving thermal comfort. Many of the properties were cold internally due to their age and type of construction. By improving thermal values to the existing buildings, this would not only reduce energy usage but also improve living standards for the occupants.

Occupants from a selected area in the South East were invited to participate in the project; the occupants were represented by liaison officers who were also tenants within the boundaries of the project. This promoted trust and further understanding between the occupants, liaison officer and the local authority.

The project commenced in August 2012, after lengthy meetings and negotiations by all the parties to establish the final conditions, with project architects providing not only the design but also entering as lead project managers.

Technologist companies were invited to tender for works at cost price only, there was also a lead contractor managing the enabling works and overseeing the works by the technology companies. SEH would take a backseat role here only being called upon when required. One of the early problems that presented itself was the fact that because several technologies were so new it was difficult to obtain a spread of quotations, which satisfied the protocol of the local authority.

At the commencement of the project, a sustainable timber framed building was constructed on site (Figure 5.1). The construction of the building had two main aims – firstly for bi-monthly site meetings by all the main parties, these included the project architects, SEH, SBC, lead contractor and technologist, secondly a place for occupants to meet with professional members of the team to discuss any issues they may have. Once the project was completed, the building was moved to another part of the borough where it would be used for a similar purpose.

In figure 5.1 The Eco Clinic used for bi-monthly meetings and occupants enquiries.

(a) (b)

Figure 5.1 The Eco Clinic: sustainable timber frame building for site meetings/ Friendly drop in centre (a) external view (b) internal view.

To create an informal environment the Eco clinic drop in centre was built, allowing occupants to provide feedback on the retrofitting process, the installation of new technologies and how they worked. Staff from the project architects and SEH where available every Wednesday to answer any questions occupants may have had, also any problems regarding installation of the new technologies could be addressed. A rapport was built up during the eco clinic drop in sessions, with all occupants in order to obtain their support with the proposed research.

The clinic was also used for occupants to relax in a quiet environment, if any noisy or dusty work was being carried out in their properties. The clinic benefited by key staff getting to know the occupants and build up a sense of trust and security for them.

All occupants were aware of the ECO Clinic and encouraged to call in; this allowed a first point of contact with the project architects and SBC. The building was located close to the ‘P’ buildings (located on the site plan) several of the tenants took on the added responsibility and were appointed resident liaison officers. This role formed a vital link between tenants and the management organisations to discuss issues or concerns occupants may have had, the liaison officers were also tenants, this allowed a mutual trust to be built upon by all the parties

The property types consisted of:-

C1 - C7 Semi- Detached Houses. (BISF) British Iron and Steel Federation

L1- L8 Mid-Terraced Houses, ground floor flats (GF) and first floor flats (FF). Brick built with flat roofs.

P1- P14 Terraced Bungalows, ground floor flats (GF) and first floor flats (FF) Brick built, pitched roofs.

PA1-PA3 Mid-Terraced and End - Terraced Bungalows.

PB1-PB10 Mid-Terraced and End - Terraced Bungalows.

In figure 5.1a shows the construction format.

Code	Property Types
C1 - C7	Semi- Detached Houses. (BIS) British Iron and Steel
L1 - L8	Mid-Terraced Houses, ground floor flats (GF) and first floor
	flats (FF). Brick built with flat roofs.
P1 - P14	Terraced Bungalows, ground floor flats (GF) and first floor flats (FF) Brick built, pitched roofs.
PA1 - PA3	Mid-Terraced and End - Terraced Bungalows.
PB1-PB10	Mid-Terraced and End - Terraced Bungalows.
R1-R6	Semi- Detached Houses. (BIS) British Iron and Steel
WC1-WC4	

Figure 5.1a Construction format

In early 2015 a further ten BISF properties received similar interventions to C1-C7 but did not form part of the original project, these were managed by SEH and works carried out by N Build, the lead contractor responsible for carrying out the construction works. N Build had previously fitted the SEWI structural external wall insulation and completed the textured finish to the C1-C7 properties so they were fully conversant with the procedures. To increase the sample these properties were included into the research study.

The location of this work was very close to the project so it was decided to include these within the study to strengthen the population being considered within the data analyses.

The properties were duly labelled R1-R6 & WC1-WC4 Semi- Detached Houses. (BISF) British Iron and Steel Federation and are clearly labelled on the site plan *Fig 5.2* below in red and blue.

The site plan below clearly defines the location of all the works; the ECO Clinic was located in between the P buildings.

In Figure 5.2 shows the Site Plan of the project and the close proximity of all the dwellings.

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for confidentiality reasons

Figure 5.2 Location of the properties investigated in this study.

5.1.1 TYPES OF THE INTERVENTIONS

The main aim of this section is to provide an overview of the technologies that were used in the project. Some technical information and data will also be included along with drawings and fitting instructions where required.

5.1.1.1 STRUCTURAL EXTERNAL WALL INSULATION- SEWI

The structural external wall insulation system (figure 5.3) allows existing dated buildings such as BISF properties to be fully externally insulated, improving the thermal insulation and cold bridging at the same time. Further benefits include the external look of the building; additionally the system does not reduce the internal room sizes. The SEWI can readily span between existing structural members.

The SEWI is based on the performance of a unique, two way spanning lightweight prefabricated panel component with a rigid insulation core – the Structural External Wall Insulation panel. These panels are joined together with mesh to provide a rigid continuous envelope around the building with real structural integrity and racking strength.

A substantial layer of basecoat is then applied to the system, which works with the panels to provided large spanning capabilities of up to 3600mm, without secondary support. The final coat comes in a variety of colours and textured finishes; finally, the system also comes with BBA approval.

In figure 5.3 External Wall Insulation used on the BISF properties.

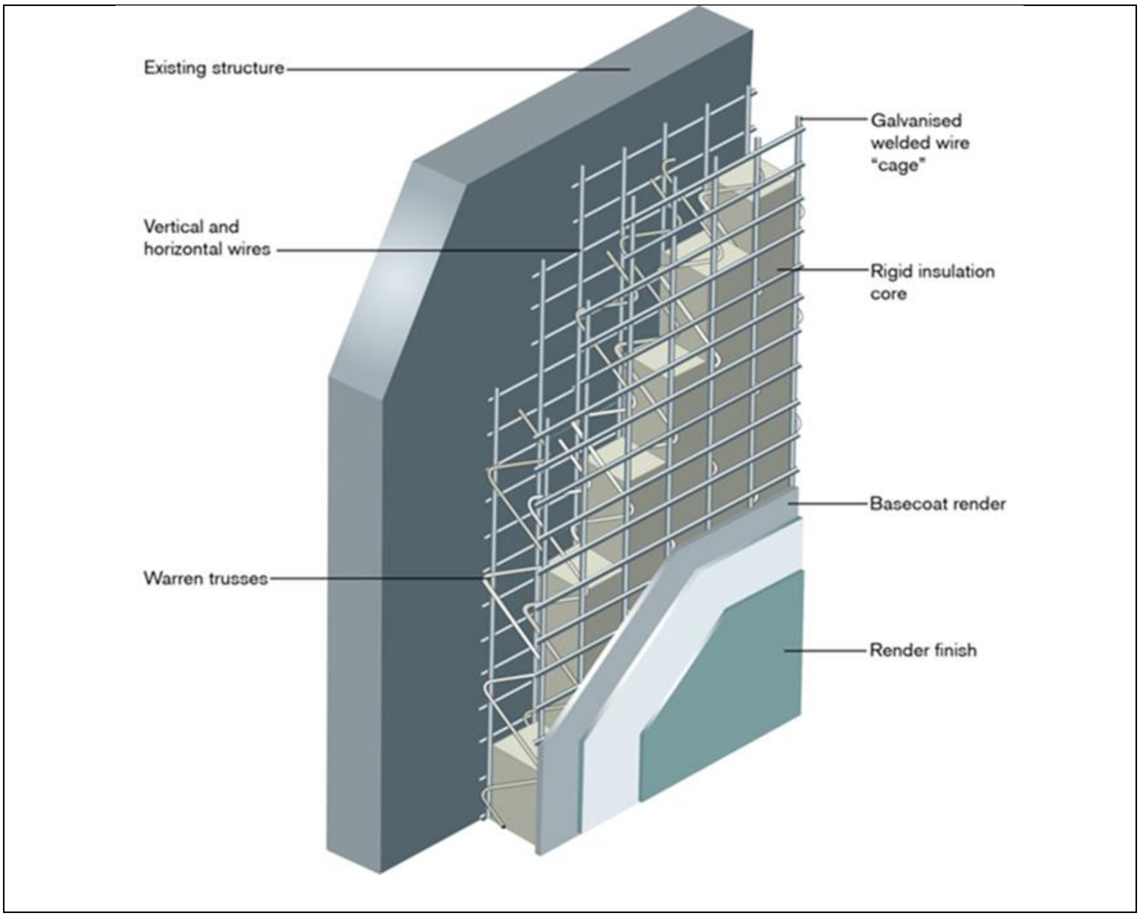

Figure 5.3 Structural external wall insulation.

(Structherm. External Wall Insulation) Technical data sheet.

5.1.1.2 EXTERNAL WALL INSULATION

To successfully refurbish an existing building the substrate must be structurally sound before the insulation board is fixed to it, once this is known the correct proprietary fixing can be used. The insulation boards are fully fixed to the existing wall, (figure 5.4) 5 fixings in a dice pattern prior to the application of the render. The system will significantly improve the thermal values of the buildings as well as reducing CO_2 emissions.

This system uses a thin build up of high polymer modified basecoat render 2-3 mm thick, with glass fibre mesh embedded within it. The finish coat consist of a mortar joint layer coloured and the face layer coloured to suit.

1. The mortar joint is applied 8-10mm thick using a hawk and trowel or projection machine and brought to a uniform level.

2. When the mortar joint layer has begun to stiffen, but before it is dry, the face layer is applied to an average thickness of 5-6mm using a hawk and trowel and immediately textured.

3. A spirit level template and other appropriate devices are used to determine levels and straight edges.

4. After the initial stiffening, the face layer is cut through to revel the mortar joint layer below, using an appropriate cutting tool, creating the effect of brickwork with a recessed mortar joints.

5. If a multi-stock effect is required then Multi-red die is applied to the top coat by brush or sponge.

In Figure 5.4 shows the insulation used on the PA buildings

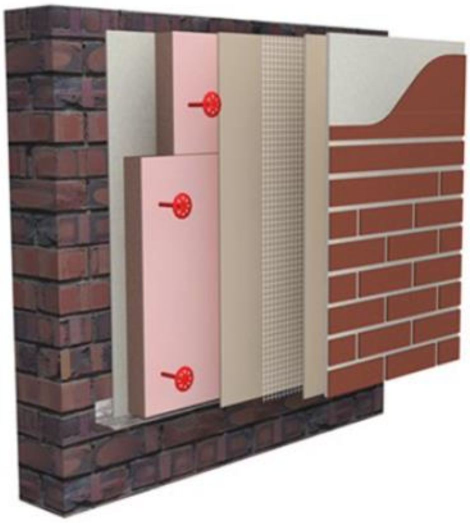

Figure 5.4 External wall insulation structure

5.1.1.3 VACUUM INSULATED PANELS (VIP INSULATION)

Kingspan Insulation-Technical data

Kingspan is a vacuum insulation panel (VIP) It is an optimum performance insulation product, which provides a high level of thermal efficiency with minimum thickness. Ref figure 5.5

- Design (aged & edge effect) thermal conductivity of 0.007 W/m.K
- Provides an insulating performance that is up to five times better than commonly used insulation materials
- High levels of thermal efficiency with minimal thickness
- Vacuum insulation panels are over 90% (by weight) recyclable
- Ideal for constructions where a lack of construction depth or space is an issue
- Available in a range of sizes and thicknesses

- If installed correctly and protected from damage and penetration, can provide reliable long-term thermal performance over the lifetime of the building.

Kingspan OPTIM-R comprises a micro-porous core, which is evacuated, encased, and sealed in a thin, gas-tight envelope, giving outstanding thermal conductivity and the thinnest possible solution to insulation problems. With a design (aged and edge effect) thermal conductivity of 0.007 W/m.K, it provides an insulating performance that is up to five times better than commonly used insulation materials. **Kingspan Insulation-Technical data, nd.**

The insulation panels are placed behind UVPC panels on the project being investigated to improve the heat loss to the building and make it warmer. The panels are thin to enable them to be placed in the empty void located behind the UVPC panels; the panels are located below and above several exterior windows.

Ii Figure 5.5 VIP insulation panels used in the PB buildings.

Figure 5.5 Vacuum insulation panels (VIP).

5.1.1.4 BALCONY ENCLOSURE

The Balco system was fitted to the north elevation, on the ground floor to the P buildings (figure 5.6), the system includes three doors to allow residents access to their back gardens, the remaining panels will be glazed. The system comprises of two sheets of glass, clear glass to the outside with heat absorbing glass internally.

Solar powered fans are fitted internally at ground level, as the column of air in between the pains are heated the fans force the warm air out internally, the opposite occurs in the summer where the warm air is diverted externally. This can be achieved by adjusting a vent under the track.

The existing corridor should now be warmer thus allowing less cold air into the flats when their front doors are opened; to further improve the temperature here a double glazed communal door was fitted to the main front entrance.

In Figure 5.6, the Balco system fitted to enclose the balconies to the P buildings.

Figure 5.6 Balco system.

5.1.1.5 MICRO CHP

Ceramic Fuel Cell Boiler and a Micro CHP were placed in the loft area of P8 – P13 flats to provide heating and hot water to 6 no flats and 2 bungalows. (Figure 5.7)

The Micro CHP boilers have a unique function, which allows them to produce heat and electricity at the same time. The occupants can benefit from discounted/free electricity. It is also possible to sell excess electricity back to the grid. The system works by using existing gases from the boiler to drive internal generators, which in turn produces electricity. Several benefits are provided by the technology, electricity will be produced only when the boiler is producing heat, this invariable will be at peak times allowing electricity to be supplemented by the use of the CHP system.

The Blue Gen Ceramic Fuel Cell boiler has the capacity to convert each KWh of natural gas to 0.6wh of electricity and 0.25KWh of heat (hot water). (Electrical Developments. 2013)

In Figure 5.7 Bluegen boiler fitted to loft area of P8-P13 flats.

(a) (b)

Figure 5.7 Ceramic Fuels cells (a) Bluegen boiler (b) Back up boiler

5.1.1.6 AIR SOURCE HEAT PUMPS

The heat pumps were placed on south facing elevations of the PA properties this allowed them to absorb heat from the air (figure 5.8). Heat captured was then used to power space heating and produce hot water that was stored in cylinders.

Internal radiators were replaced with energy efficient radiators to maximise the efficiency of the system.

The heat from the air is absorbed at low temperature into a fluid. This fluid then passes through a compressor where its temperature is increased, and transfers its higher temperature heat to the heating and hot water circuits of the house. An air-to-water system distributes heat via the wet central heating system. Heat pumps work much more efficiently at a lower temperature than a standard boiler system would. Therefore, they are more suitable for larger radiators, which give out heat at lower temperatures over longer periods.

In Figure 5.8 air source heat pumps were placed on south facing side of the PA properties

Figure 5.8 Air Source Heat Pump.

5.1.1.7 SINGLE HEAT RECOVERY VENTILATION

Single heat recovery units fitted to bathrooms and kitchens (figure 5.9). The automatic census detects condensation or rises in humidity and turns on automatically.

Figure 5.9 Single heat recovery units.

5.1.1.8 PHASE CHANGE MATERIAL

Phase change material (PCM) used to board the ceiling. (figure 5.10) The board material absorbs the heat during the daytime and releases it back at night when the room cools down. The PCM absorbs heat into its solid-state capsules changing it to a liquid state, when the room cools down the heat is released back into the room thus changing the capsule back to its solid state.

Figure 5.10 Phase change material (PCM).

5.1.1.9 Photovoltaic Panels

These panels were placed on the south side of the bungalows to the roof slopes to the PA properties (figure 5.11). These would produce electricity that would assist in powering the air source heat pumps and lighting to the bungalows.

Panels that generate electricity by converting the solar radiation into direct current electricity. The panels can power not only the lighting of the house but also provide the electricity that is needed for the heat pumps to run.

In Figure 5.11 Photovoltaic Panels fitted to the south side of the PA bungalows.

Figure 5.11 Photovoltaic Panels.

5.1.1.10 Thermodynamics

Panels are mounted to the roof (figure 5.12) and produce heat by absorbing energy from the atmosphere. This heat is then converted into hot water that is used for space heating and domestic hot water. Panels that produce heat by absorbing energy from the atmosphere and converting it into 55^0C hot water.

Figure 5.12 Thermodynamics (Smart house technical data, 2013)

5.1.1.11 LEDS-LIGHT EMITTING DIODES

The LED light bulbs are very efficient light bulb with a long life (figure 5.13); the LED is a light source that uses semi-conductors and electroluminescence to create light. The LED uses a small semiconductor crystal with reflectors and other parts to make the light brighter and focused into a single point.

In Figure 5.13 Energy, saving light bulbs fitted to all the buildings.

Figure 5.13 Light emitting diodes (LEDs). (Edison tech centre, 2013)

5.1.1.12 VOLTAGE OPTIMIZATION

Installation of Voltage Optimisation Units (figure 5.14) in order to save energy via the control of the voltage supply to the appliances (set level of 220V). The lifespan of a VPhase unit is 25 years.

Figure 5.14 Voltage Optimisation Unit (Smart house technical data, 2013)

5.1.1.13 DC Circuits

A system that coverts electricity (figure 5.15) from alternating current to direct current.

Figure 5.15 DC Circuits. (Smart house technical data, 2013)

5.1.1.14 Wi Fi Hubs

Installation of a 5 GHz 802.11n Standard hub at St Edmund's Community Center.

5.1.1.15 Smart metering

Installation of a smart metering and monitoring system (figure 5.16), monitoring Gas, Electricity (4 data channels), and Temperature.

In Figure 5.16, smart metering system fitted to all properties.

Figure 5.16 Smart metering and monitoring system (Smart house technical data, 2013).

5.1.2 PROPERTIES AND INTERVENTIONS

In this section, the property types, methods of construction and the technologies that were fitted into them will be discussed.

The majority of the properties within this study are constructed with a brick outer skin and either lightweight blocks or timber framing to the inner skin. The BISF properties consist of a lightweight steel frame with corrugated cladding covering the external facade. The flats in the P property group consist of 225mm solid brickwork Flemish bond. A site location plan will identify the exact location of the property groups and within each group section; illustrations/photos will capture the technology along with some of the installation processes that were observed.

5.1.2.1 PROPERTIES C

BISF British Iron and Steel Federation -History

The interdepartmental committee on housing construction so called Burt committee set up by the government of the United Kingdom was asked in 1944 to identify the most promising non-traditional house construction system that could be used. Formed to address the housing shortage and consider faster build times the committee investigated several new methods of construction. Foursteel walls, (2012).

One of the systems selected was a British Iron and Steel Federation steel framed house designed by architect Sir Frederick Gibberd. The plan was to construct 36,000 three bedroom semi-detached houses in England and Wales.

In 1944 in Northolt, Middlesex 2 prototype houses (A and B) were built. The type ‘A’ frame was constructed from a rolled Steel section with roof trusses of rolled steel or tubular sections and the roof was clad with protected metal sheets on fibreboard insulation.

Prototype B was very similar to the type ‘A’ but a light Steel section were used for the frame and the roof trusses were of the same type of steel. The roof cladding was as in the type ‘A’ house and both of the houses where offered with a different range of cladding. The original roof construction consisted of asbestos cement sheeting.

Although both types were designed only type ‘A’ went into production and the cladding that was mostly used was a render on expanded metal lathe on the ground floor and a steel sheet on the higher level. The external steel cladding is the main feature that identifies BISF. The dwellings where mainly built in pairs of semi-detached two storey terraced houses.

After sixty years, the properties have become tired and worn out, steel sheeting along with structural members required maintenance (figure 5.19) and some form of remedial treatment. Building regulations require buildings that perform efficiently and retain heat. The lack of insulation in these properties leaves them cold which in turn can affect the well-being of residents. As part of the retrofit programme, the seven property locations below (figure 5.17) formed part of the retrofit project. Several interventions were used on these properties (table 5.1) including structural insulation, phase change boarding to the lounge ceilings along with passive vents to the external lounge walls.

In Figure 5.17 Location, plan for the C properties BISF semi-detached houses.

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for confidentiality reasons

Figure 5.17 Properties C1-C7.

In Table 5.1 illustrates the interventions fitted to the C properties.

Table 5.1 Property and technologies installed.

Property	Type	Ownership	Wifi Hubs	DC Circuits	VOU	LEDs	DC LEDs	SHRV	PVT	PCM	Passivents	Structural Insulation
C1	Semi-Detached House	Council	🔴	🔴	🟢	🟢	🔴	🟢	🔴	🟢	🟢	🟢
C2	Semi-Detached House	Council	🟢	🔴	🟢	🟢	🔴	🟢	🔴	🟢	🟢	🟢
C3	Semi-Detached House	Private	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴	🟢
C4	Semi-Detached House	Council	🔴	🔴	🟢	🟢	🔴	🟢	🔴	🟢	🟢	🟢
C5	Semi-Detached House	Council	🔴	🔴	🟢	🟢	🔴	🟢	🔴	🟢	🟢	🟢
C6	Semi-Detached House	Private	🔴	🔴	🟢	🟢	🔴	🟢	🔴	🔴	🔴	🟢
C7	Semi-Detached House	Council	🟢	🟢	🟢	🔴	🟢	🟢	🟢	🟢	🟢	🟢

Key	
Fitted	🟢
Not Fitted	🔴

In Figure 5.18 BISF, C property type prior to any works being carried out.

Figure 5.18 BIS Property.

In Figure 5.19, (a&b) A Structural survey was carried out to inspect all the main supports of the building prior to the insulation. Rendering was carefully removed to expose the main structure frame supports. Some localised remedial works were carried out to the steel column removing any corroded metal and fabricating new sections where required. Once the repair was carried out, the facade was then reinstated.

(a) (b)

Figure 5.19 BISF Property. (a) C3 structural investigation (b) C5 structural investigation and remedial repair work undertaken.

Structherm Insulation The following is based on a performance detailed specification supplied by Structherm. (Insulation)

Overview

This insulation system was specifically designed to help to upgrade non-traditional construction methods. It differs from traditional insulated render system - it does not require support from existing cladding system but spans between existing structural members (timber post, concrete columns or steel columns). It is used where the current cladding is fragile, or could be destroyed by excessive drilling, (fixing the insulation panels). The finished render is between 24, 26mm, and thus helping with flexural rigidity (the resistance presented by a structure while going through bending) and resistance to abrasion.

The insulation improves the performance of the building, by using the existing structural members extends the life of the property allowing residents to stay in their property throughout the works. Different finishes are available along with a range of colours

The system used for refurbishment and thermal upgrading of BISF houses is the clear span fixing method. The structural panels are installed by using primary fixings, which are fixed through the existing cladding panels and into the load bearing metal columns.

Once installed the panels are joined with a rigid mesh which is mechanically clipped together to form a continuous monolithic structural system which stops movement in the walls and ties the property together.

This provides the necessary structural stability in order to resist all dead loads, design live loads, including impact and wind loads, and the capability to accommodate thermal movements. Figure 5.22 shows a C property before and after the works have been carried out.

In Figure 5.20

(a) Scaffolding was erected to carry out the structural insulation works, rendering, replace fascia boards and guttering.

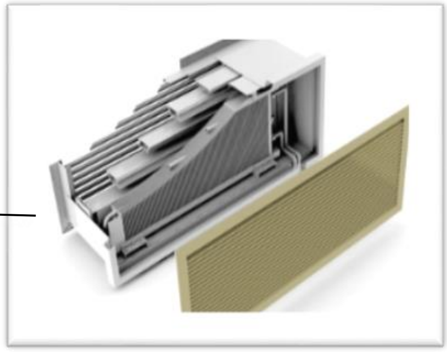
(b) A pair of semi-detached BISF properties fully insulated; the next operation consisted of the rendering coat.

(c) Structural Insulation fitted to the BIS property; note the small squares denotes where insulation has been fixed to the steel sheeting

(d) Passive vent automatic to allow air circulation.

(a) (b)

(c) (d)

Figure 5.20 Works carried out on BIS properties.(a) BIS property with scaffolding erected. (b) Structural insulation fitted to the entire house. (c) Structural insulation fitted to front elevation. (d) Passive vents.

In Figure 5.21

(a) Plastic corner beads where used to form the corner junction prior to the render coat. The plywood protruding from the wall forms the opening for the automatic passive vents. These will allow fresh air to enter the property and reduce overheating in the summer improving the comfort for the occupants.

(a) (b)

Figure 5.21 Works carried out on BIS properties. (a) prior to rendering. (b) rendered coat being applied to gable end 1st storey.

In Figure 5.22, shows C properties before and after the external works have been carried out.

(a) (b)

Figure 5.22 BIS Properties (a) before works (b) after works.

Phase Change Material (PCM)

The material is used as an energy efficient ceiling board; its qualities allow it to absorb the heat during the daytime and releases it back at night when the room cools down. The PCM absorbs heat into its solid-state capsules changing it to a liquid state, when the room cools down the heat is released back into the room thus changing the capsule back to its solid state.

The PCM is coated with several coats of PVA as per manufacturer's specification (figure 5.23). All board joints were tapped and scrimmed prior to plastering similar to standard plaster set ceiling steel trowel finish (figure 5.4 a & b). The system best suits south facing rooms and generally would not be used in bedrooms. On some occasions, the top part of the walls can also receive the PCM.

(a) (b)

Figure 5.23 PCM Phase Change Material- ceiling boards (a) PCM Phase chase material- ceiling boards (b) PVA sealer being applied to PCM.

In Figure 5.24

a) The newly boarded ceiling is prepared; all joints are scrimmed prior to plastering (b) 4mm thick skim plaster finish. (c) The plastered *ceiling is decorated along with the reinstatement of coving. (d) The floor was fully protected whilst all the works was carried out to reduce any damage. The illustration shows the protection removed.*

(a) (b)

(c) (d)

Figure 5.24 (a) Prepared PCM ceiling (b) Plastered ceiling (c) decorated ceiling (d) Existing floor

5.1.2.2 PROPERTIES L

L properties are situated in a cul-de-sac road, (figure 5.25 & 5.26) the properties are cavity brick built (cavity fill not known) approximate year of construction is 1964. The roofs are flat and majority waterproofed by a built up flat roofing system The cul-de-sac properties consists of a mixture of terraced, end-terraced properties with several ground and first floor flats (figure 5.26). Properties owned by the local authority were selected for the project even though some are privately owned. The consideration of the road and flat roofs construction was an ideal choice for solar panels.

Solar panels were originally to be installed into the selected properties within this street. However when the project commenced it was found that structurally the roof could not sustain the additional loads that would be imposed upon the buildings. Several solutions were explored including steel beams being fitted to the roofs spanning across load bearing walls, this however became very expensive and subsequently this part of the scheme was cancelled and the remaining funds spent elsewhere.

Due to the change in the scope of works, only energy efficient bulbs and single heat recovery units were installed to these properties.

In Figure 5.25 Location plan for the L properties.

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for confidentiality reasons

Figure 5.25 Properties L1-L8.

In Table 5.1 illustrates the interventions fitted to the L properties.

Table 5.2 Property type and technologies installed.

Property	Type	Ownership	Wifi Hubs	VOU	LEDs	SHRV
L1	GF Flat	Council	Not Fitted	Fitted	Fitted	Fitted
L2	Mid-Terraced House	Council	Fitted	Fitted	Fitted	Fitted
L3	GF Flat	Council	Not Fitted	Not Fitted	Fitted	Fitted
L4	FF Flat	Council	Not Fitted	Not Fitted	Fitted	Fitted
L5	Mid-Terraced House	Council	Not Fitted	Fitted	Fitted	Fitted
L6	Mid-Terraced House	Council	Fitted	Not Fitted	Fitted	Fitted
L7	Mid-Terraced House	Council	Not Fitted	Not Fitted	Not Fitted	Not Fitted
L8	FF Flat	Council	Not Fitted	Not Fitted	Fitted	Fitted

Key	
Fitted	green
Not Fitted	red

In Figure 5.26 L properties, comprised of a mixture of houses and flats.

Figure 5.26 Properties L1-L8

5.1.2.3 PROPERTIES PA

The PA properties consisted of four bungalows, two end terraced and two mid terraced; only three of the four properties entered into the scheme, the bungalow to the right hand side were omitted (figure 5.27).

The typical construction of these bungalows consisted of external skin brick built wall with cavity (insulation fill) not known. Concrete interlocking tiled roof, uvpc fascia, soffits, and plastic rainwater goods, built between, 1945-1964

All the external walls including the gable were insulated and covered with a 3 coat rendering system, the finish was quite unique as it emulated a face brickwork finish. A choice of colours were made available, the finish product would not require any maintenance (figure 5.28).

Air source heat pumps were installed to all three properties; these were located in the back garden (south facing) to the external walls *(ref figure 5.8 for technical information).* The heat captured would supplement space heating and the hot water system. All the internal radiators were changed to energy efficient radiators to maximise the efficiency of the new system.

The photovoltaic panels were placed on the South facing elevation which created electricity *(ref figure1.11 for technical information),* to supplement the power the air source heat pumps and lighting system,

Similar to the other projects, a ventilation unit with heat recovery was fitted to the bathrooms.

In Figure 5.27 Location plan for the PA properties

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for confidentiality reasons

Figure 5.27 Properties PA1-PA3

In Table 5.3 illustrates the interventions fitted to the PA properties.

Table 5.3 Property type and technologies installed.

Property	Type	Ownership	Wifi Hubs	VOU	LEDs	Air Source Heat Pumps	MVHR	Single Heat Recovery	Photo voltaics	Ex Wall Insulation
PA1	Bungalow	Council	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢
PA2	Bungalow	Council	🔴	🟢	🟢	🟢	🔴	🟢	🟢	🟢
PA3	Bungalow	Council	🔴	🟢	🟢	🟢	🔴	🟢	🟢	🟢

Key	
Fitted	🟢
Not Fitted	🔴

In figure 5.28

(a) Insulation being fitted to the external walls, holes are predrilled into the existing brickwork then special hammer fixings are used to attach the insulation to the brickwork.

(b) Rendered textured finish being applied, tradesmen use a special tool to replicate the brickwork finish here. The air source heat pump has been repositioned temporary to allow the works to proceed and the occupant to retain their heating system.

(c) The completed panel now emulating traditional brickwork. The base coat that prepares the insulation also is coloured to replicate the pointing colour that will stand out in between the brick joints.

(d) The render coat being applied to the insulation on the gable end. Careful consideration is applied to the jointing process and brick sizes to replicate the original structure.

(a) (b)

(c) (d)

Figure 5.28 Rear elevation of property PA (a) EWI (b) Final coat render being applied (c) Completed rendered panels replicating brickwork (d) Gable end finish replicating face brickwork.

In figure 5.29 (a)

A rear view elevation of these bungalows being completed except for the repositioning of the air source heat pump (figure 5.29). The photovoltaic panels were placed on the South facing elevation that created electricity to power the air source heat pumps.

The completed front elevation which includes insulation to the main wall areas, infill insulation to the recessed panels and new fascia and guttering

External Wall insulation with Brick Render Effect.

The external insulation system used on PA properties allowed not only the walls to be insulated to reduce heat loss and safe on energy usage but to replicate the original façade. *(Refer to section 5.1.1.2 for technical information)*

In Figure 5.29 shows, the brick render finish to the EWI, the air source heat pump and photovoltaic panels.

(a)

(b)

Figure 5.29 Completed EWI and rendered finish replicated face brickwork.

5.1.2.4 PROPERTIES PB

The PB properties consisted of 10 bungalows (figure 5.30) these comprised of end terraced and mid terraced properties, built between 1945 -1964.

The typical construction of these bungalows is brick built with cavity, the inside skin however was timber stud, lined with plasterboard, plaster finish. This created a problem for the cavity to be insulated; insulation was originally going to be pumped into the cavity. With this set up, there was a possibility that the internal studwork and plasterboard would not be able to sustain any pressure from this process.

The roof construction consisted of a low elevated pitched roof, weathered by a built up felt roofing system. Access to the loft voids was restricted; this presented several issues along with fixings the panels to the roof.

It was possible to insulate all the infill panels on the bungalows by removing the existing plastic cladding and replacing it after the works had been carried out

In Figure 5.30 Location, plan for the PB properties (bungalows).

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for confidentiality reasons

Figure 5.30 Properties PB1-PB10.

In Table 5.4 illustrates the interventions fitted to the PB properties.

Table 5.4 Property types and technologies installed.

Property	Type	Ownership	Wifi Hubs	VOU	LEDs	Thermo-dynamics	SHRV	Photo-voltaics	Vac Insulated Panels
PB1	Bungalow	Council	🔴	🔴	🔴	🟢	🟢	🟢	🟢
PB2	Bungalow	Council	🔴	🔴	🟢	🟢	🟢	🟢	🟢
PB3	Bungalow	Council	🔴	🔴	🟢	🟢	🟢	🟢	🟢
PB4	Bungalow	Council	🟢	🟢	🟢	🔴	🟢	🔴	🟢
PB5	Bungalow	Council	🔴	🔴	🟢	🔴	🟢	🔴	🟢
PB6	Bungalow	Council	🔴	🔴	🟢	🔴	🟢	🔴	🟢
PB7	Bungalow	Council	🔴	🔴	🟢	🔴	🟢	🔴	🟢
PB8	Bungalow	Council	🔴	🔴	🟢	🔴	🟢	🔴	🟢
PB9	Bungalow	Council	🟢	🔴	🟢	🔴	🟢	🔴	🟢
PB10	Bungalow	Council	🔴	🔴	🟢	🔴	🟢	🔴	🟢

Key	
Fitted	🟢
Not Fitted	🔴

In Figure 5.31 shows the front elevation of the PB properties and illustrates the hard to reach roof areas.

Figure 5.31 Properties PB.

In Figure 5.32 shows mid and end terraced PB bungalows.

(a) (b)

Figure 5.32 View of the terrace block of bungalows. (a) Mid terrace (b) End terrace

The project included 10 brick built bungalows figure (5.31 & 5.32) consisting of one bedroom, lounge, kitchen, bathroom, hallway and external storage cupboard. Thermodynamic panels were mounted to the roof of three of the properties, producing heat by absorbing energy from the atmosphere. This heat is then converted into hot water, which is used for space heating and domestic. *Ref to Figure 5.12 for technical information*

5.1.2.5 PROPERTIES P

P1-P14 buildings consist of two brick buildings with 3 flats per floor in each; at both ends of P8-p13 a one-bedroom bungalow is attached (figure 5.33). The construction of the buildings is typical of the early 50-60s, nine-inch (225mm) solid brickwork and Flemish bond (figure 5.34). Traditional cut and tiled roof with shared balconies to the rear elevation. The north elevation of the buildings incorporates the shared balconies. Due to the cold and low temperatures here, the half-height brick walls were removed and replaced by the Balco system. The ground floor will have three doors within the system allowing residents access to the rear gardens

For a period, these flats and bungalows were allocated to social housing residents over the age of 50 with one of the residents nominated as liaison officer between the residents and property owner.

Procedures have since changed mixing all ages together within these buildings; this included a mix between working and retired occupants living here.

The roof was modified and strengthen to P8-P13 allowing the installation of new CHP boilers to be fitted (figure 5.36), this proved somewhat controversial as the only access to the loft area was through one of the flats (table 5.50. A Velux roof window was additionally installed to the south side of the roof to allow access to the loft area to carry out more extensive works but this never took into account general servicing and maintenance after the works were completed.

The energy usage from the heating system would be subdivided to each of the occupants; this would be achieved by separately monitoring each occupant's usage per flat and sharing the cost accordingly. (By the end of this research project the boiler had yet to be commissioned, the intervention was therefore excluded from the cluster analyses).

In Figure 5.33 Location, plan for the P properties.

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for confidentiality reasons

Figure 5.33 Properties P1-P14.

In Table 5.5 illustrates the interventions fitted to the P properties.

Table 5.5 Property and technologies installed.

Property	Type	Ownership	Wifi Hubs	VOU	LEDs	Balcony Enclosure	Micro CHP	Ceramic fuel Cells	SHRV
P1	GF Flat	Council	Not Fitted	Fitted	Fitted	Fitted	Not Fitted	Not Fitted	Fitted
P2	GF Flat	Council	Not Fitted	Not Fitted	Fitted	Fitted	Not Fitted	Not Fitted	Not Fitted
P3	GF Flat	Council	Not Fitted	Fitted	Fitted	Fitted	Not Fitted	Not Fitted	Fitted
P4	FF Flat	Council	Fitted	Fitted	Fitted	Fitted	Not Fitted	Not Fitted	Fitted
P5	FF Flat	Council							
P6	FF Flat	Council	Not Fitted	Fitted	Fitted	Fitted	Not Fitted	Not Fitted	Fitted
P7	Bungalow	Council	Not Fitted	Not Fitted	Fitted	Not Fitted	Fitted	Fitted	Fitted
P8	GF Flat	Council	Fitted	Fitted	Fitted	Fitted	Fitted	Fitted	Fitted
P9	GF Flat	Council	Not Fitted	Not Fitted	Fitted	Fitted	Fitted	Fitted	Not Fitted
P10	GF Flat	Council	Not Fitted	Fitted	Fitted	Fitted	Fitted	Fitted	Fitted
P11	FF Flat	Council	Not Fitted	Fitted	Fitted	Fitted	Fitted	Fitted	Fitted
P12	FF Flat	Council	Not Fitted	Not Fitted	Fitted	Fitted	Fitted	Fitted	Not Fitted
P13	FF Flat	Council	Not Fitted	Fitted	Fitted	Fitted	Fitted	Fitted	Fitted
P14	Bungalow	Council	Not Fitted	Fitted	Fitted	Not Fitted	Fitted	Fitted	Fitted

Key	
Fitted	● (green)
Not Fitted	● (red)

In Figure 5.34 (a) & (b) shows the building prior to the works being carried out.

(a) Rear Elevation (b) Front Elevation

Figure 5.34 Original balcony (a) rear elevation (b) front elevation.

Balco System installation

The Balco system is fitted to the north elevation, on the ground floor the system includes three doors to allow residents access to their back gardens, the remaining panels will be are glazed with several opening windows. The system comprises of two sheets of glass, clear glass to the external skin with heat absorbing glass internally.

Solar powered fans are fitted internally at ground level, as the column of air in between the pains are heated the fans force the warm air out internally, the opposite occurs in the summer where the warm air is diverted externally. This can be achieved by adjusting a vent under the track.

The existing corridor should now be warmer thus allowing less cold air into the flats when the front doors to the flats are opened; to further improve the temperature here a double glazed communal door was fitted to the main front entrance.

In Figure 5.35

(a) Rear Elevation consisted of three flats/bedsits per floor. Opening were prepared prior to the installation of the Balco system this included fixing brackets secured to the existing brickwork ready to receive the Balco glazing system.

(b) The first floor balcony walls were removed, temporary boarding is secured into the existing opening for pedestrian safety

(c) A crane was located to the south side of the building, the sections were carefully lifted into place in a sequential order

(d) Fitting completed to ground floor, there are three exit doors per block on the ground floor to the rear garden

(a) Rear Elevation, flats/bedsits.

(b) 1st storey balcony walls removed

(c) Lifting Operation

(d) Balco system completed

Figure 5.35 Balco (a) rear elevation flats (b) 1st storey balcony walls removed (c) lifting operation (d) Completed Balco system.

Blue Gen Boiler installation

Ceramic Fuel Cell Boiler and a Micro CHP were placed in the loft area of P8 – P13 flats to provide heating and hot water to 6 no flats and 2 bungalows(figure 5.36*)* . *(Refer to section 5.1.1.5 for technical information).*

In Figure 5.36 the Bluegen boiler and CHP boiler fitted into the loft area in the p properties. The roof has been strengthen to carry the newly imposed loads from the boilers.

(a) (b)

Figure 5.36 Heating system placed in the loft area (a) CHP Boiler (b) Blue Gen Boiler

5.1.2.6 PROPERTIES R AND WC

These properties are similar to C1-C7 properties located in close proximity to the other property's (figure 5.37); they did not form part of the original project even though the insulation system is identical. The works were managed by SEH and carried out by N build approximately 9 months after the original project. Being of a similar nature it was decided to incorporate these ten properties into the research (table 5.6). A structural survey was also undertaken on these properties similar to the C properties, figure 5.38 (b). The project was procured under a standard LA form with normal conditions applied.

In Figure 5.37 Location, plan for the R & WC properties BISF semi-detached houses.

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for confidentiality reasons

Figure 5.37 Properties R1-R6 and WC1-WC4.

In Table 5.6 illustrates the interventions fitted to the R & WC BISF properties.

Table 5.6 Property types and technologies installed.

Property	Type	Ownership	Structural Insulation	Boiler	Thermal
R1	Semi- Detached House	Council	🟢	🔴	🔴
R2	Semi- Detached House	Council	🟢	🟢	🔴
R3	Semi- Detached House	Council	🟢	🔴	🟢
R4	Semi- Detached House	Council	🟢	🟢	🟢
R5	Semi- Detached House	Council	🟢	🔴	🟢
R6	Semi- Detached House	Council	🟢	🔴	🟢
WC1	Semi- Detached House	Council	🟢	🔴	🔴
WC2	Semi- Detached House	Council	🟢	🔴	🟢
WC3	Semi- Detached House	Council	🟢	🟢	🟢
WC4	Semi- Detached House	Council	🟢	🔴	🟢

Key	
Fitted	🟢
Not Fitted	🔴

In Figure 5.38

(a) BISF steel clad property prior to the works being carried out.

(b) Structural survey was carried out to inspect all the main supports of the building prior to the insulation similar to C1-C7 properties. Rendering was carefully removed to expose the main structure frame supports. Localised repairs were undertaken where required under the supervision of a Structural Engineer.

(c) Structural Insulation fitted to a BISF property; note the small squares that can be seen denote where the insulation has been secured to the steel sheeting. The insulation is then replaced.

(d) Two coats of render are applied by pump to the structural insulation as per the manufacturer's instructions.

(e) The first storey of the house is cladded with UVPC. The ground floor has a maintenance free coloured render applied. Facie and soffits are replaced with UVPC including gutters and downpipes. A small GRP canopy was fitted over the front doors.

(f) Completed works

(a) BIS property prior to the works being commenced

(b) Steel columns exposed

(c) Structural insulation fitted

(d) Rendering system applied

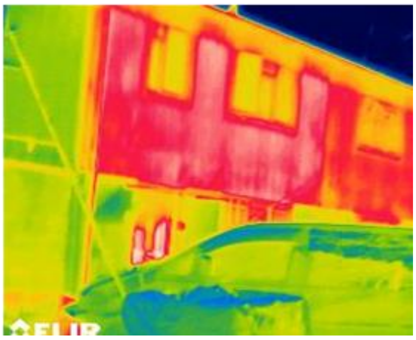
(e) UVPC cladding to the first floor

(f) Completed works

Figure 5.38 Works carried out on BIS properties (a) BIS properties prior to commencement of works (b) steel columns exposed (c) Structural insulation being fitted (d) Rendering system being applied (e) UVPC cladding to first floor (f) Completed works

5.1.2.7 THERMAL IMAGING

In figure 5.39, Thermal imaging prior to the insulation being fitted, the heat loss can be clearly seen from the red areas.

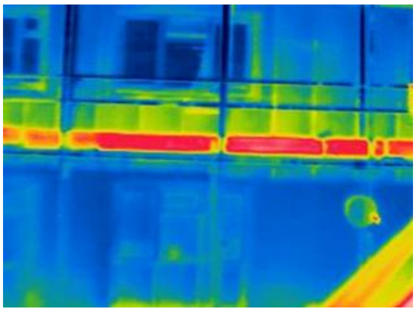


(a) Front elevation

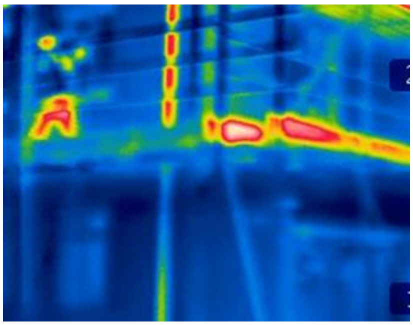
(b) Gable end elevation

Figure 5.39 Thermal imaging to BIS Properties R and Wc prior to the insulation being fitted.

In figure 5.40, Thermal imaging after the insulation has was fitted showing a considerable reduction in heat loss to the BIS properties.



(a) Front Elevation



(b) Gable end

Figure 5.40 Thermal imaging to BIS Properties R and Wc after the insulation being fitted.

5.2 DATA ANALYSES

It was decided to analyse the data obtained from the interventions that were fitted within this study in this section. This would allow the uninterrupted flow of information from the installation process through to the data sets that would be constructed.

5.2.1 CLUSTER ANALYSES

Cluster analyses was chosen in this section as a statistical tool to analyse data into groups, it has the ability to define which groups certain data should belong to. Sharing comparable values clustering is a multivariate procedure that can group information together that share similar values. Similarities are considered and this forms the basis of which group the information is categorised into, the procedure is very well suited for early exploratory data analyses and allows similar data to be grouped together. Using SPSS, Hierarchy Cluster methods were adopted, a widely used method allowing nominal, ordinal and scale data to be investigated. This method best suits a small sample.

The first step, was to look at all the interventions that were installed within this research project and group them according to the property types.

Increasing the amount of clusters changed the grouping matrix and likewise for reducing it, identifying the correct amount of clusters and the characteristics allowed an interpretable solution to be considered.

5.3 OVERVIEW OF THE DATA

5.3.1 INTERVENTION DATA

The interventions were programmed into SPSS Hierarchical cluster, 4-7 cluster options were considered. Wards method was used for each cluster this determined the means for all the variables; this was followed by the Squared Euclidean distance calculating the cluster means.

In table 5.7 identifies the interventions that were commissioned within this investigation.

Table 5.7 Coding of Interventions

Intervention	Assigned Code
Structural Insulation	1
EWI –Insulation	2
VIP - Vacuum Insulated panels	3
PSHC-Passive Solar Heat Collector (Balco system)	4
ASHP -Air Source heat Pump	5
SHRV- Single Heat Recovery Ventilation	6
PCM -Phase Change Material	7
Passivents	8
MVHR -Mechanical Ventilation with Heat Recovery	9
PV- Photovoltaics	10
Thermodynamics	11
LEDs Lights	12
VOU Voltage Optimization Units	13
DC Circuits	14
Boiler	15
Solar Panels-Hot water	16

5.3.2 ENERGY EFFICIENCY DATA

Energy data was collected from each individual household from structured questionnaires. The first round of questionnaires in 2013 collected the energy data along with other information. Occupants paid for their energy by various means these included pre-payment cards, monthly and quarterly payments. The moixa real life data system formed part of the smart technologies; this would also provide further controlled data relating to the energy usage. The moixa real life data system would have the capacity to monitor electrical circuits individually identifying energy usage for technology's occupying those circuits this for example this could be the LED lights.

Several residents were reluctant about revealing data even though clear explanations were provided regarding the privacy of the information and the benefits it would provide allowing the efficiency of the interventions to be examined.

In 2015 approximately one year after the technology had been fitted a second round of questionnaire's were carried out this would also include the collection of energy usage data from the occupants. The questionnaires also considered the aftercare.

At the time of analysing the energy data the smart energy system was not commissioned, this had a significance effect on the data analyses process, energy usage was only known in each property grouped with their associated technologies. Taking this into account cluster analyses would suit this type of situation, grouping properties not necessarily by their property types but by the interventions and relationship.

5.4 RESULTS- HIERARCHY CLUSTERING

5.4.1 HIERARCHY CLUSTER ANALYSES

The following section presents the results from the hierarchy cluster analyses; the dendrogram identifies the size of the groups within the number of cluster selected for the investigation. The dendrogram is a tree like diagram that shows how groups of information are related by grouping the data. The cluster groups will identify the property types and their relationship to the technology's fitted, table 1.7 explains the coding of the interventions signposted on the cluster charts, also 1 denotes that the technology were installed into the property types and 2 that they were not. An explanation will be provided within each cluster group regarding their grouping characteristics. To determine the nature of the data distribution exploratory data analyses was carried out. The summary statistics and boxplots for the energy usage for both gas and electric are presented in *tables 5.15 & 5.17 and figures 5.42 & 5.43.*

5.4.2 CLUSTERING OF THE PROPERTIES

The dendrogram in figure 5.41 represents 4-7 cluster groups, as the number of clusters increases so does the amount of groups. The groups finally fragment displaying little or no relationship.

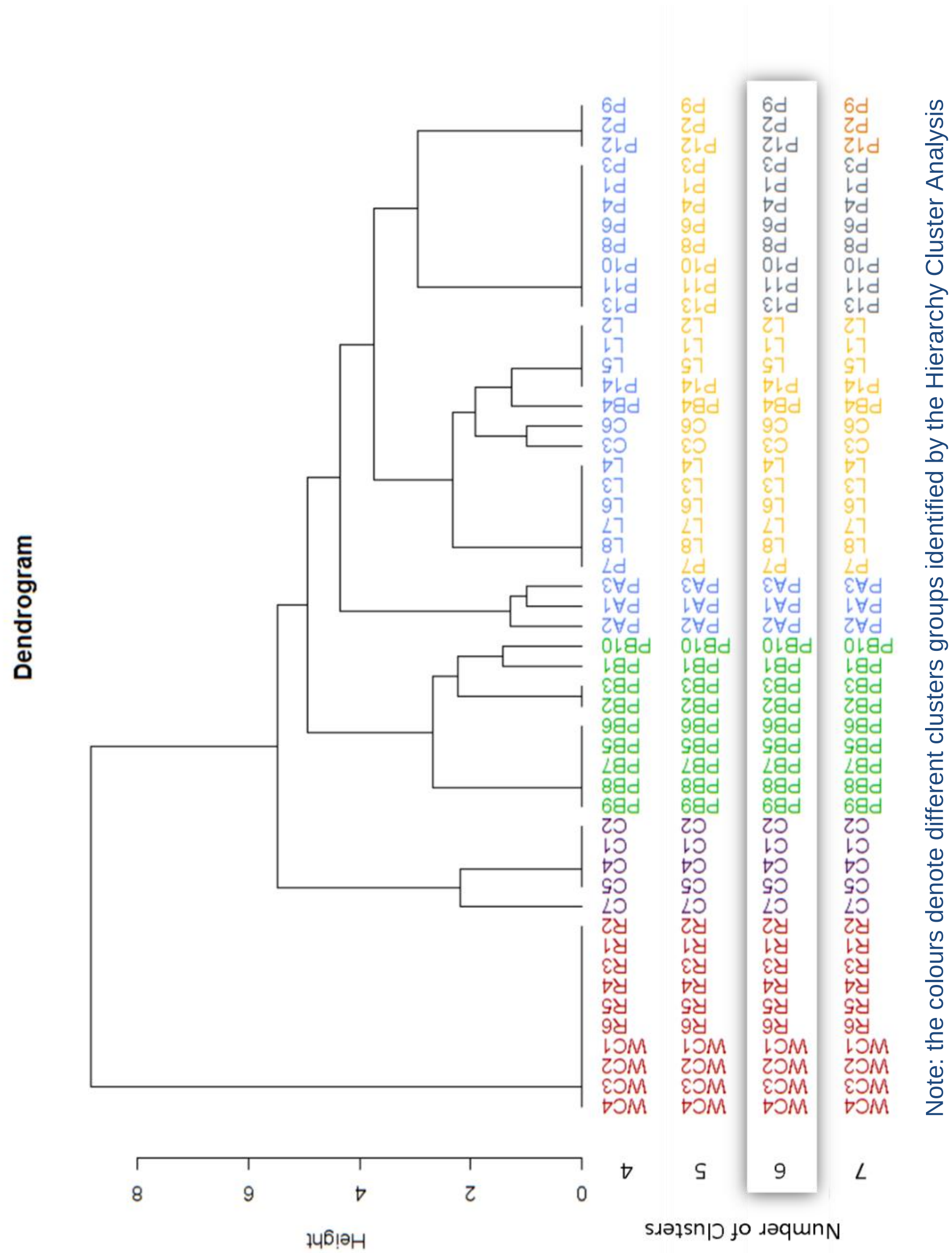


Figure 5.41 Dendrogram

Seven clusters were considered within the analyses of the data to obtain a good overall range of information; from the information, produced groupings were observed carefully to determine where similarities and relationships might be evident.

The dendrogram typically shows 4-7 clusters, predicting the size of the clusters, which would be very difficult without the use of the software. Four clusters were very predictive, groupings of property types in groups 1 and 4 revealed that interventions clustered where almost common to the property types.

When further clusters are added the groups become smaller, what is interesting is that the properties in-group 6 (table 5.13) are all matched to the same location and property type.

Careful analyses of all the clusters 4-7 identify that cluster 6 were the strongest cluster set. The alignment of interventions to groups in cluster 6 was strong and almost continuous in several groups. Clusters 4 & 5 have several large mixed property groups; cluster 7 splits ‘P’ property types further.

5.4.2.1 6 CLUSTERS

To simplify the overview of this section groups within the 6 cluster analyses are referred to as groups and not clusters. Tables 5.8 - 5.14 show the technologies that have been installed in the properties. Each table includes the properties that belong to the cluster set and are classified by ‘1’ the technology has been installed and ‘2’ the technology has not.

Properties in Group 1 are characterised by structural insulation, single heat recovery ventilation, phase change material, passive vents, LEDs and voltage optimization units. Properties in Group 2 are characterised by single heat recovery ventilation and LEDs. Properties in Group 3 are characterised by passive solar heat collectors and LEDs. Properties in Group 4 are characterised by external wall insulation, air source heat pump, Photovoltaics, LEDs and voltage optimisation units. Group 5 are characterised by Vacuum insulated panels & single heat recovery units. Group 6 are characterised by Structural insulation, Boilers and Solar panels.

In Tables 5.8 – 5.13 identify the six clusters with the associated property groups.

Table 5.8 Group 1 –cluster set

	Group 1		Interventions															
No	Cluster	Property	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1	C1	1	2	2	2	2	1	1	1	2	2	2	1	1	2	2	2
2	1	C2	1	2	2	2	2	1	1	1	2	2	2	1	1	2	2	2
4	1	C4	1	2	2	2	2	1	1	1	2	2	2	1	1	2	2	2
5	1	C5	1	2	2	2	2	1	1	1	2	2	2	1	1	2	2	2
7	1	C7	1	2	2	2	2	1	1	1	2	1	2	2	1	1	2	2

Table 5.9 Group 2 –cluster set

	Group 2		Interventions															
No	Cluster	Property	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
3	2	C3	1	2	2	2	2	1	2	2	2	2	2	1	2	2	2	2
6	2	C6	1	2	2	2	2	1	2	2	2	2	2	1	1	2	2	2
8	2	L1	2	2	2	2	2	1	2	2	2	2	2	1	1	2	2	2
9	2	L2	2	2	2	2	2	1	2	2	2	2	2	1	1	2	2	2
10	2	L3	2	2	2	2	2	1	2	2	2	2	2	1	2	2	2	2
11	2	L4	2	2	2	2	2	1	2	2	2	2	2	1	2	2	2	2
12	2	L5	2	2	2	2	2	1	2	2	2	2	2	1	1	2	2	2
13	2	L6	2	2	2	2	2	1	2	2	2	2	2	1	2	2	2	2
14	2	L7	2	2	2	2	2	1	2	2	2	2	2	1	2	2	2	2
15	2	L8	2	2	2	2	2	1	2	2	2	2	2	1	2	2	2	2
21	2	P7	2	2	2	2	2	1	2	2	2	2	2	1	2	2	2	2
28	2	P14	2	2	2	2	2	1	2	2	2	2	2	1	1	2	2	2
35	2	PB4	2	2	1	2	2	1	2	2	2	2	2	1	1	2	2	2

Table 5.10 Group 3 –cluster set

	Group 3		**Interventions**															
No	Cluster	Property	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
16	3	P1	2	2	2	1	2	1	2	2	2	2	2	1	1	2	2	2
17	3	P2	2	2	2	1	2	2	2	2	2	2	2	1	2	2	2	2
18	3	P3	2	2	2	1	2	1	2	2	2	2	2	1	1	2	2	2
19	3	P4	2	2	2	1	2	1	2	2	2	2	2	1	1	2	2	2
20	3	P6	2	2	2	1	2	1	2	2	2	2	2	1	1	2	2	2
22	3	P8	2	2	2	1	2	1	2	2	2	2	2	1	1	2	2	2
23	3	P9	2	2	2	1	2	2	2	2	2	2	2	1	2	2	2	2
24	3	P10	2	2	2	1	2	1	2	2	2	2	2	1	1	2	2	2
25	3	P11	2	2	2	1	2	1	2	2	2	2	2	1	1	2	2	2
26	3	P12	2	2	2	1	2	2	2	2	2	2	2	1	2	2	2	2
27	3	P13	2	2	2	1	2	1	2	2	2	2	2	1	1	2	2	2

Table 5.11 Group 4 –cluster set

	Group 4		**Interventions**															
No	Cluster	Property	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
29	4	PA1	2	1	2	2	1	1	2	2	1	1	2	1	1	2	2	2
30	4	PA2	2	1	2	2	1	2	2	2	2	1	2	1	1	2	2	2
31	4	PA3	2	1	2	2	1	1	2	2	2	1	2	1	1	2	2	2

Table 5.12 Group 5 –cluster set

	Group 5		**Interventions**															
No	Cluster	Property	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
32	5	PB1	2	2	1	2	2	1	2	2	2	1	1	2	2	1	2	2
33	5	PB2	2	2	1	2	2	1	2	2	2	1	1	1	2	2	2	2
34	5	PB3	2	2	1	2	2	1	2	2	2	1	1	1	2	2	2	2
36	5	PB5	2	2	1	2	2	1	2	2	2	2	2	1	2	2	2	2
37	5	PB6	2	2	1	2	2	1	2	2	2	2	2	1	2	2	2	2
38	5	PB7	2	2	1	2	2	1	2	2	2	2	2	1	2	2	2	2
39	5	PB8	2	2	1	2	2	1	2	2	2	2	2	1	2	2	2	2
40	5	PB9	2	2	1	2	2	1	2	2	2	2	2	1	2	2	2	2
41	5	PB10	2	2	1	2	2	1	2	2	2	2	2	2	2	1	2	2

Table 5.13 Group 6 –cluster set

	Group 6		**Interventions**															
No	Cluster	Property	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
42	6	R1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1
43	6	R2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1
44	6	R3	1	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1
45	6	R4	1	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1
46	6	R5	1	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1
47	6	R6	1	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1
48	6	WC1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1
49	6	WC2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1
50	6	WC3	1	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1
51	6	WC4	1	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1

5.4.3 ENERGY EFFICIENCY IN RELATION TO TYPE OF INTERVENTION

It was assumed that the variations in the smart technologies introduced in the residential buildings would have an effect on their energy efficiency. Based on this assumption, the following null hypothesis was generated: **there is *no significant difference* in energy efficiency (the difference in gas and electricity consumption) between the residential buildings with different technologies** represented by Clusters (section 5.4.1).

The hypothesis was tested using non-parametric Dunn's Kruskal-Wallis multiple comparison test with Bonferroni correction. The results of the test are presented in *Table 5.15 & Table 5.17.*

5.4.3.1 COMPARISON OF GAS USAGE- 2013 AND 2015 [TECHNOLOGIES]

Table 5.14 Summary statistics showing the difference in gas usage between 2013 and 2015 data for residential buildings clusters.

Summary Statistics, Difference in Gas usage							
Cluster		1	2	3	4	5	6
N		3	13	11	1	9	9
N missing		2	0	0	2	0	1
Mean		20.87	11.58	-23.58	-	-12.27	21.26
Median		13.41	4.76	4.76	-	4.76	23.07
Std. Deviation		20.87	15.71	65.58	-	29.02	13.82
Percentiles	4.76	-51.91	-4.05	-153.76	-	4.76	-17.91
	9.09	-9.41	4.76	-8.46	-	8.95	5.81
	13.41	9.09	4.76	4.76	-	23.07	19.20
	28.93	21.17	22.39	4.76	-	31.21	29.36
	44.44	44.44	52.36	36.49	-	41.38	41.38
Shapiro-Wilk normality test p-value		0.400	0.004	<0.001	-	0.001	0.430

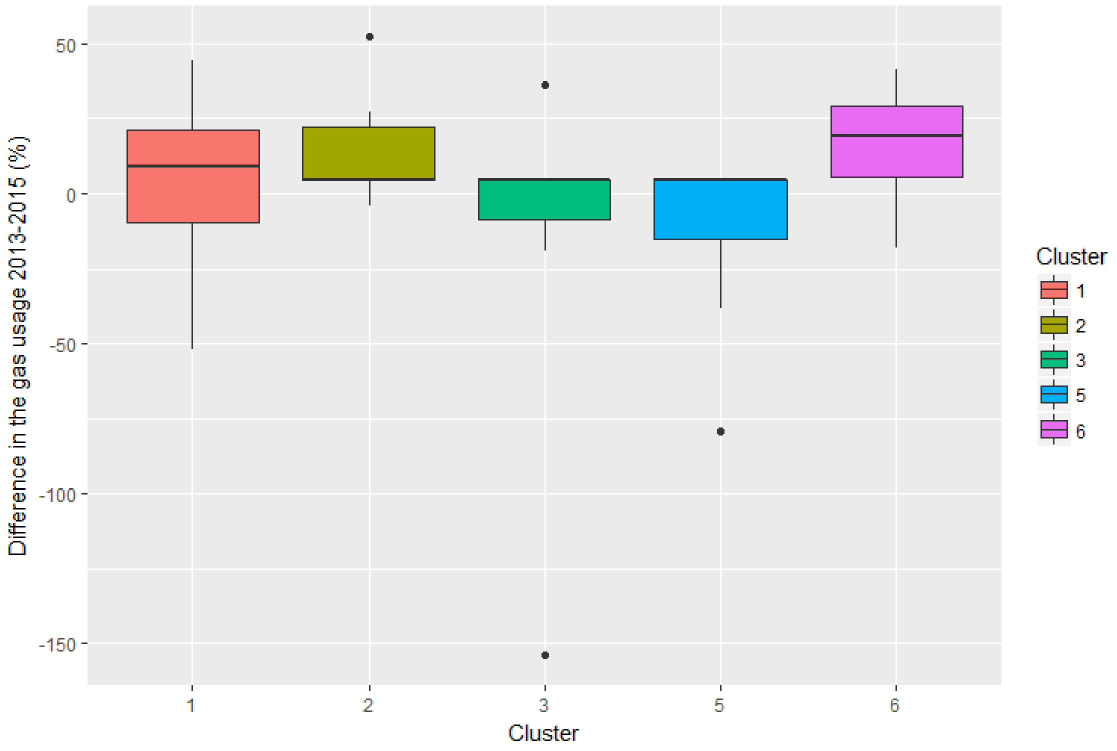


Figure 5.42 Distribution of difference in gas usage between 2013 and 2015 data for residential buildings clusters.

In table, 5.15 P-values from Dunn's Kruskal-Wallis multiple comparison test for gas 2013-15 results with Bonferroni correction applied for each combination of residential building clusters. Highlighted numbers demonstrate a statistically significant difference between plots. Italicised numbers show a statistically significant difference between plots based on uncorrected p-value.

Table 5.15 P-values from Dunn's Kruskal-Wallis multiple comparison test for gas 2013-15

Dunn's Kruskal-Wallis multiple comparison test – Gas usage						
Cluster	**1**	**2**	**3**	**4**	**5**	**6**
1	-	1.000	0.540	-	0.274 / 0.027*	1.000
2		-	1.000	-	0.800	0.583
3			-	-	1.000	0.023
4				-	-	-
5					-	0.008
6						-

* Uncorrected p-value

Null hypothesis of no statistically significant difference rejected

The Shapiro-Wilk normality test (table 5.14) p-value indicate that group 2 [0.004], 3 [<0.001] & 5 [0.001] are not normally distributed supporting the results from the boxplots in fig 5.42. (Pn. group 4 had no gas, only electricity)

The results of the boxplots in Figure 5.42 and summary statistics in Table 5.14 and 5.15 indicate that there is a *significant difference energy usage* for gas between clusters 1&5 [0.027], 3&6 [0.023] and 5&6 [0.008].

ANALYSES OF DATA – GAS

Difference between cluster/group 1 & 5

The properties in Group 1 are characterised by structural insulation, single heat recovery ventilation, phase change material, passive vents, LEDs and voltage optimization units whereas the properties in Group 5 are characterised by Vacuum insulated panels & single heat recovery units.

There was a significant difference in gas usage between cluster 1 & 5, cluster 1 obtaining the higher energy reduction, these consisted C type properties and were characterised six technologies including structural insulation. However, results for cluster 5 showed an increase in energy usage. Common features to these properties included VIP insulation, this was only carried out on vulnerable areas and subsequently with the single heat recovery, no energy reduction was noted.

Difference between cluster/group 3 & 6

The properties in Group 3 are characterised by passive solar heat collectors and LEDs, whereas the properties in Group 6 are characterised by Structural insulation, Boilers and Solar panels.

There was a significant difference in gas usage between cluster 3 & 6, cluster 6 obtaining the higher energy reduction, these consisted R & WC type properties and were characterised three technologies including structural insulation. However, results for cluster 3 showed an increase in energy usage, the properties were consisted of bedsits, flats and several attached bungalows and were characterised by passive solar heat collectors. Occupants never really understood how this system functioned several visual observation noted windows being left open on cold days allowing heat loss to the common areas. Additionally the Blue Gen Boiler was not fully commissioned at the time of collecting the data.

Difference between cluster/group 5 & 6

The properties in Group 5 are characterised by Vacuum insulated panels & single heat recovery units whereas the properties in Group 6 are characterised by Structural insulation, Boilers and Solar panels.

There was a significant difference in gas usage between cluster 5 & 6, cluster 6 obtaining the higher energy reduction, these consisted R & WC type properties and were characterised three technologies including structural insulation. However, results for cluster 5 showed an increase in energy usage, common features to these properties included VIP insulation this was only carried out on vulnerable areas, several cavities were hard to insulate due to their accessibility and method of construction. Additionally several occupants thought that the single heat recovery units came with a cost to run.

5.4.3.2 COMPARISON OF ELECTRICITY USAGE 2013-15 [TECHNOLOGIES]

In Table 5.16 shows the summary statistics of the difference in electricity usage between 2013 and 2015 data for residential buildings clusters. The Shapiro-Wilk normality test p-value will indicate whether the groups are normally distributed supporting results from the boxplots in figure 5.43.

Table 5.16 Summary statistics of difference in electricity usage between 2013 and 2015 data for residential buildings clusters.

Summary Statistics, Difference in electricity usage							
Cluster		**1**	**2**	**3**	**4**	**5**	**6**
N		4	13	11	2	9	10
N missing		1	0	0	1	0	0
Mean		23.58	-8.28	-5.28	9.27	-8.89	-9.74
Median		15.11	-4.39	4.76	9.27	4.76	-5.38
Std. Deviation		25.76	16.79	18.42	71.30	50.59	31.99
Percentiles	Min.	4.76	-50.72	-39.64	-41.15	-84.79	-54.73
	25	4.76	-16.87	-10.31	-15.94	-58.65	-23.27
	50	15.11	-4.39	4.76	9.27	4.76	-5.38
	75	33.93	4.76	4.76	34.48	17.63	3.63
	Max.	59.35	14.5	12.08	59.69	70.68	54.36
Shapiro-Wilk normality test p-value		0.203	0.133	0.001	-	0.377	0.453

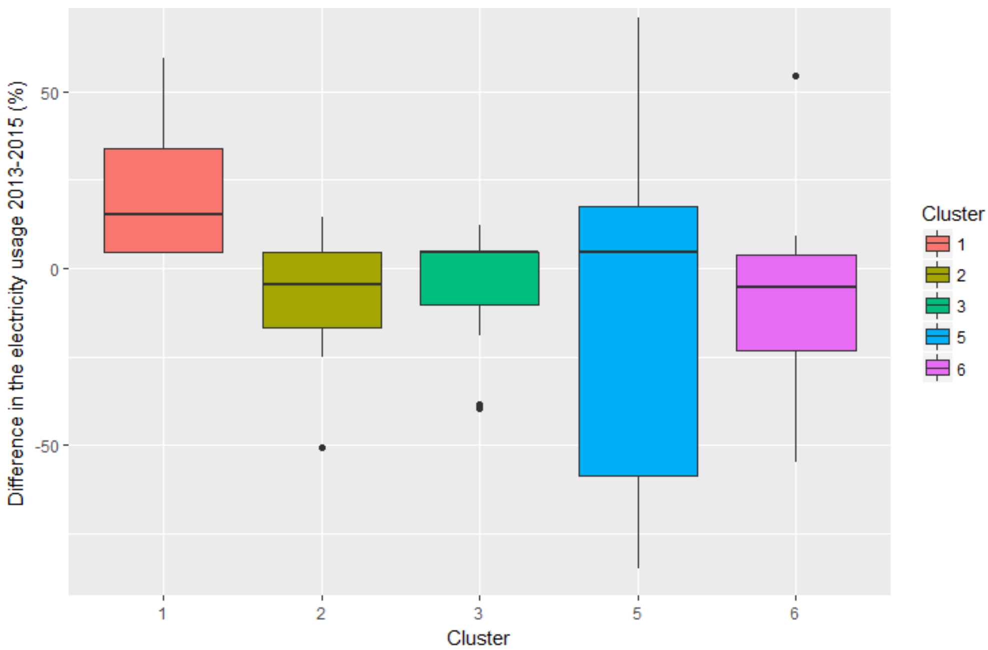


Figure 5.43 Distribution of difference in electricity usage between 2013 and 2015 data for residential buildings clusters.

In table 5.17 P-values from Dunn's Kruskal-Wallis, multiple comparison test for electric 2013-5 results with Bonferroni correction applied for each combination of residential building clusters. Highlighted numbers demonstrate a statistically significant difference between plots. Italicised numbers show a statistically significant difference between plots based on uncorrected p-value.

Table 5.17 P-values from Dunn's Kruskal-Wallis multiple comparison test for electric 2013-15

Dunn's Kruskal-Wallis multiple comparison test – Electricity usage						
Cluster	**1**	**2**	**3**	**4**	**5**	**6**
1	-	*0.250 / 0.025**	1.000	-	1.000	*0.297 / 0.030**
2		-	1.000	-	1.000	1.000
3			-	-	1.000	1.000
4				-	-	-
5					-	1.000
6						-

* Uncorrected p-value

Null hypothesis of no statistically significant difference rejected

The Shapiro-Wilk normality test p-value (table 5.16) indicate that group 3 [0.001] is not normally distributed supporting the results from the boxplots in fig 5.43.

The results of the boxplots in Figure 5.43 and summary statistics in Table 5.16 and 5.17 indicate that there is a *significant difference in energy usage* for electricity between clusters 1&2 [0.025] and 1&6 [0.030].

ANALYSES OF DATA ELECTRICITY

Difference between cluster/group 1 and 2

The properties in Group 1 are characterised by structural insulation, single heat recovery ventilation, phase change material, passive vents, LEDs and voltage optimization units, whereas the properties in Group 2 are characterised by single heat recovery ventilation and LEDs

There was a significant difference in electricity usage between cluster 1 & 2, cluster 1 obtaining the higher energy reduction, these consisted of ‘C’ type properties and were characterised six technologies including structural insulation. However, results for cluster 2 showed an increase in energy usage, common features to these properties included single heat recovery units. Cluster 2 where predominately L properties where only several interventions were fitted, the most common being single heat recovery unit. Whilst this may be seen to improve the occupant’s well-being and reduce condensation there may have been a cost to run this system.

Difference between cluster/group 1 and 6

The properties in Group 1 are characterised by structural insulation, single heat recovery ventilation, phase change material, passive vents, LEDs and voltage optimization units, whereas the properties in Group 6 are characterised by Structural insulation, Boilers and Solar panels.

There was a significant difference in electricity usage between cluster 1 & 6, cluster 1 obtaining the higher energy reduction, these consisted of ‘C’ type properties and were characterised six technologies including structural insulation. However, cluster 6 received structural insulation similar to cluster 1 but also received solar panels, these panels encompassed several teething problems causing them to trip out tripped out regularly. Due to the initial positioning of the operating system when this occurred occupants found it difficult to reset the system. Subsequently until the problem was resolved, occupants had to rely on their emersion cylinder heaters as a back-up. This additional energy usage may have accounted for the higher energy use. Additionally, as discussed earlier, one occupant in this group used high than average electricity to heat his reptile tanks.

5.5 DISCUSSION

5.5.1 TO INVESTIGATE THE RELATIONSHIP BETWEEN NEW TECHNOLOGIES AND ENERGY EFFICIENCY IN RETROFITTED RESIDENTIAL BUILDINGS:

To address the research objectives this chapter has investigated the types of technologies used within this study, looked thoroughly at all the property types, their location in relation to each other along with the technology that was introduced to them. This was achieved by grouping residential buildings with similar technologies and characteristics using Hierarchy Clusters analyses but not by street location or property type.

The cluster investigation revealed that technologies were not always grouped into their property types; this was shown in-group 1 when 6 clusters were selected. Properties C3 and C6 were placed into group 2, these two properties were privately owned so it could be assumed that this changed the grouping process. Closer investigation revealed that the privately owned properties (C3&C6) did not receive any internal works, which included the Phase Change Material PCM replacing the existing lounge ceilings this may have affected the manner in which the groups were organised. Four property types were designated to group 2 the common technology's here were LEDs and Single Heat recovery Units. The majority of property types came from L type, several from C , PB and one from P, the common denominator here was LEDS and Single heat Recovery units but several did receive Voltage Optimisation Units (VOU) this may have influenced the final group choice.

5.5.2 WHY THERE IS A DIFFERENCE OR NO DIFFERENCE IN CLUSTERS

Group 6 remained unchanged; the technology's here although similar to group 1 did not received technologies such as LEDS, single heat recovery units and PCM ceilings to their lounges. Group 4 the PA property changed from gas to electric heating with air source heat pumps being installed, this with the external wall installation may have contributed to this group selection. PB properties were grouped predominantly together one of the main factors that possibly have contributed to this selection was the vacuum insulated panels VIP even though SHRU were consistent here as well

5.6 SUPPORTING LITERATURE

As discussed in the literature review Engineers and Designer face major challenges in the future when delivering properties that address global warming, environmental conditions and energy conservation (Malmqvist, and Glaumann, 2009), (Hoffert *et al.*, 2002). This investigation has addressed several of these issues by investigating new technologies along with their capability to reduce energy consumption. Natural resources such as oil and natural gas can been seen as being responsible for greenhouse gases due to the growing worldwide demand .(Gonzalez *et al,* 2011) by introducing technologies such as insulation, energy efficient boilers, air source heat pumps the strain on fossil fuels can reduce demand, CO_2 emissions and additionally contribute in meeting government targets.

This chapter/section has categorised properties into 6 cluster groups, the results have indicated that properties predominately characterised by external wall insulation in groups 1 & 6 have achieved encouraging levels of energy reduction for gas users. According to Heeren *et al*. (2013) found that 10-17% energy saving could be achieved by insulating walls to retrofit properties the down side of this could be the reduction of floor space if the procedure was carried internally. However, the procedures used in this project allowed the insulation to be fitted to external walls with no compromise to internal floor size.

Emerging technologies such as photovoltaic panel can also be used in domestic refurbishment projects; when utilized can save part of the energy consumed for operating a house (Carutasiu et al., 2015). Results from group 4 found that there was a considerable saving in electricity for one resident when photovoltaic panels and air source heat pumps were used. The down side of these results however was a small population and only one occupant out of the three fully understood the capabilities of the system. Furthermore, due to this reduced group size the software exclude their results from the boxplots.

Energy efficient led bulbs were fitted to all property's, since the smart monitoring system was not commissioned during the study it was not possible to measure if any savings from the LEDs existed, however many properties did show a reduction in energy usage which may have been as a result of the LEDs.

According to (Kumar Soori and Vishwasb, 2013) occupancy sensing devices can also reduce energy demand additionally by determining the activities of the occupants further energy savings in such areas with smart control systems will be possible (Nagy, Yong, and Schlueter, 2016). LED light bulbs last longer than its other competitors do, which inevitably saves money over the long term with electricity bills (Carlsen, 2016).

5.7 CONCLUSIONS

This chapter has set out to describe the nature of the project, the types of technology's that were installed into the property types, grouping the properties according to the interventions using SPSS hierarchy analyses and energy consumption.

Summary statistics from *table 5.14* indicate that there may have been a relevant saving in gas usage in cluster groups 1 and 6 this could further be supported by Dunn's Kruskal-Wallis multiple comparison test *table 5.15* (gas) where no significant difference between group 6 and group 1 was noted. Figure 5.42 also supports these results; the boxplots indicate that group 6 and 1 are in the upper quartile section. Additionally, electricity results revealed a reduction in energy usage in-group 1.

Even though groups 1 & 6 were Semi-detached BIS property types, it could not be assumed that all semi-detached properties that were characterised by structural insulation would always achieve an energy reduction. Additionally it could be hypothesised that the structural insulation may have contributed toward the reduction in energy usage here.

Finally, what appeared to be interesting within this section was group 4, even though the group only consisted of three properties [type PA]. The software excluded there results from the boxplots because there was no gas appliances within these buildings now. These properties were characterised by:-

External wall insulation, air source heat pump, Photovoltaics, LEDs and voltage optimisation units.

Table 5.16 summary statistics for electricity identifies a saving of 9.27%, gas shows no data due to the fact that these properties were powered solely by electricity, due to the nature of the interventions that were fitted [air source heat pumps, photovoltaics, external wall insulation]. It could therefore be assumed that a reduction in energy usage within this group could be considered.

Chapter 6

ENERGY EFFICIENCY OF THE RESIDENTIAL BUILDINGS IN RELATION TO OCCUPANTS BEHAVIOUR

This chapter focuses on the types of occupants and their behaviour patterns that formed part of the research questions, Information extrapolated from questionnaires will be analysed using Bivariate Statistics, (PCA) Principle Component Analyses and Cluster Analyses.

As in any refurbishment project, it is very important to understand how occupants behave, who are the end users and can the technology be fully utilised by the occupant.

The second part of the aim of the research was to investigate the relationship between post occupancy behaviour in buildings and energy efficiency.

The study will investigate occupants living in semi-detached bungalows, terraced bungalows all brick built, and semi-detached BISF houses built between, 1950-1970.

Section 1

The first section of this chapter will present exploratory data taken from the results from questionnaires; this will include occupants' gender, age, employment history, habits, energy usage, behaviour, and support provided by the management organisations. The results will be presented in the form of bar charts and provide a portfolio of the occupants.

Section 2

This section will look at bivariate analyses a simple form of quantitative statistical analyses. Two variables are considered within this process to determine whether an empirical relationship between them exist.

Section 3

Variables will be analysed using PCA, the process allows the properties and technologies to be grouped together in their strongest categories, and this will effectively regroup the properties to their significance and relationships to one another.

Section 4

Finally, Cluster analyses has also been used to group properties as discussed in the Technology chapter, Cluster analyses has been chosen in this section as a statistical tool to analyse data into groups, it has the ability to define which groups certain data should belong to. Sharing comparable values clustering is a multivariate procedure that can group rows together that share similar values or characteristics.

6.1 OCCUPANTS' CHARACTERISTICS/PROFILE – EXPLORATORY DATA ANALYSIS

The most interesting/relevant information about occupants linked to the 'occupancy behaviour' write up has been set out below. The information provided will provide an insight into the type of occupants within this investigation.

6.1.1 BACKGROUND

In this section the results produced from several exploratory data methods will be investigated, the results will provide a profile of the occupants and the further areas that will be investigated. These will include government policies, age, lifestyle, employment, household size, well-being, IT skills and understanding of new technologies.

Additionally, a succinct review is provided in section 6.1.3 Energy Monitoring which analyses gas usage in property types 'R' & 'WC' the results will be compared with a data logger (temperature monitor) that was installed to 'R'1 prior to the externa insulation being fitted.

The last part of this section will examine the reliability of results, questions of a similar nature were designed and placed into the questionnaires in different sections, and this would provide us with the opportunity to compare the level of consistency in the results.

Results for this section are set out below -

Descriptive Analyses

6.1.2 AGE OF THE OCCUPANTS

The age of occupants within this study ranged between 21-88 years of age

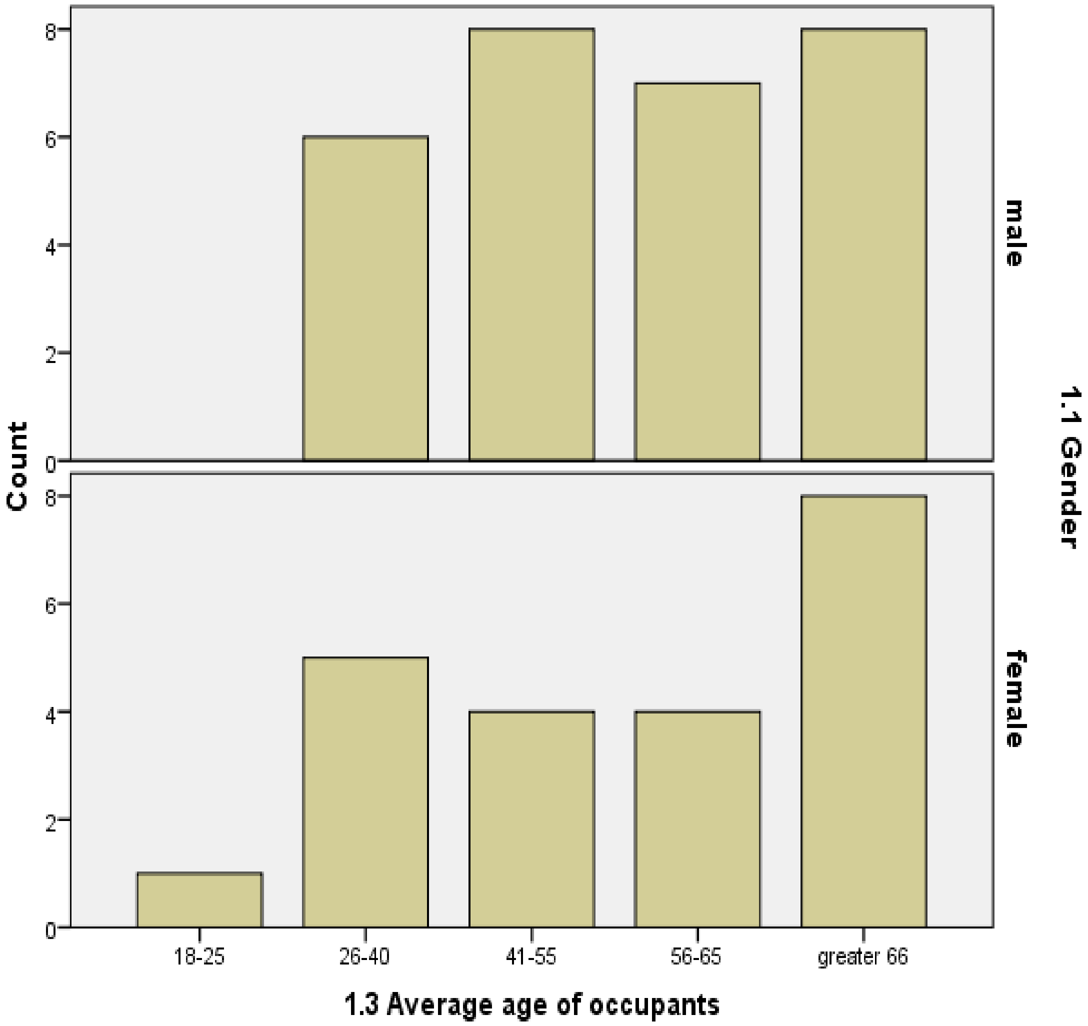


Figure 6.1 Average age of occupants.

The study involved 51 households the youngest occupant was categorised in the 18-25 group with the oldest being in the greater than 65. *Figure 6.1* categorizes the occupant into age bands, male occupants dominate the study slightly with increased numbers compared to female. No male occupants are classified in the 18-25 group compared to one female in this category. 16 occupants are grouped in the above 65 categories and it can be assume that these people are retired.

6.1.1 GOVERNMENT POLICY'S

A comprehensive review was presented within the literature review regarding Government Policies, these included schemes to improve energy efficiency in residential buildings, updating building regulations and meeting future demands in reducing CO_2 to support Government targets. The investigation categorised these into three groups (Government targets, Global warming & Green deal), residents were then asked if they were aware of any of these government policies, results from phase 2 was compared to phase 1. Results were very similar between both phases, nineteen occupants had no idea about any of these policies and this did not improve by the time the project was completed, except for property C1, *ref figure 6.2.*

Residents were asked if they had any knowledge about government policies, these were categorised as-

- None
- Global warming
- Government Targets
- Green Deal

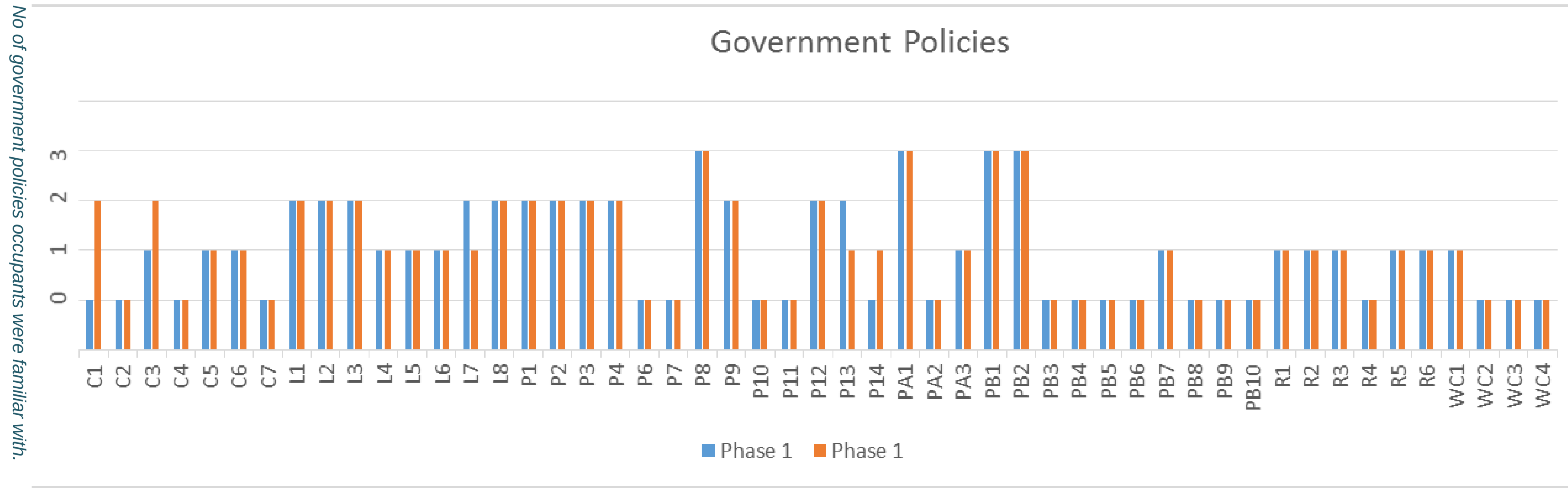


Figure 6.2 Understanding Government Policies.

6.1.2 ENERGY CONSUMPTION IN DOMESTIC BUILDINGS

During the course of the research, energy usage was recorded before and approximately one year after the installation of the interventions along with the energy providers and method of payment; this is represented with a bar chart illustrating the energy providers in [figure 6.4]. A remote smart monitoring system Moixa would record real life energy usage from all the properties that formed the smart house project, unfortunately during the period of data collection and energy monitoring the system was not fully commissioned. To compensate this shortfall of information data was calculated from energy usage provided by the occupants, the method of payments by householders varied from pre-payment cards to monthly or quarterly billing. (Ref to Appendix 5)

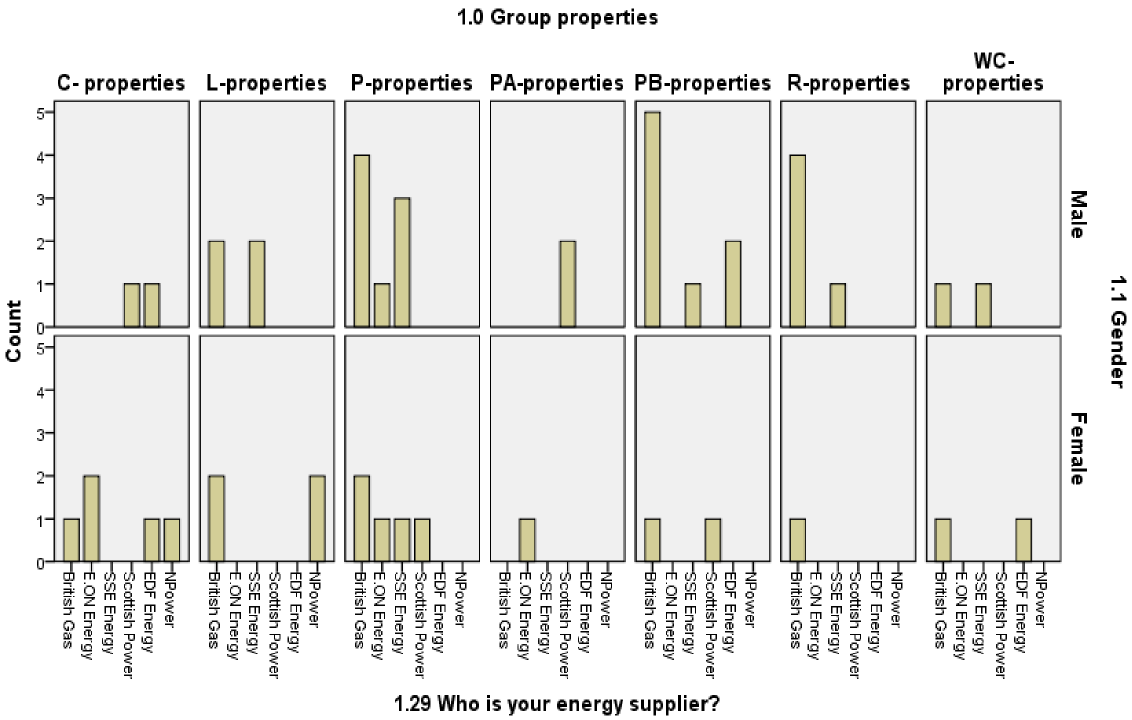


Figure 6.3 Energy providers.

From the data in Figure 6.3 it can be seen that British Gas appeared to be the most popular provider even though at the time of this study there were other suppliers offering competitive deals. Occupants were asked if they had ever considered changing providers, many were set in their ways and were reluctant to search the market place for better deals. Responses at several interviews revealed that occupants were concerned about changes, processes, and the thought of changing providers and experiencing payment problems. This was interesting as very few occupants had tried new providers, the majority of these people relied on hearsay information.

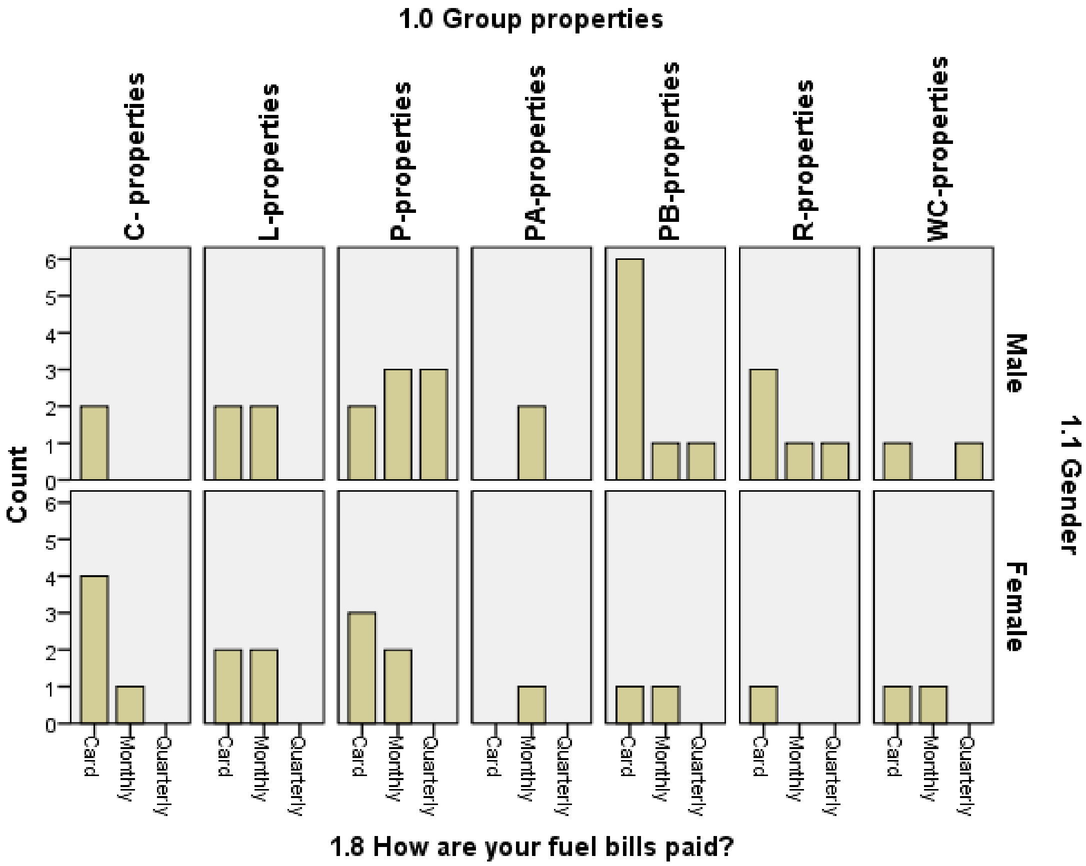
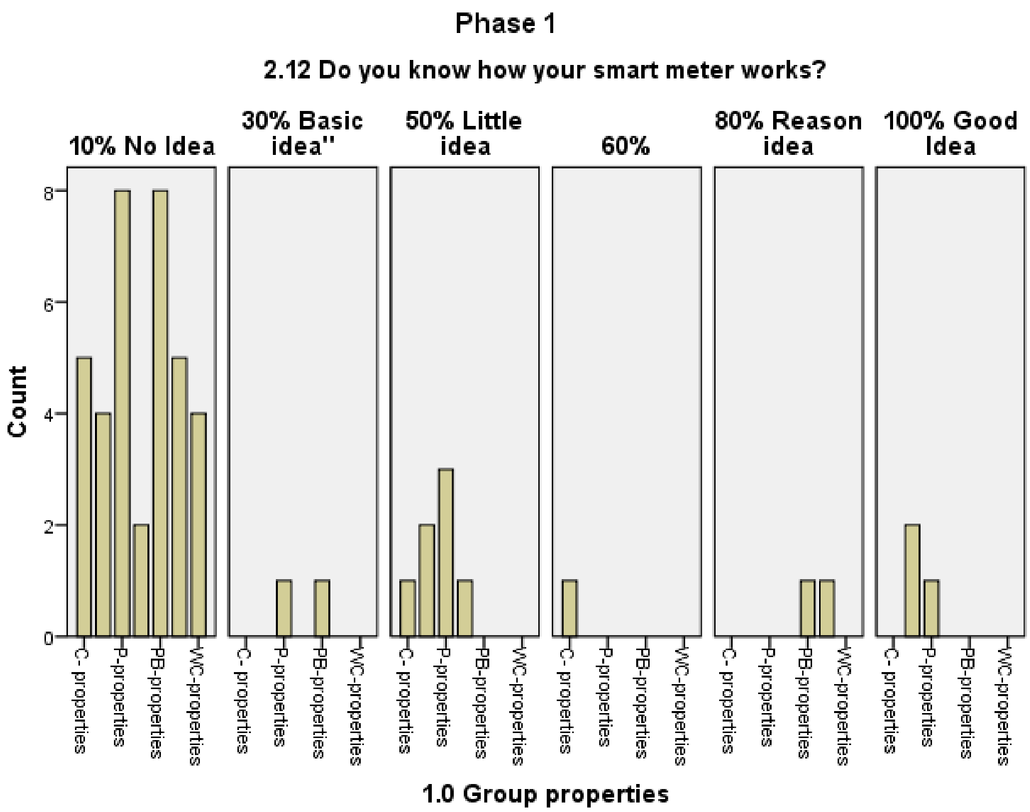


Figure 6.4 Method of payment.

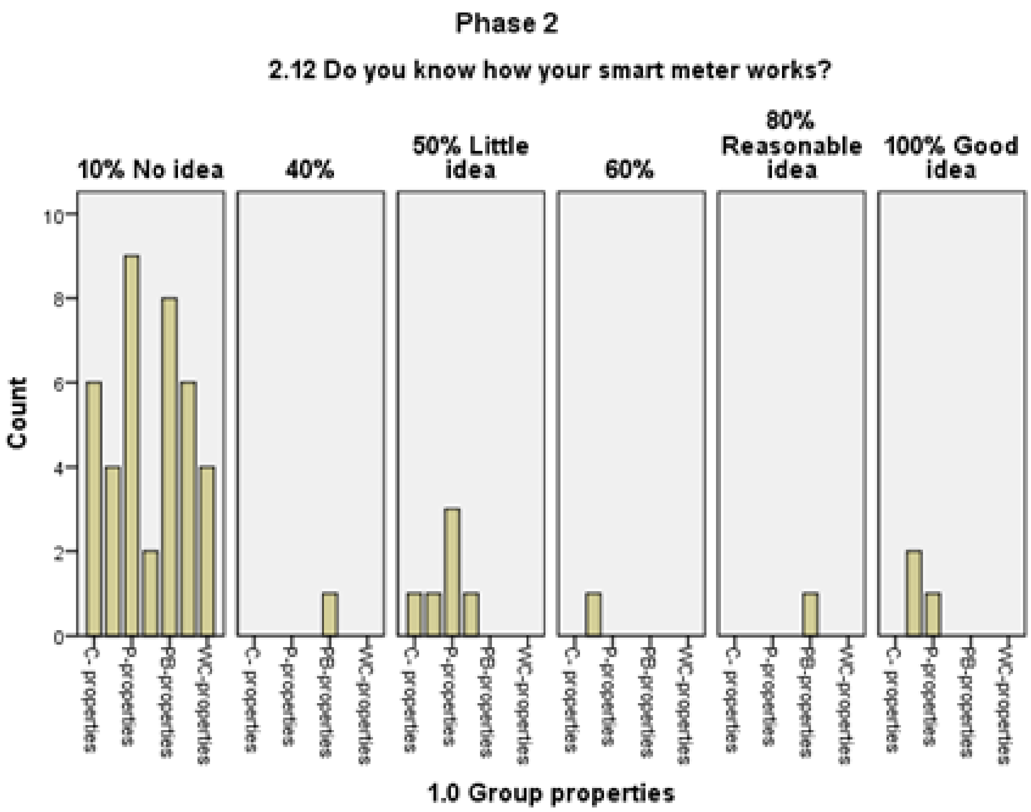
The method of payment was either quarterly, monthly of payment card, most occupants preferred the pre-payment card system [the majority being male] the remainder undertook monthly or quarterly payment methods. Tariffs on payment cards were generally higher and several occupants revealed they had problems when their credit had run out if due to lack of finances allowing them to top up the card. What was difficult to assess was whether any of these occupants actually fell into the fuel poverty bracket, as this would have exposed their incomes and personal finance. Their income was outside the scope of this research. To assist the hard to pay occupants, just recently rolled out, it is possible to top up a payment card from a mobile phone once the app has been downloaded, that system works well if funds are available.

6.1.3 Energy Monitoring

6.1.3.1 Smart meters



(a)



(b)

Figure 6.5 Understanding of how a smart meter works (a) Phase 1. (b) Phase 2.

The majority of occupants did not understand of how a smart meter worked in phase 1, there were very minor changes to the results in phase 2 but this was only at the lower end of the scale. By the time the data from occupants had been collected in phase 2 the Smart meter system was still not fully commissioned this may have influenced the results here.

6.1.3.2 DATA LOGGERS

Temperature loggers were installed into several 'R' properties to identify if any temperature changes were noted before and after the fitting of the external wall installation, (EWI).

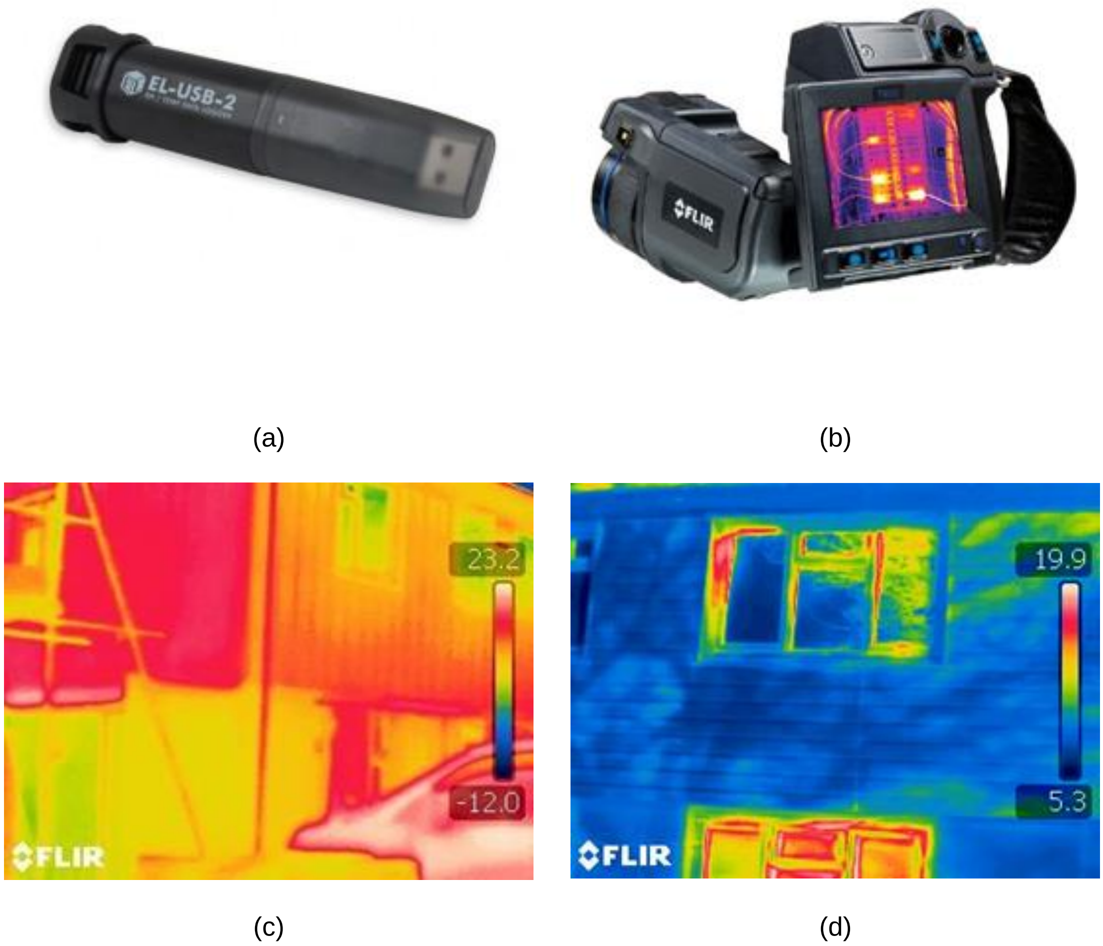


Figure 6.6 (a) Temperature logger. (b) Thermal Imaging camera. (c) Thermal image BIS property prior to the fitting of EWI. (d) Thermal image after EWI has been fitted.

The temperature loggers could be pre-programmed to take readings ranging from increments of 10 minutes up to 1-hour intervals, battery driven they had the capacity to run for up to a year depending on the settings. The loggers were set at 10-minute increments, this allowed them to run for approximately three months taking over 7 thousand readings. The more sophisticated loggers had the capacity to measure dew point and humidity. Data was then downloaded into the software provided with the loggers and a graphical illustration was produced to analyse the results, an example of these results is shown in Figure 6.6.

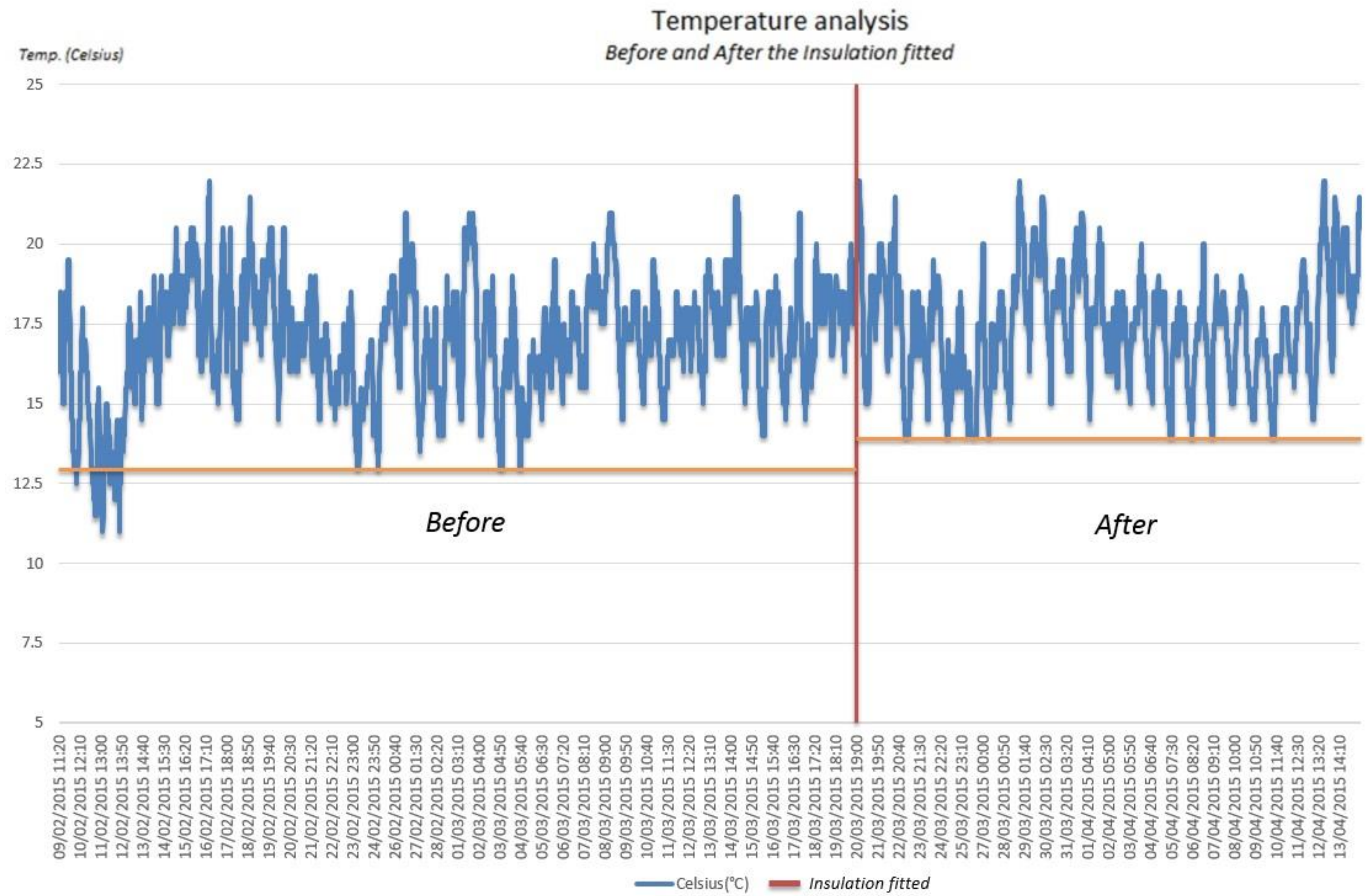


Figure 6.7 Six results from temperature logger installed in BISF (R1) property.

The external insulation was completed on the 20th March 2015; it took approximately 5 days to fit. The graph shows a distinctive improvement in lower bound temperatures generally encountered at night times, what was not considered in this analysis was the outside temperature during that time. These results can also be supported by the annual energy usage Figure 6.7 showing the energy consumption for R1, 2014 -13,747 KWh. 2015 10,475 KWh

Figure 6.6 (b) shows a high tech thermal imaging camera, this was used on several of the 'R' properties before and after the external wall insulation was fitted.

In Figure 6.6 (c) a BISF property is shown prior to the fitting of the external wall insulation; the bright thermal colours indicate a high level of heat penetration through the facade of the building to the exterior. Figure 6.6 (d) now shows the building with its external wall insulation fitted presenting a bright blue colouring to the building indicating a high level of heat retention within the building. An interesting question that did arise from this part of the investigation was there any heat loss through the party walls of these types of properties if the adjoining property was colder. This was also considered by (Meyers, Williams and Matthews, 2010) rooms that are not heated may absorb the heat through the walls from the ones that are. Unfortunately, that question fell outside the scope of this investigation

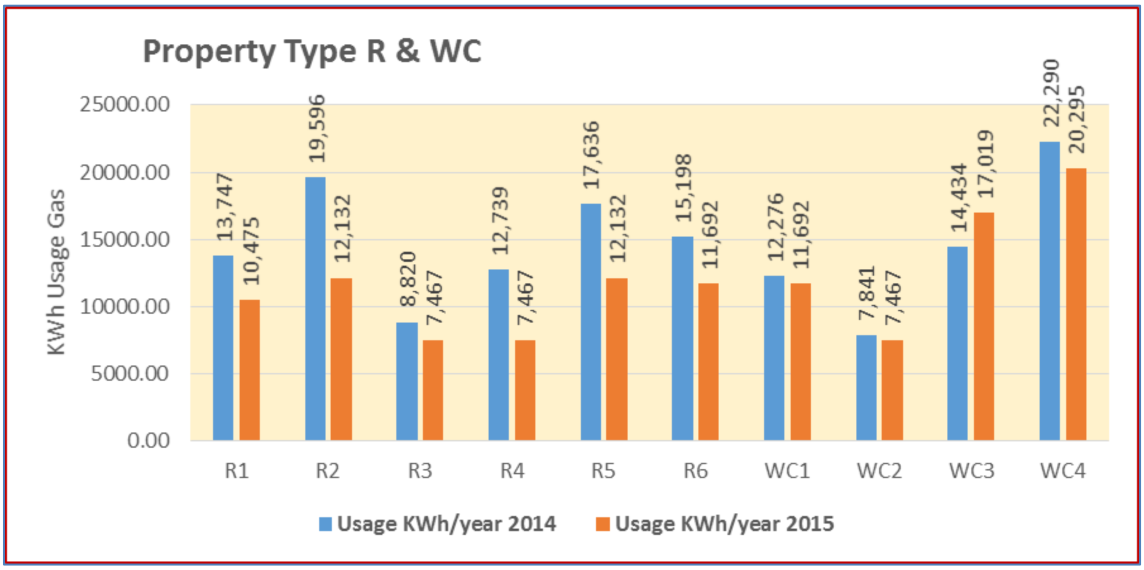


Figure 6.8 Energy usage R & WC properties.

Energy data above shows that all but one of the properties indicate a reduction of gas usage after the insulation had been fitted, WC3 does show an increase here but this was due to the occupant being elderly and recovering from a hip operation for the majority of 2015 with the heating on more frequently. Understanding ageing occupants with complex needs when technological advancement is made requires a greater understanding (Liu et al., 2016). (Please refer to appendix 4, Energy usage for all properties 2013-15).

6.1.4 LIFESTYLE

Figure 6.9 Life style.

The data collected intimated that there were more occupants out of work than in work, excluding the 16 occupants that were over the age of 65 this left 35 occupants within the working age criteria. The data reveals that out for 35 occupants 24 were in work at the time of the investigation. The one to one interviews also revealed that some of the out of work occupants could be classified as unable to work or in-between employment positions. What was interesting from the results was the fact that no females were in work between the ages of 56-65.

6.1.5 IT SKILLS

Figure 6.10 Own a Computer.

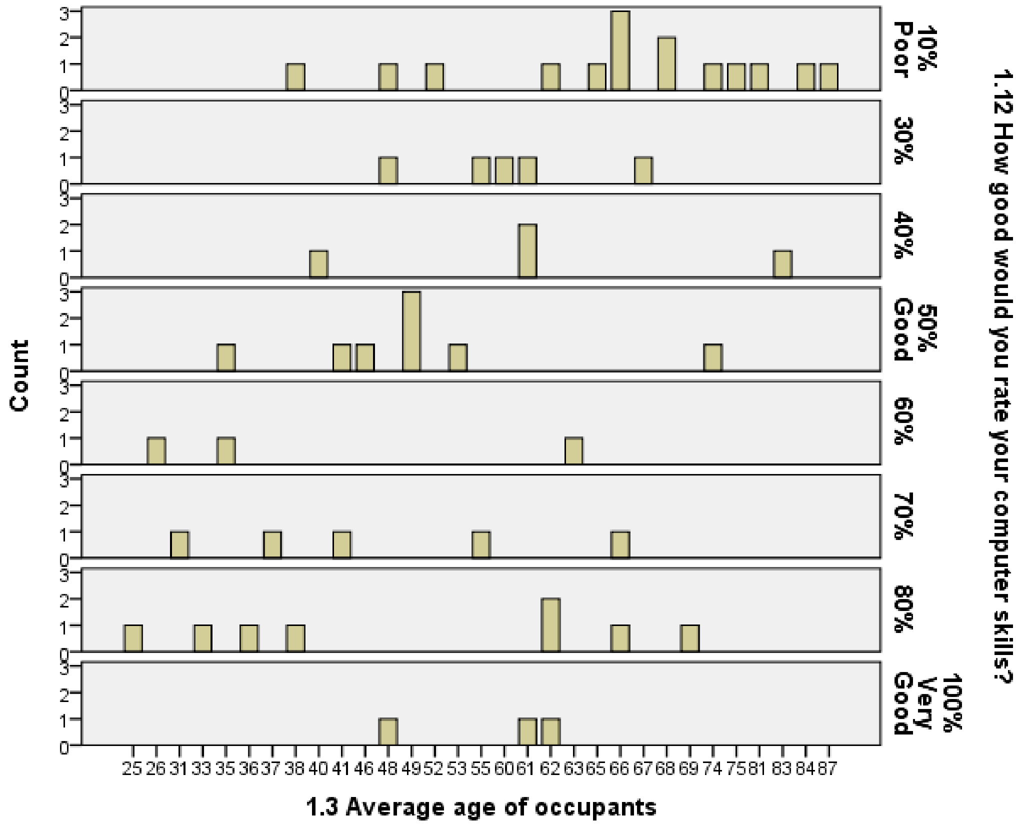


Figure 6.11 Computer skills.

Occupants were asked during the investigation how long they had owned a computer; Figure 6.10 groups the occupants and identifies how long they have owned a computer. 16 stated that they never owned a computer, the remainder of the results show that the vast majority are categorised in 3-6 years (8 no), 7-10 years (6) and more than 10 years (19). What was interesting here was the results show that 19 occupants owned a computer for over 10 years but results in Figure 6.11 indicate that only 3 occupants have good computer skills. The poor results in the lowest band may signify that these people never owned a computer and had little IT skills.

6.1.6 HOUSEHOLD SIZE

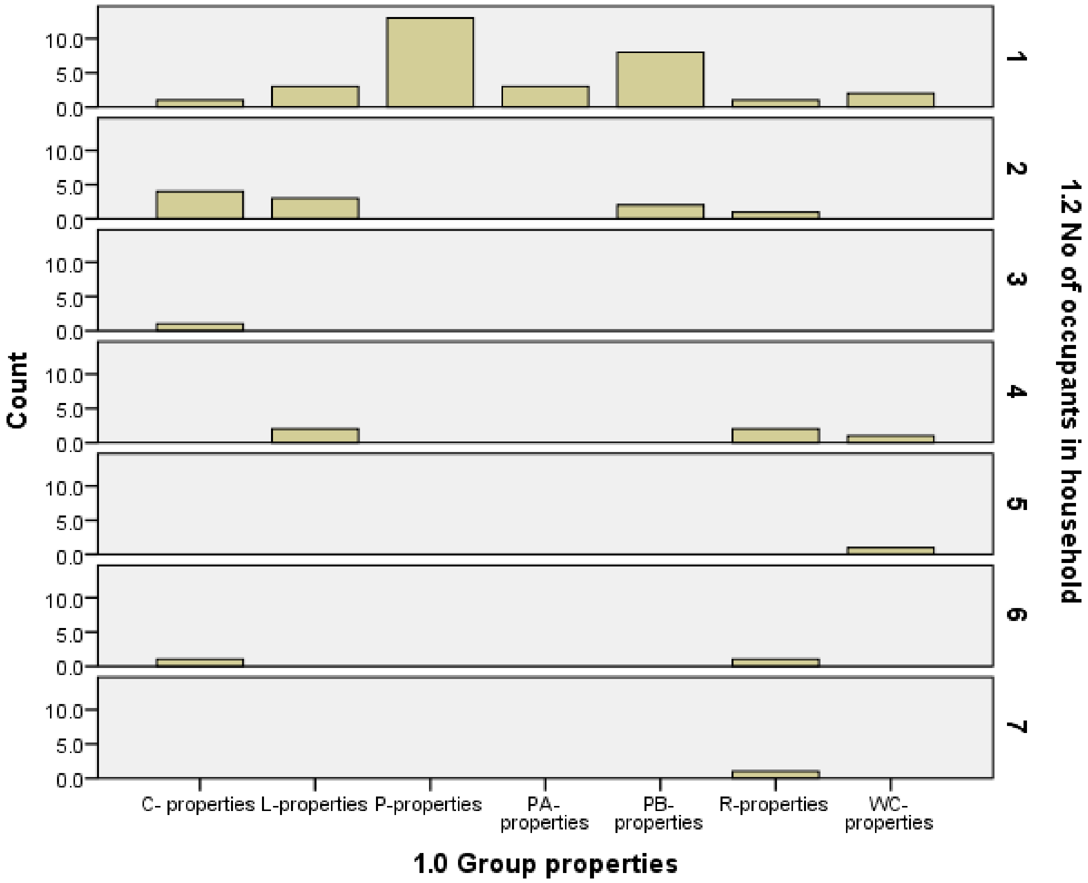


Figure 6.12 Household size.

The data in Figure 6.12 indicates that most properties were single occupancy followed by dual occupancy and several properties housing three –seven people. It was assumed that unless stated, above two occupants would include their children.

6.1.7 WELL BEING

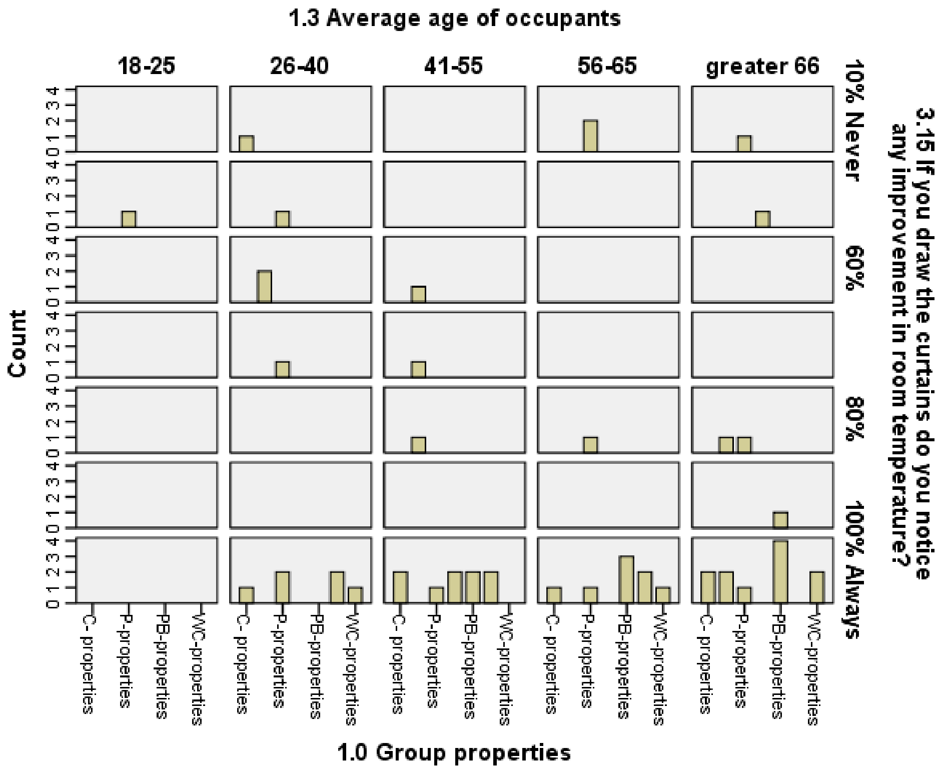


Figure 6.13 Drawing curtains at night.

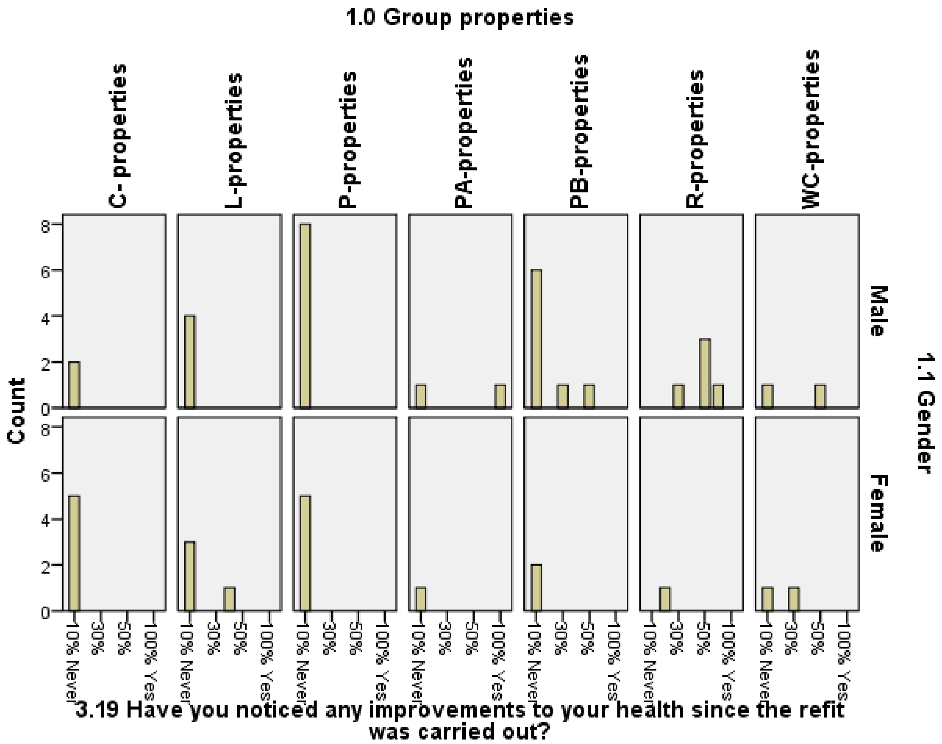


Figure 6.14 Improvements to health.

Younger people were less likely to draw curtains at night to reduce heat loss, this may have been due to décor and did they have curtains, older residents may have drawn them through routine and past experiences of draftee inefficient dated windows.

Several occupants believed their health had improved with warmer, more comfortable rooms, retaining heat longer. Results in Figure 6.14 indicate that residents of R & WC properties are healthier. An interesting fact that came out of this research indicated that the results from interviews never always matched the questionnaire. This may have been due to inconsistent thoughts by occupants resembling Cognitive Dissonance where two or more believes are considered, Festinger (1957).

An occupant from the 'P' properties commented that the single heat recovery fans fitted to the kitchen and bathroom had improved his asthma, this was not recorded within the questionnaire. This was interesting as it could be seen that behaviour here was conflicting with beliefs. There was a feeling of dissonance due to the improved air quality but this occupant was reluctant to document this evidence.

However, one occupant in the 'C' group of properties stated it was now too cool in the summer/daytime and that she had to go into the garden to warm up.

6.1.8 Uptake of New Technologies (by technology) by occupants

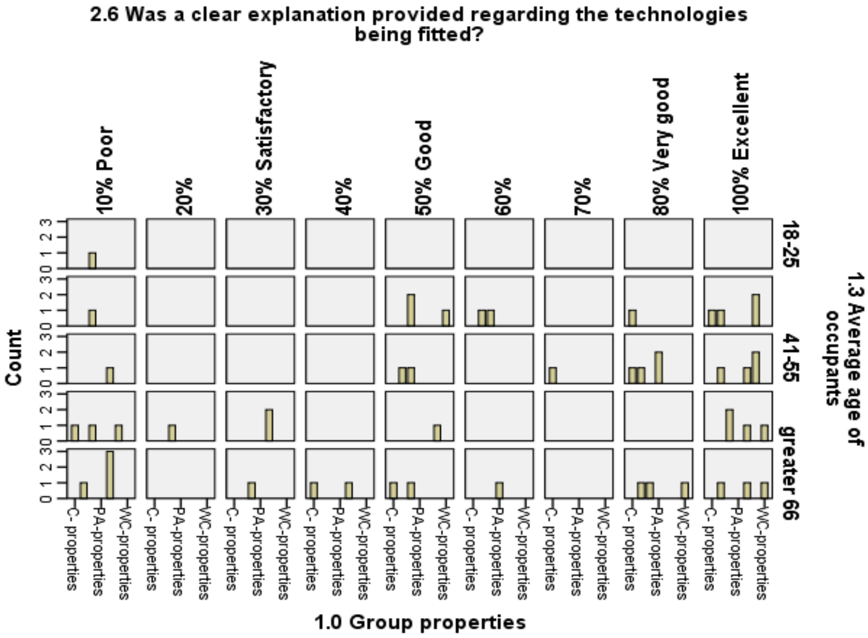


Figure 6.15 Explanation regarding Technologies'.

During the project, all occupants received the same explanation regarding the technologies and installation process; this was supported with presentations at the Eco clinic. The additional ten properties that were added to the project were managed by SEH and subsequently they carried out all explanations and one to one consultation with those residents.

Figure 6.15 explored whether a relationship existed between the occupants' ages and clear explanation was provided relating to the project. The majority of results are categorised above 50%, the poorer results were generally older residents. What was interesting here was the R and WC results indicated that 4 'R' and '2' WC properties were fully satisfied with the explanations provided by SEH.

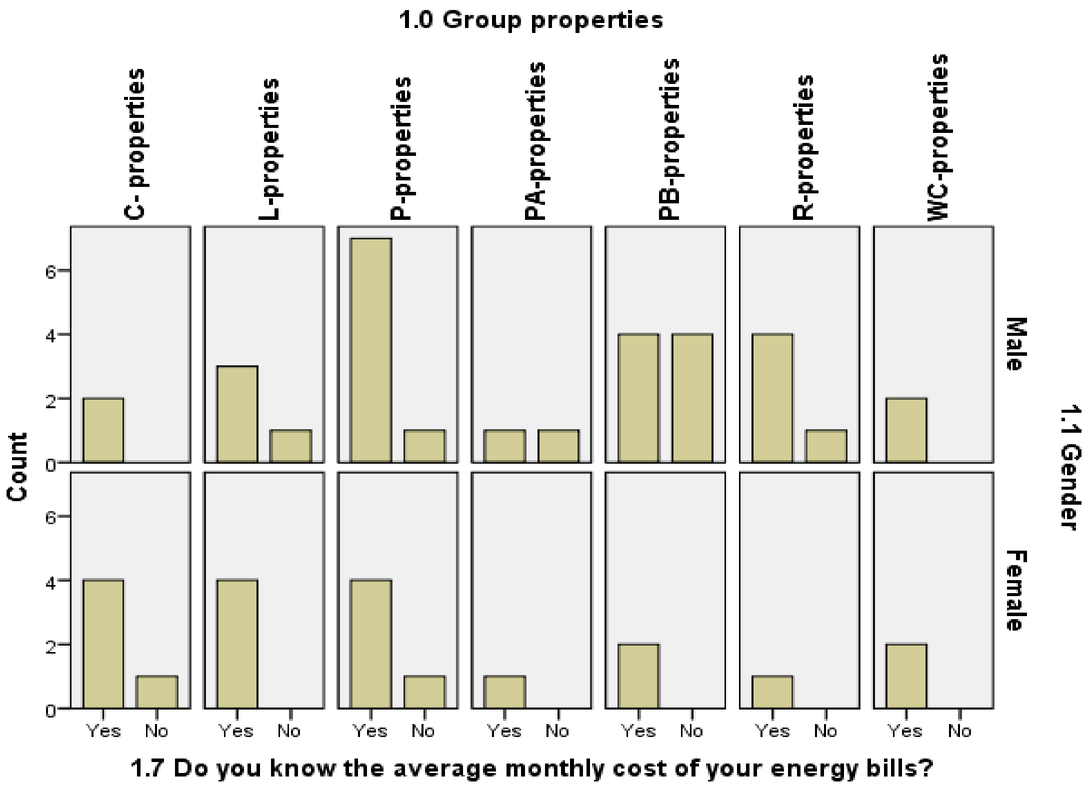
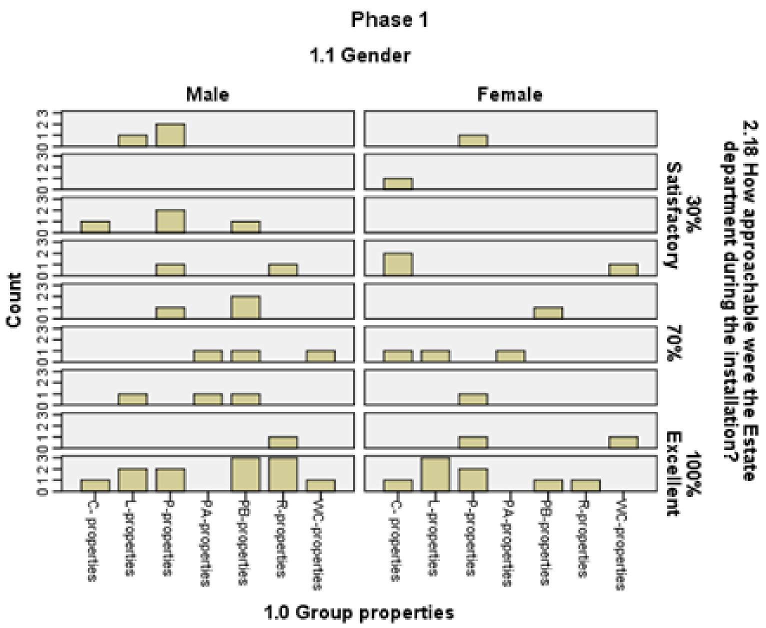
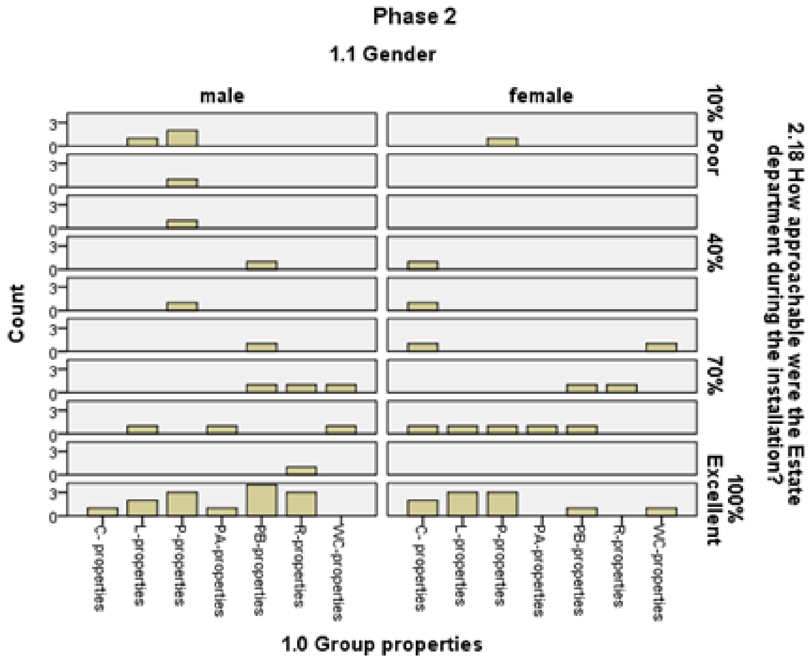


Figure 6.16 Cost monthly energy bills.

This was interesting response by occupants regarding their monthly energy expenditure, 10 occupants did not know the cost of their monthly energy bills, and this consisted of 2 females and 8 males. That accounted for nearly 20% of the sample.



(a)



(b)

Figure 6.17 How approachable were the estates department (a) [Phase 1]. (b) [Phase 2].

In Phase 2 a distinctive improvement was noted in communication with the estates department, several interventions that were either not fitted or didn't perform were reflected in the resident's results.

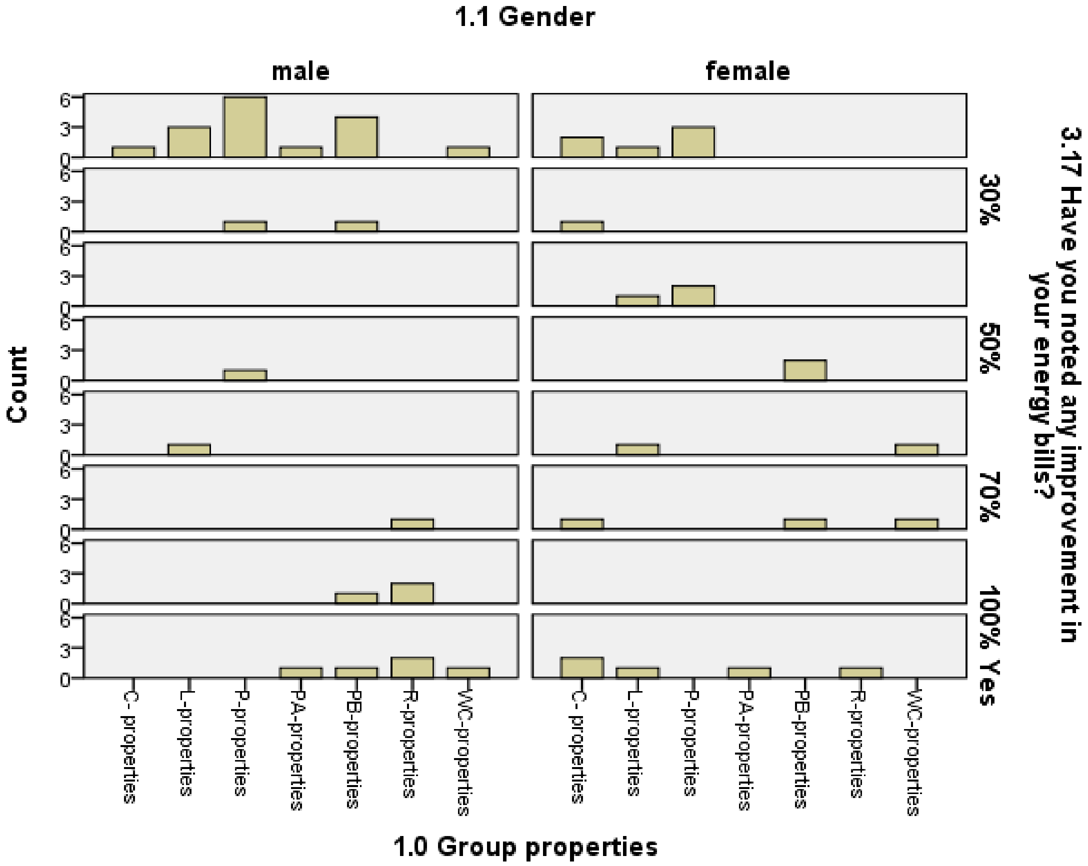
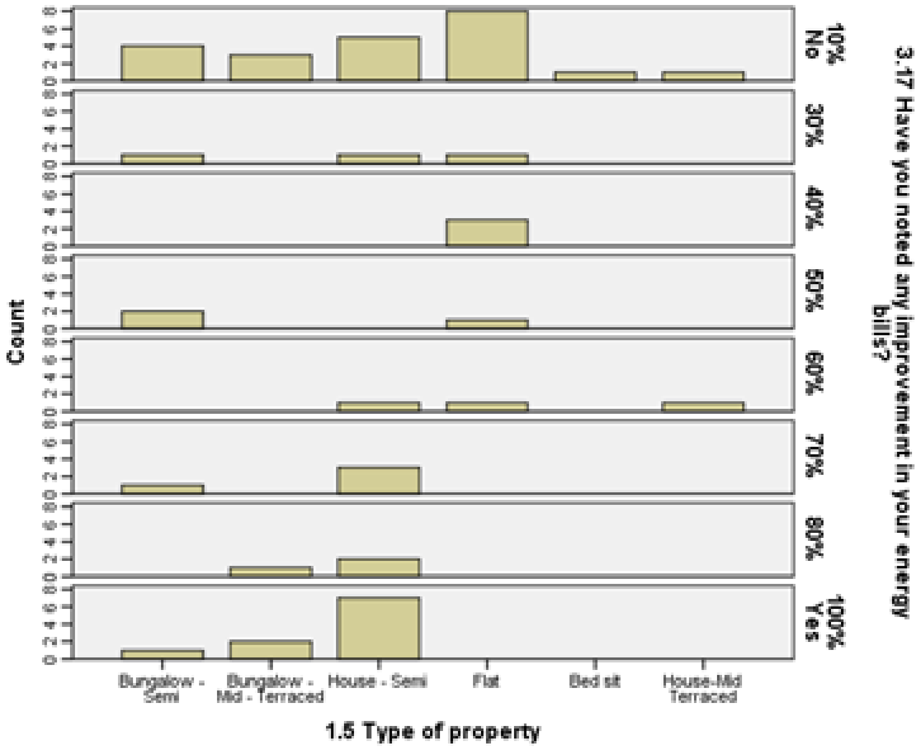
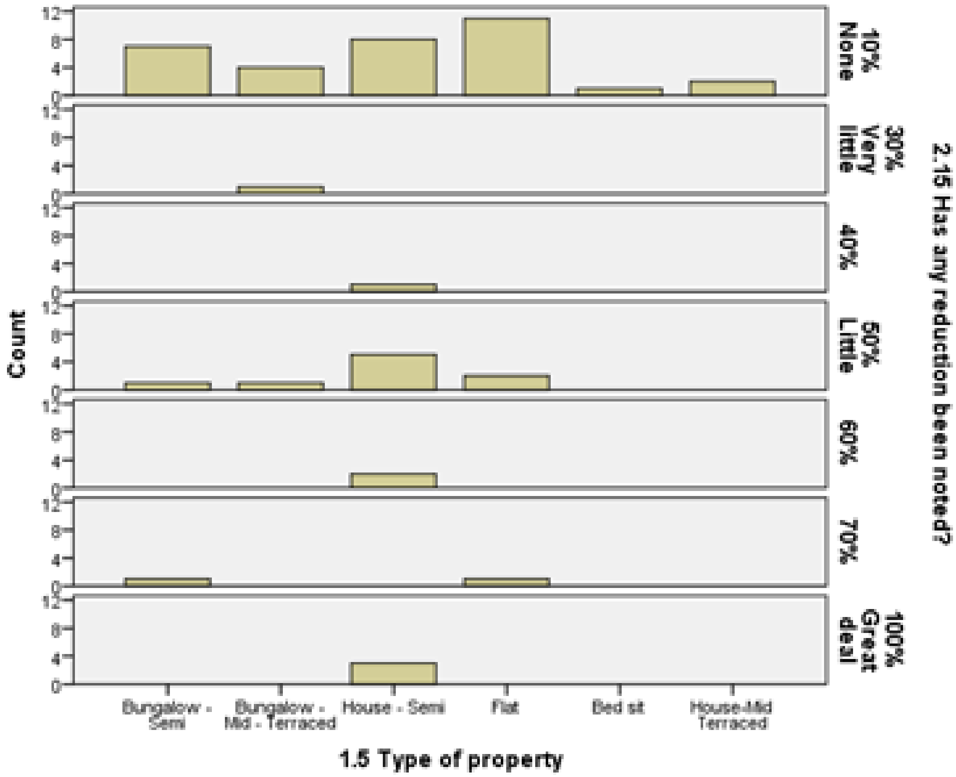


Figure 6.18 Improvements in energy bills.

The results in figure 6.18 signify break down the improvement in energy usage by gender, results are very similar between male and female except at the lower end of the results where there appears to be more males that have not noted improvements in energy reduction.



(a)



(b)

Figure 6.19 (a) reduction in energy usage. (b) Improvements in energy usage.

This was a carefully written pair of questions both were similar in nature, but several respondents provided different answers. Both bar charts above in Figure 6.18 consider energy usage, the first chart Figure 6.19 (a) 2.15. [Has any energy reduction been noted?], versus type of property, the second chart Figure 6.19 (b) 3.17 [Have you noticed any improvements b in your energy bills?] versus type of property. The results are dissimilar both questions should have provided similar results here, this is further reinforced in Figure 6.18 which as a similar designed question but different results to Figure 6.19 (a) and (b).

6.1.9 Discussion

The results from the literature review provides a platform that supports the determination by Government Agencies to fully commit to reducing the carbon foot print and supporting a more sustainable future this has been further supported by schemes such as the Green deal, Warm Front, and EPC. This investigation categorised all these initiative into three sections: - Government targets, Global warming and the Green deal.

6.1.9.1 Government policies

The drive by government agencies to introduce incentives to encourage occupants to become greener has been challenging as outlined earlier in the literature review. In order to achieve the desired long-term success in building energy performance, energy efficient measure and policies must be understood from the early design stages (Heeren et al., 2013). The results produced from this study indicated that nineteen occupants were not aware of any of these policies and this did not improve as the project progressed. Occupants were either uninterested in this very important area or just did not fully understand the long-term implications.

6.1.9.2 ENERGY RESULTS

Energy results such as the ones provided within the **R & WC** group showed an overall reduction in gas usage except for the elderly woman with a hip replacement requiring the heating to be on longer to aid her recovery. According to Liu et al. (2016) understanding ageing occupants with complex needs when technological advancement is made requires a greater understanding. This was a valid point, whilst this situation was not too complex it was made possible, due to a small sample and relationship built up between the researcher and the residents, to identify why some of the results may have changed.

Just under half the sample within the study worked, energy bills were paid by either prepayment card, monthly or direct debits the most popular being prepayment card 32 residents in total. What remained difficult to ascertain here was if any occupants fell into the fuel poverty bracket. A paper written by (Meeting the Energy Challenge a White Paper on Energy May 2007) forecast that by 2016 approximately 1 million people would still be in fuel poverty. In several cases, occupants were very cautious about revealing their outgoings; government figures related to fuel poverty may be under accessed due to the pride occupants not providing accurate data.

Additionally, occupants did not feel confident in changing energy providers, several one to one interviews revealed that they were afraid their accounts would be disrupted, and billing problems would occur.

6.1.9.3 IT

It skills were mixed within the investigation, 16 did not own a computer only a limited number had good IT skills.

6.1.9.4 SMART METERS

The government made a commitment to achieve sustainable affordable energy in the domestic sector that could be easily monitored through a series of roll out programmes; smart meters would allow occupants to monitor their energy usage. (LeBlond, S., Holt, A., and White, P., 2012). However, results taken from this investigation show clearly that residents were still unclear how the system worked, this may have been due to the fact that the Moixa system still hadn't been commissioned at the time of this study. Additionally, energy providers would be installing their own smart meters between 2014-2019 (Department of Energy and Climate Change, 2012). According to Nguyen and Aiello (2013), smart monitoring and thermostat systems could save up to 1/3 of the energy usage and costs associated with residential use. With this deadline in place occupants, need a better understanding regarding the benefits that can be achieved here. Results in Figure 6.5 indicate that even by the end of the project occupants did not understand the benefits of smart meters, the majority of the results were categorised in the lower band.

6.1.9.5 WELL- BEING

Several residents believed their health had improved these results are shown in *Figure 6.14* warmer more comfortable rooms, this was further supported in the literature review where studies carried out by (Hong et al 2006) found that improvements in bedroom and living room temperatures aided the thermal comfort and contentment of occupants.

As discussed in the technologies chapter insulation was fitted to four property types for three main reasons, energy conservation, comfort and to keep the building warm in the winter and cool in the summer. According to the literature review overheating may occur, causing discomfort to the elderly and vulnerable (Porritt *et al*, 2012).

At a one to one interview, one occupant now declared it was now too cool in the summer in the lounge, so she would go into the garden to keep warm. This could be seen as in direct discomfort; ageing occupants need to be kept warm throughout the year but in a controlled environment.

6.1.9.6 UNDERSTANDING TECHNOLOGIES - FITTING

Communication formed a big part of this project and this was supported by several questions within the questionnaire including understanding how technologies were being fitted. The results showed that the R&WC group of properties provided the better results (understanding) this may have been because a large number of them worked. However, there were still 16 residents under 40% that were not fully conversant with the technologies being fitted. This may have been due to the fact they never attended the eco clinics or did not read or understand the user manuals. According to (Podgornik, Sucic, and Blazic, 2016) technical data should be written in such a way that this is fully understood by the recipient. Additionally, the timing of delivery and how the information was presented is paramount.

Early profiling the occupants may have provided an opportunity to understand each occupant's perception of the refurbishment project allow additional measures to be introduced when shortfalls were noted. Dainty *et al.* (2013) concludes that occupant behavioural monitoring will make up a large part of the post-handover evaluation. Typically, continuity of information within this study was very important, when a one to one interview took place and the occupant was asked 'Have they read any of the user manuals' they declared 'they had never seen any of them.' A quick look onto the coffee table revealed the folder was there, delivered to them by SEH with all the manuals present. It can be assumed that people do either not like manuals or they are compromised by their usability.

A very important factor was customer satisfaction; results from questionnaires do not always portray the true results due to interpretation of information. This can be further supported from the literature review where a case study was carried out on the refitting out of a building in Malaysia (Shika et al., 2012) addressing measures to determine the occupant's satisfaction level. With questionnaires, they found that communication also played a big role in identifying roles and trends.

6.1.9.7 Approachable Estate Department

The management organisation provided support and advice when required, results from phase one against phase two revealed that this improved and they provided a good service. However, from the one to one interviews occupants did apportion blame to them when technologies did not perform which may have influenced some of the poorer results here.

The Management organisations provided support at the Eco Clinic every Wednesday for its duration (approximately 1 year) and attended all enquiries in timely manner.

6.1.10 SUMMARY

This section compared results with information presented in the literature review; the following assumptions can be drawn from these results. Occupants were either uninterested in government policies or did not fully understand them. IT skills within the sample were mixed and ranged between poor, with several in the higher band as very good. Very few occupants understood the benefits of smart metering; these results were reflected in both phases. Even though clear explanation supported by user manuals were provided to all occupant there was a mixed response here regarding understanding these new technologies.

However, the trust and relationship built up by the researcher/author and residents allowed some of the results to be further scrutinised outside of the questionnaire, this can be further supported by energy data in Figure 6.8 property WC3 increased gas consumption (14,434 KWh to 17,019 KWh) in phase 2. This increase did not reflect the fact that this ageing occupant had recently undergone a hip operation and was in recovery mode at home with the heating on all the time.

Further, on to this, it was observed that occupants were in receipt of maintenance manuals, which was not confirmed in the questionnaire. This revealed that occupants might have a dislike to instructions, information that may be difficult to understand.

6.2 BIVARIATE STATISTICS: RELATIONSHIP BETWEEN OCCUPANTS' CHARACTERISTICS

In this section bivariate analysis will be used a method of analysing the different pairs of variables to determine whether relationship/correlation exists between the two. Additionally, empirical data will be examined to identify if any further relationships between variables exist. Whilst 95% (p - value 5% level) confidence is general used to identify if any level of significance is present (Dancy & Reidy 2014) to narrow the investigation down further a confidence level of 99%(p - value 1% level) was considered. Variables falling within this category have been summarised into the following groups listed below and their results shown in *Figures 6.20-6.24.*

1. Government agency/policy's
2. Internet skills
3. Eco clinic
4. Improvement to comfort levels
5. Management Organisation

Results that fell within the above range, but were considered found 'by chance' were removed from the data set.

Due to the nature of this investigation being from small target population and pilot study , it has been assumed that if the correlation falls between the following ranges set out below the results can be classified accordingly (Dancy & Reidy 2014).

Perfect	+1	-1
Strong	+0.9 to + 0.7	- 0.9 to - 0.7
Moderate	+ 0.6 to + 0.4	- 0.6 to - 0.4
Weak	+ 0.3 to + 0.1	- 0.3 to – 0.1
Zero	0	0

Due to the small sample size, healthier results were classified into the moderate range this may not have reflected there true classification if the sample had been larger. Evidence obtained within this section will be compared further with the PCA and Cluster analyses.

6.2.1 GOVERNMENT POLICY'S- DATA ANALYSES

In Figure 6.20, this section will investigate and summarise results from questions related to government policies that suggest that a statistical significance exist between two variables.

		2.1 What is your awareness about energy usage?	2.2 Are you aware of Government Policies?	2.3 How often do you monitor your energy usage?
2.1 What is your awareness about energy usage?	Pearson Correlation	1	.449**	.433**
	Sig. (2-tailed)		.001	.002
	N	51	51	51
2.2 Are you aware of Government Policies?	Pearson Correlation	.449**	1	.247
	Sig. (2-tailed)	.001		.081
	N	51	51	51
2.3 How often do you monitor your energy usage?	Pearson Correlation	.433**	.247	1
	Sig. (2-tailed)	.002	.081	
	N	51	51	51

Figure 6.20 Government policies

From the bivariate analyses, results from variables (2.1 verses 2.2) indicate that there is a high likelihood that a relationship may exist. The statistical significance of (P- value < 0.05) 0.001 indicates that a relationship can be confirmed as acceptable statistically. This may further indicate that occupants that understood government policies may have been energy conscious as well. Additionally, because this is a pilot scheme and the data collection small from a target population it has been assumed that the correlation of 0.449 value falls within the moderate range (0.4 to 0.6) this result could be considered that a relationship may exist here.

Results from variables (2.1 verses 2.3) indicate that there is a high likelihood that a relationship may exist. The statistical significance of (P- value < 0.05) 0.002 indicates that a relationship can be confirmed as statistically acceptable. These results identify that a relationship between Qu_2.1 Awareness of energy usage and Qu- 2.3 How often do you monitor your energy usage are related.

6.2.2 THE INTERNET- DATA ANALYSES

In Figure 6.21 this section will investigate and summarise results from questions related to the internet that suggest that a statistical significance may exist between two variables.

		1.12 How good would you rate your computer skills?	1.14 How often do you use the internet?	1.17 How often do you pay any household bills online?
1.12 How good would you rate your computer skills?	Pearson Correlation	1	.742**	.399**
	Sig. (2-tailed)		0	0.004
	N	51	51	51
1.14 How often do you use the internet?	Pearson Correlation	.742**	1	.461**
	Sig. (2-tailed)	0		0.001
	N	51	51	51
1.17 How often do you pay any household bills online?	Pearson Correlation	.399**	.461**	1
	Sig. (2-tailed)	0.004	0.001	
	N	51	51	51

Figure 6.21 Internet Skills

From the bivariate analyses, results from variables (1.12 verses 1.7) indicate that there is a high likelihood that a relationship may exist. The statistical significance of (P- value < 0.05) 0.004 indicates that a relationship can be confirmed as statistically acceptable.

The results indicate that occupants that use the internet are more likely to pay bills online.

Results from variables (1.14 verses 1.17) indicate that there is a high likelihood that a relationship may exist. The statistical significance of (P- value < 0.05) 0.001 indicates that a relationship can be confirmed as acceptable statistically. The results indicate that the amount of time occupants use the internet is linked to the method of payment for their energy bills. It can also be assumed that the correlation of 0.461 value falls very closely to (0.4 to 0.6) this result could be considered that a relationship may exist here and therefore be acceptable.

6.2.3 Eco clinic Data-analyses

In Figure 6.22 this section will investigate and summarise results from questions related to the eco clinic that suggest that a statistical significance may exist between two variables.

		1.4 Do you work?	2.10 Have you attended any Eco Clinics on a Wednesday?	2.11 Have any user guides been provided yet to you?
1.4 Do you work?	Pearson Correlation	1	.086	.425**
	Sig. (2-tailed)		.551	.002
	N	51	51	51
2.10 Have you attended any Eco Clinics on a Wednesday?	Pearson Correlation	.086	1	.043
	Sig. (2-tailed)	.551		.764
	N	51	51	51
2.11 Have any user guides been provided yet to you?	Pearson Correlation	.425**	.043	1
	Sig. (2-tailed)	.002	.764	
	N	51	51	51

Figure 6.22 Eco clinic

From the bivariate analyses, results from variables (1.4 verses 2.11) indicate that there is a high likelihood that a relationship may exist. The statistical significance of (P- value < 0.05) 0.002 indicates that a relationship can be confirmed as statistically acceptable.

The results indicated that occupants who worked were more likely to confirm that they had received and read user guides, which may have influenced their understanding of the new technologies that had been fitted. What was also interesting was that there was no relationship between occupants that worked and attending the eco clinic. Energy results may not have been influenced by residents attending the eco clinic.

6.2.4 IMPROVEMENTS IN COMFORT LEVELS

In Figure 6.23 this section will investigate and summarise results from questions related to the comfort levels suggest that a statistical significance exist between two variables

		2.23 Did you sing up for the new energy technology - to improve your well-being?	3.12 Are the bedrooms warmer now?	3.17 Have you noted any improvement in your energy bills?	3.18 Does the house/bungalow fell more comfortable now from the insulation or technologies?	3.19 Have you noticed any improvements to your health since the refit was carried out?
2.23 Did you sing up for the new energy technology - to improve your well-being?	Pearson Correlation	1	.123	.425**	.381**	.187
	Sig. (2-tailed)		.391	.002	.006	.189
	N	51	51	51	51	51
3.12 Are the bedrooms warmer now?	Pearson Correlation	.123	1	.441**	.491**	.337*
	Sig. (2-tailed)	.391		.001	.000	.016
	N	51	51	51	51	51
3.17 Have you noted any improvement in your energy bills?	Pearson Correlation	.425**	.441**	1	.603**	.530**
	Sig. (2-tailed)	.002	.001		.000	.000
	N	51	51	51	51	51
3.18 Does the house/bungalow fell more comfortable now from the insulation or technologies?	Pearson Correlation	.381**	.491**	.603**	1	.521**
	Sig. (2-tailed)	.006	.000	.000		.000
	N	51	51	51	51	51
3.19 Have you noticed any improvements to your health since the refit was carried out?	Pearson Correlation	.187	.337*	.530**	.521**	1
	Sig. (2-tailed)	.189	.016	.000	.000	
	N	51	51	51	51	51

Figure 6.23 Improvement in comfort levels

From the bivariate analyses, results from variables (2.23 verses 3.17) indicate that there is a high likelihood that a relationship may exist. The statistical significance of (P- value < 0.05) 0.002 indicates that a relationship can be confirmed as statistically acceptable.

Occupants who obtained lower energy bills here may have improved their well-being additionally there was a relationship between Qu- 2.23 Occupant who signed up for the project to improve their wellbeing and Qu-3.18 Does the building feel more comfortable with the new insulation or technology being fitted (P- value < 0.05) 0.006.

These results indicate the occupants that signed up to improve their well-being felt more comfortable with the new technologies/ insulation and this may have also affected their energy usage.

Further bivariate analyses, results from variables (3.12 verses 3.17) indicate that there is a high likelihood that a relationship may exist. The statistical significance of 0.001 indicates that a relationship can be confirmed as acceptable statistically. The relationship existed between Qu_3.12 Are the bedrooms warmer now and Qu_ 3.17 Have you noted any reduction in your energy bills. These results may have been associated with the fitting of the technologies and insulation. Occupants with warmer bedroom also had improved health, the statistical significance of (P- value < 0.05) 0.016 indicates that a relationship can be confirmed as statistically acceptable.

The following results represent good correlation statistics classified as moderate or strong founded from the target population within this section of the investigation. Results may have improved if the sample population had been larger.

3.17-3.18 (0.603) strong

3.17-3.19 (0.530) moderate

3.18-3.19 (0.521) moderate

The correlation results shown above falls between (0.4 & 0.6) & (0.6 to 0.8) this can be considered as acceptable. Qu_ 3.17 versus Qu_3.18 presents a good strong correlation.

This section identified that a relationship existed between well- being, improvements in health, energy bills and technologies.

6.2.5 MANAGEMENT ORGANISATION (SEH)

In Figure 6.24, this section will investigate and summarise results from questions related to the management organisation and interventions that suggest that a statistical significance exist between two variables.

		1.24 Do you know what energy saving utilities are? Are you familiar with them?	2.6 Was a clear explanation provided regarding the technologies being fitted?	2.9 Have you had any problems with the installation process?	2.17 Does the installation meet your expectations?	2.18 How approachable were the Estate department during the installation?	2.24 Are you familiar with the technology or technologies that have been installed?
1.24 Do you know what energy saving utilities are? Are you familiar with them?	Pearson Correlation	1	-0.045	.437**	-0.223	-0.186	0.134
	Sig. (2-tailed)		0.754	0.001	0.116	0.192	0.35
	N	51	51	51	51	51	51
2.6 Was a clear explanation provided regarding the technologies being fitted?	Pearson Correlation	-0.045	1	-0.13	.284*	.419**	.329*
	Sig. (2-tailed)	0.754		0.362	0.043	0.002	0.019
	N	51	51	51	51	51	51
2.9 Have you had any problems with the installation process?	Pearson Correlation	.437**	-0.13	1	-0.082	-0.187	-0.15
	Sig. (2-tailed)	0.001	0.362		0.566	0.188	0.295
	N	51	51	51	51	51	51
2.17 Does the installation meet your expectations?	Pearson Correlation	-0.223	.284*	-0.082	1	.548**	0.241
	Sig. (2-tailed)	0.116	0.043	0.566		0	0.089
	N	51	51	51	51	51	51
2.18 How approachable were the Estate department during the installation?	Pearson Correlation	-0.186	.419**	-0.187	.548**	1	.361**
	Sig. (2-tailed)	0.192	0.002	0.188	0		0.009
2.24 Are you familiar with the technology or technologies that have been installed?	Pearson Correlation	0.134	.329*	-0.15	0.241	.361**	1
	Sig. (2-tailed)	0.35	0.019	0.295	0.089	0.009	
	N	51	51	51	51	51	51

Figure 6.24 Management Organisation (SEH) and Interventions

From the bivariate analyses, results from variables (1.24 verses 2.9) indicate that there is a high likelihood that a relationship may exist. The statistical significance of 0.001 indicates that a relationship can be confirmed as acceptable statistically.

Understanding the technologies that were fitted could have affected the understanding of the fitting process here.

Qu 2.6 was a clear explanation regarding the technologies fitted shows clear statistical significance with:-

Qu-2.17 Does the installation meet your expectation.

P- value < 0.05 (0.043)

Qu- 2.18 How approachable were the estates department (SEH)

P- value < 0.05 (0.002)

Qu_2.24 Are you familiar with the technologies fitted.

P- value < 0.05 (0.019)

The results indicate that there was a strong relationship between (SEH), the technologies fitted and the installation. This was further reinforced from the results from Qu_2.18 How approachable were the estates department and Qu_2.24 Are you familiar with the technologies providing a significant value of (0.009).

It can also be assumed that the correlation of 0.548 value falls between (0.4 to 0.6) this can be considered as acceptable for variables (2.17 & 2.18) identifying a relationship between (SEH) and the installation meeting the occupants' expectations may exist

6.2.6 SUMMARY

This section has identified several strong bivariate results found within this study identifying the strength of relationships between two variables. Further investigated within the study may identify if any other influences may have affected the results. For example, how often do you use the internet may indicate how good are your internet skills are, the more you use the internet the better you become at it. However, this could have been influenced by the support provided by from the management organisations throughout the project.

6.3 MULTIVARIATE STATISTICS: PRINCIPAL COMPONENT ANALYSIS

PCA has been selected for this research as a tool to investigate and reduce a number of variables to a smaller defined set. The 100-year-old, mathematical process originally investigated by Karl Person (1901) allowed applications into fields including ecology and psychology. The process progressed further in the 1960s due to the nature and intensity of calculations required to apply the procedure (Mackie & Ratajczak 1993) and the use of computer software.

Principal component analysis (PCA) has the capability to reduce the number of variables in a dataset by identifying the pattern of correlations or covariance's between them. According to Reyment and Savazzi (1999) the reduced dimensions obtained by the PCA transformation are linear combinations of the observed variables. By rationalizing or reducing the number of variables, a smaller data set is identified, classifying the relationship between the variables and allowing the information to be grouped.

Jolliffe (2002) identifies that when PCA is used for data reduction or exploratory purposes, normality is not a critical assumption; consequently, there is no great need to transform the data to approach the normal distribution.

Prior to using PCA, data were divided into two groups: Phase 1 and Phase 2 and classified as either nominal or ordinal allowing the analysis to be consistent. Subsequently, the PCA analysis was carried out using IBM SPSS 21 software and 'R'. The PCA analysis were performed using a combination of the scree plot inflexion point criterion and the Kaiser criterion for component selection *(the results are shown in table 6.1 and 6.2).* The line graph '*scree plot*' presents the total number of components based on the amount of variables used. When a distinct change in curvature is noted on the graph, the '*inflection point'* can be determined. Components above this point are deemed to have the strongest weightings and are therefore used in this study.

The study was based over a two-year period; a questionnaire was carefully designed to look at characteristics, behaviour of occupants, and energy consumption. The second study was similar to study 1 with additional aftercare section. The purpose of the second study was to compare results obtained from study 1 and investigate whether any changes in the results occurred and what may have caused these to happen. The project was all about energy consumption, reduction in usage and behaviour.

6.3.1 PHASE 1 STUDY

The scree plot inflexion point was used to define how many components should be retained, as components with eigenvalues below this point (even if larger than one) account for much less variance than the first components. From the scree plot in *Figure 6.25*, twenty-seven variables -ordinal (Likert scale) were used in this part of the study, six components show eigenvalues above the inflexion point for the dataset. *Figure 6.26* represents the results using 12 variables (nominal scale) where it can be observed that three components show eigenvalues above the inflexion point for the dataset. The results for both nominal and ordinal data are shown in Table 6.1*.*

6.3.1.1 (A) RESULTS-SCREE PLOT – LIKERT SCALE/ORDINAL DATA

In figure 6.25 six components are clearly shown above the inflection point

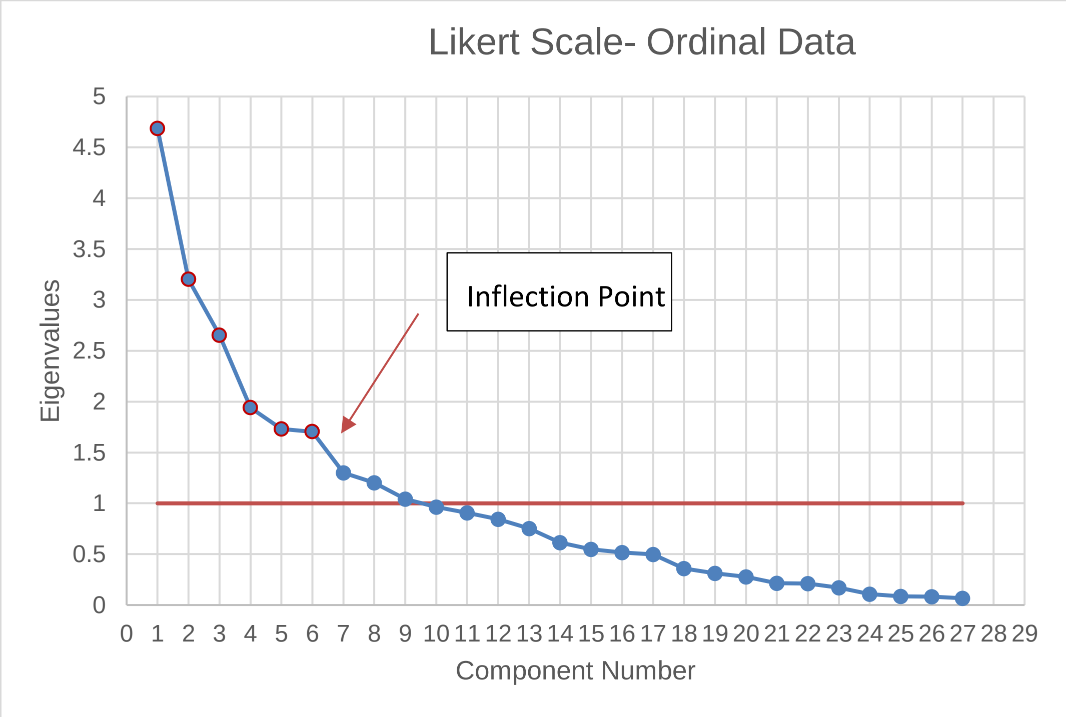


Figure 6.25 Scree plot, Inflection point –Likert scale (Phase 1).

6.3.1.1 (b) Results-Scree plot - Nominal Data

In Figure 6.26 Three components are clearly shown above the inflection point

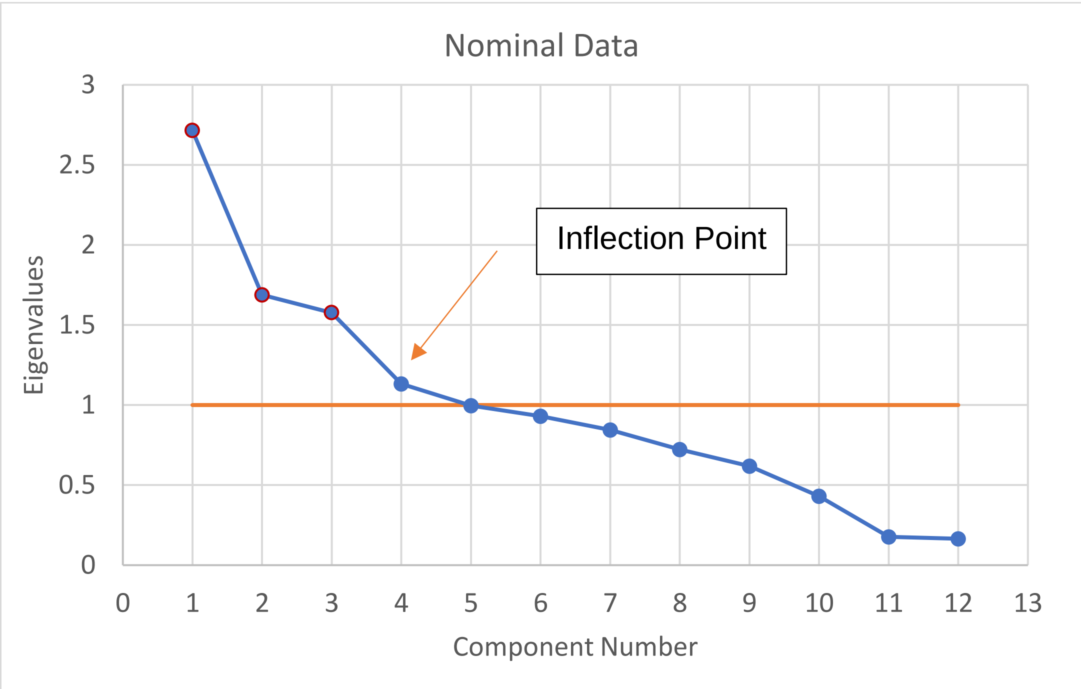


Figure 6.26 Scree plot, Inflection point –Nominal scale (Phase 1).

6.3.1.2 SUMMARY DATA FOR STAGE 1 AND STAGE 2

[PCA- stage 1] classifies the variables used in phase 1 for the data analyses using PCA, 27 variables were used and categorised as ordinal data (Likert scale). Additionally, 12 variables represented nominal data in Table 6.1 *stage 1.*

Table 6.1 Summary data for stage 1 and stage 2.

Phase 1- Ordinal-Likert Scale Data		Phase 1- Nominal Data	
PCA – stage 1	**PCA – stage 2**	**PCA – stage 1**	**PCA – stage 2**
Q_1.12	Q_1.12	Q_1.9	Q_1.9
Q_1.14	Q_1.14	Q_1.10	Q_1.10
Q_1.15	Q_1.15	Q_1.13	Q_1.13
Q_1.16	Q_1.16	Q_1.19	-
Q_1.17	Q_1.17	Q_1.20	Q_1.20
Q_1.18	Q_1.18	Q_1.27	-
Q_1.22	-	Q_2.4	-
Q_1.23	Q_1.23	Q_2.5	Q_2.5
Q_1.24	Q_1.24	Q_2.10	Q_2.10
Q_1.26	-	Q_2.11	Q_2.11
Q_1.28	-	Q_2.13	-
Q_2.1	Q_2.1	Q_2.16	Q_2.16
Q_2.3	Q_2.3		
Q_2.6	-		
Q_2.8	Q_2.8		
Q_2.9	Q_2.9		
Q_2.12	Q_2.12		
Q_2.15	Q_2.15		
Q_2.17	Q_2.17		
Q_2.18	-		
Q_2.19	-		
Q_2.20	-		
Q_2.21	Q_2.21		
Q_2.22	Q_2.22		
Q_2.23	Q_2.23		
Q_2.24	Q_2.24		
Q_2.25	Q_2.25		

The final step of the analysis was undertaken by eliminating variables with non-significant loadings from any of the previously calculated components, the results are shown above in [PCA- stage 1] classifies the variables used in phase 1 for the data analyses using PCA, 27 variables were used and categorised as ordinal data (Likert scale). Additionally, 12 variables represented nominal data in Table 6.1 *stage 1.*

Table 6.1 stage 2 for both ordinal and nominal data. Variables with low or week loadings were removed from the study, ordinal data now reduced from 27-20 variables and nominal data from 12- 8 variables. The results of which are shown in [Table 6.2 *& rotated component matrix & Table 6.4 Summary Data]*

In Table 6.2 & 6.4 results have been categorised into the following sections: -

Ordinal data-Likert scale

- Internet use
- Energy usage monitoring
- Motivation for new technologies
- Energy saving behaviour
- Knowledge of new technologies
- Technologies fitting and delay

Nominal Scale

Internet

Technologies/guides

Eco clinic/Thermostats

The final step of the analysis was undertaken by eliminating variables with non-significant loadings onto any of the previously calculated components.

6.3.1.3 PHASE 1. ROTATED MATRIX-ORDINAL DATA

In table 6.2 shows the rotated component matrix for ordinal (Likert) data, where the loading of the elements onto each component can be observed. The elements with highest loadings are summarised in *Table 6.4*, and represented in the component scree plots in *Figure 6.25.*

Table 6.2 Rotated Matrix - [phase 1]- Ordinal (Likert Scale).

NO	QUESTION – LIKER SCALE DATA (PHASE 1)	INTERNET USE	ENERGY USAGE MONITORING	MOTIVATION FOR NEW TECHNOLOGIES	ENERGY SAVING BEHAVIOUR	KNOWLEDGE OF NEW TECHNOLOGIES	TECHNOLOGIES FITTING /DELAY
Q_1.12	How would you rate your computer skills	***0.73***	0.02	0.15	-0.01	-0.04	-0.09
Q_1.14	How often do you use the internet	***0.85***	-0.07	0.14	0.01	0.23	-0.13
Q_1.15	How often do you shop on line	***0.88***	0.1	0	0.07	-0.02	0.05
Q_1.16	How often do you listen to music on line	***0.78***	0.24	0.03	0.07	0.28	0.11
Q_1.17	How often do you pay bills on line	***0.68***	0.13	0.08	-0.15	-0.35	0.14
Q_1.18	Is the heating supplemented by say electric fire	-0.22	0.29	0.34	***-0.65***	0.03	0
Q_1.23	Do you switch of lights when leaving a room	-0.19	0.19	0.12	***0.62***	-0.09	0.22
Q_1.24	Do you know what energy utilities are?	0.22	0.19	0.4	***0.63***	0.08	0.04
Q_2.1	What is your awareness about energy usage?	0.12	***0.66***	0.16	0.33	0.07	0.25
Q_2.3	How often do you monitor your energy usage?	0.08	***0.88***	0.01	0.04	-0.06	-0.06
Q_2.8	Was the fitted process carried out within the times specified?	-0.06	-0.08	-0.05	0.01	0.1	***0.88***
Q_2.9	Have you had any problems with the installation process?	-0.17	0.03	0.08	***0.7***	-0.11	-0.42
Q_2.12	Do you know how your smart meter works?	0.13	0.07	-0.08	0.12	***0.77***	-0.05
Q_2.15	Has any energy reduction been noted?	-0.18	***0.62***	-0.04	-0.04	0.21	-0.37
Q_2.17	Does the installation meet your expectations?	-0.2	-0.04	0.03	-0.21	***0.74***	0.12
Q_2.21	Did you sign up for new energy technology to save money?	0.47	-0.18	***0.67***	-0.09	0.19	-0.13
Q_2.22	Did you sign up for new energy technology to reduce the carbon footprint?	0.01	0.1	***0.85***	0.09	-0.08	-0.05
Q_2.23	Did you sign up for new energy technology to improve your well-being?	0.1	0.21	***0.75***	0.12	0.09	0.04
Q_2.24	Are you familiar with the technology or technologies that have been installed?	0.26	0.04	0.33	-0.11	***0.61***	0.1
Q_2.25	Do you monitor your energy use?	0.22	***0.71***	0.2	-0.04	-0.05	-0.03

6.3.1.4 PHASE 1. ROTATED MATRIX-NOMINAL DATA

In Table 6.3 shows the rotated component matrix for nominal data, where the loading of the elements onto each component can be observed. The elements with highest loadings are summarised in *Table 6.4*, and represented in the component scree plots in *Figure 6.25.*

Table 6.3 Rotated Matrix- [phase 1] - (Nominal Data)

NO	QUESTION – NOMINAL DATA (PHASE 1)	INTERNET	TECHNOLOGIES/GUIDES	ECO CLINIC / THERMOSTAT
Q1.9	How much water is used a month	0.26	***-0.65***	0.14
Q1.10	Do you own a computer	***0.93***	0.04	-0.04
Q1.13	Have you access to the internet	***0.89***	0.08	-0.21
Q1.20	Do you have a mobile phone	***0.82***	-0.2	0.14
Q2.5	Do you know which technologies have been fitted in your property?	0.14	***0.65***	0.01
Q2.10	Have you attended any Eco clinics on a Wednesday?	0	0.06	***0.8***
Q2.11	Have any user guides been provided yet to you?	-0.01	***0.75***	0.13
Q2.16	If your energy bills have been reduced, will you turn up the thermostat to obtain better level of comfort or benefit from the saving?	-0.06	-0.03	***0.77***

6.3.1.5 Summary Data (Phase 1) Ordinal data -Likert scale

In Table 6.4 [phase1] results were extrapolated from Table 6.2 rotated matrix and categorised as per there weighting the stronger variables [1.0-0.7].

Table 6.4 Summary Data (Phase 1) Likert scale. Ordinal data

Components – Ordinal. Likert Scale Data (Phase 1)	Loading to the components		
	[1.0-0.7]	**[0.7-0.6]**	**[0.6-0.5]**
INTERNET USE	Q_1.12 Q_1.14 Q_1.15 Q_1.16	Q_1.17	-
ENERGY USAGE MONITORING	Q_2.3 Q_2.25	Q_2.1 Q_2.15	-
MOTIVATION FOR NEW TECHNOLOGIES	Q_2.22 Q_2.23	Q_2.21	-
ENERGY SAVING BEHAVIOUR	Q_2.9	Q_1.18 Q_1.23 Q_1.24	-
KNOWLEDGE OF NEW TECHNOLOGIES	Q_2.12 Q_2.17	Q_2.24	-
TECHNOLOGIES FITTING /DELAY	Q_2.8	-	-

6.3.1.6 Summary Data (Phase 1) Nominal data

In Table 6.5 [phase1] results were extrapolated from *Table 6.3* rotated matrix and categorised as per there weighting the stronger variables [1.0-0.7]

Table 6.5 Summary Data (Phase 1) Nominal Data

Components - Nominal Data (Phase 1)	Loading to the components		
	[1.0-0.7]	**[0.7-0.6]**	**[0.6-0.5]**
INTERNET USE	Q_1.10 Q_1.13 Q_1.20	-	-
TECHNOLOGIES/GUIDES	Q_2.11	Q_1.9 Q_2.5	-
ECO CLINIC / THERMOSTAT	Q_2.10 Q_2.16	-	-

6.3.1.7 PHASE 1 –QUESTIONNAIRE

Results from the first questionnaire [Phase 1] were categorized into two groups, Likert scale 1-10 and nominal data results. Questions designed using the Likert scale methods provided occupants with a choice of answer between 1-10, 1 generally being the lowest and 10 the highest or better result in most cases. Nominal data was generally classified as a yes/no answer. These results were then placed through the PCA software and the results provided each question with a value between 0 and 1. The strongest results were presented in [Tables 6.4 & 6.5 Summary data- Phase 1] and further categorized into three distinctive groups [1.0-0.7], [0.7-0.6] and [0.6-0.5] the first group [1.0-0.7] providing the strongest results. Questions with results less than 0.5 were excluded from the data set.

6.3.1.8 RESULTS PHASE 1 PCA. ORDINAL DATA-LIKERT SCALE

The information set out below presents the results from the scree plot [*figure 6.2]*, *[*Table 6.2 *rotated matrix*] and [*Table 6.4 summary data].* Results from the scree plots inflection point shows six distinctive strong components that form the structure for this section.

Component 1 - Internet use

This section classified questions with a link to the internet, questions were based around internet usage, IT skills and on-line activity including listening to music and paying bills on line. Five results obtained from the analyses with loadings above 0.5 as shown in Table 6.4, four of which were found to be stronger and were categorised in the higher section [1-0.7] The results indicate that there was a very strong relationship with occupants that used the internet, internet skills, listening to music on line and shopping on line. Q_1.14 [How often do you use the internet] & Q_1.15 [How often do you shop on line] where classified with the highest values within this component.

Q_1.12	How would you rate your computer skills	0.73
Q_1.14	How often do you use the internet	**0.85**
Q_1.15	How often do you shop on line	**0.88**
Q_1.16	How often do you listen to music on line	0.78
Q_1.17	How often do you pay bills on line	0.68

Component 2 - Energy usage monitoring

This section classified questions with a link to energy usage, awareness, and energy monitoring, four results were found with loadings above 0.5, two of which were found to be stronger and were categorised in the higher section [1-0.7]. The results indicate that there was a strong relationship with Q_2.3 [How often do you monitor your energy usage?] & Q_2.25 [Do you monitor your energy use?]

Q_2.1	What is your awareness about energy usage?	0.66
Q_2.3	How often do you monitor your energy usage?	**0.88**
Q_2.15	Has any energy reduction been noted?	0.62
Q_2.25	Do you monitor your energy use?	**0.71**

Component 3 - Motivation for new technologies

This section classified questions with links to motivation and the technology's, three results were found with loadings above 0.5, two of which were found to be stronger and were categorised in the higher section [1-0.7]. The results indicate that there was a strong relationship in Q_2.22 [Did you sign up for new energy technology to reduce the carbon footprint?]

Q_2.21	Did you sign up for new energy technology to save money?	0.67

Q_2.22 Did you sign up for new energy technology to reduce the carbon footprint?

0.85

Q_2.23 Did you sign up for new energy technology to improve your well-being?

0.75

Component 4 - Energy saving behaviour

This section classified questions linked to energy saving behaviour of the occupants, four results were found with loadings above 0.5, one of which was found to be stronger and was categorised in the higher section [1-0.7]. The results indicate that there was a strong relationship with Q_2.9 [Have you had any problems with the installation process?]

Q_1.18 Is the heating supplemented by say electric fire? -0.65

Q_1.23 Do you switch of lights when leaving a room? 0.62

Q_1.24 Do you know what energy utilities are? 0.63

Q_2.9 Have you had any problems with the installation process?

0.70

Component 5- Knowledge of new technologies

This section classified questions with links to knowledge of new technologies three results were found with loadings above 0.5, two of which were found to be stronger and were categorised in the higher section [1-0.7]. The results indicate that there was a strong relationship in question 2.12, [Do you know how the smart meter works?].

Q_2.12	Do you know how your smart meter works?	**0.77**
Q_2.17	Does the installation meet your expectations?	0.74
Q_2.24	Are you familiar with the technology or technologies that have been installed?	0.61

Component 6- Technologies fitting /delay

This section-classified question with links to the fitting of the technology's and time delay one result was found with loadings above 0.5 in the higher category [1-0.7]. The results indicate that there was a strong relationship in question 2.8_ [Was the fitted process carried out within the times specified.]

Q_	2.8	Was the fitted process carried out within the times specified.	**0.88**

6.3.1.9 RESULTS PHASE 1 PCA. NOMINAL DATA

The information set out below presents the results from the scree plot *[figure 6.26], [table 6.3 rotated matrix]* and *[*

Table 6.5 *summary data].* Results from the scree plots inflection point. Results above the scree plots inflection point shows three distinctive strong components, which form the structure for this section.

Component 1 - Internet use

This section classified questions with links to the use of the internet, three results were found with loadings above 0.5, all of which were found to be stronger and were categorised in the higher section [1-0.7]. The results indicate that the strongest relationship was found to be question Q_1.10 [Do you own a computer].

Q_1.10	Do you own a computer?	**0.93**
Q_1.13	Have you access to the internet?	0.89
Q_1.20	Do you have a mobile phone?	0.82

Component 2 - Technologies/guides

This section classified questions with a link to the technologies that were fitted along with the user manuals and guides. Three results were obtained from the analyses with loadings above 0.5, one result was found with loadings in the higher category [1-0.7]. The results indicate that there was a strong relationship in question Q-2.11 [Have any user guides been provided yet to you?]

Q_1.9	How much water is used a month.	-0.65
Q_2.5	Do you know which technologies have been fitted in your property?	0.65
Q_2.11	Have any user guides been provided yet to you?	**0.75**

Component 3 - Eco Clinic / thermostat

This section classified questions with a links to the Eco Clinic and thermostats, only one result with a loading above 0.5 was obtained here related to the eco clinic. Q_2.10 [Have you attended any Eco clinics on a Wednesday?].

Q_2.10 Have you attended any Eco clinics on a Wednesday? **0.8**

6.3.1.10 SUMMARY

This section has looked at variables from phase 1 of the questionnaire, which were categorised as either nominal or ordinal data. This data was subjected to PCA using the scree plot inflection method in which results from above the inflection point provided the strongest components that would be analysed. Variables forming each component have been clearly shown in *tables 6.2 & 6.3* rotating matrix and further summarised in *Summary data tables 6.4 & 6.5* to categorise the variables according to their values.

6.3.2 PHASE 2 STUDY - 2ND QUESTIONNAIRE

This section will investigate data taken from the 2nd questionnaire carried out approximately one year after the first round of questionnaires were undertaken. The scree plot inflexion point was used again to define how many components should be retained. From the scree plot in Table 2.8, twenty-seven variables - ordinal (Likert scale) were used in this part of the study, three components now show eigenvalues above the inflexion point for the dataset. Table 2.9 represents the results using 12 variables (nominal scale) where it can be observed that two components now show eigenvalues above the inflexion point for the dataset. The results for both nominal and ordinal data are shown in Table 6.6

6.3.2.1 RESULTS-SCREE PLOT- LIKERT SCALE /ORDINAL DATA

In Figure 6.27 three components are shown above the inflection point.

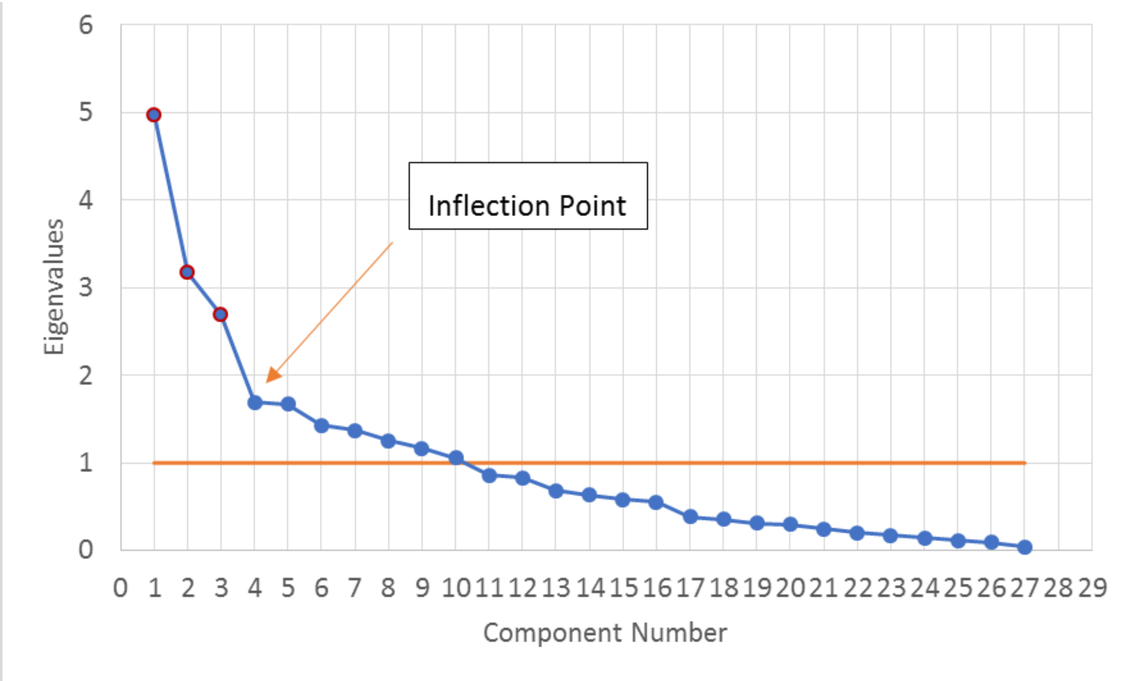


Figure 6.27 Scree plot, Inflection point –Likert scale (Phase 2)

In Figure 6.28 two components are shown above the inflection point

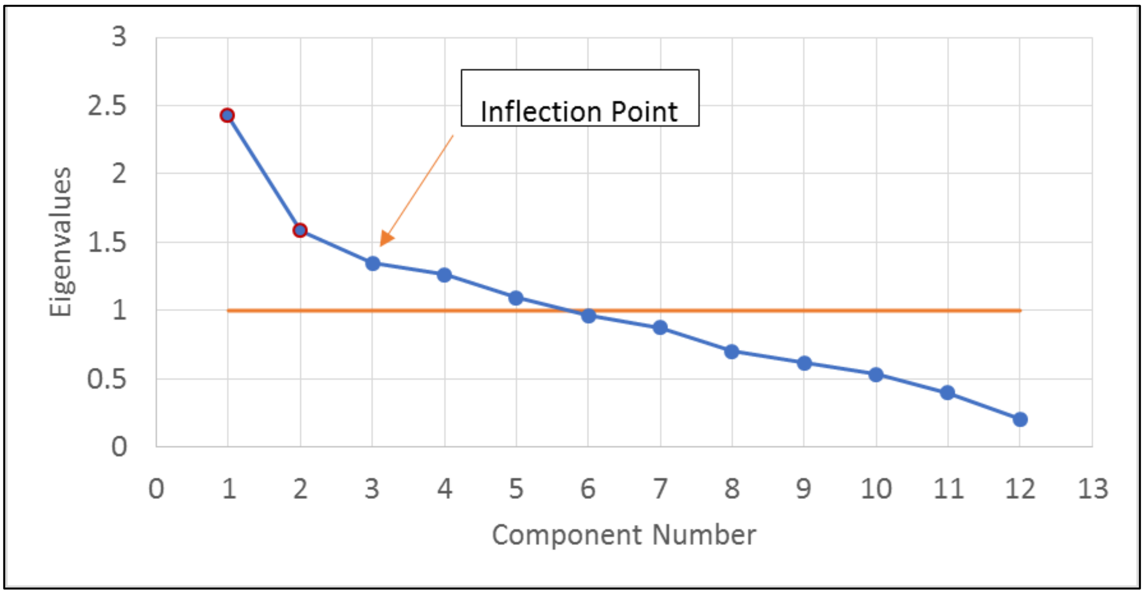


Figure 6.28 Scree plot, Inflection point –Nominal scale (Phase 2).

6.3.2.2 Summary data for stage 1 and stage 2

In Table 6.6 variables with values less than [0.5] that were subjected to PCA analyses have been removed in phase 2.

Table 6.6 Summary data for stage 1 and stage 2 (Phase 2).

Phase 2- Liker Scale Data		Phase 2- Nominal Data	
PCA – stage 1	**PCA – stage 2**	**PCA – stage 1**	**PCA – stage 2**
Q_1.12	Q_1.12	Q1.9	-
Q_1.14	Q_1.14	Q1.10	Q_1.10
Q_1.15	Q_1.15	Q1.13	Q_1.13
Q_1.16	Q_1.16	Q1.19	-
Q_1.17	Q_1.17	Q1.20	Q_1.20
Q_1.18	-	Q1.27	-
Q_1.22	-	Q2.4	Q_2.4
Q_1.23	Q_1.23	Q2.5	Q_2.5
Q_1.24	Q_1.24	Q2.10	Q_2.10
Q_1.26	-	Q2.11	Q_2.11
Q_1.28	-	Q2.13	-
Q_2.1	Q_2.1	Q2.16	-
Q_2.3	Q_2.3		
Q_2.6	Q_2.6		
Q_2.8	-		
Q_2.9	Q_2.9		
Q_2.12	-		
Q_2.15	Q_2.15		
Q_2.17	Q_2.17		
Q_2.18	Q_2.18		
Q_2.19	-		
Q_2.20	-		
Q_2.21	-		
Q_2.22	Q_2.22		
Q_2.23	Q_2.23		
Q_2.24	Q_2.24		
Q_2.25	Q_2.25		

Table 6.6 [PCA- stage 1] classifies the variables used in **[phase 2]** for the data analyses using PCA, 27 variables were used again and categorised as ordinal data (Likert scale). Additionally, 12 variables represented nominal data in Table 6.6 stage 1.

Similar to the investigation in Phase 1 variables with non-significant loadings were removed, the results are shown above in Table 6.6 [stage 2] for both ordinal and nominal data. It can be seen that some variables with low or week weightings were removed from the study, ordinal data has now reduced from 27-18 variables and nominal data from 12- 7 variables. The results of which are shown in *tables 6.7 & 6.8* rotated component matrix.

In *tables, 6.9 & 6.10* results have been further categorised into the following sections: -

Ordinal data- Likert scale

Internet use

Energy usage monitoring/ Motivation for new technologies

Knowledge of new technologies

Nominal Scale

Internet

Technologies, guides/ Eco clinic

6.3.2.2.1 SUMMARY

It can be seen, that the number of components have now reduced in Phase 2 regrouping and combining retaining the stronger variables.

6.3.2.3 PHASE 2. ROTATED MATRIX-ORDINAL DATA

In table 6.7 shows the rotated component matrix for ordinal (Likert) data, where the loadings of the elements onto each component can be observed. The elements with the highest loadings are summarised in Table 6.9 and represented in component scree plots in figure 6.27

6.3.2.4 PHASE 2. ROTATED MATRIX-NOMINAL DATA

In table 6.8 shows the rotated component matrix for nominal data, where the loadings of the elements onto each component can be observed. The elements with the highest loadings are summarised in *Table 6.10* and represented in component scree plots in *figure 6.28*

Table 6.7 Rotated Matrix- [phase 2] - Ordinal (Likert Scale)

NO	QUESTION – LIKER SCALE DATA (PHASE 2)	INTERNET USE	ENERGY USAGE MONITORING/ MOTIVATION FOR NEW TECHNOLOGIES	TECHNOLOGIES KNOWLEDGE/ FITTING
Q1.12	How would you rate your computer skills	***0.84***	0.05	-0.13
Q1.14	How often do you use the internet	***0.85***	0.04	0.11
Q1.15	How often do you shop on line	***0.84***	0.09	-0.07
Q1.16	How often do you listen to music on line	***0.83***	0.19	-0.11
Q1.17	How often do you pay bills on line	***0.69***	0	0.02
Q1.23	Do you switch of lights when leaving a room	-0.2	***0.51***	-0.18
Q1.24	Do you know what energy utilities are?	0.25	***0.66***	-0.1
Q2.1	What is your awareness about energy usage?	0.15	***0.64***	-0.15
Q2.3	How often do you monitor your energy usage?	-0.06	***0.55***	-0.33
Q2.6	Was a clear explanation provided regarding the technologies being fitted?	0.01	-0.18	***0.64***
Q2.9	Have you had any problems with the installation process?	-0.19	***0.51***	-0.21
Q2.15	Has any energy reduction been noted?	-0.01	0.6	0.25
Q2.17	Does the installation meet your expectations?	-0.26	-0.06	***0.73***
Q2.18	How approachable were the Estate department during the installation?	-0.15	-0.12	***0.78***
Q2.22	Did you sign up for new energy technology to reduce the carbon footprint?	0.14	***0.6***	0.25
Q2.23	Did you sign up for new energy technology to improve your well-being?	0.3	***0.64***	0.19
Q2.24	Are you familiar with the technology or technologies that have been installed?	0.32	0.22	***0.65***
Q2.25	Do you monitor your energy use?	0.21	***0.6***	-0.16

Table 6.8 Rotated Matrix- [phase 2] (Nominal Data)

NO	QUESTION – NOMINAL DATA (PHASE 2)	INTERNET USE	TECHNOLOGIES, GUIDE & ECOCLINIC
Q_1.10	Do you own a computer	***0.87***	0.16
Q1.13	Have you access to the internet	***0.85***	0.13
Q1.20	Do you have a mobile phone	***0.67***	-0.14
Q2.4	Do you know your expenditure here?	0.4	***0.51***
Q2.5	Do you know which technologies have been fitted in your property?	0.02	***0.75***
Q2.10	Have you attended any Eco clinics on a Wednesday?	-0.04	***0.62***
Q2.11	Have any user guides been provided yet to you?	0.05	***0.55***

6.3.2.5 SUMMARY DATA (PHASE 2) ORDINAL DATA -LIKERT SCALE

In Table 6.9 [phase2] results were extrapolated from Table 6.8 rotated matrix and categorised as per there weighting the stronger variables [1.0-0.7]

Table 6.9 Summary Data (Phase 2) Likert scale data

Components – Likert Scale Data (Phase 2)	Loading to the components		
	[1.0-0.7]	**[0.7-0.6]**	**[0.6-0.5]**
INTERNET USE	Q1.12 Q1.14 Q1.15 Q1.16	Q1.17	
ENERGY USAGE MONITORING/ MOTIVATION FOR NEW TECHNOLOGIES		Q1.24 Q2.1 Q2.15 Q2.22 Q2.23 Q2.25	Q1.23 Q2.3 Q2.9
TECHNOLOGIES KNOWLEDGE/ FITTING	Q2.17 Q2.18	Q2.6 Q2.24	

6.3.2.6 SUMMARY DATA (PHASE 2) NOMINAL DATA

In Table 6.10 [phase2] results were extrapolated from table 6.8 rotated matrix and categorised as per there weighting the stronger variables [1.0-0.7]

Table 6.10 Summary Data (Phase 2) nominal data.

Components - Nominal Data (Phase 2)	Loading to the components		
	[1.0-0.7]	**[0.7-0.6]**	**[0.6-0.5]**
INTERNET USE	Q_1.10 Q_1.13	Q_1.20	
TECHNOLOGIES, GUIDE & ECO CLINIC	Q_2.5	Q_2.10	Q_2.4 Q_2.11

6.3.2.7 Phase 2 – 2nd Questionnaire-

Similar to the first questionnaire [Phase 1], results taken from the 2nd questionnaire [phase 2] were categorized into two groups, Likert/ ordinal scale 1-10 and nominal data results. Questions designed using the Likert scale methods provided occupants with a choice of answer between 1-10, 1 generally being the lowest and 10 the highest or better result in most cases. Nominal data was generally classified as a yes/no answer. These results were then placed through the PCA software and the results provided each question with a value between 0 and 1.

The strongest results were presented in [*Tables 6.9 & 6.10 Summary data-Phase 2*] and further categorized into three distinctive groups [1.0-0.7], [0.7-0.6] and [0.6-0.5] the first group [1.0-0.7] providing the strongest results. Questions with results less than 0.5 were excluded from the data set.

6.3.2.8 RESULTS PHASE 2 PCA. ORDINAL DATA-LIKERT SCALE

The information set out below presents the results from the [figure 6.27 scree plot], [Table 6.7 rotated matrix] and [Table 6.9 summary data]. Results from the scree plots inflection point indicate that the number of components now reduce from six to three in phase 2, several components appear to merge, and this now forms the structure for this section.

Component 1 – Internet usage

This section-classified question with a link to the internet, questions were based around internet usage, IT skills and on- line activity including listening to music and paying bills on line. Five results were obtained from the analyses with loadings above 0.5, four results were categorised in the higher band [1.0-0.7] similar to phase one.

Q_1.12	How would you rate your computer skills	0.84
Q_1.14	How often do you use the internet	**0.85**
Q_1.15	How often do you shop on line	**0.84**
Q_1.16	How often do you listen to music on line	0.83
Q_1.17	How often do you pay bills on line	0.69

Component 2 - Energy Usage Monitoring & Motivation for New Technology's

This section-classified question with links to energy usage, monitoring and the benefits of the technology. Nine results were obtained from the analyses with loadings above 0.5 six results with loadings in the mid category [0.7-0.6] and three in the lower category [0.6-0.5]. No results were found in the higher band, the strongest for this component was Q_1.24 [Do you know what energy utilities are?].

Q-1.23	Do you switch of lights when leaving a room?	0.51
Q_1.24	Do you know what energy utilities are?	**0.66**
Q_2.1	What is your awareness about energy usage?	0.64
Q_2.3	How often do you monitor your energy usage?	0.55
Q_2.9	Have you had any problems with the installation process?	0.51
Q_2.15	Has any energy reduction been noted?	0.60
Q_2.22	Did you sign up for new energy technology to reduce the carbon footprint?	0.60
Q_2.23	Did you sign up for new energy technology to improve your well-being?	0.64
Q_2.25	Do you monitor your energy use?	0.60

Component 3 – Technologies and the fitting

This section classified the technologies along with the fitting process. Four results were obtained from the analyses with loadings above 0.5, two results were found with loadings in the higher category [1-0.7]. The results indicate that there was a strong relationship in Q_2.18 [How approachable were the Estate department during the installation?].

Q_2.6	Was a clear explanation provided regarding the technologies being fitted?	0.64
Q_2.17	Does the installation meet your expectations?	0.73
Q_2.18	How approachable were the Estate department during the installation?	**0.78**
Q_2.24	Are you familiar with the technology or technologies that have been installed?	0.65

6.3.2.9 RESULTS PHASE 2 PCA. NOMINAL DATA

The information set out below presents the results from the *[figure 6.28 scree plot], [Table 6.8 rotated matrix]* and [*Table 6.10 summary data*]. Results from the scree plots inflection point indicate that the number of components now reduce from three to two in phase 2, several components appear to merge, and this now forms the structure for this section.

Component 1 - Internet use

This section classified questions with links to the use of the internet, three results were found with loadings above 0.5, two of which were found to be stronger and were categorised in the higher section [1-0.7]. The results indicate that the strongest relationship was found to be question Q_1.10 [Do you own a computer].

Q_1.10	Do you own a computer?	**0.87**
Q_1.13	Have you access to the internet	0.85
Q_1.20	Do you have a mobile phone	0.67

Component 2 - Technologies, guide and eco-clinic

This section-classified question with a link to the technologies that were fitted along with the user manuals, guides and attending the eco clinic. Four results were obtained from the analyses with loadings above 0.5, one result was found with loadings in the higher category [1-0.7]. The results indicate, that there was a strong relationship in question Q_2.5 [Do you know which technologies have been fitted in your property?]

Q_2.4	Do you know your expenditure here? (Energy usage)	0.51
Q_2.5	Do you know which technologies have been fitted in your property?	**0.75**
Q_2.10	Have you attended any Eco clinics on a Wednesday?	

0.62

Q_2.11 Have any user guides been provided yet to you?

0.55

6.3.2.10 SUMMARY

This section looked at variables from [phase 2 – 2nd Questionnaire] where questions were categorised as either nominal or ordinal data. Similar to phase 1 data was subjected to PCA using the scree plot inflection method in which results from above the inflection point provided the strongest components that would be analysed. Variable forming each component have been clearly shown in *tables 6.7 & 6.8* rotating matrix and further summarise in tables 6.9 & 6.10 to categorise the variables according to their values. Distinct changes in the number of components in phase 2 became evident and this will be discussed in the section below.

6.3.3 PHASE 1 VS PHASE 2

Table 6.11 Summary Data- Phase 1 vs Phase 2 Likert scale.

<table>
<tr><td rowspan="2">Components – Likert
Scale Data
(Phase 1)</td><td colspan="2">Loading to the
components</td><td rowspan="2">Components – Likert
Scale Data
(Phase 2)</td><td colspan="2">Loading to the
components</td></tr>
<tr><td>[1.0-0.7]</td><td>[0.7-0.6]</td><td>[1.0-0.7]</td><td>[0.7-0.6]</td></tr>
<tr><td>INTERNET USE</td><td>Q_1.12
Q_1.14
Q_1.15
Q_1.16</td><td>Q_1.17</td><td>INTERNET USE</td><td>Q1.12
Q1.14
Q1.15
Q1.16</td><td>Q1.17</td></tr>
<tr><td>ENERGY USAGE
MONITORING</td><td>Q_2.3
Q_2.25</td><td>Q_2.1
Q_2.15</td><td rowspan="3">ENERGY USAGE
MONITORING/
MOTIVATION FOR NEW
TECHNOLOGIES
ENERGY SAVING
BEHAVIOUR</td><td rowspan="3">-</td><td rowspan="3">Q1.24
Q2.1
Q2.15
Q2.22
Q2.23
Q2.25</td></tr>
<tr><td>MOTIVATION FOR NEW
TECHNOLOGIES</td><td>Q_2.22
Q_2.23</td><td>Q_2.21</td></tr>
<tr><td>ENERGY SAVING
BEHAVIOUR</td><td>Q_2.9</td><td>Q_1.18
Q_1.23
Q_1.24</td></tr>
<tr><td>KNOWLEDGE OF NEW
TECHNOLOGIES</td><td>Q_2.12
Q_2.17</td><td>Q_2.24</td><td rowspan="2">TECHNOLOGIES
KNOWLEDGE/ FITTING</td><td rowspan="2">Q2.17
Q2.18</td><td rowspan="2">Q2.6
Q2.24</td></tr>
<tr><td>TECHNOLOGIES
FITTING /DELAY</td><td>Q_2.8</td><td>-</td></tr>
</table>

Summary Table 6.11 compares PCA results from Phase 1 & Phase 2 [ordinal scale data]. Results in Phase 2 have influenced several groups to merge altering the loading values to the components. It can be seen that six components from Phase 1 has now reduced to 3 components.

Component 1- Internet use

Internet use in Phase 2 still replicates similar features results found in Phase 1, loading have improved slightly here.

Component 2 - ENERGY USAGE MONITORING/ MOTIVATION FOR NEW TECHNOLOGIES /ENERGY SAVING BEHAVIOUR

Phase 2 indicates that three components have merged to form one component. Six variables have weighting between [0.7-0.6], there are no variables with strong classifications in [1.0-0.7] range.

Component 3- TECHNOLOGIES KNOWLEDGE/ FITTING

Phase 2 indicates that two components have merged to form one component, 2 variables have weightings between [0.7-0.6] and two with strong classifications in [1.0-0.7] range.

6.3.3.1 DISCUSSION- PHASE 1 VS PHASE 2 -ORDINAL

The results suggest that in phase 2 the weighting of the variables supporting the internet remain similar to phase 1 and subsequently can be considered as significant results. However, it can be assumed that in component 2 variables with strong classifications [1.0-0.7] that have now been re-classified into the [0.7-0.6] range have a reduced correlation / strength. Component 3 reveals some interesting results here [Knowledge of Technologies], phase 1 Q_2.12 Do you know how a smart meter works & Q_2.17 Does the installation meet your expectations change in phase 2. Q_12 does not receive any classification here; this may have been because this intervention was not commissioned at the end of this study. However, a strong correlation could be observed from Q-2.17 in both phases, additional there is a strong relationship with SHE here with Q_ 2.18, being categorised with a high loading.

Table 6.12 Summary Data- Phase 1 vs Phase 2. Nominal data.

<table>
<tr><th rowspan="2">Components – Nominal Data
(Phase 1)</th><th colspan="2">Loading to the components</th><th rowspan="2">Components – Nominal Data
(Phase 2)</th><th colspan="2">Loading to the components</th></tr>
<tr><th>[1.0-0.7]</th><th>[0.7-0.6]</th><th>[1.0-0.7]</th><th>[0.7-0.6]</th></tr>
<tr><td>INTERNET USE</td><td>Q_1.10
Q_1.13
Q_1.20</td><td>-</td><td>INTERNET USE</td><td>Q_1.10
Q_1.13</td><td>Q_1.20</td></tr>
<tr><td>TECHNOLOGIES/GUIDES</td><td>Q_2.11</td><td>Q_1.9
Q_2.5</td><td rowspan="2">TECHNOLOGIES, GUIDE & ECO CLINIC</td><td rowspan="2">Q_2.5</td><td rowspan="2">Q_2.10</td></tr>
<tr><td>ECO CLINIC / THERMOSTAT</td><td>Q_2.10
Q_2.16</td><td>-</td></tr>
</table>

Summary Table 6.12 compares PCA results from Phase 1 & Phase 2 [Nominal scale data]. Results in Phase 2 have influenced several groups to merge altering the loading values to the components. It can be seen that three components from Phase 1 has now reduced to 2 components.

Component 1- Internet use

Internet use in Phase 2 is still replicates similar features results found in Phase 1, loading have improved slightly here which may indicate that internet skills had improved.

Component 2 – Technologies, Guide & Eco Clinic

Phase 2 indicates that two components have merged to form one component. 1 variables have weightings between [0.7-0.6] and 1 variable with a strong classification in [1.0-0.7] range.

6.3.3.2 Discussion- Phase 1 vs Phase 2 -Nominal

Similar to discussions in section 6.3.3.1 component 1- Internet Use, obtains strong results in both phase 1 and phase 2, Q_1.20 however it does re align into the mid category. What is interesting here is that in both nominal and ordinal exploratory investigations the internet has provided significant results for this category. Two components merge to form Component 2 in phase 2, previous variables with high loadings are now reclassified into lower bands, however the result from Q_ 2.5 indicate that this variable has now becomes more significant.

6.3.3.3 Conclusion

Six groups in Phase 1 [ordinal data] consolidate to form three distinctive groups in Phase 2. The strongest variables are still similar the INTERNET classification; however variables in the TECHNOLOGIES KNOWLEDGE/ FITTING classification now realigned. It can be assumed that these results may indicate that behaviour and energy consumption may be influenced using the internet and an understanding of the technologies used. Further supporting these assumptions three groups in Phase 1 [nominal data] consolidate to form two distinctive groups in Phase 2. The strongest results include the INTERNET classification however; variables in the TECHNOLOGIES GUIDE / ECO CLINIC classification are again realigned. Qu-2.5 Do You know which Technologies have been fitted, is now re classified with a higher weighting and must be considered with a high level of importance. It can be assumed that these results may indicate that behaviour and energy consumption may be influenced using the internet and an understanding of the technologies used along with the Eco Clinic.

6.4 CLUSTER ANALYSIS

6.4.1 OVERVIEW OF THE DATA

Similar to the analyses of data carried out in the technology chapter 5 cluster analyses has been chosen in this section as a statistical tool to analyse data into groups, it has the ability to define which groups certain data should belong to. Sharing comparable values clustering is a multivariate procedure that can group rows together that share similar values. Similarities are considered and this form the basis of which group the information is categorised into, the procedure is very well suited for early exploratory data analyses and allows similar data to be grouped together. This method best suits a small sample allowing nominal and ordinal data to be analysed, variables have been compared with properties to see if any relationship exists.

Introduction

The following section presents the results from the cluster analyses, questions with the strongest results are categorised with their property types and grouped as per their strengths. The aim of this section is to investigate occupants' behaviour.

6.4.2 CLUSTERING OF THE OCCUPANTS BASED ON THEIR CHARACTERISTICS

In Table 6.13, properties in Group A-D are characterised by the following questions from phase 1 and phase 2.

Table 6.13 Summary Data- Phase 1 vs Phase 2

	Phase 1		Phase 2
Qu no	1.2		1.2
Qu no	1.3		1.3
Qu no	1.4		1.4
Qu no	1.5		1.5
Qu no	1.6		1.6
Qu no	1.8		1.8
Qu no	Internet use – nom. (1.10)		Internet use – nom. (1.10)
Qu no	1.11		1.11
Qu no	Internet use (1.15)		Internet use (1.14)
Qu no	1.21		1.21
Qu no	-		Energy usage monitoring/ motivation for new technologies (1.24)
Qu no	1.25		1.25
Qu no	2.2		2.2
Qu no	Energy usage monitoring (2.3)		-
Qu no	-		Technologies, guide & eco clinic (2.5)
Qu no	2.7		2.7
Qu no	Technologies fitting /delay (2.8)		-
Qu no	Energy saving behaviour (2.9)		-
Qu no	Eco clinic / thermostat (2.10)		-
Qu no	Technologies/guides (2.11)		-
Qu no	Knowledge of new technologies (2.12)		-
Qu no	2.14		2.14
Qu no	-		Technologies knowledge/ fitting (2.18)
Qu no	Motivation for new technologies (2.22)		

Cluster - Group A

In Table 6.14 Properties in Group A are characterised by the strongest results from phase 1 and phase 2.

Table 6.14 Group A- cluster set

		Group A			Question No					
No	Property	Cluster	P1_Q_1.6	P2_Q_1.6	P1_Q_1.10	P2_Q_1.10	P1_Q_2.7	P2_Q_2.7	P1_Q_2.14	P2_Q_2.14
1	C1	A	1	1	1	1	1	4	5	5
3	C3	A	1	1	1	1	2	2	5	5
6	C6	A	1	1	1	1	1	2	5	5
8	L1	A	1	1	1	1	1	1	5	5
10	L3	A	1	1	1	1	1	1	5	5
11	L4	A	1	1	1	1	1	1	5	5
13	L6	A	1	1	1	1	1	1	5	5
14	L7	A	1	1	1	1	1	1	5	5
15	L8	A	1	1	1	1	1	2	5	5
16	P1	A	1	1	1	1	1	1	5	5
18	P3	A	1	1	2	2	1	1	5	5
19	P4	A	1	1	1	1	1	1	5	5
20	P6	A	1	1	1	1	2	2	5	5
23	P9	A	1	1	2	2	1	1	5	5
24	P10	A	1	1	1	1	1	1	5	5
25	P11	A	1	1	1	1	1	1	5	5
26	P12	A	1	1	1	1	5	5	5	5
27	P13	A	1	1	1	1	1	1	5	5
43	R2	A	1	1	2	2	1	2	3	3

Group A: consists of C1, C3, C6, L1, L3, L4, L6, L7, L8, P1, P3, P4, P6, P9, P10, P11, P12, P13 & R2 properties.

Results from group A, Phase 1 & Phase 2.

Q_1.6 Type of heating [gas]

This entire group received gas heating. (Phase 1 and 2 obtained similar results)

Q_1.10 Do you own a computer? [Internet]

All but three of this group owned a computer. (Phase 1 and 2 obtained similar results)

Q_2.7 Was the explanation conveyed by one of the following methods.

[Technology's explained over the phone]. All but three of

This group confirmed information was conveyed regarding user manuals by phone, phase 2 changed from three to seven occupants.

Q_2.14 How often do you check your energy usage?

[Never check energy usage]

All but one of this group never checked their energy usage. (Phase 1 and 2 obtained similar results)

Summary

All the occupants in this group had gas central heating and most of them owned a computer. Improvements in acknowledging receipt of manuals and advice was improved in phase 2, but most occupants confirmed that they never checked their energy usage in phase 1, there was no improvement here in phase two. This may have been because the Moixa system head not been fully commissioned at this point.

Cluster - Group B

In Table 6.15 Properties in Group B are characterised by the strongest results from phase 1 and phase 2

Table 6.15 Group B- cluster sets

		Group B					Question No											
No	Property	Cluster	P1_Q_1.2	P2_Q_1.2	P1_Q_1.4	P2_Q_1.4	P1_Q_1.6	P2_Q_1.6	P1_Q_1.10	P2_Q_1.10	P1_Q_1.11	P2_Q_1.11	P2_Q_1.14	P1_Q_1.15	P1_Q_2.12	P1_Q_2.14	P2_Q_2.14
2	C2	B	1	1	2	2	1	1	1	1	2	3	3	1	1	5	5
9	L2	B	2	1	2	2	1	1	2	2	1	1	1	1	1	5	5
12	L5	B	1	1	2	2	1	1	2	2	1	1	1	1	10	5	5
21	P7	B	1	1	2	2	1	1	2	2	1	1	1	1	5	5	5
28	P14	B	1	1	2	2	1	1	2	2	1	1	1	1	1	5	5
30	PA2	B	1	1	2	2	2	1	2	2	1	1	1	1	1	5	5
31	PA3	B	1	1	2	2	2	2	2	2	1	1	1	1	1	5	5
34	PB3	B	1	1	2	2	1	1	2	2	1	1	1	1	1	5	5
35	PB4	B	1	1	2	2	1	1	2	2	1	1	1	1	1	5	5
37	PB6	B	1	1	2	2	1	1	2	2	1	1	1	1	1	5	5
39	PB8	B	1	1	2	2	1	1	1	1	5	5	10	5	1	5	5
40	PB9	B	1	1	2	2	1	1	2	2	1	1	7	1	1	5	5
41	PB10	B	1	1	2	2	1	1	2	2	1	1	1	1	1	5	5
50	WC3	B	1	1	2	2	1	1	2	2	1	1	1	1	1	5	5
51	WC4	B	1	1	2	2	1	1	2	2	1	1	1	1	1	3	3

Group B: consists of C2, L2, L5, P7, P14, PA2, PA3, PB3, PB4, PB6, PB8, PB9, PB10, WC3 & WC4 properties.

Results from group B, Phase 1 & Phase 2.

Q_1.2 No of Occupants [1-2] In Phase 1 a*ll but one of this group had 1-2 Occupants living in these dwellings this changed to 100% in phase 2*

Q_1.4 Occupants Occupation Work/Retired [Occupants did not work].

Results remained consistent in both phase 1 and Phase 2, no occupants worked in this group age over 65?

Q_1.6 Type of heating [Gas] *All but two occupants had gas heating in phase 1, this changed to all but one in phase 2.*

Q_1.10 Do you own a computer? [Internet] *All but two of this group did not own a Computer. (Phase 1 and 2 obtained similar results)*

Q_1.11 How long have you owned a computer? *The majority of occupants in this group have never owned a computer*

Q_1.14 How often do you use the internet? *The majority of occupants in*

this group are nor internet users.

Q_1.15 How often do you shop on line? *The majority of occupants in*

this group are nor internet users and subsequently do not shop on line.

Q_2.12 Do you know how your smart meter works?

Very little understanding how a smart meter worked

Q_2.14 How often do you check your energy usage?

Most occupants never checked their energy usage

Summary- 1-2 occupants lived in the properties in this group, none of them worked. The majority of the occupants did not own a computer and were not computer literate.

Cluster - Group C

In Table 6.16 Properties in Group C are characterised by the strongest results from phase 1 and phase 2

Table 6.16 Group C- cluster sets

		Group C							Question											
No	Property	Cluster	P1_Q_1.2	P2_Q_1.2	P1_Q_1.4	P2_Q_1.4	P1_Q_1.6	P2_Q_1.6	P1_Q_1.10	P2_Q_1.10	P1_Q_1.11	P2_Q_1.11	P1_Q_1.25	P2_Q_1.25	P1_Q_2.2	P2_Q_2.2	P2_Q_2.5	P1_Q_2.10	P2_Q_2.14	P1_Q_2.22
4	C4	C	2	1	2	2	1	1	1	1	4	4	2	2	0	1	1	1	5	10
17	P2	C	1	1	2	2	1	1	1	1	5	5	2	2	2	3	2	1	5	10
22	P8	C	1	1	2	2	1	1	1	1	4	3	3	2	3	4	1	1	1	10
29	PA1	C	1	1	2	2	2	1	1	1	5	5	2	2	3	4	1	2	5	10
32	PB1	C	2	1	2	2	1	1	1	1	5	5	2	2	3	4	2	1	5	10
33	PB2	C	2	1	2	2	1	1	1	1	5	5	2	2	3	4	1	1	1	10

Group C: consists of C4, P2, P8, PA1, PB1 & PB2 properties.

Results from group C, Phase 1 & Phase 2.

Q_1.4 Occupants Occupation Work/Retired [Occupants did not work].

Results remained consistent in both phase 1 and Phase 2, no occupants worked in this group.

Q_1.6 Type of heating [Gas] *All but one occupants had gas heating in phase 1, this changed to all with gas heating in phase 2.*

Q_1.10 Do you own a computer? [Internet] *All of this group did own a Computer. (Phase 1 and 2 obtained similar results)*

Q_1.11 How long have you owned a computer? *The majority of occupants in this group have owned a computer for a long period all however, two in both phase 1 and phase 2 have owned a computer for more than ten years.*

Q_1.25 If yes which ones do you own, (energy saving utility washing machine). *All occupants in phase 1 & 2 owned 2 energy saving machines. One occupant in phase 1 owned 3.*

Q_2.2 Are you aware of Government Policies. *This was a group that understood government policy's well four in phase 1 where aware about 3 important policy and this increase to 4 policy in phase 2*

Q_2.10 Have you attended any ECO clinics on a Wednesday? *All except one occupant from this group attended ECO clinics on a Wednesday in Phase (No comparison for phase 2)*

Q_2.14 How often do you check your energy usage? *All but two occupants in this group never checked their energy usage in phase 2.*

Q_2.22 Did you sign up for new energy technology to reduce the carbon footprint? *All occupants had a high motivation to sign up here in phase 1.*

Summary – C was a small group Occupants did not work in this group, most of them owned a computer for a long period. An interesting fact also revealed that they all knew about government policy's and were committed in owning energy saving appliances. All but one had attended the ECO Clinic at some time; in phase two, their view had changed to having a high motivation to reduce the carbon footprint.

Cluster - Group D

In Table 6.17 Properties in Group C are characterised by the strongest results from phase 1 and phase 2.

Table 6.17 Group D- cluster sets

		Group D	Question													
No	Property	Cluster	P1_Q_1.4	P2_Q_1.4	P1_Q_1.5	P2_Q_1.5	P1_Q_1.6	P2_Q_1.6	P1_Q_1.8	P2_Q_1.8	P1_Q_1.10	P2_Q_1.10	P2_Q_2.5	P1_Q_2.7	P1_Q_2.10	P1_Q_2.12
5	C5	D	1	1	5	5	1	1	2	2	1	1	1	1	1	1
7	C7	D	1	1	5	5	1	1	1	2	1	1	2	3	1	6
36	PB5	D	1	1	4	4	1	1	1	1	1	1	1	1	2	8
38	PB7	D	1	1	4	4	1	1	1	1	1	1	2	5	2	1
42	R1	D	1	1	5	5	1	1	1	1	1	1	1	1	2	1
44	R3	D	1	1	5	5	1	1	2	2	1	1	1	1	2	8
45	R4	D	1	1	5	5	1	1	1	1	1	1	1	1	2	1
46	R5	D	1	1	5	5	1	1	1	1	1	1	1	1	2	1
47	R6	D	1	1	5	5	1	1	1	1	1	1	1	1	2	1
48	WC1	D	1	1	5	5	1	1	1	1	1	1	1	1	2	1
49	WC2	D	1	1	5	5	1	1	1	1	1	1	1	1	2	1

Group D : consist of C5,C7,PB5,PB7,R1,R3,R4,R5,R6,WC1 and WC2 properties, they were characterised by the following behaviour patterns:-

Results from group D, Phase 1 & Phase 2.

Q_1.4 Occupants Occupation. [All occupants worked]. *Results* *remained consistent in both phase 1 and Phase 2.*

Q_1.5 Type of Property [All properties were semi-detached] *All properties except for two are semi-detached in phase 1 & phase 2.*

Q_1.6 Type of heating [Gas]. All *the occupants had gas heating in phase 1 & phase 2.*

Q_1.8 How are your energy bills paid? *All occupants in phase 1 except for Two paid their energy bills by payment card, this changed to all but three in phase 2.*

Q_1.10 Do you own a computer? [Internet] *This entire group did own a Computer. (Phase 1 and 2 obtained similar results)*

Q_2.5 Do you know which technologies have been fitted in your property? *All but two occupants in both phase 1 & 2 knew which technologies had been fitted.*

Q_2.7 Was the explanation conveyed by one of the following methods. [Technology's explained over the phone]. All but three of this group confirmed information was conveyed by phone in phase 1, phase.

Q_2.10 Have you attended any Eco clinics on a Wednesday?

In phase 1 all but two occupants didn't attend any eco *clinics. (Some of which are from the R & WC properties where the eco clinic had finished.)*

Q_2.12 Do you know how your smart meter works?

Occupants in P1 did not know how a smart meter worked.

Summary- All occupants worked in this group, the majority of properties were semi - detached houses and all were familiar with maintenance manuals. The majority entered the scheme after the eco clinic had finished, owned a computer and the majority payed their energy bills by payment card, they were aware of which technologies had been fitted within their scheme. They did not know how a smart meter worked in phase 1 this improved.

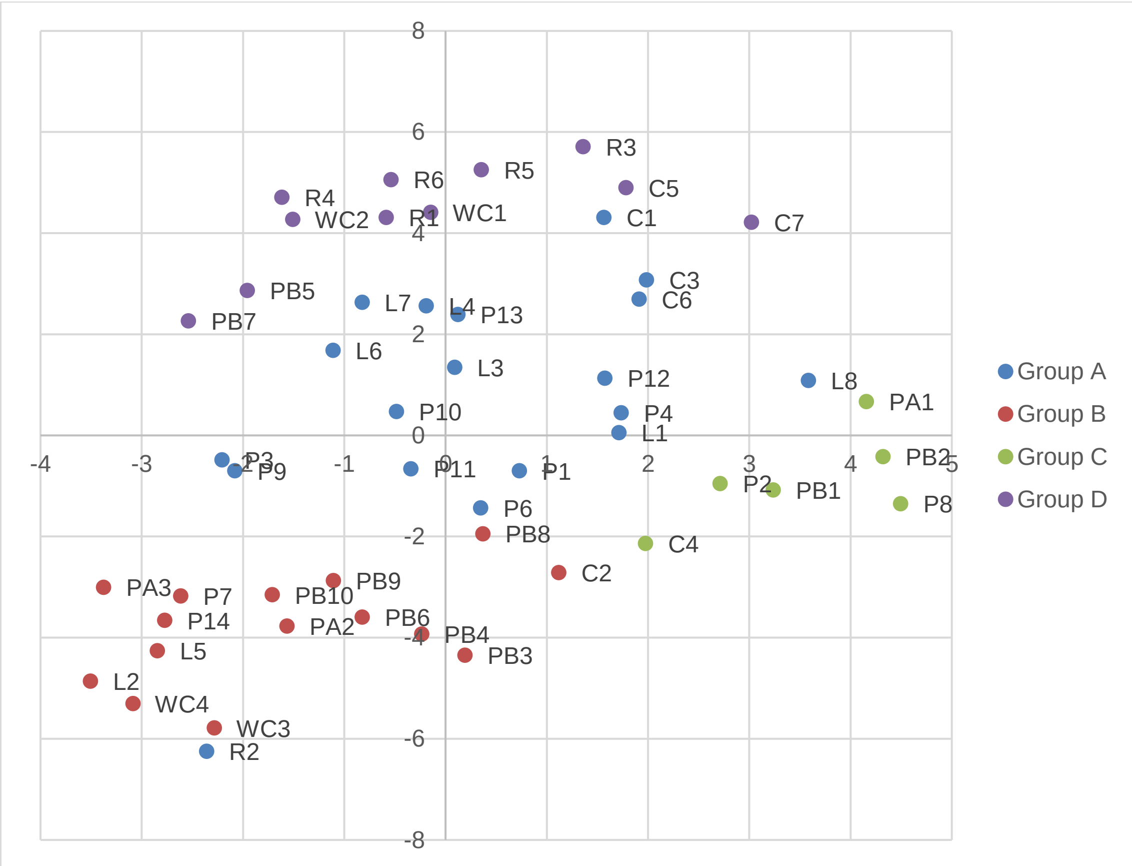
In Table 6.18 the results from the clustering have been collated and show similarities between results from the questionnaire.

Table 6.18 Showing strongest links in groups A, B, C & D cluster 4

A		**B**		**C**		**D**		**Cluster**
P1_	P2_	P1_	P2_	P1_	P2_	P1_	P2_	
		1.2	1.2	1.2	1.2			**B**- 1-2 occupants in house all but I in P1 **C**- 1-2 occupants P2. P1 similar but three have 3-4 occupants
		1.4	1.4	1.4	1.4	1.4	1.4	**B**- Not working P1 & P2 **C**- Not working P1 & P2 **D**- Working P1 & P2
						1.5	1.5	**D**- All but two are semi detached in P1 & P2
1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	**A**- Gas heating **B** -Gas heating **C**- Gas all but 1 **D**- Gas heating
						1.8	1.8	**D**- Bills paid by card except 2 in P1 & 3 in P2
1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	**A**- Own a computer except for 3 in P1& P2 **B**- Do not own a computer except for 2 in P1& P2 **C**- Own a computer in P1 & P2 **D**-Own a computer in P1 & P2
		1.11	1.11	1.11	1.11			**B**- Short period time **C**- over 10 years P1 & P2
			1.14					**B**- P2 All except 3 are non- internet users
		1.15						**B**- P1 doesn’t shop on line except 1
				1.25	1.25			**C**- Has energy saving cooker in P1 & P2 except 1 in P1
				2.2	2.2			**C**- Good awarenss of government policies in P1& P2 except for 1
					2.5		2.5	**D**- P2 Understand technologies that have been fitted except 2
2.7	2.7					2.7	2.7	**D**- Explanation of technologies. Phone for P1. P2 very mixed answers here.
				2.10		2.10		**C**- Did attend eco clinic P1 except **D**- Did not attend eco clinic except 2
		2.12				2.12		**B**- Poor understanding of how a smart meter works except for two occupants in P1. **D**-Poor understanding of how a smart meter works except for three occupants in P1.
2.14	2.1	2.14	2.14		2.14			**A**- Occuppants in both P1 & P2 never check there energy usage. **B**- Occuppants in both P1 & P2 never check there energy usageexcept for 1. **C**- Occupants check there energy usage except for two in P2. A change noted here.
				2.22				**C**- High motivation to set asside fund for energy devices in P1

In Table 6.19 Shows the four clusters/groups that have been selected, grid lines on the x & y axis show the position of each group A, B, C & D. PCA Scatterplot calculated from 51 variables representing the no of households used within the study. PCA has found 4 distinctive cluster groups A, B, C & D from the data and grouped them according to their relationships

Table 6.19 Showing 4 distinctive cluster groups A, B, C & D.



6.4.3 ENERGY EFFICIENCY IN RELATION TO OCCUPANTS' PROFILE

It was assumed that the variations in the occupant profile/characteristics would have an effect on energy efficiency of the building they live in. Based on this assumption, the following null hypothesis was generated: there is no significant difference in energy efficiency (the difference in gas and electricity consumption) between the residential buildings with occupants of different behaviour represented by [cluster / groups - section 6.4.2]

The hypothesis was tested using non-parametric Dunn's Kruskal-Wallis multiple comparison test with Bonferroni correction. The results of the test are presented in *Table 6.21 & Table 6.23.*

6.4.3.1 COMPARISON GAS USAGE 2013-2015 [OCCUPANTS]

Table 6.20 Summary statistics showing the difference in gas usage between 2013 - 2015 data for residential buildings.

Summary Statistics, Difference in Gas usage					
Cluster		A	B	C	D
N		19	11	6	10
N missing		0	4	0	1
Mean		-10.29	4.7	12.61	19.83
Median		4.76	4.76	9.09	19.2
Std. Deviation		51.96	22.2	56.53	15.47
Percentiles	min	-153.76	-38.5	-79.19	4.76
	25	-0.22	0.76	4.76	4.76
	50	4.76	4.76	9.09	19.20
	75	4.76	6.86	30.72	29.36
	max	38.09	52.36	95.43	44.44
Shapiro-Wilk normality test p-value		1.76×10^{-6}	0.1328	0.5844	0.0837

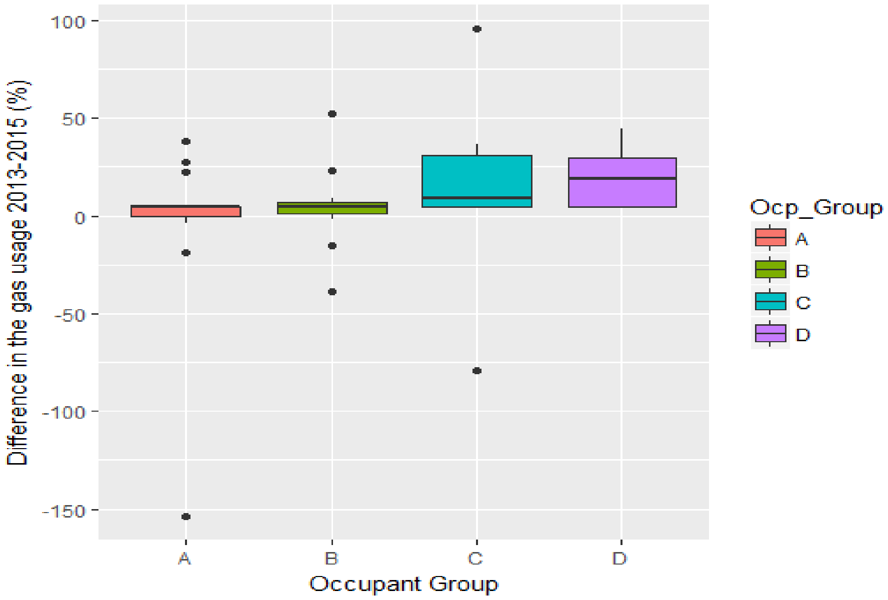


Figure 6.29 Distribution of difference in gas usage between 2013- 2015 data for occupant groups.

In table, 6.21 P-values from Dunn's Kruskal-Wallis multiple comparison test for gas 2013 -2015 results with Bonferroni correction applied for each combination of occupant groups. Highlighted numbers demonstrate a statistically significant difference between plots. Italicised numbers show a statistically significant difference between plots based on uncorrected p-value.

Table 6.21 P-values from Dunn's Kruskal-Wallis multiple comparison test for gas 2013 - 2015

Dunn's Kruskal-Wallis multiple comparison test – Gas usage				
Cluster	**A**	**B**	**C**	**D**
A	-	1.000	0.946	0.060 / 0.010*
B		-	1.000	0.278 / 0.046*
C			-	1.000
D				-

* Uncorrected p-value

Null hypothesis of no statistically significant difference rejected

The Shapiro-Wilk normality test p-value indicated that only group A [1.76×10^{-6}] is not normally distributed supporting the results from the boxplots in Figure 6.29.

The results of the boxplots in *Figure 6.29* and summary statistic in *Table 6.20 & 6.21* indicate that there is a *significant difference in energy usage* for gas between clusters A&D [0.010*] and B&D.[0.046*]

6.4.3.1.1 ANALYSES OF DATA-GAS

Difference between cluster A&D

Cluster A - occupants behaviour are characterised by:-

All the occupants in this group had gas central heating and most of them owned a computer. Improvements in acknowledging receipt of manuals and advice was improved in phase 2, but most occupants confirmed that they never checked their energy usage in phase 1, there was no improvement here in phase two.

Cluster D - occupants behaviour are characterised by:-

All occupants worked in this group, the majority of properties were semi - detached houses and all were familiar with maintenance manuals. The majority entered the scheme after the eco clinic had finished, owned a computer and the majority payed their energy bills by payment card, they were aware of which technologies had been fitted within their scheme. They did not know how a smart meter worked in phase 1 this improved.

The significant difference in gas usage between cluster groups A [-10.29] & D [19.83] can be attributed to the fact that all occupants worked in-group D, had IT skills and were familiar with user manuals. Additionally occupants in cluster A had fewer similar behaviour traits than those in cluster D.

Difference between cluster B&D

Cluster B - occupants behaviour are characterised by:-

1-2 occupants lived in the properties in this group, none of them worked. The majority of the occupants did not own a computer and were not computer literate.

The significant difference in gas usage between cluster groups B [4.7] & D [19.83] could be attributed to all occupants not working in-group B, the majority of them never owned a computer or were IT literate the results for this group can be seen as opposite to group D. However, it must be noted that this group did show a small improvement to their gas usage.

6.4.3.2 Comparison Electricity 2013-2015 [occupancy]

Table 6.22 Summary statistics of difference in electricity usage between 2013 - 2015 data for occupant groups.

Summary Statistics, Difference in Electricity usage					
Cluster		A	B	C	D
N		19	13	6	11
N missing		0	2	0	0
Mean		-4.42	-14.34	0.21	3.54
Median		4.76	-4.39	4.76	4.76
Std. Deviation		14.83	33.86	46.83	41.13
Percentiles	min	-39.64	-66.57	-84.79	-54.73
	25	-9.52	-41.15	4.76	-22.74
	50	4.76	-4.39	4.76	4.76
	75	4.76	4.76	10.25	26.45
	max	14.5	54.36	59.69	70.68
Shapiro-Wilk normality test p-value		0.001132	0.7556	0.09213	0.7261

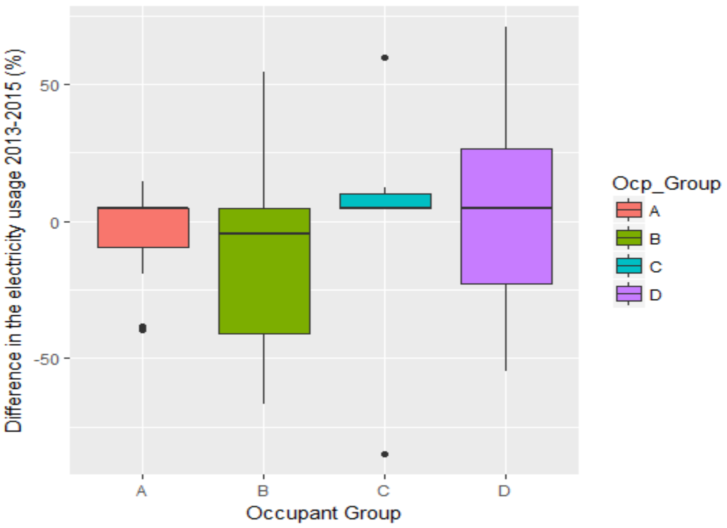


Figure 6.30 Distribution of difference in electricity usage between 2013- 2015 data for occupant groups.

In table, 6.23 P-values from Dunn's Kruskal-Wallis multiple comparison test for electricity 2013 -2015 results with Bonferroni correction applied for each combination of occupant groups. Highlighted numbers demonstrate a statistically significant difference between plots. Italicised numbers show a statistically significant difference between plots based on uncorrected p-value. [The results show there is no significance.]

Table 6.23 P-values from Dunn's Kruskal-Wallis multiple comparison test for electricity 2013 -2015

Dunn's Kruskal-Wallis multiple comparison test – Electricity usage				
Cluster	**A**	**B**	**C**	**D**
A	-	1.000	1.000	1.000
B		-	0.651	0.891
C			-	1.000
D				-

* Uncorrected p-value

Null hypothesis of no statistically significant difference rejected

The Shapiro-Wilk normality test p-value indicate that only group A is not normally distributed supporting the results from the boxplots in *Figure 6.30 .*

The results of the boxplots in *Figure 6.30* and summary statistic in *Table 6.22 & 6.23* indicate that there is - *no significant difference in energy usage* for electricity between cluster groups.

6.4.3.2.1 ANALYSES OF DATA ELECTRICITY

The results from the Dunn's Kruskal-Wallis multiple comparison test found that there were no significant difference in energy use for electricity. Cluster group D is the only group with a measurable improvement in energy usage.

6.5 DISCUSSION

This chapter focussed on the relationship between behaviour and energy efficiency in retrofitted residential buildings:

To address the research objectives this chapter clearly provides a platform that looked thoroughly at occupants' behaviour, their relationship to each other along with their energy usage. This was achieved by comparing groups of residential buildings with behaviour and energy usage using PCA and Clusters analyses.

The results from the cluster analyses revealed that occupants were not always grouped into their property types, but by the results from their behaviour. The cluster analysis divided the results into four distinctive cluster groups [A, B, C & D].

6.6 CHAPTER CONCLUSIONS

The aim of this chapter was to set out to describe the nature of the project, the types of occupants and their behaviour patterns matching these to property types, grouping the properties according to the interventions using SPSS hierarchy analyses, R, and energy consumption data.

Occupants in-group A mainly owned their own computer, they understood the user manual for the technologies and this improved further in phase 2. It was widely acknowledged by most occupants that they never checked their energy usage in either phase 1 or 2.

The majority of occupants in-group B did not work, own a computer, or were computer literate. The properties consisted of 1-2 occupants per household here even though the raw data does suggest that most dwellings were single occupancy.

Group C were a none working group, they were either retired or seeking employment, the majority owned a computer and understood government policies. They were also committed to energy saving appliances and all, but one had attended the eco clinic at some time. Views by this group changed further, in which they were more committed in phase 2 to reduce the carbon footprint.

In-group D all the occupants worked, they mostly lived in semi-detached properties [BIS] they were aware of the technologies that had been fitted along with the use of maintenance manuals. No one in this group had attended the ECO clinic.

It can be assumed from the results that smaller groups provided little or no information within the study a larger sample may have changed the results obtained making them more distinctive and significant.

The results identify those occupants with similar behaviour patterns in cluster D obtained improved energy results.

Chapter 7

ENERGY EFFICIENCY OF THE RESIDENTIAL BUILDINGS IN RELATION TO TECHNOLOGIES FITTED AND OCCUPANTS BEHAVIOUR

7.1 INTRODUCTION

This chapter focuses on results obtained from the occupancy and technology chapters. Results from previous cluster analyses investigations were taken from the technology and occupants' groups from chapters 5 & 6 and merged together as shown in *table 7.1.* This will allow further investigation to identify if any relationships between occupant behaviour and the technology's that have been used within the study exist. Additionally energy usage in these properties where groups exceeded 2 dwellings will also be investigated to identify if any energy reduction occur. Groups with less than two or less properties will be excluded from this study.

The investigation within this section will map closely to objective no 2.

Objective 2

Investigate new technologies and the way occupants adapt to them. To obtain energy efficiency, occupants will need an understanding of modern day technology and have the ability to use it effectively.

7.2 RELATIONSHIP BETWEEN OCCUPANT PROFILE AND TECHNOLOGY FITTED IN RESIDENTIAL BUILDINGS

From the cluster analyses performed in chapters, 5 & 6 *Table 7.1* categorises the number of occupants in each group, the total 51. *Table 7.2* identified which occupants belong to each of these groups, the stronger groups highlighted in table 7.2, these formed the bases of the investigation within this chapter, other groups were deemed too small.

Table 7.1 Technology Clusters v Occupants Clusters

		Technology Group/Cluster					
		1	**2**	**3**	**4**	**5**	**6**
Occupant Group	**A**	1	*8*	*9*	-	-	1
	B	1	*5*	-	2	*5*	2
	C	1	-	2	1	2	-
	D	2	-	-	-	2	*7*

Table 7.2 Property groups- interventions mapped with behaviour

NO	GROUP	PROPERTY
1	A-1	C1
8	A-2	C3,C6,L1,L3,L4,L6,L7,L8
9	A-3	P1,P3,P4,P6,P9,P10,P11,P12,P13
-	A-4	-
-	A-5	-
1	A-6	R2
1	B-1	C2
5	B-2	L2,L5,P7,P14,PB4
-	B-3	-
2	B-4	PA2,PA3
5	B-5	PB3,PB6,PB8,PB9,PB10
2	B-6	WC3,WC4
1	C-1	C4
-	C-2	-
2	C-3	P2,P8
1	C-4	PA1
2	C-5	PB1,PB2
-	C-6	-
2	D-1	C5,C7
-	D-2	-
-	D-3	-
-	D-4	-
2	D-5	PB5,PB7
7	D-6	R1,R3,R4,R5,R6,WC1,WC2

-

7.2.1 Occupants profile-technologies

Occupants' behaviour is summarised in groups A, B, C & D below, technologies are characterised according to their original group sets from the cluster analyses (technology chapter).

7.2.1.1 Group A

Summary-All the occupants in this group had gas central heating and most of them owned a computer. Improvements in acknowledging receipt of manuals and advice was improved in phase 2, but most occupants confirmed that they never checked their energy usage in phase 1, there was no improvement here in phase two.

A-1	*C1*	Properties in Group 1 are characterised by structural insulation, single heat recovery ventilation, phase change material, passive vents, LEDs and voltage optimization units.
A-2	***C3,C6,***	*Properties in Group 1 are characterised by structural insulation, single heat recovery ventilation, LEDs and voltage optimization units.*
	L1,L3,L4,L6,L7,L8	*Properties in Group 2 are characterised by single heat recovery ventilation and LEDs*
A-3	***P1,P3,P4,P6,P9,P10,P11,P12,P13***	Properties in Group 3 are characterised by passive solar heat collectors, balcony enclosures and LEDs
A-4	-	
A-6	*R2*	Group 6 are characterised by Structural insulation, Boilers And Solar panels.

7.2.1.1 GROUP B

Summary 1-2 occupants lived in the properties in this group, none of them worked. The majority of the occupants did not own a computer and were not computer literate.

PN. Property groups highlighted in blue represent groups exceeding two.

B-1	*C2,*	Properties in Group 1 are characterised by structural insulation, single heat recovery ventilation, phase change material, passive vents, LEDs and voltage optimization units
B-2	***L2, L5,***	Properties in Group 2 are characterised by single heat recovery ventilation and LEDs
	P7, P14,	Properties in Group 3 (bungalows) are characterised by LEDs
	PB4	Group 5 are characterised by Vacuum insulated panels & single heat recovery units.
B-3	-	
B-4	*PA2, PA3*	Properties in Group 4 are characterised by external wall insulation, air source heat pump, Photovoltaics, LEDs and voltage optimisation units.
B-5	***PB3, PB6, PB8, PB9, PB10***	Group 5 are characterised by Vacuum insulated panels & single heat recovery units.
B-6	*WC3, WC4*	Group 6 are characterised by Structural insulation, Boilers and Solar panels.

7.2.1.2 Group C

Summary – C was a small group Occupants did not work in this group, most of them owned a computer for a long period. An interesting fact also revealed that they all knew about government policy's and were committed in owning energy saving appliances. All but one had attended the ECO Clinic at some time; in phase two, their view had changed to having a high motivation to reduce the carbon footprint.

C-1	*C4,*	Properties in Group 1 are characterised by structural insulation, single heat recovery ventilation, phase change material, passive vents, LEDs and voltage optimization units.
C-2	-	
C-3	*P2, P8*	Properties in Group 3 are characterised by passive solar heat collectors and LEDs
C-4	*PA1*	Properties in Group 4 are characterised by external wall insulation, air source heat pump, Photovoltaics, LEDs and voltage optimisation units.
C-5	*PB1, PB2*	Group 5 are characterised by Vacuum insulated panels & single heat recovery units.
C-6	-	

7.2.1.3 Group D

Summary- All occupants worked in this group, the majority of properties were semi - detached houses and all occupants were familiar with maintenance manuals. The majority entered the scheme after the eco had finished, they were aware of which technology's had been fitted within their scheme

D-1 *C5, C7* Properties in Group 1 are characterised by structural insulation, single heat recovery ventilation, phase change material, passive vents, LEDs and voltage optimization units

D-2 -

D-3 -

D-4 -

D-5 *PB5, PB7* Group 5 are characterised by Vacuum insulated panels & Single Heat recovery units.

D-6 R1, R3, R4, R5, R6, WC1, WC2

Group 6 are characterised by Structural insulation, Boilers and Solar panels

7.2.1.4 DISCUSSION

The data from this section has allowed a character profile to be constructed identifying occupants behaviour along with the characteristic of the technologies they received to their properties.

7.3 ENERGY EFFICIENCY – GAS

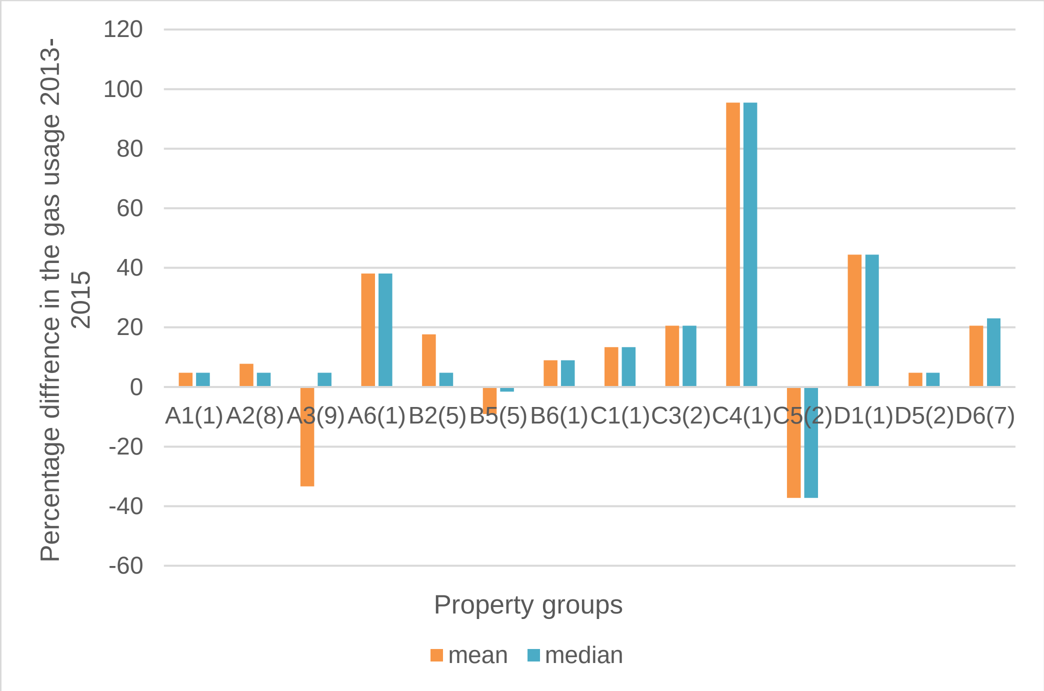


Figure 7.1 Mean and median of the gas usage difference in the groups (occupants-technology)

In figure, 7.2 groups with two or less properties were excluded from the data analyses as it was considered that the sample would be too small.

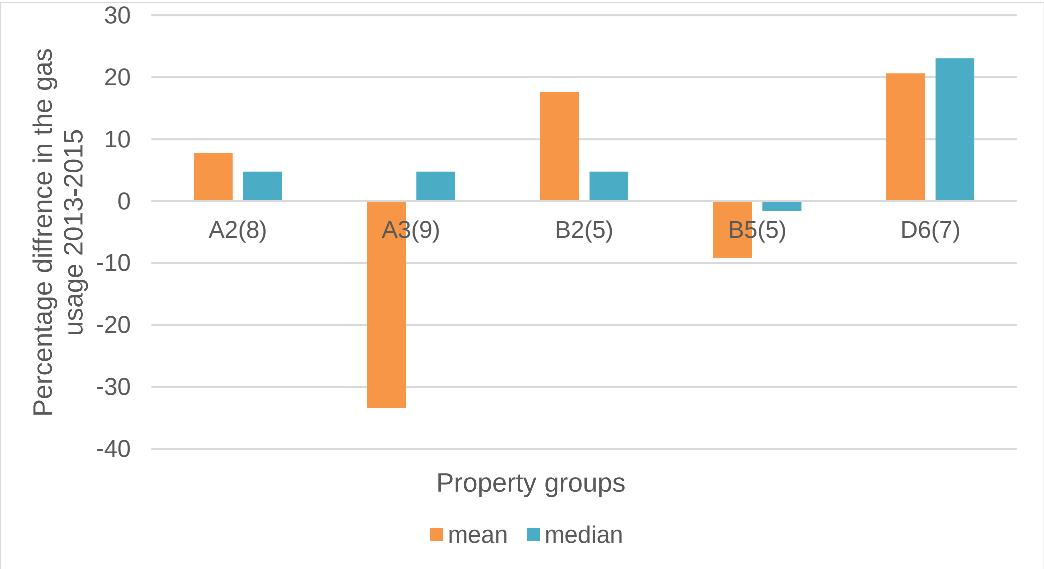


Figure 7.2 Mean and median of the gas usage difference in the groups (occupants-technology) for groups with N>2

Table 7.3 % of the gas usage difference in the groups (occupants-technology) for groups with N>2

group	no	Property type	Energy saving% Gas	Mean	Median	Outlier removed	New Mean
A2	8	C3	+27.43				
		C6	+ 4.76				
		L1	+22.39				
		L3	+ 4.76				
		L4	- 2.56				
		L6	+ 4.76				
		L7	+ 4.76				
		L8	- 4.05				
				7.78	4.76		
A3	9	P1	+ 4.76			+ 4.76	
		P3	- 19.04			- 19.04	
		P4	-153.76			-	
		P6	+ 4.76			+ 4.76	
		P9	-153.76			-	
		P10	+ 4.76			+ 4.76	
		P11	+ 4.76			+ 4.76	
		P12	+ 2.12			+ 2.12	
		P13	+ 4.76			+ 4.76	
				-33.4	4.76		0.98
B2	5	L2	+ 3.09			+ 3.09	
		L5	+ 4.76			+ 4.76	
		P7	+ 4.76			+ 4.76	
		P14	+52.36			-	
		PB4	+23.27			+23.27	
				17.65	4.76		8.97
B5	5	PB3	-38.50				
		PB6	+ 4.76				
		PB8	-14.93				
		PB9	+ 4.76				
		PB10	- 1.58				
				-9.1	-1.58		
D6	7	R1	+23.80				
		R3	+15.34				
		R4	+41.38				
		R5	+31.21				
		R6	+23.07				
		WC1	+ 4.76				
		WC2	+ 4.76				
				20.62	23.07		

7.3.1 SUMMARY- GAS USAGE

Figure 7.3 shows the percentage change in gas usage between 2013 and 2015 data was analysed where groups exceeded 2 no properties, smaller groups were eliminated as the sample was considered to be too small.

Group A2 shows an overall saving in gas of 7.78% all but two of these properties had some kind of energy reduction. The majority of occupants in this group owned a computer had gas central heating

Group A3 shows an overall loss of -33.4%, the properties here were predominantly ‘P’ type consisting of flats and bedsits. The majority of occupants in this group owned a computer had gas central heating and the technologies were characterised by passive solar heat collectors and Balcony enclosures (Balco). Two properties energy usage by increased by – 153.76% (no obvious reason why this happened) but there energy usage for 2013 was very low so this may have been underestimated by the providers. Excluding these two from the date set would provide a new mean value of 0.98% improvement. Five of these properties had mean values of 4.76% indicating that there energy bills were the same for both years

Group B2 indicates an overall saving of 17.65%, 1-2 occupants lived in the properties in this group, none of them worked. The majority of the occupants did not own a computer and were not computer literate. There were three different property types within this group L, P & PB. Energy savings were notable high for P14 +52.36% this may have been because the occupancy changed after phase 1 with a younger occupant moving in. Excluding this property from the data set would adjust the mean to 8.97%.

Group B5 consisted predominantly of PB type buildings, similar to group B2 1-2 occupants lived in the properties in this group, none of them worked. The majority of the occupants did not own a computer and were not computer literate. All the properties here were characterised by Vacuum insulated panels & single heat recovery units. This group of properties overall experience a mean value of -9.1% for gas usage.

Group D6 consisted of R and WC semi-detached BIS properties all occupants worked in this group, the majority of properties were semi - detached houses and all occupants were familiar with maintenance manuals. The majority entered the scheme after the eco had finished, owned a computer and the majority payed their energy bills by payment card, they were aware of which technology's had been fitted within their scheme. They did not know how a smart meter worked in phase 1 this improved.

7.3.2 DISCUSSION

Five groups were identified with more than two properties within each group, results varied; *table 7.1 Technology Clusters v Occupants Clusters* identifies the strongest relationships using cluster results from the technology and occupants chapters.

Energy usage from each property was recorded in *table 7.3, the* results reflected the overall energy benefits or dis- benefits for each group. Several outliers were removed which allowed results to be recalculated and produce new mean figures. Group D6 produced good overall energy results all the occupants worked here and were familiar with the technologies. However whilst these properties were all semi-detached houses it cannot be assumed that all semi- detached buildings with occupants with similar characteristics and technologies fitted will always benefit similar to these.

Furthermore, it could be assumed from the results that BIS semi-detached buildings that received external wall insulation may have contributed to the energy reduction.

Property's that showed a net gain of +4.76% indicated that occupants' weekly/monthly energy bills were similar for both 2014 and 2015 years. Annual increases in energy tariffs were taken into consideration here; this was further reflected in a decrease in their energy usage accounting for an overall saving of 4.76%.

7.4 Energy Efficiency - Electricity

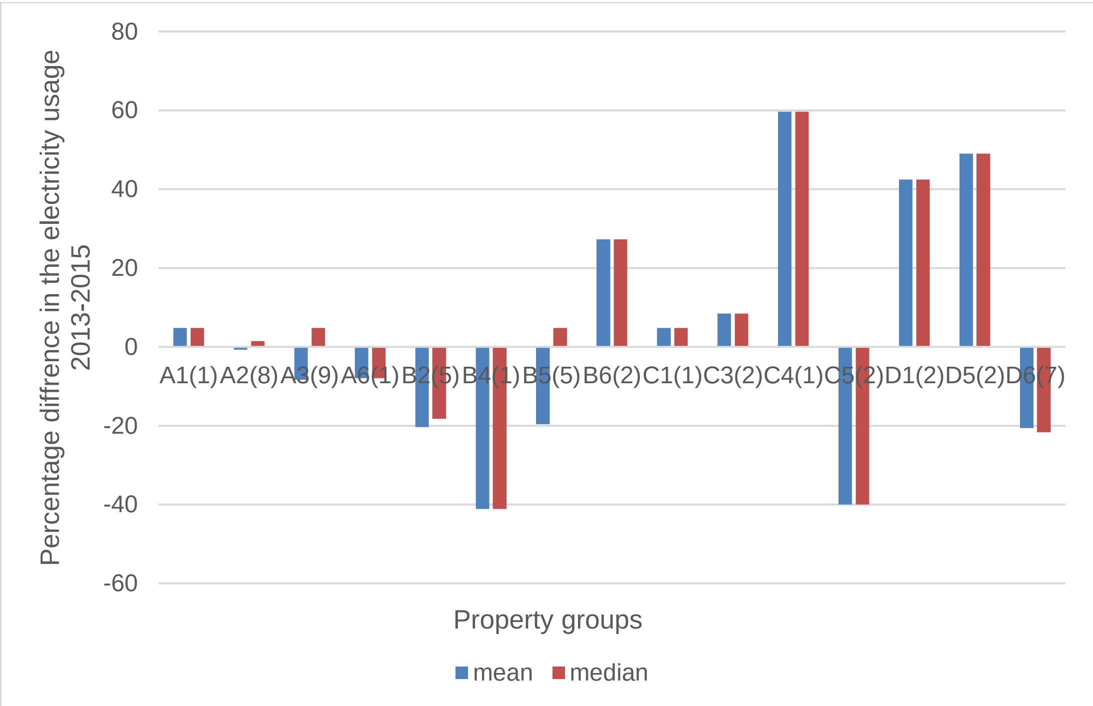


Figure 7.3 Mean and median of the electricity usage difference in the groups (occupants-technology)

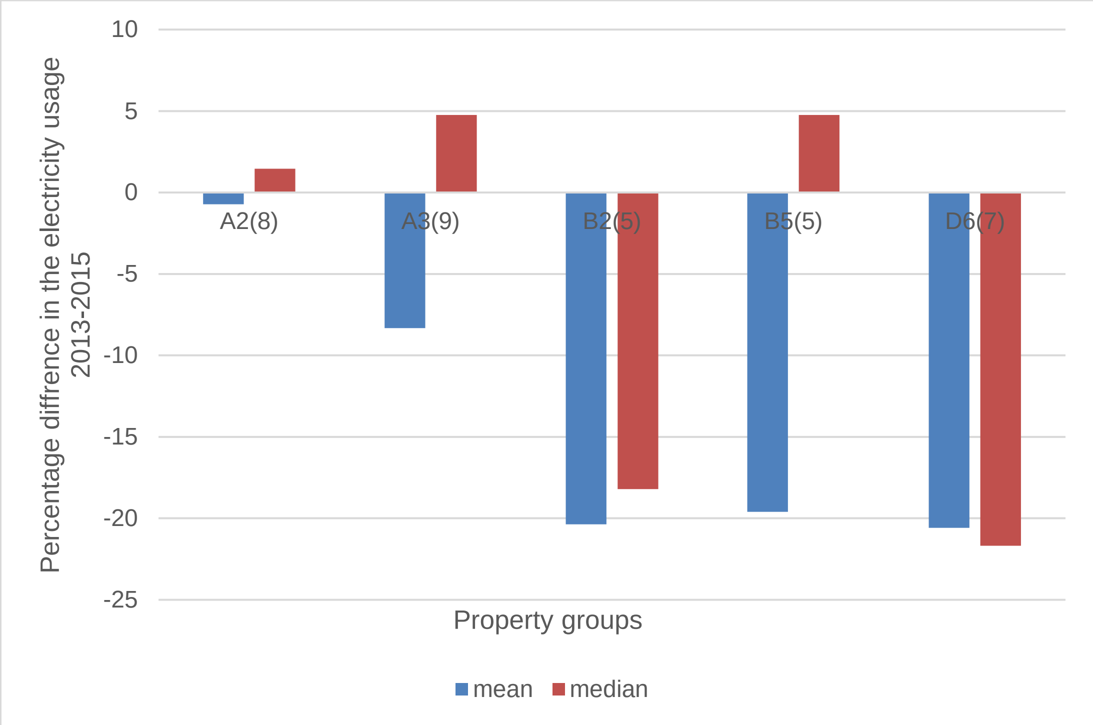


Figure 7.4 Mean and median of the electricity usage difference in the groups (occupants-technology) for groups with N>2

Table 7.4 % of the electricity usage difference in the groups (occupants-technology) for groups with N>2

group	no	Property type	Energy saving% Electricity	Mean	Median	Outliers removed	New Mean
A2	8	C3	+ 4.76			+ 4.76	
		C6	+ 4.76			+ 4.76	
		L1	+14.40			+14.40	
		L3	- 4.76			- 4.76	
		L4	- 11.11			- 11.11	
		L6	+ 4.76			+ 4.76	
		L7	- 1.85			- 1.85	
		L8	- 16.87			-	
				-0.73	1.45		1.56
A3	9	P1	+ 4.76			+ 4.76	
		P3	- 19.04	-		- 19.04	
		P4	- 39.64			-	
		P6	+ 4.76			+ 4.76	
		P9	- 38.50			-	
		P10	+ 4.76			+ 4.76	
		P11	+ 4.76			+ 4.76	
		P12	- 1.58			- 1.58	
		P13	+ 4.76			+ 4.76	
				-8.33	4.76		0.45
B2	5	L2	- 50.72				
		L5	- 4.39				
		P7	- 3.51				
		P14	- 24.99				
		PB4	- 18.21				
				-20.36	-18.21		
B5	5	PB3	- 58.65				
		PB6	+17.63				
		PB8	- 66.57				
		PB9	+ 4.76				
		PB10	+ 4.76				
				-19.61	4.76		
D6	7	R1	+ 4.76			+ 4.76	
		R3	- 2.85			- 2.85	
		R4	- 23.80			- 23.80	
		R5	- 54.73			- 54.73	
		R6	- 21.68			- 21.68	
		WC1	+ 9.00			+ 9.00	
		WC2	- 54.73			-	
				-20.58	-21.68	-14.88	

7.4.1 SUMMARY- ELECTRICITY USAGE

Table 7.4 shows the percentage change in electricity usage between 2013 and 2015, data was analysed where groups exceeded 2 no properties, smaller groups were eliminated as the sample was considered to be too small.

Group A2 shows an overall increase in electricity usage -0.73%, the majority of occupants in this group were classified as 'L 'properties and they owned a computer and had gas central heating . Due to design issues, 'L' properties only received energy saving bulbs and heat recovery ventilation units. Occupant 'L1' commented in the one to one interviews that " he had notice a considerable saving in his electricity usage since the fitting of the LEDs" however results from other L property residents had varied energy outcomes. Occupant L8 commented that the humidity fans in his flat were on constantly and he believed this may have contributed to the increase in electricity. Excluding this value (-16.87%) from the date set would provide a new mean value of 1.56% improvement overall for the group.

Group A3 shows an overall increase in electricity usage – 8.33%, these properties were mainly bedsits and flats. Several occupant here were elderly and disclosed on one to one interviews that they supplemented there heating on occasion with electric fires even though this was not revealed in the questionnaire. Excluding these outlier the results would have improve for this group. Occupant P4 (-39.64%) & P9 (-38.50%) did have a substantial increase in energy usage, bills were paid quarterly and monthly respectively.

Group B2 shows an overall increase in electricity usage – 20.36%, 1-2 occupants lived in the properties in this group, none of them worked. The majority of the occupants did not own a computer and were not computer literate. There were three different property types within this group L, P & PB. All occupants in this group experienced an increase in energy usage. What was interesting here was that all these occupants were retired and four of them paid their energy bills quarterly.

Group B5 shows an overall increase in electricity usage – 19.61% properties consisted predominantly of PB type buildings, similar to group B2 1-2 occupants lived in the properties in this group, none of them worked. The majority of the occupants did not own a computer and were not computer literate. All the properties here were characterised by Vacuum insulated panels & single heat recovery units. Two high values here effected the results and if removed could have changed the mean to 9.05%. There was no logical explanation why two properties increased usage by 58.65% and 66.57 %.

Group D6 consisted of R and WC semi-detached BIS properties all occupants worked in this group and all these occupants were familiar with maintenance manuals. The majority entered the scheme after the eco had finished, they were aware of which technology's had been fitted within their scheme. This was an interesting set of results usage increased by 20.58%. What we do know here is that firstly property WC2 usage -54.73% through one to one interviews revealed that the occupant had installed several reptile tanks, which increased his energy usage. Removing WC as an outlier reduces the increase of energy usage to 14.88%, what isn't apparent here is what the energy usage have been for this property if the reptile tanks hadn't been installed. Additional many of these occupants had problems with their solar panels tripping out causing issues with their hot water. Subsequently emersions were switched on to compensate here and this increased energy usage.

7.4.2 Discussion

Five groups were identified with more than two properties within each group; *table 7.2* Technology Clusters v Occupants Clusters identifies the strongest relationships using cluster results from the technology and occupants chapters.

Energy usage from each property was recorded in *table 7.4*, the results reflected the overall energy benefits or dis- benefits for each group. Several outliers were removed which allowed results to be recalculated and produce new mean figures. Without the removal of any outliers results showed that, there was a mean increase in electricity usage for these property groups. Smaller groups with either two or less occupants did reveal a reduction in electricity usage however, these residents could not be characterised into groups and behaviour patterns investigated due to the small numbers.

Property's that showed a net gain of +4.76% indicated that occupants' weekly/monthly energy bills were similar for both 2014 and 2015 years. Annual increases in energy tariffs were taken into consideration here this was further reflected in a decrease in their energy usage accounting for an overall saving of 4.76%.

The null hypothesis of significant difference could not be performed due to the groups with small number of observations (e.g., A6 had one observation only).

7.5 CHAPTER CONCLUSIONS

This chapter has combined results taken from previous chapters to construct a behaviour portfolio of the residents. Using cluster analyses results, residents from the occupancy and technology chapters were characterised into their strongest groups. The groups varied and did not always resemble the original property types but focused on grouping occupant, with similar characteristics and behaviour patterns along with an association with technologies that were used. Smaller groups less than two were omitted from the final analyses, all though several results were thought –provoking, small samples could be considered unique and bespoke to that individual.

Once the groups were established, energy usage was investigated to establish if behaviour patterns affected energy consumption. Several groups, which were deemed to have strong characteristics and technology relationships, provided positive gas energy results. However, electricity results were not so favourable, whilst the same groups were considered here electricity usage increased in most cases. Group D6 appeared the most constant from the overall results, gas consumption was reduced by 20.62%, electricity increased due to the issues from technology's not working efficiently.

It could also be considered here that results of +4.76% for both gas and electricity indicated no increase in expenditure for these utilities between 2014-2015. Occupants with these results mostly paid by pre-payment cards and resisted paying more for their energy a year later. This may have been because their properties were now warmer or they may have been restricted by their disposable income.

Chapter 8

DISCUSSION

The Literature Review explored the current government agency policies, new technologies, occupants' behaviour and energy usage.

Existing and dated policies implemented by government agencies could be perceived as overwhelming, to occupants with no direct cut off points between starting initiatives and finishing existing schemes. This was reflected with schemes such as the Code of Sustainable Homes, where all new buildings constructed after 2016 should have met carbon neutral standards. The Green Deal offered occupants the opportunity to improve their well-being by upgrading insulation, new efficient boilers or double/triple glazing offsetting the cost against the reduction in their energy bills.

Several occupants spoke about out- dated schemes that had finished several years prior to the commencement of this investigation. Results obtained from both phases of this study illustrated that nearly a third of the occupants were not aware or understood policies that would not only reduce the carbon footprint but also reduce household energy usage.

The investigation conducted in this study considered new technologies so new and innovative that meeting LA procurement policies proved demanding in several instances. Additionally, several technologies were technically challenging to the population, causing a lack of understanding and user- friendly qualities in several instances. Although training sessions at the ECO clinic were available, supporting the technologies and their functionality this was not taken up by the majority of occupants.

The sample of occupants considered in the study was made up primarily of residents from LA properties and their age varied along with their employment status. Many were retired and spent a great deal of time within the confines of their dwellings. Interestingly, several of them did not acknowledge either receipt of user manuals or training sessions that had been provided by SEH and the technology companies supporting the new installations and the manner in which they worked.

Within the review of the Literature, Smart Monitoring was examined in considerable depth. One of the principal themes of this study was to investigate the occupants, understanding of energy monitoring through smart metering. Many occupants were set in their ways and could be perceived as late majority (Rogers, 2005) with an inherent dislike to change or new technologies. Earlier evidence within the study supported this, where a 'LED' traffic light system was installed in some of the properties. The lights changed colour depending upon the amount of energy being used within the property, green indicating low or little usage whilst red indicated high usage. Several households switched the system off, believing the 'LEDs' where adding to their energy expenditure. This may have been due to either the induction and support sessions or just dis-believe that the cost to run low energy 'LEDs' cost were virtually immeasurable.

8.1 METHODS OF INVESTIGATION

The methods used to collect data and information comprised of questionnaires, structured interviews and visual observations. The methodology however involved a grounded theory approach where the data was collected first and used to generate a theory. SPSS, 'R' and Excel were the primary software used to analyse the data. The questionnaire consisted of two phases, Phase 1 was administered before the commencement of works and Phase 2 after the works had been completed, approximately one year. Phase I consisted of two sections, Section 1-'Occupants' and Section 2 –'The Installation'. Phase 2 was similar with the addition of Section 3- 'The Aftercare' added.

Investigating relationships between variables was an intensive process. Questions were grouped together prior to the data analysis, according to their design, in particular nominal, ordinal or scaled data. This could have been further simplified if questions had been grouped accordingly in the initial questionnaire design.

In several instances, results from questionnaires did not match the responses from occupants when discussions and interview took place. Face to face, discussions did not always reflect the participant's true feelings, with answers being masked to favour the interviewer.

8.2 TECHNOLOGY SECTION

Cluster analyses was chosen as a statistical tool to analyse data into groups, as this type of analysis has the ability to define which groups certain data should belong to. Cluster analyses was used to investigate relationships between property types and technologies. Results showed, as described earlier, (section 5.4.2.1) that technologies were not always grouped within their property types. Group one (cluster analyses) for example lost two properties into other groups, the software (hierarchy analyses) identified that these two properties were different to all the other 'C' properties. They were not owned by the LA and did not have any internal works carried out to them. This variation in data categorised the two properties into new groups, which now strengthened the relationship in-group 1 due to the similarity of the interventions. (Table 5.8).

The decision to use 6 clusters was determined by inferential analyses and visual inspection of the dendrogram. The grouping of the property types were observed. A larger population within the study may have affected the grouping of the property types. Further investigations (Summary Statistics and Boxplots) in (section 5.4.3) identified the difference of energy usage between, 2013-15. Results showed that residential buildings of group 1 &6 had significant reduction in gas usage (section 5.4.3.1) whilst residential buildings of group 1 had significant reduction in the electricity usage (section 5.4.3.2). These results however did not take into accounts occupants' behaviour.

On completion of the "Case Study" project several interventions were either incomplete or were not fully commissioned, subsequently these were removed from the study. This may not only have affected energy results within the investigation, particularly the 'P' property types, but also produced some negative feedback within the study from residents that were personally effected.

At the time of collecting energy data from each property within the study, the smart energy monitoring system was not fully commissioned, which had a significant effect on the data analyses process. Although energy usage was known for each property, their associated technologies were grouped, making it difficult to assess the performance of individual interventions. However, [(table 5.7), (section 5.4.2.1)] most property, groups did consist of at least one primary technology supported by several secondary technologies.

8.3 OCCUPANCY SECTION.

Along with cluster analyses, Principal Component Analyses was used within the occupancy section, by rationalizing or reducing the number of variables. This identified a smaller data set, classifying the relationship between the variables and allowing the information to be grouped. The scree plot inflection method, defined how many components were to be retained. The process was used for both ordinal and nominal data for phase 1 and phase 2.

The combination of results from this part of the study (section 6.3) showed that the internet in both the ordinal and nominal sections produced results with a high level of importance. This was also supported by results found in section 6.2 bivariate analyses. Additionally, results in phase 2 (ordinal data) indicated that SEH produced results with a high level of importance. This may have been due to their management roles changing in phase 2. Results shown in the rotated matrix (Phase 2) Table 6.7 and Table 6.8 indicate that Qu_2.17 and Qu_2.5 receive high loading signifying a high level of importance as discussed further in the next section.

Qu 2.17-*Does the installation meet your requirements* also produced improved results in phase 2 similarly this may have been due to the involvement of SEH.

Qu-2.5 Do You know which Technologies have been fitted, was also re-classified with a higher weighting in phase 2 and must be considered with a high level of importance. It could be assumed here that improvements were due to several anomalies, firstly, the internet being used more frequently. Secondly, occupants now reading there manuals due to advice and support offered by SEH management organisation.

Similar to the analyses of data carried out in the Technology chapter, cluster analyses was chosen in this section, as a statistical tool to analyse data into groups, this method was best suited to a small study. Due to the grouping of property types, 4 groups were finally chosen to represent the cluster sets. Variables with more than 3 dissimilar similarities were excluded from the study, which allowed the variables with stronger weightings to be considered further.

The results provided a profile of the occupants' behaviour and the property type they were associated to.

Further statistical analyses using P-values from Dunn's Kruskal-Wallis multiple comparison test results with Bonferroni correction were also applied for each combination of occupant groups, which identified whether there was a significance difference between the groups.

8.3.1 AFTERCARE

Soft landing was also discussed within the review of literature, involving residents at an early stage and then throughout the project and beyond completion, the process consisted of annual inspections and support by the design team throughout the project and after practical completion. Results found that support by the management organisations SEH in section 6.2.5 did benefit the occupants and their understanding of the technologies. It was not possible to investigate the aftercare and support given in that period due to the data collection period ending.

8.4 TECHNOLOGIES V OCCUPANTS BEHAVIOUR

Data from the technology and occupants clusters analysis sections were combined, which now began to not only group occupant with their technologies but also construct a profile of the occupants. Smaller groups ($n < 2$) were excluded from this part of the study, allowing more emphasis on the larger groups to be examined.

8.4.1 ENERGY CONSUMPTION

Whilst smaller groups from the Energy Efficiency Chapter were removed, several of these smaller groups did received positive energy results for both gas and electricity usage. However, being such a small sample, profiling energy results against technologies and behaviour would have encouraged results to be occupant specific. The use of larger groups allowed similar profiles to be built up where there was a similarity between the sample involving the new technologies, behaviour patterns and energy usage.

Several properties within the study showed a net gain of +4.76%. This indicated that the occupants' weekly/monthly energy bills were similar for both 2014 and 2015. This showing a small reduction in their energy usage for 2015 compared to 2014.

Overall gas usage reflected better results than electricity. This may have been due predominately to the nature of the interventions or the type of buildings they were fitted to. Several residents believed that the dehumidifier fans and led traffic light systems were expensive to run. Unfortunately, it was not possible to justify the running costs of these products due to the smart metering systems not being commissioned at this stage.

The results from this study in chapters 5, 6 and 7 will be summarised in chapter- 9 Conclusions.

Chapter 9

CONCLUSIONS

9.1 MAIN RESEARCH CONCLUSIONS

The aim of this research was to critically assess the use of new energy efficient technologies that government agencies have introduced to reduce carbon emissions in the sustainable built environment and to investigate the relationship between post occupancy behaviour in buildings and energy efficiency.

The study was conducted on a Pilot Retrofitting Project, comprising predominantly energy retrofitted social housing (a mixture of flats, semi-detached bungalows, terraced bungalows and semi-detached BISF houses built between 1950-1970) built in the south east of the UK, with new energy efficient technologies .

This retrofitting pilot study was undertaken by analysing data collected using mixed methods, such as interviews, questionnaires, random observations and systematically data analyses.

The retrofitting pilot study established that building performance ranks at the forefront of government policies in the UK. Energy efficient technologies can improve the subsequent performance of a building. However, this improved performance can only be achieved if all of those involved in the building process engage early in the design stage of the retrofitting technologies and support the development up to and after practical completion of the energy retrofit. Not only do building owners/tenants and clients seek information to describe maintenance scheduling (section 6.1), but also a design rationale determining the building's functionality and post occupancy usage. In addition, occupants need to be supported during and after this period to address any commissioning or running issues. This can only be successful if the monitoring period is extended beyond the post completion date, thus allowing not only further support but data collection for historical use.

Additionally, the pilot study identified that firstly, many of the UK government energy schemes were not active or out-dated, leading to possible uncertainty and confusion to the consumer. No well-defined structure was in place that would encourage occupants to carry the green batten and become energy conscious. This was supported by responses from questionnaires, where 37% of the occupants were either unfamiliar or ill-informed about these policies and government targets, as discussed in section 6.1.1.

The concept of new energy efficient technologies was not embraced by the majority of the population within the study, outcome which is in agreement with the findings of Rogers, 2003 (Diffusion of Innovations theory). Thus, according to this theory, many of the occupants participating in the current study could have been categorised as 'Sceptical' (late majority) or worst case scenario 'Laggers', where no immediate change in their social behaviour could be found when adopting new technologies (section 6.1.8).

Seminars, presentations and support were provided to occupants in this retrofitting pilot study from the offset at a venue called the Eco Clinic. However, limited attendance may have affected the occupants' understanding of the retrofitting project, how these energy efficient technologies worked and the benefits that these technologies would bring (section 6.2.3).

Preceding these sessions, an understanding of the capabilities of the end user would have been further beneficial to the design team. Complex or difficult to use, some of the installed technologies proved challenging to several residents and these issues could have been anticipated and tackled at an earlier stage. Thus, designers needed to understand not only their client's demands but also the end users' needs and their ability to understand energy efficient technologies.

Innovative energy efficiency technologies were investigated in combination with more traditional technologies. Innovative energy efficiency technologies included Balco glazing system, air source heat pumps, voltage optimisation units, phase change material, thermodynamics and passivents, whilst the traditional technologies included energy efficient boilers, solar panels and external structural insulation.

The study showed that, although the installation of smart metering/monitoring systems by 2019 is a priority for the UK energy providers, 76% of the occupants in this study had little or no idea of how a smart metering system worked (Section 6.1.3.1). Therefore, smart metering could be perceived only as a means to encourage occupants to monitor their energy usage with the view to eventually save money.

To identify if a relationship between occupants' behaviour and an interaction with innovative technologies existed, inferential data analysis methods were used in this study, in conjunction with appropriate assumptions relating to the population and their characteristics. A phenomena that did emerge within this study using qualitative methods revealed that the results from questionnaires were not always consistent with the information received from one to one interviews (section 4.10).This may have been due to inconsistent thoughts by the occupants, resembling the Cognitive Dissonance theory, where two or more believes are considered, Festinger (1957).

Quantitative methods also identified relationships between occupants' behaviour and energy usage. Data was analysed using various statistical analysis such as hierarchy clustering and multivariate analysis, which enabled technologies and behaviour patterns to be classified into groups of occupants, according to their statistical similarities (section 6.3 - 6.4).

The combination of the results from the energy efficiency technologies (chapter 5) and the occupants' behaviour (chapter 6) resulted in five distinctive groups. These groups profiled the occupants' characteristics in relation to the technologies installed and the energy usage (section *7.3)* in order to identify if a correlation existed between the technologies installed, occupants' behaviour and energy usage. Thus, the smallest reduction in gas usage (0.98 % adjusted) came from the group which included passive solar heat collectors, balcony enclosures and LEDs (group A3, section 7.2.1.1) whilst the most significant reduction in gas usage (20.62%) came from the group which included structural insulation, boilers and solar panels (group D6, section 7.3).

The occupants in the best performing group (D6) lived in BISF semi-detached houses, were employed, familiar with the installed technologies, had a good command of the internet and understood user manuals (section 7.3.1). However, whilst these properties were all semi-detached houses, it cannot be assumed that these types of buildings could always influence the results without due consideration of the characteristics of the occupants and the energy efficiency technologies that were used. Supporting these findings, bivariate results indicated that there was a high likelihood that a relationship may have existed between occupants that were employed and received user manuals (section 6.2.3).

Smaller statistical groups did provide positive results in terms of energy reduction but further consideration of behaviour traits was challenging due to the reduced sample size.

Additionally, the final outcomes in terms of energy efficiency could have changed due to the fact that not all the installed technologies had been fully commissioned by the end of this study.

The final outcomes of the study (section 7.3.2) indicated that passive technologies with little or no maintenance, such as external wall insulation, solar panels and eco boilers, provided positive energy saving results.

The innovative energy efficient technologies proved to be technically challenging to the occupants, therefore difficult to understand, thus preventing these interventions to reach their full potential.

The Pilot Retrofitting Study showed that for the energy efficient technologies to produce positive results, they not only have to be user friendly but also need to be perceived by the occupants as improving the energy usage.

9.2 Limitations of Study

The majority of the occupants within the study were living in social housing, with little input into the choice of the energy efficient technologies that were being fitted to their properties. Additionally, many of the occupants had little or no understanding in terms of technical aspects of the installed technologies or government targets to reduce carbon emissions. These traits did not improve significantly enough throughout the project in order to measure any improvement.

The retrofitting pilot study consisted of 51 dwellings (e.g. 51 questionnaire respondents), which could be considered as a small sample from a statistical point of view, and this may also have influenced the findings of this study.

9.3 Contribution to Knowledge

This study has made original contributions to knowledge in assessing the relationship between ‘Occupant’s Behaviour and Energy Efficiency’. Prior to this investigation, very little research had been undertaken in this field, investigating the relationship between energy efficiency and occupant behaviour.

These are outlined below:

- This retrofitting pilot study investigated the energy performance of innovative technologies (e.g. Balco glazing system, air source heat pumps, voltage optimisation units, phase change material, thermodynamics, passivents, solar panels) installed in mixed dwellings.

- The retrofitting pilot study was conducted on a large number of mixed dwellings (51 dwellings), equipped with innovative energy efficient technologies, with limited real life validation track record.
- Using statistical methods, this retrofitting pilot study established a correlation between occupant's traits and behaviour (employment status, computer literacy/internet skills, ability to understand technical information and interact with innovative technologies) and innovative energy efficient technologies. This correlation can be used in the future as a guide for the identification of the critical parameters that effect energy consumption and efficiency in residential buildings.

9.4 Recommendations for future work

- Further research into post-installation monitoring and aftercare is needed in order to get a more in-depth knowledge into the performance of innovative energy efficient technologies, other than those installed in this retrofitting pilot case study.

- The use of the currently investigated Retrofitting Pilot Study as the basis for a larger study in the future which will facilitate the comparison between the results obtained from this study with other similar studies.

- A comparison of results between private and social housing would be beneficial with a larger sample size.

- Further investigations into innovative energy efficient technologies that were either not fully commissioned or were not used not used within this project.

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APPENDIX 1 QUESTIONNAIRES

UEL University of East London	PhD Research Project		
Name of Surveyor:		**Date of Survey:**	
Phase:	**Phase I**	**Reference No:**	

1. SECTION 1 – OCCUPANTS

1.1 Gender

Male ☐ Female ☐

1.2 No of occupants in household.

1-2 ☐ 3-4 ☐ 5-6 ☐ 7-8 ☐ >9 ☐

1.3 Average age of Occupants

18-25 ☐ 26-40 ☐ 41-55 ☐ 56-65 ☐ >66 ☐

1.4 Occupants Occupation

Retail	☐	Construction	☐
Public Sector	☐	Retired	☐
Private sector	☐	Unemployed	☐
IT	☐	Other	☐

1.5 Type of property

Bungalow – Detached	☐	House – Semi	☐
Bungalow – Semi	☐	Flat	☐
Bungalow –End - terraced	☐	Bed sit	☐
Bungalow –Mid - terraced	☐		

1.6 Type of heating

Gas ☐ Electric ☐ Other ☐

1.7 Do you know the average monthly cost of your energy bills

Gas: Yes ☐ No ☐

Electric: Yes ☐ No ☐

1.8 How are your fuels Bills paid

Card ☐ Monthly ☐ Quarterly ☐

1.9 Do you know the how much water you use a month

Yes ☐ No ☐

1.10 Do you own a computer

Yes ☐ No ☐

1.11 How long have you owned the computer for-Years

0 ☐ 1-2 ☐ 3-6 ☐ 6-10 ☐ >10 ☐

1.12 How good would you rate your computer skills?

Poor — Good — Very good

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

1.13 Have you got access to the internet

yes ☐ No ☐ Planning ☐

1.14 How often do you use the internet?

Never — occasionally — All the time

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

1.15 How often do you shop online?

Never — occasionally — All the time

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

1.16 How often do you listen to Music on line

Never — occasionally — Frequently

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

1.17 How often do you pay any household bills on line?

Never — occasionally — Frequently

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

1.18 Do you ever supplement you heating by say an electric fire?

never — occasionally — Frequently

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

1.19 Do you know who your energy supplier is-

Yes ☐ No ☐

1.20 Do you have a mobile phone

Yes ☐ No ☐ Planning ☐

1.21 How long do you have the TV on every day

0 ☐ 1-2 ☐ 3-4 ☐ 5-6 ☐ >6 ☐

1.22 Do you switch the stand- by off?

never — occasionally — Frequently

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

1.23 Do you switch lights on and off when you leave a room?

never — occasionally — Frequently

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

1.24 Do you know what energy saving utilities are? Are you familiar with them

no — Little knowledge — yes

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

1.25 If yes which ones do you own?

Washing Machine ☐ Dishwasher ☐

Cooker ☐ Other ☐

Fridge ☐

1.26 Do you prefer to us a shower than a bath?

never — occasionally — always

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

1.27 Which one do you think is the most economical one to use?

Bath ☐ Shower ☐

1.28 Have you found that the temperature in your lounge in the past as being cold

no / yes

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

2 SECTION 2 - THE INSTALLATION

2.1 What is your awareness about energy usage?

poor — acceptable — excellent

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

2.2 Are you Aware of government Policies?

None	☐	Government Targets	☐
Global Warming	☐	Green Deal	☐

2.3 How often do you monitor your energy usage?

never — occasionally — Frequently

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

2.4 Do you know your expenditure here?

Yes ☐ No ☐

2.5 Do you know which technologies have been fitted in your property

Yes ☐ No ☐

2.6 Was a clear explanation provided regarding the technologies being fitted?

Poor — good — Excellent

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

2.7 Was the explanation conveyed by one of the following methods:

Phone ☐ orally ☐ letter ☐ manual ☐ none ☐

2.8 Was the fitted process carried out within the times specified?

late — On time

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

2.9 Have you had any problems with the installation process?

none — several — many

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

2.10 Have you attended any Eco clinics on a Wednesday?

Yes ☐ No ☐

2.11 Have any user guides been provided yet to you.

Yes ☐ No ☐

2.12 Do you know how your smart meter works?

No idea — Little idea — Good idea

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

2.13 Have you been on line to check your energy usage?

Yes ☐ No ☐

2.14 How often do you check your energy usage

daily ☐ weekly ☐ monthly ☐ quarterly ☐ never ☐

2.15 Has any energy reduction been noted?

None — little — Great deal

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

2.16 If you energy bills have been reduced will you turn up the thermostat to obtain better level of comfort or benefit from the saving.

Turn up the thermostat ☐ Benefit from saving ☐

2.17 Does the installation meet you expectations?

Poor — good — Excellent

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

2.18 How approachable were the Estate department during the installation

Poor — good — Excellent

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

2.19 Would the retrofit encourage you to purchase energy saving devices in the future ie. Bulbs, washing machines, fridges or other

Strongly disagree ... Strongly agree

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

2.20 Would you set aside funds to purchase energy saving devices?

No ... possible ... Yes

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

2.21 Did you sign up for the new energy technology- to save money?

no ... Yes

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

2.22 Did you sign up for the new energy technology- to reduce the carbon foot print?

Don't no ... no ... Yes

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

2.23 Did you sign up for the new energy technology- to improve your well- being?

Don't no ... no ... Yes

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

2.24 Are you familiar with the technology or technologies that have been installed?

Strongly disagree ... Strongly agree

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

2.25 Do you monitor your energy usage?

Never ... sometimes ... always

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

	PhD Research Project		
Name of Surveyor:		**Date of Survey:**	
Phase:	**Phase II**	**Reference No:**	

1. SECTION 1 – OCCUPANTS

1.1 Gender

Male [ ] Female [ ]

1.2 No of occupants in household.

1-2 [ ] 3-4 [ ] 5-6 [ ] 7-8 [ ] >9 [ ]

1.3 Average age of Occupants

18-25 [ ] 26-40 [ ] 41-55 [ ] 56-65 [ ] >66 [ ]

1.4 Occupants Occupation

Retail	[ ]	Construction	[ ]
Public Sector	[ ]	Retired	[ ]
Private sector	[ ]	Unemployed	[ ]
IT	[ ]	Other	[ ]

1.5 Type of property

Bungalow – Detached	[ ]	House – Semi	[ ]
Bungalow – Semi	[ ]	Flat	[ ]
Bungalow –End - terraced	[ ]	Bed sit	[ ]
Bungalow –Mid - terraced	[ ]		

1.6 Type of heating

Gas [ ] Electric [ ] Other [ ]

1.7 Do you know the average monthly cost of your energy bills

Gas: Yes ☐ No ☐

Electric: Yes ☐ No ☐

1.8 How are your fuels Bills paid

Card ☐ Monthly ☐ Quarterly ☐

1.9 Do you know the how much water you use a month

Yes ☐ No ☐

1.10 Do you own a computer

Yes ☐ No ☐

1.11 How long have you owned the computer for-Years

0 ☐ 1-2 ☐ 3-6 ☐ 6-10 ☐ >10 ☐

1.12 How good would you rate your computer skills?

Poor 1 ☐ 2 ☐ 3 ☐ 4 ☐ Good 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ Very good 10 ☐

1.13 Have you got access to the internet

yes ☐ No ☐ Planning ☐

1.14 How often do you use the internet?

Never 1 ☐ 2 ☐ 3 ☐ 4 ☐ occasionally 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ All the time 10 ☐

1.15 How often do you shop online?

Never 1 ☐ 2 ☐ 3 ☐ 4 ☐ occasionally 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ All the time 10 ☐

1.16 How often do you listen to Music on line

Never 1 ☐ 2 ☐ 3 ☐ 4 ☐ occasionally 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ Frequently 10 ☐

1.17 How often do you pay any household bills on line?

Never 1 ☐ 2 ☐ 3 ☐ 4 ☐ occasionally 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ Frequently 10 ☐

1.18 Do you ever supplement you heating by say an electric fire?

never | occasionally | Frequently
1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

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Yes ☐ No ☐

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no | Little knowledge | yes
1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

1.25 If yes which ones do you own?

Washing Machine ☐ Dishwasher ☐

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1.27 Which one do you think is the most economical one to use?

Bath ☐ Shower ☐

1.28 Have you found that the temperature in your lounge in the past as being cold

no yes

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

2 SECTION 2 - THE INSTALLATION

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poor acceptable excellent

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

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None ☐ Government Targets ☐

Global Warming ☐ Green Deal ☐

2.3 How often do you monitor your energy usage?

never occasionally Frequently

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

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Yes ☐ No ☐

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Yes ☐ No ☐

2.6 Was a clear explanation provided regarding the technologies being fitted?

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Phone ☐ orally ☐ letter ☐ manual ☐ none ☐

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late On time

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

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none several many

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

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Yes ☐ No ☐

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2.17 Does the installation meet you expectations?

Poor | good | Excellent

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Strongly disagree ... Strongly agree

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No ... possible ... Yes

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

2.21 Did you sign up for the new energy technology- to save money?

no ... Yes

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

2.22 Did you sign up for the new energy technology- to reduce the carbon foot print?

Don't no ... no ... Yes

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

2.23 Did you sign up for the new energy technology- to improve your well- being?

Don't no ... no ... Yes

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

2.24 Are you familiar with the technology or technologies that have been installed?

Strongly disagree ... Strongly agree

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

2.25 Do you monitor your energy usage?

Never ... sometimes ... always

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

3 SECTION 3 - THE AFTERCARE

3.1 How many times since the refit was completed have the technologist or managing agents visited you to discuss how the system s work

Never ☐ once ☐ twice ☐ Three ☐ More ☐

3.2 Were clear explanations provided regarding any concerns you may have had.

No ☐ Yes ☐

3.3 Have you IT skills improved since the technology's have been installed

no — yes

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

As a result of the refit or increased insulation standards have you-

3.4 Turned the room thermostat down.

never — Some times — regularly

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

3.5 Left the thermostat at the same setting

never — yes

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

3.6 Altered the settings to allow the heating to come on later

never — some times — Many times

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

3.7 Felt warmer since the insulation was fitted

never some times Many times
1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

3.8 During the autumn and spring when the outside temperatures can drop rapidly the house will feel cool do you have to turn the heating on.

never some times Many times
1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

3.9 Are there any cold spots in the house?

No ☐ Yes ☐

3.10 Is the lounge warmer now?

never yes
1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

3.11 Is the hallway warmer now?

never yes
1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

3.12 Are the bedrooms warmer now?

never yes
1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

3.13 Do the rooms heat up quicker now if you need to turn the heating on during the day?

never sometimes always
1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

3.14 Do you have double glazing?

No ☐ Yes ☐

3.15 If you draw the curtains do you notice any improvement in room temperature?

never sometimes always

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

3.16 In the summer is the house now cooler on a sunny day.

never sometimes always

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

3.17 Have you noted any improvement in your energy bills?

no yes

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

3.18 Does the house/bungalow feel more comfortable now from the insulation or technology's?

no yes

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

3.19. Have you noticed any improvements to your health since the refit was carried out?

never yes

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

3.20 How many years have you live in the property?

1-5 ☐ 6-10 ☐ 10-20 ☐ 20-30 ☐ 30 + ☐

3.21 Has the thermal comfort improved?

No yes

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

3.22 Has the air quality improved?

No yes

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

3.23 Have you considered changing you energy provider?

No yes

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

3.24 Would you be confident enough to discuss alternative energy plans?

No Maybe yes

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

3.25 What time do you turn your heating on in the morning and afternoon, or do you leave it on all day

Morning ☐ Evening ☐ All day ☐

Total Hours per day ☐

3.26 What temperature do you normally set the thermostat to?

$19\text{-}21^0$ ☐ $21\text{-}25^0$ ☐ Higher 25^0 ☐

Is there anything you would like to say?

Comments

APPENDIX 2 INTERVENTIONS

	Property Code	Property Type		1 Structural Insulation	2 External Wall Insulation	3 VIP Insulation	4 Balcony Enclosure	5 Micro-CHP	6 Ceramic Fuel Cells	7 Air Source Heat Pumps	8 Single Heat Recovery Ventilation	9 Phase Change	11 MVHR	13 PV	14 PVT	15 Thermo-dynamics	16 LEDs	17 Voltage Optimisati	18 DC Circuits	19 Wifi Hubs	20 Smart Metering	21 Airtight	22 DC LEDs	23 Solar Thermal	24 Boiler	25 Solar panel
1	C1	Semi-detached House	Council	🟢	🔴	🔴	🔴	🔴	🔴	🔴	🟢	🟢	🔴	🔴	🔴	🔴	🟢	🟢	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴
2	C2	Semi-detached House	Council	🟢	🔴	🔴	🔴	🔴	🔴	🔴	🟢	🟢	🔴	🔴	🔴	🔴	🟢	🟢	🔴	🟢	🟢	🔴	🔴	🔴	🔴	🔴
3	C3	Semi-detached House	Private	🟢	🔴	🔴	🔴	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴	🟢	🟢	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴
4	C4	Semi-detached House	Council	🟢	🔴	🔴	🔴	🔴	🔴	🔴	🟢	🟢	🔴	🔴	🔴	🔴	🟢	🟢	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴
5	C5	Semi-detached House	Council	🟢	🔴	🔴	🔴	🔴	🔴	🔴	🟢	🟢	🔴	🔴	🔴	🔴	🟢	🟢	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴
6	C6	Semi-detached House	Private	🟢	🔴	🔴	🔴	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴	🟢	🟢	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴
7	C7	Semi-detached House	Council	🟢	🔴	🔴	🔴	🔴	🔴	🔴	🟢	🟢	🔴	🟢	🔴	🔴	🔴	🟢	🟢	🟢	🟢	🔴	🟢	🔴	🔴	🔴
8	L1	GF Flat	Council	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🟢	🔴	🔴	🟢	🔴	🔴	🟢	🟢	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴
9	L2	Mid-Terraced House	Council	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🟢	🔴	🔴	🟢	🔴	🔴	🟢	🟢	🔴	🟢	🟢	🔴	🔴	🟢	🔴	🔴
10	L3	GF Flat	Council	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🟢	🔴	🔴	🟢	🔴	🔴	🟢	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴
11	L4	FF Flat	Council	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🟢	🔴	🔴	🟢	🔴	🔴	🟢	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴
12	L5	Mid-Terraced House	Council	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🟢	🔴	🔴	🟢	🔴	🔴	🟢	🟢	🔴	🔴	🟢	🔴	🔴	🟢	🔴	🔴
13	L6	Mid-Terraced House	Council	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🟢	🔴	🟢	🔴	🔴	🟢	🟢	🔴	🔴	🔴	🔴	🔴
14	L7	Mid-Terraced House	Council	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴
15	L8	FF Flat	Council	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🟢	🔴	🔴	🟢	🔴	🔴	🟢	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴
16	P1	GF Flat	Council	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴	🟢	🟢	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴
17	P2	GF Flat	Council	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴
18	P3	GF Flat	Council	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴	🟢	🟢	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴
19	P4	FF Flat	Council	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴	🟢	🟢	🔴	🟢	🟢	🔴	🔴	🔴	🔴	🔴
	P5	FF Flat	Council	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴
20	P6	FF Flat	Council	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴	🟢	🟢	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴
21	P7	Bungalow	Council	🔴	🔴	🔴	🔴	🟢	🟢	🔴	🟢	🔴	🔴	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴
22	P8	GF Flat	Council	🔴	🔴	🔴	🟢	🟢	🟢	🔴	🟢	🔴	🔴	🔴	🔴	🔴	🟢	🟢	🔴	🟢	🟢	🔴	🔴	🔴	🔴	🔴
23	P9	GF Flat	Council	🔴	🔴	🔴	🟢	🟢	🟢	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴
24	P10	GF Flat	Council	🔴	🔴	🔴	🟢	🟢	🟢	🔴	🟢	🔴	🔴	🔴	🔴	🔴	🟢	🟢	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴
25	P11	FF Flat	Council	🔴	🔴	🔴	🟢	🟢	🟢	🔴	🟢	🔴	🔴	🔴	🔴	🔴	🟢	🟢	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴
26	P12	FF Flat	Council	🔴	🔴	🔴	🟢	🟢	🟢	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴
27	P13	FF Flat	Council	🔴	🔴	🔴	🟢	🟢	🟢	🔴	🟢	🔴	🔴	🔴	🔴	🔴	🟢	🟢	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴
28	P14	Bungalow	Council	🔴	🔴	🔴	🔴	🟢	🟢	🔴	🟢	🔴	🔴	🔴	🔴	🔴	🟢	🟢	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴
29	PA1	Bungalow	Council	🔴	🟢	🔴	🔴	🔴	🔴	🟢	🟢	🔴	🟢	🟢	🔴	🔴	🟢	🟢	🔴	🟢	🟢	🟢	🔴	🔴	🔴	🔴
30	PA2	Bungalow	Council	🔴	🟢	🔴	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🟢	🔴	🔴	🟢	🟢	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴
31	PA3	Bungalow	Council	🔴	🟢	🔴	🔴	🔴	🔴	🟢	🟢	🔴	🔴	🟢	🔴	🔴	🟢	🟢	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴
32	PB1	Bungalow	Council	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🟢	🔴	🔴	🟢	🔴	🟢	🔴	🔴	🟢	🔴	🟢	🔴	🟢	🔴	🔴	🔴
33	PB2	Bungalow	Council	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🟢	🔴	🔴	🟢	🔴	🟢	🟢	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴
34	PB3	Bungalow	Council	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🟢	🔴	🔴	🟢	🔴	🟢	🟢	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴
35	PB4	Bungalow	Council	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴	🟢	🟢	🔴	🟢	🟢	🔴	🔴	🔴	🔴	🔴
36	PB5	Bungalow	Council	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴
37	PB6	Bungalow	Council	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴
38	PB7	Bungalow	Council	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴
39	PB8	Bungalow	Council	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴
40	PB9	Bungalow	Council	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴	🟢	🔴	🔴	🟢	🟢	🔴	🔴	🔴	🔴	🔴
41	PB10	Bungalow	Council	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🟢	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🟢	🔴	🟢	🔴	🟢	🔴	🔴	🔴
41	R1	Semi-detached House	Council	🟢	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🟢	🟢
43	R2	Semi-detached House	Council	🟢	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴
44	R3	Semi-detached House	Council	🟢	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🟢	🟢
45	R4	Semi-detached House	Council	🟢	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🟢	🟢
46	R5	Semi-detached House	Council	🟢	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🟢	🟢
47	R6	Semi-detached House	Council	🟢	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🟢	🟢
48	WC1	Semi-detached House	Council	🟢	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🟢	🟢
49	WC2	Semi-detached House	Council	🟢	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🟢	🟢
50	WC3	Semi-detached House	Council	🟢	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🟢	🟢
51	WC4	Semi-detached House	Council	🟢	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🟢	🟢

APPENDIX 3 CLASSIFICATION OF VARIABLES

Table A3.1 Variables Classification

Question Phase I	***Variable Classification***	***Question Phase II***	***Variable Classification***	***Question Phase III***	***Variable Classification***
1.1	Nominal	*2.1*	Scale	*3.1*	Nominal
1.2	Ordinal	*2.2*	Nominal	*3.2*	Nominal
1.3	Ordinal	*2.3*	Scale	*3.3*	Scale
1.4	Nominal	*2.4*	Nominal	*3.4*	Scale
1.5	Nominal	*2.5*	Nominal	*3.5*	Scale
1.6	Nominal	*2.6*	Scale	*3.6*	Scale
1.7	Nominal	*2.7*	Nominal	*3.7*	Scale
1.8	Nominal	*2.8*	Scale	*3.8*	Scale
1.9	Nominal	*2.9*	Scale	*3.9*	Scale
1.10	Nominal	*2.10*	Nominal	*3.10*	Scale
1.11	Ordinal	*2.11*	Nominal	*3.11*	Scale
1.12	Scale	*2.12*	Scale	*3.12*	Scale
1.13	Nominal	*2.13*	Nominal	*3.13*	Scale
1.14	Scale	*2.14*	Nominal	*3.14*	Scale
1.15	Scale	*2.15*	Scale	*3.15*	Scale
1.16	Scale	*2.16*	Nominal	*3.16*	Scale
1.17	Scale	*2.17*	Scale	*3.17*	Scale
1.18	Scale	*2.18*	Scale	*3.18*	Scale
1.19	Nominal	*2.19*	Scale	*3.19*	Scale
1.20	Nominal	*2.20*	Scale	*3.20*	Scale
1.21	Ordinal	*2.21*	Scale	*3.21*	Scale
1.22	Scale	*2.22*	Scale	*3.22*	Scale
1.23	Scale	*2.23*	Scale	*3.23*	Scale
1.24	Scale	*2.24*	Scale	*3.24*	Scale
1.25	Nominal	*2.25*	Scale	*3.25*	Scale
1.26	Scale			*3.26*	Scale
1.27	Nominal				
1.28	Scale				

Table A3.2 Code used on SPSS - Questionnaire Section 1

Question Section I	*(SPSS Code)*	*Question Section I*	*(SPSS Code)*	*Question Section I*	*(SPSS Code)*
1.1	1 – Male 2 – Female	*1.11*	1 - '0 years' 2 - '1-2 years' 3 - '3-6 years' 4 - '7-10years' 5 - '>10 years'	*1.21*	1 - '0 hour' 2 - '1-2 hours' 3 - '3-4 hours' 4 - '5-6 hours' 5 - '>6 hours'
1.2	1 – '1-2' 2 – '3-4' 3 – '5-6' 4 – '7-8' 5 – '>9'	*1.12* *(Scale 1 to 10)*	1 - 'Poor' 5 - 'Good' 10 - 'Very Good'	*1.22* *(Scale 1 to 10)*	1 - 'Never' 5 - 'Occasionally' 10 - 'Frequently'
1.3	'Exact age'	*1.13*	1 - 'Yes' 2 - 'No' 3 - 'Planning'	*1.23* *(Scale 1 to 10)*	1 - 'Never' 5 - 'Occasionally' 10 - 'Frequently'
1.4	1 – 'Retail' 2 – 'Public Sector' 3 – 'Private Sector' 4 – 'IT' 5 – 'Construction' 6 - 'Retired' 7 - 'Unemployed' 8 - 'Other'	*1.14* *(Scale 1 to 10)*	1 - 'Never' 5 - 'Occasionally' 10 - 'All the time'	*1.24* *(Scale 1 to 10)*	1 - 'No' 5 - 'Little knowledge' 10 - 'Yes'
1.5	1 - 'Bungalow-Detached' 2 - 'Bungalow-Semi' 3 - 'Bungalow-End-Terraced' 4 - 'Bungalow-Mid-Terraced' 5 - 'House-Semi'	*1.15* *(Scale 1 to 10)*	1 - 'Never' 5 - 'Occasionally' 10 - 'All the time'	*1.25*	1 - 'Washing machine' 2 - 'Cooker' 3 - 'Dishwasher' 4 - 'Other'

	6 - 'Flat' 7 - 'Bed sit'				
1.6	1 - 'Gas' 2 - 'Electric' 3 - 'Other'	*1.16* *(Scale 1 to 10)*	1 - 'Never' 5 - 'Occasionally' 10 - 'All the time'	*1.26* *(Scale 1 to 10)*	1 - 'Never' 5 - 'Occasionally' 10 - 'Always'
1.7	1 - 'Yes' 2 - 'No'	*1.17* *(Scale 1 to 10)*	1 - 'Never' 5 - 'Occasionally' 10 - 'All the time'	*1.27*	1 - 'Bath' 2 - 'Shower'
1.8	1 - 'Card' 2 - 'Monthly' 3 - 'Quarterly'	*1.18* *(Scale 1 to 10)*	1 - 'Never' 5 - 'Occasionally' 10 - 'Frequently'	*1.28*	1 - 'No' 10 - 'Yes'
1.9	1 - 'Yes' 2 - 'No'	*1.19*	1 - 'Yes' 2 - 'No'		
1.10	1 - 'Yes' 2 - 'No'	*1.20*	1 - 'Yes' 2 - 'No' 3- 'Planning'		

Table A3.3 Code used on SPSS - Questionnaire Section 2

Question Section II	***(SPSS Code)***	***Question Section II***	***(SPSS Code)***	***Question Section II***	***(SPSS Code)***
2.1 ***(Scale 1 to 10)***	1 - 'Poor' 5 - 'Acceptable' 10 - 'Excellent'	***2.10***	1 - 'Yes' 2 - 'No'	***2.18*** ***(Scale 1 to 10)***	1 - 'Poor' 5 - 'Good' 10 - 'Excellent'
2.2	1 - 'None' 2 - 'Global Warning' 3 - 'Government Targets' 4 - 'Green Deal'	***2.11***	1 - 'Yes' 2 - 'No'	***2.19*** ***(Scale 1 to 10)***	1 - 'Strongly disagree' 10 - Strongly agree'
2.3 ***(Scale 1 to 10)***	1 - 'Never' 5 - 'Occasionally' 10 - 'Frequently'	***2.12*** ***(Scale 1 to 10)***	1 - 'No idea' 5 - 'Little idea' 10 - 'Good idea'	***2.20*** ***(Scale 1 to 10)***	1 - 'No' 5 - 'Possible' 10 - 'Yes'
2.4	1 - 'Yes' 2 - 'No'	***2.13***	1 - 'Yes' 2 - 'No'	***2.21***	1 - 'No' 10 - 'Yes'
2.5	1 - 'Yes' 2 - 'No'	***2.14***	1 - 'Daily' 2 - 'Weekly' 3 - Monthly' 4 - 'Quarterly' 5 - 'Never'	***2.22***	1 - 'No' 10 - 'Yes'
2.6 ***(Scale 1 to 10)***	1 - 'Poor' 5 - 'Good' 10 - 'Excellent'	***2.15*** ***(Scale 1 to 10)***	1 - 'None' 5 - 'Little' 10 - 'Great deal'	***2.23***	1 - 'No' 10 - 'Yes'
2.7	1 - 'Phone' 2 - 'Orally' 3 - 'Letter' 4 - 'Manual' 5 - 'None'	***2.16***	1 - 'Turn up the thermostat' 2 - 'Benefit from saving'	***2.24*** ***(Scale 1 to 10)***	1 - 'Strongly Disagree' 10 - 'Strongly Agree'
2.8 ***(Scale 1 to 10)***	1 - 'Late' 10 - 'On time'	***2.17*** ***(Scale 1 to 10)***	1 - 'Poor' 5 - 'Good' 10 - 'Excellent'	***2.25*** ***(Scale 1 to 10)***	1 - 'Never' 5 - 'Sometimes'

					10 - ‘Always’
2.9 ***(<u>Scale 1 to 10</u>)***	1 - ‘ None’ 10 - ‘Many’				

Table A3.4 Code used on SPSS - Questionnaire Section 3

Question Section III	***(SPSS Code)***	***Question Section III***	***(SPSS Code)***	***Question Section III***	***(SPSS Code)***
3.1	1 - 'Never' 2 - 'Once' 3 - 'Twice' 4 - 'Three' 5 - 'More'	***3.10 (Scale 1 to 10)***	1 - 'Never' 10 - 'Yes'	***3.19 (Scale 1 to 10)***	1 - 'Never' 10 - 'Yes'
3.2	1 - 'No' 2 - 'Yes'	***3.11 (Scale 1 to 10)***	1 - 'Never' 10 - 'Yes'	***3.20***	1 - '1-5 years' 2 - '6-10 years' 3 - '10-20 years' 4 - '20-30 years' 5 - '30+ years'
3.3 (Scale 1 to 10)	1 - 'No' 10 - 'Yes'	***3.12 (Scale 1 to 10)***	1 - 'Never' 10 - 'Yes'	***3.21 (Scale 1 to 10)***	1 - 'No' 10 - 'Yes'
3.4 (Scale 1 to 10)	1 - 'Never' 5 - 'Sometimes' 10 - 'Regularly'	***3.13 (Scale 1 to 10)***	1 - 'Never' 5 - 'Sometimes' 10 - 'Always'	***3.22 (Scale 1 to 10)***	1 - 'No' 10 - 'Yes'
3.5 (Scale 1 to 10)	1 - 'Never' 10 - 'Yes'	***3.14***	1 - 'No' 2 - 'Yes'	***3.23 (Scale 1 to 10)***	1 - 'No' 10 - 'Yes'
3.6 (Scale 1 to 10)	1 - 'Never' 5 - 'Sometimes' 10 - 'Many times'	***3.15 (Scale 1 to 10)***	1 - 'Never' 5 - 'Sometimes' 10 - 'Always'	***3.24 (Scale 1 to 10)***	1 - 'No' 5 - 'Maybe' 10 - 'Yes'
3.7 (Scale 1 to 10)	1 - 'Never' 5 - 'Sometimes' 10 - 'Many times'	***3.16 (Scale 1 to 10)***	1 - 'Never' 5 - 'Sometimes' 10 - 'Always'	***3.25***	
3.8 (Scale 1 to 10)	1 - 'Never' 5 - 'Sometimes' 10 - 'Many times'	***3.17 (Scale 1 to 10)***	1 - 'No' 10 - 'Yes'	***3.26***	*'Temperature*

APPENDIX 4 ENERGY

Table A4.1 Gas usage for Type C Properties – Gas 2013-2015

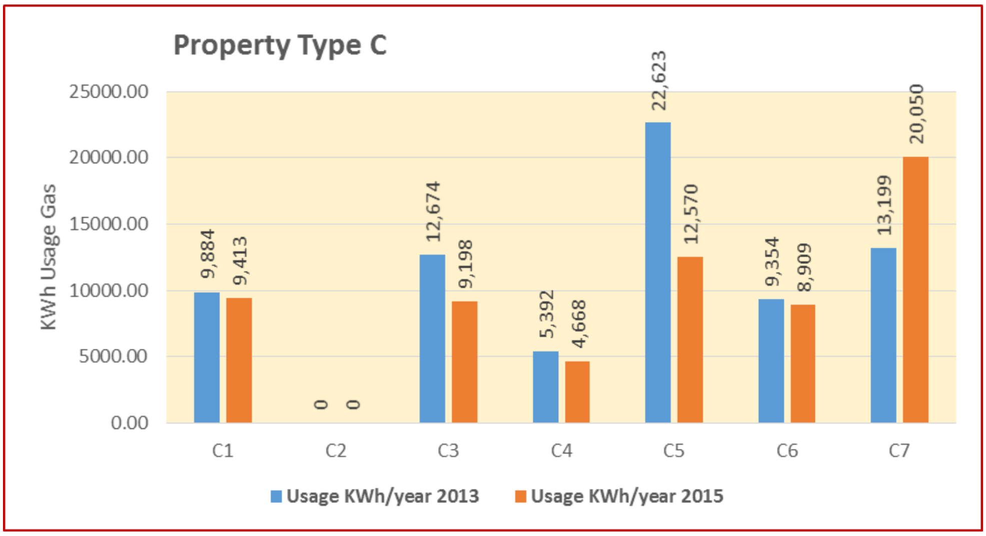


Table A4.2 Electricity usage for Type C Properties – Electric 2013-2015

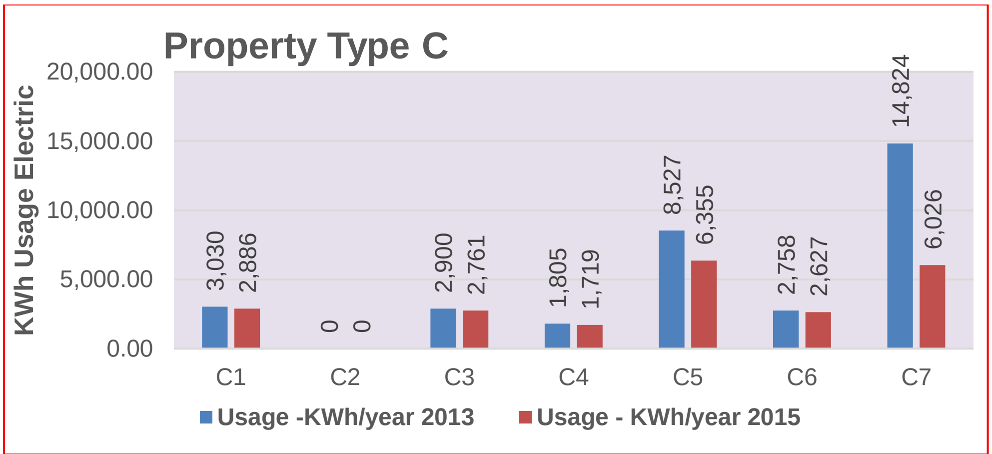


Table A4.3   Gas usage for Type L Properties – Gas 2013-2015

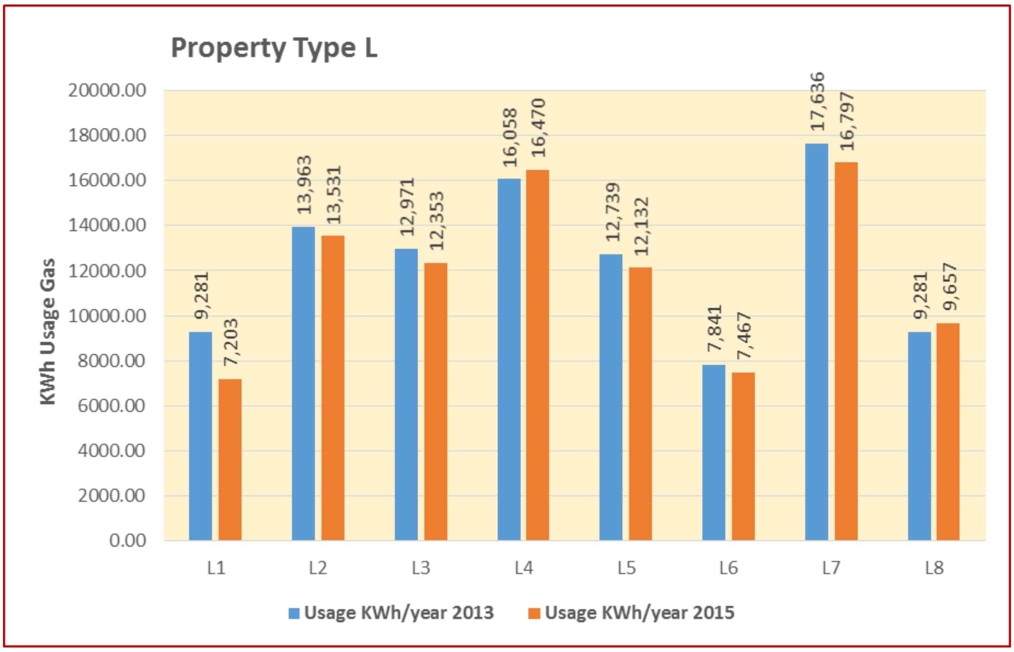


Table A4.4   Electricity usage for Type L Properties – Electric 2013-2015

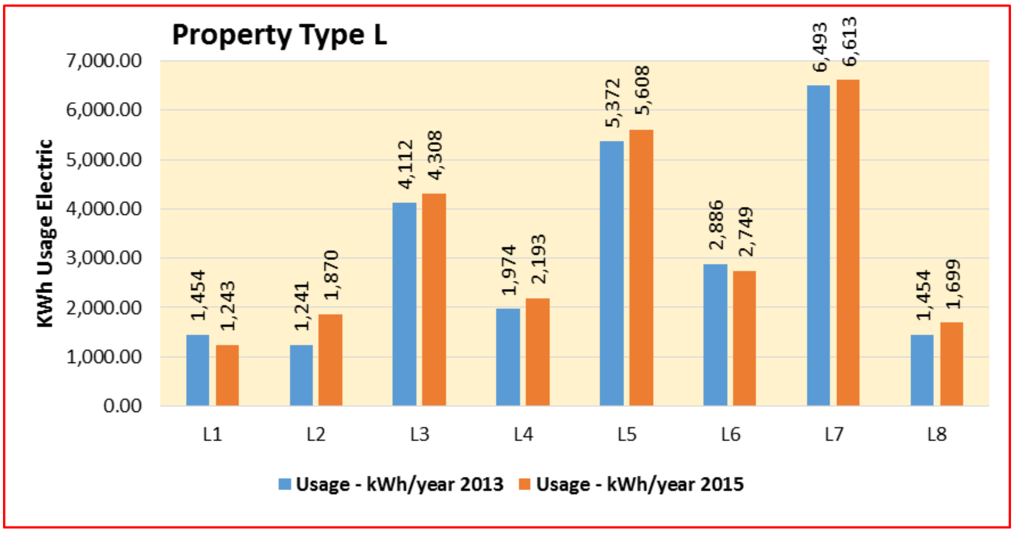


Table A4.5 Gas usage for Type P Properties – Gas 2013-2015

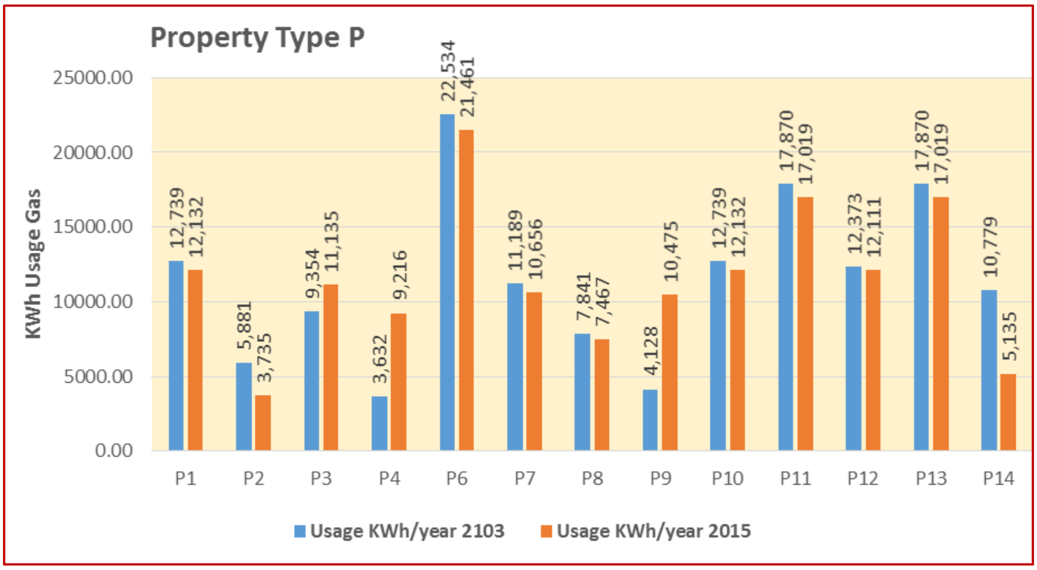


Table A4.6 Electricity usage for Type P Properties – Electric 2013-2015

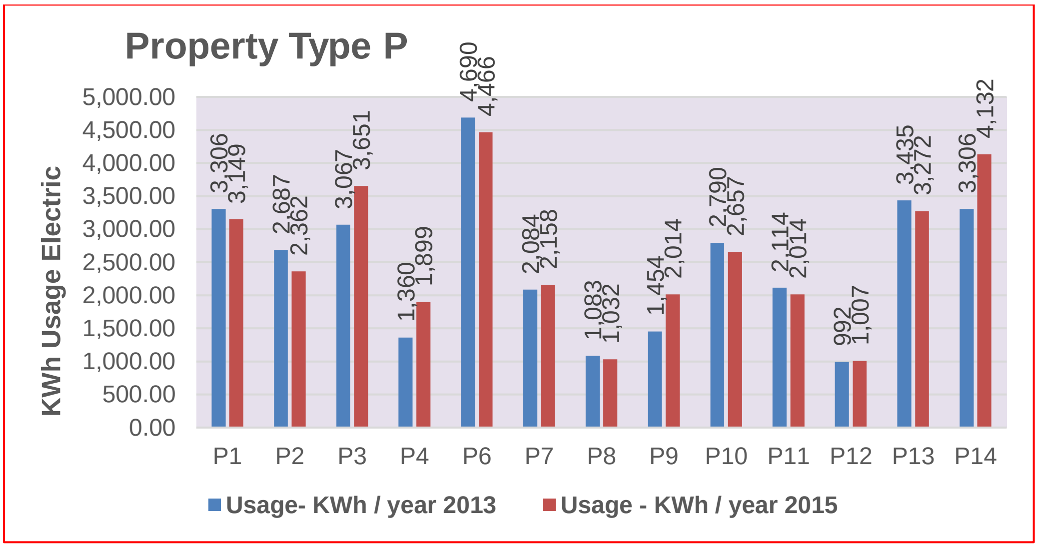


Table A4.7 Gas usage for Type P Properties – Gas 2013-2015

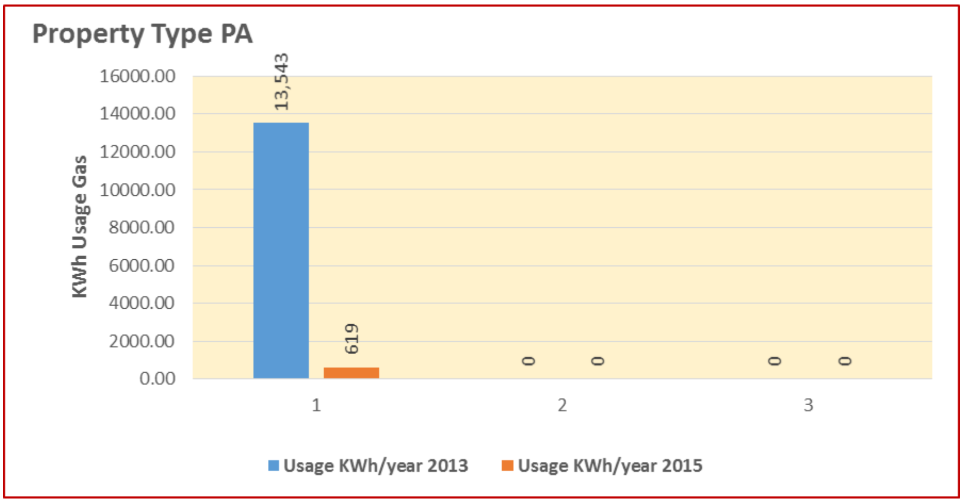


Table A4.8 Electricity usage for Type P Properties – Electric 2013-2015

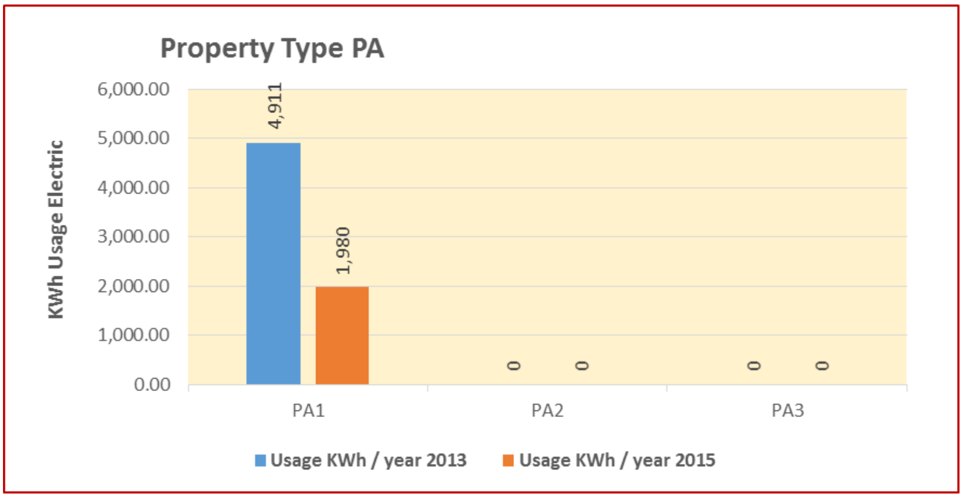


Table A4.9 Gas usage for Type PB Properties – Gas 2013-2015

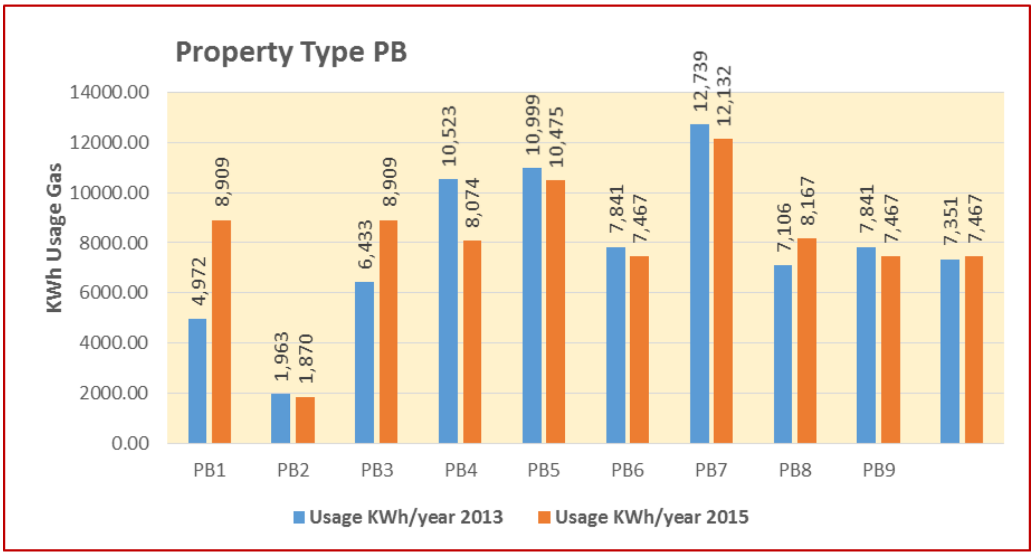


Table A4.10 Electricity usage for Type PB Properties – Electric 2013-2015

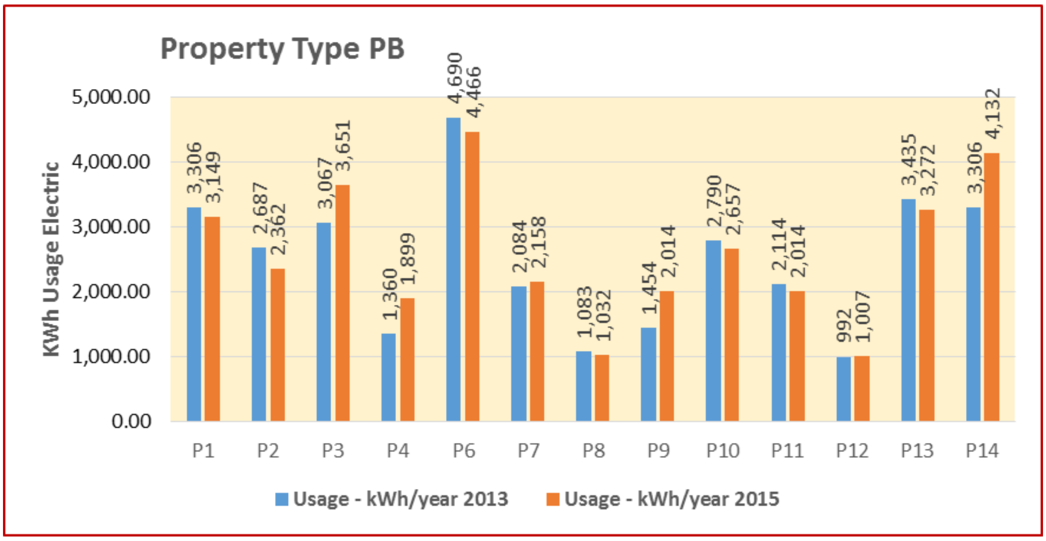


Table A4.11 Gas usage for Type R & WC Properties – Gas 2013-2015

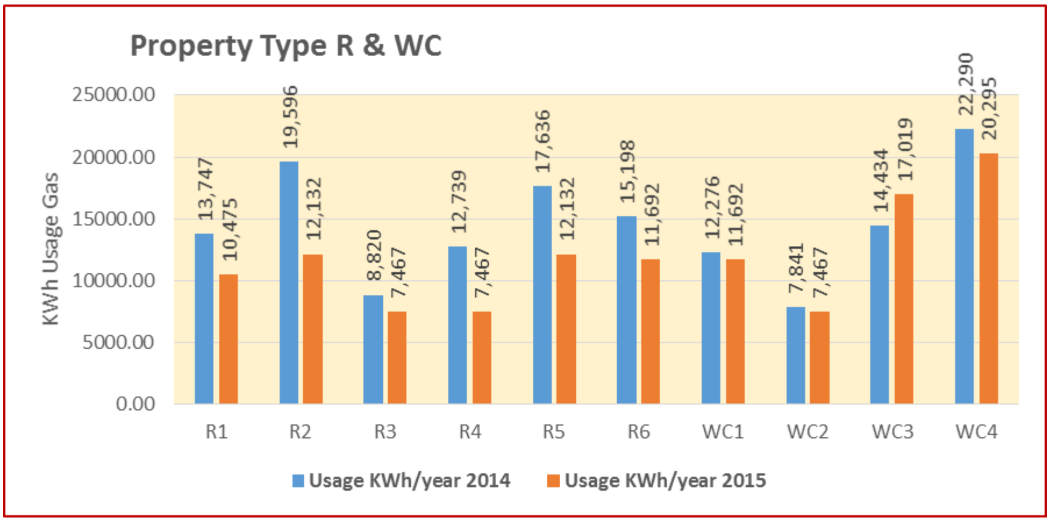
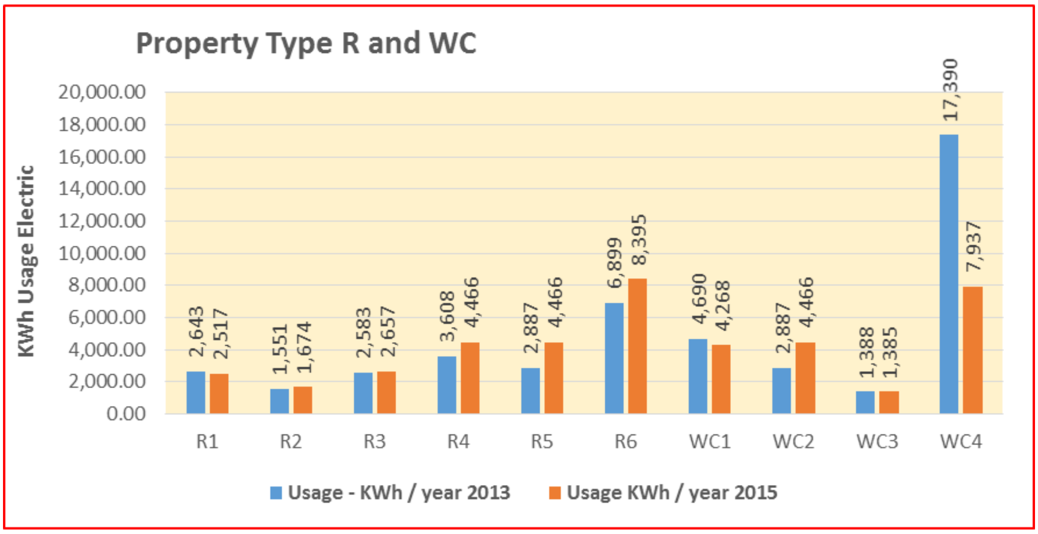


Table A4.12 Electricity usage for Type R & WC Properties – Electric 2013-2015



Appendix 5 Energy Consumption 2013-2015

Electricity Consumption 2013-2015

Code	Supplier	Method of Payment	Elec ref. 2015 - before any technology fitted (£/month)	ELECTRIC ref. 2015(£/year) [cost per month x12]	Usage - kWh/year 2015	Usage - kWh/year 2013	Difference (kWh)	CO_2 Electric - (0.296kg CO_2/kWh)	% Difference 2015 - 2013 Electric
C1	nPower	Monthly	£40.00	£480.00	2,886.00	3,030.30	-144.30	-42.71	-4.76
C2	E.ON_Energy	Card	No data	No data	No data	no data	No data	No data	No data
C3	E.ON_Energy	Card	£40.00	£480.00	2,761.46	2,899.53	-138.07	-40.87	-4.76
C4	British_Gas	Card	£28.00	£336.00	1,718.63	1,804.56	-85.93	-25.44	-4.76
C5	EDF_Energy	Monthly	£80.00	£960.00	6,355.49	8,526.54	-2,171.06	-642.63	-25.46
C6	EDF_Energy	Card	£40.00	£480.00	2,626.65	2,757.99	-131.33	-38.87	-4.76
C7	Scottish_Power	Quarterly	£75.00	£900.00	6,025.91	14,824.45	-8,798.54	-2,604.37	-59.35
L1	SSE_Energy	Monthly	£35.00	£333.00	1,243.22	1,453.98	-210.76	-62.38	-14.50
L2	British_Gas	Monthly	£27.00	£324.00	1,870.24	1,240.86	629.38	186.30	50.72
L3	nPower	Card	£55.00	£660.00	4,308.23	4,112.41	195.83	57.97	4.76
L4	nPower	Card	£28.00	£336.00	2,193.28	1,973.95	219.33	64.92	11.11
L5	British_Gas	Monthly	£65.00	£780.00	5,607.63	5,371.67	235.97	69.85	4.39
L6	British_Gas	Card	£40.00	£480.00	2,749.01	2,886.46	-137.45	-40.69	-4.76
L7	British_Gas	Card	£85.00	£1,020.00	6,612.91	6,492.77	120.14	35.56	1.85
L8	SSE_Energy	Monthly	£35.00	£420.00	1,699.23	1,453.98	245.25	72.59	16.87
P1	British_Gas	Monthly	£40.00	£480.00	3,148.82	3,306.26	-157.44	-46.60	-4.76
P2	British_Gas	Monthly	£32.00	£384.00	2,362.00	2,686.64	-324.64	-96.09	-12.08
P3	Scottish_Power	Card	£48.00	£576.00	3,650.69	3,066.88	583.81	172.81	19.04
P4	E.ON_Energy	Quarterly	£30.00	£360.00	1,898.92	1,359.91	539.02	159.55	39.64
P6	British_Gas	Card	£60.00	£720.00	4,466.30	4,689.61	-223.31	-66.10	-4.76
P7	E.ON_Energy	Monthly	£33.00	£396.00	2,157.68	2,084.43	73.25	21.68	3.51
P8	British_Gas	Card	£20.00	£240.00	1,031.72	1,083.30	-51.59	-15.27	-4.76
P9	SSE_Energy	Monthly	£40.00	£480.00	2,013.72	1,453.98	559.74	165.68	38.50
P10	British_Gas	Quarterly	£35.00	£420.00	2,657.06	2,789.91	-132.85	-39.32	-4.76
P11	SSE_Energy	Card	£40.00	£480.00	2,013.72	2,114.41	-100.69	-29.80	-4.76
P12	SSE_Energy	Quarterly	£24.00	£288.00	1,007.35	991.68	15.68	4.64	1.58
P13	SSE_Energy	Card	£60.00	£720.00	3,271.68	3,435.26	-163.58	-48.42	-4.76
P14	British_Gas	Monthly	£50.00	£600.00	4,132.35	3,306.26	826.08	244.52	24.99
PA1	Scottish_Power	Monthly	£30.00	£360.00	1,979.60	4,911.00	-2,931.40	-867.69	-59.69
PA2	Scottish_Power	No data	No data	No data	No data	no data	No data	No data	No data
PA3	E.ON_Energy	Monthly	£40.00	£480.00	2,814.53	1993.87	820.66	242.91	41.15
PB1	Scottish_Power	Card	£41.00	£492.00	3,012.07	1,629.98	1,382.09	409.10	84.79
PB2	British_Gas	Monthly	£16.00	£192.00	788.36	827.78	-39.42	-11.67	-4.76
PB3	EDF_Energy	Card	£28.00	£336.00	1,642.14	1,035.09	607.05	179.69	58.65
PB4	EDF_Energy	Card	£44.00	£528.00	2,954.83	2,499.55	455.27	134.76	18.21
PB5	SSE_Energy	Card	£40.00	£480.00	2,013.72	2,774.83	-761.12	-225.29	-27.43
PB6	British_Gas	Card	£40.00	£480.00	2,749.01	3,337.25	-588.24	-174.12	-17.63
PB7	British_Gas	Card	£24.00	£288.00	1,375.17	4,689.61	-3,314.44	-981.07	-70.68
PB8	British_Gas	Monthly	£29.00	£348.00	2,066.94	1,240.86	826.08	244.52	66.57
PB9	British_Gas	Card	£40.00	£480.00	2,749.01	2,886.46	-137.45	-40.69	-4.76
PB10	British_Gas	Monthly	£27.00	£324.00	1,870.24	1,963.75	-93.51	-27.68	-4.76
R1	SSE_Energy	Card	£48.00	£576.00	2,516.90	2,642.71	-125.81	-37.24	-4.76
R2	British_Gas	Quarterly	£25.00	£300.00	1,673.53	1,550.67	122.86	36.37	7.92
R3	British_Gas	Monthly	£35.00	£420.00	2,657.06	2,583.37	73.69	21.81	2.85
R4	British_Gas	Card	£60.00	£720.00	4,466.30	3,607.77	858.52	254.12	23.80
R5	British_Gas	Card	£60.00	£720.00	4,466.30	2,886.50	1,579.80	467.62	54.73
R6	Scottish_Power	Card	£100.00	£1,200.00	8,394.72	6,898.87	1,495.85	442.77	21.68
WC1	EDF_Energy	Card	£60.00	£720.00	4,267.51	4,689.68	-422.17	-124.96	-9.00
WC2	British_Gas	Card	£60.00	£720.00	4,466.30	2,886.50	1,579.80	467.62	54.73
WC3	SSE_Energy	Quarterly	£30.00	£360.00	1,384.74	1,387.91	-3.17	-0.94	-0.23
WC4	British_Gas	Monthly	£100.00	£1,200.00	7,936.66	17,390.09	-9,453.44	-2,798.22	-54.36

Gas Consumption 2013-2015

Code	Supplier	Method of Payment	Gas ref. 2015 (£/month)	GAS ref. 2015 (£/year) [cost per month x12]	Usage - kWh/year 2015	Usage - kWh/year 2013	Difference (kWh)	CO_2 Gas kg CO_2 x kWh (0.185)	% Difference 2015 - 2013 Gas
C1	nPower	Card	£40.00	£480.00	9413.25	9883.91	-470.66	-87.07	-4.76
C2	E.ON_Energy	Card	No data	No data	No data	No data	No data	No data	No data
C3	E.ON_Energy	Card	£40.00	£480.00	9197.91	12674.40	-3476.49	-643.15	-27.43
C4	British_Gas	Card	£28.00	£336.00	4668.37	5391.58	-723.21	-133.79	-13.41
C5	EDF_Energy	Monthly	£50.00	£600.00	12570.12	22622.71	-10052.59	-1859.73	-44.44
C6	EDF_Energy	Card	£40.00	£480.00	8909.01	9354.46	-445.45	-82.41	-4.76
C7	EDF_Energy	Monthly	£75.00	£900.00	20049.55	13198.63	6850.93	1267.42	51.91
L1	SSE_Energy	Monthly	£30.00	£360.00	7203.18	9281.06	-2077.88	-384.41	-22.39
L2	British_Gas	Monthly	£66.00	£792.00	13531.34	13963.01	-431.67	-79.86	-3.09
L3	nPower	Card	£50.00	£600.00	12353.45	12971.12	-617.67	-114.27	-4.76
L4	nPower	Card	£64.00	£768.00	16469.73	16058.34	411.40	76.11	2.56
L5	British_Gas	Monthly	£60.00	£720.00	12131.92	12738.52	-606.60	-112.22	-4.76
L6	British_Gas	Card	£40.00	£480.00	7467.20	7840.56	-373.36	-69.07	-4.76
L7	British_Gas	Card	£80.00	£960.00	16796.65	17636.48	-839.83	-155.37	-4.76
L8	SSE_Energy	Monthly	£37.50	£450.00	9657.07	9281.06	376.01	69.56	4.05
P1	British_Gas	Monthly	£60.00	£720.00	12131.92	12738.52	-606.60	-112.22	-4.76
P2	British_Gas	Monthly	£24.00	£288.00	3735.42	5881.38	-2145.95	-397.00	-36.49
P3	Scottish_Power	Card	£48.00	£576.00	11135.17	9354.46	1780.71	329.43	19.04
P4	E.ON_Energy	Quarterly	£40.00	£480.00	9216.44	3631.93	5584.52	1033.14	153.76
P6	British_Gas	Card	£100.00	£1,200.00	21461.37	22534.44	-1073.07	-198.52	-4.76
P7	E.ON_Energy	Monthly	£45.00	£540.00	10655.81	11188.60	-532.79	-98.57	-4.76
P8	British_Gas	Card	£40.00	£480.00	7467.20	7840.56	-373.36	-69.07	-4.76
P9	SSE_Energy	Monthly	£40.00	£480.00	10475.03	4127.90	6347.13	1174.22	153.76
P10	British_Gas	Quarterly	£60.00	£720.00	12131.92	12738.52	-606.60	-112.22	-4.76
P11	SSE_Energy	Card	£60.00	£720.00	17018.73	17869.67	-850.94	-157.42	-4.76
P12	SSE_Energy	Quarterly	£45.00	£540.00	12110.96	12372.96	-262.00	-48.47	-2.12
P13	SSE_Energy	Card	£60.00	£720.00	17018.73	17869.67	-850.94	-157.42	-4.76
P14	British_Gas	Monthly	£30.00	£360.00	5134.84	10779.34	-5644.50	-1044.23	-52.36
PA1	Scottish_Power	Monthly	£10.00	£120.00	618.74	13542.51	-12923.77	-2390.90	-95.43
PA2	Scottish_Power	No data	No data	No data	No data	No data	No data	No data	No data
PA3	E.ON_Energy	Monthly	No data	No data	No data	5391.64	No data	No data	Gas not needed now S/C still paid
PB1	Scottish_Power	Card	£40.00	£480.00	8909.01	4971.69	3937.31	728.40	79.19
PB2	British_Gas	Monthly	£16.00	£192.00	1869.53	1963.01	-93.48	-17.29	-4.76
PB3	EDF_Energy	Card	£40.00	£480.00	8909.01	6432.62	2476.39	458.13	38.50
PB4	EDF_Energy	Card	£37.00	£444.00	8074.19	10523.19	-2449.00	-453.06	-23.27
PB5	SSE_Energy	Card	£40.00	£480.00	10475.03	10998.78	-523.75	-96.89	-4.76
PB6	British_Gas	Card	£40.00	£480.00	7467.20	7840.56	-373.36	-69.07	-4.76
PB7	British_Gas	Card	£60.00	£720.00	12131.92	12738.52	-606.60	-112.22	-4.76
PB8	British_Gas	Monthly	£43.00	£516.00	8166.91	7105.87	1061.04	196.29	14.93
PB9	British_Gas	Card	£40.00	£480.00	7467.20	7840.56	-373.36	-69.07	-4.76
PB10	British_Gas	Monthly	£40.00	£480.00	7467.20	7350.77	116.44	21.54	1.58
R1	SSE_Energy	Card	£40.00	£480.00	10475.03	13747.14	-3272.11	-605.34	-23.80
R2	British_Gas	Quarterly	£60.00	£720.00	12131.92	19595.66	-7463.74	-1380.79	-38.09
R3	British_Gas	Monthly	£40.00	£480.00	7467.20	8820.15	-1352.95	-250.30	-15.34
R4	British_Gas	Card	£40.00	£480.00	7467.20	12738.52	-5271.32	-975.19	-41.38
R5	British_Gas	Card	£60.00	£720.00	12131.92	17636.48	-5504.56	-1018.34	-31.21
R6	Scottish_Power	Card	£50.00	£600.00	11691.71	15198.14	-3506.43	-648.69	-23.07
WC1	EDF_Energy	Card	£50.00	£600.00	11691.71	12276.30	-584.59	-108.15	-4.76
WC2	British_Gas	Card	£40.00	£480.00	7467.20	7840.56	-373.36	-69.07	-4.76
WC3	SSE_Energy	Quarterly	£60.00	£720.00	17018.73	14434.23	2584.51	478.13	17.91
WC4	British_Gas	Monthly	£95.00	£1,140.00	20295.19	22289.54	-1994.35	-368.95	-8.95