Closing the Loop

The use of post occupancy evaluation to inform adaption choices to overheating in Derwenthorpe

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List of abbreviations and acronyms

ARCC	Adaptation and Resilience in the Context of Change Network
BRE	Building Research Establishment
CCC	Committee on Climate Change
CIBSE	Chartered Institute of Building Services Engineers
CSH	Code for Sustainable Homes
DCLG	Department for Communities and Local Government
DECC	Department for Energy and Climate Change
EFUS	Energy Follow Up Survey
EP	English Partnerships
GHA	Good Homes Alliance
GHG	Greenhouse gases
HCA	Homes and Communities Agency
HM	Her Majesty's
IPCC	Intergovernmental Panel on Climate Change
JRHT	Joseph Rowntree Housing Trust
MtCO2e	Million tonnes carbon dioxide equivalent
MVHR	Mechanical Ventilation Heat Recovery
NHBC	National House Building Council
SAP	Standard Assessment Procedure
TSB	Technology Strategy Board
UN	United Nations
UK	United Kingdom
UKCP09	UK Climate Projections
ZCH	Zero Carbon Hub

Abstract

In 2008, the UK committed to legally binding targets to reduce carbon emissions by 80% by 2050 (CCC, 2008). Although the target applies to all sectors, approximately 29% of carbon emissions are generated from the residential sector (DECC, 2013). Whilst there is a focus to improve the energy efficiency of existing homes, there has been a drive to significantly reduce carbon emissions in new homes, mainly through improvement of the Building Regulations (DCLG, 2010b). Whilst this approach has reduced consumption of fossil fuels, especially in terms of heating and hot water, there is an increasing body of evidence that an unintended consequence of energy efficiency improvements is that homes are overheating (DCLG, 2012). Compounding this issue is the fact that there is little regulation for overheating assessments for new and existing buildings, especially in the residential sector.

There is a concern that whilst many buildings are already overheating, there is a growing body of scientific evidence (IPCC, 2013, UKCP09) that shows that the overheating risk will increase in the future, when considered in the context of climate change and increasing summertime temperatures.

To address the issue a substantial number of studies, domestically and internationally, have assessed how a range of adaptation measures can reduce internal temperatures to reduce the risk of overheating. Adaptation measures can range from passive measures, such as curtains, to energy consuming measures, such as air conditioning units.

Whilst this activity has developed knowledge on what are, technically, the most effective adaptation measures, the role of the building occupant has been ignored to date. Given that the application of adaptation measures can not only change the appearance of the building, but also require user input and incur maintenance costs, the role of the resident is a key consideration when addressing overheating in the residential sector.

This research seeks to explore this gap. Firstly, a survey of residents of Derwenthorpe showed that 47% of residents thought their homes were overheating, especially in main bedrooms and living rooms. The same survey identified that residents recognised that summertime temperatures would increase in the future, and as a result they would need to adapt their home, and how they live in their home, to manage this increase in temperature.

The preferred adaptation measures, as selected by residents, were low cost measures that they were already familiar with including internal blinds, curtains and night ventilation.

The research aimed to assess the impact of the measures that were chosen, and whilst the use of an online retrofit toolkit showed the measures were highly effective at reducing overheating, a comparison run through dynamic simulation software suggested that the measures were less effective. Further work in this area is required to understand the reason for this difference.

There are clear benefits to developing a method to allow residents to select adaptation measures which they believe are appropriate for their homes. Consideration needs to be given to a range of criteria that inform the decision making process, as criteria that were used as part of this study may not be applicable to another development.
Lastly, the range of adaptation measures that were considered as part of this study could be developed as part of a wider study, to include a greater range of passive measures, whilst introducing a number of energy consuming measures that may be of preference to residents.

Word count: approximately 21,250

1 Introduction

This thesis represents the work undertaken to complete the dissertation element of an MSc in Climate Change and Sustainable Development at De Montfort University. The introduction section provides a summary of the research context and rationale, the key aims and objectives of the project, an introduction to the case study development, and an outline of the thesis structure.

1.1 Climate change- the background

There are a number of greenhouse gases that are present in the environment to warm the earth, namely carbon dioxide (CO_2), methane (CH_4), Nitrous oxides (NO_x) and water vapours. Whilst these gases have always been present within the earth’s atmosphere, the increase in the presence of these is causing accelerated change.

The IPCC (2007) has shown that as a result of human activity, the emissions of these gases has increased significantly. This can most significantly be seen in the increase in the level of emissions from the industrial revolution to 1970. To minimise the risk of these emissions the IPCC recommended that to keep global warming below 2 °C, emissions of carbon dioxide (CO_2) and other GHGs must be halved by 2050 (compared with 1990 levels).

Most recently, the IPCC (2013) has published further findings on the impact of climate change, and has stated that the last three decades have been successively warmer that any decade since 1950.

This pattern of climate change has seen a steady increase in number of climate change related disasters, with temperature extremes becoming frequent since 1975, as shown in Figure 1.1.

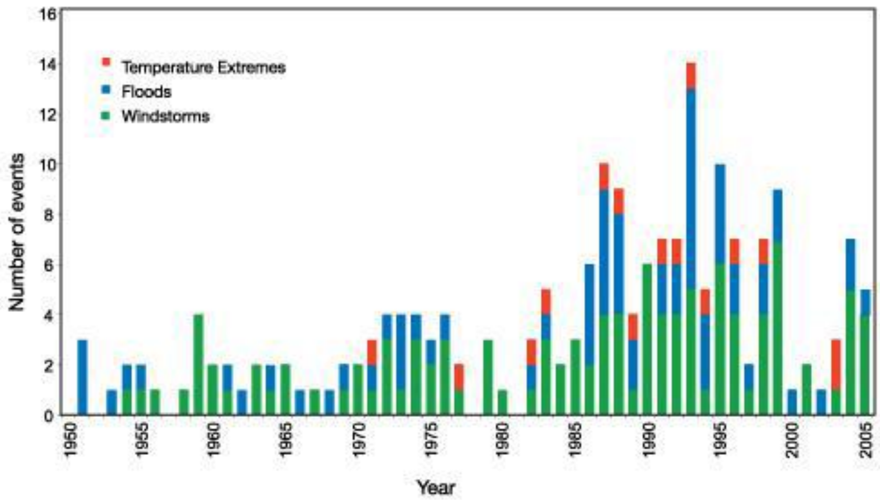

Figure 1.1 The number of climate related disasters, by event, from 1950 to 2006 (Hoppe et al, 2006)

Whilst the warming to date is alarming, a greater concern is the prediction for future warming of the climate system, as shown in Figure 1.2.

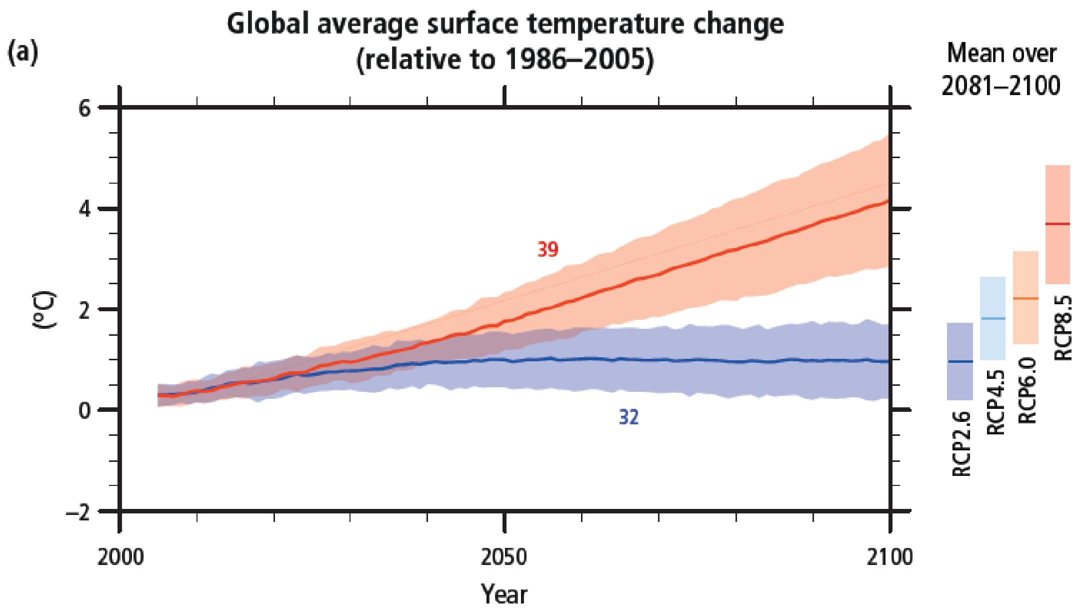

Figure 1.2 Changes in mean surface temperature for emissions scenarios (IPCC, 2013)

Figure 1.2 shows that the mean surface temperature change in the short-term, that is 2016 to 2035, will likely be in the 0.3°C to 0.7°C range, based on a medium confidence scenario. In the longer term, the impact of temperature increase varies significantly dependent on the choice of emissions scenarios and confidence factors, but could range from 0.3°C to 4.8°C.

Evidence provided by the scientific community (e.g. Meinshausen, 2006) has shown that an increase beyond 2°C compared to pre-industrial levels would take the climate outside of the range of observations which have been made over the last several hundred thousand years. The impact of such an increase could be catastrophic in terms of the melting of the ice caps.

Given that the main catalyst for the increase in surface temperature is the increased rate of GHG emissions, there has been a concerted effort to formalise an approach to reduce GHG, resulting in the Kyoto Protocol (UN, 1998), an agreement between 193 countries, committing to reducing GHG emissions by 5% by 2012, based on 1990 levels.

In the UK, The Stern Review report (HM Treasury, 2006) , commissioned by the Government, brought the prominence of climate change impacts, in terms of economics, to the fore. The report not only focussed on the costs of addressing climate change, but also the costs of doing nothing. Through the publication of this report, the importance of addressing climate change at Government level became clear, which was subsequently addressed through the Climate Change Act (CCC, 2008). The Act builds on the targets of Kyoto and commits the UK to a legally binding framework for reduction of carbon dioxide emissions of 34% by 2020, and an overall 80 per cent reduction by 2050.

1.2 Domestic Household Emissions

In 2013, UK emissions of the basket of seven greenhouse gases covered by the Kyoto Protocol were estimated to be 568.3 $MtCO_2e$ (DECC, 2013).

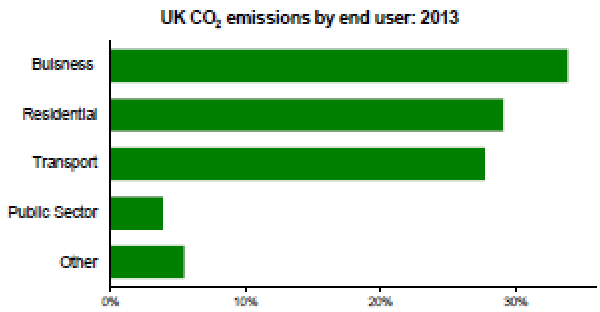

Figure 1.3 Proportion of CO2 emissions by end user (DECC, 2013)

Of this total, the proportion of emissions by end user is shown in Figure 1.3. Whilst the greatest contribution of emissions occurs within the business sector, at 34%, the residential end user accounts for 29% of total CO_2 emissions (DECC, 2013). The residential emissions are associated with the burning of gas for heating and hot water, and the use of electricity for power and appliances (and in some cases heating where properties are not connected to the gas grid)

1.3 Sustainable Homes

In order to meet the targets set through the Climate Change Act (CCC, 2008), the Government has developed a range of programmes and incentives to reduce the level of emissions in the residential sector, including financial support for the installation of energy saving measures. Given the fact that 87% of existing buildings will still exist in 2050 (DCLG, 2008), much of this focus is rightly targeted towards existing homes.

However, to focus solely on existing homes would mean that new homes that are built may be faced with similar refurbishment challenges in the near future in order to meet carbon reduction targets.

In order to ensure that this is prevented, the Government has introduced a number of legislative policies and regulation to drive energy efficiency and emissions reduction in the new build residential sector. A timeline illustrating the key developments is shown in Figure 1.4

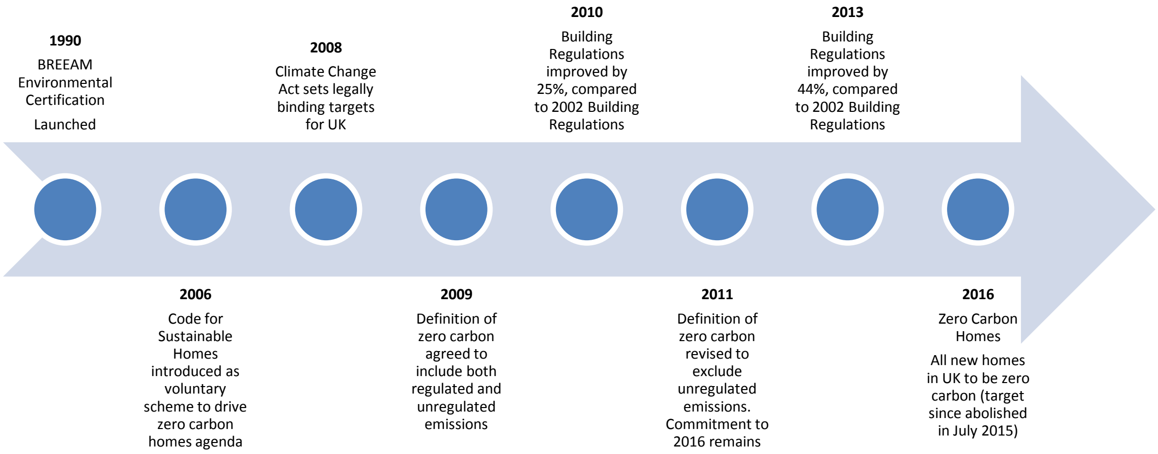

Figure 1.4 Timeline for sustainable homes in the UK

Figure 1.4 demonstrates the significant journey, in terms of legislation and regulation towards reducing emissions in homes. Until the Government's Summer Budget in 2015 , the UK was focussed towards delivering zero carbon homes from 2016. However, a policy change from the Government means that target has now been abolished. This withstanding, the key development in sustainable homes occurred in 2006, when the UK Government made a commitment that all new homes would be 'zero carbon' from 2016 and introduced the Code for Sustainable Homes (DCLG, 2010a) against which all new homes would be rated, on a range of different sustainability measures.

Since the CSH was introduced in 2007 and through to December 2014, statistics show that 76% of completed dwellings achieve the CSH Level 3 standard (DCLG, 2015), which means the homes achieve a 25% reduction in CO_2 emissions as compared to 2006 Building Regulations.

Driving the approach to low carbon buildings are the Building Regulations , specifically Part L, which prescribes improved standards associated with building insulation, air tightness and services. Of the energy used in homes, the highest proportion of energy by end use is associated with space heating, as shown in Figure 1.5, which shows a 62% share of household energy being used for space heating (DECC, 2013)

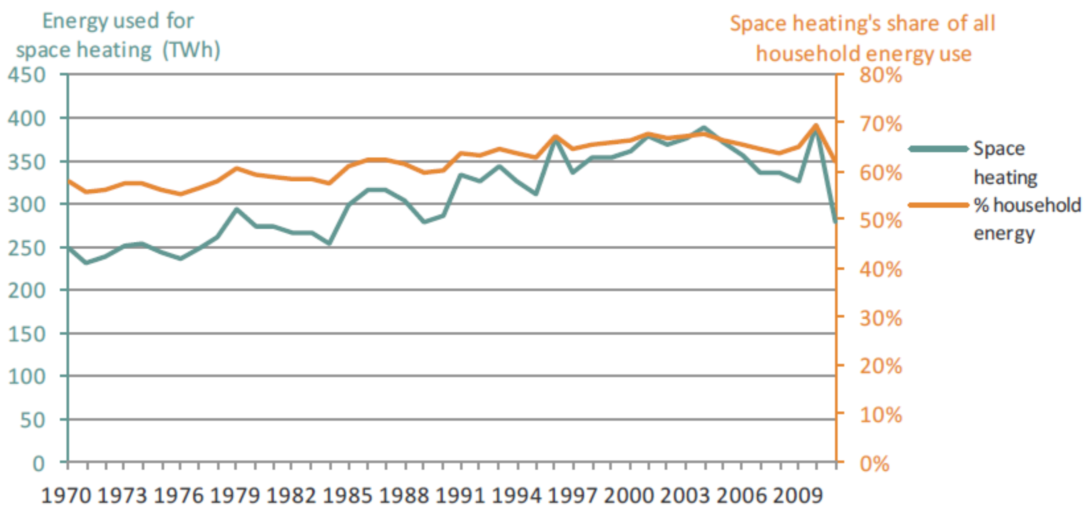

Figure 1.5 Household energy use for space heating (DECC, 2013)

Whilst the improvements associated with these measures assists in the reduction of emissions, there is a growing body of evidence to suggest that a consequence of energy efficiency improvement to existing homes, and higher new build standards, is that some properties are at risk of overheating (GHA 2014, ZCH 2012 etc).

1.4 Sustainable Homes and Overheating

A study of summertime temperatures in homes in Leicester (Lomas and Kane, 2012) showed that 28% of living rooms and 88% of bedrooms were overheating in the summer of 2007. Similarly the European heat wave of 2003 triggered numerous studies into heat related deaths. A study by Wright et al (2005) studied the internal temperatures of dwellings during the 2003 heat wave, where internal temperatures of dwellings in Manchester were recorded as high as 36^0C. For standard domestic dwellings, the particular risk is for overheating in bedrooms, with these areas struggling to reduce temperature overnight (Peacock et al, 2010).

The issue of overheating in dwellings is not just limited to existing buildings. The Zero Carbon Hub (2012) recognises that overheating in new homes is a particular issue, and this is supported in findings from various other sources (NHBC Foundation, 2012; Orme and Palmer, 2003; Collins et al, 2010). The risk of overheating for recently built properties is related to improved energy efficiency standards, particularly enhanced insulation and air tightness (ZCH, 2010).

In order to ensure that homes yet to be constructed can adapt to climate change, there have been a number of studies, mainly through thermal simulation, as to how dwellings can adapt to overheating through a changing climate (e.g. Arup Research + Development and Bill Dunster Architects, 2005). The focus of these studies has been on technical interventions that have the desired effect i.e. to reduce overheating risk and ensure thermal comfort.

Whilst such simulations have developed a suite of solutions, there has been no consideration of how acceptable prescribed solutions are with the occupant of the home. Given that the Code for Sustainable Homes (DCLG, 2010a) does not include overheating as a design issue, and with over 197,000 homes built to CSH up until December 2014 (DCLG, 2015), there is a significant possibility that a high proportion of these homes may be at risk of overheating, and will need to be retrofitted with measures to prevent overheating.

Therefore the research rationale is that there is a gap in knowledge between the relationship of recognised adaptation measures and the preference of adaptation measure for the occupant of the home. This gap in knowledge could impact on the ability of overheating to be mitigated in homes, and may be linked to understanding and attitudes of the occupant to climate change. This study contributes to the research agenda by undertaking a qualitative and quantitative approach to assessing overheating through an open source simulation tool to understand how adaption choices that occupants make will affect their thermal comfort.

1.5 Research Aims and Objectives

With an understanding for the basis of the research, the aims and objectives of the study can be introduced. The two main research aims are:

Aim(s)

- To develop a methodology to allow households to review adaptation measures in order to reduce overheating of Derwenthorpe dwellings.
- To assess and validate the adaptation measures selected by households in terms of predicted reduction in overheating.

Objectives

In addition to the aims, there are eight key objectives that are to be delivered through the project:

1. Develop initial analysis methodology.
2. Conduct a stage one survey to obtain feedback on existing thermal comfort and overheating issues.
3. Conduct stage two interviews to rank a range of adaptation measures.
4. Review results of stage two interviews to determine ranking of adaptation measures.
5. Assess and review the impact of selected adaptation measures through an online adaptation tool.
6. Assess the impact of selected adaptation measures through dynamic simulation software.
7. Review the analysis results and investigate the viability of the methodology, and identify limitations where appropriate.
8. Provide key conclusions, and make recommendations for future research.

1.6 The research case study: Derwenthorpe

Derwenthorpe is a mixed tenure community being developed by the Joseph Rowntree Housing Trust (JRHT, 2015) which when complete in 2019 will consist of around 500 new family homes on the outskirts of York, as shown in Figure 1.6. The scheme is being built in four phases; the first phase of 64 homes was completed in 2013, with the first residents moving in during 2012. The remaining phases are currently under construction.

Figure 1.6 The vision for Derwenthorpe in 2020

Environmental sustainability is a key consideration at Derwenthorpe. Phase One homes were developed to CSH level 4 as a minimum, representing a 44% reduction in CO_2 emissions compared to 2010 Building Regulations (DCLG, 2010b). In order to achieve this, the homes are built with high levels of insulation, air tightness and daylight provision along with a communal biomass boiler. Marketing literature for the homes describe these design features as achieving a thermos flask effect (Barratt, 2015).

The development also includes interventions designed to promote sustainable lifestyles and support the reduction in car use, including being sited on the Sustrans cycle way, provision of cycle voucher or bus vouchers and an on-site car club. Eighteen acres of green space and a pond include sustainable urban drainage and habitat provision (JRHT, 2015)

This study focuses solely on Phase One of the development, (see Figure 1.7) as this phase contains an established community of residents who have lived in their homes for up to three years. This will allow residents to provide personal experience of living in the homes, a factor which is pivotal to the success of this project.

Figure 1.7 Derwenthorpe Phase One layout

1.7 <u>Thesis Structure</u>

The structure of the thesis is based on the following approach. Section Two covers the theoretical background to climate change, and the reasons for homes overheating. Section Three is a literature review focussed on the definitions of overheating, as well as providing an overview of current activity to understand the extent of, and associated adaptation to, overheating in dwellings. Section Four explains the methodology for the thesis. Section Five presents the results of the stage one activity, and Section Six presents results of stage two activity. Section Seven reviews the impact of adaptation measures, and Section Eight validates the impact of the two approaches. Section Nine reviews the research rationale, before Section Ten presents conclusions and recommendations. The Appendices provide further supporting information.

2 Theoretical Background

This chapter reviews the theoretical background which supports the research project, and introduces the reader to the key concepts which are required to be understood within the scope of this research study.

2.1 Climate change- how will temperatures change?

There is an increasing level of scientific knowledge in relation to climate change. The IPCC collates the range of scientific knowledge, and has produced a number of key findings. The IPCC has found that the warming of the climate is unequivocal, and many of the changes observed since the 1950s are unprecedented over decades to millennia. (IPCC, 2013). This has recently been demonstrated in the UK, with the finding that 2014 was the UK's warmest since records began in 1910 (BBC, 2015).

The cause of climate change is closely related to anthropogenic greenhouse gas emissions, to such an extent that the IPCC have concluded that their effects are extremely likely to have been the main cause of the observed warming since the mid-20th century (IPCC,2013).

The result of these changes manifests itself in two forms in relation to external summertime temperatures. Firstly there is an increased likelihood of summertime heat waves globally (IPCC 2013, BBC 2015). Secondly with the continued emission of greenhouse gases, further long lasting warming will be witnessed within the climate system (IPCC, 2013).

However, because it is not possible to determine the exact level of emissions and associated level of climate change, a range of possible scenarios are used to predict future temperature change. The IPCC has developed four scenarios which correspond to a set of global story-lines defining local, regional and global socio-economic driving forces. The scenarios can be summarised as follows (IPCC, 2000)

Scenario A1

Describes a future world of very rapid economic growth, a global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Within the A1 scenario, there are three sub scenarios based on level of fossil fuel usage;

A1FI represents fossil fuel intensive; A1T represents non-fossil fuel intensive; and A1B represents a balanced approach.

Scenario A2

Describes a very heterogeneous world, where self-reliance and preservation of local identities are key. Global population increases continuously rather than in peaks and troughs.

Scenario B1

Describes a world with the same global population as in scenario A, which peaks in midcentury with a decline thereafter, but differs through rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies.

Scenario B2

Describes a world in where local solutions to economic, social, and environmental sustainability are prioritised. Global population is continuously increasing, although at a rate lower than scenario A2, and there are intermediate levels of economic development, and less rapid and more diverse technological change than in scenario B1.

When these scenarios have been assessed in terms of future climatic change, the temperature change at the end of the century, compared to a baseline year range of 1980 to 1999, shows "best estimates" for temperature change ranging from 1.8°C to 4°C, depending on the scenario (IPCC, 2007). The changes are presented in Table 2.1.

Table 2.1 Projected global average surface warming at the end of the 21st century (IPCC, 2007)

	Temperature Change (oC at 2090 to 2099 relative to 1980 – 1999)	
B1 Scenario	1.8	1.1 – 2.9
A1T Scenario	2.4	1.4 – 3.8
B2 Scenario	2.4	1.4 – 3.8
A1B Scenario	2.8	1.7 – 4.4
A2 Scenario	3.4	2.0 – 5.4
A1FI Scenario	4.0	2.4 – 6.4

Whilst the IPCC scenarios present future climate predictions globally , climate projections for the UK have been produced since the 1990s by the UK Met Office. The latest datasets, which will be referred to for this work, are widely known as the UK Climate Projections 2009 (UKCP09, 2015) datasets. There are three classifications for the scenarios based on the predicted level of atmospheric CO_2 resulting from that scenario - High, Medium and Low

.

The **High** scenario represents what the effect of a "business as usual" approach would be. It is characterised by very rapid economic growth, and the rapid introduction of new and more efficient technologies, but energy sources remain fossil fuel intensive.

The **Medium** scenario represents the middle ground between successfully shifting to a sustainable future and the 'business as usual' approach. It is also characterised by very rapid economic growth and the rapid introduction of new and more efficient technologies, but in contrast to the High scenario, energy sources are more mixed and there is a balance between fossil and non-fossil fuel energy sources.

The **Low** scenario is the 'ideal' scenario in terms of CO2 emissions, and in this scenario the economy shifts to a service and information economy with reductions in material use intensity. Clean and resource-efficient technology is introduced and globalisation
becomes a reality, with global solutions to economic, social and environmental sustainability in place.

Given that the UK is one of the global leaders in the low carbon agenda, with its leading approach to a 2050 GHG target, it is feasible to assume that the UK and the rest of the world will follow this path. If this is the case, then the most likely scenario for the future would be the Medium emissions scenario.

On this basis, using the 50% (central estimate) and 90% (worst case scenario) probabilistic projections under the Medium emissions scenario for 2030, 2050 and 2080, the UKCP09 projections for temperature change in Leeds (the closest dataset to Derwenthorpe) are shown in Table 2.2.

Table 2.2 Changes in external temperature for a future Leeds climate (UKCP09, 2015)

Year	Average Summer Temperature ^{o}C	Maximum Annual Temperature ^{o}C
2015	14.5	28.5
2030	17.6	28.3
2050	18.2	35.5
2080	19.1	31.8

2.2 Why do homes overheat?

Overheating in homes can occur as a result of a number of factors, including heat gains from internal and external sources, combined with ineffective or inappropriate ventilation solutions.

With a focus to reduce emissions from homes in the UK, the Building Regulations played a pivotal role in driving emissions reduction, with Part L1 of the Building Regulations (Conservation of Fuel and Power) (DCLG, 2013) defining standards for key building elements in order to conserve energy use within dwellings. Whilst the standards have continually been improved since 1985, since 2000 the standards relating to energy efficiency have improved significantly, as shown in Table 2.3.

Table 2.3Fabric Element U-Values in 2000 and 2013 editions of Building Regulations

Fabric Element	U-Value (in 2000 Building Regulations	U-Value (in 2013 Building Regulations	Percentage Improvement
Roof	0.25	0.2	20%
Wall	0.35	0.3	14%
Floor	0.25	0.25	0%
Party wall	n/a	0.2	100%
Windows, roof windows, glazed rooflights	2.2	2.0	9%

The level of improvement in insulation measures as shown in Table 2.3, from no change in levels of floor insulation, to the introduction of insulation standards for party walls, has been brought about to ensure that new homes have higher levels of energy efficiency.

However, these increasing standards introduce the issue of overheating, both in the current climate and in the future.

A conventional house built to lower energy efficiency standards, as shown in Figure 2.1 (NHBC, 2012) allows heat to be lost through the building fabric due to lower levels of insulation, and through ventilation heat losses where the fabric is “leaky” with minor gaps around windows and openings. Whilst this home does not conserve heat in terms of energy efficiency, it does perform better in terms of overheating risk as heat trapped within the home can escape to the external environment.

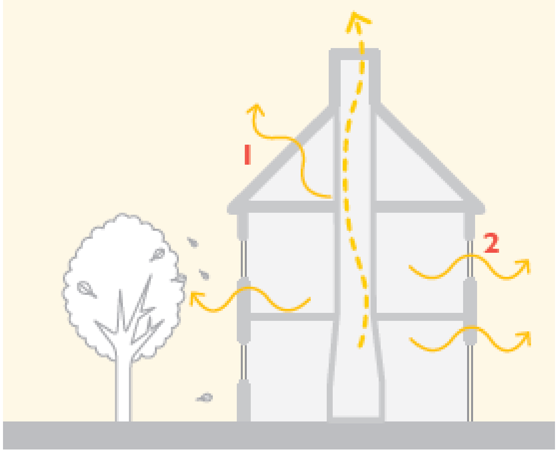

Figure 2.1 Heat loss from a conventional house (NHBC, 2012)

However, a modern new build home built to more recent building regulations has higher insulation standards and improved air tightness, which means that when the temperature inside the home increases, there are fewer opportunities for the heat to escape, causing discomfort for the occupant.

The source of heat gain can be linked to a number of factors. External gains from direct sunlight and external temperature are the key factors, and when considered in the context of a future climate it is possible to understand the potential severity of overheating. Further compounding the overheating risk are internal gains associated with heating and ventilation services, lighting, equipment and even the occupants of the home. Whilst internal gains can be reduced by switching off appliances, and managing services appropriately, it is not possible to completely remove the impact of internal gains.

The impact of internal and external gains can result in the risk of overheating. The result can be temperatures that can not only cause discomfort to the occupant, but can also present health related risks.

2.3 <u>Health related impacts of overheating</u>

The human body is designed to thermo regulate, but the body's ability to regulate is affected by a number of factors, including temperature. Thermoregulation is designed to maintain core body temperature between 36.1°C and 37.8°C, but the body can cope with temporary increases in temperature of up to 39°C without damage to health (ZCH, 2015).

However, when the thermoregulation function is exposed to extreme temperatures, the outcome can be heat related stress (including sleep deprivation), illness, and in worst cases death (Carmichael et. al, 2011; Dengel, 2012).

However, it is difficult to determine the exact level of overheating that can cause health consequences due to individuals responding to heat in different ways (Dengel, 2012; Nicol, 2012). In order to attempt to quantify threshold temperatures that affect health, a range of design tools have been developed, which are discussed further in Section Four

3 Literature Review

This section presents a literature review relevant for this dissertation topic, and is split into the following sections:

Defining overheating in homes: this examines various definitions of overheating, and methods used to determine it.

Overheating in practice: this examines cases of overheating in various forms, from dynamic simulations to physically monitored case studies.

Adapting to a future climate: this examines the range of adaptation measures that are available to understand how the risk of overheating can be reduced.

Discussion: the key points and implications from Sections 3.1-3.3 are discussed, leading to the MSc research rationale and key aims.

3.1 Defining overheating in homes

The broadest definition of overheating is understood to be when there is an accumulation of warmth within in a building to such an extent that it causes discomfort to the occupants (NHBC, 2012).

However, discomfort, or comfort, is a selective matter, and therefore cannot formally be defined around such a personal variable. The study of overheating is a recent field of science, started in earnest in 2010 with the publication of CIBSE guide KS16: How to manage overheating in buildings (CIBSE, 2010). Whilst this study focussed on cooling in office buildings, it brought together learning on contributory factors to discomfort.

There are three main quantitative methodologies used to define overheating thresholds in dwellings, which are discussed in the following section.

3.1.1 SAP Methodology

Whilst SAP (DECC, 2009) is the methodology used by Government to assess and compare energy performance of dwellings, SAP Appendix P (Assessment of Internal Temperature in Summer' (DECC, 2009) focuses specifically on overheating risk. This is a self contained calculation based on various factors: the region, orientation, over shading, the thermal mass of the building, ventilation method and window area. In addition, factors that are driven by the occupant, such as the presence of blinds, curtains or shutters are assessed.

The purpose of Appendix P is to produce a predicted internal temperature for a dwelling for each of the summer months, and to compare this to threshold temperatures to define the level of overheating risk, as shown in Table 3.1.

Table 3.1 Range of threshold temperatures corresponding to likelihood of high internal temperature during hot weather (DECC, 2009)

Threshold Temperature	Likelihood of high internal temperature during hot weather
< 20.5°C	Not significant
≥ 20.5°C and < 22.0°C	Slight
≥ 22.0°C and < 23.5°C	Medium
≥ 23.5°C	High

Whilst the presence of Appendix P is generally supported by Building Control as a building compliance process (ZCH, 2015), the tool has been criticised for its simplistic nature (DCLG, 2012). The criticism is aimed at the fact that Appendix P is used as a compliance tool rather than design tool (DCLG, 2012; NHBC, 2012), and some of the proposed solutions, such as the use of window opening for night time cooling , are not robust in terms of applicability (ZCH 2010). In addition, Appendix P uses standard internal heat gains for occupancy, equipment and lighting which cannot be adjusted (ZCH, 2015)

3.1.2 CIBSE Guide A (2006)

CIBSE Guide A (2006) is an Environmental Design Guide providing a methodology to assess overheating. Unlike SAP (DECC, 2009), the guide provides comprehensive guidance for designers and defines peak internal temperatures for a range of buildings, including domestic dwellings. The guide advises that the criteria in Table 3.2 are met for overheating

Table 3.2 Threshold peak summer temperature and overheating criteria, CIBSE Guide A (2006)

Dwelling space	Threshold peak summer temperature (°C)	Overheating criteria
Living areas	28°C	1% annual occupied hours over operative temperature of 28ºC.
Bedrooms	26 °C	1% annual occupied hours over operative temperature of 26ºC.

In addition to the specific criteria detailed in Table 3.2, the guide also provides comfort temperatures for non air-conditioned dwellings in summer, of living areas at should be an operative temperature of 25ºC and bedrooms (CIBSE, 2006). Specific attention is drawn to the fact that sleep may be impaired above an operative temperature of 24ºC (CIBSE, 2006).

The guide develops and improves on the SAP methodology by working on the principle of threshold criteria of exceedance of actual occupied hours above operative temperatures, rather than standard benchmark occupancy hours. However, it fails to consider the severity of the overheating event in terms of the extent and duration of overheating, which would have an impact on comfort and health.

Unlike SAP, which is criticised for being an assessment tool only, the guide has been widely used to inform design (DCLG, 2012). Although not formally recognised by the HCA, English Partnerships who predated the HCA developed a quality standard based, with overheating addressed within it:

> *"In order to ensure homes shall not be susceptible to overheating in rising summer temperatures, English Partnerships adopts the CIBSE (Chartered Institute of Building Services Engineers) standard. CIBSE Vol A (2007) [sic] [CIBSE, 2006] requires that:*
> *For living areas, less than 1 per cent of occupied hours are over an operative temperature of 28ºC.*
> *For bedrooms, less than 1 per cent of occupied hours are over 26ºC.*
> *This must be proven using appropriate simulation software in the design process, and adequate measures must be introduced to ensure it is maintained within the completed dwelling."*
> *(EP, 2007)*

Unlike SAP, meeting the criteria for the guide are not mandatory, and as alluded to within the English Partnerships Quality Standard (EP, 2007), the calculations require the use of specialist simulation software, meaning it is less practically applicable.

3.1.3 CIBSE TM52

CIBSE TM52 (2013) uses a methodology to assess adaptive thermal comfort. Whilst CIBSE Guide A (2006) measures overheating in terms of exceedance of a particular temperature, it fails to measure the impact of external temperature on comfort. Research on adaptive thermal comfort (de Dear, 1998) demonstrates that what is determined as a comfortable room temperature varies with external temperature. As such, in warmer weather a higher internal room temperature can be deemed as comfortable.
CIBSE recommends that analyses should conform to different categories which set the maximum acceptable temperatures above the comfort temperature, for buildings in free-running mode.

Criterion 1- Hours of Exceedence (He): is based on a limit for the number of hours that the operative temperature can exceed the threshold comfort temperature by 1^{o}C or more during the occupied hours of a typical non-heating season. The non heating season is defined as 1st May to the 30th September.

Criterion 1 states that the threshold temperature shall not be exceeded for more than 3% of occupied hours per year.

Criterion 2- Daily Weighted Exceedence (We): addresses the severity of overheating, which is a function of both temperature rise and its duration. Criterion 2 is based on a daily limit for acceptability.

Criterion 2 states that the severity of weighted exceedance of must not be greater than six hours daily.

Criterion 3- Upper Limit Temperature: sets an absolute maximum temperature, beyond which overheating is unacceptable

For homes to be assessed as not overheating, two of the three criteria must be met.

TM52 builds on the advanced approach of using actual occupancy hours, as per CIBSE Guide A, but enhances the assessment to address severity of overheating. Whilst this is a more complex model which requires the use of specialist simulation software, TM52 has the potential to use future weather data to assess overheating risk based on predicted changes in the climate.

3.2 Overheating in practice

Although the study of overheating is a relatively recent development, there has been a significant level of activity in the area. Whilst evidence from monitoring surveys is critical to understand overheating, such studies are relatively few in number (Crump, 2009). Instead, the majority of evidence is based on simulated models.

3.2.1 Monitoring studies

Where monitoring studies have been undertaken, these have typically been generated from a small sample of housing stock. The European heat wave of 2003 triggered numerous studies into heat related deaths. For example,a study by Wright et al (2005) showed that the internal temperatures of dwellings during the 2003 heat wave in Manchester were recorded as high as 36^{0}C. In the next UK heat-wave of 2006, a study of summertime temperatures of 62 existing homes in Leicester (Firth et al, 2007) showed that annual overheating levels were exceeded in a number of bedrooms.

Beyond heat wave conditions, a national study of 224 homes in the summer of 2007 (Firth and Wright 2008) further supported the finding that bedrooms were more at risk from overheating. A summary of the findings supporting this statement is shown in Table 3.3.

Table 3.3 Findings from national study of homes in summer 2007 (Firth and Wright, 2008)

Threshold Criteria	Room	Temperature	% of time
Average daily maximum temperature	Living room	25.9°C	n/a
	Bedroom	26.6°C	n/a
Range of temperature	Living room	18.5°C to 25.9°C	n/a
	Bedroom	18.1°C to 26.6°C	n/a
Average hours exceeding 25oC	Living room	n/a	3.2%
	Bedroom	n/a	4.6%

Moreover, the results showed purpose-built houses built after 1990 were at high risk of overheating; with temperatures in excess of 25°C recorded in the bedrooms of these dwellings.

A larger survey of summertime overheating risk in UK homes (Baizee et al, 2013) monitored temperatures during a relatively cool summer. Despite the lower external temperatures, living rooms and bedrooms exceeded CIBSE threshold temperatures, and in dwellings built after 1990, overheating in bedrooms was even more significant. Flats, as well as houses built after 1990, were at highest risk of overheating (Firth et al, 2007).

The GHA (2014) review of overheating found that of 185 instances of overheating, 40 occurred in homes built post 2000. The study mainly focussed on flats as opposed to other dwelling types, with 31% of newly built flats experiencing overheating. Such findings are supported by various case studies summarised by the NHBC (2012), identifying specific cases of overheating in a range of flats and apartments. Whilst the work of Firth and Wright (2008) also found that purpose built flats were at highest risk of overheating, the study also identified houses built after 1990 as at risk.

One of the largest studies into overheating and thermal comfort is the Energy Follow Up Survey (EFUS), conducted by the DECC and BRE (2011), which interviewed over 2,600 households, and installed data loggers into around one third of households interviewed. Responses showed that 20% of households found that at least one room was too hot in summer, with 9% identifying the living room as a problem area, and 11% the main bedroom (DECC & BRE, 2011).

With regards to the reason that overheating was reported, the majority (41%) of respondents identified lack of shade or tree coverage around the home as an issue, as shown in Figure 3.1 (DECC & BRE, 2011). This response- as well as others such as poor ventilation, poor air movement, internal heat gains and direct solar gain- link with the theoretical background (see Section 2.2).

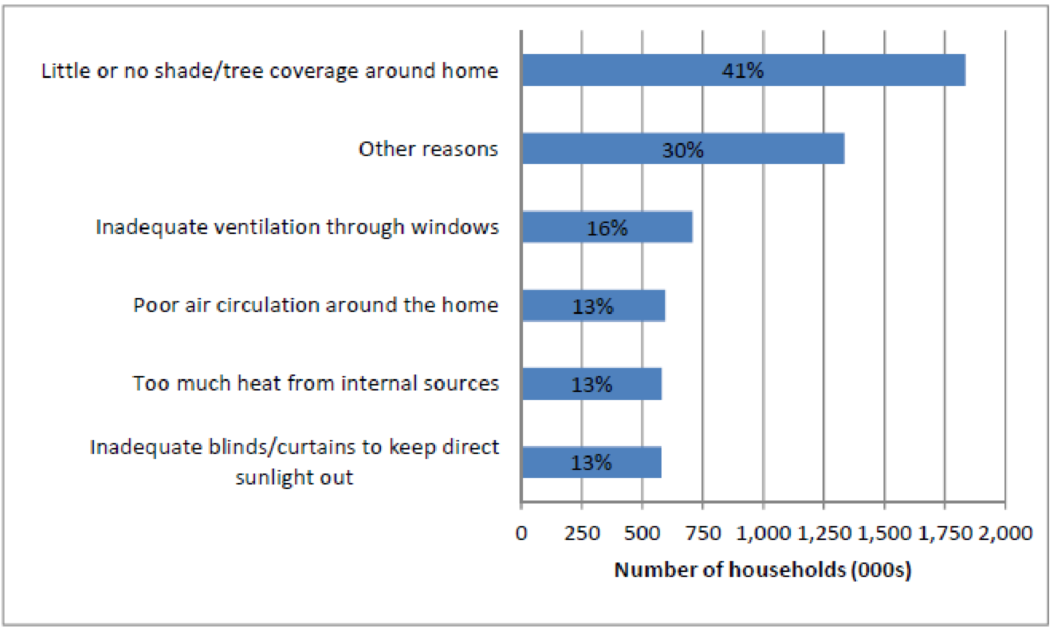

Figure 3.1 Responses to the cause of overheating in EFUS (DECC & BRE, 2011)

Finally, in terms of the study, 39% of households reported that areas of the dwelling were overheating for between one to four days per week (DECC & BRE, 2011).

As energy efficiency standards continue to improve there has been a small number of studies on high efficiency homes. A study by the BRE (NHBC, 2012) focussed on two homes built to Swedish energy efficiency standards, and compared these to two identical homes built to, what were then, UK building regulations. The homes built to Swedish fabric standards were found to experience high internal temperatures associated with poor ventilation.

A more recent study by Wingfield et al. (2008), focussing on homes built to high fabric efficiency and air tightness standards found that four masonry built homes that were monitored experienced internal temperatures in excess of 30ºC. Although the study only focussed on four homes, the nature of the overheating in what is a typical approach to delivering low energy homes, led the author to state summer overheating as likely in the future in new housing developments, with either a lightweight structure, as well as heavyweight structures that have been internally insulate.(Wingfield e al, 2008).

3.2.2 <u>Simulated studies</u>

More commonly, modelling of buildings has been used to assess impacts of overheating and identify adaptation measures, rather than monitoring studies. The term "modelling" actually relates to the use of dynamic thermal simulation packages to enable the effects of indoor overheating to be examined at a fine temporal resolution, and are based on methods developed by Belcher et al. (2005) in the use of transforming historic weather files into future weather predictions.

Whilst modelling studies often only target a small number of dwellings, they have typically tried to target key dwelling archetypes in the UK housing stock to ensure relevance of the outputs.
A number of modelling studies have shown a strong link with the monitored studies described above, with dwellings built around the 1960s, and purpose built top floor flats as being at significant risk of overheating (Orme and Palmer 2003, Orme et al. 2003, CIBSE 2005, Hacker et al. 2005, Capon and Hacker 2009).

However, modelling studies are not limited to these findings. Hacker et al (2005) modelled the overheating risk of a modern detached house built to 2002 Building Regulation standards. Using the medium-high emissions scenario of UKCIP02 (2002) report, overheating risk was modelled for living room and bedroom. Peak temperatures of 36^{o}C were modelled for the living room in 2050, and 34^{o}C for the bedroom. Further studies have used cooling loads, an alternative method to demonstrate overheating, and have found that modelled cooling loads to maintain the temperature of bedrooms at around 22oC are approximately double that of living areas (He et al. 2005). The same study showed that detached archetypes have the highest cooling loads followed by semi-detached and mid-terrace dwellings (He et al. 2005).

Findings from simulated studies support some of those of monitored studies, in that new build dwellings will incur increased cooling demands by the 2080s due to the nature of insulation, air tightness and thermal efficiency of modern homes (Collins et al. 2010).

The CIBSE TM36 Study (2005) demonstrated that the use of natural ventilation brings both benefits and disadvantages to dwellings, especially when considered in the context of a changing climate. As external ambient temperature increases, the temperature differential between the internal and external conditions may mean that heat cannot be "lost" from the inside of the dwelling to the outside, and this may even occur at night (CIBSE, 2005).

3.3 Adapting homes to a future climate

In order to reduce the exposure to high internal temperatures, there are a range of measures that can be applied directly to the building, or to the surrounding area.

Although adaptation measures can be classified into five main themes: urban/public realm measures, building measures, equipment changes, behavioural changes and health interventions. Only three of these are considered as part of this literature review. The reason for this is that the review is focussing on adaptation measures that can be retrofitted to existing dwellings, and as such building measures, equipment changes and behavioural changes are the themes to be reviewed.

Whilst measures are separated into specific adaptation themes, it is often difficult to treat the measures in isolation. For example, Orme and Palmer (2003) identified that thermal mass i.e. a building related adaptation measure, to create a heavyweight building in order to reduce the speed at which a building heats up is an effective measure. However, it is only effective when considered with night ventilation in order to purge warmer internal air, which is either an equipment related measure or behavioural measure dependent on use of technology. In the same study, night ventilation consisted of 25% of windows being left open at night, even on the ground floor, which can pose potential security issue, and links to behavioural activity. The approach of using thermal mass with night ventilation has been found to be effective in dwellings from a number of other studies (Arup Research + Development and Bill Dunster Architects, 2005, Coley and Kershaw, 2010)

Adaptation measures are considered for both existing and new build dwellings. A wider climate study focussing on flooding, water stress and overheating (Arup Research + Development and Bill Dunster Architects, 2005), identified a range of potential adaptation measures. When these were applied to case study homes, the most effective, in terms of impact and cost, were found to be external solar control, natural ventilation and increased air movement through use of fans.

As part of the TSB project "Design for a Future Climate" (Gething, 2010), an extensive list of generic adaptation measures were identified as being effective for keeping a building cool.

A similar range of adaptation measures have been determined through ARCC (2013), and rather than trying to categorise the measures into adaptation theme (e.g. equipment changes) instead they were categorised in terms of implementation cost. The range of measures is shown in Table 4.4.

Table 3.4 Potential domestic adaptation measures (ARCC, 2013)

No Cost	Low Cost	Low to medium cost	Medium to high cost
Close windows and curtains/blinds during hottest part of day, and open at other times	Increase air circulation by using fans	Fit external shading in homes with higher levels of insulation and air tightness	Consider using external wall insulation as opposed to internal wall insulation (existing buildings)
Drink more cold drinks (non-alcoholic)	Fit solar reflective blinds and/or curtains	Use solar reflective coating for flat roofs	
Switch off lights and appliances in rooms that are not in use	Apply solar reflective paint to external walls and roof		
	Consider using external wall insulation as opposed to internal wall insulation (new buildings		
	Reduce internal heat gains associated with domestic hot water distribution		

Various studies (Porritt et al., 2010a, 2010b, 2011, 2012) provided insight into the most effective adaptations measures shown in Table 4.4, either in isolation or as part of a suite of measures. The resulting online tool (Extreme weather impacts, 2015) allows for four different dwellings types to be modelled (detached, terrace, semi-detached house, flat) for a variety of ages, orientations and occupancy patterns, and models the overheating impact against CIBSE Guide A (2006).

In terms of newly built dwellings, the online tool uses a detached house built to the 2006 Building Regulations, and suggests the following adaptation measures:

- External shutters
- External fixed shading
- Internal blinds
- Night ventilation
- Low e triple glazing
- Curtains
- Light walls
- Light roof
- Window rules

Of all the measures considered across the range of dwellings in the tool, the use of external shutters and shading prove to be most effective (Extreme weather impacts, 2015).

3.4 Discussion

Section 3.1 found that the assessment of overheating has developed with the use of three models. Whilst the SAP Appendix P is the most simplistic model, it is also the least beneficial in terms of addressing overheating risk, and is seen as a compliance tool rather than a design tool. Although the use of CIBSE Guide A is more robust in terms of the use of dynamic simulation software to model overheating risk, it is not currently a requirement in terms of design regulation, despite the benefit it can bring. The use of CIBSE TM52 strengthens the modelling of overheating by considering adaptive thermal comfort and accurate occupancy patterns, whilst also introducing more stringent criteria to demonstrate that a building does not overheat. However, CIBSE TM52 is a complex design tool, and in terms of practical deployment its impact is not yet fully understood.

Section 3.2 found that, despite being a relatively new area of interest and expertise, there is a good evidence base of knowledge on overheating in dwellings. Despite the relative small number of monitored studies, the results show consistency in terms of exposure to overheating in bedrooms and living rooms. The monitored studies also demonstrate a greater prevalence of overheating in newly built dwellings, and particularly detached new build dwellings. The output of simulated studies reinforces these findings, although simulations are often limited to a small archetype of dwelling types, intended to represent a large proportion of the UK housing stock. The overwhelming finding is that homes are already experiencing overheating, regardless of the impact of a changing climate in the future.

Section 3.3 demonstrates the steps that are being taken to understand the potential to adapt homes to overheating. Current knowledge is based on the use of simulations, and shows a correlation of the need for heavy thermal mass, ventilation and shading. Some attempt has been made to classify adaptation measures into cost effectiveness as part of a potential decision making, and the use of the online retrofit tool allows for not only the physical effectiveness of adaptation measures to be understood, but also the cost effectiveness.

3.4.1 Findings of literature review on research approach

The literature review identified that, through a variety of methods used to assess overheating, there is evidence of overheating in dwellings, particularly so in new build dwellings.

Whilst adaptation measures have been modelled in terms of their ability to reduce the extent of overheating, and the associated cost of installing the measures, there is no evidence from the residents' perspective of adaptation measures.

Given that adaptation measures could not only have a visual impact to the building, but could also change the way that resident of the dwelling needs to use and live in their home, and also potentially incur costs for the resident. With this in mind there is a need to understand the residents perspective of adaptation measures in greater detail..

By developing a pilot methodology for a feedback based approach to adaptation of homes, there is the potential to further refine an extensive range of options of adaptation measures as to those that are desired by the resident. The pilot methodology could be used at a wider scale to existing developers, and particularly social housing landlords, to determine a range of adaption measures that meets their residents' needs and expectations whilst addressing overheating.

4 Methodology

The methodology for the research activity is divided into three parts.

The ***first part*** is to identify how the Derwenthorpe homes currently perform with regards to overheating.

The ***second part*** is to identify and assess the impact of adaptation measures chosen by households at Derwenthorpe

The ***third part*** is to validate the impact of adaptation measures selected by households in terms of overheating in the future, using recognised climate projections.

4.1 Part One: How do Derwenthorpe homes currently perform?

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4.1.1 Quantitative and Qualitative feedback from residents

In order to collect the quantitative data needed to answer the research aims, a questionnaire was developed (see Appendix A) to survey residents on Phase One of Derwenthorpe. The purpose of targeting this section of residents was to gain an understanding of residents' experiences of summertime temperatures, as residents of Phase One have experienced at least two summers in situ at Derwenthorpe.

The questionnaire was developed in line with the functions described below. Throughout the development of the questionnaire, its purpose and functionality was tested with work colleagues in order to ensure desired outputs were achieved. Once a full draft questionnaire had been developed, this was tested as a pilot with one resident to ensure it was practical from a residents' perspective. The final stage of the questionnaire development was to receive ethics approval for the proposed approach from DeMonfort University.

The quantitative data collection performs three key functions, as discussed in the following subsections.

4.1.1.1 Comparison with EFUS survey findings

As part of the EFUS, conducted by DECC and BRE (2011), over 2,600 households were interviewed to assess their experience of overheating and thermal comfort in the home. This base of interview responses provides one of the largest depositories of resident feedback.

As one of the driving aims of this project is to determine residents' views and experience of overheating in the home, it is possible to provide a direct comparison of findings from the resident responses at Derwenthorpe to those identified in EFUS.

The specific questions that are replicated from the EFUS study are shown in Table 4.1.

Table 4.1 Derwenthorpe survey questions based on EFUS survey

Question Theme	Question Detail	Possible Answers
Location of overheating risk in the dwelling	During a typical summer (June to August), do you find it difficult to keep any of the mentioned rooms comfortably cool?	Main Living Room Main Bedroom Other bedrooms Other rooms (bathrooms, kitchens) None of the above
Reasons for overheating	If you reported that you experience overheating in at least one room, please provide a reason from the list below	Little or no shade/tree coverage around the home Inadequate ventilation through windows Poor air circulation around the home Too much heat from internal sources

		Inadequate blinds/curtains to keep direct sunlight out
Frequency of overheating	How often do the affected rooms overheat?	Every day 5 or 6 days a week 1 to 4 days a week Less than once a week Don't know

4.1.1.2 Collation of resident responses to adaptation and climate change

In order to gain a greater understanding of residents views of current comfort conditions, and to understand how to maintain these comfort conditions in a changing climate, five additional questions are included in the survey, as shown in Table 4.2.

Table 4.2 Comfort, climate change and adaptation specific questions

Question Theme	Question Detail	Possible Answers
Comfort	Are you able to cool the rooms in your house to comfortable temperatures?	Always Often Sometimes Rarely Never
Comfort	How do you cool the rooms in your house if you get too hot?	Open windows Open doors Use electric fans Use local air conditioning units Other
Comfort	How happy are you with the conditions in your home in Summer?	Very unhappy Unhappy Neither unhappy/happy Happy

		Very Happy
Climate Change	How do you think climate change will affect outside temperatures in summer?	Cooler summers No change Warmer summers
Adaptation	Do you think you will need to change how you live in your home to adapt to a changing summertime climate?	No change at all Very little Some Quite a lot A great deal

4.1.1.3 Collation of demographic data

In order to allow results from surveys to be analysed by various demographic criteria, the survey collects information on:

- Number of adults living in the home
- Number of children living in the home
- Date of occupancy
- Tenure

4.2 **Part Two: Household assessment of adaptation measures.**

4.2.1 **The use of the retrofit toolkit**

In order to determine how residents would assess a range of adaptation measures, it is necessary to utilise a model to assess the performance of measures that are chosen by the resident.

To facilitate this, the retrofit toolkit forms the basis of this assessment. The tool is able to assess the effectiveness of a range of adaptation measures during heat wave conditions.

The heat wave conditions are based on London data for the UK heat wave of August 2003. The range of monitored external temperatures during that heat wave is shown in Figure 4.1.

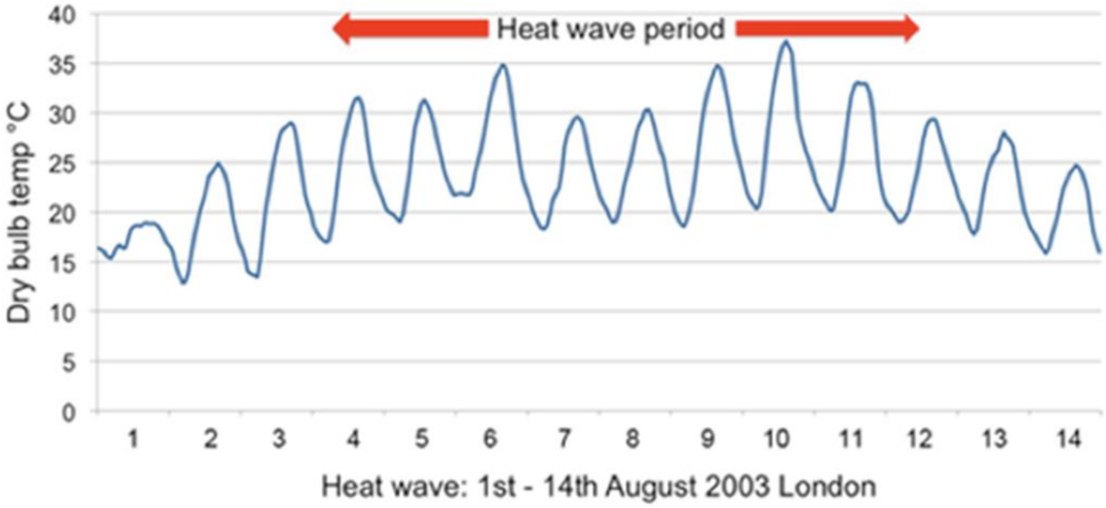

Figure 4.1 Monitored external temperatures for London heat wave 2003 (Porritt, 2012)

The temperatures shown in figure 4.1 represents an extreme weather event in 2003, but based on climate projections, the severity and frequency of temperatures shown here are possible. Thus it is feasible that dwellings will need to be able to adapt to temperatures of these extremes.

Four properties are modelled within the tool: detached, terraced, semi-detached and flats. The detached home used in the tool is based on construction to the 2006 UK Building Regulations, a direct correlation with Derwenthorpe homes.

The detached home, as with all homes in the tool, is assessed for overheating through the use of CIBSE Guide A (2006), such that exceedance over threshold temperatures for bedrooms and living rooms can be assessed. The threshold temperatures and hours of exceedance are defined in table 3.2.

By modelling the detached home through EnergyPlus, dynamic thermal simulation software, the performance of the “un-adapted” detached home can be determined in “degree hours” . Degree hours are a feature of the tool, and are calculated by multiplying the difference in modelled temperature over threshold temperature by the number of hours that temperature is exceeded for.

For this study, it is proposed to use the detached house model in the tool as the basis for an un-adapted Derwenthorpe home.

4.2.2 <u>Adaptation measures to be considered</u>

The tool uses a range of adaptation measures that were discussed in section 3.3. The specific adaptation measures recognised in the tool are:

- External shutters

- External fixed shading
- Internal blinds
- Night ventilation
- Low e triple glazing
- Curtains
- Light walls
- Light roof
- Window rules

The impact of the adaptation measures can be measured through the tool in two ways either as a single intervention, or as a combination of interventions. The impact of the interventions is measured in reduction in degree hours of overheating compared to the un-adapted home.

An example of how the retrofit toolkit can be used to assess the impact of the adaptation measure is shown in Figure 4.2.

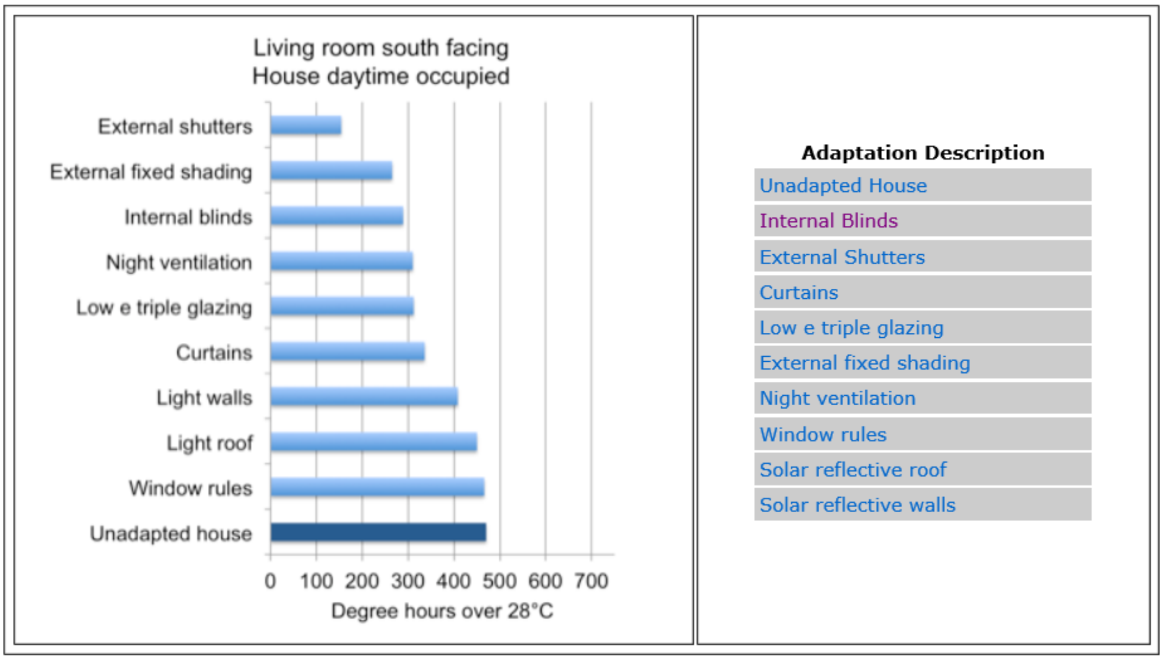

Figure 4.2 Impact of adaptation measures through retrofit toolkit

The methodology allows the impact of measures to be assessed as such that in Figure 4.2 it can be shown that by using external shutters on a south facing detached home, the degree hours over 28^{o}C in the living room is reduced from 470 hours to 150 hours.

A more detailed set of adaptation impact data was accessed from the retrofit tool, which allows for accurate degree hour data to be determined for single and combinations of adaptation measures.

4.2.3 How would residents adapt their homes?

Although the effectiveness of the adaptation measures is known within the retrofit toolkit, there is no demonstration of the acceptability and preference of measures from a residents' perspective.

This section of the study allows residents to rank their preference to adaptation measures, based on a range of criteria. By using the adaptation measures which are included in the retrofit tookit, it will allow for impact assessment of resident decisions to be assessed.

Residents were provided with a full descriptive overview of adaptation measures contained within the retrofit toolkit, along with costs of implementing that measure, where available, based on those used within the tool. This information is shown in Table 4.3.

Table 4.3 Description and costs of adaptation measures

Adaptation measure	Description	Cost
Internal blinds	Fitting of internal solar reflective blinds to each window, which are closed during daytime hours. They are not as effective as external shutters due to some of the short wave radiation, which has passed through the window, being converted to long wave radiation and transferred to the room	£200 per window
External shutters	Fitting of external solar reflective shutters to each window that provide a total block to solar radiation, which are closed during	£5,700 for detached house

	daytime hours.	
Curtains	Use of existing curtains which are closed during daytime hours	No cost
Low e triple glazing	Replace existing windows with low solar heat gain low emissivity triple glazing. Inner and outer panes coated to reflect solar radiation and prevent overheating. Negative impact is reduced solar heat gain in winter	£13,000
External fixed shading	Installing fixed overhang shading on east, south and west facing windows to depth of 1m.Larger awnings (2m) to ground floor windows that are east and west facing. Potential for increased winter heat bill if awnings are not retracted in winter	£315 per meter
Night ventilation	The un adapted house assumes ground floor windows are closed at night for noise, security or air quality reasons. Night ventilation adaptation increases ventilation to ground floor rooms either through use of windows or use of vents (possibly with small fans).Some possible cost due to associated works (security, vents or fans), but winter heating bills not impacted.	
Window rules	The un adapted house assumes windows begin to be opened when the room temperature reaches 22oC, and are fully opened when the temperature reaches 28oC. The use of this	

	adaptation measure reduces overheating as windows are prevented from being opened when the external temperature is greater than the internal room temperature	
Solar reflective roof	Coating the roof tiles with a high performance solar reflective paint	£1,600 for 4 bed detached house
Solar reflective walls	Coating external walls with a high performance solar reflective paint	£2,300 for 4 bed detached house.

In addition to the descriptions provided to residents in Table 4.3, a range of visual examples of the adaptation measures were presented in order to assist the resident in the decision making process. The examples were found from a range of sources available on the internet. The visual examples are shown in Appendix C.

4.2.4 Ranking of adaptations

In order for residents to choose measures that would be effective, achievable and acceptable for a variety of reasons, a decision making matrix was developed, based on the criteria shown in Table 4.4.

Table 4.4 Criteria for ranking of adaptation measures

Criteria	Description
Effectiveness	How effective is the measure at reducing overheating?
Relative Cost	How costly is the measure compared to the other measures?
Maintenance	How easy and cost-effective is the measure to maintain?
Aesthetics	How acceptable is the measure in terms of preserving the design quality of the development?

Phase ability	How easy would it be to add the measure as a retrofit solution at a later date?
Usability	How easy is the measure to use and operate?

Residents were presented with a score matrix, and asked to score each measure on a scale of 0 (zero) to 10, with 10 representing the maximum score and 0 (zero) representing the minimum score. An example of a single output is shown below in Table 4.5.

Table 4.5 Example output of adaptation ranking matrix

	Effectiveness	**Relative Cost**	**Energy Efficiency**	**Maintenance**	**Aesthetics**	**Feasibility**	**Future proofing**	**Phase ability**	**Usability**	**TOTAL SCORE**
Internal Blinds	7	10	6	8	2	5	8	9	4	59

Data was collected from households that had responded to the initial survey as a follow up interview. The data was collected with the researcher present to provide clarification on any areas that required it.

4.2.5 What does resident feedback mean in terms of overheating?

For each of the four main orientations (north, east, south, and west) of the detached house, and for both occupied hours and unoccupied hours, the retrofit toolkit can be used for ranking of interventions to assess:

- Single intervention impact based on the top three ranking interventions
- Multi intervention impact based on combination of top three ranking interventions.

Based on the input of these measures, the impact of the interventions can be evaluated in terms of reduction in degree hours over threshold temperature, and percentage reduction in temperatures over the threshold temperature. The comparison using percentage allows for ranking of the impact of measure to be easily determined.

By using the retrofit toolkit, it is possible to assess how overheating is reduced in heatwave conditions using a publicly available tool.

4.3 Part Three: Validation of adaption measures using dynamic simulation

The use of the retrofit toolkit provides a readily available assessment of the impact of adaptation measures on overheating. The tool itself has been developed through dynamic simulation, specifically using EnergyPlus software. This approach provides robustness to the model.

However, there are a number of factors in the tool which affect the output of adaptation measure performance. These are specifically:

- The dwelling archetype to be used. In this case, the detached archetype built to 2006 Building Regulation was used, as this provided a close similarity with Derwenthorpe homes.
- The local weather data, which in the case of the online tool was based on heat wave temperatures in the south of the UK.

Given the location of Derwenthorpe in the north of the UK, and the assessment of overheating in terms of current climate and future climate, the potential weakness of the retrofit toolkit is that it will have increased the severity of overheating due to weather data used.

Given that the aim of this research was to assess the impact of adaptation measures chosen by residents, both now and in a future climate, a more accurate and specific assessment to Derwenthorpe is required.

To facilitate this, a dynamic thermal model of a detached Derwenthorpe home was developed in EnergyPlus simulation software. The model was prepared from as built drawings of the Derwenthorpe property, and through the model allowed the following to be assessed:

- Impact of orientation.
- Overheating of the un-adapted Derwenthorpe dwelling.
- Application of single and combination adaptation measures.
- Impact of a changing climate i.e. overheating at current year, and overheating in a future climate.

Support for the delivery of the simulation was provided by a PhD student at DeMontfort University, and as such resource availability was limited.

In order to ensure that the use of the simulation provided the validation of the adaptation measures, the following criteria were agreed to be included in the simulation:

- Base case weather file of 2015.
- Future climate weather file based on 2050, high emissions scenario to present a "worst case" model.
- Two orientations to be assessed: front north facing, and front east facing.
- Un-adapted house to be modelled for 2015 and 2050 scenarios for both orientations.
- Adapted house to be modelled for 2015 and 2050 scenarios for both orientations, based on:
    - Single intervention impact based on the top three ranking interventions.
    - Multi intervention impact based on combination of top three ranking interventions.

- A selection of adaptation measures from the results of stage one.

Based on the input of these measures, and the associated outputs from the simulation model, the impact of the interventions for a specific Derwenthorpe house can be evaluated in terms of actual reduction in internal temperature for current and future climate projections, and also in terms of reduction in degree hours over threshold temperature.

The use of the dynamic simulation method will validate the impact of measures selected by residents, and will allow for an assessment of how overheating in a specific Derwenthorpe home can be reduced when modelled using specialist software tools.

5 Stage One Results

A total of sixty three (n=63) households were approached to complete the stage one survey. A total of fifteen households provided full responses, giving a sample size of 24%.

Section 5.1 provides a summary of the results, section 5.2 compares the results to other research findings, and section 5.3 discusses the implication of the findings.

5.1 Summary of Results

5.1.1 Question One

Household were asked to identify if, in a typical summer, they found it difficult to keep a selection of rooms comfortably cool. The results are shown in Table 5.1

Table 5.1 During a typical summer, do you find it difficult to keep any rooms comfortably cool?

Room	Number of households
Main Living room only	**0**
Main Bedroom only	**3**
Other Bedroom only	**1**
Other Room only	**0**
Multiple Rooms	**3**
None	**8**

Table 5.1 shows the household responses to the question of whether, during a typical summer (June to August), they find it difficult to keep any of the mentioned rooms comfortably cool. The majority of households (seven, equating to 53%) do not report any difficulty keeping rooms cool during the summer.

The remaining 47% of households did identify overheating as a problem. Of these responses, three households (20%) reported that their main bedroom in their dwelling was too hot during the summer months, with a further one households (7%) reporting difficulty in keeping other bedrooms comfortably cool. A further three households (20%) reported difficulty in keeping more than one room comfortable cool, with one household reporting the main bedroom and other bedroom as a problem, one household reporting the living room, main bedroom and other bedroom as a problem, and one household reporting the main bedroom and other room as a problem. Qualitative feedback identified this other room as being a study.

5.1.2 <u>Question Two</u>

Households that reported difficulty in keeping at least one room cool during the summer months were asked to provide a reason for this from a prescribed list of options. Householders were able to provide multiple responses. The responses to this question are shown in Figure 5.1.

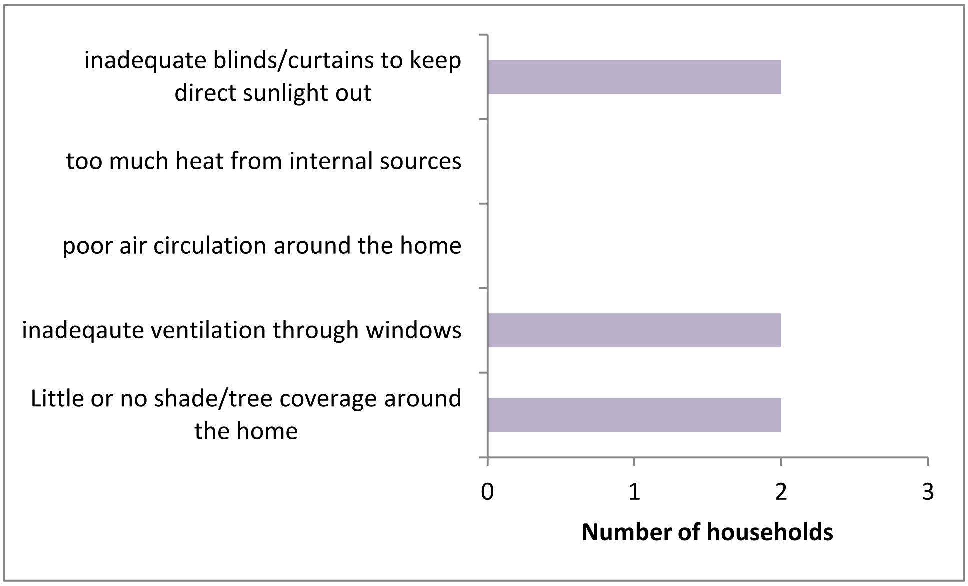

Figure 5.1 If you reported that you experience overheating in at least one room please provide a reason

Figure 5.1 shows the reasons that overheating occurs, with two households (13%) reporting "inadequate blinds/shade to keep daylight out", two households (13%) reporting "inadequate ventilation through windows", and two households (13%) reporting "little or no shade/tree coverage around the home" as the issues. No residents reported too much heat from internal sources, or poor air circulation, as contributing to their reported overheating.

A number of households provided further qualitative narrative, which gave the following additional views:

- "Large ceiling to floor windows inevitably lead to direct sunshine and its effects being amplified. We do not wish to shut out the sun though."
- "The reason is the design of the house i.e. Greenhouse effect from glazing, insulation and low air change rate."

The remaining nine households (61%) did not report overheating as a problem, and therefore no reasons were selected.

5.1.3 Question Three

Households that reported difficulty in keeping at least one room cool during the summer months were asked how frequently the problem occurred. The responses to this question are shown in Figure 5.2.

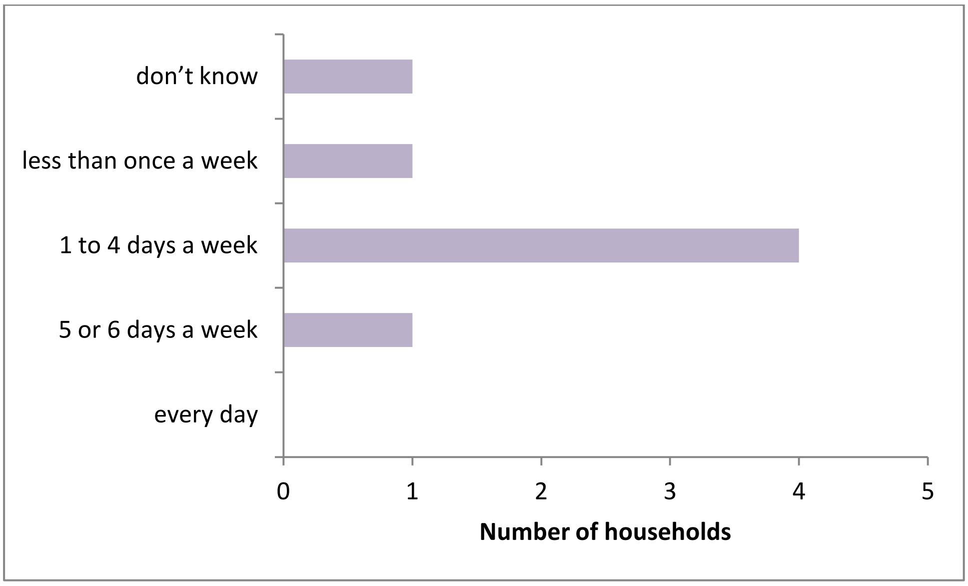

Figure 5.2 How often does overheating occur?

Figure 5.2 shows that four households (27%) stated that it was difficult to keep rooms comfortably cool between one to four days a week. One household (7%) stated that this happened more frequently, between five and six days a week, whilst a further household (7%) stated that it occurred less than once a week.

One household did not know how often the overheating issue occurred.

A number of households provided additional qualitative narrative as per the statements below, suggesting the frequency of the event is linked with direct sunshine.

- "Depends on whether it's sunny. No problem on cloudy day"
- "Highly dependent on sunshine"

5.1.4 Question Four

All households were asked how often they are able to cool the rooms in their house to a comfortable temperature. The responses to this question are shown in Figure 5.3.

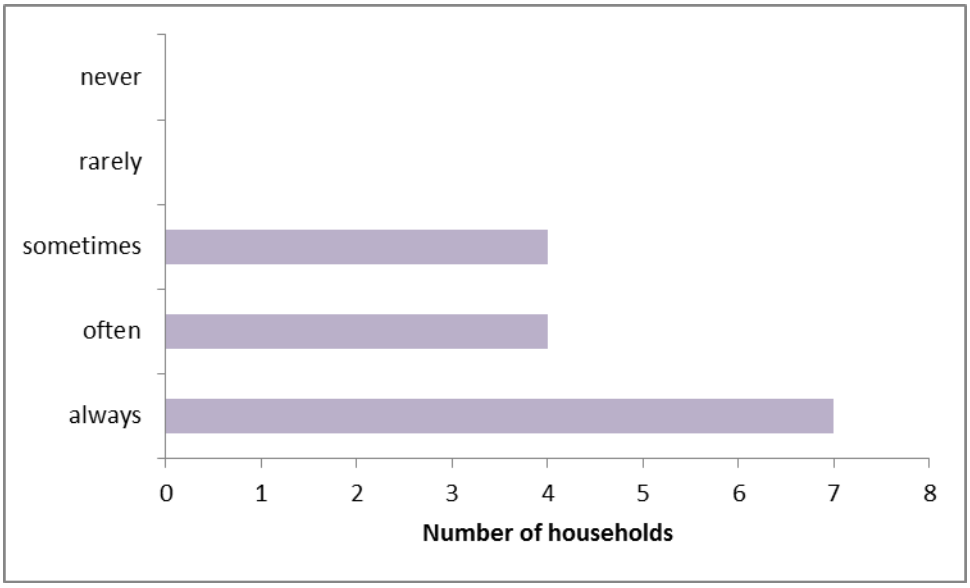

Figure 5.3 Are you able to cool the rooms in your house to comfortable temperatures?

Figure 5.3 shows the household responses to the question of how often the households are able to cool rooms to a comfortable temperature. Of the responses, seven households (47%) reported that they can always cool rooms adequately.

Four households (27%) stated that they can often cool rooms adequately, and a further four households (27%) stated that they can sometimes cool rooms adequately.

No households reported that they could rarely or never cool rooms to a comfortable temperature.

5.1.5 <u>Question Five</u>

All households were asked what measures they use to cool any of the rooms they find too hot. Householders were able to provide multiple responses. The responses to this question are shown in table 5.2.

Table 5.2 How do you cool the rooms that are too hot?

Measure	Households responding
Open windows	4
Open doors	1
Use electric fans	0
Use local air conditioning units	0
Other	0
Multiple Measures	10

Table 5.2 shows that four households (27%) open windows to cool rooms, one household (7%) open doors to cool rooms, and ten households (66%) use multiple measures to cool their rooms.

More detail of the measures used is provided in Figure 5.4, which shows that the opening of windows and doors is the most significant measure used by residents to cool rooms. Two households who use multiple measures to cool their rooms use electric fans or local air conditioning units, and two households also reported the use of other measures. The households provided further qualification of this, with one household stating that they use the MVHR system to cool the house, and one household stating that they close the curtains.

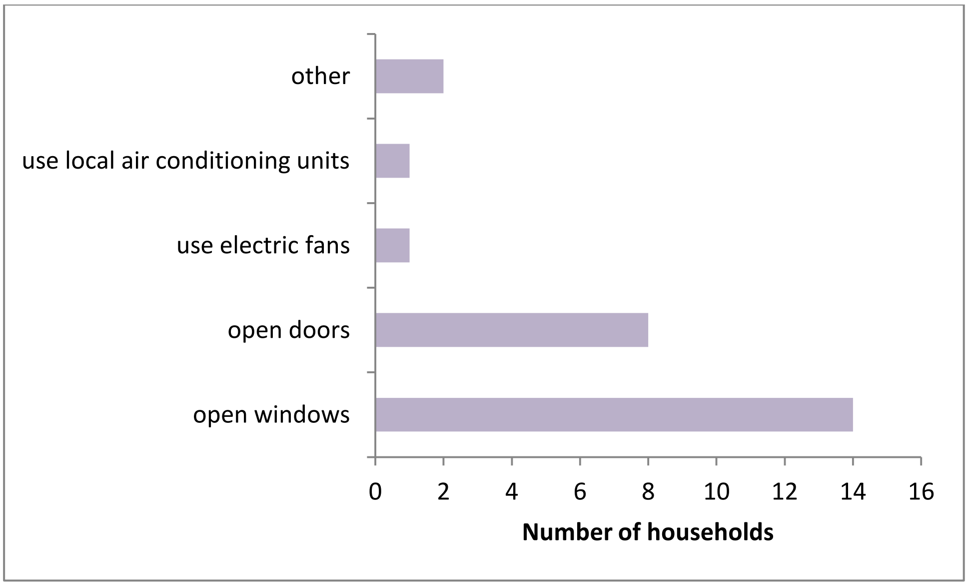

Figure 5.4 How do you cool the rooms in your house if you get too hot?

5.1.6 Question Six

All households were asked to summarise how happy they are with the conditions in their house during the months of June, July and August. The responses to this question are shown in Figure 5.5.

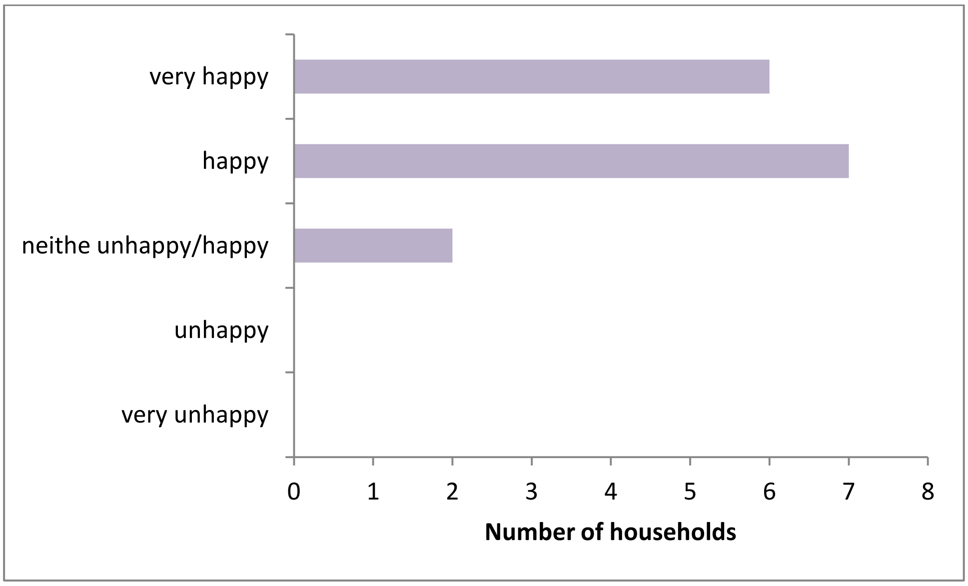

Figure 5.5 How happy are you with the conditions in your home in summer?

Figure 5.5 shows the household responses to the question of how happy they are with conditions in their home in summer months, this being June, July and August. The majority of households are happy or very happy, with six households (40%) stating they are very happy, and seven households (47%) stating they are happy.

Only two households (13%) stated that they were indifferent i.e. neither happy nor unhappy, and no households reported that they were unhappy or very unhappy.

5.1.7 Question Seven

All households were asked to provide their views as to how summertime temperatures will change in the future as a result of a changing climate. The responses to this question are shown in Figure 5.6.

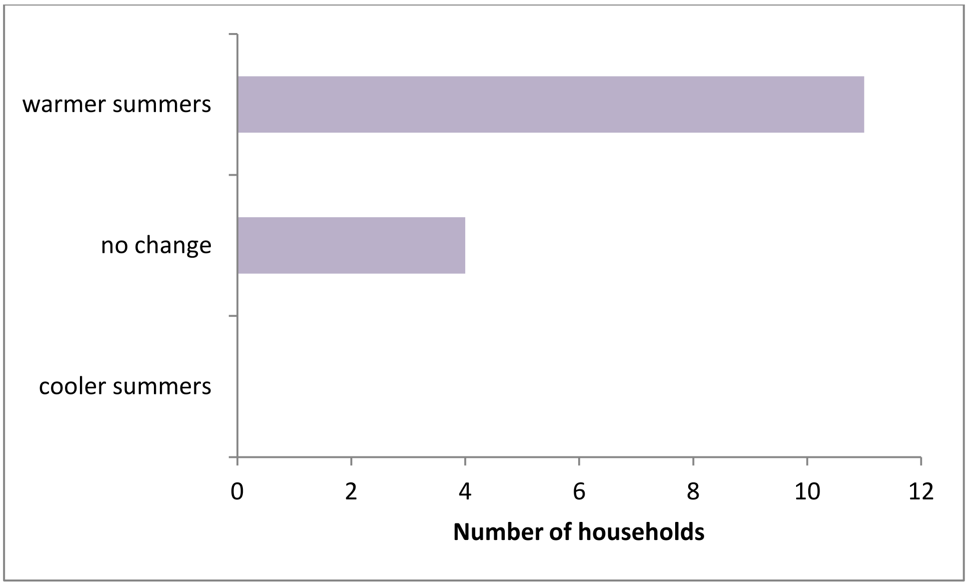

Figure 5.6 How do you think climate change will affect outside temperatures in the summer?

Figure 5.6 shows the response to the question of how summertime temperatures may change in the future. Eleven households (73%) stated that they think climate change will result in warmer summers in the future, whilst four households (27%) stated that they think there will be no change to summertime temperatures.
No households thought that they would experience cooler summers as a result of climate change.

5.1.8 Question Eight

All residents were asked their views as to, based on current summertime comfort and potential impacts of climate change, whether they would need to change how they live in their home to adapt to a changing climate. The responses to this question are shown in Figure 5.7.

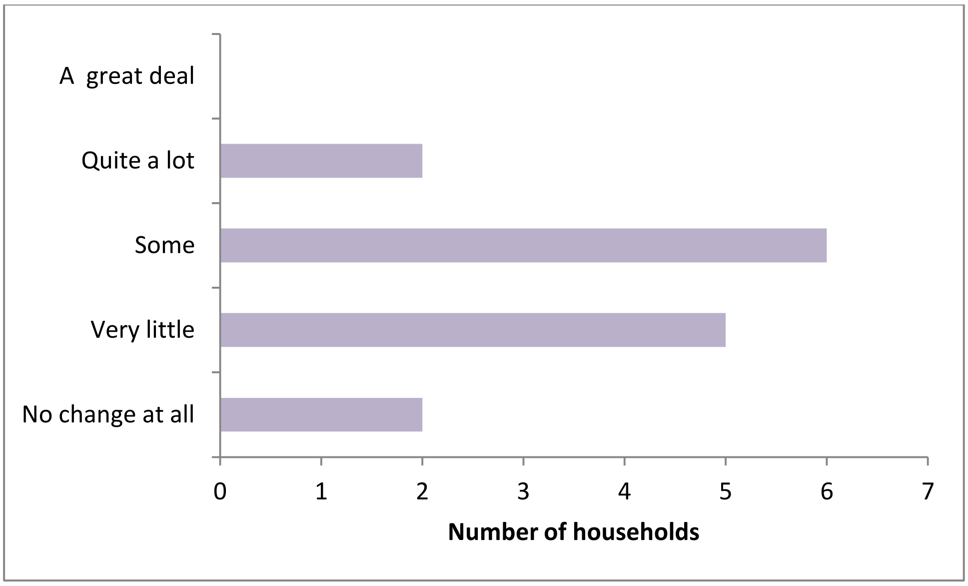

Figure 5.7 Do you think you will need to change how you live in your home to adapt to a changing climate?

Figure 5.7 shows the response to the question of how residents may need to adapt living in their homes to deal with a changing climate. The majority of residents agreed they would need to make some level of change, with five households (33%) stating they would need to make very little change; six households (40%) stating they would need to make some change; and two households (13%) stating they would need to make quite a lot of change. No residents stated they would need to make a great deal of change to how they live in their homes.

A further two households (13%) stated that they would not need to make any change as to how they live in their home to adapt to a future climate.

5.1.9 <u>Question Nine</u>

All residents were asked to provide some demographic information, in relation to how many adults lived in the house. The responses to this question are shown in Figure 5.8.

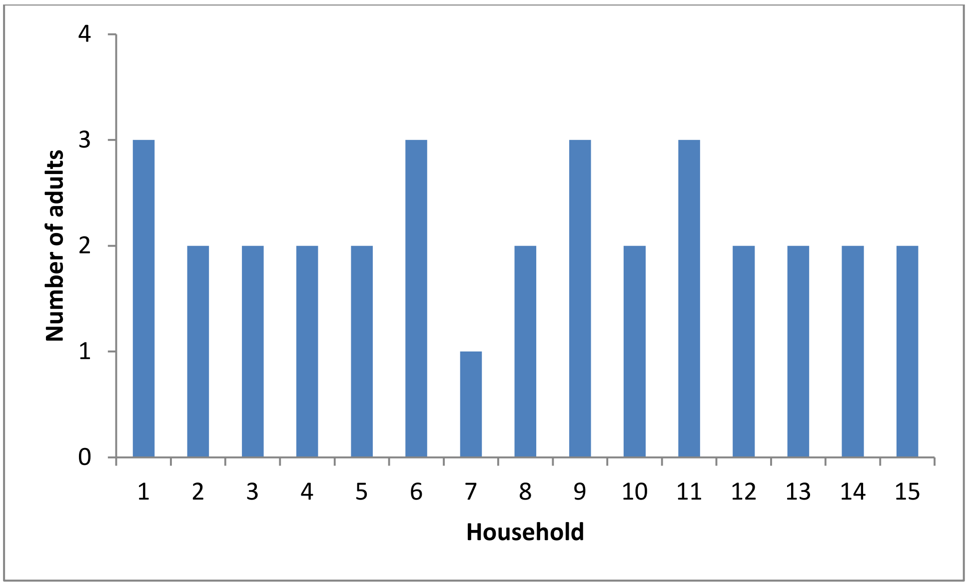

Figure 5.8 Including yourself, how many adults live in your house?

Figure 5.8 shows the response to how many adults live in the house. Of the fifteen households that responded to the survey, one household was single occupancy, ten households had two adult occupants, and four households had three adult occupants

5.1.10 <u>Question Ten</u>

All residents were asked to provide some demographic information, in relation to how many children lived in the house. The responses to this question are shown in Figure 5.9.

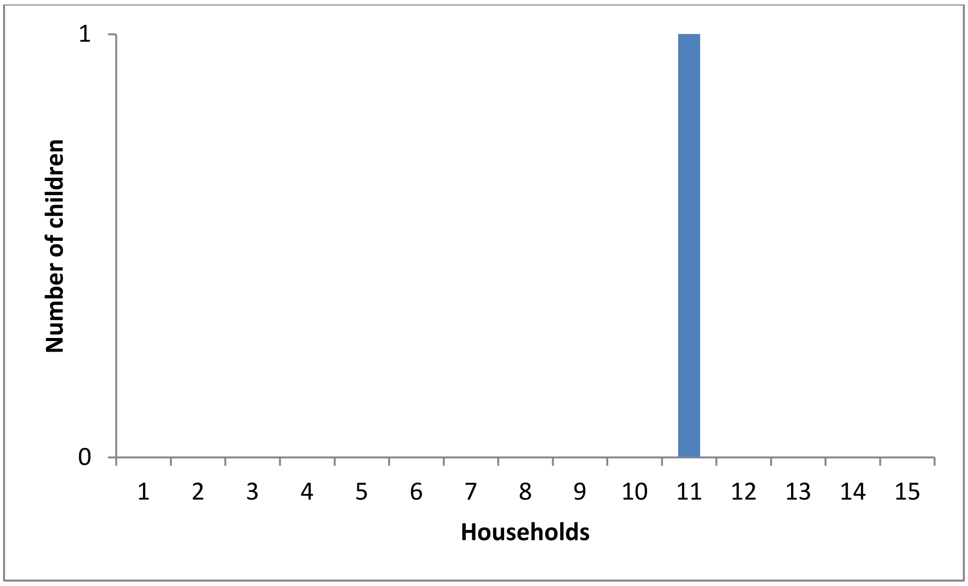

Figure 5.9 How many children live in the house?

Figure 5.9 shows the response to how many children live in the house. Of the fifteen households that responded, one household reported that a child lived in the home with them.

5.1.11 Question Eleven

All residents were asked to indicate when they moved into the house. The responses to this question are shown in Table 5.3.

Table 5.3 Date of move to Derwenthorpe

	Jun 12 - Aug 12	**Sep 12- Dec 12**	**Jan 13- Mar 13**	**Apr 13 - Jun 13**	**Jul 13- Sep 13**	**Oct 13- Dec 13**	**Jan 14 – Mar 14**	**Apr 14 – Jun 14**	**Jul 14 – Sep 14**	**Oct 14- Dec 14**	**Jan 15 – Mar 15**	**Apr 15 – Jun**
Number of house-holds moving in	5	4	3	1	0	0	1	0	0	0	0	1

Table 5.3 shows that, at the time of the questionnaire being issued to residents, all households had experienced at least one summer living in their home in Derwenthorpe. A total of thirteen households that responded had experienced two full summers living in Derwenthorpe.

5.1.12 Question Twelve

All residents were asked to indicate their property tenure. The results are shown in Table 5.4.

Table 5.4 Property tenure of respondents

Tenure	Number of respondents
Owner	**14**
Shared Owner	**0**

Table 5.4 shows that the majority (93%) of households that responded to the survey were owner occupiers, with only a single household (7%) being a rented property.

No shared owners responded to the survey.

5.2 Comparison with other survey findings

As discussed in Section 4.1, a number of questions on the Derwenthorpe survey were designed to provide a direct comparison with other research findings. The key comparison is with EFUS (BRE & DECC, 2011), as this provides provide one of the largest depositories of resident feedback on overheating and thermal comfort.

For the first questions, households were asked if they find it difficult to keep any rooms comfortably cool. The results in Table 5.5, and presented graphically in Figure 5.10, demonstrate the findings, which show:

1. The findings from both studies show that a significant number of households do not currently experience overheating in any rooms. EFUS findings of nearly 80% of households experiencing no overheating are nearly double that of the Derwenthorpe survey.
2. The main bedroom is most prone to overheating in the EFUS study and the Derwenthorpe survey. At Derwenthorpe, 24% of households reported this room as a problem, compared to 11% in the EFUS study.
3. The “other bedroom” was more prone to reported overheating at Derwenthorpe compared to EFUS, with 18% of households reporting this as a problem room compared to 8% in the EFUS study.
4. The findings for the main living room and other room were similar between the Derwenthorpe and EFUS findings.

Table 5.5 Area of overheating: comparison with EFUS results

	EFUS Results		Derwenthorpe results	
	Sample Size	% of households	Sample Size	% of households
Main living room	240	8.7	2	11.8
Main bedroom	295	10.9	4	23.5
Other bedroom	204	7.8	3	17.6
Other rooms	92	3.5	1	5.9
None	2077	79.6	7	41.2

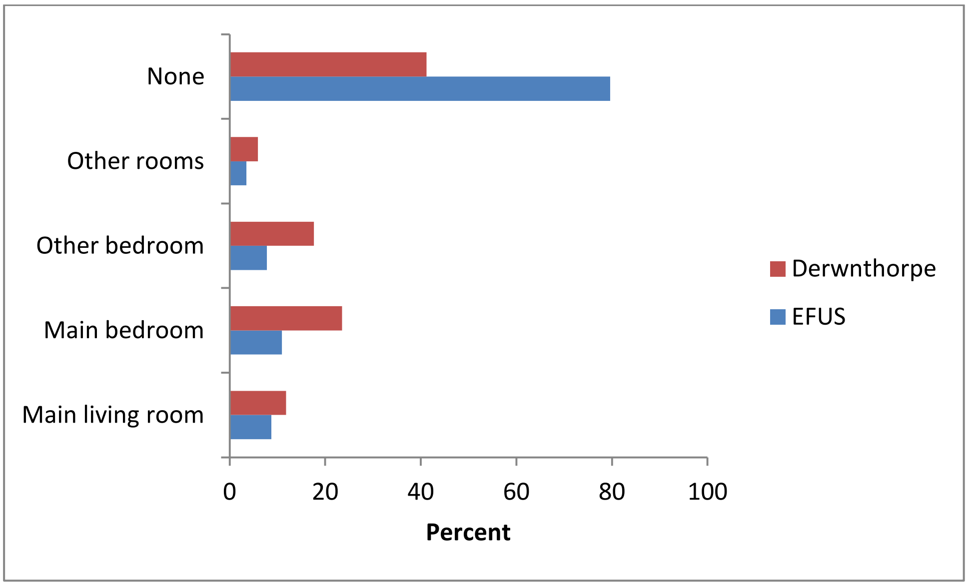

Figure 5.10 Area of overheating: comparison with EFUS results

For the second question, households were asked to provide a reason for finding it difficult to keep any rooms comfortably cool. The results in Table 5.6, compare Derwenthorpe findings with EFUS, and are presented graphically in Figure 5.11, which shows:

1. Over 40% of households in the EFUS study stated that the lack of shade/tree coverage around the house contributed to overheating, compared to only 13% of Derwenthorpe households.
2. Findings were similar between the EFUS study and Derwenthorpe study for response to natural ventilation. 16% of EFUS households stated that inadequate ventilation through windows contributed to overheating, compared to 13% of Derwenthorpe households.

3. Findings were similar between the EFUS study and Derwenthorpe study for response to direct sunlight. 13% of EFUS households stated that inadequate blinds/curtains contributed to overheating, compared to 13% of Derwenthorpe households.
4. There were no other causes of overheating identified by Derwenthorpe households. However, a further 13% of EFUS households stated that poor air circulation contributed to overheating, and 13% of EFUS households state that internal heat gains contributed to overheating.

Table 5.6 Reason for overheating: comparison with EFUS results

	EFUS	Derwenthorpe
	% of households	% of households
Inadequate blinds/curtains to keep direct sunlight out	13	13
Too much heat from internal sources	13	0
Poor air circulation around the home	13	0
Inadequate ventilation through windows	16	13
Little or no shade/tree coverage around the homes	41	13
Other reasons	30	0

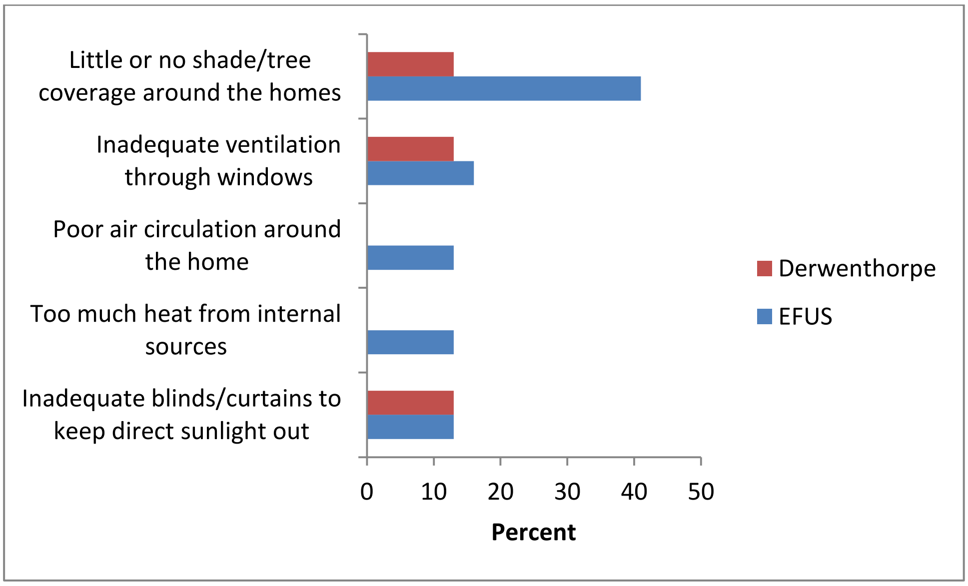

Figure 5.11 Reason for overheating: comparison with EFUS results

For the third question, households were asked to provide the frequency of overheating in the home. Figure 5.12 compares Derwenthorpe findings with EFUS results and shows:

1. In both the EFUS study and the Derwenthorpe survey, the greatest proportion of households reported that overheating occurs between one and four days a week.
2. Whereas 24% of EFUS households reported that overheating occurs less than once a week, only 7% of Derwenthorpe households reported the same finding.
3. Findings were similar between the EFUS study and Derwenthorpe survey for households reporting overheating on five to six days a week, with 8% of EFUS households and 7% of Derwenthorpe households reporting this frequency.
4. 22% of EFUS households reported overheating every day, whilst no Derwenthorpe households reported this level of frequency.

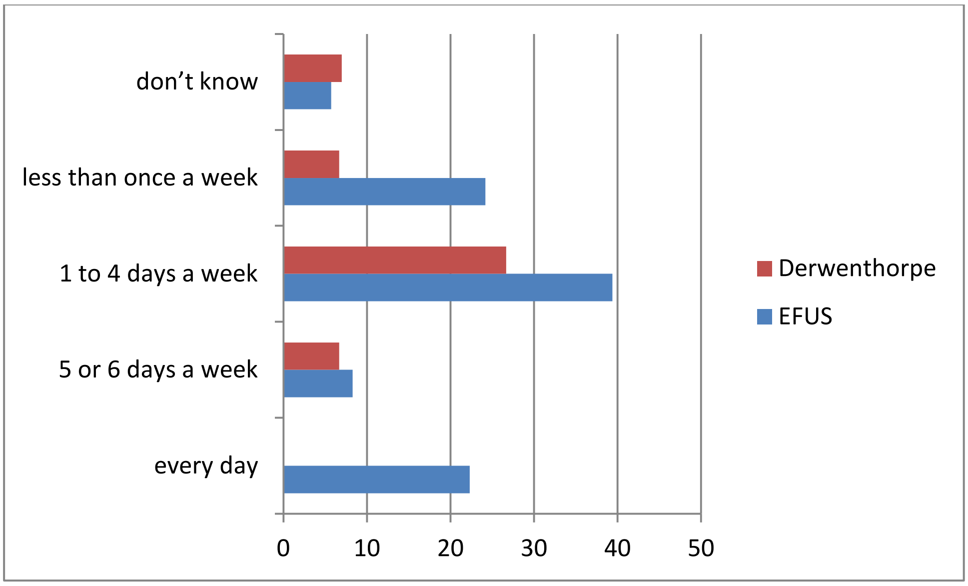

Figure 5.12 Frequency of overheating: comparison with EFUS results

5.3 <u>Stage One Results- Discussion</u>

The survey that was carried out with Derwenthorpe households provided a number of useful findings, some of which inform the second stage results.

Whilst there is a small majority of households reporting that they do not currently experience difficulty in keeping rooms cool, a significant proportion of households do find this to be a problem.

Of households reporting overheating as an issue, the most common rooms for this to occur are the main bedroom. The results from the Derwenthorpe study closely reflect those of EFUS. However, the Derwenthorpe sample size is statistically insignificant when compared to the EFUS results. Considering this, given that the scale of Derwenthorpe is a limitation, the results need to be considered in terms of similarity with EFUS findings despite this statistical insignificance. Other bedrooms were also reported as problem rooms by Derwenthorpe households, along with the main living room. Without monitored temperatures available as part of this study, the feedback from households supports the findings of Firth and Wright (2008) in terms of risk of these rooms overheating.

The reason for overheating can be attributed to direct solar gain, and the associated lack of shading, along with the lack of adequate ventilation. These reported findings from residents support the links to modern home design attributing to overheating (Firth and Wright, 2008; NHBC, 2012) Issues around natural ventilation and direct solar gain are reported as significant findings in EFUS (BRE & DECC, 2011)

With the majority of Derwenthorpe residents who experience overheating reporting that this occurs between one and four days a week, their exposure to overheating is significant, especially when considered in the context of future climate change. This frequency of overheating was also reported by EFUS households.

To address this exposure to overheating, households currently manage temperature mainly through the opening of doors and windows. The location of Derwenthorpe partly assists with the ability to carry out this action, as its location in a semi-rural environment means that air quality is good, and external noise levels are low. Although the majority of households use passive actions, such as window and door opening, a small number have resorted to measures that consume energy, including electric fans and air conditioning units. Given that consumption of energy generated from fossil fuels contributes to GHG emissions, the promotion of the uptake of passive measures is important in the overall environmental context of climate change adaptation.

However, when the issues discussed above are considered, the majority of households report that they are happy with the comfort conditions in their home in summer. Given the number of households reporting that the use of simple passive cooling measures, such as door and window opening, can produce a satisfactory internal environment, this does suggest that the extent of temperature within the home is not at a level that would cause dissatisfaction and discomfort. If this were the case, we would be likely to see a higher reported use of energy consuming cooling measures.

In terms of a future climate, the majority of households believed that climate change would result in warmer summers. Whilst this means that external summertime temperatures could be higher, this temperature change did not trigger a significant change in terms of how residents would live in their homes, with no households reporting that they would greatly change how they live in their homes. However, the majority of households did state that they would make some or very little change to how they lived in their homes, which may be reflected in terms of adaptation measures selected in the second stage results.

The demographic data results show that the majority of households that responded to the survey had low levels of occupancy, typically consisting of just two adults living in the home. This low level of occupancy could partly contribute to the reported causes of overheating, as no households reported internal gains as a source of overheating, something that can often be associated with higher levels of occupancy and a higher number of lights and appliances in use in the home.

Despite the small sample size of the survey, the households that responded had all experienced at least one summer living in their home at Derwenthorpe, meaning that the survey responses were based on a reasonable experience of summertime temperatures in the home.

In summary, the results of stage one support the aims of the research project, as feedback obtained from residents has shown that there is currently an overheating risk in the homes, and residents recognise that they will need to make some level of change as to how they live in their homes to adapt to a changing climate.

The second stage of the results explores the adaptation measures in more detail.

6 Results Stage Two

The follow up stage to the household survey involved residents ranking a range of prescribed adaptation measures. The following sections firstly present the results of this activity, in terms of how residents ranked a range of adaptation measures, before the ranking is considered in greater detail in the discussion section.

6.1 Ranking of Interventions

A total of seven households were asked to rank a range of nine adaptation measures against six criteria in order to provide a total score for the adaptation measure. The scores of each household were totalled, to give a potential maximum score of 420. The total scores out of 420 were then ranked, with the highest ranking being given a ranking of 10, and the lowest ranking a score of 0.

A summary of the results is shown in Table 6.1 and is also presented in Figure 6.1.

Table 6.1 Household scoring and ranking of adaptation measures

	Internal Blinds	External Shutters	Curtains	Low e triple	External fixed	Night ventilatio	Window rules	Solar reflective	Solar reflective
Effectiveness	45	55	39	36	44	51	40	30	29
Cost	43	24	50	17	28	53	34	29	30
Maintenance	47	27	54	46	37	47	37	32	32
Aesthetics	55	39	55	51	48	56	36	39	43
Phase ability	58	37	56	32	43	50	43	42	44
Usability	50	28	49	55	46	54	53	60	60
TOTAL	298	210	303	237	246	311	243	232	238
RANKING	3	9	2	7	4	1	5	8	6

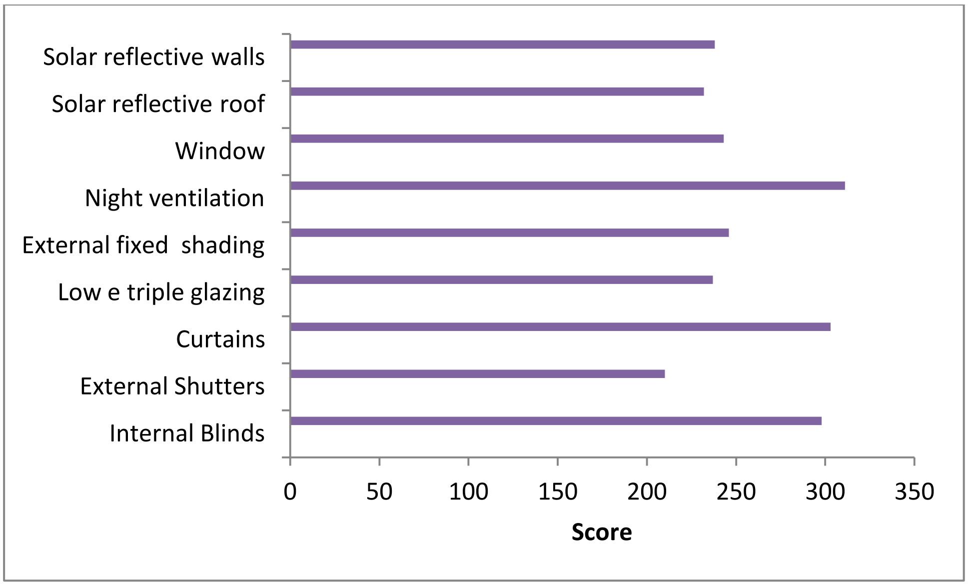

Figure 6.1 Household scoring of adaptation measures

Based on the results of the household scoring, as shown in Table 6.1 and Figure 6.1, the scoring of adaptation measures can be summarised, in order of ranking, as:

1. Night Ventilation
2. Curtains
3. Internal blinds
4. External fixed shading
5. Window rules
6. Solar reflective walls
7. Low e triple glazing
8. Solar reflective roof
9. External shutters

6.2 <u>Criteria ranking of adaptation measures</u>

In addition to the overall ranking of the adaptation measures, the scoring system also allows for analysis of the section criteria to determine the drivers for selection. This is discussed below, with a summary of the results in Table 6.2

Effectiveness

Households were asked to rank the effectiveness of the adaption measure at reducing overheating. External shutters were ranked the most effective by households, followed by night ventilation and internal blinds.

The least effective adaptation measure was determined to be solar reflective walls.

Cost

Households were asked to rank how costly the measure is compared to other measures. Households were provided with indicative costs of the measures as a guide.

Night ventilation was ranked the most cost effective by households, followed by curtains and internal blinds.

The least cost effective measure was determined to be low e triple glazing.

Maintenance

Households were asked to rank how easy the measure is to maintain, both in terms of practicality of maintenance and cost of maintenance.

Curtains were ranked the easiest measure to maintain, followed by night ventilation and internal blinds.

The most difficult measure to maintain was determined to be external shutters.

Aesthetics

Households were asked to rank how acceptable the measure is in terms of preserving the design quality of the home.

Night ventilation was ranked the most aesthetically acceptable measure, followed by internal blinds and curtains

The least aesthetically acceptable measure was determined to be window openers.

Phase ability

Households were asked to rank how easy it would be to retrofit the measure at a later date.

Internal blinds were ranked the easiest to retrofit, followed by curtains and night ventilation

The most difficult measure to retrofit was determined to be low-e triple glazing.

Usability

Households were asked to rank how easy the measure is to use and operate.

Solar reflective walls and solar reflective roof were both ranked the easiest measures to use, followed by low e triple glazing.

External shutters were determined be the most difficult measure to use.

Table 6.2 Summary of highest ranking adaptation measures

	Highest ranking measures	Lowest ranking measure
Effectiveness	External shutters Night ventilation Internal blinds	Solar reflective walls
Cost	Night ventilation Curtains Internal blinds	Low-e triple glazing
Maintenance	Curtains Night ventilation Internal blinds	External shutters
Aesthetics	Night ventilation Internal blinds Curtains	Window openers
Phase ability	Internal blinds Curtains Night ventilation	Low-e triple glazing
Usability	Solar reflective roof Solar reflective walls Low-e triple glazing	External shutters

6.3 Stage Two Results- Discussion

The overall ranking of adaptation measures, against the six criteria, showed that there were three measures that households preferred over the other adaptation measures presented to them. As shown in Figure 6.1, night ventilation, internal blinds and curtains scored significantly higher than the other measures.

Equally so the use of external shutters was also shown to be the least preferable measure.

The summary provided in section 6.2 provides further insight into the reasons that measures were chosen or rejected.

All three of the highest ranking measures (i.e. night ventilation, internal blinds and curtains) scored the highest in terms of cost, aesthetics, maintenance and phase ability. In addition, both night ventilation and internal blinds were amongst the highest ranking measures in terms of effectiveness.

Effectiveness

In terms of effectiveness of the measures, night ventilation and internal blinds were ranked highly. Residents stated that in the case of night ventilation, the ability to remove warm air from the dwelling through the night was a measure that they currently value in terms of operable windows, and thought they would be a very effective measure in the future. With regards to the ranking of internal blinds, households were familiar with the use of internal blinds, and recognised their effectiveness in reducing solar gain and associated heat gain to dwellings.

The ranking of effectiveness of external shutters by households is of note, as although it was shown to be the least preferable measure in terms of all criteria, households did recognise its effectiveness as a measure. Households stated that the use of external shutters in warmer climates demonstrates the effectiveness of the measure, and a number of households had personal experience of using external shutters when staying in accommodation in warmer climates.

Solar reflective walls were ranked the lowest in terms of effectiveness. The reason for this was that residents were aware that their homes were highly insulated to retain heat in the winter, and during the summer they felt that the insulation would prevent warmth entering the house. Because of this, residents failed to see how solar reflective paint would add to the benefits provided by the cavity wall insulation in the homes.

Cost

The prevalence of the top three ranking measures in terms of cost can be attributed to the costs that were presented to the households during the interview (see Appendix C) The costs of curtains and internal blinds were both based on £200 per window, as per the costs used in the retrofit toolkit. Whilst these costs are very low, for many households they already had curtains and/or internal blinds fitted, in which case they assumed there would be no additional costs.

The costs of natural ventilation, at £400, were associated with costs that residents allocated to the modification of adapting the MVHR systems installed in the homes. The MVHR systems extract warm air from “warm rooms” i.e. kitchens and bathrooms, and circulate this through the house whilst filtering the air. During the summer months, a summer bypass function is enabled on the systems, which can prevent warm air being drawn into the house. During the interviews, residents were of the view that as the homes had a fan connected as part of the MVHR installation, it could be feasible to modify this fan to provide ventilation at night. Where households assumed that night ventilation would be achieved through window opening, it was assumed there would be no costs associated with the measure, as windows would be opened and closed by the resident.

Low-e triple glazing was ranked the lowest by residents. This was based on the costs presented to them at interview stage. However, whilst residents did see this as a high cost, they were unaware of the cost of replacing the existing double glazed windows in the house on a like for like basis, so dependent on these costs they may consider the cost uplift to triple glazing when whole house window replacements took place, but only at this point in time.

Maintenance

The ranking of the top three measures in terms of maintenance can partly be reflected by the familiarity of the measures. At the household interview stage, all of the households interviewed had internal blinds and/or curtains installed, and as such were aware of the maintenance issues associated with these measures. All households reported that they had rarely had to maintain these measures, and if maintenance was required, for example replacing a broken curtain hook, it was easy for them to carry out themselves. In terms of night ventilation, residents based their decision both on the use of windows and also through the use of the MVHR. Households felt that, based on experience, the MVHR systems had minimal maintenance associated with them, mainly involving the cleaning of filters to allow for good air circulation. This could be carried out with a domestic vacuum cleaner, and if the filter was in too poor condition, residents had information on where to purchase filters. With regards to windows, again the resident experience was of limited maintenance issues with windows, both in their Derwenthorpe home and previous homes.

External shutters were ranked the lowest by residents, as they felt that as they were located on the outside of the house, they would be exposed to weather conditions which would result in the need for pre-paining/painting treatments to the shutters. In addition, hinge mechanisms, or roller shutters were a concern for residents in terms of reliability and associated maintenance.

Aesthetics

The ranking of the top three measures in terms of aesthetics again reflected the familiarity of the measures, especially in the case of internal blinds and curtains. At the household interview stage, all of the households interviewed stated that they had chosen to fit internal blinds or curtains based on their appearance, with some households preferring the appearance of blinds, others preferring the appearance of curtains, and some households having both blinds and curtains fitted in different rooms in the house. The assessment of the aesthetics of night ventilation was based on familiarity and experience of windows in the home, which were felt to have a positive visual impact on the home. In terms of the installation of a fan for night ventilation, although the image presented to households suggested a ceiling hung unit, given the MVHR system installed in the dwellings it was recognised that the fan unit for this system (either installed in the loft space or upstairs cupboards in the dwellings) would meet the night ventilation function, and therefore there would be no further aesthetic impact of installing a fan unit.

Window openers (window rules) were ranked the lowest by residents, as they felt that the appearance of these units on their windows would have a significant detrimental impact to the window. Given the small size of the unit this response was unexpected, although residents further developed their reasoning by stating that other "visual" measures such as solar reflective paints were in line with the existing development, as many of the homes already have white painted brickwork externally. The installation of window openers was felt to detract from the aesthetic value of the home.

Phase ability

The ranking of the top three measures in terms of phase ability reflected the ease at which they could be installed. In the case of internal blinds and curtains, households were familiar with the ease of fitting either of these measures, and felt that if required they could be easily installed in the future. In the case of night ventilation, households referred to the existing MVHR installation, stating that any changes to the system would probably consist of works to the fan unit (either installed in the loft space or upstairs cupboards in the dwellings) which would be completed by a contractor with relative ease.

Low-e triple glazing was ranked the lowest by residents, partly linked to the reasoning associated with costs. Residents felt that the only reason they would install low-e triple glazing was as part of a whole house window replacement, and as the existing windows would be expected to be installed for at least thirty years, the likelihood and ease of installing triple glazing in the future was low.

Usability

The usability criteria did not feature any of three top ranking measures, instead reflecting measures that do not require any user input once installed. In the case of solar reflective roofs and solar reflective walls, households stated that once these paints had been applied, they would perform their function with no user intervention required for a number of years, at which point a new coat of paint would be required.

In the case of low-e triple glazing, again households stated that once the windows were installed, the low-e coating and solar reflectivity of the glazing would perform the desired function with no user intervention required, as is currently the case with their double glazed units. Residents did recognise that whilst windows do require cleaning, this is unrelated to the consideration of windows as an overheating adaptation measure.

In summary, the results of stage two support the aims of the research project, as the methodology that has been developed has allowed residents to rank adaptation measures against a range of criteria. This methodology has produced some clear findings in terms of the preference for adaptation measures, and the next stage of the project is to assess the impact of these choices in terms of impact on overheating.

7 Impact of interventions

The ranking of the adaptation measures provided a hierarchy of measures selected by residents. This section firstly focuses on assessing the impact of these measures by using the retrofit toolkit and assessing the degree hours over CIBSE guidance, before summarising the effectiveness of the measures selected by residents.

7.1 Daytime occupied home

Figure 7.1 shows that for a daytime occupied house, the un-adapted house has an overheating risk ranging from 464 to 719 degree hours over threshold temperature, dependent on orientation of the dwelling. The greatest overheating risk occurs on east and west facing orientations, with the lowest risk on north facing orientations.

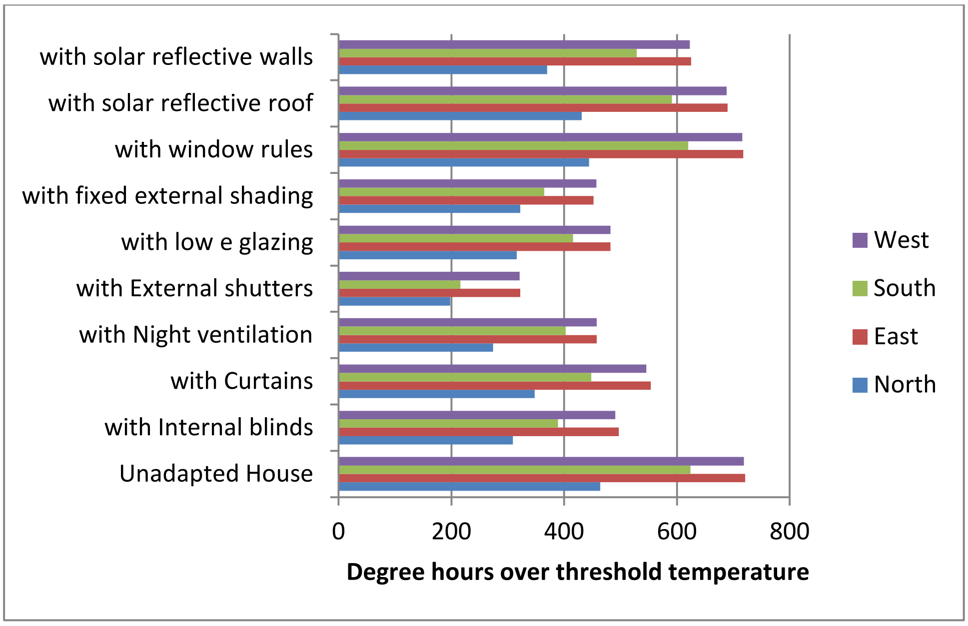

Figure 7.1 Impact of adaptation measures- daytime occupied

The adaptation measures have a varying impact on the risk of overheating, as shown in Figure 7.2.

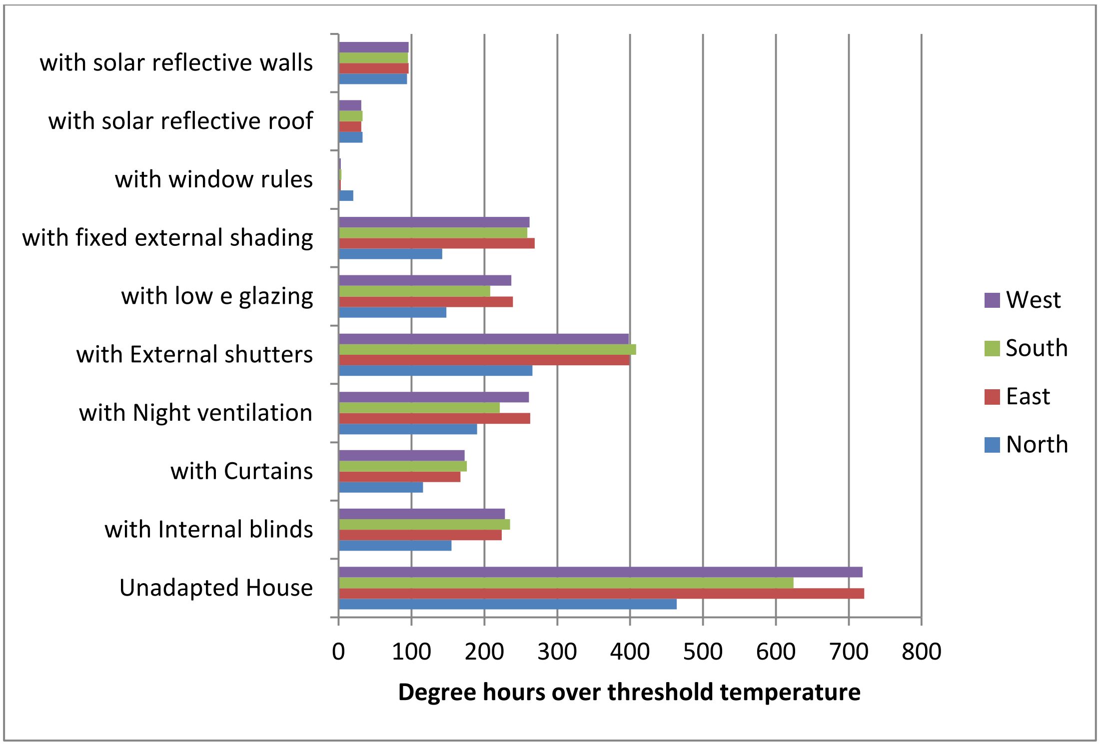

Figure 7.2 Reduction in degree hours over threshold temperature- daytime occupied

Figure 7.2 shows that greatest reduction in overheating risk is achieved through the installation of external shutters, reducing overheating by between 266 and 408 degree hours. The smallest reduction is achieved through the use of window rules, reducing overheating between 3 and 20 degree hours.

Whilst Figure 7.2 presents the reduction on overheating risk in terms of actual values, Figure 7.3 presents this information in terms of percentage reduction.

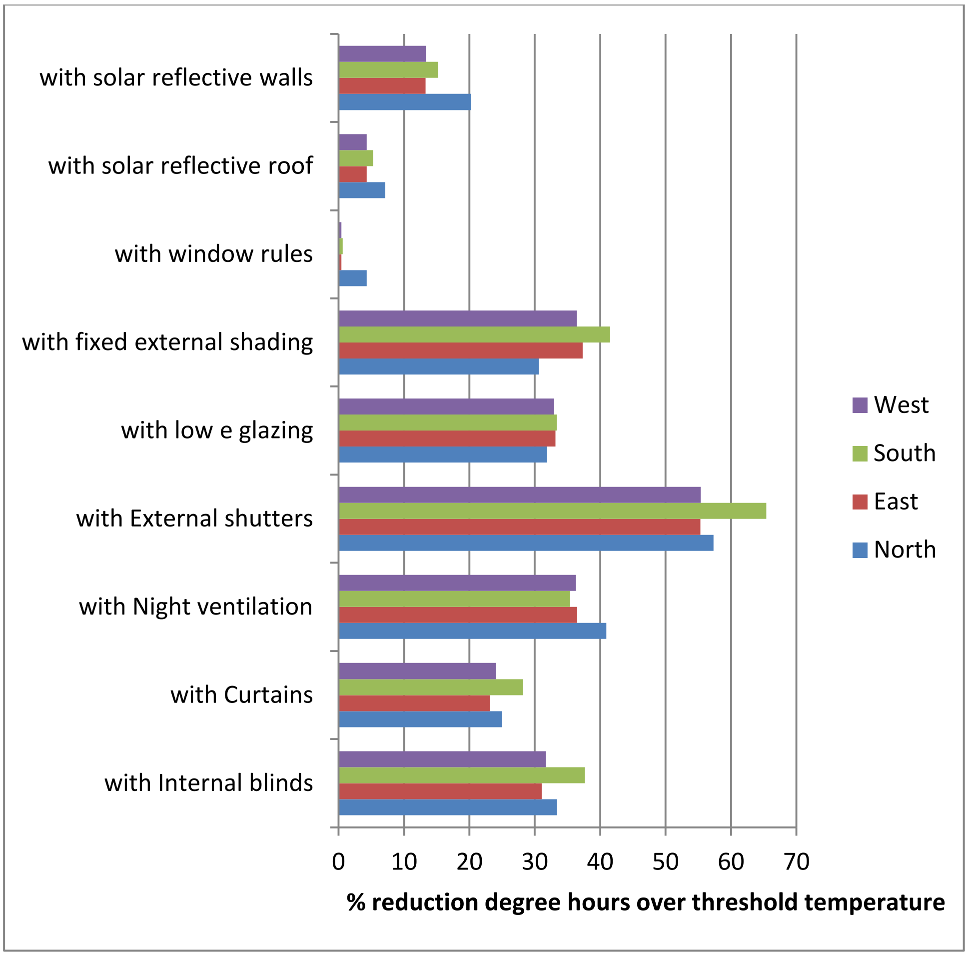

Figure 7.3 Percentage reduction in degree hours over threshold temperature- daytime occupied

Figure 7.3 translates actual reduction into percentage reduction, and provides a visual interpretation of the ranking of measures.

In terms of ranking, the effectiveness of the measures can be summarised as:

1. External shutters reduce overheating by 55% to 65%.
2. Night ventilation reduces overheating by 35% to 41%.
3. Fixed external shading reduces overheating by 31% to 42%.
4. Internal blinds reduce overheating by 31% to 38%.
5. Low-e glazing reduces overheating by 32% to 33%
6. Curtains reduce overheating by 23% to 28%.
7. Solar reflective walls reduce overheating by 13% to 20%.
8. Solar reflective roofs reduce overheating by 4% to 7%.
9. Window rules reduce overheating by up to 4%.

7.2 <u>Daytime Unoccupied home</u>

Figure 7.4 shows that for a daytime unoccupied house, the un-adapted house has an overheating risk ranging from 229 to 339 degree hours over threshold temperature, dependent on orientation of the dwelling. The greatest overheating risk occurs on east and west facing orientations, with the lowest risk on north facing orientations.

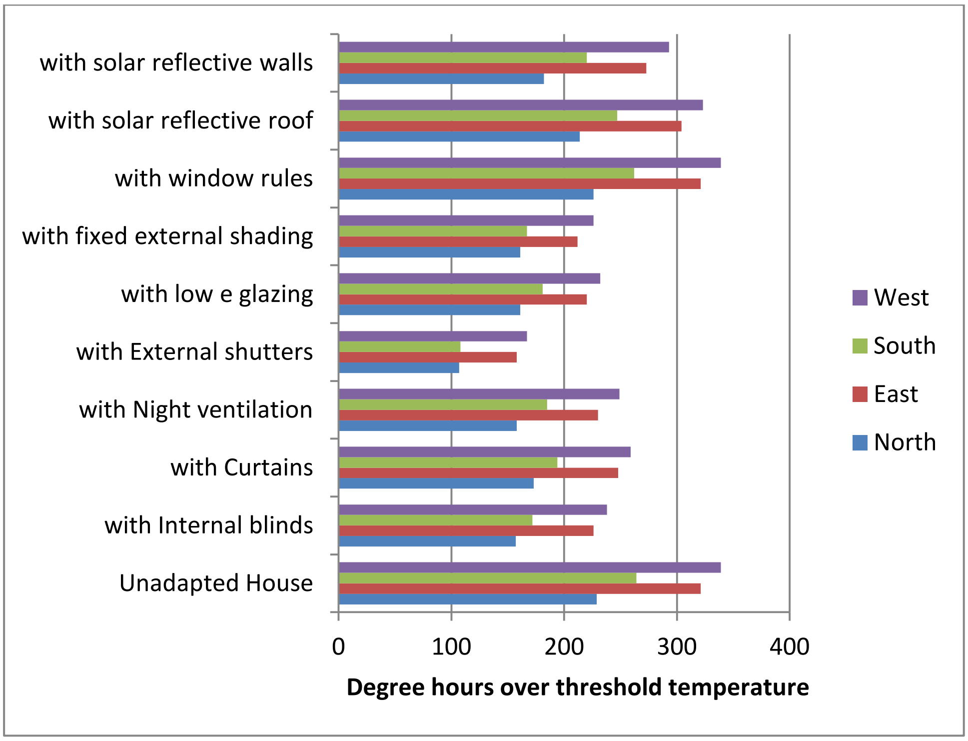

Figure 7.4 Degree hours over threshold temperature- daytime unoccupied

The adaptation measures have a varying impact on the risk of overheating, as shown in Figure 7.5

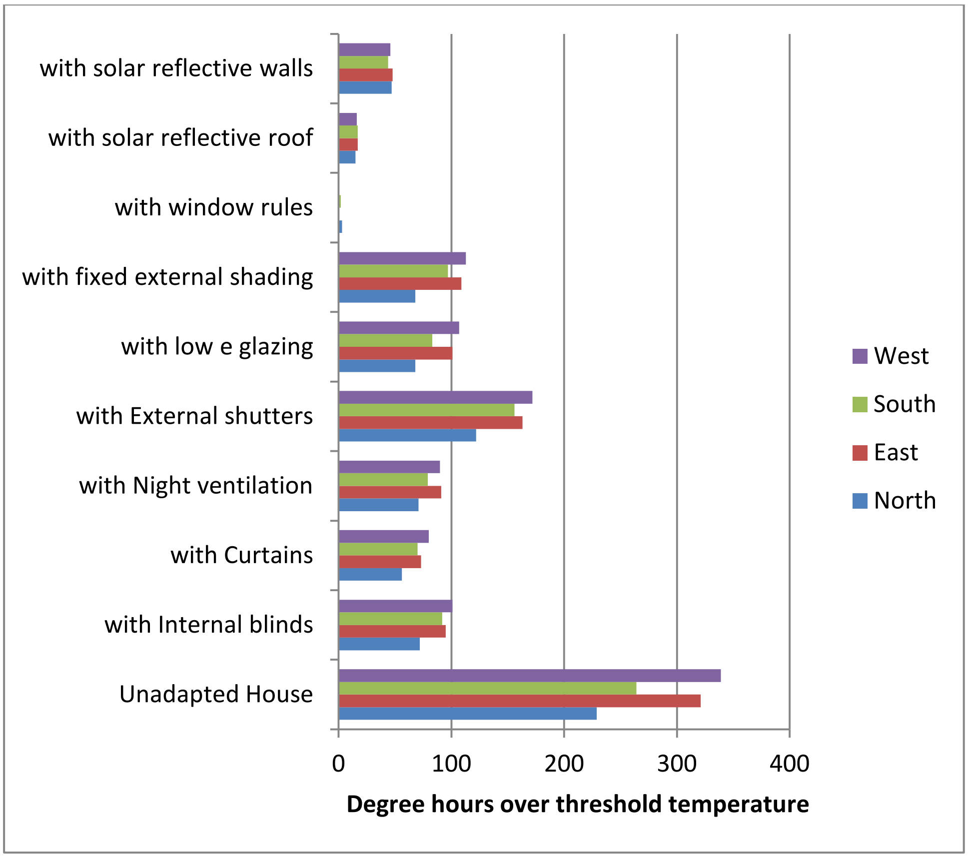

Figure 7.5 Reduction in degree hours over threshold temperature- daytime unoccupied

Figure 7.5 shows that greatest reduction in overheating risk is achieved through the installation of external shutters, reducing overheating by between 122 and 172 degree hours. The smallest reduction is achieved through the use of window rules, reducing overheating by up to 3 degree hours.

Whilst Figure 7.5 presents the reduction on overheating risk in terms of actual values, Figure 7.6 presents this information in terms of percentage reduction

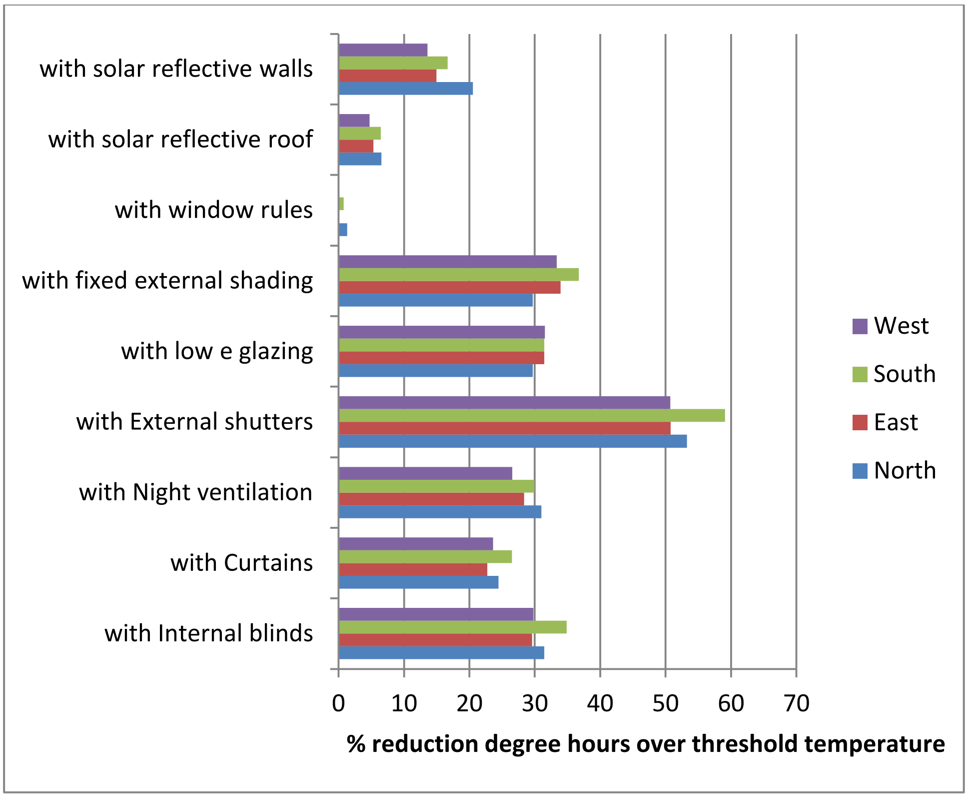

Figure 7.6 Percentage reduction in degree hours over threshold temperature- daytime unoccupied

Figure 7.6 translates actual reduction into percentage reduction, and provides a visual interpretation of the ranking of measures.

In terms of ranking, the effectiveness of the measures can be summarised as:

1. External shutters reduce overheating by 51% to 59%.
2. Fixed external shading reduces overheating by 30% to 37%.
3. Internal blinds reduce overheating by 30% to 35%.
4. Low-e glazing reduces overheating by 30% to 32%
5. Night ventilation reduces overheating by 28% to 31%.
6. Curtains reduce overheating by 23% to 27%.
7. Solar reflective walls reduce overheating by 14% to 21%.
8. Solar reflective roofs reduce overheating by 5% to 7%.
9. Window rules reduce overheating by up to 1%.

7.3 Impact of measures selected by households

Based on the output of the household interviews and the analysis of the impact of the adaptation measures, it is known that households ranked night ventilation, curtains and internal blinds as their preferred measures. It is also known from the impact analysis that external shutters are the most effective adaptation measure in terms of actual reduction of overheating risk.

In order to understand how the households selection of preferred measures addresses overheating risk, the three ranked adaptation measures have been compared to the most effective adaptation measure i.e. external shutters.

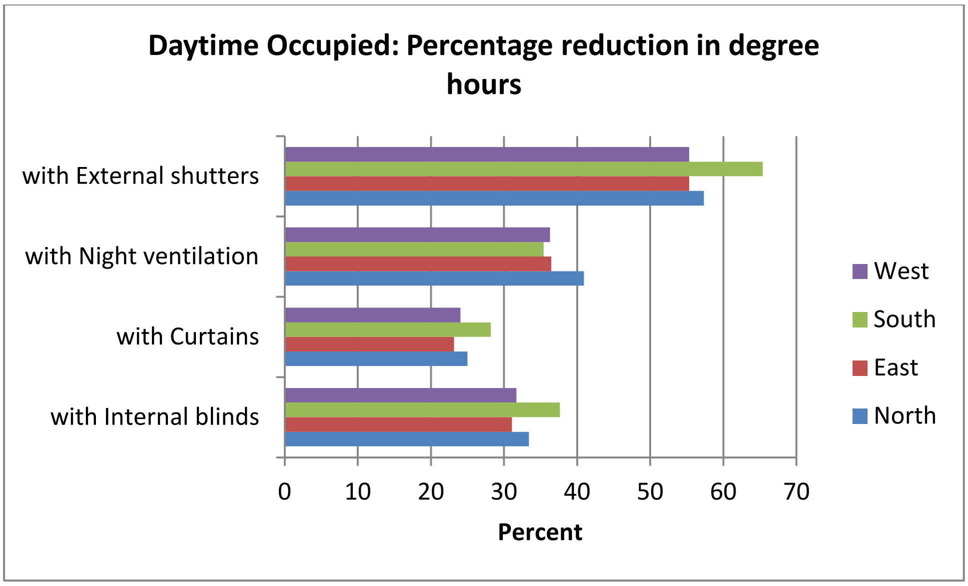

Figure 7.7 Percentage reduction in degree hours over threshold temperature- daytime occupied

Figure 7.7 shows the percentage reduction in degree hours over threshold temperature for a daytime occupied home, and highlights the effectiveness of external shutters compared to the three measures selected by households.

Even though external shutters the most effective measure in terms of performance,, the measures selected by households still present a significant reduction in overheating risk, with night ventilation achieving an average (average of all orientations) reduction in overheating of 37% compared to the average reduction of external shutters of 58%.

Internal blinds achieve a smaller average reduction in overheating of 33.5%, and curtain an average reduction of 25%.

For a daytime unoccupied home, the results present a similar pattern, as shown in Figure 7.8.

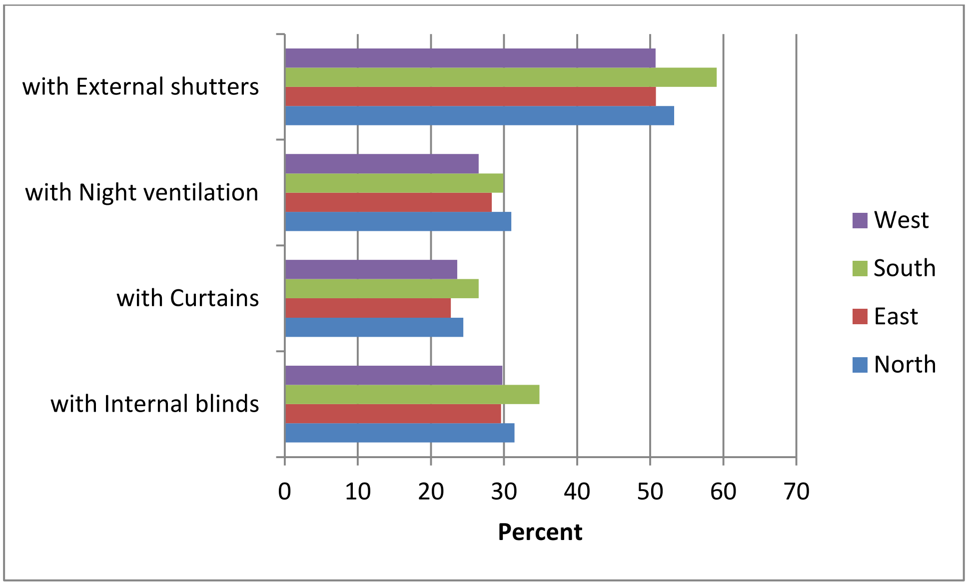

Figure 7.8 Percentage reduction in degree hours over threshold temperature- daytime unoccupied

Figure 7.8 shows that again external shutters are the most effective measure at reducing overheating, with an average reduction in overheating of 53.5%.

The measures selected by households again provide a significant reduction in overheating risk. However, unlike the daytime occupied home which found that night ventilation was the most effective measure chosen by households, for the unoccupied house internal blinds are the most effective measure with an average 31.5% reduction in overheating. Night ventilation provides an average 29% reduction, and curtains an average 24.5% reduction.

The results for both types of occupation pattern show that whilst reduction in overheating can be achieved through the measures selected by households, they are not as effective as external shutters.

Given the criteria that led households to selecting night ventilation, curtains and internal blinds as preferred measures, it is known that households ranked the three measures the most cost effective and the easiest to install.

It is feasible to consider a combination of the measures selected by residents, such that two combinations are possible: night ventilation with internal blinds, and night ventilation with curtains. Given the function of curtains and internal blinds, and the nature of their installation, it is unlikely that these would be installed on the same window, therefore limiting the options to two combinations.

The impact of the combination of measures is shown in Figure 7.9 and Figure 7.10.

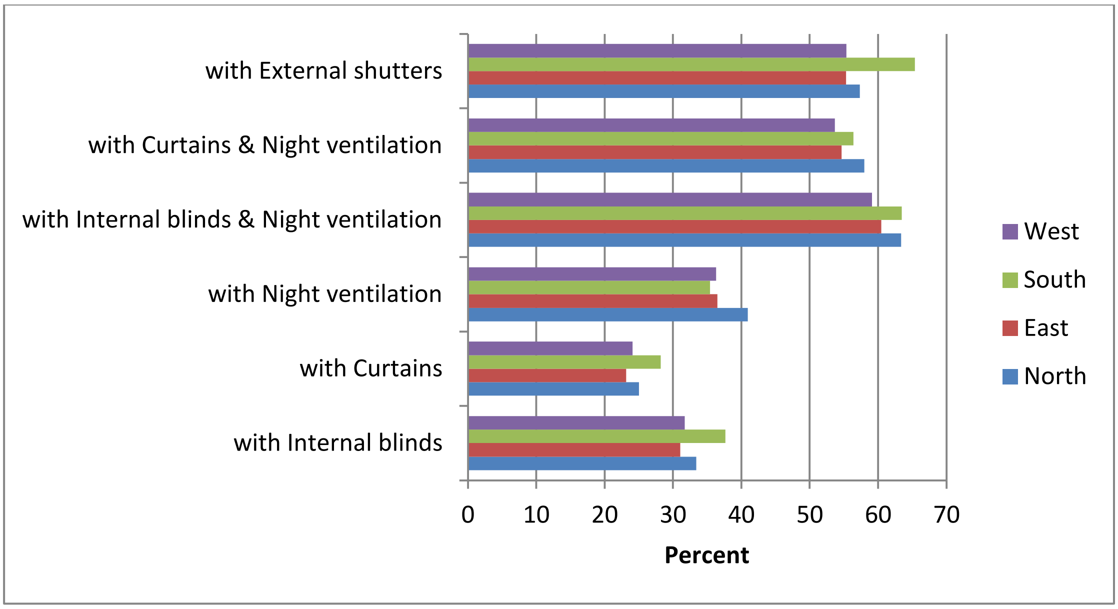

Figure 7.9 Percentage reduction in degree hours over threshold temperature- daytime occupied

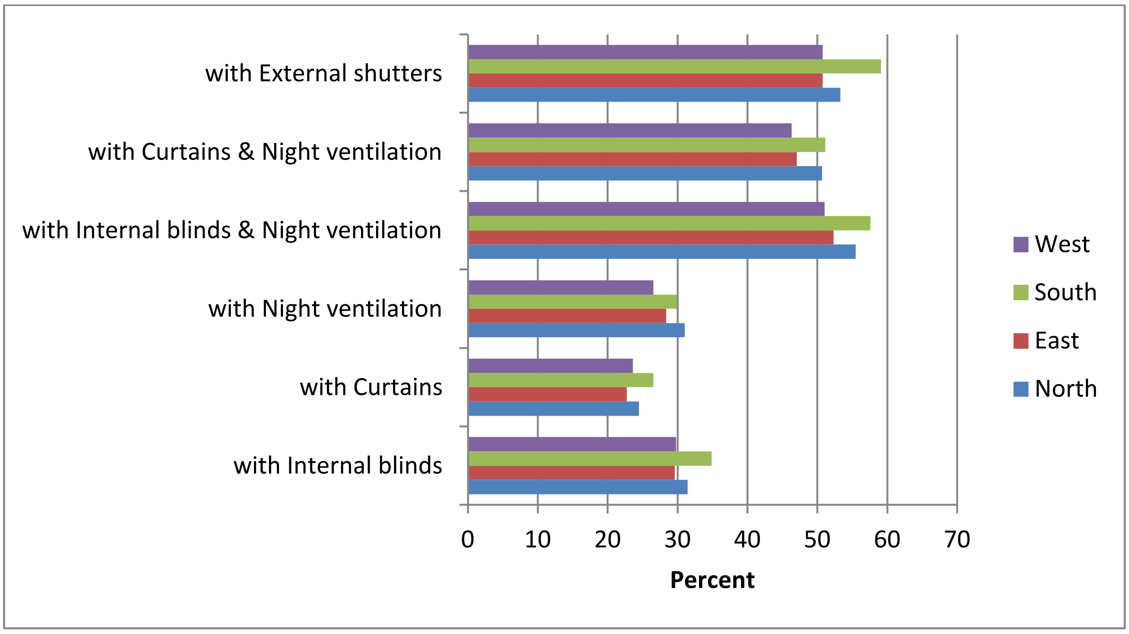

Figure 7.10 Percentage reduction in degree hours over threshold temperature- daytime unoccupied

Figure 7.9 and Figure 7.10 show the impact of the combination of measures in terms of percentage reduction of overheating. For both occupancy patterns, combining adaptation measures significantly increases their effectiveness.

For the daytime occupied home, the combination of internal blinds and night ventilation achieves an average overheating reduction of 61.25%, and the combination of curtains and night ventilation achieves an average reduction of 55.75%, compared to a 58% reduction from the use of external shutters.

Similarly, for a daytime unoccupied home, the combination of internal blinds and night ventilation achieves an average overheating reduction of 54%, and the combination of curtains and night ventilation achieves an average reduction of 48.75%, compared to a 53% reduction from the use of external shutters.

7.4 Summary

The results show that when the measures selected by residents are considered as single interventions, they can reduce overheating by a considerable amount: between 23% and 41%. However, the adaptation measures in isolation are not effective as external shutters, which can reduce overheating by between 51% and 65%.

The type of measures that were chosen by residents means that they can be combined with ease and at little cost. When combinations of measures are assessed, the effectiveness of the measures significantly improves, such that the combination of internal blinds with night ventilation is more effective than external shutters.

Given the cost, appearance, maintenance issues and aesthetic issues that were highlighted as negatives in terms of external shutters in the stage one results, the alternative of a simple combination of measures is an encouraging result. Given that residents ranked night ventilation and internal blinds as their preferred measures, the fact that they are also highly effective provides a useful output to the research study.

However, these results are based on the outputs of the retrofit toolkit only. In order to validate these findings, the following section models a Derwenthorpe house in simulation software to assess the impact of the measures.

8 Validation of results

Based on the dynamic simulation that was completed in Energy Plus software, the temperatures that were simulated were provided as outputs by room (living room and bedroom) and by hour.

By applying the threshold temperatures in CIBSE Guide A (2006), it was possible to calculate the number of degree hours over threshold temperature for each room, and present this a total number of degree hours over threshold temperature for the dwelling. This approach allows for a comparison of the impact of the results with the retrofit toolkit.

Figure 8.1 provides the level of overheating based on predicted weather files for York in 2050. This is based on a high emissions scenario, and shows that based on the months of June, July and August, the north facing un-adapted house exceeds threshold temperatures by 609 hours, and by 796 hours for an east facing house.

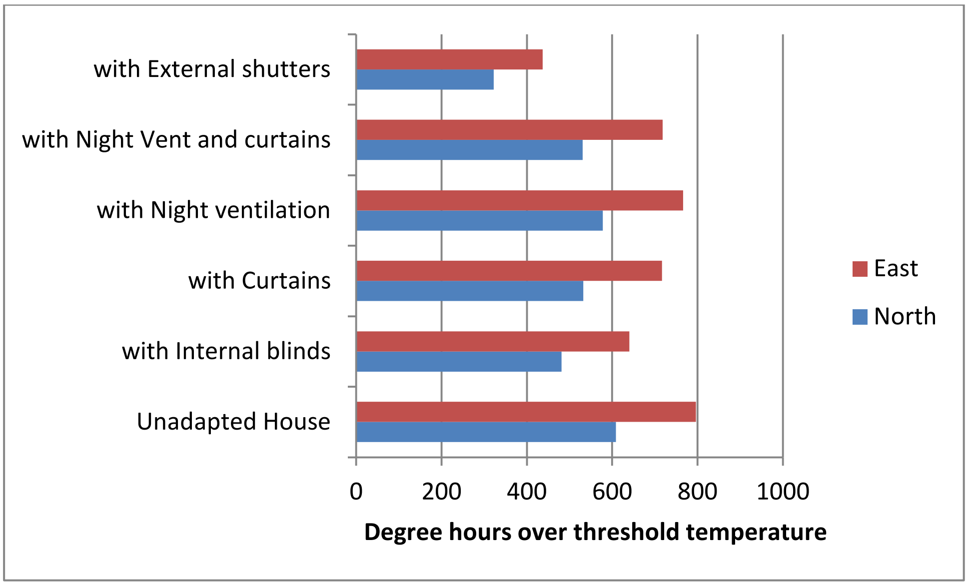

Figure 8.1 Degree hours over threshold temperature- Derwenthorpe dynamic simulation

The impact of the adaptation measures selected by households, along with external shutters, is also shown in Figure 8.1. This shows that external shutters are the most effective at reducing overheating, followed by internal blinds, curtains, night ventilation with curtains, and finally night ventilation alone.

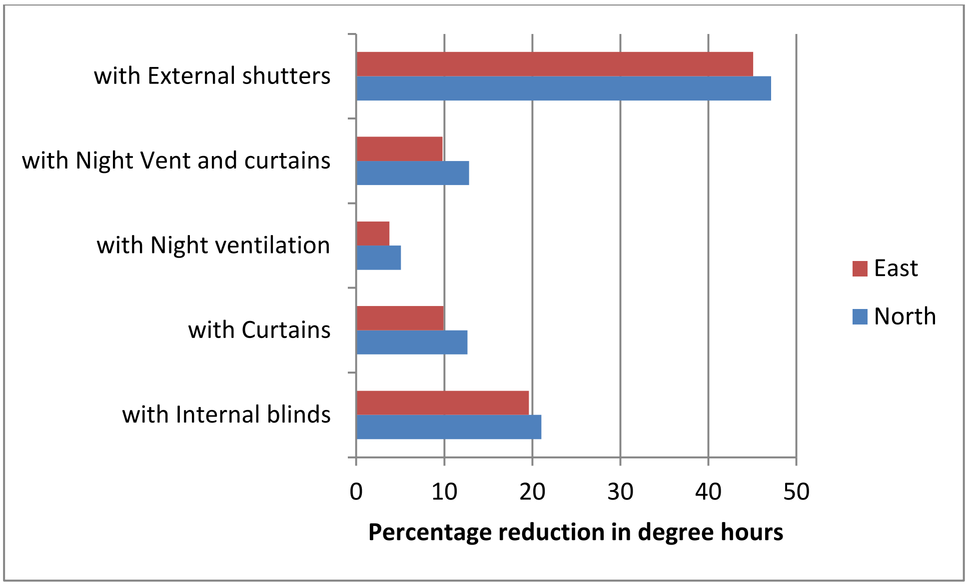

Figure 8.2 Percentage reduction in degree hours over threshold temperature- Derwenthorpe simulation

Figure 8.2 presents the results in terms of percentage reduction. The results show that external shutters have the biggest impact in terms of percentage reduction in degree hours over threshold temperature of approximately a 45% reduction. This is by far the most effective measure as internal blinds, the second most effective measure, reduces overheating by approximately 20%. Curtains as a single measure reduce overheating by approximately 11%, whilst curtains with night ventilation achieve a reduction of around 10%. The least effective measure in the dynamic simulation was night ventilation, with a reduction in overheating of only 5%.

The results of the dynamic simulation are significantly different to the retrofit toolkit. Some of this is to be expected; the retrofit toolkit is based on assessing overheating for a two week period only, whilst the dynamic simulation is based on the months of June, July and August. However, by presenting the effectiveness of the adaptation measure in terms of percentage reduction, this method attempts to overcome these differences.

The dynamic simulation is based on an actual Derwenthorpe home, with different floor areas, wall areas, glazing areas etc to the model used in the retrofit toolkit. In addition, the dynamic simulation does not take account of occupancy patterns and internal gains, and is a model based on an empty house. The impact of these variations may account for the difference in the results.

However, in terms of the difference between the results, for both the retrofit toolkit and the dynamic simulation, the use of external shutters has been shown to be a very effective measure. The discrepancy between the results relates to the measures that were selected by households; internal blinds, curtains and night ventilation.

When the percentage reduction in overheating is compared, as in Figure 8.3, the discrepancy between the two approaches is highlighted, with only the use of external shutters showing some consistency between the two approaches.

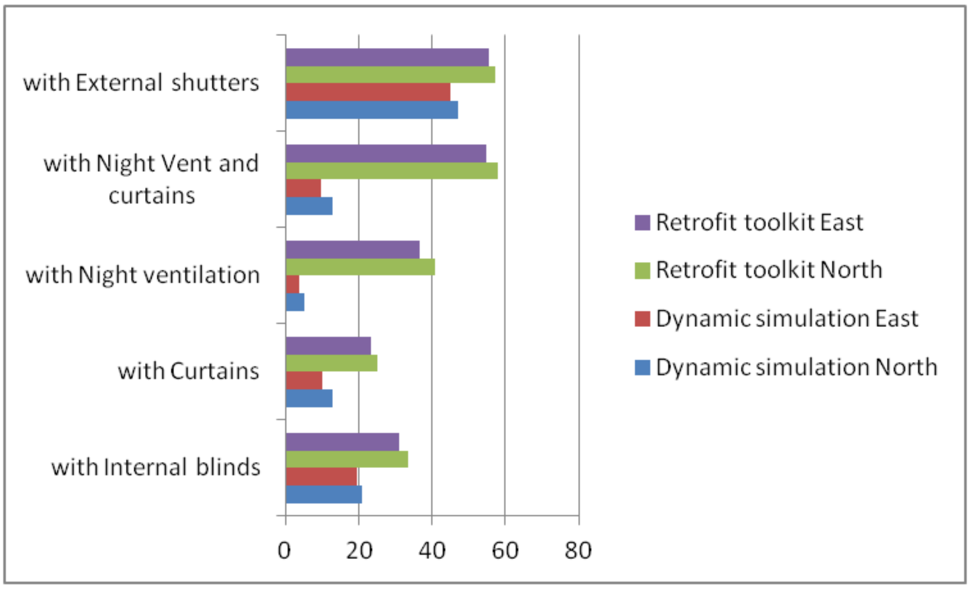

Figure 8.3 Percentage reduction in degree hours over threshold temperature- retrofit toolkit vs. Derwenthorpe simulation

8.1 <u>Summary</u>

Whilst it is not possible to verify a relationship between the two approaches, the results from both approaches do highlight the impact of the measures selected by households. Bearing in mind that that the selected measures are the most cost effective of the measures assessed as part of this research study, the results show that overheating in a future climate can be reduced through the use of low cost/no cost measures. In order to investigate the reasoning behind the difference between the two methods, a number of further research recommendations are made at the end of this report. However, both the retrofit toolkit and the dynamic simulation have shown the effectiveness of external shutters as an adaptation measure, despite the feedback from residents in terms of their non-acceptance of this measure.

9 Research Rational Review

Before overall conclusions and recommendations are presented in Section Ten, in order to assess the technical viability and benefits of using a household based approach to addressing overheating, the content of the research thesis is reviewed against the two original aims.

Aim One: To develop a methodology to allow households to review adaptation measures in order to reduce overheating of Derwenthorpe dwellings.

Objective 1: Methodology

A methodology was developed based on a number of stages and processes. In order to ensure the ranking of adaptation measures was resident led, a two stage questionnaire and interview process was developed, the results of which could be assessed through a number of methods to determine the effectiveness of residents preferred adaptation measures.

Objective 2: Stage One Survey

The first stage questionnaire obtained quantitative and qualitative feedback from residents towards their views on thermal comfort and overheating, management of internal temperatures and consideration of climate change and adaptation in the future. Some of the results were compared with national findings from EFUS (ref)

Objective 3: Stage Two interviews

The results of the stage one survey provided information to present to residents as part of the second stage interviews, including an overview of nine passive adaptation measures. The interviews were conducted using a ranking matrix (Appendix B) and information prompts (Appendix C) to allow residents to select their preference for adaptation measures.

Objective 4: Ranking of adaptation measures

The output of the second stage interviews was assessed in terms of collating responses from all residents to provide an overall ranking of adaptation measures. A total of nine adaptation measures were ranked against six criteria that were determined to be of value to the resident, which allowed measures to be assessed in terms of overall preference to the resident, and individual ranking against the six criteria.

<u>Aim Two: To assess and validate the adaptation measures selected by households in terms of predicted reduction in overheating.</u>

Objective 5: Impact of adaptation measures through the online tool

The ranking of the adaptation measures were assessed through the use of the online tool, a model that was developed on the basis of the 2003 heat wave. The use of the tool allowed the effectiveness of the measures selected by residents to be quantified in terms of the reduction in extent of overheating, and for these to be assessed against the most effective measure, namely external shutters

Objective 6: Assess the impact of selected adaptation measures through dynamic simulation software.

The ranking of the measures that was achieved in Objective 5 was validated by running a dynamic simulation of a Derwenthorpe home for a future 2050 scenario in order to determine extent of overheating. This found that overheating was a significant factor, and the measures that were selected by residents assisted in reducing overheating.

Objective 7: Review and analysis of results and investigate the viability of the methodology, and identify limitations where appropriate;

The results of Objective 5 and Objective 6 demonstrated the impact of measures selected by residents in terms of reduction of overheating.
Whilst both approaches are based on the use of a dynamic thermal simulation, there are a range of input parameters that can affect the outputs. The validation compared the two approaches but there was little correlation in terms of the effectiveness of the measured impacts.
Whilst the online tool provided a simple method to test the effectiveness of adaptation measures, the dynamic simulation showed that the measures were not as effective as the online tool had demonstrated. Although the methodology of arriving at the ranking of measures was successful, there were limitations in the reliability of the outputs in terms of effectiveness of the measures
The overall research conclusions and recommendations (objective 8) follow in Section Ten.

10 Conclusions

With the effects of climate change already visible in terms of changing weather events, there is a strong focus on reducing carbon emissions in the UK. The implementation of the Climate Change Act (CCC, 2008) has resulted in significant activity to reduce carbon emissions in the domestic sector. However, there are unintended consequences on deep emissions reductions in housing; whilst homes are insulated to retain heat in the winter, in the summer homes are now overheating as a result of heat retained in the building. When a changing climate- and predicted increases in summertime temperatures- is considered, the extent of overheating, and associated impacts on comfort and health, could be significant.

To address this issue, this research study set out to develop a methodology to determine the extent of overheating in Derwenthorpe homes, and to provide a framework to allow residents to rank their preference of adaptation measures. Based on the output of the research that has been presented in this thesis, the aim of developing the methodology has been met, as an adaptation ranking matrix determined clear priorities for preference for adaptation measures. However, the aim to verify the impact of the ranking measures has not been met, due to discrepancies in the outputs from the two approaches.

Based on the review of the interpretation of the results, the following conclusions are made:

- Firstly, the evidence of overheating in homes collated as part of the literature review was found to be reflected, in part, through reported feedback from Derwenthorpe residents. Bedrooms and main living rooms were found to be most at risk of overheating, and although residents currently manage this mainly through opening of doors and windows, the majority of residents recognised they would need to change how they live in their home to manage overheating as a result of a changing climate.

- Secondly, adaptation measures that were ranked by residents were typically low cost, easy to maintain and install, and were measures that had no detrimental visual impact on the home, The preferred measures (internal blinds, curtains and night ventilation) were all solutions that residents were already familiar with. External shutters, the measure least preferred by residents, was actually the most effective measure at reducing overheating.

- Thirdly, the results of the effectiveness of adaptation measures have shown the complexity of measuring adaptation measures. Whilst results through the retrofit toolkit demonstrated the effectiveness of combining the low cost measures selected by residents, the independent dynamic simulation showed that the combined measures were significantly less effective. However, both approaches showed the effectiveness of external shutters as an adaptation measure.

11 Recommendations

In order to gain further understanding of the main conclusions, there are five recommendations for further research:

1. **Sample Size**

   Whilst results from the adaptation matrix drew conclusions, the sample size limits significance of these findings. In order to further understand the ranking of the adaptation measures, a greater sample size of resident responses is required. It is recommended that the survey work is repeated at Derwenthorpe post summer 2016, when a greater number of households will be occupied.

2. **Validation of results**

   Given the disparity of the results in terms of the assessment method used, further investigation needs to be carried out to understand if this was caused by an error in the thesis, or a compatibility issue between the two approaches. To address this it is recommended that the dynamic simulation undertaken as part of this study is reviewed and checked for input parameters and re-run. Additional dynamic simulations of alternative Derwenthorpe homes will assist to determine if there is a fault with the research methodology.

3. **Comparator results**

   The results for the Derwenthorpe study produced clear findings for preferred adaptation measures. The results need to be compared to other housing developments in order to determine whether the results of this thesis are unique to Derwenthorpe residents and their homes. It is recommended to link with Registered Social Landlords to extend the study to other new build developments and existing communities in order to gain a greater sample.

4. Adaptation criteria

The adaptation matrix that was used in this study is flexible both in terms of criteria and adaptation measures to be considered. The criteria used as part of the adaptation matrix need to be assessed to determine if they are appropriate for other developments. It is recommended that JRHT test the methodology on alternative housing developments within their ownership in order to obtain a consensus of the key criteria for residents

5. Adaptation measures

The adaptation measures used in this study were passive in terms of energy use. Whilst passive adaptation measures are most beneficial in terms of carbon emissions, consideration needs to be given as to how residents rank energy consuming measures, such as air conditioning units, when compared to passive measures. It is recommended to increase the number of adaptation measures for future field work to include energy consuming measures.

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Appendices

Appendix A: Resident questionnaire

Appendix B: Adaptation ranking matrix

Appendix C: Adaptation descriptions

Appendix A: Resident questionnaire

Dear Derwenthorpe resident

Overheating and a Future Climate- Resident Survey Information

I am currently studying for a Master's Degree (MSc) in Sustainable Development and Climate through DeMontfort University. For the final part of my qualification I am required to produce a dissertation into the impact of a changing climate, how this may result in overheating in homes, and how occupants of these homes plan to address any overheating.

I am particularly interested in understanding how new homes built to high environmental standards will perform in a changing climate, and I am interested in the views of the residents of Derwenthorpe as to how they will manage in a changing climate.

I enclose a short questionnaire that I would be extremely grateful if you could take the time to complete and return to me. I expect that the survey will take you no more than 15 minutes to complete.

The information from the questionnaires is important to help me understand, analyse and produce reports based on the views of residents. Once I have prepared my initial findings, I will contact a number of residents to arrange informal one to one discussions to further understand how homes, and residents of the homes, will adapt to a changing climate.

Please be as honest as you can with your responses; there are no right or wrong answers. Any answers you give and reported findings will be anonymised. No personal information will be disclosed and any reported findings will not be attributable to any particular address.

If you would prefer to answer anonymously please leave the "about you and your home" section blank.

Please note that although I have communicated with you all previously in my role through JRHT, the request for the completion of this survey is related to my academic studies and personal development. The results will be used in my dissertation report which will be available on request, and will be shared with JRHT in the case of key learning points.

I appreciate your time in helping me with this work, and if you have any questions about the process please do not hesitate to contact me at owendaggett@hotmail.co.uk

Many thanks

Owen Daggett

Post Occupancy Feedback Survey

Question 1

During a typical summer (June to August), do you find it difficult to keep any of the mentioned rooms comfortably cool? **(*Please tick as many answers that apply)***

Main Living Room.. ☐
Main Bedroom... ☐
Other bedrooms.. ☐
Other rooms (bathrooms, kitchens)................. ☐
None of the above.. ☐

Question 2

If you reported that you experience overheating in at least one room, please provide a reason from the list below **(*Please tick all answers that apply)***

Little or no shade/tree coverage around the home................ ☐
Inadequate ventilation through windows.............................. ☐
Poor air circulation around the home................................... ☐
Too much heat from internal sources.................................... ☐
Inadequate blinds/curtains to keep direct sunlight out.......... ☐

Question 3:

If you answered yes to Q1, how often do the affected rooms overheat? ***(please tick one answer only)***

Every day... ☐
5 or 6 days a week........................... ☐
1 to 4 days a week........................... ☐
Less than once a week..................... ☐
Don't know...................................... ☐

Question 4:

Are you able to cool the rooms in your house to comfortable temperatures? ***(please tick one answer only)***

Always.................................. ☐
Often.................................... ☐
Sometimes............................ ☐
Rarely................................... ☐
Never .... ☐

Question 5:

How do you cool the rooms in your house if you get too hot? (***Please tick all answers that apply)***

Open windows....................................
Open doors..
Use electric fans.................................
Use local air conditioning units..........
Other..

Question 6:

How happy are you with the conditions in your home in Summer? ***(please tick one answer only)***

Very unhappy..........................
Unhappy.................................
Neither unhappy/happy..........
Happy.....................................
Very Happy.............................

Question 7:

How do you think climate change will affect outside temperatures in summer? ***(please tick one answer only)***

Cooler summers.........................
No change ....
Warmer summers.....................

Question 8:

Do you think you will need to change how you live in your home to adapt to a changing summertime climate? ***(please tick one answer only)***

No change at all.........................
Very little..................................
Some...
Quite a lot.................................
A great deal...............................

Question 9:

Including yourself, how many adults live in the house? **(*Please write in the box below.)***

Question 10:

How many children (under 18 years old) live in the house**? (*Please write in the box below*.)**

Question 11:

When did you move into your home? ***(Please indicate month and year in the box below.)***

Question 12:

Please indicate your property tenure? ***(please tick one answer only)***

Owner occupied........................ ☐
Shared owner .... ☐
Rented..................................... ☐

<u>ABOUT YOU AND YOUR HOME</u>

(Providing this information will help me contact you as part of the project)

Name:
Address:
Contact telephone: Contact email:

<u>Thank you for taking the time to complete this survey.</u>

<u>Please return the survey and a signed copy of the Consent Form in the stamped address envelope by 22nd May.</u>

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Closing the loop: the use of post occupancy evaluation to adapt homes to a future climate.

Consent form

Please put a tick or cross in the relevant boxes.

I ________________________________ [participant's name] agree that the material generated by my involvement in this research project may be used by the research teams at De Montfort University and shared with the Joseph Rowntree Housing Trust.	☐
I have received a copy of the 'resident survey information sheet' and have read and understood this document.	☐
I understand that the material generated by my involvement in this research project may be used for a variety of research purposes during and after the lifespan of the project (e.g. reports, publications, presentations, websites, broadcasts, websites and for teaching purposes).	☐
I understand that I can withdraw my consent at any point by contacting Owen Daggett, the research leader.	☐

Signature of the participant ____________________________ Date: __________________

Signature of the researcher ____________________________ Date: __________________

Contact Details

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Appendix B: Adaptation Ranking Matrix

Adaption Ranking Matrix

Address:

Criteria	Internal blinds	External shutters	Curtains	Low e triple glazing	External fixed shading	Night ventilation	Window rules	Solar reflective roof	Solar reflective walls
Effectiveness *How effective is the measure at reducing overheating?* *(10 = highly effective, 1 = highly ineffective)*									
Cost *How costly is the measure compared to the other measures?* *(10 = v cheap,1 =v expensive)*									
Maintenance *How easy and cost-effective is the measure to maintain?* *(10 = v. easy to maintain, 1 = very difficult to maintain)*									
Aesthetics *How acceptable is the measure in terms of preserving the design quality of the development?* *(10 = no impact on aesthetics, 1 = major aesthetic impact)*									

Phase ability *How easy would it be to add the measure as a retrofit solution at a later date?* *(10 = v easy to retrofit, 1 = impossible to retrofit)*									
Usability *How easy is the measure to use and operate?* *(10 = no user input needed, 1 = full understanding required)*									
TOTAL									

Additional comments:

Appendix C: Adaptation descriptions

Measure 1: Internal Blinds

Internal blinds	Fitting of internal solar reflective blinds to each window, which are closed during daytime hours. They are not as effective as external shutters due to some of the short wave radiation, which has passed through the window, being converted to long wave radiation and transferred to the room	£200 per window


silver back
PLENTY
OF FABRICS

Measure 2: External Shutters

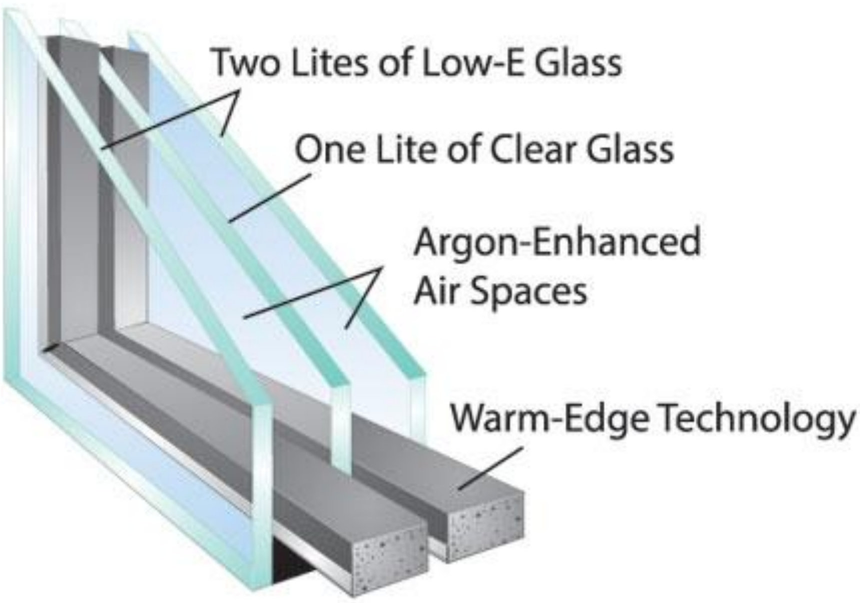
External shutters	Fitting of external solar reflective shutters to each window that provide a total block to solar radiation, which are closed during daytime hours.	£5,700 for detached house

Measure 3:Curtains

Curtains	Use of existing curtains which are closed during daytime hours	No cost


Measure 4: Low e triple glazing

Low e triple glazing	Replace existing windows with low solar heat gain low emissivity triple glazing. Inner and outer panes coated to reflect solar radiation and prevent overheating. Negative impact is reduced solar heat gain in winter	£13,000 for a 4 bed detached house



Measure 5: External fixed shading

External fixed shading	Installing fixed overhang shading on east, south and west facing windows to depth of 1m.Larger awnings (2m) to ground floor windows that are east and west facing. Potential for increased winter heat bill if awnings are not retracted in winter	£315 per meter

Measure 6: Night Ventilation

Night ventilation	The un-adapted house assumes ground floor windows are closed at night for noise, security or air quality reasons. Night ventilation adaptation increases ventilation to ground floor rooms either through use of windows or use of vents (possibly with small fans).Some possible cost due to associated works (security, vents or fans), but winter heating bills not impacted.	Potentially no cost


Measure 7: Automatic window openers

Window openers	The un-adapted house assumes windows begin to be opened when the room temperature reaches 22oC, and are fully opened when the temperature reaches 28oC. The use of this adaptation measure reduces overheating as windows are prevented from being opened when the external temperature is greater than the internal room temperature	£200 per window

Measure 8: Solar reflective roof

Solar reflective roof	Coating the roof tiles with a high performance solar reflective paint	£1,600 for 4 bed detached house


CB Mountain Blue


Slate Grey

Measure 9: Solar reflective walls

Solar reflective walls	**Coating external walls with a high performance solar reflective paint**	**£2,300 for 4 bed detached house.**