<u>Declaration of originality</u>

I certify that this is my own work, and it has not previously been submitted for any assessed qualification. I certify that the use of material from other sources has been properly and fully acknowledged in the text. I understand that the normal consequences of cheating in any element of an examination, if proven and in the absence of mitigating circumstances, is that the Examiners' Meeting be directed to fail the candidate in the examination as a whole.

Signed: ……..………………………………………………………………………………

Date: ……………………….……………………………………………………………….

Abstract

Adapting 1965-1980 semi-detached dwellings in the UK to reduce summer overheating and the effect of the 2010 Building Regulations

~ Steven Howse

The aim of the report was to produce recommendations for occupants to undertake, concerning passive changes to the building design and changing occupant activity to reduce overheating in 1965-1980 semi-detached dwellings. To do so, interventions in these two topics were tested to reduce overheating on a post 2010 Building Regulations base case.

This base case and interventions simulations were developed using IES software. To measure the level of overheating, internally, a degree hours over the CIBSE overheating threshold (CIBSE, 2006) method was used.

The basic upgrades to the building implementing the 2010 Building Regulation were found to decrease the total degree hours. When changed to two elderly (vulnerable) occupants, the total degree hours decreased overall. Other interventions that were found to decrease the total degree hours below the 2010 Building Regulation model were the updated appliances/occupancy trends, the cross ventilation strategy, north orientation and most prominently, the nigh time ventilation. A combined model of these interventions were then able to remove all degree hours beyond the threshold, even in a heat wave simulation; for both occupancy types.

As well as the combined intervention model, external wall paint shutters and curtains (sourced from previous research) are recommended for reducing overheating, based on ease-of-use and cost.

Executive Summary

In the UK, there is a growing debate over the importance of decreasing winter fuel allowance through energy efficient upgrades to the building fabric against their effect on summer overheating. The focus of this report is to present a set of design and occupant recommendations on what occupants can do to passively reduce overheating in their 1965-1980 semi-detached dwellings. This is achieved by testing changes to occupant behaviour and building aspects; through different interventions, post 2010 Building Regulations.

IES software was chosen to simulate the different scenarios of possible interventions to overheating upon a base case design of a four person family 1965-1980 semi-detached dwelling. Standard dimensions, materials, occupant/appliance gains and time profiles were chosen to justify the base case. To measure the degree of overheating internally in the dwelling, a degree hours over the CIBSE overheating threshold (CIBSE, 2006) was used. This method measures the severity of overheating and allowed the comparison of the effect of these interventions on key rooms.

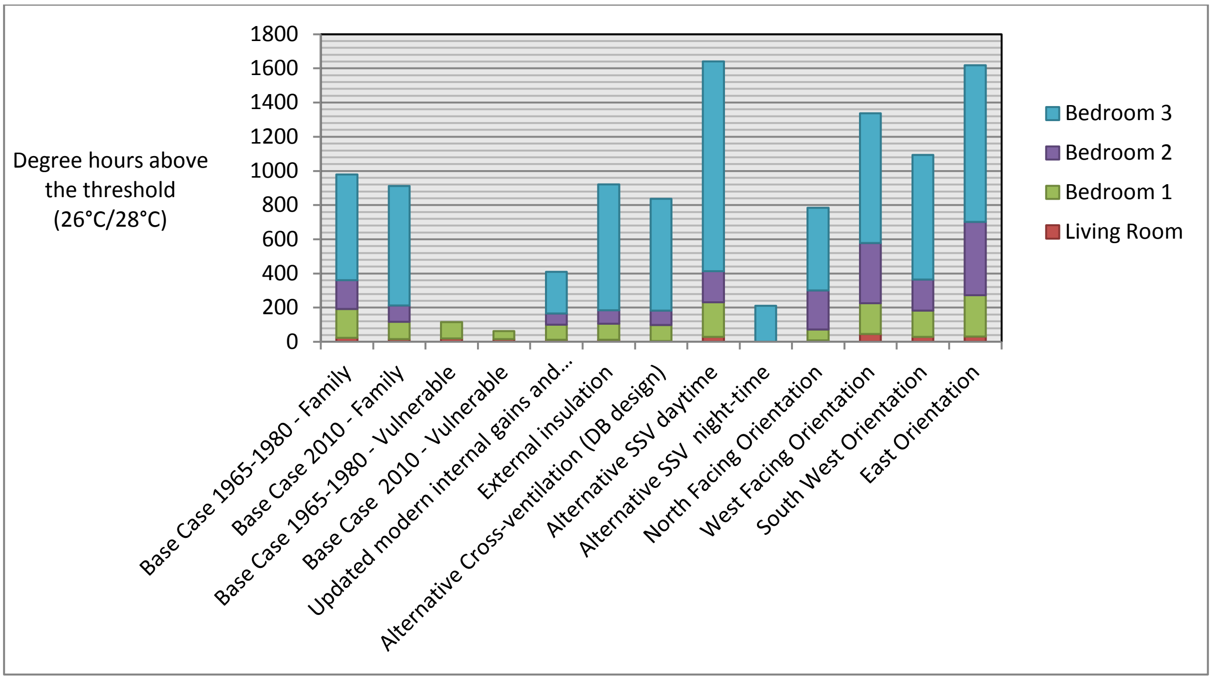

Figure 1 - Comparison of degree hours above the threshold (26°C/28°C) temperature for 1965-1980 semi-detached dwelling and rooms, testing different interventions

The basic upgrades to the building with the improved U-values of the 2010 Building Regulation were found to decrease the total degree hours; dispelling the main theory of health risk associated with improving the air tightness of the dwelling. When changed to two elderly (vulnerable) occupants, the total degree hours decreased overall compared to the original family profile. From the multiple interventions there are many that were found to increase the total degree hour of the dwelling.

Methods such as daytime single sided ventilation and east/west orientation were the most costly interventions, although there were question on the legitimacy of the increase in degree hours caused by external insulation. On the other hand, interventions that were found to decrease the total degree hours below the 2010 Building Regulation model were the updated appliances/occupancy trends, the cross ventilation strategy, north orientation and most prominently, the nigh time ventilation.

From the comparison of all the simulations combined (Figure 1), none of the proposed simulations were individually able to remove total degree hours over the threshold. However when combining the effective interventions, the generated results showed even in heat waves it was able to remove risk of overheating altogether (Figure 2). Although in the family heat wave scenario, the 1% over the threshold maximum was noted. (CIBSE, 2006)

Overall in merging both the combined reduction techniques of this particular study with a previous study, a definitive set of recommendations were made. Taking into account both the ease of implementation and cost of the method, as well as the previously stated degree hours reducing interventions, external wall paint, shutters and curtains could be used.

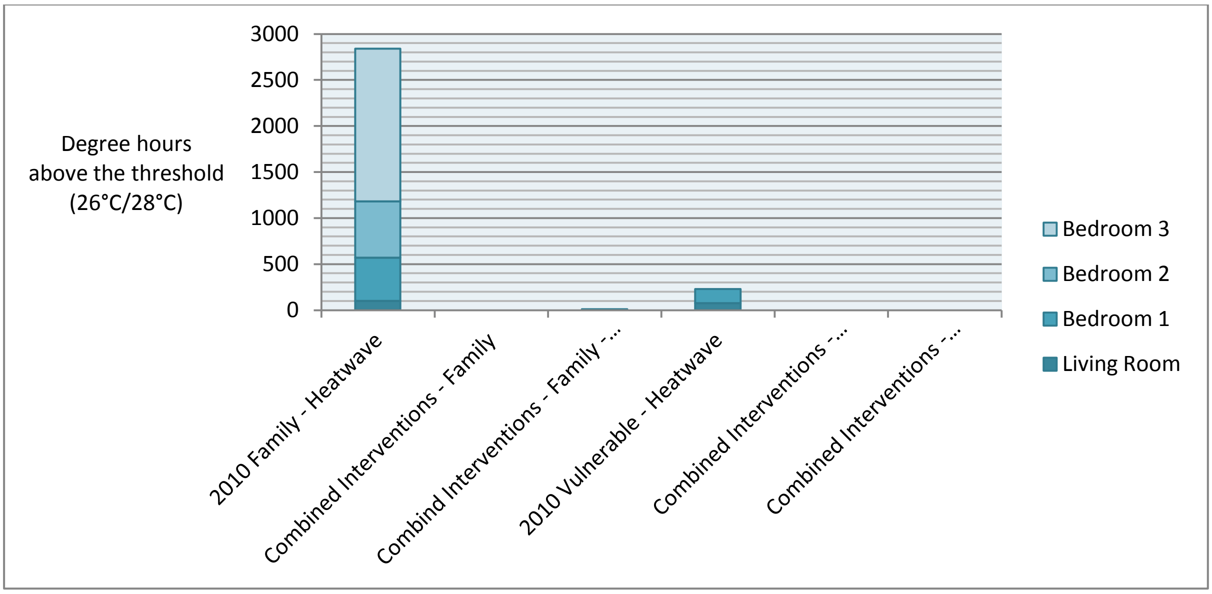

Figure 2 - Comparison of degree hours above the threshold (26°C/28°C) temperature for 1965-1980 semi-detached dwelling and rooms, testing different interventions

In the wider relevance of the research, it can be used to judge the severity of risk that it may cause to occupant health. Furthermore, it can be used to adapt more criteria in current guidance reports for overheating, with the interventions tested on other types of dwellings.

Table of Contents

Abbreviations

ACH - Air Changes per Hour

BRE - Building Research Establishment

BS – British Standards

CIBSE - Chartered Institution of Building Services Engineers

CREW - Community Resilience to Extreme Weather

DCLG - Department for Communities and Local Government

DEFRA - Department for Environment, Food and Rural Affairs

d.h – Degree Hours

EU - European Union

IES - Integrated Environmental Solutions

IT – Information Technology

LUCID - The Development of a Local Urban Climate Model and its Application to the Intelligent Design of Cities

NHBC - National House Building Council

NHS – National Health Service

PMV - Predicted Mean Vote

PPD - Predicted Percentage Dissatisfied

RIBA - Royal Institute of British Architects

SAP - Standard Assessment Procedure

SSV – Single-Sided Ventilation

TUC – Trade Union Congress

UHI - Urban Heat Island

UK –United Kingdom

UKCIP - United Kingdom's Climate Impacts Programme

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Acknowledgements

I wish to acknowledge the contribution that the following people have made to the completion of the dissertation:

Thanks to Dr Li Shao, my dissertation supervisor. For continual assistance and support throughout the writing of the dissertation until completion.

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1 Introduction & Background

1.1 Background and Rationale

1.1.1 Background

In the UK, a multitude of issues have arisen which at present, and more prevalently, in the future will cause a serious overheating problem in UK buildings. At present studies are being undertaken to look into different simulation methods to assesses the risk of overheating present and future based on housing types and age headed by researchers such as the CREW project, BRE affiliated projects and Stephen Porritt. From these studies, the current research is looking into methods to passively reduce overheating. Aside from this, a study that is yet to be fully investigated is to assess the effects of individual aspects of the occupant activity and appliances, dwelling specifics and solar/thermal gains, with the modern developments in these factors changing yearly. Furthermore, with the increasing energy efficiency values from developing Building Regulations, further risks are predicted, influencing all factors considered.

This issue of balancing legislation between summer overheating and reducing fuel bills to stay comfortable is extremely difficult. With a recent Green deal (HMGovernment, 2013) to support loans of retrofit to further insulate dwellings in winter; this deal would counteract the opposite effects of climate change in winter. Reports such as Three Regions climate change group (2008) reference the 2003 heat wave as a sign of the climate in 2050, citing that UK buildings need retrofit such as smaller windows or shutters to reduce risk. However, with 45,000 dying in Europe as a whole (Robine, et al., 2007), this shows that further adaptation is needed beyond just physical features, with occupant behaviour having the potential to reduce the risk further.

Causes of Overheating

The most publicised cause of overheating is climate change. In a study of climate projections Patidar, et al. (2012) notes that with growing increase of emissions into the atmosphere (Figure 1.1) the increase in global temperature and resultant altered weather patterns will lead to more frequent extreme temperature events.

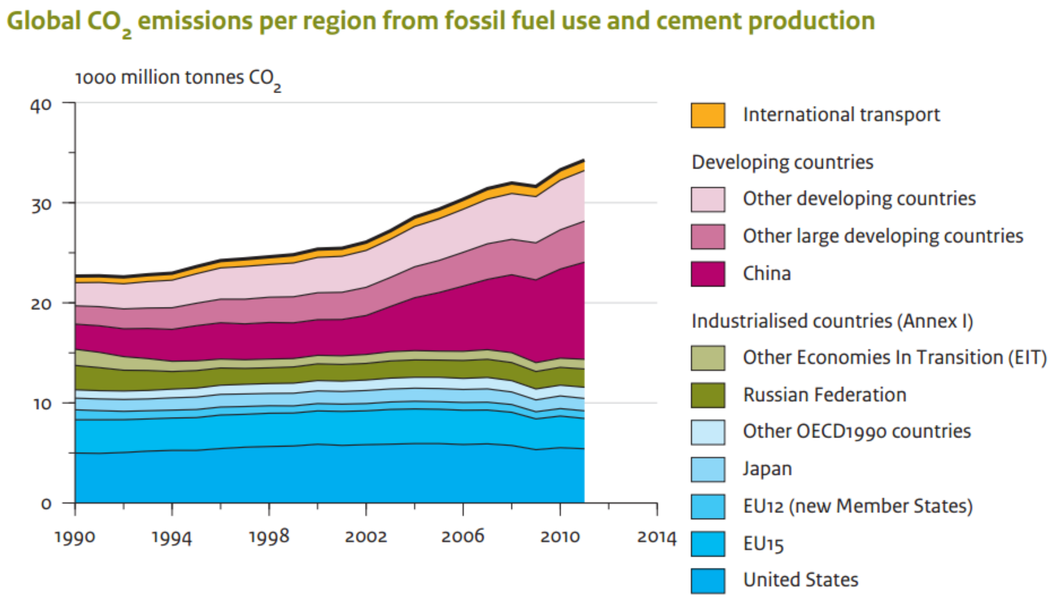

Figure 1.1 - Global CO2 emissions per region from fossil fuel use and cement production (PBL Netherlands Environmental Assessment Agency, 2012)

More specific causes can be rooted in to the building itself, as with dwellings, any retrofitting will involve increasing insulation, which, adhering to Building Regulations updates (such as 2010) will increase air-tightness and high performance insulation; further increasing overheating (Jenkins, et al., 2013). Looking deeper into the dwelling itself, research has found more specific causes. Beizaee et al. (2013) found two specific trends, that due to modern insulation post 1990 dwellings had greater risk of overheating and that detached homes have less of a risk of overheating than flats/attached dwellings. This is caused by both the increased floor area ratio of detached housing and high U-values of pre 1990 housing masonry walls, causing greater conductive heat loss. (Beizaee, et al., 2013)

Overall it can be seen that the causes of indoor overheating take into account both the factors of geometry and construction; to which there is a current need for a balance between indoor environment quality and reduced emissions.

Chances of Overheating

A significant area of research currently undertaken is looking into the chances of overheating based on current global activity. Within a standard domestic home the average temperature is 28˚C and overheating is defined as being "when these temperatures are exceeded for more than 1% of the time" (Zero Carbon Hub, 2012). The issue that has been arising however is the amount of time this threshold is broken (degree hours) is increasing, with examples such as the 2003 heat wave where there were very high degree hours (d.h). (Figure 1.2) (Zero Carbon Hub, 2012)

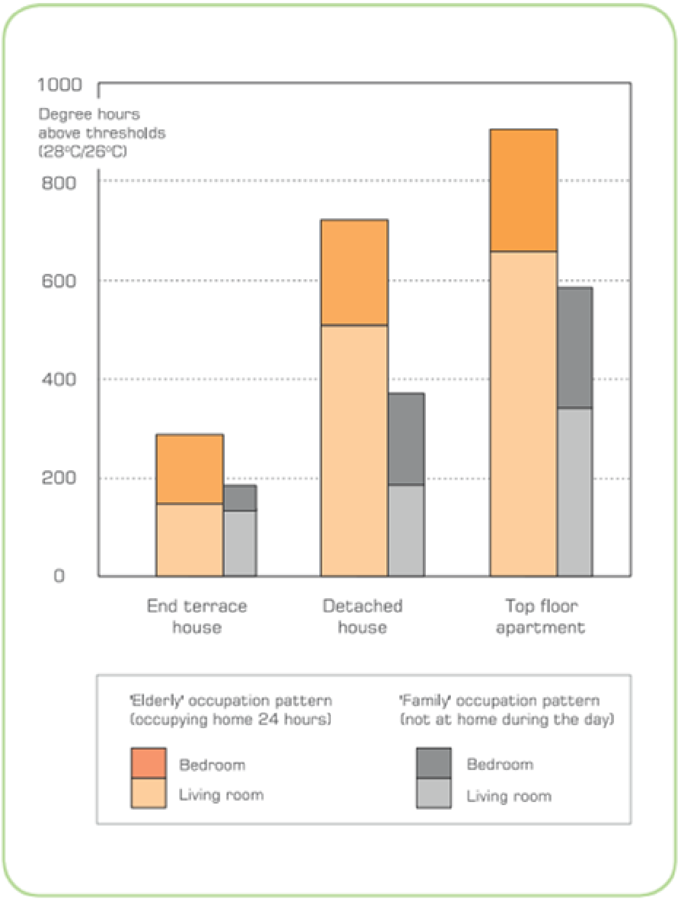

Figure 1.2 – Degree hours above threshold (Zero Carbon Hub, 2012)

UK climate projections in 09 (DEFRA, 2010) predicted that with a current temperature increase of 1 °C over the last century this will steadily increase to 2–3.5 °C by 2080. Furthermore, this can be supported by the trends of the past century whereby in the past 13 years the UK mean daily minimum temperature of both August and July have steadily increased (Figure 1.3) (Met Office UK, 2013). This leads Gul & Menzies (2012) to state that the resultant mechanical ventilation increases emissions and creates an unsustainable cycle.

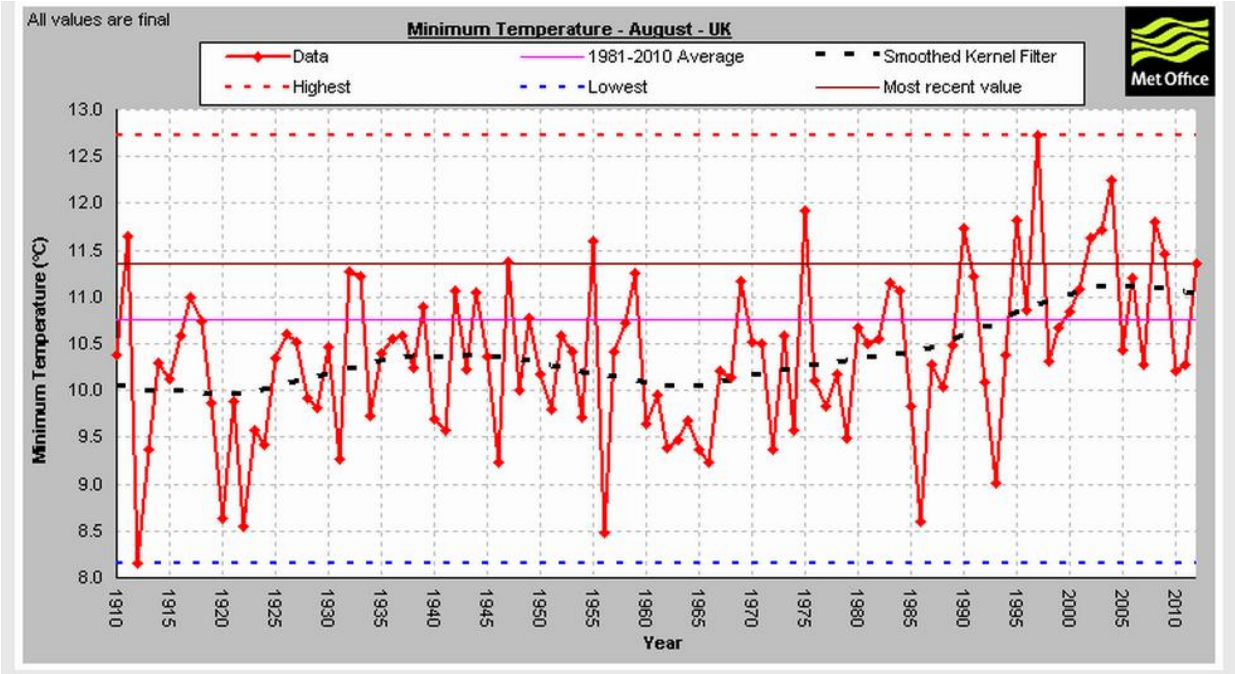

Figure 1.3 – UK mean daily minimum temperature – August (0.5°C average increase from 1990-2013) (Met Office UK, 2013)

Building Regulations

The main emphasis by the 2010 Building Regulations in the case of overheating is covered in Part L1B (HMGovernment, 2010). These Regulations strive for the heating demand in the winter to be reduced, by making the building envelope more efficient by increasing the standards for U-values (Table 1.1), heating, glazing and other services; thus reduces heat loss from conduction and infiltration.

Table8 - U-values for refurbishing and upgrading thermal elements		
Element	**(a) Threshold U-value (W/m²K)**	**(b) Improved U-value (W/m²K)**
Wall - cavity insulation	0.70	0.55
Wall - external or	0.70	0.30
internal insulation Floor	0.70	0.25
Pitched roof - insulation at ceiling level	0.35	0.16
Pitched roof - insulation at rafter line	0.35	0.16
Flat roof or roof with integral insulation	0.35	0.16

Table 1.1 – U-values for refurbishing and upgrading thermal elements (Evans, 2010)

While it does mostly cover improving the energy efficiency, there are some parts to assist in reducing overheating. This requires that to reduce excessive heat gains, solar gains in the summer are limited; enforced by the use of Standard Assessment Procedure (SAP) calculations (Silcock & Dawson, 2010).

Overall, the implementation of the updated Building Regulations will result in the risk of overheating in retrofitted housing to increase. This will put further strain on the issue, increasing the need for an analysis of this to gauge the impact. While the 2010 Regulations made the most significant change, the energy efficiency of dwellings has been increasing over the past decade encompassing the Regulations and amendments of 2006-13. Governing these standards is the EU Energy performance in building directive which has set up legislation which "required all EU countries to enhance their Building Regulations and to introduce energy certification schemes for buildings" (Energy Performance of Building Directive, 2013) updating every 3 years before any new UK policy is released.

How appliances and occupants etc could affect overheating

The main goal of the study is to look into the effect of different factors of occupants and the building that could increase overheating. With changing occupant activity and new household appliances, the new generation are having a greater impact on internal heat gains. Building orientation, landscaping, construction and location all affect it as well, including the rise of urban heat islands. This also encompasses the definition of overheating itself, as the new generation may change the threshold for what is defined as overheated. (Zero Carbon Hub, 2012)

In light of the 2010 Building Regulations, the use of appliances has become more prevalent in the causes of overheating. Overheating reduction guidance from Partington (2012) stresses that "Increased insulation in new homes limits heat losses and gains through the building fabric." And with changing occupant activities and electrical appliance use, the potential effects are increasing exponentially.

1.1.2 Rationale

Health Risk

The central reasoning for this study is to assess the risk of overheating, as one of the core outcomes related to overheating is occupant health risk. With overheating affecting all people, the greatest risk of heat stroke comes to the infant, elderly and sick (a increasing risk with the elderly due to a growing older population; (Figure 1.4)); who as well as being less resistant to heat, who "will often be at home for most of the day and be exposed to peak day temperatures, unlike those who go out to work or to study." (Zero Carbon Hub, 2012)

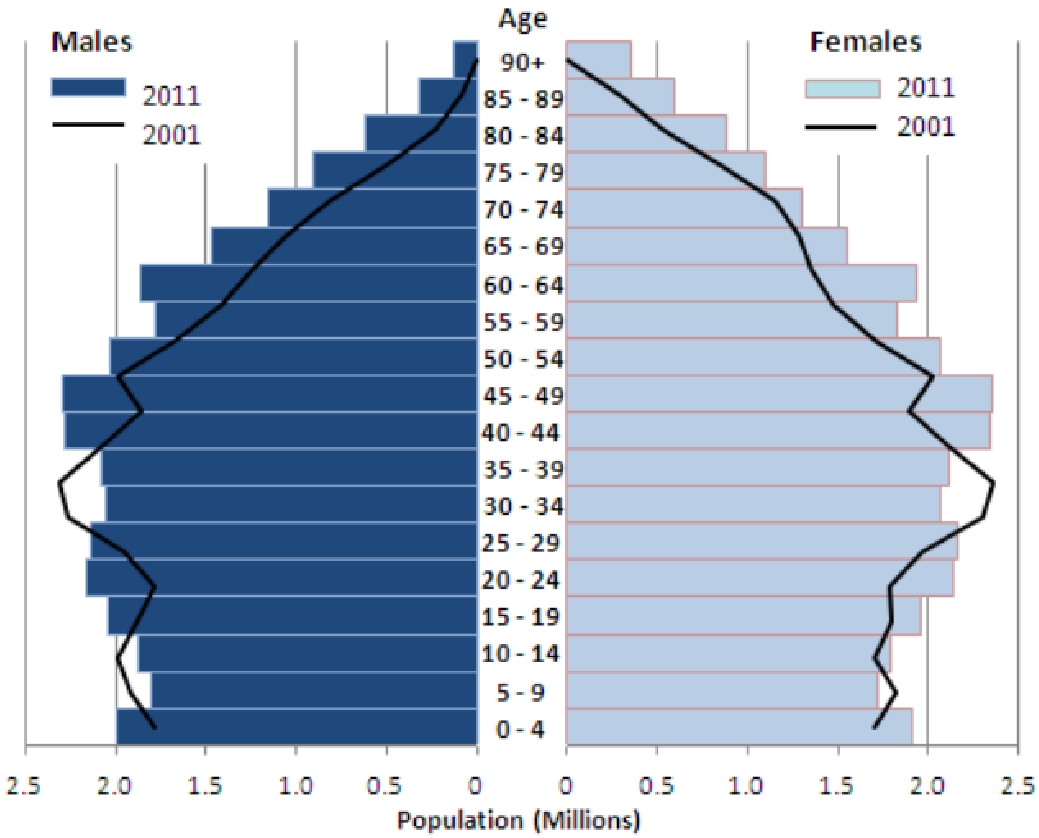

Figure 1.4– UK Population Pyramid (Office for National Statistics, 2012)

Most significantly, high night time temperatures that are exposed to all the population cause an inability to recover from heat stress affecting health and productivity. (NHBC Foundation, 2012)

Leading on from the study of the possible consequences of the overheating on health, a key discussion in this argument is defining the threshold to which overheating and thus health risks occur. Currently, thresholds are based on outdoor temperature, however with sectors of the UK population spending more time indoors, the interior heat variables and indoor temperature must be assessed and a relationship between it and mortality rates made. Furthermore, as proposed by the NHBC Foundation, the threshold is based on “the upper limit of thermal comfort, rather than the threshold for long-term temperature” (NHBC Foundation, 2012) which can cause a different set of long term health risk than immediate risks.

Semi-detached 1965 dwellings

For the study of UK retrofitted housing, the dwelling age chosen for the study was based on the number of dwellings of that age. Currently, based on housing stock statistics, in the past 100 years, 1965-80 housing is the most prevalent (4,602 dwellings, Table 1.2) and therefore, the most relevant area of study. For the industry itself, finding the impact of overheating on this type of housing is most significant.

Dwelling age	owner occupied	private rented	all private	local authority	housing association	all social	all dwellings in group (000s)
1919-44	2,819	456	3,275	289	187	476	3,751
1945-64	2,816	398	3,214	685	498	1,183	4,397
1965-80	2,978	505	3,483	626	492	1,118	4,602
1981-90	1,243	274	1,518	109	253	362	1,880
post 1990	1,879	591	2,469	*24*	399	422	2,892

Table 1.2 - Housing Stock Profile 2010 (Department for Communities and Local Government, 2012)

Building Regulations

One of the most significant steps in the overheating narrative is the measures executed by the Building Regulations updates from 2006 to 2013. The key issue that arose from this Building Regulations update was the increased focus in heat retention, covering areas such as reducing U-values when renovating thermal elements and tightening air permeability. These measures are detrimental to overheating as there is no mention of passive cooling in the Building Regulations and only energy inefficient mechanical (HMGovernment, 2010). These standards need to be analysed to understand the impact on overheating this may cause if dwellings are retrofitted to meet these standards.

Changing occupant activity to cause overheating

While the building design has been analysed previously, the impact of the Building Regulations in this has not been considered. More significant however, is the changing occupant internal gains and degree hours. Appliances and occupant activity patterns change continuously and while previous studies have found no risk in internal gains (UKCIP, 2010); new trends in occupancy and appliance use may increase internal gains along with the adjusting occupant comfort threshold. As while more efficient appliances may have less internal gains this may cause the occupant to take less notice to the total time it is on, which combined with other contributing factors may be increasing degree hours.

Looking further into occupant activity, the window opening and air flow pattern instigated by the occupant, needs to be considered. Tied in with dwelling occupation hours, the ventilation strategy imposed in either increasing or potentially decreasing air changes per hour (ACH) would have substantial effects on internal temperatures, and is yet to be fully investigated.

How the industry could use the results

These results can be used within the industry to influence the future adaptation of the next instalment of the Building Regulations/guidance publication in light of the possible high risks to occupant health. By finding what are the new sources of overheating by the occupant and building, this can be used to adapt dwellings and advise occupant activity to the interventions found accordingly in light of the updated Building Regulations in 2013.

1.2 Aims and Objectives

1.2.1 Aims

1. Analyse the results of a simulation of the impact of energy efficiency increase in UK 2010 Building Regulations on the overheating of 1965-1980s semi-detached dwelling.
2. With a base case model of the 2010 Building Regulations, look into what are the contributing factors of occupant and building features that will affect overheating, and possible interventions to reduce it.
3. Make recommendations on what occupants can do to reduce overheating in their 1965-1980s semi-detached dwelling during current and future climates, by changes to occupant behaviour and building aspects.

1.2.2 Objectives

1. Through a literature review, look into the extent of risk that overheating in 1965-1980s semi-detached dwellings could pose on the occupants and what causes this risk. Additional considering the thresholds used to determine risk.
2. In assessing previous studies into overheating, what aspects of the occupants and the building are contributing to overheating? Giving specific attention to areas that have not yet been researched, or gaps within previous studies.
3. Identify a base case version of 1965-1980s semi-detached dwellings to use throughout the simulations based on estimations and literature based evidence of a common standard of construction.
4. Through simulations, look into the overheating affects of the multiple contributing factors of the occupants behaviour and activity.
5. Through simulations, look into the overheating affects of the multiple contributing factors of the building design and room uses.
6. Apply a UK heat wave climate condition simulation on both the original 2010 Building Regulations model and the combined interventions model aimed at reducing overheating.
7. Based on assumptions and exterior sources, briefly assesses the mitigating factors that can be used to reduce overheating, and what are the likely options for the occupants. Taking into account the cost and ease of use of the feature. Thus producing a definitive set of recommendations for reducing overheating

1.3 Methodology

The software choice will be based upon pros/cons analysis of different dynamic modelling options (Appendix F). The software used will be Integrated Environmental Solutions (IES) due to previous experience with it and knowledge of its full capabilities and thus its appropriateness for this report. Within the model itself the building will be designed based on standardized construction and building dimensions and layouts. Along with the typical occupancy, appliance and window time profiles, a base case will be presented for the multiple interventions to be tested upon, with appropriate parameter changes applied.

The simulations will use two key points to create the results. Firstly the threshold temperature to which overheating is initiated will be defined and used in conjunction with the results presented. With this data, degree hours beyond this defined threshold analysis will be used to compare the different interventions and situations proposed. A degree hours method was proposed as based on recent CIBSE publications (CIBSE, 2013), it is seen to be the future of overheating measurements as it takes into account a weighted total of both the number of hours and the temperature of these threshold surpassing hours. With this data, the scale of either reduction or increase in overheating degree hours can be obtained, as explanations for these changes can be compared to that of previous studies. Through this an optimum model of interventions created and the success of these interventions can be applied to both vulnerable occupants and during heat waves to show the scale of possibility they may create in mitigating the future and present effects of summer climate change.

1.4 Layout

Introduction

The introduction will outline the background behind the subject matter leading into the rationale for the study in general using the background information as a basis for reasoning behind the different aspects of the study. From this aims and objectives are laid out shaping the individual factors of the study needed to be covered in order to provide the industry with answers.

Literature Review

This section will take an in-depth look at the areas of focus, taking into account defining and assessing overheating. More extensively, comparing and evaluated the previous studies undertaken in the same field of overheating, looking into different theories and concepts of methodology and overheating factors that have been used and could be considered in this study.

Methodology

Within the methodology, the software used will be assessed giving reasoning why it was chosen over other options. In this section, the simulation base case will be established, using a design determined based on statistical analysis, covering standard housing size, occupant behaviour and ascertaining a new standard threshold for occupant comfort. Through the assistance of the literature review, a set of simulation scenarios will be ascertained.

Data Section and Results

The data section will be the explanation and representation of the multiple simulation results for the multiple changes to the building and occupant activity. Secondly the trends and notable findings in the results will be analysed.

Discussion

In this section, the results are collated and using various simulations a combined table of comparison will be presented. Through this an analysis of what the trends in differing degree hours over the threshold mean and what they represent will be applied, ultimately creating an optimum case for heat wave examination.

Conclusion

This section will summarise the findings and the discussion giving conclusions to the study, covering if the objectives were met. Furthermore, the limitations in the research will be identified and any areas of research that could follow the work are suggested.

2 Literature Review

This section will first look into what previous studies were undertaken into this subject, giving specific focus on areas that were not fully investigated and potential areas to research. Furthermore, current research into what is the overall health risks of overheating; the regulations on the subject and a study of the definition of the threshold were also considered.

2.1 Previous Studies

Within the field of overheating, the range of studies previously undertaken explores multiple facets of the issue, however only a few can be associated with the simulation study in this report. The fore front research comes from the CREW project; Stephen Porritt and BRE affiliated projects whose research look to adapt housing to mitigate the effects of overheating whilst also looking into the causes.

The most in depth study into overheating was Stephen Porritt, whose research was developed to look into “passive interventions that could reduce overheating during heat wave periods... further expanded to assess the effect of interventions on space heating energy use and to consider the cost of interventions” (Porritt, 2012). Whilst also analysing the causes of overheating in dwellings, Porritt chose to analyse the UK’s most popular types of housing (purpose built flats, terraced houses, semi-detached houses and detached houses (DCLG, 2011), chosen for their ability to show a range of dwelling types, ages, construction methods; allowing a full spectrum of overheating effect on UK dwellings. The use of multiple dwellings is similarly used in other studies, as Oikonomou, et al. (2012) chose the 15 most common housing stock in construction type and dwelling age when analysing the effects of energy use and other parameters on overheating, whilst Orme, et al. (2010) chose a housing stock that would reflect the most popular UK stock of the future. On the other hand, separate studies have analysed specific types of housing stock, such as Porritt, et al. (2011) and de Wilde & Beck (2008) whose research focused upon terraced housing due to its quantity and the extent of modern retrofit applied to it. It can be seen however that having a wide range of housing types and construction methods such as with Jenkins, et al. (2009), Peacock, et al. (2010) and Jenkins, et al. (2011) is the most productive method.

More significantly, the methodologies chosen to measure the level of overheating will dictate the direction of the research studies. Porritt (2012) analysed the multiple methods to use for simulating the effect of mitigation factors and chose DesignBuilder as it “provides a user friendly graphical user interface (GUI), enabling easy and accurate input of building geometry, construction materials, gains and profiles” whilst using the capabilities EnergyPlus.

From reviewing the literature the key study that utilizes IES software is Porritt, et al. (2011) whereby a standardised terraced house was sampled to assess "the effectiveness of a series of passive heat wave mitigating interventions." This shows that with the majority of research using other software, there is a gap in the research to utilise the detailed facets of the software to analyse the causes of overheating. Furthermore, Jenkins, et al. (2013) analysed the suitability of different methods of assessing overheating and found that "such detail is essential for any useful, and accurate, overheating analysis." In opposition, Porritt (2012) was against using IES, as while stating its ease of use and consistency it does force researchers to adapt to the software unlike the more basic software packages.

Another key study to assess is Oikonomou, et al. (2012),who while finding that the key factors to causing overheating were the construction, geometry and building fabric, the debates created concerning climate, occupant behaviour and location are more significant. With a similar study, Mavrogianni, et al. (2012) had key findings that the geometry and building age were the main overheating indicators (contrasting Oikonomou, et al. (2012)), although realized that for a more in-depth, original analysis, indoor temperature profiles and vulnerable occupant lifestyle patterns are needed. This highlights the opinion of Porritt (2012) and Oikonomou, et al. (2012) as well who believed various groups occupancy schedules would need more research, in particular, looking into the room by room analysis on different groups. This is particular importance as the threshold temperatures concern mostly living rooms and bedrooms where the vulnerable groups spend their time during peak heat wave hours. An issue stressed by Beizaee, et al. (2013) who in partaking in study to measure the frequency of dwellings exceeding temperature thresholds found the living room and bedroom temperatures to be essential factors to occupant overheating. More specifically finding that there is substantial overheating in bedrooms regardless of heat wave or not shows a point of concern. This research could be used more effectively in the industry as while there are multiple overall causes and mortality risk studies, individual room and group assessment is needed as increased insulation and increasing temperatures will further the issue.

Furthermore, with numerous studies looking into future temperature simulations or different UK climates impact, Mavrogianni, et al. (2012), Jenkins, et al. (2011), Peacock, et al. (2010) and Shao, et al. (2011), all found the growing risk with increased energy efficiency, although a key area of research proposed was assessing the different heat wave durations. Oikonomou, et al. (2012) suggested that the health risks would change in prolonged heat wave periods, particularly with high thermal mass dwellings as previous studies have concentrated on short term temperature increases. Similarly, Porritt, et al. (2011) suggested assessing the occupants' ability to adapt to heat waves and have a reducing risk of health issues, as they progress as a key industry need.

From the studies covered, while many look into simulating the mitigating factors, those that cover the causes made contrasting findings from the results. Whether it was previously installed or potential retrofit, the level of insulation can be debated to reduce or increase overheating. While Oikonomou, et al. (2012) study found that dwellings cannot control solar heat gains in the housing, due high or low insulation standards, Shao, et al. (2011) went into further detail stating that external insulation can in fact reduces overheating. On the other hand, a more striking observation was by Mavrogianni, et al. (2012) who found that internal insulation reduced overheating and that the different materials and positioning of insulation has capabilities to reduce or increase overheating as seen by Jenkins, et al. (2009). While Mavrogianni, et al. (2012) supported this observation, they also noted that night-time ventilation and heat transfer is key to whether insulation is a cause or solution of overheating, an assertion supported by Jenkins, et al. (2009). While both Orme, et al. (2003) and Oikonomou, et al. (2012) give substantial evidence that night-time would reduce overheating, the scale of reduction is debatable as due to the thermal mass changes, the house would re-radiate heat during the night, less than that of insulation (15% less to 30%).

A discussion in studies that took particular focus in this work is the impact of internal gains in dwelling causing overheating. Debating their own point, Jenkins, et al. (2009)'s study of schools suggested that reducing the usage and internal gains of IT equipment would be a "prudent" solution for reducing overheating. Contrastingly however, future IT usage and growth will be intensified in future climates. This concept is supported by Peacock, et al. (2010) who affirms that thermal mass will have the greatest effect in the day when absorbing external gains, coincidentally when IT is used the most. An area of internal gains not researched is the effect of increased appliance efficiency on internal gains. Research shows that currently there is a state of flux as Schlomann (2009) suggests that growing quantity and size is increasing gains regardless of efficiency, but shows that in the future increased efficiency reductions will reduce it, a theory that is shared by Borg & Kelly (2011) who believe that the reduction will come by 2020.

An issue that has been only briefly investigated is that of ventilation strategies and window opening strategies. Porritt (2012) raised the point that there is little research into this sector, while Peacock, et al. (2010) assumed a simplistic method of cross ventilation. While, window opening is studied, using different cross ventilation and single sided ventilation (SSV) strategies are not considered as changing this can alter ACH, a significant factor in reducing overheating.

2.2 Health Impacts

Outside of this research, the key purpose for this report is to be used in real life application. Therefore, looking into the evidence supporting the need for reducing overheating in UK dwellings is the possible risks it creates to the occupants' health. In 2003 in the most severe recent case of heat waves, there were 2,000 to 3,000 excess deaths (NHS, 2012), while in 2013 as 18th of July there were between 540 and 760 excess deaths (London School of Hygiene & Tropical Medicine, 2013). With such data in mind, this section looked into the current publications and debates the causes and impacts. The basic facts are that with increase outdoor temperature, internal temperature increases in UK dwellings causing discomfort and increase chance of death (Zero Carbon Hub, 2012).

Based on studies by the NHS and the UK health protection agency a comprehensive table of potential overheating health effects and who are most vulnerable can be established:

Overheating effects

NHS: Heat wave Plan for England 2012 (Department of Health, 2012)	Health Protection Agency (Carmichael, et al., 2011)
Mild heat related health effects	
Heat Cramp	Heat Cramps
Heat Rash	Heat Rash
Heat Oedema	Heat Oedema
Heat Syncope	Heat Syncope
	Dehydration
Severe heat illness	
Heat Exhaustion	Heat Exhaustion
Heatstroke	Heatstroke
Air pollution related illness from increased levels of SO_2, NO_2 and O_3	Mental Health Complications *

*While not directly linked to UK dwellings, the increased temperature that can be attributed to the indoor temperature can potentially cause increased alcohol consumption, serotonin levels and generally more risks that could lead to increased suicides. (Page, et al., 2007)

Table 2.1 - Potential Overheating effects

Vulnerable groups to overheating*

NHS: Heat wave Plan for England 2012 (Department of Health, 2012)	Health Protection Agency (Carmichael, et al., 2011)
Children and Infants	Children and Infants
Elderly	Elderly
People with chronic illness	People with chronic illness
people with alcohol dependence and drug dependence (poorer health)	Obese
People on thermoregulation medication	People on thermoregulation medication
People in an urban heat island district	People in an urban heat island district
People who do have high level of physical exertion in their own home	
Old women (fewer sweat glands to men)	

* It must be noted that all of the UK is potentially at risk from overheating however specific groups have higher risks

Table 2.2 - Vulnerable Groups to Overheating

With such a wide expanse of society included, the risks established in Table 2.1/2.2 show that the risk would have a serious impact upon the UK population. With evidence to support the effects in the given reports, the need for immediate action to reduce the risks is evident.

One of the areas of discussion found on the subject is the occupant's ability to adapt to the heat wave after an extended period of time. While the overheating effects noted can become worsened due to extended exposure there is evidence of adaption. The NHS Heat wave Plan makes note of this occurrence, however highlighting that there is an initial comfort adaption period as "thresholds vary for each region and risks to health appear to be greater earlier in the summer" (Department of Health, 2012). Expanding on this point, Hajat, et al. (2002) found that even with a temperature increase to 19°C some heat effects were seen, suggested that the brief temperature spurts earlier in the year can have just as great an impact as extended heat waves due to the occupants inability to adapt (Hajat, et al., 2002).

Recent changes to the UK housing environment have had significant effects on the health risks of occupants. By using Building Regulations to increase energy efficiency of housing, the argument is that these measures have greater impact on mortality rates in the UK seasons with evidence that "On average, over 25,000 additional people die in England over the winter months because of cold weather than during other times of the year" (Health Protection Agency, 2011), significantly greater than the 2003 heat wave (NHS, 2012); further supported by the health benefits of reduced fuel poverty and higher winter temperatures suggested by (Barton, et al., 2007), (Green & Gilbertson, 2008) and (BMJ, 2007).

In fact, NHS: Heat wave Plan for England (Department of Health, 2012) states that by insulating dwellings further, mitigation through reducing climate change and reducing thermal gains with external wall insulation can reduce health risks. On the other hand, arguments made by Russell-Croucher (2013) suggest that as well as overheating, condensation and mould growth are further risks.

One of the biggest changes in UK dwelling overheating is the rising issue of Urban Heat Island (UHI). With modern urban design and planning, less evaporation and shading whilst greater inputs of heat are created with both the LUCID-Project (2011) and Mavrogianni, et al. (2012) have found a connection between Heat-related mortality risk and postcode areas with high average building height.

Concerning overheating, the major debate is whether indoor temperature can be successfully used to indicate overheating with the majority of research linked with outdoor temperature risks. Currently, debates question correlations of mortality with outdoor temperature as while DCLG (2012) (Figure 2.1) show evidence of a connection (mortality rates increase at 24.7°C), Carson, et al. (2006) believes the connection has been declining, as environmental conditions and health care increase.

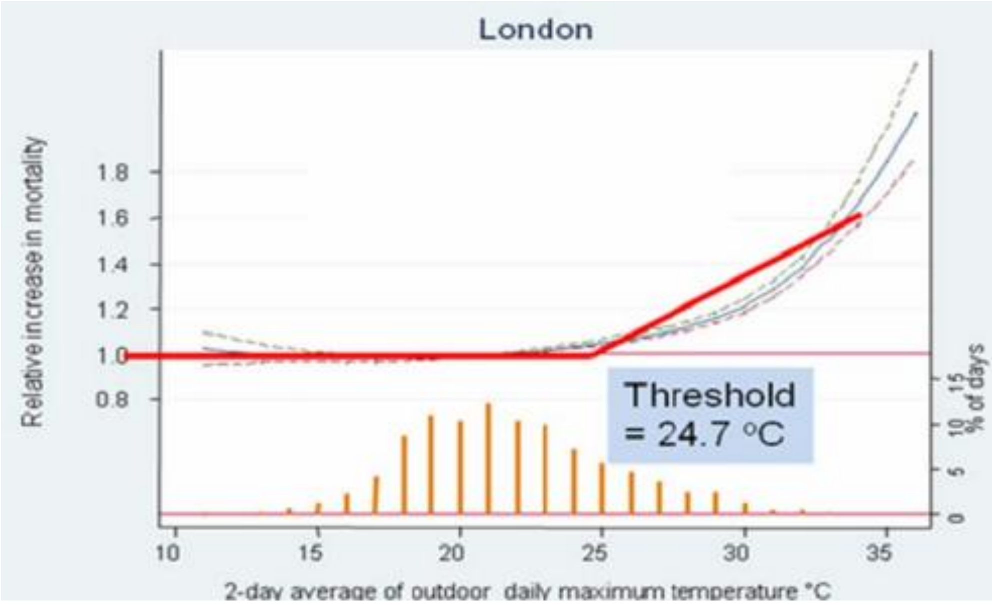

Figure 2.1 - Relative risk for summer temperature-related mortality in London

While outdoor temperatures are fixed, indoor temperatures can adjust based on multiple parameters, and are key due to the vulnerable group's concerned being primarily indoors. Therefore, the health risks concerned with the indoor varying temperatures are more important to gauge. (DCLG, 2012)

While NHBC Foundation (2012) has found that "Due to differing climates across the world, people have adapted differently over thousands of years both in their physiology and in the behavioural, cultural and social practices they adopt to cope with heat", the relationship between indoor and outdoor temperature is key. As Carmichael, et al. (2011) believes, indoor variables exacerbate the effects of overheating beyond their hypothesised threshold of 26 C at a rate greater than occupants could adapt to.

Overall, with global mean temperature increase of 1.4–3 K by 2050 Rowlands (2012), the risks stated will significantly increase chance of overheating in the UK (Table 2.3) making it a priority area for action.

	Observed	1961–1990			2080s Medium		
	50%	10%	50%	90%	10%	50%	90%
Heatwaves (2 days with Tmax>29°C and Tmin>15°C)							
Heathrow	0	0	0	1	1	7	22
Yeovilton	0	0	0	0	0	4	15
Coltishall	0	0	0	0	0	1	7
Dale Fort	0	0	0	0	0	0	3
Ringway	0	0	0	0	0	1	7
Aldergrove	0	0	0	0	0	0	2
Eskdalemuir	0	0	0	0	0	0	2
Wick	0	0	0	0	0	0	0
Hot days (>28°C)							
Heathrow	2	0	2	5	10	32	67
Yeovilton	1	0	1	4	8	28	60
Coltishall	0	0	0	2	2	11	35
Dale Fort	0	0	0	0	0	1	13
Ringway	0	0	0	1	1	9	29
Aldergrove	0	0	0	0	0	2	11
Eskdalemuir	0	0	0	0	0	3	12
Wick	0	0	0	0	0	0	0
Hot days (>25°C)							
Heathrow	15	7	12	19	36	70	104
Yeovilton	8	4	8	14	32	63	96
Coltishall	7	1	4	8	15	37	71
Dale Fort	0	0	0	0	1	12	40
Ringway	4	0	2	6	10	29	59
Aldergrove	0	0	0	2	3	13	34
Eskdalemuir	0	0	1	3	3	12	29
Wick	0	0	0	0	0	0	5
Frost days (Tmin <= 0°C)							
Heathrow	39	27	37	51	2	9	23
Yeovilton	54	36	46	60	5	14	30
Coltishall	49	40	50	63	3	13	30
Dale Fort	11	2	6	11	0	0	3
Ringway	43	29	39	52	2	10	24
Aldergrove	44	35	43	56	3	11	26
Eskdalemuir	94	84	97	112	19	40	66
Wick	52	42	51	63	5	17	37
Annual highest Tmax (°C)							
Heathrow	29.9	27.6	29.6	31.8	31.3	34.6	39.3
Yeovilton	28.4	26.8	28.7	30.7	30.3	33.9	39.0
Coltishall	28.0	25.7	27.7	29.6	29.2	32.3	36.2
Dale Fort	24.8	21.7	23.1	25.0	27.8	31.1	35.8
Ringway	27.6	24.6	26.6	28.9	28.9	32.1	36.5
Aldergrove	24.2	22.6	24.4	26.9	26.3	29.3	33.6
Eskdalemuir	24.8	23.2	25.4	28.0	25.6	29.0	33.5
Wick	21.6	19.7	21.1	22.5	24.5	27.0	30.2

Table 2.3 - Future and control percentiles of various temperature indices for eight representative sites. Counts are days per year. (Jones, et al., 2009)

2.3 Retrofit and Regulations

Currently, the 2013 amendment Building Regulations have created certain trends to be taken up in housing stock for adaption to increasing energy efficiency standards. The first major adjustment to the Building Regulations to adapt to the need for energy efficiency and higher insulation in winter was in the 2006 Approved document edition. Based on outlined plans of the 2003 energy white paper, the 2006 Regulations developed the Dwelling Carbon Dioxide Emission Rate measurement for measuring energy efficiency also taking into account the air tightness (Energy Saving Trust, 2006). The change for this was further supported by the governments plan for zero carbon housing, with plans to align the standards of the code for sustainable homes (DCLG, 2006) with the building standards updates. Reviewing the legislation, the carbon trust realized the changes would allow for "maximum flexibility for innovation within the design limits on building fabric" (Carbon Trust, 2008), also giving space for possible overheating adaption.

In regards to the 2010 and 2013 Regulations, the issues with the 2006 Regulations was that Pan & Garmston (2012) found that the required standard of CO_2 emissions reductions through energy efficiency methods was at a level of 35% of all dwellings tested. Consequently, in the context of overheating, it can be seen that from past testing, the energy efficiency standard was not clearly met and therefore, overheating can be seen to be attributed to both the improved building structure and other occupant activities/building features. Therefore, by introducing the Fabric Energy Efficiency Standard (FEES) and current method of showing modelled emissions (Lupo, 2012) in the 2013/2016 Regulations, would allow for flexibility to adjust for overheating whilst also becoming stricter on energy efficiency.

In light of these action, with current U-values standards (Table 2.4) for walls dropping to (0.28 W/m^2.K)[2] (HMGovernment, 2010), new methods for reducing energy efficiency whilst also considering overheating are needed.

Table 3 Upgrading retained thermal elements

Element[1]	(a) Threshold U-value W/m^2·K[8]	(b) Improved U-value W/m^2·K[8]
Wall – cavity insulation[2]	0.70	0.55
Wall – external or internal insulation[3]	0.70	0.30
Floor[4,5]	0.70	0.25
Pitched roof – insulation at ceiling level	0.35	0.16
Pitched roof – insulation between rafters[6]	0.35	0.18
Flat roof or roof with integral insulation[7]	0.35	0.18

Table 2.4 - Standards for existing thermal elements (HMGovernment, 2010)

The DCLG Investigation into Overheating in Homes suggested that having external insulation, night-time and thermal mass are passive methods advised (DCLG, 2012). From recent trends however, the retrofit methods have not been as effective as noticed with the 2006 test on building standards. Dowson, et al. (2012) found that due to a lack of monitoring, poor quality installation the retrofit was not successfully implemented. While this may support the concept that there are greater impacts to overheating than energy efficiency methods, it can be seen that the lack of efficiency in retrofit could cause further overheating effect. This is supported by both Dowson, et al. (2012) and Jankel (2013) who suggest that the combined impact of partial increased air tightness and the increased chance of a rebound effect ("increased consumption that results from actions that increase efficiency and reduce consumer costs" (Jankel, 2013)) would have a greater impact on global climate change and heat waves. With the government plans to "insulate 3.5 million homes over a period of two years from autumn 2012", any simulation must take into account the error in quality of energy efficiency. Therefore, legislation such as BS EN 15251:2007 aims to:

"define indoor environments consistent with occupant satisfaction in order to ensure that energy efficiency is as far as possible achieved without cost to the comfort, performance or wellbeing of building occupants." (British Standards, 2008)

2.4 Defining the Overheating Threshold

In regards to both the project simulations and more significantly in the interest of health, the comfort threshold to which overheating reaches a dangerous level must be established. With multiple different researchers using different methods and standards for defining overheating, a comprehensive temperature for comfort could be used for both these studies as well as others. (Full table of studies and their chosen threshold in Appendix A).

While the studies in Appendix A show a range of thresholds used, the two most important factors to consider when considering their use in this study are the studies definition of overheating and how this can be related to this report. The basic definition used by DCLG (2012) is that overheating threshold is when "The temperature that limits the ability to carry out pre-specified levels of physical activity", however, when considering the many parameters of the indoor environment and the individual occupants' ability to adapt these features must be considered. With similar disadvantages to the DCLG definition, the widely used definition by CIBSE (2006) has the same principle, however specifying the exceedance of temperature must occur during occupied hours.

A part of the defining that comes under most debate is how to define the timescale of constant discomfort before that day can be defined as a period of overheating. This is analysed by Nicol &

Roaf (2005) who highlight the lack of research in “moment-by moment comfort of occupants and the overall perception that a building overheats” and Nicol, et al. (2009) who criticize the definition inability to take into account long term adaption to initial overheating data. Resultantly, Nicol, et al. (2009) found that having a definition where:

“The risk and magnitude of overheating can be calculated according to the amount by which the operative temperature for any given hour or day exceeds the predicted comfort temperature for that day. The predicted level of discomfort is related to the difference between the two.” (Nicol, et al., 2009)

Therefore, taking into account the occupant’s ability to adapt daily would show more accurate evidence of overheating. Another point covered in the literature key to defining the overheating threshold is analysing the room by room overheating status. Both and He, et al. (2005) and Jenkins, et al. (2013) stress the need to select the most “vulnerable” place in the house (the bedroom)” as point of measurement; as this leads to occupants having disrupted sleep and forces mitigating action from discomfort. Furthermore, under CIBSE (2006) guidance, the summer thresholds are based upon living area and bedroom temperatures, as these two points are where the occupants spend most of their time, with particular focus upon bedrooms due to the risk of disturbed sleep. Contrastingly, the Department of Health (2013) believes the overheating threshold should be based on the thermal comfort of the most “vulnerable” group’s limits, not just any occupant of the room.

If an approach to defining the overheating threshold was to make it the point of loss of thermal comfort rather than point of mortality risk, a definition of “thermal comfort” is needed. The universally recognised definition used by Fanger (1970) and implemented by ISO 7730 is “that condition of mind which expresses satisfaction with the thermal environment” (ISO, 2005). This was developed into the Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD) models to gauge the occupants’ thermal condition and adaptability to the conditions. Therefore, taking into account the occupants ability to adapt to the surrounds and taking into account ASHRAE Standard 55 (ASHRAE, 2010) thermal comfort model, overheating can be seen as the point to which behavioural, psychological and physiological adaption is not sufficient. As both Gul & Menzies (2012) and Mavrogianni, et al. (2012) suggest that the point at which mitigating action is taken by occupants signals overheating. A recent report by CIBSE (2013) however stressed the subjectivity in this assessment and that for a whole building assessment; multiple occupants in multiple rooms’ responses are needed.

The most widely used definition is that of Basu & Samet (2002) who states that the overheating threshold is met when mortality effects due to heat begin, a definition supported by Ormandy & Ezratty (2011), DCLG (2012), Koppe, et al. (2004) and Kovats & Kristie, (2006). However, the argument in using specific temperature thresholds is deciding what type of temperature data should be used as NHBC Foundation, (2012) states that minimum, maximum or apparent temperature have all been used and have advantages.

Finally, recent analysis by CIBSE, (2013), aimed to define overheating to a more in-depth standard, choosing to base it upon three criteria.

- Criteria 1 "sets a limit for the number of hours that the operative temperature can exceed the threshold comfort temperature by 1 K or more during the occupied hours of a typical non-heating season"
- Criteria 2 sets a daily limit for acceptability for a temperature rise and duration in a single severe overheating day
- Criteria 3 "set an absolute maximum daily temperature for a room, beyond which the level of overheating is unacceptable."

While these criteria combine many other noted features, the theory of using multiple criteria to define one state can be useful in future studies.

3 Methodology

The methodology will present the argument for the use of IES software and the final decision on the threshold temperature and method to measure the degree of overheating over the chosen threshold. From this data, the base case design and full details and justification to be applied to IES software will be presented. Finally the final list of interventions and justifications for so will be produced.

3.1 Software

In this report, the main aim was to research the effects of multiple factors in UK semi-detached dwellings on overheating, before and after the inclusion of recent energy efficiency upgrades including 2010 Building Regulations. Theses simulations were applied to two different groups, an average UK family and a vulnerable resident household. In order to perform these simulations, a software package was needed to produce results. Based on previous literature, the options available are assessed (Table 3.1) and IES was chosen for its specific advantages*:

Software Package	Advantage	Disadvantages	Previous studies
IES Virtual Environment	• Personal previous experience • User friendly interface • Industry and academic recommended (Porritt, 2012) • Presentation of simulation results allows for simple conversion to analytical data • "Comprehensive analysis options offered across a wide range of metrics" (U.S Department of Energy, 2011)	• Time consuming to do many parametric simulation studies (U.S Department of Energy, 2011)	• (Porritt, et al., 2011), a standardised terraced house was sampled to assess "the effectiveness of a series of passive heat wave mitigating interventions."

*Full table of comparison to other software in Appendix B

Table 3.1 - IES Software advantages and disadvantages

3.2 Report definition for thermal comfort and overheating threshold

In order to decide upon the best threshold to be used in this study an analysis of the literature and its suitability for this particular report was needed. Overall the most frequent threshold used was CIBSE Guide A – Environmental Design (CIBSE, 2006) threshold of 28ºC, more specifically, 3°C above the design temperature of standard dwellings; as this standard is most widely used and reputable source for previous simulation research. For this particular study, the definition of thermal comfort must also be considered. Taking into account the previous literature, the overheating threshold can be seen as the point at which the occupant's behavioural, psychological and physiological adaption is not sufficient and mortality effects due to heat begins. Therefore a room by room threshold temperature was used based in CIBSE publication (CIBSE, 2006).

By using a room by room measurement technique, the vulnerable areas of the dwelling with the greatest occupancy were measured. This allows for more accurate figures on the risks to occupants and not be skewed by cool rooms such as hallways/roof with little occupation and risk.

- Living Area Threshold: 28ºC
- Bedroom Threshold: 26 ºC
- Total Interior Threshold: 28 ºC

3.3 Overheating degree hours analytical method

Once the threshold was set, the level of overheating was quantified by using a total degree hours over the threshold method. While an hour over criteria or % of hours over method as originally used in CIBSE guide A was considered. Based on recent CIBSE publications on overheating, CIBSE (2013) degree hours is a better and future method as it is able to measure the severity of overheating by taking into account the temperatures of the individual hours of overheating above the threshold. Furthermore, with multiple models of migration and analysis using degree hours method (Orme, et al., 2010), (Shao, et al. (2011), it is a more accurate method moving forward with overheating studies.

- 1 degree hour = 1 ºC over threshold temperature for 1 hour

Taking into account both the threshold temperatures and the degree hours calculations, the results were presented comparing the degree hours value for the two room types for each intervention simulation to show the effects of these interventions on key rooms. Two sets of base cases were established, one before 2010 Building Regulations and one with the adaptation included. All interventions were applied to the 2010 base case; however they were also compared to one another.

3.1 IES climate data

The weather file chosen was based on CIBSE data using the standard test reference year file. As explained by University of Exeter (2010), this composed of:

"12 separate months of data each chosen to be the most average month from the 23 years of data, typically 1983 to 2005 [although now updated to 2008] but this varies depending upon data availability. The most average months were chosen based on the cumulative distribution functions of the daily mean values of the three parameters: dry bulb temperature (DryT), the global solar horizontal irradiation (GlRad) and wind speed (WS)" (University of Exeter, 2010)

Contrastingly, the heat wave weather data was composed of a design summer year file, which is produced as the year within the period with third hottest April to September period. Both files were located in London Heathrow.

3.2 Base case design

The base case design was based on a 1965-1980 semi-detached dwelling due to a number of reasons. One proposed by Utley & Shorrock (2008) is that within the UK, the majority of people who would undertake passive mitigation retrofit would be owner occupied dwelling, of which the most (31%) own semi-detached housing.. In addition, the highest quantity of worst energy efficient housing is in semi-detached dwellings (25%). (DCLG, 2011)

Furthermore, of all occupied homes in the UK, housing built in 1965-80 was the most populous (21%) of all the types (DCLG, 2011). While studies show that the overall most populous housing type is terrace housing, taking the other factors in mind and the limitations of the simulation software, 1965-1980 semi-detached dwellings are more important. Furthermore, another reason for using this type of housing is that it has not been studied yet, as previous studies have instead focused on 1919-1964 housing, showing a gap in the research.

For the interest of the building design and the simulations, the base case was designed upon standardised designs for 1965 -1980 semi-detached dwellings. Further details of the building are seen in Table 3.2 and Appendix C.

Building Size and Dimensions	Detail	Reference
Total Floor area (m^2)	$88.5m^2$	40% of all semi-detached houses had a useable floor area of $70\text{-}89m^2$ (DCLG, 2011) In 3 bedroom semi-detached the average floor area was 87 m^2 (DCLG, 2011)
Orientation	South facing	In the UK, buildings with south or north facing buildings, whereby the long side of the building faces the sun ensures reduces summer heat gain (GreenSpec, 2012)
Location and climate	Heathrow	Based on the IES Software capabilities, Heathrow is the closest site to Reading. (IES, 2013)
Building Simulation Period	1st June-15th September,	Based on Met office Heat-Health Watch system for heat wave analysis (Department of Health, 2013)

Table 3.2 - Building Design features

3.4.1 Building layout and dimensions

The building design and dimensions were based upon multiple sources that exhibited the typical dimensions and layout for a semi-detached dwelling 1965-1980. Layouts of semi-detached housing from studies such as Energy Saving Trust (2011), Zero Carbon Hub (2012), Cuéllar-Franca & Azapagic (2012) and the design manual Allen & Pinney (1990) were used to establish a typical base case. (Figure 3.1/3.2/3.3/3.4/3.5)

Figure 3.1 - 3D Model of base case 1965-1980 semi-detached dwelling

3.4.2 Floor Plan

Floor plan key: Window = Door =

Within the simulation models the semi-detached building was be connected to its adjacent semi-detached building to ensure that the impact of the party wall and thermal influence of the other half is considered.

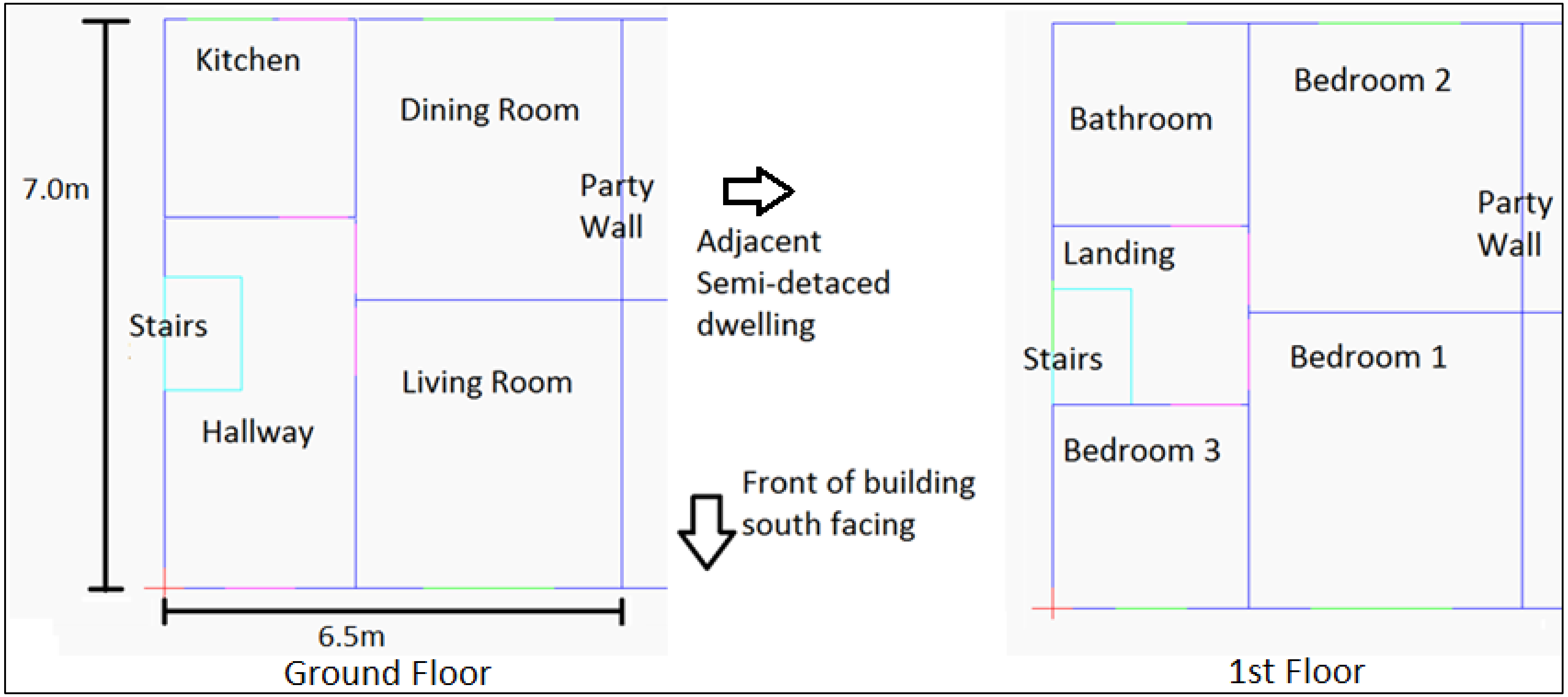

Figure 3.2 - Base Case 1965-1980 semi-detached dwelling typical floor plan

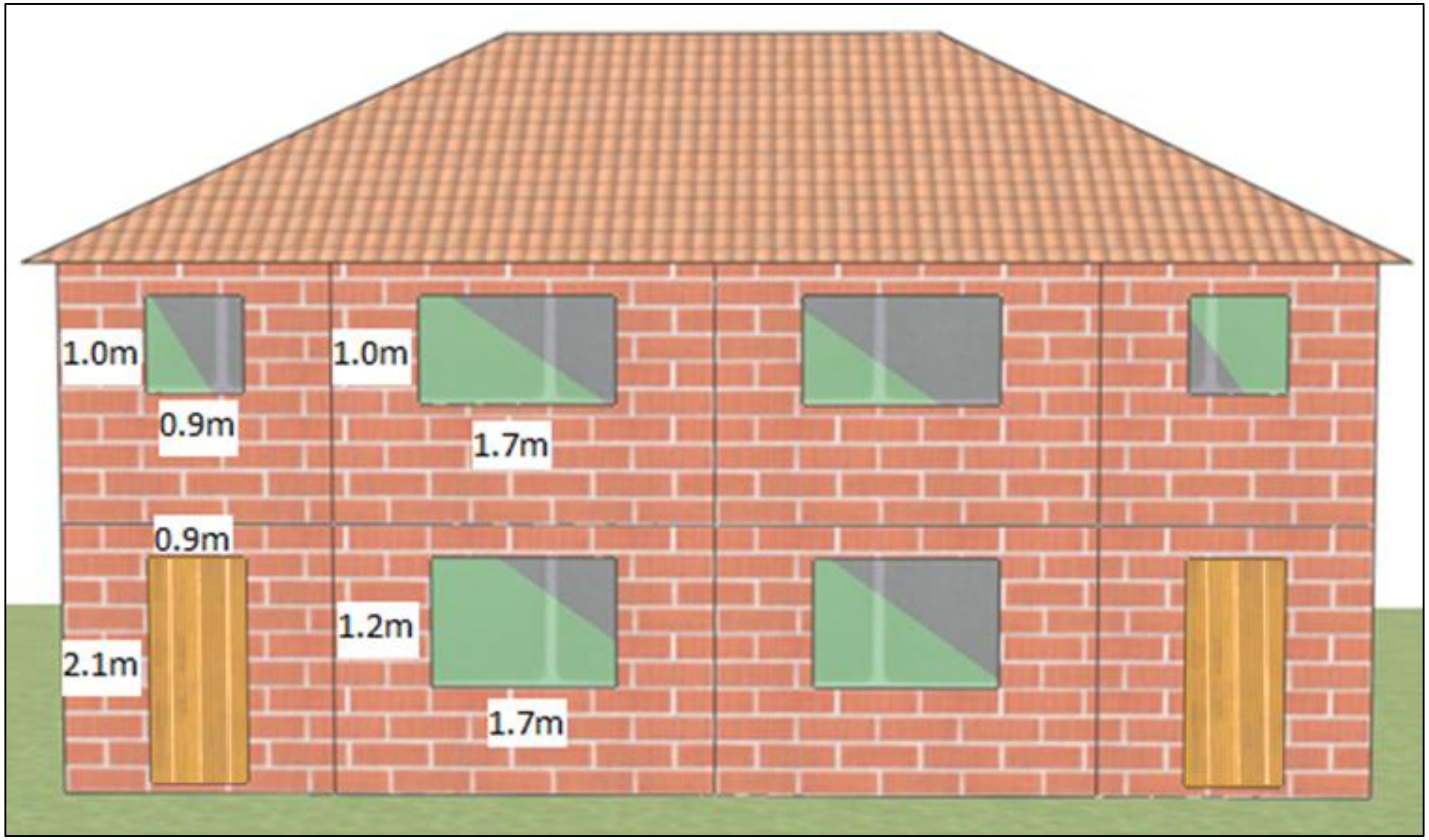

Figure 3.3 - Base Case front (south facing) wall

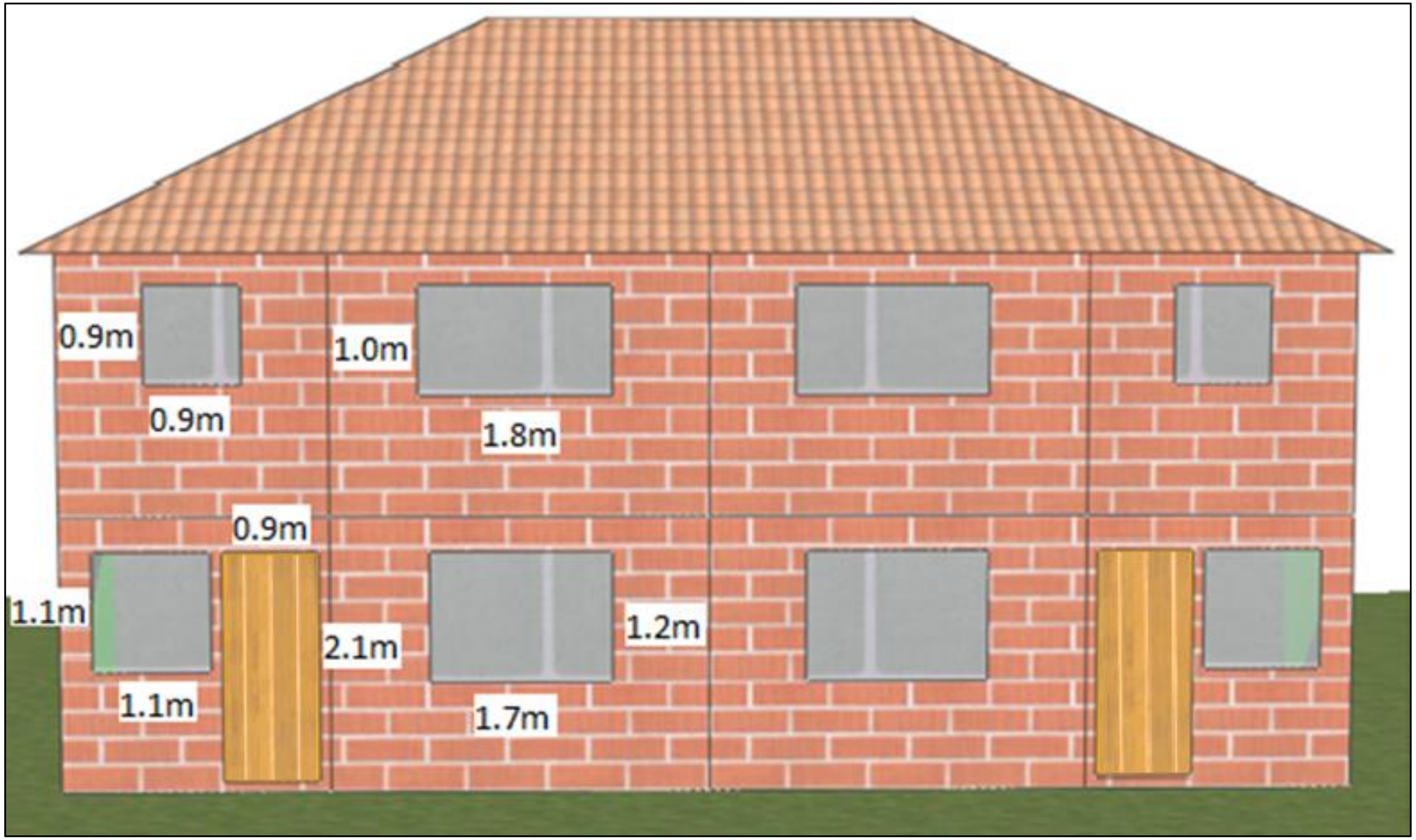

Figure 3.4 - Base Case rear (north facing) wall

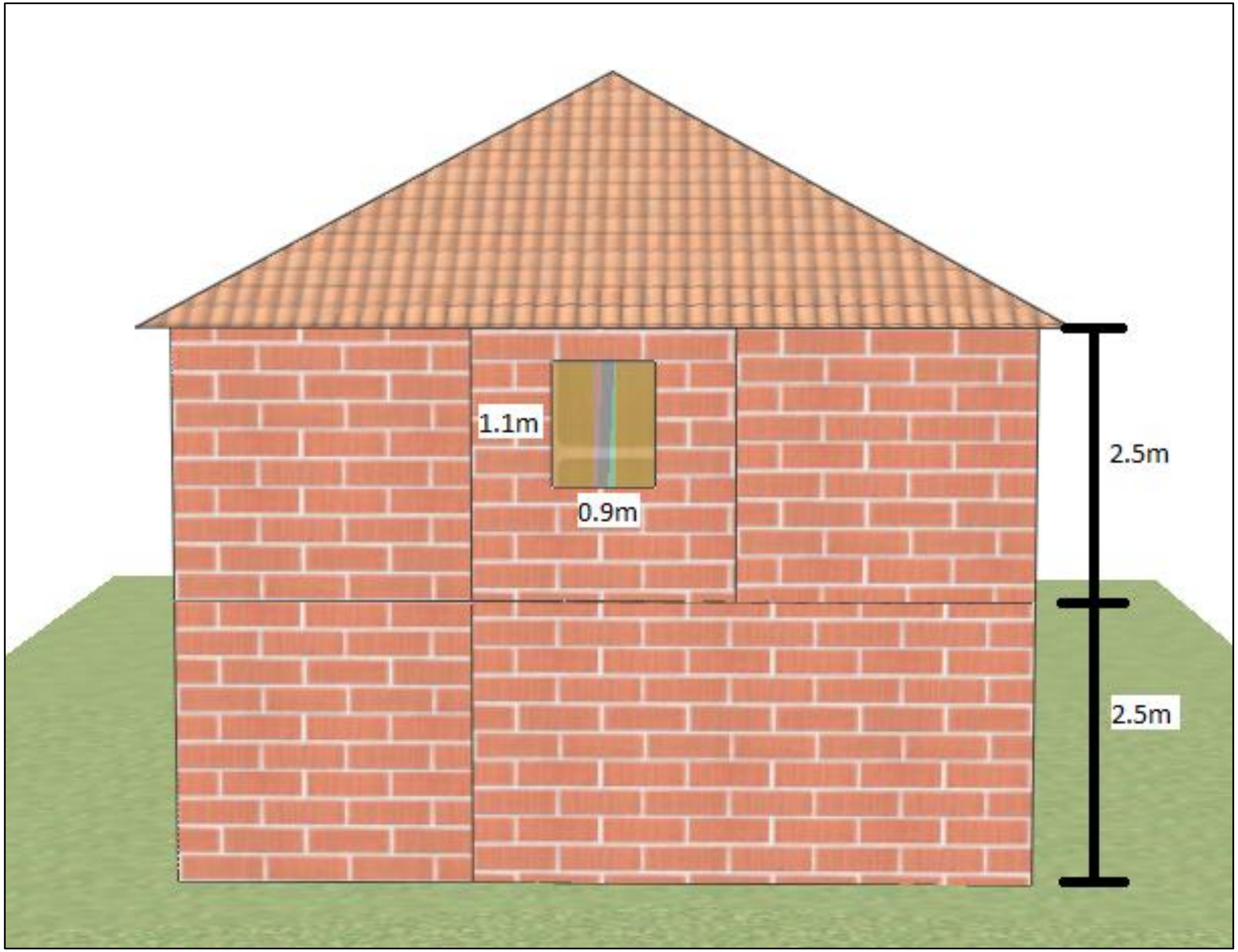

Figure 3.5 - Base Case left hand side wall (west facing) wall Internal Gains and Occupancy/Electrical Profiles

3.2.1 Appliance and occupant internal gains and time profiles

To calculate the internal gains and the electrical profiles (Table 3.3), external data was used from multiple sources. To find the array of appliances and heat gains used, a list of the different appliances and quantity within a standard UK household were found using a population survey study by (Svehla, 2011). The most integral factor was using accurate estimates of internal gains of the appliances and occupants; with (CIBSE, 2006) sensible heat gain data as the basis or all previous studies, appliance gains were estimated using the values by CIBSE (2006), Porritt (2012) and Warwickshire County Council (2011). Similarly, the occupant heat gains were estimated using sensible and latent heat gains combined from Peacock, et al. (2010) and Porritt (2012) (sourced from Allen & Pinney (1990)) once again. Considering the performance of the appliances, the kitchen items were working at 50% total output to mirror occupant appliance use, while other appliances were working at 100% output. While electrical with short usage time such as microwaves, vacuum cleaner etc have not been included as the time profiles were not set or substantial enough to make a difference.

In order to gauge the occupant overheating exposure, an accurate time profile for occupants and appliances was needed to measure the extent of internal gains over an average day (Table 3.3). Estimations on appliance time profiles were gauged using both assumptions as well as previous studies and profiles by (Taherian, et al., 2010) while time profile estimation by Porritt (2012) sourced data from The United Kingdom 2000 Time Use Survey Office for National Statistics (2003) to find both occupant time profiles and appliance. More importantly, from The United Kingdom 2000 Time Use Survey, and supported by Cuéllar-Franca & Azapagic (2012), the occupant profiles were estimated based on standard profiles for a modern family (2 adults and 2 children) that un-occupy the dwelling during the day. The second set of profiles using the same sources was based on the vulnerable sector of society (2 elderly residents who spend 24 hours in the dwelling. For weekend profiles the same sources were used, as profiles were generally the same. For the elderly case study the weekend study was the same, while for the average family assuming the family were taking advantage of the weather and spending more time outside; both occupancy and sleeping patterns change. Moreover, considering weekly and yearly profiles, the national holidays used a weekend profile, and no extended holiday was taken by either group.

Heat Gain	Room(s)	Max Internal Gains (W)	Week day Profile for standard dwelling for modern family	Weekend Profile for standard dwelling for modern family	Weekday Profile for standard dwelling for two elderly residents	Weekend Profile for standard dwelling for two elderly residents
Hot Water	Bathroom	100	24 hours	24 hours	24 hours	24 hours
Oven	Kitchen	1670	1700-1730	1230-1300 1700-1730	1230-1300 1700-1730	1230-1300 1700-1730
Hobs	Kitchen	1930	1730-1800	1730-1800	1730-1800	1730-1800
Fridge-Freezer	Kitchen	630	24 hours	24 hours	24 hours	24 hours
Washing Machine	Kitchen	160	1800-1900	1800-1900	1800-1900	1800-1900
Dishwasher	Kitchen	160	1900-2000	1900-2000	1900-2000	1900-2000
TV	Living Room	150	1900-2300	1900-2300	0900-2200	0900-2200
	Bedroom 3		1600-1800 1900-2200	1600-1800 1900-2200		
Games Console	Bedroom 3	125	1600-1800 1900-2200	1600-1800 1900-2200	-	-
Laptop/ Desktop and Monitor	Bedroom 2	125	1600-1800 1900-2200	1600-1800 1900-2200	-	-
Bedroom Lighting (Based on modern energy saving light bulbs (lightbulbs-direct, 2012)	Bedroom 1	12	0730-0830 2230-2300	0900-1000 2230-2300	0800-0900 2200-2230	0800-0900 2200-2230
	Bedroom 2/3	12	0730-0830 1900-2200	0900-1000 1900-2200		
Kitchen Lighting	Kitchen	12	0730-0830 1700-1800	0900-1000 1700-1800	0800-0900 1230-1300 1700-1800	0800-0900 1230-1300 1700-1800

Living Room Lighting	Living Room	15	1900-2300	1900-2300	1900-2200	1900-2200
Dining Room Lighting	Dining Room	15	0730-0830 1800-1900	0900-1000 1800-1900	0800-0900 1300-1400 1800-1900	0800-0900 1300-1400 1800-1900
Bathroom Lighting	Bathroom	15	0730-0830 2130-2230	0900-1000 2130-2230	0800-0900 2200-2230	0800-0900 2200-2230
Adult Seating (Cuéllar-Franca & Azapagic, 2012)	Living Room (x2)	108	1900-2300	1600-1800 1900-2200	0900-2200	0900-2200
	Dining Room (x3)		0730-0830 1800-1900	0900-1000 1300-1400 1800-1900	0800-0900 1300-1400 1800-1900	0800-0900 1300-1400 1800-1900
Adult Cooking	Kitchen	189	1700-1800	1230-1300 1700-1800	1230-1300 1700-1800	1230-1300 1700-1800
Adult Sleeping	Bedroom 1	72	2300-0730	2300-0900	2230-0800	2230-0800
Child Seated	Bedroom 2/3	80	1600-1800 1900-2200	1600-1800 1900-2200	-	-
	Dining Room		0730-0830 1800-1900	0900-1000 1300-1400 1800-1900		
Child Sleeping	Bedroom 2/ 3	54	2200-0730	2200-0900	-	-

Table 3.3 - Internal Gains and occupants type's weekday and weekend profile

3.4.3 Windows and Doors

The natural ventilation ACH given is based British Standards (2002) data that would be used, however within the model the wind generation software was used instead with similar resultant ACH values however, a time profile and further window opening details were given to give more accurate ventilation data.

For the base case the window opening profiles (Table 3.4) were based mostly on personal assumption and typical patterns. As stated by Porritt (2012), the majority of data on window opening trends is for office buildings therefore, the parameters used were assumptions with CIBSE references as a basis for the window opening data. Further assistance in designing the windows was achieved by the design guidance of IES, (2012) and IES (2012). The full window and door parameter details are given in Appendix D.

Window	Time Profile Weekday	Time Profile Weekend	Temperature threshold
Window	0730-0830 1700-1900	0900-1000 1700-1900	22°C
Internal Door	0730-0830 1700-1900	0900-1000 1700-1900	22°C
Doors (Interior/Exterior)	Always Closed		0°C

Table 3.4 - Window and Door Opening Profile

3.4.5 Base Case Materials

The building fabric and materials used in the base case building were based on multiple sources in order to create and accurate model to the building type and current regulations. Data from the English Housing Survey Homes Report 2011 (DCLG, 2011) states that from 1965-1980, 83% of dwellings built were cavity masonry. Additionally, 96% of non-flats built in that time period were pitched roofs and 80% had a tile finish, 85% had double glazed UPVC windows and for pre 2006, 62.7% had over 100mm of loft insulation. Along with this data, various other sources were used to describe the construction of a standard 1965-1980 semi-detached dwelling; these include Porritt (2012), Brinkley (2008), Energy Saving Trust (2011) and Cuéllar-Franca & Azapagic (2012). To affirm that the building fabric has undertaken some retrofit, the U-values were set above the threshold to which upgrades are advised to meet the 2010 Building Regulations (HMGovernment, 2010) to show a difference between the two. Because of this, unlike the Porritt (2012) study, the base case dwelling design included cavity wall and loft insulation.

Within new dwellings, U-values for party walls were included with a U-value of 0.2 for unfilled cavities. While this level is described an “effective U-value” than an official one, the base case design took this low value into account, as did the 2010 upgrades materials take into account an “effective U-value of 0.” (MIMA, 2010)

The full table of Materials for the different building fabric components are found in Appendix E

3.5 Simulation Scenarios

Using the base case model a series of simulation were made to assess the impact of different parameters on the overheating risk in 1965-1980 semi-detached housing (Table 3.5). While some of these factors have been assessed previously, the holes in their own research are being reviewed and in respect to this report, as expressed by Porritt (2012) "further detailed monitoring of real buildings, both with and without interventions, would contribute to modelling validation and increase confidence in the simulation outputs."

Simulation parameters	Justification
Base Case 1965-1980 semi-detached dwelling – Typical Family/Vulnerable (Section 3.2)	Many other cases have focused upon 1930s semi-detached dwelling, the 1965-1980 semi-detached dwelling has had little research even with its significance in the UK housing stock. These types of dwellings however are predominantly occupied by four person families so this parameter was important. Furthermore, many UK semi-detached dwellings have not been upgraded to recent Building Regulations and this type of dwelling needs to be simulated as well.
Retrofitted to 2010 Building Regulations , 1965-1980 semi-detached dwelling – Typical family (Appendix E.1)	With increased energy efficiency and air tightness measures of (HMGovernment, 2010), the thermal mass of the building will change and heat loss is reduced thus an assessment of the impact of this on the overheating of dwellings is needed. This comes into significant importance as the code for sustainable homes (DCLG, 2010) is putting increasing pressure on home owners to increase energy efficiency and further the impact of heat retention.
Retrofitted to 2010 Building Regulations , 1965-1980 semi-detached dwelling – Typical vulnerable (Elderly resident) family (Appendix E.1)	Multiple sources stress the need for research in this area as the key health risks come first and hardest to the vulnerable old, young, ill etc. Taking into account the time profile of these groups (usually up to 24 hours a day in the dwelling) overheating will have a different affect (Porritt, et al., 2011). Furthermore, these vulnerable groups may spend more time in specific rooms that may cause them to be exposed to the different rooms' temperatures. (Oikonomou, et al., 2012). Overall the core health risks (Section 2.2) are associated to this group and therefore this simulation may be considered the most important.

<table>
<tr><td>Building Regulations 2010 Approved Document material upgrades to include external insulation

(Appendix E.2)</td><td>Considering the analysis of increased insulation causing greater heat retention, and reduced ventilation and infiltration, there are few studies into the types of insulation available under the increased energy efficiency standard and how they impact overheating. While Porritt, et al. (2011) does so, the standard external insulation material and thickness is updated to current trends.</td></tr>
<tr><td>Updated modern and future internal gains and the occupant type’s weekday and weekend time profile

(Appendix F.1)</td><td>Concerning future appliance use and types, studies by Fessey (2005) and Jeeninga & Huenges Wajer (2010) suggest certain trends that combined are reasons for increased appliance gains:
Individualisation of certain appliances by occupants
Reduce medical expenditure and increase self-reliance causing more appliances at home (vulnerable occupants)
Increase in disposable income (family occupants)
Increased number of small electrical appliances
With previous studies by Peacock, et al. (2010) were inconclusive of the effect of greater quantity of appliances and increased efficiency having not yet been fully considered further investigation is needed.

Considering occupancy and appliance time profiles, the increase in appliance quantity has naturally led to increased usage by occupants.</td></tr>
</table>

<table>
<tr><td>Alternative Cross-ventilation (double banked rooms) design

(Appendix G.3)</td><td rowspan="3">Two parameters are combined within these simulations taking into account air flows and window openings.

Occupant behaviour will force a window opening strategy, and a combination of the ventilation strategy and the orientation will impact the level of ACH and reduction in overheating. While Peacock, et al. (2010) has undertaken a study of a altering window opening strategy, a combination of window opening and door opening to optimise different air flow strategies has not yet been assessed as alteration to building form can potentially reduce overheating. Furthermore, as proposed by Mavrogianni, et al. (2012) nocturnal ventilation is an area in need of further work.

The benefits of this will show what the best air flow strategy to use is and as stressed by Beizaee, et al. (2013) room by room analysis could be key.</td></tr>
<tr><td>Alternative single sided ventilation design - daytime

(Appendix G.1)</td></tr>
<tr><td>Alternative single sided ventilation design – night-time

(Appendix G.2)</td></tr>
<tr><td>Retrofitted to 2010 Building Regulations, 1965-1980 semi-detached dwelling – North/East/West/South West Facing Orientation

(Appendix H.1/2/3/4)</td><td>Solar shading can be a measure of reducing the overheating risk. And while without extreme construction work the orientation cannot be change, understanding the different effects of different orientation on the chosen location is useful to the results.

While it is considered that a north or south facing orientated dwelling is best for reducing overheating (Haase & Amato, 2009); with the focus on helping improve winter energy efficiency the value of east west facing to optimise winter solar gains is greater. Thus analysing the scale of impact on overheating differing orientations cause is needed.</td></tr>
<tr><td>Heat wave Weather simulation - Base Case 1965-1980 semi-detached dwelling – Typical family/Typical Vulnerable</td><td>While studies such as Jenkins, et al. (2011) have investigated the multiple climate projection on dwelling overheating, current climate is generally chosen due to the existing data. Therefore, with the greatest health risk yet to come in UK summers with heat waves such as in 2003 and 2013 becoming more frequent estimating the degree hours and risks in future climates may be a more significant finding. Furthermore, long periods of heat waves are seen as a gap in previous studies.</td></tr>
</table>

Best case combined interventions - Typical Family/Vulnerable	In order to see the resultant use of this research the combined effects of these interventions must be considered and in many cases these interventions may enhance each other. The scale of reduction in degree days that the combined interventions created can be used in future housing retrofit for both vulnerable households and families
Best case combined interventions – heat wave weather data – Typical Family/Vulnerable	Following on from the previous simulation an even more important study would be to indicate the reaction caused by combined interventions during a heat wave. It is through this simulation that the level of risk attributed to the occupants can be assessed and recommendations on further action can be made.

Table 3.5 - Simulation scenarios testing different parameters

4 Data Section

4.1 Simulation Scenario Results

Full series of simulation scenario hourly room temperature data found in Appendix I (I.1-19)

4.1.1 Base Case 1965-1980 semi-detached dwelling – Typical family

	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Degree Hours above thresholds (26°C/28°C)
Location	> 26.00	> 27.00	> 28.00	> 29.00	> 30.00	> 31.00	> 32.00	> 33.00	> 34.00	
Bathroom	0	0	0	0	0	0	0	0	0	0
Bedroom 2	151	97	48	20	4	0	0	0	0	169
Bedroom 1	121	89	49	24	8	0	0	0	0	170
Kitchen	31	19	9	8	3	2	1	0	0	14
Dining Room	10	5	2	1	0	0	0	0	0	1
Living Room	89	54	29	14	8	0	0	0	0	22
Hallway Ground Floor and Stairs	0	0	0	0	0	0	0	0	0	0
1st Floor Hallway and Stairs	0	0	0	0	0	0	0	0	0	0
Bedroom 3	379	256	160	99	63	33	15	6	2	618

Table 4.1 - Base Case 1965-1980 semi-detached dwelling – Typical family - Simulation Degree Hours results

Within the base case, the simulated data presents a starting point to which the proceeding results can be compared (Table 4.1). As widely assumed in previous studies, there is a significant overheating issue within the key rooms measured based on the guidance by CIBSE (2006) defining overheating as the point at which the temperature exceeds the room threshold by 1% as achieved in these results. With a high thermal mass in masonry and no passive or mechanical mitigation techniques used, the building will naturally increase. From Table 4.1 it can be seen that the greatest number of degree hours can be found within the Bedrooms, a room where occupant comfort is key, especially during evenings. The highest amount of degree hours over the period was found in Bedroom 3 (618 d.h), whereby the substantial internal gains produced by the occupants use of electrical in such a small space, restricted the influence of infiltration and natural ventilation, with the window associated being the smallest within all the Bedrooms. This coupled with the double glazed windows increasing the solar gains of the room and with no release of the thermal mass in the evenings through night ventilation, this causes the d.h to increase by trapping the solar gains absorbed.

The reason for the degree hours being so high in the building can also is attributed to the building construction and design. With degree hours being greatest in the Bedrooms (170d.h, 169d.h, 618d.h) and further degree hours over the threshold found in the Living room (22d.h) the combination of internal gains and thermal mass have surpassed the estimated threshold for the building itself. This threshold was established during the buildings original constructions as CIBSE (2006) states that room by room thresholds are based on 3°C above the original design capabilities, and such internal gains, external climates and retrofit changes were not as extreme as they are now. To reduce the impact of high thermal mass the methods used are counteracted by modern building retrofit and ventilation strategies. Even with the minor adaptions done to modern 1965-1980 semi-detached dwellings, the increased air-tightness and heat retention is only enhanced by a lack of thermal mass re-emitting to exterior from night-time. The principle of thermal mass can also be associated with the smaller value of degree hours (22d.h) in the Living room compared to the Bedrooms, whereby Living room has 13% of the d.h compared to Bedroom 2 while 3.5% compared to the total Bedroom 3. In Bedroom 3, the thermal mass would be considerably smaller due to the surface area of the exterior wall, which increases both the absorption and re-admittance of heat. On the other hand, by having a smaller window in Bedroom 3, the solar gains are reduced.

While this can be taken into account, the more significant influence on this data is the greater threshold for Living rooms (28°C). Had the Living room had a 26°C threshold, the degree hours would have been 105d.h showing that the orientation (causing the north side to have reduced d.h) and occupant/internal gains to be greater causes. These findings show the importance of the established threshold as it can be directly linked to the health of the occupants. This indicates that greater measures must be instigated to reduce overheating in Bedroom where the risk is greatest and the results are most disconcerting for occupant health.

The explanations above for the base case 1965-1980 semi-detached dwellings can be attributed to all of the following simulations as the basic issues with the building are recurring as they are based on the same design, only with individual parameter adjustments to change the overheating value. Therefore, in the results the explanations covered only that of the simulation intervention change as the contributing factors above are generally recurring throughout.

4.1.2 Retrofitted to 2010 Building Regulations, 1965-1980 semi-detached dwelling – Typical family

	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Degree Hours above thresholds (26°C/28°C)
Location	> 26.00	> 27.00	> 28.00	> 29.00	> 30.00	> 31.00	> 32.00	> 33.00	
Bathroom	0	0	0	0	0	0	0	0	0
Bedroom 2	171	72	19	5	0	0	0	0	96
Bedroom 1	162	71	24	7	0	0	0	0	102
Kitchen	44	32	23	13	4	4	1	1	23
Dining Room	10	5	2	1	0	0	0	0	1
Living Room	114	63	28	12	3	0	0	0	15
Hallway Ground Floor and Stairs	0	0	0	0	0	0	0	0	0
1st Floor Hallway and Stairs	0	0	0	0	0	0	0	0	0
Bedroom 3	519	341	194	98	43	17	5	0	698

Table 4.2 - Retrofitted to 2010 Building Regulations, 1965-1980 semi-detached dwelling – Typical family - Simulation Degree Hours result

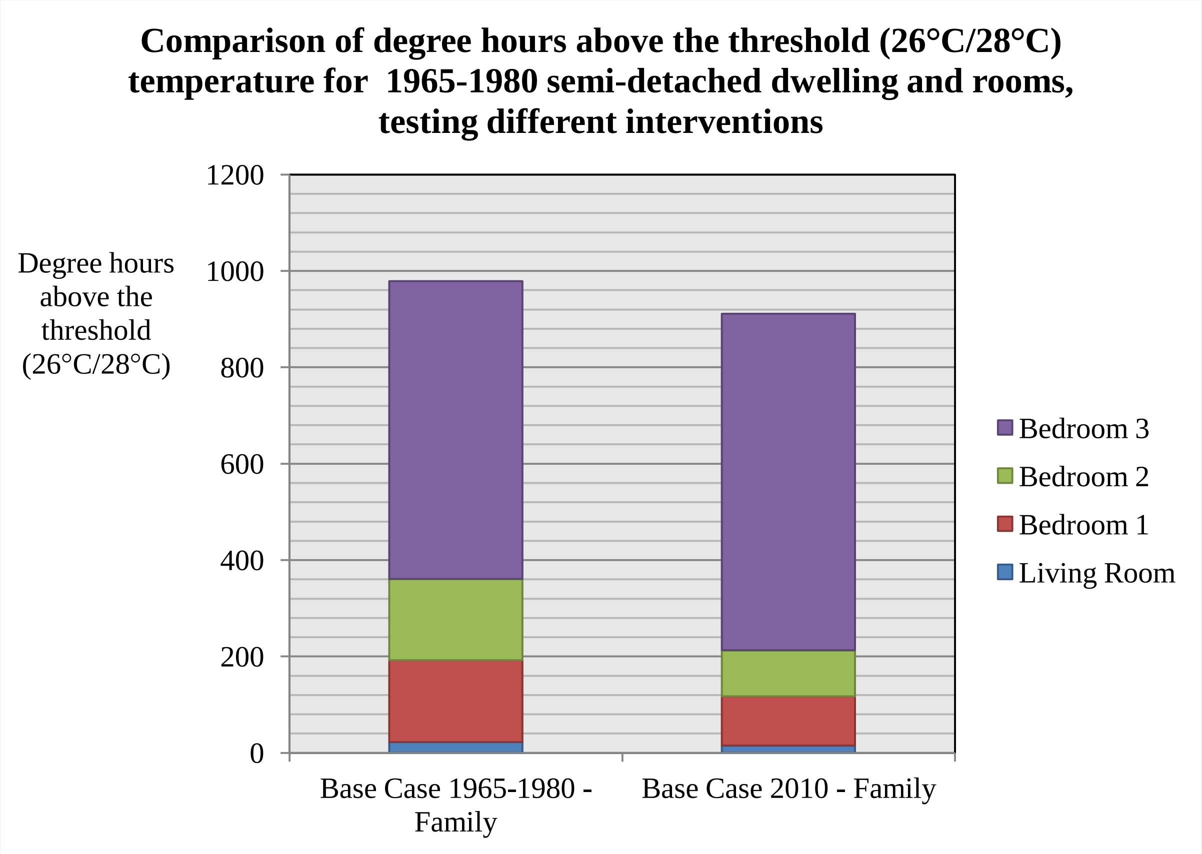

Figure 4. 1 - Comparison of degree hours above the threshold (26°C/28°C) temperature for 1965-1980 semi-detached dwelling and Base case Retrofitted to 2010 Building Regulations

The results above (Table 4.2/Figure 4.1) show that the measured imposed by the 2010 Building Regulations had in fact reduced the degree hours in the building for all rooms except Bedroom 3.While multiple reports and journal papers (eg. Porritt (2012), Partington, (2012) and Energy Saving Trust (2005)) give evidence that the improved levels of insulation increase heat loss and ventilation, there are theories that the increased insulation would reduce gains through the fabric through thermal mass. As with the work of Mavrogianni, et al. (2012) the same reduction was found, however he was inconclusive to the reasons why, citing the need for more research into the link with thermal mass. One explanation is that the thermal insulation restricts convection heat flow into the building, as the while the exterior material has high thermal conductivity the insulation has a low thermal conductivity and high thermal capacity to store the heat. Therefore when the heat is absorbed by the outer masonry the rate of heat transfer into the building is reduced compared to unfiled cavities with higher rates of conductivity. This principle is also used for the triple glazed windows as the rate of heat transfer is based on the panes being at optimum thickness from each other to reduce the level of radiant heat transfer, thus reducing the solar gains through the window. The risk with this pattern however, is that during the evening the high thermal mass of the build may radiate the heat back into the rooms due to lack of infiltration and ventilation in the dwelling. Further explanation may be made into the type of material used for the insulation as a change in materials when retrofitting to the 2010 Regulations would adjust the level of conductivity, thickness, density etc. The other anomaly found is within the Bedroom 3 degree hours increased contrary to the rest of the dwelling. With such high level of internal gains and reduced ventilation, the explanation for the reduced overheating may be offset by the scale of overheating in the room. Further research is needed in this field, as changes to the window glazing may be contributing factor to these results. On the other hand, if this type of simulation is repeated and similar trends are found, this would be extremely useful information. By showing that the introduction of 2010 Regulations in fact reduces overheating risk, the opportunity for thermal comfort in winter and summer is momentous to occupant health and the consideration of overheating to future Building Regulations.

4.1.3 Base Case 1965-1980 semi-detached dwelling – Typical vulnerable (Elderly resident) family

	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Degree Hours above thresholds (26°C/28°C)
Location	> 26.00	> 27.00	> 28.00	> 29.00	> 30.00	> 31.00	
Bathroom	0	0	0	0	0	0	0
Bedroom 2	0	0	0	0	0	0	0
Bedroom 1	70	57	28	10	0	0	95
Kitchen	22	16	8	6	1	1	8
Dining Room	15	10	5	1	1	0	2
Living Room	85	53	32	15	4	0	19
Hallway Ground Floor and Stairs	0	0	0	0	0	0	0
1st Floor Hallway and Stairs	0	0	0	0	0	0	0
Bedroom 3	0	0	0	0	0	0	0
Shared hours ('OR' tests)	176	125	68	31	5	1	230

Table 4.3 – Base Case 1965-1980 semi-detached dwelling – Typical vulnerable (Elderly resident) family - Simulation Degree Hours result

4.1.4 Retrofitted to 2010 Building Regulations, 1965-1980 semi-detached dwelling – Typical vulnerable (Elderly resident) family

	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Degree Hours above thresholds (26°C/28°C)
Location	> 26.00	> 27.00	> 28.00	> 29.00	> 30.00	> 31.00	
Bathroom	0	0	0	0	0	0	0
Bedroom 2	0	0	0	0	0	0	0
Bedroom 1	57	29	17	0	0	0	46
Kitchen	20	16	8	7	1	1	9
Dining Room	12	9	5	1	1	0	2
Living Room	83	50	32	13	3	0	16
Hallway Ground Floor and Stairs	0	0	0	0	0	0	0
1st Floor Hallway and Stairs	0	0	0	0	0	0	0
Bedroom 3	0	0	0	0	0	0	0

Table 4.4 - Retrofitted to 2010 Building Regulations, 1965-1980 semi-detached dwelling – Typical vulnerable (Elderly resident) family - Simulation Degree Hours result

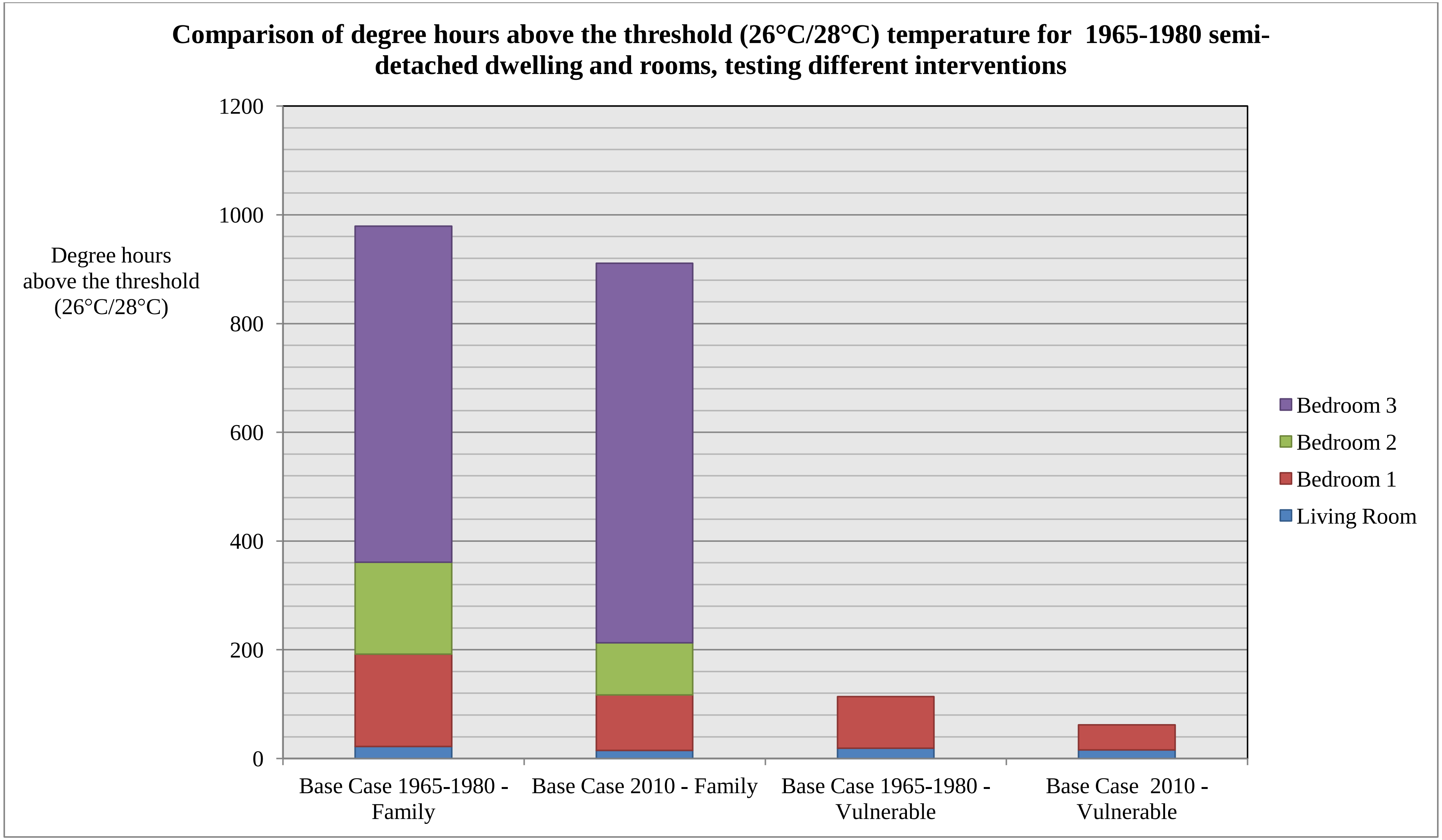

Figure 4.2 - Comparison of degree hours above the threshold (26°C/28°C) temperature for both base cases for Family and Vulnerable profiles

By applying the vulnerable occupancy and appliance usage data to the original 2010 Building Regulations adapted dwelling it can be seen that the amount of overheating is substantially less within the Bedroom (56d.h in Bedroom 1), while increase by 1d.h in the Living room (Table 4.3/4.4/Figure 4.2). This data is further evidence of the extent of impact thermal mass and internal gains have upon the internal temperature and number of degree hours created. While the elderly couple spend 13 hours in the Living room the family spend only 4 hours a day in the Living room, yet only have ones less degree hours. Similarly, Bedroom 1, which is used by both and only one hour of occupancy less by the two family adults has 221% greater degree hours. Two factors are therefore used to explain this situation as with greater number of occupants in the building and greater number of appliances in the building the impact these have on the internal temperature is greater than that of the elderly couples' gains. The first possible cause is with the greater number of occupants this will incur higher levels of latent heat (immediate heating load) as with the building absorbing more heat from the occupant's sensible heat gains. Secondly the typical family has a greater density of appliances and occupant sensible heat gains in the evening, possibly causing a reduction in the rate of re-radiation of heat to the exterior, further reduced by the cooling factor of the internal gains re-releasing heat in the interior during the night. (Varkie, 2003)

While it is suggested by previous studies that these occupants would have a greater number of degree hours (Zero Carbon Hub, 2012); with increased level of exposure during peak day times, it can be seen that the occupancy of the dwelling and internal gains are suggested to reduce the risk. On the other hand, different types of dwelling with higher occupancy density for the elderly may show different results. However, what must be established is that there is still considerable risk and evidence of overheating in this scenario and interventions and mitigation is still needed to reduce the degree hours below the thresholds.

As with the family profile, the degree hours were seen to increase when the 2010 Building Regulations were implemented into the building. The same arguments can be made once again for the causes of this increase.

4.1.5 Updated modern and future internal gains and the occupant type's weekday and weekend time profiles

	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Degree Hours above thresholds (26°C/28°C)
Location	> 26.00	> 27.00	> 28.00	> 29.00	> 30.00	
Bathroom	0	0	0	0	0	0
Bedroom 2	137	54	11	1	0	66
Bedroom 1	137	64	24	0	0	88
Kitchen	19	12	8	3	2	5
Dining Room	8	4	2	1	0	1
Living Room	81	44	21	11	0	11
Hallway Ground Floor and Stairs	0	0	0	0	0	0
1st Floor Hallway and Stairs	0	0	0	0	0	0
Bedroom 3	268	146	65	29	4	244

Table 4.5 - Updated modern and future internal gains and the occupant type's weekday and weekend time profile - Simulation Degree Hours result

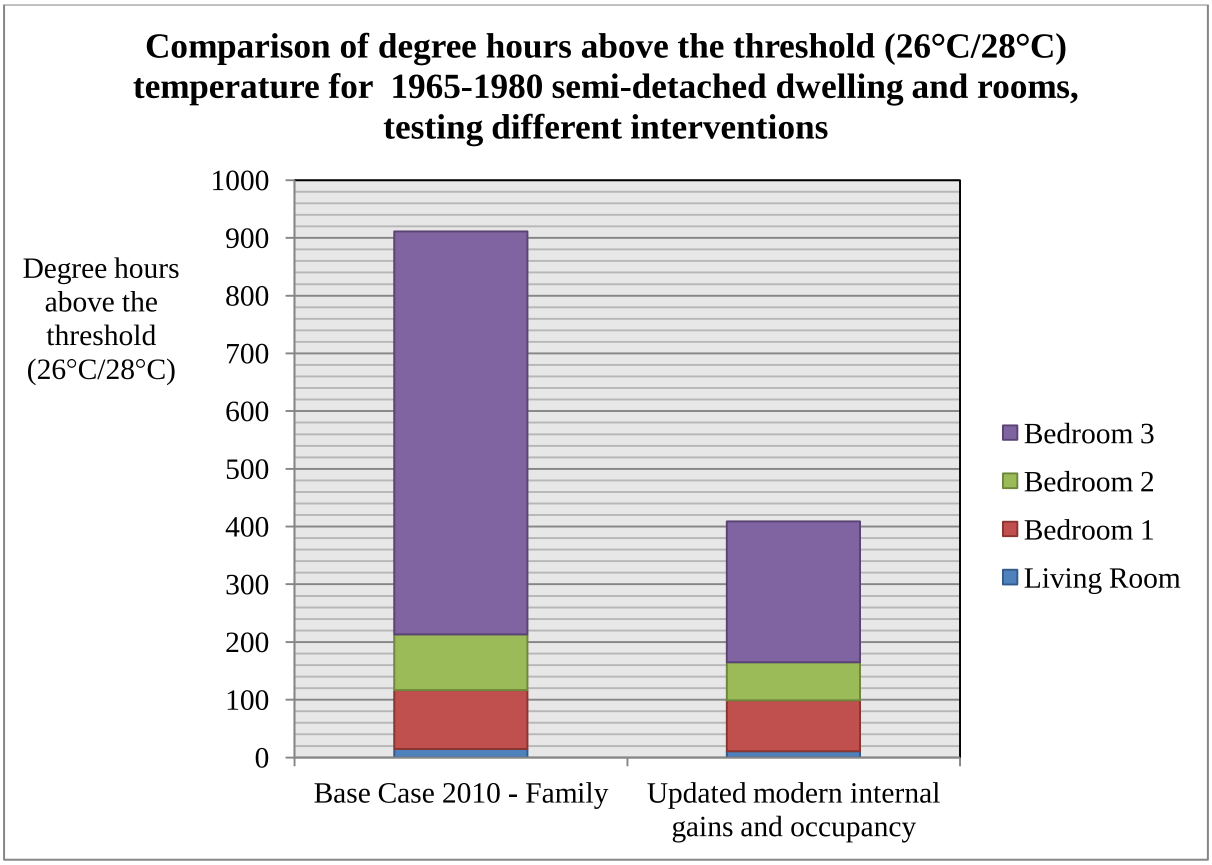

Figure 4.3 - Comparison of degree hours above the threshold (26°C/28°C) temperature for Base case Retrofitted to 2010 Building Regulations for Family and Updated modern internal gains and occupancy

These results (Table 4.5/Figure 4.3) effectively highlight the importance of internal gains and the efficiency of appliances to the chances of overheating in dwellings. Contradicting the evidence of (Jenkins, et al. (2009) that adjusting the total amount of internal gains and time profiles of appliances would be a “prudent” solution, this evidence supports Peacock, et al. (2010), and stressing the impact it has upon increasing thermal mass during the day. This impact is non-so-apparent as in Bedroom 3, whereby the reduced efficiency and resultant internal gain reduction caused 34% reduction in degree hours. An important factor to consider however is suggested by Schlomann (2009) on the state of flux in this scenario. Currently, the efficiency of appliance is not yet up to the estimated efficiency used in these simulations as they are based on 2020 appliances. Therefore, taking into account only the current increase in quantity of appliances in UK dwellings, a model based on current efficiency, time and quantity increases would have greater total degree hours. In the wider aspect of these results, it can be seen that predicted future adjustments to appliance usage, quantity and efficiency will in fact reduce the impact of overheating, compared to the inefficient current usage, however this is constantly changing. Beyond the technological upgrades one of the causes for this increase in efficiency is appliances having a quicker response to shifting to stand-by power or in other cases occupants turning the power off instead.

4.1.6 Building Regulations 2010 Approved Document material upgrades to include external insulation

	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Degree Hours above thresholds (26°C/28°C)
Location	> 26.00	> 27.00	> 28.00	> 29.00	> 30.00	> 31.00	> 32.00	
Bathroom	0	0	0	0	0	0	0	0
Bedroom 2	188	64	13	2	0	0	0	79
Bedroom 1	181	72	22	0	0	0	0	94
Kitchen	46	32	26	15	5	3	1	24
Dining Room	10	5	2	1	0	0	0	1
Living Room	123	65	28	11	0	0	0	11
Hallway Ground Floor and Stairs	0	0	0	0	0	0	0	0
1st Floor Hallway and Stairs	0	0	0	0	0	0	0	0
Bedroom 3	580	362	218	98	41	15	2	736

Table 4.6 - Building Regulations 2010 Approved Document material upgrades to include external insulation - Simulation Degree Hours result

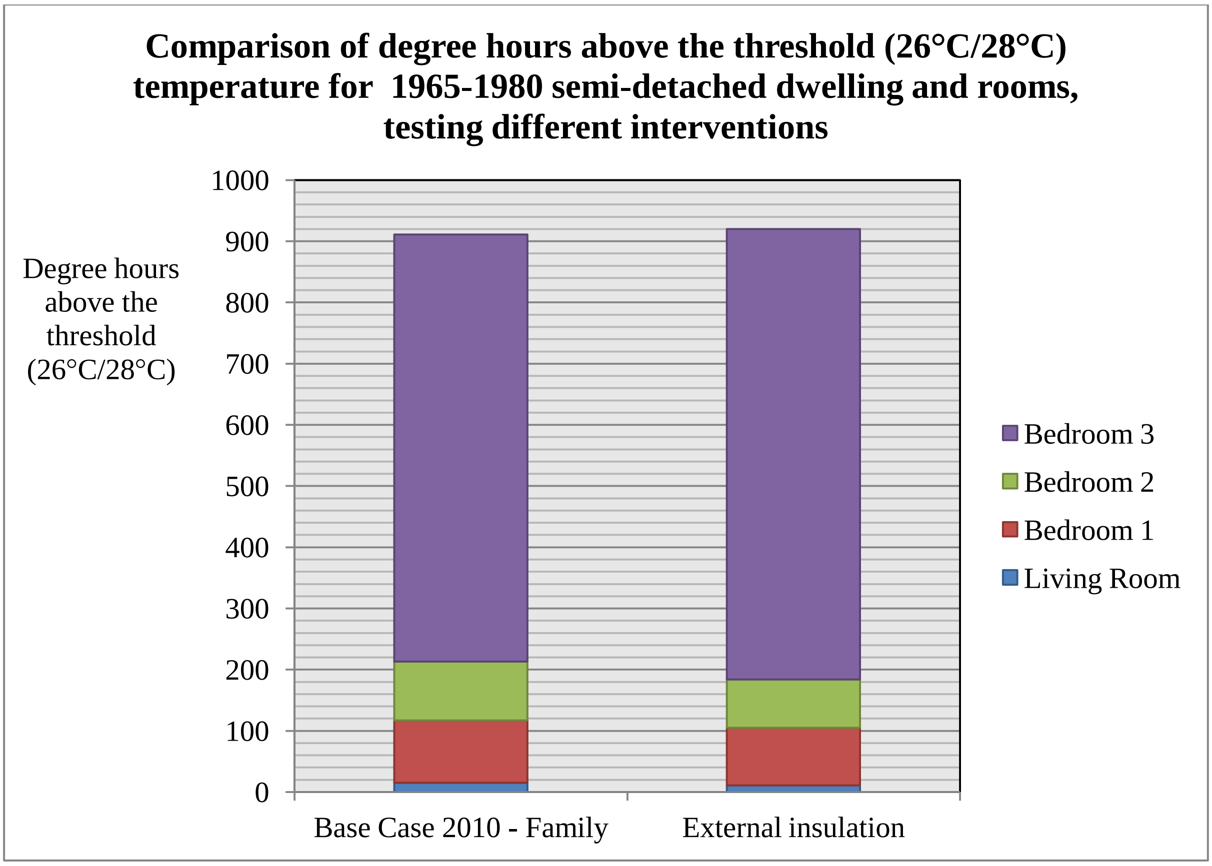

Figure 4.4 - Comparison of degree hours above the threshold (26°C/28°C) temperature for Base case Retrofitted to 2010 Building Regulations and External insulation upgrades

Unlike previous studies into mitigating overheating, such as by (Porritt, 2012) and (Shao, et al., 2011), the results in Table 4.6/Figure 4.4 show that for all the Bedrooms and the Living room, external insulation in fact caused an increase in the amount of degree hours over the thresholds overall. Individually, however, the degree hours in Bedrooms 1 and 2 and the Living room decreased, which can be attributed to the effects of thermal mass once again. By having the insulation on the exterior, the thermal mass is reduced as insulation has a low absorption rate compared to thermally heavy material such as brick. On the other hand, other than possible anomalies, the Bedroom 3 increase can be attributed to other factors. By changing the insulation to exterior, there will be changes to the insulation materials used, the conductivity and the thickness to take into account. All of these factors affect the buildings ability to retain heat and control infiltration rates, as by applying external insulation can cause increases in air tightness and counteract the reductions in thermal mass created, potentially impacting some areas of the building more than others (eg. Bedroom 3).

4.1.7 Alternative Cross-ventilation (double banked rooms) design

	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Degree Hours above thresholds (26°C/28°C)
Location	> 26.00	> 27.00	> 28.00	> 29.00	> 30.00	> 31.00	> 32.00	
Bathroom	0	0	0	0	0	0	0	0
Bedroom 2	157	66	16	3	0	0	0	85
Bedroom 1	146	65	24	5	0	0	0	94
Kitchen	34	27	15	5	4	2	1	12
Dining Room	10	5	2	1	1	0	0	2
Living Room	60	30	12	4	0	0	0	4
Hallway Ground Floor and Stairs	0	0	0	0	0	0	0	0
1st Floor Hallway and Stairs	0	0	0	0	0	0	0	0
Bedroom 3	490	318	183	94	38	17	4	654

Table 4.7 - Alternative Cross-ventilation (double banked rooms) design - Simulation Degree Hours result

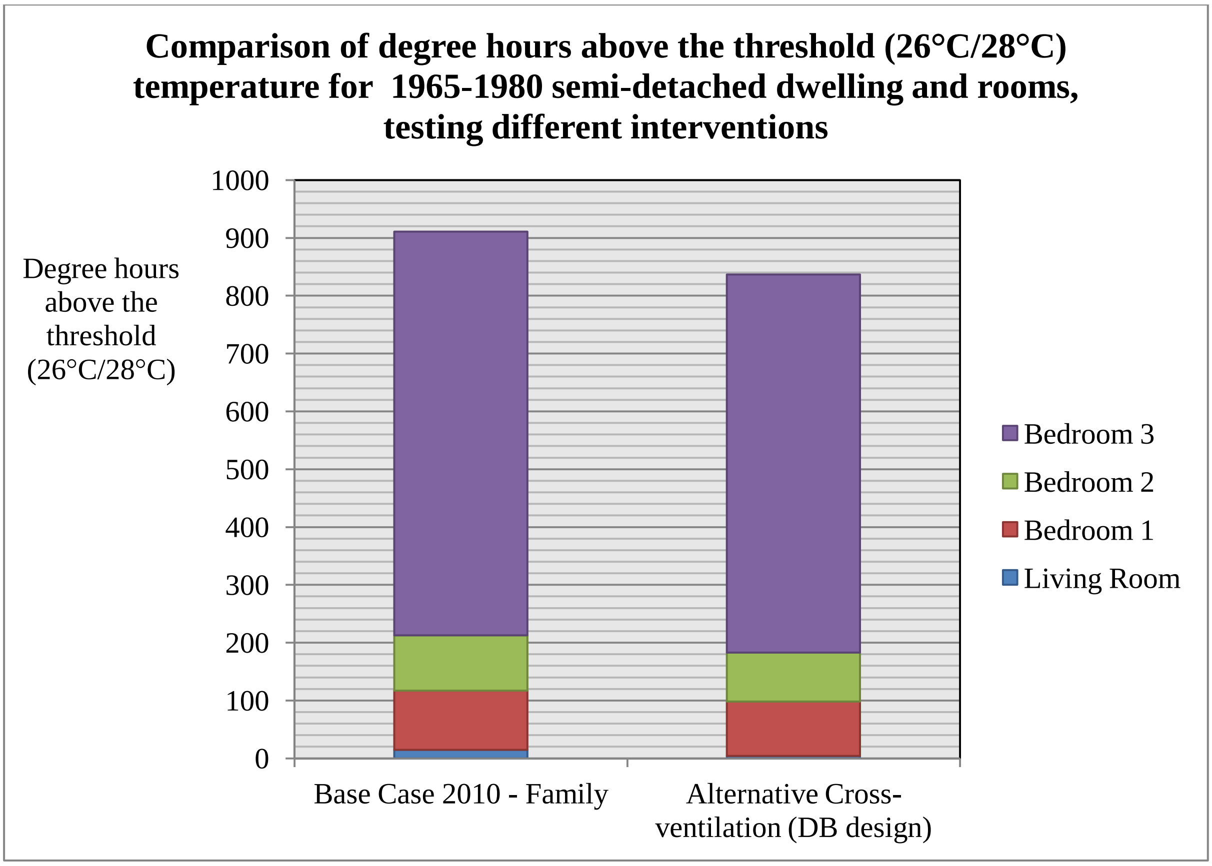

Figure 4.5 - Comparison of degree hours above the threshold (26°C/28°C) temperature for Base case Retrofitted to 2010 Building Regulations and Alternative cross-ventilation (double banked rooms) design

In order to show the impact of different ventilation strategies on the overheating degree hours, the base case had a set window and doors opening schedule based on a threshold temperature of 22°C. These results (Table 4.7/ Figure 4.5) show that by implementing this particular strategy the number of degree hours decreased to 94d.h, 85d.h and 654 d.h, caused by the influence of air changes in the dwelling, enhanced by the cross ventilation design. This design in particular had substantial improvement on other ventilation strategies. By having both a Living room archway built and a door opening strategy that was permanently open during the occupied day time, the number of air changes an hour increased. As the warm air in the building was recycled at an increased rate (caused by differing pressures on the two sides of the building) forcing out the built up heat, as Porritt (2012) stated, with cross ventilation, the building has is 8 ACH compared to 5 ACH without. Another explanation for these findings are that the orientation of the building is at an angle to which the flow of wind is greater than a west/east wind direction, as different types of buildings without adjoined dwellings or facing another direction may have different results. Conversely however, the extent of difference to the base case is not as great as expected, possible due to the effects of increased solar gains and warm air incursion. Other explanation are that with the principle of cross ventilation, that with the internal velocity being less than that of external (prevailing wind dependant), the cross ventilation does not accelerates air movement at the other end at the same rate, with cross ventilation single space a better (yet less feasible) option. (RIBA, 2012)

4.1.8 Alternative single sided ventilation design – daytime

	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Degree Hours above thresholds (26°C/28°C)
Location	> 26.00	> 27.00	> 28.00	> 29.00	> 30.00	> 31.00	> 32.00	> 33.00	
Bathroom	0	0	0	0	0	0	0	0	0
Bedroom 2	317	139	37	6	0	0	0	0	182
Bedroom 1	270	129	65	8	0	0	0	0	202
Kitchen	70	56	39	32	15	8	4	2	61
Dining Room	16	7	2	1	0	0	0	0	1
Living Room	169	100	48	24	4	0	0	0	28
Hallway Ground Floor and Stairs	0	0	0	0	0	0	0	0	0
1st Floor Hallway and Stairs	0	0	0	0	0	0	0	0	0
Bedroom 3	775	542	345	200	91	34	15	2	1229

Table 4.8 - Alternative single sided ventilation design - daytime - Simulation Degree Hours result

4.1.9 Alternative single sided ventilation design - night-time

	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Degree Hours above thresholds (26°C/28°C)
Location	> 26.00	> 27.00	> 28.00	> 29.00	> 30.00	> 31.00	> 32.00	> 33.00	> 34.00	
Bathroom	0	0	0	0	0	0	0	0	0	0
Bedroom 2	10	0	0	0	0	0	0	0	0	0
Bedroom 1	0	0	0	0	0	0	0	0	0	0
Kitchen	75	51	39	21	13	7	4	2	1	42
Dining Room	5	0	0	0	0	0	0	0	0	0
Living Room	31	14	0	0	0	0	0	0	0	0
Hallway Ground Floor and Stairs	0	0	0	0	0	0	0	0	0	0
1st Floor Hallway and Stairs	0	0	0	0	0	0	0	0	0	0
Bedroom 3	202	116	60	26	8	0	0	0	0	210

Table 4.9 - Alternative single sided ventilation design – night-time - Simulation Degree Hours result

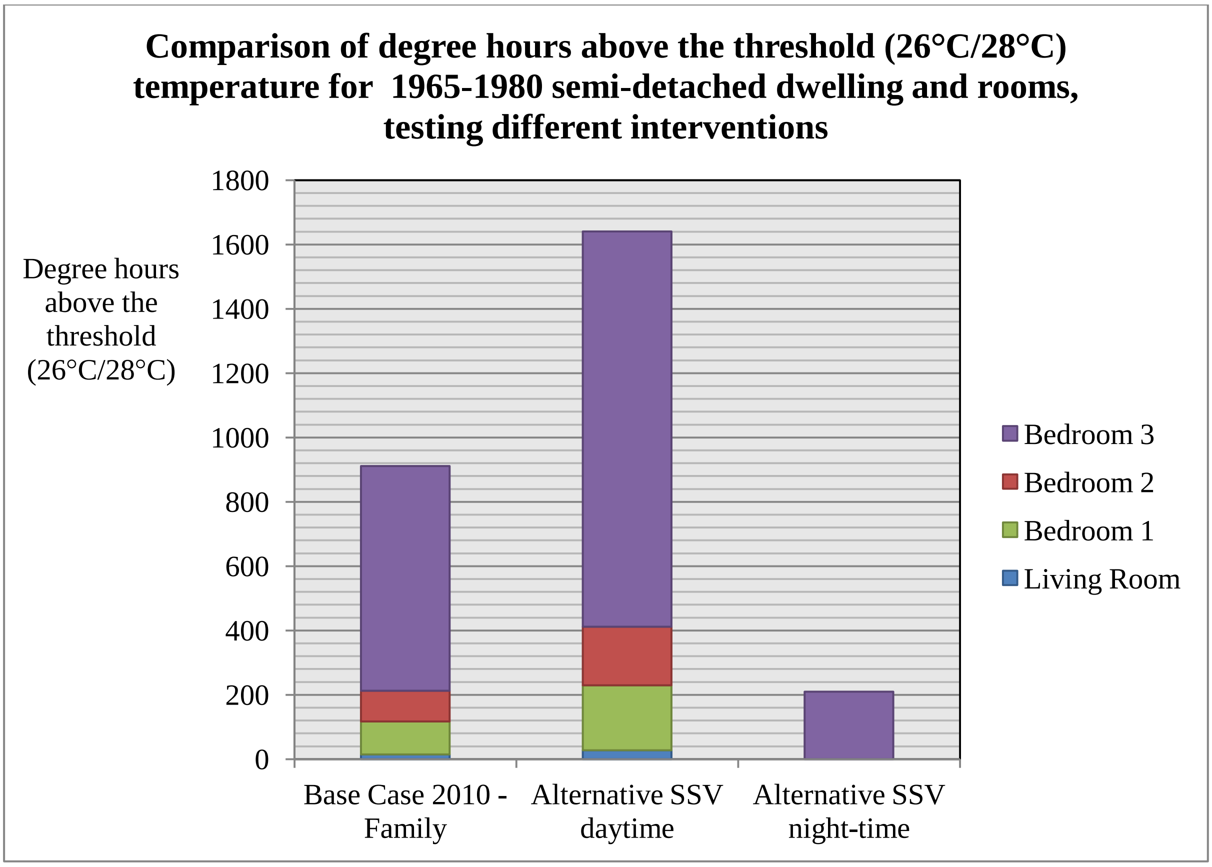

Figure 4.6 - Comparison of degree hours above the threshold (26°C/28°C) temperature for Base case Retrofitted to 2010 Building Regulations and both SSV day and SSV night-time

By using single sided ventilation strategies the results can differ based on the period of day it is implemented, highlighting the impact of night time ventilation in dwellings as a successful form of overheating mitigation. Covering the Bedrooms 1/2 and the Living room, the night time ventilation (Table 4.9/Figure 4.6) in fact removed the risk of overheating altogether, whilst causing a 582% increase in degree hours when using daytime over night time ventilation (Table 4.8/ Figure 4.6) in Bedroom 3. The most effective method of thermal mass reductions is night-time, as the hot air absorbed in the building fabric is most effectively emitted by the building during the night. By using a day single sided ventilation strategy, the absorbed thermal mass is continually trapped in the building and with no door opening strategy, can only be emitted during the day when the building re-absorbs further heat through infiltration. Ina wider scale these results prove the effectiveness of night ventilation, while opening up further question to whether if combined with the cross ventilation strategy of increasing the ACH during the night, what effect would this have on removing overheating in all rooms, even during heat waves. Overall, the results show the importance of ventilation strategies in reducing the number of degree hours over the threshold, as the two extremes of the methods cause both the largest contributor and mitigator of the scenarios to overheating. This proves that the most effective method and most contributing factor to overheating are ventilation and air flow controls, rather than the reduction and or limitation of internal gains.

4.1.10 Retrofitted to 2010 Building Regulations, 1965-1980 semi-detached dwelling – North Facing Orientation

	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Degree Hours above thresholds (26°C/28°C)
Location	> 26.00	> 27.00	> 28.00	> 29.00	> 30.00	> 31.00	> 32.00	> 33.00	> 34.00	
Bathroom	0	0	0	0	0	0	0	0	0	0
Bedroom 2	277	146	65	16	2	0	0	0	0	229
Bedroom 1	108	48	16	0	0	0	0	0	0	64
Kitchen	46	35	32	18	11	4	4	1	1	33
Dining Room	12	6	2	1	1	0	0	0	0	2
Living Room	86	41	21	8	0	0	0	0	0	8
Hallway Ground Floor and Stairs	0	0	0	0	0	0	0	0	0	0
1st Floor Hallway and Stairs	0	0	0	0	0	0	0	0	0	0
Bedroom 3	439	261	129	61	23	6	2	0	0	482

Table 4.10 - Retrofitted to 2010 Building Regulations, 1965-1980 semi-detached dwelling – North Facing Orientation- Simulation Degree Hours result

4.1.11 Retrofitted to 2010 Building Regulations, 1965-1980 semi-detached dwelling – West Facing Orientation

	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Degree Hours above thresholds (26°C/28°C)
Location	> 26.00	> 27.00	> 28.00	> 29.00	> 30.00	> 31.00	> 32.00	> 33.00	> 34.00	> 35.00	
Bathroom	0	0	0	0	0	0	0	0	0	0	0
Bedroom 2	395	214	97	32	8	0	0	0	0	0	351
Bedroom 1	240	118	41	16	6	0	0	0	0	0	181
Kitchen	50	41	29	19	12	7	4	2	1	1	45
Dining Room	13	6	2	1	1	0	0	0	0	0	2
Living Room	171	104	54	26	11	8	0	0	0	0	45
Hallway Ground Floor and Stairs	0	0	0	0	0	0	0	0	0	0	0
1st Floor Hallway and Stairs	0	0	0	0	0	0	0	0	0	0	0
Bedroom 3	564	354	213	110	55	17	6	4	0	0	759

Table 4.11 - Retrofitted to 2010 Building Regulations, 1965-1980 semi-detached dwelling – West Facing Orientation- Simulation Degree Hours result

4.1.12 Retrofitted to 2010 Building Regulations, 1965-1980 semi-detached dwelling – South West Orientation

	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Degree Hours above thresholds (26°C/28°C)
Location	> 26.00	> 27.00	> 28.00	> 29.00	> 30.00	> 31.00	> 32.00	> 33.00	
Bathroom	0	0	0	0	0	0	0	0	0
Bedroom 2	251	127	42	11	1	0	0	0	181
Bedroom 1	203	99	39	16	0	0	0	0	154
Kitchen	47	33	26	15	6	4	2	1	28
Dining Room	11	6	2	1	0	0	0	0	1
Living Room	139	80	44	19	8	1	0	0	28
Hallway Ground Floor and Stairs	0	0	0	0	0	0	0	0	0
1st Floor Hallway and Stairs	0	0	0	0	0	0	0	0	0
Bedroom 3	534	348	201	104	50	18	7	1	729

Table 4.12 - Retrofitted to 2010 Building Regulations, 1965-1980 semi-detached dwelling – South West Facing Orientation- Simulation Degree Hours result

4.1.13 Retrofitted to 2010 Building Regulations, 1965-1980 semi-detached dwelling – East Facing Orientation

	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Degree Hours above thresholds (26°C/28°C)
Location	> 26.00	> 27.00	> 28.00	> 29.00	> 30.00	> 31.00	> 32.00	> 33.00	
Bathroom	0	0	0	0	0	0	0	0	0
Bedroom 2	436	252	114	44	14	5	0	0	429
Bedroom 1	263	155	65	21	0	0	0	0	241
Kitchen	49	38	31	17	8	4	1	1	31
Dining Room	16	7	4	1	1	0	0	0	2
Living Room	157	92	51	23	8	0	0	0	31
Hallway Ground Floor and Stairs	0	0	0	0	0	0	0	0	0
1st Floor Hallway and Stairs	0	0	0	0	0	0	0	0	0
Bedroom 3	631	420	257	140	66	24	7	2	916

Table 4.13 - Retrofitted to 2010 Building Regulations, 1965-1980 semi-detached dwelling – East Facing Orientation- Simulation Degree Hours result

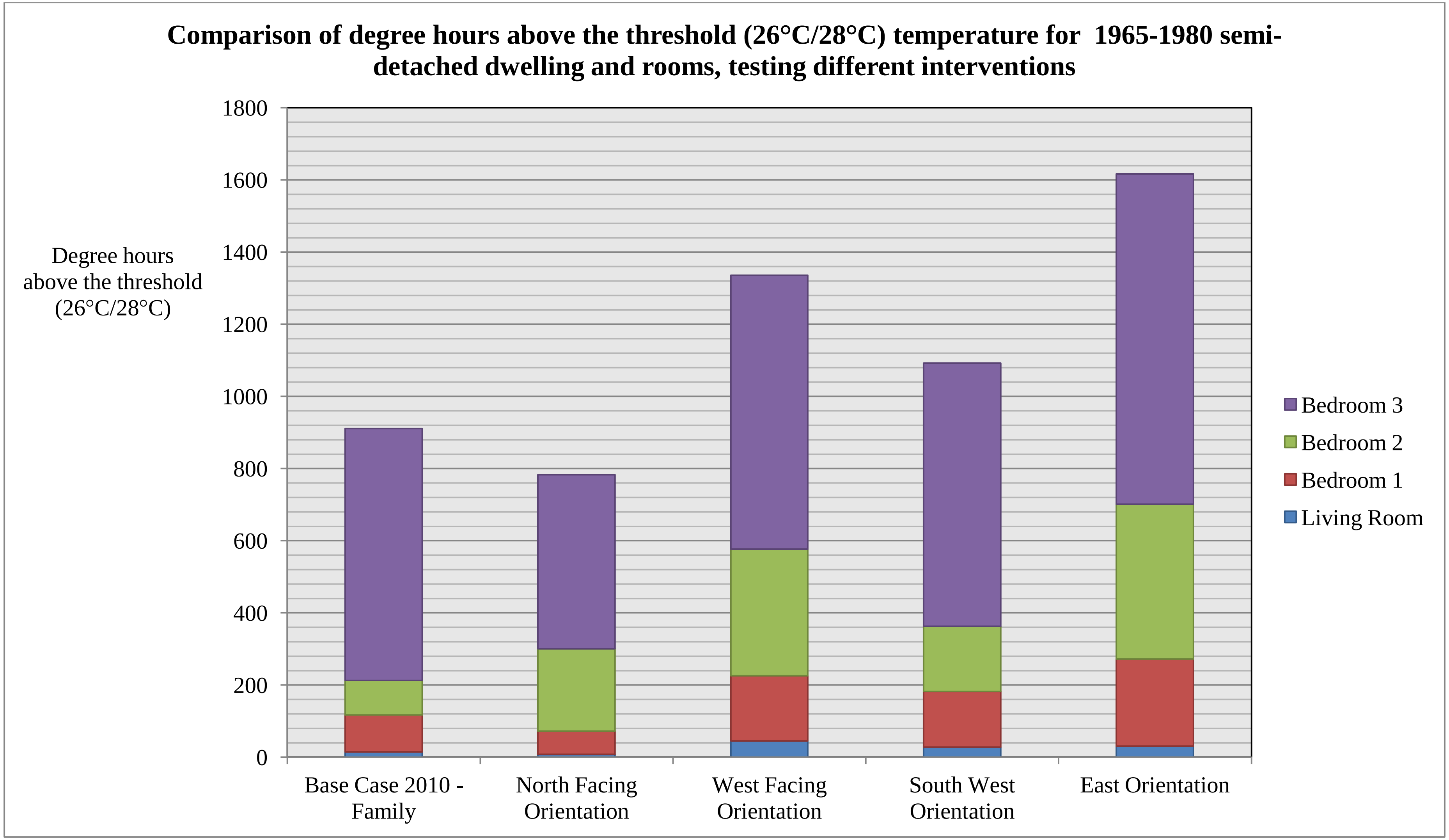

Figure 4.7 - Comparison of degree hours above the threshold (26°C/28°C) temperature for Base case Retrofitted to 2010 Building Regulations and different orientations

In terms of orientation it is widely understood from research such as (Haase & Amato, 2009) that a North/ South orientation is the most effective in reducing overheating, however these results (Table 4./10/11/12/13, Figure 4.7) would help prove the scale of the advantages the different orientations have. Taking the dwelling as whole, the combined degree hours totals for the chosen rooms for each orientation is show In Table 4.14:

	Orientation				
	South	North	East	West	South West
Total Degree hours above thresholds (26°C/28°C)	972	783	1617	1336	1092

Table 4.14 - Comparison of total Degree hours above thresholds for different orientations

Based on the theories of solar gains, these results follow the standard expectations of East, West gains being the greatest as the largest windows at the back of the building face the sun later in the day when the external temperature is greatest and the internal gains are at their highest. Another aspect of the orientation which was investigating was a room by room analysis, as the orientation change can affect different rooms at different times of the day. However from the results above, it can be seen that the orientation changes has no anomalies between rooms and the standard pattern seen in total degree hours is seen in individual room comparisons.

As established by Haase & Amato (2009) the optimum orientation for summer is 90° to the optimum orientation for winter, therefore, by showing that there is a 834d.h difference between the optimum North facing orientation and East facing orientations, highlight the need for further investigation into which orientation is best for occupants thought the year. If standard retrofit is sufficient to improve winter comfort needs, then the orientation to suit summer needs is more important, a comparison that can be made using degree hours over the threshold in summer and degree hours under in winter. As the report is based on retrofitting previously built dwellings, the cost of changing the orientation of a dwelling is beyond recommendations, therefore, these results would instead highlight the extent of need for other mitigatory action to be made for East/West orientations, such as solar shading.

4.1.14 Heat wave Weather simulation - Retrofitted to 2010 Building Regulations, 1965-1980 semi-detached dwelling – Typical family time profile

	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Degree Hours above thresholds (26°C/28°C)
Location	> 26.00	> 27.00	> 28.00	> 29.00	> 30.00	> 31.00	> 32.00	> 33.00	> 34.00	> 35.00	
Bathroom	0	0	0	0	0	0	0	0	0	0	0
Bedroom 2	481	269	159	95	67	20	1	0	0	0	611
Bedroom 1	371	219	103	68	44	36	0	0	0	0	470
Kitchen	71	56	45	27	18	12	6	4	3	1	58
Dining Room	28	16	9	6	3	2	1	0	0	0	12
Living Room	221	148	89	41	27	17	14	0	0	0	99
Hallway Ground Floor and Stairs	0	0	0	0	0	0	0	0	0	0	0
1st Floor Hallway and Stairs	0	0	0	0	0	0	0	0	0	0	0
Bedroom 3	869	654	437	271	168	103	59	26	13	4	1659

Table 4.15 - Heat wave Weather simulation - Retrofitted to 2010 Building Regulations, 1965-1980 semi-detached dwelling – Typical family time profile - Simulation Degree Hours result

The aim of this report is to produce a comprehensive study into what are the contributing factors and instigators to overheating in UK 1965-1980 semi-detached dwelling and the effects of the newly introduced 2010 Building Regulations on this. The rationale for this question is to understand how the occupants' actions to adapting their own dwelling to winter energy efficiency standards can impact their own health and how this risk is reduced. With this in mind, the growing urgency for a reaction to this issue is based upon the rising temperatures in the UK summer, and increasing probability of heat waves caused by climate change. Therefore with this data (Table 4.15), the scale of hours beyond the threshold shows the extent of risk associated with current lifestyles coupled with modern retrofit adaptions that in future will only increase. Under current conditions, the effects of a heat wave have had well documented impacts on the health of both the vulnerable and standard families and therefore, implementation of interventions to increasing overheating and passive adaption are needed.

Figure 4.8 and Table 4.16 below compares the scale of increase in degree hours caused by a heat wave on the same dwelling. Ultimately it shows the size of the reduction required to make the dwelling thermally comfortable and safe for occupants.

	Simulation Scenario		
	Base Case 1965-1980 semi-detached dwelling – Typical family (Degree Hours)	Heat wave simulation - Base Case 1965-1980 semi-detached dwelling – Typical family (Degree Hours)	Percentage increase in Degree Hours between before and after heat waves (%)
Living Room	15	99	560%
Bedroom 1	102	470	361%
Bedroom 2	96	611	537%
Bedroom 3	698	1659	138%

Table 4.16 - Percentage increase in Degree Hours between before and after heat waves – typical family

4.1.15 Heat wave Weather simulation - Base Case 1965-1980 semi-detached dwelling – Typical vulnerable (Elderly resident) time profile

	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Degree Hours above thresholds (26°C/28°C)
Location	> 26.00	> 27.00	> 28.00	> 29.00	> 30.00	> 31.00	> 32.00	> 33.00	
Bathroom	0	0	0	0	0	0	0	0	0
Bedroom 2	0	0	0	0	0	0	0	0	0
Bedroom 1	106	65	48	22	18	0	0	0	153
Kitchen	49	33	19	12	8	3	2	1	26
Dining Room	31	15	11	4	4	1	1	0	10
Living Room	176	97	57	41	19	12	3	0	75
Hallway Ground Floor and Stairs	0	0	0	0	0	0	0	0	0
1st Floor Hallway and Stairs	0	0	0	0	0	0	0	0	0
Bedroom 3	0	0	0	0	0	0	0	0	0

Table 4.17 - Heat wave Weather simulation - Base Case 1965-1980 semi-detached dwelling – Typical vulnerable (Elderly resident) time profile

Based on the previous study of the "Retrofitted to 2010 Building Regulations, 1965-1980 semi-detached dwelling – Typical vulnerable (Elderly resident) family" the results (Table 4.17) show that there is only a small amount of risk associated with the vulnerable when 1965-1980 semi-detached dwellings are retrofitted to 2010 Building Regulations. From the further test of heat wave situations, the risk follows the pattern of the family profile and increases substantially. Within the key rooms the total number of degree hours increase as seen in Table 4.18 and Figure 4.8, to a point at which significant risk is now attributed to the occupants whilst in the dwelling. When the heat wave data was implemented for the typical family the total number of degree hours increase by 211% while by 268% for the vulnerable. Even though Figure 4.8 shows that the risk is greater for the family, the percentage increase highlights the increase that can occur to the vulnerable. Seeing as the occupants are classified as vulnerable, the health risks concerned are greater than that of a standard family, expressing a similar need for interventions or mitigation to be implemented now.

	Simulation Scenario		
	Base Case 1965-1980 semi-detached dwelling – Typical vulnerable (Elderly resident) time profile (Degree Hours above thresholds (26°C/28°C)	Heat wave simulation - Base Case 1965-1980 semi-detached dwelling – Typical vulnerable (Elderly resident) time profile (Degree Hours above thresholds (26°C/28°C)	Percentage increase in Degree Hours between before and after heat waves (%)
Living Room	16	75	369%
Bedroom 1	46	153	233%
Bedroom 2	0	0	0%
Bedroom 3	0	0	0%

Table 4.18 - Percentage increase in Degree Hours between before and after heat waves – typical elderly residents

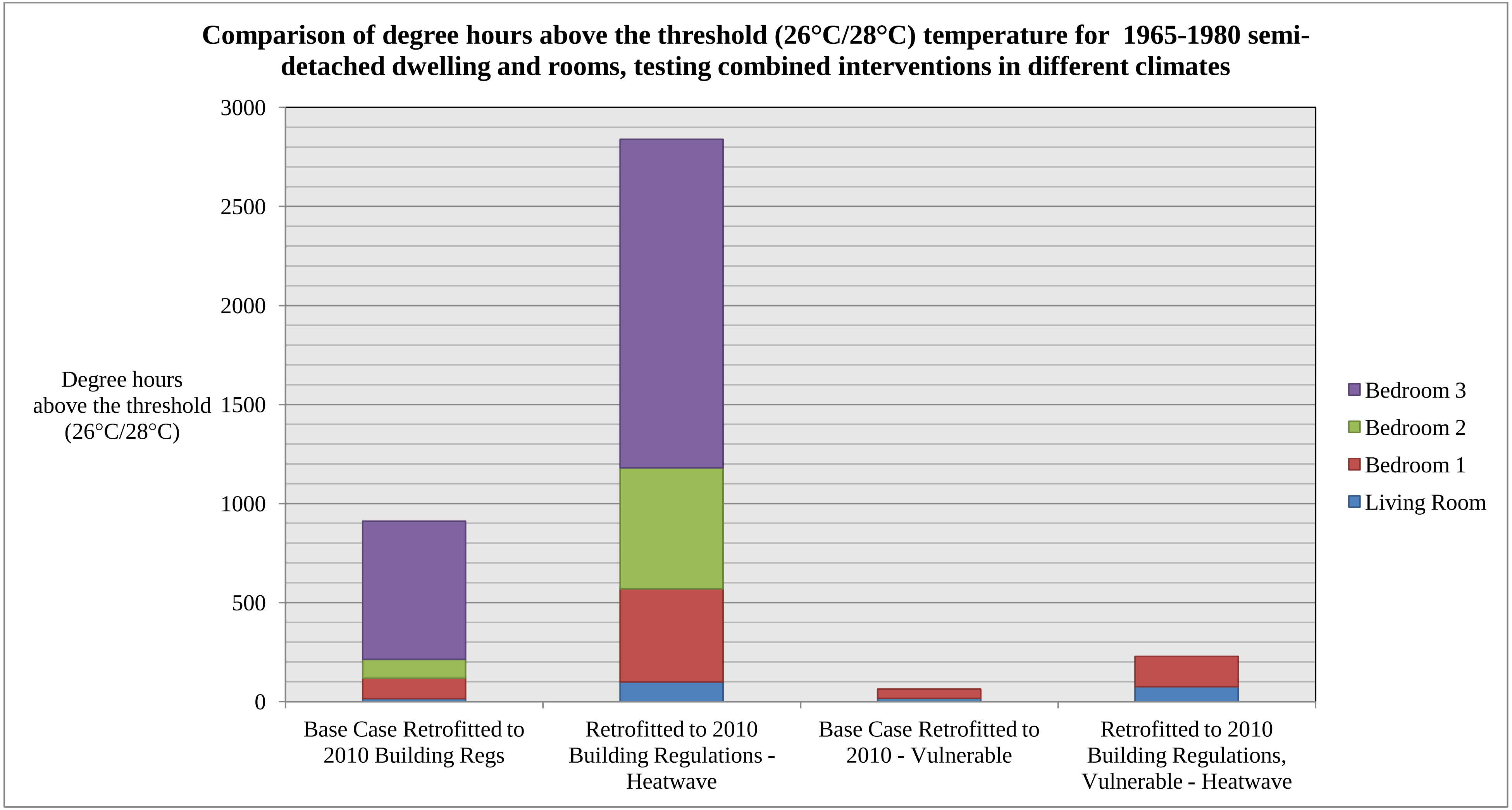

Figure 4.8 - Comparison of degree hours above the threshold (26°C/28°C) temperature for Base case Retrofitted to 2010 Family/Vulnerable and Heat wave situations

5 Discussion

5.1 Summary of Results

	Simulation and the number of Degree Hours above thresholds (26°C/28°C) of the corresponding rooms					
Room	Base Case 1965-1980 semi-detached dwelling	Retrofitted to 2010 Building Regulations	Retrofitted to 2010 Building Regulations, Vulnerable	Updated modern and future internal gains and occupancy trends	Material upgrades to include external insulation	Alternative Cross-ventilation (double banked rooms) design
Living Room	22	15	16	11	11	4
Bedroom 1	170	102	46	88	94	94
Bedroom 2	169	96	0	66	79	85
Bedroom 3	618	698	0	244	736	654
Totals	979	911	62	409	920	837

Table 5.1 - Summary of simulation scenario results – Part 1

Room	Alternative single sided ventilation design - daytime	Alternative single sided ventilation design – night-time	North Facing Orientation	West Facing Orientation	South West Orientation	East Orientation
Living Room	28	0	8	45	28	31
Bedroom 1	202	0	64	181	154	241
Bedroom 2	182	0	229	351	181	429
Bedroom 3	1229	210	482	759	729	916
Totals	1641	210	783	1336	1092	1617

Table 5.2 - Summary of simulation scenario results – Part 2

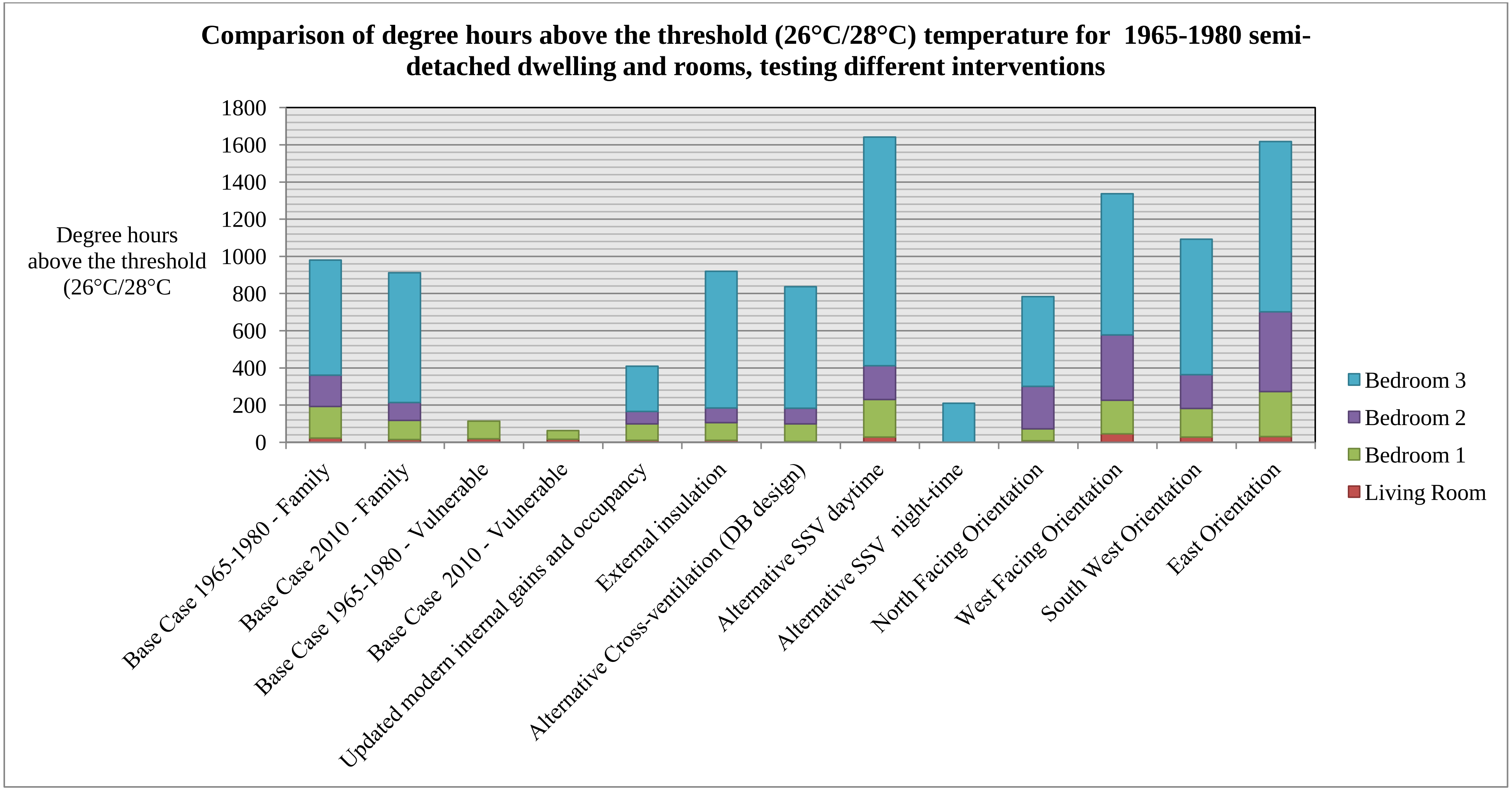

Figure 5. 1- Comparison of degree hours above the threshold (26°C/28°C) temperature for 1965-1980 semi-detached dwelling and rooms, testing different interventions

From the degree hours over the threshold comparison graph (Figure 5.1) and Table 5.1/5.2 it can be seen that the most effective passive measures introduced that had the greatest reduction to overheating in 1965-1980 semi-detached dwellings retrofitted to 2010 Building Regulations were the single sided ventilation – night-time and the updated modern and future internal gains and occupancy trends. This highlights to two key findings in the report that the most significant interventions in dwellings to either increase or reduce overheating degree hours from the is the choice of appliances used in the dwelling, their resultant internal gains produced in the dwelling and the successful recycling of thermal mass of the building through accurate ventilation strategies.

Overall however, a core principle of the results are that upgrading to the 2010 Building Regulations resulted in a reduced degree hours. These results agree with multiple previous studies into overheating and insulation, as Mavrogianni, et al. (2012) and Stazi, et al. (2013) both agree that cavity insulation was beneficial in the winter and reducing overheating in summer. In the wider context, this aspect is integral to occupant health as beyond reducing summer overheating this data can be used to show that beyond summer, as expressed by Porritt, et al. (2012) it benefits both summer and winter occupant health. However, what may need further research is considering the potential for excessive or low levels of insulation to increase overheating. (Oikonomou, et al., 2012)

While most research has external insulation consistently outperforming internal (eg. (Porritt, et al., 2011), (Porritt, et al., 2012)), Figure 5.2 shows there is not such a large gap, allowing for possible discrepancies as seen within the results.

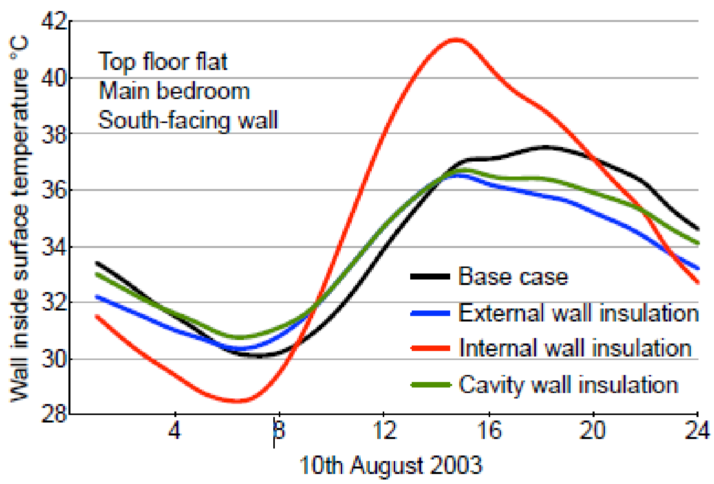

Figure 5.2 – Effect of Wall insulation on inside surface temperature (Porritt, 2012)

Supporting the explanation of the reasons why this occurred, two studies to hypothesized possible reason for the poor performance of external insulation. Yingchun & Webster (2011) suggested that the external insulation creates a higher area exposed to solar radiation and increased level of solar gains. These results highlight a need for future research into all the possible effects of different types and aspects of wall insulation options in different parts of the building. More importantly however it shows that there is little difference between applying internal cavity insulation and external insulation in reducing overheating as it can potentially create different issues with heat retention in dwellings. More likely is this used solid external insulation where the benefits are marginal over cavity insulation. Whereas a more efficient type of external insulation that would remove any discrepancies and show distinctive advantages over cavity insulation is a ventilated external insulation layer; widely used in studies such as Stazi, et al. (2013).

Previous studies such as Peacock, et al. (2010) suggest that in domestic buildings, climate effect will have a greater impact than that of internal gains. Taking this point into account, it’s a fact that the climate cannot be controlled, therefore changes to the internal gains is the only manageable factor in reducing the overheating effect of the climate. Peacock, et al. (2010) believed that time profiles and quantity of internal gains would not be a solution to overheating. However from the results, the combination of time profiles and efficiency was able counteract the influence of the increased number of appliances now within modern society. Although the time profile would have a substantial impact on the total internal gains, current patterns of occupancy will only come under slight changes in the future for both the vulnerable and standard families.

Overall night ventilation was the most effective measure (77% total decrease), showing that although cross-ventilation was able to reduce degree hours (8% total decrease), the change in thermal mass is the most effective method. Night time ventilation would also have reverberation into the impact of all the other factors. This is due to the other scenarios contribution to overheating coming in the form of increasing the thermal mass of the building, through either increasing the difficulty for re-radiating the absorbed thermal mass, or producing gains to increase it. Both Orme, et al. (2003) and Oikonomou, et al. (2012) debate the scale of influence night-time ventilation would have dwellings, instead highlighting insulations greater impact of reduction. The reason for this is suggested by Peacock, et al. (2010) who beleives that that a nigh time threshold is lower than day threshold as thermal mass has a greater impact in the day and discomfort levels are different at night. However in these results, the effects of night ventiation and reduced thermal mass are integral.

While the contribution of changing orientation can be seen to produce considerable difference in results, the increase was not to the scale of >100% increase as with Porritt, et al. (2012). More significantly however, the alteration and adaption to this intervention is conceivably far greater financial costs than any other intervention. These results not only prove the effect of orientation but also highlight the possible need for significant mitigatory action needed, such as solar shading or shutters to restrict the impact of increased solar gains. A factor that has not yet been considered based on orientation is its possible capacity to increase ventilation rates, as by being orientated to the flow of the prevailing wind may have also contributed to a lower degree of degree hours above the thresholds.

Another result of the study is the severely reduced degree of degree hours over the threshold that vulnerable (elderly) occupants have in comparison to the modern family. This has been connected with the amount of internal gains that they produce in comparison to the standard family, with room occupancy a particular difference that is contributing to these results. While this may show that the elderly have a visibly reduced risk, the room occupation and degree hour's method discredits these results. In a similar study (Shao, et al., 2011) however, the elderly exposure during the day resulted in far greater degree hours beyond the threshold. Regardless of the scale of degree hours beyond the threshold for vulnerable people, there is still considerably more risk to the health of the vulnerable during the degree hours beyond the threshold than the average family. With this evidence, a more accurate method of showing the vulnerable occupants risk would be an empirical study. As stated by both (Zero Carbon Hub, 2012) and (Oikonomou, et al., 2012), the vulnerable will spend extended amounts of time exposed to the high temperatures throughout the day/night, as even though they are below the threshold, Hajat, et al. (2002) states that signs of risks can appear at 19°C. Also based on the theory of Oikonomou, et al. (2012) that people are able to adapt to the surroundings, this may be so for healthy occupants but with the amount of time exposed and the lack of control of the surroundings, heat stress can quickly occur, regardless of degree hours. Even with the results generated, the actual risk may therefore be different based on an observed than numerical analysis.

5.2 Combined Interventions best case scenario

<table>
<tr><th colspan="5"><u>Interventions</u></th></tr>
<tr><td>Retrofitted to 2010 Building Regulations - Family</td><td rowspan="2">Updated modern and future internal gains and occupancy trends</td><td rowspan="2">Alternative Cross-ventilation (double banked rooms) design (Back door closed)</td><td rowspan="2">Alternative single sided ventilation design - night-time</td><td rowspan="2">North Facing Orientation</td></tr>
<tr><td>Retrofitted to 2010 Building Regulations - Vulnerable</td></tr>
</table>

Table 5.3 - Optimum combined interventions and Base Case

Room	Retrofitted to 2010 Building Regulations - Heat wave	Retrofitted to 2010 Building Regulations - Multi Interventions Best Case	Retrofitted to 2010 Building Regulations - Multi Interventions Best Case - Heat wave	Retrofitted to 2010 Building Regulations, Vulnerable - Heat wave	Retrofitted to 2010 Building Regulations, Vulnerable - Multi Interventions Best Case	Retrofitted to 2010 Building Regulations, Vulnerable - Multi Interventions Best Case - Heat wave
Living Room	99	0	0	75	0	0
Bedroom 1	470	0	0	153	0	0
Bedroom 2	611	0	5	0	0	0
Bedroom 3	1659	0	3	0	0	0
Totals	2839	0	8	228	0	0

Full tables and graphs provided in Appendix I.*

Table 5.4 - Summary table of optimum combined interventions for different occupants during standard conditions and heat waves*

In order to gauge the potential that the degree hour reduction methods could incur on a 1965-1980 semi-detached dwellings retrofitted to 2010 Building Regulations, a combined base case was presented (Table 5.3/5.4); taking into account the most effective interventions within the different construction and occupant behaviour categories. This simulation would prove the potential for the combined version to remove all risk of overheating without any costly mechanical or even some passive methods of mitigation. Further proving that using a method that counteracts the effects of the other scenarios that caused excessive degree hours over the threshold can potentially remove the risks of overheating throughout current climates or heat wave periods.

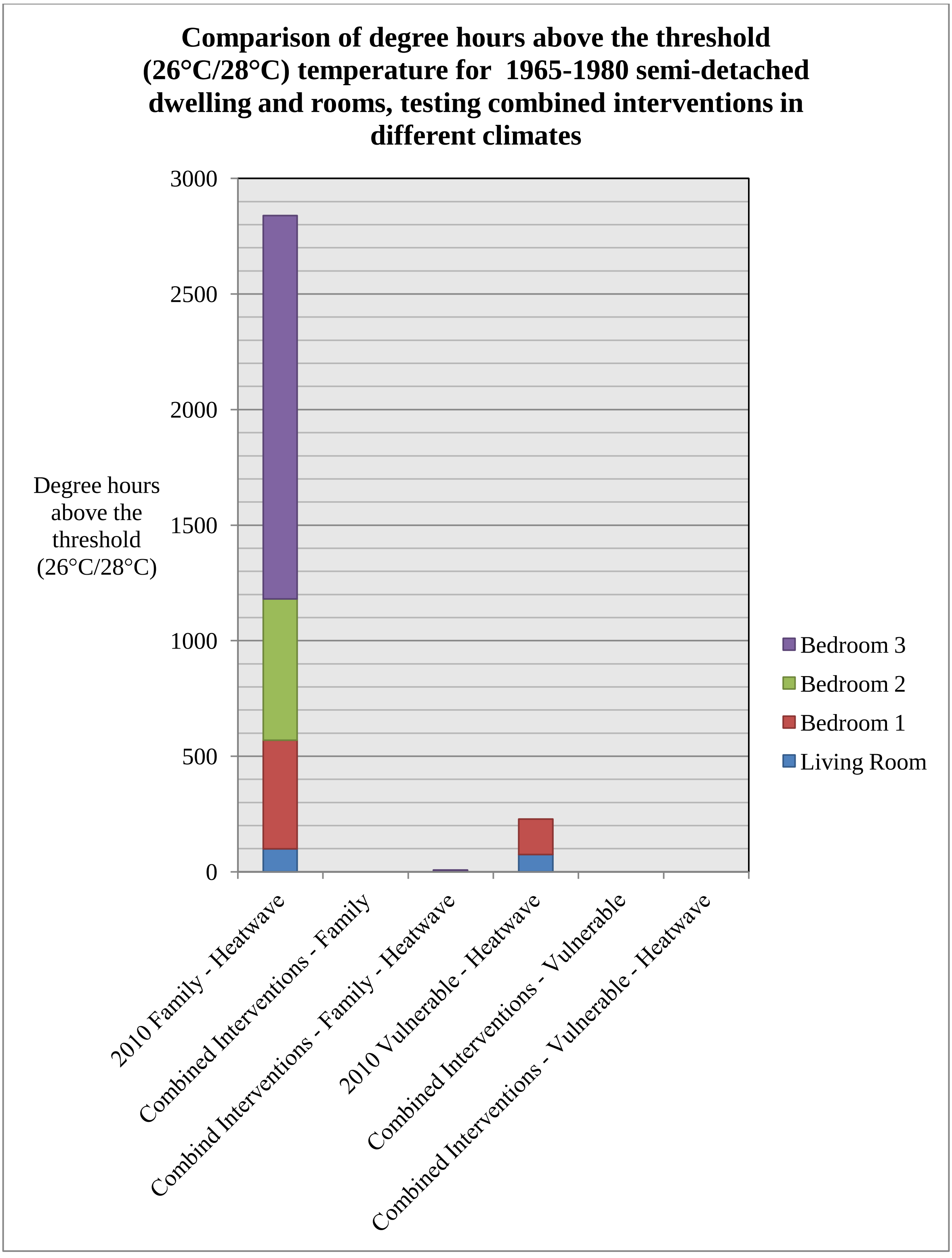

Figure 5.3 - Comparison of degree hours above the threshold (26°C/28°C) temperature for 1965-1980 semi-detached dwelling and rooms, testing combined interventions in different climates

These results (Figure 5.3) help prove that by applying a combination of the interventions to the 1965-1980s semi-detached dwellings which has been retrofitted to 2010 Building Regulations can effectively remove any risk of overheating to the dwelling. This is due to there being no degree hours beyond the threshold for any of the designated room. By combining the interventions, different aspects come together to enhance each other’s effect on reducing overheating. By combining nigh time ventilation with cross ventilation, the heat built up during the day can be re-radiated and at an accelerated rate by the increased ACH of cross ventilation. Furthermore, the issues of heat transfer with cross ventilation when the temperature outside exceeds that inside is not prevalent due to night temperatures being utilised. Furthermore, the combined solar gains of northern orientation and reduced internal appliance gains will also influence the reduced temperature to be below the thresholds as less heat is absorbed during the day.

While there are a total of 8 degree hours above the threshold in the family heat wave, the total number of degree hours falls below the CIBSE definition of overheating as over 1% of the time over the threshold (CIBSE, 2006). Thus assuring the overheating reducing interventions are not compromised when extreme weather occurs and occupant health is not at risk.

5.3 Effect on occupant health of individual interventions and optimum case

From the diagram in Figure 5.1 showing the comparison of degree hours above the threshold (26°C/28°C) temperature the evidence shows that no individual method can reduce overheating substantially enough to remove all risk of overheating for the specified rooms. On the other hand, the implementation of a combined intervention in all cases of either standard weather or heat waves show that it removes any degree hours above the threshold entirely. (Figure 5.2)

While the amount of degree hours beyond the threshold only increase the risks and severity associated with overheating covered in Section 2.2 the severity itself can come into question based on the evidence given. With many of the interventions having degree hours surpassing the threshold and especially within the base cases, with current assumption that there is not an overheating issue, this raised questions. Based on the scale of degree hours above the threshold there must be a reason for the current only minor health risks with standard summer temperatures. These results can thus be shown to prove the evidence suggested by Oikonomou, et al. (2012) that during extend periods of time the occupants are able to adapt their comfort levels, seemingly increasing the threshold for comfort. However, with the scale of increase in degree hours once heat wave data is applied, the health impacts grow more severe and the recordings of both minor and major risk incidents increase (DCLG, 2012). This evidence is key to future studies which in order to understand the occupants ability to adapt, instead of using quantitative data to show hours of overheating, empirical data of occupant response would be more effective to gauge their ability to adapt. Furthermore, what is not indicated by the results is the nature of the health risk which could be established through complete building analysis, as other issues such as pollution and mould growth are considered to be by-products of overheating.

5.4 Review of passive interventions for mitigating overheating and cost analysis

By looking into the costs of the interventions (Table 5.5) a recommendation can be made for owners of the 1965-1980 semi-detached dwellings in light of the 2010 Building Regulations to reduce the risk of overheating taking into account both costs and ease of implementation.

	Simulation						
Room	Retrofitted to 2010 Building Regulations (Energy Saving Trust, 2013)	Updated modern and future internal gains and occupancy trends (Energy Saving Trust, 2013)	Material upgrades to include external insulation (Energy Saving Trust, 2013)	Alternative Cross-ventilation (double banked rooms) design (Family Handyman, 2013)	Alternative single sided ventilation design - daytime	Alternative single sided ventilation design – night-time	Change of Orientation
Cost (£)	£1100 to £1400	£3000 to £3500	£9,400 to £13,000	£50 to £200	Free	Free	Unachievable with attached dwelling with different occupants
Ease of Implementation (scaled 1-10, 1=easy, 10=impossible)	8	3	7	6	1	1	10

Table 5.5 - Cost and ease of implementation of the possible interventions to reduce the risk of overheating

To understand the options available to mitigate the contributing factors to overheating, multiple other options need to be assessed. By using the building adaption tool in the CREW Project (Shao, et al., 2011) (Figure 5.4), a series of passive adaption techniques can be recommended for the particular dwelling type, orientation and room for a standard family. Displayed in Figure 5.4, a combination of both the most successful passive adaption techniques recommended (external shutter, fixed shadings, internal blinds) and the interventions from this study, a set of recommendations for reducing overheating in both heat waves and standard conditions can be established. What also must be assumed is that the dwelling being adapted with the recommendation has been adapted already to the 2010 Building Regulations.

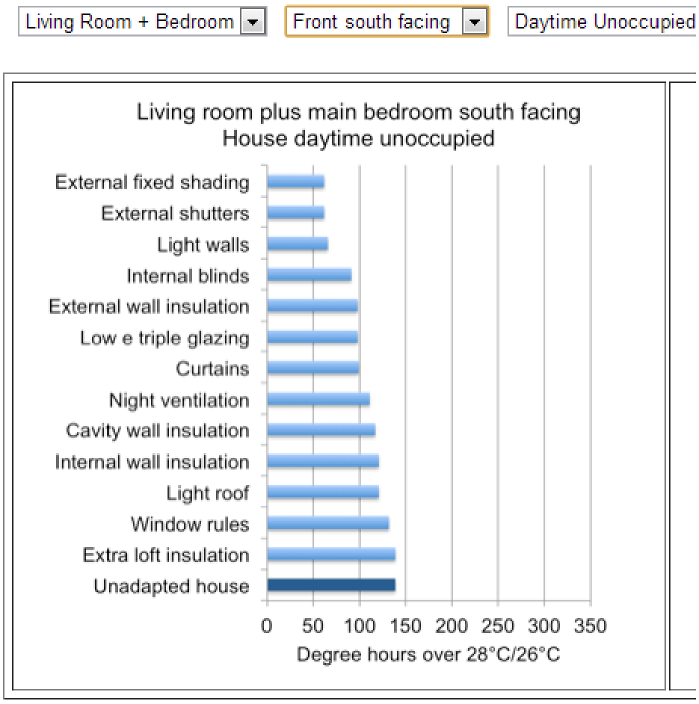

Figure 5.4 - Semi-Detached Dwelling adaptions ranked in order of effectiveness (Shao, et al., 2011)

5.5 Recommendations

5.5.1 Structural

Besides the upgrades to the 2010 Building Regulations, taking into account both this study and that of exterior sources, the recommendation for structural changes to the building would be to install external shutters onto the exterior of the building due to its cost comparison to the fixed shading option. Furthermore, the construction of a door and archway in the building to enhance cross ventilation would be another easy and inexpensive option. With triple e-glazing already installed due to the Building Regulations standards, the other change would be to have the exterior walls paint for a reasonably cheap price.

5.5.2 Behavioral

The main areas of recommendations came in the occupant's behavior. Having night-time ventilation and using curtains (Shao, et al., 2011), the amount of solar gains will decrease and enhance thermal cooling. While it is expensive, making a change towards more energy efficient appliances can be done over an extensive period of years and would be recommended.

6 Conclusion

6.1 Summary of Findings

1. **“Through simulations, look into the overheating affects of the multiple contributing factors of the occupants behaviour and activity.”**

From analysing the internal gains it can be seen that the appliance efficiency as key to overheating. By changing the appliance efficiency, the total degree hours reduced by 56%, showing that even with the state of flux between increased quantity of appliances and efficiency, the future reduced efficiency will reduce degree hours.

While the reduced number of occupants for vulnerable profile evidently reduced the Bedroom and Living room gains, even with an extra 9 hours of Living room occupancy the degree hours only increased by 1d.h for the vulnerable. Therefore, it is suggested the insignificant difference in degree hours is due to higher density of latent and sensible heat gains from occupancy and appliances in the Living room and Bedrooms for the families. The ramifications may suggest that there is a reduced risk, however with evidence suggesting that health risk begin at 19ºC, the vulnerable occupants reduced probability of adapting is an issue. As a result by spending more time exposed during the day a potential empirical study could reveal that heat stress may occur regardless of the reduced total of degree hours, but on the basis of repeated daily exposure.

With differing night/day SSV strategies, day strategy increased degree hours in all rooms. Specifically, Bedroom 3 increased by 582% compared to night, by increasing warm air incursion during the day with only infiltration as ventilation at night. Conversely, the night ventilation was the most successful of all interventions, as it accelerated the effect in reducing the thermal mass, with 0d.h in Bedroom 1/2 and Living room. The debate however will come in the possible need for a night time threshold.

2. **“Through simulations, look into the overheating affects of the multiple contributing factors of the building design and room uses.”**

The overall upgrade to 2010 Building Regulations was found to decrease the total degree hours of the dwelling. By both installing and increasing the level of insulation in the dwelling, the amount of convection heat flow was reduced due to the lower conductivity. Equally, the triple e glazing was at an optimum thickness to reduce conductivity of solar gains. This creates a scenario that benefits both summer overheating and winter energy efficiency/occupant health.

Through studying different ventilation strategy, the cross ventilation strategy was seen to decrease the amount of degree hours in dwelling by increasing the amount of ACH. However this strategy could also cause warm air incursion which decreased its overall effect.

Unlike previous or predicted result, the installation of external insulation increased the total degree hours. While it is expected that the insulation would decrease the thermal absorption rate, the different material, thicknesses and conductivity of external insulation can produce differing results as they all have different heat retention attributes. In this case, by using an external insulation that implemented a ventilation cavity inbetween the insulation, more expected results may occur. Furthermore, increased surface area of exterior may also expose the building to higher solar gains.

For the orientation changes, the results were as expected, with excessive gains for East/West orientations; although there were no room by room orientation differences. Therefore, in order for recommendations to be made, the extent of overheating compared to extent of winter cooling must be compared for these orientations. Although upgrades such as external shutter, reflective wall paint and vegetation shading could help reduce the total solar gains in the East/West orientations.

3. **“Apply a UK heat wave climate condition simulation on both the original 2010 Building Regulations model and the combined interventions model aimed at reducing overheating.”**

Before the optimum case was installed the heat wave increased the degree hours in the 2010 Base case by 211% (family) and 268% (vulnerable). This highlights the need for housing adaptation as health risk incurred will produce more severe outcomes with the higher average temperature. This raises the question that the occupants are able to adapt (behaviourally, psychologically, physiologically) as the severity of degree hours for before and after does not match the real world overheating issue. Although no individual aspect was able to reduce degree hours below the threshold, the combined case could. By the interventions enhancing each other effect upon reducing overheating the maximum threshold was not surpassed for either standard weather or heat waves.

4. **“Based on assumptions and exterior sources, briefly assesses the mitigating factors that can be used to reduce overheating, and what are the likely options for the occupants. Taking into account the cost and ease of use of the feature. Thus producing a definitive set of recommendations for reducing overheating”**

The optimum case interventions were combined with previous research in passively mitigating overheating and a recommendation based on both behavioural and structural changes was presented. These took into account the cost and ease of installation for the options (eg. The inability to change orientation):

Structural

- Upgrades to 2010 Building Regulations
- Upgrades to enhance cross ventilation
- Exterior wall paint
- External shutters
- External shading to reduce effect of East/West Orientated buildings

Behavioural

- Nocturnal Window opening strategy
- Curtains with opening/closing profiles
- Appliance upgrades

6.2 Wider relevance of the Research

In the wider context of the study, these results can be used as a basis for future guidance reports such as the NHS Heat wave Plan 2013 (Department of Health, 2013). Furthermore, while not directly studied in this report, the inclinations it can have with studies in the link between overheating and health is a key point. From these studies it is suggested that there is a degree of adaption that the occupants may have, therefore future studies may take this into account or specify their research upon this.

With the study taking into account both different types of occupants, the difference in degree hours between general families and vulnerable raise concerns. As while it can be attributed to the dwelling type, it raises the consideration that there could be change in threshold for vulnerable as while this data shows a reduced risk, real world evidence show a contrasting view. (Carmichael, et al., 2011)

Overall the most significant use of the report is to provide evidence in disputing the idea that the 2010 Building Regulations will increase overheating. Through the evidence and explanation provided (Section 4.1.2) it can be seen that current 1965-1980 semi-detached dwellings are at greater risk and the 2010 Building Regulations will in fact reduce the total degree hours.

6.3 Limitations

6.3.1 Number of Assumptions

On reflection one of the limitations of the study found was the need for multiple assumptions to be made for sections of appliance use, occupancy and window opening profiles. While the evidence was based on the prescribed sources, many time profiles were assumed due to a lack of data associated with that particular appliance. In particular, multiple research stress the need for window profile analysis as there is minimal research on this for housing, instead it concentrates on office window opening patterns and thresholds (Nicol, et al., 2007). Further limitation in the window opening assumptions were made for its degree of opening and crack length, as such parameters are specific to the occupant preference and window manufacturer.

6.3.2 Not all mitigation methods assessed or tested

Based on the limitations of time, one of the limitations for the study was the scale of scenarios tested. With extensive time and ability to fully asses all possible contributing factors through a practical assesses of a 1965-1980 semi-detached dwelling comprehensive study of overheating can be made. Had simulation software such as EnergyPlus been used, a greater number of results could have been automatically generated instead of individual files

6.3.3 Different occupancy profiles

Another limitation of the study was the limitations imposed by using only one base model of occupancy for families and elderly. A more precise method of analysis would incur multiple different occupancy profiles for different UK families. As different families have different number of children and jobs etc, a wider range of profiles could have been used, especially with a growing trend of people working from home. (TUC, 2013)

6.3.4 Recommendations section

For the recommendations sections only brief analysis and assessment was made in order to gauge what would be the best options. Why this research garnered a more comprehensive set of results the exterior source was only briefly assessed and more sources could have been used. Furthermore, the costs assessments were based on only website/company enquiries for general houses rather than a full industry comparison for the base case dwelling. As with other studies such as Porritt (2012) a full assessment of original research on causes and mitigation options could have been completed.

6.3.5 Weather data

A limitation of the software chosen was the weather data used. The current weather file was sourced from Heathrow in 2008; however a more accurate evaluation would be set to 2013 data where there has been a change in summer weather patterns in the past few years.

6.4 Recommendations for future Research

6.4.1 More studies of the vulnerable occupants

While the study undertaken in this report was able to identify the risk of the 2010 Building Regulations on the vulnerable occupants, not all parameters were tested for such occupants. A future study could look to assess the risk of all parameters on vulnerable occupants as different factors could influence the vulnerable that were not found for a standard family. Furthermore, studies into a possible new threshold for vulnerable should be considered.

6.4.2 Window rules changing, amount open

As found within the limitations section, as of yet there is only marginal research into domestic window opening schedules and degree of opening. Therefore, a separate study into window opening patterns for domestic occupants in summer periods would be useful for base cases of all future overheating studies.

6.4.3 Empirical study

Within the entire individual results tables it can be seen that overheating is prevalent in all individual cases originally simulated. With this is mind the possibility for adaption is by the occupants to the elevated level of degree hours is highly suggested, as with current national statistics, there is not a risk to occupant health to the scale that is equal to excessive number of degree hours over the thresholds. While a comparison between mortality risk and degree hours could be achieved, a more accurate assessment of occupants risk would be an empirical study of occupant comfort and health during this period.

6.4.4 New CIBSE Criteria for Overheating

While CIBSE degree hours beyond the threshold method was chosen for this study, future studies may implement the new CIBSE three criteria method to “provide a robust yet balanced assessment of the risk of overheating” (CIBSE, 2013). In this particular report, an accurate yet reliable method was used, yet future studies could both test the legitimacy and the possibly more accurate data produced by the new criteria for overheating.

6.4.5 Changing base case parameters

For this particular study the base case had a very limited range. In a future study multiple other parameters can be adjusted for the base case and simulated for a wider set of results, parameters such as:

- Location
- Climate
- Dwelling type
- Age of the dwelling
- Occupant
- Construction Materials (thickness, type and conductivity)

6.4.6 Nature of the health risk

What has not yet been fully understood is the nature of the health risks involved. While this study would be more of a medical investigation that a construction issue, the multiple risks associated with overheating from the direct influence of the sun to more long term issues such as mould growth is a question that has arisen from this study.

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Appendix A

Overheating Thresholds

A1. Comparison of Threshold limits for thermal comfort used by previous studies

Research Study	Sources	Threshold limit for thermal comfort/ mortality risk increases	Comment
Heat wave Plan for England 2013 (Department of Health, 2013)	Met Office National Severe Weather Warning Service (Met Office, 2012)	Daytime: 30ºC Night: 15ºC (excess seasonal deaths start to occur at approximately 25°C)	Reaching threshold limit incurs Level 3 heat wave warning. "Heat wave alert system is based upon temperature thresholds where the odds ratio is above 1.15–1.2 (a 15–20% increased risk)."
Suggestion for new approach to overheating Diagnostics (Nicol, et al., 2009)	CIBSE Guide A – Environmental Design (CIBSE, 2006)	Daytime: 28ºC	Bedroom threshold of 26ºC
Approved Document L2A of the Building Regulations (2008)	CIBSE Guide A – Environmental Design (CIBSE, 2006)	Daytime: 28ºC	Bedroom threshold of 26ºC
Suggestion for new approach to overheating Diagnostics (Nicol, et al., 2009)	Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics (British	Daytime: > 25 ºC Under summertime comfort conditions	

	Standards, 2008)		
NHBC : Overheating in new homes (NHBC Foundation, 2012)	(World Health Organisation, 2007)	Daytime : > 24˚C	
CIBSE Guide A – Environmental Design (CIBSE, 2006)	CIBSE Guide A – Environmental Design (CIBSE, 2006)	Daytime: 3°C above the design temperature Night: > 24˚C	"While CIBSE gives recommendations for residential buildings, the basis for these figures is data from office or school buildings only." (CIBSE, 2005)
Building characteristics as determinants of propensity to high indoor summer temperatures in London dwelling (Mavrogianni, et al., 2012)	CIBSE Guide A – Environmental Design (CIBSE, 2006)	Daytime: > 25˚C Living room Daytime: > 23˚C Bedroom	recommendations on general summer indoor comfort temperatures for non-air conditioned dwellings assuming warm summer conditions
Designing domestic buildings for future summers: Attitudes and opinions of building professionals (Gul & Menzies, 2012)	Air Conditioning Energy Use in Dwellings in Southern England, Dynamic Analysis, Simulation and Testing Applied to the Energy and Environmental Performance of Buildings Conference (He, et al., 2005)	Night: > 23.9˚C	individual might act to change the internal environment in a dwelling due to them feeling too warm During the hours of 2300 to 0700.
Methods for assessing domestic overheating for future building (Jenkins, et al., 2013)	SAP (DECC, 2013)	Daytime: > 28˚C	Used in IES simulations

Investigation into Overheating in Homes: Literature Review (DCLG, 2012)	Association of mortality with high temperatures in a temperate climate: England and Wales (Armstrong, et al., 2011)	Daytime: > 24.7˚C	"This type of epidemiological evidence relates to the association of mortality/morbidity with outdoor temperature. The results cannot be directly extrapolated to indoor temperatures" (Armstrong, et al., 2011)
Control of Overheating in Well-Insulated Housing (Orme, et al., 2010)	IES ApacheSim Calculation Methods (IES, 2013)	Daytime: > 27˚C	
Overheating in Homes (Zero Carbon Hub, 2012)	CIBSE Guide A – Environmental Design (CIBSE, 2006)	Daytime: > 28˚C Living room Daytime: > 26˚C Bedroom	"Defines overheating as when these temperatures are exceeded for more than 1% of the time."
Heat wave Plan for England 2011 (Department of Health, 2011)	Met Office National Severe Weather Warning Service (Met Office, 2012)	Daytime: 26˚C	
Health Protection Agency (Carmichael, et al., 2011)	CIBSE Guide A – Environmental Design (CIBSE, 2006)	Daytime: > 28˚C Living room Daytime: > 25˚C Bedroom	
ASHRAE (ASHRAE, 2001)	ASHRAE (ASHRAE, 2001)	Daytime: 35˚C	"this threshold can decrease by several degrees depending on the humidity level (heat index) or for particularly vulnerable groups"
Housing Health and Safety Rating System Operating Guidance (Office of the Deputy Prime Minister, 2004)	Housing Health and Safety Rating System Operating Guidance (Office of the Deputy Prime Minister, 2004)	No indication of a threshold for overheating	

Relation between Elevated Ambient Temperature and Mortality: A Review of the Epidemiologic Evidence (Basu & Samet, 2002)	US National Weather Service (National Weather Service, 2013)	Daytime: > 40˚C	US threshold study
An empirical mechanistic framework for heat-related illness (Chan, et al., 2001)	An empirical mechanistic framework for heat-related illness (Chan, et al., 2001)	Threshold temperature of 37.17°C for human body	"We assumed that persons would begin to sense heat discomfort when their core temperature reached 0.50°F (0.28°C) above normal, where normal is defined as core temperature at rest in air-conditioning (25°C, 50% relative humidity)"
Health and thermal comfort: From WHO guidance to housing strategies (Ormandy & Ezratty, 2011)	Health and thermal comfort: From WHO guidance to housing strategies (Ormandy & Ezratty, 2011)	Daytime: > 24˚C	"Comfort Zone for the temperature range 18-24˚C"

Table A.1 - Comparison of Threshold limits for thermal comfort used by previous studies

Appendix B

Simulation Software options comparison

B1. Simulation Software options comparison

Software Package	Advantage	Disadvantages	Previous studies	Software chosen
EnergyPlus	Used in the case of automatically comparing thousands of simulations (Shao, et al., 2011) Complex modelling capabilities for looking into the interaction of objects and thermal production	There is a need for extensive training in the software, and understanding the analysis section. (U.S Department of Energy, 2011)	(Mavrogianni, et al., 2012), where 3456 combinations of dwelling types and characteristics were simulated for overheating analysis Specific study into the multiple advantages covered in EnergyPlus (Crawley, et al., 2001)	
DesignBuilder	Integrated with EnergyPlus software, taking those advantages but with "user friendly" graphical interface for easier use Creates environment where design options, environmental comfort and energy consumption can be assessed (U.S Department of Energy, 2011)	Training needed if necessary Costly programme No previous experience	Study into "passive interventions that could reduce overheating during heat wave periods... further expanded to assess the effect of interventions on space heating energy use and to consider the cost of interventions." (Porritt, 2012)	

IES Virtual Environment	Personal previous experience User friendly interface Industry and academic recommended (Porritt, 2012) Presentation of simulation results allows for simple conversion to analytical data "Comprehensive analysis options offered across a wide range of metrics" (U.S Department of Energy, 2011)	Time consuming to do many parametric simulation studies (U.S Department of Energy, 2011)	(Porritt, et al., 2011), a standardised terraced house was sampled to assess "the effectiveness of a series of passive heat wave mitigating interventions."	
ESP-r	Able to simulate different in building technologies Has basic functions for simple projects easy to use Technical assistance provided	There are some specialist subjects of software that require previous experience Limited detail in geometry and construction Limited database size (Porritt, 2012)	(Jenkins, et al., 2009) investigated the impact of rising internal gains and climate change on overheating in the school	

Table B.1 - Simulations software advantages and disadvantages comparison

Appendix C

Base Case building design information

C1. Base Case building design information

Feature	Details and Reference	
Number of Floors	2 Floors and Roof room	The case study by (DCLG, 2011)
Rooms Included:	3 Bedrooms Living Room Dining Room Kitchen Bathroom Entrance Hallway (Stairs)	Using data from (DCLG, 2011) the most populous types of semi-detached had 3 bedrooms (18% of all dwellings). Additionally, studies from both (Cuéllar-Franca & Azapagic (2012), (Energy Saving Trust (2011) and (Allen & Pinney (1990) have these rooms included and floor plans that include 4 rooms across 2 floors.
Interior room temperature	19°C (Cuéllar-Franca & Azapagic, 2012)	
Infiltration rate	0.5 ACH (CIBSE, 2009) 0.35 ACH (Based on 2005 Building Regulations) (CIBSE, 2009)	
Heating	Off continuously	
Cooling	Natural ventilation	
Natural ventilation/Air Exchange Rate	Max Flow 1.5 ACH (Average dwelling, 1965-1980) Max Flow Rate 1 ACH (Well sealed dwelling, 2010 Building Regulations) (British Standard, 2002) (Cuéllar-Franca & Azapagic, 2012)	
Kitchen Extractor Fan	Time Profile Weekday: 17:00-1900 Time Profile Weekend: 1230-1400, 17:00-1900 20ACH (Vent-Axia, 2013)	

UK prevailing wind direction	South East (Lapworth & McGregor, 2008)	
General Room Attributes		
	Floor lettable area (Percentage of the floor area that is lettable, (IES, 2013))	Circulation
Lift/ stairs/ corridor	100	0
Other	80	20

Table C.1 - Further building design information

Appendix D

Base Case Window and Door Opening parameters

D1. Base Case Window and Door opening parameters

Window/Door	Details and Reference
External Windows	
	Exposure type: Semi Exposed
	Opening: Window/Door Side Hung (weather stripped)
	Max Open °: 70°
	Crack Flow Coefficient: 0.13 (Orme, et al., 1994)
	Crack Length: 2%
	Opening Threshold: 22°C (CIBSE, 2005)
Internal Door	
	Exposure type: Internal
	Max Open °: 90°
	Crack Flow Coefficient: 1.3 (Orme, et al., 1994)
	Crack Length: 95%
	Opening Threshold: 22°C (CIBSE, 2005)
External Door	
	Exposure type: Semi Exposed Door
	Opening: Window/Door Side Hung (weather stripped)
	Max Open °: 90°
	Crack Flow Coefficient: 0.27 (Orme, et al., 1994)
	Crack Length: 5%
	Opening Threshold: 0°C (CIBSE, 2005)

Table D.1 - Window and Door Opening parameters

Appendix E

Construction Materials

E1. Base Case Materials and construction details

Construction (Outside to inside)	U-value (W/m2K)	Materials (from outside to inside)	Thickness (m)	Conductivity (W/m.K)
External Wall (Cavity Masonry Wall)	1.45			
		Brick (outer)	0.1025	0.770
		Cavity	0.0700	-
		Brick (inner)	0.1025	0.560
		Plaster	0.0130	0.570
Internal Wall	1.76			
		Plaster	0.0130	0.210
		Brick (inner)	0.1025	0.560
		Plasterboard	0.0130	0.210
Party Wall (Cavity Masonry Wall)	1.25			
		Plaster	0.0130	0.570
		Brick (outer)	0.1025	0.770
		Cavity	0.0700	-
		Brick (inner)	0.1025	0.560
		Plaster	0.0130	0.570

Ground Floor	0.7			
		Clay	-	1.410
		Stone Chippings	0.1000	0.960
		Cast Concrete	0.1000	1.350
		Underlay and Carpet	0.0200	0.160
Roof (Joist insulated)	0.26			
		Clay Tile	0.0100	0.100
		Roofing Felt	0.0050	0.500
		Glass Fibre Quilt Insulation	0.1350	0.040
		Ceiling Tiles	0.0100	0.056
First Floor	0.78			
		Underlay and Carpet	0.0200	0.160
		Floorboard	0.0100	0.140
		Air Gap	0.0700	-
		Plasterboard	0.0130	0.210
Windows	2.14			
	1.99	Pre 2002 double-glazing	2 x 6mm and 12mm air gap	2.060
	3.4	uPVC frame	0.0020	
Doors	2.7	Pine	0.0400	0.200

Table E.1 - Base Case Materials and construction details

E2. Building Regulations 2010 Approved Document material upgrades to minimum standard

Data sourced from (Porritt, 2012) (DCLG, 2011), (Brinkley, 2008), and (Cuéllar-Franca & Azapagic, 2012)

Construction (Outside to inside)	U-value (W/m2)	Materials (from outside to inside)	Thickness (m)	Conductivity (W/m.K)
External Wall (Cavity Insulation Masonry Wall)	0.55			
		Brick (outer)	0.1025	0.770
		Wall Cavity Insulation	0.0700	0.050
		Brick (inner)	0.1024	0.560
		Plaster	0.0130	0.570
Internal Wall	1.76			
		Plaster	0.0130	0.210
		Brick (inner)	0.1025	0.560
		Plasterboard	0.0130	0.210
Party Wall (Cavity Insulation Wall)	0.38			
		Brick (outer)	0.1025	0.770
		Wall Cavity Insulation (mineral fibre)	0.0700	0.035
		Brick (inner)	0.1025	0.560
		Plaster	0.0130	0.570

Ground Floor	0.25			
		Clay	-	1.410
		Stone Chippings	0.1000	0.960
		Floor Insulation	0.0700	0.040
		Cast Concrete	0.1000	1.350
		Underlay and Carpet	0.0300	0.160
Roof (Joist insulated)	0.18			
		Clay Tile	0.0100	0.100
		Roofing Felt	0.0050	0.500
		Glass Fibre Quilt Insulation	0.1540	0.040
		Ceiling Tiles	0.0100	0.056
First Floor	0.25			
		Underlay and Carpet	0.0200	0.160
		Floorboard	0.0100	0.140
		Air Gap	0.0700	-
		Plasterboard	0.0100	0.210
Windows	1.6			
	1.6	Low e triple-glazing,	3 x 3mm (inner and outer coated) 2 x 6mm air gaps	2.060
	3.48	uPVC frame	2	
External Doors	1.8	Pine	0.0400	0.103

Table E.2 - Building Regulations 2010 Base Case Materials and construction details

E3. Building Regulations 2010 Approved Document material upgrades to include external insulation

Construction (Outside to inside)	U-value (W/m2)	Materials (from outside to inside)	Thickness (m)	Conductivity (W/m.K)
External Wall (External Insulation Masonry Wall)	0.31			
		External Polystyrene Insulation	0.0500	0.02
		Brick (outer)	0.1025	0.77
		Cavity	0.0700	-
		Brick (inner)	0.1025	0.56
		Plaster	0.0130	0.57

Table E.3 - Building Regulations 2010 Base Case Materials and construction details upgrades to increased level of insulation to reduce U-values

Appendix F

Updated Internal Gains and Occupancy/Electrical Time Profiles

F1. Updated modern and future internal gains and occupant's type's weekday and weekend profile

Data assumed based on the advice of by (Svehla, 2011), (Fessey, 2005), (Jeeninga & Huenges Wajer, 2010), (Jenkins, et al., 2009), (CBS Outdoor, 2005) and

(De Lacey, 2013).

The changed internal gains however of the appliances are based on the conclusions of current studies into how appliance quantity and efficiency is increasing from (Borg & Kelly, 2011) and (Bertoldi, et al., 2012).

Heat Gain	Room(s)	Max Internal Gains (W)	Week day Profile for standard dwelling for modern family	Weekend Profile for standard dwelling for modern family	Weekday Profile for standard dwelling for two elderly residents	Weekend Profile for standard dwelling for two elderly residents
Hot Water	Bathroom	100	24 hours	24 hours	24 hours	24 hours
Oven	Kitchen	1670	1700-1730	1230-1300 1700-1730	1230-1300 1700-1730	1230-1300 1700-1730
Hobs	Kitchen	1930	1730-1800	1730-1800	1730-1800	1730-1800
Fridge-Freezer	Kitchen	295	24 hours	24 hours	24 hours	24 hours
Washing Machine	Kitchen	143	1800-1900	1800-1900	1800-1900	1800-1900
Dishwasher	Kitchen	135	1900-2000	1900-2000	1900-2000	1900-2000

TV	Living Room	117	1900-2300	1900-2300	0900-2230	0900-2230
	Bedroom 2/3		1600-1800	1600-1800		
Games Console	Bedroom 2/3	46	1600-1800	1600-1800	-	-
Total Personal Electronic Equipment	Living Room (x2)	7	24 hours	24 hours	-	-
	Bedroom 2/3					
Laptop/ Desktop and Monitor	Bedroom 2	46	1900-2200	1900-2200	-	-
	Bedroom 3		1900-2200	1900-2200		
Bedroom Lighting	Bedroom 1	12	0730-0830 2230-2300	0900-1000 2230-2300	0800-0900 2200-2230	0800-0900 2200-2230
	Bedroom 2/3	12	0730-0830 1900-2200	0900-1000 1900-2200		
Kitchen Lighting	Kitchen	12	0730-0830 1700-1800	0900-1000 1230-1300 1700-1800	0800-0900 1230-1300 1700-1800	0800-0900 1230-1300 1700-1800
Living Room Lighting	Living Room	15	1900-2300	1900-2300	1900-2230	1900-2230
Dining Room Lighting	Dining Room	15	0730-0830 1800-1900	0900-1000 1300-1400 1800-1900	0800-0900 1300-1400 1800-1900	0800-0900 1300-1400 1800-1900

Bathroom Lighting	Bathroom	15	0730-0830 2130-2230	0900-1000 2130-2230	0800-0900 2200-2230	0800-0900 2200-2230
Adult Seating (Cuéllar-Franca & Azapagic, 2012)	Living Room (x2)	108	1900-2300	1900-2300	0900-2200	0900-2200
	Dining Room (x2)		0730-0830 1800-1900	0900-1000 1300-1400 1800-1900	0800-0900 1300-1400 1800-1900	0800-0900 1300-1400 1800-1900
Adult Cooking	Kitchen	189	1700-1800	1230-1300 1700-1800	1230-1300 1700-1800	1230-1300 1700-1800
Adult Sleeping	Bedroom 1	72	2300-0730	2300-0900	2230-0800	2230-0800
Child Seated	Bedroom 2/3	80	1600-1800 1900-2200	1900-2200	-	-
	Dining Room		0730-0830 1800-1900	0900-1000 1230-1330 1800-1900		
Child Sleeping	Bedroom 2/ 3	54	2200-0730	2200-0900	-	-

Table F.1 - Updated modern and future internal gains and occupant's type's weekday and weekend profile

Appendix G

Alternative air flow and ventilation strategy

G1. Alternative single sided ventilation design - daytime

This design is based on the principle of single-sided ventilation, whereby the opening is found on only one side of the room. To achieve this, a window opening strategy is employed.

Window/Door	Profile Weekday	Profile Weekend	Temperature threshold
Window	0730-0830 1700-1900	0900-1000 1700-1900	0°C
Doors (Interior/Exterior)	Always Closed		0°C

Table G.1 - Alternative single sided ventilation design - daytime Window/Door profiles and temperature threshold

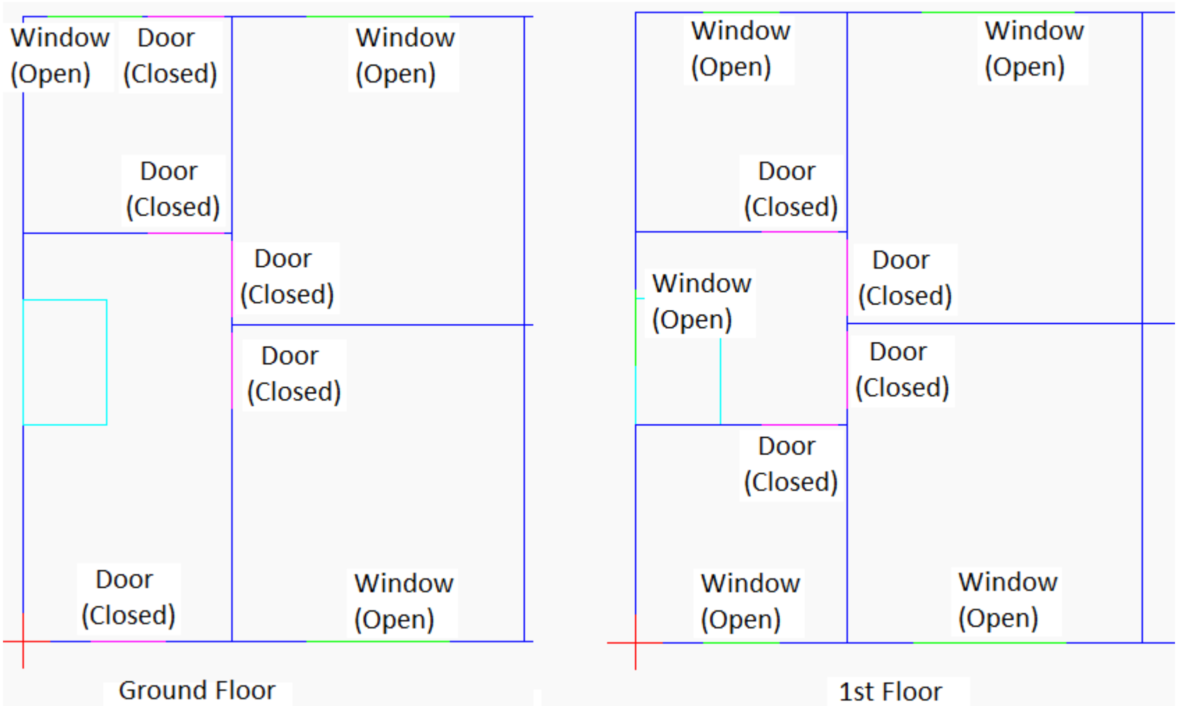


Figure G.1 - Alternative single sided ventilation - design daytime window and door opening floor plan

G2. Alternative single sided ventilation design – night-time

This design is based on the principle of single-sided ventilation, whereby the opening is found on only one side of the room. Unlike the previous simulation, the potential of night-time ventilation is tested. To achieve this, a window opening strategy is employed.

Window	Profile Weekday	Profile Weekend	Temperature threshold
Window (20° opening)	2300-0730	2300-0900	0°C
Doors (Interior/Exterior)	Always Closed		0°C

Table G. 2 - Alternative single sided ventilation design – night-time Window/Door profiles and temperature threshold

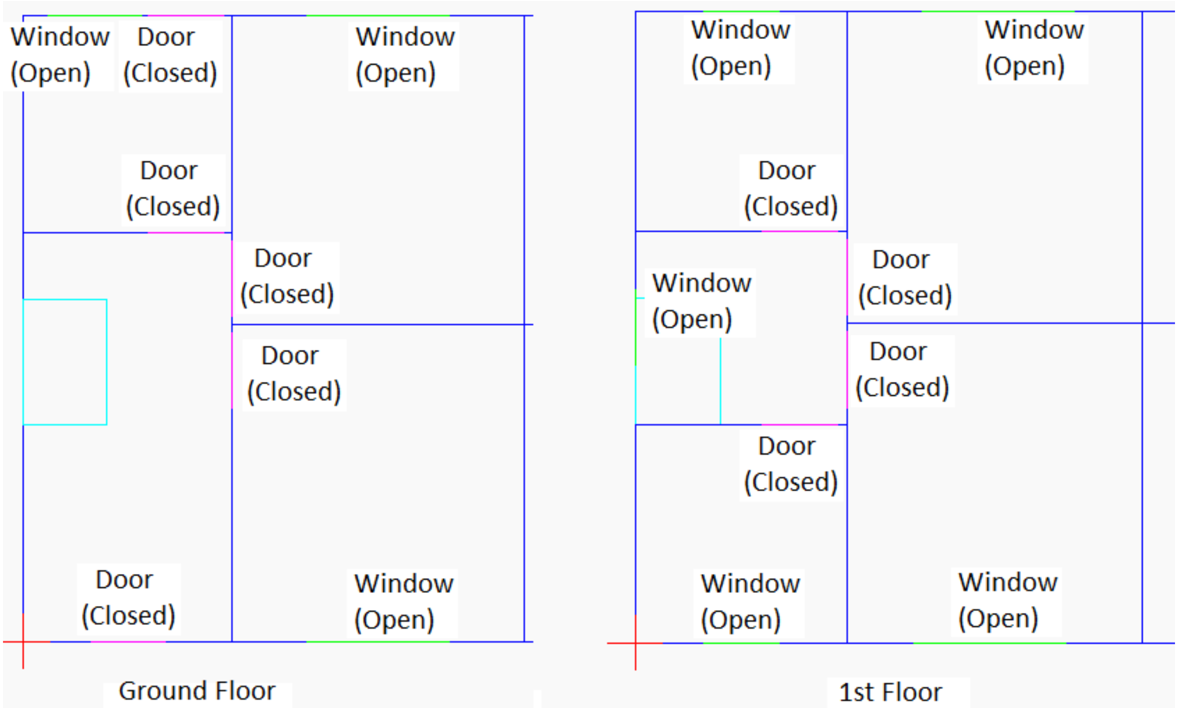


Figure G.2- Alternative single sided ventilation design – night-time window and door opening floor plan

G3. Alternative Cross-ventilation (double banked rooms) design

This design is based on the principle cross ventilation, whereby the openings are found on two sides of the room. Unlike single space ventilation however, openings between partitions to achieve opposite wall ventilation is utilized as well as daytime door/window strategies. These strategies are below in Table G.3, and Figure shows the floor plan changes.

Window	Profile Weekday	Profile Weekend	Temperature threshold
Window	0730-0830 1700-1900	0900-1000 1700-1900	0°C
Doors (Interior/Exterior)	0730-0830 1700-1900	0900-1000 1700-1900	0°C

Table G.3 - Alternative Cross-ventilation (double banked rooms) design Window/Door profiles and temperature threshold

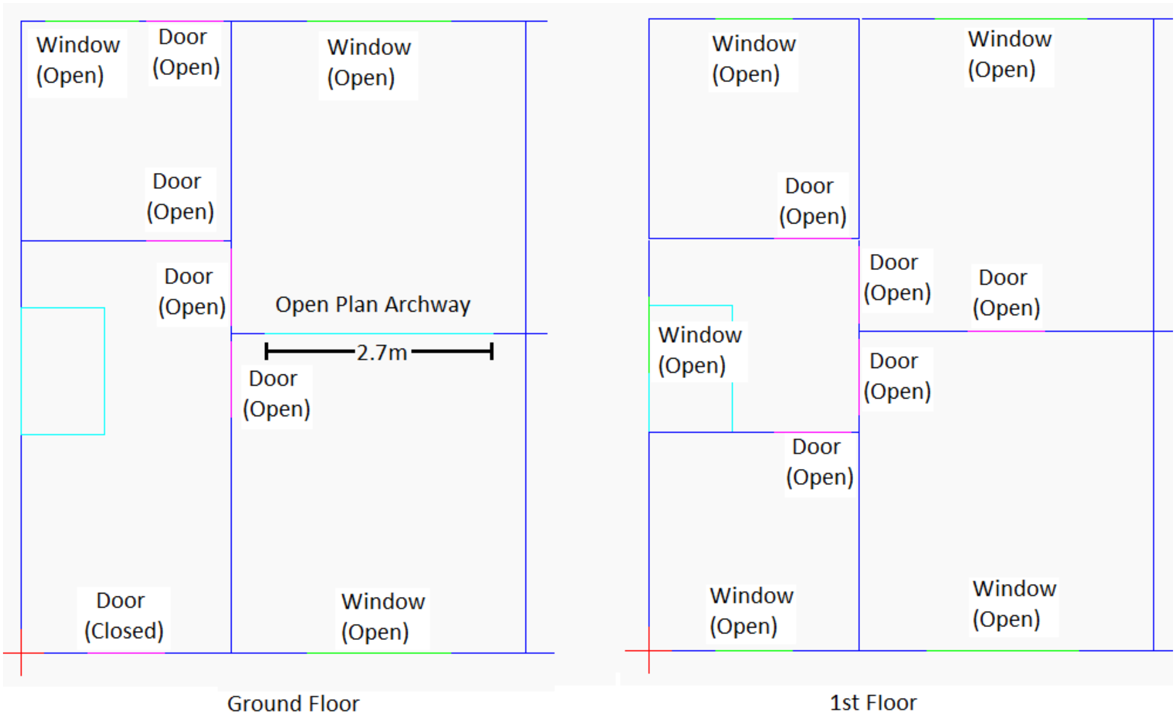


Figure G.3 - Alternative Cross-ventilation (double banked rooms) design window and door opening floor plan

Appendix H

Alternative Orientations

All the diagrams below are taken on the 1st July

I1. East facing

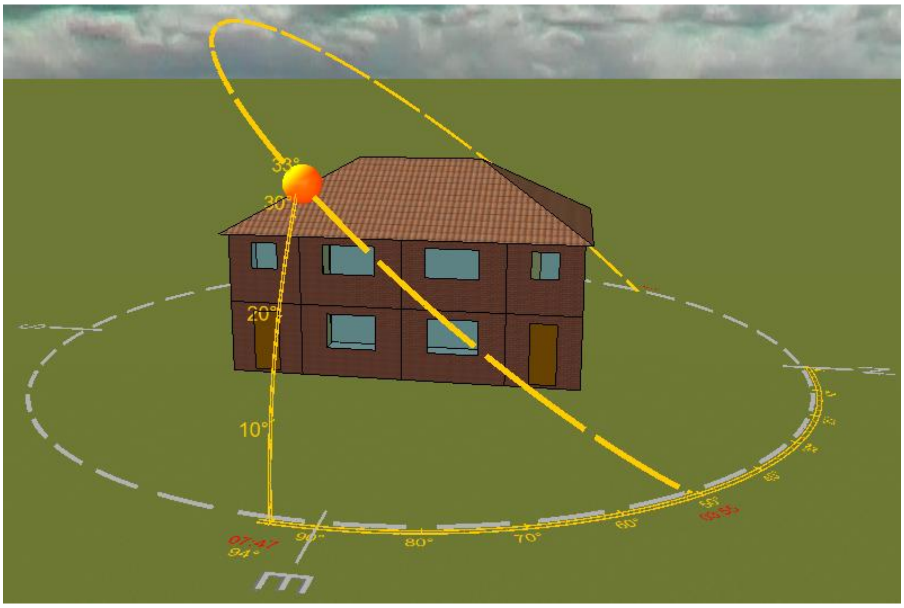


Figure H.1 - East Facing Diagram

I2. West facing

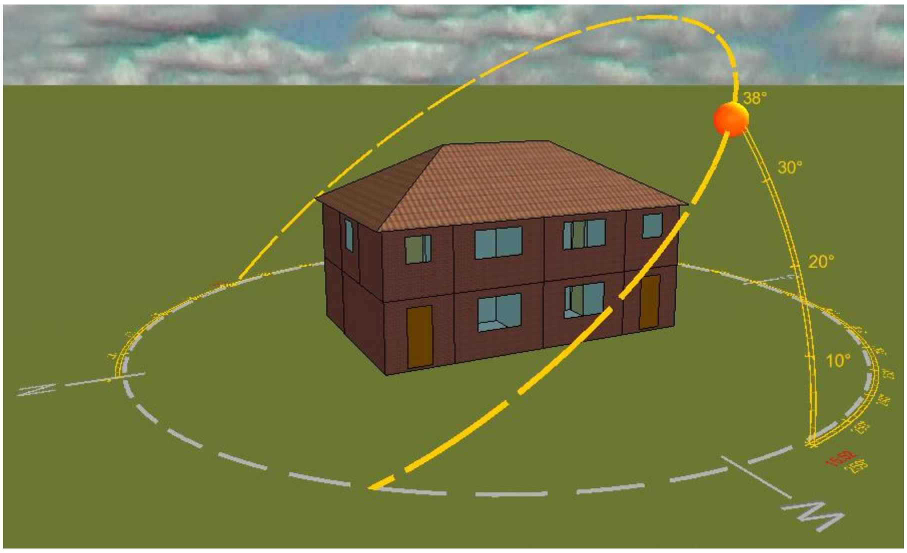


Figure H.2 - West Facing Diagram

I3. South West facing

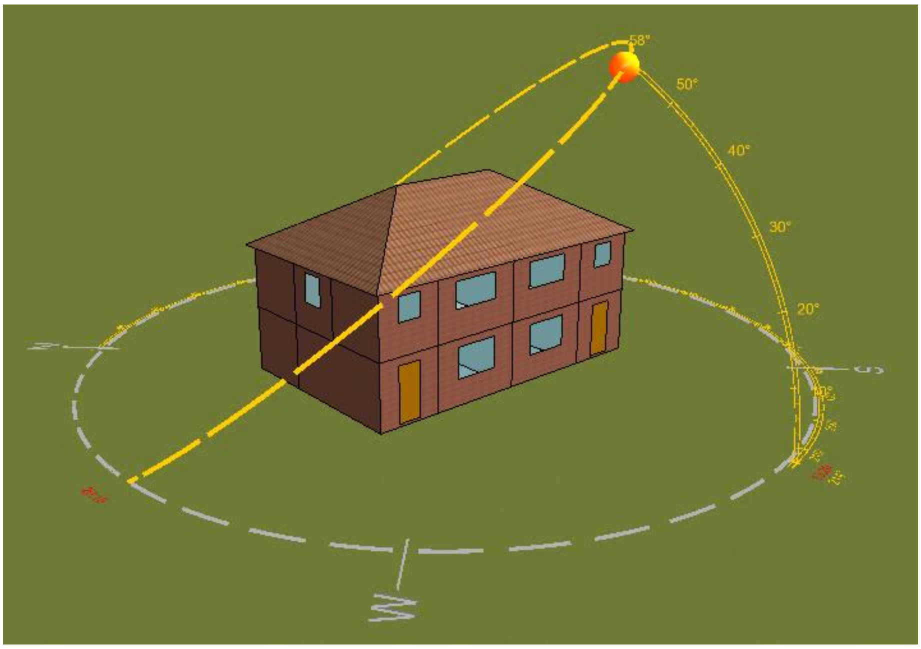


Figure H.3 - South West Facing Diagram

I4. North facing

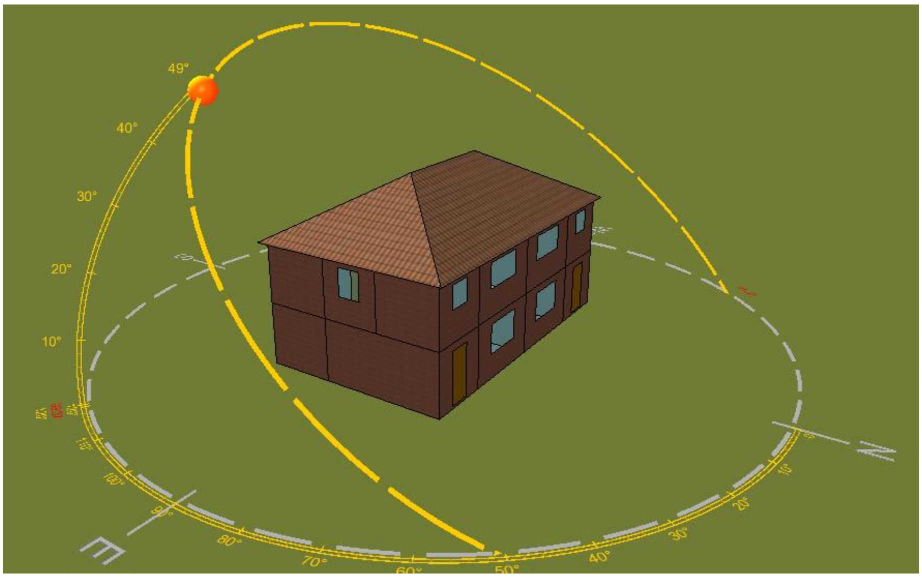
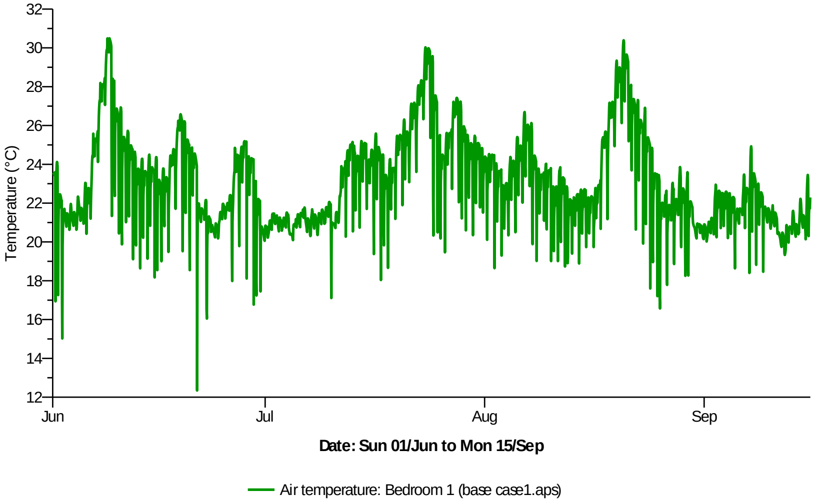


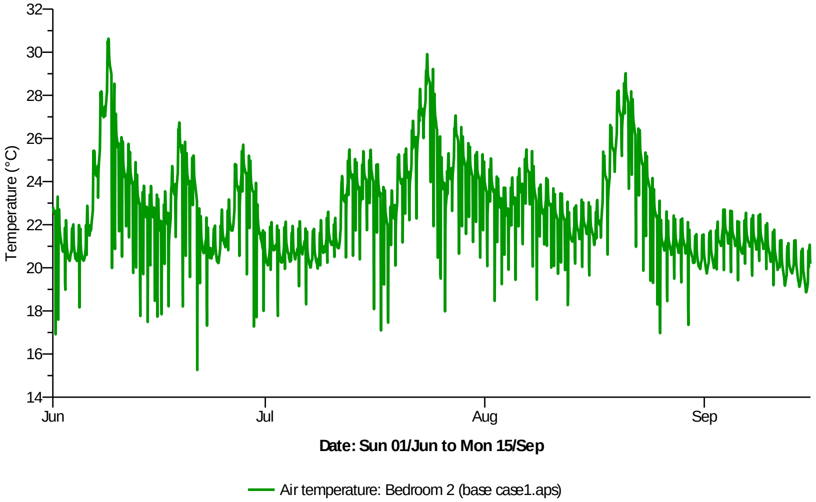
Figure H. 4 - North Facing Diagram

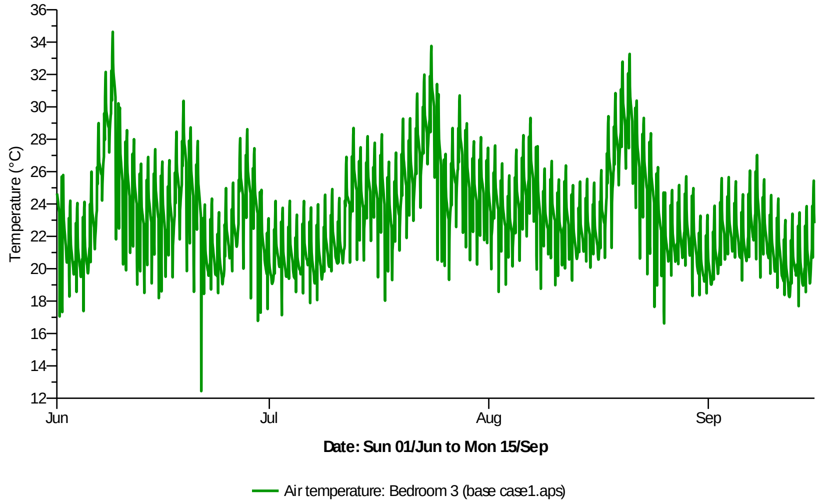
Appendix I

Hourly temperatures data of specific rooms across the entire testing period for each individual simulation scenario

I1. Base Case 1965-1980 semi-detached dwelling - Typical Family







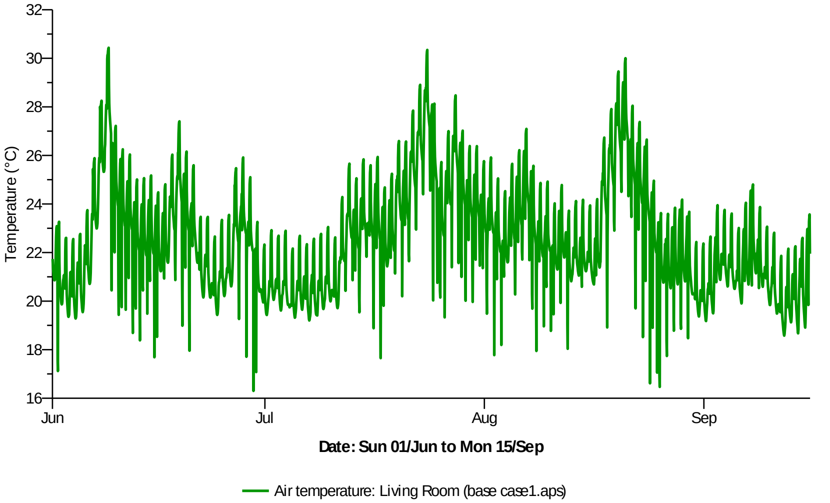
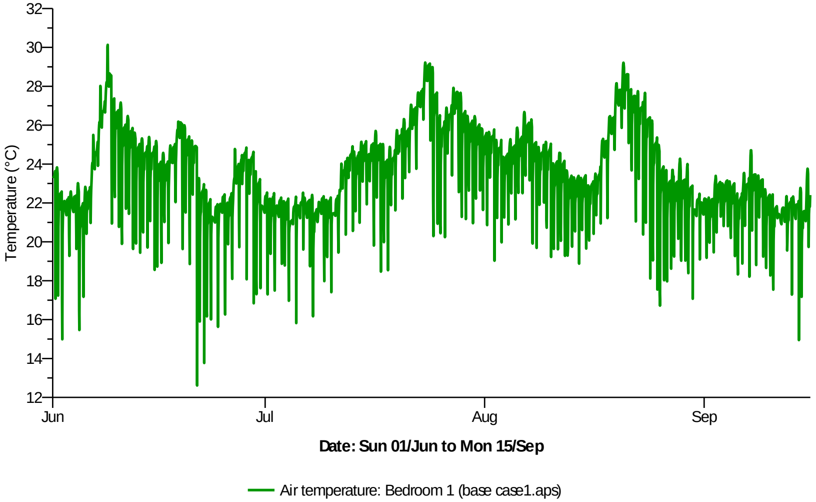
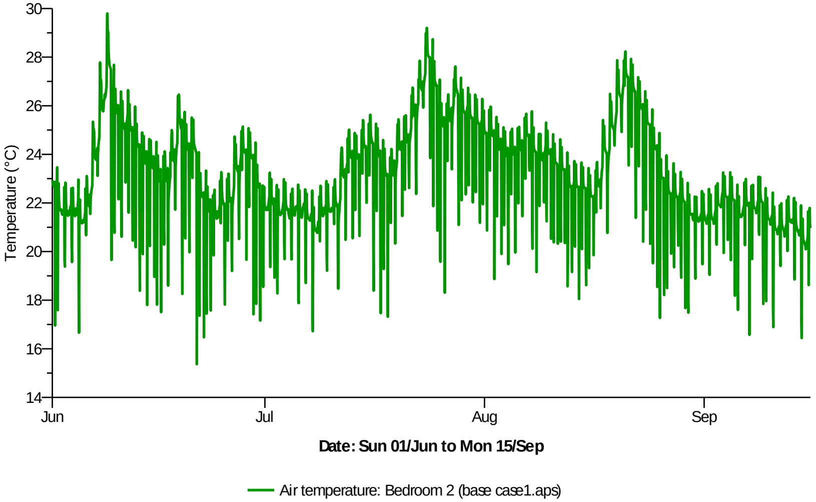
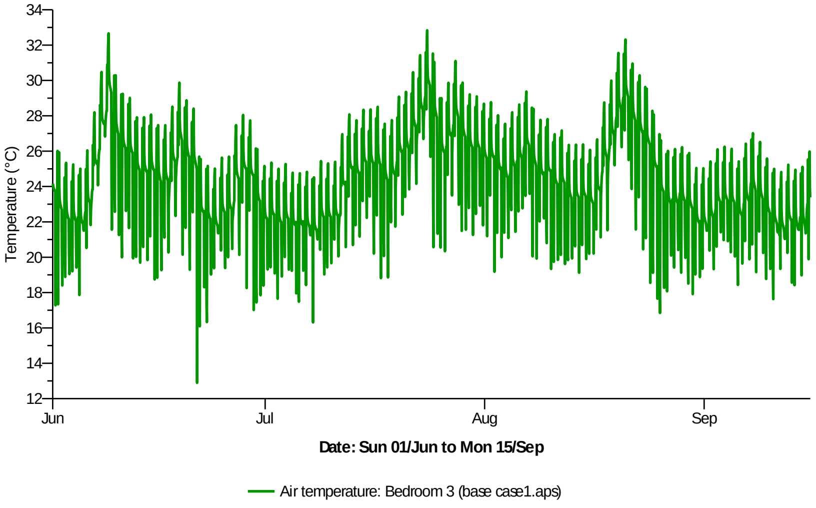


Figure I.1 - Hourly temperatures data of specific rooms across the entire testing period

I2. Retrofitted to 2010 Building Regulations, 1965-1980 semi-detached dwelling – Typical Family







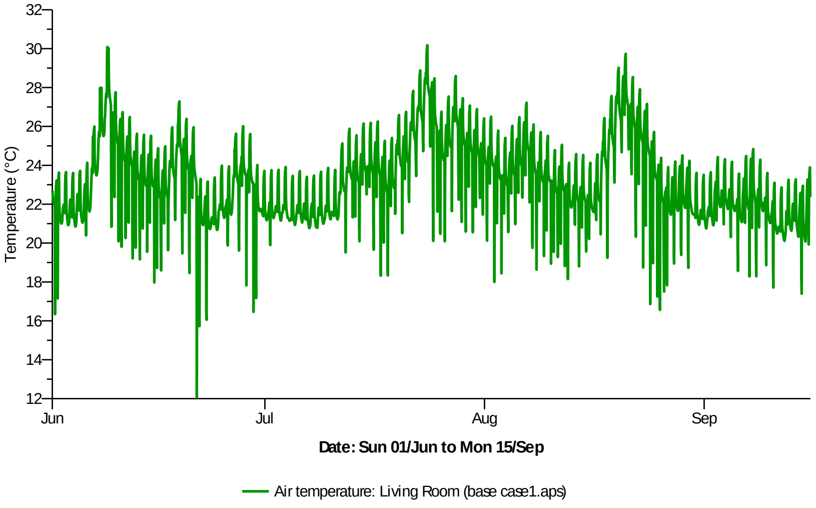
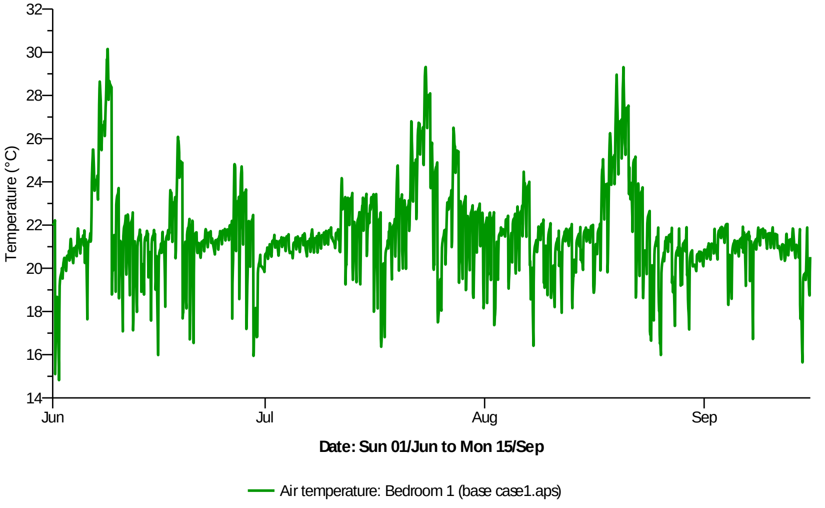
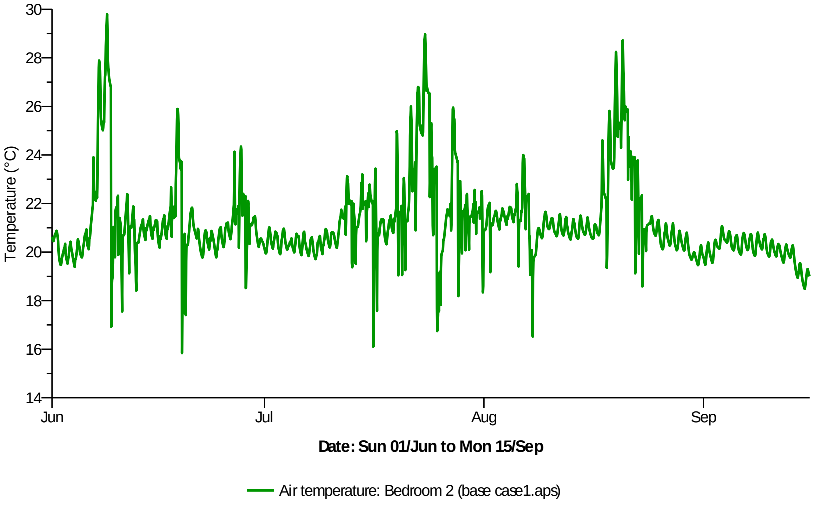
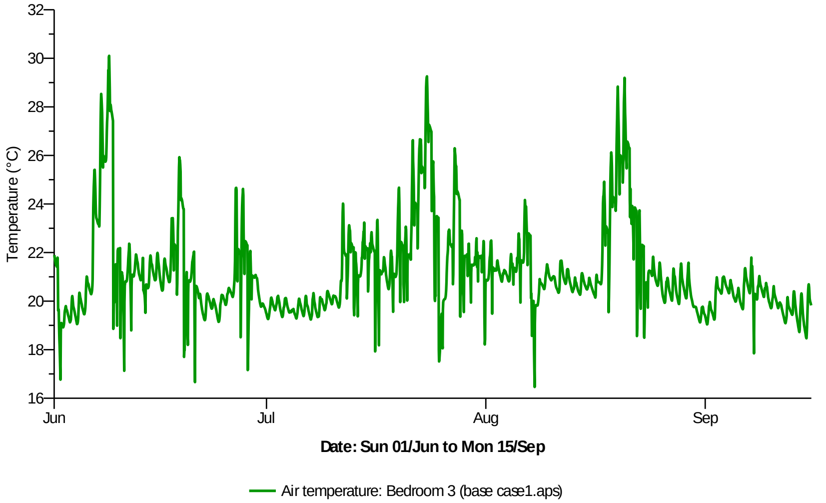


Figure I.2 - Hourly temperatures data of specific rooms across the entire testing period

I3. Retrofitted to 2010 Building Regulations, 1965-1980 semi-detached dwelling - Typical Vulnerable (Elderly residents) family







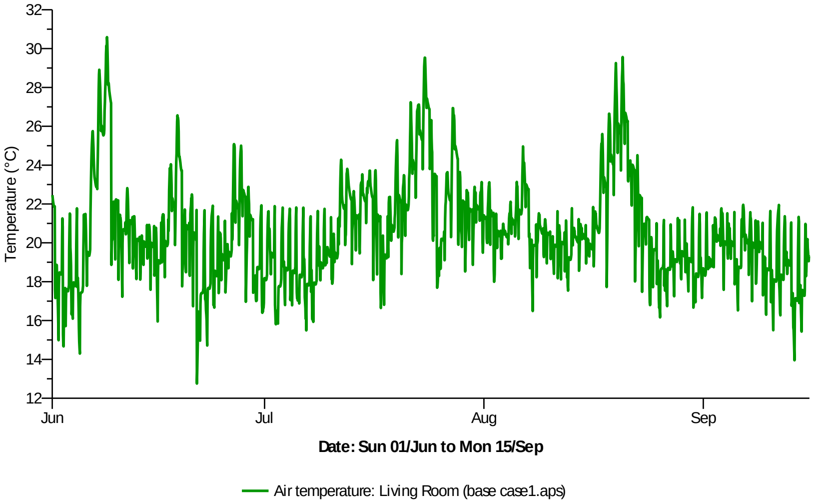
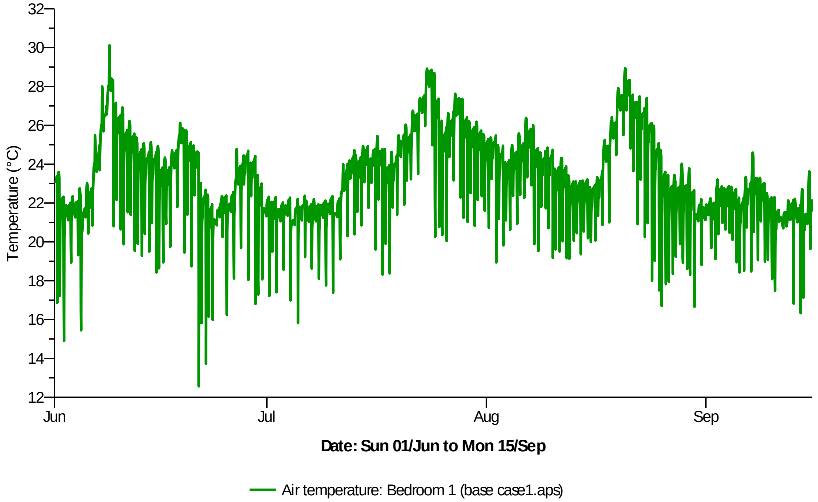
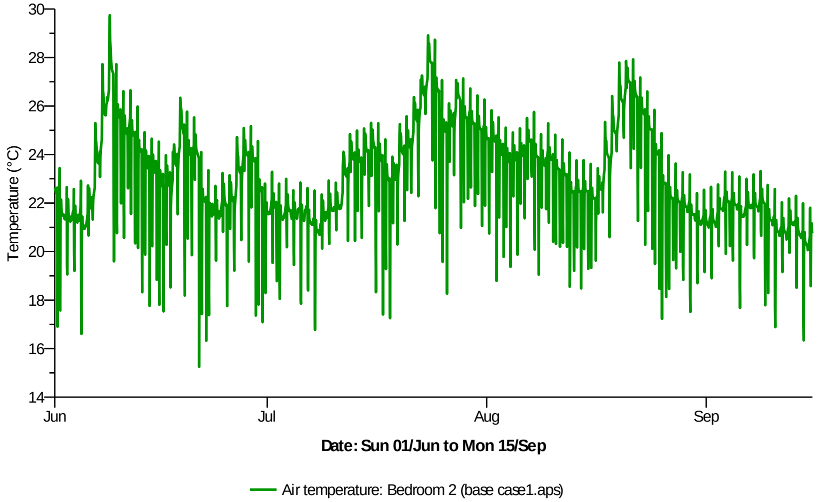


Figure I.3 - Hourly temperatures data of specific rooms across the entire testing period

I4. Updated modern and future internal gains and the occupant type's weekday and weekend time profile





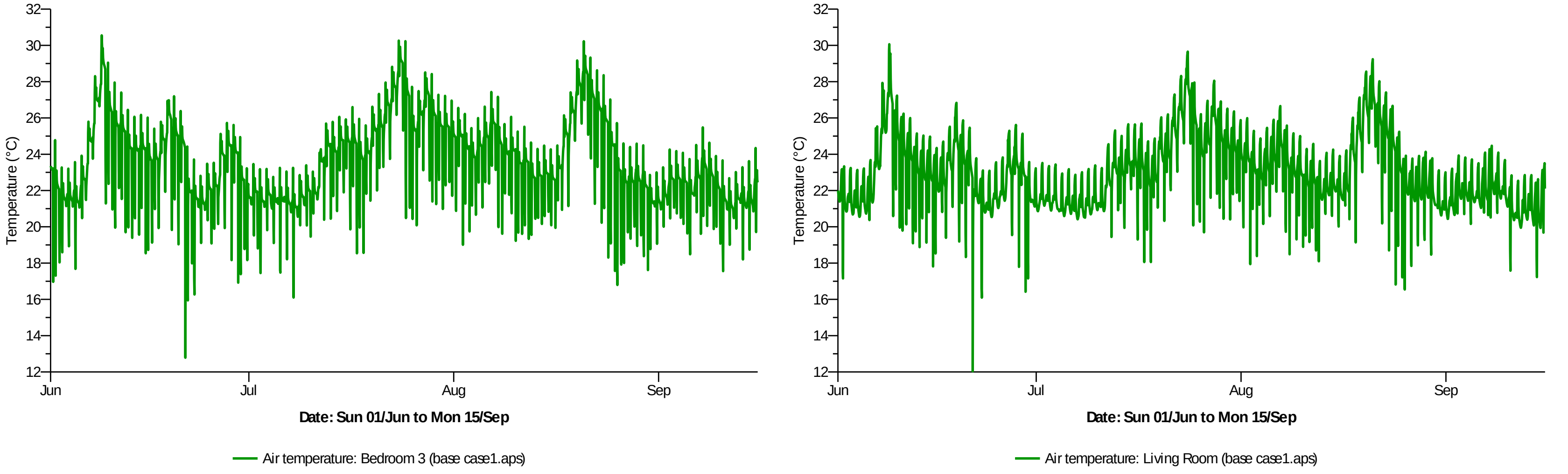
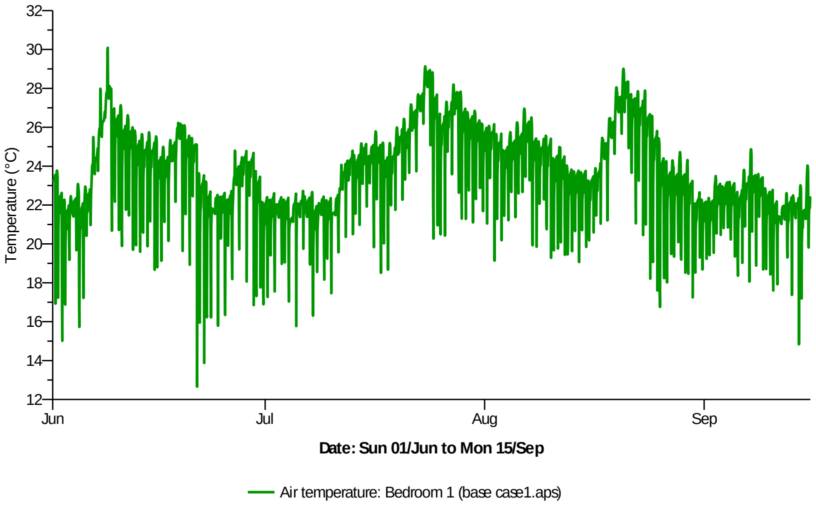
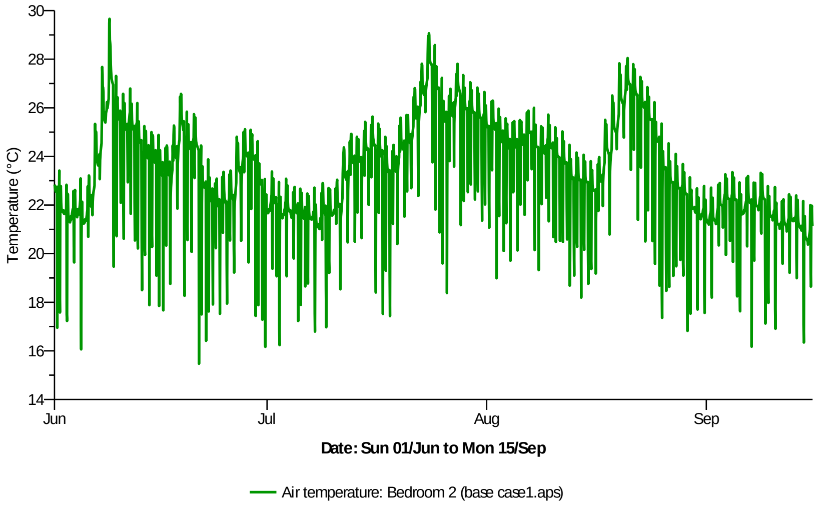


Figure I.4 - Hourly temperatures data of specific rooms across the entire testing period

I5. Building Regulations 2010 Approved Document material upgrades to include external insulation





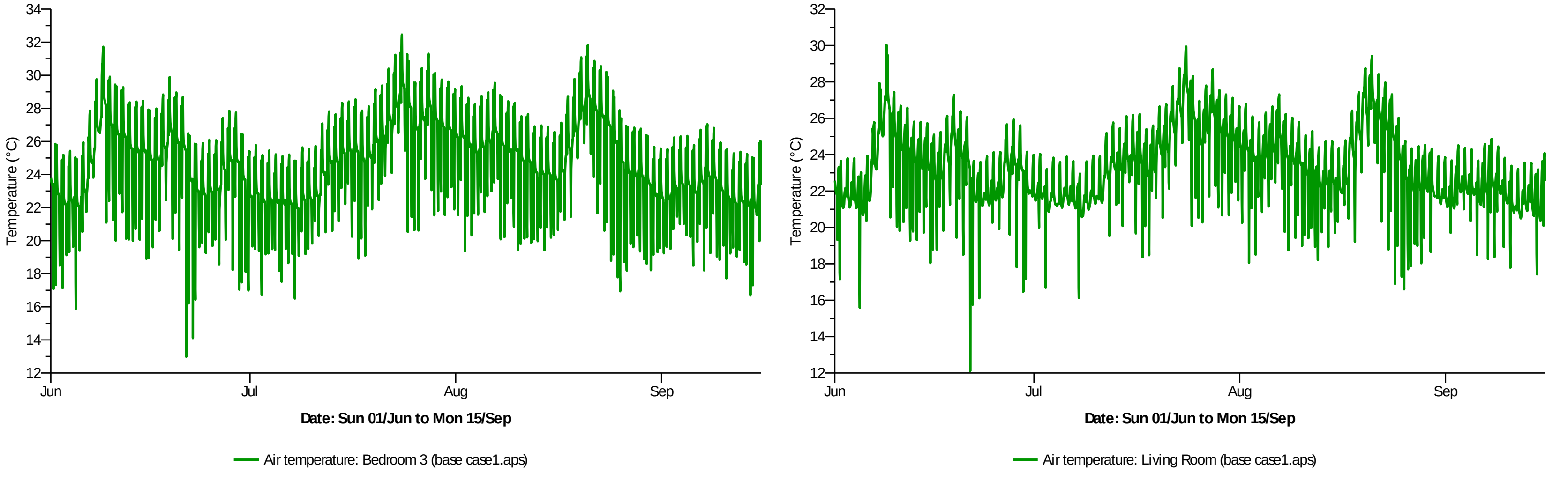
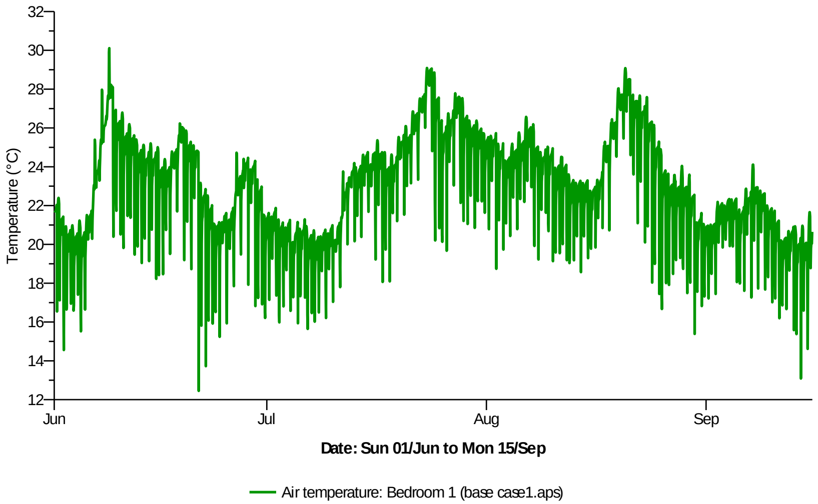
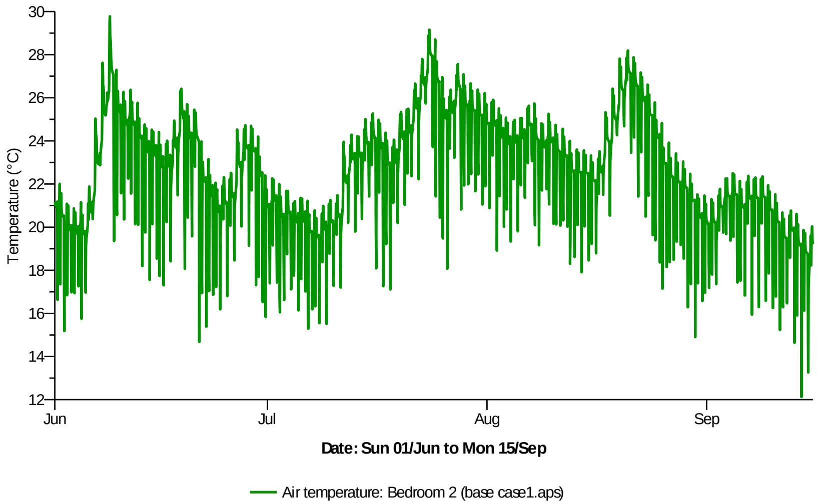
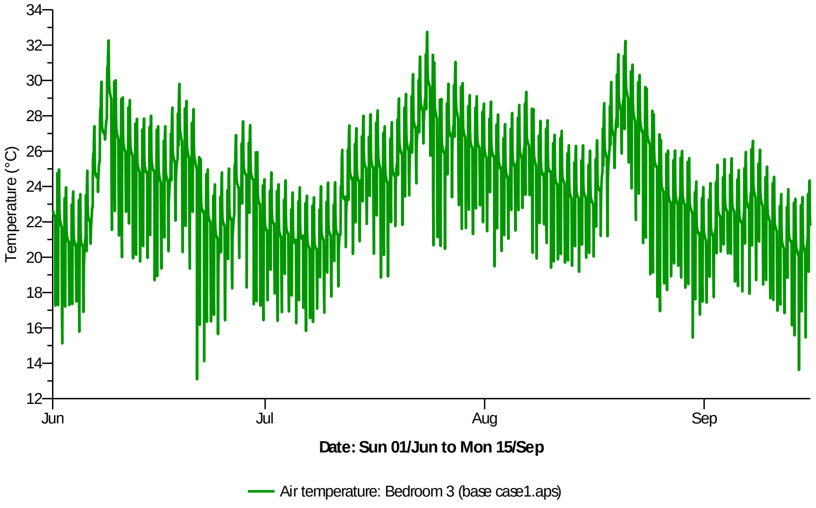


Figure I.5 - Hourly temperatures data of specific rooms across the entire testing period

I6. Alternative Cross-ventilation (double banked rooms) design







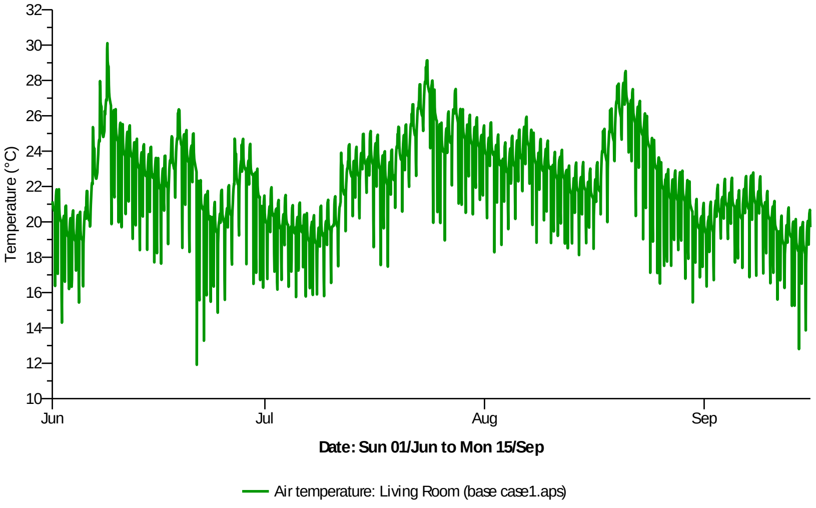
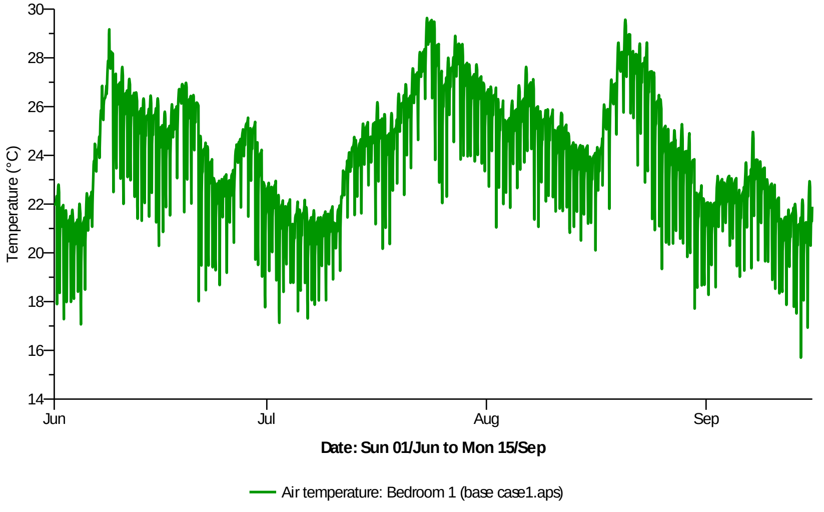
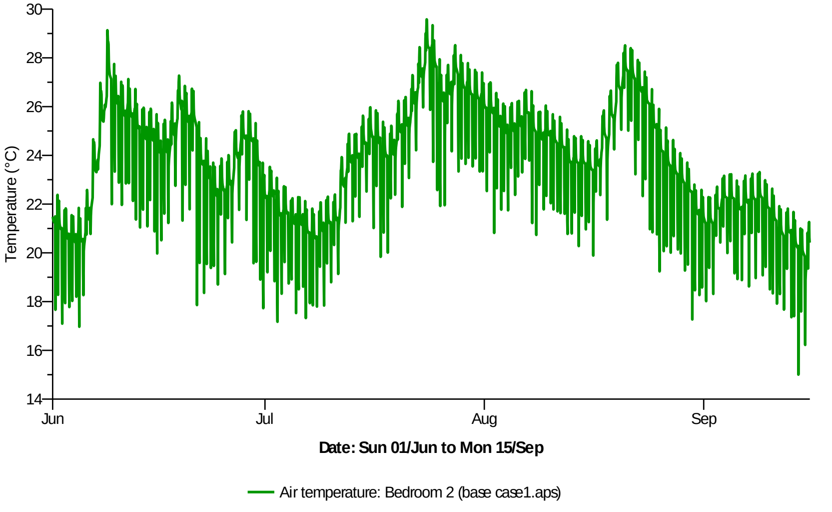
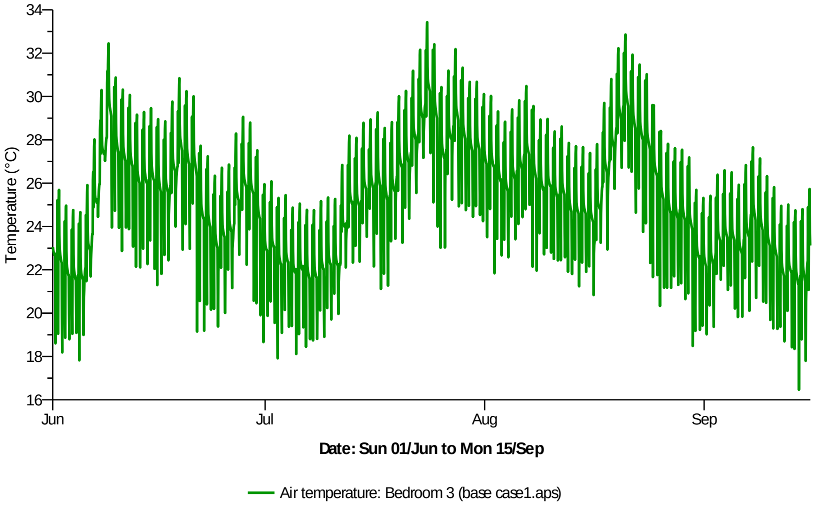


Figure I.6 - Hourly temperatures data of specific rooms across the entire testing period

I7. Alternative single sided ventilation design - daytime







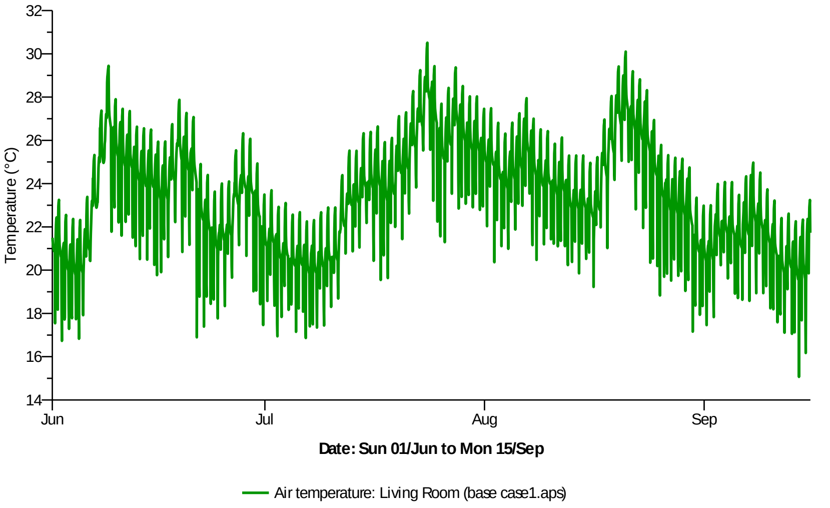
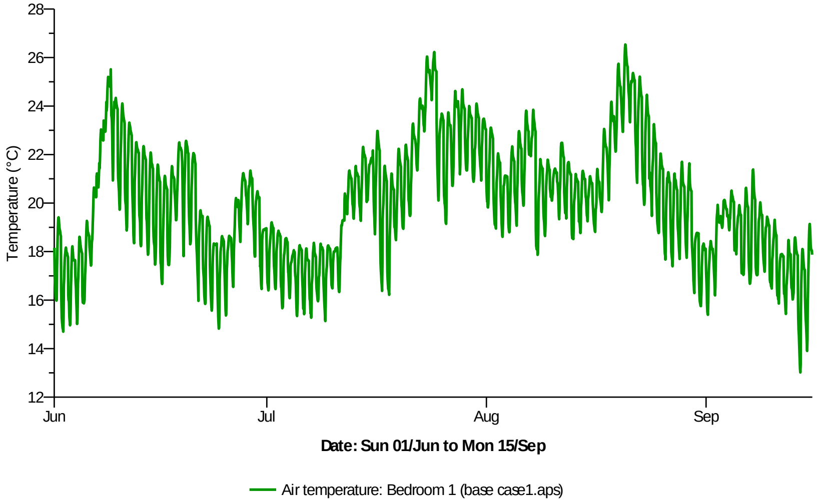
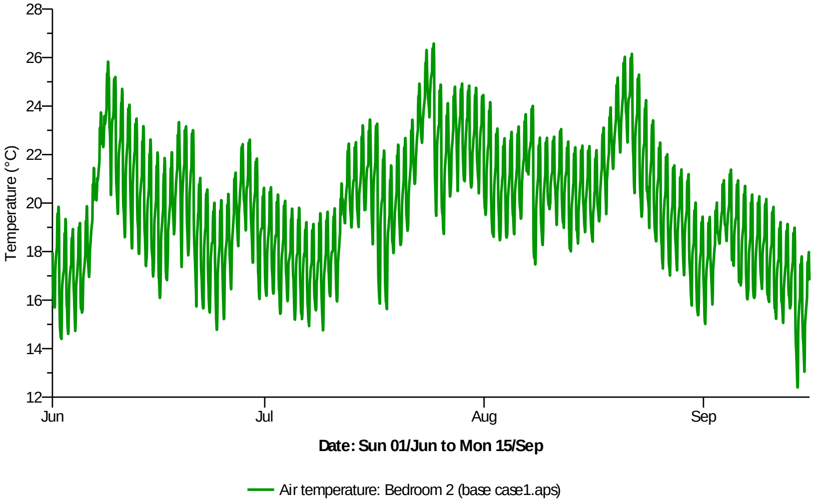


Figure I.7 - Hourly temperatures data of specific rooms across the entire testing period

I8. Alternative single sided ventilation design – night-time





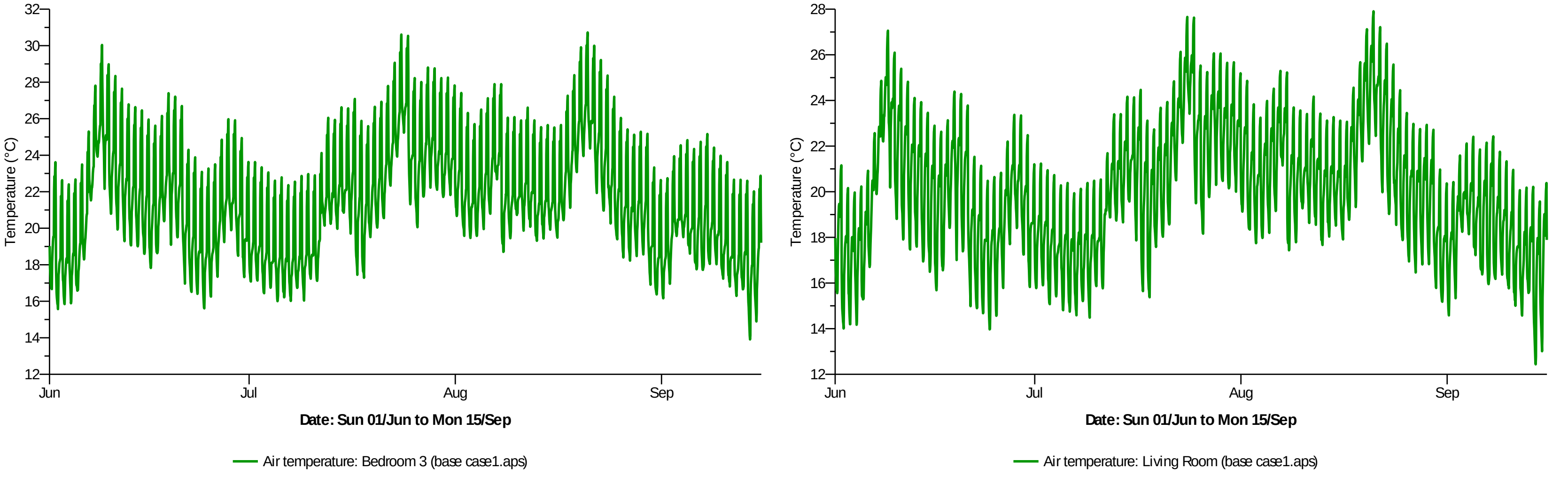
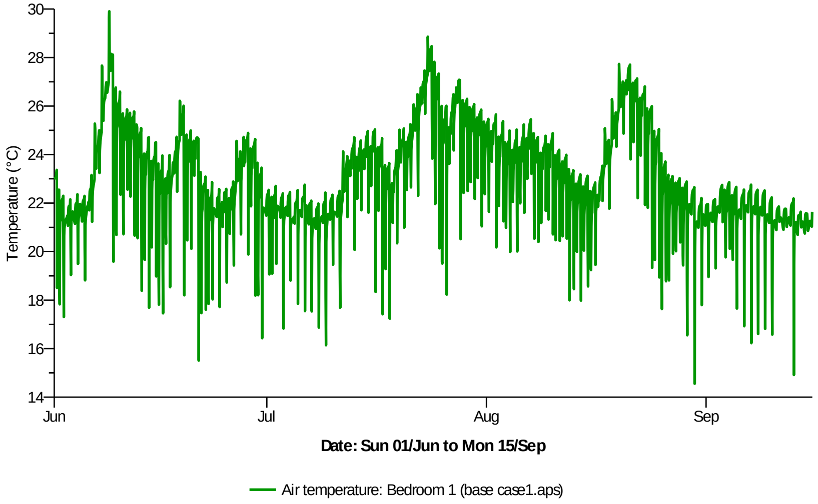
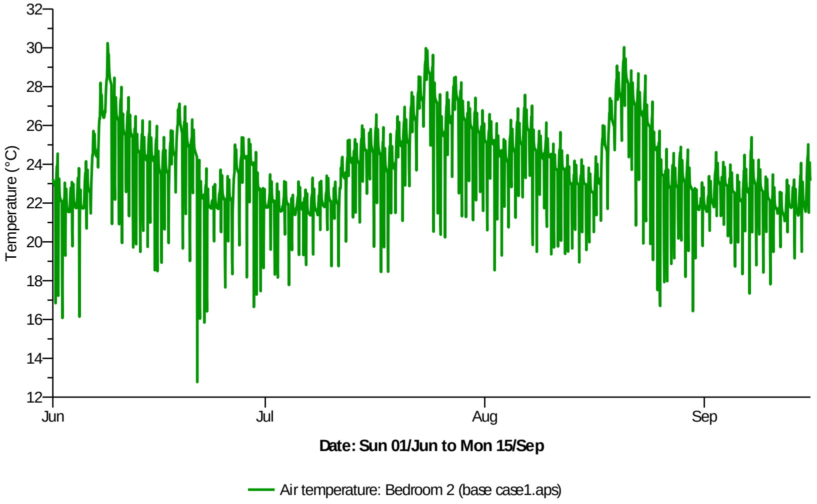
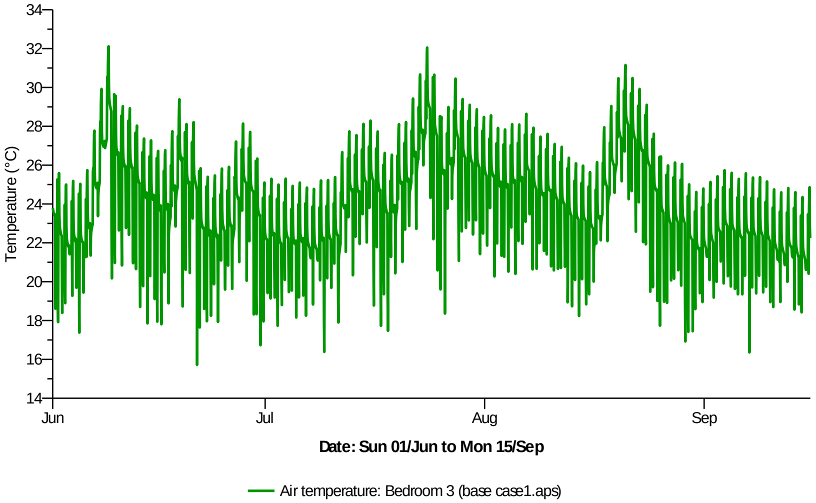


Figure I.8 - Hourly temperatures data of specific rooms across the entire testing period

I9. Retrofitted to 2010 Building Regulations, 1965-1980 semi-detached dwelling – North Facing Orientation







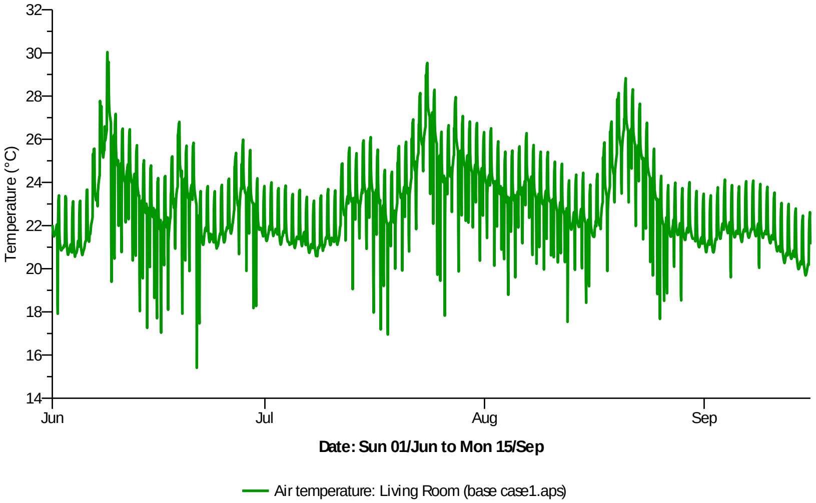
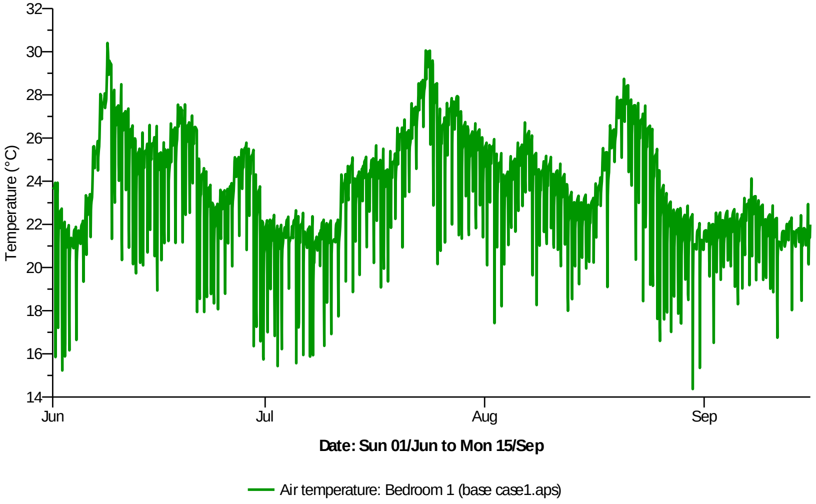
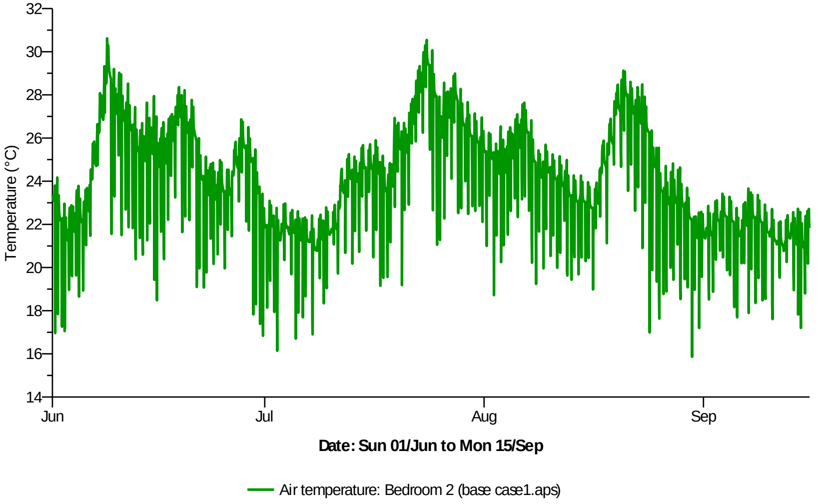


Figure I.9 - Hourly temperatures data of specific rooms across the entire testing period

I10. Retrofitted to 2010 Building Regulations, 1965-1980 semi-detached dwelling – West Facing Orientation





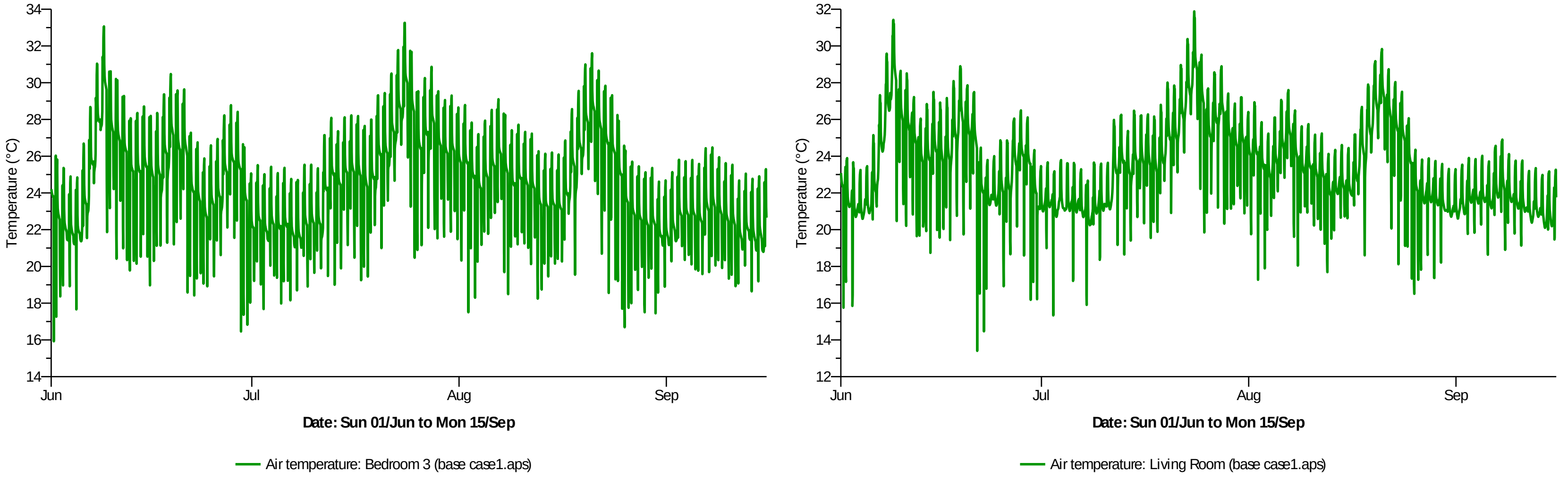
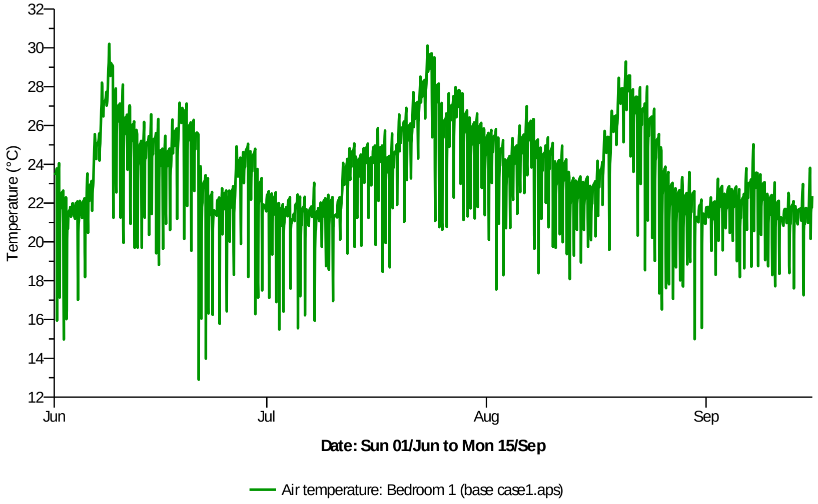
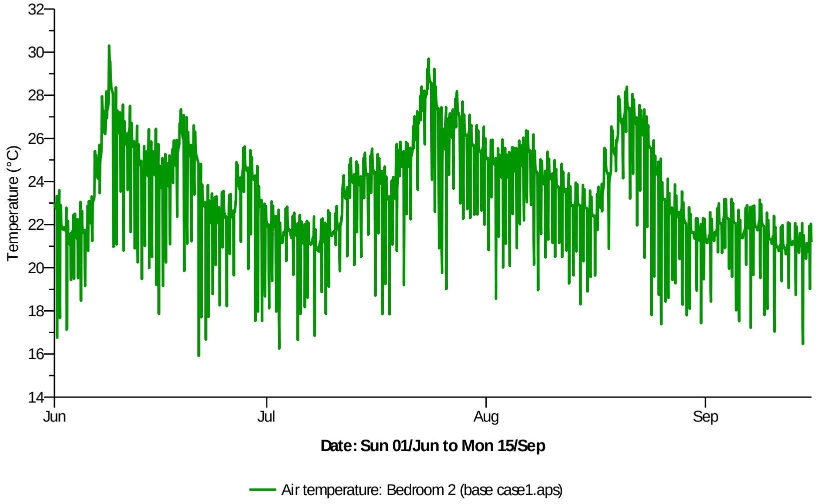
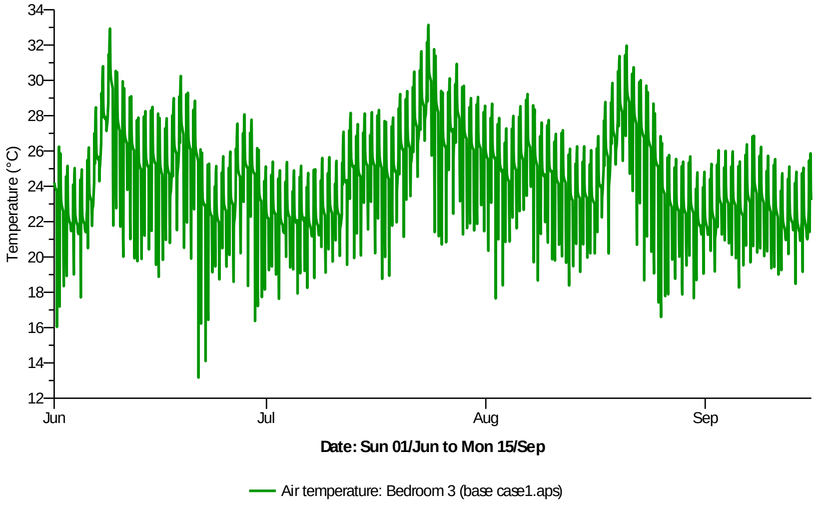


Figure I.10 - Hourly temperatures data of specific rooms across the entire testing period

I11. Retrofitted to 2010 Building Regulations, 1965-1980 semi-detached dwelling – South West Facing Orientation







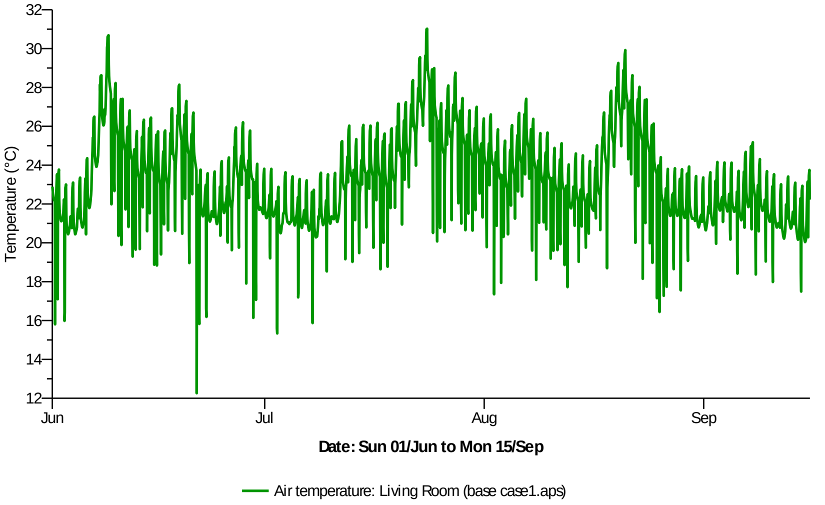
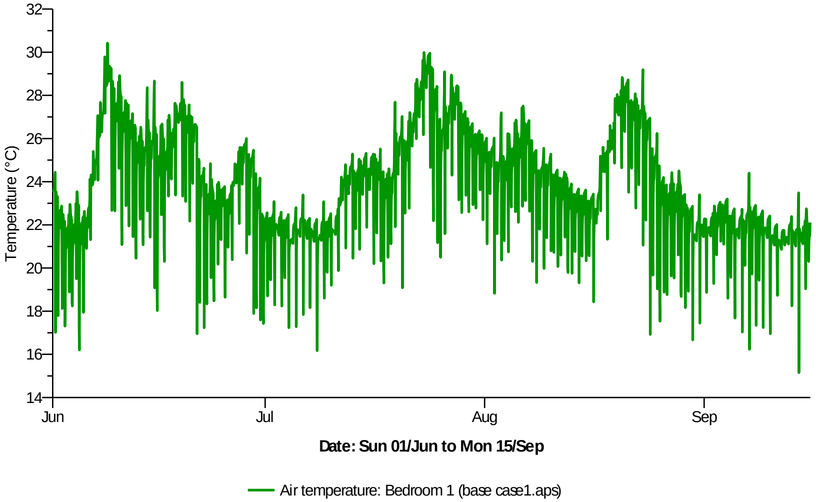
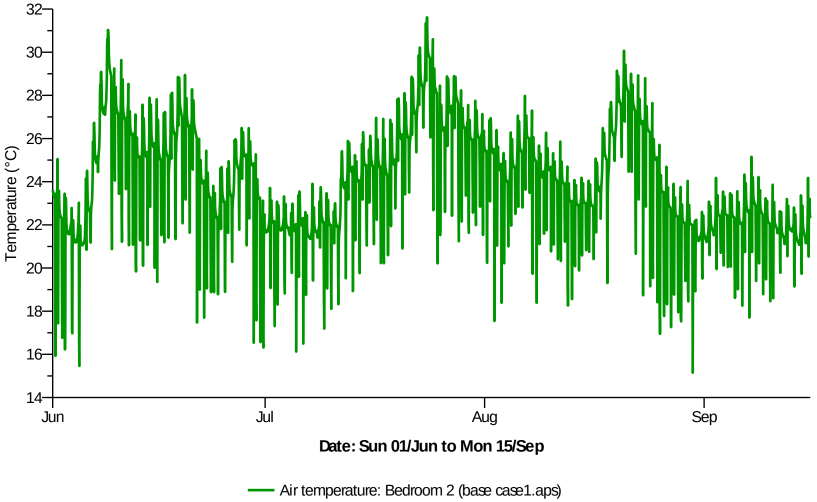
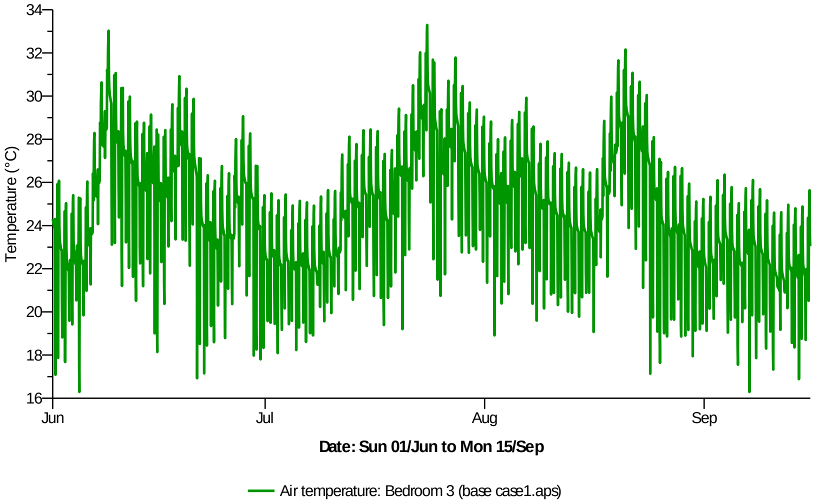


Figure I.11 - Hourly temperatures data of specific rooms across the entire testing period

I12. Retrofitted to 2010 Building Regulations, 1965-1980 semi-detached dwelling – East Facing Orientation







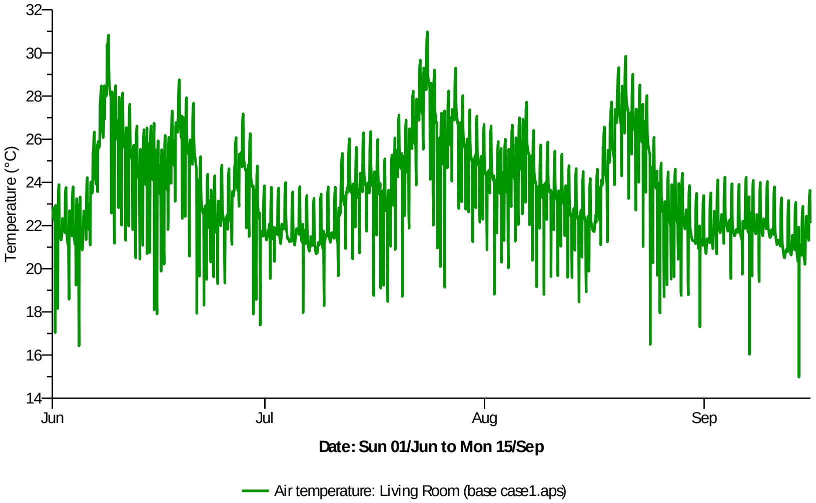
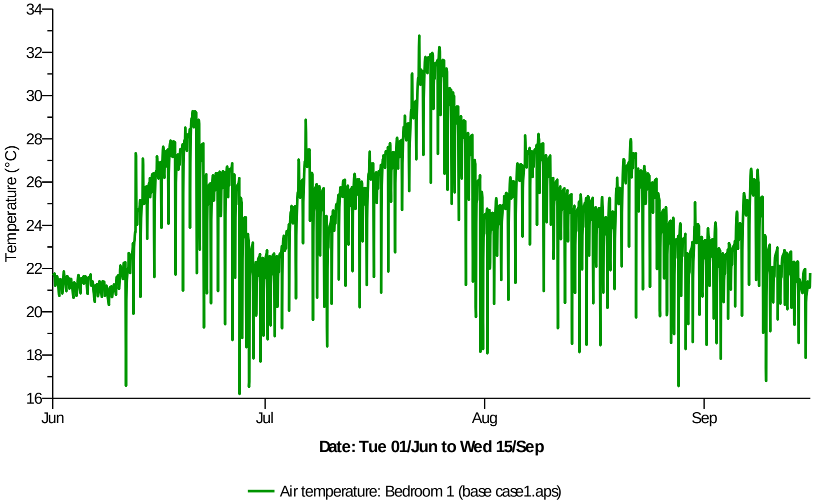
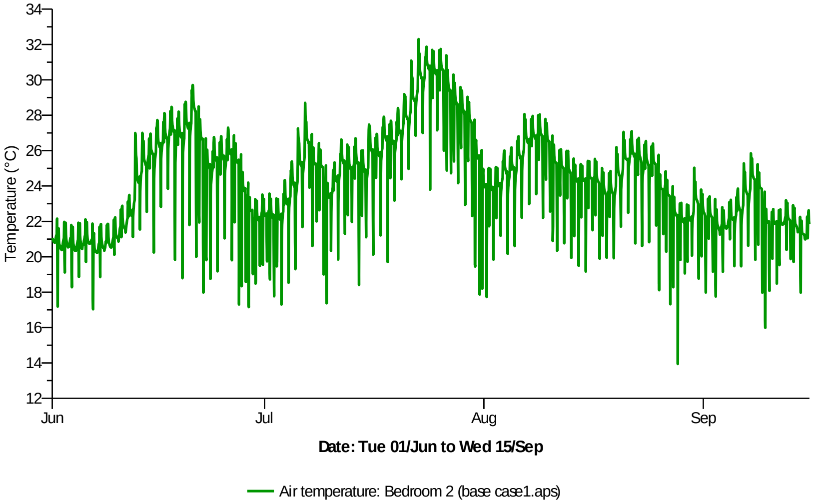
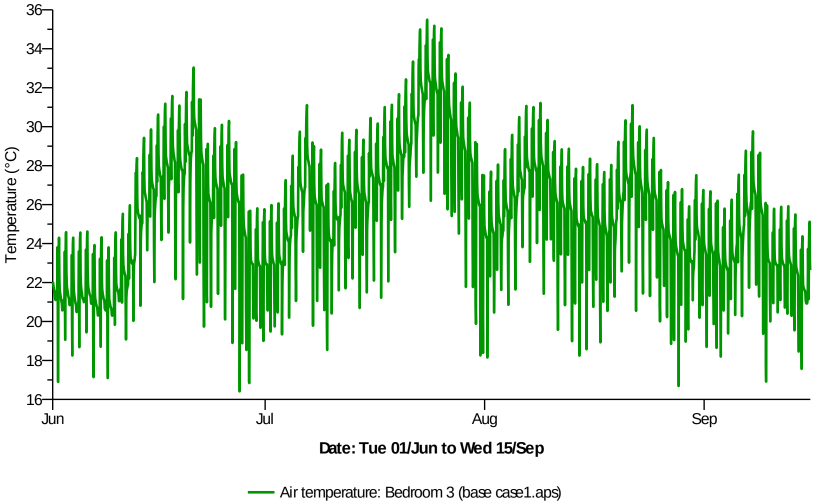


Figure I.12 - Hourly temperatures data of specific rooms across the entire testing period

I13. Heat wave Weather simulation - Retrofitted to 2010 Building Regulations, 1965-1980 semi-detached dwelling – Typical family time profile







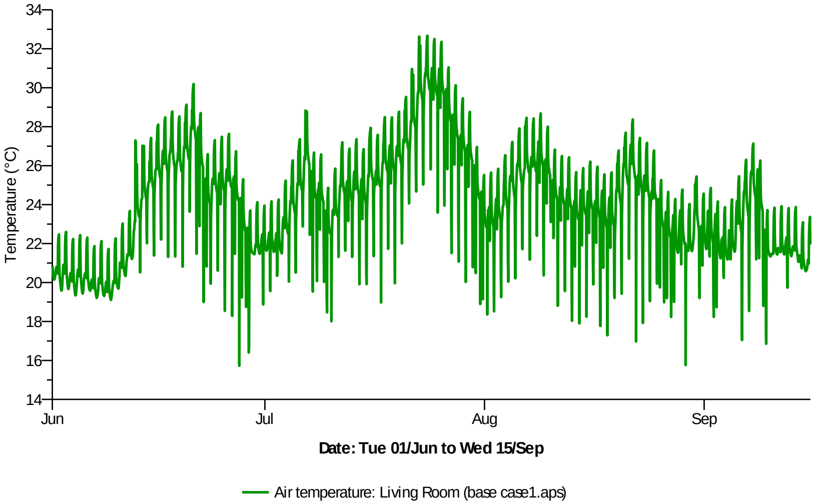
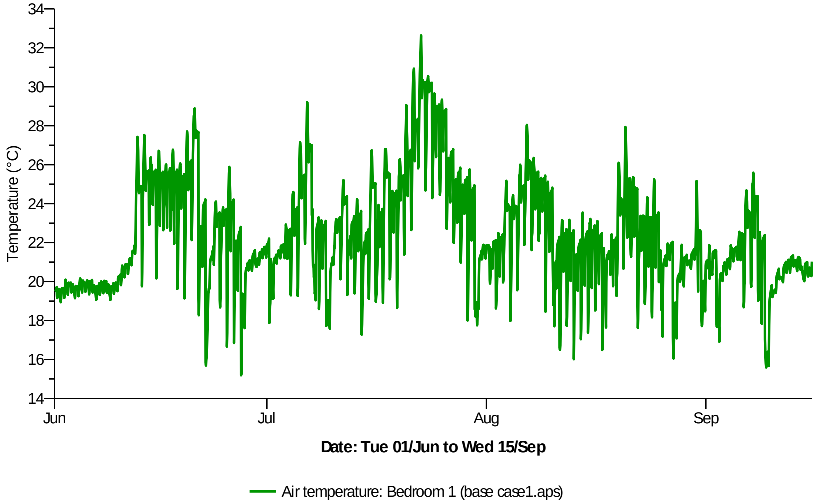
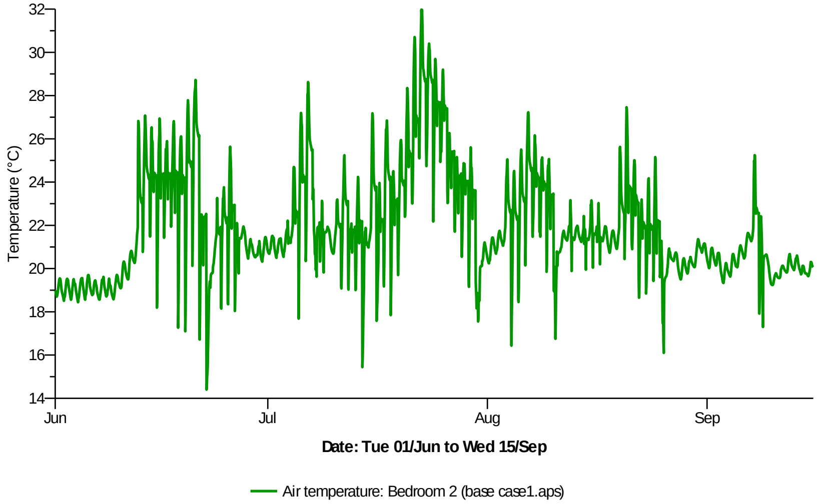
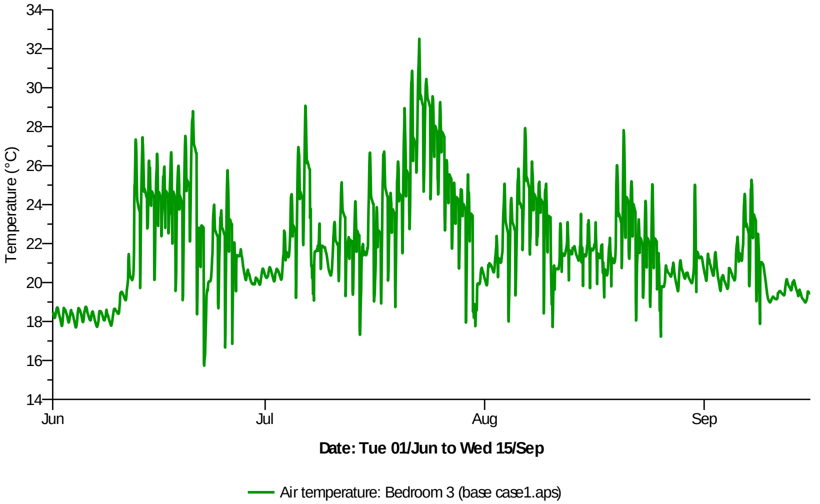


Figure I.13 - Hourly temperatures data of specific rooms across the entire testing period

I14. Heat wave Weather simulation - Base Case 1965-1980 semi-detached dwelling – Typical vulnerable (Elderly resident) time profile







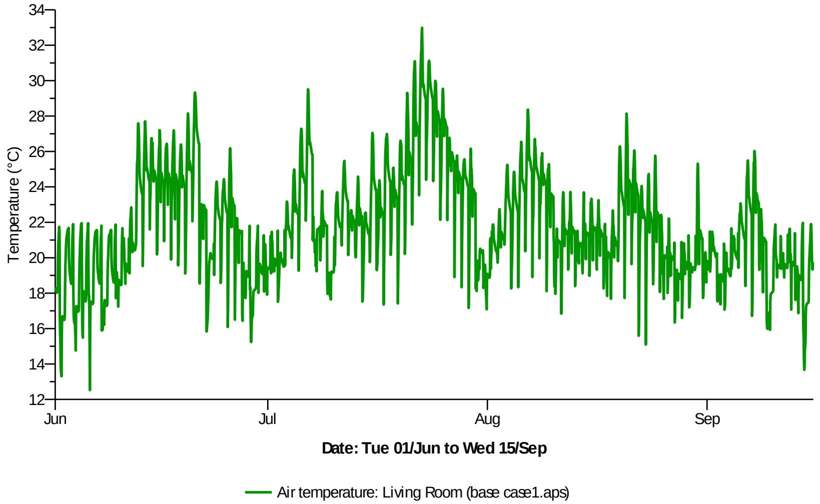
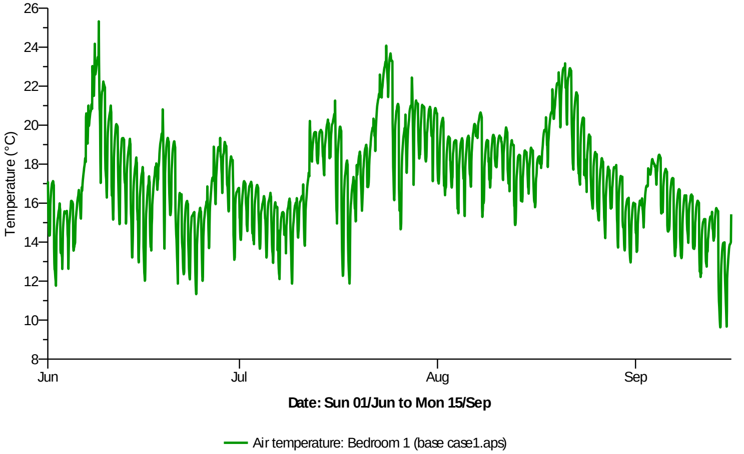


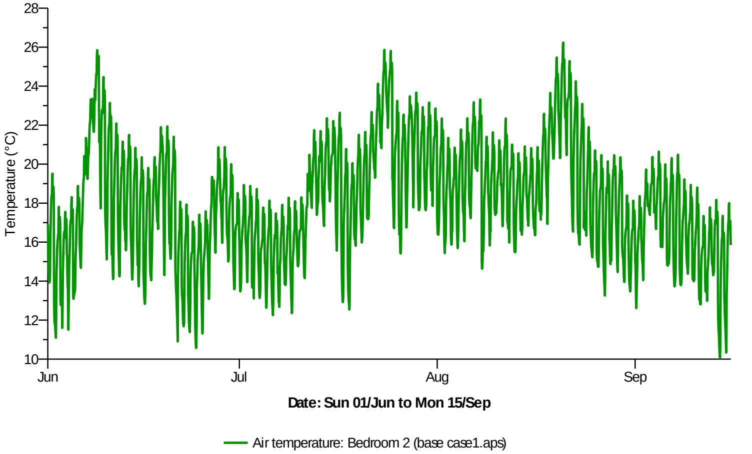
Figure I.14 - Hourly temperatures data of specific rooms across the entire testing period

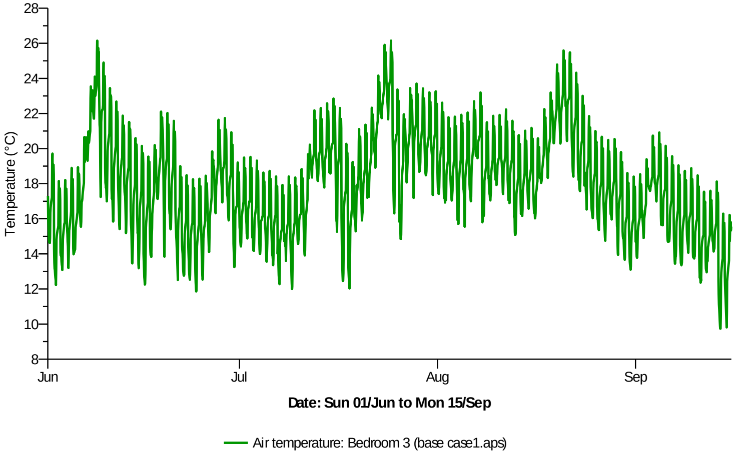
I15. Combined Interventions Best Case Scenario

	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Degree Hours above thresholds (26°C/28°C)
Location	> 26.00	> 27.00	> 28.00	> 29.00	> 30.00	> 31.00	> 32.00	> 33.00	
Bathroom	0	0	0	0	0	0	0	0	0
Bedroom 2	2	0	0	0	0	0	0	0	0
Bedroom 1	0	0	0	0	0	0	0	0	0
Kitchen	38	21	14	9	6	4	1	1	21
Dining Room	0	0	0	0	0	0	0	0	0
Living Room	0	0	0	0	0	0	0	0	0
Hallway Ground Floor and Stairs	0	0	0	0	0	0	0	0	0
1st Floor Hallway and Stairs	0	0	0	0	0	0	0	0	0
Bedroom 3	2	0	0	0	0	0	0	0	0

Table I.1 - Combined Interventions Best Case Scenario, Air temperature (°C) - hours in range and Degree Hours above thresholds (26°C/28°C)







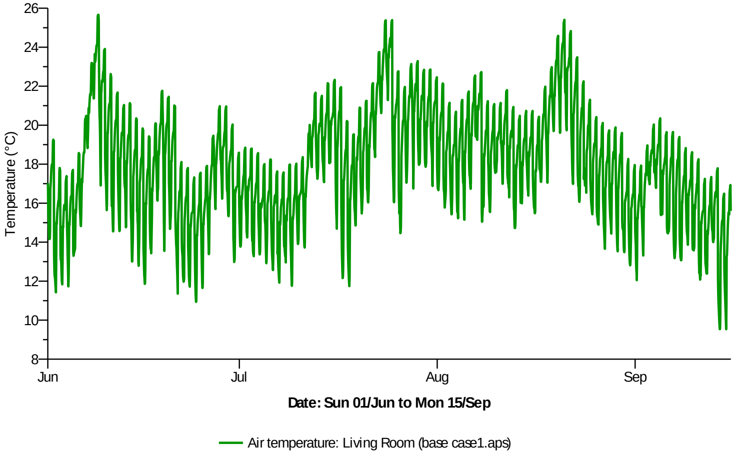


Figure I.15 - Hourly temperatures data of specific rooms across the entire testing period

I16. Combined Interventions Best Case Scenario– Heat wave

	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Degree Hours above thresholds (26°C/28°C)
Location	> 26.00	> 27.00	> 28.00	> 29.00	> 30.00	> 31.00	> 32.00	> 33.00	> 34.00	
Bathroom	0	0	0	0	0	0	0	0	0	0
Bedroom 2	29	5	0	0	0	0	0	0	0	5
Bedroom 1	1	0	0	0	0	0	0	0	0	0
Kitchen	60	51	38	23	11	6	5	2	1	42
Dining Room	3	0	0	0	0	0	0	0	0	0
Living Room	15	0	0	0	0	0	0	0	0	0
Hallway Ground Floor and Stairs	0	0	0	0	0	0	0	0	0	0
1st Floor Hallway and Stairs	0	0	0	0	0	0	0	0	0	0
Bedroom 3	24	3	0	0	0	0	0	0	0	3

Table I. 2 - Combined Interventions Best Case Scenario – Heat wave, Air temperature (°C) - hours in range and Degree Hours above thresholds (26°C/28°C)

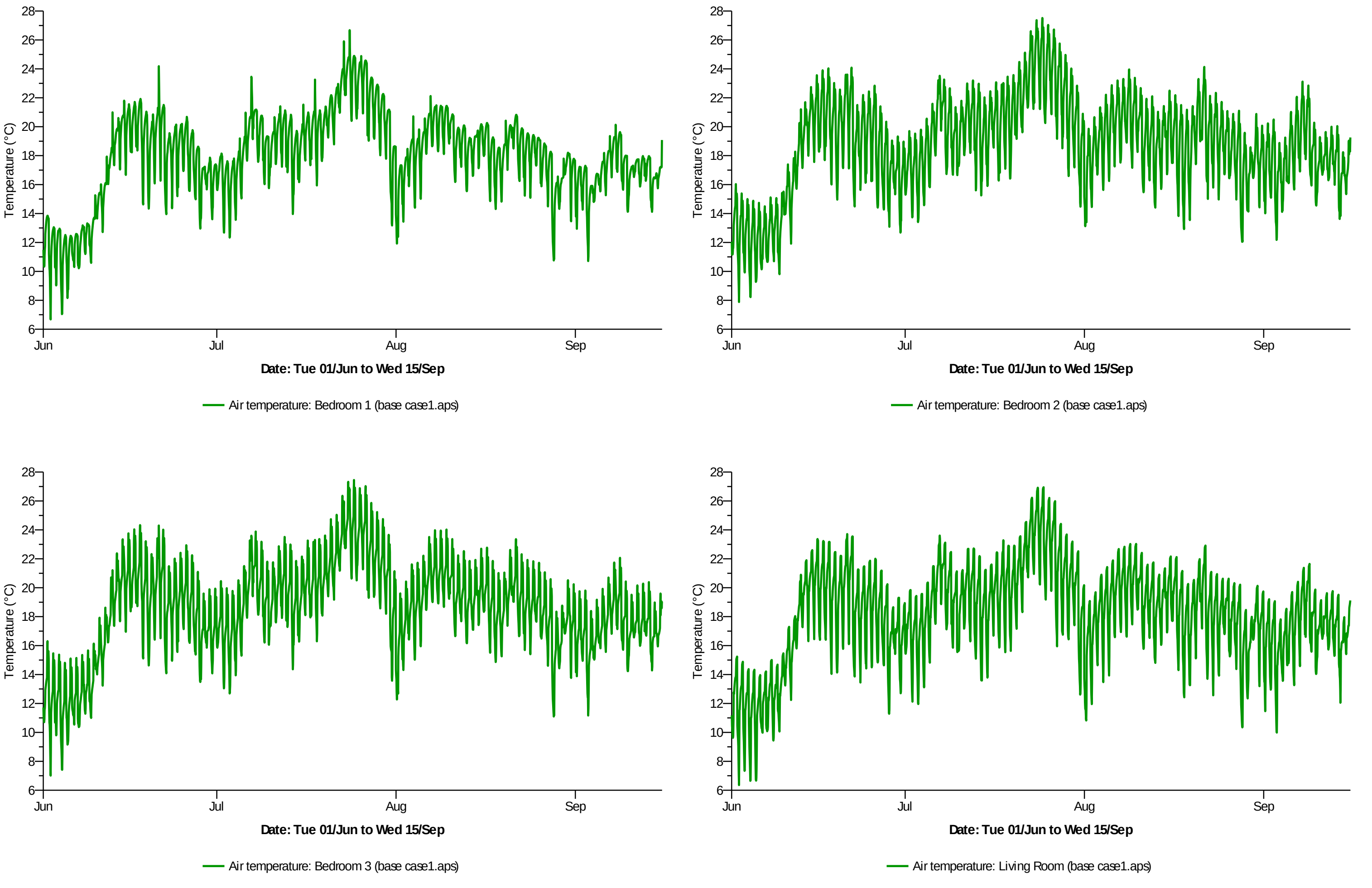


Figure I.16 - Hourly temperatures data of specific rooms across the entire testing period

I17. Combined Interventions Best Case Scenario – Vulnerable (Elderly) Occupants

	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Degree Hours above thresholds (26°C/28°C)
Location	> 26.00	> 27.00	> 28.00	> 29.00	> 30.00	> 31.00	> 32.00	> 33.00	
Bathroom	0	0	0	0	0	0	0	0	0
Bedroom 2	0	0	0	0	0	0	0	0	0
Bedroom 1	0	0	0	0	0	0	0	0	0
Kitchen	39	22	15	9	6	4	2	1	22
Dining Room	6	1	0	0	0	0	0	0	0
Living Room	42	5	0	0	0	0	0	0	0
Hallway Ground Floor and Stairs	0	0	0	0	0	0	0	0	0
1st Floor Hallway and Stairs	0	0	0	0	0	0	0	0	0
Bedroom 3	0	0	0	0	0	0	0	0	0
Total hours	87	28	15	9	6	4	2	1	65

Table I.3 - Combined Interventions Best Case Scenario – Vulnerable (Elderly) Occupants, Air temperature (°C) - hours in range and Degree Hours above thresholds (26°C/28°C)

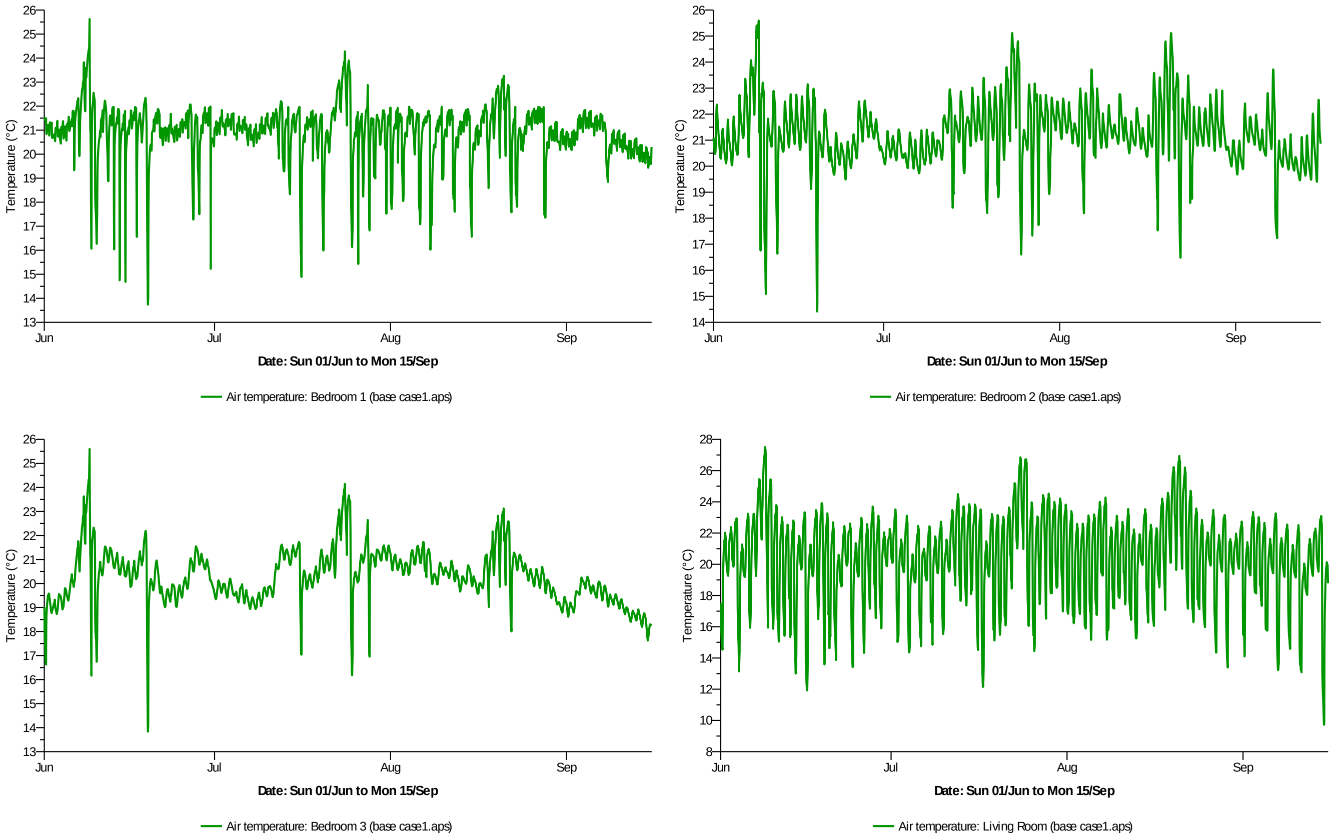


Figure I.17 - Hourly temperatures data of specific rooms across the entire testing period

I18. Combined Interventions Best Case Scenario – Vulnerable (Elderly) Occupants – Heat wave

	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Air temperature (°C) - hours in range	Degree Hours above thresholds (26°C/28°C)
Location	> 26.00	> 27.00	> 28.00	> 29.00	> 30.00	> 31.00	> 32.00	> 33.00	> 34.00	
Bathroom	0	0	0	0	0	0	0	0	0	0
Bedroom 2	0	0	0	0	0	0	0	0	0	0
Bedroom 1	2	0	0	0	0	0	0	0	0	0
Kitchen	62	50	37	24	10	6	5	2	1	42
Dining Room	5	5	1	0	0	0	0	0	0	0
Living Room	52	35	7	0	0	0	0	0	0	0
Hallway Ground Floor and Stairs	0	0	0	0	0	0	0	0	0	0
1st Floor Hallway and Stairs	0	0	0	0	0	0	0	0	0	0
Bedroom 3	0	0	0	0	0	0	0	0	0	0
Total hours	121	90	45	24	10	6	5	2	1	175

Table I.4 - Combined Interventions Best Case Scenario – Vulnerable (Elderly) Occupants - Heat wave, Air temperature (°C) - hours in range and Degree Hours above thresholds (26°C/28°C)

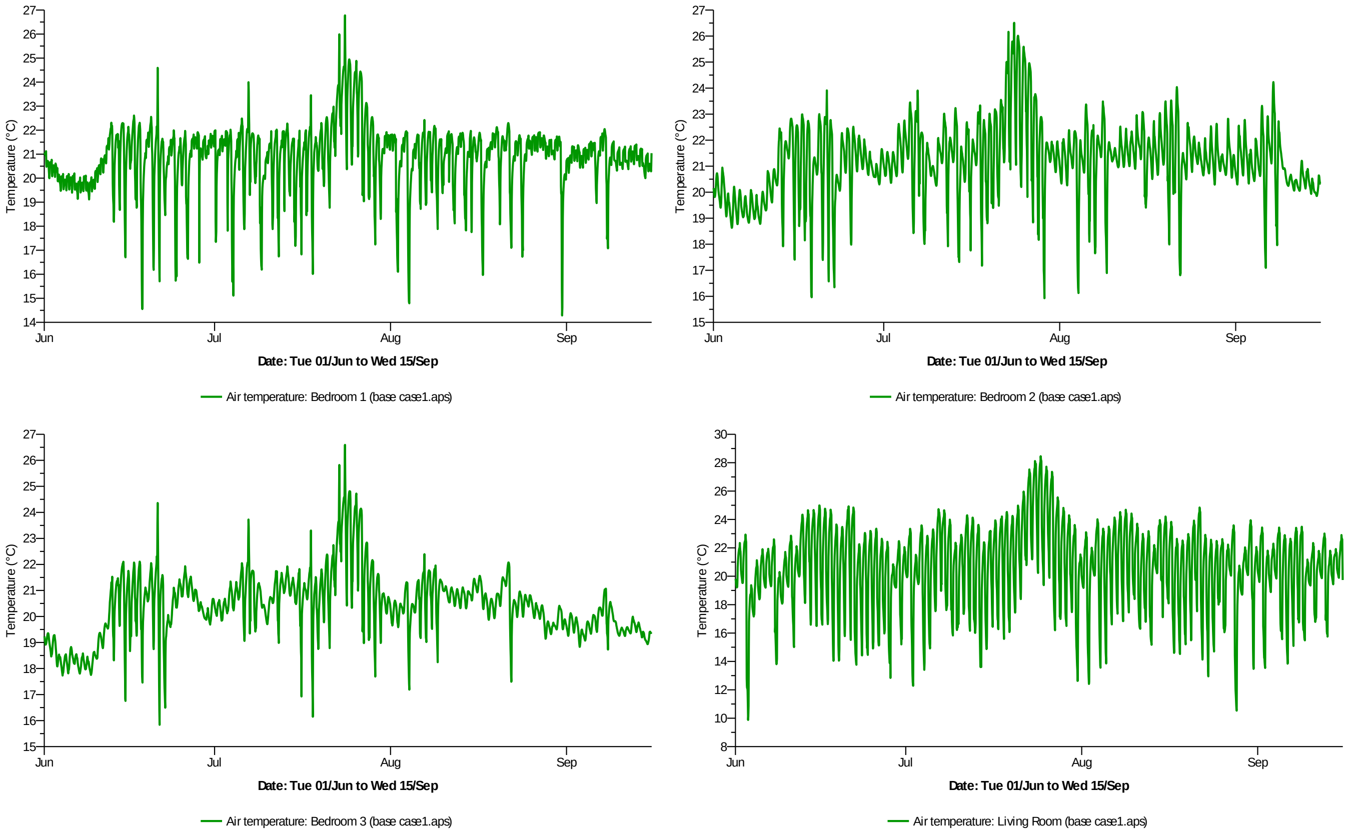
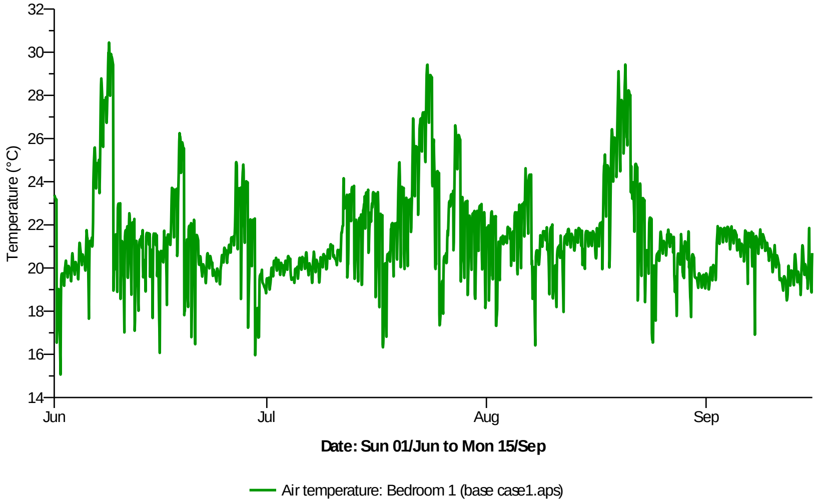
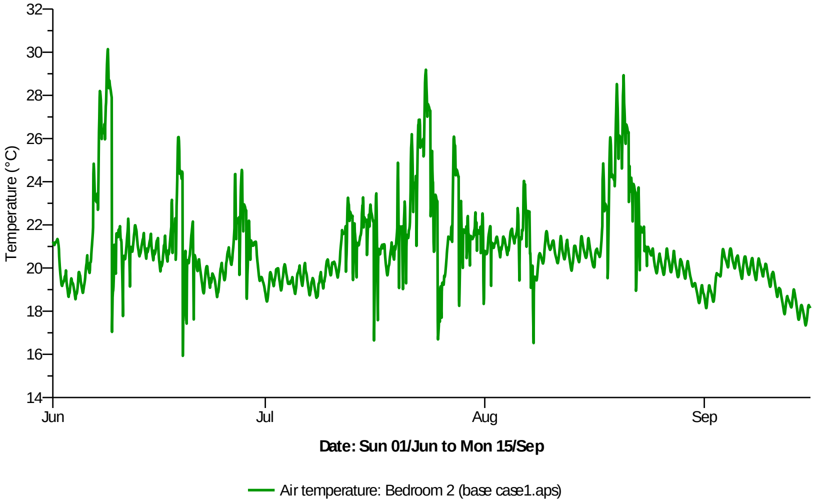


Figure I.18 - Hourly temperatures data of specific rooms across the entire testing period

I19. Base Case 1965-1980 semi-detached dwelling – Typical vulnerable (Elderly resident) family





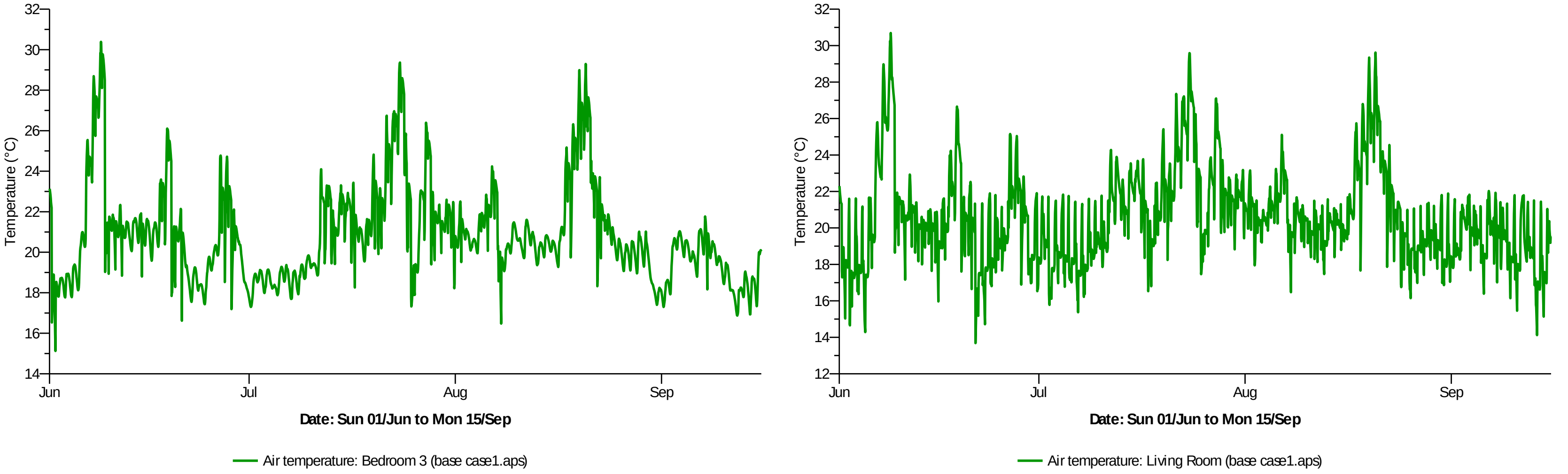


Figure I.19 - Hourly temperatures data of specific rooms across the entire testing period