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Case Study of the Home Energy Saving Scheme:

A multidisciplinary approach

A thesis submitted to Trinity College Dublin in partial fulfilment of the requirements for the degree of Ph.D.

June 2014

Supervisors:

Dr. Anthony Robinson

Prof. Anna Davies

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Summary

The EU has set itself the objective of achieving 20% primary energy savings by 2020. Because of the relatively recent move towards sustainability, there is a limited understanding of how effective related policies and actions have been. This in turn stymies the development and impact of such policies. To this end, this thesis examines the case study of the Irish government's national grant scheme to encourage energy efficiency retrofit in private housing. That is the Home Energy Saving (HES) Scheme, later rebranded the Better Energy: Homes (BEH) scheme. The methodology design draws from the disciplines of structural engineering, thermal engineering and human geography. It is separated into three analyses, monitoring houses before and immediately after retrofit, laboratory controlled testing on retrofit walls, and discussions with occupants and stakeholders who have been involved in the scheme's policy design or implementation.

Accurate understanding of the thermal behaviour of building components is essential for predicting heating or cooling needs and facilitates the implementation of more successful energy saving strategies and retrofits. The technical aspect of this thesis focuses on specific measures commonly introduced through the HES/BEH programme – cavity and external wall insulation. A specially designed test rig facilitated controlled wall sample testing alongside *in situ* house testing. It was found that a significant decrease in heat loss through the walls was observed in all cases. The occupant played a considerable role in the change in energy use in the buildings, and it was found that the main motivation for retrofit was comfort. This resulted in much of the potential energy savings foregone in favour of increased comfort levels.

Adopting a multidisciplinary approach to the case study, the thesis argues that Ireland is in the first stages of transforming a system built on unsustainable foundations. Energy inefficient dwellings, policy based on EU directives or public popularity, and uninformed/uninterested public has lead to this scheme falling short of its potential. The Thesis concludes with recommendations for policy makers and future researchers.

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Abbreviations

BEH	Better Energy Homes
BER	Building Energy Rating
BEWHS	Better Energy Warmer Homes Scheme
DEAP	Dwellings Energy Assessment Procedure
EE	Energy Efficiency
EPA	Environmental Protection Agency
EPBD	Energy Performance of Buildings Directive
EPC	Energy Performance Certificate
ETS	Emission Trading Scheme
GHS	Greener Homes Scheme
GHG	Green House Gas
HES	Home Energy Saving
IEA	International Energy Agency
IPCC	International Panel on Climate Change
NEEAP	National Energy Efficiency Action Plan
OECD	Organisation for Economic Co-operation and Development
PAYS	Pay-As-You-Save
PCT	Personal Carbon Trading
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
WHS	Warmer Homes Scheme

Nomenclature

A	Surface area (m^2)
C	Heat capacity ($J.K^{-1}$)
c	Specific heat capacity ($J.kg^{-1}.K^{-1}$)
d	Thickness of specimen (m)
HC/A	Heat capacity per unit area ($J.K^{-1}.m^{-2}$)
k	Thermal conductivity ($W.m^{-1}.K^{-1}$)
m	Mass (kg)
$\dot{m}$	Mass flow rate ($kg.s^{-1}$)
q	Heat flow rate (W)
q_x	Heat transfer rate, or heat flux ($W.m^{-2}$)
R	Thermal resistance of the total structural element being examined ($m^2.K.W^{-1}$)
R_{se}	Thermal resistance of the external surface ($m^2.K.W^{-1}$)
R_{si}	Thermal resistance of the internal surface ($m^2.K.W^{-1}$)
T_s	Surface Temperature (K)
T_{se}	External surface temperature (K)
T_{si}	Internal surface temperature (K)
T_{sur}	Temperature of the surroundings (K)
T_{wi}	Temperature of water in (K)
T_{wo}	Temperature of water out (K)
T_{oc}	Ambient air temperature (K)
δ	Wall sub layer thickness (m)
ρ	Density ($kg.m^{-3}$)

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"A holistic view brings realistic action"

Dalai Lama

Chapter 1. Introduction

1.1 Introduction

This thesis is an evaluation of the Home Energy Saving Scheme (HES), later rebranded the Better Energy: Homes scheme (BEH). Adopting a multidisciplinary approach, which makes use of three different empirical studies, it argues that Ireland is in the first stages of transforming a system built on unsustainable foundations. Energy inefficient dwellings, policy based on EU directives or public popularity, and uninformed/uninterested public has lead to this scheme falling short of its potential. This thesis contends that a tipping point must be reached whereby sustainability becomes a basic necessity reflected in all government policies, public attitudes, human systems and built environments.

The analysis is based in the disciplines of structural and thermal engineering but also adopts aspects of human geography to provide a more holistic understanding of the scheme. The examination is separated into, case studies of houses undergoing retrofit[1], laboratory controlled testing on retrofit walls, and discussions with stakeholders who have been involved in the scheme's policy design or implementation. The case studies involved monitoring houses before and immediately after retrofit. The occupant plays a significant role in the impact of the scheme, therefore, it was important to incorporate them into the analysis using structured and open ended questions during interview. Still this does not answer the issue of how to increase the number of retrofits and what the barriers and drivers for change on a grander scale might be. Interviews with occupants and stakeholders discussed these issues. The known theory in the field shows that we have knowledge regarding these separate elements (Harrje, 1978, Bell & Lowe, 2000, Frontczak & Wargocki, 2011, Al-Sanea et al., 2012, Murphy et al., 2012, Pelenur & Cruickshank, 2012, Valkila & Saari, 2013), but there is a lack of knowledge in relation to considering energy efficiency retrofit in a holistic manner. Using combined knowledge in all aspects of the scheme can lead to the streamlining of the system.

This introductory chapter explains the underlying rationale behind the HES/BEH scheme and gives an account of the approach used in this thesis. It begins by placing the research in the wider context of climate change and the resulting sustainability reaction. The history of the scheme is then traced giving an explanation of the motivations and policies behind it. Such an understanding is necessary in order to illustrate the relevance of the empirical chapters that

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1 In this thesis, retrofit is used in lieu of energy efficiency refurbishment. This includes, for example, the introduction insulation or a high efficiency boiler into an already existing building.

follow so that the overall approach can be evaluated in the broader context of sustainability and governance issues. The second chapter presents the first case study house which was unoccupied allowing for the author to monitor the change in building physics due to cavity and attic insulation. This first examination was necessary in order to understand the behaviour of buildings *in situ* without the added influence of occupant behaviour. The in-depth study serves as a reference for methodology and analysis for the site tests that followed. The third chapter then delves solely into the technical aspect of retrofit by testing a wall sample with and without insulation in the laboratory. Many uncontrollable variables are encountered *in situ* with lab testing omitting the majority of these. The design of the testing rig was also created in order to facilitate progression of analysis in the field beyond the confines of this research project. Chapter 4 then presents the remaining site tests. The first of which was semi-controlled in that the heating supply was maintained at the same times and power input for the pre and post testing and two rooms were sealed off from human interaction. The next seven site tests fully incorporated the human variable by allowing occupants to use the house and heating system as they wished. This was stipulated in order to provide the actual changes in energy usage and building behaviour due to retrofit under the HES/BEH scheme. The author also interacted with the occupants during surveys and interviews in order to add to the understanding of the monitored data but also to gauge the experience from their perspective. The 5th chapter then presents interviews with experts involved with the scheme who have influence on policy making. Such accounts were necessary to triangulate findings from the lead up chapters but also to foster their years of experience in the field allowing common barriers, successes and potential areas for change to be identified. In the final chapter the research findings are combined to draw conclusions as discussed in terms of the research objectives. These conclusions allow for the production of policy recommendations presented in this chapter.

1.2 Structure of the current chapter

This first chapter is structured in such a way as to give the reader an understanding of the evolution of the project and how the research focus naturally narrowed to the final definition. The discussion begins by outlining the steps in the sustainability movement in section 1.3, both in realising its necessity and the resulting major policies. This is followed by a further examination of the available political instruments to mitigate climate change in section 1.4. In this section buildings and the residential sector are identified as centres of activity for political action in the mitigation of climate change. This area is examined more closely in section 1.5. The explanation and justification of the focus area of energy efficiency retrofitting is detailed in this section along with the introduction of the case study in order to give the necessary context. This

leads to the objectives and research questions identified in section 1.6. This in turn begets the designed breakdown of the examination asserted in section 1.7 as a holistic and multidisciplinary assessment. Finally, the objectives of the research justifies the layout of the thesis itself as described in section 1.8. A basic introduction to concepts and contexts within the distinct disciplines are included in this first chapter. Fundamental explanations are provided mindful of a multidisciplinary readership and the relevance of the research beyond academia.

1.3 Sustainability

1.3.1 Introduction

Before describing in more detail the specific study area, there is a need to broaden the perspective. A new political era has begun with focus shifting to mitigation of climate change. There is no previous similar global effort from which to draw experience nor is there any model for a sustainable country to guide design. Every location has different physical and climatic parameters with different cultures and economic and social needs (Blassingame, 1998). The sustainability reaction involves difficult political challenges as previous practices in politics and development often involved undesirable environmental impacts with economic development being high on the agenda (Haughton & Hunter, 1994). Despite the large number of policies and actions in energy efficiency since the 1970s, energy use is still increasing. In order to improve policies and their outcomes; their affect should be quantified, the policy evaluated, and experience learned from.

1.3.2 Acceptance of climate change

The concept of global warming was initiated in 1896 by Svante Arrhenius who predicted that the burning of fossil fuels may eventually result in global warming (Environmental Defence, 2003). Climate change or 'global warming' is the increase in mean annual surface temperature of the earth's atmosphere due to increases in greenhouse gases (Bulkeley & Betsill, 2003). The theory gained momentum in 1957 when it was reported by Roger Revelle and Hans Seuss that much of the CO_2 emitted into the atmosphere is not absorbed by the oceans as had frequently been argued (Environmental Defence, 2003). Later, in 1983, a National Academy of Sciences report confirmed that doubling CO_2 levels would eventually warm the earth by 3-8 $^{\circ}$F (1.7-4.4°C) (Environmental Defence, 2003).

1.3.3 Political Action to mitigate climate change

Evidence of climate change was put into political action in the first United Nations conference on Climate Change in Stockholm in 1972 and led to the establishment of the UN Environment

Programme (UNEP). The Summit has reconvened every ten years after this. The Brundtland Report is generally hailed as the initiation of the political concept of sustainability. It defines sustainability as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987). Blassingame (1998) further proposes that there are two levels in which change can occur in order to make cities more sustainable. One is the improvement of the existing processes using technology. The other is by changing the values under which we currently operate. The first targeted international action occurred under the Kyoto protocol adopted in 1997 and enforced in 2005 which committed countries to emission set targets to be achieved between 2008 and 2012 (United Nations, 1998). There has been a concurrent global recognition that integrated perspectives and holistic approaches are required to solve this crisis (European Environmental Bureau, 2005, McKinsey & Company, 2009). More recent political action reflects the need to combine approaches. In 2007, EU leaders endorsed an integrated approach to climate change and energy policy with the aim of creating a highly energy efficient and low carbon economy (Council of the European Union, 2007). This became known as 'the EU 20-20-20' and included targets for 2020 to reduce energy use by 20%, increase the use of renewable sources of energy by 20% and reduce overall emissions by 20% of those recorded in the base year 1990. The more ambitious target of 30% emission reduction for developed countries has been more recently discussed (Commission of the European Communities, 2007).

Understanding how political actions can incite or precipitate the sustainability movement requires a conceptual approach integrating political, technical and social influences on the system. This explanation begins by looking at the political context and the available policy instruments to incite sustainability.

1.4 Political context

1.4.1 Introduction

For a thesis such as this it is necessary to understand the policy process and factors that affect policy change in order to isolate a single policy action for examination. Examining previous policy efforts, what encouraged and hindered both their creation and the embracing of such policy by the relevant actors, has the potential to inform future decisions and designs. Before describing the context of energy efficiency retrofit policy in more detail and the case study under investigation, there is a need to understand the broader contextual area.

As Roberts (2004) notes the uncertain science around climate change means that policy makers often respond in two ways. They adopt 'no-regrets' strategies and they apply the 'precautionary principle'. No-regrets options are greenhouse gas reduction options which have negative net costs, because they generate benefits which offset the cost of implementation. One example of the no-regrets strategy is the implementation of cost-effective energy efficiency improvements. The improvement of processes, which result in the elimination or reduction of pollutants, is often accompanied by reductions in costs or improvements in quality. Because of the economic benefits, the uncertainty of the polluting effects is no longer an issue. Roberts (2004) proposes that the precautionary principle is only looked to when all potential of the no-regrets approach is exhausted but the problem still exists. The precautionary principle enables rapid response in the face of possible harm, in particular where the scientific data does not permit complete evaluation of risk. A small and immediate price is accepted in order to minimise the risk of future costs which could be far greater. In this situation the policy makers must look to the principles of sustainable development.

For the purpose of this research, the political aspect encompasses 'Environmental Governance'. This is often used in the context of the complex process of policy making and implementation, which involves participation of local, national and international governments as well as non-government actors (Davies, 2008). Policies are described as government interventions through different instruments and resources. This next section describes the various policy instruments governments have at their disposal to combat climate change.

1.4.2 Instruments for change

1.4.2.1 *Regulation, Standards and Control Mechanisms*

There are two types of regulation. Regulatory-normative regulations set standards and include appliance standards, building codes, procurement regulations and energy efficiency obligations and quotas. Regulatory-informative regulations serve to inform the user but the user is not obliged to follow the advice such as mandatory audits, utility demand-side management programmes and mandatory labelling and certificate programmes (Koeppel & Ürge-Vorsatz, 2007). It has been thought that political competition leads parties to favour the use of standards over a taxation (Damania, 2001), however, there can be monitoring difficulties with regulation (Lindeneg, 1992).

1.4.2.2 *Taxes and Charges*

Environmental tax reforms shift the tax base from other areas such as labour and business to taxes on pollution and the use of natural resources. Carbon taxes help to place responsibility on the polluting party. The tax can be levied on the polluters or on the consumers of the polluting product, similar to the Value Added Tax (VAT) system. Governments need to enact legislation or related mechanisms to set the taxes on volumes of greenhouse gas. Andrew et al. (2010) argue that a carbon tax which uses the existing tax collection system will be less costly as well as easier to enforce than an emissions trading scheme which requires a new market structure, enforcement, audit, fraud prevention and control mechanisms. Revenue could be used to remove or reduce existing taxes or compensate lower income households. A carbon tax aims to have two counteracting effects. It would incentivise people and companies to use less energy if possible. It would also encourage them to use different types of energy if they have an alternative option. If properly recycled, a carbon tax stimulates economic growth and this offsets the reduction in energy use (Tol et al., 2008).

An important point with environmental taxation is that the charge of going outside limits or quotas should be more than the cost incurred when trying to comply. This was highlighted in the case of China where low penalties for violators of environmental impact assessment laws and regulations did not deter polluters (Zhang, 2008). Zhang (2008) postulates that to make environmental taxation effective the pollution charges should reflect the cost of abating pollution, and the fines for offending should be set higher than the abatement cost. This idea of sufficiently high taxation is reflected in other literature in which it is put forth that if taxes are set at random and under pressure from political groups, ecological taxes will not display the qualities of a market-based policy instrument that gives an economic incentive to undertake more sustainable practices (Kohlhass, 2000). Furthermore, carbon taxing is primarily seen as an environmental policy instrument but it has aspects of economic, energy, industrial and other policies which contribute significantly to its formation (Vehmas, 2005).

Flynn (2003) proposes that the Irish rejection of and scepticism towards taxes could originate, in part, from a legacy of the heavy burdens of the 1980s and the historic relative lack of wealth in Ireland compared to other EU states. It could also be a consequence of Ireland's semi-colonial historical development, with the colonial state having a legitimate claim upon private income.

1.4.2.3 *Tradable Permits and Offsets*

A trading system could be put in place whereby buildings, households, companies or producers trade their carbon credits. The indirect, or downstream, approach to tradable permits involves the end user receiving an emission quota or allowance. The direct, or upstream, approach involves the producer of the emissions bearing the brunt with the goal that products with high carbon content become more expensive and therefore less appealing to consumers driving the market towards more sustainable products (Bertoldi & Rezessy, 2006).

The Kyoto Protocol provides flexibility for achieving greenhouse gas emission targets through the so-called Kyoto Mechanisms. International emission trading is allowed under which countries may buy and sell their assigned quotas of emissions. Directive 2003/87/EC, amends 96/61/EC, of the European Parliament and of the Council establishing a scheme for greenhouse gas emission allowance trading within the Community. It was launched in 2005 and follows the upstream approach. It is the world's first international company level cap-and-trade system of allowances for CO_2 and other GHG emissions (European Commission, 2009). It was introduced on a phased basis. The cap on allowances creates a scarcity which drives trade (European Commission, 2009). Companies keeping within their quota can sell their remaining allowances at a price determined by supply and demand. Companies who exceed it can make efforts to reduce emissions, purchase extra allowances or credits or use a combination of the two. If this is not done, a fine is imposed.

In contrast to the ETS which is a quantity based system, green and white certificate systems are baseline-and-credit systems. Green certificates are for renewable energy while white certificates are for energy saved in demand side energy efficiency (Bertoldi & Huld, 2006). Tradable green certificates are thought to help member states to achieve renewable energy targets.

Tradable White Certificate schemes aim to meet energy-saving targets at lowest cost (Mundaca, 2008). These schemes generally endeavour to achieve mandatory energy-saving targets over a given time period. The parties involved tend to be energy suppliers or distributers are required to meet their individual target measured out using their market share. These parties must implement energy efficiency measures in the required sectors, such as residential or commercial, and use only technologies approved by the authorities. Certificates of realised energy savings can be traded as a way of making the scheme more proficient in meeting mandatory energy saving targets (Mundaca, 2008).

Another, more radical, form of carbon trading could be personal carbon trading (PCT). Fawcett (2010) examined past research in the area and concluded that this measure is not yet a fully worked out policy. However, it appears that personal carbon trading is more accepted than the alternatives of direct or indirect carbon taxation (which are cheaper to increase than PCT would be to implement) (Fawcett, 2010).

1.4.2.4 *Information/ Knowledge*

Information can be a form of persuasion and comes in three forms, passive information persuasion, active information persuasion, and active persuasion and propaganda (Roberts, 2004). Passive information is that which contains neutral information available to those who enquire. It has the least impact of the three forms but is of least cost. Active information includes advertising and mail in promotional campaigns. Active persuasion is the use of argument designed to engage emotion and create guilt in those who do not comply (Roberts, 2004).

It is generally perceived that the better informed a person is about climate change the more likely they are to act in a sustainable manner. This is not necessarily the case as was found with one Belgian study where households that were better informed on climate change issues and factors on renewable energies did not act in a more environmentally friendly way (Bartiaux, 2008). The same study found that interested householders who receive customised and expert advice to save energy rarely follow this advice. This is reflected in studies conducted in the UK which found that widespread awareness and concern about climate change often does not translate into personal engagement (Lorenzoni et al., 2007). However, it must be noted that the effects of information appear gradually over time and can be difficult to quantify.

The analysis and explanation of human behaviour has been dealt with by researchers in disciplines ranging from psychology to sociology. To account for all of their findings and theories would be beyond the scope of this research. Information is necessary, but insufficient to change behaviour when used solely. Lorenzoni et al. (2007) found that the degree of people's engagement relates to the individual's underlying knowledge, values, experiences and lifestyles. These in turn are influenced by the wider social landscape. The authors found that the best approach for information provision is to be through using trusted channels and in a transparent manner. The message needs to be sustained and should be provided in context in relation to previous findings or mainstream scientific opinion and relating it to local and personal impacts.

They propose that focus should be made on educating younger generations and providing formal training.

In Ireland, information has been provided through regulation for energy labelling or Building Energy Rating (BER), but has also been seen through information campaigns such as the 'power of one' campaign and the 'Reduce, Reuse, Recycle' campaign. Clinch and Dunne (2006) found that high profile media driven areas, such as recycling in Ireland at the time, tend to form the bulk of the public's knowledge in sustainable behaviour. The waste campaign launched in September 2004 used a high profile television and media advertising strategy. The outcome was that 23% stated that they made an attempt to reduce waste, 19% to reuse and 25% claimed they increased the amount they recycled (Department of the Environment Heritage and Local Government, 2004).

1.4.2.5 *Subsidies and Tax Relief*

"Subsidies comprise all measures that keep prices for consumers below market level or keep prices for producers above market level or that reduce costs for consumers and producers by giving direct or indirect support" (de Moor, 2001). The optimal level of subsidy is when cost equals benefit. If the subsidy is any lower than this, the result is less carbon saved while remaining in credit. A subsidy in excess of this, means that additional expenditure could have been allocated to more needed areas. In terms of environmental measures installed in households, for instance, this means that the optimal subsidy would be one which exactly matches the cost of the measure (McGilligan, Sunikka-Blank et al. 2010).

Historically, the reason behind subsidies to support consumption was to fuel economic growth, with developed countries subsidising production (de Moor, 2001). The need to make the economy less susceptible to external shocks by safeguarding domestic energy supply and growth was the motive behind this subsidisation. When G20 leaders met in Pittsburgh in September 2009 they agreed to "rationalize and phase out over the medium term inefficient fossil fuel subsidies that encourage wasteful consumption" (OECD, 2010).

1.4.2.6 *Voluntary Approach*

The OECD and European Environment Agency (2010) define voluntary agreements in four groups. 'Negotiated agreements' are contracts negotiated between public authorities and one or more private parties. 'Voluntary programmes' are standards developed by public bodies, to which participating firms can agree. 'Unilateral commitments' are environmental improvement

programmes set up by firms and communicated to their stakeholders. 'Private agreements' are contracts between a firm and those who are harmed by its emissions. Voluntary action works best in areas where behavioural change is relatively easy to make and monetary costs are low (Roberts, 2004).

A number of utilities offer a high share of green electricity in their mix although they have not been shown to successfully convince a significant share of electricity consumers to switch to green electricity technologies (EPIA, 2008). Some literature portrays the voluntary approach as being more flexible, effective, and less costly than the traditional policy instruments (Arimura et al., 2008). However, other literature has shown that businesses enrolled in self-regulatory initiatives do not display better environmental performance than those which do not. Evidence has even revealed that for purely voluntary programmes (those without any performance-based standards, independent certification or sanctions) show worse environmental performance than those with none at all (Rivera & deLeon, 2008).

Voluntary agreements emerged in the 1990s in Ireland, mainly in the waste sector. The first voluntary scheme was the REPAK scheme adopted in 1995 as a reaction to the EU Packaging Waste Directive (Hale, 2010). This and other early examples suggest that the voluntary approach was the environmental policy instrument which received widest political support in Ireland at the time (Flynn, 2003).

1.4.3 The Irish political and economic landscape

Ireland joined the EU in 1973. After the recession of the early 1980s, Ireland became one of the fastest growing economies in the world in the 1990s. From 1987 until the end of the century economic growth (GNP) averaged over 5%, while in some years, growth was over 10% (Ferriter, 2010). The boom period experienced high levels of construction, property ownership and consumer spending. Dublin grew by 15% in population 1986-2002 (Central Statistics Office, 2011). This period was followed by the economic slowdown beginning in 2005 and leading to recession. Ireland employs a partnership approach to policymaking whereby interest groups can also contribute to decision making. Interest groups include trade unions, employers, business, farming, the community and voluntary sector. This means that the social partners will need to be convinced of the benefits of any impending policies.

Ireland does not compare well with other European countries when it comes to fossil fuels and energy use. Ireland's emissions in 2007 were 25% higher than the 1990 baseline which is well above its Kyoto allowance of 13% (OECD, 2010). The agricultural sector contributes to a large proportion of this at 28% (CSO, 2007). Ireland's economy has since contracted by 7.3% which

may contribute largely to the reduction of energy related CO_2 to 20% above 1990 levels (Howley & Holland, 2013) The Department of Communication, Energy and Natural Resources is responsible for energy efficiency and energy research and has an overarching role in the delivery of related policy. Sustainable Energy Authority of Ireland (SEAI) is Ireland's national energy agency and is in charge of implementing significant aspects of government policy on sustainable energy and climate change abatement. The SEAI's primary objective is to put energy efficiency first. Secondary objectives of the organisation are to encourage low carbon energy sources and innovation and integration (Dennehy et al., 2010).

Most Irish political actions in this arena are rooted in European Union (EU) and international directives. The timeline of political actions at international, EU and national level are displayed in Table 1. Plans or reports highlighted in this table are often informed by several studies and methodologies, and these are also revealed here. This is not an exhaustive list, but aids the understanding of how the historical and current political landscape led to the formation of the specific area examined in this research (energy efficiency residential retrofitting) which is more extensively discussed in the next section.

Table 1 Timeline of international and national policy which lead to the current case study

Irish action	*International/EU action*
	1988 IPCC formed
	1992 Earth Summit in Rio establishing UNFCCC
	1997 Kyoto Adopted, enforced in **2005** (Limits Irish GHG emission growth to 13% above 1990 levels, 2008-2012)
2000: National Climate Change Strategy: ***Residential sector responsible for 29% of CO2 emissions in 1998***	
Homes for the 21st Century Study (based on CSO data and Energy Rating and SAP procedure)	**2002** EPBD
EPA projections	**2008:** EU 20- 20 by 2020
2006: Ireland's Pathway to Kyoto Compliance: ***residential sector accounts for 10% of GHG emissions 2004***	
2007: National Climate Change Strategy 2007-2012: retrofit in social housing, BER 2007 for new build, existing sold or rented from 2009	
2007: Draft National Energy Efficiency Action Plan	
2009: National Energy Efficiency Action Plan	
2008: Pilot HES	
2008: Kema report on demand side management	
2009: Greenprint National Energy Efficiency Retrofit Programme	
-2009: Ireland's low carbon opportunity (based on McKinsey&Co study) -BER & DEAP -Stakeholder engagement -Academic studies on cost-benefit and comfort takeback -EPSSU statistics database shows ***25% Irish CO_2 is from residential sector***	
	2011: EU Energy Efficiency Action Plan Identifies buildings as having the greatest energy saving potential & identifies co-benefits
2011: National Energy Efficiency Retrofit Programme launched as Better Energy: the national Upgrade Programme	Green paper on energy efficiency: "***building sector accounts for more than 40% of the final energy demand in Europe***"
2013: National Energy Efficiency Action Plan 2	**2008:** EC Energy Efficiency: delivering the 20% target: "***30% less energy use within the sector is feasible***" for res and commercial buildings
	Odyssee indicators: ***2/3 of energy in residential buildings is for space heating***

1.5 Residential sector and energy efficiency

1.5.1 Introduction

Energy use in residential and commercial buildings is responsible for approximately 40% of the EU's total final energy consumption and 36% of its total CO_2 emissions (Commission of the European Communities, 2008). Globally, improving energy efficiency in new and existing buildings "encompasses the most diverse, largest and most cost-effective mitigation opportunities in buildings" (IPCC, 2007). The largest potential of carbon savings by 2030 is attributed to retrofitting existing buildings and replacing energy using equipment due to the slow turnover of the stock. With such estimated potential in the residential building sector, it is imperative that authentic achievements and potential within this area are quantified. Adding to this argument is The European Commission's assessment of National Energy Efficiency Action Plans (NEEAPs) which found that while residential building renovation is the focal point of most national plans there was at most, sporadic indication of savings estimated along with very limited degrees of detail on assumptions made in approximating savings from different measures (Commission of the European Communities, 2008). 2011 figures for primary energy requirement in Ireland show the total primary energy consumption for the residential sector to be 27% (Dennehy & Howley, 2013) compared to 35% in Dublin City according to 2008 figures (Dublin City Council in association with Codema, 2008).

1.5.2 Mitigation actions

Initial policy in the area of energy efficiency in dwellings targeted mainly new build (Department of the Environment and Local Government, 2000, Department of the Environment, 2006, Department of the Environment Heritage and Local Government, 2007). One of the recommendations by the International Energy Agency (IEA) and the Organisation for Economic Co-operation and Development (OECD) when reviewing Irish Energy Policy in 2007 was to consider the potential impact of energy efficiency and fuel-switching in the residential and building sectors for the achievement of climate change goals (IEA & OECD, 2007). The review advised the Irish Government to implement, deploy or expand programmes aimed at reducing energy use and carbon emissions in the home. Focus on improving energy efficiency in the existing stock was introduced more recently in the first and second National Energy Efficiency Action Plans (Department of Communications Energy & Natural Resources, 2009, Department of Communications Energy & Natural Resources, 2013). A number of actions have already been implemented in the residential area and are discussed here:

1.5.2.1 *BER*

The Building Energy Rating (BER) system was formed as part of the action plan for the Energy Performance of Buildings Directive 2002/91/EC (The European Parliament and the Council of the European Union, 2002, Roche T.D., 2006) and recast as 2010/31/EU (The European Parliament and the Council of the European Union, 2010). It became a requirement for new dwellings from 2007, for non-domestic buildings from 2008 and for existing buildings being sold or rented from 2009. It is a key component of the European Union's Energy Efficiency Action Plan (Commission of the European Communities, 2006) formed under the EU 20-20-20 targets (Council of the European Union, 2007). It is based on DEAP software which involves surveyed inputs of the major components in dwellings. These are the building's dimensions, construction type, levels of insulation, air-tightness and ventilation, air and water heating systems and lighting.

BERs were estimated for the existing housing stock in Dublin with the vast majority falling in to the E1 category on the A to G scale (Dublin City Council in association with Codema, 2008). This low grade is attributed to the mainly pre 1990 housing stock currently in Dublin (building regulations were first introduced in 1991). Post 1990 housing falls in to the CI and D2 range (Dublin City Council in association with Codema, 2008).

1.5.2.2 *Building Regulations*

The first national building standards in Ireland were introduced by the Building Control Act of 1990 (Office of the Attorney General, 1990). 74% of dwellings in Dublin were built before the first Building Regulations in 1991 (CSO, 2003). Part L of the Building Regulations refers to the conservation of fuel and energy giving minimum requirements for energy efficiency standards and BER grades for new buildings as well as change of use and material alterations of existing buildings. It was first introduced in 2005 (Department of the Environment Heritage and Local Government, 2006) partly transposing the EU Energy Performance of Buildings Directive (EPBD) (The European Parliament and the Council of the European Union, 2002) and made more ambitious with regard to efficiency levels in 2007 (Department of the Environment Heritage and Local Government, 2007) and 2011 (Department of the Environment Community and Local Government, 2011).

1.5.2.3 *National Smart Metering Plan*

On the 15th September, 2008 Minister Eamon Ryan launched the Smart Meter Plan with 60,000 ESB customers receiving a letter inviting them to take part in the first phase of the national roll-

out of smart meters (Department of Communications, 2008). The number one objective of the smart metering plan is to promote energy efficiency. Other objectives include improving peak load management while supporting microgeneration and renewable energy. Enhancing competition and improving consumer experience as well as improving network services also fall under the aims for the plan (CER, 2010).

The meters monitor and record the electricity used by the householder when it is used. This data is communicated directly to the electricity supply company. It is hoped that by recording the electricity usage throughout the day at half hour intervals it makes users more aware (Department of Communications, 2008). Benefits include more accurate billing and time-of-use pricing. The Commission for Energy Regulation (CER) is leading the implementation. Minister Ryan hoped to have all homes with these metering systems within four to five years of the initial rollout (Department of Communications, 2008). Late in 2011 CER decided to proceed with a full rollout of the plan based on the results from the pilot. Rollout will take place from 2014 to 2019. At the time of writing, the scheme is in a period of consultation in advance of the start date (Commission for Energy Regulation, 2013, Commission for Energy Regulation, 2013).

1.5.2.4 *The Power of One Campaign*

This was an extensive media campaign in 2006 aiming to (Department of Communications Energy & Natural Resources, 2008):

1. build awareness on energy sources, costs and environmental impacts;
2. build awareness of energy inefficiency effects on driving up costs and its economic and environmental impacts;
3. inform and empower homes, businesses and sectoral users on best practice in energy saving; and
4. complement existing programmes.

Market research played an integral part in the success of the project (Department of Communications Energy & Natural Resources, 2008) in which it was pretested qualitatively and assessed using a benchmark attitudinal study (Diffney et al., 2009).

1.5.2.5 Energy labelling of appliances

This was introduced to make consumers more aware of the energy consumption of the product. The initiative aimed to promote the uptake of more energy efficient appliances. The requirements for this initiative are outlined in the EU Energy Labelling Directive (The European

Parliament and the Council of the European Union, 1992), recast (The European Parliament and the Council of the European Union, 2010), and underpinned by the Eco-Design Directive (The European Parliament and the Council of the European Union, 2005) and more recently (The European Parliament and the Council of the European Union, 2008) and (The European Parliament and the Council of the European Union, 2009). Products that do not meet requirements may not be placed on the market.

1.5.2.6 SEAI energy efficiency and retrofit schemes

The Sustainable Energy Authority of Ireland commenced its operations in 2002. SEAI is funded by Ireland's EU Structural Funds Programme co-funded by the Irish Government and the European Union (SEAI website). A Fund Disbursement Programme was launched in February 2003, with a call for proposals inviting community-based organisations to apply for funding to install energy efficiency measures into the homes. This focused on alleviating fuel poverty and supporting energy efficiency in low income housing. The Fund Disbursement programme was later rebranded as the Warmer Homes Scheme (WHS) (SEAI, 2004). In 2006 the Greener Homes Scheme (GHS) was launched offering grants to homeowners for the installation of renewable technologies in the home. In 2008, SEAI launched the Government's Home Energy Saving (HES) pilot scheme (SEAI, 2008) with full rollout in 2009 offering grants to supplement the cost of energy saving features in the home.

Under the newly elected government In May 2011, the Better Energy Programme replaced the three private residential retrofit schemes. The GHS effectively ended, although solar heating support was continued along with the features offered under HES under one scheme, branded the Better Energy: Homes (BEH) scheme with most grant levels reducing by 20% later that year. The WHS was rebranded the Better Energy: Warmer Homes (BEWH) scheme.

At the beginning of the research and monitoring for this thesis, grants were at the original level shown for the HES scheme in Table 2 but part way through the testing period and at the time of writing the grant levels are as shown for the BEH scheme in the same table. A post retrofit BER is also a requirement as per the EPBD.

Measure	*HES 2009-2011 grant*	*BEH 2011-present grant*
Roof Insulation	€250	€200
Cavity wall insulation	€400	€250
Internal Wall Dry-Lining	€2,500	• Apartment (any) OR Mid-terrace House €900 • Semi-detached or End of Terrace€1,350 • Detached House €1,800
External wall insulation	€4,000	• Apartment (any) OR Mid-terrace House €1,800 • Semi-detached or End of Terrace €2,700 • Detached House €3,600
High Efficiency Gas or Oil fired Boiler with Heating Controls Upgrade	€700	€560
Heating Controls Upgrade	€500	€400
Solar heating	Available under GHS	€800
An after works BER assessment must be completed	€200	€50

Table 2 Grant levels for the HES and BEH scheme

Discussions on changing from a grant system to more market based support mechanisms has been in the political discourse since the birth of the HES scheme. The first official public document outlining possible alternative options was released in 2011 as "Thinking deeper: financing options for home retrofit". This described the potential of a "Pay As You Save" (PAYS) model (by attaching a loan to the meter or the property) following the UK's Green Deal[2], leveraging private savings (such as tax free savings accounts), and traditional financing mechanisms (green loans, green mortgage top up or green equity release products) (Curtin & Maguire, 2011). The document focused on barriers to retrofit and particularly how to ignite deeper retrofit. The recent release of the consultation document for Better Energy Financing in July 2013 moves away from a PAYS model based on discussions with stakeholders and other research. Findings were that the new design needs to be normal, easy, affordable and trustworthy (Better Energy Financing Project Team, 2013). This translates to the decision to have:

- A 'one-stop shop' model
- Trusted recommendations of measures tailored to individual consumers' requirements

2The Green Deal plan introduced in the UK in 2010 introduced a framework which allowed private firms to offer consumers energy efficiency improvements to their homes, community spaces and businesses at no upfront cost, and recoup payments through a charge in instalments on the energy bill (Department of Energy and Climate Change (2010). The Green Deal, A summary of the Government's proposals. UK.)

- Clear statements of typical standardised costs, expected savings and likely cost of repayments.
- A choice of attractive and accessible loan products with convenient repayment options.
- A quality assurance scheme with warranties and clear dispute resolution procedures

It also marks the arrest of efforts to motivate deeper retrofits, focusing instead on taking the consumer on "a journey" of retrofit. This document was not released until all of the interviews, surveys and monitoring work for this thesis were complete, and consequently the bulk of the analysis is based on the scheme as it was formed up until the time of consultation.

The consultation document does, however, mark the most recent amalgamation of research within the area of residential retrofit in Ireland. The barriers to retrofit identified in the report are shown in Table 3.

Table 3 Barriers to energy efficiency retrofit for the Irish consumers (Better Energy Financing Project Team 2013)

Overarching barrier	*Specific barriers*
Finance	• Upfront cost/ Cost of Measures • Attitudes to Debt • Interest rates • Expectation of subsidy • Economic distress (arrears, negative equity, consumer sentiment)
Information/awareness	• Lack of public awareness of energy efficiency • Lack of awareness of measures available • Overestimation of cost of measures • Lack of awareness of link of building performance with comfort. • Suspicion of costs vs. benefits driven analysis. • Lack of awareness of own energy consumption • Lack of knowledge among building community/supply chain
Motivation	• Inconvenience and disruption barriers • Behavioural barriers
Trust	• Trustworthiness of energy efficiency information • Trustworthiness of sellers and lenders • Trustworthiness of assessors and contractors
Occupancy Related Barriers	• Tenure • Split incentives

1.5.3 Examining the case study of the HES/BEH scheme

External wall, cavity wall and roof insulation account for the three highest percentages of money paid out by SEAI since the beginning of the scheme at 24%, 22% and 16% respectively (SEAI, 2013). The scope of this project was therefore reduced to homes receiving either cavity wall or external insulation due to limitations in resources and with the aim of limiting variables. A number of the sample houses examined in this study included additional measures beyond these. Those aspects will not be examined in as great detail in this thesis. A few basic concepts of

energy use in the home must first be understood before the overall objectives and aims of the research can be presented in section 1.6.

1.5.4 Energy use in the home - concepts

The determinants of home energy use are complex. It is the product of interaction of occupant(s), the building, equipment and climate leading to different behaviour and energy use (Yun & Steemers, 2011). Occupant factors include, age, income, education, gender, awareness and comfort. Building factors include size, type, age and location. Each of these impacts energy use in the home (Harrje, 1978, Vine & Kazakevicius, 1999, Milne & Boardman, 2000, Healy & Clinch, 2002, Watson & Williams 2003, Kerkhof et al., 2009, Guerra-Santin & Itard 2010, Nair et al., 2010). In the past, building design mainly focused on meeting aesthetic and functional needs. Materials used were based more on visual quality, availability and cost. There was no real understanding or appreciation of the thermal performance of the design. Energy efficiency, thermal comfort and sustainability are more recent trends as highlighted by the shift in political and industry discourse.

Furthermore, the propensity of occupants to undertake energy efficiency retrofit in their home is dependent on a similarly long list of interacting factors (Clinch & Healy, 2000, Crosbie & Baker 2010, Pelenur & Cruickshank, 2012, Better Energy Financing Project Team, 2013, Gamtessa, 2013). It is understandable then that the potential savings in energy due to retrofit are therefore undefined and rely on a number of variables (Ahern et al., 2013)

When it comes to retrofit in Irish homes, grants for insulation constitute the highest payout by the SEAI (SEAI, 2013). Moreover, according to the EU Action Plan for Energy Efficiency wall and roof insulation offer the greatest opportunity to save energy and emissions in this sector (Commission of the European Communities, 2006). The basic concepts needed to understand changes due to the retrofit of insulation in the home are presented in this section and further elaborated on as required in chapters 2, 3 and 4.

1.5.4.1 Heat flow through the building envelope

The building envelope acts as a barrier between the internal environment and the external ambient conditions. The envelope in a house comprises the windows, walls, roof and doors. The ability of these members to resist heat flow is termed as its thermal resistance, or R-value. This is the opposite to, and inverse of, the thermal conductivity. Insulation can be used to increase thermal resistance of the wall system restricting the flow of heat between the cold and hot environments.

One-dimensional, steady-state models can be used to represent many engineering systems including the plane or composite wall (Incropera et al., 2007). Heat transfers to the wall surface by convection from the hot air, by conduction through the wall, and by convection from the surface of the wall on the other side to the cold air. In the case of Figure 1 the 'hot air' is the internal heated space and the 'cold air' is the external colder ambient air. In this example the composite wall is made up of three materials – A, B and C.

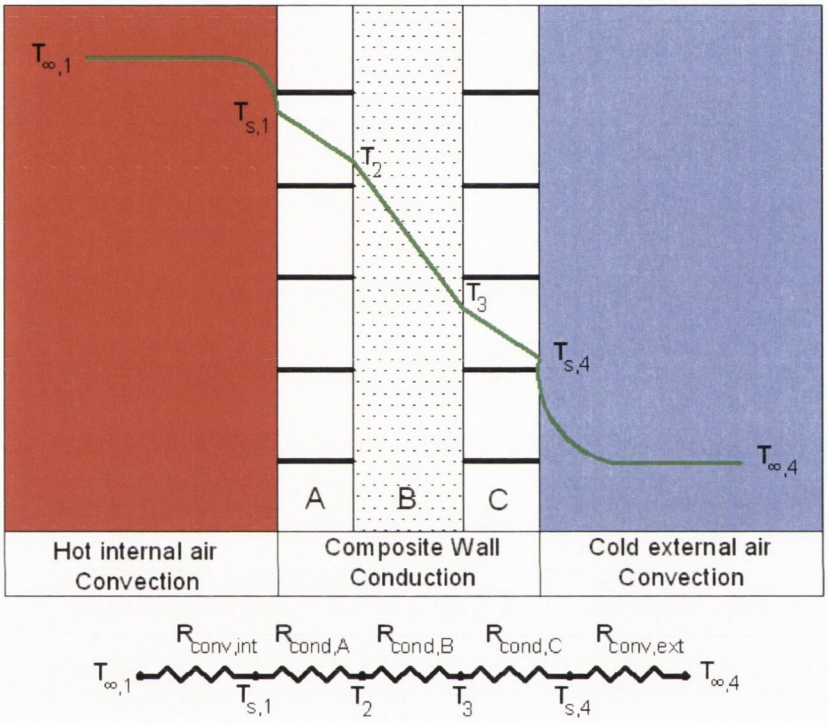


Figure 1 Heat flow through the composite wall system

Many heat transfer conditions are time dependant, or transient. This usually arises when boundary conditions are changed. For the building in use, the boundary conditions are likely to change. In this case boundary conditions are the surface temperatures either side of the wall. This leads to a change in temperature at each point in the system until a steady-state is reached (Incropera et al., 2007). In reality, buildings rarely achieve steady-state as internal and external environments fluctuate, usually cyclically, leading to dynamic heat flow through the wall. Walls or other building envelope types with high thermal mass, have the capacity to store heat, and the response rate of the system is slower when this occurs, meaning that a change in temperature at one side of the wall takes longer to cause any change on the other side.

1.5.4.2 Insulation

Thermal insulation is used to resist the flow of heat and so raises the thermal impedance of the element to which it is attached. Thermal resistance can also be described as a measure of the insulating ability of the material layer or composite structure. A higher R-value indicates a more effective insulator which can reduce heating needs and costs as well as improve the thermal comfort of the internal environment. Cavity wall and roof insulation are generally considered as "low hanging fruit" when it comes to sealing the building envelope due to cost and ease of installation. External insulation is then regarded as the better option if a cavity is not present in terms of thermal performance (Kolaitis et al., 2013, Stazi et al., 2013), and difficulties in installation internally which can lead to mould growth if not properly designed (Little & Arregi, 2013).

1.5.4.3 The human element

"Thermal comfort is that condition of mind which expresses satisfaction with the thermal environment" (ISO 7730, 2006). It is personal and perceptual and therefore impossible to exactly specify, yet it is dependent on a large number of measurable variables. There is a wealth of research in the area of what thermal comfort is, its relation to outdoor conditions (Oseland, 1994, Indraganti, 2010), profile of the subject (Karjalainen, 2007) and activity of the subject (Rowe, 2001) amongst many other variables (Newsham, 1997, CIBSE, 2006, ISO 7730, 2006, ASHRAE 55, 2010, Frontczak & Wargocki, 2011, Nicol et al., 2012, Kang et al., 2013). The biggest influence on indoor comfort is the air temperature. An exact value for this has not been standardised. EN 15251 (2007) designates acceptable temperatures for residential living spaces as 18˚C for existing building, 20˚C new buildings or renovations and 21˚C for sensitive or fragile occupants such as the elderly. The SEAI proposes that 20˚C in living areas and 16˚C in bedrooms are sufficient temperatures to ensure comfort (SEAI website). CIBSE Guide A recommends a temperature of 17-19˚C for residential kitchens and bedrooms and 22-23˚C for living rooms (CIBSE, 2006). However, comfort levels were indicated by occupants themselves in one retrofit study at 18.9˚C (Hong et al., 2009). Furthermore, humidity can change the apparent temperature[3] as felt by the occupants. A 10% increase in relative humidity is felt to be up to a 0.3˚C rise in temperature (ISO 7730, 2006). However, in moderate environments, such as those

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3 Apparent temperature is also known as heat index, This index is an accurate measure of how hot it feels (in degrees) when moisture (relative humidity) is added to the actual air temperature Geography-dictionary.org. "Definition: Apparent Temperature " Retrieved 5 Sept, 2013, from http://meteorology.geography-dictionary.org/HEAT_INDEX_-_(APPARENT_TEMPERATURE).

generally experienced inside buildings in Ireland, humidity only has a modest impact (CIBSE, 2006, ISO 7730, 2006).

According to Clinch and Healy (2003) if it is assumed that all dwellings are already heated to a safe and comfortable temperature it can be presupposed that any energy efficiency programmes will result in a reduction in energy bills and emissions. However, as the paper points out, if a portion of the housing stock is heated to sub-optimal levels any programmes will result in a portion of the savings being used up in increasing internal temperatures to a more comfortable temperature. Fuel consumption may remain the same or even increase as users may now choose to heat the entire house as opposed to just the mainly used rooms. Occupants may also use the same amount of energy to achieve more comfortable conditions overall, known as "comfort take-back" (Department of Social and Family Affairs, 2009). This is why it is important to combine quantitative measurable results such as temperature and energy use as well as qualitative measurements of user behaviour and perceptions. Research comparing predicted energy savings and actual savings from retrofit often attribute a large proportion of any shortfall to comfort take-back. Other examples of percentage take-back after retrofit include 28% for a house in the UK (Bell & Lowe, 2000). A study conducted by SEAI on the gas savings in retrofit houses under the HES scheme found that predictions overestimated savings by 36% +/-8% attributing this to increased comfort amongst other reasons (Scheer et al., 2013). Other total direct rebound effects[4] have shown to be in the range of 10-30% (Haas & Biermayr 2000, Sorrell et al., 2009). Increases in temperature can vary considerably and are dependent on how low the homes were heated to before retrofit (Dinan & Trumble 1989, Milne & Boardman, 2000, Deurinck et al., 2012), though these increases are generally reasonably low (1˚C or less). Conversely Deurinck et al., (2012) appropriates a portion of the rise in temperature to the change in building physics experienced after retrofit as opposed to the behaviour of the occupant. Furthermore, the shortfall in savings can be attributed to incorrect predictive techniques, other changes in behaviour and ranging qualities of workmanship (Sorrell et al., 2009, Rosenow & Galvin, 2013, Scheer et al., 2013). Predicted savings can also *under*estimate the energy savings in what it called the 'prebound effect' (Sunikka-Blank & Galvin 2012)

1.5.5 Potential for change

Irish research for the National Energy Retrofit Programme found that the key obstacles to retrofitting are (IIEA, 2009):

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4 Improvements in energy efficiency make energy services cheaper, and therefore encourage increased consumption of those services Sorrell, S., J. Dimitropoulos, et al. (2009). "Empirical estimates of the direct rebound effect: A review." Energy Policy 37(4): 1356-1371.

1. the high upfront costs;
2. homeowner's reluctance to prioritise long-term savings over short-term expenses;
3. differing priorities of landlords and tenants, insufficient reliable information about improving energy efficiency;
4. uncertainty of the benefits, shortage of certified
5. experienced providers and contractors;
6. inconvenience; and
7. difficulty in coordinating homeowners to act collectively which would bring down the cost.

The more recent research conducted by the Better Energy Financing group are similar to these findings and displayed in Table 3. An analysis compiling data from several sources on Irish houses, occupancy and indoor temperatures for rural housing found that there is potential to reduce running costs and CO_2 emissions by an average of 63% for pre 1979 houses and 26% for newer ones, however this study does not account for user habits for heating (Ahern et al., 2013). It is with the overarching motivation of achieving this potential that the objectives of this investigation were formed.

1.6 Motivation, objectives and aims

Previous sections outline the fundamental need to reduce energy usage internationally and nationally. The resultant focus of policy within this area and the prevalence of residential energy efficiency action as a means to aid the mitigation of climate change were then highlighted. Because of the relatively recent move towards sustainability, there is a limited understanding of how effective related policies and actions have been. This in turn stymies the development and impact of such policies. To this end, this thesis examines the case study of the Irish government's national grant scheme to encourage energy efficiency retrofit in private housing. This is the HES/BEH scheme.

In order to gain a more complete evaluation of the scheme, a holistic approach was taken, combining quantifiable data with perceptual information. The overall objective of the research is to inform stakeholders and policy makers on how to make the scheme more effective. It is to contribute to the knowledge base of policy learning in energy efficiency and retrofit as well as contribute to the technical understanding of how residential buildings change in behaviour due to retrofit. The overall objectives can be split into three aims:

1. To add to the understanding of how Irish residential buildings perform in terms of energy efficiency due to the installation of cavity and external wall insulation introduced under the HES/BEH scheme
2. To collate the learning from the Irish experience in energy efficiency retrofit policy at different levels and from multiple perspectives
3. To analyse the HES/BEH scheme holistically in order to highlight overall barriers, successes and potentials within the sector with a view to informing policy in the area of energy efficiency retrofitting and more generally to sustainability policy

These aims are further fragmented and explained in chapters 2-5 by detailing how each section of the methodology was designed to feed into these overall aims.

The significance of this research is that it examines a complex and current topic by exploring how different aspects of it perform individually and interactively. The individuality of the project is firstly in the design of the methodology. Attempts to create a combined analysis of multidiscipline sustainability projects are more common in industry (Kema, 2008, McKinsey & Company, 2009), though they tend to be macroeconomic based. Such studies are less common in engineering academic spheres where multidisciplinary research is generally confined to examining design-user interfaces. Specifically within residential retrofit, qualitative methodologies in engineering tend to focus on explaining monitored data (Bell & Lowe, 2000, Pilkington et al., 2011, Ridley et al., 2013). The originality and unique contribution to knowledge of the different methodologies of this project are discussed in the 'Basis for the methodology' sections in chapters 2-5. Lastly, being industrially relevant, yet intentionally completely independent of funding or influence by industry or government partners has allowed for a more objective examination of the test subjects, resulting in less bias in conclusions and arguably a more reliable analysis. The next section gives an initial introduction to the breakdown of the examination.

1.7 Overview of the methodology - a three pronged approach

The use of case studies[5] can provide "a form of inquiry that elevates a view of life in its complexity" (Thomas, 2011). The counter argument to this form of research is the need to fragment research into study-sized pieces in order to give a thorough examination of its constituent parts. A further limitation of using only one case study is that findings from this area

5 *Extensive discussion and defence of case study research is presented in reference Flyvbjerg, B. (2006). "Five misunderstandings about case-study research." Qualitative Inquiry* ***12****(2): 219-245.*

are not necessarily true for other areas. In examining the residential energy efficiency retrofit for this research, one cannot, for example, extend the policy recommendations to energy efficiency policies for commercial buildings. More specifically, the houses and homeowners being examined in this study are not representative of the wider population in Ireland on the basis that they are of the typical demographic who use the HES/BEH scheme. Case studies do not aim to make such generalisations, instead it is by looking at the case from many different angles, that the researcher can gain a richer, more balanced understanding of it.

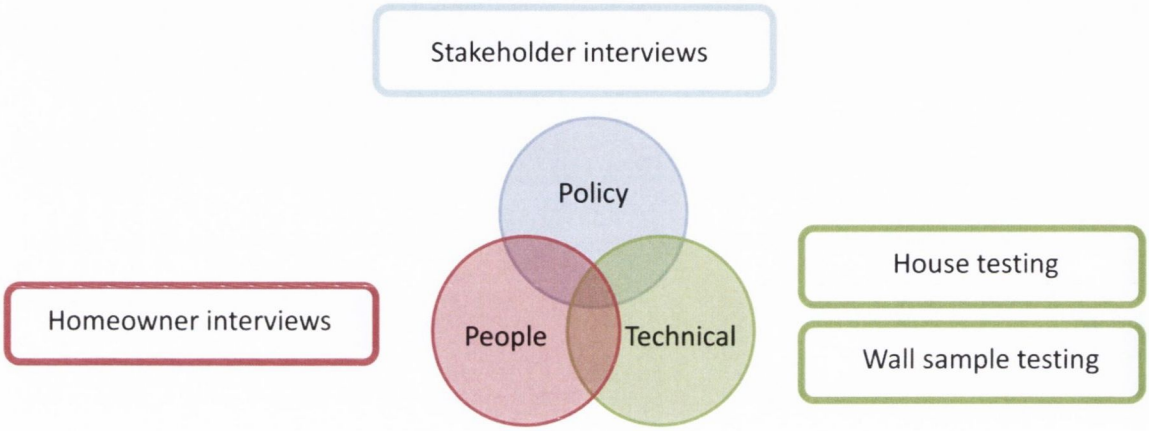


Figure 2 The three pillars of the examination

This understanding that sustainable action involves effort in different disciplines to achieve a common goal, as discussed in section 1.3 informs the design of the analysis for this research project. The study splits into three focus areas of analysis, policy implementation, technical analysis, and the occupant's perspective. The methodological framework for achieving this assessment is divided into three work packages. The first is the household testing involving monitoring and interaction with the occupant as discussed in chapters 2 and 4. This is further explained by the laboratory testing in chapter 3. Finally this leads to the formulation of stakeholder interviews discussed in chapter 5.

The case study involves looking at something as a whole. It mimics the ethos of holistic examination seen in multidisciplinary studies. Previous research which has informed this study tends to examine in depth one of the three perspectives investigates in this project, political/stakeholder (Murphy et al., 2012, Valkila & Saari 2013), technical (Harrje & Grot, 1978, Bell & Lowe, 2000, Al-Sanea et al., 2012), and that of the occupant (Frontczak & Wargocki, 2011, Pelenur & Cruickshank, 2012). The author postulates that this can be attributed to the separate fields of study from which the researchers originated, splitting between social sciences /economics and engineering/building physics. The methodological design of this project, therefore, offers a unique contribution to research in and of itself. In order to allow a holistic

analysis of the scheme, a multidisciplinary approach must be adopted encompassing both qualitative and quantitative methods and spreading over multiple disciplines. Interdisciplinary research can be defined as "the integration or synthesis of two or more disparate disciplines, bodies of knowledge, or modes of thinking to produce a meaning, explanation, or product that is more extensive and powerful than its constituent parts" (Rhoten & Pfirman, 2007). This is an individual's piece of research and thus combines the contribution of the authors own original discipline to the problem and locating and integrating the necessary tools from other fields in order to entirely examine the problem and achieve the objectives of the study. It must be noted that due to this multiple level approach, the depth of examination in any single area is constrained. The findings take a first step towards creating viable multilevel studies.

Typical quantitative research disciplines, such as engineering, do not tend to examine the epistemological[6] and ontological stance of the author or examination (Brannen 2005). Within social science research, experimental or quantitative methods are generally associated with an objective[7] epistemology and is related to the theoretical perspective[8] of positivism[9] (Crotty, 2011). While qualitative social and behavioural scientists primarily work within the constructivist[10] paradigm (Teddlie & Tashakkori, 2009). As this is a mixed methods case study it employs both qualitative and quantitative methods. Mixed methodologists tend to work within the pragmatist[11] paradigm (Teddlie & Tashakkori, 2009) focusing on the 'what' as well as the 'how' and interested in both narrative and numeric data in their analysis. The pragmatic approach forms under the basis that while the adoption of a particular epistemology may warrant the use of a particular methodology, the use of a particular methodology does not in turn require adherence to a certain philosophical position. The use of triangulation[12] is common in mixed-methods research. It has been described as 'almost an essential prerequisite' for using

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6 The theory of knowledge, esp. with regard to its methods, validity, and scope. Crotty, M. (2011). The foundations of social research: meaning and perspective in the research process, Sage publications.

7 The epistemological view that things exist as meaningful entities independently of consciousness and experience, they have a truth and meaning residing in them as objects Ibid.

8 The philosophical stance that lies behind the chosen methodology. It is a way of looking at the world and making sense of it. Ibid.

9 The theoretical perspective of treating 'social facts' as existing independently of the activities of both participants and researchers. The belief that there is a 'true' reality that can be objectively studied. Silverman, D. (2010). Doing Qualitative Research Sage Publications.

10 The epistemological view that each individual constructs his/her own reality so there are multiple interpretations argues that humans generate knowledge and meaning from an interaction between their experiences and their ideas) paradigm and principally interested in narrative data and analysis Teddlie, C. and A. Tashakkori (2009). Foundations of Mixed Methods Research: Integrating quantitative and qualitative approaches in the social and behavioural sciences. London, SAGE Publications Inc. .

11 Pragmatism is not committed to any one system of philosophy or reality.

12 The viewing from several points. Thomas, G. (2011). How to do your case study: a guide for students and researchers London Sage Publications Ltd. .

case study research (Thomas, 2011). The research project presented here does attempt to use this approach in order to back up hypotheses in some areas, however in many instances the methods are analysed separately in order to gain knowledge in different aspects of the scheme. As Brannen (2005) points out, triangulation as used to corroborate findings is only one of many other possibilities, which are:

1. to elaborate and expand findings;
2. to initiate a hypothesis or research question to be pursued using another method
3. to create complimentary insights that create a bigger picture; and
4. to explore contradictions between different data types assumed to reflect the same phenomenon.

The site testing marked the beginning of the experimental process. Controlled testing on wall samples in the laboratory served to inform the often sporadic changes in heat flow experienced under site conditions, eliminating the uncontrollable variables. The variables referred to being mainly user behaviour and outdoor conditions. Stakeholder interviews were informed by site findings, and so only commenced once site testing and occupant interactions were fully completed and analysed.

1.8 Thesis Structure

Chapter 1 provided an introduction to the general research area. It provided the historical background and current knowledge in the discipline. It established the concepts and current understanding in the areas of policy and policy instruments, energy usage in buildings, heat flow and occupant behaviour and perspective. The information provided in this chapter is necessary in order to fully understand the following chapters. It was shown how this has informed the design of the current research and its aims and objectives. A brief introduction to the breakdown of the research is then described highlighting its significance.

The methodologies for this thesis are separated into four chapters 2-5, presenting the first site case in chapter 2 examining only technical aspects. Chapter 3 depicts the laboratory testing which again focuses only on technical aspects of retrofit but in a more controlled environment. The semi-controlled site case is discussed in chapter 4 alongside the remaining houses in-use site cases which introduces the crossover of technology with occupant behaviour. Chapter 5 covers the stakeholder interaction which primarily focuses on the policy perspective, however triangulates findings related to technological and occupant perspectives. In each of these chapters the justification for the methodology design is argued using previous research by

highlighting their strengths and limitations. Results are presented at the end of each individual chapter along with a brief discussion.

The total research findings come together in chapter 6. Initially findings are discussed in how they relate to the overall objectives of the thesis showing the interconnectivity of the findings and formulating hypotheses and conclusions based on a holistic examination of the process. Using this, the policy recommendations are presented. The limitations of the study are then highlighted as potential areas for further study in the final section.

Technical

Chapter 2. Site test case 1

"However beautiful the strategy, you should occasionally look at the results."

Winston Churchill

This chapter is based on an article written by the author and published in the international journal "Energy and Buildings" (Byrne et al., 2013)

2.1 Introduction

Accurate understanding of the thermal behaviour of building components is essential for predicting heating and cooling needs and facilitates the implementation of more successful energy saving strategies and retrofits. This chapter focuses on a specific measure commonly introduced through the HES/BEH Scheme. Traditionally, assessments of the performance of building envelopes have been based on assumed thermal resistances of the materials involved, laboratory tests and computer modelling. The aim of the present chapter is to investigate the *in situ* thermal behaviour of a case study building and its components under transient and quasi-steady environmental conditions, comparing data before and after the fixing of cavity wall and ceiling insulation. The investigation specifically focused on the value added to the property by wrapping it in common types of insulation. The value determined includes the internal temperature achievable, the fuel usage per degree increase in internal temperatures, the heat storage behaviour of the walls and ceiling and their ability to resist the flow of heat out of the building as well as the damping effect of its thermal mass. The chapter concludes by proposing that predicted values of heat loss using standardised assumed material properties of the existing structure do not reflect the actual values achieved *in situ* for this test case. These values greatly overestimated the impact of the retrofitted insulation on heat loss through the ceiling and wall. The study presented in this chapter marks the beginning of the site testing and forms the basis for the design of the methodology and analysis of further site cases discussed in chapter 4 where the unknown variable of occupant behaviour is introduced. This site test was performed following a pilot study of a house in a North Dublin suburb and focuses on the technical perspective of a dwelling before and after retrofit.

Section 2.2 presents previous methods in examining thermal behaviour of buildings and walls with and without insulation, presenting a justification for the methodology designed for this case

study. This section then discusses the current understanding of the effect of insulation on buildings and walls using standard comparison methods. Section 2.3 then describes the case study building along with the instrumentation used for the methodology adopted for monitoring the building. The results are reported in section 2.4 comparing the pre retrofit behaviour to the post retrofit. The chapter is summarised and discussed in relation to the overall thesis in the final section 2.5.

Before proceeding, a number of technical terms require explanation. Thermal resistance or R-value is a measure of the insulating ability of the material layer or composite structure. A higher R-value indicates a more effective insulator which can reduce heating needs and costs as well as improve the thermal comfort of the internal environment. The thermal resistance of a material is its thickness divided by its thermal conductivity. The thermal conductivity is a normalised (1m thick) measure of the thermal performance of a substance. The R-value of a composite wall or system is the summation of the thermal resistances of the layers. U-value is more commonly used in industry when discussing the insulating ability of materials. It is the inverse of R-value and includes surface heat transfer coefficients. Surface heat transfer co-efficients are site and climate specific values. They affect heat transfer according to radiative exchange, wind velocity, solar radiation and air temperature. The experimentation for this thesis has therefore concentrated on surface to surface heat transfer and thermal resistances to 'normalise' results and compare pre and post performance by reducing the impact of R_{si} and R_{so}. However, the author acknowledges that the temperature of the surface will be affected by changes in the external conditions. Heat retention refers to a body's ability to maintain its temperature. In this chapter it is used in connection with the ability of the building to retain the heat provided to it by the heating system, and to the building envelope's ability to store heat and return it to the internal space acting in a similar way to a storage heater. Damping, as discussed here, is the decrease in amplitude of fluctuations in temperature.

2.2 Basis for the methodology

Cavity and roof insulation are the two most common grants taken up by occupants under the Better Energy Homes Scheme highlighted in the NEEAP for Ireland (SEAI, 2013). Thermal insulation is used to resist the flow of heat and so raises the thermal impedance of the element to which it is attached.

The industry method for estimating the potential thermal changes due to insulation is by using nominal R- and U-values or other tabulated properties. Design guides and handbooks only provide the design values for thermal properties which are based on idealised steady-state

conditions. Generally, estimates for thermal properties tend to underestimate the insulating ability of walls compared to *in situ* findings (Baker, 2011), with values for ceilings showing particularly poor agreement with *in situ* values. Density is usually cited as the key factor influencing the thermal resistance of insulation (Domínguez-Muñoz et al., 2010), however, due to the manufacturing process, density and other properties are often unknown. Even if the value is known for that material type, uncertainty is still present due to uncontrollable factors in processing and the limited accuracy of measurement. Furthermore, the building structure surrounding the insulation is often made of heavier materials such as concrete and masonry which have variable constituents, meaning that estimates of their thermal resistances can only ever be approximate (Valore, 1980).

Site influencing factors, such as temperature and moisture content, impact on the practical thermal resistance and behaviour of the wall unit (Ochs & Müller-Steinhagen, 2005, Björk & Enochsson, 2009). A further uncertainty is introduced in the specific case of cavity walls. The movement of air and heat flow in such a cavity is quite complex especially for larger cavities combining conduction, convection and radiation (Anderson, 1981). Air tightness (Hens et al., 2007) and cavity depth (Aviram et al., 2001) affect the wall units thermal performance along with other unknown *in situ* aspects such as ground surface temperature at the base of the cavity, type and quality of sealing detail at the top of the cavity and general workmanship of the walls. Attempts have previously been made to examine the thermal behaviour of buildings *in situ*. Due to the exposed nature of the test, certain conditions cannot be controlled as in a laboratory or in computer models.

There are generally two separate approaches taken in examining the effectiveness of the building envelope *in situ*. The first methodology involves monitoring the internal conditions and energy usage (Frank, 1978, Harrje & Grot, 1978, Hong et al., 2006). These studies tend to focus on the building-in-use data (Milne & Boardman, 2000, Hong et al., 2006, Hens, 2010) and testing tends to involve a number of retrofit procedures, not just insulation. However, this test methodology does not quantify the behaviour of the building with and without insulation under standardised conditions so that the true benefit of individual retrofit measures can be quantified. The second methodology involves using a heat flux meter and surface temperature sensors to monitor the heat transfer through a specific building element being examined (Doran, 2000, Baker, 2008, Wingfield, 2010). The temperature difference measured across the structure indicates the thermal resistance of the element (Lorente et al., 1998). The higher the

temperature difference across the wall, the higher the accuracy of the *in situ* methods. A temperature difference below 10°C is not considered sufficiently accurate (Desogus et al., 2011).

A number of studies using simulations have served to postulate the thermal behaviour of building envelopes with and without insulation. This is because there are very few examples of *in situ* testing, and fewer still that are relevant to this research as retrofitting insulation is a relatively new trend. However, models have been shown to underestimate peak heat fluxes by 17% on average and the cumulative difference between fluxes by 9.6% (Medina, 1999). Furthermore, a lag of up to an hour was observed between predicted and measured values. Medina (1999) believed that a discrepancy between simulated values for heat flux and actual values was mainly attributed to the heat storage effect of the wall frame and that elements within the wall were not accounted for along with the question of what environmental conditions to simulate. The reliability of simulation has been shown to become even more spurious in the case of composite walls (Wong et al., 2008). Moreover, comparisons of the same wall with and without insulation showing the true value of the retrofit could not be found.

The following sections examine the current understanding of the behaviour of walls and insulation layers as based on theoretical simulations and calculations. It is these proposed performances of wall masses, with and without insulation, which form the basis of the *in situ* methodology designed for this study. The theories formulated through simulations in previous studies are then compared with actual findings *in situ* in section 2.4 quantifying the reliability of their deductions.

2.2.1 Thermal time constant

The thermal time constant is used to compare the dynamic response of a structure to a change in the internal environment from a position of equilibrium. It is a parameter reflecting how rapidly the wall responds to a step change in air temperature, that is how long it takes for the heat flowing through the wall to become a constant rate. Previous research conducted by Tsilingiris (2004) using simulations, found that there is a higher thermal time constant on the side of the wall closest to the materials of higher thermal mass. Thermal mass, or heat capacity, in equation 1 represents the structure's capability in storing heat; per unit area this becomes equation 2. For composite structures, *i* represents each homogeneous layer with n homogeneous layers in the system.

$$C = \sum_{i=1}^{n} m_i c_i \qquad (1)$$

$$HCA = C/A = \sum_{i=1}^{n} \rho_i c_i \delta_i \quad (2)$$

While the total heat capacity of the composite wall is the same no matter which direction heat is flowing through it, heat capacity is closely related to the wall's thermal time constant (Tsilingiris, 2006). A low thermal time constant of heat flow from the interior of the wall to the exterior (which can be achieved by placing insulation internally) has been shown to be beneficial in intermittently heated/cooled and scarcely occupied spaces (Lukić, 2003, Tsilingiris, 2004). Conversely, positioning the insulation externally has been shown to result in the minimum annual heating and cooling energy demand compared with other positions (Kossecka & Kosny, 2002). Simulated evidence has shown that it is more beneficial to locate insulation internally if the interior is so intermittently heated that the wall returns to equilibrium with the external environment every time the heat source is removed. This results in the wall going through a transient state as it is heated up again each time. But for continuously lived in homes, the walls do not have adequate time to return to such cool levels and so external insulation proves to be more advantageous. This is due to its moderating effect on the internal space and its capacity to act as a thermal storage medium.

As discussed, while heat capacity strongly influences both transient heat flow and the time it takes to reach steady-state, it does not have any impact on the steady or quasi-steady-state heat flow behaviour (Tsilingiris, 2006). Under realistic winter and summer conditions, the average heat flux is not dependant on heat capacity of the wall but on its R- and U-values. It is therefore expected that most benefit of installing insulation (of high R-value, but low thermal mass) should be observed during steady-state and in-use heating conditions of the used building.

2.2.2 R-value and constant heat flow

Thermal resistance values taken from standardised material values in industry are based on area, thickness and thermal conductivity or in research by testing prototype walls in laboratory conditions (British Standard, 1996, British Standard, 1998, Ghazi Wakili & Tanner, 2003). Under the correct environmental conditions, it has been proposed that evaluating R-value of buildings by direct measurement using a heat flux sensor and surface temperature sensors is more useful than using standardised R-values of the various layers of the composite system (Desogus et al., 2011).

$$R = {}^{\delta}/_{kA} \quad (3)$$

Effective thermal conductivity of composite materials is related to the rate of heat flow at steady-state and the temperature difference across the material. Tabulated values of thermal conductivity used to determine thermal resistance of existing and new structures include Part L of the Building Regulations (Department of the Environment Heritage and Local Government, 2007) or CIBSE Guide A (2007). *In situ*, steady environmental conditions can be difficult to achieve. When heating the internal environment, the point at which steady-state is achieved can itself be difficult to identify. For laboratory testing, it has been determined as the point at which deviations between successive temperatures over a period of four hours have diminished to less than 0.5˚C (Aviram et al., 2001) i.e. when the thermal results begin to vary randomly rather than monotonically. According to Baker (2010), under typical in-use conditions and starting from equilibrium, a period of at least a week is required to attain U-values (and therefore R-values) within 5% of the final 27 day value. However, this stipulation is for fluctuating indoor temperatures of a used building and so the required time for the study presented in this paper is greatly reduced. Baker then uses the averaging method (equation 4) as outlined in ISO 9869 (1994). Using this method, thermal resistance can be calculated from surface to surface. The standard specifies that a minimum of 72 hours of recording is needed if the temperature is stable around the heat flow meter.

$$R = \frac{\sum_{j=1}^{n} T_{sij} - T_{sej}}{\sum_{j=1}^{n} q_j} \quad (4)$$

Conversely, Al-Sanea et al. (2012) proposed separating R-value as it is conventionally used from dynamic R-value. Under their definition, dynamic R-value is summed per day using equation 4 to find variations in the thermal resistance of walls over different seasonal periods. This means that the normal R-value of a given wall or other building envelope structure remains the same while its dynamic R-value varies depending on internal and external environments. This is particularly important when designing elements for varying conditions as is the case with building envelopes.

2.2.3 Heat retention

For an uninsulated wall, it is understood that materials can continually transfer heat from the warmer side of the shell and transfer it to the cooler side. However, if the structure is insulated, a large proportion of this stored heat within the wall can return to the internal environment. The implications of this ability to absorb, store and release heat back into the interior include moderation of the internal temperature and reduction in heating costs (Tsilingiris, 2006). Furthermore, the thermal mass of the wall creates a damping effect on internal temperature fluctuations and filling a wall cavity has been shown to greatly enhance the damping effects of

the wall (Hens et al., 2007). Other than individually measuring the losses through individual building elements, the whole house heat heat loss coefficient can be determined in what is called a coheating test. It involves measuring the amount of electrical energy required to maintain the elevated internal mean internal temperature each day (Wingfield et al., 2010)

2.2.4 The current study

The next section presents the findings of a thermally monitored vacant house which was heated from an initial condition where it was in thermal equilibrium with the ambient surroundings. It was maintained at its maximum achievable temperature for approximately one week and allowed to cool naturally. No thermostat was present in the central heating system instead the boiler was set to its maximum position. The study was then repeated after insulation was pumped into the wall cavities and laid over the ceiling in order to define the immediate and achievable benefits of the procedure. The heating up phase of this study tests the theory of thermal time constants *in situ* which has already been shown to be relevant in previous simulations and discussed in this section. Specifically, it tests the finding that the introduction of cavity insulation increases the thermal time constant of the wall (Tsilingiris, 2004). Data from the quasi-steady heat flow phase of the experiment is used to compare dynamic R-values and heat flows for the insulated and uninsulated building envelope. This data is also used to compare the damping ability of the building shell before and after retrofit. The third phase of the study involves examining data after the heat is turned off, giving an indication of the ability of the building to retain heat. It also shows the ability of the walls to resubmit their stored heat back into the internal space. By comparing the cooling down heat transfer and the heating phase heat transfer for the same system, the effectiveness of the building envelope as an insulator and heat store can be examined. This study is not focused on wall and ceiling types, but on the difference in thermal behaviour achieved due to the introduction of insulation. Therefore, the unknown nature of workmanship, quality and composition of the existing structural elements are not of importance to the analysis as they remain the same before and after retrofit. In the results and discussion section the data is compared using the same time period and heat energy input showing changes in internal temperatures, degree of influence of the external environment, time for the internal environment to reach steady-state, quasi-steady-state heat flow through the wall along with heat retention of the building when heat is turned off.

2.3 Case study

2.3.1 Case study building

The case study building is located near the north-west coast of Ireland experiencing a temperate oceanic maritime climate. Fluctuations in external temperature of between 4 and 16°C were experienced over the monitored period and are typical of October/November and April/May temperatures for the region (myWeather2.com). The local conditions while testing were mainly wet with variable wind direction and speed. The house remained vacant for the monitored period so as to reduce additional behavioural variables and to ensure that no heat was lost through temporary opening of doors or windows.



Figure 3 View of case study house 1 from north-west

The building is a two storey detached family home facing west and built in the 1970s (Figure 3). The external walls are of cement block construction, separated by a 100mm uninsulated cavity, with plaster to the internal face and render to the external face. Cavity walls became the standard construction for external walls in North Western Europe after World War II due to their water tightness with the cavity acting as a capillary break (Hens et al., 2007). Regulations to reduce heating demand in buildings were introduced in European countries from the 1970s, but many countries (including Ireland) only introduced them in the 1990s (Eichhammer & Schlomann

1998). This has resulted in a high potential to save energy in this sector through retrofitting of thermal insulation. The loft is insulated with its original minimal fibreglass insulation blankets, including many areas of no insulation.

Over the monitored period the building was retrofitted with pumped polystyrene bead insulation in the external wall cavity and thick glass wool insulation layers in the loft using the standard methods allowed under the grant scheme. Loft insulation also surrounded water tanks and piping to prevent freezing of the contained water during cold periods.

2.3.2 Monitoring

Monitoring of the building occurred for a two week period before and two after retrofit during October/November 2011. Each of these two week periods consisted of the house beginning in equilibrium with the external and internal environments. For phase one, the central heating was turned on to its full power until quasi-steady-state heat flow through the building envelope was observed. Phase two involved leaving the house in this state of heat flow for a number of days (a total of a week of heating) with the central heating remaining at a constant setting. For phase three, the heating was then turned off and the house allowed return to its cold state. The modifications to its thermal behaviour due to the retrofitted insulation could then be compared under all three conditions.

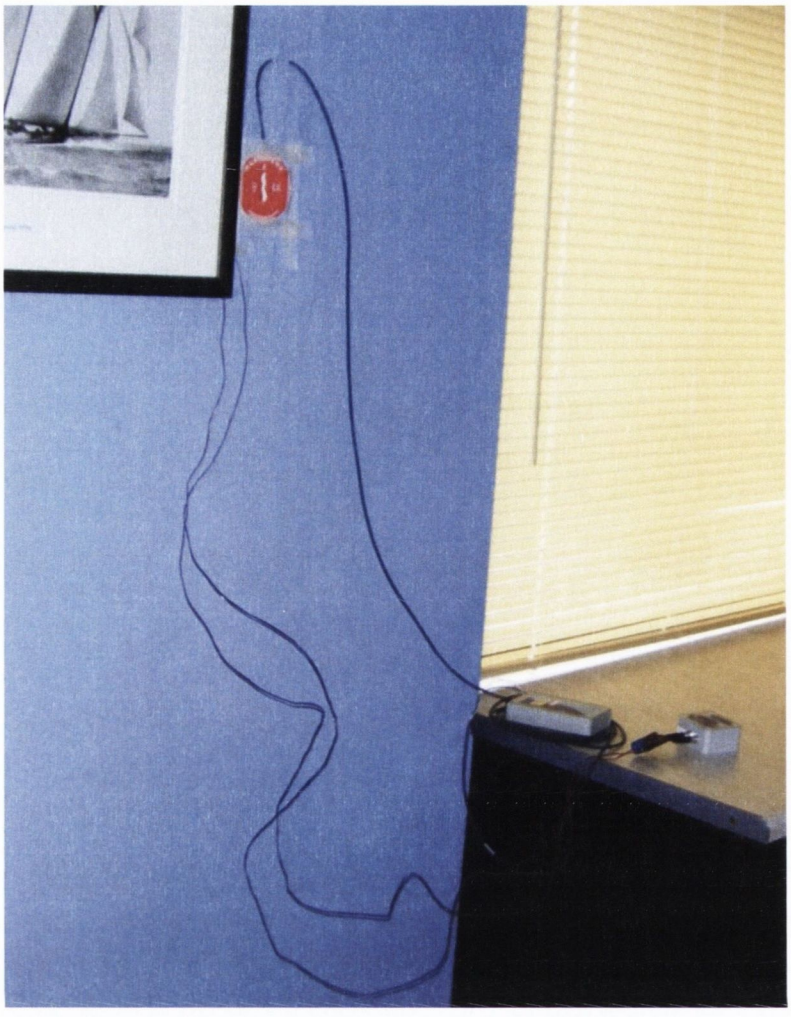


Figure 4 Position of wall heat flux metre and internal surface temperature sensor

A Hukseflux HFP01 heat flux sensor with a LI19 datalogger was used to measure the heat flow through a location on a north facing wall and away from windows (lateral heat flow) or sources of heating, cooling or solar gains as well as positions of thermal bridging such as wall tie locations (Figure 4). A north facing wall ensured that no direct sunlight could influence heat flow from the outside as solar gains would increase the temperature of the external surface and surrounding air. Furthermore, all windows and other openings were covered so as to limit the influence of solar gains on internal temperatures. The area on the wall was chosen by placing the heat flux sensor at a number of locations to pinpoint a position which was representative of general heat flow through the entire wall. Thermal imaging was used to certify further that the location chosen was representative of overall wall conditions pre and post retrofit. Thermal paste was used to maintain even contact with the wall. The sensor itself has been factory calibrated within the limits of +/- 0.1%. Internal and external surface temperatures were also recorded at this location using thermocouples and Logbox dataloggers. The external surface thermocouple is placed within a small drilled hole in the outermost layer of the wall. A similar

setup was used to measure heat flowing between the house and attic through the ceiling structure. Here the heat flux sensor was placed on the underside of the ceiling and the surface temperature sensors placed at the same location on the ceiling and the attic floor. Measurements were logged every 3 minutes for heat flux and every 15 minutes for temperature. Internal room conditions were recorded using Logbox dataloggers. Air temperature was monitored every 15 min in the living room, the kitchen, three of the four bedrooms, stairs, and outside the north and south walls of the house.

Fuel consumption for heating over the period was estimated using the fuel storage tank diameter and level reading. A temperature sensor was attached to the flue of the boiler to record firing cycles every 15s and sensors attached to the inlet and outlet flow to the radiator circuit to record the temperature difference across them every 15 min. These values give an indication of the amount of work the heating system is doing to ensure that there was approximately the same amount of heat energy input into the building for both pre and post retrofit testing periods.

Thermal images were also taken of the ceiling and exterior of the building to identify locations where excessive heat is being lost (or "thermal bridges"). In a poor insulator, heat sources can be readily located from the outside, such as radiators or heated flues as much of this heat is escaping through the building envelope.

2.4 Results

2.4.1 Variables

As this is an *in situ* study, errors were limited to within what was achievable for *in situ* testing. As the external climatic conditions could not be controlled, ambient temperatures were on average 0.9˚C higher during pre retrofit testing compared to post retrofit. If anything, this would lead to slightly conservative estimates of potential savings in heat and energy due to insulation. The boiler ignition times and fuel consumption over the two analysis periods were not significantly different. This means that heat energy input was the controlled factor in comparing the two test periods. The same sensors were positioned in the same locations for the pre and post retrofit case so that errors in measurements are the same for both sets. The post retrofit test began one week after retrofit to ensure similar climatic conditions for both tests.

2.4.2 Pre retrofit

External Walls

Testing began with the internal temperature of the building at the same temperature as the outside. The building and its envelope were considered to be in thermal equilibrium with its surroundings. Under these conditions, after the heating was turned on to full power, the time it took for heat flow to become quasi-steady was found to be approximately 20-34 hrs for those conditions (heat up phase in Figure 5). It is at this point that the heating phase is complete and heat flux begins to fluctuate. Under quasi-steady heat supply of phase two, the average heat flux of the wall was 31.3 $W.m^{-2}$) with a standard deviation of 2.21. As is visible in Figure 5 the heat flux mimics the pattern of temperature difference across the wall, displaying the degree of influence of the external environment on heat flow. The average heat flux value was taken over a period which is a multiple of 24hrs in order to counteract the influence of daily fluctuations.

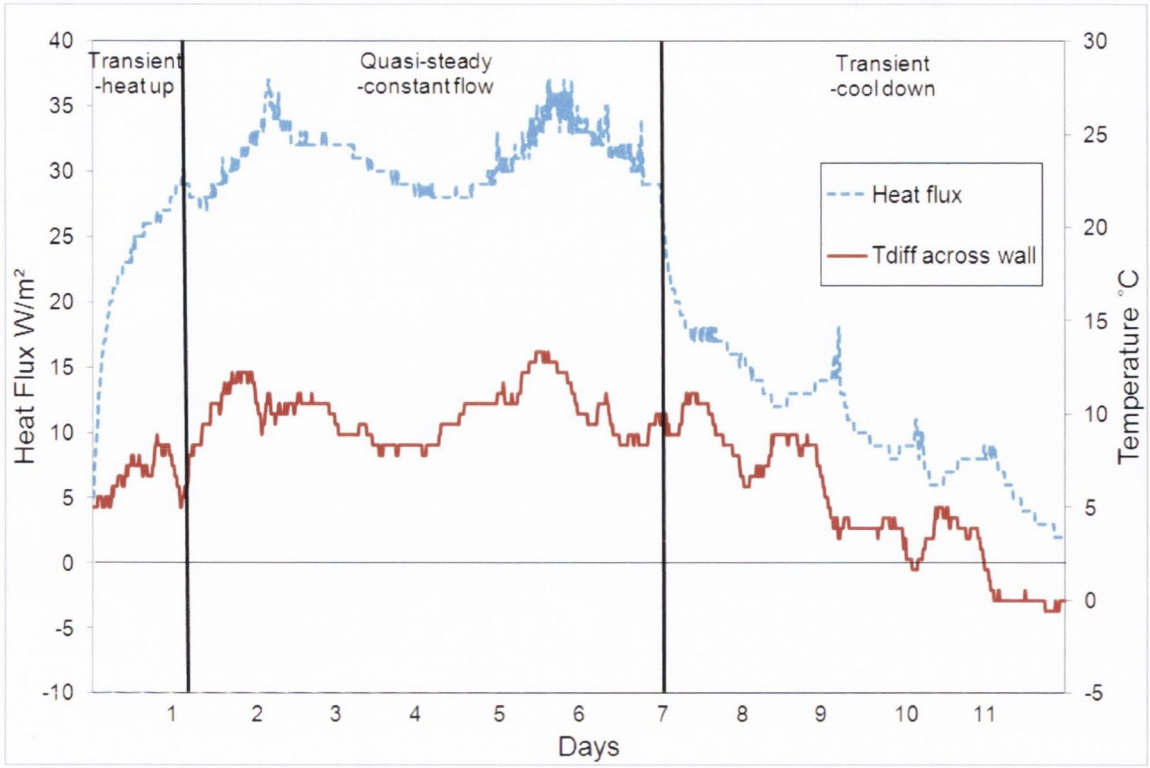


Figure 5 Heat flux and temperature difference across the uninsulated wall during heating up, quasi-steady heat loss and cooling down phases in site case 1.

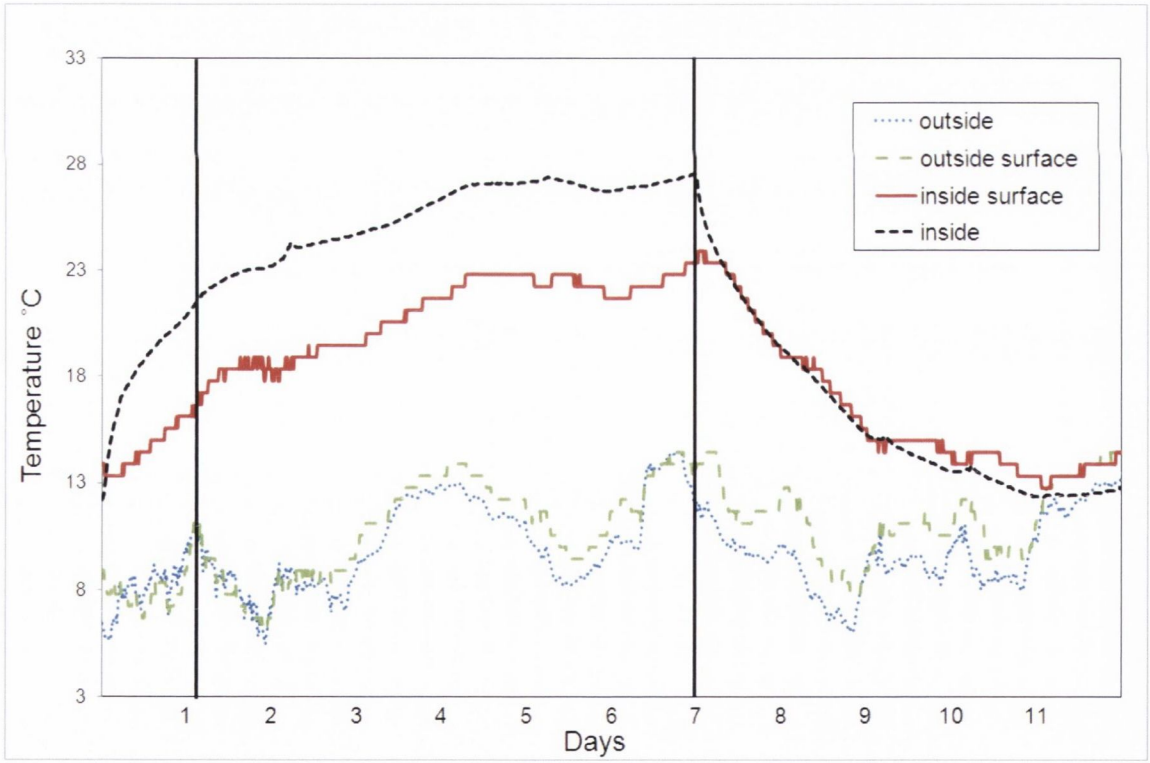


Figure 6 Surface and air temperatures around the uninsulated wall in site case 1

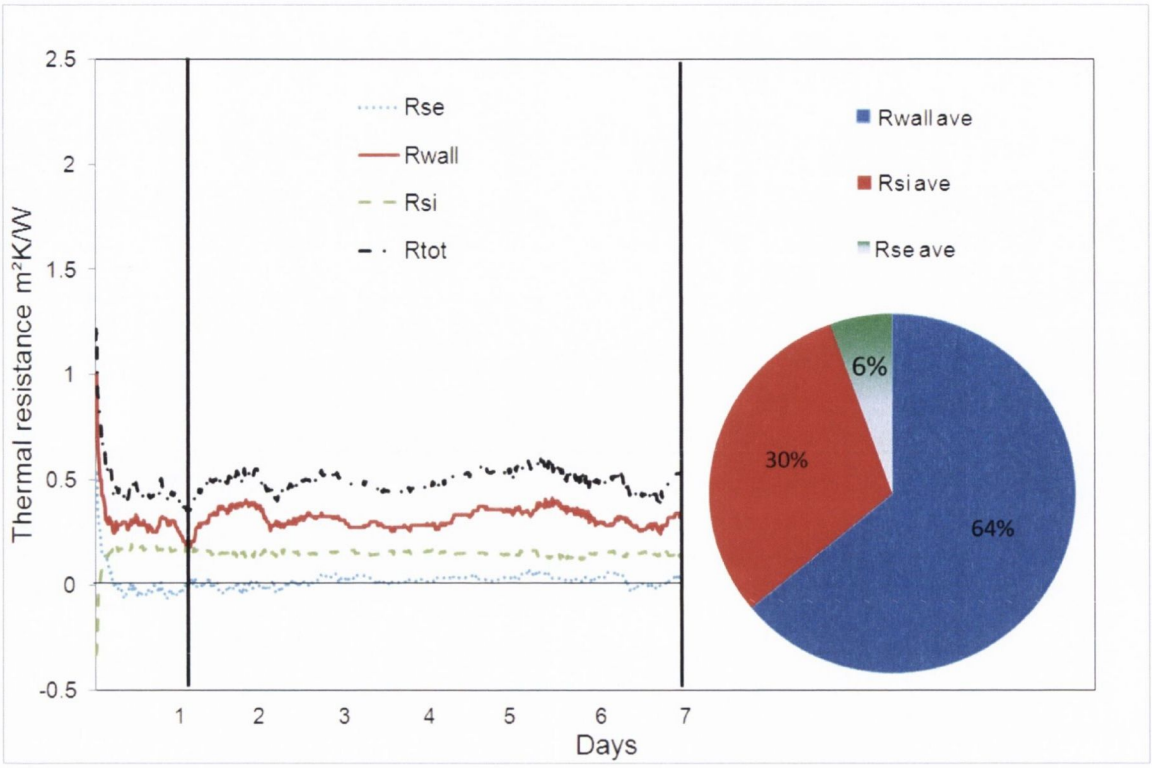


Figure 7 Total thermal resistance of the uninsulated wall system with breakdown of resistance of each layer in site case 1

Thermal imaging was used during the quasi-steady heat loss phase to identify locations and severity of thermal bridging in the building and compare images of before and after the insulation was installed. Examining Figure 8, the locations of the radiators under the two first floor windows show high temperatures on the outside of the wall. This indicates that a large portion of the radiator heat is being lost at these locations. Other bridging points were identified at joints of the wall with the attic and the bay above the front door. As seen in Figure 6 the wall surface temperature internally remains on average 4.7˚C lower than the internal air temperature. This, along with the similar, albeit damped, pattern of peaks and troughs to the external environment, shows the high degree of influence that the external weather conditions have on the enclosed space.

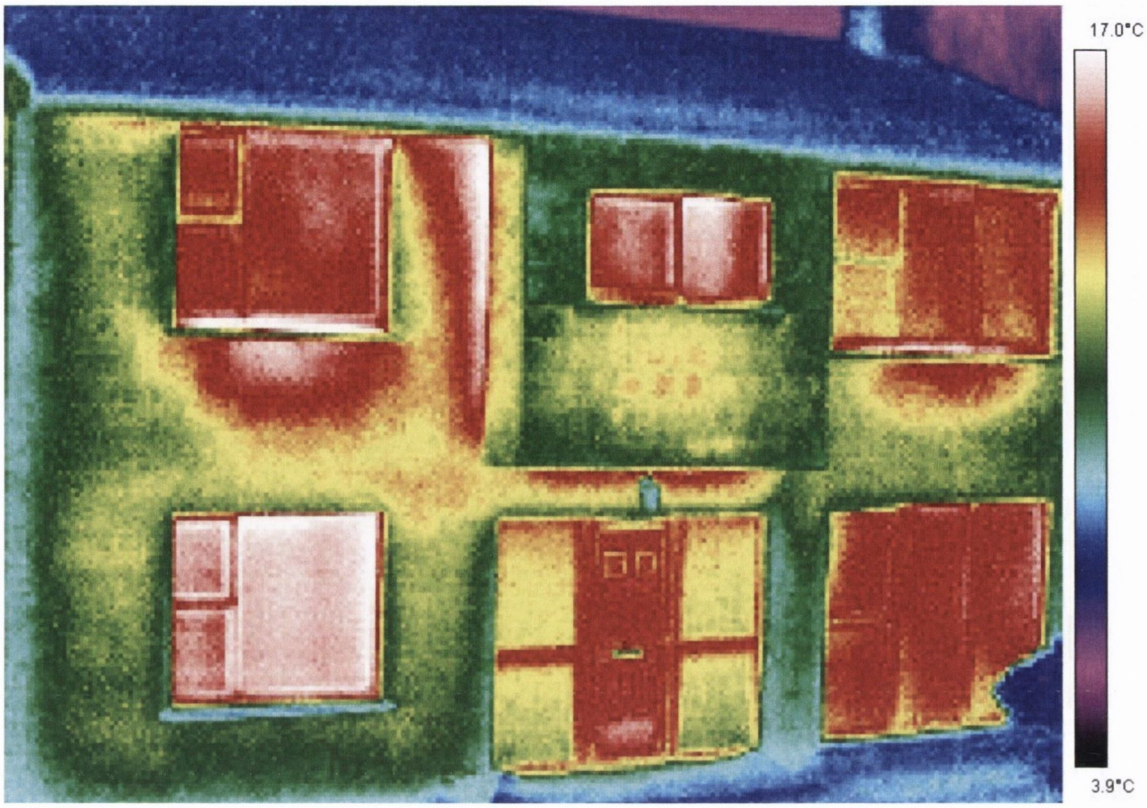


Figure 8 Thermal image of the front face of site case 1 pre retrofit

As discussed in section 2.2, steady-state conditions are used to calculate the thermal resistance of building materials and envelopes. Using the averaging method of equation 4, the instantaneous thermal resistance values for the wall are displayed in Figure 7 for heating and quasi-steady heat flow phases. The achievable thermal resistance under steady boundary conditions was 0.372m²K.W^{-1} with a low level of deviation of 0.041. The thermal resistance of the full wall system is higher due to the inclusion of surface resistances (equation 5). By assuming that temperature of the medium (T_∞) used to calculate convective surface resistance,($T_\infty - T_s)/q$), is the same as the temperature of the surroundings (T_{sur}) used to calculate radiation surface resistances, (($T_s - T_{sur}$)/q), the effective surface resistances can be calculated using the air and surface temperature values and are displayed in the pie chart in Figure 7. The wall mass occupies the vast majority of the overall thermal resistance, however, the internal surface resistance is still considerable. Here it is likely that internal radiation resistance to the wall is negligible as its position meant that it was not "seen" by any hot bodies. Externally the radiation resistance is presumed to be minimal compared to the high convective resistances experienced in that highly exposed location. According to ISO 6946 (NSAI 2007) is usually taken as 0.13 m²K.W^{-1} in the absence of information on boundary conditions for horizontal surfaces. The average value for this study was found to be 0.15 m²K.W^{-1}. R_{se} is taken as 0.04 m²K.W^{-1}, but was found to be 0.02 m²K.W^{-1} in this experiment. Neither values found differed significantly

from the ISO 6946 standard values which are based on combined radiation and convection at the surface.

$$R_{tot} = R_{si} + R + R_{se} \quad (5)$$

Data after the heat is turned off showed that the wall continued to draw heat from the internal space over the following five days, albeit at a continuously lowering rate (cool down phase, Figure 5).

Ceiling

The ceiling took much less time to reach quasi-steady heat flow than the walls at 5.5 hrs (see Figure 9). This shorter time is attributed to the low thermal mass and therefore low heat capacity of the single plaster layer of the ceiling. During phase two, the ceiling showed an average heat flux of 44.2 $W.m^{-2}$) for a constant heat energy input and high standard deviation of 3.81. When comparing Figure 9 with the thermal behaviour of the wall in Figure 5 it can be seen that the heat flux is higher through the ceiling, while the temperature difference across the ceiling remains similar to that of the wall. Using equation 4, this difference in heat flux can therefore be assumed to be due to the much lower thermal resistance of the ceiling.

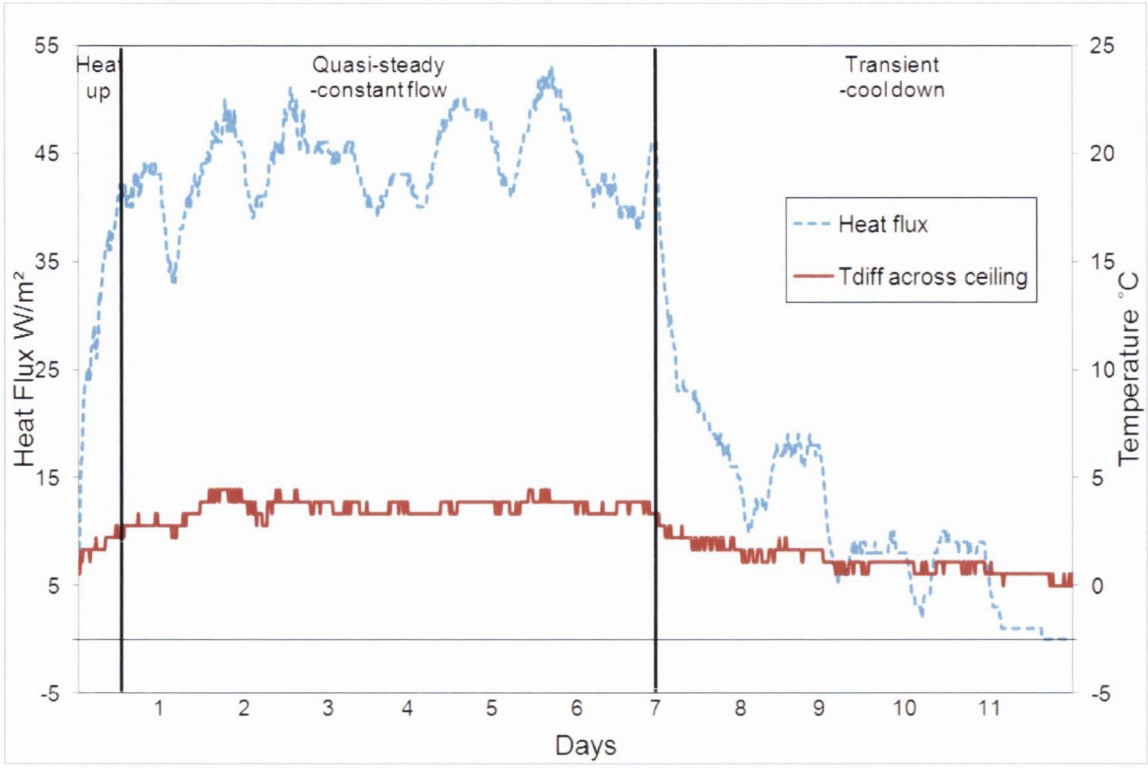


Figure 9 Heat flux through the uninsulated ceiling during heating up, quasi-steady heat loss and cooling down phases of site case 1

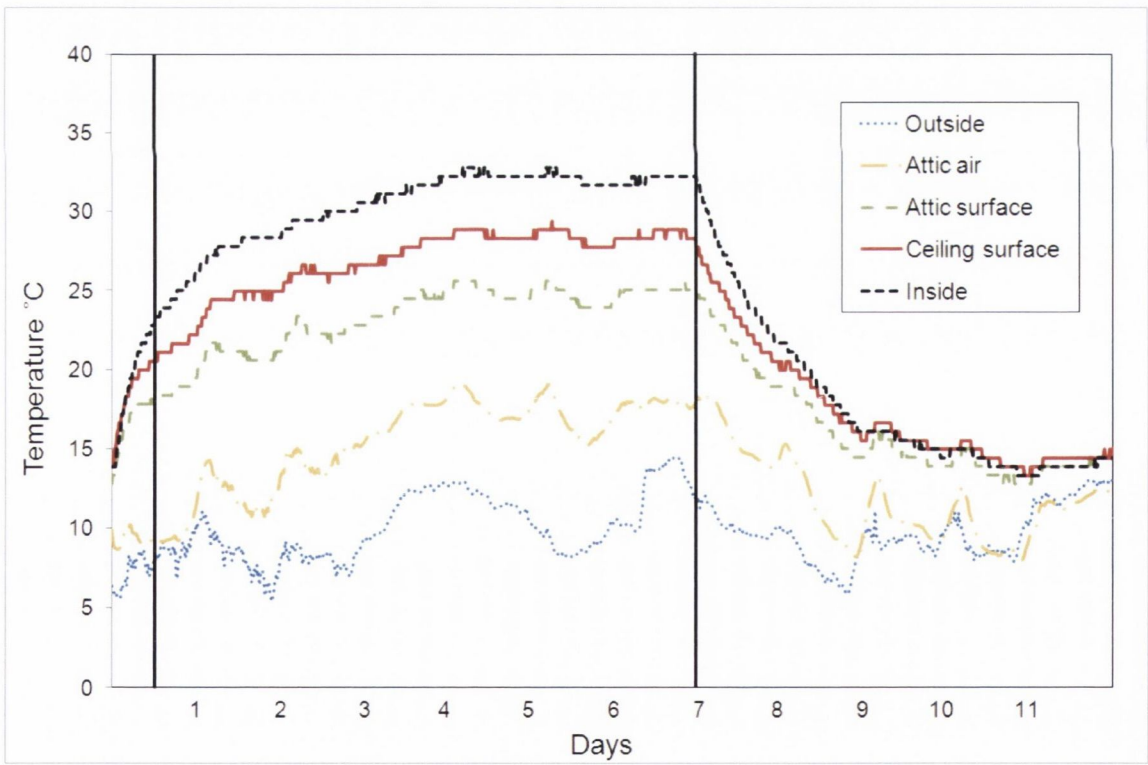


Figure 10 Surface and air temperatures around the uninsulated ceiling of site case 1

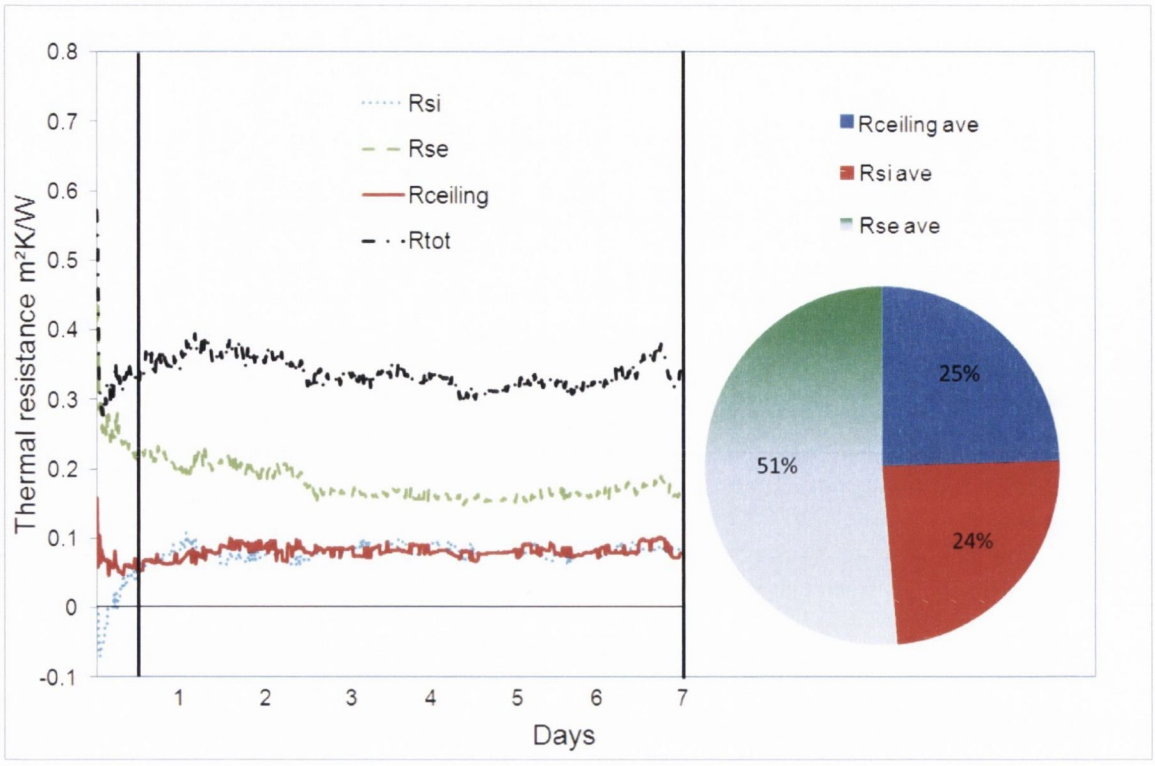


Figure 11 Total thermal resistance of the uninsulated ceiling system with breakdown of resistance of each layer in site case 1

Internally, the ceiling shows a number of areas completely lacking in insulation. Figure 12 displays an area above the main bedroom where thermal bridging was extensive, due to large areas of missing insulation. Similar cold spots were identified in every room on the upper floor. This led to the very gradual change in temperature at the various ceiling layers shown in Figure 10. It is also observed in this Figure that the troughs and peaks in ambient temperature become more and more diminished, yet still identifiable, at each ceiling layer.

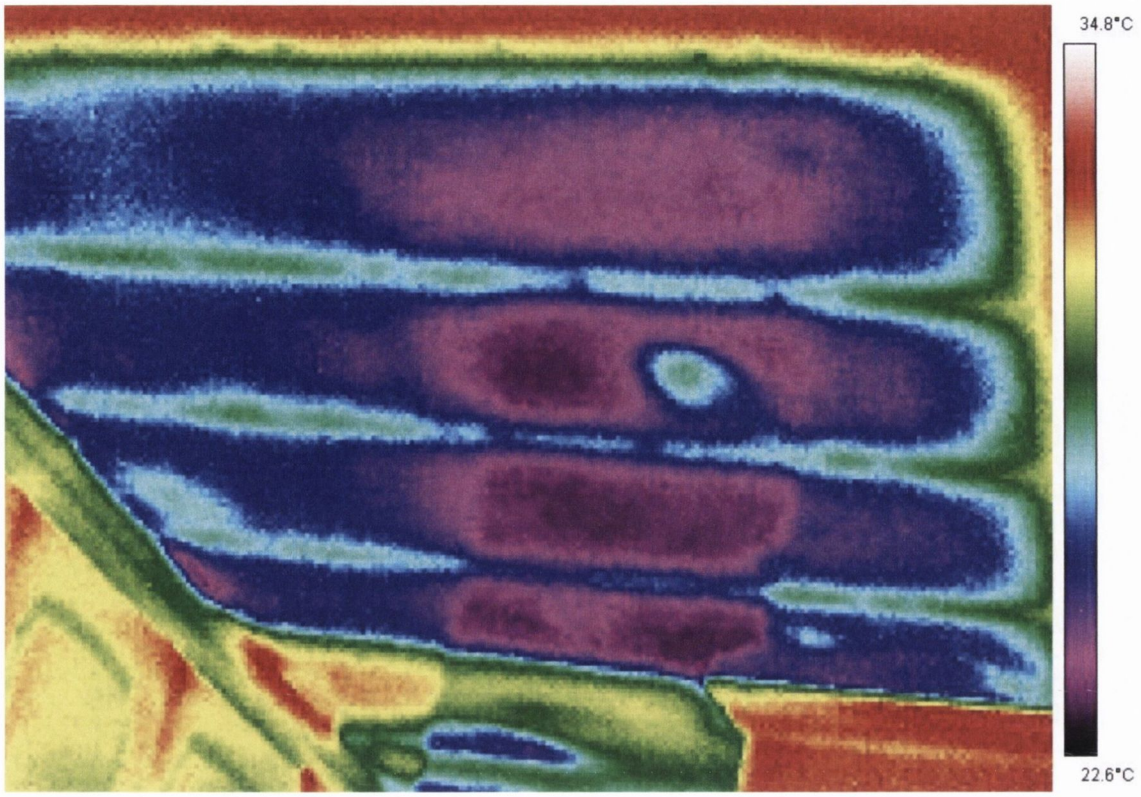


Figure 12 Area lacking in ceiling insulation above the main bedroom pre retrofit for site case 1

Using the averaging method, the thermal resistance of the ceiling was found to be 0.082 $m^2K.W^{-1}$ at the measurement location (Figure 11). It displayed a standard deviation of 0.007 which is significantly lower than the fluctuations for heat flux during the same period. Using equation 4 and examining the fluctuations in external temperature (Figure 10) with heat flux fluctuation patterns of Figure 9, it is shown that the heat flow through the ceiling is highly dependent on the temperature difference across it as is expected. Changes in external temperatures are followed by a short delay before similar fluctuations are observed in the heat flow across the ceiling. R_{se} accounts for half of the overall thermal resistance of the system with R_{si} and $R_{ceiling}$ sharing the remaining half. R_{se} was found to be 0.173 $m^2K.W^{-1}$ compared to standard 0.1 $m^2K.W^{-1}$ for upward heat flow into an unheated space (NSAI 2007). Because of the high temperature of the attic floor layer and attic space the radiation resistance is assumed to be very high. Unlike for the wall, the high temperature difference in equation 4 between the external surface and the external air seen in Figure 10 leads to higher heat flow. The attic surface itself being of high temperature due to the low thermal resistance of the thin ceiling layer. R_{si} was found to be 0.08 $m^2K.W^{-1}$ compared to 0.1 $m^2K.W^{-1}$ taken in the standard, a low value as the internal surface and air temperatures are closer.

For phase three of the test, when the heating system is turned off the heat flux to the ceiling returns to zero more quickly than for the wall by over three days (Figure 9 compared to Figure 5). This factor, which is presumed to be due to the considerable difference in thermal mass, is consistent with the heating up phase results.

2.4.3 Post retrofit

External walls

Once insulation was installed, the heating up phase one took 76hrs for the heat flux to become steady. This was twice the amount of time as the pre case. As per previous studies using simulations (Tsilingiris, 2004, Tsilingiris, 2006), cavity insulation is known to cause an increase in the thermal time constant of the wall. Simulations under similar temperature differences show an approximate doubling of the value when comparing brick cavity walls without and with 40mm insulation in the gap (Tsilingiris, 2004) and in comparing a 250mm concrete wall to the same one with 50mm of insulation in the middle (Lukić, 2003). From examining the different heat flux patterns in Figure 13 and Figure 5, it is observed that by introducing insulation, heat is initially transferred from the internal space similar to the pre case. However, after a relatively short period of time, the amount of heat being lost to the wall begins to decrease from its peak (unlike the pre retrofit case). Due to the presence of insulation in the cavity, the path of heat flowing through the wall is blocked half way, to some extent, by the low conductivity insulation layer and encounters resistance to passing fully through the wall. By comparing Figure 13 to Figure 5 it is immediately obvious that the temperature difference across the wall greatly increases (almost doubling) with the introduction of insulation. Furthermore by comparing Figure 14 to Figure 6 the pattern of the internal surface and air temperatures no longer show any similarity to the external temperature fluctuation pattern and have become much more uniform with each other. Because of this evident block to heat flow between the internal hot and external cold space, the inner leaf of block work then begins to heat up reaching its capacity of heat storage. Only once this capacity is reached does the heat flux reading reflect the amount of heat passing fully through the wall and not just being retained in the inner block work. This is evidenced further by examining the cooling down phase, discussed later in this section.

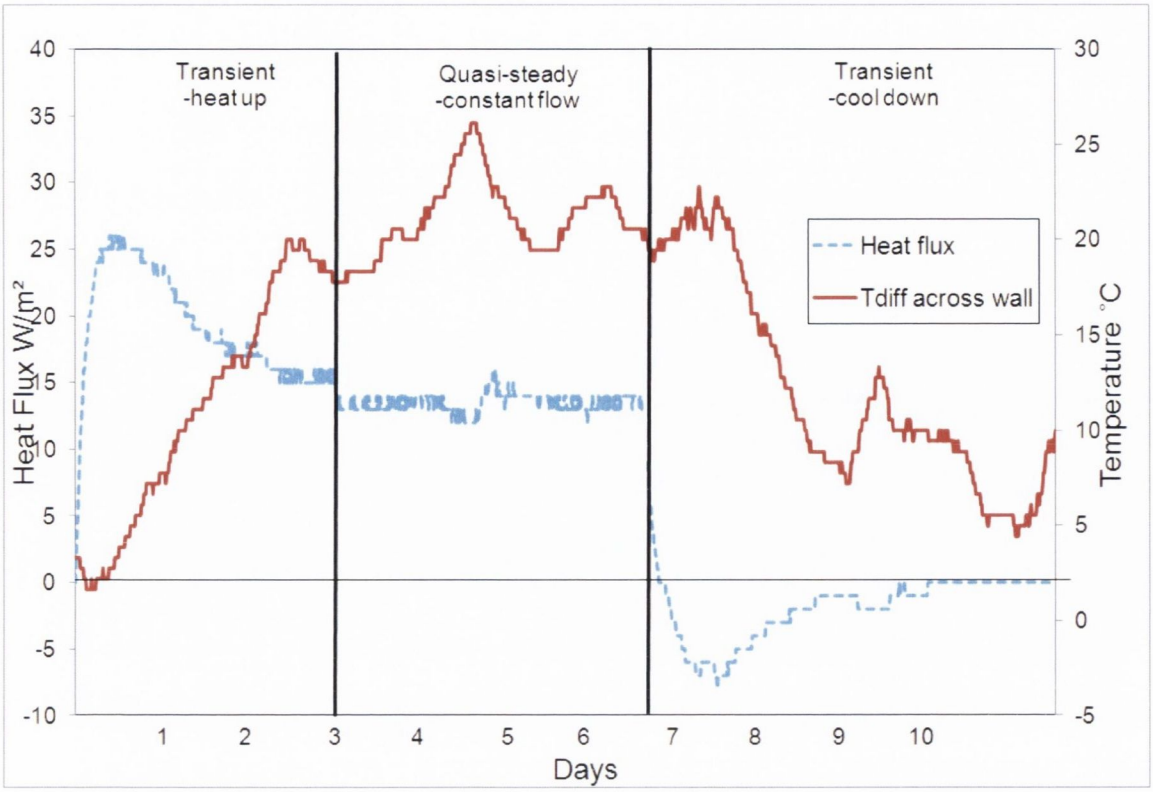


Figure 13 Heat flux through the insulated wall during heating up, quasi-steady heat loss amd cooling down phases for site case 1

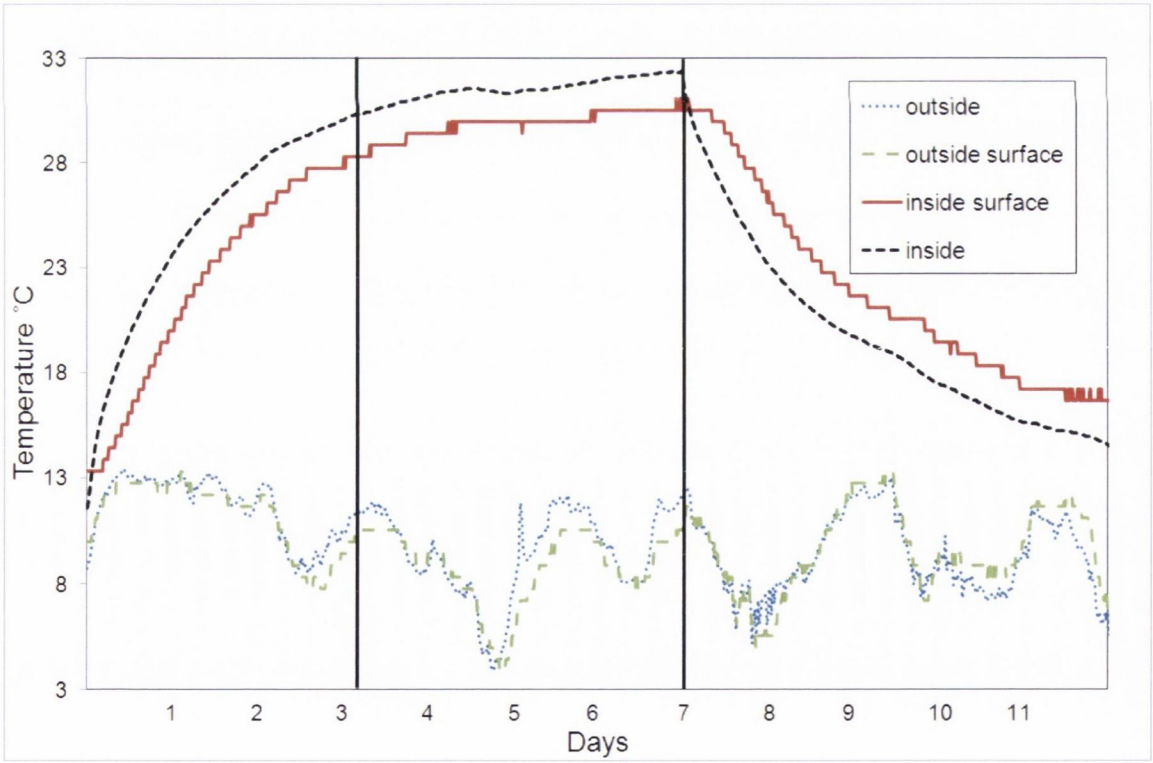


Figure 14 Surface and air temperatures around the insulated wall in site case 1

Thermal images show the reduction in thermal bridging and overall heat loss through the wall when comparing Figure 8 and Figure 15. For example, the space under the windows lowers from 17˚C to more uniform temperatures of approximately 9˚C. Both images were taken under similar weather conditions and assuming an emissivity of 0.9. It is evident that the internal temperature of the wall has become much more uniform post retrofit. Heat leakage remains visible at joint locations, between the roof and wall, and around the more recently added bay window fitted above the front door, however they are less extensive and have become focused at the joint line. The positions of the radiators under the windows are almost unidentifiable.

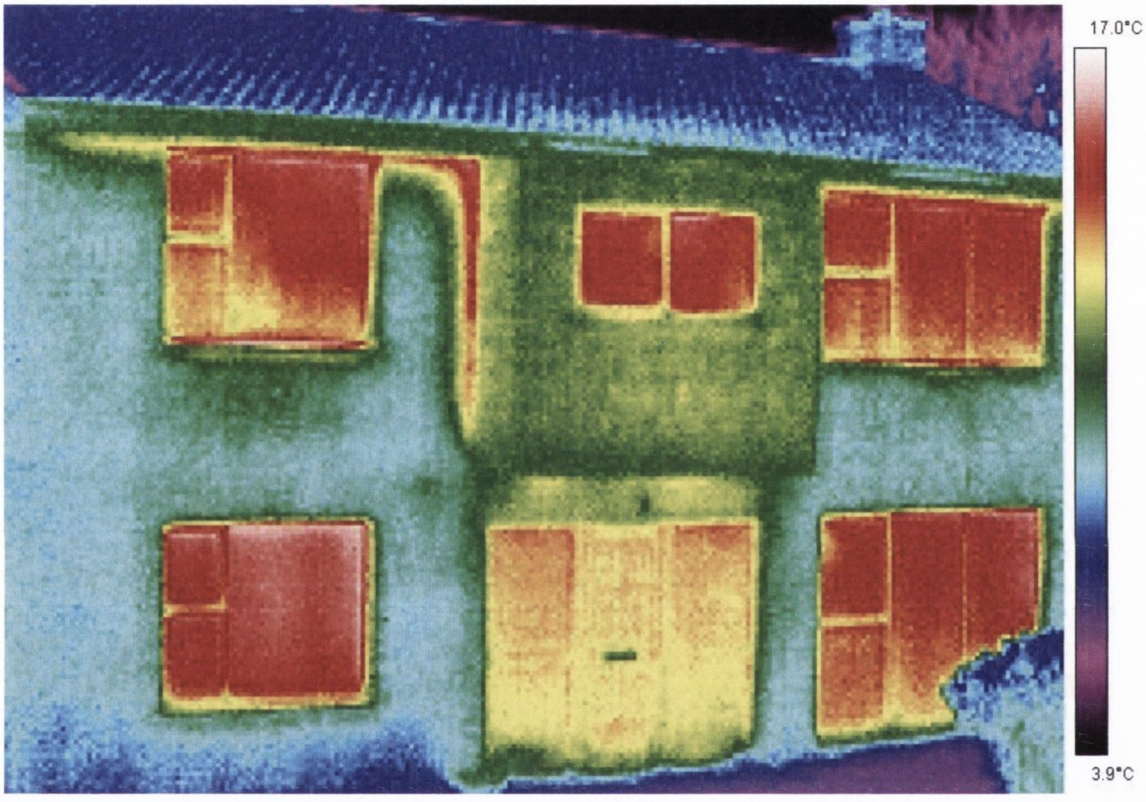


Figure 15 Thermal image of front face of site case 1 building post retrofit

Under steady-state heat flow, the average heat flux to the wall reduced by 56% to 13.5W.m^{-2}) for a quasi-constant heat energy input. The standard deviation also reduced by 33% to 0.73. Calculated R-values for the wall using internal and external air temperatures and ISO 6946 predict a heat flow reduction of 75.3% due to the retrofitted insulation, overestimating the actual change achieved. This is because calculated R-values greatly overvalue the actual working resistance of the wall particularly in the post retrofit case. Using the averaging method outlined in ISO 9869 (ISO9869, 1994), the achievable thermal resistance value of the wall rose by 1.232 m^{2}K.W^{-1}. However, the stated thermal resistance value for 100mm of pumped insulation of this type is 3.125 m^{2}K.W^{-1} (The Irish Agrément Board and NSAI, 2002). Under idealised conditions using ISO 6946 the R-value of the wall should increase by 2.949 m^{2}K.W^{-1}. Post retrofit this

measurement becomes comparatively much more erratic with a standard deviation of 0.189. It is 461% higher than in the pre retrofit case. This is the opposite of what happens to the heat flux which becomes much smoother. By examining equation 4 it is understandable how this may occur. In both cases the ambient weather conditions fluctuate and therefore the temperature difference across the wall is fluctuating also. In the pre retrofit case, the heat flux into the wall also fluctuates, increasing when the temperature difference is high, and decreasing when it is low. This results in a consistent R-value. But in the post retrofit case, the heat flux into the wall is no longer as influenced by these external conditions, remaining steady while the temperature difference fluctuates. A varying numerator and a constant denominator results in a fluctuating R-value. The implication is that under dynamic thermal loading the post retrofit wall thermal impedance must include a capacitance component and the calculated R-value, which reflects steady-state behaviour, is an incorrect metric to gauge the wall thermal performance.

During the cooling down phase, after the heat is turned off, both pre and post retrofit wall heat flux patterns looked similar. However, two significant findings were observed. In the post retrofit case, the heat flow into the wall returned to zero within 3 hrs 44 min, in the pre retrofit condition, the wall continued to draw heat from the internal space over the following days, never fully returning to zero over the recorded period. Furthermore, for the post retrofit case, heat is then seen to flow back into the internal space from the wall, recorded as negative heat flux in Figure 13. The insulated cavity now acts as a block to heat flow between the warm interior and the external heat sink. The heat follows the path of least resistance which is back into the internal air. This adds further evidence to the argument earlier in this section that heat is being stored in the internal block layer. Indeed the area difference between steady-state heat flux and the heating up curve, and the area difference between the steady-state cold (i.e. zero flux) and heat return to the room show a similar pattern. The heat built up and stored in the wall in phase 1 was 1813.46 kJm^{-2}, 826.20 kJm^{-2} of which was returned to the inner space during phase 3. It is essential to note here that the wall and internal air temperature were significantly higher at 17.2˚C and 14.5˚C respectively at the completion of the experiment (compared to 13.3˚C and 11.6˚C at the beginning) and so it can be proposed that if internal temperatures were forced to drop to the original level, that all stored heat in the wall would be returned to the inner space. Because of this returned heat, total heat lost through the walls over a 12 day period (including a 7 day period of heating at maximum power) reduced from 22806.00 kJm^{-2} to 8937.90 kJm^{-2} i.e. a 60.8% reduction in total heat lost through the walls at that point for the same heat energy input.

Ceiling

Similar to the wall's behaviour, the time it took for the ceiling to reach quasi-steady heat loss for phase one increased from approximately 12 hrs to 21 hrs (see Figure 9 and Figure 16). However, unlike the wall, evidence of significant heat storage is not present as both pre and post retrofit ceilings reach a high point of heat flux and remain fluctuating about this point. This is attributed to the low thermal mass and therefore low heat capacity of the ceiling. Here the longer time in the post retrofit ceiling is attributed to lowered influence of the cold attic space on the heat transfer. Heat transfer through the ceiling reduces as there is now a layer of insulation between the cold space and the ceiling resulting in less heat being transferred and thus a longer time to reach steady heat loss.

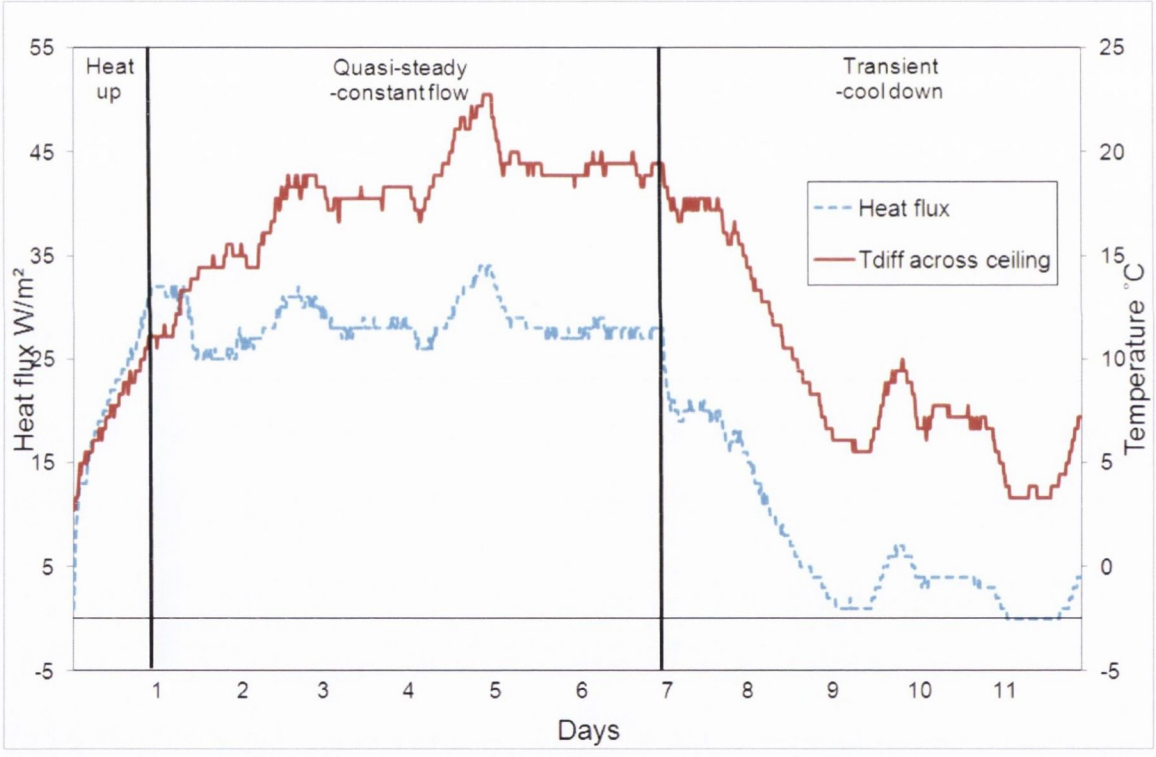


Figure 16 Heat flux through the insulated ceiling during heating up, quasi-steady heat loss and cooling down phases of site case 1

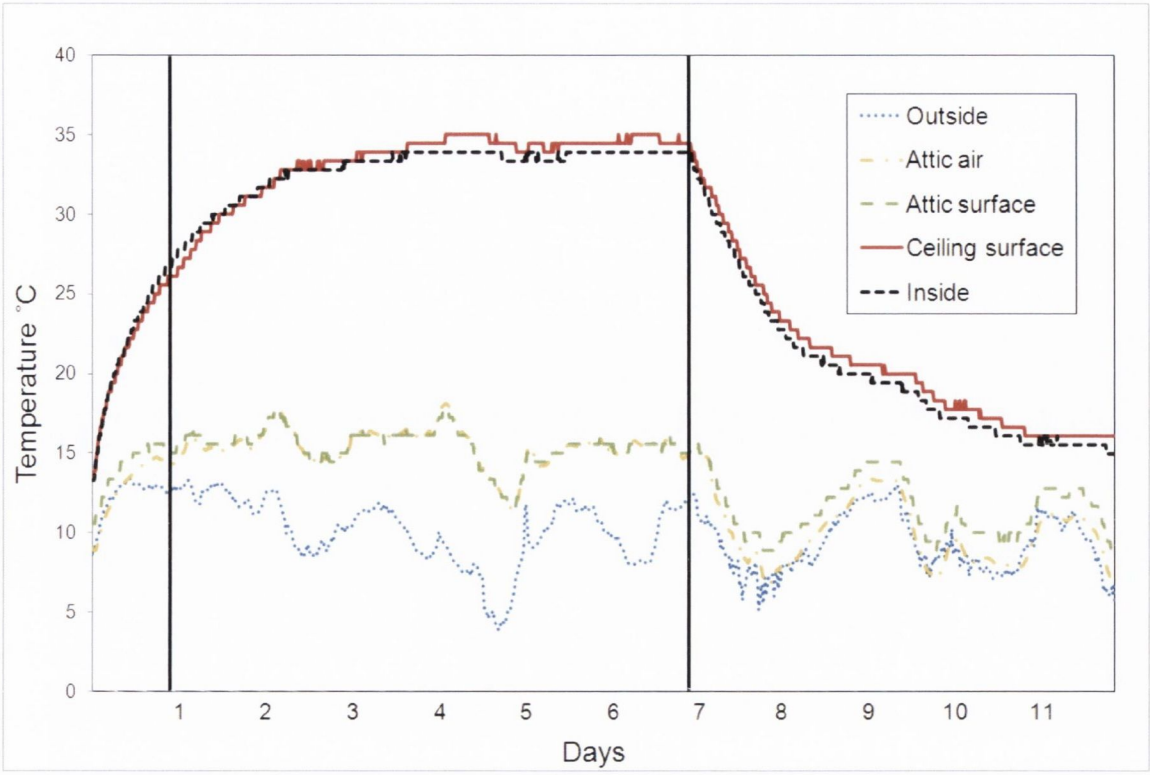


Figure 17 Surface and air temperatures around the insulated ceiling in site case 1

Visually the ceiling shows a significant change in a number of areas where originally there was no insulation installed. Figure 18 displays the same area of ceiling as Figure 12 in the main bedroom. There is a visible reduction in heat loss to the attic in this area, with internal surface temperatures reducing from averages of 24˚C to 32˚C. Similar areas were identified in a number of locations. The internal surface temperature also changed to closely follow the internal air temperature (Figure 10 changing to Figure 17) which reflects this reduction in heat loss through the ceiling.

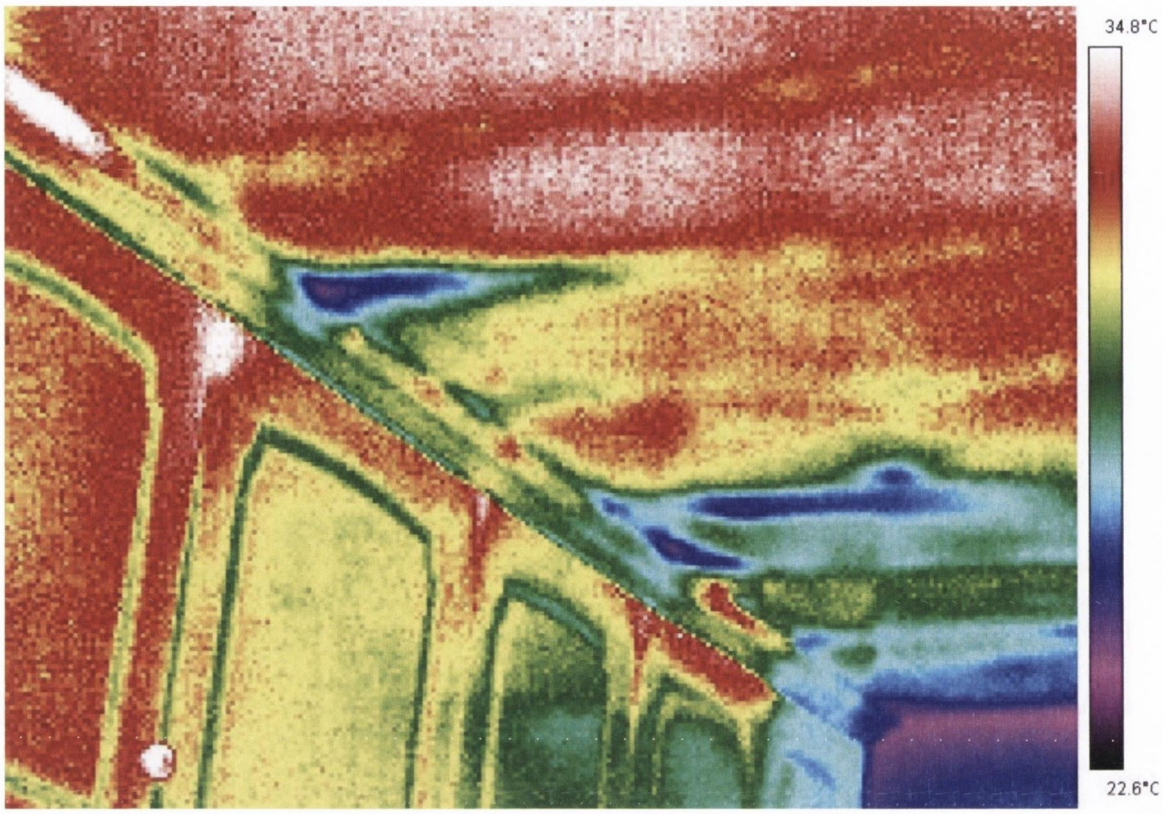


Figure 18 Area of ceiling above main bedroom once insulation has been fitted

During phase two, quasi-steady heat flow, the ceiling showed an average reduction in heat flux of 35.5% to 28.5 $W.m^{-2}$) over an integer multiple of 24 hrs for a constant heat energy input and a moderate reduction in standard deviation of 1.81 to 2.0. The predicted reduction in heat loss using the calculation method was much higher at 83.3% reduction using air temperatures encountered *in situ*. Similar to the wall case, thermal resistance of the ceiling rose from 0.082 $m^2K.W^{-1}$ to 0.682 $m^2K.W^{-1}$ with a standard deviation of 0.027. Again, while this is a significant increase, it remains below the calculated change due to insulation which was predicted to increase R by 2.33 $m^2K.W^{-1}$ (The Irish Agrément Board & Saint-Gobain, 2008). Once more the increase in temperature difference across the body and decrease in heat flux as shown in Figure 16 compared to previous Figure 9 resulted in an increase in dynamic R-values. Figure 17 displays that the internal air and surface temperatures are very much in synch as is the case in the attic. This is due to the block to heat flow between the two spaces due to the installed insulation. Furthermore the fluctuating pattern of the external temperature is no longer identifiable internally.

For the cooling down phase shown in Figure 9 and Figure 16, while the heat flux to the ceiling returns to zero more quickly post retrofit, no stored heat is returned from it to the internal space and heat flux remains at zero or positive after this point. While R-value has increased, the overall heat capacity of the system has not significantly changed as the insulation has a low heat

capacity. This further explains the difference in behaviour, and the difference in the change in behaviour due to insulation, between the wall and ceiling.

Damping/moderating and heat retention

The reduction in heat loss through the ceiling and walls resulted in an overall increase in indoor temperature of 3.66˚C on average during the 5 day period of heating after the initial day of heating (Figure 19). Most rooms increased by over 4˚C, with the south-west facing living room increasing by 4.83˚C. The time it took for the internal temperature to increase by 8˚C to roughly 20˚C in phase 1 reduced from 11hrs 15min to 8hrs 45min for average internal temperature. The time it took for individual rooms to reach approximately 20˚C was reduced to a greater extent. The highest of these was a 5hr reduction in the living room. As the heat input and fuel consumption was the same in both pre and post retrofit cases, the fuel efficiency of the building increased by 0.4litres/˚C above ambient/day. Furthermore, the household temperatures became more uniform throughout the building. The temperature difference between the living room and the warmest bedroom reduced from 4.7˚C to just 1.7˚C after retrofit.

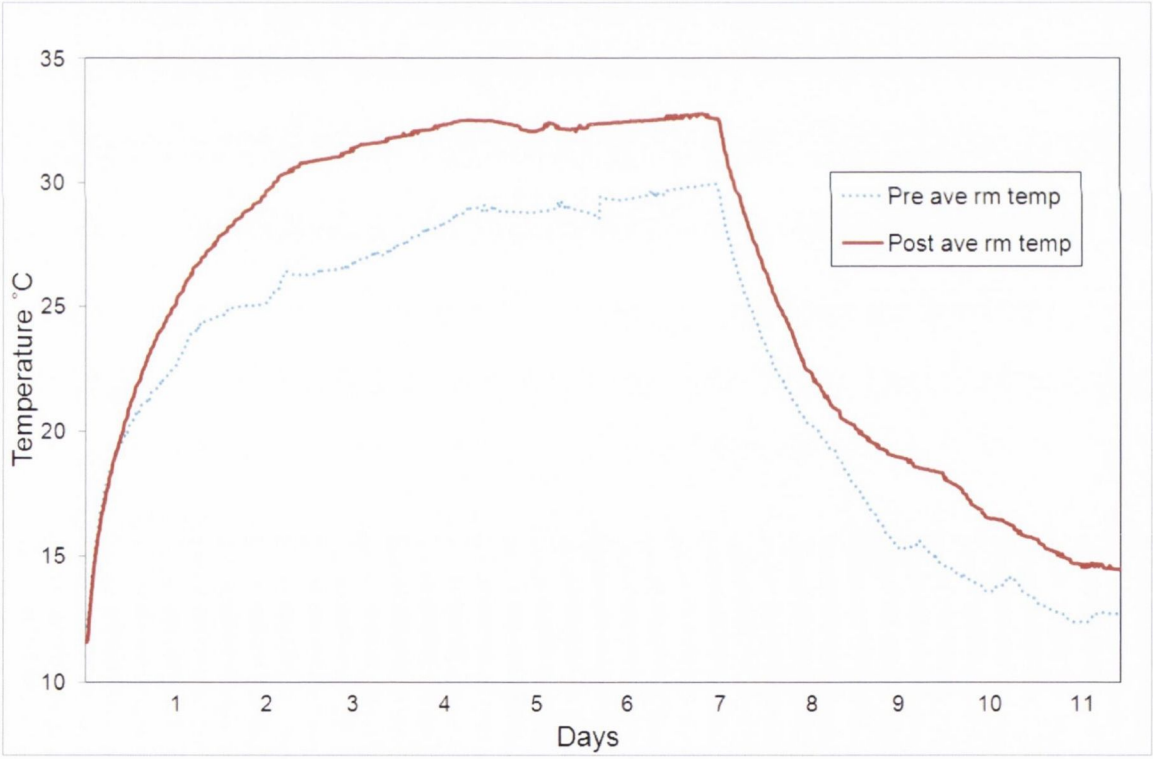


Figure 19 Average room and hall temperatures over the test periods in site case 1

It was observed that the room temperature profiles became smoother reducing in standard deviation by 18% and steadied out much more quickly when insulation was present as external environmental fluctuations became less influential. As seen in Figure 20, while external weather fluctuations remain similarly high pre and post retrofit, the fluctuations in temperature of the

internal surface of the wall drops significantly post retrofit. A similar reduction in internal fluctuations can be seen in the ceiling system temperatures of Figure 21. However, in the case of the attic, due to the lower thermal mass available, there is no observable pattern of ever reducing standard deviation in the layers. Indeed fluctuations remain high at each layer, even surpassing the pre insulation scenario in some cases.

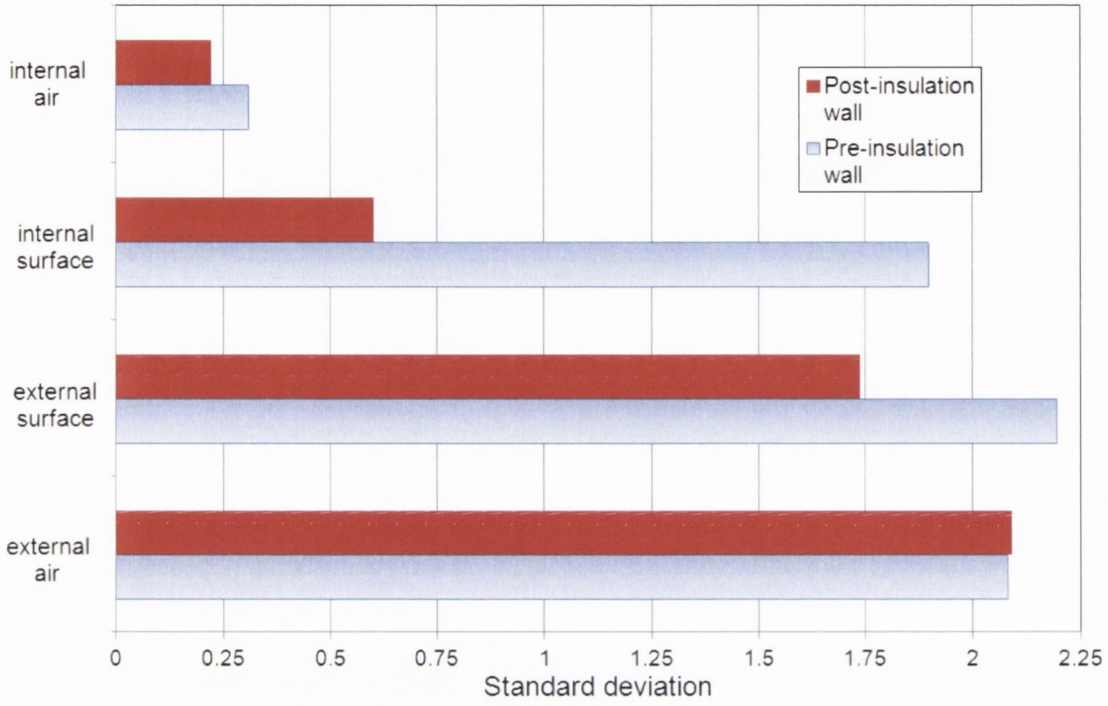


Figure 20 Standard deviation of wall layers pre and post insulation fitting in site case 1

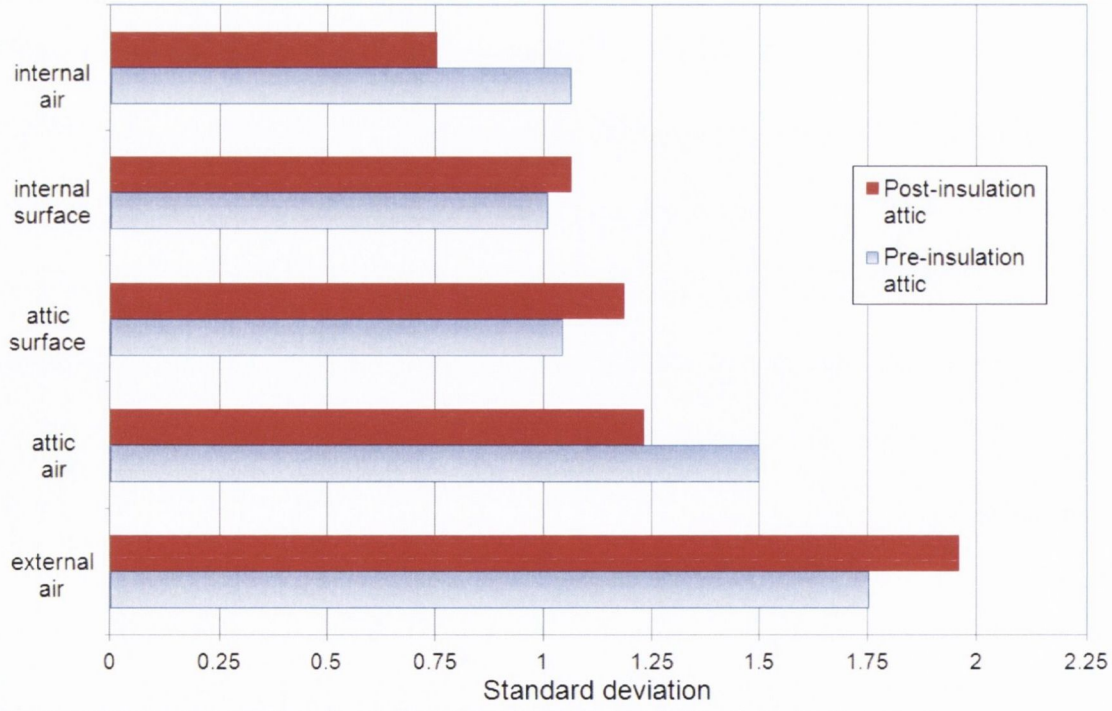


Figure 21 Standard deviation of attic layers pre and post insulation fitting in site case 1

2.5 Summary and Discussion

This chapter shows that not only are calculated R-values unable to precisely reflect this case study building's reduction in heat loss through its walls and ceiling due to retrofitting insulation, but that these values do not reflect the change in behaviour of the entire system. This calculation method does not take into account the benefit of the thermal mass of the wall layers on the wall's behaviour. Building walls can store heat, which acts as a passive source and sink of heating energy. This is most useful during cooling down of the internal environment when the heat stored in the wall can be released to the cooler internal space. This behaviour was only observed once cavity insulation was introduced with heat stored in the inner leaf of the walls in heating up the property partially returned back to it when the heating was turned off. Graphically, the change in behaviour of the wall system is prominent when comparing Figure 5 with Figure 9 in which heat loss behaviour becomes dramatically different. This meant that not only were average heat losses for the same heat energy supply reduced, but the total heat lost over the measurement period was even further reduced when the returned heat from this inner layer is included. In use, this results in lengthening the periods between artificial heating use, lowering energy use and carbon dioxide emissions. Moreover, internal fluctuations in temperature were damped and there was a notable reduction in thermal bridging observed using thermal imaging especially at joints and positions of radiators.

The change in heat flow behaviour through the ceiling did not show as dramatic a difference due to insulation when comparing Figure 9 to Figure 16. This is essentially due to the significantly lower thermal mass of the internal ceiling layer compared to the internal wall layer. The internal layer in this case was not enacted as a heat storage device. However, there was still evidence of damping of internal surface temperatures and heat flow as well as a general lowering of heat losses.

The findings regarding R-value from this study presented the necessity to create more ideal conditions in order to determine the thermal resistance of walls with and without insulation. Based on the experience of *in situ* monitoring, it was decided that a rig should be designed so that wall samples could be tested in a more controlled environment. This means that various insulation types and positions could be tried on different wall types so that the most effective solution could be determined. The next chapter presents the newly designed test facility building on the lessons from this initial study.

Technical

Chapter 3. Laboratory wall testing

"Science is not about making predictions or performing experiments. Science is about explaining."

Bill Gaede

3.1 Introduction

In order to better understand how buildings might behave under different circumstances, the thermal properties of building components need to be quantified. In chapter 2 the thermal behaviour of building walls were examined *in situ* giving a valuable insight into heat flow and heat storage changes due to retrofitted cavity wall insulation However, the variable conditions encountered in this test case led the author to seek a method of controlling the environment while examining the wall. Furthermore, *in situ*, heat transfer methods of radiation and convection are unpredictable and vary depending on air flow, exposure levels, surface emissivities among many other environment dependant conditions. However, the wall structure would be constant under these changing conditions, therefore, it was decided to devise a way of examining the heat flow through the wall components only in the laboratory. The measurement of heat transfer across materials can be done using various standardised laboratory tests (Yesilata & Turgut 2007). There have also been previous attempts at designing new, or using alternative, test methods (Kunc et al., 1984, Modera et al., 1984; Irving et al., 1995, Yesilata & Turgut, 2007, Curley, 2009). This chapter introduces the design of a new test rig which expands and adapts previous designs with the intention of limiting errors and facilitating the testing of walls using a more compact apparatus than the commonly used 'hot-box'. For this purpose a specially constructed test rig has been designed to induce boundary conditions on either side of a material or multilayered sample. For this thesis the sample under analysis is the cavity block wall, though other wall, ceiling and floor types could also be tested. The intention of designing this rig was to determine the thermal resistance of wall assemblies using conductive heat transfer. Thus, the thermal resistance of the wall alone can be determined, excluding convection and radiation heat transfer which forms part of the hot-box calculation. It is proposed that future work with this rig should include a repeat of the tests presented here, adding various typical insulation types and thicknesses to the wall sample. This would be conducted to facilitate a controlled comparison of the thermal behaviour of cavity block walls before and after different types of external insulation is fitted allowing for the most economic solutions to be identified.

This chapter begins by introducing the previous rig designs to test heat flow through material samples in section 3.2. These previous designs inform the design for the new rig as described in section 3.3. This section also defines the steady and transient tests carried out on the wall sample. The results of these tests are then presented in section 3.4 along with a single comparison test after typical external insulation was fitted. Results of the tests are discussed in reference to future tests and the potential of the rig in section 3.5.

3.2 Basis for the design

The most commonly used of the standardised test facilities for measuring the thermal resistance of walls is the 'hot-box', presented in section 3.2.1. This is usually a very large rig as it includes two convection chambers, one either side of the wall sample. Otherwise, thermal testing is generally limited to much smaller samples of homogenous materials such as insulation panels as presented in sections 3.2.2 to 3.2.4.

3.2.1 Hot-box

Hot-boxes measure the overall heat transfer through large, inhomogeneous structures such as walls, roofs and windows. There are two types, the guarded hot-box and the calibrated hot-box. Measurements are normally taken under steady-state conditions but the calibrated hot-box can also make dynamic measurements. Measurements include the D.C. power required to maintain the temperature difference across the external chambers, air temperatures, the temperatures of the surfaces in radiant exchange with the specimen and sometimes the specimen surface temperatures if measuring thermal conductance or resistance.

The hot-box configuration involves two closed spaces kept at constant temperatures. One being hot – the metering chamber, the other cold – the climate chamber. The test specimen divides the two enclosures. The thermal resistance of the specimen is determined by measuring the power necessary to maintain the hot chamber at a constant temperature. The amount of heat transferred from one side of a specimen to another for a given temperature difference is determined but this value is not dependant on the modes of heat transfer (conduction, convection or radiation) (British Standard, 1996). The convection depends on air temperature and velocity, the radiation depends on temperatures and total hemispherical emittance of the specimen surface and surfaces "seen" by the specimen.

Testing can be steady-state or dynamic. The steady-state testing uncovers the total thermal resistance of the wall (Sala et al., 2008). Response time can first be calculated so that the duration can be determined using an estimated total thermal resistance of the specimen.

Dynamic testing involves changing the temperature on one side of the wall. In one example these tests are carried out measuring the surface temperatures of the wall and determining the thermal resistance of internal and external air layers (Sala et al., 2008). By finding these values and using a triangular signal in air temperature of the cold side, the surface temperatures are recorded and heat flow is calculated.

3.2.1.1 Sizing

The metered area should be big enough to be representative of the full system, thought this is not standardised (British Standard, 1996). If it is a modular component, it should span an integral number of modules. This idea was adopted for the rig design for this project.

The size of the metering box determines the minimum size of other apparatus elements. The depth of the metering box should not be more than that needed to maintain desired boundary conditions and accommodate equipment. One research project used $2m^2$ wall samples (Sala et al., 2008).

3.2.1.2 Materials

High emissivity surfaces are often typical of actual building components (British Standard, 1996). A low emissivity environment requires greater convective component, for example higher velocities, to achieve conventional surface coefficients. This should not be an issue with rig design for this project as the methods of heat transfer to and from the wall surface are through conductive heat transfer.

3.2.1.3 Calibrated hot-box method

The calibrated hot-box is surrounded by temperature controlled space which is not necessarily at the same air temperature as inside the metering box (British Standard, 1996). Heat loss through the box walls is through the use of high thermal resistive walls. Corrections for heat losses are found by tests on specimens of known thermal resistances, which cover the same thickness and resistance range as the test samples (Ghazi Wakili & Tanner, 2003, Gao et al., 2004).

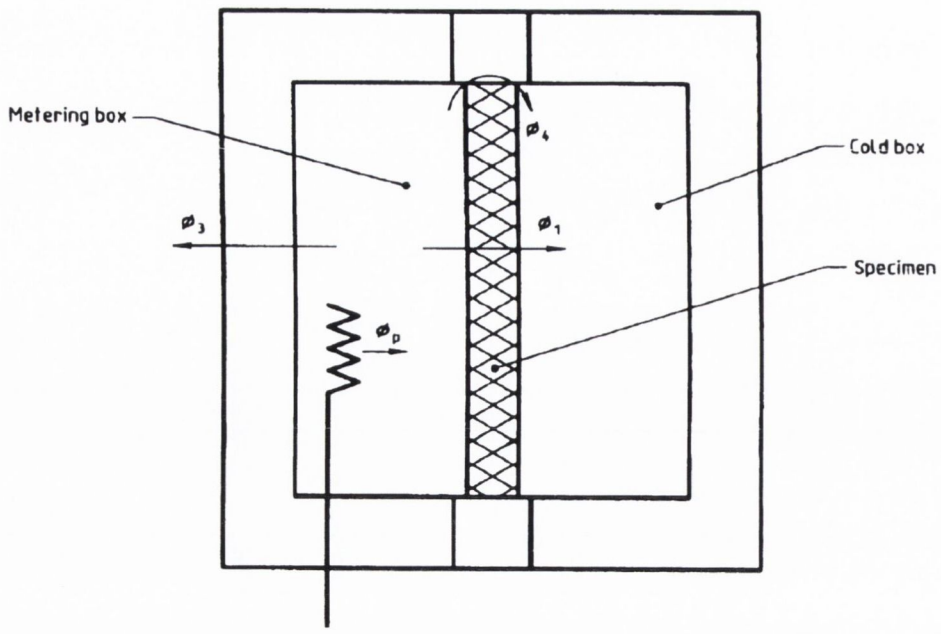


Figure 22 Calibrated Hot-box (British Standard, 1996)

3.2.1.4 Guarded hot-box method

In this instance the metering box is surrounded by a guarded box in which the environment is controlled, limiting lateral heat flow to the specimen as well as heat flow through the meter box walls (British Standard, 1996). This format has been extensively used in research of the thermal characteristics of walls (Nussbaumer et al., 2006; Sala et al., 2008, Martín et al., 2010).

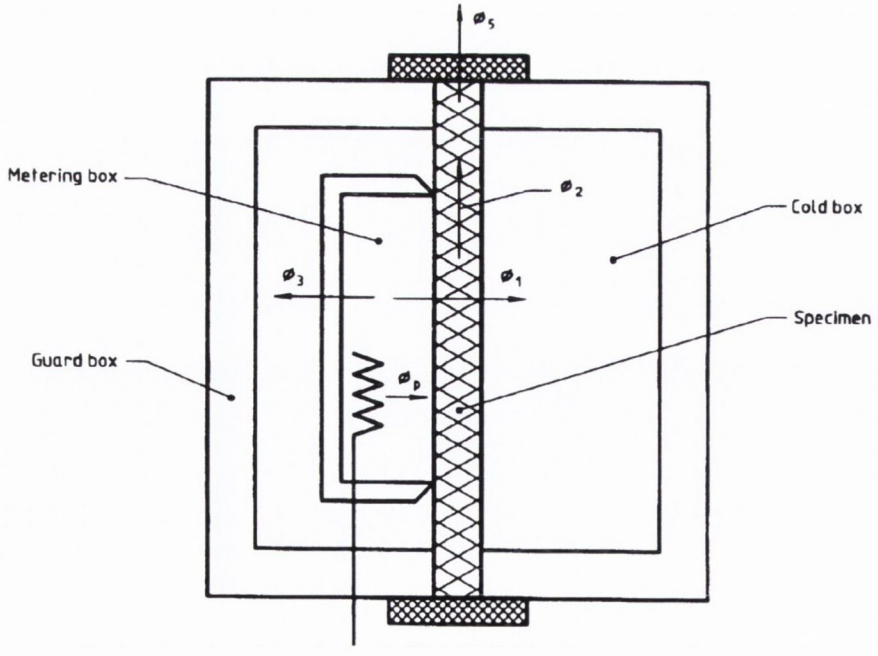


Figure 23 Guarded Hot-box (British Standard 1996)

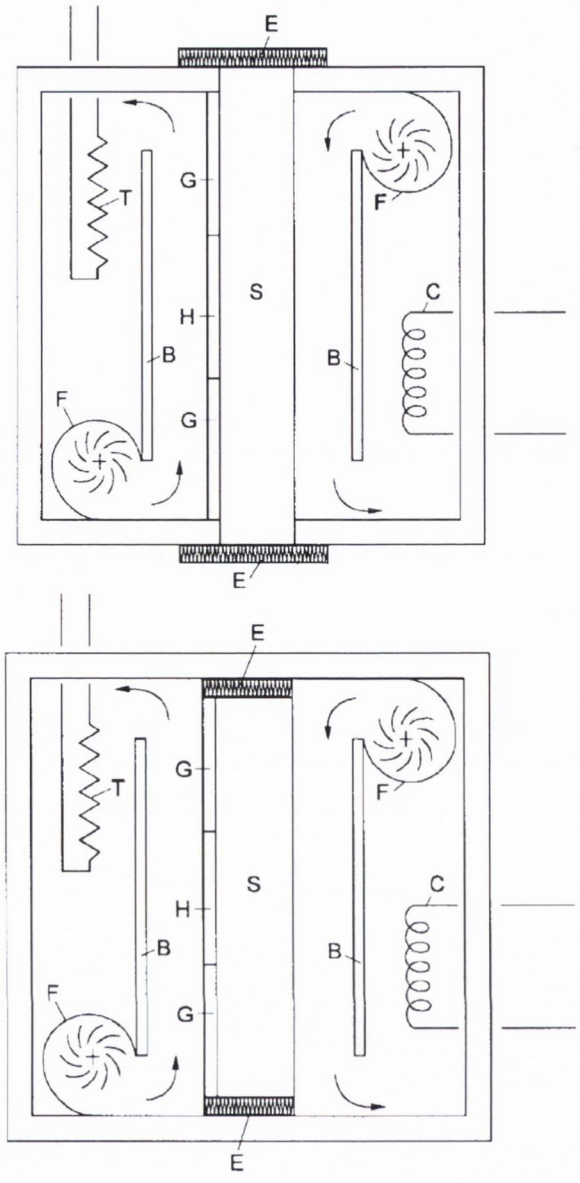
Oak Ridge National Laboratory (2004) has undergone extensive research using their rotatable guarded hot-box facility (Figure 24).



Figure 24 Oak Ridge National Laboratory Rotatable Guarded Hot-box (Oak Ridge National Laboratory, 2004)

3.2.1.5 Metered hot-box method

This method is similar to the others, with the addition of a heat flow meter attached to the specimen on the warm side (British Standard, 1996). A sheet is used to cover the rest of the specimen, which is of the same thermal resistance and thickness as the meter so as to provide uniform thermal resistance across the surface.

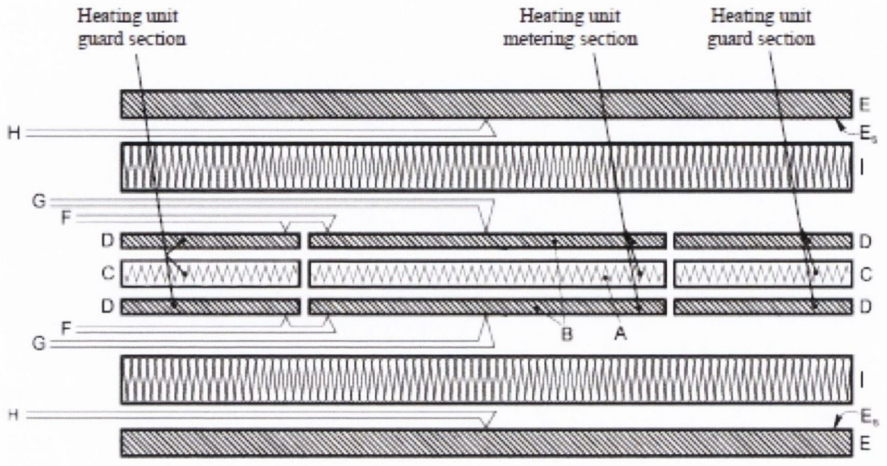


B	baffle	G	guard sheet
C	cooling coil	H	heat flow meter
E	edge insulation	S	specimen
F	fan	T	is the electric heater

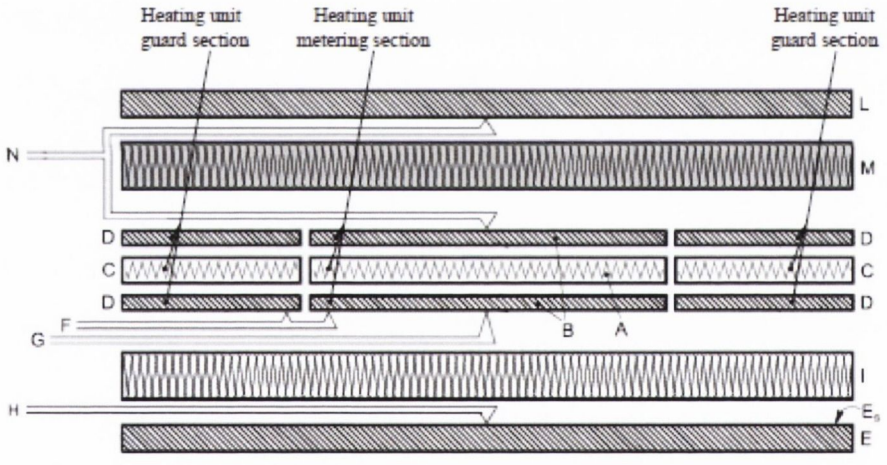
Figure 25 Heat Flow Meter Hot-box Typical Arrangement (British Standard, 1998)

3.2.2 Guarded Hot Plate

The guarded hot plate method is for homogeneous composites, usually insulation material (Yesilata & Turgut, 2007). As per Figure 26 heat flow rate is obtained by measuring power input to the heating unit in the metering section.



a) Two-specimen apparatus



b) Single-specimen apparatus

Key

A Metering section heater
B Metering section surface plates
C Guard section heater
D Guard section surface plates
E Cooling unit
E_s Cooling unit surface plate
F Differential thermocouples
G Heating unit surface thermocouples
H Cooling unit surface thermocouples
I Test specimen
L Guard plate
M Guard plate insulation
N Guard plate differential thermocouples

The gap is the separation between metering section (see A and B) and the guard section (see C and D)

Figure 26 Two-specimen and single-specimen hot plate apparatus (British Standard, 2001)

3.2.2.1 Two specimen

In this setup, a central round or square flat plate consists of a heater and metal surface plates which is called the heating unit (British Standard, 2001). It is positioned between two of the same specimens and the outermost part of the apparatus consists of round or square isothermal flat cooling units at either extreme. Heat flow rate is transferred from the heating unit, through the specimens to the cooling units.

3.2.2.2 Single specimen

The setup is similar to that of the two specimen apparatus with one of the specimens replaced by insulation and a guard plate (British Standard, 2001). Zero temperature difference is established across the combination.

3.2.2.3 Design details

Edge insulation and/or auxiliary guards are required when operating outside of room temperature. The heating unit consists of a separate central metering section where the unidirectional constant and uniform density of heat flow rate can be determined. The heating unit is surrounded by a guard section separated by a narrow gap. The cooling unit's dimensions are at least the size of the heating unit including guard heaters and consist of metal plates maintained at a constant uniform temperature.

An example of the guarded hot plate shown in Figure 27 is used to examine plaster materials (Ashour et al., 2010). Polystyrene is used to insulate around the sample.

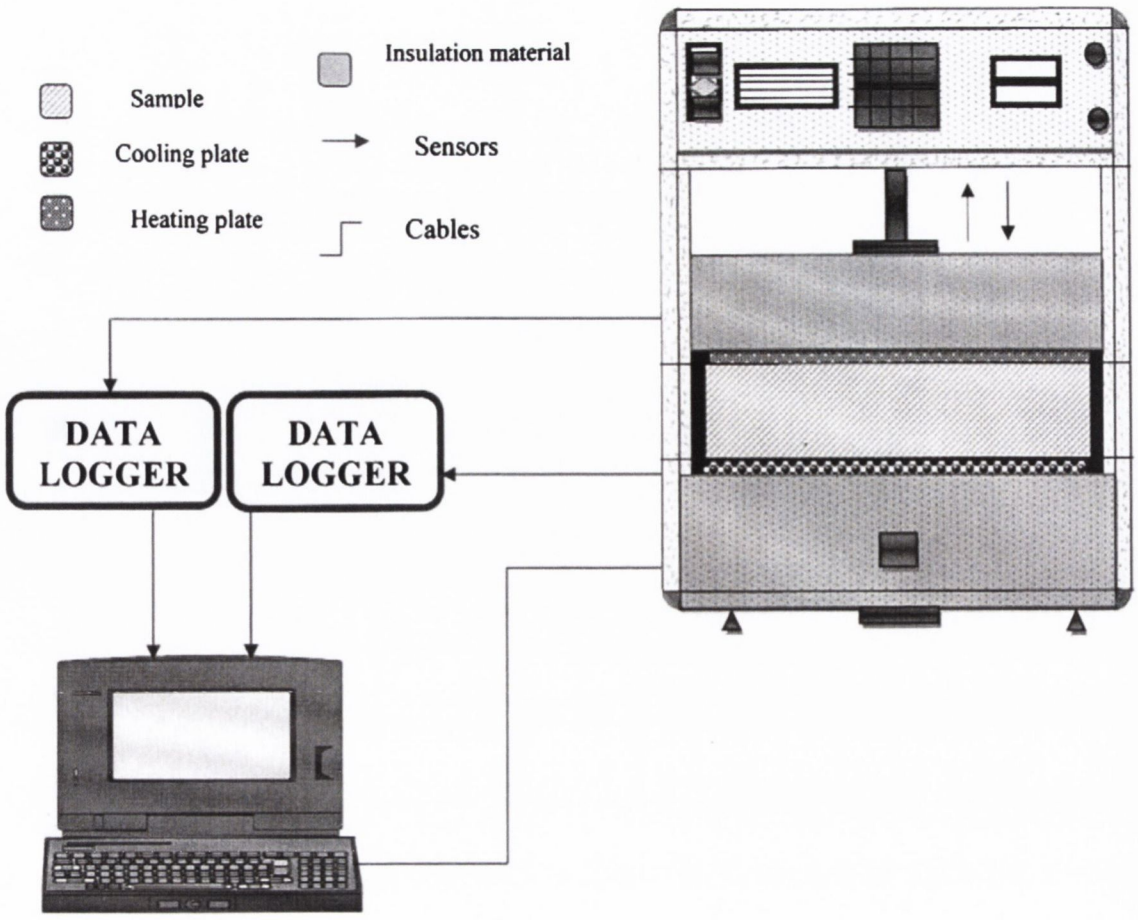
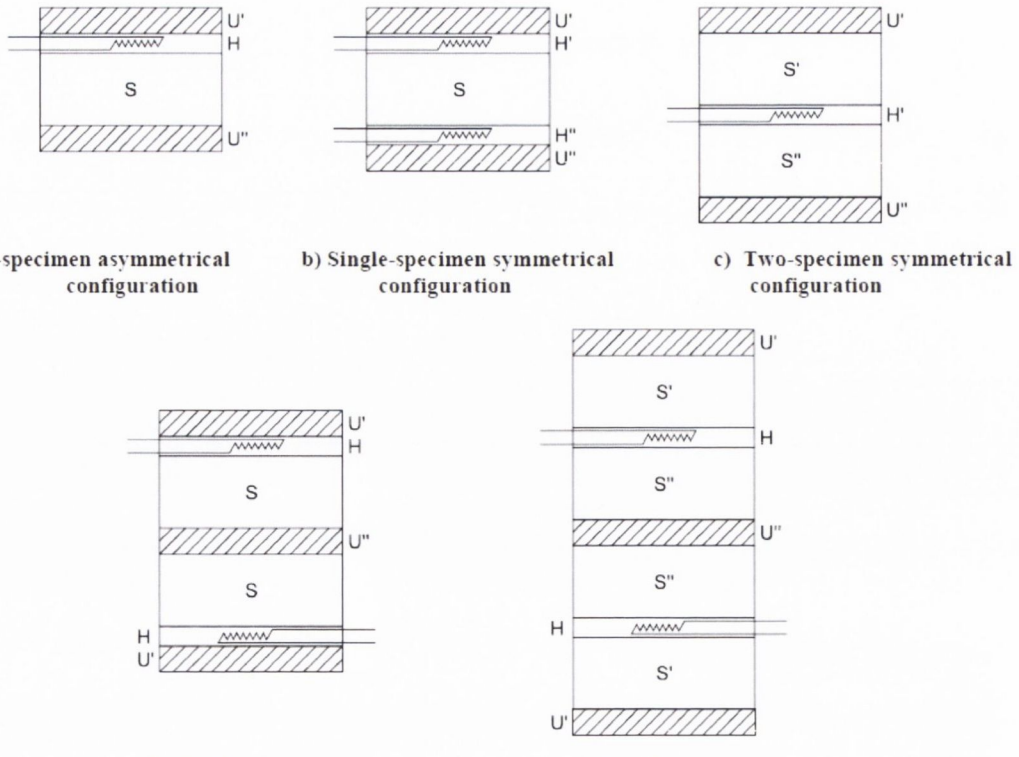


Figure 27 Testing thermal conductivity of insulation using the guarded hot plate apparatus (Ashour et al., 2010)

3.2.3 Heat Flow Meter

In this method, the density of heat flow rate is measured using one or two heat flow meters placed against the specimen as shown in Figure 28. This method is generally used to test insulation materials (Yesilata & Turgut, 2007). The apparatus consists of a heating unit, one or two heat flow meters, one or two specimens and a cooling unit as shown.



a) Single-specimen asymmetrical configuration

b) Single-specimen symmetrical configuration

c) Two-specimen symmetrical configuration

d) Double apparatus

e) Double apparatus

Key

U', U"	Cooling and heating units
H, H', H"	Heat flow meters
S, S', S"	Specimens

Figure 28 Heat flow meter apparatus configurations (British Standard, 2001)

In the heat flow meter and hot plate methods the specimens may be conditioned to the mean test temperature prior to being placed in the apparatus to speed up the process (British Standard, 2001).

3.2.4 Other Relevant Tests

3.2.4.1 The adiabatic box

The adiabatic box method was proposed by Yesilata and Turgut (2007) as a dynamic method of cheaply testing thermal transmittance of materials, including concrete. This was to be used as a pre-estimation method before using one of the other techniques outlined in sections 3.2.1, 3.2.2 and 3.2.3, if necessary. The design consists of an insulated chamber, and the test specimen forms the lid of the chamber. The specimen must be thinner and of much higher conductivity than the insulation. A heater is positioned close to the bottom of the chamber and is controlled by a thermostat. It heats a small amount of water within the chamber. According to the designers, the water helps to obtain a more homogeneous temperature in the enclosed space. This chamber is placed within a cold compartment under controlled temperature, humidity and

air flow. The specimen is fitted as the lid of the chamber once the water is heated to the desired temperature. The heater is then turned off and the transient behaviour of the sample recorded. The cooling rate of the water is a measure of the thermal transmittance of the sample and the measured time-temperature curve gives an estimation of the overall heat transfer coefficient.

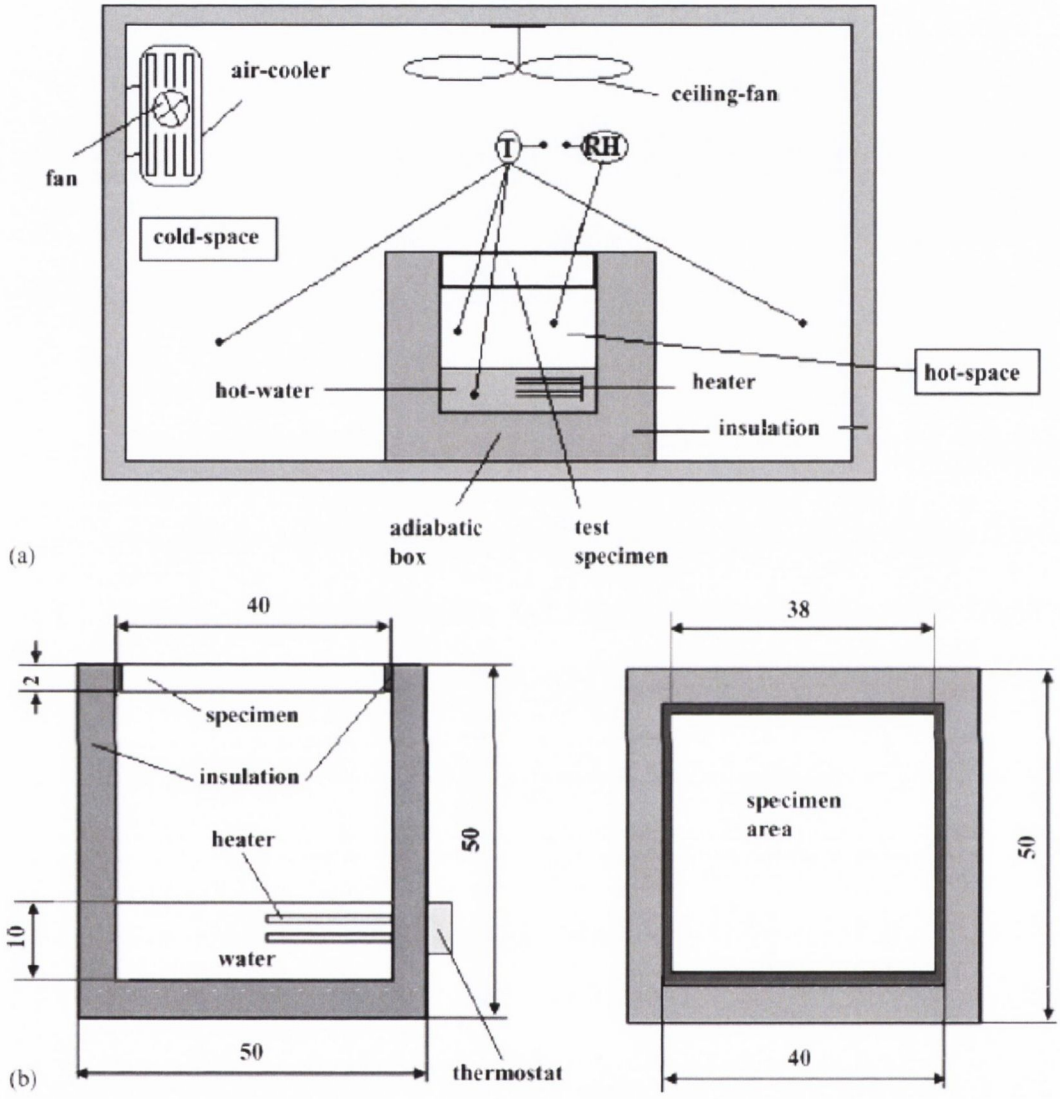


Figure 29 The adiabatic box (Yesilata & Turgut, 2007)

3.2.4.2 Envelope thermal test unit

The Energy Performance of Buildings Group at the University of California designed the Envelope Thermal Test Unit to examine sections of wall (Modera et al., 1984). The devise is controlled by a micro computer which heats the wall surfaces and records heat fluxes and surface temperatures on both sides of the wall. The setup consists of two insulation blankets of extruded polystyrene which are fitted with temperature sensors and electric resistance heaters to the front and back.

The blankets are pressed against each side of the test wall using a wooden support structure as shown in Figure 30.

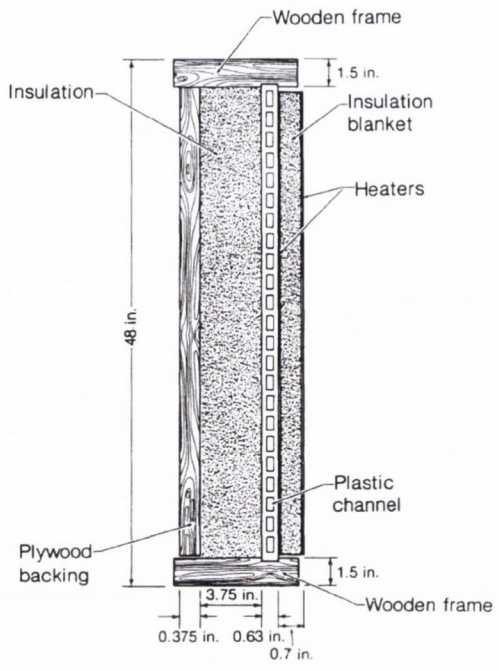


Figure 30 Cross Section of the Envelope Thermal Test Unit blanket within its support structure (Modera et al., 1984)

By controlling the power supplied to the electric resistance heaters, the heat flux on the surface can be managed. The methodology involves driving the heat through the wall at specified heat fluxes on one side and measuring the resulting heat flux on the other side as well as the temperature difference across the wall. The guard heater on the backside of the blanket is heated to minimise heat flow across the blanket. This ensures that heat from the surface heater or wall is not lost to surroundings. On the cold side of the wall, only the surface heater is powered providing high-frequency, low amplitude perturbations to the exiting heat flux. This test was performed by the group both on laboratory sample walls and those *in situ*. Time constants and U-values were compared with simulation results, which showed that laboratory testing was more reliable than *in situ* testing using the rig. This was attributed to the lateral conduction in the wall as well as the simulation assumption that heat entering is equal to heat exiting the wall, which is not necessarily true *in situ*.

3.2.4.3 Copper heat pipe apparatus

A test facility created by Irving et al. (1995) to measure the thermal conductivity of building materials, used copper heat pipes to control temperatures on the hot and cold side of the specimens. The experimental setup is as per Figure 31.

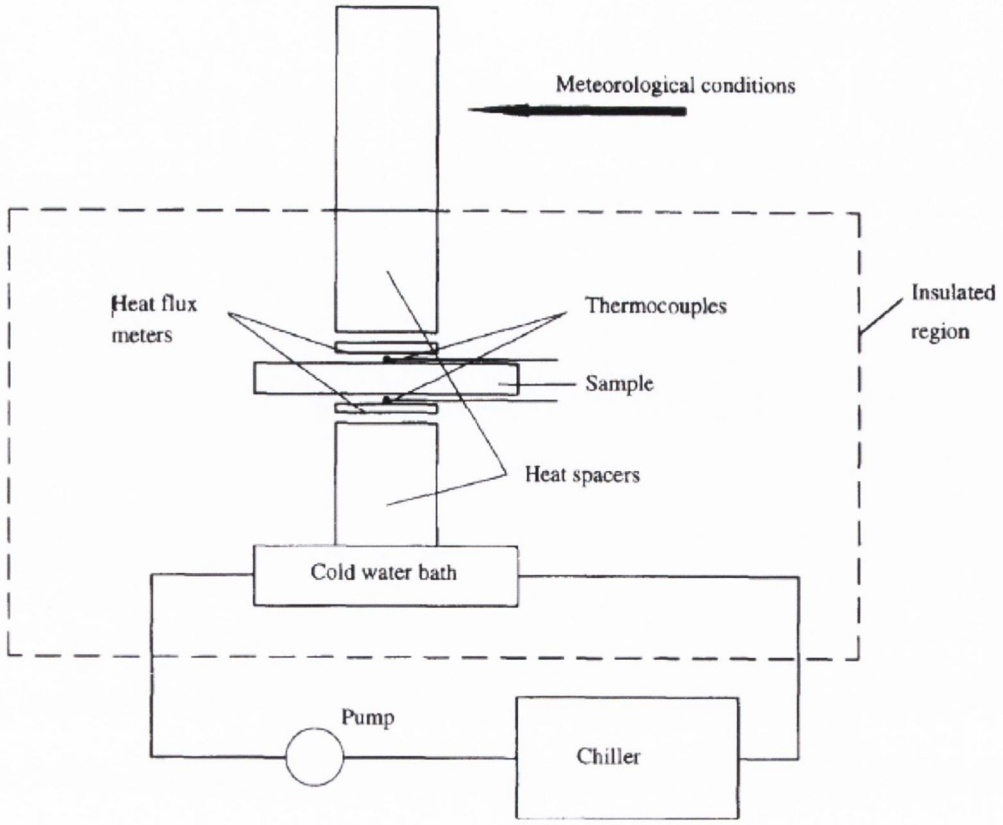


Figure 31 Copper heat pipe apparatus for testing thermal conductance of building material samples (Irving et al., 1995)

The experiment is designed for testing low to medium conductivity specimens. It consists of a copper heat pipe to atmospheric conditions and another to a controlled cold temperature bath. The bath is enclosed in a copper heat exchanger which has cold water pumping through. The water is cooled using a chiller and is fixed at 10°C. Temperature distribution is not measured across the sample as this could cause error due to increased contact resistance. Heat flux is measured using heat flow mats. Temperature and heat flux are measured above and below the sample and the specimen is surrounded by loose insulation which is contained within a box.

3.2.4.4 Heat flux meter rig

This rig was designed to separate the conduction and radiation parts of combined heat transfer in semi-transparent materials using the heat flux meter as shown in Figure 32. A plane heater acts as a heat flux meter and a Mach-Zahnder interferometer allows visualisation of the temperature field across the glass.

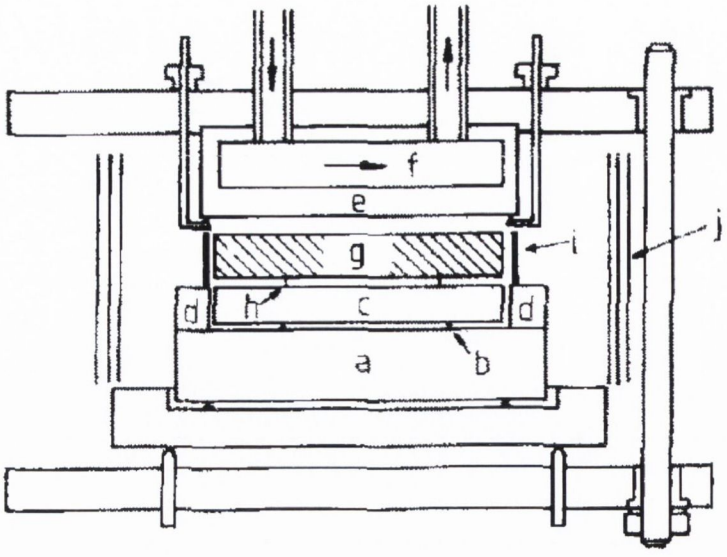


FIG. 5. The heat fluxmeter : (a) heat plate ; (b) alumina ; (c) heat fluxmeter ; (d) guard plate ; (e) cold plate ; (f) circulation thermostat ; (g) glass sample ; (h) thermocouples ; (i), (j) metallic shield.

Figure 32 Experimental setup of the heat flux meter for measuring coupled heat transfer through a glass sample (Kunc et al., 1984)

A pile of thick copper plates are engraved to receive a wire heater ("a" above). The upper plate is separated from the others using small pieces of cylindrical alumina ("b" above) and the central heater sits on this upper plate ("c" above). Lateral heat loss is limited using a guard plate ("d" above). When temperatures are balanced between c and a, and c and d, then the balancing electric power feeding the central heater measures the total heat flux emitted. The cold plate ("e" above) is kept a few millimetres above the sample, and its temperature maintained at room temperature using a water circulation thermostat ("f" above). The sample ("g" above) is the same area as the flux meter. Three thermocouples measure the temperature of the sample's hot face. No contact is necessary between the specimen of glass and the plates. Thermocouples are also fixed to the cold and hot plates in several locations. A controlled power supply automatically balances the temperatures between the different heat plates. The interferometer is also used to allow the visualisation of the temperature field inside the glass.

3.2.4.5 Lee's Disc apparatus

Lee's Disc apparatus is designed for measuring thermal conductivity of commercial polymers. The layout is displayed in Figure 33.

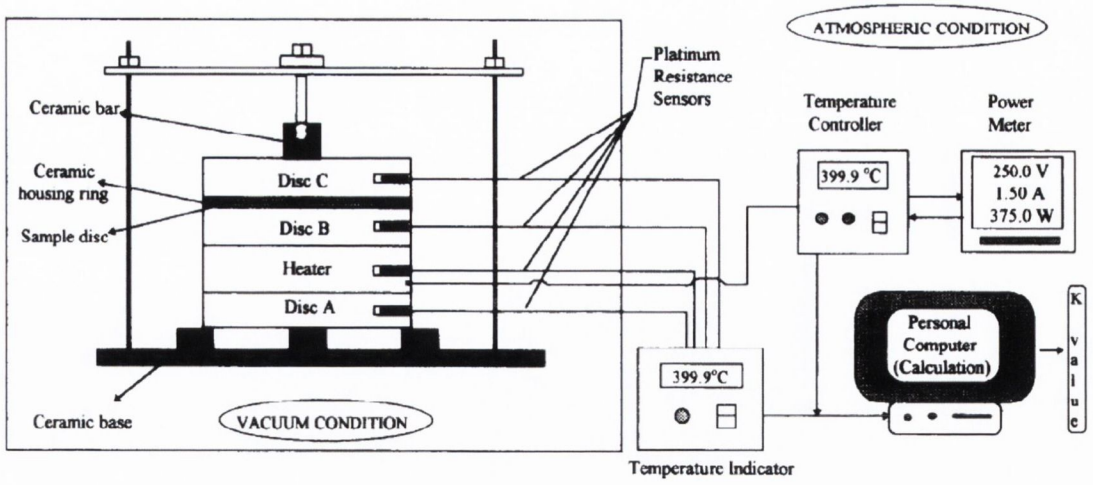


Figure 33 Experimental arrangement of Lee's Disc Apparatus (Sombatsompop & Wood, 1997)

Discs A, B and C are copper and a cast aluminium heater is placed between A and B. The power input to the heater is measured using a power meter via a temperature controller. A housing ring of ceramic of known thermal conductivity is used to retain the polymer melt in position. Temperature of the copper discs and the ambient temperature are measured. The apparatus can be placed in a vacuum oven to eliminate convective heat loss (Sombatsompop & Wood 1997). Ceramic bars are used to position the assembly before being removed for the test. The apparatus is placed on three ceramic pillars and clamped using a ceramic rod which is tightened using a bolt.

The procedure involves turning on the heater in the vacuum oven, and controlling the temperature. Once the required temperature is reached and the temperature of all components have stabilised, the current and voltage across the heater is determined using the power meter. Thermal conductivity can be determined using equation 6.

$$q = \mathrm{k.\,A.}\frac{T_{se} - T_{si}}{\mathrm{d}} \qquad (6)$$

The test temperature is then changed and the experiment repeated.

3.2.5 Informing design

The following ideas gleaned from the previously discussed experimental apparatus' have informed the design of the rig for this project:

- To make the rig for use in the laboratory only so that the test specimen can be enclosed within the rig and surrounded by insulation. This mitigates the majority of lateral heat flow.
- To engrave the heating or cooling plates to receive a heating or cooling element
- To use cold water flowing over a plate as a heat sink. For the new design, this extended to the hot plate also.
- To use a guard heater to limit heat flow away from the test specimen, thereby reducing thermal losses. For the new rig this idea also extended to a guard cooler.
- To size the specimen space to fit a multiple of any modular element. The size of the wall sample for the new rig was built to 900x900mm as this allowed for two modules of concrete blocks with mortar.
- To use a second method to validate findings.

3.2.6 Aims of rig design and testing

There were a number of aims in designing a new test rig. The first was to present a viable alternative to the hot-box method. The second was to measure the thermal resistance of individual wall types and compare this to tabulated or calculated resistances as per industry method, thus developing findings from chapter 2. The third aim was to examine wall behaviour under controlled transient and steady-state conditions, building on site tests presented in chapters 2 and 4. Finally, it was to facilitate future testing with the rig on building samples with and without insulation. This final aim could potentially be highly influential on standards used in the HES/BEH scheme as different insulation thicknesses and types could be tested on typical Irish wall types. This would allow the most cost effective solution for achieving the required change in thermal properties under the scheme to be determined. In achieving these aims, this chapter primarily contributes to the first overall objective of the doctoral research which is to add to the understanding of how Irish residential buildings perform in terms of energy efficiency due to retrofitted insulation under the HES/BEH scheme.

3.2.7 Pilot rig

The pilot rig comprises a heat source (a heated plate) on one side and a heat sink (a cooled plate) on the other. It behaves similarly to the hot plate apparatus (section 3.2.2) but heating and cooling methods differ. The basic structure consists of a copper plate with a heater mat adhered to the back of it which acts as a heat source for the sample. Copper is used to spread the heat from the mat evenly across the sample surface due to its high thermal conductivity. A guard heater was set up behind the hot plate to limit the heat travelling away from the plate

through the surrounding insulation. The heat sink consists of a coil of copper pipe soldered onto a second copper plate. The plate is kept cool by feeding cool water through the pipe as shown in Figure 34. This setup is then surrounded by very low thermal conductivity insulation (k = 0.02 $W.m^{-1}.K^{-1}$).

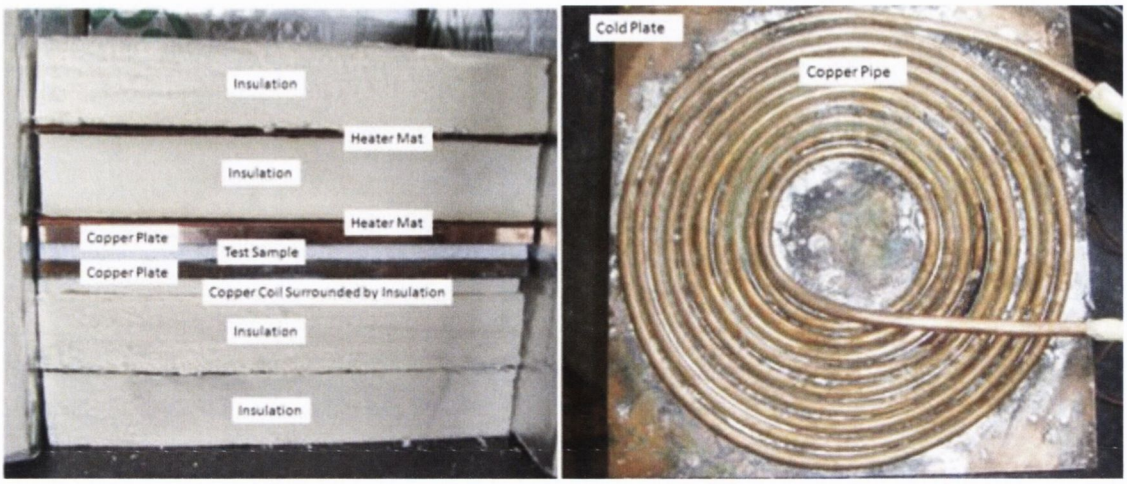


Figure 34 Pilot test rig with detail showing copper pipe to cool plate

The purpose of the test rig was to try out methods of conductive heat transfer, comparing the use of heater mats and water as methods of controlling temperature either side of a test specimen. It was also to ensure that the theory of the rig design could work in practice before resources were focused on building the main rig.

3.3 Rig design and tests

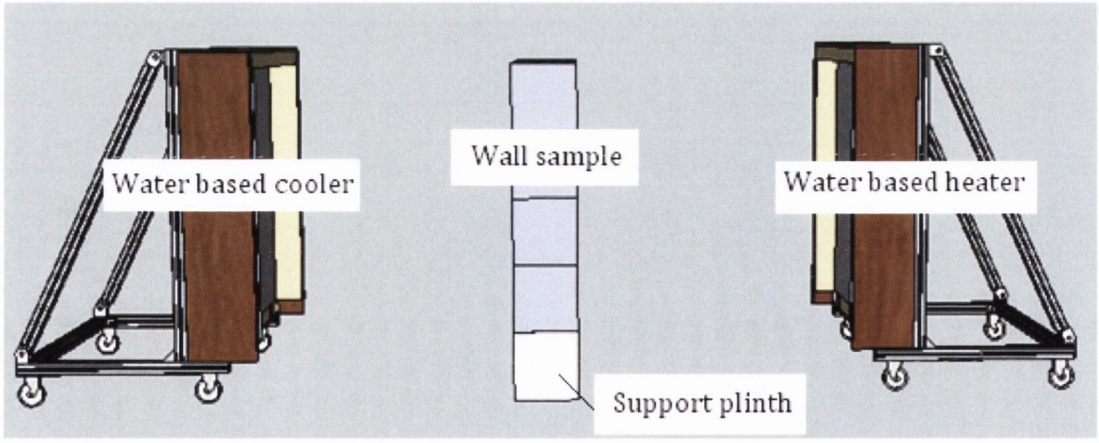


Figure 35 Overall rig layout with test wall

3.3.1 Components of the rig

The main rig works on the same principles as the pilot rig except that it tests samples standing vertically to reflect *in situ* conditions and is considerably larger to facilitate the 900x900mm wall sample. For this rig both a guard heater and guard cooler were designed. The overall design of the heater and cooler systems are the same. These are placed either side of the wall sample and

fastened to the wall. The sections of the design are presented in Figure 36. The basic components begin with a main plate to heat or cool the surface of the wall sample, directly behind the plate is a layer of rigid thermal insulation panelling. The insulation chosen for the rig design needed to be of a lower thermal conductivity than that of the wall sample in order to reduce heat flow through the rig to the ambient laboratory. Kooltherm K5, 70mm thickness, was chosen which has a thermal conductivity of under 0.02 $W.m^{-1}.K^{-1}$ (Kingspan Insulation Ltd. 2011). This ensured that the path of least resistance would be through the wall sample even after typical external insulation were to be added to the specimen. The typical insulation used in industry and in most of the external insulation site cases for this study was EPS 100, which has a thermal conductivity of $0.035W.m^{-1}.K^{-1}$ (Quinn Lite Pac).

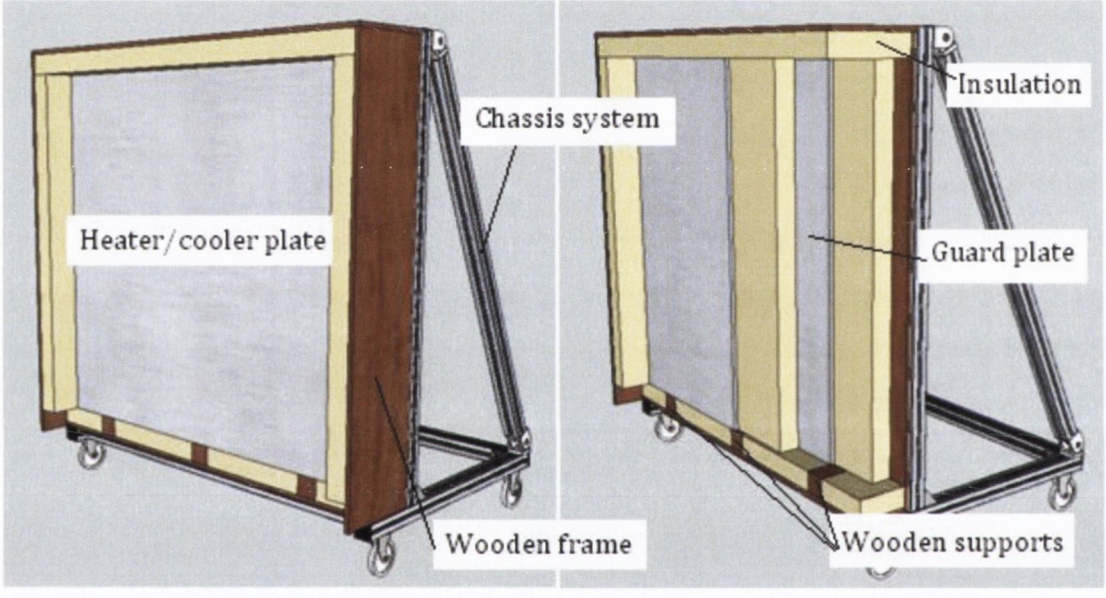


Figure 36 Key components of test rig

Behind the insulation layer is the guard plate. A further layer of insulation is behind the guard plate and to the sides, top and bottom of the rig. The plates had to sit on three wooden blocks as shown in the diagram to prevent the insulation from being crushed by the weight of the plates. The whole system sits within a 19 mm plywood frame. The frame and insulation extend 50 mm out from the plate face to fit around the wall sample. The frame in turn is attached to an aluminium support structure on wheels.

Heater and cooler plates and guard plates

It was decided to use a water based system for heating and cooling as this would allow both sides of the sample to be set to a wide range of temperatures. It was decided to embed the water channel within the metal plate to limit heat losses and ensure even contact with the plate. The channels were therefore machined into the plate itself. Due to the size of the rig, the

heating and cooling plates had to be assembled from smaller sections to facilitate machining. These sections were then fastened together using male and female slots and sealed with silicon sealant. Aluminium was chosen over copper for economic and fabrication reasons. The plates are displayed in Figure 37.

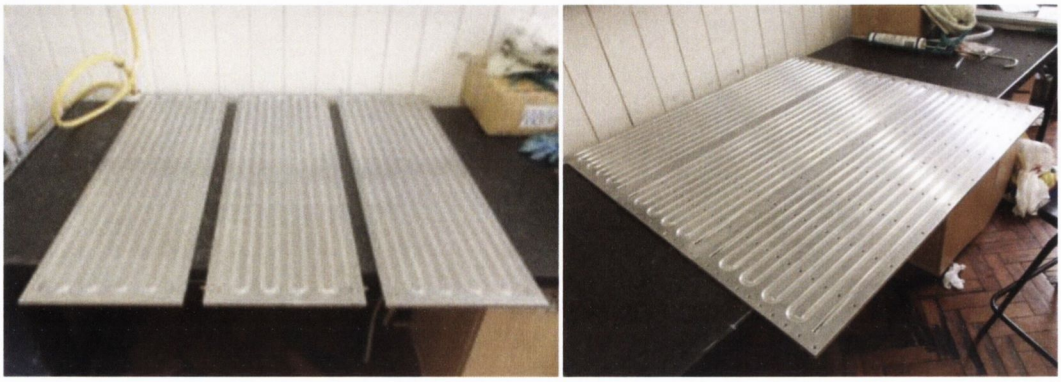


Figure 37 Assembly of channelled plates for the test rig

A PVC back plate was bolted to the aluminium plate using machined groves in the PVC plates and machined threaded holes in the aluminium plates. Furthermore, the connection was sealed using silicon sealant. This is shown in Figure 38. This figure also displays the fittings inserted and glued into the plate. These were to facilitate plastic piping to allow the transfer of fluid from one channelled section to the next.

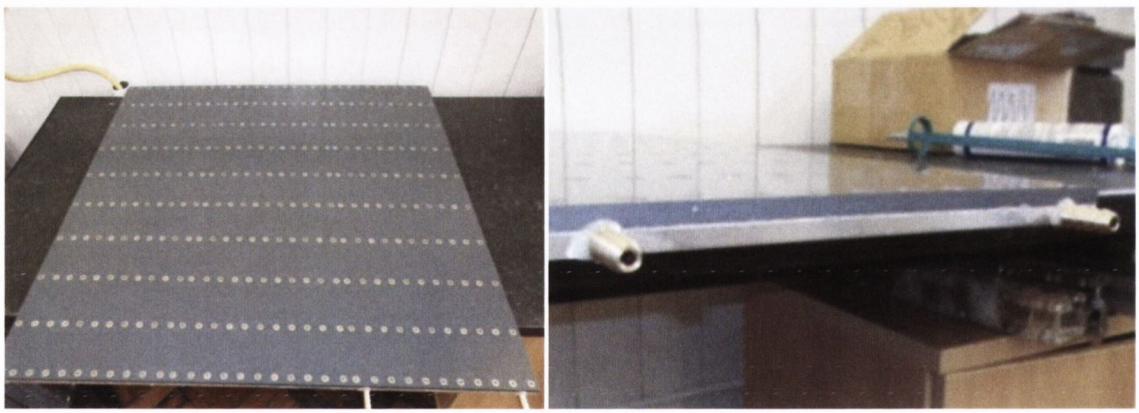


Figure 38 PVC plate bolted to channelled aluminium, showing detail of fittings

Supporting structure

Further construction stages of the rig are shown in Figure 39 to Figure 41. A layer of insulation was fitted within the frame and around the guard plate as per Figure 39. Piping was fed through drilled holes in the frame and insulation and attached to the guard plate in the second of these images. The tubing is attached to the six fittings of the plate using clips. The flow was designed to enter the plate through the top tube and fitting, next the upper section flow is connected to

the next section by a curved tube and fittings, similarly the middle section is connected to the lower section and finally the flow exits from the bottom plate.

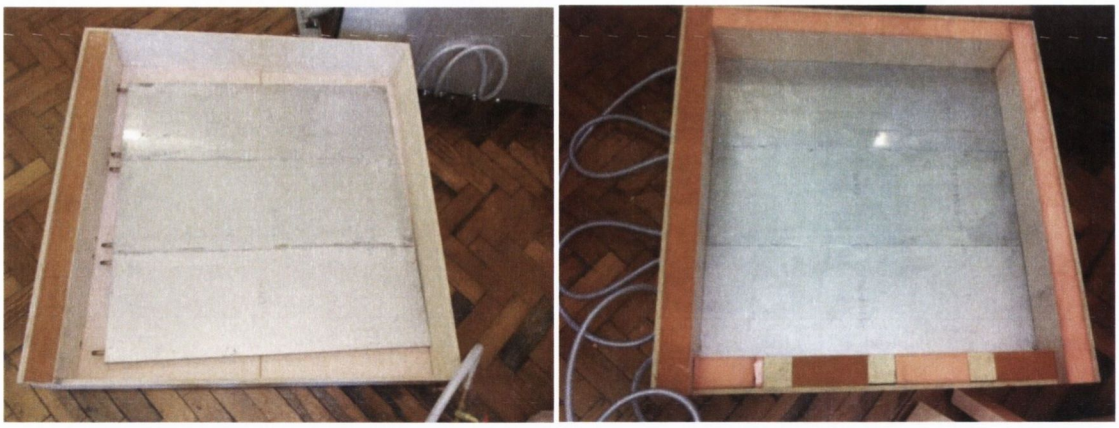


Figure 39 Fitting of guard plate and piping into the rig frame

Another layer of insulation was fitted in front of the guard plate before the final main plate was fitted and piping attached as per the guard plate. A plinth for the wall sample was formed using a wooden frame and filled with insulation as per the second image in Figure 40. This was drilled in place and the wall sample was built on top of this as per Figure 41.

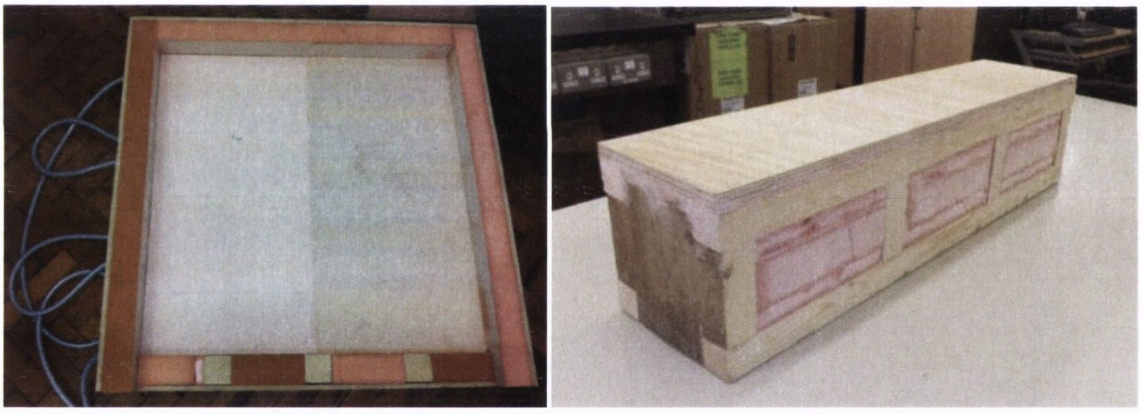


Figure 40 Further construction of the rig showing insulation layer between active plate and guard plate, and insulated plinth constructed for under the wall sample

Typical construction details were used for the wall sample. The basic wall construction is shown in Figure 41. This includes a damp proof membrane between the plinth and the wall. The wall as shown was further finished off with typical details of rendering[13] to either side and capping slates[14] to top off the wall.

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13 A mixture, typically of sand and cement, applied to the surface of a wall
14 Thin slate stone fitted to the top of a cavity block wall to seal it off



Figure 41 Construction of the wall sample for testing before render and capping slates are applied

3.3.2 Design principles

An energy balance following the first law of thermodynamics under steady-state conditions was used to determine the thermal resistance of the wall sample using simple equations as presented in Figure 42.

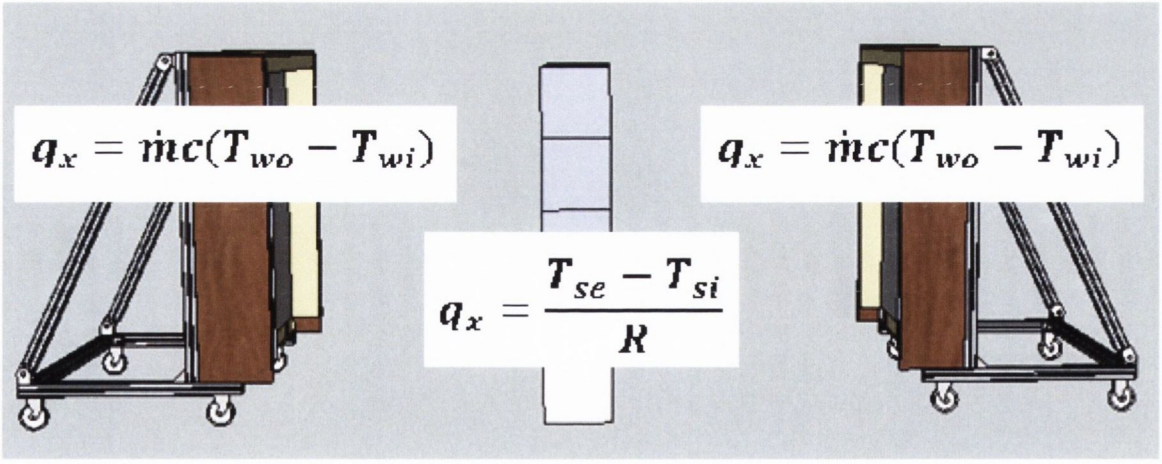


Figure 42 Graphical representation of energy balance in the test rig

The rig was designed based on the first law of thermodynamics. The first law states that the addition of a quantity of heat $\Delta \dot{Q}$ to a control volume in time Δ t will increase its energy by ΔE and also perform work Δ W (Long, 1999):

$$\frac{dQ}{dt} = \frac{dE}{dt} + \frac{dW}{dt} \tag{7}$$

This law observes the principle of conservation of energy, energy can neither be created nor destroyed but can be converted from one form to another. Under steady-state conditions heat flows at a constant rate through any cross section parallel to the surfaces of the plate.

Theoretically, therefore, in the absence of any heat loss, the heat provided by the hot side of the rig should equal the heat flow through the wall sample and the heat removed at the other side of the sample on the cold side. In Figure 42, all q_x should, in principle, be equal. A steady-state of heat flow occurs when q_x, calculated from equation 8, is equal for both the hot and cold plate systems. A value for thermal resistance, R, is then calculated using this value for $q_x$and recorded surface temperature values either side of the wall sample. T_{se} is the average surface temperature on the cold side of the wall and T_{si} is the average on the hot side.

$$q_x = \dot{m}c(T_{wo} - T_{wi}) \tag{8}$$

$$q_x = \frac{T_{se} - T_{si}}{R} \tag{9}$$

3.3.3 Measurements

In order to ascertain the required values for the equations 8 and 9 in the previous section 3.3.2 the sensors presented in Table 4 were necessary. Details of the specific instrumentation used for the rig are included in Appendix A.

Table 4 List of measurements required for tests on the new rig

Value needed	*Description*	*Sensor*
	Wall surface temperature hot side	9 type-T thermocouples
	Wall surface temperature cold side	9 type-T thermocouples
	In-flow on the hot and cold side plates	2 type-K thermocouple probes
	Out-flow on the hot and cold side plates	2 type-K thermocouple probes
	Flow of water through hot and cold side plates	4 low-flow flow meters (0.07-0.55L/min)

The nine thermocouples determined the average surface temperature of the wall sample on either side. These were placed at locations which represented all of the different possible heat flow route types through the cavity block wall. This included through the web, the cavity and the mortar joints at various levels and intersections as per Figure 43.

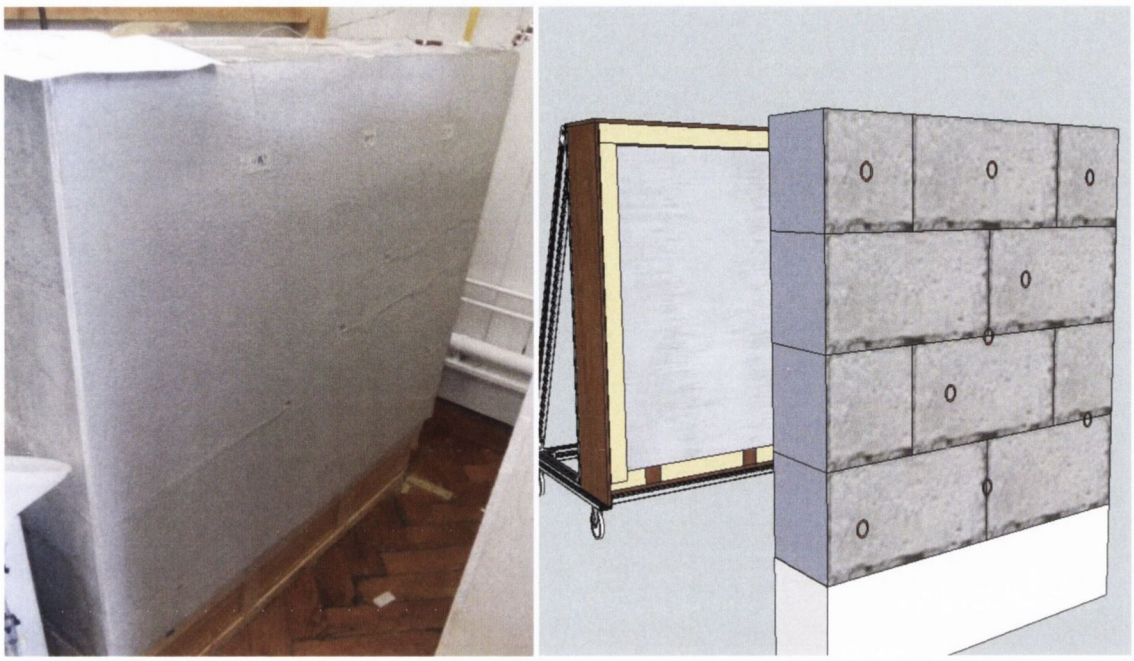


Figure 43 Locations of thermocouples on wall surface

The flow of water through the heater and cooler plate was measured as per Figure 44. A Fischerbrand IsoUK 250LC closed system circulator unit was used to control the temperature and flow of water either side. Flow from the unit was split in two, one to the main plate and the other to the guard plate. Similarly, the out flow from the respective plates was rejoined before returning to the circulation unit. This ensured that the water temperature provided to each plate was the same, while allowing for the temperatures and flow rates of the main plate to be accurately, and separately, measured. The temperature probes were attached at the inlet and outlet ports of the heater and cooler plates. The flow was measured using the two low flow meters (0.07-0.55 L/min) shown and controlled using valves.



Figure 44 Internal channels of plates showing the location of temperature measurement on in and out flow, and flow meters to measure flow to the heater/cooler plate and guard plate

Additional measurements were also taken. The intention of these measurements was to determine losses and eliminate errors. These are listed in Table 5 including an explanation for the measurements.

Table 5 List of additional measurements recorded to increase the accuracy of the rig measurements

Description	*Sensor*
Flow to the 2 guard plates. Measured to ensure that the guard plates are maintaining a flow from the circulation unit	2 flow meters (0.2-2L/min)
Heat loss through the surrounding Kooltherm insulation of the rig. Two temperature sensors are placed on the top of the wall and another is placed in the centre of the insulation above the main plates on both sides of the rig.	4 type-T thermocouples
Ambient temperature. This is measured on both sides of the rig.	2 type-T thermocouples
Surface temperature on the main plates at two locations to ensure uniformity of heat supply or removal.	4 type-T thermocouples

All thermocouples were attached to a Data Acquisition System (DAQ) and recorded to excel files using labVIEW. The flow readings were taken manually and recorded. Further to the losses determined using the thermocouples listed in Table 5, spot assessments of heat loss through the rig walls were made using a Resistance Temperature Detector (RTD) probe, which was accurate to within +/-0.1˚C.

3.3.4 Test methodology

The wall sample was built and adequate time allowed for the materials to dry out. Two weeks was determined as sufficient from discussions with contractors. The measurement sensors were attached as per section 3.3.3. An estimation of likely heat flow for a set steady-state

temperature gradient across the wall was determined using an estimation of the thermal resistance of the sample wall. This was completed using standard calculation procedures and material properties for the cavity block wall (CIBSE, 2007, Department of the Environment Heritage and Local Government, 2007, NSAI, 2007) along with some actual building properties listed in supplier manuals (Roadstone).

It was decided that thermal padding of 5mm which is highly compressible, soft and flexible was required to ensure adequate contact between the plates and the rough wall surface. Once these pads were applied to the face of the heater and cooler plates, the two sides of the rig were pushed together, enclosing the wall sample. The remaining gaps were filled with more Kooltherm K5 insulation board to ensure a sealed system. The two sides of the rig were then clamped and tightened into place using threaded bars. Images of the test facility in-use are available in section A.1 of Appendix A.

3.3.4.1 Steady-state test: determining R-value

Temperatures were set to record every 60s. Flow readings were taken manually. The circulation units were set at specified temperatures to ensure an adequate temperature gradient across the wall sample (20°C), and a water flow was estimated using the previously explained estimated heat flow. Adjustments to the flow were made along with changes to the water supply temperatures and left to stabilise (with small adjustments 2 hrs was found to be sufficient). This was repeated until the energy supply on both sides of the wall was equal.

The wall surface temperatures were averaged for either side of the wall, removing the maximum and minimum readings. A value for energy loss was removed from this number as per section 3.4.3 and using the readings across the rig insulation from Table 5. Equating values and rearranging equations (8) and (9), an R-value for the wall is determined as follows:

$$q_{hot\,side} = q_{cold\,side} = q_{through\,wall}$$

$$= \frac{T_{se} - T_{si}}{R}$$

$$R = \frac{T_{se} - T_{si}}{q_x}$$

The test was repeated for another two temperature settings to ensure consistency of the R-value.

3.3.4.2 Transient test

The plumbing for the system was reorganised so that the cold circulator unit fed both the heater and cooler plates. Thus cooling both plates and the enclosed wall sample. The hot circulation unit was rearranged so that the hot water from it did not circulate through any plate, but simply flowed through an extension of piping and returned back to the unit. Valves were installed into the plumbing system to control the flow on each pipe flowing and returning from the plates. They were positioned so that they could be used to switch the water source from the cold circulator unit to the hot circulator unit instantaneously. From starting with the whole system in cold equilibrium, the switch instantly introduced a step in temperature on one side of the wall. This was conducted for a step change from 5˚C to 25˚C, while maintaining the cold side input at 5˚C during the test. In this way the conditions for examining the thermal time constant for the wall were created as explained in section 2.2. The method was then repeated after EPS 100 (typical external insulation used on site and tested *in situ* in the next chapter) with plaster finish was fitted to the wall. The steps in the test were as follows:

1. Temperature readings were set to record every 30s.
2. The valve system was set up so that the cold circulation unit supplied both sides of the rig. This circulation unit was set to the desired temperature.
3. The hot circulation unit was set to the desired hot temperature and the valves set up so that the water was not circulating through any of the plates.
4. Adequate time was left in order for the plates and enclosed wall to reach equilibrium, this usually meant overnight.
5. Simultaneously the required valves were turned, redirecting the flow so that the cold circulation unit only served the cold side of the wall. The hot circulation unit was now serving the hot side of the wall.
6. Once the recorded data showed that the plate-wall-plate system was in equilibrium, the data was analysed.

3.4 Results

3.4.1 Steady-state: determining thermal resistance

The repeated steady-state tests found the thermal resistance of the wall sample to be 0.3 $m^2K.W^{-1}$ after losses through the rig walls have been accounted for. The calculated value by the author for this wall type was between 0.272 $m^2K.W^{-1}$ and 0.285 $m^2K.W^{-1}$ for lower and upper limits. Simulations using Irish cavity block only has shown R-value to be 0.238 $m^2K.W^{-1}$ (Little & Arregi 2009). If the render is added on to this value as per the sample wall, and excluding the mortar joints this value for the whole wall increases to 0.286 $m^2K.W^{-1}$. Therefore, it has been shown that the thermal resistance measured in this test is more than what has been shown in calculation by the author or in simulations by other researchers.

3.4.2 Transient curve: thermal time constant comparison

The resulting curves from step changes in temperature on one side of the wall are presented in Figure 45 and Figure 46. These graphs show the changes in surface temperature at various locations on each side of the wall. The figures remained steady beyond the recordings shown.

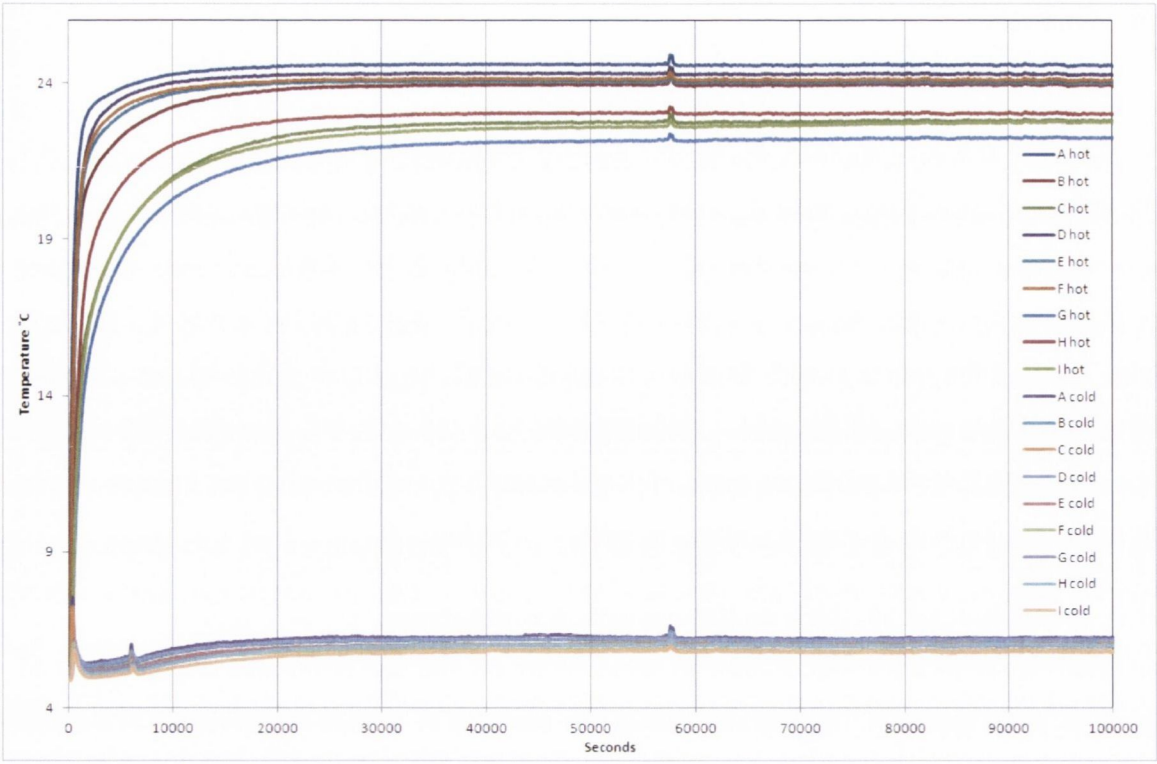


Figure 45 Step change in circulation unit settings to 25˚C on one side, both sides starting at 5˚C, for the cavity block wall

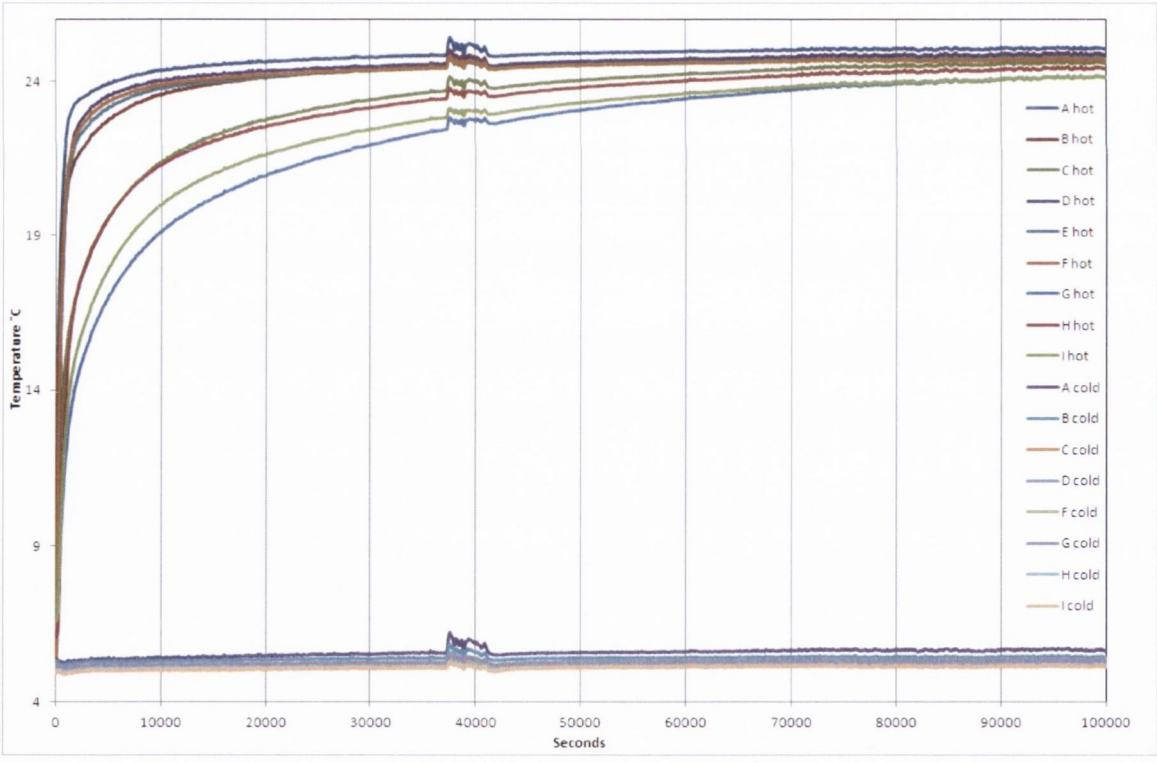


Figure 46 Step change in circulation unit settings to 25˚C, both sides starting at 5˚C, for the cavity block wall retrofitted with typical external insulation

Both curves compare well with what can be expected from simulated findings from Tsilingiris (2004) and with the controlled *in situ* testing in chapter 2 . The time it took for the system to

balance and heat flow to become steady is demonstrated by the amount of seconds recorded before the wall surface temperatures became constant. For the cavity block wall this occurred within 5hrs 30min and 8hrs 20 min. This increased significantly once insulation was installed to between 19hrs 25min and 22hrs 15min. Furthermore, the temperature of the wall's surface on both sides became more uniform under steady state. This demonstrated that the retrofitted insulation caused a reduction in thermal bridges as demonstrated using thermal imaging in chapter 2. An observation was made that the temperature difference across the wall increased from 17.5˚C to 19.3˚C due to the insulation. The irregularities shown near 60000s in Figure 45 and at 40000s in Figure 46 are assumed to be due to the an error in the equipment or program at a point between the DAQ system and the readout as readouts from both DAQs and all thermocouples show similar irregularities at the same time. The error could have occurred in the Labview program whereby instantaneous temperatures were read briefly as opposed to the average. Another likely possibility is voltage interference as the laboratory, and indeed the building, in which the rig was built is highly trafficked and full of electrical and magnetic equipment.

3.4.3 Limitations, losses and error

3.4.3.1 Losses

Heat lost through the rig walls was calculated using equation (9) and the manufacturer provided value for thermal resistance of Kooltherm insulation. The area over which heat could be lost through the rig was measured. The temperature values in the equation were taken from those in Table 5 and spot readings using an RTD probe. It was assumed that due to the presence of a guard heater and cooler that there were insignificant losses through the two back faces of the rig. Total heat losses through the rig structure to the ambient laboratory were estimated to be approximately 1.1 W during testing, which is under 2% of the energy input. This value was removed from the total energy supply calculations.

3.4.3.2 Calibration

All thermocouple – DAQ systems were calibrated from temperatures of 0˚C to 50˚C using a RTD probe. The probe is accurate to within 0.1˚C.

3.4.3.3 Accuracy - Quantifiable errors

Temperature readings were all calibrated to 0.1˚C. The accuracy of the flow measurement units were +/- 2% of the full scale deflection on the flow meter. Therefore, this value was +/- 0.011L/min or an error of up to +/- 2.6%.

The total uncertainty in measured thermal resistance of the wall sample is the propagation of uncertainties of the constituent parts in the following equation 10:

$$= \frac{T_{se} - T_{si}}{\dot{m}c(T_{wo} - T_{wi})} \tag{10}$$

For a difference of 2˚C across the water measurements, maximum error encountered in flow rates results in an uncertainty of +/- 0.006 or 2% of the measured R-value.

3.4.3.4 Precision - Unquantified Errors

Thermal contact resistance

Thermal contact resistance could have been an issue at the interface between the heater or cooler plates and the wall sample surface. Thermal contact resistance is due mainly to surface roughness effects leading to the temperature drop across the interface between materials to be substantial (Ghoshdastidar, 2004). At the interface heat is transferred through solid-to-solid conduction at the points of contact, and through conduction and/or radiation through entrapped air in the voids. Because the conductivity of gas is small compared to a solid, this is believed to be the main contributor to the resistance. Contact resistance should decrease where joint pressure is increased as it leads to a greater contact area between solids.

This error was limited as much as possible by using thermal heat pads on the interface between the heater or cooler plates and the wall sample surface. The entire sample was clamped and tightened together so that the compressible material of the pad took the shape of the surfaces it came in contact with. It was hoped that in doing so, the air voids were limited.

Instrument drift

Electronic measuring devices can have readings that drift over time. However, calibration of the equipment was conducted directly before testing began.

Parallax

This error may be present in the manual readings of the flow meter as this was done by taking visual readings.

Workmanship causing variability

The wall sample built is not a perfectly symmetrical sample. There are irregularities in the blocks, in the mortar joints and in the surface render. These inconsistencies in the structure can cause small changes in the thermal resistance at different points. This was limited by taking temperature readings at a variety of points on the surface of the wall, removing the maximum and minimum readings and then averaging them.

However, *in situ* walls also experience such variability in workmanship and materials. Therefore, the wall sample, though not reflective of an ideal structure, is reflective of *in situ* structures.

Unknown behaviour of cavity block walls

Hollow block is commonly used in walls in Ireland, however, thermal behaviour is not as straightforward as other possible homogenously layered walls as the heat flow is much more multidimensional. Therefore, there are limited examples of R-value testing for such walls. The scarcity of such data means that there is limited understanding of the reliability of this rig design and methodology presented here. However, future testing using the rig will help to quantify its reliability.

3.5 Discussion

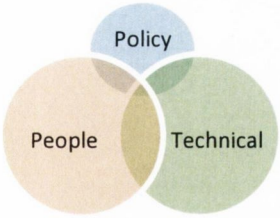
This chapter presented the new design of a test rig for wall samples. This rig offers a more straightforward and compact version of the traditional hot-box apparatus. Furthermore, it allows for the elimination of convection and radiation heat transfer to and from the wall surface, which the author argues allows for a more accurate measurement of the thermal resistance of the wall itself. In *in situ* conditions, heat transfer methods of radiation and convection are unpredictable and vary depending on climatic conditions, exposure levels, surface emissivities among many other site influences. However, the wall structure would be constant under these changing conditions. It is therefore argued that the wall structure should be isolated for such laboratory examinations as this rig allows.

Secondly, this chapter adds to the conclusion in section 2.5. This was that predicted or tabulated thermal resistance values can vary greatly form actual resistances of the structure. Therefore, it

is heat flow behaviour of the wall and changes in that behaviour that should be analysed when determining changes that wall insulation can make.

Thirdly, this chapter presents the first steps in future work which began with a comparison of the thermal time constant before and after typical external insulation was fitted. It was shown to agree with findings from simulations and the previous chapter in this thesis. The insulation resulted in a longer time to reach steady state heat transfer, more uniform surface temperatures and an increase in the temperature difference across the wall for the same boundary conditions. Beyond this, many other typical Irish wall types and insulation types and positions should be tested under comparable conditions. The thicknesses of insulation and insulation types could be compared so that the most economic solutions can be prescribed. This could inform the regulations for retrofitting under the HES/BEH scheme as it could potentially result in cheaper retrofits for clients making the scheme more appealing and reaching a wider demographic.

This chapter concludes the examination of the isolated technical aspect of retrofitting cavity and external insulation to Irish residential walls. This and the previous chapter's data provided the necessary understanding of building physics before and after insulation is introduced, without the difficulty in analysis added by incorporating occupant behaviour. A similar technique to chapter 2 is used in the site cases that follow in chapter 4. However, control of the heating system is left to the discretion of the occupants. By allowing the houses to be used freely the data helps to assess the real saving potential of the retrofit grant scheme and its contribution to national energy saving targets.



Chapter 4. In-use site cases

"Maybe we have enough technology to save the planet but it is not enough because the people are not ready."

Thich Nhat Hanh

4.1 Introduction

This portion of the study builds on the methodology and findings of chapter 2 by introducing the variable of the occupant. As described in section 1.5.4, energy use in similar homes can produce vast diversities in consumption, furthermore, the potential change in energy use after retrofit is heavily dependent on a number of human factors. This element of the study is not aimed at gaining a complete understanding of human behaviour in the home. Instead the aim is to incorporate the variable of human behaviour into the examination. This is in order to gain a preliminary understanding of how occupants influence the dynamics of energy consumption, in particular subsequent to a retrofit scenario. This is achieved by triangulating it with monitored data and survey observations to gain a richer understanding of how the building-in-use system performs prior compared to post retrofit. In this way, site cases are the primary contribution to the first aim of the research project as presented in section 1.6.

This chapter also introduces the first qualitative aspect of the research. Occupants are interviewed as stakeholders in the HES/BEH scheme in order to ascertain the drivers and experiences from their perspectives. In doing so, the interviews contribute to the second aim of the overall project as a client's insight. It is hoped that by combining methods in this manner a more comprehensive understanding of the delivery side of the retrofit scheme can be achieved, contributing to the third aim.

Section 4.2 presents the basis for the design of the methodology using examples of standard practice in industry and academic research. The methodology includes the use of surveys, monitoring and qualitative interviews. Each of these are presented and discussed separately. Section 4.3 then introduces the nine site case studies of dwellings in-use. The first case acts as an intermediary study between the controlled case discussed in the previous chapters, and the full introduction of occupant behaviour. This is the semi-controlled case, in which heating habits are allowed to involve intermittent heat supply, however this is kept consistent between before and after monitoring periods. The remaining site cases then allow the occupants to use the buildings and heating systems freely. Combined results of the site cases are presented in section 4.4 incorporating the occupant behavioural aspects. The findings from the interviews are presented

separately here. A discussion and summary of the studies is presented in the final section of this chapter.

4.2 Basis for the methodology

4.2.1 Introduction

Energy performance of a house is typically evaluated using numbers derived from calculation, experiments, monitoring or surveys and occasionally from occupant interviews. The numbers may give the 'how much?', but they do not answer the 'why?'. This is a mixed methods examination of the case study that is the HES/BEH scheme. The work package of site studies examines the scheme on the ground, splitting into three phases: the survey, monitoring of the building, and an interview with the occupant.

4.2.2 Survey

4.2.2.1 Basis for the survey methodology

Surveys are suited to uncomplicated "factual" data gathering (Hoggart et al., 2002). The Survey/Audit form created for this research project involves a combination of current existing residential energy assessment procedures RdSAP (BRE, 2005), BER (SEAI, 2011) and CIBSE guide on energy assessments (CIBSE, 2006) along with other online home energy assessment forms (Warm Zone, NIE Energy, 2007, Energy Saving Trust and Energy Efficiency Advice Centre, 2009). CIBSE Guide F, section 18.3.1 (CIBSE, 2004), establishes what should be covered in an energy survey as:

- Building (insulation, ventilation etc.)
- Pattern of use (occupancy, temperature, humidity, activities etc)
- Energy supply
- Main building services
- Electric lighting
- Transport of energy within the building (insulation of hot water etc.)
- Plant (condition of boiler etc.)
- Small power (other than plant)
- Energy management (not relevant to domestic)
- Building performance (compared to standard benchmarks)
- Identification of opportunities

Though some of these are clearly aimed more at the commercial sector, many of them are relevant or can be reinterpreted for domestic assessment as is the case for this investigation. The current practices and guidelines for energy surveys and audits provide the basis for the question types and layout of the final survey form.

This section describes the current energy rating systems in Ireland for the domestic sector and the UK. This is the RdSAP (BRE) procedure for the UK and the DEAP (BER) procedure for Ireland. These methods form the topics that should be examined in assessing energy use in the home. Reviewing energy surveying in light of the aims for the overall project helped to further define the details that needed to be determined in the survey. How the survey acts in compliment to the monitored data and occupant interview facilitated the completion of the survey structure. A pilot study refined the final survey methodology. It was decided not to use pre and post BER assessments as part of the procedure so as not to encroach on work being conducted in The Energy Policy Modelling Research Group at University College Cork. Furthermore, the needs of BER assessments did not fit the needs of the study as well as a prescribed survey.

The RdSAP (Reduced Data Standard Assessment Procedure) is the UK Government's official procedure for the Energy Rating of Dwellings and is a part of the methodology in calculating the energy performance of buildings. The assessor collects information on the building. This includes the age, construction, and insulation present, together with information about the heating and hot water systems and any renewable energy systems (Theodolite.net, 2009). The Domestic Energy Assessors Handbook for the RdSAP procedure (Parnham & Russen, 2008) advises on the methodology for inspectors to make the most reliable investigation of properties. It is designed to comply with the UK Building Regulations 2011 Part L Section 2 for existing dwellings. It suggests that the inspectors take the following steps on arriving at the property:

1. Introduce the occupant to what the survey will entail and include a walk around to allow for sketches of outline later on.
2. Carry out a loft inspection (if safe and accessible)
3. Inspect each room similarly recording along with other features such as presence of heaters. Follow this by completing the same method on the next floor down and so on.
4. Record details of the electricity meter and fuel used for space and water heating as well as cooking.
5. Examine the exterior by standing back and attempting to understand the design and construction of the property. Include a walk around and note details such as the number of chimneys and flues and where any work has been carried out.

6. Complete floor plan sketches.

The BER method was first introduced in section 1.5.2. The survey guide for the DEAP software follows a similar process to that of the RdSAP (SEAI, 2011). The external survey includes dimension taking, examination of ventilation and construction features, any age indicators and the orientation of the building. The internal survey again begins with an initial walk around the building, sketching, room by room surveying and attic examination. The guide also suggests asking the occupant about any cold areas of the house and any work that they know has been done on the building.

4.2.2.2 The survey aims

The main aim of the survey was to establish how energy is used within the home and the features and materials of the house itself. While standard practice within the field of auditing and surveying forms the foundations of the survey, this project had additional needs. One such need was for the survey to act in a complimentary manner with the monitored data. Measures of oil and gas usage as well as electricity data and room condition data could be more confidently assessed once the behaviour of the occupants was well established. In addition to the traditional walk around survey, therefore, it was necessary to question the occupant in relation to appliance and heating usage as well as movement and activity in the home. Certain questions in the survey were repeated after the retrofit works in the interview questions. This was done in order to help determine whether there were any behavioural or usage changes between the pre to post scenarios.

4.2.2.3 Pilot Study

While some dimension measurements were completed for the survey, this was not as extensive as those listed for the RdSAP procedure. This decision was made following the pilot test, completed on an empty house in suburban Dublin. Due to the length of time it took to extract this data, it was decided that minimising disruption to the householders was a priority. In addition, such detail was not necessary in order to meet the identified objectives. Furthermore, on the basis of the pilot survey, it was determined that much of the information required could be obtained from photographs after the site visit rather than transcribing notes at the scene, which reduced the time required on-site and disruption to the occupants.

4.2.2.4 Survey Methodology

Steps in completing the surveys on each property are presented here:

- The first step in the process was the interaction with the on-site contractor. Information on the building and planned measures as well as key dates and contact details for the occupant were obtained at this stage.
- A desk study, map use and internet research were completed in order to gain any additional information that could give further details to the case. These uncovered details such as the year that the house was built, its location and orientation.
- Upon arrival at the home, the survey procedure guided by practice as discussed was followed. A walk about was conducted, establishing details of the property and services. This was undertaken in the company of the occupant as they could answer the appropriate questions along the way.
- A number of photographs were taken during the inspection of elements such as boiler controls, insulation in the attic and window type to be added to sketches later on.
- During the survey the appropriate monitoring equipment was set up, so as to minimise disruption to the occupant.
- After leaving the site, further details on the survey form were filled out using the photographs.

The final survey form is included in section B.1 of Appendix B. It is divided into the following sections: pre arrival; external inspection; sketches; occupant questionnaire. Pre-arrival basic information on building and wall type was obtained from conversations with the on-site contractor, while particulars of location and orientation were gained using maps. These were backed up upon arrival at the site. The external inspection involved an overview of the building allowing details such as exposure level to be observed. Sketches were made using recorded notes from the walk around in combination with photographs and included as much detail as possible on anything that influenced the efficiency of the building and thermal behaviour within it (including fireplaces, windows and radiator positions). The occupant questionnaire involved basic questions on energy usage and activity in the home as well as questions about the building itself. Upon completion of the survey, the monitoring phase began.

4.2.3 Monitoring

4.2.3.1 Basis for monitoring methodology

Much of the basis for the monitoring methodology is outlined in chapter 2, however, additional studies have informed the design of the building-in-use site studies methodology. Most relevant literature reviewed for this project examined buildings for at least one year, however there were

a few examples of shorter monitoring periods of a couple of weeks to a month (Hong et al., 2006, Stazi et al., 2009) which produced valuable results. One examination of the Warmer Front Scheme in the UK (Hong et al., 2006) considered the effect of energy efficiency retrofit on domestic space heating fuel consumption. Houses were monitored before, or after retrofit or both, over a 2 – 4 week period over two winters (December to early May). A total of 390 houses were monitored pre and post retrofit. Another study focuses on external insulation in an apartment block after 20 years to assess its performance with monitoring occurring over a month (Stazi et al., 2009). Retrofit houses in another project were monitored for 6 weeks before and two weeks after retrofit (Harrje, 1978, Harrje & Grot, 1978, Socolow, 1978). Common recordings in previous studies are as follows:

- **Temperature:** Room temperature is commonly recorded in energy monitoring and energy efficiency retrofit assessments. The most common locations for these sensors include the main bedroom (Bell & Lowe, 2000, Hong et al., 2006; Oreszczyn et al., 2006), the living room or most frequently used room (Bell & Lowe, 2000, Hong et al., 2009)and outside the building (Harrje & Grot, 1978, Rosenfeld et al., 1981, Milne & Boardman, 2000, Oreszczyn et al., 2006, Stazi et al., 2009, Cantin et al., 2010). Often outdoor readings come from a weather station which also includes wind, solar and pressure information (Harrje & Grot, 1978, Stazi et al., 2009).
- **Humidity:** Humidity is commonly recorded along with the temperature readings (Hong et al., 2006, Oreszczyn et al., 2006, Cantin et al., 2010). It is also a reading in weather stations.
- **Energy Usage:** Energy consumption is usually obtained from bills or by manually reading the gas and electricity meters (Goldman, 1985, Bell & Lowe, 2000, Hong et al., 2006, Oreszczyn et al., 2006, Hens, 2010).
- **Air Tightness:** A common test in the literature to examine the 'leakiness' of the building includes the pressurization test (Bell & Lowe, 2000). This has also been used by Energy Action in their work with low income homes and is an option for assessing the air leakiness of properties for BER assessment as part of their sampling regime. The test involves pressurizing the building using fans installed into doorways.
- **Building Heat Retention:** Co-heating or the heating of a house to a specific temperature and examining the data (Bell & Lowe, 2000) has been used as a method of determining the ability of the building to retain the heat put in to it. Thermal imaging is also often used to locate areas of heat leakage from a building (Stazi et al., 2009, Cantin et al., 2010).

- **Element Thermal Transmittance:** Some studies obtained data for thermal performance of building elements such as walls, roofs and floors. Theoretical estimates can be made based on standard values for material types (Cantin et al., 2010) or actual values can be found through *in situ* measurement using heat flux meters and temperature sensors (Stazi et al., 2009).

4.2.3.2 The monitoring aims

The monitoring share of this project is the major contributing factor in determining:

- The immediate impact of cavity and external insulation introduced under the HES/BEH scheme. The impact includes that on comfort, behaviour, energy usage
- The immediate impact on building physics as seen in site case 1, but as a building-in-use scenario, giving an insight into the actual impact of the scheme.

4.2.3.3 The Pilot Study

Building testing began with a pilot study on a vacant Dublin City Council house located in the suburb of Donnycarney. Testing was completed before and after external wall insulation and attic insulation was installed in the building along with a new high efficiency boiler. The heating system was set to switch on and off in typical in-use cycles. Unfortunately, the heating system was not working in the pre retrofit case, but the new system installed in the post retrofit case provided useful readings. The study allowed for the reliability of the equipment to be checked, necessary recording intervals to be determined and a base understanding of how a building behaves under cyclical heating patterns to be created. Furthermore, it was on the basis of this study that the required minimum monitoring periods were chosen, as the building's thermal behaviour adapted quickly to the changes in the thermal envelope introduced by the retrofitted insulation. After this, site case 1 provided a deeper understanding of the thermal behaviour and change in behaviour of an insulation retrofitted dwelling, as discussed in chapter 2.

4.2.3.4 Monitoring methodology

Monitoring equipment was set up during and after the survey on the first visit to the building. Photographs of all of the monitoring equipment described here are available in section B.2 of Appendix B and further details of them are provided in section 2.3.2. Equipment was set up as shown in the typical example Figure 47 and explained as follows:

- Temperature and humidity sensors were positioned in the main bedroom and most frequently used room (living room). An external sensor was also set up outside, above the ground at a location sheltered from sunlight and away from heat sources in an area that gives an accurate determination of room conditions. Other rooms were also deemed suitable on a case by case basis. This helped to establish room conditions and the differential between outside and inside temperature for a given heating input. These values were also combined with the occupant interview to gauge comfort level.
- If a boiler was present, temperature of the output flue of the boiler was monitored using a thermocouple and datalogger in order to give an indication of the use and ignition times of the heating system. The flow and return pipes for the radiator circuit were also monitored to find the differential in temperature of the water across the boiler and thus how much 'work' the boiler is doing. If another heating system was installed whereby the same method cannot be used, the survey addresses this under questions regarding fuel usage, for example the number of briquettes used daily to heat the fire, operating settings and use (if any) of electric heaters.
- *In situ* heat flow apparatus was set up on a north facing wall if available as per site case 1. If not available, a wall sheltered from sunlight was chosen.
- An electricity meter was fitted on the mains supply to monitor electricity usage.
- Oil or gas consumption was established by weekly visual recordings of oil or gas levels. This was combined with the readings from the sensors on the boiler to determine heating usage and patterns over the monitored periods.
- The equipment was set up and left in the house over at least seven days before the retrofit and seven days after. If recording time passed over a week, the data is downloaded every seven days.
- If possible, the house was photographed with a thermal imaging camera at a time when the heating system is in use. In order to increase the reliability of the comparison, similar indoor and outdoor conditions were required. This was not possible in all site cases due to location of the building, availability of equipment and unsuitable weather conditions.
- Some or all of the equipment was removed during the retrofit works and re-installed afterwards depending on the time required for retrofit, and what measures were being installed. This marked the second and third visits to the property.

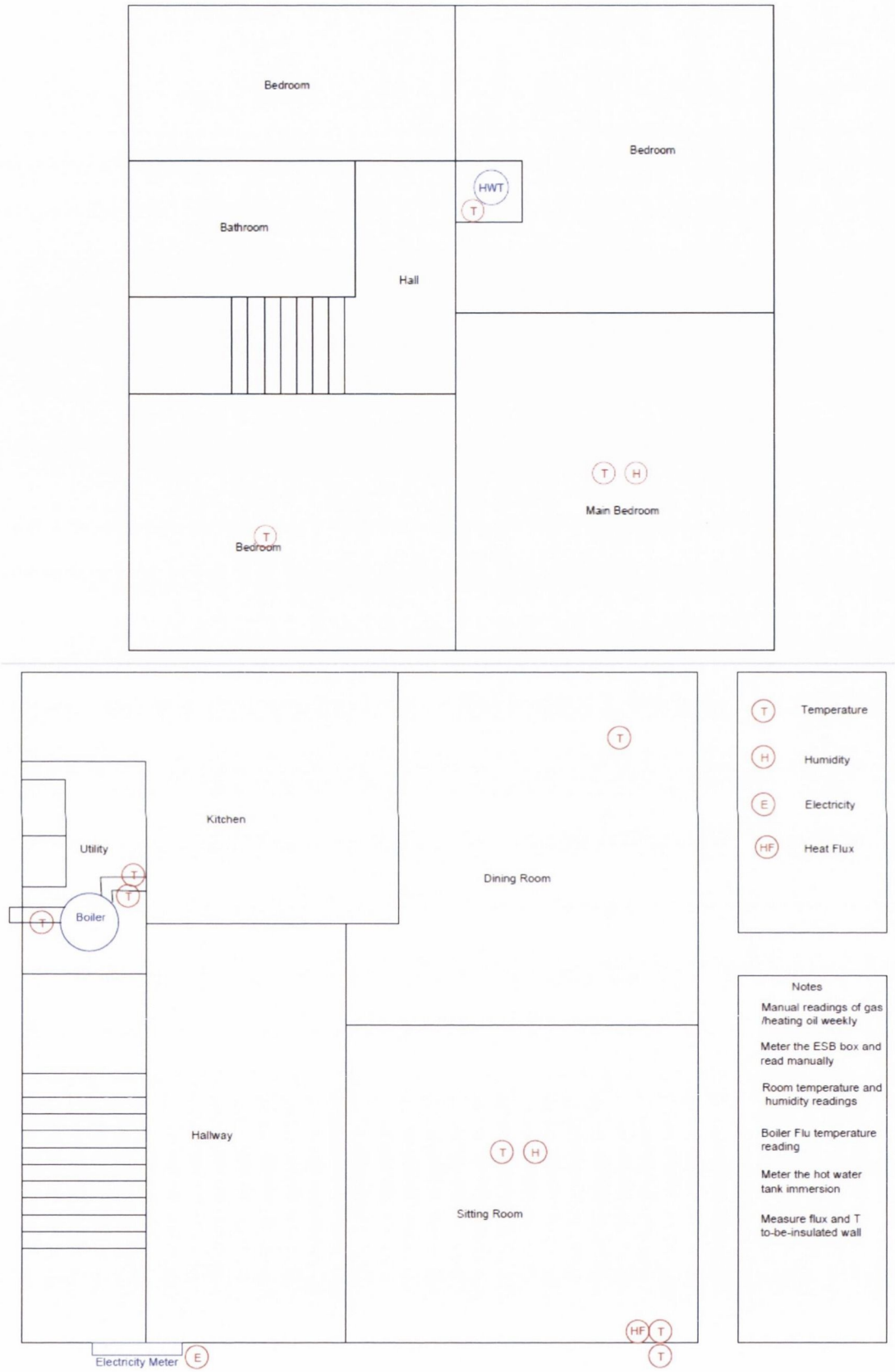


Figure 47 Standard instrumentation of a house for monitoring

The final day after monitoring is complete involved removal of equipment as well as the occupant interview.

4.2.4 Interview

Occupant interviews occurred after the monitoring period and were used gauge the occupants' perspectives as well as determine certain facts as the occupants saw them. In addition to this, the interviews were used in combination with the pre survey and monitored findings in order to gain a richer understanding of behavioural aspects of retrofit. The policy aspect is touched on in the occupant interviews as the occupants were enacted in their role as client stakeholders in the HES/BEH scheme.

4.2.4.1 Basis for the interview methodology

Qualitative and quantitative research are usually discussed within the confines of social science methodologies and are generally seen in opposition to each other (Grix 2004), with quantitative research asking 'how many' and qualitative asking 'how' (Silverman 2010). However, many examinations of research methods suggest that there is a blurred division between these two forms (Newman and Benz 1998; Thomas 2003). Further to this, methods which are commonly classed as either one or the other can incorporate aspects of both, for example interviews can contain closed response questions. These are questions which offer a limited number of listed answers and are more typical in surveys.

Qualitative research is generally open to more interpretation and looks for meaning and understanding (Kitchin & Tate, 2000). While quantitative research is more structured, and the data often consists of observed facts that are readily quantifiable and tending to apply to the use of numerical data (Grix, 2004). Quantitative research has been described as having variables, being subject to verification and involving an attempt at value-free analysis. However, Grix argues that value-free (or detached) analysis is not possible because the researcher will already have some preconceptions and assumptions which cannot be removed[15]

The three most common qualitative methods are described in Table 6 using amalgamated definitions from the literature. This form of research often seeks to accumulate information on a particular event, institution or issue which may be contested or generate different views, values

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15 Positionality: How 'who a person is' shapes what they know about the world. It includes attributes such as race, nationality, and gender which are fixed or culturally ascribed. It is also shaped by subjective-contextual factors such as personal life history and experiences. Such attributes require textual disclosure when they affect the data Chiseri-Strater, E. (1996). Turning In upon Ourselves: Positionality, Subjectivity, and Reflexivity in Case Study and Ethnographic Research. Ethics and representation in qualitative studies of literacy, Urbana.

and perceptions. Criticisms of qualitative research often focuses on how representative a small group can be of the wider reality, the validity of the research due to the small sample size, and the degree of objectivity that a researcher is capable of attaining (Grix, 2004). The aim of qualitative research is not to be statistically representative. Furthermore, a small sample size can be sufficiently representative in cases where the community being examined is itself small. Political discussions are not necessarily rational or scientific and so the issue being examined is not automatically an objective one, diminishing the need for excessive objectivity.

Table 6 Qualitative research methods and their purpose in information gathering as per the literature (Kitchin & Tate, 2000, Gubrium & Holstein, 2002, Hoggart et al., 2002, Grix, 2004, Kvale & Brinkmann, 2009, Silverman, 2010, Thomas, 2011)

Information gathering method	***Use / aims***
Interviews	• Used to seek deep information and knowledge, conventionally deeper than surveys/questionnaires and focus groups • Allow a more thorough examination of experiences, feelings, or opinions that questionnaire style questions cannot attain • Can involve very personal matters including lived experience, values and decisions, cultural knowledge, or perspective. • Are appropriate for discussions on complex issues, with face to face interaction enabling unobtrusive interviewer observations of the respondents and their surroundings.
Survey/ questionnaires	• Address surface level aspects of human behaviour and values • Better suited to factual data gathering
Observation/ participation	• Used more commonly in ethnography and anthropology with aims generally directed at understanding everyday life and culture.

Kitchin and Tate (2000) present four forms of interview. These are the closed quantitative interview, structured open-ended interview, the interview guide approach and the informal conversation. Grix (2004) separates interview type similarly as structured, semi-structured, unstructured, and group interviews (or focus groups) as described in Table 7 combining discussions from the literature.

Table 7 Interview types with their pros and cons as per the literature (Kitchin & Tate, 2000, Gubrium & Holstein, 2002, Hoggart et al., 2002, Kvale & Brinkmann, 2009, Silverman, 2010, Thomas, 2011)

Interview type	*Pros*	*Cons*
Structured Interview This form is similar to a verbal questionnaire. It is highly controlled by the interviewer with structured and standardised open ended questions and the same order with exact wording and sequence followed.	• Increased comparability between transcripts • Ensures responses to all questions • Ease of coding	• Does not allow for flexibility to relate the interviews to particular people or circumstances • Can limit the flow and relevance of questions and answers • Does not allow interesting answers to be followed with more probing questions. • The research question often necessitates a deeper process of reciprocated self-disclosure trust building than this form allows.
Interview guide approach In this approach topics and issues to be covered are specified in advance, however, the interviewer can vary wording and sequence of questions.	• Allows for greater depth of information about specific topics • Allows wording to be changed and freedom to explore new pathways which may arise.	• Areas can be accidentally omitted • Comparison between interview transcripts can be difficult
The conversational interview This is considered to have no structural form with questions arising from the direction that the conversation naturally takes	• Gives the interviewer freedom to discuss any topic at any length	• Data collected from different interviews can vary hugely • Requires great skill and experience on the part of the interviewer.
Focus groups These can be structured, semi-structured or unstructured and involve conversation about specific topics. They are concerned only with in-depth responses and have a focus for the discussion. The definition can be split into 'focus group' where discussions are between interviewees and 'group interview' where the researcher takes more of a lead role (Thomas 2011)	• While one-on-one interviews offer individual values, opinions and views, the focus group produces debate, argument and conversation resulting in general understandings and feelings on a group level. • Exposes a spectrum of views that individuals hold on an issue • Allows interviewer to gain insight into the nature of interaction and dialogue over the issue.	• members of the group can influence each other • One-on-one individual's responses may be different to the ones which emerge in the group situation. • Can cause some members to become less vocal due to shyness or fear of embarrassment. • Interviewer has less control over the direction of conversation, occasionally leading to chaotic transcripts

The semi-structured in-depth interview was deemed most appropriate for achieving the related research objectives for this project. It is considered as getting the 'best of both worlds' (Thomas, 2011) and allows for the degree of structure to be determined by the interviewer. It has been

used as a follow up to questionnaires (Davies & Osmani, 2011) and as a way of deciding the structural framework of questionnaires (Dapeng & Weiwei, 2009). Under this interview type - the interviewee is allowed to venture down tangential paths, which can reveal important information. Nevertheless, the required questions must still be answered. It allows the respondents to fully explain their experiences of and opinions on the scheme by going in to as great a depth as necessary. It also provides the flexibility for discussion, in privacy and with confidentiality, of any grievances they may have experienced or observed. It allows new routes of conversation to be explored which can provide the appropriate environment for the interviewees own suggestions or recommendations on the subject.

An interview is a complex social interaction involving a high level of interpersonal skills (Kitchin & Tate, 2000). The interviewer needs to put the Interviewee at ease, asking questions in an interesting manner. The interviewer must also listen carefully and not upset the flow of conversation. A trusting relationship is established while at the same time the neutral position of the interviewer must not be compromised[16]. It can be difficult to ensure that the required questions are answered because this form of interview allows for more freedom in the conversation. It can require more complex analysis of answers than the structured form as transcripts are less easily compared. The face-to-face format of the interview also means that the interviewer's own behaviour can unconsciously influence the responses given as the respondent tries to please the interviewer.

Gubrium and Holstein (2002) offer four sources of error – interviewers, respondents, questions, and mode of data collection. The interviewer can influence the interview by their own social background characteristics. Age, skin colour and accent can influence how the interviewee will react. Kitchin and Tate (2000) propose that by dressing accordingly and acting with respect this can be overcome to some degree. The questions need to be in the correct form for gathering the required information, the wording is important as is the order. Respondents can interpret questions differently, their memory can be confused, their judgment can be inaccurate and they may have a motivation behind the answer they choose to give. Even the recording of the interview may influence the respondent (Gubrium & Holstein, 2002). Kitchin and Tate (2000) offer guidance, which can limit some of the negative aspects or errors associated with interviews. The interviewers should help the interviewee give an answer, the interviewer should avoid any vagueness and the interviewer should explore any interesting answers further. Finally,

16 Although it is beyond the scope of this project to discuss the matter further, some argue that an interviewer can never be truly neutral, see footnote 15 on positionality Ibid.

the interviewer should not pose any leading questions. These are questions framed in a way that evokes a specific response from the interviewee, for example beginning a question with "Don't you think that....". Interviews can also include prompt or follow up questions to the initial open-ended question, asking specifically about topics not covered in the answer (Weenig & Staats, 2010).

Furthermore, Gray (2009) outlines four areas of ethical principles which need to be considered. Interviewers should avoid causing harm to participants, interviewers should ensure informed consent and respect the privacy of the Interviewee and avoid the use of deception. This involves examination of many aspects of the methodology and analysis including questions on how deep to probe, possible areas of misuse of information, any potential harm that can be caused to specific communities of groupings from the findings, and the interviewer's honesty (Gubrium & Holstein, 2002). Consent is needed either through a signed paper or recorded agreement (Gubrium & Holstein, 2002). Standard practice is to use a tape or video recorder to document the interview. However, this may influence to respondent and they may therefore continue to speak after it is turned off.

4.2.4.2 The interview aims

These interviews contributed to all three aims of the research project (section 1.6). For the first aim the information obtained from the occupant aided the technical analysis in quantifying the changes, if any, that the retrofit measures made. This is because this first aim also requires examining the perceived improvement in comfort and quality by the occupants, which enriched the results with anecdotal evidence. Further to this, and also contributing to the same aim, the findings from interviews combined with the survey questions and monitored data in order to determine what constitutes 'comfort' for the HES client.

The perspective examined under the second aim, is that of the occupant, or receiver of the grant under the HES/BEH scheme. Interviews with the occupants also aimed to uncover perceived barriers, successes and potentials within the system from their perspective contributing to the third aim. As part of this, interviews combined with monitored data to gain a greater understanding of what constitutes 'satisfaction' for the current HES client.

4.2.4.3 Pilot study

The research already conducted by the SEAI with clients of the scheme (Motherway & Halpin 2010, Curtin & Maguire, 2011) served as a pilot, allowing for the initial formulation of question

topics including financing, barriers and motivations to retrofit, influences on decision making, demographics, and satisfaction levels. Furthermore, each interview acted as a pilot for the next as discoveries in one interview were posed or used as follow up prompts in the following ones. This allowed for theories and hypotheses to be formed as the interviews were ongoing. To this end, it was important to allow the interviewees to speak freely providing additional information which the interviewer may not have anticipated.

4.2.4.4 Interview methodology

The interviews took place on the final visit to the home after all readings are taken and the equipment has been removed. The interviewees chose locations in their houses which were comfortable for them. At this stage they were already aware of the background to the research from previous interactions. The interview was recorded as well as notes taken. The questioning began with quantitative questions, mainly the same ones posed in the initial survey to determine any changes in how the home was used over the monitored period. Interviews finished with a number of questions to establish the demographic of the householders. The bulk of the interviews involved more open-ended questions and included follow up prompts. Areas covered by the interview were as follows, with the full question form available in section B.3 of Appendix B.

- **Demographic:** Demographic questions allowed for a greater understanding of the customers of the current scheme and gave an indication of the activity levels in the home. These included questions on age and occupation.
- **Behaviour in the home:** This aspect was essential for aiding the comprehension of the monitored data. Appliance usage, space and water heating, movement within the home and activity levels all aided in the explanation of various peaks and troughs in the monitored records.
- **Perception of comfort:** Questions uncovering descriptions on levels of comfort and reasons for comfort or discomfort within the home were explored. The aim was to combine answers with monitored data in order to augment the understanding of the building before and after retrofit as well as gain an insight as to what constitutes 'comfort' for that occupant.
- **Process of retrofit:** The journey to retrofit for the interviewee was of interest in this study. It added to the overall understanding of the barriers and drivers for retrofit as well as the consumer/ retrofit-policy interaction. Questions probed how the occupant found out about the scheme, how they decided on the retrofit options and their personal experience of the

entire process from beginning to end. The aim of these questions was to ascertain how the process can be made more efficient, effective and conspicuous to the public.

- **Results of retrofit:** Answers under this heading aimed at revealing the percieved improvements of the retrofits. This was mainly with regard to changes in comfort, but also whether the occupant has noticed any changes in energy usage behaviour. The questions focused on satisfaction levels with several different aspects of the scheme. The intention of these questions was to uncover perceived barriers, drivers and potential for improvement from the viewpoint of the occupant as a client of the scheme.

4.2.4.5 Coding methodology

Investigation of the interviews followed a grounded theory approach. It is a systematic methodology in social sciences which involves the creation of a hypothesis or theory based on analysing the collected data rather than beginning with a hypothesis and testing it (Silverman, 2010). The analysis of qualitative data begins with a description of the data, followed by classification. Any interconnections are then uncovered. The process tends to be iterative (Kitchin & Tate, 2000). Descriptions of data for the interview process comprise transcribing the interviews and fully understanding what has been said. Interview transcription for the purpose of this research does not focus on language used or search for hidden meaning in pauses or body language as this is not the objective of the qualitative portion of the study. The content of the answers are of primary importance (King & Horrocks, 2010). However, any significant observation beyond what is being said is nonetheless noted.

The classification portion marks the first step into interpretation. Coding and compiling of sections is usually the approach taken. Coding is essentially the use of abbreviations or acronyms used for areas of commonality. There can be crossover between codes and sections. All sections under a specific code can then be grouped together. Recoding may be necessary and some codes can be broken down further into subsections (Flowerdew & Martin, 2005). 'Emic' codes are terms used by the interviewee, while 'etic' codes are ones assigned by the analyst and are more theoretical. Of course, these are not mutually exclusive categories.

Stage one of coding involves identifying the parts of the interview which are likely to help answer the research questions (King & Horrocks, 2010). The next step involves identifying areas where the interviewees own experiences, views and understanding of the subject are expressed. The final step is coding the pieces of writing according to their description, without any interpretation of what is behind what has been said. In analysis of relevant stakeholder

interviews, NVivo is commonly used on the transcribed text (Fischlein et al., 2010, Pellegrini-Masini & Leishman, 2011, Stidham & Simon-Brown, 2011). This is a qualitative data analysis package. Such software allows coding or annotation of text and retrieval of information. It can help to speed up sorting of material and allow very quick retrieval of sections labelled with a certain code. It also allows searches of variation. As Flowerdew and Martin (2005) note, if there are only few materials and limited time, using software tends to be counterproductive. This is because such packages are designed to speed up the analysis process when examining large amounts of data. However, for smaller datasets, because of the time required to learn the software it can conversely slow down the analysis process. As there were only six occupant interviews (and five stakeholder interviews) for this study, it was decided to do all analysis manually.

Analysis begins during the first interview as "the ideal interview is already analysed before the sound recorder is turned off" (Kvale & Brinkmann, 2009). Subsequent interviews follow the same questions as the initial one, the follow up prompts expand to include topics or elements which the interviewer had not originally considered. It also helps to determine any changes which are needed to the interview layout or wording. Common themes, views and theories can be formulated from the final transcripts. Themes in the interview answers can be identified when repeated across a number of interviews. They can also be identified within one interview. The analysis depends on the researcher making sense of the responses based on their own research and reading of literature (Flowerdew & Martin, 2005). Classification involves the identification of consistent classes of data. Here the interactions between categories is the focus (Kitchin & Tate, 2000). Often looking for recurring patterns helps, such as, 'do individuals with a certain characteristic tend to hold a common view?'. This portion of the analysis looks for reasons for the connections. However, to convey the complexity of the different interactions and perspectives of the schemes, the individual words of the interviews must also be portrayed (Rubin and Rubin 2005).

Thomas (2011) simplifies the analytical process for case studies in the constant comparative method. This approach was adopted for this thesis in order to examine occupant interviews as well as stakeholder interviews (chapter 5). It essentially involves examining the interview recordings and transcripts repeatedly, comparing phrases, sentences and paragraphs with all other elements resulting in a number of themes:

1. Examine data by reading transcripts and save the electronic recording
2. Read through them highlighting and underlining important parts. Listen to the interview audio as well. Recurring ideas or subjects will become clearer – call these "temporary constructs" and list them.
3. Read data again using these constructs. Draw up a grid referencing where these constructs are evidenced by referring to where in the transcript they were seen. Simultaneously make notes and observations on the grid.
4. Remove any construct headlines that were not reinforced elsewhere. Note and highlight counter-examples and list them separately.
5. From a second reading come up with second order constructs that seem to fit with the data – these should summarise well the important themes of the data.
6. Look through again, refining the second order constructs and once satisfied that they capture the essence of the data let these become the final themes
7. Examine how the themes connect together, look for any unanimous agreements, contradictions or paradoxes.
8. Map the themes.
9. Select good quotations or sections, which illustrate the themes well.

4.3 Case Studies

4.3.1 Introduction

The site studies were, for the most part, self selecting. The criteria required limited the number of relevant cases:

1. The retrofit works had to be carried out during a period where the occupants would naturally be using their heating systems.
2. The cases had to be identified through either one of the two retrofit companies who agreed to take part in the study - facilitating introduction to the clients. Alternatively, for two of the cases, the occupant was already known by the author.
3. The retrofit works had to include either cavity fill or external wall insulation, preferably with as few other measures as possible.
4. The retrofit works had to follow the criteria of HES/BEH usually as grant recipients (or to the standards outlined under the scheme as was the case for two houses)
5. The demographic, occupancy and activity level in the house had to remain the same for the weeks leading up to and after the retrofit

Two of the houses for the study were not under the HES/BEH scheme, but were retrofitted as part of Respond Housing Authority's improvement process of social housing. These houses did not contribute to the overall evaluation of HES/BEH, but served to increase the understanding of how cavity insulation changes the behaviour of buildings.

All homes were built between 1960 and 1990 and owner occupied, apart from the two Respond council houses which were built in 2000 and occupied by council tenants. Site 'Con' was initially pumped with cavity insulation (where it is referred to as Con(c) in the text) then fitted with external insulation some months later (referred to as Con(e)). This building was the first of the site tests in an occupied home and so acts as a semi-controlled examination of the building in-use. A north-facing and a south-facing room were chosen for examination on the basis that they would not be occupied over the monitored periods. The curtains were drawn and the doors closed for both rooms with agreement obtained from the occupants that they would not enter the rooms during the monitoring period. Furthermore, the occupants agreed to leave their heating on a timer and at a set power so that the heat energy provided to the house was consistent over the full monitoring period. This aided the before and after comparison. This was specified so that a baseline understanding of the effect of insulation on the thermal behaviour of intermittently heated dwelling could be established before introducing the additional unknown of occupant behaviour. In this way, the first of the site cases discussed acts as an intermediary step between the highly controlled in-depth tests described in the previous chapters, and the completely uncontrolled buildings in use discussed in this chapter. For all other site cases SemiD1(e) – Res2(c) the occupants were instructed to use the buildings and heating systems as they pleased over the monitored period.

4.3.2 Con(c)



Location	Co. Meath
Monitoring period	December 2011
Weather conditions	(-1.4) to 8.3˚C
Occupancy	2 adults, one working full time
Building type	4 bed bungalow, south facing, 1980s
Wall type	Cavity
Retrofit features	Cavity fill (Certainfill 27 plus graphite bead) and attic insulation
Rooms monitored	North facing bedroom, south facing bedroom, both unoccupied
Notes: heating was set to agreed timer and power settings, to come on at typically used times as discussed with the occupant.	

4.3.3 Con(e)



Location	As per Con(c)
Monitoring period	February-March 2012
Weather conditions	2.4 – 18.8˚C
Occupancy	As per Con(c)
Building type	As per Con(c)
Wall type	Retro-filled Cavity
Retrofit features	External insulation (EPS100)
Rooms monitored	As per Con(c)
Notes: As per Con(c)	

4.3.4 SemiD1(e)



Location	South Dublin suburb
Monitoring period	January- May 2012
Weather conditions	7.2 - 20˚C
Occupancy	2 adults, 2 dependants over 16
Building type	Semi-detached, NW facing, 1960s
Wall type	Hollow block with small cavity wall to the front
Retrofit features	External insulation (120mm rockwool), new windows, attic insulation, flat roof insulation on garage
Rooms monitored	Ground floor: back extension, front living, garage 1st floor: back bedrooms, 2 front bedroom Outside

4.3.5 SemiD2(c)



Location	South Dublin suburb
Monitoring period	February – March 2012
Weather conditions	0.5 – 6.6˚C
Occupancy	1 Adult retired
Building type	Semi –detached, S facing, 1978
Wall type	Cavity, no insulation
Retrofit features	Cavity (Certainfil 27 plus graphite bead), attic insulation, new boiler and controls
Rooms monitored	Ground floor: back kitchen, front living 1st floor: back bed, front bed Outside

4.3.6 SemiD3(e)



Location	South Dublin suburb
Monitoring period	January – March 2012
Weather conditions	4.7 – 13.2˚C
Occupancy	3 adults, 1 unemployed, 1 retired, 1 full time employed
Building type	Detached, W facing early 1970's
Wall type	Hollow block
Retrofit features	External insulation (EPS 10)
Rooms monitored	Ground floor: back kitchen, front living 1st floor: back bed, front bed Outside

4.3.7 Dor(e)



Location	Co. Meath
Monitoring period	November – December 2012
Weather conditions	(-1) - 15˚C
Occupancy	4 adults, 3 full time employed, 1 wk on wk off part time
Building type	Dormer, detached, bungalow 1970s, 1996 renovated adding extension and expanding and converting loft space
Wall type	Hollow block, Internal dry lining, converted loft is mainly timber
Retrofit features	External insulation (EPS 100)
Rooms monitored	Ground floor: back living, 1st floor: bed back, bed side Outside

4.3.8 Bun(e)



Location	Co. Meath
Monitoring period	November-December 2012
Weather conditions	(-1) - 15˚C
Occupancy	1 Adult, retired
Building type	Bungalow, E facing, late 1970 – early '80s
Wall type	Cavity wall with blown in insulation.
Retrofit features	External wall insulation (EPS 100), attic insulation
Rooms monitored	Front bed x 2, back living, Outside

4.3.9 Res1(c)



Location	Co. Louth
Monitoring period	April-May 2013
Weather conditions	Clear, 6.7 – 16.7˚C
Occupancy	1 adult unemployed, 3 children
Building type	Semi-detached, Already got attic insulation, NW facing, 2000
Wall type	Cavity (60mm as already minimal insulation present)
Retrofit features	Pumped (Certainfill 27 plus graphite bead)
Rooms monitored	Ground floor: back kitchen, front living 1st floor: back bed, front bed outside
Notes: Retrofitted under Respond Housing Authority therefore does not contribute to all of the aspects of the studies covered by the other site cases	

4.3.10 Res2(c)



Location	Co. Louth
Monitoring period	April-May 2013
Weather conditions	Clear, 6.7 – 16.7˚C
Occupancy	2 adults (1 unemployed, 1 student), 1 child
Building type	Semi-detached, Already got attic insulation, SE facing, 2000
Wall type	Cavity (60mm as min insulation already present)
Retrofit features	Pumped cavity (Certainfill 27 plus graphite bead)
Rooms monitored	Ground floor: back utility rm, front living 1st floor: front bed, back bed outside
Notes: Retrofitted under Respond Housing Authority therefore does not contribute to all of the aspects of the studies covered by the other site cases Secondly, tenant did not heat their home over the monitored period, leading to very limited contribution of this test case to the study.	

4.4 Results

The results from the site cases are separated into two distinct discussions. Firstly the survey, monitored data and aspects of the occupant interviews relevant to the monitored data are presented together in sections 4.4.1 to 4.4.5. This primarily contributes to the first objective of the research. The results of discussions with occupants in their capacity as client stakeholder of the HES/BEH scheme are then presented in section 4.4.6. The findings are then discussed together in section 4.5 with reference to how they contribute to the overall objectives and how they inform the next stages of the research.

4.4.1 Overall findings

The following table summarises the findings from the case study houses. The headings in the table are the changes that were expected to occur due to the installation of insulation. Green denotes that the listed change was observed in the data, yellow means that no significant change occurred and red shows that the opposite was observed. The table combines the data gleaned from all three stages of the site study: the survey, monitoring and the occupant interview.

Table 8 overall findings from site case houses

	Ave rm T increase	Baseline rm T increase	iTdiff between rooms decrease	Average heat loss through walls decrease	Baseline heat loss to the walls decrease	Heat stored in walls returned internally	Fuel use /day decrease	Hours of heating/ day decrease	Usage of additional heating elements decrease	No. rooms heated increase	Occupant claims comfort increase	Occupant claims heat use decrease	Signs of heat retention in interview
Con(c)							n/a	n/a	n/a	n/a		n/a	
Con(e)							n/a	n/a	n/a	n/a		n/a	
SemiD 1(e)													
SemiD 2(c)													
SemiD 3(e)													
Dor(e)							n/a						
Bun(e)													
Res1(c)													
Res2(c)							n/a					n/a	

Expected improvement observed

Opposite of expected improvement observed

No significant change observed

Overall, as highlighted by this graphic, the findings were as expected or hoped. Both baseline heat losses to the wall and comfort improvement to the occupant showed unanimous improvements regardless of time of year, housing type, occupancy or heating patterns. The average and baseline room temperatures showed similarly positive results. Improvements in heat retention and storage were identified in most cases either through interview or in the data. Most disagreements with the expected results occurred around the changes in heat energy use with hours of heating per day and fuel use per day increasing or staying the same in almost half of the cases. These findings are discussed in more depth in the following sections with careful consideration of the anomalies as shown in red in the graphic. All site case comparison graphs for heat loss, indoor temperature and central heating usage are available in Appendix C.

4.4.2 Variables in the analysis

Houses which obtained cavity insulation are cases Con(c), SemiD2(c), Res1(c) and Res2(c). Con(c) is the semi-controlled case as described in the section 4.3.1. Site case 1 described in chapter 2 was also a cavity fill test case which was fully controlled and unoccupied. Cases vii and viii are the two Respond Housing Authority houses. Data from Res1(c) is largely usable. In the case of Res2(c), the occupants did not use their heating system over the entire monitored period and so only very limited use of this data can be made.

Houses which obtained external insulation are cases Con(e), SemiD1(e), SemiD3(e), Dor(e) and Bun(e). Con(e) is the semi-controlled case, though unusually it had its cavity pumped as test case Con(c), therefore the thermal quality of the walls was already reasonable before testing began for the external insulation in Con(e).

Timeframes for comparison were chosen on the basis of encountering similar external temperature, for analysis purposes. However, as matching ambient conditions exactly was not possible, timeframes were chosen on the basis of external temperature being greater (though insignificantly so) than the pre period in order to avoid overestimating the potential changes. This leads to a slight underestimation of the true changes. The only cases where this could not be achieved were in the two Respond Housing Authority buildings Res1(c) and Res2(c). Furthermore houses SemiD1(e) and Dor(e), ambient conditions were significantly colder during the post period by over 5˚C. This did not seem to affect the positive outcomes which are readily viewable in green for house SemiD1(e) in Table 8. The effects appear to be much more visible for Dor(e) in the same table.

The second, and most influential variable, is the introduction of the occupant into the analysis. Occupants were asked to use the house and heating as they pleased over the monitored period

(except for the semi-controlled cases of Con(c) and Con(e) as discussed previously). This was an intentional introduction as the objective of the project is to determine actual changes in energy usage and building physics due to the retrofit measures as related to the government's retrofit scheme. While it is intentional, comparing like-with-like as was done in chapters 2 and 3 and for SC.i.i and Con(e) was not possible. Instead, general conclusions could be drawn by using overall combined findings.

Thirdly, while the occupants were asked if there were any changes in the occupancy of the building over the timeframe, their recollections may not have been completely accurate and do not account for all members of the house. This means that the number of occupants per hour per day could have varied from the pre to the post case. This is an unknown variable, however, it is assumed that these changes could not have been dramatic if they were not recalled. Furthermore, because of the number of cases studied, any cases where occupancy increased post retrofit is likely to be balanced by any cases where it decreased when making generalisations of the findings in the Conclusions chapter.

4.4.3 External walls

4.4.3.1 Cavity fill

For the semi-controlled case of Con(c), average heat flux reduced by 11.42W.m^{-2}) through the north facing wall and 10.86 W.m^{-2}) through the south over the monitored period. This equates to a reduction of the average heat loss by 52% and 50%. This is shown in Figure 48. In the other cavity fill cases of SemiD2(c) and SC.vii the average reduction in heat loss through the walls was 66% and 21%.

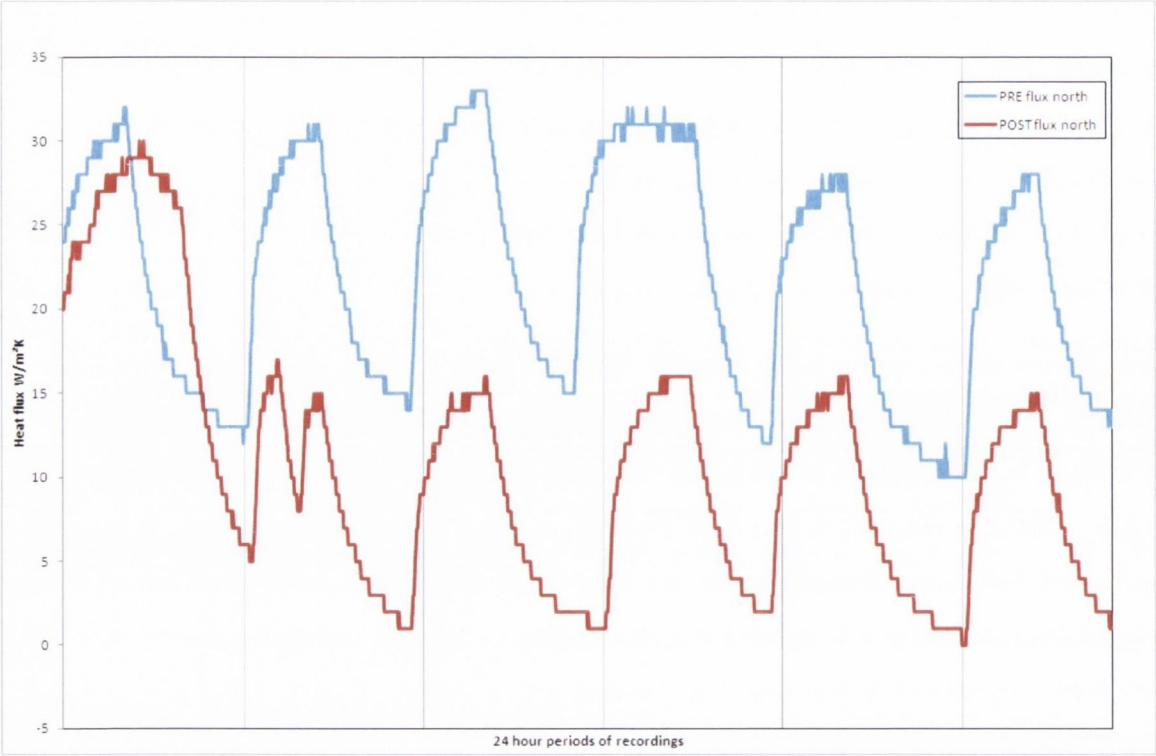


Figure 48 Con(c) north wall, used as an example of heat flux change for cavity fill walls

As can also be observed in Figure 48, after the initial day of heating post retrofit, the baseline heat loss through the wall can also be reduced when the insulating ability of the wall is enhanced with retrofit cavity fill. Baseline heat loss refers to the minimal or constant heat loss that is experienced through walls even when there is no heat supply present. It is shown in the Con(c) example in this figure that the baseline loss to the wall was in the range of 14W.m^{-2}) and reduced to roughly 0W.m^{-2}) post retrofit (the south facing wall observed a similar reduction). The baseline heat lost in the other case studies was still observable as 10 to -2 W.m^{-2}) for SemiD2(c) and less observable in Res1(c) as 1 to 0W.m^{-2})

Furthermore the maximum daily heat loss through the walls decreased by a large amount for the semi-controlled case Con(c). This reduced from 32 to 15 W.m^{-2}) for the north wall with similar findings for the south wall. SemiD2(c) observed a smaller reduction from 27 to 25W.m^{-2}) and SemiD2(c) observed no change

Table 9 summary of thermal changes to cavity fill walls

	Reduction in heat loss	***Reduction in baseline heat loss W.m^{-2})***	***Reduction in ave daily max heat loss W.m^{-2})***
Con(c) north	52%	14	17
Con(c) south	50%	10	16
SemiD2(c)	66%	12	2
Res1(c)	21%	1	0

A summary of the findings is provided in Table 9. As discussed, in all cases the baseline heat loss to the walls reduced to at least no heat loss, or 0W.m^{-2}) recorded at the internal surface. However there was a negative baseline flux observed in SemiD2(c) showing that some of the heat stored in the internal block layer of the wall was returned to the internal space when the heating was turned off as detailed in chapter 2, section 2.4.

Thermal imaging was used where possible to compare pre and post cases where the heating had been on for a similar amount of time and the external conditions were comparable and favourable for the application. An emissivity value of 0.9 was used in all cases. Figure 49 shows a thermal image of a west and north facing wall for site case Con(c) before and after insulation is pumped into the cavity. The image shows that a large portion of heat was being lost through the walls before insulation was introduced, especially on the west facing wall and at locations around windows and joints with the roof and other walls. In the post retrofit image, the overall temperature of the external wall was more uniform and cooler. It thus visually displayed the monitored findings; there was now a block to heat flow between the internal warm and external cool environments.

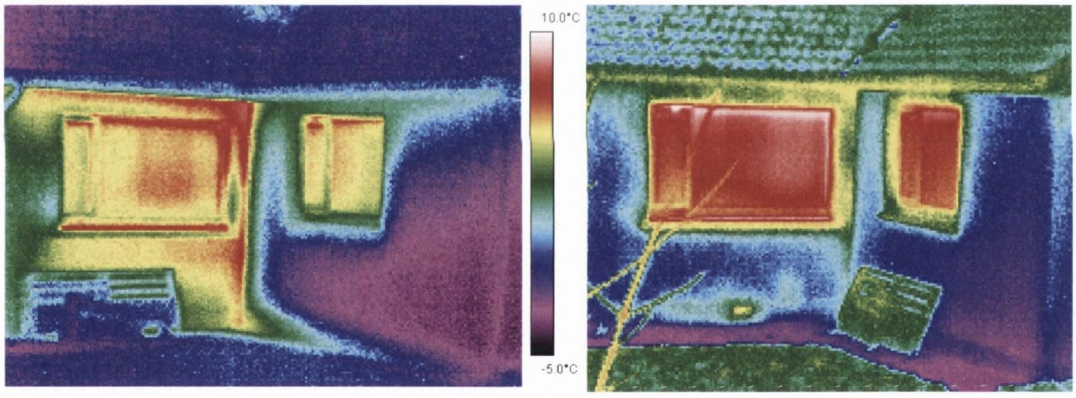


Figure 49 Con(c) thermal image back wall pre (left image) and post (right image) cavity fill insulation

4.4.3.2 External insulation

For the semi-controlled case of Con(e), the average heat flux reduced by 2 and 2.6 W.m^{-2}) through the north and south walls equating to a reduction of 48% and 60% over the monitored period. The remaining test cases saw reductions in heat loss of as little as 1.8 W.m^{-2}) in Dor(e) to as high as 16.1 W.m^{-2}) in SemiD3(e). These values equate to reductions of between 37-77% in average heat loss. However site case Bun(e) showed an increase in heat loss of 40%, though this can be explained by the dramatic change in heating usage in the building post retrofit as will be discussed in section 4.4.5. The site case of SemiD1(e) is used as the example of typical changes in heat flux recordings displayed in Figure 50.

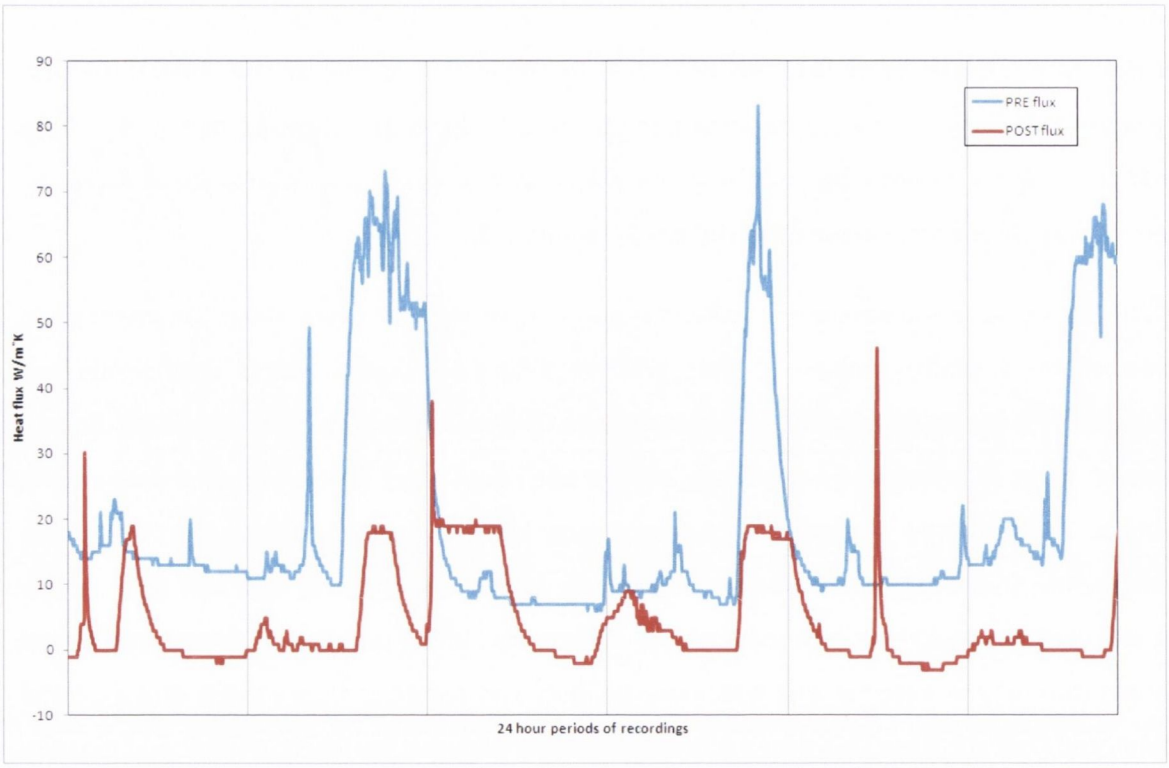


Figure 50 SemiD1(e) used as an example of heat flux change for external insulation walls

The baseline heat loss was reduced in all cases, even for Bun(e) despite the increase in heating usage. Baseline losses reduced from 1 to 0 $W.m^{-2}$) in the north wall, and 2 to -3 $W.m^{-2}$) through the south wall as observed at the internal surface. SemiD1(e) experienced a reduction from 0 to -1$W.m^{-2}$), SemiD3(e) wall reduced from 7 to -3 $W.m^{-2}$), Dor(e) reduced from 2 to 0 $W.m^{-2}$), and Bun(e) reduced from 0 to -3$W.m^{-2}$). It should be noted there that four out of the six cases showed negative heat flux as the stored heat in the wall was returned to the inner space when the heating system was turned off contributing to an overall reduction in heat loss.

The average maximum heat losses experienced by the test walls decreased in all cases including case Bun(e). These values were Con(e) decreased from 14 to 7$W.m^{-2}$) on the north wall and 11 to 10$W.m^{-2}$) on the south wall, SemiD1(e) reduced from 33 to 21$W.m^{-2}$), SemiD3(e) from 71 to 23$W.m^{-2}$), Dor(e) from 15 to 11$W.m^{-2}$),and Bun(e) from 36 to 30$W.m^{-2}$). All of these reductions are displayed in Table 10.

Table 10 summary of thermal changes to external insulation walls

	Reduction in heat loss	***Reduction in baseline heat loss ($W.m^{-2}$)***	***Reduction in ave daily max heat loss ($W.m^{-2}$)***
Con(e) north	48%	1	7
Con(e) south	60%	5	1
SemiD1(e)	75%	12	12
SemiD3(e)	77%	10	48
Dor(e)	37%	2	4
Bun(e)	GAIN 40%	3	6

Thermal imaging was again used where possible and appropriate and an example image is shown in Figure 51. The pre image for this location shows clearly the structural ring beam as warmer than the surrounding wall areas meaning that it was acting as a thermal bridge. External insulation was introduced in the second image and the insulation now blocks heat from escaping fully to the external environment resulting in more uniform surface temperatures. Similar results are shown along the chimney flue. This house had attic insulation fitted as reflected in the decrease in external surface temperatures of the roof. Generally the external surface temperature of the wall and roof become much more uniform in the post case as the building envelope became more resistant to heat loss.

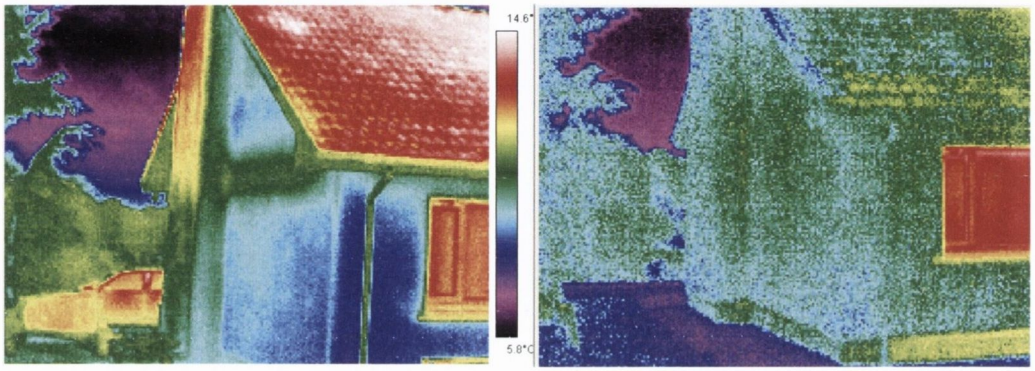


Figure 51 Con(e) thermal image of east facing wall pre (left image) and post (right image) external insulation and attic insulation. Image shows location of ring beam as a thermal bridge in the pre case

4.4.4 Damping/moderating and heat retention

Overall house air temperature fluctuations became less extreme after retrofit, as exemplified by case SemiD1(e) below.

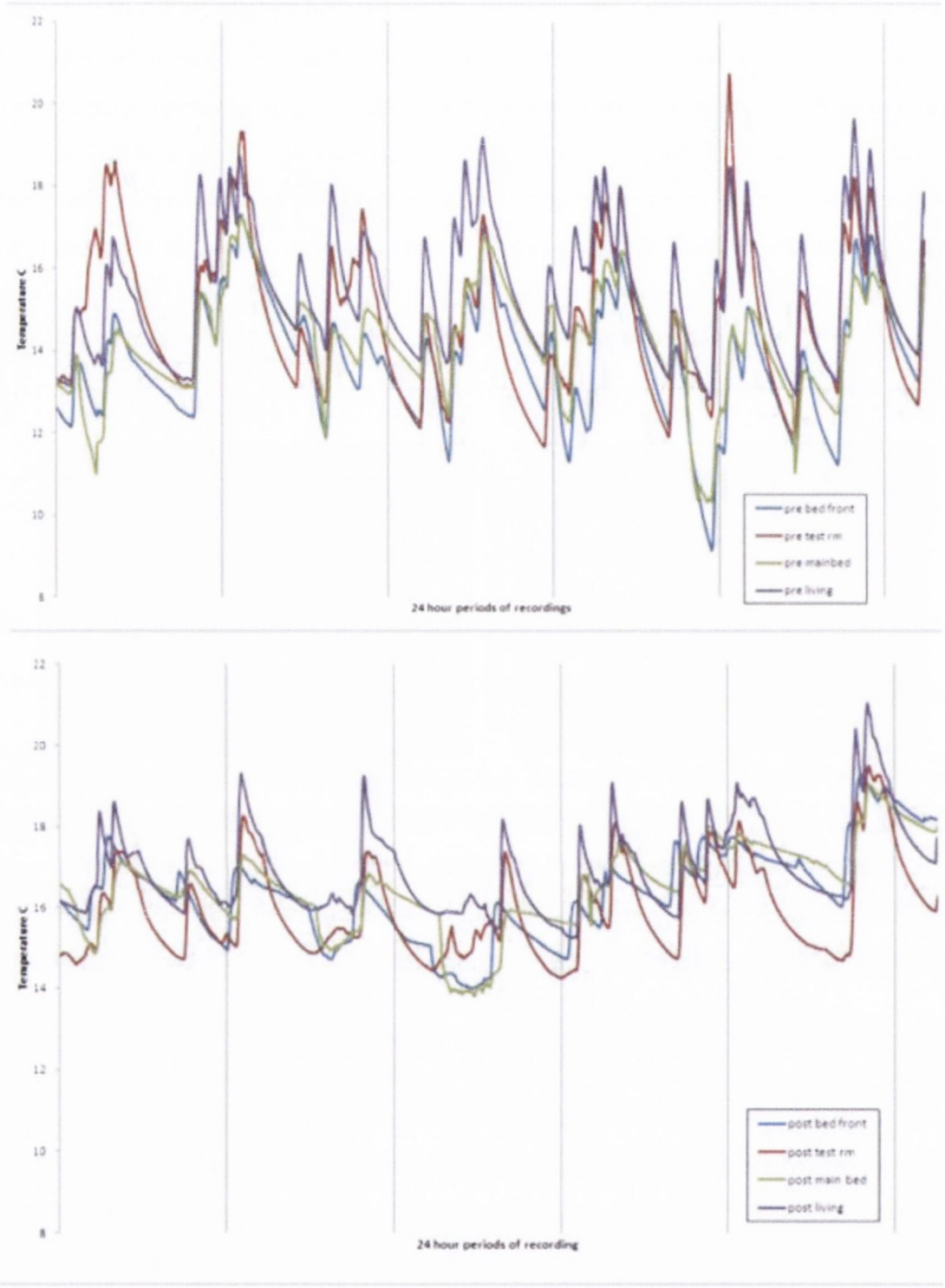


Figure 52 SemiD1(e) comparison of graphs as an example of reduction in indoor temperature swings after retrofit

Most of the site cases experienced an average increase in indoor temperature as displayed in Table 11. The only abnormality is shown in Dor(e) where the average room temperature decreases. This can be attributed to two causes. The first as was discussed in section 4.4.2; the external climatic conditions worsened considerably in the post retrofit monitoring with the occupant mentioning during the interview that there had been frost observed after the retrofit

works. Secondly, the data showed that there was a great variation in temperature between the ground floor and the upper, timber converted dormer portion of the house with the colder 1st floor contributing most to the anomaly in the figures.

Table 11 Summary of changes to the average internal air temperatures and uniformity of room temperatures in all retrofit site cases

Cavity fill	*Average rm T increase °C*	*Pre Tdiff °C*	*Post Tdiff °C*
Con(c)	0.3	1.6	1.1
SemiD2(c)	0.1	3.0	0.3
Bun(e)	1.2	0.6	0.6
External insulation			
Con(e)	2.3	0.6	2.8
SemiD1(e)	1.9	1.7	0.6
SemiD3(e)	2.0	2.3	2
Dor(e)	-1.0	2.0	3.4
Bun(e)	2.4	3.3	0.6

The temperature of different rooms also became much more uniform. The dramatic change in uniformity observed in case SemiD2(c) is justified using the interview with the occupant in which it was explained that before retrofit occurred the homeowner would alternate what bedrooms were heated by turning off the radiators, whereas once the house became more effective at retaining the heat, all vacant bedroom radiators were switched on to a permanently low setting. Bun(e) also showed a similarly significant increase in uniformity, though as will be explained further in the next section 4.4.5, the central heating use was increased greatly after retrofit. The only in-use case that actually increased the variation in temperature experienced in the house is Dor(e), though as explained in section 4.4.2 the external temperatures decreased significantly for the post retrofit testing. This can be further explained by examining the data which shows that the converted timber loft space did not show as significant an improvement in temperatures post retrofit compared to the original portion of the house which had external insulation fitted. This resulted in an increased variation in temperatures between the ground floor and the converted dormer. The semi-controlled site case for external insulation Con(e) also displayed a significant increase in variation of room temperatures. The south facing room increased its temperature by over 3°C while the north facing room only increased its average temperature by over 1°C. Despite the curtains being drawn during the test period, solar gains can still be quite influential on room temperatures with the north facing room receiving no sun.

4.4.5 Impact of wall insulation on heating regime: occupant interaction

The impact of the retrofit on space heating was examined by comparing the average number of hours in which the house was heated using the sensor place on the boiler flue. The total fuel used was also measured where possible. This result is not as reliable because in many cases the

same fuel source was used for water heating or cooking. The use of additional heating measures (such as a fire) was identified through questions to the occupant during the pre retrofit survey and the post retrofit interview. Furthermore, it was determined during these questions if any radiators were turned off and if this changed in any way after retrofit. Occupants all reported great improvements in comfort levels and were not motivated to use the benefits of the retrofit to save energy. Energy bills were not acquired for comparison as the billing system in Ireland is still heavily reliant on estimated usage. Furthermore, it was the immediate change in energy use under a fully monitored environment that was to be compared.

Fuel use

Table 12 presents the changes in average hours of usage of the central heating system in the monitored data over periods of similar outdoor temperatures. The total percentage change in fuel used covers the total monitored period including times when ambient conditions are not comparable. Three out of the five uncontrolled site cases showed an increase in hours usage per day. The fuel use for Con(c) was controlled as described in section 4.3.1.

Three out of the five homes whose heating fuel use could be monitored, experienced measurable reductions in fuel used per day after retrofit. The reduction in fuel usage was 63% (SemiD1(e)), 42% (SemiD3(e)) and 21% (Res1(c)). This was not at the cost of internal temperatures as these homes also experienced measurable increases in average and baseline room temperatures and all three occupants professed that they were more comfortable post retrofit.

Occupants can choose to increase their energy use in favour of extra comfort. The most relevant case being Bun(e). This occupant used coal and briquettes on the fire in the living room as a primary source of heating pre retrofit and supplemented this by using the central heating system on average once every two days for 2 hours. Post retrofit central heating usage increased greatly to 1.5 hours twice a day. This translates to three times the amount of heating as shown in Figure 53 which displays the temperature of the flue on the boiler system pre retrofit in blue and post in red.

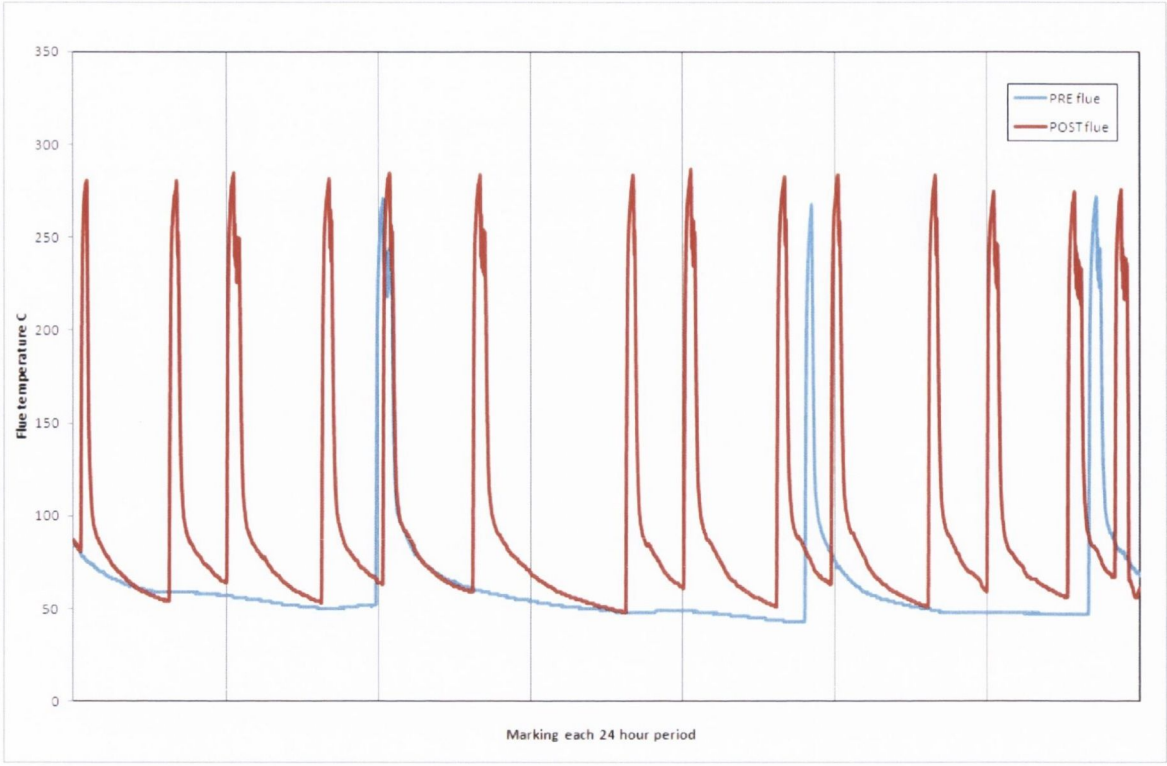


Figure 53 Bun(e) change in central heating usage

Post retrofit the use of the fire decreased from almost a full bucket of coal or wood and two briquettes every day, to just once a week. The occupant stipulated that during the post retrofit period the fire was only used for aesthetic reasons when guests visited. This household was of a lower income than most of the other cases, possibly with the exception of Res1(c) and Res2(c). It was also occupied by a single retiree. This combination of demographic may explain the reluctance to heat the whole house pre retrofit, however, when the system became more efficient and more affordable to heat the whole house the occupant was able to do so.

Table 12 change in fuel usage for all site cases

Cavity fill	***Pre heating/day***	***Post heating/day***	***Reduction in fuel % /day***
Con(c)	Kept constant	Kept constant	Kept constant
SemiD2(c)	5hrs 5min	3hrs 33min	increase 19%
Res1(c)	2hrs	1hrs	21%
External insulation			
Con(e)	Kept constant	Kept constant	Kept constant
SemiD1(e)	9hrs 30min	4hrs 22min	62%
SemiD3(e)	4hrs 3min	5hrs 35min	42%
Dor(e)	5hrs 20min	6hrs 36min	N/A
Bun(e)	1hr	3hrs	N/A

Time to reach comfortable temperatures

Two out of the six homeowners who were interviewed reported that their homes took a shorter time to heat up (SemiD1(e) and SemiD2(c)), however, increased speed of temperature increases was not evident in the monitored data. Instead it was observed that the baseline temperature in all houses was increased therefore the time it took to reach comfort level was lessened. This was noticed by two of the occupants in the mornings:

> *SemiD2(c) "....the house is warmer, the chill is gone out of it in the morning when I get up and even, we've had frost, a lot of frost since, but when I get up in the morning the chill is gone"*

> *Dor(e) "we don't put the heating on in the mornings at all, we come down in here* [to the kitchen] *and it's lovely and warm"*

The monitored data from these houses also recorded increase their baseline temperatures as discussed under the previous section 4.4.4.

4.4.6 Occupant as a stakeholder

Occupant profiles and how they interact with the scheme

Five interviews were conducted with clients of the HES/BEH scheme who were occupants of site case houses SemiD1(e)-vi. One of the interviewees had been told about the scheme from a family relative while the other four occupants could not recall how they originally learned about the scheme. They indicated that they had encountered it several times in many different forms

Two of the interviewees were very interactive during the testing period, asking questions about equipment and general energy use and insulation. These occupants claimed to also exhibit general energy efficient behaviour stating that they "always" switch off lights and appliances when not in use. These same interviewees showed signs of personally researching the retrofit procedure in some way:

> *SemiD1(e): "I was thinking of getting something done so I investigated it...we had out a catalogue and I could see, next they're doing the such and such and I could see it"*

While the other had attended a "Build It Yourself" show and talked about enthusiastically seeking knowledge from the contractors.

These two interviewees cited such information sources as advertising, building shows, television programmes, discussions with contractors and the internet. The same interviewees had both 'shopped around' when it came to choosing a contractor. Each tried four different ones before deciding.

The other 3 interviewees were much less interactive during the surveying, monitoring and interview. They also showed signs that they did not have an interest in finding out any technical information or understanding the retrofit features or processes. The occupant of Bun(e) allowed a relative to arrange the whole process after she had participated in the same scheme with regard to her own home. He used wording such as "wasn't bothered" or "I never thought of that" when asked questions in the area of increasing knowledge in energy use or retrofitting. He stated that he is "not very good on the uptaking" and that he just went along with the process. The occupant of Dor(e) expressed a similar disinterest and displayed a lack of knowledge about the process:

> *Dor(e): "I don't know.... it's all too technical for me, I know, like, the house wasn't up to standard, so we needed to get it up to standard"*

SemiD2(c) also gave signs of these traits when asked questions in the areas of carbon: *"I wouldn't be conscious of that alright"* and on BER rating: *"I'm not up to speed with that"*. She described herself generally as *"not very technologically minded"*.

The sources of information cited by these three interviewees included a person close to them (neighbour/ relative/ friend), advertising and assessors. In all three cases they had been relayed positive stories about the experience from someone they knew who had already installed wall insulation using the grant scheme.

> *SemiD2(c) "I was aware there was a grant but I hadn't looked it up and I had a friend who had external cladding done in her house this winter passed and she didn't have the cavity walls and she said it made such a difference to the comfort of her home so that's really why I went, why I considered it and the grant, she told me about the grant"*
>
> *Dor(e) "Well we kinda knew ourselves what we had to do and em, people with similar got it done and it came highly recommended by them"*
>
> *Bun(e) "I used to go over [to his sister's house] and I'd say it's a very warm house and then I decided to get it upgraded and she sorted the whole thing....Just picked the same contractor as my sister. She was the first around here to get it done with this man"*

There was also evidence throughout the interviews that the occupants had already discussed the positive experience with other people, or were highly likely to do so in the future.

Drivers

Unanimously and repeatedly throughout the interviews, comfort was cited as the main, if not the sole, motivation for homeowners to undergo retrofit. For example:

> *Dor(e) "comfort is the main thing, and the others came as an added bonus."*

The ability to retrofit was then only facilitated by having the available funds for retrofit. All interviewees professed that they would not have done the works if they did not have sufficient funds:

> *SemiD3(e) "the main thing is the money was there, I don't think I'd borrow for it....I feel that if the money is there...if the money is sitting in the bank why not put it to that use...for money that was dead money for 10 or 15 years or money that was going to end up with your children ....put it to that use"*

As mentioned in this quotation, and echoed by all interviewees, the clients interviewed would not have taken a loan or availed of other financing mechanisms had they been on offer:

> *Dor(e): "...if I were to need a loan I wouldn't get it done"*

The proposed new financing mechanisms for the scheme were individually proposed to the interviewees. All interviewees stated that they would not avail of such offers, though they thought they may be good options for others.

The degree to which the offer of a grant motivated the homeowners to retrofit was uncertain. The interviewees offered sentiments that the grant is a driver for retrofit in reference to the general public:

> *SemiD3(e) "...the only way they are going to get people to do it is if they offer the grant"*

> *SemiD2(c): "Oh definitely people need an incentive, I agree with them"*

In spite of these comments, the interviewees attested that they would have considered getting the upgrade even without the offered grants.

The possibility of saving money, either through bills or the added value to the home when selling, was not cited as a driver for any of the occupants. Some believed that they would be

unlikely to experience savings or at least would not get back the money they invested (Bun(e) and SemiD3(e)):

> *SemiD3(e): "...people have asked me that so I tell them straight....listen I don't think you'd get your money back on this you know at our age but certainly the comfort."*

Positive experiences

All occupants attested to high satisfaction levels on all aspects of the scheme, using terms such as "excellent" (SemiD1(e), SemiD2(c), Dor(e), Bun(e)). They each expressed particular satisfaction with the workers and the comfort levels achieved. Such a positive response in interviews may not be taken entirely at face value. The occupants may have seen the interviewer as associated with the scheme and therefore someone to whom positive feedback should be given.

Negative experiences or suggestions

Any complaints or difficulties were presented alongside the disclaimer that they were not upset about such difficulties and that overall they were happy with the process and results. Difficulties mentioned were as follows:

- No regulation on the cost of BER assessment leading to great variety in quotes between assessors (SemiD1(e))
- Added time required to move gullies or cables (Dor(e)), in one cases adding to the quoted costs (SemiD1(e))
- The need to placate the neighbours with gifts due to the noise and disruption over the retrofit period (SemiD1(e) and SemiD3(e))
- SEAI or contractors should create and present a basics guide to the homeowner on the process (SemiD3(e), Res1(c))
- Multiple delays in start dates (Bun(e))
- Dor(e) was unaware that the attic could have been retrofitted at the same time
- SemiD2(c) occupant unable to heat water to appropriate levels for a shower, due to either an incorrectly prescribed water heating system or inadequate explanation of the system installed. The occupant was therefore forced to use her electric shower[17].

17 Electric showers are high energy users

4.4.7 Limitations of the methodology

Theoretically, there are two argument forms against mixed methods. There is the embedded methods argument, which believes that the decision on a particular method is a commitment to one epistemological attitude because research methods are entrenched in their respective epistemological stances. The second objection is the paradigm argument, which contends that it is not possible to combine qualitative and quantitative methodology based on interconnectedness of their epistemological assumptions.

Having a rapport built with client by the time the interview occurred could have encouraged conversation as the interviewee was more comfortable with the interviewer. However, this could have also influenced the answers given as the interviewee was more aware of the research needs of the interviewer (Silverman 2010).

The Hawthorne effect[18] (Thomas 2011) is the theory that more positive behaviour is enacted by people being examined due to the interest shown in them. The presence of monitoring equipment could have changed how people behaved in the home. Interactions with the interviewer and equipment could also have lead to a learning in energy efficiency and how the home and its envelope perform, this in turn could have influenced the behaviour within the home over the monitored period as well as influenced the answers to the interviews.

General interactions were with one occupant of each dwelling instead of all. Therefore answers may only reflect their experience of the process as well as limit the reliability of questions on activity within the house. However the interviewee tended to be the person who initiated the process to retrofit, so for the most part they were the most reliable occupant within the house to give a true reflection of the process.

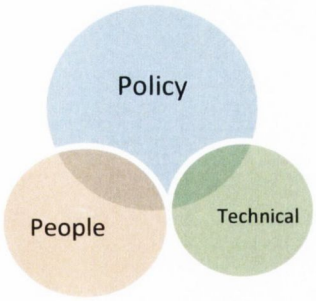
4.5 Summary and discussion

Occupants were generally satisfied with the scheme. As comfort was presented as the driver for retrofit, this was not surprising. By combining discussions with the occupants and monitored data it is clear that the buildings, in general, can now be heated to a higher level, retain the heat for longer, show fewer fluctuations in internal temperatures and more uniformity in temperature throughout. The reasons for this change become clear when we examine the change in behaviour of the wall system. This shows similar changes in behaviour to the initial in-depth study presented in chapter 2.

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18 This is based on effect of staff productivity increasing if there is an interest shown in them, named after a factory in Chicago. Also known as the experimenter effect. In this case instead of productivity it can be increased efforts in energy conservation.

The implications for energy use are less straightforward with data showing varying degrees of reductions in energy used for space heating with some properties even displaying an increase in usage. Energy saving was not cited as a motivation for any of the occupants. This disconnect between the motivation of the scheme to enhance energy savings and contribute to EU 20-20-20 targets on energy consumption and the motivation of the occupant to increase comfort is an aspect which needs further discussion. This informs some of the questions for expert stakeholders in chapter 5. The next chapter presents the primary contribution to the policy analysis of the scheme before the findings from all aspects are brought together in the final chapter.



Chapter 5. Stakeholder perspectives

"Human beings, who are almost unique in having the ability to learn from the experience of others, are also remarkable for their apparent disinclination to do so."

Douglas Adams

"Everything has been said before, but since nobody listens we have to keep going back and beginning all over again."

André Gide

5.1 Introduction

This chapter presents the primary contribution to the analysis at the policy making level. The purpose of the stakeholder interviews is to build on the previous chapters through triangulation of the findings which includes uncovering new findings. In this way, this final aspect of the study closes off the research by filling in any gaps in reaching the second and third objectives as outlined in section 1.6. This portion of the research serves to highlight the perceived positive and negative aspects of how the schemes are currently funded, managed, implemented and promoted from those directly involved with it. This creates a better understanding of the current scheme, its future and the potential for progress incorporating a variety of perspectives and expertise. It gives space for stakeholders to reflect on experiences and clarify or extend findings of written evaluations of the scheme and findings presented in the previous chapters of this thesis.

The basis for choosing the method of semi-structured in-depth interview is as presented for the occupant interviews in section 4.2.4. The specifics for engaging with expert stakeholders are elaborated on in the following section 5.2. The methodology for interview, including question types and interviewees, is relayed in section 5.3. The findings relevant to the research objectives are displayed in section 5.4. Lastly section 5.5 summarises the findings, discussing how it finishes off the research allowing for conclusions to be drawn in the next chapter.

The research presented in this chapter comes with an important note of warning. The aim here is not to say anything definitive about prevailing attitudes within policy making as a whole in this area. Such a project would be a thesis in itself and it would require analysis of hundreds of stakeholders involved at the policy making level. Conducting this type of research would have

left little to no room for the technical aspects of the project to have been conducted in an academically rigorous manner. It would instead be a project wholly devoted to social policy. The point instead is to get an indication, from a smaller number of expert stakeholders, as to what the key themes are from their perspective so that this can be linked to the technical and human aspects. Such an approach has been adopted in previous literature, as discussed in section 5.3.1, below.

5.2 Basis for the methodology

5.2.1 Methodology selection

For the same reasons outlined in the occupant interviews in section 4.2.4, the semi-structured in-depth interview type was adopted. This interview type has been used extensively in research to gauge stakeholder perspectives in areas of environment, policy and energy (Cooke et al., 2007, Dapeng & Weiwei, 2009, Fischlein et al., 2010, Davies & Osmani, 2011, Pellegrini-Masini & Leishman, 2011, Stidham & Simon-Brown, 2011).

5.2.2 Interviewee selection

In contrast to the case for the occupant interaction, in the case of expert interviews, interviewees could be explicitly chosen to best serve the research aims. Interviews are often used as the primary methodology in research examining government based energy initiatives. A number of different stakeholder groups are frequently used and a variety is sought within each group (Cooke et al., 2007, Stidham & Simon-Brown, 2011). Specific people may be targeted due to their experience or knowledge (Cooke et al., 2007, Dapeng & Weiwei, 2009, Pellegrini-Masini & Leishman, 2011), to give a broad perspective and variety on the issues (Stidham & Simon-Brown, 2011) or on the basis of representing all stages of the element being examined (Keirstead, 2007). They are usually selected as experts in their field, and not as a representative from their organisation, as is the case in examinations of stakeholder opinion in areas of nuclear power (Rogers-Hayden et al., 2011), carbon capture and storage (Dapeng & Weiwei, 2009), wind power (Fischlein et al., 2010), and energy efficient housing (Bodach & Hamhaber, 2010). However, stakeholder interviews have contained questions specifically about their organisation's stance on an issue or the structure of it (Cooke et al., 2007, Keirstead, 2007, Bodach & Hamhaber, 2010). According to Gubrium and Holstein (2002) finding key interviewees can be very important to the research. They are people who have contemplated the situation for an extensive time before the interview. They can be politically ambitious individuals who have studied the setting. Independent verification through other interviews should be used to support their claims. The best informants are proposed by the authors to be those who have been

thoroughly immersed in the setting and have some provisional interest in assisting the interviewer.

Stakeholders can be identified as members of relevant institutions (Davies & Osmani, 2011, Pellegrini-Masini & Leishman, 2011), from business directories (Pellegrini-Masini & Leishman, 2011), as mentioned in related documentation (Fischlein et al., 2010) or even via contacts in the sector among the personal networks of the researcher (Svenfelt et al., 2011). More interviewees can then be identified through recommendation by the original interviewees especially those whose opinions differed from their own (Rogers-Hayden et al., 2011). The number of stakeholder interviews is usually in the range of 16 to 41 (Cooke et al., 2007; Bodach & Hamhaber, 2010, Johnsson et al., 2010, Rogers-Hayden et al., 2011). However, the number of interviews needed depends on the research questions (Gubrium & Holstein 2002) and context.

The grouping of interviewees is also a common theme when analysing similar topics. One study examining the struggles within climate change mitigation and energy security discourses assembled interviewees into groups such as non-governmental organisations and advisory bodies, government, social commentators and energy systems commentators (Rogers-Hayden et al., 2011). Other groupings found in different studies include researchers, utilities and developers (Weis et al., 2008). However, only one specific stakeholder group may be targeted, as was the case in one study examining low carbon housing refurbishment (Davies & Osmani, 2011).

5.2.3 The stakeholder interview aims

The purpose of the interviews for this study was to gauge perspectives from several different vantage points within the current residential energy efficiency retrofit programme in Ireland. This included discussion of the proposed changes to the programme. The aim of the stakeholder interviews was to determine how the scheme could have been better. Discussions included design aspects, better implementation, alternative options and barriers to achieving energy saving in the sector and how the scheme was perceived at all levels including the policy level and implementation level. The interviews were also used to test out hypotheses the interviewer had formulated or to explore multiple meanings or perspectives (Gubrium & Holstein 2002). For these theories to be formulated an iterative approach to interviewing was used.

Examining questions used in interviews in other relevant research helped to form the basis for interview structure in this study. It also enabled the comparison of results and findings. Common question areas within the climate change and energy discourse include (Cooke et al., 2007,

Keirstead, 2007, Weis et al., 2008, Bodach & Hamhaber, 2010, Johnsson et al., 2010, Rogers-Hayden et al., 2011):

- The importance of the event/measure. This can be in relation to other associated issues or as an important area to focus efforts or funding.
- How to improve the uptake of a scheme or programme
- Drivers and barriers
- Suggestions for policy or financial incentive mechanisms
- Questions on the future of the process
- Interactions with customers
- The structure of the system, building or organisation and its stance
- Reasons for limited demand

Stakeholder interviews, as with the occupant interviews, employed the grounded theory. However, the stakeholder interview portion of the study was used both to deduce new hypotheses and to confirm those created in the previous site studies of chapter 4. In serving the overall objectives of the project, the stakeholder interviews held several purposes:

1. To fact find, that is filling in blanks from the desk study on origins of retrofit related policy as well as understanding future plans for the scheme.
2. To extract what the stakeholder has learned about the scheme (its processes, motivations, barriers, understanding and potential) from being so immersed in it for a long time.
3. To present relevant findings from the case studies which warrant further discussion
4. To uncover new hypotheses which feed into the overall objectives of the research

In serving these purposes, the stakeholder portion of the study also contribute to the research aims of the project (section 1.6). The perspectives referred to in the second aim are those of the experts involved heavily in the scheme as described in the section 5.3 below. These experts are involved at different levels of the scheme and with different degrees of association to it. Interviews contribute also to the third aim by identifying common barriers, successes and potential for improvement as perceived and proposed by that stakeholder, drawing on their own area of expertise and understanding.

5.2.4 Pilot Study

A pilot interview was first conducted with a stakeholder, who was involved with the scheme at many levels. This included working on research of the scheme for a government agency, working

as a BER assessor for houses in Dublin and current work for a consultancy firm contracted by the EU in efforts to combine learning from various climate change mitigation efforts. The interviewee was provided with the entire list of questions prior to the interview proper and asked to think about other appropriate potential interviewees for the question types. This allowed the interviewee to put considered thought into the answers. The questions covered several different expertise areas. From this, the interviewee was able to identify lists of potential experts within each field. The final four interviewees were chosen from this list after a review of profiles and experience.

Kitchin and Tate (2000) suggest that the pilot Interviewee can be asked specifically if they understood why the research was being conducted[19]. They also suggest that the pilot interviewer can be asked if the instructions were clear, if there were any unclear or confusing questions, if they objected to answering any of the questions, if there were any important topics omitted from the questions and if there are any other comments. Adopting this process, the interview questions were made more clear and concise.

Thirdly, the pilot interview was recorded, transcribed and coded similarly to the expert interviews and included in the analysis.

5.3 Stakeholder interview methodology

In the discipline of engineering, when qualitative research is combined with more traditional quantitative methods, the focus tends to be on gaining an understanding of the user-design interface. Within residential energy efficiency the mixing of qualitative and quantitative research methods usually involves interviews or surveys with occupants as an explanatory method for monitored data on energy use (Bell & Lowe 2000, Pilkington et al., 2011, Ridley et al., 2013). This was previously undertaken in chapter 4 for the site studies. Previous examples of combining experimental engineering methods and policy examination within the field could not be found by the author. Therefore, the identification and number of interviewees and the design of the interview questions were primarily based on the overall objectives of the research and the findings from previous chapters.

5.3.1 Interviewees

The stakeholder group examined in this study was specifically those immersed in the HES/BEH scheme within the policy making arena. Interviewees were and are directly involved in the scheme's design and implementation. This therefore excludes, for example, the non-

19 These are recommendations for piloting surveys, which can be transferred to a large extent to interviews

governmental organisation community, climate change advocates, researchers and fuel poverty campaigners. The justification for this is that it was the 'insiders' experience on HES/BEH processes at a policy making level that was the focus for the engagement rather than the opinions from the population who do not have direct experience. The author concedes, however, that a greater level of understanding and more diverse insights could have been achieved if the additional groups participated. Time restraints did not allow for their inclusion as stakeholder interviews only began after full site studies and analysis was completed. This was a requirement as hypotheses formed during the site studies informed the questions for stakeholder interviews.

Although interviews may not be representative of the total population under examination, they can be illustrative, offering a range of divergent and corroboratory perspectives. The final expert interviewee list comprised five people. This is a relatively small number compared with other studies that examine stakeholder perspectives on a specific policy as discussed in section 5.2.2. However, the total population under examination is itself relatively small as the basic requirement for interview was the long-standing substantial involvement with the HES/BEH scheme. Furthermore, the stakeholder interview portion of this study is not a stand-alone method, but combined with the desk study and previous chapters to fill in gaps or expand on findings.

More importantly, the number of interviews required is not standardised but considered to be study specific (Guest et al., 2006). Within policy examinations, the policy makers group chosen to be representative of federal experience tend to contain a similarly small number of interviewees. This was between five and six per country in a study which likewise sought to determine barriers to energy savings and the policy measures to overcome them (Tuominen et al., 2012). As with this doctoral research project, the interviews were combined with quantitative methods, in their case it was calculations of energy savings. Other research studies in the same field focused on similarly small numbers of interviewees. Seven federal employees were deemed sufficiently representative in an examination of the Energy Star home retrofit program study (Tonn et al., 2013) and another study examining expert views on Finland's energy policy interviewed eight experts, with just two interviewed from the government. Guest et al. (2006) found that the vast majority of codes in one study were achieved after just six purposively sampled interviews. For the current study, there was found to be reasonable agreement between interview transcripts. No new codes were identified in the final interview

which had not already been found in the previous interviews. Therefore it was deemed that a reasonable level of saturation had been reached within the confines of the research project.

Individuals identified for this research needed to have the potential to influence and/or have influenced decisions for the scheme to varying degrees and in diverse capacities. The required expert types were identified to support the research aims. Individual stakeholders were then identified from discussions with the pilot interviewee, through playing active roles in HES/BEH scheme related events and examination of their education and work history. Occupants were also considered to be stakeholders in the scheme in their capacity as a customer as discussed previously in section 4.2.4. The expert stakeholders interviewed along with their interviewee reference are as follows:

1. Pilot Interviewee (P): This was the HES/BER/EU policy experienced Interviewee P as described in the previous section. She would not be deemed an expert in any one particular field but has experience at different levels of the scheme and policy area. This meant that the interviewee could easily identify other potential interviewees and had the ability to answer all questions that would be later posed to the experts.
2. Retrofit expert (R): R is an architect, as such he has been immersed in buildings since the beginning of his career, but he has specific expertise in sustainable design. R started up his own retrofit consultancy, which has been operational for the past 10 years. Further to this, R has been involved with several FP7 projects with a Dublin University, three of which were focused on retrofitting.
3. Scheme expert (S): This was the HES/BEH scheme expert. With qualifications in environmental science and economics, this stakeholder is mainly involved in the analysis for the NEEAP - identifying potential savings. S also works closely with policy makers on energy efficiency and renewable energy policy.
4. Policy making expert (PM): This stakeholder works in policy making including the area of energy efficiency in the residential sector. PM helped design HES and BEH schemes and has been involved with a number of government policy publications in the area.
5. Financing expert (F): The financing expert F has been involved in examining scenarios for financing retrofit projects in Ireland in the residential (both HES and BEH) and non residential sectors. Currently this stakeholder is involved in the changeover to the new financing model, which moves away from the current grant scheme to a more market-based system. This expert is not just looking at the financing needs for the changeover, but also general support mechanisms and the transition itself.

While the study sample cannot be considered representative of the full population involved in the scheme, they can be considered to be illustrative of them. The main purpose of the interviews was not to make generalisations but to determine barriers to retrofit from several perspectives within policy making and how they might be overcome. To this end, while most interview questions were repeated in at least one other interview, each script of questions was tailored to suit the expertise of the individual. These questions were designed to uncover a broad range of bureaucratic, environmental, personal, technical, and process issues and successes experienced as well as how they interrelate.

Findings from the site studies were presented to the subject as hypotheses for discussion. Analysis of the interview began as the first interview was being recorded. Further hypotheses were created as interviews progressed, forming and informing questions for the next interview, as discussed in section 4.2.4. These interviews also involved fact finding questions for elements which could not be found during the desk study, for example, whether Ireland's progress towards 2020 targets are assessed through bottom-up or top-down analyses.

5.3.2 Interview Questions

A discussed in section 1.7, the purpose for triangulation in the research was:

1. To find corroborations, contradictions and hypotheses from the site study findings and desk study or elaborate/expand on these findings.
2. To form new hypotheses
3. To create complimentary insights that create a bigger picture

To achieve this, and with overarching objectives of the research project in mind, questions were formed to cover several different areas. This included financing methods (current, future and potential), policy instruments, HES/BEH client profiles, policy learning, processes, interaction with research, drivers and barriers limiting the impact of such schemes. All interview question scripts are available in Appendix D. Interview analysis was conducted as per the Thomas method (2011) described in section 4.2.4. Similar to other studies, interviews included prompts or follow up questions to the initial open-ended question asking specifically about the topics not covered in their answer (Weenig & Staats, 2010).

5.4 Results

5.4.1 Introduction

This section describes the findings from stakeholder interviews and analysis. It is divided into headings based on how they relate to the overarching second and third objectives of the research project:

1. To collate the learning from the Irish experience in energy efficiency retrofit policy at multiple levels and from multiple perspectives
2. To analyse the scheme holistically in order to highlight overall barriers, successes and potentials within the sector with a view to informing policy in the area of energy efficiency retrofitting and more generally

Section 5.4.2 highlights the perceived barriers to more widespread retrofit. Section 5.4.3 describes the common potential efforts which are postulated to overcome these barriers. Section 5.4.4 examines the gap between policy and academic research with the aim of informing how research projects such as this one could inform policy. Answers may not necessarily be taken as true relations of experiences with the HES/BEH scheme as the interviewer has been seen as an outsider to whom internal differences and dissent should not be revealed.

5.4.2 Barriers / limitations

Process barrier 1: changeability of policy

Changes in government present a specific challenge to the scheme. The electoral cycle in almost all developed countries of four to five years is seen by Hale (2010) as a powerful disincentive to long term strategies required for climate change policy resulting in an abundance of long term targets, without the policies to deliver them. National studies reflect this finding (Fagan et al., 2001). This barrier was highlighted by three of the interviewees.

As one political party was viewed negatively by the public because their term of office coincided with the recession, the next party in power was perceived by Interviewee R (retrofit expert) as blindly changing policies just to be seen as different:

> *R: "It's a political dogma. It's a reaction to the banking and political crisis – bad boys were Fianna Fáil so they have to do something different"*

Compston (2009) suggests creating cross-party agreements on climate policies as a means of putting through more radical policies.

Fluctuations in policy became a recurring theme in the interviews. Interviewee R cited uncertainty and unreliability of policies as a cause of reluctance to invest within industry:

> *R: "this happens all the time with government grant systems and there is a lot written on this. And people say don't bother with grants the governments mess with them and the industry builds up and then they get removed and it all falls back again and people are saying "you did this last time why should I build a business when on some political whim?"."*

Interviewee PM (policy making expert) also expressed the desire for more permanent government investments and commitments in the area of energy efficiency:

> *PM: "we need to have a marketing budget that is sustained for 10 or 20 years and then commit to that, just, like, you know we have drink driving campaigns and there is a budget and the budget is protected"*

Vacillation in policy and approach has not just been experienced in Ireland, however, and was experienced by Interviewee P (pilot interviewee) at a European level:

> *P: "Brussels - they had grants for passive houses or nearly passive houses and from one day to the next they got rid of the grant scheme..... people who had done all this work didn't receive the grant....so it's cases like that that's halting people from doing any kind of work"*

Process barrier 2: a system which does not facilitate innovation or initiative

The author identified that the current federal processes do not allow for innovation and testing of alternative or new methods. It is also felt that the lack of innovation and progress has been caused by the attitude in government related institutions by Interviewee P:

> *P: "it was.... public sector work, it wasn't... the most amazing....much more work gets done in private sector ....Some of the energy companies I see across Europe are privately run or let's say the government sub-contract or local authorities sub contracts it out and sometimes they just work better."*

Though the same interviewee perceived the EU as similarly behaving like a "European Civil Service". Much of the Irish policy was seen to originate in European legislation, both in evidence from the desk study and anecdotally from the stakeholder interviews. However, this obedience to higher orders seemed to limit innovation in policy and methods of implementation. When

asked why there is no requirement for an assessment of dwellings so that a prescribed retrofit solution can be made, Interviewee P made the following statement:

> *P: "I think let's say the EPBD directive....it wasn't a pre-requisite to have a pre BER.... although it should be done, really that's how it should be done"*

The following of EU constraints also limited the direction of research. On the topic of what is researched in Ireland Interviewee R offered the following explanation:

> *R: "I think we're taking EU money and if we get EU money we'll spend it. And at the moment there is no other source of money for research unless Brussels gives it to us."*

Interviewees P and PM mirror this thought referring to R&D as being "handed down from the EU" or that " ...you need to have policy buy in" in order to get research grants.

On a national level, years of standard practice and habit in processes do not seem to be questioned or tested. This is seen as an issue for Interviewee R, when discussing building regulations considering the current ventilation methods as "Neanderthal", and by Interviewee P when discussing the BER procedure:

> *P: "the question on reliability of DEAP. As far as I know there was not much consideration of the reliability of it, it's what we had"*

Although previous, related literature on policy barriers in the field does not specifically identify the current processes as inhibiting innovation and initiative, a reluctance to invest in unproven technology at an international level has been identified (Reddy 1991). Fear of the unknown was also seen in the literature as a human behaviour resulting in the rejection of new policy actions (Fagan, O'Hearn et al. 2001).

Process barrier 3: A process for prediction that lacks scientific rigour

The BER system was uncovered both in the desk study and from interviews as one of the main methods of evaluating the current energy efficiency of Irish homes as well as the potential savings in the sector. However, the attitude towards the BER procedure is ambiguous. Individuals tended to perceive it as both a good and bad. Interviewee P believed it to have merits, though not very reliable:

> *P: "From an engineering point of view there are holes in it, but in terms of being able to use the same thing for all houses and can be used by many people.... You take away any of the mega variables. So despite its issues, it's not the worst."*

While it is often referred to as being a step in the right direction "working with what they have" (Interviewee R), or a good method for drawing comparisons between homes, its use in predicting savings is seen as misuse by Interviewee R particularly:

> *R: "It is very dangerous to use that to predict energy savings, to use it to predict energy savings for a PAYS[20] scheme because you are going to mislead people and you are going to lead them into debt....the government is gonna say "oh we can save all that carbon" and they're gonna report all that carbon using DEAP but actually they're only gonna be able to save that much carbon* [referencing back to the BER scale and the line he drew over it showing that actual savings are less than predicted]*."*

The cited reasons for the perceived unreliability of BER originate in the assumptions it makes (Interviewee P) and the unknown difference between predictions and actual energy use (Interviewee R and the scheme expert – Interviewee 'S').

Policy Instruments 1: Grants are not the answer

At the time of writing the BEH scheme is grant based only. It is unlikely to change over to a new financing model until 2014 (financing expert - Interviewee 'F'). The process of using grants was described by four out of the five Interviewees as "free" or "free money" (Interviewees P, R, S and F). It is also seen as a popular policy tool with the public (Interviewees R, S and PM) and all Interviewees stated that the offer of grants had a big influence on the number of people retrofitting. However, the grants were considered by most of the stakeholders to fall short of the required uptake Ireland needs in order to achieve 2020 targets (Interviewee P, S, PM and F). Interviewee F claimed:

> *F: "if you're on a handout thing you haven't cracked it, you haven't made it normal, you haven't made it something that people think they should do for its own sake"*

Only one out of the five interviewees was very much in favour of the original grant system and felt that it needed to be kept on. Others were much more ambivalent, as Interviewee PM exemplifies:

> *PM: "After being involved in energy efficiency and grant programmes since 2009, I'm sort of turned off grant programmes to be perfectly honest, the policy drivers should be elsewhere in the system."*

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20 Pay As You Save, as introduced in section 1.5.2.6

Grants were referred to as sending the wrong message (Interviewee PM), costly (Interviewee PM), limiting market of people who have available funds (Interviewee S). Grants were also perceived to devalue the real benefits of retrofit, as Interviewee F describes:

> *F: "There is also the thing that if you offer something for free then nobody puts a value on it."*

Policy instruments 2: weak regulation

Interviewee R proposes that the lack of regulations of certain trades, involved with the grant scheme, means that the same solutions are prescribed for every home. Each case is different and needs its own design. Two of the interviewees were concerned with the lack of regulations of retrofit processes outside of the HES/BEH scheme, or "off-grant" retrofit, fearing that this leads to subpar standards of efficiency.

> *R: "creating a legacy of defects and problems [because] work is being done, it's not audited there is no quality assurance by contractors who are not registered by SEAI and standards are not met so I think it's a disaster"*

> *S: "we'd have very high quality standards associated with the grant so it's a rigorous quality standard. I imagine there are builders out there who are happy enough to work away at a reduced price, suggest to people to not take the grant"*

Furthermore, Ireland's late arrival to building regulations is thought to have been a major cause for the low energy efficiency of Irish buildings. Interviewee P also suggests that even after building regulations were changed to include energy efficiency standards, during the boom, these standards were not checked. P proposed that the regulations often do exist, but more auditing is needed:

> **P: "we have enough regulation, just no enforcement."**

Resources

Resource restraint was a common grievance articulated by the interviewees. Interviewees expressed an eagerness to progress and make real efforts towards 2020 targets, but the lack of resources was thought to stymie this. This was presented as a barrier to better consultation and engagement by Interviewee PM:

> *PM: "again it takes time and resources and we are very very very stretched, far too thin to be perfectly honest."*

The time restraint is presented as one of the reasons for government bodies not looking into academic research by interviewees S and F. Resource constraints extend to the number of people employed in the sector:

> *PM: "it's a huge amount of work to get done for effectively three policy people in here...it's very very difficult to run an engagement."*

Interviewee R also encountered the limitations of progress in government bodies due to lack of manpower:

> *R: "people retire and aren't replaced...at a time when what they should be doing is building up a really good strong technology base and all the rest of it."*

Interviewees P, PM and F have also encountered this and suggested it as a possible reason for the lack of interaction with academic research. But money seems to be at the root of all resource restraints, with changes to policy efforts expressed in terms of the available funds. As Interviewee PM proclaims:

> *PM: "...we review in the context of the budget discussions each year in the context of our available envelope, what can we do.... we can tailor things to the money. So if we get lots of money we can do lots of things, if we don't then we can't do as many things."*

This is a view shared by Interviewee's F and S. In Interviewee S's opinion, the government has to choose carefully what to finance during the economic downturn:

> *S: "in a world where you've got no money you gotta cut the cost somewhere....so instead of doing the HES they're gonna build a hospital or something"*

This is exemplified by the cutting of the 'power of one' campaign as interviewees S and PM point out. Nevertheless, in S's opinion, such refocusing has been experienced across Europe:

> *S: "It's not Irish specific, it's all across Europe, and governments are looking to not spend as much money.....it's about getting it done without governments having to put the money up"*

Not only does lack of money prevent the progress of policy creation and improvement, it is also listed by interviewees as a major reason for the low uptake of energy efficiency retrofit by the public (interviewees P, S, PM and F). As P highlights:

> *P: "...the key thing is finance, people don't have money, people aren't spending..."*

Economic downturn and resulting lack of disposable income was identified in a previous study on domestic energy efficiency in Ireland (Clinch and Healy 2000), however, this study predated the current downturn, referring to the previous recession of the 1980s. So while lack of finance is thought to impact the number of people retrofitting, it was also thought to limit the depth of retrofit people are getting done. This is an opinion shared by interviewees P, R, PM and F. Though P argues that people do have the money, but are not spending it.

> *P: "..., so you get people spending a little bit and a bit of stability in the market, people relax and you'll get people more likely to spend...I mean people have money"*

The need to get people spending again in the sector is reflected by Interviewee PM:

> PM: *"....*[it's] *a recessionary reaction all across Europe, which ironically results in a reduction of the economy which is a natural reaction, but not a good macroeconomic reaction."*

5.4.3 Successes, learning and potential for change

Harmonisation: a shared learning

Evidence of interaction, collaboration and learning from and with EU countries was scattered throughout the interviews and spoken of in a very positive manner as "great", "useful", "very good" making things "more joined up", "sharing information" with "a lot of learning there" by interviewees P, R, S and F. As Interviewee P succinctly puts it:

> *P: "The EU is all about finding things that work and replicating it"*

The EU is described as organising regular meetings and workshops where relevant people from different countries across Europe come together and share their experiences. It is seen as a way of not duplicating work that has already been done successfully (Interviewee P); a platform for sharing the Irish experience (Interviewee P); a way of informing European legislation based on Europe wide studies and experiences (Interviewee P); explaining new legislation and how to enact it (Interviewee P and R); discovering how other countries have implemented legislation, their failures, successes and learning (Interviewee S).

> *P: "that's one great thing with the EU is that people collaborate, there's more openness so you are doing a project and if you can find something that is similar in another project you don't actually keep doing the same thing, you collaborate or you help or you get some of their information"*

Previous research on climate change policy tends to view the strengthening of agreed international actions and processes as an area for improving success in actions (Hale, 2010)

Germany was mentioned several times in discussions (Interviewees P, R and PM) as showing exemplary policies and structures for reducing energy use. This was in specific reference to the quality of their buildings, but also in their financing mechanisms for retrofit based on achieving set standards. The UK was also discussed as a country which Ireland can learn from for very different reasons. Mostly it was in reference to the UK's Green Deal[21], with Ireland able to learn from their mistakes, or as Interviewee F puts it:

> *F: "I think that they have been great at going over to the UK and figuring out what's going on there – we've been quite lucky in that the UK's almost two years ahead of us."*

The idea of learning from others in order to reach a common goal was a common theme running through the interviews. As Interviewee R asserts:

> *R: "I believe were at the stage in history where we should share everything and open source research....we don't have time to try to be secretive and if you have important information everyone should be able to have access to it"*

A refocus to the greater good and the common goal: a paradigm shift

Interviewees suggest that the entire system needs to be overhauled. Interviewee F summarises that there is a need to make energy efficient behaviour "normal" and retrofit something that people should do "for its own sake" and not because they are being forced by regulation or incentivised by grants. Interviewee PM also uses the concept of normalising a new behaviour/ attitude and culture:

> *PM: "we need to normalise this to people's behaviour so they engage and understand the consequences."*

However, the converse argument is that regulation is necessary as the choice is removed. Interviewees PM and F both propose that the "carrot and stick" approach to policy making for energy efficiency is the best method to reach 2020 targets. PM proposes that by introducing a

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21 The Green Deal in the UK has fallen far short of its estimates with only 1,612 households having Green Deal plans in progress at the end of 2013, compared to the 10,000 estimated leading the UK Government to seriously consider scrapping the Golden Rule (Shankleman, 2014). Government mulls scrapping Green Deal's 'golden rule'. www.businessgreen.com.).

suite of measures, which all deliver the same message, would ingrain energy efficiency in people's minds:

> *PM: "...that you put in mechanisms that embed concepts into the psyche of Irish people. That they understand that there is a positive and a negative depending on them participating and that's why I think you need policy drivers in the system to drive the activity"*

This expert explains that the government needs to make energy efficiency and sustainability their ethos as leaders:

> *PM: "So you need to say "this is where we want to be", it becomes a societal issue. We need to do what the Danes have done or the Germans and say "this is who we are" and therefore all our policies will have that objective. And we will effectively force our own departments to look at their policies and say "what can we do to assist this policy?"."*

Interviewee R believes this is why Germany has been so successful as their whole economic and political system reflects the message of sustainability:

> *R: "...in 1991 the government made a decision to go after renewable energy and sustainability, that's why they have such a huge export business in photovoltaics, energy efficient hardware etc.....When you buy a house in Germany...the buyer has to within a year of buying bring it up to a minimal standard of energy rating. So if you are gonna buy a G rated house the price reflects the money you are going to have to spend doing it up."*

Process solution: database and prescribed solutions

The unknown impact of energy efficiency improvements has also been highlighted as a barrier to retrofit in previous studies (Clinch & Healy, 2000, Baek & Park, 2012). The suggestion of a database of Irish houses along with details of their efficiency levels was made independently by three interviewees who saw this as a gap in the knowledge and a way of advancing progress in the field. It was suggested by interviewees as a way of supporting scenario projections for energy saving potential in the sector (Interviewee S), by aiding in the reliability of predicting savings that each measure could provide for each house type and demographic (interviewees P and R):

> *S: "The biggest gaff is we don't have a great dataset with thousands of homes, we have BER of some and then you'd like to know things about their demographic and social status as well so all of that plays a huge role"*

However, Interviewee R goes a step further and would like to see a database which included ex post facto monitored data included so that the predicted savings per measure, per house type, would be based purely on experienced savings. Essentially the model could suggest a prescribed solution which would give the most effective and efficient retrofits. The concept of a prescribed solution as a better solution was another repeated theme in the responses. This was brought up by interviewees R and S on several occasions throughout their interviews within different topic arenas. Interviewee R mainly focused on using prescribed solutions to get over sealing the building envelope versus increased ventilation contradiction:

> *R: "They tell me that using gas for cooking, heating and hot water their annual bill is €500 .... So yes you can do it, but it was designed..... at the time I was in contact with the right people and they used ESP-r simulation to design the vents for that house type"*

Though the topic was mainly discussed in terms of a new financing model where the move is towards offering several financing options for the public to choose which one suits them the best. S describes it as "the best package of measures rather than putting all their eggs in one basket" and F agreeing:

> *F: "One size does not fit all, one person wants a loan, one person wants cash back, one person might want income tax rebate another it might not suit them.... you can segment the market into 4 or 5 chunks"*

But it was also discussed in terms of making predictive models better which in turn inform future policy:

> *S: ".....all our efforts now on the modelling side is to look at the demand and space particularly in the residential sector and to try to divide that into different cohorts, so who's got a mortgage? What energy savings potential is in households with mortgages? Who's renting? What sort of energy savings potential is* [there]*?"*

This is called targeted marketing with interviewees S and F suggesting the need to have targeted marketing aimed at the different groups defined under the future new financing options. Interviewee P explained that targeted marketing is not a new concept in this realm as HES marketing employed this tactic. It is difficult to determine exactly how effective this marketing method has been for the HES/BEH. It may identify the means by which occupants initially subconsciously learned about the scheme as indicated in section 4.4.6.

People focus: Word of mouth and reaching the tipping point

The consensus among interviewees was that the technology is available, therefore the focus needs to be on getting people to adopt it. Interviewee F describes how without people buying into a scheme, it will not succeed:

> *F: "to me the key is always the consumer. You can design things to suit banks, electricity suppliers, banks, SEAI, contractors...if the consumer doesn't buy it....you've failed. The number of retrofits that get done on homes every year is the measure if you're a success"*

However Interviewee PM suggests that instead of bending to consumer preferences and attitudes, what should be done is to take people out of the equation, and remove the choice:

> *PM:"...we need to make sure that every product going into every house is super efficient... I'm a big believer in the more we take out of people's decision making processes the least amount we leave to behavioural issues the better chance we have"*

The current method of creating new HES/BEH clients, as experienced by many of the interviewees, is based on someone they knew already having received the retrofit (interviewees R, S, PM and F). As Interviewee R has experienced there is usually a first mover in a group of housing, who gets the retrofit under the grant scheme. Once this is complete, a large number of different homeowners from the same group of houses follows suit.

> *R: "We've found that if we get one house on a street, we put up a sign while we work and nobody comes near you, and you go away, remove everything and three weeks later you might get a call from someone who lives down the street and saw this going on and when we went away they went and talked to that person who got the work done..... We spent a fortune on advertising all the conventional routes, didn't work, wasn't cost effective, couldn't afford it. Had to stop"*

A number of reasons were assumed for this "word-of-mouth" or "community" effect. Trust was mentioned as one of the reasons. Trust as people are thought to be more likely to trust their neighbours than the government:

> *PM: "Irish people believe and listen to neighbours, people who have had positive experiences."*

R: "Trust is the biggest issue. People don't trust the governmet...Trust and the relaying of information are the two biggest obstacles to retrofit happening, solved by people having access to local information"

Distrust of politicians is a commonly identified barrier in climate change policy literature (Clinch and Dunne 2006; Lorenzoni, Nicholson-Cole et al. 2007; Hale, 2010). As included in the above response, local proof and action were also suggested as reasons:

S: "and even when there was snow all around the place and you could see the people who had no insulation the snow melted off their roofs"

Again local delivery and examples is a common method highlighted in the literature to encourage greater action (Fagan et al., 2001, Lucas et al., 2008).

Competition was another proposed reason, as exemplified by Interviewee R:

R: "...there is a company called O-power... tried different tactics, one was 'save the world be green', one was 'save energy save money' .... the only one that work was 'did you know your neighbour spends less money on heating than you do?'. It was competition, and to do with your neighbour."

Another reason suggested was the preference for face to face information seeking which Interviewee F believes to be normal human behaviour:

F: "I've talked to the likes of "behaviour and attitudes" who are people like that who do research and they say that's not unusual...it's how people tend to do it; they prefer that face to face"

That is how people currently are perceived to be 'tipped' from considering (or not) retrofit to actually doing it. The interviewees also highlighted a number of gaps and even made some suggestions during the discussion which could encourage retrofit and more energy efficiency in homes and in behaviour. The most prominent gaps included:

1. The need to create competition:

As discussed above and mentioned by both interviewees R and S;

2. Education/knowledge (P,R and PM);

Interviewee P suggests that people should be educated about building physics and energy use to a much higher degree:

P: "Look at how much people know about their car, its horsepower, engine size. There is a real lack of knowledge of buildings. I think it should be taught in schools."

Interviewee PM agreed in part. He also noted how little the clients of HES/BEH understood about retrofit and energy efficiency. Nevertheless, Interviewee PM did not regard this as a significant gap in the efforts to reach targets.

3. Local action (P, R and S);

Local action was discussed positively by the three interviewees. Each described local action as a display of local evidence. In addition, the smaller scale creates more favourable conditions for action:

P: "But local energy agencies are really where we need to focus [because] that gets people on the ground and gets people to focus, get people to do things"

4. Need for a simple and easy system (P and R);

Simplicity of design as a means to aid public understanding was discussed in terms of technology interfaces between occupants and the energy efficiency measure, as well as in terms of the new financing mechanisms. The interface between sophisticated systems and the occupants who use them have been shown to cause misuse of the systems. This, in turn, leads to uncomfortable occupants and confusing energy bills because the system isn't used correctly or to its full potential. Interviewee R has encountered this many times and so highlights it as an area to focus on:

R: "...the answer is people, it has to be dramatic, quiet, working away in the background and people don't have to tweak and twiddle the thing [otherwise] it's not gonna work"

For the new possible financing options Interviewee P believes that whatever options are decided upon after consultation, the public needs to find them easy to understand:

P: "But the PAYS... it took me ages to get my head around it...There are so many loose ends. People want to know; "ok I pay this and I get this back"."

5. Awareness of co-benefits (P, R, S and F);

Highlighting the 'co-benefits' of retrofit were brought up a number of times by interviewees as a method to convince people in the public as well as people in government, to invest in energy efficiency. These benefits appear to be well understood by the four interviewees that mentioned

them. In government, co-benefits means that applications for funding can be made to different departments and gain support from different bodies such as health organisations to "get more backing as P puts it, and R agrees:

> *R: "the National Health Service can turn around and say "we support retrofitting because it's reducing our costs" and that's what the government is trying to do to reduce the cost of the National Health Service. It's joined up thinking and all that."*

Conversely, related Irish literature identifies the cross disciplinary nature of domestic energy efficiency policy as a barrier (Clinch & Healy, 2000).

Nevertheless, the intangible nature of co-benefits can make this a difficult argument:

> *R: "there isn't cash you can count, you don't get receipts for it"*
>
> *S: "in theory that's all the government needs to know and they should spend that money....but in a world where you've got no money you gotta cut the cost somewhere"*

On the other hand it appears that there is an effort at the European level to educate policy makers about co-benefits:

> *S: "I did a workshop in Copenhagen ..... and they're gonna produce a handbook for policy makers including the health impacts, mental and physical health, and then there is a whole bunch of other...so there are huge benefits looking at these in a bit of detail quite seriously and looking to get policy makers to incorporate them"*
>
> *F: "you've got to remember, and it's the thinking all across Europe, the wider benefits. The socio-economic benefits – comfort, wellbeing, health issues...it even stems into education, that kids studying at home do better at school, there is some research on that...and there is you know, don't forget that apart from savings to energy bills, you've increased the value of your home by somewhere between 3 and 5%, this is from the BER perspective"*

While for the public, the co-benefits are thought to be a way of convincing more people to retrofit:

> *F: "You've gotta communicate to people that this is a good thing for them to do in and of itself, for their comfort, their health, also their savings"*

Four out of the five interviewees commented that comfort is categorically the main driver for homeowners choosing to retrofit, for example R and F state:

> *R: "If you think about it; it's comfort. It's not CO_2 savings, it's not energy savings, it's comfort"*
>
> *F: "I'll tell you now from all the research in here, it all points to comfort."*

6. The need for progressive change (all).

The need to introduce change in a progressive manner was affirmed and reaffirmed throughout the interviews by all interviewees. It was consistently mentioned in reference to the changeover to a new scheme or financing model as a phasing in:

> *P: "Absolutely, I think this should be a phasing out, like a reduction in the amount of grants over 2 years as you phase in your PAYS or something"*

This phasing in requirement appears to be as a reaction to the difficulties and failures seen in the UK's PAYS or Green Deal difficulties, meaning that the Irish change will be more cautious and involve more piloting:

> *S: "I'd imagine they'll have to take a look at that because if they get rid of grants and flick straight to this PAYS system it's untested and failing in the UK. We could really fall off a cliff in terms of deployment"*
>
> *F: "and trialing, testing and piloting because that's where the UK has lost out. ... the recommendation is slow, gradual introduction, test, pilot, let's not think were gonna do this big bad launch"*

Progressive change was also mentioned several times when discussing deep retrofit. It was stated that the government's effort has also been refocused from encouraging deep all-in-one retrofits to gradual upgrading of the home over many years.

> *R: "We've had customers who have become repeat customers...they don't have enough money at the time to do it all in one and I don't see a big problem with that actually"*
>
> *PM: "that they are given a clear pathway so when people come in they can say well I can do my attic insulation or I can do my cavity, when they do that they can be given a pathway of future measures..... and ideally you encourage them in and it becomes*

something of a journey towards 2050 as opposed to saying no you must do a deep retrofit"

F: "it's about taking the consumer on a journey that feels comfortable for them, doing it in chunks that works for them"

Finally, progressive change is talked about in reference to changing people's behaviour, attitude and culture to that of a more energy efficient one. Efficiency should thereby be a "badge of honour" (Interviewee S), creating "societal change" (Interviewee P), which "normalises" a new behaviour (Interviewee PM). It was claimed that until this change occurs – Ireland hasn't "cracked it" (Interviewee F). Interviewee PM talks extensively of the need to instil the longer term message of sustainability to create a paradigm shift in people's thinking:

PM: "That's the message in people's head as opposed to a longer and more sustained message which is "this is bad for the environment" "this is bad for....lots of other reasons" and therefore we need a fundamental shift in behaviour"

"If you go back the NEST[22] research I think they talk about a paradigm shift. I understand that that would reflect my own beliefs, that we need to normalise this to people's behaviour so they engage and understand the consequences"

5.4.4 The research-policy gap

The main purpose of questions under this heading is with a view to understanding how the research from this project (and other university based research) could inform future policy in the field.

A different world

Four out of the five interviewees assumed 'research' referred to in the questions did not refer to university or academic-based institution research but instead discussed the topics in reference to government-based research only. It was only after specifically asking about the links with academic research that the conversation would move into that sphere. Research, it seems, as they are used to encountering it, is not from the academic arena. Furthermore, most rated their knowledge of research within the area from 'low' to 'medium' with just one rating their knowledge as 'high'.

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22 New England SusTainability consortium (NEST) has the goal of advancing the scientific basis of decision-making regarding sustainability challenges through a co-production process involving collaboration between researchers and diverse stakeholders (www.newenglandsustainabilityconsortium.org).

The aims of academic research are seen as different from those of government organisations, with academics focusing on getting published rather than informing policy, as Interviewee PM puts it:

> *PM: "One of the big problems is academics generally like to be published, but we don't subscribe to academic journals and all our policy makers don't"*

Even when a government-related body is involved in academic research, they do not necessarily view the research as being relevant to them, as Interviewee F explains:

> *F: "we probably assume universities have their audience as well....we think it's good and we'll publish it and part fund it and all of that but probably we're not specifically thinking we're gonna take that piece of research and run with it"*

Interviewee P examines the process from the other direction demonstrating that there is also not much evidence of government bodies attempting to infiltrate the academic world:

> *P: "I know SEAI; it's a public body and it's not their mandate to publish journals like that. It eats into the time that they should be doing other things, getting stuff done...They aren't a research group, they aren't a think-tank"*

There is evidence that this attitude could originate in EU funding, directives and communications.

> *R: "I think that the EU is about is a shift....So for FP7, it is industry led. Up until then with FP6 it was over 50% academic institutions."*

Government or EU-led research is generally viewed as being "closer to market" (Interviewee F) than academic research. It was proposed that the national focus change was a follow on from EU-based advice:

> *PM: "I think one of the results was that energy research was overseen by this department as opposed to Science Foundation Ireland."*

Interviewee S proposes that goals of policy makers and researchers should be aligned:

S: "I suppose getting the whole engine driving in the same direction as opposed to research being some kind of seething mass of all things going on instead of looking at things that are kind of interesting but not really related."

Onus on the researcher

All of the interviewees were very open and available to the interviewer, very eager to assist and answer any questions posed. However, as with much academic research that is not funded by industry, there was no other way that the interviewees would have been made aware of this research project without the researcher initiating it. Terms such as getting 'on the radar' (Interviewee S) or 'knocking on our door' (Interviewee F) were used in reference to researchers getting noticed by policy makers.

Furthermore, they expressed interest in publications, research findings, and future work of the researcher with most asking to keep in contact after interview. They suggested ways in which research findings can be brought forward by the researcher include:

1) By bringing the knowledge and skills acquired into a position which influences policy after an academic project is complete (Interviewee P and S);

   P: "People do this great body of work. And if they are gonna stay doing research in that area you refer back to it and develop it and that's how the research gets brought forward."

2) By presenting or sending out findings to the relevant influential bodies (Interviewee R, S and PM);

   S: "...and really it's when we have someone like you comes to me and says look I'm looking at this that you get on the radar"

3) By fostering long standing relationships with the relevant bodies (Interviewees PM and F)

   F: "We have connections with universities, so they would tend to, and it's probably more personality based, if somebody new came into the area and started doing a piece of research how would we know about it unless somebody came knocking on our door?"

4) By getting published (Interviewee P and R)

   R: "And you've done one good thing to get your findings out there is you have a journal paper and it's peer-reviewed and you can show that to people."

Go-between

The need for some sort of go-between academic research and industry or government was proposed by four out of the five interviewees. The hypothesis was posed to the final interviewee who was very supportive of the idea.

The platform for creating this relationship was suggested as a 'think-tank' to compile and disseminate relevant findings to relevant players (Interviewee P) or 'working group' (Interviewee F). That is, a person or people who can summarise the essential findings in journal papers, as Interviewee S suggests:

> *S: "what they want is for you to say "look this is what the literature is telling me" and give one two three bullet points... you need people who can somehow be in the middle"*

The idea of a national database of research online was mentioned by four of the interviewees, for example:

> *PM: "one of the things I would like to see is a repository of freely available research"*

> *F: "Or even a working group of the various bodies that produce this stuff to come together to say let's come up with a national database"*

Alternatively, a government provided online forum for discussions and research questions could be posted to inform academic research design:

> *R: "some of the ideas I had were we could have a forum on our website where we can share data and interesting policy questions for people who are doing masters and PhDs"*

Journals and academic language

Journals were highlighted as barriers by three out of the five interviewees. The cost to gain access to relevant journals or subscribe to them is too high for industry or government related bodies to deem them worth investing in. Interviewee R stated:

> *R: "Say in here, because we are not an academic institution, we can only get abstracts for papers not the full thing, unless we pay a load of money to become a member and you know it's a pretty hefty fee."*

Further to access, the language used and depth of detail required for publications were viewed negatively:

PM: "As a lapsed academic myself, it's horribly written, so not very accessible, that's one of the problems, it's written to demonstrate how good they are at writing"

It was proposed that in order for those influencing policy to take note of journal findings, they need to be made into "one, two, three bullet points" by "someone who knows how to message things" (Interviewee S).

5.5 Summary and discussion

The interviews took place at a time of change, just before a consultation document for new financing mechanisms for the scheme was published. Interviewees had all been immersed in the field for many years and involved with the HES and BEH schemes in differing capacities. Despite the different expertise and experience areas, many common opinions, experiences and gaps emerged during the analysis of the interview transcripts.

5.5.1 Triangulation – testing hypotheses and exploring them further

Irish action in the field originates in the EU

The desk study conducted by the author identified that Irish advances in residential energy efficiency originated from EU publications and directives. The most relevant ones to this research topic were presented in Table 1. There were few examples of Irish specific research in the publications despite the fact that the expert interviewees proposed that the Irish context needs to be specifically designed for.

As presented in this chapter, EU harmonisation was discussed positively by the experts and believed to create an efficiency of actions as Ireland can learn from other countries methods and experiences with a united goal. However, the author identified this harmonisation as stymieing the creation of original and case specific solutions.

Understanding of the client of HES/BEH as anti-loan, having available savings and seeking comfort

The most recent research on energy efficiency retrofit and the consumer was conducted by the SEAI and published in their consultancy document immediately after the final stakeholder interview was conducted. This publication included a focus on barriers to consumers as included in Table 3. Therefore, it was not surprising that this is an aspect which the interviewees had thought about and had some level of understanding on. The findings from section 4.4.6 that the driver for the current clientele was comfort was well understood by interviewees and not interpreted as an issue.

Secondly, the reluctance of occupants to take out a loan is also well understood by the experts and further identified by the consultation document. Despite this clear identification, the movement towards more loan-style support mechanisms was confirmed by interviewees as in the future for the scheme. All interviewees believed that the barometer of how effective a retrofit policy is whether people buy into it. However, at this early stage of consultation on the new marketing mechanisms, identifying and targeting new demographics was not on the priority list. Furthermore, government related documents tend to still include and attempt to 'sell' the idea of loan-style funding mechanisms. This perhaps is another example of EU harmonisation resulting in Ireland following suit despite acceptance that the new design may fail. Without piloting these possible mechanisms, the future uptake of the scheme is uncertain.

Similarly, they understood, and independently identified word-of-mouth as being the third pillar in client description. Though no interviewee identified this as a method by which major change could be harnessed.

Identification of knowledge gap in <u>real</u> impact of energy efficiency retrofit and the importance of filling this gap

The experts identified the gap in understanding real *in situ* energy efficiency in residential buildings and the changes that retrofit can make as a barrier to designing schemes and predicting their outcomes. This highlights the previously identified relevance of this research and the gap in the knowledge that the importance of the previous chapters intend to contribute to closing.

5.5.2 New hypotheses

The gaps which remained in the research findings from previous chapters were the barriers, successes and potentials to incite greater impacts from the perspective of those who influence the policy. Many of the findings reflect previous national and international research in the specific field of retrofitting and the broader context of climate change policy as referenced in section 5.4. In combining the findings, the impression of over-cautiousness was interpreted by the author. This was reflected in the common reliability on old and inefficient methods within regulation, auditing, standards and communication as well as the blind following of EU directives and methods. This over-cautiousness appears to be enhanced by the lack of resources and the unknown potential. This combination means that predictions of potential are unreliable without the resources to adequately pilot or research alternative ideas. The first step is understanding the current situation properly.

Furthermore, the author wished to gain an understanding of how to take her own research further in order to have an impact on policy. In analysing these answers it became clear that academic research could be the solution to the resource restraint which hinders energy efficiency policy. This is discussed in greater detail in the concluding chapter.

5.5.3 The root of the problem

Figure 54 presents the previously discussed barriers and resulting issues which have been perceived as the cause of the HES/BEH and related policies falling short of their targets. The overarching barrier of limited resources was identified as the common theme running through the discussions. Low resources have lead to many unknowns and no ability to investigate these unknowns. This has meant that a cautious approach has been taken in actions and an over-reliance on the existing, flawed system.

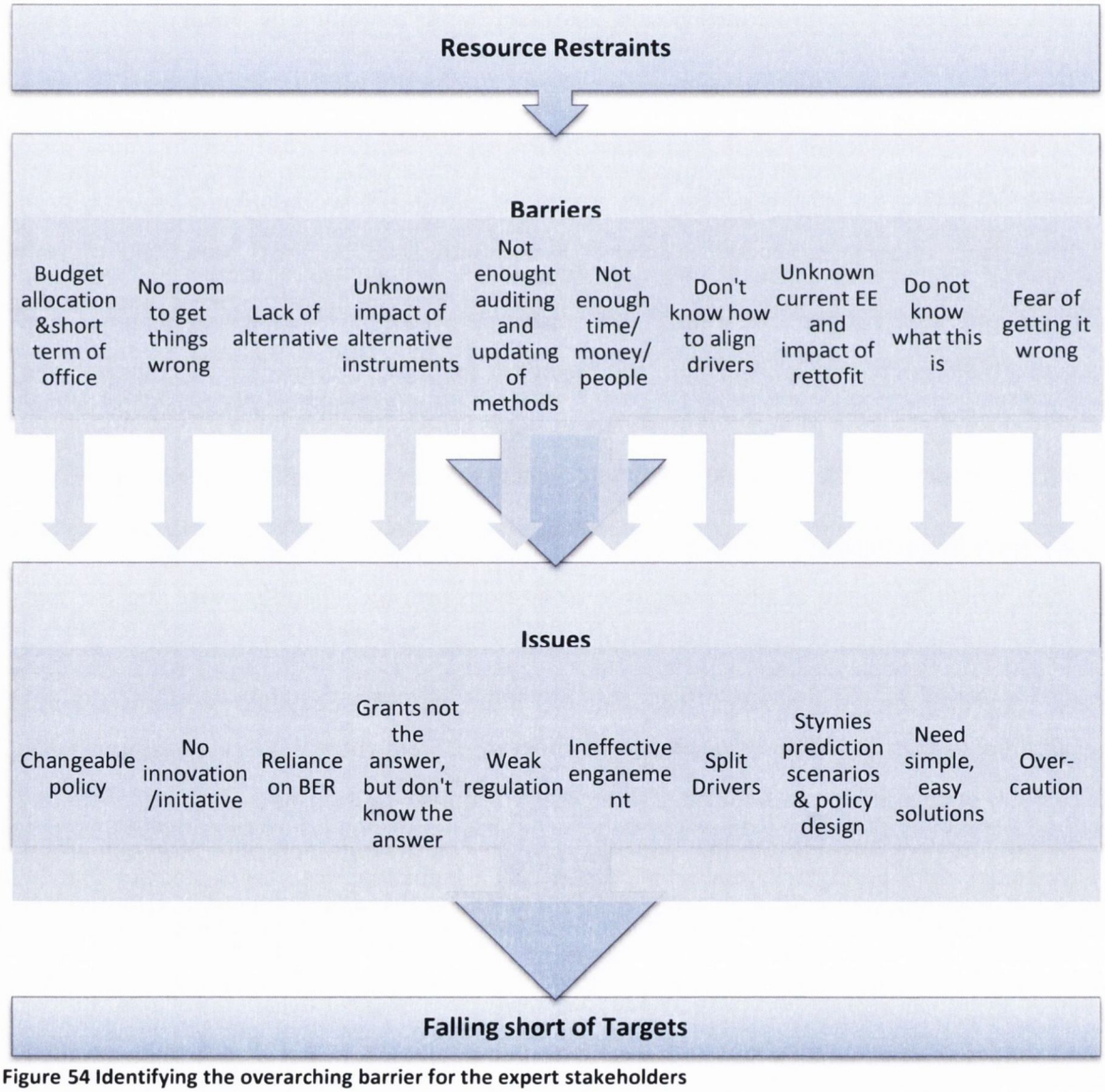


Figure 54 Identifying the overarching barrier for the expert stakeholders

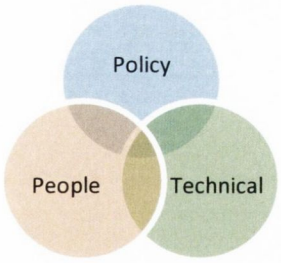
The identification of this overarching barrier has lead to the decision to focus on mitigating it in the next concluding chapter.

5.5.4 Limitations and reliability

Although interviewees were explicitly asked to present their own views and not that of their organisation, number of times terms were repeated such as "no silver bullet" and taking the occupant on a "journey" to retrofit. This suggests that this may be common dialogue within the policy arena as opposed to conclusions individually and independently drawn. The presentation of an organisation stance as opposed to a personal one may have been facilitated further by the location for the interviews. Interviews occurred at a time and place that suited the interviewee. This was always chosen to be within working hours in their place of work. The interviewees may therefore have had an attitude of being in 'work mode'. A more neutral location may have resulted in more personalised responses.

Interviewees were chosen on the basis of covering all speciality types involved with the scheme at the policy making level. However, it cannot be assumed that their views are representative of all those specialising in that area and engaged with the scheme. The examination of the scheme could have been expanded to those not directly involved with the scheme, but still being well informed about it. This could have given rise to more interesting and diverse suggestions for how barriers encountered could be overcome and how the potential of energy efficiency retrofit could be realised without the influence of the government mission (though they may have their own motivations).

There can an agenda in the answers given by the expert interviewees. For example, the retrofit expert is involved in a number of new technology projects and hopes to gain support from the government in driving a market for these technologies. Within the interview, the interviewee was seen to refer back to these technologies several times.



Chapter 6. Discussion and conclusions

"What we find changes who we become."

Peter Morville

6.1 Introduction

This thesis has sought to evaluate the Irish residential energy efficiency retrofit scheme. This is the HES/BEH scheme. A multidisciplinary approach was adopted primarily rooted in technical engineering aspects, but drawing from the discipline of human geography to inform the methodology design and analysis. This was undertaken with the overall objective of informing stakeholders and policy makers on how to make the scheme more effective.

This final chapter begins with a short reminder of the steps carried out in the examination of the HES/BEH case study in section 6.2 along with how the research is an original contribution to knowledge. This is followed by the key findings and conclusions of the examination in relation to the overall objectives of the doctoral research in section 6.3. These conclusions allow for the formulation of policy recommendations presented and discussed in section 6.4. Finally the limitations of the research are discussed with a view to informing future studies.

6.2 Summary of the examination steps

The research began with a literature review and desk study to determine the current knowledge in the areas of energy efficiency policy and retrofit. This highlighted gaps in knowledge and determined that the validity of identifying the HES/BEH scheme as a case study worth examining with specific focus on wall insulation. A multidisciplinary approach was employed aiming to incorporate three perspectives. These were – that of the engineer, that of the occupant and that of the expert or stakeholder related to the policy making end of the scheme.

The technical examination began with academic literature research on methods used to determine the thermal properties of buildings and building components with a specific focus on previous studies into the effectiveness of retrofit. Further research was conducted into academic and industry standard practice in the field. From this a methodology was designed and pilot testing conducted on a vacant building. The final test procedure was then used on another

vacant dwelling before and after cavity wall and loft insulation was installed. From this a greater understanding of the effect that retrofit has on the thermal behaviour of a building under heating up, steady heat supply and cooling down conditions was made possible. This tested theories of behaviour on a real *in situ* case study and informed both the design of a new rig for wall testing that followed and the methodology and analysis used for further site studies.

At a stage when some of the site studies were completed, it became clear that a greater understanding of wall behaviour could be achieved by limiting the variables encountered during *in situ* studies. A laboratory test rig was designed based on these needs and drawing on previous rig designs, but tailoring to the needs of this doctoral project. Tests were completed on a cavity wall which was later fitted with external insulation and retested. The tests chosen were steady-state (which could not be facilitated on site) and a ramp up test which is a standard test used in simulations to examine the transient behaviour of the wall.

The in-use site case studies involved the additional understanding of dynamic heat supply to lived in homes. The first of these studies was semi-controlled, acting as a first step into the introduction of occupant behaviour. This building underwent two stages of thermal envelope enhancement by first introducing cavity wall insulation, then introducing external insulation. A north facing and south facing room were closed off and examined before and after each of these stages and added to the understanding of a building with intermittent heat supply (as is the case with residential buildings). The site cases which followed included either cavity wall or external wall insulation as part, or all, of their energy efficiency retrofit. These studies introduced the unknown and variable influence of human behaviour to the investigation. The occupants were allowed to use the building and the heating system as they pleased during the pre and post retrofit monitoring periods. The overall aims for introducing this variable included the need to understand actual changes in thermal behaviour and heat energy usage due to the retrofit of insulation. As a result, the occupants had to be incorporated into the study in order to achieve this understanding. Surveys and interviews were conducted with occupants in order to aid the interpretation of the monitored data.

Interviews with the occupants also included questions aimed at extracting their experience of retrofit including the drivers and barriers from their perspective. In this way the occupant was treated as a stakeholder or client of the scheme adding to the non- technical objectives of the study. For the design of the interviews, careful consideration was given to the interview method. A semi-structured, in-depth interview format was decided upon.

The findings from the site studies informed the design of the expert stakeholder interviews. Again, careful consideration of interview method and questions were made. This drew upon previous examinations of energy efficiency policy. The interviews aimed to add to the findings already formed at this stage as well as fill gaps still encountered in the analysis. Experts were chosen on this basis.

Finally, the findings from all of the research packages were examined separately before analysing them collectively. This was done with a view to achieving the objectives of the case study project as will be presented in this chapter. The final conclusions then informed the ultimate step of the thesis which is to construct policy recommendations.

6.3 Relating findings to the objectives

6.3.1 Objective 1:

To add to the understanding of how Irish residential buildings perform in terms of energy efficiency due to the installation of cavity and external wall insulation introduced under the HES/BEH scheme

Impact of technical intervention on thermal behaviour of the building envelope – the results summary

It was found that steady-state conditions used in simulations from previous laboratory studies to determine R-value of the wall could not be recreated under site conditions. However, dynamic R-value was obtained for the site case 1. This is the instantaneous thermal resistance of the wall which is a reflection of how the wall is behaving at any given time and therefore is not readjusted using decrement factors. Predicted values were found to overestimate the change in thermal resistance, which in turn resulted in an overestimation of the potential of reduction in heat loss through the wall. The unreliability of using tabulated or calculated R-values was further demonstrated using the laboratory testing which revealed a thermal resistance of a cavity block wall sample to be at least 7% higher than the nearest prediction, with a 2% error margin. It is argued that focus should be made on developing better estimates of heat losses and changes in heat loss due to retrofit instead of relying on standardised R- and U- values which are so prevalently quoted during retrofit discussions in industry.

The first site case provided the expectations for the following *in situ* cases. These included, a reduction in overall heat loss through the wall, evidence of heat storage in the internal thermal mass layer and a reduction in both internal temperature, and heat flow fluctuations, post

retrofit. All residential walls in the case studies showed a reduction in the average heat loss. This ranged from 21% to 66% due to cavity filling, and 37% to 77% due to external insulation. For the controlled cases of site case 1, steady heat loss was attainable showing a reduction in losses of 56%. While values vary greatly, this does present conclusive *in situ* evidence that the addition of cavity and external insulation irrefutably reduces the amount of heat lost through the walls for the buildings examined.

The baseline heat losses to the wall were seen to reduce to at least 0 in all site cases. The implications of this are that the introduction of cavity and external wall insulation results in the walls no longer continually siphoning heat from the inner space. This limits the degree to which the internal environment cools. This continual heat loss even when the heat source is turned off was shown in the majority of the pre retrofit cases. This means that the internal spaces cooled to a much lower temperature.

The introduction of both cavity wall and external wall insulation showed evidence of enacting the heat storage capacity of the inner mass of the wall. This was shown in the in-depth case study 1 as well as in five out of the nine cases studies that followed. The result of this is that some of the heat that is stored in the walls is returned to the inner space when the heating source is turned off. The walls thus acted as a passive heat source.

The evidenced improvement in thermal behaviour of the walls results in a changing of the internal environment and how the occupant interacts with the heating systems available. Occupant comfort levels are more easily attainable by increasing the insulating ability of the wall and harnessing its heat storage capacity. However, this more achievable comfort was shown to result in occasional increases in energy used for space heating.

Impact of technical intervention on space heat energy use behaviour- the results summary

The unanimous result of improvements in the building envelopes' thermal behaviour was the increased comfort of the internal environment. This was evidenced by discussions with occupants. As discussed previously, comfort is a complex and subjective issue that is mainly dependant on temperature. Occupants were allowed to freely interact with the heating systems during the majority of the site cases. Therefore the impact of the interventions on energy use for space heating is not straightforward.

Where the heating system was controlled to be the same in pre and post retrofit monitoring, the average internal temperatures rose considerably. This was by 3.66°C for a constant heat supply

in controlled site case 1, and for the semi-controlled case of Con this was 0.3˚C after cavity insulation and a further 2.3˚C after external insulation for intermittent heat supply. The in use site cases generally reflected this finding in all but one case. These ranged from very low changes of 0.1˚C to much higher at 1.9˚C with no discernible difference between cavity fill and external insulation cases. As the occupants were free to use the heating systems as they wished, the implications are that the homes were not heated to satisfactory levels before retrofit, a hypothesis which is supported by qualitative evidence in occupant interviews. Each occupant reported that they were much warmer and comfortable after the retrofit.

The perceived increase in comfort is not only due to the average temperature in the dwellings, but it is also dependant on the baseline temperatures. Occupants reported that the "chill" was gone out of the house, especially after long periods of not heating (in the morning). Baseline temperatures were shown to increase in eight out of the nine site cases.

The uniformity of temperature throughout the site cases were shown to increase. In the controlled case the difference in temperature between the warmest and coolest rooms reduced by 3˚C. The remaining site cases were very variable ranging from insignificant changes up to 2.8˚C. Two of the site cases even showed a reduction in the uniformity, increasing the disparity by up to 2.2˚C. By combining monitored data with survey and interview evidence it was found that the variability between cases was as a result of a number of factors. Such factors included changes in the external environmental conditions, change in the use of supplementary heating devices, change in the number of rooms that are heated and the difference in thermal behaviour between an original building and building extensions.

It is generally assumed that retrofit results in less energy use. This notion is complicated by the occupant's aim to achieve a high level of comfort and the fact that such comfort levels are more attainable due to retrofit. Fuel used per day only reduced in three out of the five cases that could be measured. Furthermore the number of hours of central heating usage were only reduced in three of the seven measurable cases. There was even seen to be an increase in the number of hours of central heating usage in a different three of the seven cases. However these cases showed a vast reduction in the use of less efficient supplemental heat sources such as coal fires which are associated with greenhouse gas emissions.

Conclusions

Table 8 in Chapter 4 shows a succinct summary of how expected improvements from retrofit compare to the *in situ* findings. The site and laboratory testing showed that the introduction of

external and cavity insulation has a positive effect on the energy efficiency of the system. The conclusive improvement is the reduction in total and average heat lost through the wall. How this affects the internal environment and the use of energy for space heating is less certain. It was shown that while overall comfort levels increased, not all cases showed a reduction in heating fuel use or any improvement in energy efficiency behaviour. This compares poorly with findings from the UK's 'Retrofit for the Future' data which showed that the majority of retrofit houses experienced high CO_2 savings and great reductions in energy use from gas and electricity (Technology Strategy Board, 2013). It should be noted, however, that these were innovation demonstration projects which focused on integrated solutions so cannot be compared directly with the findings from this research. CALEBRE (Consumer Appealing Low Energy technologies for Building Retrofitting) homes project, which focused on solid wall construction showed similarly positive results (Loveday & Vadodaria, 2013). Findings from the CALEBRE project show that the order of retrofit impacts the time until payback. They recommend introducing wall insulation in the first stage as a high impact retrofit so as to yield the greatest cumulative savings.

The houses examined for this thesis saw a general improvement in internal temperatures in terms of uniformity, average and baseline temperatures. Both the UK and Irish clients of retrofit are driven by comfort as opposed to energy saving (Loveday and Vadodaria 2013). However, the improvement in comfort levels that the Irish client wanted from the scheme may have been greater than recipients of similar UK schemes. In all cases examined for this thesis comfort levels were reported to be "excellent" on Likert-type scale post retrofit, while the majority of 'Retrofit for the Future' UK homeowners reported their comfort levels as "good" post retrofit. Although sustainability issues were not of concern to the homeowners in this study, a beneficial by-product of the retrofit was the reduction in the use of 'dirty' fuels such as coal due to retrofit.

6.3.2 Objective 2:

To collate the learning from the Irish experience in energy efficiency retrofit policy at different levels and from multiple perspectives

The different perspectives of the occupant or client, the structural engineer and the policy expert were engaged in the case study examination in order to triangulate findings. This meant using different elements of the research to corroborate, compliment, contradict and expand on findings as well as fill gaps in understanding in order to create complimentary insights into the case study and the broader issue of energy efficiency policy

Current situation

As evidenced in the desk study, discussions with stakeholders and technical monitoring undertaken for this research, the houses in Ireland are of particularly poor quality with regard to energy efficiency. The reasons cited for this are varied, including the mild climate and poor, late or unaudited building regulations. Policy within the area is relatively new and mainly based in EU directives. The Irish political system is fraught with barriers to inciting more effective change after many years of policies based on public popularity, with a focus on re-election. Policies also focused on economic growth and therefore encouraged heavy energy using industries such as agriculture.

When attempting to enact the relatively new policy focus on energy efficiency and sustainability a major difficulty is encountered as resources run low due to the economic downturn. This is experienced in policy making. The full potential of consultation and public engagement, research, learning and piloting is limited as departments compete for funding. It is also experienced by the consumer who was shown in this study to be limited by costs of retrofit. The consumer was also shown to be against the prospect of loans to overcome this resource issue, which may be as a result of the banking crisis leading the public to mistrust both banks and politicians.

Drivers for change

As discussed for objective 1, technically, retrofits show an improvement in the thermal behaviour of the wall. In theory this should translate to a reduction in energy used for space heating. However, this has not been shown to come to fruition in all of the cases examined. It was hypothesised from occupant interviews that the motivation for the current client of HES/BEH is to increase comfort levels. This hypothesis was supported by expert stakeholder interviews. This goal was achieved, as evidenced in the monitored data as well as reported perceptually in interviews in the examined cases. This lead to reports of high satisfaction levels with the scheme.

There is a divergence in motivations to retrofit between the public and those involved in energy efficiency policy making. Policy makers' motivations are to increase the numbers of energy efficiency retrofits with a view to furthering the advancement towards EU 2020 targets. Experts acknowledge the importance of co-benefits of retrofit which added comfort can introduce, however, high levels of comfort take back limit the progress towards targets. Therefore there is a need to synthesise drivers.

Conclusions

Ireland is going through a period of change as attempts are made to realign the system. It is clear that much more needs to be done in order to reach energy saving targets of 20% by 2020 or a reduction in the national energy consumption by 31,925GWh. Projections show that the HES has contributed 365GWh until 2010, the GHS contributing 120GWh and the WHS contributing 130GWh, and that its continuation as BEH scheme will contribute a further 3000GWh by 2020 (Department of Communications Energy & Natural Resources, 2013). This is equivalent to 9.4% of the total required energy consumption reduction by 2020. Interviews with stakeholders revealed that such projections are primarily estimated through the DEAP procedure while determination of whether targets will have been met in 2020 will be made based on actual energy provision. The site cases presented in Chapter 4 suggest that the predictions for the impact of the BEH scheme are grossly overestimated, with very little, or no, reduction in energy consumption due to wall insulation retrofit. Without more extensive similar testing it is not possible to state this conclusively.

The Irish Government is currently focused on changing the financing mechanisms surrounding the scheme with a view to broadening the demographic, however, there is little discussion, or indeed effort, in how to achieve the assumed energy savings from retrofit. Under the UK's Green Deal "hard-to-treat" houses such as those with solid walls which require external insulation are not covered by The Golden Rule which uses a lifetime of 25 years (Booth & Choudhary, 2013). This presumption is reinforced by the findings in this thesis, that external insulation won't necessarily result in the required energy savings to offset the cost of the measure. Ireland is learning from the Green Deal's failures in the UK as consultancy is in progress for designing new financing mechanisms. However, regardless of financing mechanisms, Ireland cannot base future potential energy savings in the sector on the UK experience as Irish houses are on average of a lower thermal quality to the UK to begin with. In 2005 Irish houses emitted 47% more CO_2 than the average UK dwelling (Ahern et al., 2013). It is known that the poorer the quality of the house initially, the greater the comfort take back (Milne & Boardman, 2000). The findings from this research suggest that Irish houses are built to a poorer thermal standard than those in the UK. Uninsulated solid wall construction constitutes 26% of houses in the UK with cavity blocks not significant enough to show in statistics (Tahir et al., 2013). Cavity blocks have a much lower thermal mass than solid walls and so the heat losses through such walls both with and without external insulation is expected to be greater. The frequency of this wall type in Ireland results in many more Irish households having to opt for the more expensive and intrusive external wall

insulation, raising the cost of retrofit, increasing the payback time, and making the wall insulation grants more exclusive.

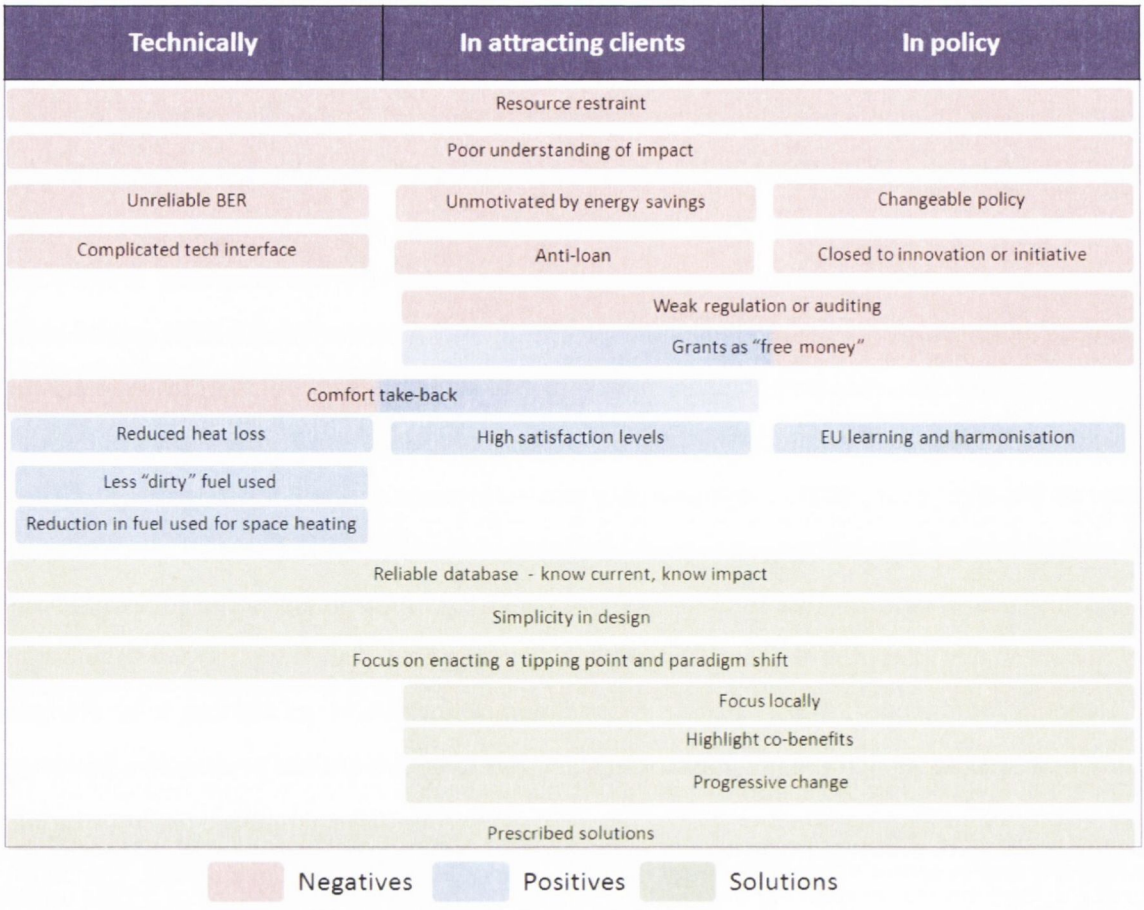
Irish policy makers and advisors should acknowledge that much of the retrofit under HES and the current BEH scheme is simply a first step in retrofit with the majority of energy savings is being sacrificed in favour of greater comfort. Lessons should be learned from better examples of successful retrofit schemes such as those adopted in Germany. Ireland is already looking to Germany as an exemplar of good financing for retrofit, therefore this will not be discussed here, however, there are other aspect of the German effort in retrofit which Ireland can learn from. While Irish plans appear to abandon the idea of focusing on deep retrofit, Germany's aims still include this (Neuhoff et al., 2011). German policy makers and advisors acknowledge that retrofit costs are higher than the resulting savings, however costs have been reduced by clustering of buildings for retrofit to form one tender (Cities, 2005-2010). Information is the focus used to move the consumer along the process to retrofit, advancing from "uninterested" to "planning, and "planning" to "action". These include mass media, information on heating bills, energy performance certificates and energy audits. Germany has long established prescriptive building energy efficiency requirements since 1977. The first performance-based code was introduced following the implementation of the Energy Performance of Buildings Directive (2002). The 2009 version and supporting policies encompasses many progressive aspects including, low maximum u-values established relevant to climate, mandatory computer simulation, air-tightness requirements, well established incentive schemes, frequent boiler and HVAC testing. Further to this, targets in the sector are highly ambitious, with aims to be carbon neutral in the sector by 2050 (Schirmer, 2011)

6.3.3 Objective 3:

To analyse the scheme holistically in order to highlight overall barriers, successes and potentials within the sector with a view to informing policy in the area of energy efficiency retrofitting and more generally

The following Table 13 lists the key barriers encountered under the three pillars of the examination. This is a triangulation of findings from the different methodologies adopted in this research project.

Table 13 Barriers, incentives/positive experiences and proposed solutions



Through the qualitative and quantitative analyses of the case study a number of positive findings emerged. Further to this, the discussions regarding barriers led to the uncovering of gaps in the knowledge and suggestions of ways in which more substantial energy savings could be achieved through residential energy efficiency retrofit schemes and general policy in the field. These are presented in Table 13 and are the predominant findings used to devise policy recommendations in section 6.4.

How this and similar research can inform policy

Currently, the onus is on the researcher to bring their findings to the attention of those involved in influencing or making policy. The stakeholders were very open to new research, though resource restraints make it difficult to sift out the relevant pieces to policy. Therefore, the suggestion of creating a go-between to bridge this gap was made. Suggestions included a database of research where stakeholders can find relevant studies, a think-tank or working group to compile and disseminate relevant research to the correct people, or have a person or people employed in government organisations to take on the role.

The systems, goals and even language are disparate between research and policy. Academic research is viewed by policy stakeholders as using elaborate or ornate language and going into unnecessary detail. Policy stakeholders conversely prefer short bullet points of key findings. Stakeholders also did not believe that academic research was relevant to them with one suggesting that policy makers could provide a list of questions or study areas where academic researchers such as Ph.D and Masters Students could pick project titles from.

6.3.4 Contribution to knowledge

The contribution to knowledge of the present thesis comes in three forms:

1. The methodology design
2. The provision of new and relevant data and findings
3. The design of a new test rig.

Firstly, the project introduces a methodology, which incorporates disparate disciplines, and is designed to give a holistic understanding of a single case study. Methods were primarily drawn from structural and thermal engineering, but also incorporated aspects from human geography.

Secondly, the findings of the research are an original contribution in the field of energy efficiency retrofit and related policy. The case studies in particular offer often untested *in situ* assessments of insulation types under natural uncontrolled circumstances to compliment the more common methods of simulation and calculation.

Thirdly, the project involved the original design of a new test rig to examine the thermal properties of building wall types. This is a more compact version of the commonly known 'hot-box' method. It remains available for future testing. In addition, the design is replicable in other research institutions and for other research needs using the details presented in this thesis.

6.4 Policy recommendations

The overall conclusion from the findings is that a tipping point must be reached whereby sustainability no longer arises from dictated directives or for economic reasons but that it becomes a basic requirement reflected in all government policies, public attitudes and all environments. A change due to economic reasons would only occur if savings in energy meant monetary savings overall, both for the state and for the individual. Currently the cost of retrofit is uncertain in terms of payback, indicating in many instances that the cost of the measures may never be recouped through savings on energy bills. A paradigm shift is needed with regard to sustainability. Not only must all policies instil this ethos, but we must change how people think by changing their surroundings and their daily discourse. Sustainability must be seen as a human

need, included alongside more accepted needs such as happiness and wellbeing. It must also infiltrate all societal networks including education and politics.

The research presented in this thesis offered a deeper understanding of the behaviour of buildings due to energy efficiency retrofit and allowed for the formation of a number of hypotheses on how to reach the full potential of the HES/BEH scheme. More specific ways and means of discovering the factors to incite this large scale change could be reached by harnessing a new connection with academic research and aligning research with policy. Sections 6.4.1 to 6.4.4 present the developed hypotheses, section 6.4.5 then presents the proposal of how these hypotheses could be further strengthened into theories, deeper understandings, and more impactful political actions in the field using proposals for future work and highlighting the identified gaps in knowledge.

6.4.1 Focus on lowering costs

As interviews in Chapter 5 suggest, Irish Building Regulations and Compliance checking have been below standard in the past. The celtic tiger saw 0.4 million houses built between 2000-2010 with poor insulation standards which may not have met Building Regulations of the time due to a lack of compliance checking (Irish Academy of Engineering, 2013). While Ireland has generally lagged the rest of Europe with regard to quality of standards, the current Part L U-values are quite ambitious. The author proposes that the wall U-values standards for retrofit may be unnecessarily high for the Irish climate. Technical guidance documents for retrofitters under the HES/BEH scheme are required to aim for 0.27 $Wm^{-2}K^{-1}$. The most recent German standards require 0.24 $Wm^{-2}K^{-}1$ for external walls or to prove that the building as a whole does not exceed 140 % of the requirements for a (similar) new building (INFORSE-Europe1 2008). Considering that the German winter extremes reach -10°C (http://www.worldtravelguide.net/) compared to the milder Irish climate with winter mean daily minimum of 2.5 °C (www.met.ie) it is argued that this requirement is perhaps excessive and needs re-evaluation.

The findings from this thesis did not show any obvious correlation between heat flow reduction and either position of insulation, or the type and thickness of insulation used. This suggests that while it is true that more thermally resistant insulation placed externally achieves the most resistance to heat loss, such a high level may not be necessary for the milder Irish climate. Currently it is cheaper to continue to waste energy than to invest in retrofit meaning that the scheme is reaching only a small demographic. The possibility of making panels thinner could save money on materials as well as unexpected additional costs to move items such as gutters. The author suggests, therefore, that a greater understanding of heat flow through typical Irish

walls for typical Irish conditions should be examined using different insulation thicknesses and resistances in order to determine the optimal design. The optimal design would balance upfront cost with improved thermal performance and payback period. Furthermore, focus should be shifted from ever strengthening of standards in this regard, to more stringent quality checks both within the scheme and those doing private retrofit. Stakeholder interviews suggest that the quality of compliance checking has become more rigorous for BER assessment in the past couple of years and that this has lead to improvements in the sector.

6.4.2 Make sustainability a valuable asset

Currently the main driver for people to undergo energy efficiency retrofit is comfort. The current clientele of the scheme are not focused on saving energy or reducing emissions. This combination results in energy savings due to retrofit falling short of predictions. The driver at a political level is to reach EU 2020 targets, which is to reduce energy consumption by 20% of 1990 levels. Policy and funding in the area is changeable, with insufficient regulation and low resources of money, time and people.

There is a need to normalise a new behaviour or create a paradigm shift. The public could put a value on retrofit for reasons of sustainability as a global concern as opposed to the government requiring other tactics to convince such as grants or promises of increased comfort or money savings. One method of doing this is through education. In a similar way as the introduction of CSPE[23] to the education system, sustainability should be taught as a full subject. One of the core modules of the subject would be energy in the home which would include building physics. This should be introduced at the primary school level and continued into the senior cycle. However, the fruits of this labour would not be fully seen for many years as future generations become adult consumers. More immediate results have been shown through education in what marketers refer to as pester-power (Fell & Chiu, 2014).

Within government, the ethos needs to change also, with consistent long term policy and sustained funding. This would include cross-party statutory agreements, not just on targets but means for achieving targets. Furthermore, sustainability should be on the agenda for discussions on any new or existing policy whether directly related to the issue or not.

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23 Civic, Social and Political Education: a subject taught for the Junior Certificate Examination in Ireland. It was introduced in 1997

6.4.3 Focus on people

It was clear from this study that the technology is available, the potential to conserve much more energy exists and that it works well. However, there is a disconnect between the technology and the willingness of people to adopt the energy efficient technology or practice.

Current experience has shown that there are two main client types of the HES/BEH scheme. The 'first movers' client type tend to show an interest in the area and have researched it independently from sources such as the internet, television shows and contractors. The second are the 'word of mouth' type who showed less interest and less knowledge in the area and decide to undertake retrofit based on the positive experience of someone they know. The combination of these demographic types leads to sudden jumps in client numbers "when you do two you usually end up getting six in the same neighbourhood". This lesson could be learned from and used to enact change on a bigger scale. The findings echo Malcolm Gladwell's "The Tipping Point" (Gladwell, 2000) in its identification of what he calls mavens[24], who he believes are essential first movers and starters of word of mouth epidemics.

> *"The tipping point is that magic moment when an idea, trend, or social behaviour crosses a threshold, tips, and spreads like wildfire"*

The technical findings from this research and others could be used by the SEAI to inform the already existing and interested mavens in the public on the actual, evidence-based impact that retrofit would have. The selling points would be the measured reduction in heat loss through the retrofitted element, the increased comfort and the reduction in fuel use. It would be important to present theses as scientific findings in a clear and concise way.

More research or focus needs to be made into how sustainability can become a new, highly embraced trend. The author suggests that the government should identify and enact popular figures in the public eye as champions of the cause. In a similar way to how sponsorship deals for sports players currently work and eliciting new media forms such as Twitter and Facebook to reach their respective fan bases. Furthermore, clustering of homes for retrofit could possibly harness the 'word of mouth' or 'community effect' as well as providing more local targeted action. Ireland could learn from German examples where local councils oversee the processes.

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24 People who research something heavily and explain the findings to others with the aim of helping them "A Maven is someone who wants to solve other people's problems, generally by solving his own" Gladwell, (2000). The Tipping Point: How Little Things Can Make a Big Difference. United States, Little Brown.

6.4.4 Overhaul all systems

Overhauling the systems could aid the introduction of a paradigm shift and tipping point, discussed in the previous sections. Within policy making, the idea of all policy reflecting the same ethos of sustainability was suggested. These policies need also to be long term and enhance each other. Experts consider the "carrot-and-stick" approach as a positive method of aligning policy, sending a clear message and showing the public that sustainability is the governments focus and ideology. The use of policy instrument suites is a common recommendation at EU level (OECD/IEA, 2011), and have been adopted in Ireland, however, these strategies have proven to fall short of targets. The identification of Irish actions as being overly cautious in section 5.5.2, leads to the conclusion that further or more forceful action and efforts are needed. These would potentially be unpopular, though due to cross-party agreements as mentioned and the making of certain agreements as statutory, the unpopularity would not impact on elections.

Secondly, man-made environment and systems built on years of energy inefficient design needs to be updated to more sustainable ones. This means focusing on improving the built environment, transport networks and energy systems but it also means educating people in schools and focusing academic research to policy relevant sustainability projects. For residential buildings, for example, adopting the carrot-and-stick approach could include a property tax which reflects the energy efficiency of the building and its energy sources. There could be a regulation that all rented properties be of a minimal BER with additional taxes on the income from rent which does not comply. There could be tax relief for properties which achieve over a specific high level BER. A similar system could extend to selling properties so that the final selling price reflects the efficiency of the building. Information on energy sources and carbon could be made more visible on energy billing by regulations for energy companies.

In summation this means progressively realigning the drivers in all areas and on all levels to reflect sustainability and energy efficiency so that there is no longer a question of whether to behave in a sustainable manner because there is no longer another option.

6.4.5 Future Work

Within these policy recommendations there are still gaps in the knowledge, particularly in 'how' to create these big changes and what needs to be discovered so that these changes can occur. For the HES/BEH case study, it was found that much greater resources are needed in order to fully understand the scheme and how deeper impacts could be achieved. In terms of practicality, an all-encompassing style research project, such as this one, limits the depth of investigation one

can make into any specific aspect of it. The problems under investigation are all interconnected and at times contradictory. Depth in one aspect of the project is sacrificed in order to achieve the necessary breath. For this Irish case study the key gaps where government actors wanted to have realistic findings included:

1. Real data on the current housing and their energy use and behaviour
2. Values for actual changes to energy use are achieved due to retrofit measures
3. Better understanding of take back and actual savings
4. Understanding of how a tipping point could be reached

The initiation into understanding and closing these gaps are presented in the findings from this thesis in sections 6.3.1 to 6.3.3 and 6.4.1 to 6.4.4. However, much deeper understanding is still required. The author, therefore, recommends the following future work to be carried out.

- **Deeper, year-long comparison studies.** These would add greatly to the understanding of total changes in comfort and energy usage. Furthermore, more houses should be monitored including those being retrofitted outside of the HES/BEH scheme.
- **Create relationships in the data.** All current and future monitored data could be used to create relationships between certain housing and occupant demographics and the likely change in energy consumption per retrofit measure type. This would facilitate the creation of a database or interface system much like Tabula[25] but created using experienced changes instead of the DEAP procedure which cannot be used to predict savings as it is based on a standard occupancy. Collaboration with the central statistics office and government department based housing surveys would be necessary to collect details on both occupants and buildings.
- **Determine optimal insulation types and thicknesses**. As this research project was completed, the newly designed test rig presented in Chapter 3 was only at its starting point in testing. This facility could be used for testing the thicknesses of insulation, positioning and insulation types to identify most cost effective solutions for Irish wall types and climatic conditions. This would be with the aims of, reducing upfront material and installation costs, increasing indoor comfort and enhancing long term savings in energy used for space heating and the money spent on doing so. Wall types would be

25 Tabula is an EU effort which presents national sets of common building typologies with showcase calculations of possible energy savings for retrofit measures. For Ireland the calculations are based on DEAP software. Further details available at http://www.building-typology.eu/

chosen based on the housing surveys. Findings from this could also feed back into the aforementioned database.

- **Quantify Irish comfort take back**. Current and future monitored data could also help to quantify comfort take back under the scheme. This would involve big dataset analytics where relationships between take back and demographic, building type and average indoor temperature are formed. The human geography aspects of comfort also require further research in understanding the 'why' of the relationships.
- **Examination into achieving a tipping point within the Irish context.** Examination of how a tipping point could be reached would encompass disciplines of marketing, social science, economics, politics, psychology and anthropology.

Learning from the findings in this thesis, in order to strengthen ties between academia and government bodies, the future information should be presented as a summary, in bullet point form, written in a reader-friendly manner and sent to those involved in policy making, as well as within the academic sphere.

"You'd be amazed how much research you can get done when you have no life whatsoever."

Ernest Cline

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Appendix A

A.1 Details of the designed rig

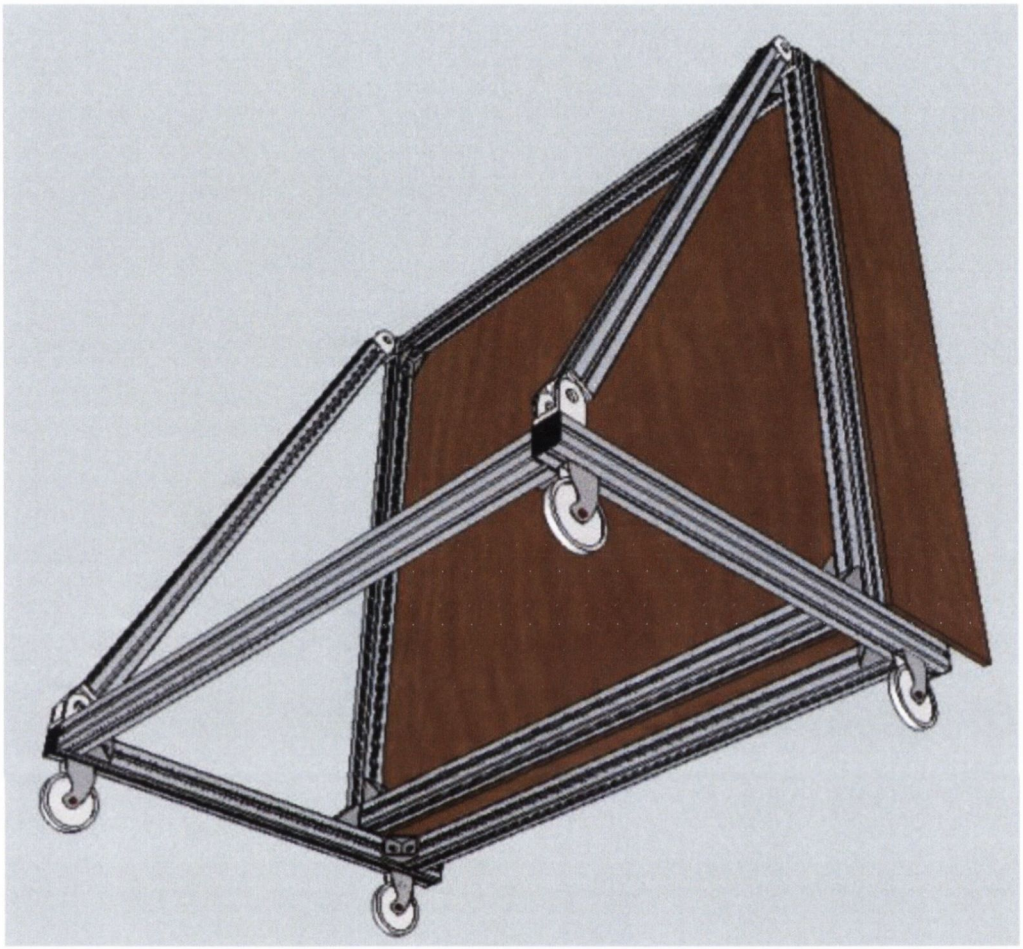


Figure A 1 Aluminium chassis system using Rexroth (Bosch Group) aluminium profiles and connections http://www.boschrexroth.ie

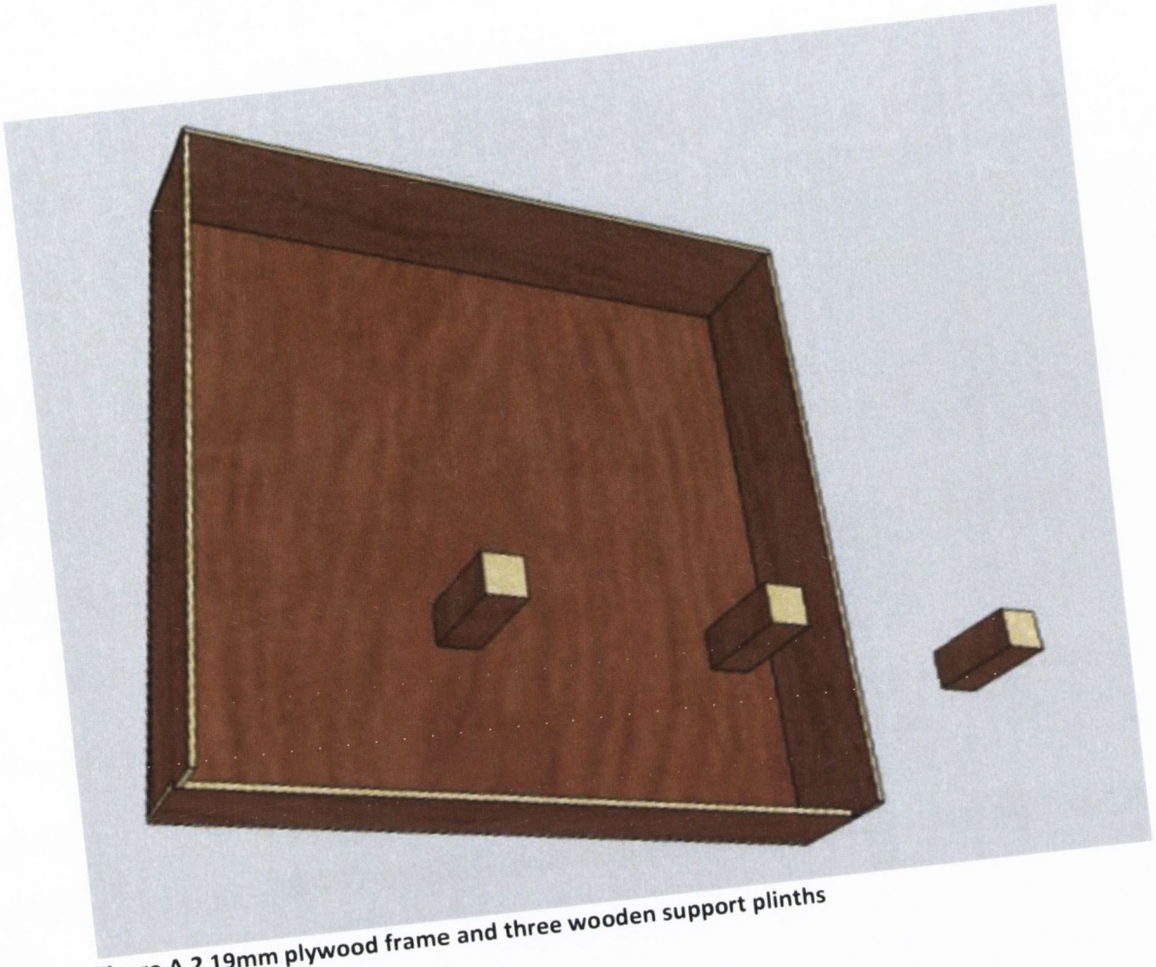


Figure A 2 19mm plywood frame and three wooden support plinths

Thermal Conductivity

The boards achieve a thermal conductivity (λ–value) of 0.024 W/m·K (insulant thickness 15–24 mm), 0.023 W/m·K (insulant thickness 25–44 mm), 0.021 W/m·K (insulant thickness ≥ 45 mm).

Thermal Resistance

Thermal resistance (R–value) varies with the thickness and is calculated by dividing the thickness of the board (expressed in metres) by its thermal conductivity.

Insulant Thickness (mm)	Thermal Resistance (m^2·K/W)
20	0.80
25	1.05
30	1.30
35	1.50
40	1.70
45	2.10
50	2.35
55	2.60
60	2.85
65	3.05
70	3.30
75	3.55
80	3.80

Refer to local distributor or Kingspan Insulation price list for current stock and non-stock sizes.

Figure A 3 Thermal details for Kooltherm K5 70mm as used on the rig structure (Kingspan Insulation Ltd. 2011)

Physical properties:

Test item	Test method	Unit	LC250 Test Value
Color	Visual		Grey
Thickness	ASTM D374	mm	0.3 to 14
Specific Gravity	ASTM D792	g/cc	1.6 to 1.9
Hardness	ASTM D2240	Shore C	15 to 50
Tensile Strength	ASTM D412	kg/cm^2	8
	ASTM D412	Pa	$5.88*10^9$
Continuous Use Temp	EN344	℃	-40 to +220
Volume Resistivity	ASTM D257	Ω-CM	$1.0*10^{11}$
Breakdown Voltage	ASTM D149	KV/mm	4
Flame Rating	UL-94		V-0
Conductivity	ASTM D5470	w/m-k	2.5

Configuration available: 200mm*400mm, 300mm*300mm, customized size available.

Figure A 4 LC25O used as thermal pad interface between heater/cooler plates and the wall surface



Figure A 5 Image of test rig showing wall sample with retrofitted external insulation and water supply adjusted for transient testing

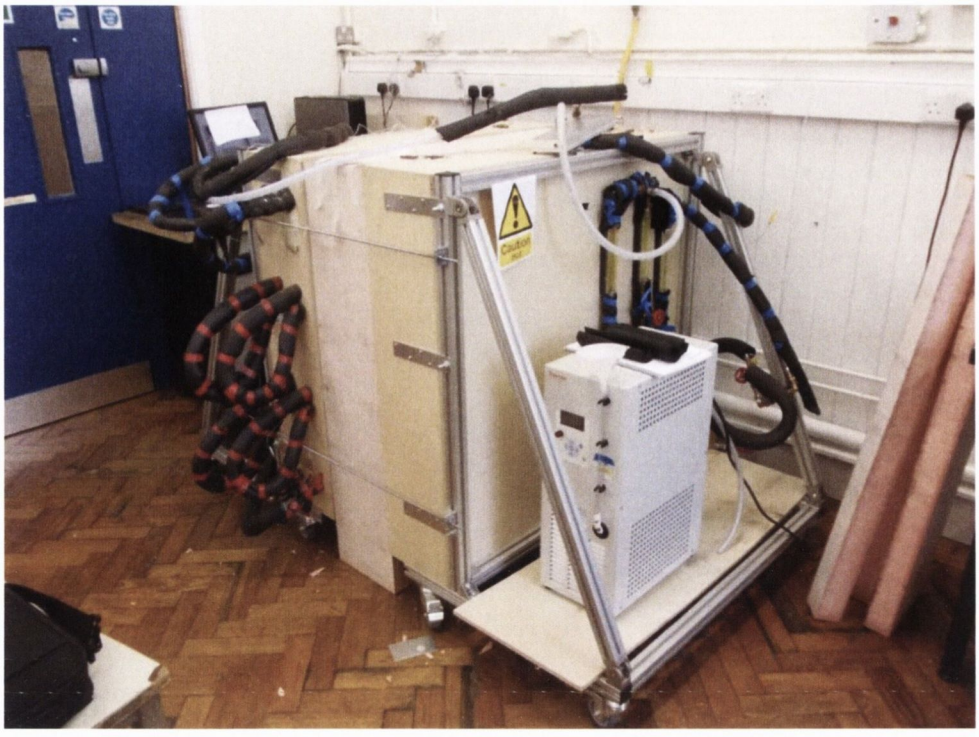


Figure A 6 Image of test rig during transient testing, showing the sealing details



Figure A 7 Water circulation unit 250 LC

A.1 Instrumentation for the rig

NI USB-9213

16-Channel Thermocouple Input Module

This user guide describes how to use the National Instruments USB-9213 and lists the device specifications.

Introduction

The NI USB-9213 consists of two components: an NI 9213 module and an NI USB-9162 carrier, as shown in Figure 1.

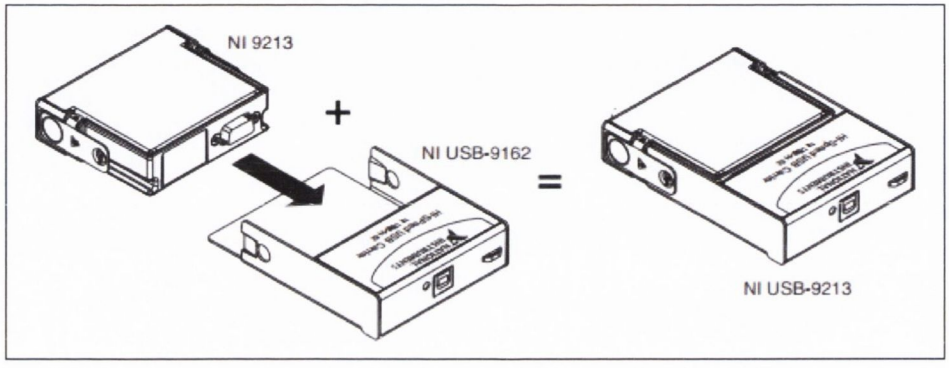


Figure A 8 16-channel Data Aquisition (DAQ) unit. Two of these were used.

Figure 1. NI cDAQ-9174 Dimensions

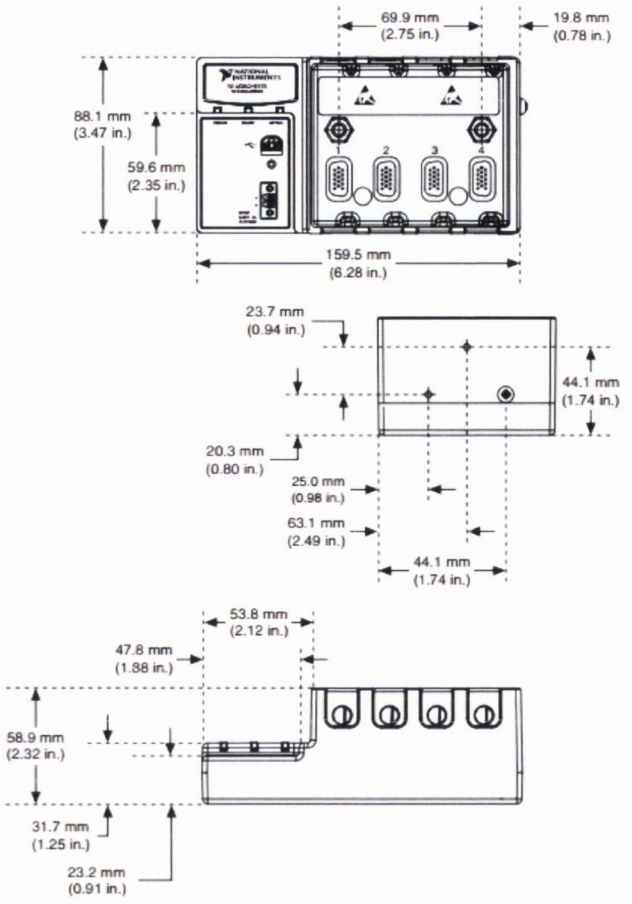


Figure A 9 Chassis for the two DAQ to fit into

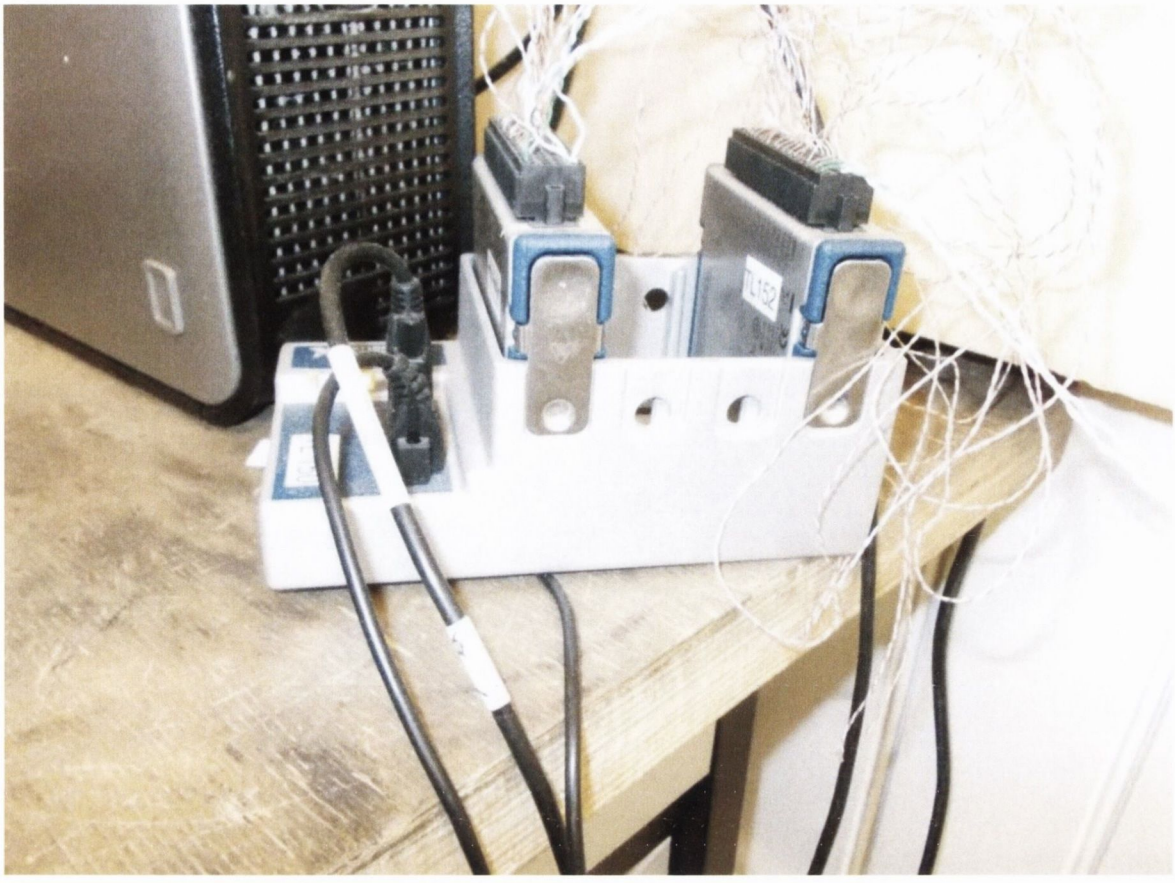


Figure A 10 DAQ and chassis system

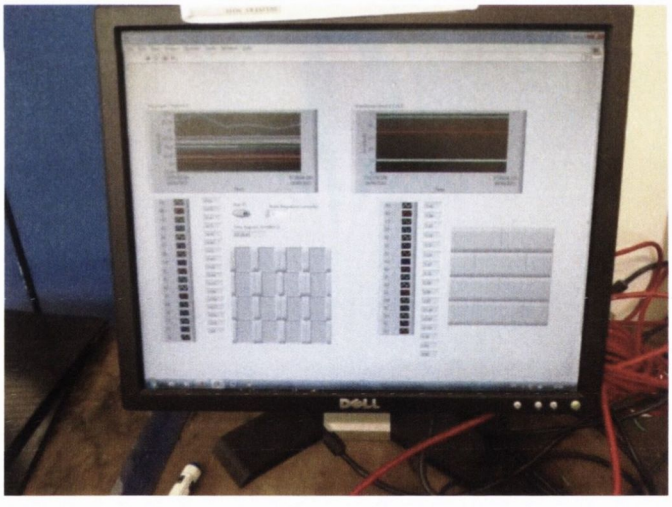
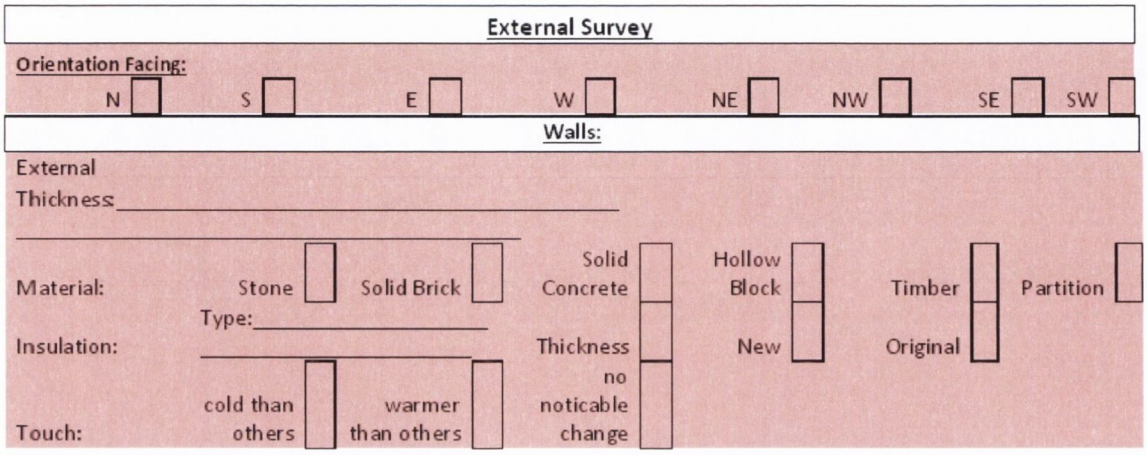


Figure A 11 LabVIEW screen display

Appendix B

B.1 House survey form

PRE ARRIVAL:



MANUAL OBSERVATIONS:

Name:

Address:

Date:

Outline

Sketch Ground Floor:

Note: Include wall numbers, room dimensions - w,b,h, location of sensors, window location from ground and walls & its dimensions, door dimentions & position, location and size of vents/fans/fires, location and size of radiators,

Sketch 1st Floor:

Note: Include wall numbers, room dimensions - w,b,h, location of sensors, window location from ground and walls & its dimensions, door dimentions & position, location and size of vents/fans/fires, location and size of radiators,

Sketch additional floors:

Note: Include wall numbers, room dimensions - w,b,h, location of sensors, window location from ground and walls & its dimensions, door dimentions & position, location and size of vents/fans/fires, location and size of radiators,

Walls:

Internal:
Thickness:_____

Material: Stone ☐ Solid Brick ☐ Solid Concrete ☐ Hollow Block ☐ Timber ☐ Partition ☐

Insulation: Type:_____ Thickness ☐ New ☐ Original ☐

Touch: cold than others ☐ warmer than others ☐ no noticable change ☐

Further Details/ sketch:

To adjoining property:
Thickness:_____

Material: Stone ☐ Solid Brick ☐ Solid Concrete ☐ Hollow Block ☐ Timber ☐ Partition ☐

Insulation: Type:_____ Thickness ☐ New ☐ Original ☐

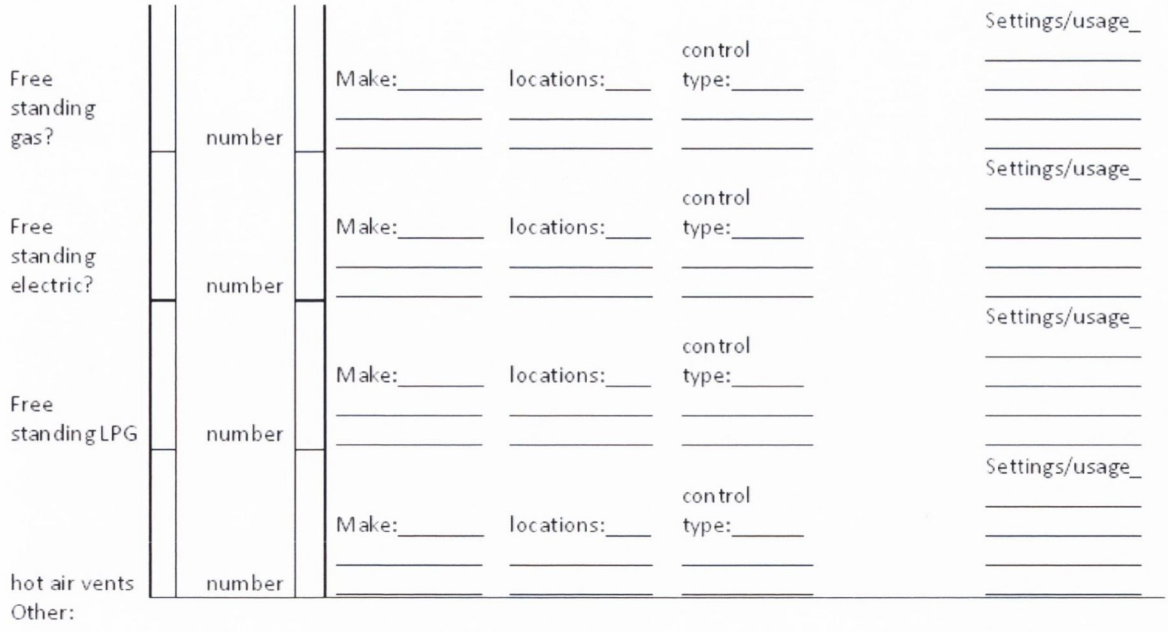
Touch: cold than others ☐ warmer than others ☐ no noticable change ☐

Further Details/ sketch:

Heating:

Thermostat yes ☐ no ☐ location_____

Central Heating? ☐	number radiators ☐	Make:_____	locations:____	control type:_____	dimensions_	Settings/usage_
Electric Convection? ☐	number ☐	Make:_____	locations:____	control type:_____		Settings/usage_
Electric storage? ☐	number ☐	Make:_____	locations:____	control type:_____		Settings/usage_
Storage and fan? ☐	number ☐	Make:_____	locations:____	control type:_____		Settings/usage_



- Oil tank level

1 Oil tank dimensions

PHOTOGRAPHS

External:

- Overall
- Porch details
- Roof details
- Chimneys
- Garage
- Shelter/shadow giving proximities (trees, houses, walls)

House Type:

Detached ☐ Semi-d ☐ End of terrace ☐ Mid Terrace ☐ 1-storey ☐ 2-storey ☐ 3-storey ☐ other ☐

Porch:

None ☐ With external door ☐ Without external door ☐ External to wall ☐ Draught lobby ☐ New ☐ Existing ☐

Roof:

Flat ☐ pitched ☐

Chimneys:

None ☐ Shared stack ☐ Conventional ☐ Metal Flue ☐

Number of Stacks ☐

Number of Flues per stack ☐

Garage:

None ☐ Yes ☐ Converted ☐

Shadowing:

Any major shadows cast?
Include in Sketch

Sheltering:

Indicate sheltered sides on sketch

Internal Rooms:

- Floor (Type and coverings, including any sealing details),Note if suspended,Note if underfloor heating
- Windows – overall and glazing details
- Doors – location and draught details
- Vents/fans/flues – position and if open
- Fireplaces and material used
- Lightbulbs – showing details of wattage
- Radiators and settings
- Thermostat setting

Floor:

Dimensions: width_____ breath_____ height_____

Floor insulation: Yes ☐ No ☐ Thickness_____ Type_____

For Wood: Suspended ☐ Not Suspended ☐ Sealed boards ☐ Not Sealed ☐ Sealed with wall ☐ Not Sealed ☐

Concrete: Yes ☐ No ☐

Tiles: Yes ☐ No ☐

Lino: Yes ☐ No ☐

Coverings: Carpet ☐ Rug ☐ Partial Carpet ☐ None ☐

Heated: Yes ☐ No ☐ Type:_____

Windows:

Position: wall_____ from floor_____ from ceiling_____ from each side wall_____

Dimensions: width_____ breath_____ height_____

Glazing: Single ☐ 2 layers of glazing ☐ double, air filled ☐ double, argon filled ☐ triple, air filled ☐ triple, argon filled ☐

Glazing manufacturer if available:_____

Low E coating and thickness ? (0.2, 0.15, 0.1, 0.05)_____

Frame: Wood ☐ PVC ☐ Metal, thermal break ☐ Metal, no thermal break ☐

Any overshadowing, size, type, location?_____

Draught Stripping: Present ☐ No ☐ chaulking ☐ feel air coming through?_____

Curtains: Net Full ☐ Net half ☐ Roller Blind ☐ Curtain ☐ Venetian Blind ☐ Shutter ☐

Further Details:

Doors:

Material:

Frame thickness:_____ Frame material :_____

Draught Stripping: Yes ☐ no ☐ chaulking ☐ feel air coming through?_____

Further Details/sketch:

Other Openings:

Vents/fans: Number_____ open or closed?_____

Type

location

dimensions

Flues: Number

Type

location

Fireplace:	diameter Number Type : location dimensions	open coal	☐	closed	☐	gas open front	☐	gas closed front	☐	back boiler	☐

Lighting

Main Light:	Number of bulbs	☐	Wattage	☐	Type_____
Additional	Number of bulbs	☐	Wattage	☐	Type_____

- Boiler type

1 Boiler setting

QUESTIONS TO THE OCCUPANT(S):

Initial Questionnaire

Age of the house?_____
Any Extensions? Age?_____
Ownership status_____
Electricity supplier_____
Gas?_____
___
oil
supplier_____
other_____
__
Can you give rough winter electricity and heating bill?_____
Summer?_____
__
How do you heat water?

Immersion		instant gas		instant electric		central heating boiler		back boiler	

peak		one sink	
off peak		multi-sink	
timer			

settings_____

Weekday water heating hours&
times_____
Weekend water heating hours &
times_____
Is there a hot water
cylinder?_____

Cooking Fuel?	gas		oil		electric		LPG		wood		coal	

When and for how long would you use cooking/microwave appliances
weekdays_____
_____
Weekends_____
_____

What type of heating system do you have?

How do you control the temperature of your house?

room thermostate		multi room thermostates		control on the boiler		controls on the room rads		thermostates on rads		zoned	

other_____
_____
Is your heat on a timer? What is this set
at?_____
_____
_____
_____
Is this how it is generally set over the heating
period?_____
_____

Do you often override the thermostate/timer settings?_____

What is your general space heating habits during the weekdays?_____

and at weekends?_____

are any radiators turned off?_____

Do you use a fire?
When?_____

Fire fuel type?_____

How many wood pieces/coal bags/briquettes do you get through a night?_____

Do you generally switch off lights and appliances when not in the room?_____

Do you generally turn items off fully or leave them on standby when not in use?_____

IS WHAT I SEE AROUND THE HOUSE THE NORMAL SETTING FOR THE RADIATOR/ THERMOSTAT/BOILER _____

B.2 Instrumentation and details of site case testing Chapters 2 and 4

Electricity measurement



Figure A12: Wattson 01 Electricity Monitor Display and Logger (http://www.diykyoto.com/uk/aboutus/wattson01)

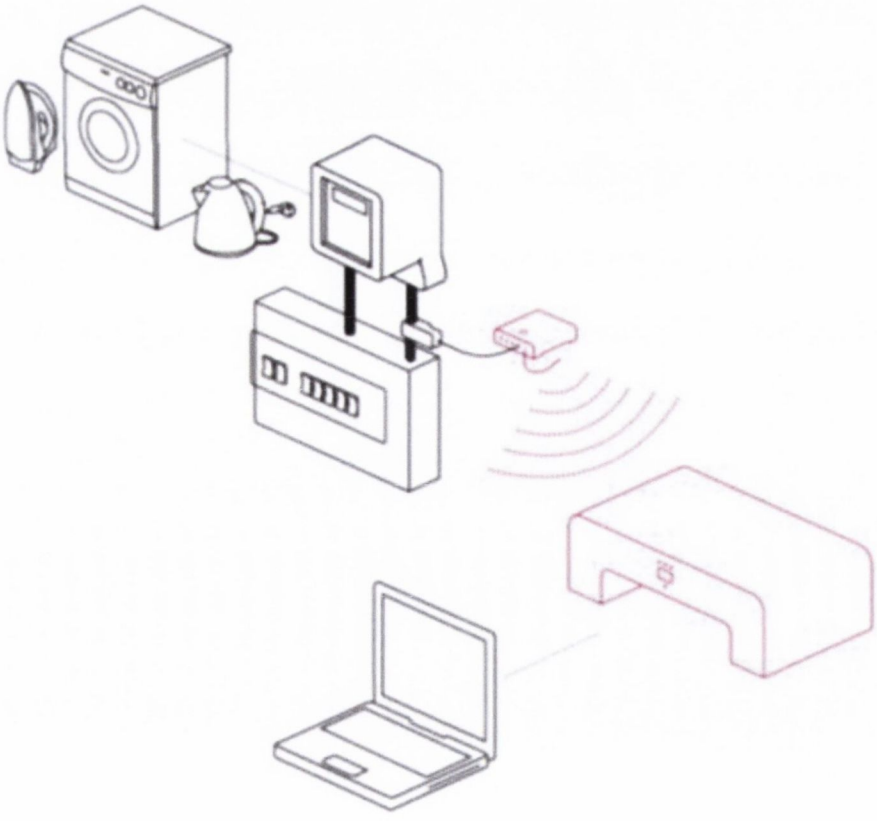


Figure A13 Electricity Monitor Setup showing Wireless Clamp-on Sensor in the Meter Box (DIY_Kyoto)

Temperature and Humidity Sensor



Figure A14: Novus Logbox RHT-LCD Temperature and Humidity Sensor and Logger in one (Novus)

Surface Temperature Sensor



Figure A15: Novus Logbox-AA-IP65 Temperature Sensor and Logger in one. Thermocouples can be attached at the end points to measure air or surface temperatures (Novus)



Figure A16: Type T Thermocouple to be attached to Temperature Logger (above) at one end and to the body being examined at the other (www.omega.com)

Thermal Transmittance

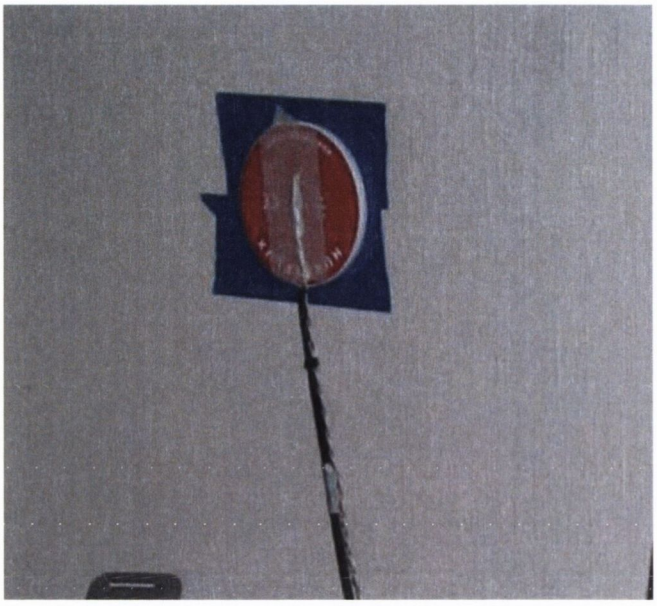


Figure A 17 Close up of Hukseflux HP01 Heat Flux with Surface Temperature Thermocouple attached (Baker 2010)



Figure A18: Hukseflux LI19 Data Logger for Heat flux Sensors (Hukseflux)

Insulation types

Table 2 Declared thermal conductivity ($\lambda_{90/90}$ values)

Grade	Thermal conductivity* ($W \cdot m^{-1} \cdot K^{-1}$)
EPS 70	0.038
EPS 100	0.036
EPS 150	0.035
EPS 200	0.034
EPS Pearl (70 and 100)	0.031

Figure 55 EPS 100, typical external insulation





PRODUCT DESCRIPTION:
This Certificate relates to the Certainfil Bonded Bead Cavity Wall Insulation System. The bonded bead is a polystyrene material which is injected in bead form with a binding agent into cavity walls. There are two types of bonded bead available:

- Certainfil, standard grade white bead with a density of 12kg/m^3
- Certainfil Graphite 27 Plus, high λ value grey bead with a density of 12 kg/m^3

This Certificate certifies compliance with the requirements of the Building Regulations 1997 to 2002.

This Certificate replaces IAB Certificate no. 05/0168 and is a confirmation of BBA Certificate No. 00/3706 issued by the British Board of Agrément, PO Box 195, Bucknalls Lane, Garston, Watford WD25 9BA.

USE:
The product is used for the thermal insulation of new or existing masonry walls up to 12 meters in height, subject to the conditions contained in Part 3 of this Certificate. It also facilitates the control of surface and interstitial condensation in walls. The current Building Regulations requirements can be met with this product, as shown in Table 1.

MANUFACTURE AND MARKETING:
The product is manufactured and marketed by:

Energystore Ltd.,
42 Barnfield Road,
Derriaghy,
Lisburn BT28 3TQ.

Figure 56 Certainfil Graphite 27 Plus typical pumped cavity insulation (The Irish Agrément Board and NSAI 2002)

B.3 Occupant interview script

Introduction

Thank you for agreeing to take part in this study. I am going to ask you a number of questions in relation to retrofit and the Better Energy Homes Scheme. Please be as accurate as possible with your answers. All information will be treated with complete confidentiality. Your answers will not be attached in any way to your name. The purpose of these interviews is to find out about the scheme from the perspective of the occupant. Do you agree to the interview being recorded?

Interview Questions

Initiation

Firstly I am going to ask you a few questions to establish a profile of your house and the retrofit that was implemented.

1. What energy efficiency interventions were completed in your home?
    a. Loft insulation
    b. Wall insulation.....type
    c. Boiler upgrade
    d. Heating controls
2. What was your heating temperature set to since retrofit?
    a. What times do you have it set to come on, or do you do it manually? When?
    b. What difference is there, if any, on weekends?
3. Are there any radiators turned off at the moment? Or do you ever turn any of them off?
4. Did you use the fire or other additional heating devices beyond your central heating since retrofit?
5. Do you switch off lights in rooms that are not in use?
   Never ☐ occasionally ☐ sometimes ☐ mostly ☐ always ☐
6. Do you fully turn off electrical items such as the TV/computer (i.e. not just leave them on standby) when not in use?
   Never ☐ occasionally ☐ sometimes ☐ mostly ☐ always ☐
7. What made you decide to undertake energy efficiency retrofit? (Follow up prompts – ethical – carbon saving, money saving, energy saving, comfort, BER requirement, added value to home, advertisements, word of mouth etc.)
8. How did you hear about the SEAI grant/retrofit?
9. How long did it take between initially considering the retrofit and the beginning of the works?
10. What are your views of the application process?
11. How did you decide upon which contractor to use?

12. How were the retrofit measures decided upon? (Follow up with prompts – relative cost, feasibility of installation in the house.) Did you feel like you were part of the process of deciding what to install? Do you feel that you were supplied with enough information to make this decision?
13. Is there anything you would have liked to get done which was not offered under the grants? Are you still likely to get this other work done?

Installation and outcome

These following questions are on the retrofit works in your home, including the installation of the energy saving feature and the changes, if any, which you have noticed since.

1. How did you find the information provided by SEAI in the following areas and feel free to elaborate: (very useful, useful, somewhat useful, not particularly useful and not at all useful)
    a. BER rating system
    b. Technical details on the measures
    c. Financing options to pay for measures
    d. Cost of measures
    e. Contractors
2. How did you find the installation process and contractors installing the measures? (Follow up with prompts – disruption, dirt, damage, noise, time, workers, information provided by the installers on using the system
3. How do you feel about the quality of the finished work?
4. Has the experience changed your level of knowledge of energy and energy use in the home?(Follow up prompt – do you feel that your knowledge of how to save energy in the home has improved/worsened/no difference/more confused?)
5. What changes, if any, have you made to how you behave within the home since the retrofit with regard to energy and heating - such as turning off lights/timer for heating/changing thermostat settings etc.?
6. What changes, if any, have you found in comfort, warmth or air quality since the retrofit?

Overview

This section aims to understand your overall view of the retrofitting process

1. How satisfied are you with the entire grant to retrofit process?

Very satisfied ☐ satisfied ☐ somewhat satisfied ☐ not particularly satisfied ☐ not at all satisfied ☐

    a. Would you recommend it to others?
    b. Would you participate in further retrofitting initiatives? (Follow up prompt: If not - what is preventing you from doing it again? What would motivate you to do it again?)

2. Government aims in this area is to focus more on introducing multiple retrofit into people's homes. How do you feel about a possible multiple-retrofit option which would involve many new elements being introduced at a time such as efficient boiler and insulation?
3. Would you like to see such schemes extended into other areas e.g. water, waste etc.
4. What were the main issues/problems you had with any element of the process?
5. What were the main elements which were successful in the whole process?
6. What are your recommendations to improve the process for the consumer?
7. What are your views on the use of grants to encourage people to undertake energy saving retrofits in their home? (Follow up with prompts – How affordable was the retrofit for you? is there an alternative way of funding the retrofits which would encourage you more? What about low interest green loans from banks, or pay as you save where the home owner pays for energy upgrades over time on their utility bills or by other method? Green mortgage top-up?)
8. Finally, is there anymore information you would like to add to the interview?

Demographic

The following brief set of questions is in the area of occupant profiles

1. How many occupants live in this house?
2. What age ranges do they come under and their relation to you?
    a. 16 and under.....relation to you
    b. 16-25.....relation to you
    c. 26-35.....relation to you
    d. 36-45.....relation to you
    e. 46-55.....relation to you
    f. 55-65.....relation to you
    g. 65+.....relation to you
3. How would you describe each occupant's employment status at the time of applying for the grant, and what was their job title?
    a. Working for payment or profit full time.....job title
    b. Working for payment or profit part time.....job title
    c. Unemployed
    d. Student or pupil.....type
    e. Looking after home and family
    f. Retired
    g. Disability preventing work

Appendix C

C.1 Heat Flux

All of the following graphs display heat flux in W/m^2 on the y-axis, logging number on the sensor on the x-axis.

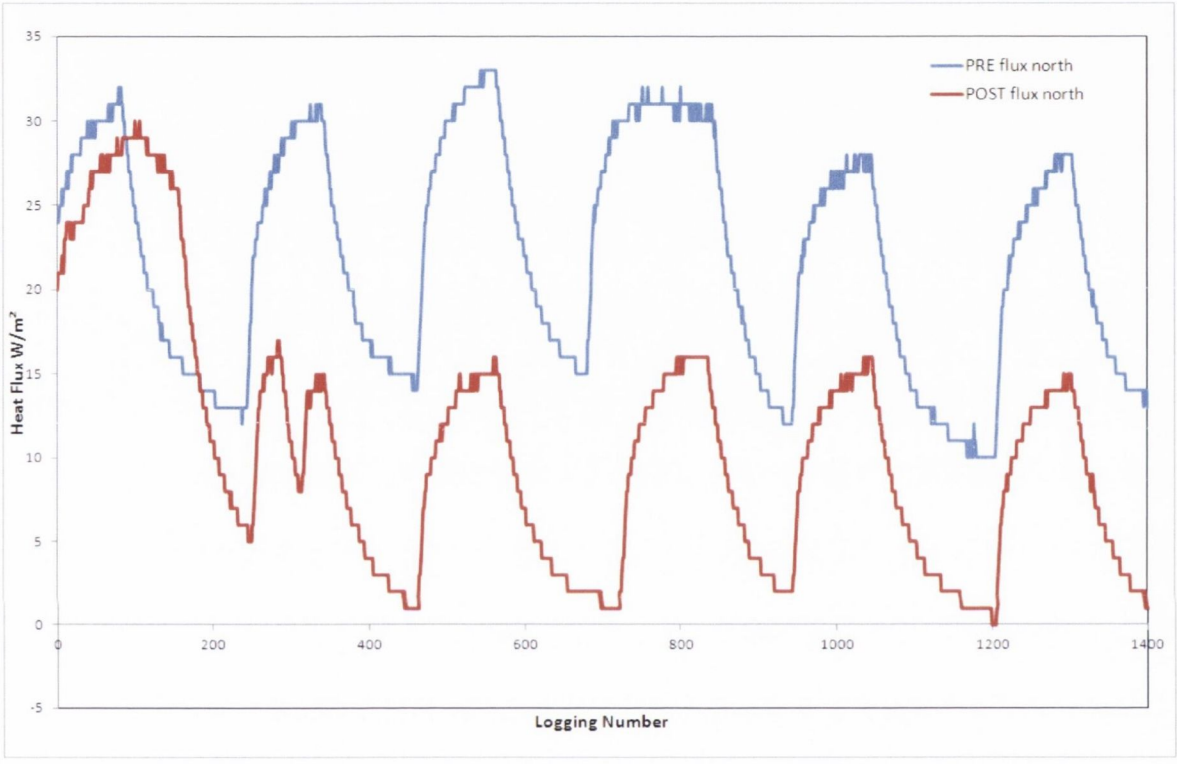


Figure A 19 Con(c) North room

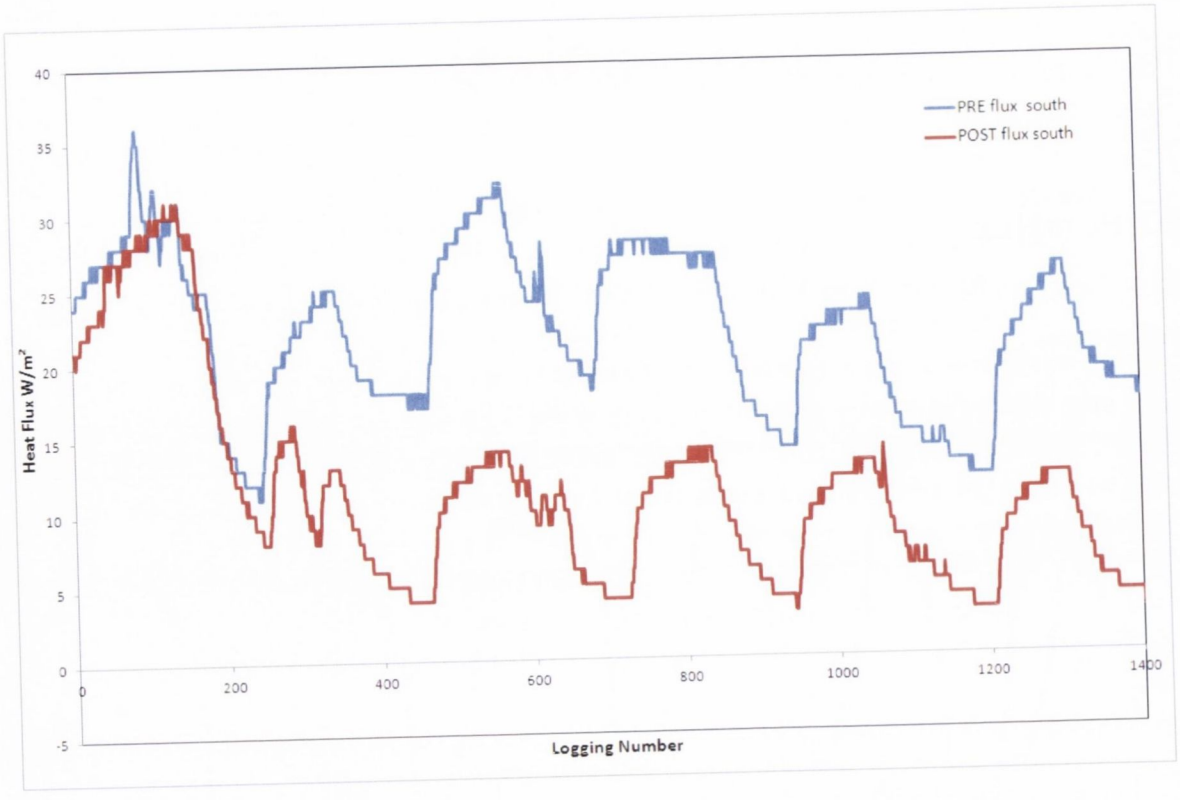


Figure A 20 Con(c) South room

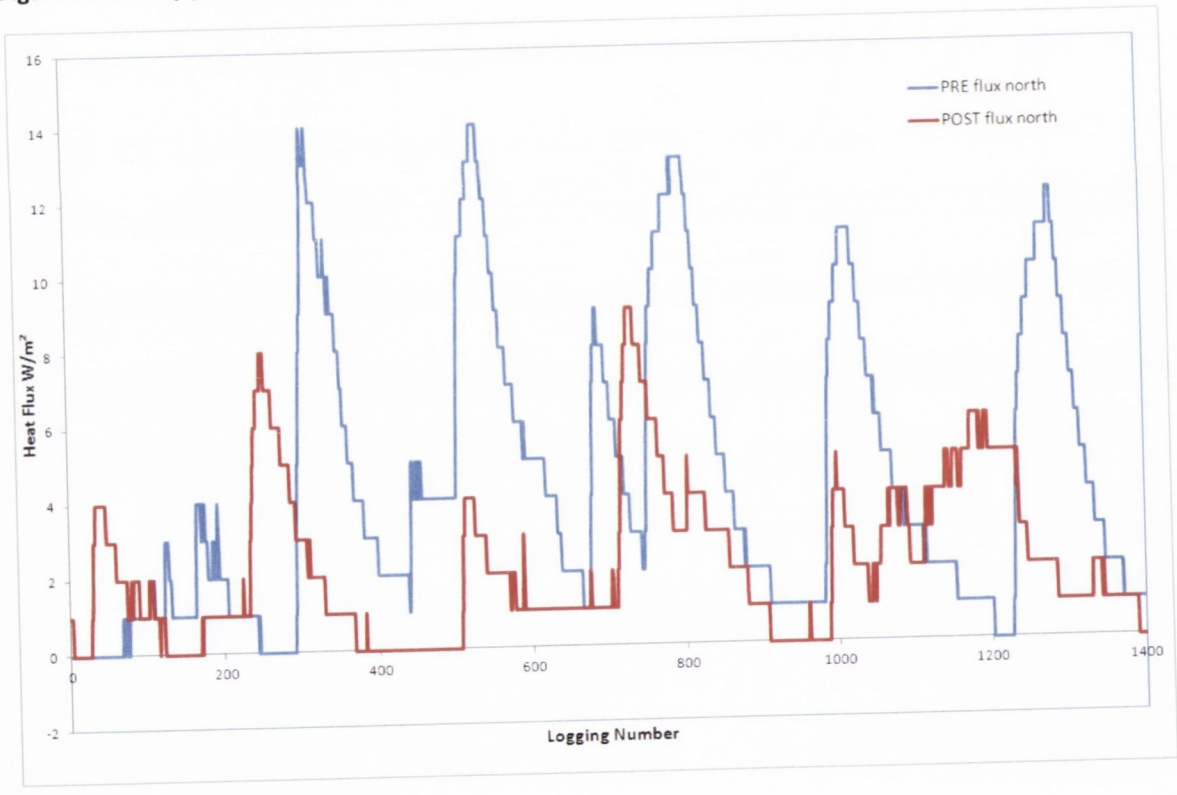


Figure A 21 Con(e) north room

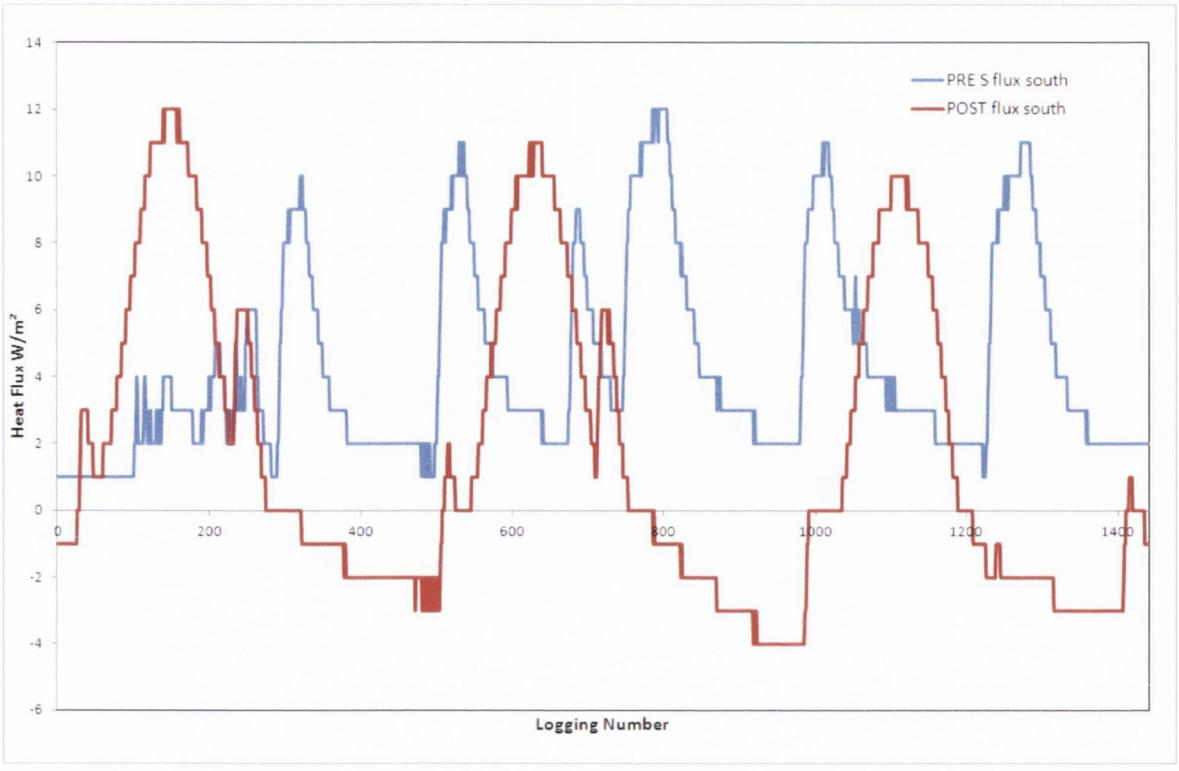


Figure A 22 Con(e) south room

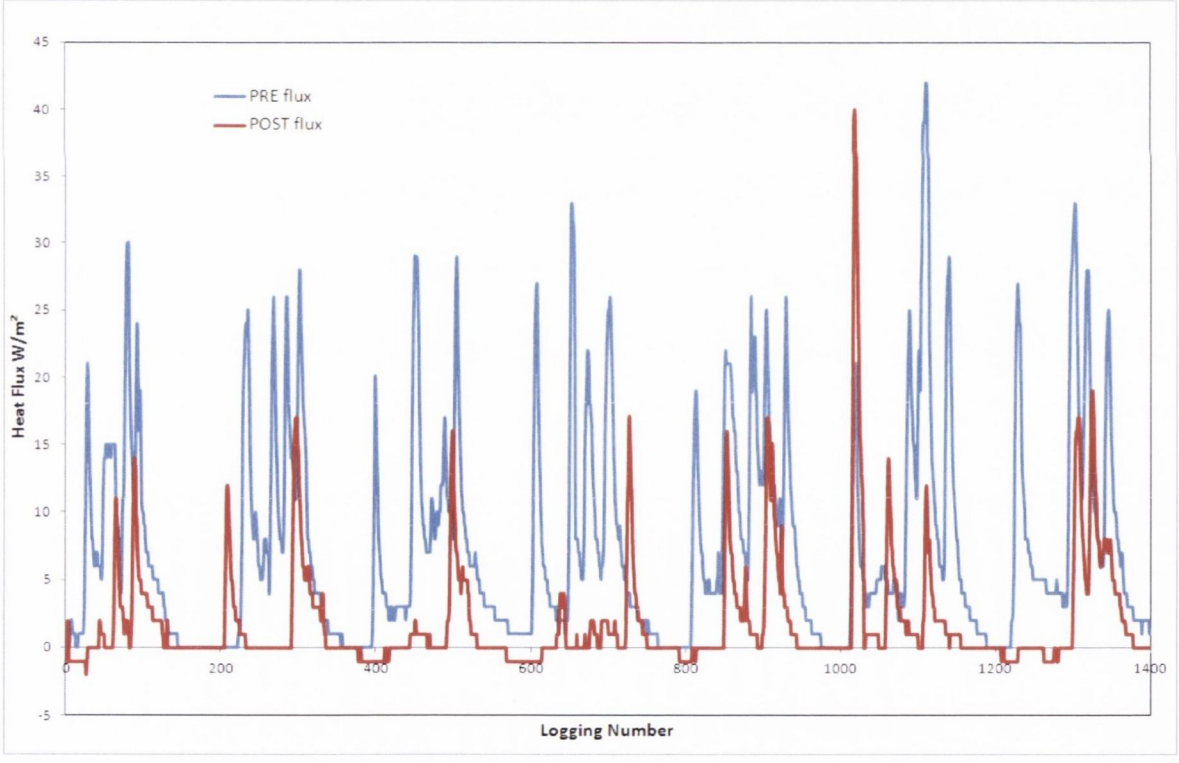


Figure A 23 SemiD1(e)

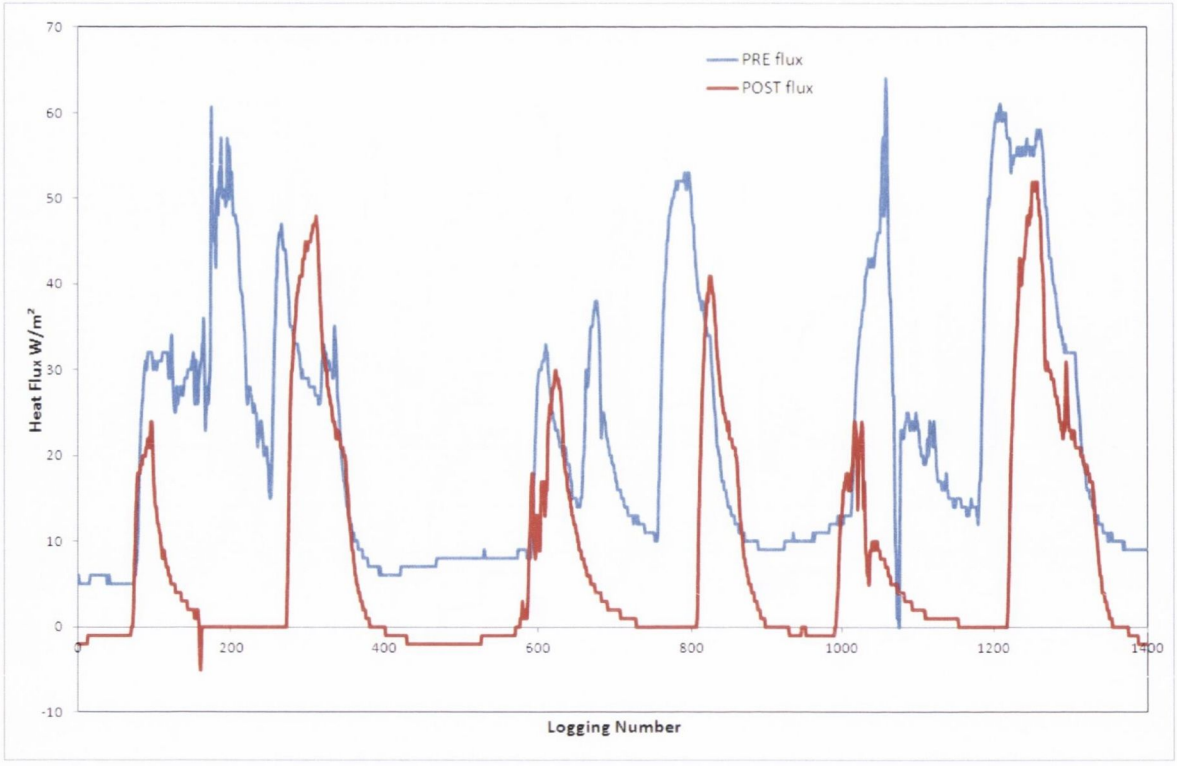


Figure A 24 SemiD2(c)

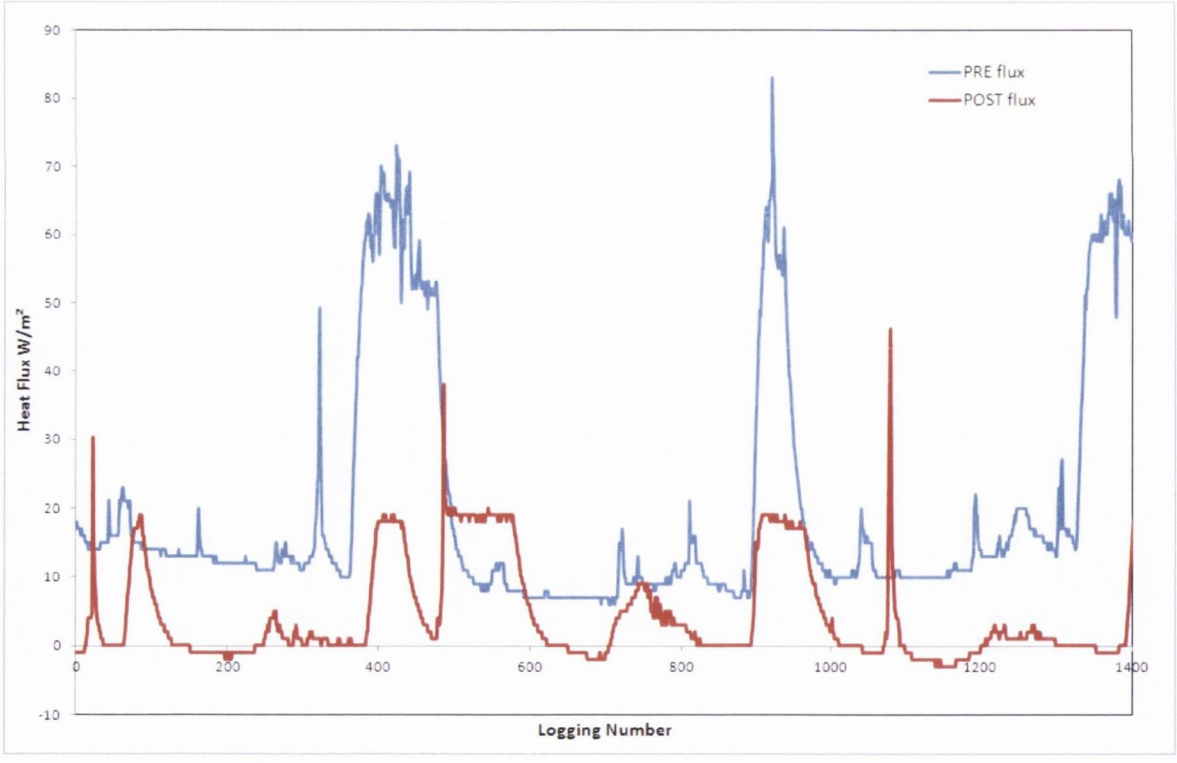


Figure A 25 SemiD3(e)

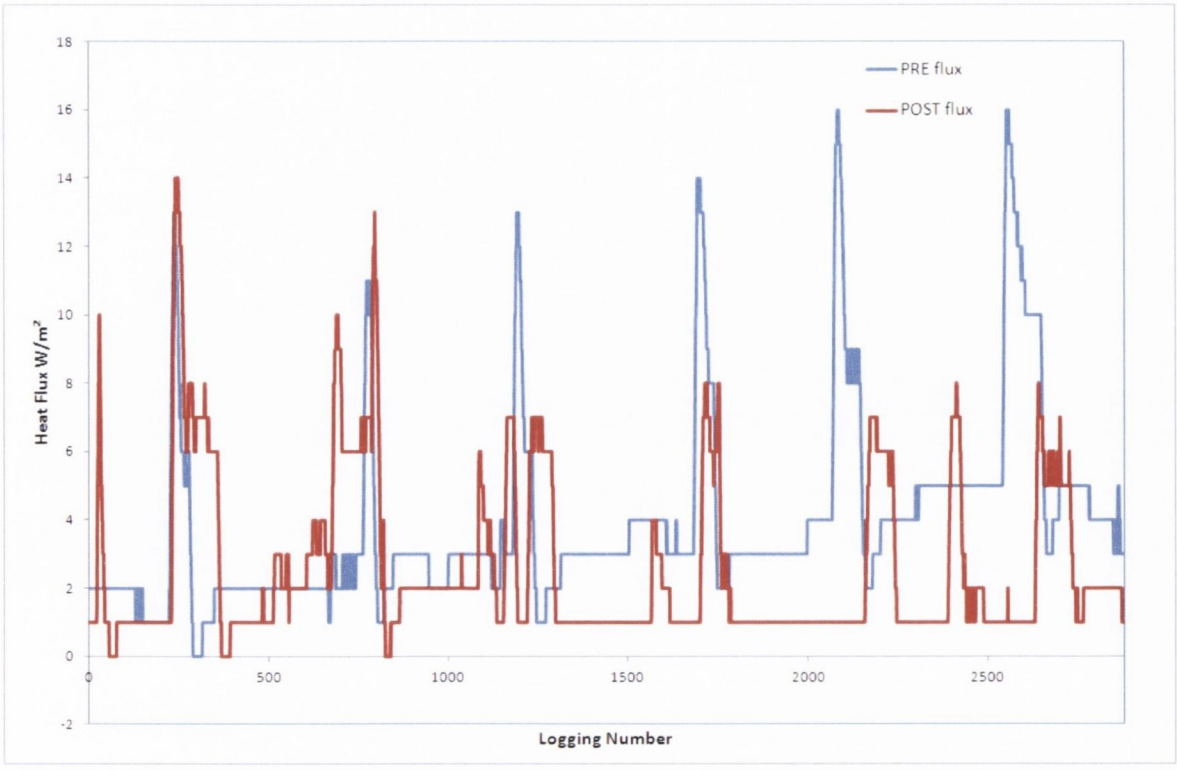


Figure A 26 Dor(e)

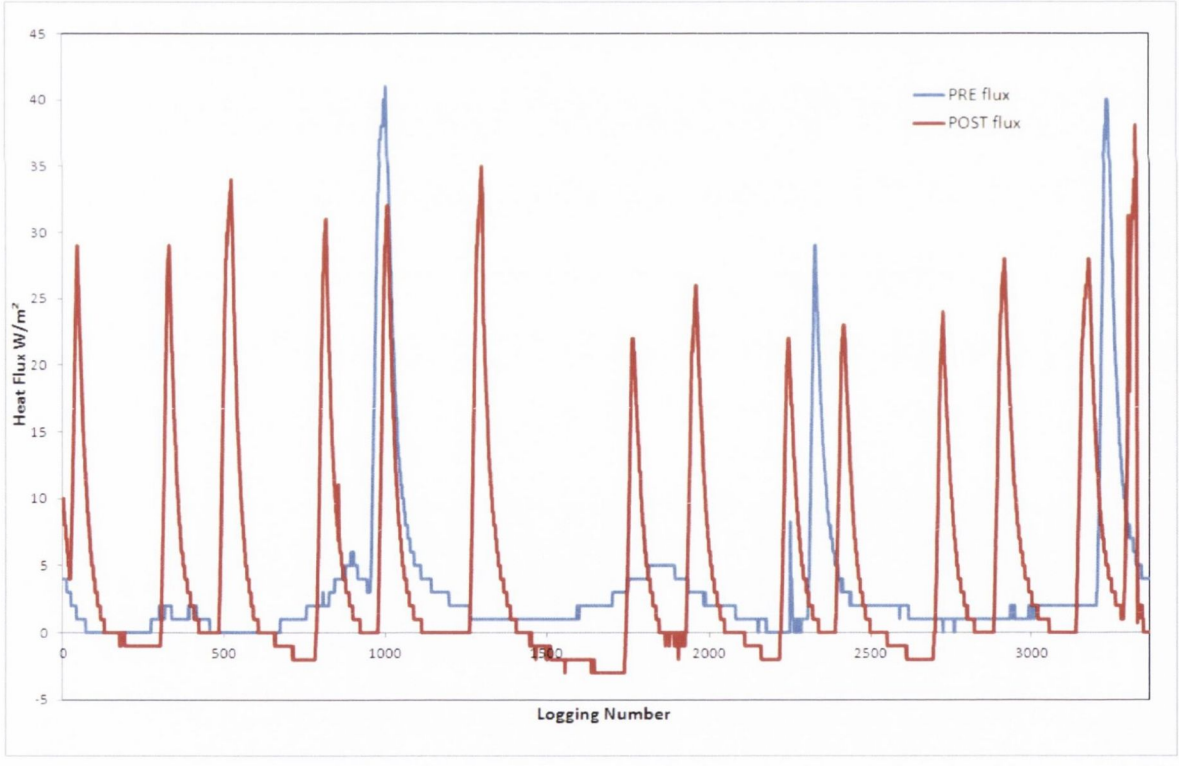


Figure A 27 Bun(e)

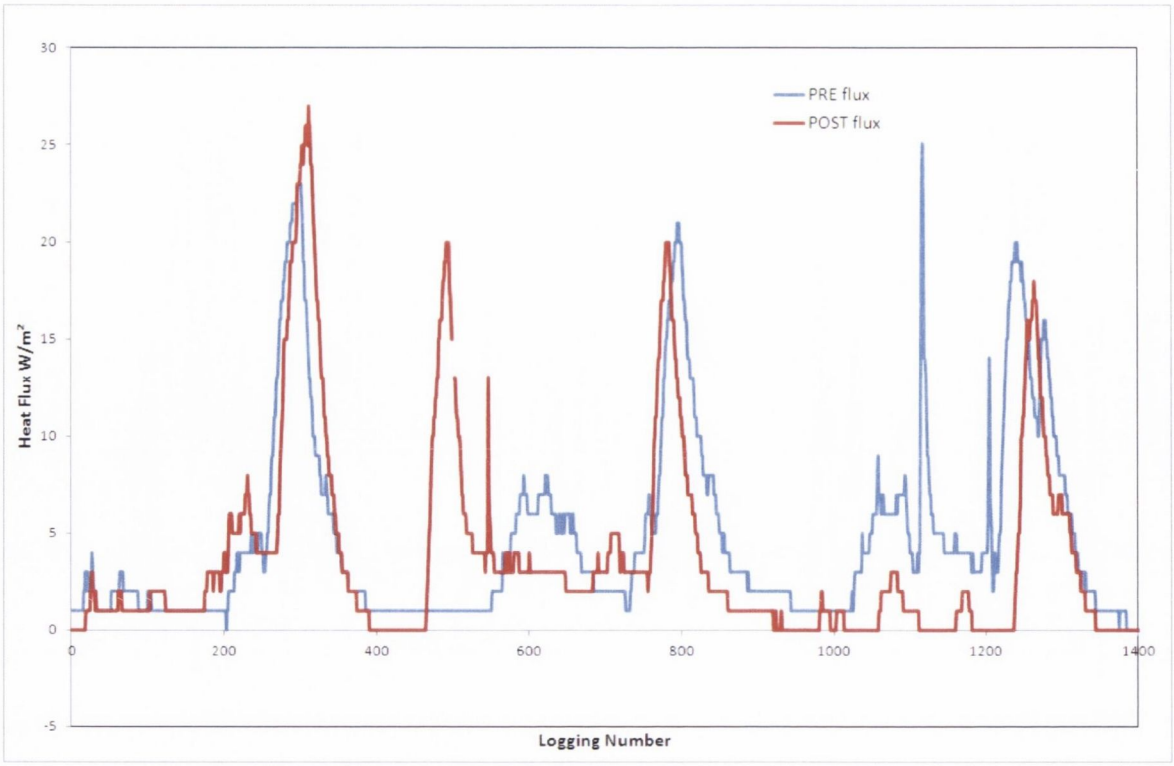


Figure A 28 Res1(c)

C.2 Internal temperatures in two rooms

All of the following graphs display flue temperature in °C on the y-axis, logging number on the sensor on the x-axis.

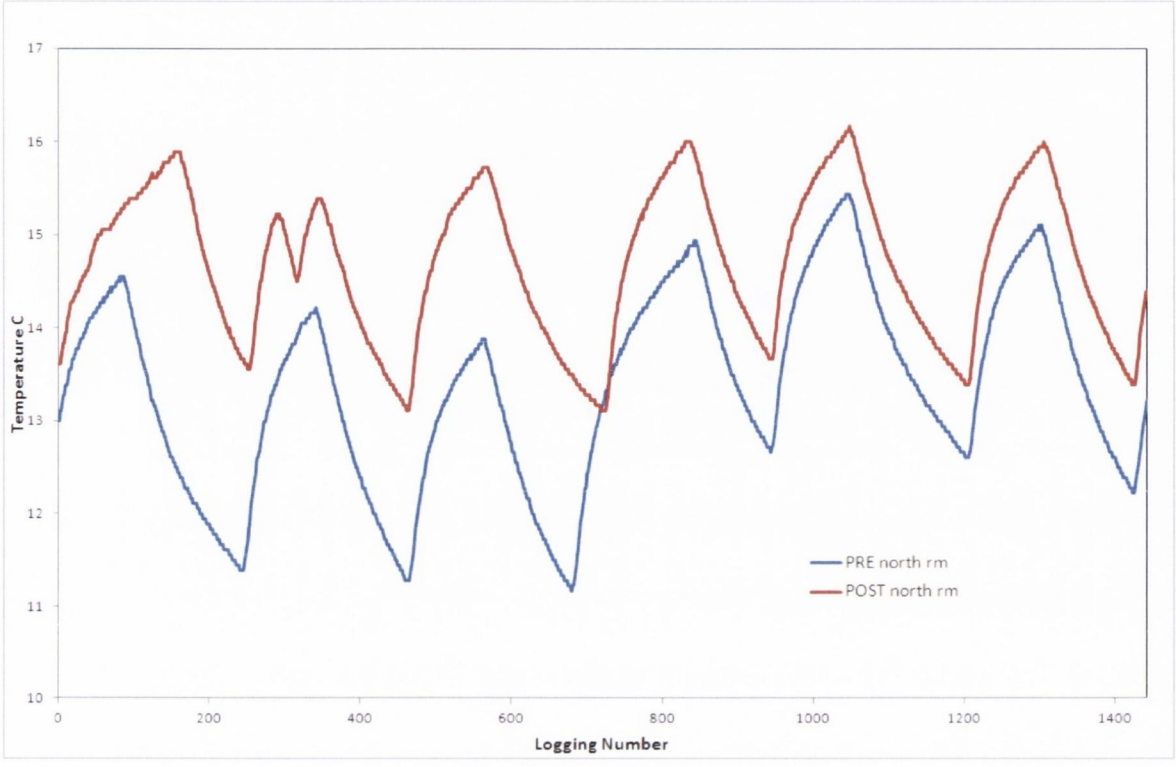


Figure A 29 Con(c) North room

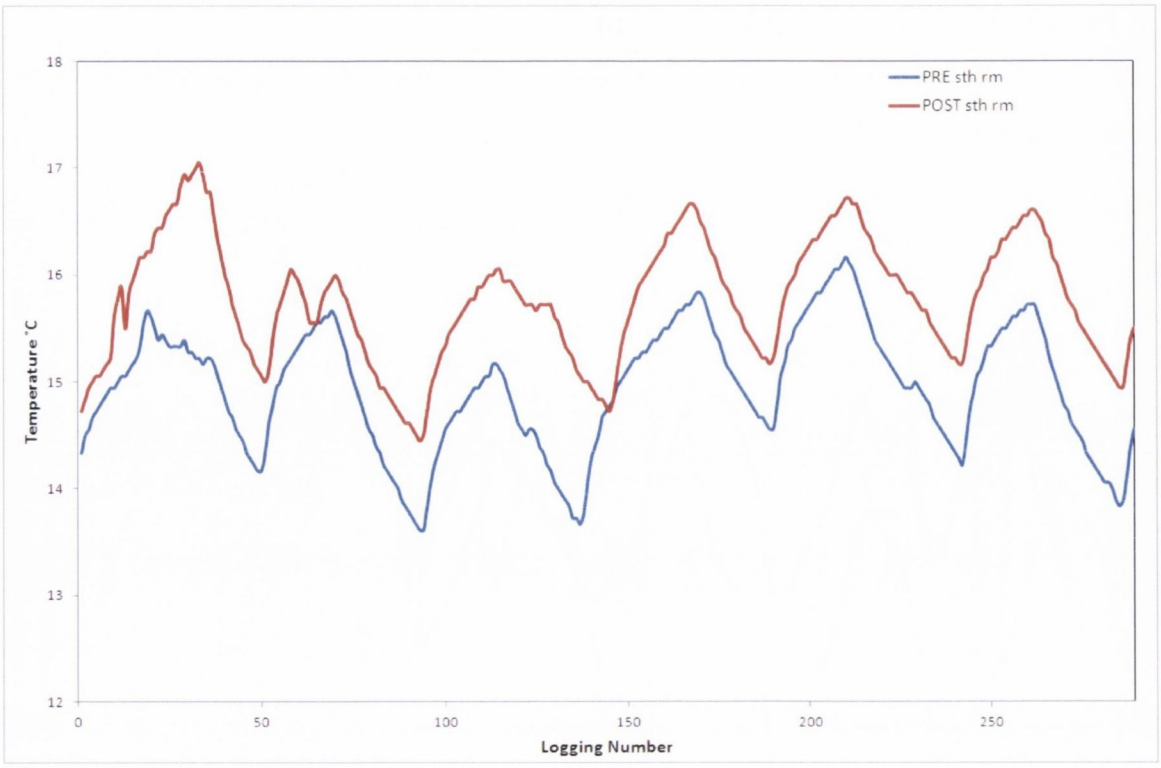


Figure A 30 Con(c) South room

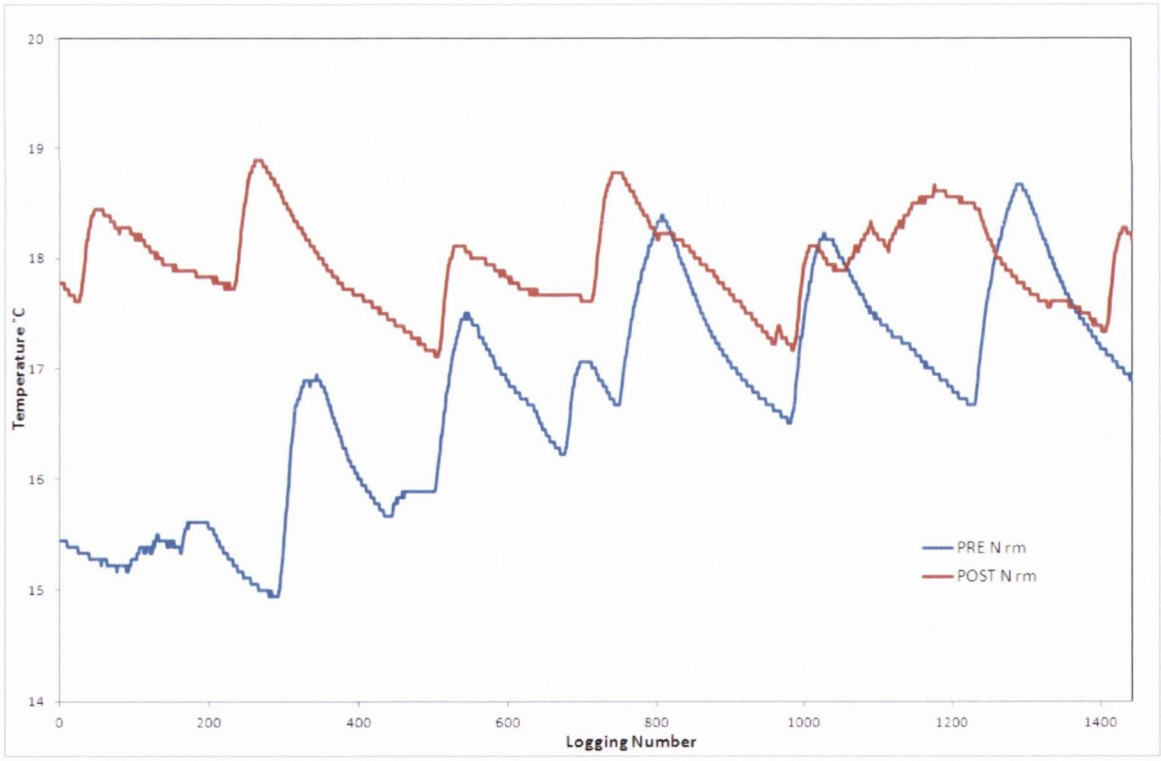


Figure A 31 Con(e) North room

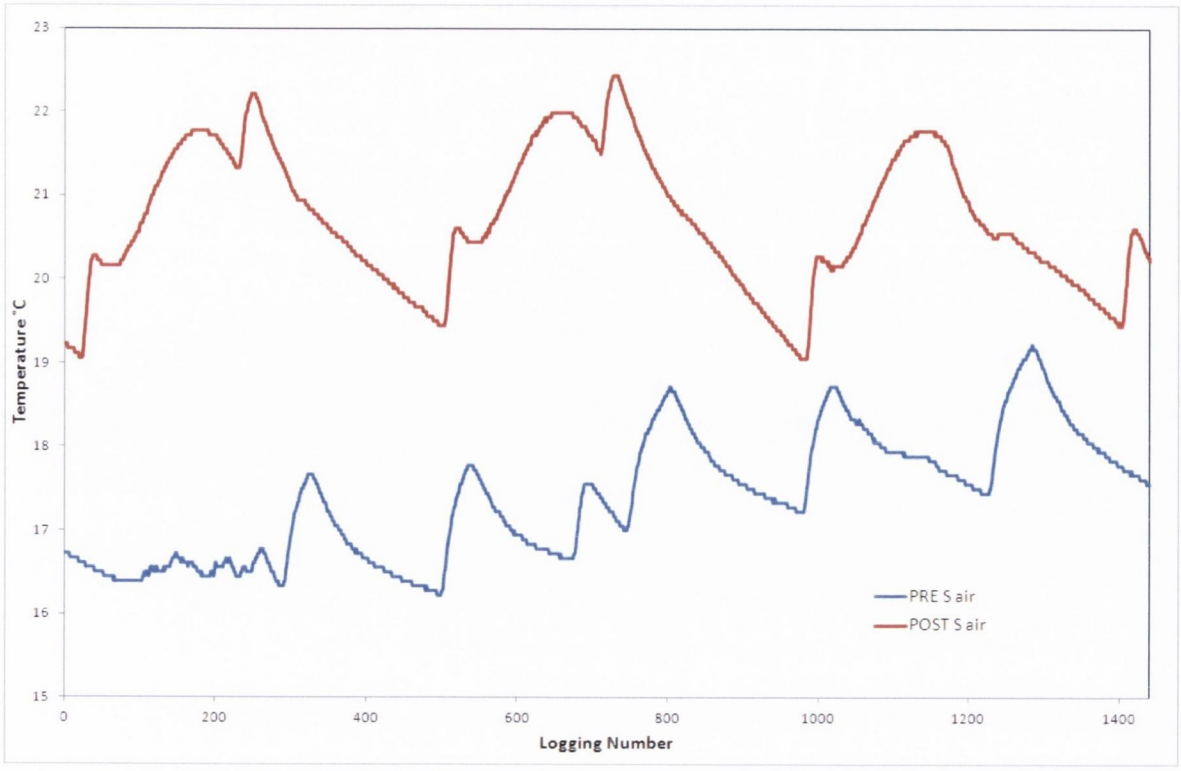


Figure A 32 Con(e) south room

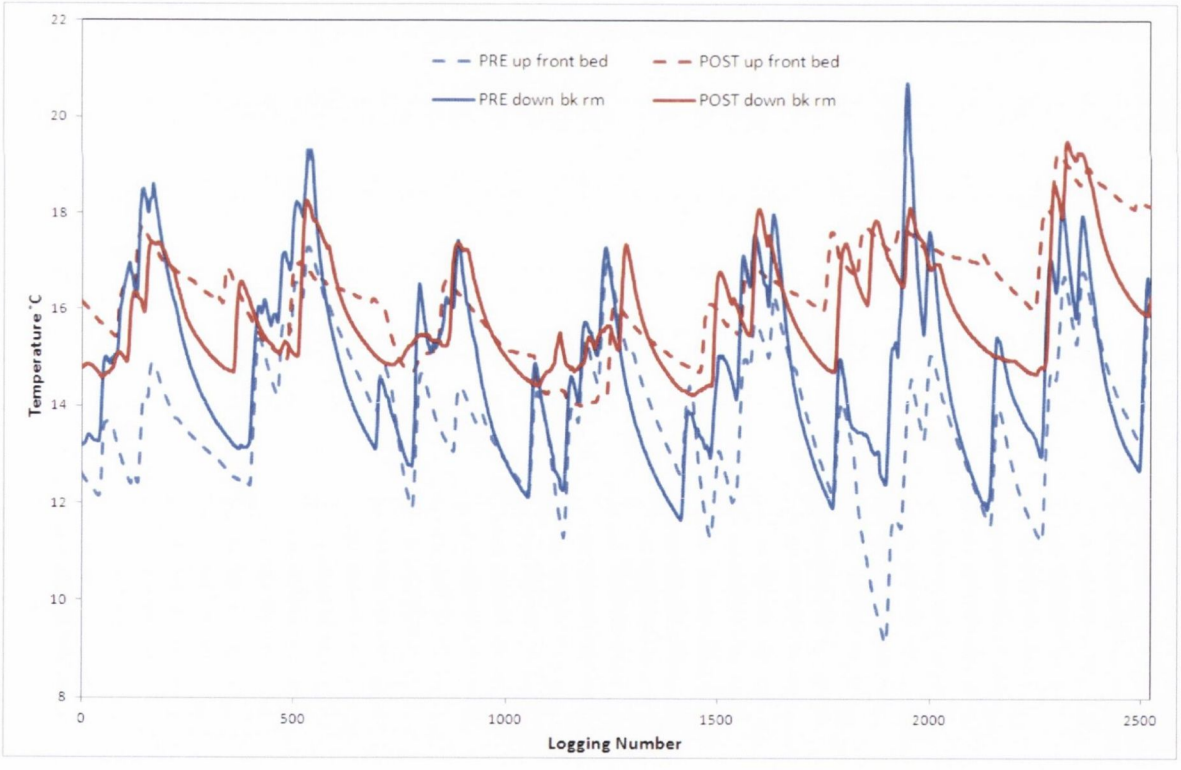


Figure A 33 SemiD1(e)

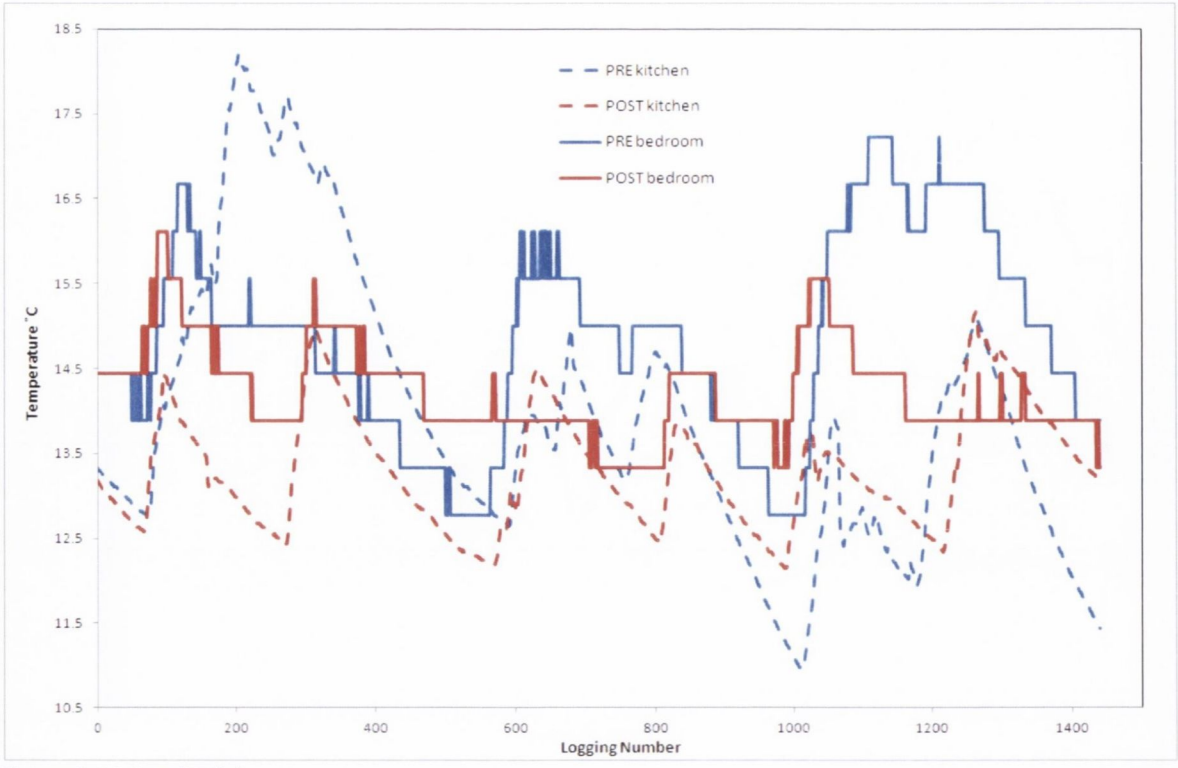


Figure A 34 SemiD2(c)

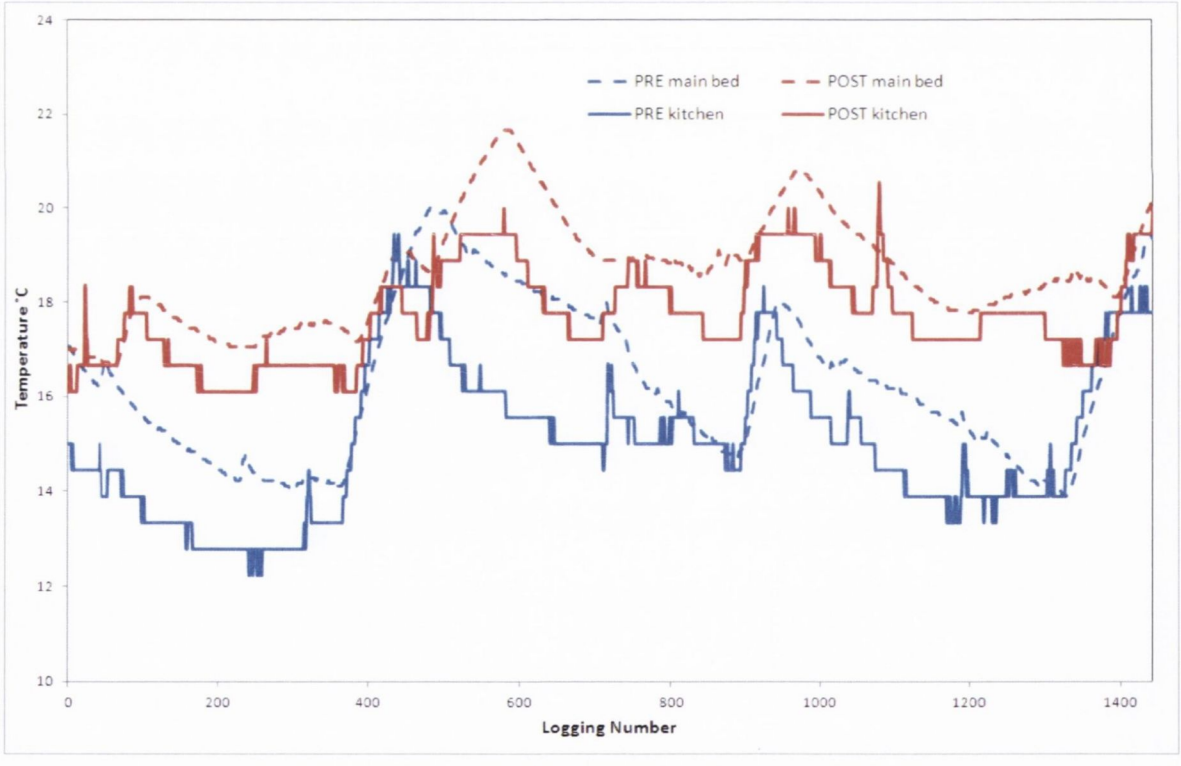


Figure A 35 SemiD3(e)

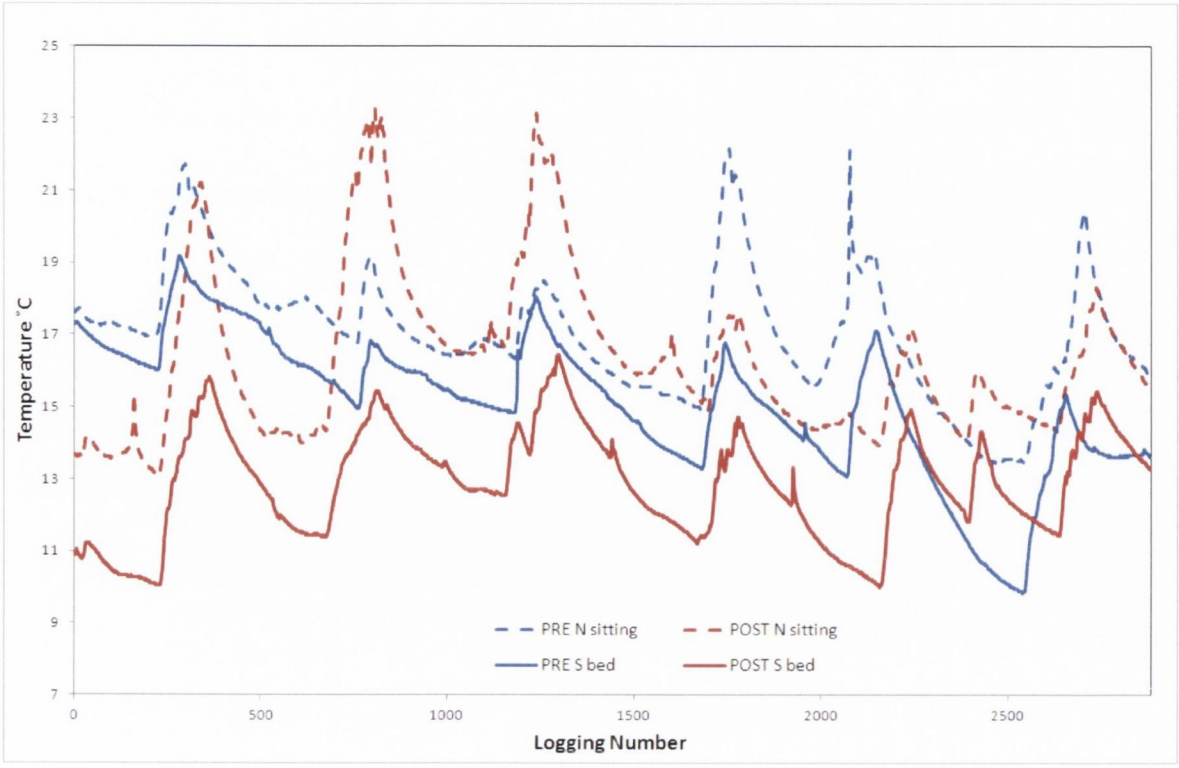


Figure A 36 Dor(e)

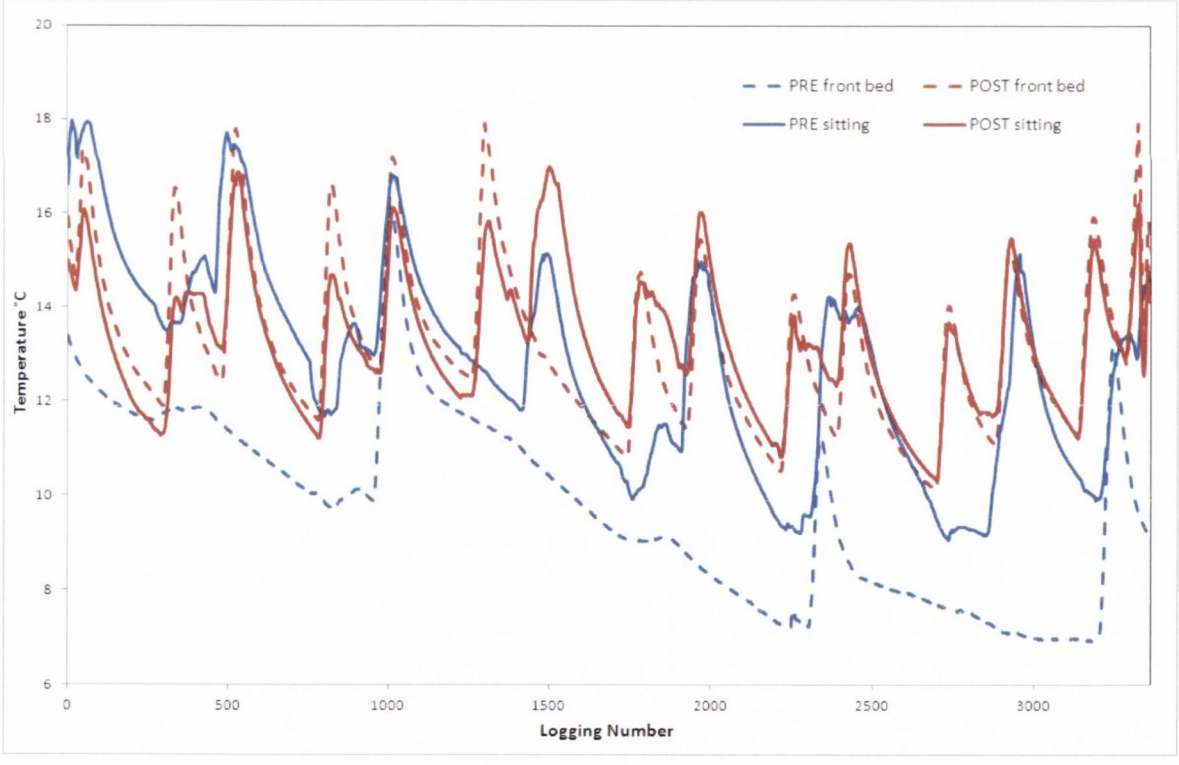


Figure A 37 Bun(e)

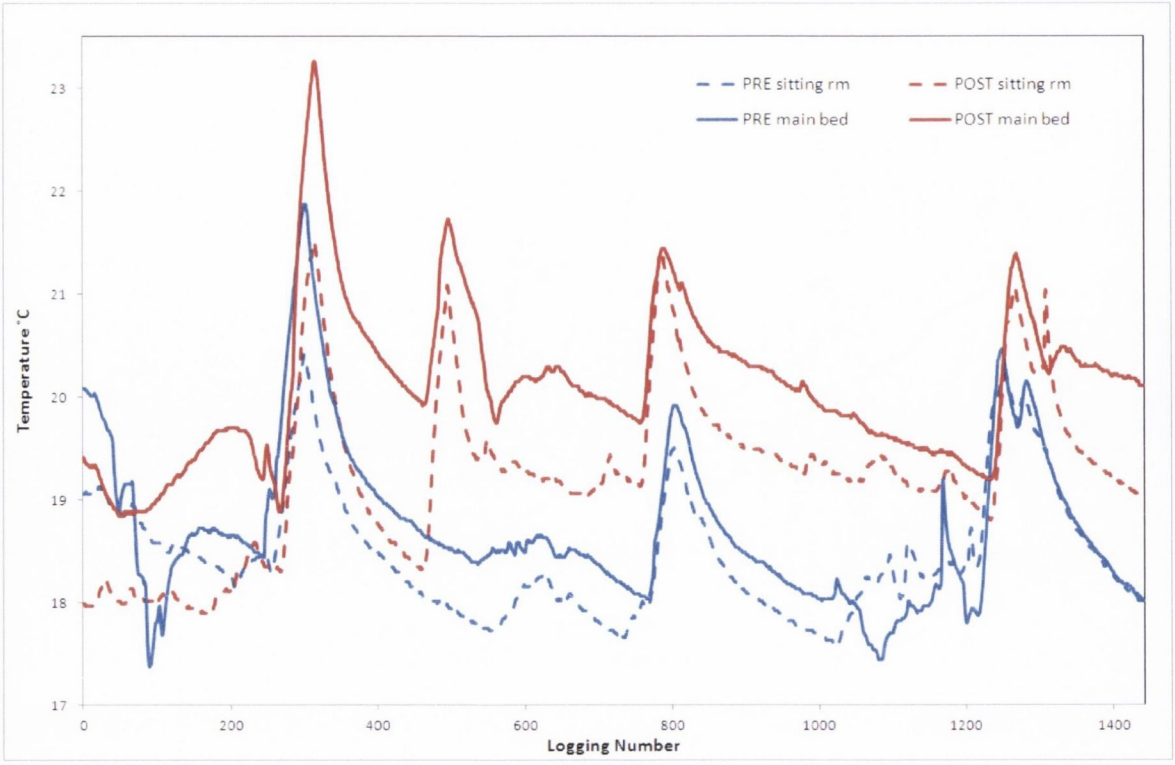


Figure A 38 Res1(c)

C.3 Flue

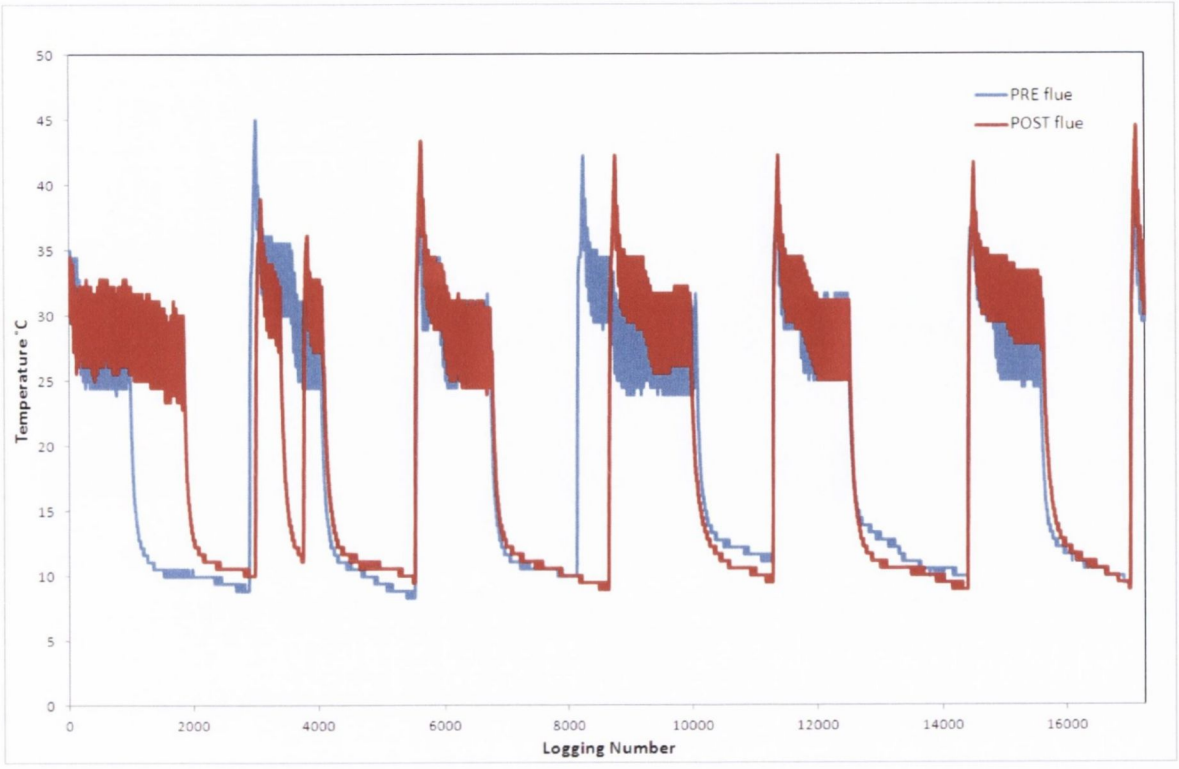


Figure A 39 Con(c)

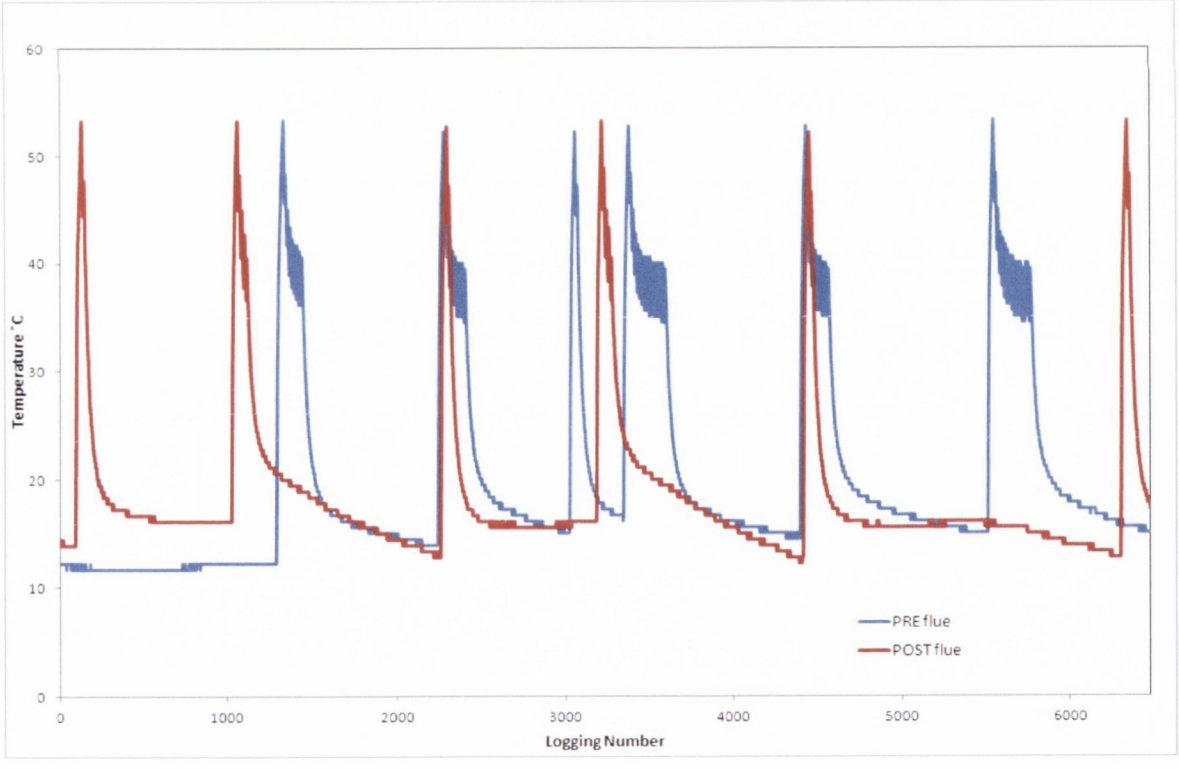


Figure A 40 Con(e)

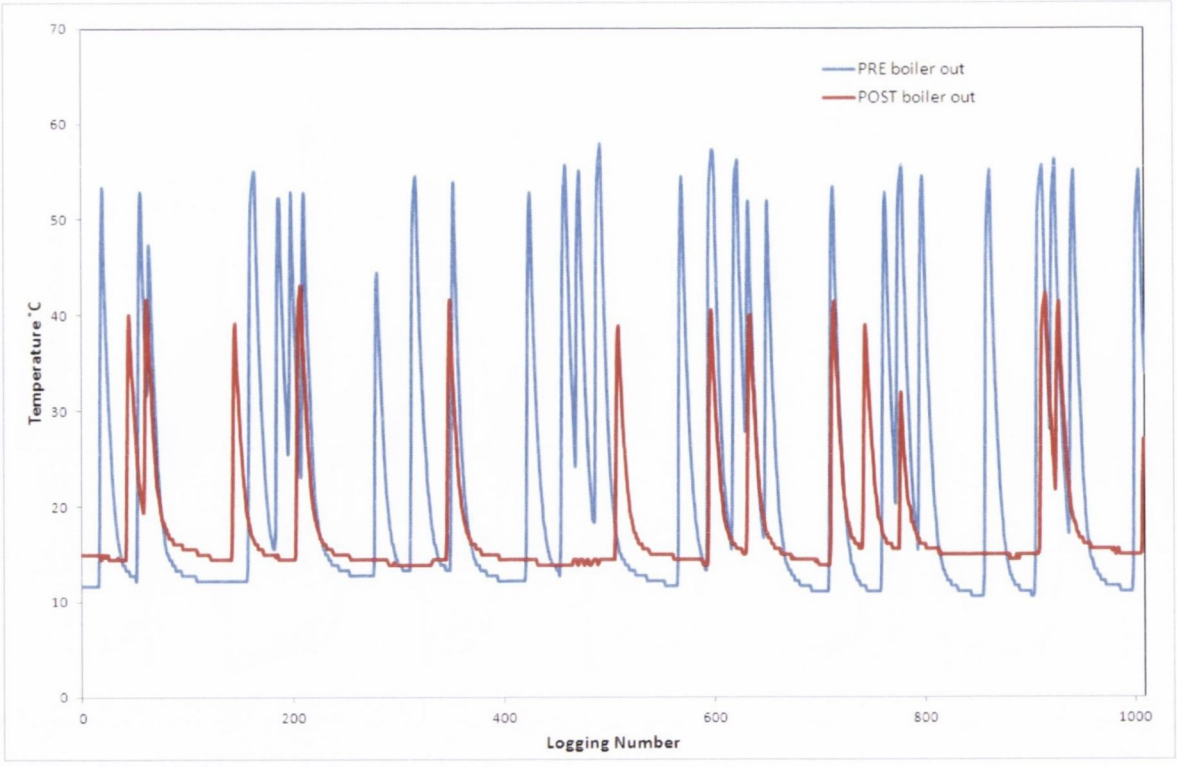


Figure A 41 SemiD1(e)

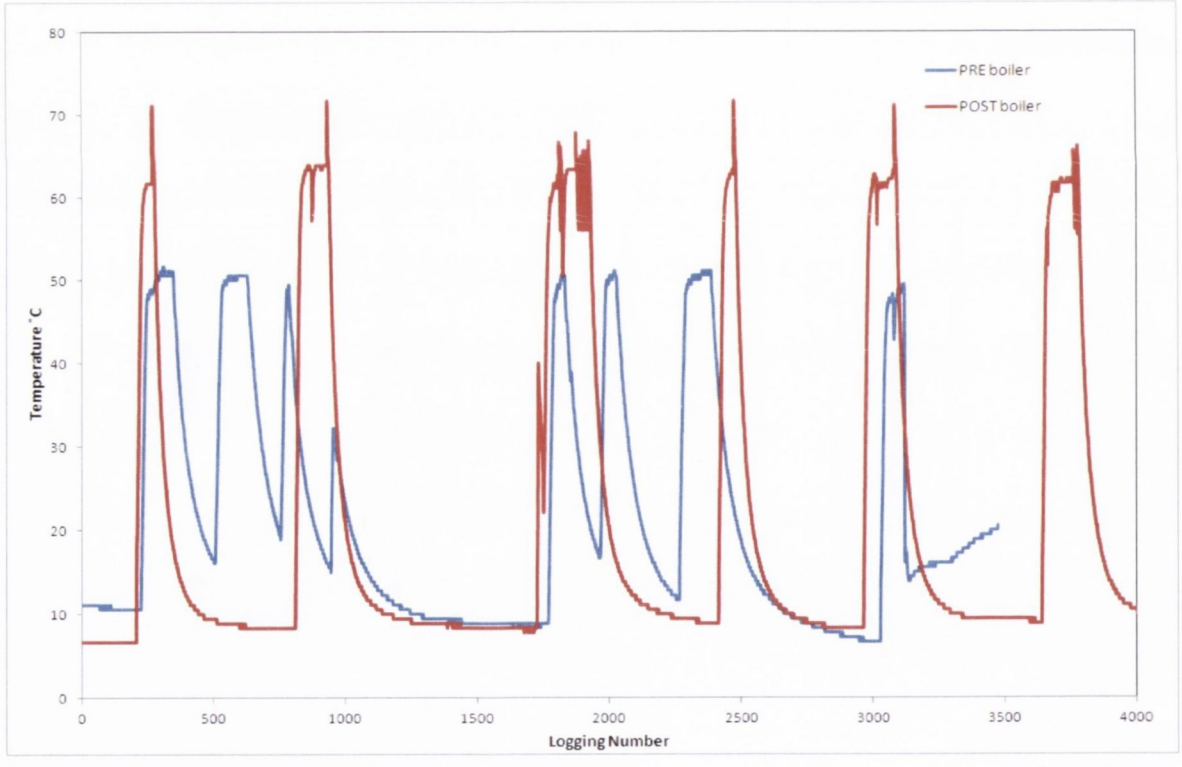


Figure A 42 SemiD2(c)

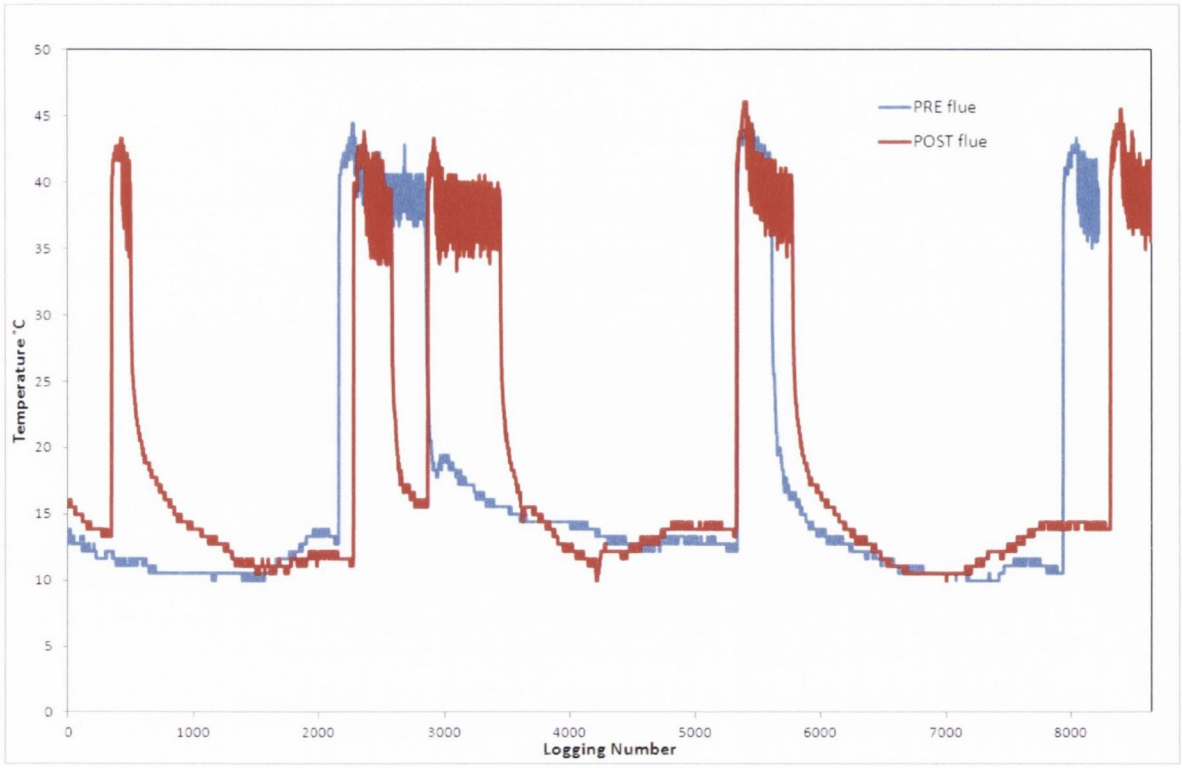


Figure A 43 SemiD3(e)

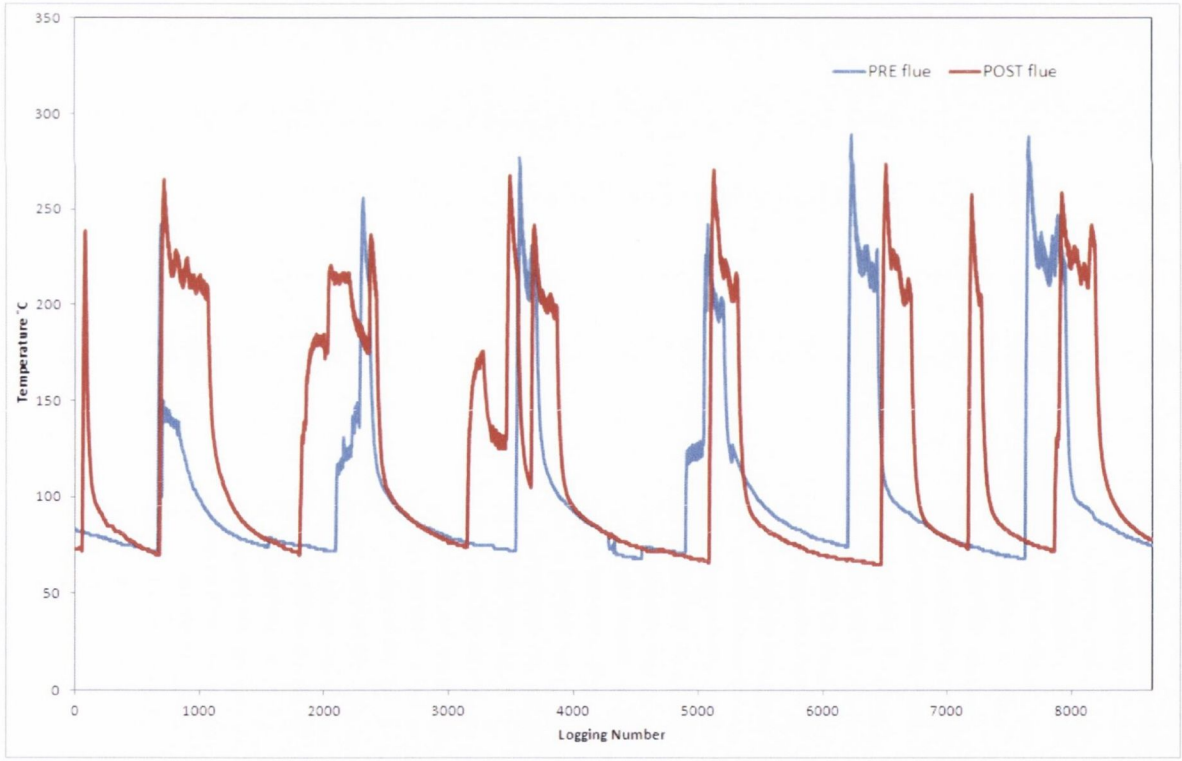


Figure A 44 Dor(e)

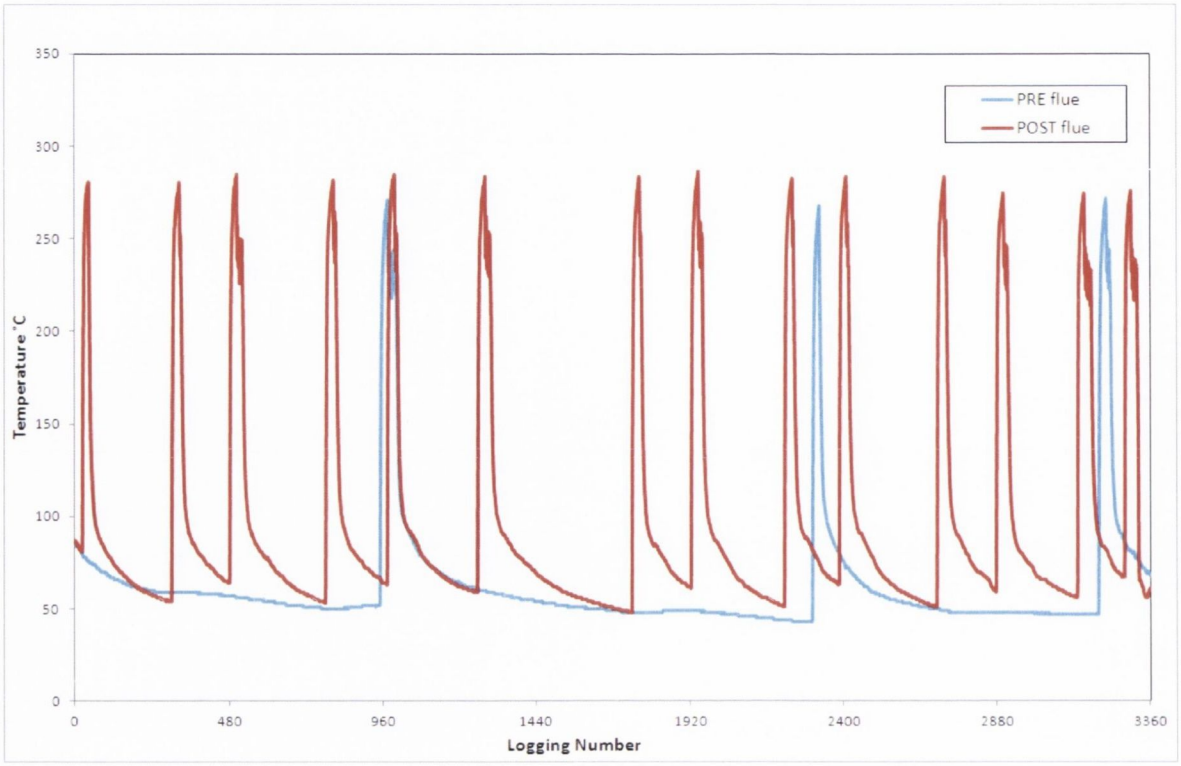


Figure A 45 Bun(e)

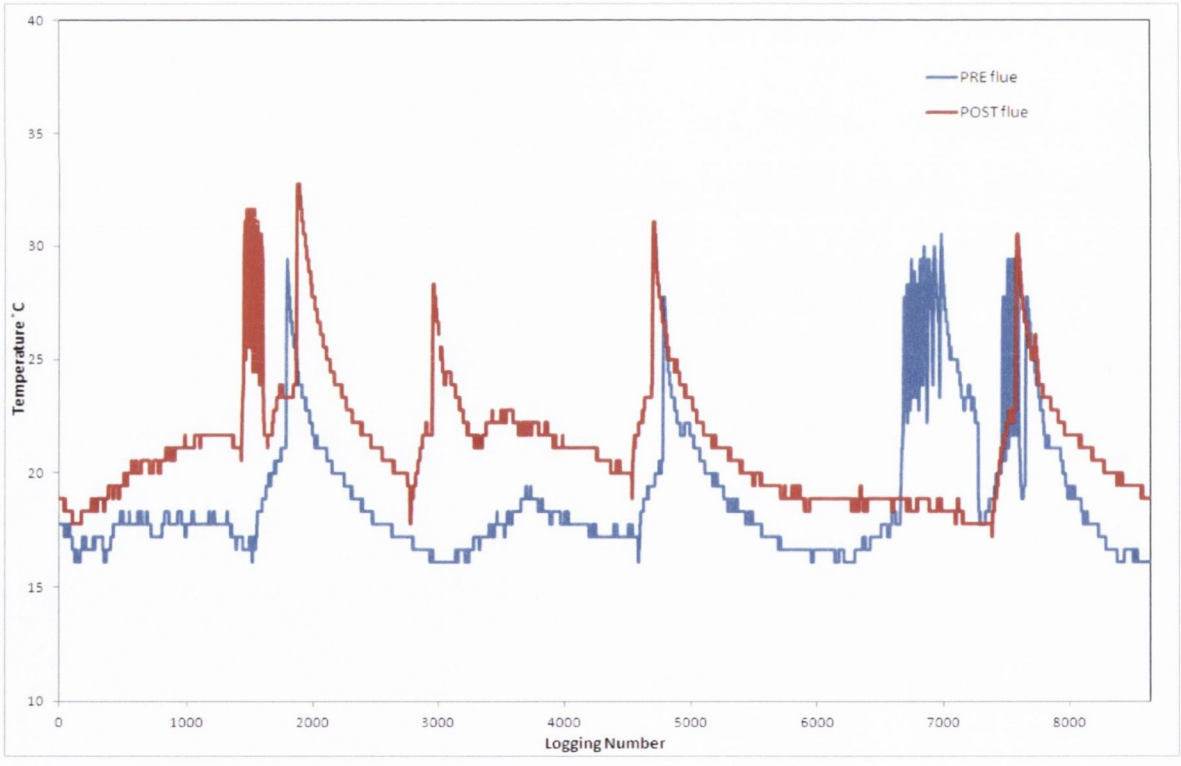


Figure A 46 Res1(c)

Appendix D

D.1 Stakeholder B interview script

Introduction/Consent

I am going to ask you a number of questions in relation to energy efficiency, climate change and governance with a particular focus on the SEAI's Better Energy Homes Scheme. Please be as frank as possible with your answers. All information will be treated with the utmost confidentiality. Your answers will not be attached in any way to your name, and your name will not appear in any publication so please give your own opinions and not the stance of your organisation, unless specifically asked for it. The purpose of this study is to find out about the drivers and barriers to energy efficiency and retrofit as well as perceived ways in which the system could be more effective. Do you agree to take part in this interview and allow it to be recorded?

Interviewee Profile

1. Please can you describe your occupation and expertise?
2. Please can you describe your involvement with the Better Energy Homes Scheme?
3. How would you rate your knowledge of the following: very low, low, medium, high, very high
    a. Energy Policy making and policy actions
    b. National climate change mitigation targets and associated actions
    c. Sector specific energy consumption and forecasting
    d. Action in the area of residential climate change mitigation
    e. The operating of and actions by the SEAI and other government/non-government organisations
    f. The technical aspects of retrofitting
    g. The BER system
    h. The Better Energy Homes Scheme
    i. The changeover to PAYS model
    j. Energy Efficiency and Renewable energy research both in Irish universities and other agencies

Better Energy Homes Scheme (SEAI)

1. To what extent do you believe that the offering of grants has improved the frequency of home energy efficiency retrofit? (Follow up: as opposed to better information available and the global paradigm shift towards sustainability)

2. What is your opinion on the items currently offered under the Better Energy Homes Scheme? (Follow up: what is your opinion on offering internal insulation? External insulation is high cost and long payback period – is this economically sound? Should anything else be offered?)
3. What is your opinion on the current structure of the scheme? (Follow up: the offering of grants as encouragement? No pre assessment required so homeowner chooses whatever they like? Is there a need for deeper retrofit/prescribed solution?)
4. The SEAI website holds a lot of useful information to homeowners on the Better Energy Homes Scheme. Yet none of the BEH clients I interviewed had accessed any of the links, obtaining all information instead from word of mouth or contractors. Why do you think this is? (Follow up: Could there be a better way of information dissemination?)
5. From examining the National Energy Efficiency Retrofit Programme which states "Programmes must be consistently monitored, evaluated and revised...must be able to adapt as new information and technologies emerge". It appears that the intention is to have a reiterative improvement process. Has this been done in the residential or retrofit area to your knowledge?
6. Why do you think the grant scheme, as it stands, is being abandoned and the Pay As You Save model preferred? (Prompts: cost to the exchequer, targeting new groups, following the UK/EC policies, advice from EC?)
    a. Has the model essentially been copied from the UK?
7. From my experience and SEAI research, the current clientele tend to be older, own their homes outright and have savings available. In my interviews this same group were in general personally against anything that resembled a long term loan, including the PAYS option. How do you foresee the demographic changing with the changeover to PAYS?
8. How do you perceive it affecting employment in the industry? (Follow up: Will smaller utility companies be able to handle to long payback periods? Will utility companies subcontract out retrofit work or create their own retrofit sectors which could lead to a number of retrofit companies closing?)

DEAP/BER

1. What is your opinion on the consistency of BER assessments? (Follow up: it has been shown that the same house can be given different building energy certification depending on the assessor)
2. In your experience, how much are the standard/default or tabulated values in the DEAP software used?
3. Does the DEAP methodology differ much from the UK SAP? Should it?
4. The potential of different national retrofit investments and schemes are usually examined using DEAP software. What is your opinion on using this software in this way? (Follow up: do you believe DEAP reflects the potential savings due to retrofit?)
5. What could be done to make predicted savings more reflective of true savings?

Research/Learning

1. In what way do you think that the government has learned lessons in EE policy? (Follow up: through experience? from other countries? IEA/Kema/EU assessments of our policies? Projections and future scenario studies?)
2. How would you rate the network/ institutional structures for knowledge transfer and communication of information? (follow up: Does this structure facilitate or constrain the movement of ideas and information? To your knowledge is there any follow up by the IEA or EC to examine where the research ends up?)
3. How could this be improved?
4. What did you think of the consultation phases on NEEAP and NEERP?
5. What in your opinion is the reasoning behind the drive at EU and national level (Ireland has signed up to EU target of 3% GDP in R&D by 2020) to increase research in energy efficiency and renewable? (Follow up: Is the aim to inform policy or more to create experts/specialisation?)
6. Other than combining research into databases, what happens to the findings in Renewables and Energy Efficiency research?
7. Is there any responsible body in charge of examining and disseminating research findings?
8. Has any of this research informed policy/government actions?

Finishing up

1. Do you have any further comment or questions?

D.2 Stakeholder C interview script

Introduction/Consent

I am going to ask you a number of questions in relation to energy efficiency, climate change and governance with a particular focus on the SEAI's Better Energy Homes Scheme. Please be as frank as possible with your answers. All information will be treated with the utmost confidentiality. Your answers will not be attached in any way to your name, and your name will not appear in any publication so please give your own opinions and not the stance of your organisation, unless specifically asked for it. The purpose of this study is to find out about the drivers and barriers to energy efficiency and retrofit as well as perceived ways in which the system could be more effective. Do you agree to take part in this interview and allow it to be recorded?

Interviewee Profile

1. Please can you describe your occupation and expertise?
2. Please can you describe your involvement with the Better Energy Homes Scheme?
3. How would you rate your knowledge of the following: very low, low, medium, high, very high
    a. Energy Policy making and policy actions
    b. National climate change mitigation targets and associated actions
    c. Sector specific energy consumption and forecasting
    d. Action in the area of residential climate change mitigation
    e. The operating of and actions by the SEAI and other government/non-government organisations
    f. The technical aspects of retrofitting
    g. The BER system
    h. The Better Energy Homes Scheme
    i. The changeover to PAYS model
    j. Energy Efficiency and Renewable energy research both in Irish universities and other agencies

Estimates and forecasting

1. What is the role of the Energy Modelling Group?
2. How is the energy demand per sector estimated? Specifically the residential sector?
3. What is the process involved in forecasting changes in demand due to policy? (Follow up: where to the estimates for potential savings per sector come from?)
4. What is the reason behind performing such energy reporting and forecasting? (Follow up: to what extent is it due to EU reporting/forecasting obligations versus informing policy?)

5. How is Ireland's progress towards European and national energy efficiency targets monitored? (Follow up: is it based on top-down or bottom up estimates?)
6. How close is Ireland to achieving these targets?
7. How much of this is due to policy efforts versus the economic downturn and emigration?
8. Why was the billing analysis of the Home Energy Saving scheme conducted?
9. Have the findings been used in any way to reshape the HES scheme to the new Better Energy Homes Scheme? (Follow up: to your knowledge have the findings been used anywhere (else)?)
10. In the same study the difference between expected savings and actual was 36%. Is this finding being used in any way? (follow up: any change to future policy forecasting? Any plan to move away from DEAP or calibrating/improving it to be more reflective of actual potential?)

Better Energy Homes Scheme (SEAI)

1. To what extent do you believe that the offering of grants has improved the frequency of home energy efficiency retrofit? (Follow up: as opposed to better information available and the global paradigm shift towards sustainability
2. What is your opinion on the current structure of the scheme? (Follow up: the offering of grants as encouragement? No pre assessment required so homeowner chooses whatever they like? Is there a need for deeper retrofit/prescribed solution?)
3. The SEAI website holds a lot of useful information to homeowners on the Better Energy Homes Scheme. Yet none of the BEH clients I interviewed had accessed any of the links, obtaining all information instead from word of mouth or contractors. Why do you think this is? (Follow up: Could there be a better way of information dissemination?)
4. From examining the National Energy Efficiency Retrofit Programme which states "Programmes must be consistently monitored, evaluated and revised...must be able to adapt as new information and technologies emerge". It appears that the intention is to have a reiterative improvement process. Has this been done in the residential or retrofit area to your knowledge?
5. Why is the grant scheme, as it stands, being abandoned and the Pay As You Save model preferred? (Prompts: cost to the exchequer, targeting new groups, following the UK/EC policies, advice from EC?)
    a. Has the model essentially been copied from the UK?
6. From my experience and SEAI research, the current clientele tend to be older, own their homes outright and have savings available. In my interviews this same group were in general personally against anything that resembled a long term load, including the PAYS option. How do you foresee the demographic changing with the changeover to PAYS?
7. How do you perceive it affecting employment in the industry? (Follow up: Will smaller utility companies be able to handle to long payback periods? Will utility companies subcontract out retrofit work or create their own retrofit sectors which could lead to a number of retrofit companies closing?)

Research/Learning

1. In what way do you think that the government has learned lessons in EE policy?
    a. (Follow up: through experience? from other countries? IEA/Kema/EU assessments of our policies? Projections and future scenario studies?)
2. How would you rate the network/ institutional structures for knowledge transfer and communication of information? (follow up:Does this structure facilitate or constrain the movement of ideas and information? To your knowledge is there any follow up by the IEA or EC to examine where the research ends up?How could this be improved?
3. What did you think of the consultation phases on NEEAP and NEERP?What in your opinion is the reasoning behind the drive at EU and national level (Ireland has signed up to EU target of 3% GDP in R&D by 2020) to increase research in energy efficiency and renewable? (Follow up: Is the aim to inform policy or more to create experts/specialisation?)
4. Other than combining research into databases, what happens to the findings in Renewables and Energy Efficiency research?
5. Is there any responsible body in charge of examining and disseminating research findings?
6. Has any of this research informed policy/government actions?

Finishing up

1. Do you have any further comment or questions?

D.3 Stakeholder D interview script

Introduction/Consent

I am going to ask you a number of questions in relation to energy efficiency, climate change and governance with a particular focus on the SEAI's Better Energy Homes Scheme. Please be as frank as possible with your answers. All information will be treated with the utmost confidentiality. Your answers will not be attached in any way to your name, and your name will not appear in any publication so please give your own opinions and not the stance of your organisation, unless specifically asked for it. The purpose of this study is to find out about the drivers and barriers to energy efficiency and retrofit as well as perceived ways in which the system could be more effective. Do you agree to take part in this interview and allow it to be recorded?

Interviewee Profile

1. Please can you describe your occupation and expertise?
2. Please can you describe your involvement with the Better Energy Homes Scheme?
3. How would you rate your knowledge of the following: very low, low, medium, high, very high
    a. Energy Policy making and policy actions
    b. National climate change mitigation targets and associated actions
    c. Sector specific energy consumption and forecasting
    d. Action in the area of residential climate change mitigation
    e. The operating of and actions by the SEAI and other government/non-government organisations
    f. The technical aspects of retrofitting
    g. The BER system
    h. The Better Energy Homes Scheme
    i. The changeover to PAYS model
    j. Energy Efficiency and Renewable energy research both in Irish universities and other agencies

General

1. How is Ireland's progress towards European and national energy efficiency targets monitored? (Follow up: is it based on top-down or bottom up estimates?)
2. How close is Ireland to achieving these targets?
3. How much of this is due to policy efforts versus the economic downturn and emigration?
4. In your opinion, where should efforts be focused?
5. In your opinion, which policy tools are the most successful? Follow up -Do you think that the carrot (incentives such as grants), stick (e.g. tax) or voluntary approaches (e.g. information) work best for encouraging more energy efficient practices?

6. How much do you think that the current efforts in the residential sector contribute to reducing climate change E.g. BER, the power of one campaign, retrofit schemes, appliance labelling, and energy efficient lighting?
7. Do you have any suggestions of where efforts should be focused when trying to mitigate climate change contributions from the residential sector?
8. Or does this sector even have that much potential for savings?

Better Energy Homes Scheme (SEAI)

1. In what way does the Department of Communications, Energy and Natural Resources work with the SEAI?
2. To what extent is the DCENR involved in the design of the national retrofit effort and specifically the Better Energy Homes Scheme?
3. To what extent do you believe that the offering of grants has improved the frequency of home energy efficiency retrofit? (Follow up: as opposed to better information available and the global paradigm shift towards sustainability
4. What is your opinion on the current structure of the scheme? (Follow up: the offering of grants as encouragement? No pre assessment required so homeowner chooses whatever they like? Is there a need for deeper retrofit/prescribed solution?)
5. The SEAI website holds a lot of useful information to homeowners on the Better Energy Homes Scheme. Yet none of the BEH clients I interviewed had accessed any of the links, obtaining all information instead from word of mouth or contractors. Why do you think this is? (Follow up: Could there be a better way of information dissemination?)
6. From examining the National Energy Efficiency Retrofit Programme which states "Programmes must be consistently monitored, evaluated and revised...must be able to adapt as new information and technologies emerge". It appears that the intention is to have a reiterative improvement process. Has this been done in the residential or retrofit area to your knowledge?
7. Why is the grant scheme, as it stands, being abandoned and the Pay As You Save model preferred? (Prompts: cost to the exchequer, targeting new groups, following the UK/EC policies, advice from EC?)
8. Has the model essentially been copied from the UK?
9. From my experience and SEAI research, the current clientele tend to be older, own their homes outright and have savings available. In my interviews this same group were in general personally against anything that resembled a long term load, including the PAYS option. How do you foresee the demographic changing with the changeover to PAYS?
10. How do you perceive it affecting employment in the industry? (Follow up: Will smaller utility companies be able to handle to long payback periods? Will utility companies subcontract out retrofit work or create their own retrofit sectors which could lead to a number of retrofit companies closing?)

Research/Learning

1. In what way do you think that the government has learned lessons in EE policy?
    a. (Follow up: through experience? from other countries? IEA/Kema/EU assessments of our policies? Projections and future scenario studies?)

2. How would you rate the network/ institutional structures for knowledge transfer and communication of information? (follow up:Does this structure facilitate or constrain the movement of ideas and information? To your knowledge is there any follow up by the IEA or EC to examine where the research ends up?
3. How could this be improved?
4. What did you think of the consultation phases on NEEAP and NEERP?
5. What in your opinion is the reasoning behind the drive at EU and national level (Ireland has signed up to EU target of 3% GDP in R&D by 2020) to increase research in energy efficiency and renewable? (Follow up: Is the aim to inform policy or more to create experts/specialisation?)
6. Other than combining research into databases, what happens to the findings in Renewables and Energy Efficiency research?
7. Is there any responsible body in charge of examining and disseminating research findings?
8. Has any of this research informed policy/government actions?

Finishing up

1. Do you have any further comment or questions?

D.4 Stakeholder E interview script

Introduction/Consent

I am going to ask you a number of questions in relation to energy efficiency, climate change and governance with a particular focus on the SEAI's Better Energy Homes Scheme. Please be as frank as possible with your answers. All information will be treated with the utmost confidentiality. Your answers will not be attached in any way to your name, and your name will not appear in any publication so please give your own opinions and not the stance of your organisation, unless specifically asked for it. The purpose of this study is to find out about the drivers and barriers to energy efficiency and retrofit as well as perceived ways in which the system could be more effective. Do you agree to take part in this interview and allow it to be recorded?

Interviewee Profile

1. Please can you describe your occupation and expertise?
2. Please can you describe your involvement with the Better Energy Homes Scheme?
3. How would you rate your knowledge of the following: very low, low, medium, high, very high
    a. Energy Policy making and policy actions
    b. National climate change mitigation targets and associated actions
    c. Sector specific energy consumption and forecasting
    d. Action in the area of residential climate change mitigation
    e. The operating of and actions by the SEAI and other government/non-government organisations
    f. The technical aspects of retrofitting
    g. The BER system
    h. The Better Energy Homes Scheme
    i. The changeover to PAYS model
    j. Energy Efficiency and Renewable energy research both in Irish universities and other agencies

Better Energy Homes Scheme (SEAI)

1. To what extent do you believe that the offering of grants has improved the frequency of home energy efficiency retrofit? (Follow up: as opposed to better information available and the global paradigm shift towards sustainability
2. What is your opinion on the current structure of the scheme? (Follow up: the offering of grants as encouragement? No pre assessment required so homeowner chooses whatever they like?)

3. The SEAI website holds a lot of useful information to homeowners on the Better Energy Homes Scheme. Yet none of the BEH clients I interviewed had accessed any of the links, obtaining all information instead from word of mouth or contractors. Why do you think this is? (Follow up: Could there be a better way of information dissemination?)
4. From examining the National Energy Efficiency Retrofit Programme which states "Programmes must be consistently monitored, evaluated and revised...must be able to adapt as new information and technologies emerge". It appears that the intention is to have a reiterative improvement process. Has this been done in the residential or retrofit area to your knowledge?
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    a. Has the model essentially been copied from the UK?
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7. How do you perceive it affecting employment in the industry? (Follow up: Will smaller utility companies be able to handle to long payback periods? Will utility companies subcontract out retrofit work or create their own retrofit sectors which could lead to a number of retrofit companies closing?)
8. The documents from 2011 on financing options for retrofit and the recent related document in April 2013 (have both to show them), alot of barriers to takeup are examined alongside possible adjustments to the schemes to ensure highest takeup. In your own personal opinion, what is the key factor(s) in determining how the scheme is being redesigned – lowest cost to the exchequer? Highest takeup? Highest energy/carbon saving?
9. Has your research indicated how the potential take-up of the new PAYS scheme differs from the current?
10. What were the priorities of the study – lowest cost? Highest take-up? Highest energy/carbon saving?

Research/Learning

1. In what way do you think that the government has learned lessons in EE policy?
    a. (Follow up: through experience? from other countries? IEA/Kema/EU assessments of our policies? Projections and future scenario studies?)
2. How would you rate the network/ institutional structures for knowledge transfer and communication of information? (follow up:Does this structure facilitate or constrain the movement of ideas and information? To your knowledge is there any follow up by the IEA or EC to examine where the research ends up?
3. How could this be improved?

4. What did you think of the consultation phases on NEEAP and NEERP?What in your opinion is the reasoning behind the drive at EU and national level (Ireland has signed up to EU target of 3% GDP in R&D by 2020) to increase research in energy efficiency and renewable? (Follow up: Is the aim to inform policy or more to create experts/specialisation?)
5. Other than combining research into databases, what happens to the findings in Renewables and Energy Efficiency research?
6. Is there any responsible body in charge of examining and disseminating research findings?
7. Has any of this research informed policy/government actions?

Finishing up

1. Do you have any further comment or questions?