Welsh School of Architecture.
University of Wales, College of Cardiff.

An Analysis of the Potential Impact of Climatic Change on Risks to Health and Comfort for Housing Occupants in Neath Port Talbot, South Wales.

Julie Gwilliam
Thesis submitted for the degree of Doctor of Philosophy,
Welsh School of Architecture, Cardiff University.
2007

Thesis copyright declaration

to be signed by each user of this thesis

author GWILLIAM, J.

title An analysis of the potential impact of climate change on risks to health and comfort for housing occupants in Neath Port Talbot, South Wales.

year 2007

degree Ph.D.

accession no.

I undertake not to publish any portion of or use any information derived from, this thesis without the written consent of the Director. I further undertake to allow no one else to use this thesis while it is issued to me.

date	name and address in capitals	signature

IS 244/1008

INFORMATION SERVICES PO BOX 430, CARDIFF CF24 0DE

Declaration

This work has n

concurrently sub

Signed…………

Date………………

STATEMENT 1

This thesis is the

Other sources ar

A bibliography is

Signed…………

Date……………

STATEMENT 2

I hereby give c

inter-library loa

organisations.

Signed……………………………………………………………… (candidate)

Date………………………………………………………………

Declaration

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

Signed .... (candidate)

Date ....

STATEMENT 1

This thesis is the result of my own investigations, except where otherwise stated.

Other sources are acknowledged by footnotes giving explicit references.

A bibliography is appended.

Signed .... (candidate)

Date ....

STATEMENT 2

I hereby give consent for my thesis, if accepted, to be available for photocopying and for inter-library loan, and for the title and summary to be made available to outside organisations.

Signed .... (candidate)

Date ....

Summary

The inter-relationship between the internal environment of buildings and the external environment is likely to alter in the presence of climate change. The potential implications of this changing relationship for the health and comfort of housing occupants in Neath Port Talbot (NPT), south Wales, are considered in this thesis through an analysis of health and comfort risk systems

A literature review of climate change, occupant thermal comfort, health and housing and architecture has been undertaken to establish the risk systems for risks to occupant health and comfort, through the application of the source-pathway-receptor model of risk. This review has been summarised through the production of risk matrices including an evaluation of the potential for increase or decrease in the risk to occupant heath and comfort in the domestic environment, due to climate change

Questionnaire surveys were undertaken to establish the current distribution of occupant health and comfort risks in households in NPT during hot summers and average winters, considered as temporal proxy for future average conditions. Further to this these surveys considered the influence of occupant behaviour and housing, neighbourhood and socio-economic factors. Detailed monitoring of a case study home, built in the year 2000, was also undertaken, using temperature and relative humidity loggers, An air leakage test and thermography survey wer also undertaken. This enabled a quantitative analysis of conditions in relation to comfort thresholds during the hot summer of 2003.

It has been found that homes in NPT present health and comfort risks to their occupants under current extreme climate during both the winter and summer. These risks include inadequate and excess heating, damp and mould and inadequate ventilation levels.

Future work should focus on quantitative impact research and risk distribution in housing, as well as on passive methods to alleviate summer overheating, in order to avoid an increase in energy usage for cooling and its potential impact on climate change mitigation.

Contents

Appendices

SEE ENCLOSED CD (PC FORMAT)

List of Illustrations

List of Tables

Acknowledgements

I would like to express my gratitude to Professor Phil Jones for his guidance as my supervisor throughout this research and to EPSRC for providing funding. Similarly I would like to thank the following staff at the Welsh School of Architecture for their help, advice and time

Don Alexander
Sylvia Harris
Huw Jenkins
Simon Lannon
Jo Patterson
Wouter Poortinga
Nikki Weaver

I would also like to thank Truda Bell at the Department of Epidemiology, Statistics and Public Health and my partner Mike Rhodes for his help and support.

Chapter 1 Introduction

'To see the future is good: but to prepare for it is better' - ***Chinese proverb***

(Source: DEFRA, 2001, p1)

In June 1992, at the Rio Earth Summit, the Intergovernmental Panel on Climate Change (IPCC) presented its findings on global climate change (IPCC Website, accessed 2005). This report identified the global consequences of climate change, including: increases in global mean temperature, rises in sea level, the melting of polar ice caps and loss of global bio-diversity. This was a scientific finding that could not be ignored, as it had implications for every nation and every member of the World's population. As a result of the findings of this initial work, the United Nations Framework Convention on Climate Change (UNFCCC) was written, accepted and has since been ratified by more than 180 countries (UNFCC Website, 2005). This convention can be seen as the starting point for the debate within the international scientific community, governments and the media on the subject of global climate change and how the World should adapt to its consequences and work to mitigate further change.

Since the adoption of the UNFCCC, much research has been undertaken to further understand the subject, with three working groups of the IPCC assessing and providing peer review of work. The focus of much early work has been on the global climate system, using sophisticated computer models to explore possible future climate change under a series of emissions scenarios (Houghton et al, 1996), which concluded with agreement in March 2001 that:

'*........there is new and stronger evidence that most of the warming observed over the last fifty years is attributable to Human activities*' (IPCCa, 2002, pix).

This also placed the responsibility for the scale of future global impacts of these changes on human decisions and actions over the coming decades. The IPCC reports identify the reliance of humans on fossil fuels and thereby the creation of greenhouse gases, as one of the main driving forces of the changes in climate (UNFCCC, Website 2005). Thereby mitigation of emissions of this suite of gases became the second focus for global research.

However, mitigation of future climate change through responsible and sustainable development will not be sufficient to alter the course of future climate. According to the IPCC findings to date, there will already be consequences as a result of the emissions created, mostly by the western world, during the industrial revolution through to the present day. It can be seen that due to the inherent delays in the global climate system, the atmospheric pollution already emitted will have a significant impact on our climate over the coming century and whatever our actions with respect to energy-type and usage over the coming decades, climatic change at some scale will be unavoidable. It is therefore vital that we understand these changes, their affects on the climate, the environment and our health and that we successfully adapt to accommodate them. Studies of the potential impact on all sectors of society will be necessary to ensure the continued, health, comfort and prosperity of the human population. Research must therefore be undertaken to explore the risk inherent in existing systems, as well as the systems' ability to adapt to the climate. The former is referred to as 'risk assessment' and the latter as 'adaptation'.

The central aim of this work, to explore the potential risk due to global climate change for the health and comfort of occupants in the domestic built environment in south Wales, can be seen to fit within this wider research framework. This research focuses on the assessment of health and comfort risk due to interrelationships between the changing climatic hazard, the exposure unit of homes and the vulnerability of their occupants.

This research can be seen to draw from a broad community of climate change research in the UK which is being co-ordinated by the UK Climate Impacts Programme (UKCIP website, 2005). The UKCIP are responsible for distributing current UK regional climate change scenarios, developed by the Hadley centre (a section of the Meteorological Office) and methodological guidance on climate impacts research. In the UK to date there have been a number of regional impact surveys (McKenzie-Hedger & Merylyn eds., 2000), including regional scoping studies, for example: 'Wales: Changing Climate, Challenging Choices', prepared for the National Assembly for Wales in May 2000 (Farrar & Vaze, 2000) and sectoral studies, for example: 'Health Effects of Climate Change in the UK, An Expert Review for Comment' published by the Department of Health in February 2001 (DoH, 2001).

Studies considering the potential impact of climate change on the built environment have been limited to date (Steemers, 2003, p15), and have included the following work:

- Roberts et al at the Welsh School of Architecture in 1994, under contract to the BRE, carried out 'An Investigation of the Response of Building Fabric Performance to Projected Climatic Changes in the UK'. This work concentrated on the physical impact of climatic change on the materiality and structure of buildings.
- The BRE carried out further work which is summarised in their publication, 'Potential Implications of Climate Change in the Built Environment' (Graves & Phillipson 2000). This publication provides a '*technical assessment of potential impacts and adaptation strategies based on the UK Climate Impacts Programme 'Medium – High' Climate Change Scenario'*. This work was based on the earlier 1998 UKCIP scenarios (UKCIP 1998) and provides a suggested methodology for further research on impacts and adaptations in the built environment.
- A study by the Association of British Insurers on the impact of climate change on the insurance sector, considered the impact on buildings (ABI, 2004) from the perspective of the insurance sector. This did not, by its nature, consider occupant impact.
- Arup Associates have carried out research into the impact of the UKCIP 02 climate change scenarios on the internal environment under contract to CIBSE in 2004-5. This work, 'Climate Change and the Internal Environment' (Hacker et al, 2005, CIBSE, 2005), is based on thermal modelling of the future thermal environment using case study built forms.

Further to this. the UKCIP announced an initiative to study the impact of climate change on the built environment. under the Building Knowledge for a Changing Climate (BKCC) portfolio (BKCC Website. 2005). Launched in 2003 these projects are wide ranging and include the following:

- ASCCUE: Adaptation Strategies for Climate Change in the Urban Environment.
- AUDACIOUS: Adaptable Urban Drainage - Addressing Change in Intensity, Occurrence and Uncertainty Of Stormwater.
- BESEECH: Building Economic and Social information for Examining the Effects of Climate Change.
- BETWIXT: Weather scenarios for investigation of Impacts and Extremes.
- BIONICS: Biological and Engineering Impacts of Climate Change on Slopes.
- CRANIUM: Climate change Risk Assessment: New Impact and Uncertainty Methods
- EHF: Engineering Historic Futures.
- GENESIS: Examining climate change impacts on the electricity supply industry.

This portfolio of projects has widened the scope of work undertaken in the field of climate change and the built environment, although there is no consideration of health and comfort impacts for occupants. This series of research projects does not include a focus on internal health and comfort, although it is likely that some of the results of the external comfort work being carried out by Oxford Brookes University will have some relevance to this research.

In 2000, McKenMaynard & Gawith wrote that *"Understanding the links between housing, energy use climate and health need to be improved if meaningful responses are to be developed"* (McKenzie Hedger et al, 2000, p95).

The research into the impacts of global climate change on the built environment and on occupant health and comfort can therefore be interpreted as being in its infancy. Therefore, this study is well placed to expand current knowledge into the explicit interconnections between the four research areas of climate change, health, comfort and the built environment. Through this research it is proposed that the ability of current buildings to continue to provide comfort and maintain the health of occupants over the changing climate of the 21st Century can begin to be assessed. It should be noted that this sustained health and comfort should be achieved through low or no energy solutions, and as such should follow sustainable development guidelines, in order to mitigate further climatic change.

The measurable objectives of the work are defined as:

- Through literature review, establish those current risks to health and comfort in the built environment that are likely to be influenced by a changing climate.
- Through analysis of the literature, evaluate the potential change in current risk due to climate change through analysis of the factors that consitute occupant health and comfort risk.

- Through primary research, establish the extent to which vulnerability, exposure and risk are currently distributed during extreme weather conditions, enabling an approximation of the extent of future risk in south Wales housing.
- Through further analysis of health and comfort risk, establish appropriate adaptation measures to ensure continued occupant comfort and health within existing and new-build housing under global climate change during the 21st Century.

In order to achieve these objectives it is first necessary to place them within the context of the adjacent and multidisciplinary research areas from which they have been developed. This will help to ensure that these findings are not isolated within the research literature. The literature review, that forms the basis of the next two chapters, can be seen to provide a foundation for the methodology and research findings.

Chapter Two, "Risk to Occupant Health & Comfort Due to Climate Change", explores the concept of risk assessment and establishes its application as the logical framework for this research into the potential risk due to a changing climate on the occupant health and comfort system for housing in south Wales. The DETR (2000) source-pathway-receptor model has been selected for application within this research to enable definition of the health and comfort system to be studied. Definitions have been established for each of these factors where the source can in the first instance, be referred to as the hazard or the climate, the pathway, as the home or exposure factor and the receptor as the occupant or vulnerability factor. Finally, to enable interpretation of these systems, problem mapping has been applied, enabling the development of visual descriptions of the factors associated with the risk systems being considered.

Chapter Three, 'Risk Factors', applies this logical framework to the evaluation of climatic risk for the occupant health and comfort systems to achieve the initial objectives of this research. These risks are divided into winter and summer risk families and each risk factor is considered in turn. The source or climate hazard factors for each risk are identified, together with the pathway or home and receptor or occupant factors which influence the exposure and vulnerability to each risk. A problem map is then provided for each risk factor, making explicit the linkages between the source, pathway and receptor factors, and where appropriate their inter-relationships. Finally, the potential for change in the risk system over the coming century, mirroring the timeframe for the current UKCIP02 climate change scenarios is provided, illustrating the potential changes in each element of the risk system and providing a qualitative analysis of the potential direction of change for each of the risks.

The combined methodology developed for this research is described in Chapter Four. It was found that despite being able to draw from the four broad and traditional research areas, climate, comfort, health and architecture, it was not appropriate to apply a single research methodology. It was therefore necessary to draw from existing methodologies as had been applied in research described in the literature review to create a combined method. This aims to combine the strengths of two widely used methods, namely, questionnaire survey and monitoring of the internal thermal environment, in order to develop a combined methodology appropriate to this emerging research topic. The study population and sampling method utilised within the surveys and the case study chosen for monitoring aspects are also identified.

The results from this combined methodology are then presented in Chapter Five. The results from the winter survey, summer survey and monitoring of the case study home are considered in turn. The results from the two surveys will first consider the pathway factors, divided between those associated with the home and neighbourhood followed by those associated with the receptor or occupant, divided between socio-economic and existing health factors. These factors being derived directly from the literature review summarised in chapter 3. The risks to the internal environment from climate change in these two extreme seasons, also identified through the literature review, will then be considered. Finally, the results from the monitoring of the case study property are examined. This is undertaken with consideration of the external climate, occupant behaviour as well as through application of relevant comfort thresholds.

Chapter Six will draw from the conclusions of the three sets of findings described in Chapter Five and, where appropriate, identify possible methods of adaptation that can be seen to address the risks being considered. Broadly these adaptations will address those housing, neighbourhood and behavioural factors identified as influencing the risk systems being considered in this study. Housing and neighbourhood factors will consider the potential for adaptation both for the existing built environment, as well as providing potential for adaptation to new build homes. Finally Chapter Seven, 'Conclusions & Discussion', will present succinctly the conclusions to this research corresponding to the aims and objectives set out earlier in this section. Recommendations for futher work are also provided.

Chapter 2 : Risk to Occupant Health & Comfort Due to Climate Change

2.1 Introduction

Buildings are an enduring element of society that, often lasting through generations of human life, reflect important historical, social, economic, physical and psychological issues and events relevant to the society that has constructed them. The design of housing, the focus for this work, has developed in response to this same wide range of factors and the design response to climate is of particular interest. Due to the evolution of housing design within society and within the climate of the UK, it can be suggested that an equilibrium has evolved between the annual and seasonal variation of weather, the climate, the performance of housing stock. This is moderated by services such as heating, ventilation and in some cases cooling services and finally the occupants. That is to say, occupants of housing in south Wales understand, through a combination of experience and social and cultural norms, how to "use" the physical dimension of their homes and associated services to produce a comfortable internal environment. For example, given a typical summer's day it would be reasonable to assume that an average occupant would be likely to expect to both know how to and be able to achieve a comfortable and healthy internal environment in their home. In this case, following the principles set out by the adaptive theory of comfort it would be reasonable to assume that an occupant may seek to adapt his environment, for example by promoting ventilation, searching out a cooler space in their home or garden, drinking a cool drink, going swimming, or visiting a friend with air conditioning (Humphreys & Nicol, 1995, Humphreys & Nicol, 1998 (abc), deDear & Brager, 1998, ASHRAE, 2004). It can be suggested that the theoretical performance of the "home environment system", considered here to be comprised of three factors: climate, house and occupant(s) is well understood. However, this is a situation that climate change may alter as the climatic environment is moving away from that which the home has been designed for. This can be described as a shift in the existing equilibrium in the house environment.

It must be acknowledged here that the equilibrium described above for an ideal internal environment is not fully achieved in reality in all homes. This can be due to a complex combination of factors including: inadequate housing design, inappropriate or inadequate services, poverty, which may in turn influence a variety of factors as well as a specific or heightened occupant vulnerability to environmental factors, resulting in the need for a differing internal environment than the standard equilibrium. For example: inadequate housing design over past decades has resulted in homes that suffer from internal damp, mould and condensation; inadequate services resulting in homes that are difficult and or expensive to heat adequately; occupant poverty influencing many factors including an inability to afford to heat homes to a comfortable standard; a low level of maintenance leading to wider internal environment problems; and vulnerable occupants such as the elderly, sick or very young requiring a different and often warmer internal environment to achieve a healthy environment, perhaps beyond the equilibrium discussed above.

These wider influences on the housing system therefore suggest further potential drivers for change in this balance. For example: rising fuel bills, an aging and therefore increasingly vulnerable population, an aging housing stock, a changing regulatory regime; as well as alterations in occupant comfort standards, for example: as a result of changing expectations due to wider experience of air conditioning, on holiday, at work and in vehicles.

Therefore, in order to assess risk to occupant health and comfort as a result of a changing climate regime it is first necessary to establish a framework through which to interpret any potential impact. The recent OST Foresight project states that a logical framework requires a set of definitions and a conceptual structure (Working Paper 1 Office of Science and Technology Foresight Flood and Coastal Defence Project Phase 1 Technical Report Drivers, scenarios and work plan January 2003, pg 5). This chapter will therefore explore the definition of risk and develop a conceptual framework for this work.

2.2 Risk Assessment

Risk assessment is a broadly applied research method in relation to climate change as previously applied by Brooks (2003), Chen et al (2004), Cova (1999), Crichton (2001), Evans et al (2003), Granger (2001), the New Zealand Climate Change Office (2004), UKCIP, EA, DEFRA (2003). A risk assessment aims to characterise the nature of risk as well as to either quantitatively or qualitatively estimate risk. A common first stage to the application of the method is to ensure that the system to be studied is fully defined and clarified. This is of particular concern given that factors to be explored within risk assessment utilise words and phrases such as hazard, vulnerability and risk that are in common use as synonyms in the English language. The breadth of definitions available for application in risk assessment was summarised by Theuray et al (2004) and a summary table of hazard, vulnerability and risk is reproduced below:

Hazard
Some threat, natural, technological, or civil to people, property, and the environment. (Cova, 1999)
Probability of occurrence, within a specified period of time in a given area, of a potentially damaging natural phenomenon. (Granger, 2001)
Physical manifestations of climatic variability or change, such as droughts, floods, storms, episodes of heavy rainfall, long term changes in the mean value of climatic variables, potential future shifts in climatic regimes. (Brooks, 2003)
A source of potential harm to people or property, e.g erosion or inundation. (NZ Climate Change Office 2004)
Vulnerability
Refers to the magnitude of harm (to receptor within an exposure unit) that would result from a particular hazardous event. Climate vulnerability defines the extent to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. It depends not only on a system's sensitivity but also on its adaptation capacity. (UKCIP, 2003)
Degree of loss to a given element at risk or set of such elements resulting from the occurrence of a natural phenomenon of a given magnitude. (Granger, 2001)
The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity. (Brooks, 2003)
Risk
The probability that a hazard will occur during a particular time period. (Cova, 1999)
Expected number of lives lost, person injured, damage to property and disruption of economic activity due to a particular natural phenomenon, and consequently the product of specific risk and elements at risk. (Granger, 2001)
Probability * Loss / Probability of hazard occurrence. (Brooks, 2003)
A function of hazard, vulnerability and exposure. (Crichton, 2001)

Table 1: Alternative definitions of risk, hazard and vulnerability. *(Adapted from Theuray et al, 2004, p15)*

Therefore, to ensure clarity Crichton's Risk Triangle, (Crichton 2001), where risk is considered to be a function of hazard, vulnerability, and exposure, was selected as an appropriate risk assessment to be applied in this study. This structure has previously been applied to climate change risk assessment in the built environment (Gwilliam & Fedeski, 2006, Theuray et al, 2004, Lindley et al, 2006).

Crichton, 2001, describes an approach to the evaluation of risk where the probability and severity of the hazard are not considered as the only factors that affect risk. This develops the concept of risk as defined above, where risk is broadly seen to be a function of the probability of occurrence of a hazard and the magnitude of the consequence. Crichton suggests that risk could be seen as a function of three risk elements, namely the *hazard*, climate change (in this work), *exposure* of person to a risk and *vulnerability* of a person to that risk. This function can be represented by the "Risk Triangle", where the area of the triangle can be interpreted as the measure of risk.

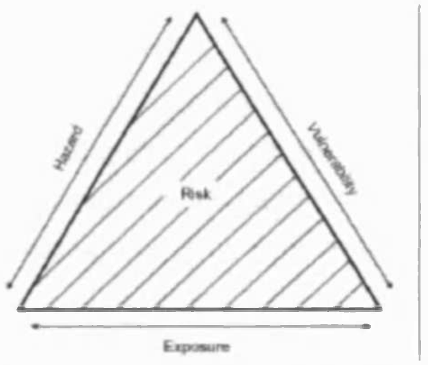


Figure 1: Crichton's Risk Triangle (after Crichton, 2003)

This graphical representation of risk points both to the value of separating the influence of these three elements in the estimation of risk and to the need for all three to be present for there to be any risk at all. That is, if any of the three risk elements: hazard, vulnerability or exposure is absent then there is no risk present. This concept can be demonstrated through consideration of the following simple scenarios (for all scenarios it can be taken that he hazard of climate change is present):

- Where housing is occupied by a disadvantaged family with very young children, a high measure of vulnerability can be assumed. This is due to the high level of health and comfort vulnerability of young people to extremes of temperature. However, if their housing is designed to be resilient to climatic hazard, exposure to the hazard is found to be absent and therefore no risk is present. Were the housing found not to be resilient to climate change as a hazard, risk would have been present.
- A home presents an internal environment that would expose a vulnerable occupant to a health and comfort risk under climate change. However, the occupant is a young and healthy adult. In this case although exposure is present it can be interpreted that vulnerability is absent and therefore there is also no risk present.

So to place the thesis considered herein within this risk assessment framework suggested by Crichton. 2001

Risk	is that which is related to the change in occupant health and comfort in housing as a result of climate change.
Hazard	a quantification of climate change, in relation to the property's specific location. All housing in the UK (and indeed the world) can be interpreted as located within this hazard's geographic area. i.e. climate change is a global effect. It should be said that macro, meso and micro effects are also likely to be result from this climatic hazard.
Exposure	of the occupants to the risk (i.e. internal environment's sensitivity to the hazard). Factors affecting the exposure of the occupants to the hazard would include, building fabric, layout, servicing within the property that impacts on the internal environment, for example use of windows, production of moisture and humidity.
Vulnerability	of the occupants and their behaviour to the risk. The internal environment of the property would not be an issue were there no occupants and therefore risk is also related to the specific occupants of a property. For example, the very young and very old as well as socially disadvantaged occupants may be considered as a different level of exposure to that of a healthy, middle aged, non-disadvantaged individual.

For further clarity, this graphical representation can also be expressed as the following function:

Risk = f { Exposure . Hazard . Vulnerability }

where the components can be expressed as follows:

Hazard:	The extent, severity and probability of the type of hazard being considered, climatic variables effected by climate change.
Exposure:	The extent to which the internal environment of housing would be affected were the hazard to occur.
Vulnerability:	The susceptibility of occupants to the risk were the hazard to occur.

This risk assessment framework could be interpreted as providing a more complete description of risk, in terms of both a quantification of the hazard as well as an expansion of the concept of the magnitude of the consequence.

It should be noted here that although risk assessment can often be interpreted as having a predetermined verbal association with detrimental or harmful events, according to Willows and Connell (2003, p8), risk assessment procedures can also be validly applied to situations where the outcomes may also be positive. For example, the increasing temperatures included within current scenarios for south Wales winters are likely to produce positive impacts for internal temperatures, resulting in increased internal temperatures and lower heating requirements to achieve comfort (Farrar & Vaze, 2000, p50-51). This could be described as a "positive" risk, with beneficial associated outcomes.

2.3 Logical Frameworks

Having established a suite of definitions for the risk assessment to be undertaken here it is necessary to place risk assessment within an appropriate, logical, methodological framework. A number of methodological frameworks have been produced for application in the field of climate change impact studies. The first was a procedure proposed by Carter et al in "Technical Guidelines for Assessing Climate Change Impacts and Adaptations" (1994), that developed the seven stage framework outlined below. This set of guidelines is based upon the concept of impact assessment and not risk, although this could be considered to be an issues of semantics as Jones, 2001, has since adapted the structure to produce a risk assessment and risk management procedure for individual predetermined vulnerable exposure units.

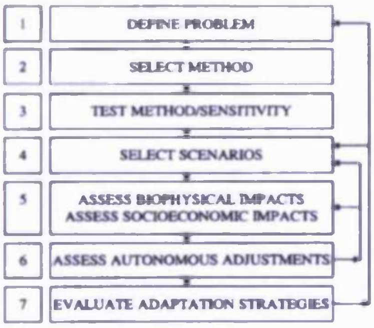


***Figure 2: Seven steps of impact assessment** (IPCC-TGCIA, 1999, p5)*

A further development of this framework was produced by the UKCIP in their risk assessment guidance document published in 2003. This was specifically designed to aid in the decision-making process necessary to select adaptation methods in the light of climate change scenarios. Willows and Connell (2003) 'Climate Adaptation: Risk, Uncertainty and Decision-making' provides an iterative process designed to guide decision makers through the climate change risk assessment procedure for defined receptors or exposure units. It can be seen that this circular, iterative framework draws significantly from Carter et al's original impact and adaptation methodological structure, although the stages of iteration are more explicit and Willows & Connell is very much focussed upon policy development.

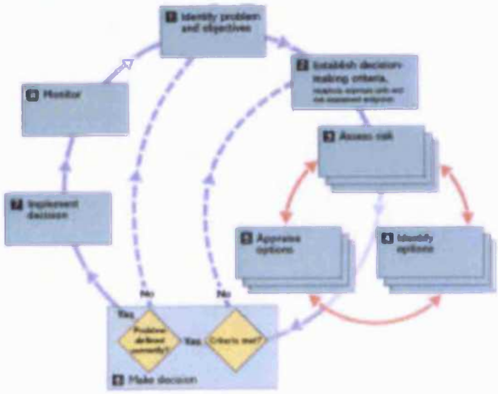


Figure 3: A framework to support good decision-making in the face of climate change risk
(Willows & Connell, 2004, p7)

In relation to this thesis the focus for the work to be undertaken is on stages 1 to 3 with a secondary consideration of stages 4 and 5. Stages 6 to 8 are considered to be beyond the scope of this work. Stages 1 to 3 are therefore considered below in detail, while the exploration of stages 4 – 5 will be undertaken in Chapter 4, Methodology.

Stage 1: Identify Problem & Objectives

The problem to be considered, has already been set out in Chapter 1 and if phrased in line with this framework could be framed as the following question:

> "How will occupant health and comfort in south Wales housing be affected by climate change?"

However, it is not appropriate to frame the objectives of this research in line with those decision making objectives defined by Willows & Connell (2003, p11-12). For example, a policy objective may be read: increase thermal comfort in housing by 20% by 2050. The objectives also set out in Chapter 1 are therefore retained.

Stage 2: Establish Decision-Making Criteria

This stage calls for the establishment of decision making criteria of receptors, exposure units and risk assessment endpoints where these are defined as:

Receptors:	The entity that may be harmed by a particular set of hazardous events. : ***housing occupants in south Wales.***
Exposure units:	The system considered to be at risk. The exposure unit will often be defined in terms of geographical extent and the location and distribution of the populations of **receptors** at risk. In some cases the exposure unit and receptor may be synonymous. : ***The housing system***
Risk assessment endpoints:	An explicit expression of the attributes associated with a **receptor** that are to be protected or achieved. Risk assessment endpoints may represent an intrinsic (e.g environmental) **threshold**, or an agreed, policy-defined threshold, at which explicit decisions to manage the risk will be required. A measurement endpoint may be defined for the attribute in terms of the probability that a certain level of performance will be achieved over a defined period of time, and with a specified level of confidence. : ***Change in health and comfort risk***

It is considered that the framework of decision making for policy objectives taken within this approach again makes the direct application of this stage of the UKCIP methodological framework inappropriate for research. In addition the definition and understanding of risk already selected has begun to establish a structure for the risk assessment to be undertaken, hereby fulfilling the objective of this stage of the UKCIP risk assessment methodology, to represent *"an important link between the objectives in Stage 1, criteria established by the decision-maker in Stage 2, and the subsequent risk assessment and options appraisal activities in Stages 3 and 5."* (Willows & Connell, 2003, p15).

However, it is considered appropriate to explore more fully the housing system within a logical framework of risk at this stage in the methodology and indeed the DETR framework (DETR et al, 2000) expands the definition of risk, as developed through application of Crichton's risk triangle, to enable a more thorough exploration of the risk system. The Willows & Connell framework developed for UKCIP is considered to be in line with this DETR framework, however, it is adapted to enable policy decision making. The reader is therefore directed to Evans et al (2003) and the Foresight Flood risk project (2003) for a relevant application of this source-pathway-receptor model to a risk assessment application. Evans et al describe how an initial step to undertaking an environmental risk assessment is to develop a logical framework through which the formal system can be explored. For example, in the light of flood risk, the logical framework is defined: *"The formal system for the analysis of drivers of flood risk and evaluation of responses" (Evans et al, 2003, p7).* In relation to the work undertaken here the following definition is proposed:

> **The Logical Framework:**
>
> The formal system for the analysis of drivers of health and comfort risk in the domestic built environment in south Wales and the evaluation of responses.

While the system at risk can be defined as:

> **Occupant Health and Comfort System:**
>
> All of those physical and human systems that cause, influence, or are influenced by health and comfort in the domestic built environment in south Wales.

The risk model for the logical framework can then be developed around the concept of sources, pathways and receptors to develop an estimate of risk as illustrated in the diagram below. This expands on the definition of risk developed earlier in that this calls for the development of an explicit relationship between the factors. It may be that there are both feedback and inter-relationships within the system and this is considered later.

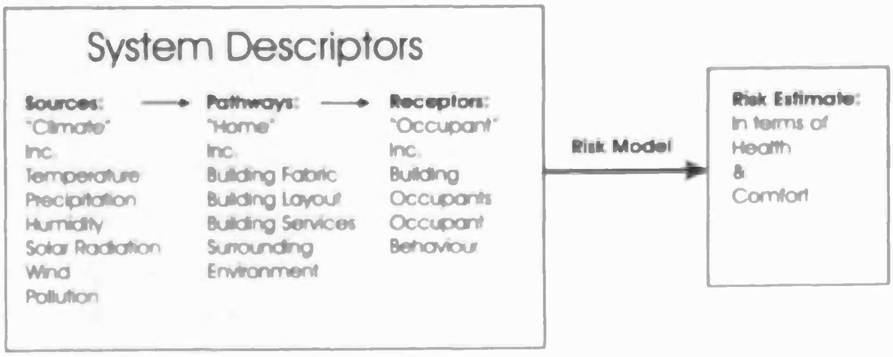


Figure 4*: *"Time stationary source-Pathway-Receptor Framework for risk" *(After Evans et al, 2003)*

In relation to the system illustrated above it is then necessary to develop definitions for the system descriptors illustrated in the source-pathway-receptor model. Evans et al, described the source for flood risk as *"weather-related phenomena (rainfall, marine storms, snow melt etc.) that generate water with flooding potential"*. It can be seen that a similar source – or climatic causal factor is present for the system to be studied here. Thereby for this work:

Sources are defined as the weather events or sequences of events that result in an uncomfortable or unhealthy change in the internal environment in housing in South Wales. These are likely to include, but may not be limited to temperature, precipitation, solar radiation, wind, pollution and humidity.

The definition for the second system descriptor, pathways, for flood risk created by Evans et al is *"Mechanisms by which water is transmitted from its source to places where it may impact receptors (e.g. runoff, fluvial flows, sea defence overtopping, floodplain inundation)"*. In relation to the "occupant health and comfort system" to be considered here this "pathway" system descriptor is complex. The pathway can simply be described as the home. However, complex factors relating to the neighbourhood in which the house is placed, the influence of the surroundings of the home on the immediate microclimate together with the behaviour of occupants in the home, (including their interaction with the internal environment and the building itself) will all influence the pathway for the source. For this work the following definition is adopted:

Pathways are the mechanisms that cause changes to the internal environment of buildings that may impact on the receptors. Pathways can therefore be interpreted as the neighbourhood and microclimatic surroundings of the domestic built environment, the homes themselves including their services. It must be noted that as some receptors (or occupants as defined below) are able to interact with the home and services and so they are also part of the pathway in this system.

Finally the receptor system descriptor is defined for flood risk by Evans et al as *"People, industries, built and natural environments that can be impacted upon by flooding"*. As this study is focussed on occupant health and comfort, the receptors are limited to people and namely the occupants of specific homes or (as previously defined) the pathways. For the purposes of this work the receptors are defined:

Receptors are the people or occupants that may be impacted upon by the health and comfort risk system.

It can therefore be seen that the dividing lines between the source-pathway-receptor factors of the system are not definite. For the occupant health and comfort system it has already been suggested that there is interaction between the source and pathway in relation to microclimate and between the pathway and receptor in relation to behaviour.

These definitions of logical framework, occupant health and comfort system and for the three system descriptors of source, pathway and receptor, can be seen to provide a rational mechanism to enable analysis of both current and future risks to occupants in homes in south Wales. The previous definition of risk is hereby expanded to provide an understanding of both a logical framework for the research as well as a description of the occupant health and comfort system in which the risk assessment takes place. Explicitly, the source is seen to be a synonym for the hazard of Crichton's risk function, pathway for exposure and receptor for vulnerability.

There is one aspect of the study that is left to consider and that is the factor of change over time. It is a logical assumption that where a change is to be identified a baseline must first be established. Evans et al employ the Pressure-State-Impact-Response (PSIR) model which is widely applied in the field of change analysis in environmental and social systems and can therefore be seen to be appropriate to the study of change due to the alteration in climatic hazard. The interaction between the PSIR model and the logical risk assessment framework of the source pathway receptor model can be most clearly illustrated in the diagram below, which considers this model in relation to the thesis to be studied here.

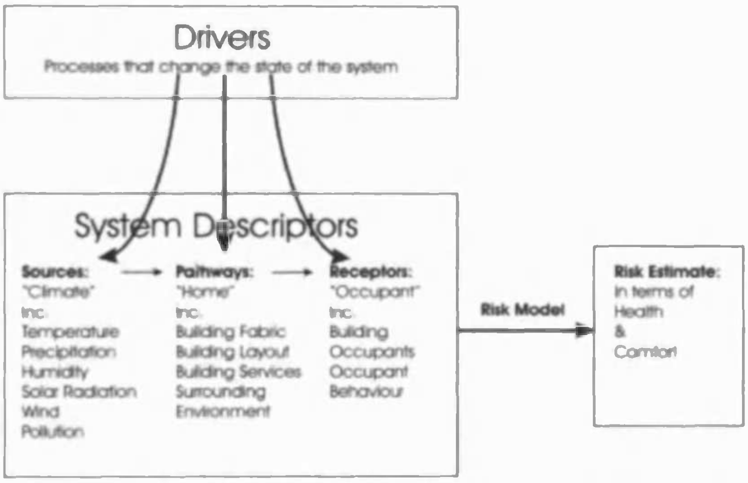


Figure 5: Occupant Health and Comfort system as changed by the action of drivers from the P-S-I-R model.

(After Evans et al, 2003)

Climate change, as described by Hulme et al (2002), can be identified as the primary driver for the PSIR model for this work, altering as it does the hazard or source factor of the occupant system to be studied. However, climate change will also have both direct and indirect influence on the pathway. The direct influence has been quantified by work undertaken by Roberts et al (1994) and Graves & Phillipson (2000) and is considered likely to include increased levels of damage to property, increased maintenance requirements and specific issues including more frequent and widespread incidence of damp penetration due to a combined effect of more intense rainfall and wind. However, where the neighbourhood is included as an indirect aspect of the pathway factor of the occupant health and comfort system, climate change is also likely to have a direct influence on this. For example, (McEvoy et al, 2006, p13), has identified that people are increasingly likely to spend more time outside and later into the evening, reflecting the more Mediterranean evening temperatures. It could be suggested that this would result in greater levels of noise hazard resulting from increased use of gardens and other external spaces, as well as a shifting diurnal pattern of occupation of such external spaces.

Although climate change is the primary driver identified for this research, Lancaster et al (2004, p 25), in their work on risk due to flooding in the built environment suggest that drivers for change in the source pathway system are likely to be present in relation to environmental, economic and social issues. These are likely to include:

Governmental policy drivers: These may alter the system descriptors of source, pathway and receptor, such as changes in the pathway through policy to promote development and alteration in the building stock.

Social drivers: These may alter the pathway and receptor factors of the occupant health and comfort system. For example they could include occupant education to promote appropriate behaviour, namely interaction between the pathway and receptor, under the changing climate.

Economic drivers: These may also influence the source (for example as a result of the Stern review, 2006), the pathway (through provision for funding and support for housing renewal, appropriate renovation and maintenance regimes as well as support for appropriate new build development, such as the introduction of zero rate stamp duty on zero carbon homes) and the receptor through support to remove housing occupants from poverty, enabling them to achieve thermal comfort in their homes.

The identification and evaluation of the three factors of the occupant health and comfort system, source, pathway and receptor, as well as the changes in risk through time as a result of the primary driver, climate change, together with secondary drivers including government policy, society and economics, then form the basis of the third stage of the UKCIP risk assessment methodology.

Stage 3: Assess Risk

The third stage of the UKCIP risk assessment procedure calls for a process of risk assessment at one of three levels or tiers, risk screening, generic quantitative risk assessment or detailed quantitative risk assessment. Each tier calls for a 5 stage risk assessment procedure, as described in the figure below

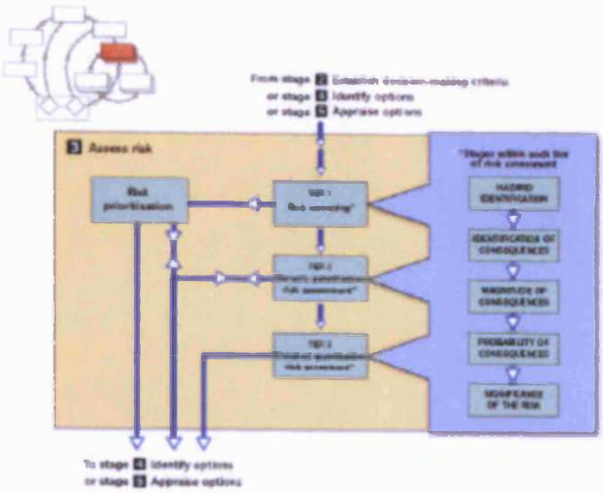


***Figure 6**: **The Stages Within & Purpose of the Three Tiers of Risk Assessment** (Willows & Connell, 2003, pg 18)*

The key decision matrix provided by Willows & Connell, (2003, pg 20) is again framed around the concept of policy based decision making and therefore does not provide a direct resolution for selection of an appropriate tier of risk assessment for this work. However, through interpretation of this matrix within the framework of the system to be considered herein, together with the previously stated aim and objectives, it is considered that the tier 1 risk assessment is most appropriate. An example of the process by which the selection was made can be given through consideration of the "importance of climate change to the decision" row of the decision matrix. The tier 1 entry, *"Start at this tier if unsure about how, or if, climate change could affect your decision"*, was considered to be the statement that most closely mirrored the previously stated objectives of this research. Again, as was the case for the first two stages of the UKCIP methodological framework, interpretation of the policy based decision making tool is required in the light of this risk assessment based research.

The final aspect of this stage of the risk assessment framework is to select a methodology with which to undertake the first stage of the risk assessment. Willows and Connell (2003, p25) suggest the following tools for tier 1 risk assessment: brainstorming, checklists, consultation exercises, problem mapping tools, process influence diagrams, deliberate imprecision, pedigree analysis, expert elicitation / judgement, fault / event trees, climate change scenarios, cross-impact analysis or scenarios analysis (brief description of each of these tools are included in Appendix A. A problem mapping approach was selected to provide a structured visual description of each of the risks associated with the occupant health and comfort system being studied. This tool enables representation at a flexible level of detail producing an appropriately detailed map of the risk being considered (Willows & Connell, 2003, p133).

Stage 4 - 5: Identify & Appraise Options

As previously stated these two stages will be undertaken as a final aspect of the work to be undertaken herein. The framework for this work will again not be directly in line with the Willows & Connell framework as the adaptation options to be considered will not be formally assessed as policy options. The methodology to be applied at the stage will be described, where appropriate, in Chapter 4, Methodology.

Stage 6 - 8: Make decision, Implement decision & monitor

These final stages of the Willows & Connell methodology are deemed to be beyond the scope of the risk assessment.

Although the UKCIP methodology was developed to establish a decision making framework for future policy, allowing for climate change to be acknowledged as a future driver, it has been found to be possible and appropriate to adapt the first three stages for application in this research. It can also be seen to provide a clear logical risk assessment framework for the work to be undertaken.

2.4 Climate Change & Risk Assessment

There are two overarching issues associated with the application of risk assessment in relation to climate change. These are associated with the concepts of probability and uncertainty.

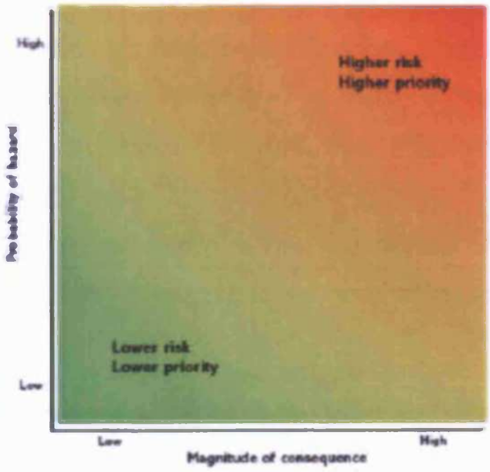


Figure 7: Relationship Between Probability, Consequence and Risk (Hulme et al, 2002)

The explicit relationship of risk to probabilistic measures, as illustrated above, is problematical where climate change scenarios are to be applied within a risk framework. This is due to the absence of a probability of occurrence for scenarios as would be associated with predictions. Uncertainty, on the other hand, exists in relation to both a lack of knowledge concerning outcomes as well as in relation to the scenarios themselves. That is to say uncertainty can result from an imprecise knowledge of the risk, where the probabilities and magnitude of either the hazards, vulnerability and exposure, are all unknown or unknowable. The sources of scientific uncertainty in the production of climate change scenarios were illustrated by the IPCC in Figure 8 'The Cascade of Uncertainty'. The potential interaction and feedback into this system of adaptation and mitigation on this system are also included. This does not negate the worth of undertaking this work but emphasises the importance that the results are placed within a context of uncertainty.

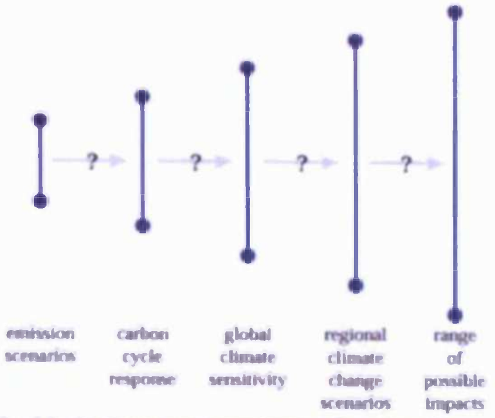


***Figure 8**: Range of major uncertainties that are typical in impact assessments, showing the "uncertainty explosion"* *(IPCC 2002b,Section 2.6.4)*

The issue of uncertainty, as related to the current UK climate change scenarios,is more broadly due to both the model itself as well as the unknown level of climate change drivers that will be present in the future. The complexity of any attempt to model the global climate system in order to produce predictions of future changes is further hampered by the inherent un-knowable nature of the future. Human influence on radiative forcing in the future will be the result of actions that will be taken by our generation as well as those of future generations. Socio-economic scenarios and related emissions scenarios have been developed to enable the consideration of these possible future actions, and for the purposes of this work, it is sufficient to acknowledge their role in climate change modelling (IPCC, 2002, UKCIP, 2001, BETWIXT, 2004). The key impact of these un-knowable factors for impact research is that the results of climate change models must never be considered as predictions for the future and always as potential or possible scenarios.

'Predictions, in the sense of being able to attach probabilities to the outcomes of specific model experiments, are not yet possible.' (Hulme & Jenkins, 1998, p3)

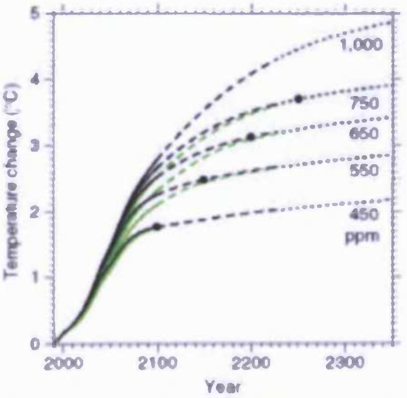


***Figure 9**: Simple model results: Projected global mean temperature changes following stabilization of CO_2 concentration* *(IPCC, 2001a, section 9.3.3.1)*

Further to uncertainty, the sensitivity of the global climate to changes in past, present and future emissions must also be considered, as illustrated in Figure 9. This figure also serves to illustrate the uncertainty inherent in any scenario attempting to demonstrate future changes. It must be emphasised in this summary that the uncertainty attached to the current scenarios is a complex issue, as illustrated by the cascade of uncertainty. Each stage of research that has been undertaken in order to create the scenarios has its own level of uncertainty attached. The cumulated level of concern must be considered carefully in the development of a methodology to study the possible impact of these levels of change anticipated under the UKCIP02 scenarios for the UK on any system.

'Even if atmospheric greenhouse gas concentrations were stabilised immediately, we could still experience a changing climate and sea-level rise for more than 1,000 years into the future due to past emissions. Furthermore, the greenhouse gases we emit today and in the near future will initiate changes in climate that will be felt far into the future'. (Hadley Centre, 2002b, p2)

Despite this uncertainty it must be repeated here that the consensus of climate scientists have now agreed that current climate change is the result of past and present human activities and therefore research into both the mitigation of further change and adaptation to change already instigated is necessary (IPCC, 2002a).

In order to enable direct application of climate change scenarios into a risk assessment and decision making tool a quantification of the uncertainty would be required. This gap in knowledge was acknowledged by the IPCC in IPCC-TGCIA, 2001 and it is hoped that this will be further addressed within the next set of climate change scenarios, anticipated in 2008, for which both probabilities and quantification of uncertainty are anticipated (UKCIP, 2005). However, during current work Willows and Connell (2003) suggest applying expert judgement to both probability and uncertainty in the current application of this risk assessment methodology and so it is suggested that neither the lack of probabilistic measurement of climate change, nor the absence of uncertainty quantification should preclude the application of a risk assessment procedure to climate change research.

For a thorough consideration of the impacts of risk, uncertainty and confidence in the risk assessment procedure the reader is referred to Willows and Connell (2003, Part 2, Section 1, pg 43 – 53) and to Hulme et al (Chapter 7, p81-90) for risk and uncertainty associated with climate change scenarios.

2.5 Conclusion

Risk assessment has therefore been established as the logical framework for this research into potential risk due to a changing climate on the occupant health and comfort system for housing in south Wales. While the DETR (2000) source pathway receptor model has been established within this research to enable definition of the health and comfort system to be studied. Definitions have been established for each of these factors where the source or hazard can, in the first instance, be referred to as the climate, the pathway or exposure factor, the home and the receptor or vulnerability factor of the occupant. Finally, to enable exploration of this system the problem mapping tool has been selected. This tool will enable a visual interpretation of risk associated with the system to be created from secondary data identified through a literature review that forms the basis of Chapter 3. The next chapter will now explore how this logical framework can be applied directly to the evaluation of climate change risk for the occupant health and comfort system to achieve the objectives of this research.

Chapter 3 : Health and Comfort System Descriptors

3.1 Risk as a Framework for Health and Comfort Risk in Homes

The occupants of homes in the UK experience risks to their health and comfort as a result of the internal environment in the buildings they inhabit. For example, inadequate heating in a space during the winter, combined with poor insulation of the building and low level of activity by the occupant will provide an environment that is likely to be considered too cold. Depending on the level of cold this could lead to health implications for the occupants including diminished resistance to respiratory infection, hyopothermia, bronchospasm, ishaemic heart disease, myocardial infarction, stroke, anxiety and depression (Hwang et al, 1999, Burridge & Ormandy, 1993, Keatinge & Donaldson, 2000, Collins, 2000, Krieger & Higgins, 2002). It is this understanding of the inter-relationship between the source, pathway and the receptor that will now be explored.

It has been previously discussed that the Crichton Risk Triangle, the Source-Pathway-Receptor framework and the Pressure-State-Impact-Response model undertaken within an adapted UKCIP risk assessment framework together provide a logical framework for the research to be undertaken herein. Having established this structure, the first two objectives of this work are to be undertaken. Firstly, to establish current risks to health and comfort in the domestic built environment and secondly to evaluate these risks in relation to the potential change in future risk due to climate change. This is to be achieved through analysis of the factors of occupant health and comfort risk or system descriptors, by ascertaining:

- the change in the source or hazard regime, a function of the changing climate;
- the changes to the pathway or exposure, the extent to which the interior environment of housing in south Wales would be affected were the hazard to occur;
- the factors in the evaluation of the receptor or occupant vulnerability, the susceptibility of occupants to hazard exposure.

Beyond the primary driver of climate change there are likely to be wider drivers of change present in the source, pathway and receptor system descriptors. These will not form a focus of this literature review, but where appropriate will be established and referred to as secondary drivers. The scope of the risks to be evaluated will now be established through consideration of the meaning of comfort and health. Having established the scope of the health and comfort system to be studied each risk will then be considered in turn in relation to the source pathway receptor risk system established previously, while a process influence diagram will be established to describe the system associated with each health and comfort risk.

3.1.1 Comfort

Evidence from the natural world shows how animals have evolved, adapted and responded to their environment in order to achieve thermal comfort. Without this development it would be impossible for living creatures to survive the extreme temperatures of either the polar regions or

> *to be comfortable (that is neither too warm nor too cold; or thermally neut*
> *conditions the strain on the body's thermal regulatory system is minimal.*
> *(Markus, & Morr*

While the British Standard BS EN ISO 7730 defines it as:

> *'that condition of mind which expresses satisfaction with the thermal environr*

Throughout history human beings have used many methods to achieve thermal c wide variety of climates, beginning by using objects and materials readily available provide shelter from the elements. Using such simple methods of shelter, humans v survive under all but the most extreme of climates. However, with a mastery of development of clothing, humans were able to achieve greater thermal comfo development of buildings to further mitigate and filter the climatic elements, humar the range of climates in which they could live beyond those to which other animals v Instinct and bodily systems were at work to guide humans to achieve thermal co their environment. However, it was not until recent history that these instincts we and their functions defined.

Research relating to the effects of the environment on human thermal comfort has b out for the last three hundred years, with the first recorded experiment in 1733 ca Arbuthnot. This concerned the *'chilling effect of wind by dispersing the layer of war around the body'* (Markus & Morris, 1980, p37). The current CIBSE guide (Race, 20 that the result of subsequent research undertaken over the next centuries establis maintenance of thermal equilibrium between the human body and its environment d the following environmental factors:

- Air temperature
- Humidity
- Temperature gradient in the environment
- Mean radiant temperature of the surroundings
- Air movement / speed (measured in m/s)

The environmental factors in the internal built environment are directly associat interaction between the source and the pathway of the comfort risk system being s The following subjective aspects of comfort can be interpreted within this research f

Bedford		**Fanger**	
Much too cool	1	Cold	-3
Too cool	2	Cool	-2
Comfortable cool	3	Slightly Cool	-1
Comfortable	4	Neutral	0
Comfortably warm	5	Slightly Warm	1
Too warm	6	Warm	2
Much too warm	7	Hot	3

These scales may also be followed by a thermal preference scale:

McIntyre
I would prefer:
Warmer
No change
Cooler

Nicol
I would prefer:
Much warmer
Slightly warmer
No change
Slightly cooler
Much cooler

Further to this understanding of both objective and subjective factors involved i thermal comfort, as well as the methods used to allow occupants to rate their o comfort experience the adaptive theory of comfort introduced further variables into system (Humphries 1993, Nicol 1993, deDear & Brager 1997, 2002). These r interaction between the receptor and the pathway. The adaptive theory suggests available an occupant will take action to remain comfortable and that the methods o available to adapt or control thermal comfort include, but are not limited to:

- Changing clothing levels
- Increase / decrease ventilation
- Changing the rate of work
- Leave the cold area to seek a warmer place
- Carrying out long term improvements (e.g. to windows / doors)
- Turning on / off of a heater / making a
- Turning on / off the air conditioning
- Diet
- Moving location e.g. going to bed
- Emigrating
- Acclimatising

ASHRAE state that the value of the adaptive model increases where the occupar adapt is maximised (ASHRAE 2001). It is therefore appropriate that the adaptiv adopted for this study where housing fits this optimised adaptive capacity. It mus however, that an individual's ability to adapt and therefore control environmer especially within the built environment, can be further affected by external issue economic pressures. For example, the possibility of the restrictive cost of energ homes in fuel poverty (Boardman, 1991, Rudge & Nicol, 2000), and cultural issues, requirement to wear a uniform or conform to social norms, could influence the ability to adapt. Furthermore, this method also acknowledges the pervasive influence of the outdoor climate and seasons on behaviour and thermal comfort expectations (deDear & Brager, 2002). The following definition of thermal comfort may be more appropriate to adopt for this work:

Thermal Comfort:
That condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation *(ASHRAE, 2001, p8.1)*

In summary it can be interpreted that the comfort risk system is complex and relates to the source/climate, the pathway/home and the receptor / occupants as well as to a complex interrelationship between the adaptive opportunities afforded by the pathway and the behaviour of the receptor. The comfort risk factors to be considered in more detail can be summarised as:

Risk Factor

Too cold for comfort
Too hot for comfort

3.1.2 Health

Health is defined as a state of complete physical, social and mental well-being and not merely the absence of disease and infirmity (WHO, 1948).

This definition of health is widely quoted in many fields of research linked to the health and well being of human beings. It seeks to broaden the generic perception of understanding of health as a concept. The inclusion of social and mental well being along with the physical aspects more usually associated with health, also expands the subject to embrace less easily defined and measurable issues. Physical diseases often have visible and therefore measurable effects and causes, while, social and mental well-being are more often subjective, with what may be perceived as less scientifically measurable external causes.

In relation to health in the built environment the World Health Organisation Regional Office for Europe has also produced a definition for '*Healthy Housing*' which is reproduced below:

> A human habitation that is structurally sound and relatively free from accidental injury hazards, provides sufficient space for all normal household activities for all the members of the family, has readily and easily available an adequate supply of potable and palatable water, has a sanitary means of collection, storage and disposal of all liquid and solid wastes, is provided with appropriate installed facilities for personal and household hygiene and cleanliness, is sufficiently weatherproof and watertight, provides proper protection from the elements, especially for those persons who may be particularly susceptible, for physical and/or physiological reasons to those potentially adverse environmental conditions, provides a hydro-thermal indoor environment which is healthful and comfortable, is free from excessive noise from both interior and exterior sources of the structure, has natural and artificial means of the illumination that are safe and adequate in quality and quantity for the fulfilment of all normal household activities and functions, is free from toxic and/or noxious odours, chemicals and other air contaminants or pollutants, has adequate but not excessive microbial and thermal characteristics, provides sufficient but not excessive solar radiation, provides adequate protection from insects and rodents which may be reservoirs

> and/or vectors of disease agents, and is served by the necessary and/or desirable health, welfare, social, educational, cultural and protective community services and facilitates.
>
> *(Ranson, 1991, p1-2)*

This description serves to reinforce the concept that the home can be considered as a "pathway" in the occupant health risk system as explored in chapter 2. The home is explicitly placed in this position of a potential causal factor in an unhealthy living environment. Meanwhile the definition also refers explicitly to a number of aspects of the "source" system descriptor which are given reference as contributing to the internal housing environment and therefore potential to influence health and comfort risk in housing. For example:

- *is sufficiently weatherproof and watertight, provides proper protection from the elements*

  This refers to the control of climate (source) broadly, by the appropriate design of the home (pathway).
- *provides a hydro-thermal indoor environment which is healthful and comfortable:*

  This *can be interpreted to* relate to the control of humidity, ventilation, temperature, solar radiation and precipitation.
- *provides sufficient but not excessive solar radiation.*

  This relates to both the source and pathway in relation to both control of solar radiation or solar gain and therefore internal temperature. In turn this also relates to the climatic variables of temperature and cloud cover.

Further to this, the WHO definition refers to the vulnerability of occupants or the receptors through the statement *"especially for those persons who may be particularly susceptible, for physical and/or physiological reasons to those potentially adverse environmental conditions"*. It can be seen that this definition therefore supports the concept of the health and comfort "source-pathway-receptor" system of climate, house and occupant.

Health as related to housing (and therefore the pathway within the system to be studied) has also been found to be directly affected by specific aspects of the built environment (Mant & Muir Gray, 1986, Ranson, 1991, Warsco, 1992, Burridge & Ormandy, 1993, Conway, 1995, Hwang et al, 1999, Marsh et al, 1999 Krieger & Higgins, 2002). For example, the materials from which buildings are made, such as lead and asbestos, have well documented and significant health and morbidity impacts. Additionally, housing density, building type, high rise structures, the floor level of occupancy, overcrowding, housing tenure, neighbourhood and satisfaction all have possible links to health impacts for occupants.

Aspect of Housing	**Impact**	**Potential Causal Link**
Building materials	• Various	Various
Various characteristics	• Falls	Definitive
Building type	• Psychological distress	Possible
Floor level	• Psychological distress	Possible
High rise structure	• Psychological distress & General physical health	Possible

Overcrowding & Density	• Psychological distress • General physical health • Mortality • Haemophilus influenza type B Infection • Hepatitis B Infection • Type 1 diabetes melitus	Possible
Housing tenure	• Cancer incidence & survival • General physical health • Mortality	Possible
Housing satisfaction	• Psychological distress	Possible

Table2: Summary of Health Impacts of Housing *(After Hwang et al. 1999, p. x - xi)*

Causal links are defined as follows:

Where:

Definitive: numerous well-designed studies showing the effect, most or all causal criteria met, essentially, complete agreement among experts that a health effect exists.

Possible: Small number of studies showing the effect, some or few causal criteria met, no consensus among experts that a health effect exists.

Various: Conflicting or negative evidence regarding the effect, few or no causal criteria met, consensus among experts that a health effect is not proven or unlikely.

It is therefore reinforced that the occupant health system to be explored is extremely complex where the influences on health are widespread and must be taken into account in their full breadth when health based research is to be undertaken (Hwang et al, 1999, Marsh et al, 1999). The following lists of influences on occupant health, derived from the wider literature, should not be taken as exhaustive but is included here to serve to indicate the breadth (and therefore the complexity) of the occupant health system to be considered:

Standard of Living

- Low income
- Material deprivation
- Social deprivation
- Unemployment

Behaviour

- Smoking
- Drinking
- Diet
- Exercise

Housing

- Overcrowding
- Poor amenities
- Disrepair
- Cold / Heat

Social

- Limited education
- Family stress
- Ethnicity
- Prejudice

Environment / Neighbourhood

- Area amenities
- Accidents
- Radon
- Pollution

Genetic

- Birth weight
- Age
- Heredity
- Gender

Firstly, this list brings to the fore the factors relating to the receptor or occupant that must be considered more widely in relation to occupant health (the occupant's standard of living and social, behavioural and genetic factors). Secondly, this table serves to reinforce the complexity of the system to be studied as both the source, in terms of cold and heat, as well as the pathway (housing and environment) are again present.

The impact of climate change on health has only recently become a subject of significant discussion in research, where work is currently being undertaken to develop a research agenda as well as to develop methodologies appropriate to the emerging discipline (Haines et al eds, 1999, Koppe et al, 2003). 2001 saw the publication of a report by the Department of Health that had been undertaken by the Expert Group on Climate Change on Health (DoH, 2001). This report was a scoping study that considered the potential for impact on health in the UK, through the application of expert judgement. The Parliamentary Office of Science and Technology provided an up to date summary of the potential health impacts in the light of the more recent UKCIP02 climate change scenarios in November 2004. Other than acknowledgement of over 2000 deaths that were caused by the August 2003 heatwave in England and Wales, this added little to the findings previously reported by DoH. This review, therefore serves to re-emphasise the findings of the previous expert review; while on a global scale both the World Health organisation (WHO, 1996, 1999, 2003) and the IPCC (IPCC(b)) have published wide ranging documents on the potential health impacts of climate change, including a series of publications by WHO-Europe under the Climate Change and Adaptation Strategies for Human Health (cCASHh) project. Research considering the health impacts for building occupants has been limited, although some scoping of possible impacts was included in Graves & Phillipson, (2000). The mechanisms by which climate change may impact on health are illustrated below, where they have been divided into those considered to be direct and indirect. Direct impacts on health are those caused by heatwaves, storms and floods, while climate impacts on ecological, economic and social balance factors, may indirectly affect the health of the population (DoH, 2001, IPCC, 2001b, Kovats, Ebi & Menne, 2003).

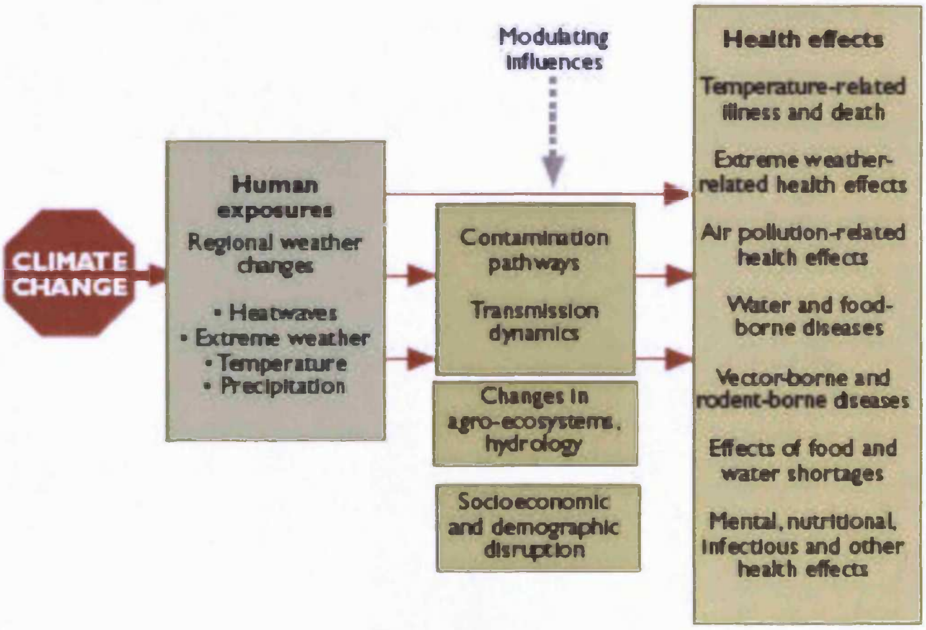


Figure 10: Ways in which Climate Change can affect Human Health *(WHO, 200c, p11)*

The current understanding of the route by which climate change may impact upon widespread health outcomes was represented clearly by the IPCC, reproduced above. Here the majority of health outcomes can be seen to relate to those already widely considered to be related to internal environment found in housing, for example: cardiovascular and respiratory diseases, death and injuries allergies and mental disorders. Although housing may not have a direct influence on other diseases included in the table, such as vector borne disease, waterborne and food borne disease, human behaviour in and around the home may be considered likely to influence occupant health in relation to these health outcomes.

Health Outcome	Known Effects of Weather & Climate
Cardiovascular respiratory Mortality & heat stroke mortality	- Short term increases in mortality during heat-waves. - V- & J- shaped relationships between temperature and mortality in populations in temperate climates. - Deaths from heatstroke increase during heat-waves.
Allergic rhinitis	- Weather affects the distribution, seasonality and production of aeroallergens.
Respiratory & cardiovascular diseases & mortality	- Weather affects the concentrations of harmful air pollutants.
Death & injuries	- Floods, landslides and windstorms cause death and injuries.
Infectious diseases & mental disorders	- Flooding disrupts water supply and sanitation system and may damage transport systems and health care infrastructure. - Floods may provide breeding sites for mosquito vectors and may lead to outbreaks of disease. - Floods may increase post-traumatic stress disorders.
Mosquito, tick borne diseases and rodent borne diseases (such as malaria, dengue, tick-borne encephalitis and lyme disease)	- Higher temperatures shorten the development time of pathogens in vectors and increase the potential transmission to humans. - Each vector species has specific climate conditions (temperature and humidity) necessary to be sufficiently abundant to maintain transmission.
Waterborne and food-borne diseases	- Survival of disease-causing organisms is related to temperature. - Climate conditions affect water availability and quality. - Extreme rainfall can affect the transport of disease-causing organisms into the water supply.

Table 3: Summary of the Known Effects of Weather and Climate *(Kovats, Ebi & Menne, 2003, p24)*

> *The adaptation potential of socioeconomic systems in Europe is relatively high because of economic conditions [high gross national product (GNP) and stable growth], a stable population (with the capacity to move within the region), and well-developed political, institutional, and technological support systems.*
>
> *(IPCC, 2001b. p904)*

It should be noted that the scale of the effects is influenced by the demographic, social and economic factors, that influence what might be called a community's 'resilience' or 'adaptive capacity' to resist impacts from these changes (IPCC, 2001b, Kovats, Ebi & Menne, 2003). In the occupant health system to be studied herein these are considered to be secondary drivers.

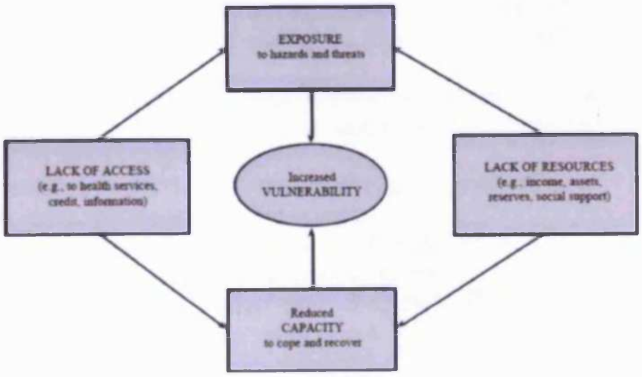


Figure 11: Diagrammatic illustration of vulnerability to disasters *(Reproduced from IPCC, 2001b , p459)*

It is vital to maintain the centrality of the concept of the breadth of influences on occupant health, however, a focus must be maintained for this research, whereby only those health risks to housing that have the potential to be influenced by climatic change will be explored in depth. Furthermore, housing and health is a complex research area that has been the subject of a large field of research. Hwang et al, 1999, produced a conceptual model of the housing health relationship that provides a useful summary of this multi-factor inter-relationship. For example, health can be seen to affect socio-economic status (SES), which in turn affects health, while housing affects SES which also affects housing. In the meantime this relationship can be seen to be mediated by chemical exposures, biological exposures, the physical characteristics of housing, social and economic characteristics of the housing and psychological factors. The further factor of a changing climate must now be introduced into this relationship. It is suggested that climate could be inserted as a further factor that mediates housing / health, and in the case of this work, comfort relationship.

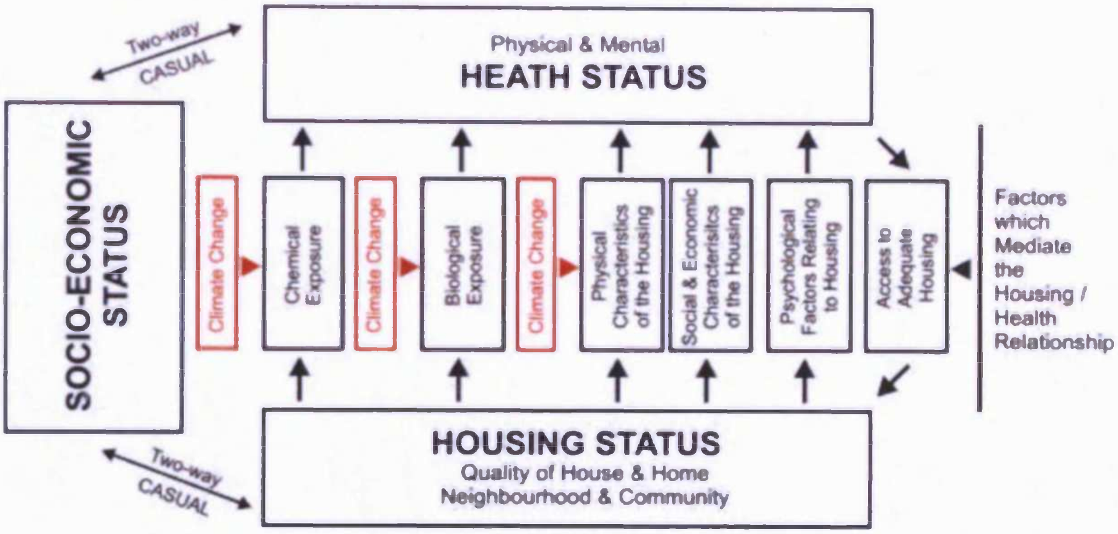


Figure 12: Conceptual Model of the Possible Impact of Climate Change on the Housing / Health Relationship as Described by Hwang et al (Adapted from: Hwang et al, 1999)

The following risk families and related risk factors and health risks have been identified through a literature review of the health and housing fields and the occupant health system with which they are each associated will be fully expanded on and referenced later in this chapter.

Risk Family	Example Risk Factor	Associated Health Risks including:
Temperature:	Cold	Diminished resistance to respiratory infection, Hypothermia, Bronchospasmm Ishaemic heart disease, Myocardial infarction, Strokes.
	Hot	Heat stroke, Mortality, Respiratory tract infections, Cardiac events
Ventilation	Ozone	Eye irritation, respiratory tract irritation, reduced exercise capacity, exacerbation of respiratory disease.
	Particulate Matter	Eye irritation, respiratory tract infections, allergies, exacerbation of respiratory and cardiovascular disease, cancer.
	Pollen	Exacerbation of allergic rhinitis, asthma and other atopic diseases
Moisture	Incidence of Condensation, Damp & Mould	Cough, Wheeze, Asthma, Rhinitis, Alveolitis, Eczema, Respiratory Symptoms, Respiratory tract infections, Psychological distress, Aches and pains, Headaches, Diarrhoea, Rheumatic fever, Depression in women.
Pests & vermin	Mosquitoes, ticks & rodents	Malaria, Dengue, Tick-borne encephalitis and Lyme disease, Waterborne and food-borne diseases.
Noise		Sleep deprivation, leading to psychological stress and activation of the hypothalamic-pituitary-adrenal axis and sympathetic nervous system.
Structural and material damage		Damage to property leading to psychological stress and / or physical injury.

3.1.3 Health & Comfort Risks

The following risks have therefore been selected for study and will now be explored in relation to the risk system they present currently and in the future. Future risk will be considered in the light of changes due to climate change (considered here to be the primary driver for change) and previously identified secondary drivers to the system descriptors including governmental policy, social and economic drivers. The structure produced for the further study of these risks can be derived from the extremes of the hazard or source in the risk system namely that of the summer and winter climates in the UK.

The internal environment risk families to be considered in this thesis are therefore summarised for winter and summer as:

For Winter:

1. Thermal: Inadequate Heat
2. Ventilation & Air Pollution
3. Incidence of Condensation, Damp & Mould
4. Material & Structural Damage

For Summer:

1. Thermal: Excess Heat
2. Noise
3. Pests & Vermin
4. Ventilation & Air Pollution
5. Material & Structural Damage

The following structure will be followed to enable evaluation of the risk function, through the creation of process influence diagrams, in relation to each of these risk factors:

1. Risk:	The specific health and comfort impacts associated with the risks to be studied.
2. Source:	Those aspects of the climate that have a relationship to the risk.
3. Pathway:	Those aspects of the form or structure of the house that represent he pathway of the hazard / source to the receptor.
4. Receptor:	Those attributes of the occupant(s) including behaviour that influences vulnerability to the risk.
5. Current Risk:	The creation of a problem map linking together the hazard, exposure and vulnerability factors of risk, to produce a visual representation of current risk.
6. Future Risk:	Through assessment of changes within the occupant health & comfort system, relating to hazard, exposure and vulnerability over the coming century and, an assessment of potential strength and direction of future change in risk will be carried out.

3.2 Winter

Each of the risk factors identified as part of the winter occupant health and comfort risk family will now be described and explored using the structure highlighted in the previous section. In order to provide a framework for this risk assessment in relation to the major driver for change in the system, climate change, a summary of current climate change scenarios for the winter in South Wales has been produced. This is included here in order to prevent the need for repetition below as well as to place the risk assessment in an appropriate context. The data is summarised using data from the HADCM3 grid box no 370 from the UKCIP02 dataset, corresponding to Neath and Port Talbot County Borough Council (NPT) the spatial focus for this work. The winter climate anticipated under the UKCIP02 scenarios (Hulme, 2002) can be summarised as follows:

In relation to the future scenarios for temperature in South Wales:

- An annual warming by the 2080s of between 1.5°C and 3°C.
- It is expected that less warming will occur in winter and spring than in summer and autumn.

The following graph illustrates the mean temperature change in south Wales for both annual and winter means for 2020s, 2050s and 2080s scenarios as well as for the four emissions scenarios illustrated by UKCIP02, low, medium-low, medium high and high (Hulme, 2002, p28 – 32). It should be noted that suggested uncertainty margins are provided for these average temperature scenarios, which for the average temperature vary in equal intervals from +/- 0.5°C for low emissions scenarios to +/- 2°C for high emissions scenarios (Hulme, 2002, p25). These uncertainty margins are not provided for all variables and their availability for this variable reflects the high relative confidence with which it is attributed.

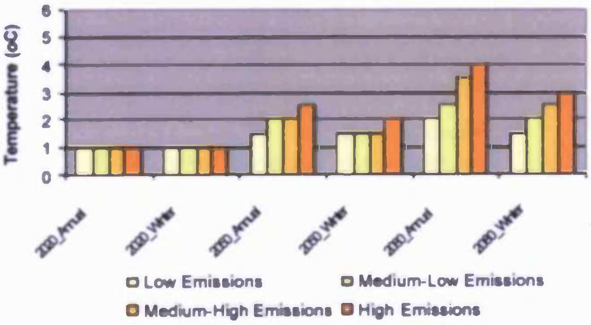


Figure 13: Mean Temperature Change for South Wales (°C) *(Derived from UKCIP02 Data (Hulme, 2002, p29-32))*

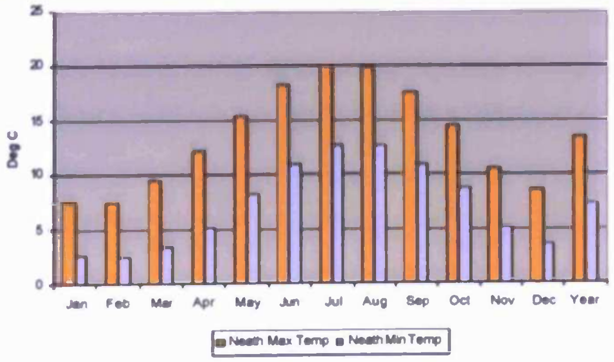


Figure 14: Monthly Average temperatures for Neath for baseline climate 1961–90 *(www.met-office.gov.uk, 2003)*

The cloud cover is expected to increase during the winter under climate change and as a result there would be an associated decrease in insolation of the order of 10 – 15 w/m^2 in the summer (Hulme, 2002, p44). No uncertainty margins are available for this variable and a low relative confidence is claimed by UKCIP (Hulme, 2002, p53).

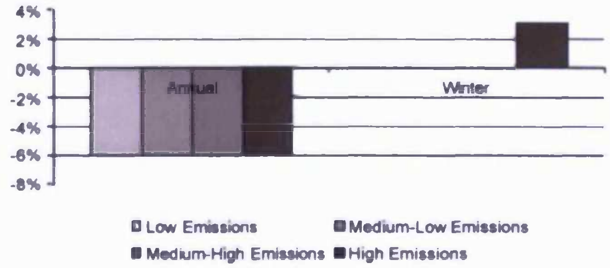


Figure 15: Mean Change in Annual & Winter % Cloud Cover for South Wales (2080s only) *(Derived from UKCIP02 Data (Hulme, 2002, p46))*

52o N	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Year
Possible sunshine hours	8.3	9.9	11.8	13.8	15.6	16.6	16.1	14.6	12.6	10.6	8.8	7.8	12.2

Table 4: Possible Sunshine Hours on the 15th Day of the Month for Cardiff *(www.met-office.gov.uk)*

Winter diurnal ranges are expected to decrease by up to 0.4°C by the 2080's (Hulme, 2002, p43). Nights are anticipated to warm more than days during winter due to the anticipated increase in cloud cover. This aspect of the scenarios is associated with a low relative confidence (Hulme, 2002, p53). The change in annual and winter diurnal temperature range in south Wales under UKCIP0-2 scenarios is:

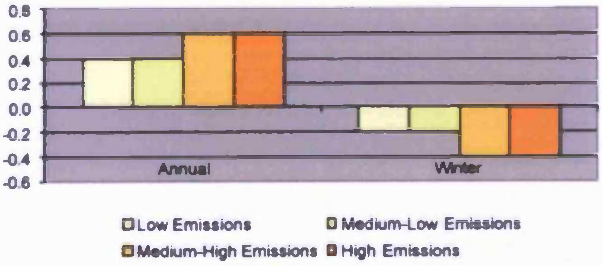


Figure 16: Change in Annual & Summer Diurnal Temperature Range for South Wales (2080s only) *(Derived from UKCIP02 Data (Hulme, 2002, p45))*

In addition to this the frequency of occurrence of extreme temperatures for south Wales by the 2080s is anticipated to rise. The relative confidence for this anticipated change is high (Hulme, 2002, p71):

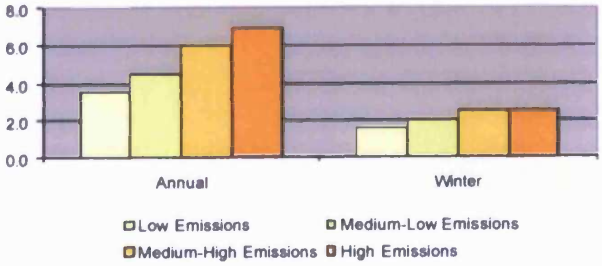


Figure 17: Change by the 2080s in the daily-Average Temperature Threshold which Constitutes an Extremely" Warm (90th Percentile Day (oC)) for South Wales *(Derived from UKCIP02 Data (Hulme, 2002, p63))*

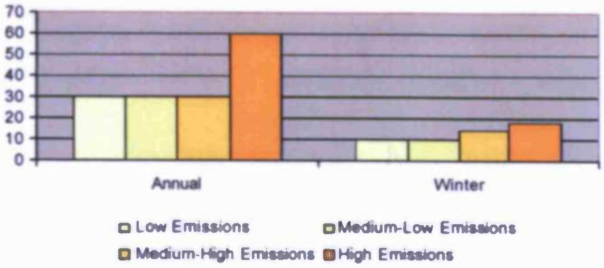


***Figure 18:* Change by the 2080s in the Average Number of "Extremely" Warm days per season (defined as the 90th Percentile threshold temperature for the periods 1961 – 1990) for South Wales**
(Derived from UKCIP02 Data (Hulme, 2002, p64))

One measure of the impact of these changes on the built environment can be seen in the commonly applied derived unit of "Heating Degree Days" (HDD). This is calculated:

HDD = 15.5 °C- **Tmean**

Where: ***Tmean*** is estimated as the average of the min and max temperatures for each day.

Long term trends in this measure over time can be interpreted as an indication of changes to the winter thermal environment. To calculate the yearly figure for HDD's these figures are summed for all days in a year, with negative values being discounted.

Currently a baseline average year in the south of England has approximately 2100-2300 HDD's and Scotland has in the region of 3000-4000 HDD's (Hulme, 2002, p70). The 20 year average for Wales has been calculated as 2147 (Carbon Trust, 2007). Figure 24 illustrates the possible changes in HDD regime for the four UKCIP02 2080's scenarios, where it can be seen that south Wales is subject to a decrease of between 20 to 35 HDD's by this period.

Low Emissions	**-20**
Medium-Low Emissions	**-20**
Medium-High Emissions	**- 30**
High Emissions	**- 35**

***Table 5:* South Wales HDD's under current Climate Change Scenarios for 2080s.**
(Derived from UKCIP02 Data (Hulme, 2002, p70))

In relation to average precipitation the main conclusions from current scenarios, both associated with medium relative confidence (Hulme, 2002, p53) are:

- Wetter winters (by up to 25 % by the 2080's).
- Little change or slight drying in the annual total (Hulme, 2002, p28).

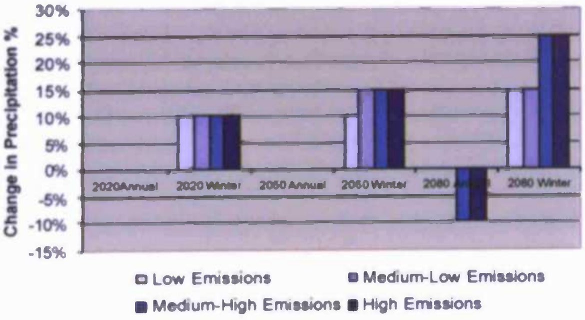


***Figure 19:* Mean % Change in Annual & Summer Precipitation for South Wales (2080s only)**
(Derived from UKCIP02 Data (Hulme, 2002, pp 33 – 36))

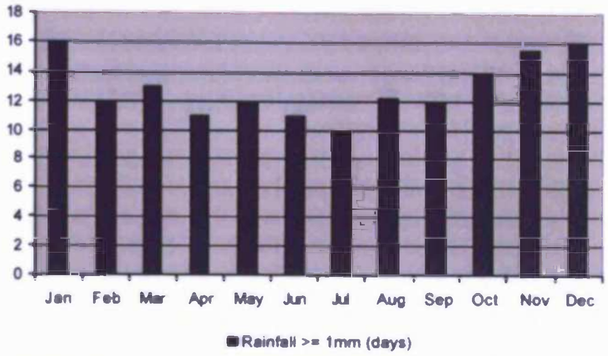


Figure 20: Neath Monthly Average Precipitation for period 1961-1990. N.B.Yearly Avg 1267mm
(Source: www.met-office.gov.uk)

It should be noted that this is the only other variable for which uncertainty margins are provided where for summer scenarios, for low emissions +/-10%, for medium low emissions +/-15%, for medium high emissions +/-30%, and for high emissions +/-40 (Hulme, 2002, p25). While for extreme precipitation events the main conclusions from current scenarios, both associated with high relative confidence (Hulme, 2002, p71), are illustrated below:

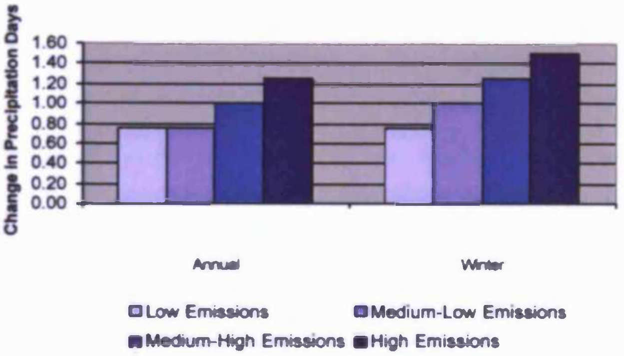


Figure 21: Change in Number of Intense precipitation Days Annually & Summer for South Wales (2080s only)
(Derived from UKCIP02 Data (Hulme, 2002, p57))

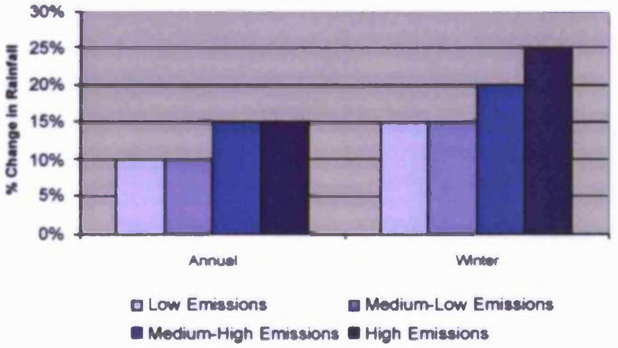


Figure 22: % Change in Rainfall During a 2 Year Return Preciptation Event, Annually & Summer for South Wales (2080s only). *(Derived from UKCIP02 Data (Hulme, 2002, p59))*

The values of specific humidity are expected to increase within all scenarios, however, due to the rise in temperature, relative humidity will decrease in most areas (Hulme, 2002, p44). A reduction in RH of up to 3% may occur in some parts of Wales during the winter. The increase in specific humidity is associated with high relative confidence in the model, while the decrease in RH in the summer is associated with medium confidence. No scenarios are available for the diurnal variation of this climatic variable, although the implicit association of this variable to diurnal temperature range suggest that the diurnal variation will increase due to the associated increased diurnal variation in temperature. The change in RH proferred by the current scenarios is illustrated below:

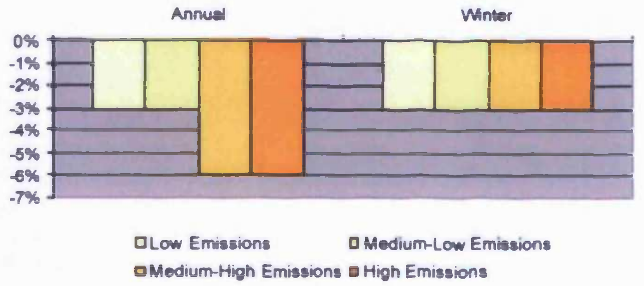


Figure 23:* *Mean % Change in Annual & Summer Average Relative Humidity for South Wales (2080s only) *(Derived from UKCIP02 Data (Hulme, 2002, p47))*

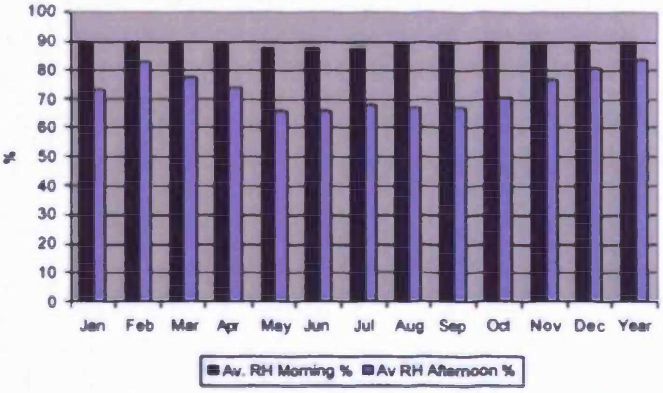


Figure 24:* *Cardiff Monthly Average relative Humidity 1961-1990 *(Source: www.met-office.gov.uk)*

The mean daily wind speed in south Wales is expected to increase slightly both annually and in the winter by the 2080s (UKCIP02, p48, p44). The scenarios for wind speed have been found to be less consistent between models and therefore the certainty with which these scenarios should be considered is much less than that associated with that of either the mean precipitation or mean temperature.

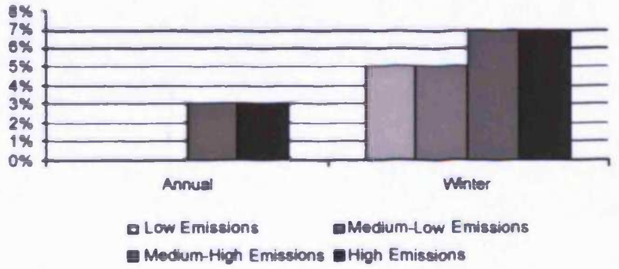


Figure 25: % Change in Annual & Summer Daily mean Wind Speed for South Wales (2080s only) *(Derived from UKCIP02 Data (Hulme, 2002, p48))*

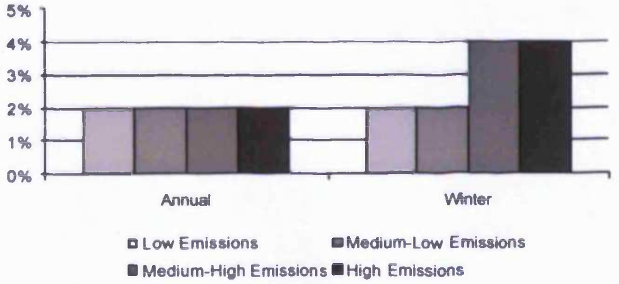


Figure 26: % Change in Annual & Summer Daily Daily Average Wind Speed which can be Expected on Average every 2 years for South Wales (2080s only). *(Derived from UKCIP02 Data (Hulme, 2002, p68))*

Atmospheric pollution, should be considered to be a meteorological natural hazard according to Beer (2001) due to its close relationship to the prevailing weather and is therefore included at this point in the discussion of climate. Furthermore, the sporadic nature of pollution and its potential to cause damage to both property and the health and comfort implications for people reveal its relevance to this work. Pollution includes both naturally sourced particles, such as, various salts from sea spray, dust blown up from soil, airborne spores and insects as well as manmade pollution. Anthropogenic pollution includes larger particles, such as grit or dust that settle near to the place from which they are emitted, as well as smoke gasses and soluble matter that is much more widely and uniformly transmitted. The latter has the potential for impacts with radii of up to 100's of km, where they may travel mixed with the air unless they may be eventually be washed out by rain or settle as a fog (Lacy, 1977). Further to this, public concern is rising as to air pollution as a result of combustion of waste products and recommendation for investigation of their potential health impacts for nearby occupants has been made (IEH, 1997b).

Industrial areas in Wales are mainly located in coastal locations and are thus relatively breezy. Neath Port Talbot is a highly polluted region of the UK, with Port Talbot itself considered to be the most polluted area in Wales and the second most polluted location in Britain (Friends of the Earth Website, 2000). There is a significant presence of heavy industry in the study area of Neath Port Talbot such as steel works and petrochemical industry, resulting in an increased importance of this data. There are also a number of air pollution sources identified by the environment agency as well as a substantial road network including the M4 motorway providing further air pollution sources.

The table below shows the current scenarios for some pollutants associated with effects on health. These scenarios are only available at an annual temporal scale and UK spatial scale.

Pollutant	**Year 2020**	**Year 2050**	**Year 2080**
Particles	Large Decrease	Large Decrease	Large Decrease
Ozone (No threshold)	Large Increase (c.10%)	Large Increase (c. 20%)	Large Increase (c. 40%)
Ozone (threshold)	Small Increase	Small Increase	Small Increase
Nitrogen Dioxide	Small decrease	Small decrease	Small decrease
Sulphur Dioxide	Large decrease	Large decrease	Large decrease

Table 6: Predicted Climate Change Associated Pollution Effects on Health

(Reproduced from: IPCC, 2001c, section 9.6.1)

The uncertainty discussed earlier in relation to the extent of future climatic change should be reiterated here, where the unknown future levels of emissions may be the most significant factors. This aside a number of observed changes in climate to date, including:

- The length of the freeze season has decreased.
- Decrease in the number of snow lie days since 1980s
- 10 of the 16 warmest years in the CET record (since 1659) have occurred since 1981.
- There have been no long term trends found in annual precipitation, although a trend towards wetter winters has been indicated (*Hulme, 2002, p 8-11*):

It should be noted that the potential overturning of the North Atlantic Drift has been the subject of much media attention, not least the film 'The Day After Tomorrow', where a Hollywood take on a scenario for rapid climate change was illustrated. The Gulf Stream, North Atlantic Drift or Thermalhaline Circulation (THC), currently supplies the UK with much of its thermal energy, enabling the British Isles to maintain its temperate climate and promoting mild winters (Hulme, M. And Barrow, A., 1997, Hulme, 2002, p89). However, were this heating conveyor belt to be switched off or slowed, the cooling influence on the UK climate could be just as significant as the warming associated with current global climate change scenarios with air temperatures in the Northern Hemisphere up to 9°C cooler (Manabe and Stouffer, 1988. p297).

The mechanism by which North Atlantic Drift is maintained is related to the high temperature and salinity of the water flowing from the south and the sinking of north Atlantic deep water in the northernmost part of the ocean (Vellinga & Wood, 2001). However, this mechanism is sensitive to changes in input of freshwater in the North and there have been suggestions that the drift could be slowed, overturned, or even reversed over relatively short periods of time were there to be significant increases in the levels of melting ice introduced into the system (Vellinga & Wood, 2001). This last occurred during the last ice age, 10,000 years ago, when a large input of fresh water at a low density, from melting ice, altered the drift and caused a period of warming at the pole and cool, yet dry, period in the tropics and sub tropics. This period, known as Younger Dryas, was subsequently reversed. Significantly the entire cycle of reverse and return occurred within a relatively short period of time, within 1000 years (Broecker, W.S. et al, 1988).

Research into the possibility of the re-occurrence of this phenomenon, has been concerned partly with the stability of the West Antarctic ice sheet under climatic change and global warming (Oppenheimer & Alley 2004; Dessai et al, 2003). The collapse of this grounded ice sheet could produce a similar reversal of the THC. The likelihood of such an occurrence during the 21st Century, was reported to be very low (1-10%) by the IPCC TAR, although the dynamics of the ice sheet were acknowledged to not yet be fully understood. The stability of the THC has, however. been described as unclear (Vellinga, M., Wood, R. A., 2001), due to the large uncertainty in its modelled stability. The possibility that the UK climate may cool as a result of climate change cannot therefore be ruled out. However, for the purpose of this research it is suggested that this possibility be discounted in order to maintain clarity in the application and interpretation of current climate scenarios.

Having established the current scenarios for summer climate change in the south Wales UKCIP grid box, no 370, the occupant health and comfort system will now be explored in relation to the summer risk family identified previously, namely:

1. Inadequate Ventilation.
2. Thermal: Inadequate Heat.
3. Material & Structural Damage.
4. Damp & Mould.

It should be noted that there are significant interconnections between the risk factors that are illustrated below, where inadequate heat and ventilation are inter-related and heat, ventilation and damage each influence the incidence of damp and mould.

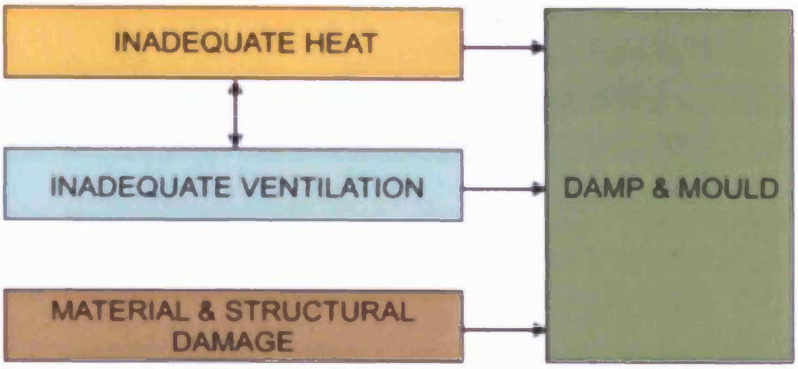


Figure 27: Inter-Relationships Between Winter Family of Risk Factors.

3.2.1 *Risk Factor: Thermal – Inadequate Heat*

The first risk factor to be considered here is inadequate heat. The risks to occupant comfort and health associated with this risk factor can be identified from literature as:

Discomfort

Where a home is too cold for its occupants to consider themselves comfortable, discomfort can be considered to occur. In the short term heat loss is reduced by the body through its thermoregulatory system, where: vasoconstriction, reduces blood flow to the surface of the skin, reducing skin temperature and increasing metabolic heat production; reducing or preventing perspiration; goose pimples, where tiny muscles lift hairs on the skin that act to decrease the airflow across the surface of the skin (and therefore reduce the heat loss from this surface) and shivering, where heat production is encouraged through involuntary muscle action. Conscious adaptation and short term unconscious adaptation are combined with unconscious longer term changes to physiological set points. These unconscious adaptations include shivering, changes in skin blood flow, sweating, body fluid levels and salt loss (ASHRAE, 2001). Comfort, is a subjective condition, where quantification of the temperature at which a sample of people considers themselves to be comfortable for a given activity and clothing level is likely to be relatively wide. For example the Adaptive Comfort Standard (ACS) ASHRAE Standard 55 (ASHRAE 55 Rev, 2003) suggests that the optimum comfort temperature is found through application of the equation:

$$T_{comf} = 0.31\ T_{a,out} + 17.8\ (^{\circ}C)$$

Where:
T_{comf} = Optimum Comfort Temperature
T_o = Mean monthly of the Outdoor Dry Bulb Temperature

With a range of:
5°C for 90% thermal acceptability and 7°C for 80% thermal acceptability.

This equation can be plotted thus:

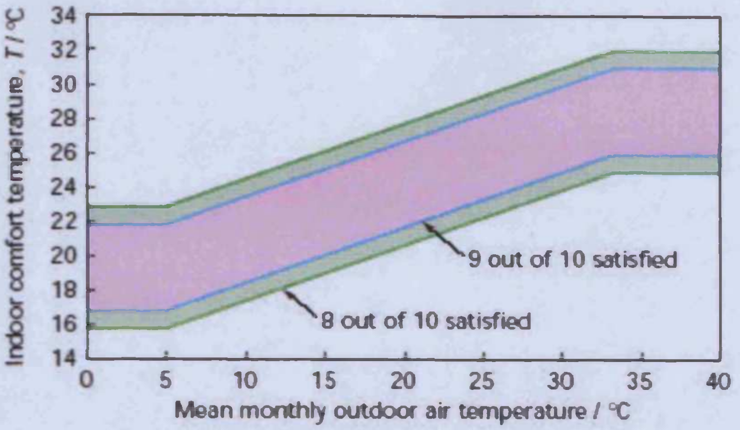
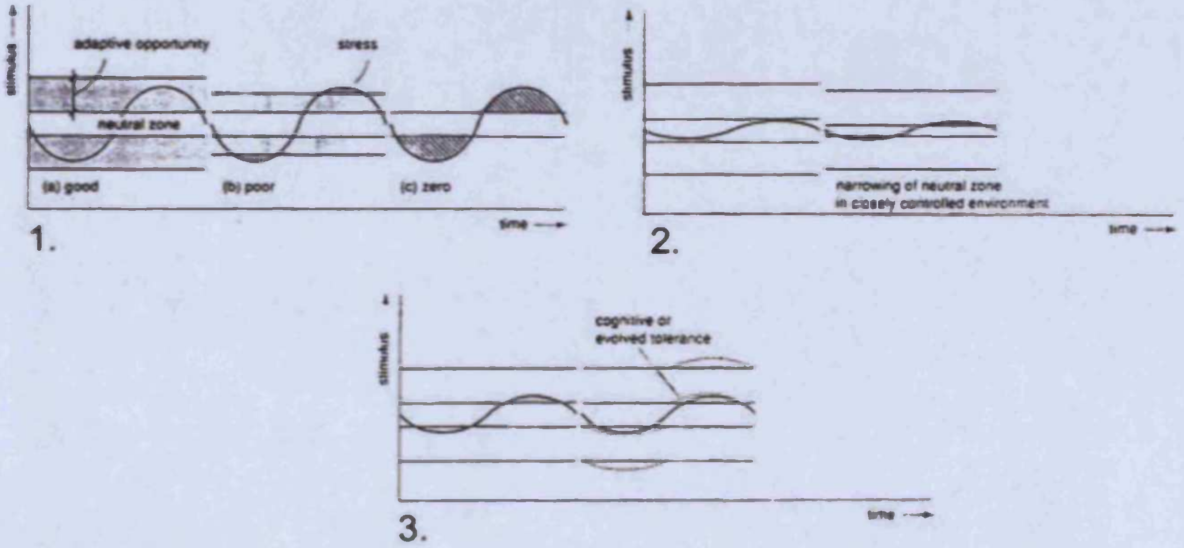


Figure 28: Adaptive Comfort Standard after ASHRAE Standard 55

It can be seen that the adaptive method for comfort embraces a wide range of air temperatures at which thermal comfort can be achieved, approximately 17°C – 31°C, in which thermal comfort can be seen as a 'self regulating system' (Humphreys and Nicol, 1998). A home must therefore be capable of achieving comfortable conditions for this same wide range of comfort. This model assumes that occupants will become active in the achievement of thermal comfort, through conscious behavioural actions including those described earlier in section 3.1.1.



1. Insufficient adaptive opportunity results in stress.

2. Narrowing of stimulus amplitude results in narrowing of neutral zone.

3. Tolerance of stimulus is increased with knowledge of and sympathy with the cause.

Figure 29: Adaptive Opportunity and Cognitive or Evolved Tolerance (Baker, 1996)

Further to the concept of adaptive comfort is the concept of adaptive opportunity and cognitive and evolved tolerance. This suggests that where adaptive opportunity is limited stress is more likely to occur. This theory, put forward by Baker (1996), suggests that where an environment is very closely controlled, the comfort zone is likewise limited. At the other end of this scale, it is suggested that where an occupant has sympathy with a cause, for example, saving energy, it is possible to evolve tolerance to a thermal environment.

It is suggested here that in the home the presence of an optimum temperature at which a large number of human occupants is likely to be comfortable is less appropriate and the presence or absence of thermal comfort for the individuals occupying a property and experiencing the indoor environment is the focus.

The concept of human comfort is not limited to the aspects of thermal comfort that have been discussed up to this point. Indeed it has been suggested that it is when the thermal situation is controlled and the environment offers no opportunity for adaptive control such as is the situation in many air conditioned or mechanically ventilated buildings, occupants may be more likely to become sensitive to acoustics, lighting, odour or even colour (Baker 1996). A wider definition of comfort therefore embraces and is interrelated with sophisticated psychological concepts such as well being, work and life satisfaction and control. It is important to consider this wider concept of occupant comfort in the built environment. Where occupants are satisfied with their lives and with their occupation they are less likely to be pre-occupied with comfort considerations. Perceived comfort will again be positively influenced by higher levels of occupation satisfaction (Jones et al 1995, Brasche, 2001, Muhic & Butala, 2004). To achieve this the definition of comfort must be widened from that of the thermal environment to include the visual, aural, social and cultural environments (Humphreys, 1978). The potential interaction of these stimuli are a further factor that should be taken into consideration (Toftum, 2002, Pellerin & Candas 2004, Clausen, et al, 1993). With this in mind it may be necessary to consider issues such as:

- *A pleasant environment and/or view*
- *Perceived occupant control of the environment*
- *Work and life satisfaction and interest*
- *Control and removal of unpleasant odours*
- *Control and consideration of light levels*
- *Cultural and social issues*
- *Corrections to ambient noise levels in an internal environment*

Health

Inadequate indoor temperatures have been found to be linked with or to induce the following illnesses:

- Diminished resistance to respiratory infection [1]
- Hyopothermia [1]
- Bronchospasm [2]
- Ishaemic heart disease [2]
- Myocardial infarction [2]
- Stroke [2]
- Anxiety, Depression [3]

Sources:

[1] Hwang et al 1999, Collins 1993 & 2000, Markus 1993

[2] Hwang et al 1999, Collins, 1993 & 2000, Markus 1993, Keatinge & Donaldson 2000

[3] Hwang et al 1999, Markus 1993, Hyndman 1990, cited in Krieger & Higgins 2002

Cold temperatures in homes, where the temperature deviates beyond established comfort bands, have been found to have significant links with increased cardiovascular (Hwang et al 1999, Collins 2000) and respiratory disease (Hwang et al 1999, Collins 1993 & 2000, Markus 1993, Keatinge & Donaldson 2000) and has been linked to anxiety and depression (Hwang et al 1999, Markus 1993). The excess winter deaths due to all causes in the UK stand at approximately 40,000, the highest rate in Europe. These deaths have been found to be reducing over the past twenty years (Goodwin, 2000, p51), for example a reduction of 69% between 1964 and 1984 of deaths due to respiratory disease. However, deaths from coronary and cerebrovascular disease have not declined significantly.

These risks are influenced by the hazard, exposure and vulnerability regime for individual occupants. The factors associated with these occupant health and comfort risks will now be explored and a problem map produced for this risk factor.

3.2.1.1 Source

The hazards in relation to the occupant health and comfort risk system for inadequate heat are defined as those climatic variables that influence the risks described above.

3.2.1.1.1 Comfort

The main environmental factors that affect thermal comfort are:

- Air temperature (affects evaporation and convection)
- Humidity (affects evaporation)
- Temperature gradient in the environment
- Mean radiant temperature of the surroundings (affects radiation)
- Air movement / speed (affects evaporation and convection)

The relationship between comfort and temperature is made explicit in the comfort equations of ASHRAE (2003), Humphreys & Nicol (1998) and deDear and Brager (1998). Both Humphreys & Nicol (1998) and deDear and Brager (1998) have proffered the following thermal comfort models for likely comfort temperatures t_c, or temperature ranges, predicted using monthly mean outdoor temperatures t_{out}. The climate in which the building and occupant are located is therefore a determining factor in the actual comfort range. Equations are provided for free-running and heated or cooled buildings. The estimated comfort temperature can then be calculated to a standard error of 1.0°C for free-running buildings and 1.4°C for heated or cooled buildings using the following equations:

Free-Running Buildings:

$$T_c = 11.9 + 0.535\ T_o \quad (^\circ C)$$

Heated or Cooled Buildings:

$$T_c = 23.9 + 0.295\,(T_o - 22)\ \exp(-[(T_o - 22)/(24.2)]^2) \quad (^\circ C)$$

Where:
T_c = Indoor Comfort Temperature
T_c = Monthly Mean Outdoor Temperature

Further to this the Charted Institute of Building Services Engineers (CIBSE) has set the following benchmarks for winter operative temperatures. With reference to the adaptive comfort model, especially fig. 28, it can be seen that the comfort temperatures suggested below appear to be relatively high. Where, for example, a winter monthly mean average temperature of 5°C, as would be likely in South Wales, would suggest comfort temperature in the range of 16 – 23°C.

Room Type	Winter Operative Temperature Range (°C)
Bathrooms	20 - 22 °C
Bedrooms	17 - 19 °C
Halls / Stairs	19 - 24 °C
Kitchen	17 - 19 °C
Living Rooms	22 - 23 °C

Table 7 Recommended Thermal Comfort Criteria for Dwellings *(Adapted from Race, 2006, p20)*

In relation to the other factors that affect occupant thermal comfort, during cold weather:

The Temperature Gradient and Mean Radiant Temperature (MRT) also have influence on indoor thermal comfort, however, this is more directly influenced by the detail design of the home and is therefore discussed within the following pathway section, 3.2.1.2 (Race, 2006, p12). However, it is appropriate to note here that the MRT, may have a relationship to direct solar gain and therefore solar radiation and cloud cover may be considered to be a climatic source.

Air Movement:

In addition, air movement will also have an influence on thermal comfort due to its interaction with convective and evaporative heat loss from the body (Race, 2006, p11). During the heating season, when air movement is great, it is likely to be experienced as a draught and where there is too little air movement the environment will be perceived to be stale and stuffy. (Race, 2006, p11) and air movement in the range of 0.1 – 0.3 m/s is considered to be good practice by CIBSE (Race, 2006, p12), It is therefore important that the level of air movement within a space is appropriate to the temperature, the clothing level and the activity of the occupant of the space. For example, when an occupant is sitting in their lounge watching the television on a cold winters night and their skin, especially that around either their neck or ankles, is exposed to air movement, this will be interpreted as an uncomfortable draught. It should be noted that the temperature of the air is also critical. If the air in the scenario is the same as the ambient air temperature the draught would not be as uncomfortable as if the air movement was due to air entering the space directly from the cold night outside. As such air movement is related both to the hazard factor of wind and draughts as well as the detailed design of the home, and therefore the exposure factor in the risk system being studied here. The wider influence of air movement and ventilation on indoor air quality will be considered in section 3.2.2.

Relative Humidity (RH):

Although humidity does have a association with thermal comfort through its relationship with heat transfer through evaporation, it does not have a significant impact on thermal comfort at average temperatures in UK domestic properties (Race, 2006, p11).

It has further been suggested that an adaptive comfort algorithm that considers this wider range of climatic variables may be appropriate but to the author's knowledge this has not yet been published. It can be seen therefore that air temperature is considered to be the driving factor in occupant internal comfort.

3.2.1.1.2 Health

In relation to health the concept of a cold temperature below that which is perceived to be comfortable is the main hazard for occupant risk. Some temperature standards for health in the internal environment include (Hunt & Gidman, 1982):

- Minimum indoor temp for health – considered to be 16°C
- Below 18°C: Discomfort (subjective)
- Below 16°C: Adverse health effects
- Below 12°C: Increased strain on cardiovascular system with an associated increase of myocardial infarction & stroke

3.2.1.1.3 Inadequate Heat: Source Factors

The climatic hazard variables that influence the occupant health and comfort risk system for inadequate heat are therefore:

- Temperature:
  - Monthly mean average temperature
  - Daily minimum temperatures
- Solar Radiation
- Cloud Cover
- Wind

3.2.1.2 Pathway

The pathway factors in relation to the occupant health and comfort risk system for inadequate heat are defined as those aspects of the pathway that influence the risks described above.

Vernacular housing in Wales can provide some guidance as to appropriate housing design for the Welsh climate having developed as a result of availability of materials together with appropriate response to climate. Timber framed buildings are a common vernacular style in the border counties between England and Wales, where the climate is relatively dry and mild, due to the area being in the lee of the Welsh mountains.

Figure 30: Traditional Timber Frame and Cob House *(Source: National Museum of Wales)*

Where the regional climate is less mild and both strong wind and heavy rain are frequent, buildings with greater thermal mass constructed of cob, stone or brick are more common. This high thermal mass construction is the common vernacular style in and around Neath Port Talbot.

Figure 31: Traditional Stone Cottage with Lime Render *(Source: National Museum of Wales)*

The choice of roofing material in vernacular buildings: stone, thatch, slate and clay tile, was often a question of availability. The question of suitability of roofing materials to a location is appropriate, however, financial and material availability were often more important considerations. Common features of all traditional roofing in Wales are the presence of a pitch and an overhang of the walls. Both of these design features are appropriate to the damp weather experienced throughout the country. Where buildings were of a lime construction the overhang would prevent excess moisture penetrating the lime and where buildings were of a 'Cob' or compacted earth construction (Figure 32), this overhanging roof would serve to protect the material from erosion by the action of driving rain.

Figure 32: Typical Cob Wall Construction – Vulnerable to Driving Rain

In addition to the above constructional methods, orientation, window form and location and stoves, hearths or fireplaces have also been significant aspects of vernacular housing design throughout Wales and the UK (Hawkes, 1996). Homes in the UK were traditionally oriented to face south, in order to maximise the solar gain during the winter months. Windows were also traditionally larger and more frequent on the southerly walls as compared to those found on northerly aspects (Hawkes, 1996). In addition, where westerly winds were prevalent, openings were avoided on facades facing this direction in order to reduce draughts or where openings were unavoidable a 'storm porch' would be built for protection. Finally, despite the use of the passive approaches of heavy thermal mass construction, maximisation of solar gain and minimising of thermal loss through the north façade, additional sources of heat were also required in order to achieve thermal comfort for housing occupants. Typically this was achieved through the incorporation of a fire within the property. Although often located on the external wall, many traditional properties were designed with centrally located chimneys in order to benefit from the stored heat in the chimney breast itself (Hawkes & Forster, 2002). Additionally, agricultural dwellings were sometimes designed with a space for animals directly adjoining the living space so that in winter benefit could be gained from their collective warmth, see below.

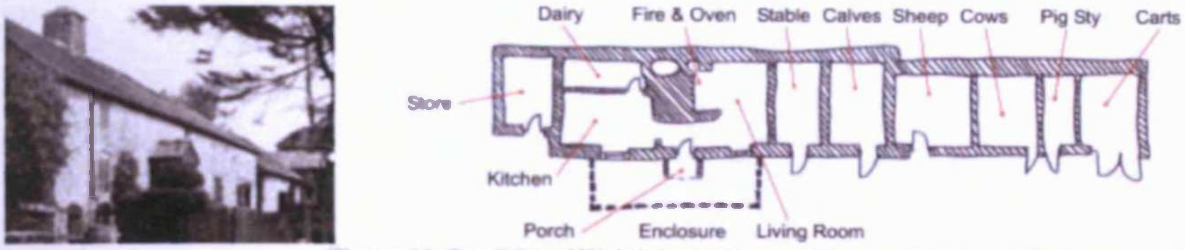


Figure 33: Traditional Welsh Long House (Maes-y-Gellynen, Montgomeryshire)

However, the vernacular built form has not prevailed in housing and the design of housing building forms has been driven more recently by the increased need for mass housing in urban locations, close to the new jobs in industry. This social change resulted in a need for changes in both design and construction methods. One of the key requirements for this new housing was for higher densities than was ever found in the traditional vernacular forms (such as countryside cottages) and as such was a significant driving force in the development of new built forms. The result of this was more standardised and less region specific 'Back to Back houses', tenements and terraced houses, see below. With this came a move away from the climatic responsiveness of regional vernacular architecture.

1. 'Back to Back' (Birmingham)
2. Tenement (Glasgow)
3. Terraced houses (Ipswich)

Figure 34: Typical post-industrial revolution urban house types

Since the burgeoning of the market for urban housing and the subsequent rise of suburbia, increasingly complex services began to be provided (and then expected) in housing. These began to bridge the gap that had appeared as a result of non-region specific and non-climatically responsive housing design and therefore to serve to temper the external climate. The role of building form and design in the control of the internal environment began to diminish. The proliferation of services in domestic properties throughout the nineteenth and twentieth centuries has culminated in the present day situation where mechanical ventilation and air conditioning, having become commonplace in the workplace, are now beginning to find a market in the domestic setting (Graves and Phillipson, 2000). Energy usage to provide internal occupant comfort can therefore be seen to increase as housing design began to move further away from the vernacular This occurred in synergy with a rise in expectations, as occupants began to expect higher standards together with greater controllability in their domestic comfort. It is therefore possible to reject the external climate and to design buildings solely on aesthetic grounds relying on mechanical methods to temper the external climate to produce internal comfort However the energy use required to achieve this, where not derived from a renewable source does not serve the purposes of climate change mitigation A further discussion of the significance of delivered energy use in the domestic environment and its place in the causal link with climatic change is beyond the scope of this work

It may be that a return to practices that maximise the energy derived passively from the environment for example through minimising direct solar gains during summer months, while minimising non-renewable energy requirements, would be an appropriate design approach to adopt for the future, in short a re-application of traditional building methods and vernacular design in a modern setting The adoption of passive and low energy design principles has formed the basis of the reinstatement of this inter-relationship. However, the existing domestic built environment consists of a majority of buildings not designed with these principles in mind. Therefore the appropriate combination of orientation, thermal mass, ventilation and solar shading through carefully considered architectural design can be seen to be one of the key challenges for designers of the built environment in the light of climate change. There are a number of significant bodies of research in this area (Olgyay, 1963, Jones, 1998, Hawkes & Forster, 2002) and it is not necessary to reproduce this work here. However, in summary the following aspects of passive design can be considered significant to any study of the internal thermal environment of existing domestic properties in the UK.

3.2.1.2.1 Housing: State of Repair

The state of repair of a property may also affect its performance in terms of delivery of a comfortable and healthy internal environment This is highlighted by the legal definition of the concept of unfitness, (whether or not a dwelling is fit for human habitation), as considered through the WHCS and set out in Section 604 of the Housing Act 1985, as amended by Schedule 9 of the Local Government and Housing Act 1989 This applies to all types of dwellings in both Wales and England According to the Act dwellings should:

be structurally stable
be free from serious disrepair.
be free from dampness prejudicial to the health of the occupants
have adequate provision for heating.
have adequate provision for lighting
have adequate provision for ventilation
have an adequate piped supply of wholesome water
have satisfactory facilities for the preparation and cooking of food
have a suitably located water-closet for the exclusive use of the occupants; and a suitably located fixed bath or shower and a wash-hand basin, each with a satisfactory supply of hot and cold water, for the exclusive use of the occupants.
have an effective system for the draining of foul and waste water

Additionally for buildings containing flats the entire building should:

- *be structurally stable.*
- *be free from serious disrepair.*
- *be free from dampness.*
- *have adequate provision for ventilation.*
- *have an effective system for the draining of foul, waste and surface water.*

It can be seen that the majority of these factors do not have a direct bearing on the thermal performance of a property, although: the presence of adequate heating; being free from serious disrepair, including windows and doors, which in turn can influence thermal performance through their influence on draughts and heat loss through excessive ventilation are both influential on the thermal environment. The Welsh House Condition Survey (WHCS) found that the age of property was a significant variable in the identification of unfit housing (WAG, 1998, p3). When reasons for unfitness were analysed by age of construction, it was found that the same five factors were identified as the most frequent causal factors, where state of repair was a significant factor for housing built pre-1944. Inadequate heating was a less frequent causal factor for unfit housing.

	Pre 1919		**1919-1944**		**1945-1964**		**Post 1964**		**All**	
Repair	**21,100**	**38%**	**3,400**	**23%**	2,800	15%	1,000	11%	**28,300**	**29%**
Structural Stability	3,800	7%	800	5%	1,100	6%	400	4%	6,100	6%
Dampness	**13,800**	**25%**	1,400	9%	900	5%	1,000	11%	17,000	17%
Ventilation	9,700	18%	2,400	16%	1,500	8%	300	4%	14,000	14%
Lighting	4,800	9%	300	2%	200	1%	-	-	5,300	5%
Heating	5,300	10%	400	3%	1,100	6%	200	2%	7,000	7%
Cold Water Supply	2,700	5%	600	4%	700	4%	200	2%	4,200	4%
Food Preparation	**19,500**	**36%**	**6,600**	**44%**	**8,300**	**44%**	**2,700**	**29%**	**37,100**	**38%**
Bath/ Shower/ Wash hand basin	11,800	21%	2,400	16%	**4,600**	**24%**	**2,100**	**23%**	20,800	21%
WC	10,900	20%	**2,800**	**19%**	**5,800**	**41%**	**3,100**	**33%**	**22,600**	**23%**
Drainage	1,900	4%	300	2%	800	4%	-	-	3,000	3%
Total	**55,100**		**14,900**		**18,900**		**9,300**		**98,200**	

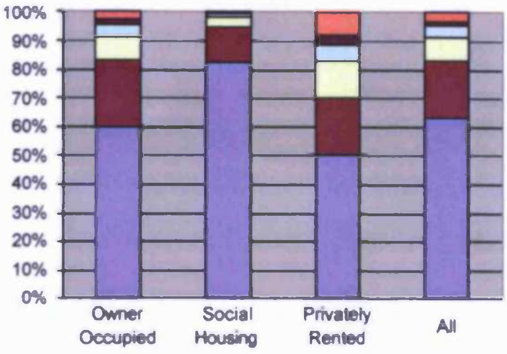
Table 8: Reasons for Unfitness by Date of Construction for Wales (Derived from WAG, 1998)

Unfitness can be seen to be related age of property, where older properties are more likely to be unfit.

	Pre 1919		**1919-1944**		**1945-1964**		**Post 1964**		**All**	
	NPT	**Wales**	**NPT**	**Wales**	**NPT**	**Wales**	**NPT**	**Wales**	**NPT**	**Wales**
Percentage Unfit	14.5%	14.9%	10.1%	9.3%	8.4%	8.0%	3.3%	2.4%	**9.5%**	**8.5%**
Number Unfit	2,740	55,260	1,020	14,990	1,240	19,020	440	9,300	5,410	98,370
Total Stock	18,900	370,900	10,100	161,200	14,700	237,800	13,200	387,300	56,900	1,157,300

Table 9: Unfitness by date of construction for Wales & NPT (Derived from WAG, 1998)

The distributions for those properties found to be unfit for one or more reasons are illustrated below, where social housing was found to be least likely to have more than one factor influencing its unfitness. Privately rented housing is more likely to have more than one unfit item contributing to its designation as unfit.



	Owner Occupied	Social Housing	Privately Rented	All
🟥 6 or More Unfit Items	2.4%	0.6%	8.0%	2.9%
■ 5 Unfit Items	2.0%	0.0%	3.1%	1.7%
☐ 4 Unfit Items	4.5%	1.3%	5.5%	4.0%
☐ 3 Unfit Items	7.9%	2.9%	13.5%	7.8%
■ 2 Unfit Items	23.4%	12.9%	19.6%	20.6%
■ 1 Unfit Item	59.8%	82.2%	50.3%	63.0%

***Figure 35: Reasons for unfitness by tenure for Wales** (Derived from WAG, 1998)*

Privately rented properties are proportionally 3½ times more likely to be unfit than social housing in NPT (25.7% compared with 7.3%). However, this is contrasted by there being lower numbers of privately rented properties, resulting in far greater numbers of unfit owner occupied properties (over 4000 in NPT compared to 390 privately rented properties). This distribution is in part explained by the age and type of accommodation where social housing constructed prior to 1919 is rare and is most prevalent in privately rented properties, especially pre-1919 terraced properties. However, these factors do not fully explain this distribution, as privately rented properties in all age categories except post-1964 are more likely to be unfit.

	Terraced		**Semi**		**Detached**		**Flats & Other**		**All**	
	NPT	**Wales**	**NPT**	**Wales**	**NPT**	**Wales**	**NPT**	**Wales**	**NPT**	**Wales**
Percentage Unfit	13.8%	11.4%	8.9%	6.8%	6.5%	6.1%	2.9%	9.5%	9.5%	8.5%
Number Unfit	2,480	46,170	2,250	24,970	550	16,110	150	9,590	5,410	98,370
Total Stock	18,000	405,000	25,300	367,200	8,400	264,100	5,300	100,900	56,900	1,157,300

***Table 10: Unfitness by type of accommodation for Wales and NPT** (Derived from WAG, 1998)*

Terraced properties are both proportionally, and in terms of actual numbers, the most likely to be unfit in both NPT & Wales as a nation. The age structure of this type of property influences this finding, as most terraces were constructed in the period preceding 1919. Finally, the distribution in terms of location for unfit housing reveals that a higher proportion of rural properties are defined as unfit using this categorisation, where NPT borough is the eighth highest borough for rural housing unfitness.

	Urban		**Rural**		**All**	
	NPT	**Wales**	**NPT**	**Wales**	**NPT**	**Wales**
Percentage Unfit	8.7%	8.1%	14.5%	10.3%	9.5%	8.5%
Number Unfit	4,250	75,560	1,180	5,860	5,410	98,370
Total Stock	48,800	932,800	8,100	56,900	56,900	1,157,300

***Table 11: Unfitness by nature of area for Wales and NPT** (Derived from WAG, 1998)*

The opinion of occupants regarding the state of repair is also a relevant finding from this survey, where 70% of households believed that their home was in good repair, 25% in need of minor repair and 5% in need of major repair This proportional finding is not dissimilar to the overall findings of the survey however there was a frequent mismatch between the occupants and surveyors findings For example many households believed their homes to be in good repair when the property was unfit as well as other households where the reverse was true. It should be noted that this is likely to be influenced by the low importance given in the unfitness survey to superficial disrepair This mismatch accounted for 42% of all unfit properties in Wales, some 42 000 homes where occupants believed their homes to be in good repair and in fact they were unfit 16% of occupants of unfit dwellings identified their home as in need of major repair, while 39 000 occupants believed their homes were in need of major repair, yet live in fit homes.

3.2.1.2.2 Housing: Age of Property / Construction Type

As described above the presence of thermal mass in a building can be used to store heat for 'use' later in the day when applied as part of a passive design strategy Therefore its presence should be considered when assessing thermal comfort in a building However, the SAP assessment procedure referred to previously does not model the impact of thermal mass on the internal environment of a property Thermal mass can reduce the thermal swings due to daytime warming and night time cooling and therefore lessens the need for fuel or electricity to regulate temperature However, where a heavy thermal mass property, such as an old stone cottage is unheated for period of time during the heating season, the thermal mass can result in the internal environment being less temporally responsive to heating being turned on and off than a similarly insulated property with lower thermal mass This influences the internal thermal comfort as occupant bodies radiate heat to the walls producing a cooling influence on their thermal comfort This quality stems from the thermal capacity and the thermal resistance of the material in question For example the conduction of heat through a dense masonry wall may take up to 12 hours

This suggests, therefore, that the impact of heavy thermal mass on occupant thermal comfort during the winter is likely to be related to both the source of heating and occupant usage or interaction with that system In relation to occupant behaviour, where a heating system is on almost constantly at a low level, the thermal mass will not cool down and will therefore not be a source of radiant cooling However, where a heating system is used intermittently, radiant cooling may produce an uncomfortable environment during the period at which the thermal mass heats up The type of heating source is relevant for example where an aga / rayburn type stove is installed and run constantly, the thermal environment is likely to be more constant, as would the case be with under-floor heating, where the thermal mass of the floor is often utilised as a low temperature radiator However, where a higher temperature radiator based central heating system is installed, this is often used for short bursts of heating and therefore may result in a less responsive internal environment, especially when the environment is being heated up from cold.

Pre-1919

Housing built prior to 1919 is likely to be constructed of solid walls with lime mortar, although un-insulated cavity walls were introduced during this period. Foundations are likely to be shallow, less than 45cm, and it is likely that there would be no damp proof course present. Walls are likely to have air bricks through their whole depth. Original windows would have been timber and single glazed and ground floors are likely to be suspended timber with ventilated cavities below. Insulation would not have been present in cavities or in walls and draughts from air bricks, windows, doors and beneath the floor would be likely. The construction could be seen as designed to be 'breathable' (i.e. allowing the passage of water vapour through the building fabric by absorption / evaporation).

Alterations to these standards may include double glazed windows, draught exclusion, insulation to the loft and blockage or removal of air bricks. Cement rendering to the original lime construction is frequent as well as the injection of damp proof courses. Much of this modernisation would have changed the original breathable construction to more modern methods where moisture is excluded from the internal environment and construction. This alteration may or may not succeed and is often the cause of internal damp in older properties through the trapping of moisture in walls and floors.

1919 – 1944

During this period construction methods altered significantly and included the rejection of lime construction methods and the adoption of methods of construction that aimed to ensure moisture exclusion. This approach is common to housing built from this period onwards. Cavity walls were adopted in the mainstream and solid walls were rare in this period. Foundations became deeper and damp proof courses widespread. Air bricks were still present, especially to ventilate the wall cavities. However, insulation levels were low, and double glazed windows were not available.

These properties are likely to have had similar modernisation to those within the previous age group including insulation and replacement windows.

1944 – 1964

This period of house construction reflects a period of change in methods of construction. Modern and innovative construction methods became widespread, including prefabrication and greater use of concrete, due to the post war rise in the construction of housing. It is beyond the scope of this work to describe these construction methods in greater detail, nor is it appropriate to consider the reasons for this increase in housing construction. Ground floors were likely to be solid concrete from this period onwards. Insulation to these homes was low and single glazed windows, either metal or timber framed, were the norm. Similar renovation methods would be applied to this age of housing as for the previous groups, although re-cladding of prefabricated homes is a further method of modernisation.

1965 - 1980

Housing built since 1965 is likely to have increased levels of insulation in line with step changes in Building Regulations since this time. Foundations are likely to at least 90cm or deeper in reference to the bearing capacity of the ground. Double glazing, cavity wall and loft insulation is widespread in both of these age groups. Almost all homes in these categories will have damp proof courses and cavity walls. Refurbishment for this group is likely to be limited to the replacement of modern features and improvements to loft and cavity insulation.

Post-1980

The majority of houses constructed post-1980 are either of masonry or timber framed construction with insulated cavity walls, usually with block internal and brick external skins. These properties are completed with uPVC double glazed windows and highly insulated pitched tiled or slate roofs. This medium (block or brick) or low (timber) thermal mass construction is applied countrywide irrespective of regional climate or the site-specific microclimate and it is the internal central heating, ventilation systems and more recently air conditioning that temper the internal environment, in order to maintain internal thermal comfort for occupants. Exceptions to this are the exposure to wind and driving rain indexes that must be consulted for detailed roof design (Building Regulations Part A: Structure, 2000). Despite this move towards homogenisation of building design throughout the country, the connection between internal and external environment, that was explicit in the vernacular, persists.

It should be noted that the high insulation levels afforded by these homes in comparison with older properties have resulted in a reduction in energy usage per property. In contrast to this current benefit, their design and construction, especially the lighter weight construction methods, may be of concern in relation to their ability to continue to offer comfortable environments in the light of a warming climate (Hacker & Twinn, 2005).

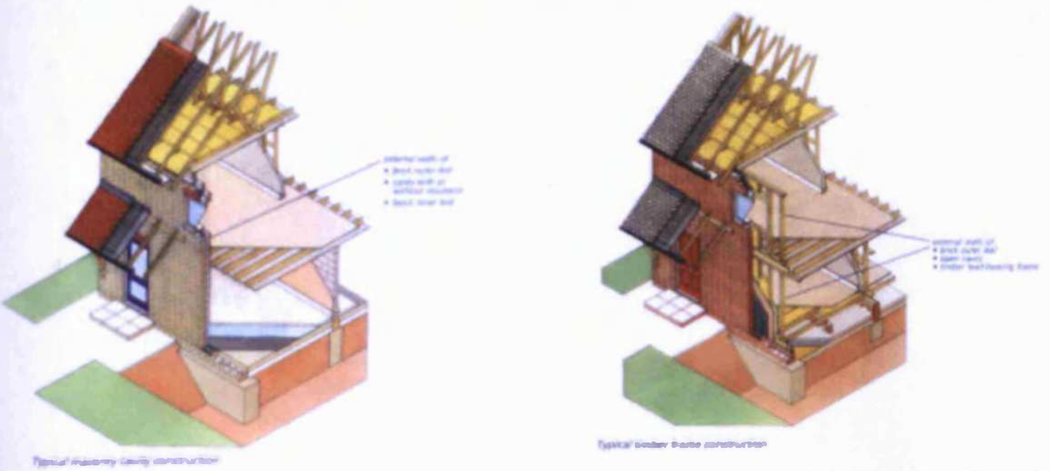


Figure 36: Typical contemporary construction methods *(National House Building Councils (NHBC, 2000)*

Figure 37: Typical external wall constructions (blockwork) (NHBC, 2000)

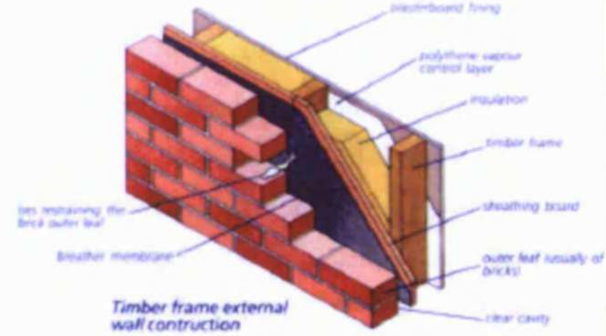


Figure 38: Typical external wall construction (timber frame) (NHBC, 2000)

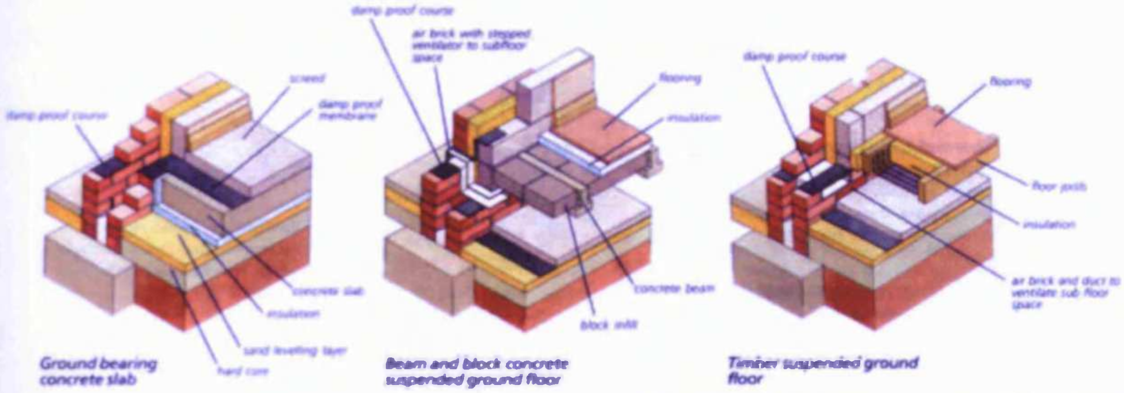


Figure 39: Typical floor constructions (NHBC, 2000)

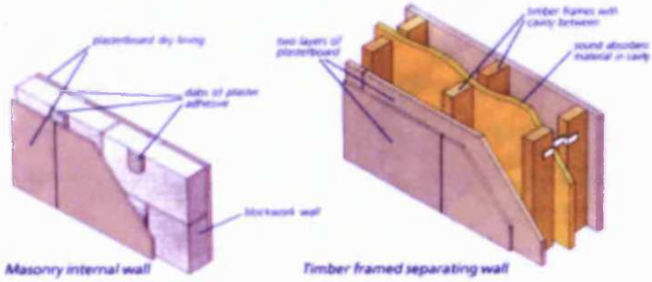


Figure 40: Typical internal wall constructions (NHBC, 2000)

Figure 41: Typical contemporary house (Wimpey Homes, volume housing)

3.2.1.2.3 Housing: Heating Type

Following on from the interaction between heating sources and thermal mass, the type of heating source also influences the temperature gradient in a space, which in turn can influence thermal comfort. This is illustrated in below, where the impact of differing heating distribution systems can produce a varying temperature gradient between feet head and ceiling. Where there ideal strategy for thermal comfort is "warm feet and a cool head" it can be seen that during the heating season underfloor heating may be the most suitable (where the temperature is typically between 19 & 29°C), while the more traditional radiator system, found in the majority of UK homes, produces the reverse and a less comfortable gradient (Race, 2006, p12).

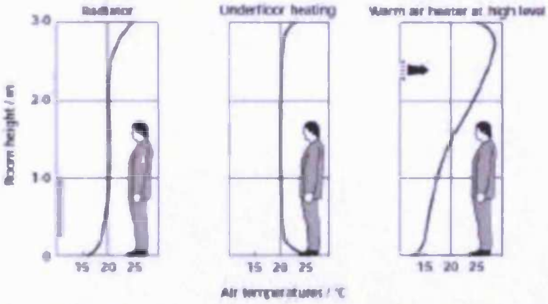
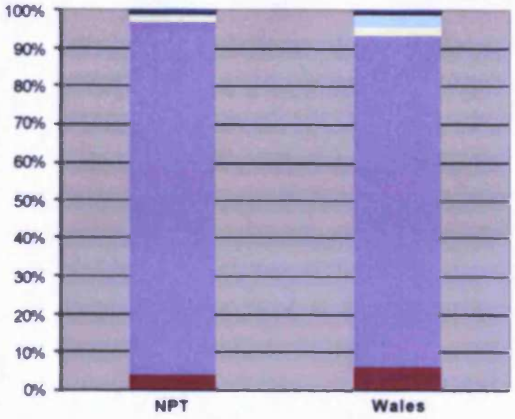


***Figure 42: Vertical Air Temperature Gradients for Different Heating Types**, (Race, 2006, p22)*

Central heating is found in 89% of homes in Wales. This represents an increase following a trend since 1986 where only 67% of homes reported central heating. By the Census of 2001 this figure had increased to nearly 93% (Census, 2001). Neath Port Talbot has a deeper penetration of central heating than the nation as a whole with 94.8% (2001 Census – 95.8%). The second most prevalent main form of heating in NPT is gas fires or heaters with 3.7% and solid fuel with 1.2%. The provision of central heating is related to the potential for increased winter thermal comfort in housing (Rudge & Nicol, 2000, Boardman, 1991).

	Central Heating	
	NPT	Wales
Number	53,000	1,030,100
Percentage	94.8	89.0



	NPT	Wales
■ No Heating	0.3%	0.2%
■ Other Heating	0.4%	0.5%
■ Oil or Paraffin Heaters	0.2%	0.2%
■ Solid Fuel Fires or Stoves	1.2%	3.9%
■ Electric Fires or Heaters	1.0%	2.0%
■ Central Heating	93.2%	87.1%
■ Gas Fires or Heaters	3.7%	6.1%

Figure 43: Main form of heating for Wales & NPT *(Source: WHCS, 1998)*

A further impact of building services and specifically central heating can be its impact on relative humidity, one of the environmental variables associated with thermal comfort. Although humidity does not have a significant impact on thermal comfort at average temperatures in UK domestic properties, an RH below 30% can lead to the eyes, throat and skin feeling uncomfortably dry (Race, 2006, p11). This can happen where ambient external cold air is heated 15-20°C to produce internal comfort temperatures. Guidance from CIBSE recommends that a RH of between 40–70% can be considered good practice.

3.2.1.2.4 Housing: Insulation

The provision of adequate thermal insulation in a building reduces heat loss from the building during the heating season. Insulation is described in terms of R-value or thermal resistivity. The higher the R-value, the greater the thermal resistivity of the material.

In construction, the standard figure used to describe the heat loss of a building material or element is called the U-value. It refers to Unit Heat Loss Rate, and its unit is the watt per metre squared per kelvin, $W\,m^{-2}\,K^{-1}$. In practice, it is usual to use a figure for a particular structure, e.g. a brick wall, rather than take the values of the conductivities of its constituent materials. The U-value is defined as the rate at which thermal energy is conducted through unit area, per kelvin temperature difference between its two sides.

$$U = \frac{\text{rates of loss of energy}}{\text{surface area} \times \text{temperature difference}}$$

As opposed to R-values where a higher figure indicates greater insulation properties, the lower the U-value the better the insulation. If a structure has a U-value of 1, this means 1J per second will pass through each square metre for each kelvin (degree Celsius) difference in temperature between the two sides of the structure.

Table 12 (below) gives *typical* U-values for housing of different ages and constructions illustrating the impact of increased insulation as a result of the evolution of the English and Welsh Building Regulations standards. These theoretical values depend on the materials used in its construction and the amount and type of insulation added, while the performance of the construction as built may well be different as a result of effects in the construction as well as the concept of thermal bridging in the structure. Put simply the effect of adding insulation to a house is to reduce the U-values of the different structural elements.

Age of property	Walls			Roof
	Solid	Cavity	Timber Frame	Unknown Thickness
Post 2002	0.35	0.35	0.35	0.16 / 0.2 / 0.25
1996 – 2002	0.45 / 0.6	0.45 / 0.6	0.45	0.25
1990 – 95	0.45 / 0.6	0.45 / 0.6	0.45	0.25 / 0.35
1982 – 90	0.6	0.6	0.45	0.35
1977 – 81	1.0	1.0	0.45	0.6
1966 - 76	1.5	1.5	0.8	1.0
1950 – 65	2.1	1.6	1.0	1.5
1930 – 49	2.1	1.6	1.9	2.0
1900 – 29	2.1	1.6	1.9	2.0
Pre 1900	2.1	2.1	2.5	2.0

(U Value Units: W m^{-2} K^{-1})

Table 12: U Values for areas of typical existing housing in Wales. *(BREDEM 12, 2001, p68)*

Figure 44: House types & ages matrix *(Source: English House Condition Survey, 2001)*

A further influence on heat loss from a property is related to the air tightness of the construction, where air tightness is related to the amount of heat loss due to uncontrolled air leakage. The location of a building, in terms of its exposure to wind, can also have an influence on its performance in relation to the internal thermal environment as the actual air leakage rate (or infiltration rate) for a property will be related to the local wind speed together with a measure of the exposure to the wind (BREDEM 12, 2001, p 26, p88).

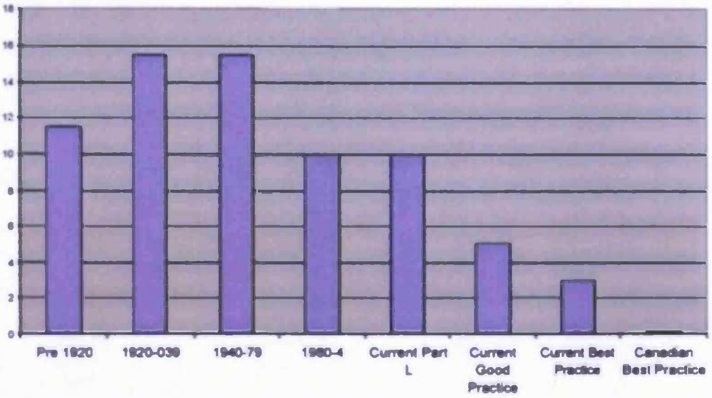


Figure 45: Typical Air Leakage Standards (m^3 / m^2. hr @ 50PA) *(Derived from Olivier, 1999)*

The Welsh House Condition Survey considered the following forms of domestic insulation:

- Roof or loft
- Cavity walls
- Hot water tanks
- Double glazing of windows
- Draught stripping of windows and doors.

Those homes built post-1964 were most likely to have all five forms of insulation being considered, compared with 2% of homes built prior to 1919. It can be seen that the distribution of types of insulation in NPT were similar to those found throughout Wales except for cavity wall insulation and draught stripping, where these types are less likely to have been undertaken. Further to those findings illustrated, detached homes were most likely to have all five forms of insulation and terraced houses and flats or other housing forms were least likely.

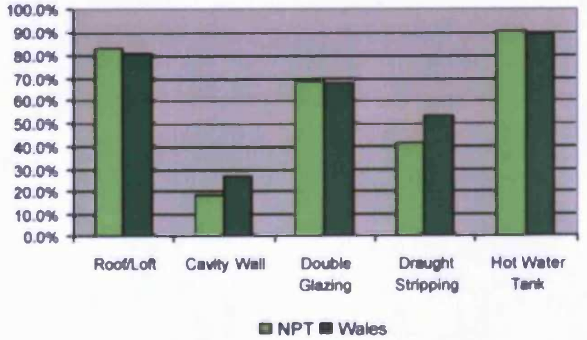


Figure 46: Summary of type of insulation provision in all Welsh Housing for Wales & NPT *(WHCS, 1998)*

	NPT		Wales	
All Insulation	**4.8%**	**2,731**	6.5%	75,225
Some Insulation	**93.1%**	**52,974**	90.6%	1,048,514
No Insulation	**0.6%**	**341**	0.7%	8,101
Don't Know / Refused	**1.5%**	**854**	2.3%	26,618

Table 13: Summary of Insulation Provision in All Welsh Housing for Wales & NPT *(Source: WHCS, 1998)*

3.2.1.2.5 Housing: Orientation

In order to optimise solar gain in the winter months (or heating period), and therefore "free heat", it is necessary to orientate buildings along the north south axis in the UK, ensuring availability of sunlight into the space. Living rooms are best located to take advantage of this gain (i.e. south facing), while secondary, non living spaces such as bathrooms, kitchens, circulation and storage spaces should be located elsewhere. A sunspace can be introduced to enable further capture of solar energy in this way. It should be noted that the majority of homes are unlikely to have been designed to optimise orientation in this way. This is in part as a result of the common application of standardised floor plans in housing, where these are placed on a site irrespective of orientation. In addition, existing road layouts and surrounding buildings, topography and even vegetation may negatively influence the availability of solar gain.

3.2.1.2.6 Inadequate Heat: Pathway Factors

The Housing Pathway / Exposure variables that influence the occupant health and comfort risk system for inadequate heat are therefore:

- **Housing:**
    - Age of Property
    - State of Repair
    - Construction type (Associated with building age)
        Thermal Mass
    - Heating Type (Associated with fuel poverty)
        Building Size
    - Insulation
        U Values of building elements
        Air Tightness
    - Orientation
        Window type
        Overshadowing (Due to buildings / topography or location / vegetation)
- **Neighbourhood:**
    - Exposure to Wind (See section 3.2.2.2.2)

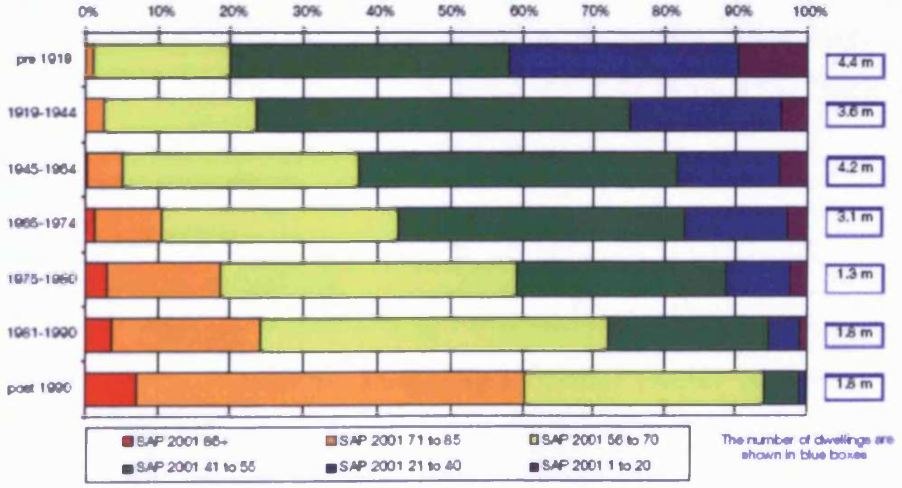


Figure 47: The Profile of Energy Performance in Existing English Dwelling Stock, 2004 *(DCLG, 2006, p5)*
NB: this information is not currently available at a national scale for Wales.

A valuable indicator for exposure to the risk factor of inadequate heat has been identified as the SAP rating for each property, which is available from the Energy and Environmental Prediction dataset (EEP). Typical SAP values for English domestic properties are provided above. SAP is a rating based on the annual energy costs for space and water heating on a scale of 1 to 120, with a higher figure indicating greater energy efficiency (BRE, 2001) and can used to demonstrate compliance with Part L1 of the Building Regulations. A SAP rating has been calculated for each property in NPT as part of the Welsh School of Architecture's EEP project using an in-house SAP calculation tool. The average SAP rating for the NPT housing is 47.2 with a standard deviation of 5.9. It can be seen from the figure of SAP rating distribution (below) that housing built between 1919 and 1944 is most likely to have a lower SAP rating (mean 43.2, STD 2.7) due to low levels of insulation and a need for relatively high levels of energy to achieve winter thermal comfort. Housing built post-1980 has a mean SAP rating of 55.5 with a STD of 5.4. The reader should be made aware that since this work the SAP assessment procedure has been updated in line with the Part L of the 2006 building regulations (SAP 2005). However, for the purposes of this project the existing dataset has been utilised, and therefore this work makes use of the associated previous SAP assessment method.

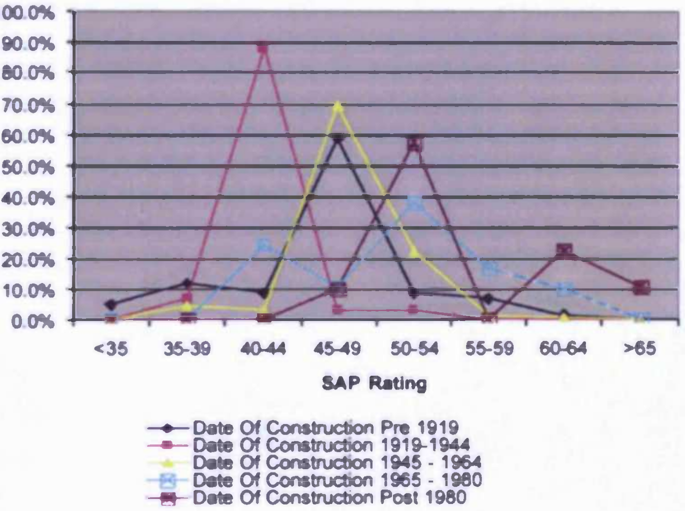


Figure 48: Distribution of NPT housing by window to wall, SAP rating and date of construction

The variables required to calculate a SAP rating are listed below, where those directly influencing the thermal performance of the home are in bold and those influencing water heating requirements in normal text.

- **Dimensions of the property, including:**
    - **Floor / Wall / Ceiling Height**
- **Factors influencing ventilation, including:**
    - **Chimneys / Flues / Passive Vents / Fans / Construction Type (Masonry or Steel) / Draught Lobby / Draught Stripping / Shelter Factor (Relating to Microclimatic Conditions)**
- **Dimensions and U values for external building fabric**
- **Internal gains including:**

  - **Lights / Appliances / Metabolic (the number and type of occupants) /** Hot Water / **Cooking**
- **Solar Gains**
- **Heating Source**
- Water heating requirements
- **Mean internal temperature**

Predicted annual energy usage is also calculated through the SAP process and is illustrated in the figure below for the NPT housing stock. It can be seen that energy usage in pre-1919 homes has a flat distribution between <100 to >300 GJ/year. This distribution is greater but similar to the distribution for homes built between 1965 & 1980. Those distributions for housing built between 1944-1964 and 1919-1944 both display sharper peaks, where greater proportion of homes have lower energy consumption. Housing built post-1980 consistently has the lowest predicted energy use distribution. This is in line with the changes in building regulations, however, other factors including sizes of homes influence these distributions.

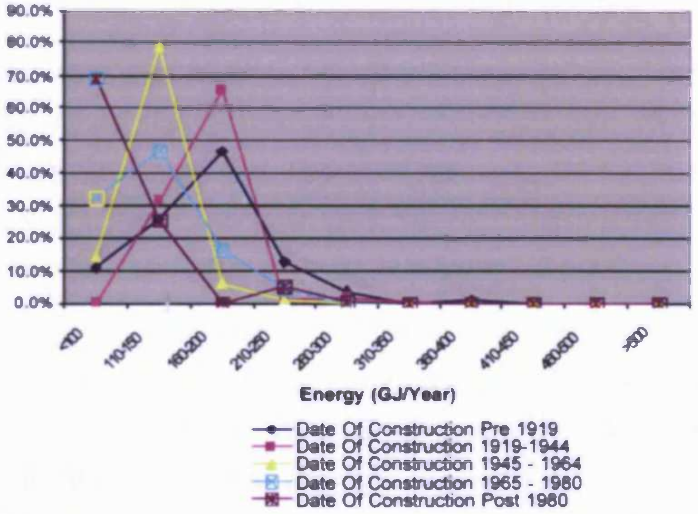


Figure 49: Distribution of NPT housing by energy use (GJ/Year) and date of construction

3.2.1.3 Receptor

The exposure factors in relation to the occupant health and comfort risk system for inadequate heat are defined as those aspects of the receptor that influence their vulnerability to the risks described above.

3.2.1.3.1 Age

The age of housing occupants has a significant bearing on their vulnerability to the health and comfort risks associated with inadequate heat. This is especially valid for elderly occupants as well as other more vulnerable populations such the very young (Burridge & Ormandy, 1993, Keatinge & Donaldson, 2000, Collins, 2000, Krieger & Higgins, 2002). For example, fuel poverty and its association with inadequate heating, is of particular concern where it impacts on the elderly and the very young, especially where cot deaths are found to be more frequent in the winter (Mant & Muir Gray, 1986).

The occupant age may also affect their behaviour in relation to the building services. For example, elderly people are more likely to have colder homes. This has been identified by a survey of the internal environment of living rooms in homes occupied by those over 65 years old, which found the following distribution of temperatures, with the lowest recorded temperature of 6°C (Mant & Muir Gray, 1986). The reason for this may be complex, relating to occupation of older properties, relatively low disposable income and perhaps even a tendency to wear more clothes during the winter than younger housing occupants.

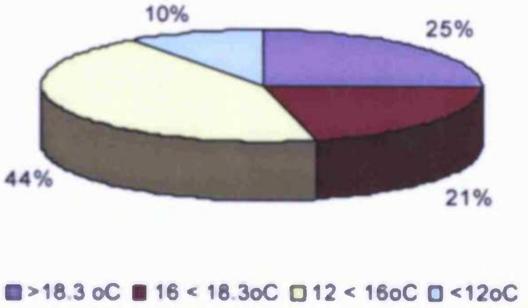
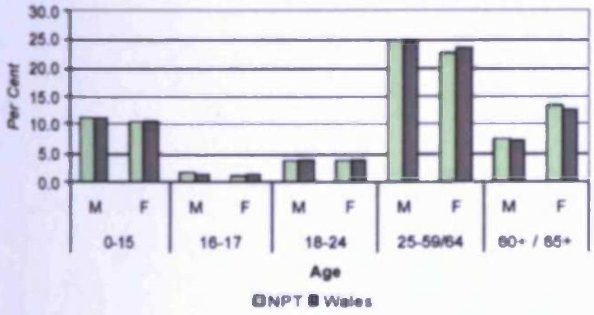


Figure 50: Monitored Living Room Temperatures for Homes with Occupants > 65 Years of Age
(Data derived from Mant & Muir Gray, 1986)

The age of occupants and time at address were also found to be related to occupancy of unfit housing in the WHCS (WAG, 1998, p78). Young male heads of households, between 16-29, occupant for less than one year and also householders who had been the occupant for more than 20 years (especially where the heads of these households were retired) were found to be most at risk of occupying unfit homes. This in turn can influence their health see 3.2.1.2.1.

The Welsh Household Information Survey (WHIS) estimated the population of Wales in 1998 to be 2,885,500. This compares well to the Census finding for 2001 of 2,903,085. While both the WHIS and the Census found that 52% of the population were female and 48% male. The distribution estimated from the WHIS is illustrated in Figure 51 (below).



Per cent	**Male**		**Female**		**All People**
NPT	**48.6**	**68,600**	**51.4**	**72,600**	**141,200**
Wales	48.1	1,387,200	51.9	1,498,300	2,885,500

Figure 51: Population Distribution: By Age (Left) Total for Wales & NPT (Right)
(WAG, 1998)

The population of Neath and Port Talbot was perhaps overestimated by the WHIS survey, as the Census provides a population of 134, 468, that would represent a fall of 6,700 in the population over three years.

3.2.1.3.2 *Socio-economic: Status*

The impact of socio-economic factors at a household level have already been considered to some extent through the discussion of the impact of fuel poverty on exposure through its influence on occupant behaviour in relation to building services. This inter-relationship between wider socio-economic considerations such as poverty and unemployment, with both direct and indirect health impact factors, is complex and the subject of much literature, Ambrose (1997) , Kellet (1989), Lowry (1989c), Lowry (1991), Lynch (2000), and Ambrose (2002). For example, where an individual suffers from long-term or intermittent ill-health; this is likely to lead to low earning capacity that may lead to loss of choice in the housing market where quality of the accommodation is likely to be lower (Conway 1995).

Further to this there is an association between poverty and unemployment with the duration and maintenance of common mental disorders (Weich & Lewis, 1998, Robinson, 2004), while the existence of financial strain was found to be a predictor for future psychiatric morbidity. It has been estimated that approximately 15% of the UK community are considered to be subject to common mental disorders. As the presence of mental health is closely inter-related with both housing (on many levels) as well as with socio-economic factors, this is a significant factor for this research. The standard of housing has in turn been associated with mental health, where this relationship has been considered to be circular. The occurrence of mental health both negatively influences the accessibility and availability of good housing as well as being impacted on and exacerbated by the presence of poor housing (McCarthy et al, 1985, Kellet, 1989, Smith et al, 1992, Kearns et al, 1993, Conway, 1995, Ambrose, 2002). Many further considerations exist that may add further complexity to this relationship between mental health, housing and socio-economics, such as the presence of mental health brought on by the presence of chronic disease in an occupant (Verhaak, 2004, Schnittker, 2005) and the mediating effects of psychosocial resources available (Bisschop et al, 2004, Shields & Price, 2005).

The highest educational or vocational qualification gained is often considered to be related to socio-economic status and has been gathered for Wales and NPT during the Census. The findings for the population of Wales at the time of the Census for all people aged 16 – 74 are illustrated in the table below. The population of NPT is more likely to have no qualifications (or to have any qualifications at a level higher than level 1 or above) than the population of Wales as a whole. The NPT population is, however, more likely to have other qualifications of an unknown level.

Area	No Qualifications	Highest Qualification Level 1	Highest Qualification Level 2	Highest Qualification Level 3	Highest Qualification Level 4/5	Other Qualification Level Unknown
NPT	39.04	16.50	18.46	5.16	12.86	7.99
Wales	33.02	15.46	19.78	7.12	17.39	7.21

Table 14: Qualifications for Wales & NPT *(Source: 2001 Census data, ONS, 2001a)*

The final socio-economic variable collected, either within the WHIS or the Census, of interest to the socio-economic level of occupants of Wales or NPT is the National Statistics Socio-

Economic Classification (ONS, 2002, National Statistics Website, accessed 2002). As the variable relates only to those members of the population of working age, this variable is only illustrated for people aged 16 – 74.

Area	Large Employers and Higher managerial Occupations	Higher Professional Occupations	Lower Managerial and Professional Occupations	Intermediate Occupations	Small Employers and Own Account Workers	Lower Supervisory and Technical Occupations	Semi-Routine Occupations	Routine Occupations	Never Worked	Long-Term Unemployed	Full Time Students	Not Classifiable for Other Reasons
NPT	1.58	2.47	13.61	7.96	4.61	8.62	13.16	12.03	3.34	1.28	5.07	26.26

***Table 15**: **National Statistics Socio-Economic Classification for Wales & NPT** (2001 Census data ONS, 2001a)*

Those classified as 'not classifiable for other reasons' relate to those occupants that have not been asked this question, which in the majority of cases relates to the elderly or those members of the population who have not worked since 1996 (long-term unemployed). Through simple analysis of these statistics it can be seen that the occupants of NPT are less likely to hold higher graded occupations, such as managerial or professional positions, and more likely to be employed in lower supervisory and technical occupations, semi-routine occupations or routine occupations, as well as being less likely to be students. The NPT population is also more likely to be unemployed or to have never worked than Wales as a whole.

3.2.1.3.3 Socio-Economic: Household composition

A further complication in the achievement of thermal comfort in the home may be disagreement between housing occupants. For example, anecdotal evidence, seemingly present in many places of work and homes, suggests that female occupants are comfortable at higher temperatures then males. This has not been corroborated through research, where despite the lower insulative levels of women's clothing, especially in offices, male and female workers in the same building were found to be comfortable at the same temperatures (Fishman & Pimbert, 1978). Further to this, during controlled experiments men and women have been found to have the same comfort temperature ranges (Fanger, 1970) and it is therefore suggested that the occupants, both male and female, in these studies were choosing to accept temperatures mildly warmer or colder than comfortable for a psychological reason. That is to say there seemed to be a psychological component to their responses in this research. Work to establish similar findings in housing has not been undertaken nor is the author aware of any work undertaken to explain this phenomenon further.

It should be noted that research to establish the causal factors for Sick Building Syndrome (SBS), a condition that causes symptoms affecting the skin, mucous membranes and nervous system (Jones et al, 1995), has identified a higher incidence of SBS in women (Brasche et al, 2001, Stenberg & Wall, 1995). This has been found to be independent of work related or other psycho-social factors. In this case it is hypothesised that a route may exist between the identification of a sick building by a work force (through the perception of building symptoms) to complaints by the occupants. The increased reporting of SBS symptoms by women therefore remains unexplained.

Density and overcrowding, often considered interchangeable, can also influence an occupant's vulnerability to health and comfort risks due to inadequate heat where, density should be considered as a measure of available space, and overcrowding to a perception of 'exposure to limited space' (Stokols, 1972). Low density occupation can exacerbate the impact of fuel poverty, for example, where an individual occupies a large home alone it may be prohibitively expensive to heat all rooms to a comfortable level, leading to large heat differentials between rooms, which may be associated with thermal stress for vulnerable housing occupants (Goodwin, 2000, p54). While high density has been linked to the spread of tuberculosis and respiratory infections (Lowry, 1989b, Marsh et al, 1999, Krieger & Higgins, 2002).

Density & Overcrowding	• Increased risk of infectious disease • Increased risk of respiratory disease • Reduced stature • Emotional problems • Developmental delay in children • Social tension • Psychological distress

Further to these physical health impacts, density has also been widely associated with psychological distress, where overcrowding (in the sense of high density) is associated with psychological distress. A similar relationship has been suggested between lower densities, (for example living on your own) and therefore the overall relationship is therefore seen to be non-linear in form (Gabe & Williams, Hwang et al 1999). With reference to the 1957 Housing Act, Mant & Muir Gray (1986) suggested links to airborne infection, odour, water vapour and other airborne pollutants. All of these associations between overcrowding and health are considered to be possible causal links by Hwang et al (1999).

For the WHIS the type of households were assessed by the number of occupants.

	Number of People in the Household							
Per cent	1	2	3	4	5	6 or More	Avg. Household Size	All Households
NPT	**24.6**	**33.6**	**18.9**	**16.7**	**5.1**	**1.1**	**2.48**	**56,900**
Wales	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

***Table 16**: Number of People in Household and Average Household Size for Wales & NPT*
(Source: WAG, 1998)

The types of household were also defined in the WHIS using nine categories, the distribution of which is illustrated in the Figure 52 (below). These categories assessed household types by number of adults, pensioners and children, resident in the home.

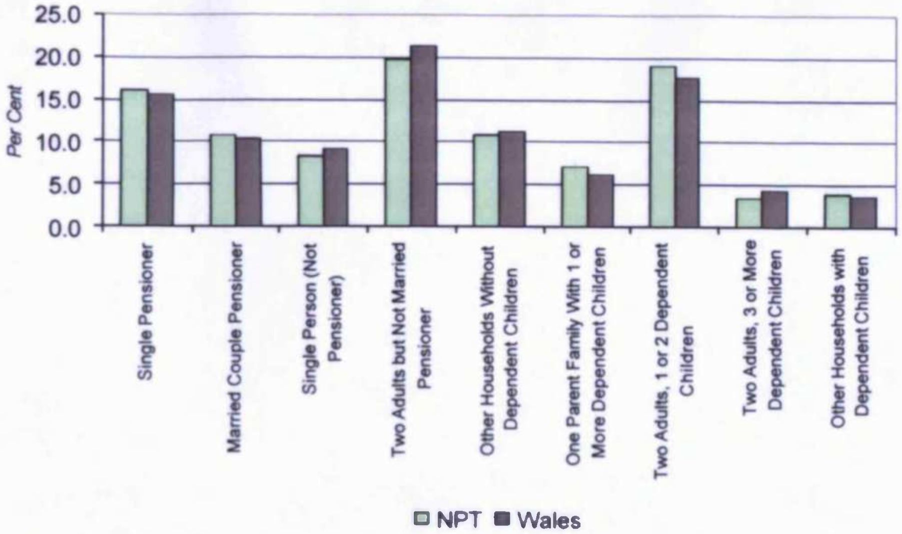


Figure 52: Distribution of Types of Household for Wales & NPT (Source: WAG, 1998)

This estimated distribution for 1998 can be compared with the 2001 Census findings from three years later, summarised below. Due to differences in the categorisation of the variables, this is only possible for a limited number of categories. Despite the three years between the surveys it can be seen that the distribution of single pensioners is very similar. However, the comparative table may suggest that the number of married couple pensioners is overestimated in the WHIS, while the number of single person households is underestimated.

		Single Pensioner	Married Couple Pensioners	Single Person (Not Pensioner)
CENSUS	**NPT**	16.35	9.56	13.91
	Wales	15.46	9.62	13.69
WHIS	**NPT**	16.2	10.8	8.4
	Wales	15.6	10.4	9.2

Table 17: Household Structure (Source: 2001 Census Data, ONS, 2001a)
N.B. For this variable only population aged 16 and over were considered.

The WHIS also reported the following for household type and most prevalent housing in terms of form, tenure, size and age.

Household Types	Form	Tenure	Size	Age
Single Pensioner	Flats or Other	L.A. Rent	1 – 2 Bed	-
Other Single Occupancy	Flats or Other	Private Rent	1 bed	Pre 1919 or Post 1964
Single Parent	Terrace	Rent	3 Bed	Post 1944
Other Households	Detached	Owner Occ	3+ Bed	-

Table 18: Summary of Most Prevalent Housing Form by Household Type

Overcrowding of housing was assessed in the WHIS using two standards, the number of people per-room and the bedroom standard. The number of people per-room is calculated through consideration of the number of living rooms, not including the kitchen, bathroom, hallway or other rooms that cannot be considered living or bed rooms. This standard provides a guide as to the density of occupation of homes.

Per cent	>1.5	1<1.5	0.5<1.0	<0.5	All Households
NPT	0.4	3.0	41.6	55.0	56,900
Wales	0.4	3.9	40.3	55.4	1,157,300

***Table 19: Overcrowding Standards: Persons Per Room for Wales & NPT** (Source: WAG, 1998)*

The 'bedroom standard' is a nationally defined standard calculated through the comparison of the number of bedrooms in a dwelling with the calculated requirements of the occupants. The standard number is one bedroom each for:

- *Any married couple*
- *Other person over 21*
- *Two persons of the same sex aged 10 to 20*
- *Person aged 10-20 paired with a child under 10 of the same sex*
- *Two of any remaining children*
- *Any child remaining*

Typically where a bedroom standard of below 'equal' exists, the building should be considered overcrowded. It can be seen that 3.3% of households should therefore be considered to be overcrowded.

Per cent	2+ Below	1 below	Equal	1 Above	2+ Above	All Households
NPT	0.2	3.1	25.0	36.4	35.3	56,900
Wales	0.3	3.0	24.1	37.6	35.0	1,157,300

***Table 20: Overcrowding Standards: Difference from bedroom Standard for Wales & NPT** (Source: WAG, 1998)*

Where analysis is undertaken of overcrowding in relation to household type and unfitness, it can be seen that 'Other' household groups, without dependent children, are most likely to live in unfit and overcrowded homes. Unfortunately this information is not available at a Unitary Authority level.

	Below		Bedroom Standard Equal or Above		All	
	%	No.	%	No.	%	No.
Unfit						
Single Pensioner	-	-	11.3%	20,200	11.3%	30,300
Other Single Person	-	-	11.9%	11,500	11.9%	11,500
Lone Parent	9.3%	400	8.5%	6,000	8.5%	6,400
Other with Dependent Children	14.6%	3,600	6.5%	18,300	7.2%	21,900
Other without Dependent Children	17.1%	1,300	7.5%	36,900	7.6%	38,300
	14.6%	**5,300**	**8.3%**	**93,000**	**8.5%**	**98,200**

***Table 21: Unfitness and Overcrowding by Household Type** (Source: WAG, 1998)*

3.2.1.3.4 *Existing Health: Presence of Long Standing Illness*

The presence of long standing illnesses (including diabetes, respiratory, and cardiovascular disease) has an influence on the vulnerability of an occupant to the risks associated with inadequate heat (Keatinge & Donaldson, 2000, p19, Collins, 1993, 129, 131 & 2000, p38, 43-44). Its presence can also influence mental health, as well as the potential impact on access to housing, due to reduced income and other wider factors where mental health is concerned (McCarthy et al, 1985, Smith et al, 1992, Sturm & Gresenz, 2002).

In turn, the drivers for occupant health are very complex as illustrated in figure 12 section 3.1.2. Part of this influence is that of the wider neighbourhood or area of residence. Reliance in much of this work has been placed on area level data, such as levels of deprivation, and little work has considered features of the social and physical environment (Macintyre et al, 1993, Kawachi & Berkham, 2003, WSA, 2004). Physical variables that have been considered in the past include: air pollution, water hardness, nitrates in the drinking water, distance from the coast, latitude, altitude, mean temperature, rainfall and toxins or other substances from industrial processes. Deprivation variables, derived from Census data, are either used in isolation or are often combined to produce indexes, for example Townsend et al (1988). This index comprises Census data for percentages of households with no car, overcrowding, non-owner occupied homes and unemployment. A relationship seems to exist between the deprivation of an area and the health of its occupants (McCarthy, 1985, Macintyre et al, 1993). Indeed a study carried out by Dorling et al (2000), seems to suggest a historical trend to these findings, where deprivation mapped by area in London in 1896 predicted the health of occupants in 1991, similarly to that of a modern index. Indeed in causes of death, stroke and stomach cancer that have previously been found to be sensitive to deprivation in earlier life, the historical index was more strongly related to the actual findings. In the study social class was indicated as a proxy for the poverty of an area in both the historical and present day data. Further to this, it has been shown that urbanicity may also be a factor for psychiatric disorder (Sundquist et al, 2004, Peen & Dekker, 2004).

Urbanicity has a wide-spread impact on occupant health, including: elevated intentional injury, poor birth outcomes, cardiovascular disease, HIV, gonorrhoea, tuberculosis, depression, physical inactivity and all cause mortality, in neighbourhoods of lower socio-economic status (Krieger & Higgins, 2002, Nordstrom, 2004, Ross, 2004). It may be that physical features of the neighbourhoods influence this, such as poor air quality due to close proximity to polluting major roads or other sources of pollutants. Additionally, higher levels of noise (see previous consideration under comfort) and improper waste disposal (Joseph, 2004) are widely considered as potential impacts on health. Improvements to neighbourhoods that can increase health include provision of green space and recreational sites and the location of facilities including schools, shops and work within walking distance of homes.

Data appertaining to the household and population health of the occupants of NPT and Wales is available from the Welsh Health Survey (WHS) and the Census of 2001, together with a small amount of historical trend data from the now dissolved Morgannwg Local Health Authority. The Census data relating to heath is limited to the prevalence of long-term illness together with a simple general health question.

The results from the 2001 Census, the first Census to incorporate questions relating to health, suggest that the general health of the population of NPT does not compare favourably with that of Wales as a nation.

Area	**General Health**		
	Good	**Fairly Good**	**Not Good**
NPT	59.69	23.95	16.36
Wales	**65.06**	**22.49**	**12.45**

Table 22: Self-reported General Health for Wales and NPT *(Source: 2001 Census data, ONS, 2001a)*

While the distribution of those suffering form long term illness, as assessed by the 2001 census and the WHS, is similarly higher for NPT than for Wales as a whole.

Data Source	Area	% of Total Population with Long Term Illness	% of Population of Working Age with Long Term Illness
2001 Census	NPT	29.37	24.11
	Wales	23.27	18.38
WHS	Morgannwg	36.0	-
	Wales	34.1	-

Table 23: Self-reported general health for Wales and NPT *(Source 2001 Census data ONS, 2001a)*

The Census of 2001 indicates a higher than average preponderance of people suffering from long-term illnesses in NPT, 6% higher than that found on average in Wales. The response to the same question posed to the WHS sample produced an increased estimate of long term illness in the population (25% higher). The Government Statistical Service (GSS) reported a similar increase (approximately 20%) between this figure and that found in the 1991 Census. GSS suggested that this might indicate non-response bias in the WHS survey, where those with worse health are more likely to respond to a health survey than those in good health. This is perhaps reinforced by the same finding between the WHS figure and the 2001 Census, although the increase between 1991 and 2001 Census may indicate a rise in long-term illness in Wales. A further consideration, however, must be given to the second suggested reason for the difference, whereby the respondents may be more likely to report the presence of a long term illness during a health questionnaire than during a more general survey, even when the question is identical.

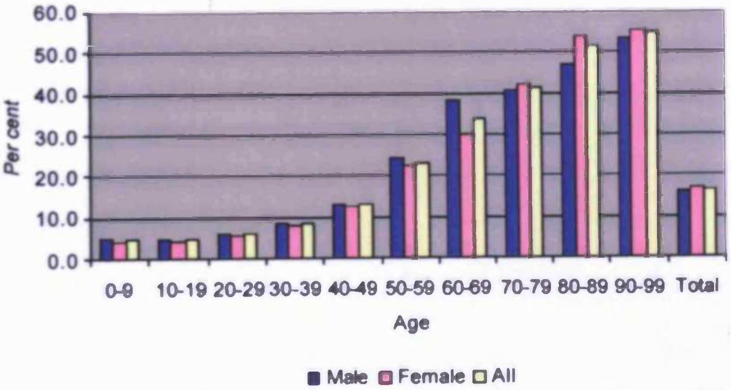


Figure 53: Long Term Illness (Percentage) by Age and Sex *(Derived from the Welsh Household Survey, 1998)*

The data drawn from the WHIS suggests that the instances of long term illness are found to increase with age, while men are more likely to suffer from long-term illness than women until the age of 70 when the prevalence in women overtakes that in men. This is likely however, to relate more to women living beyond this age than men. The WHS also reports that the presence of long-term illnesses were also found to increase with age for both sexes, where 25% of those under 65 are likely to suffer, compared to 61% of those aged 65 - 74, and 73% of those aged over 75. Finally, the WHIS also reports the presence of long term illness in relation to housing tenure and age of occupant. Here it can be seen that those with long term illnesses are most likely to be social housing tenants and least likely to be owner occupiers.

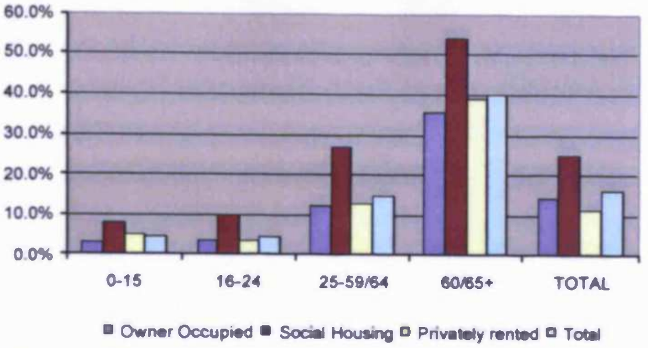


Figure 54: Long terms Illness (Occupant %) by Occupant Age Group and Housing Tenure
(Based on data from the Welsh Household Information Survey, 1998)

The health of the NPT borough and Wales as reported within the WHS, WHIS, and 2001 Census has been considered here, in order to understand the health status of the population at national and borough levels. Further data relating to the NPT population and health status is provided in Appendix C. This identifies that long term illnesses, respiratory illness, and heart disease were found to be more widespread in NPT than in Wales nationally. The physical health aspects of the general health status of the population of NPT was also below the average found throughout Wales, although mental health status was close to average.

3.2.1.3.5 *Inadequate Heat: Receptor Factors*

The Occupant Receptor / Vulnerability variables that influence the occupant health and comfort risk system for inadequate heat are therefore:

- Age
- Socio-Economic
    - Status
    - Household composition
      including occupant sex and occupant density / overcrowding
- Existing health:
    - Long Standing Illness

3.2.1.3.6 *Receptor-Pathway Interaction: Behaviour*

A number of subjective characteristics relating to the behaviour of the occupant including clothing level, activity level and an individual's acclimatization to a given environment, influence the thermal comfort level required for a given situation. Fanger (Markus, 1980) illustrated this theoretical relationship with the following thermal comfort equation:

$$H_{met} - E_{diff} - E_{rsw} - E_{res} - C_{res} = K = R + C$$

Where:

- H_{met} Internal heat production of the body – metabolic heat
- E_{diff} Heat loss by water diffusion through the skin
- E_{rsw} Heat loss by evaporation of regulatory sweat secretion from the skin
- E_{res} Latent heat loss by respiration
- C_{res} Dry heat loss by respiration
- K Heat transfer from the skin to the outer surface of the clothed body
- R Heat loss by radiation from the outer surface of the clothed body to the environment
- C Heat loss by convection from the outer surface of the clothed body to the environment

Where clothing levels are a matter of personal preference for a housing occupant and metabolic heat production is directly associated with an occupants age, weight and activity level.

Clothing levels can be seen to be extremely important in terms of thermal comfort prediction, where an individual's clothing level is directly related to its provision of heat insulation or thermal resistance. Therefore, it was important to develop a definition for levels of clothing and this was achieved by Gagge et al and is known as the *'clo'* unit (Charles, 2003). This is defined as *'the dimensionless expression for the thermal insulation of clothing'*, where:

$$1 \text{ clo} = 0.155 \text{m}^2 \, {}^\circ\text{C W}^{-1} \qquad \text{OR}$$

'the insulation provided by an average lounge suit with standard underwear'

Tables of standard clo for ranges of clothing levels exist (see table below for examples). It should be noted, however, that these values often relate to an individual standing in free space. If they are sitting or lying on a chair, sofa or bed, the ratings should be altered accordingly (the reader is referred to CIBSE Guide A, 2006, p1-6 for further details).

Clothing level	*Clo*
Nude	0
Shorts	0.1
Men's light summer ensemble	0.5
Typical men's business suit	1
Women's indoor ensemble	0.7 – 0.9
Men's heavy suit	1.5
Men's heavy suit + woollen overcoat	2.0 – 2.5

Table 24: Typical Clo Values by Clothing Type

While activity levels can be defined as the metabolic energy released by an individual is equal to metabolic heat in addition to work, measured in watts per square metre. Although metabolic heat is also related to bodily size and the mechanical efficiency of the body when performing certain tasks, for the purpose of comfort prediction the met unit is utilised and this more complex relationship is ignored. A further assumption of 1m^2 as the area of the human body is also taken in these measurements.

Activity Level	W/m^2	Met
Reclining	46	0.8
Seated relaxed	58	1.0
Standing relaxed	70	1.2
Sedentary activity (office, dwelling, school, laboratory)	70	1.2
Graphic profession - book binder	85	1.5
Standing, light activity (shopping, laboratory, light industry)	93	1.6
Domestic work - shaving, washing and dressing	100	1.7
Standing, medium activity (domestic work)	116	2.0
Building industry - brick laying (Block of 15.3 kg)	125	2.2
Washing dishes standing	145	2.5
Domestic work – raking leaves on the lawn	170	2.9
Domestic work - washing by hand and ironing	170	2.9

***Table 25: Example activity and corresponding metabolic energy ratings** (CIBSE Guide A, 2006, p1-6)*
NB 1 met = 70 W/m^2 = An average person at rest (sitting)

Occupant interaction and behaviour in relation to orientation can have a significant impact on the performance of a building in relation to maximising solar gain in a space. For example, may block solar access to spaces, thus negatively affecting the winter thermal en

However, it is in relation to the ability to control the internal environment that occ can have the most significant influence on vulnerability to health and comfo inadequate heat. This forms a very significant aspect of the adaptive comfort m degree of control in an environment influences an occupant's perception of c occupants feel that they have control over their working or living environment, th comfort will be increased. This is also an important aspect of Sick Building Syn (Jones et al 1995, Brasche, 2001, Engvall et al, 2005, Chappells & Shove, 2005 in an office environment, the ability to control light, ventilation and temperature v environment, has been found to increase occupant perception of comfort (Jon The subjective perception that an environment within a building, (including the building), is pleasant is likely to increase the perception of occupant comfort including that of ergonomics and spatial syntax, has been associated with intern built environment and has been established through detailed research related Syndrome (Jones et al 1995, Muhic & Butala 2004).

A further relationship between control and comfort may be hypothesised w provided, but is not understood due to complexity, misunderstanding or where th lack of explanation or education. It could be considered likely that where c received adequate education in physics, for example, covering many of the conc heat storage as well as the methods for heat transfer through convection, radiation, a greater understanding of appropriate heating control may be prese may be also be argued that control of a home's heating system and achiever comfort is such a fundamental requirement for occupants that methods to achiev intuitive, not calling for an educated understanding of the theory by which environment is delivered. Ms-control of lighting, heating or cooling is conside similar discomfort within the internal environment (Bordass & Leaman, 1997 Steemers, 2005).

Heating is mainly provided by central heating and / or fires in the main living areas. Control of these is vital to maintain thermal comfort within the home. However, it must be noted that Liao, Swainson and Dexter (2005) have reported that both boiler and heat emitter controls in the UK are generally poor. Following questionnaire surveys and computer simulation they found that impacts of these poorly controlled heating systems can result in under-heating and over-heating, both of which could have significant impact on occupant thermal comfort. It was suggested in 1996 that in the region of 90% of domestic heating systems were operating inefficiently due to inadequate or inappropriate control systems (BRECSU, 1996). The problem is further exacerbated by the fact that as thermostats and TRV's age they loose efficiency (Liao, Swainson and Dexter, 2005).

Figure 49 in section 3.2.1.2.1.2 illustrated the distribution of predicted required energy use and indicated that the age of home will influence the financial cost of achieving thermal comfort for occupants. This can lead to the concept of "fuel poverty", defined as where 10% of income would need to be expended to achieve 21°C in the living room and 18°C in other rooms, (Wilkinson et al, 2000, Boardman, 1991). A survey of 1000 homes was conducted in the February and March of 1978 to consider mean temperatures in living rooms, kitchens and bedrooms (Hunt & Gidman, 1982). Results were found to be related to the presence of central heating, where an increase of 3°C was found when compared to non-centrally heated homes, as well as correlations with dwelling age and heating system type. The key temperature findings are summarised in the table below:

Space	**Mean Measured Temperature**
Living room	18.3°C
Kitchen	16.7°C
Warmest bedroom	15.2°C
Average dwelling temperature	15.8°C

Table 26: Mean Measured Temperature for Domestic Rooms *(Source: Hunt & Gidman, 1982)*

Previous English House Condition Surveys have also included a sample set of measurements of the internal temperatures in UK housing (Boardman, 2005). This information has not been gathered for Wales, but it can be considered that the internal environment in housing is likely to be similar. These results do illustrate a reduction in the number of homes where internal conditions are below the 12°C standard, defined by Collins et al (1985) as the point at which cardiovascular strain is likely to occur.

Temperature °C	**Warmest Room**		**Coldest Room**	
	1986	**1996**	**1986**	**1996**
>24.0	1.6%	2.3%	1.3%	0.7%
21.0 – 23.9	12.1%	21.0%	8.6%	10.2%
18.0 – 20.9	31.5%	42.8%	24.6%	31.0%
16.0 – 17.9	27.7%	21.4%	22.1%	25.6%
12.0 - 15.9	22.3%	10.7%	28.2%	24.9%
9.0 – 11.9	4.2%	1.2%	9.4%	4.2%
<9.0	0.7%	0.6%	5.9%	3.4%
Total Households (000s)	**18,063**	**19,643**	**18,063**	**19,643**

Table 27: Distribution of Households by temperature bands when external temperature is below 5°C for 1986 & 1996 *(Source: EHCS)*

The interaction of the occupant with ventilation through the use of open windows to ventilate a property may also negatively influence the thermal environment within a property. The author is not aware of any research in this field, however, from anecdotal evidence the use of open windows to regulate the thermal environment as well as humidity within the home may negatively influence the thermal performance through the resulting draughts. For example where district heating was provided without a form of metering, open windows may be used to regulate the temperature rather than turning off radiators, as there would be no financial penalty for so doing. Finally, occupant behaviour may itself have a feedback on occupant health, this may include the use of ventilation when cooking, smoking and cleaning.

3.2.1.4 Current Risk

The current risk due to the occupant health and comfort risk factor of inadequate heat is illustrated in the following problem map.

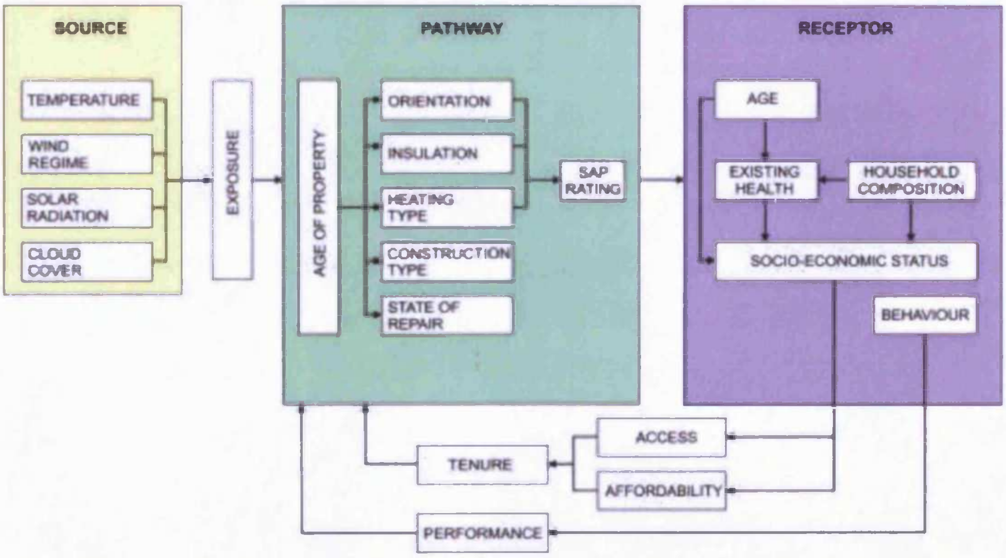


Figure 55: Problem Map for Occupant Health & Comfort Risk Factor: Thermal – Inadequate Heat

It should be noted that the nature of the relationships between the source, pathway and receptor illustrated are in some cases non-linear in fashion and more complex than this problem map suggests. The interaction between the receptor and the pathway is non linear, where the occupant's socio-economic status is likely to affect affordability of housing and therefore tenure, which may in turn influence availability of good quality housing. Further to this the influence of occupant behaviour on the performance of the pathway is also significant. While the relationship between the source and the pathway is mediated by the exposure pattern of the surrounding microclimate, where the influence of site conditions can be considerable. Local Influences on climate can be as a result of altitude and local geographical features including hills and valleys, forests and plains, lakes and rivers and urban and rural locations. For example, the altitude of a location has a significant influence on wind speeds, temperature and precipitation.

Wind speed is seen to increase with height, while temperatures are seen to decrease with altitude, with figures within the 'standard atmosphere' of a loss of 6.5°C for every 1000m of altitude. While the temperature at the bottom of valleys is lower than the surrounding areas, both at night-time and during winter months. In contrast, during the daytime and in summer months, valleys tend to experience higher temperatures than the hills. In winter months high temperatures can also occur in the lee of high ground. Mountain valley wind systems in turn influence these temperature cycles. This is due to the flow of heavy cold air down the sides of the valley at night, known as katabatic wind, which also increases the likelihood of frost and fog formation in valley bottoms, with anabatic winds flowing up the valley slopes during the day time. Despite this diurnal wind cycle within valleys, where wind speeds of up to 35ms^{-1} can be found, they are often more sheltered locations than hills and mountain tops that are subject to higher wind speeds due to their altitude.

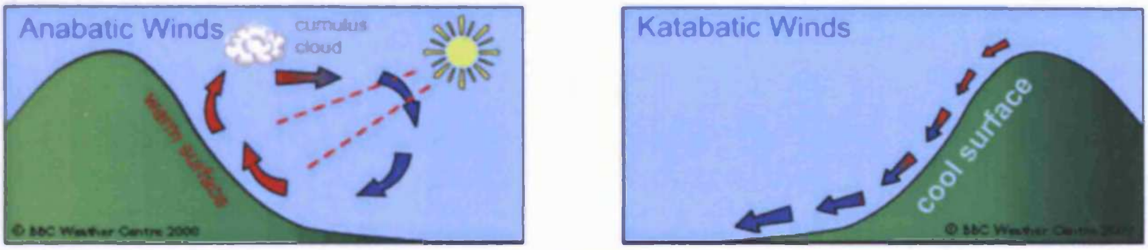


Figure 56: Anabatic and Katabatic Winds *(BBC Weather Centre Website, Accessed, March 2003)*

Different topographies have an affect on the micro-climate of an area due to their differing heat storage capacities. The heat capacities of differing environments range from that of bodies of water that have the highest heat capacity through to plains that have the lowest. Those areas with higher heat capacity retain their heat during the winter months and are therefore warmer at this time than plains. In the summer the situation is reversed, with the time lag in 'recharging' the capacity of forests and water delaying the impact of higher summer temperatures in comparison to the plains. On a national scale the effect of the significantly heated mass of water from the tropics brought to the UK via the Gulf Stream helps to 'flatten the peaks' in climate in the UK, leading to milder winters and cooler summers. Topographical features also have considerable impact on the humidity of a locality, with higher humidities found within forests and close to expanses of water than those found over plains.

A simple example of human control of climate using these principles can be seen in the introduction of shelterbelts (plantations of trees) with the purpose of sheltering the leeside from the wind. These windbreaks can work to reduce the cooling effect of the wind by reducing wind speeds near to the ground by up to 80% as well as increasing the relative humidity of the body of air by 2-4% within the sheltered zone. Actual figures are dependent on the effectiveness of the design and growth of the windbreak.

Figure 57: Shelterbelt *(www.forestry.iastate.edu)*

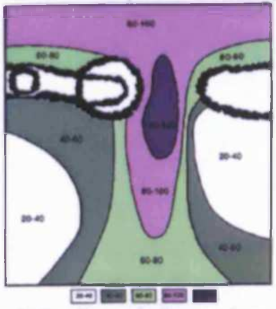


Figure 58: Windbreak *(www.ianrpubs.unl.edu)*

The difference between climate as experienced in urban and rural locations is best characterised through the introduction of the effect known as the 'urban heat island'. This effect works to increase both maximum and minimum temperatures experienced in an urban location when compared to those in rural areas. The effect is caused by the heat storage capacity of the built environment together with the industrial and commercial processes at work in urban locations. In large cities such as London the effect can be as much as 2°C to 5°C in excess of regional figures. It should also be noted here that rainfall as a result of convection and the formation of smog and ozone air pollution can also occur more frequently in urban areas for similar reasons. Wind regimes in built up areas are also difficult to predict with localised areas of gusts and high winds as well as areas sheltered from the prevailing wind (Santamouris,1999).

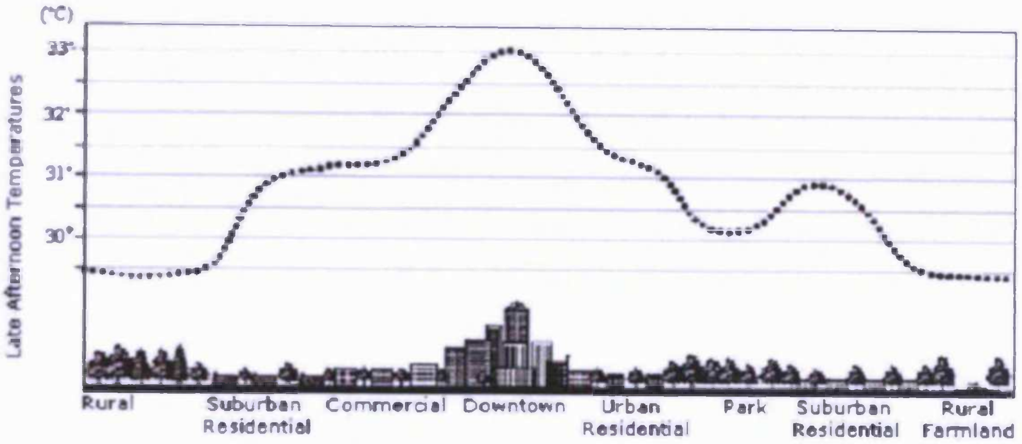


***Figure 59: Urban Heat Island Effect** (Source: www.brunel.ac.uk)*

3.2.1.5 Future Risk

Having identified the current risk due to inadequate heat for housing occupants in south Wales, it is now necessary to identify the potential for change over the coming decades. In relation to changes in the source, this will be undertaken through reference to section 3.2, where a summary of climate change in NPT under the current UKCIP 02 scenarios was provided. In relation to the pathway and receptor, likely change to these two over the same period will be considered, relating where possible to current government policy.

Likely Change in Source or Hazard

Climatic Variable		Climate Change Scenario	Scale of Change	Impact on Internal Environment
Temperature:	Daily Average	Increase	+1.5 – 3°C	Positive
	Daily Minimum	Increase	Unknown	Positive
Solar Radiation		N/A	+3%	Negative
Cloud Cover		Increase		
Daily Average Wind		Increase	+5-7%	Negative

The increase in temperature, both monthly mean and daily minimum, will result in an increase of temperature in homes and therefore a reduction in additional heat required to be delivered to homes through heating systems. The potential for energy reduction has been suggested to amount to as much as 45% by the 2080's, where an increase of 1°C represents approximately a 10% decrease in heating energy requirements (Johns & Fedeski, 1994, Milbank, 1989). An increase in cloud cover will result in less available solar radiation during the winter months, resulting in a negative impact on passive gain. Finally, an increase in the daily mean wind speed may result in an increase in the occurrence of draughts.

Although this relationship is complex it is currently considered likely that the increase in temperature will result in an over-riding positive change in risk and therefore an enhanced thermal environment in buildings due to current climate change scenarios.

Anticipated total Influence of Source on Occupant Health and Comfort: Positive

Likely Change in Exposure or Pathway

Current Government policy relating to the Home Energy Conservation Act (1995) has encouraged increases in energy efficiency in the domestic sector in the UK. This has been supported by the practice of providing grants and subsidies through schemes such as the Home Energy Efficiency scheme (Warm Front in England), Energy suppliers obligations, low carbon buildings programme renewable energy grants and through the work of the Energy Savings Trust. This is a significant driver to further positive changes in the risk system relating to occupant health and comfort due to inadequate heat.

Anticipated total Influence of Pathway on Occupant Health and Comfort: Positive

Likely Change in Vulnerability or Receptor

Changes to the receptor may occur as a result of the current drive for advertising the importance of energy efficiency and energy saving measures. For example, the www.energysavingwales.org.uk initiative of the Welsh Assembly Government. This is likely to increase the installation of energy saving measures such as insulation. This is a feedback to produce a further positive risk impact on the performance of the pathway in delivering a comfortable and healthy thermal internal environment.

However, a negative driver for thermal comfort may be derived from the recent increasing trajectory of fuel costs which have been rising after a period of relative affordability. If this trend were to continue, despite the increasingly favourable climatic environment and the changes to the housing stock, or risk system pathway, the numbers of housing occupants in fuel poverty may remain stable or eventually rise as affordability of thermal comfort reduces.

It is however, possible that occupants may continue to adapt to a changing thermal environment. For example, where the scope exists, it may be possible for occupants to adapt their behaviour to a cooler thermal environment, thereby negating the potential impact of rising fuel costs Smith (1997, 253 - 54) suggests that adaptation can occur before, during, or after any external stimulus or threat and therefore advertising, for example calling for people to turn their thermostat down by 1 °C, may drive a widespread adaptation to cooler temperatures prior to the need due to cost, where this adaptive measure would be considered anticipatory or preventive adaptation. As there are both negative and positive impacts on the future occupant health and comfort risk system in relation to the receptor it is considered that the total influence on the internal environment is likely to be neutral.

Anticipated total Influence of Receptor on Occupant Health and Comfort: Neutral

---

Likely Change in Occupant Risk

In combination it is expected that the occupant health and comfort risk due to inadequate heat will be reduced as a result of climate change.

Anticipated total Future Change in Risk on Occupant Health and Comfort: Positive

---

3.2.2 *Risk Factor: Inadequate Ventilation*

Ventilation is required in buildings to deliver fresh air for occupants for the purposes of respiration, providing oxygen and diluting CO_2, as well as for the removal of contaminants and to deliver a feeling of freshness. The risks to occupant comfort and health associated with this inadequate ventilation can be identified from literature as:

Comfort

Discomfort due to inadequate ventilation is perceived by an occupant when the internal environment is considered to either be smelly, too stuffy or too draughty. The relationship between ventilation and the thermal environment, is considered in a later section, where air movement in the range of 0.1 – 0.3 m/s is reported as good practice during the heating season (Race, 2006, p12) and where levels below this are perceived as stuffy (and above as draughty). Further to this, discomfort due to inadequate indoor air quality is also perceived by occupants through both smell and sensitivity to irritants including pollen, tobacco smoke or other pollutant sources. Sensitivity and indoor air pollutants will be dealt with below under Health, however, it can be noted here that to maintain an odour free internal environment a level of ventilation in the order of 5 litres per second is required and to maintain a perception of fresh air for occupants a rate of 10 litres per second per person would be necessary (Race, 2006, p14). In contrast, the amount of fresh air required to maintain the ability to respire is in the order to 0.2 litres per second per person, while to dilute CO_2 from the internal environment a delivery rate of 1.0 litre per second is required, while for a space where smoking is permitted ventilation rates in the order of 45 l/s may be necessary (Race, 2006, p14)

• Headache [1,2] • Nausea [1,2] • Dizziness [1,2] • Breathlessness [1,2] • Fatigue [1,2] • Visual disturbances [1,2] • Mental confusion [1,2] • Angina [1,2]	• Exacerbation of cardiov disease [2] • Exacerbation of asthma • Irritation of bronchi [2] • Impaired pulmonary fun • Exacerbation of cardiop disease [2] • Exacerbation of allergic

Source:

[1] Hwang et al, 1999
[2] Kovats, Ebi, Menne, 2003

Table 28: Potential Health Impacts Associated with Inade

Health impacts due to inadequate ventilation and indoor air quality are the resul pollution sources, inadequately expelled by ventilation, together with externa sources. Internal air pollution sources include: carbon monoxide, particulate m oxides, sulphur oxides, pollen, volatile organic compounds (VOCs) and formal external air pollution sources include ozone, particulate matter, nitrogen oxides, and pollen. It should be noted here that, unlike temperature and humidity, no sing acceptable air quality has yet been defined. Therefore standards for concentratio are available for some indoor air contaminants. These risks are influenced exposure and vulnerability regime for individual occupants. The factors asso occupant health and comfort risks associated with inadequate ventilation and in risks will now be explored and a problem map produced for this risk factor.

3.2.2.1 Source

The hazards in relation to the occupant health and comfort risk system ventilation, are defined as those climatic variables that influence the risks describ

3.2.2.1.1 Comfort

As defined above, an appropriate level of ventilation can be considered to be than 10 l/s/person, i.e. that which is required to deliver an air to the interna perceived as fresh by occupants. However, rates of ventilation within a property by differentials between internal and external temperature as well as the wind re can be considered the most significant source within the occupant health and comfort risk system being considered here.

3.2.2.1.2 Health

Further to the two climatic source variables of temperature and wind already identified above, external pollution levels area also a key factor in the adequacy of ventilation and indoor air quality. Atmospheric pollution has been defined as a meteorological natural hazard in section 3.2. while the link between pollutants and health can be illustrated through reference to work undertaken by Kovats, Ebi, Menne (2003) who identified external air pollutants, their likely external sources and resulting health impacts. The following table is reproduced from this work:

Pollutant	Sources	Health Effects
Carbon Monoxide	Biomass and fossil fuel combustion, cigarette smoke, vehicular emissions	Headache, nausea, dizziness, breathlessness, fatigue, low birth weight, visual disturbances, mental confusion, angina, coma, death
Ozone	Vehicular emissions, hydrocarbon release, fossil fuel combustion (primary pollutant)	Eye irritation, respiratory tract irritation, reduced exercise capacity, exacerbation of respiratory disease
Particulate Matter	Biomass and fossil fuel combustion, cigarette smoke, vehicular emissions	Eye irritation, respiratory tract infections, allergies, exacerbation of respiratory and cardiovascular disease, cancer.
Nitrogen Oxides	Biomass and fossil fuel combustion, construction materials, industry, cigarette smoke, vehicular emissions	Eye irritation, respiratory tract infections (children are particularly vulnerable), exacerbation of asthma, irritation of bronchi
Sulphur Oxides	Biomass and fossil fuel combustion, industrial emissions	Respiratory tract irritation, impaired pulmonary function, exacerbation of cardiopulmonary disease
Pollen	Flowering plants	Exacerbation of allergic rhinitis, asthma and other atopic diseases

Table 29: Air Pollutants, Sources and Health Effects *(Kovats, Ebi, Menne, 2003, p59)*

The Committee on The Medical Aspects Of Air Pollutants (COMEAP) (1998), reports deaths brought forward by PM_{10}, SO_2 and ozone pollution as being in the order of 20,000 per year in urban areas of the UK, with hospital admissions due to respiratory disorder in the same order. It should be noted that these figures are likely to have included synergistic or additive impacts from air pollutants, and as a result the actual figure may be lower. Low level ozone has been associated with reduced lung function in fit individuals as well as those with chronic respiratory conditions such as asthma. Further to this, increased levels of low level ozone have been seen to have a positive link with mortality rates in London (DoH, 2001).

A further example of the inter-relationship between external air quality, internal air quality and health is found in relation to both the onset and aggravation of asthma, which has been found to have a strong relationship with external air pollution including natural sources such as pollens (COMEAP, 1995a, COMEAP, 1998, Peden, 2004, O'Connor et al, 2004). Asthma has a complex genesis and both the development and risk factors for triggering symptoms have been found in a wide variety of housing factors including internal and external air quality as well as internal damp and also genetic factors (Becklake, 1997, Peden et al, 2004).

Category	Determinants	Primary or Secondary
Host	**Genetic factors**	Primary
	Family history of allergies (in particular maternal history)	Primary
	Atopy	Primary
	Race and or ethnic origins	Primary
Environmental	**Certain occupational exposures e.g. sensitising chemicals**	Primary
	Community air pollution by allergen	Primary
	Sustained exposure to indoor allergens (**post-natal** and pre-natal)	Primary and secondary
	Viral infections	Secondary, possibly primary
	Environmental exposure to tobacco smoke (in childhood, pre- & post-natal)	Secondary, possibly primary
	Changing lifestyles	
	Westernised lifestyle, urban vs rural, migration, changing homes, community air pollution related to vehicle exhausts	Probably all secondary but some may be primary
	Certain diets and breastfeeding practices (absence or short duration) and absence of certain infections particularly in the first year of life	Probably secondary but may be primary
	Certain home characteristics (dampness, gas cooking, carpeting, electric home heating)	Probably all secondary but some may be primary
	Socio-economic disadvantage (poverty)	Probably secondary

NB – Established determinants are in bold type

Primary: **Will increase the incidence (new cases).** If the determinant is susceptible to intervention and if the intervention is successful, the incidence of asthma is reduced.

Secondary: **Triggers symptoms and/or exacerbates the disease and increases its severity.** Clinical management depends on interventions on these factors.

***Table 30: Determinants of Asthma** (Becklake, 1997)*

3.2.2.1.3 Inadequate Ventilation: Source Factors

The climatic hazard variables that influence occupant health and comfort risk system for inadequate ventilation are therefore:

- Temperature
- Wind
- Air Pollution

3.2.2.2 Pathway

The pathway factors in relation to the occupant health and comfort risk system for inadequate ventilation are defined as those aspects of the pathway that influence the risks described above. These can be divided into two factor groupings relating to the ventilation sources including natural and mechanical as well as air pollution sources including building materials, building services and location.

3.2.2.2.1 Housing: Ventilation

In addition, building form is likely to influence the promotion of ventilation through the concepts of:

Stack ventilation: where the buoyancy of hot air serves to drive ventilation in a property is more likely to occur in properties with more than one floor.

Figure 60: Diagram illustrating natural stack ventilation

Cross Ventilation: Where air is allowed to pass through a property from one side to another. When carefully designed in association with the prevailing wind this can be used to promote ventilation in a property. A maximum depth of 8m is suggested for achieving natural ventilation where a ceiling height of 2.7m is available. Lower ceiling heights equate to a narrower floor plan in order to achieve appropriate rates of ventilation.

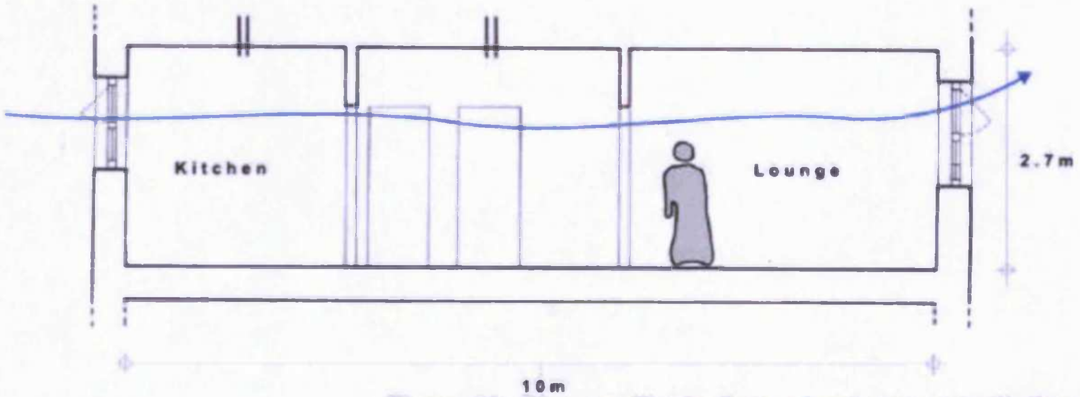


Figure 61: Diagram illustrating natural cross ventilation

Therefore bungalows and single storey flats and maisonettes, may be more at risk of low levels of natural ventilation. In addition, where properties cannot achieve cross ventilation, (for example where flats are only single sided) lower levels of natural ventilation are likely to be present.

The level of ventilation required in a space is related to the sources of pollutants in the space. The ventilation of a home can be divided into three main forms. Background ventilation is typically provided by gaps in construction, air bricks in walls and trickle vents in windows. This level of ventilation is present all year round and should be at a level that ensures adequate air changes to enable a healthy internal environment in the majority of rooms of the house, 1 to 2 air changes per hour (ACH). This should provide adequate levels of air changes to avert the build-up of carbon dioxide, other air pollutants and to eliminate low-level odour throughout the year. The second level of ventilation is typically provided by windows and provides an increased level of ventilation, usually up to 4 ACH, that enables the 'flushing' of the house, for example to increase comfort or swiftly expel odours. The third level of ventilation, typically provided in kitchens, bathrooms and WC's, is mechanical extraction and this is provided where increased levels of ventilation are likely to be required to expel excess odour and humidity, possibly up to 13 ACH (Evans, 1980, Jones et al, 1997).

Required ventilation rates for domestic environments are available, for example those given by the England and Wales building Regulations, as well as in the ASHRAE standard 62, 'Indoor Air Quality and Ventilation' (ASHRAE, 2003) and the European Standard Organisation CEN technical report CR1752, 'Ventilation for Buildings: Design Criteria for the Indoor Environment' (CEN, 1998). These standards do not rely on required quality for indoor air, rather they specify ventilation rates for a variety of occupation modes and spaces. These are specified either through prescription, for example a table of ventilation rates, or through analysis and calculation on the basis of types, rates and sources of indoor air pollutants, including occupant rates, together with acceptable concentrations of the pollutants, used to and then formulated through consideration of internal emission rate, external levels and concentration limit (Olesen, 2004). Further to this the current building regulations approved document part F requires the following in relation to domestic ventilation (ODPM, 2006):

Background Ventilation: Minimum areas of background ventilators for dwellings upwards from 25,000mm^2 for a one bedroom property of less than 50m^2 floor area

Flushing Ventilation: Provision for purge ventilation from all habitable rooms through the provision of windows and or doors capable of achieving 4 air changes per hour in each space.

Extraction Ventilation: Minimum extract ventilation rates for bathrooms, kitchens, utility rooms and sanitary accommodation, for example intermittent extract in kitchens is required of 30 l/s above the hob or 60 l/s elsewhere in the kitchen.

Adequate delivery of ventilation can therefore be considered to be significantly influenced by detailed design of the pathway within the risk system being studied. While design for mechanical ventilation is provided for within the regulations this is not considered here as it is currently a relatively unusual method of whole house ventilation.

A common measure of the ventilation rate achieved in a home is through undertaking a fan pressurisation test (CIBSE, 2000). This technique actually measures the Air Leakage Index or air permeability of the building, the volume flow per hour ($m^3 h^{-1}$) of air supplied to the space by the air-moving equipment, per square metre (m^2) of building envelope area for a specified internal to external pressure difference of 50Pa, for example, $10m^3h^{-1}m^{-2}$ at 50Pa (CIBSE, 2000). An air infiltration rate can be calculated from the Air Leakage Index through application of a simple rule of thumb, derived from a large number of measurements (CIBSE, 2000). The air infiltration rate measured in air changes per hour is approximately 1/20 of the 50Pa air leakage rate (Q_{50}/V). Where Q_{50} is the Air Leakage Index and V is the internal volume of the building.

	Air Leakage Index ($m^3 h^{-1} m^{-2}$) @ 50Pa		Air Permeability ($m^3 h^{-1} m^{-2}$) @ 50Pa	
	Good Practice	**Best Practice**	**Good Practice**	**Best Practice**
Dwellings	15.0	8.0	10.0	5.0
Dwelling (with balanced whole house mechanical ventilation)	8.0	4.0	5.0	3.0

Table 31: Air Leakage Standards *(Reproduced from CIBSE, 2000)*

3.2.2.2.2 Neighbourhood: Exposure to Wind

Wind can be a driving factor for ventilation in the built environment, as well as a significant cause of draughts. IT is therefore logical that exposure to wind will have a direct relationship with the ventilation in a home.

3.2.2.2.3 Air Pollution

The internal air quality of a home is influenced by the sources of possible contaminants present in the home as well as the quality of the ambient external air, together with the rate of ventilation (Lowry, 1989a, COMEAP, 1995a, 1995b & 1998, Bernstein et al, 2004, Sundell, 2004, Vandenberg, 2005). From this literature, the following indicate potential sources of internal air pollutants:

Source	**Examples of Pollutants**
Metabolic Products	Water Vapour, Carbon Dioxide, Body Odour
Combustion Products	Carbon Monoxide, Nitrogen Dioxide, Tobacco
Volatile Organic Compounds	Formaldehyde, Wood Preservatives
Non-Viable Particulates	Respirable Suspended Particles, Fibres e.g. Asbestos
Viable Particulates	Small insects, Protozoa, Fungi, Bacteria, Viruses
Ground	Radon

Metabolic products are considered as a feedback from the receptors into the pathway and as such this is considered in section 3.2.2.3.3. Viable particulates are considered in section 3.2.3. while, combustion products, volatile organic compounds, non-viable particulates and ground are considered below.

3.2.2.2.3.1 Housing: Internal Air Pollutants

Sources of indoor air pollutants include many commonly used building materials (Mant & Muir Gray, 1986). There is a growing research field considering the health impacts of off-gassing from building materials (Ranson, 1991, Hwang et al, 1999, IEH, 2000, Coward et al, 2001, IEH, 2001, Sherriff et al, 2002 & Crump 2004). For example, Coward et al (2001) carried out monitoring and a questionnaire survey to assess pollution, in terms of nitrogen dioxide, carbon monoxide, formaldehyde and volatile organic compounds (VOC's) in homes in the UK. Where the internal air pollution is found to exceed WHO guidelines, these pollutants are likely to have an impact on the health of housing occupants (Krieger & Higgins, 2002). Ranson (1991) identified the main sources of formaldehyde in housing as insulation, particle board, such as that used in much modern furniture, carpeting and the associated health impacts of increasing concentrations of the gas as:

Effect	Concentration (ppm)
Neurophysiological (e g tiredness, nausea and infant vomiting)	0.05 – 1.5
Odour Threshold	0.05 – 1.0
Eye Irritation, Menstrual Irregularities	0.01 – 2.0
Upper Airway Irritation	0.01 – 25.0
Lower airway and pulmonary	5 - 30
Pulmonary Oedema, pneumonia	50 - 100
Death	100+

***Table 32: Adverse Health Effects from Formaldehyde** (Reproduced from Ranson, 1991)*

During their work Coward et al found formaldehyde concentrations which exceeded the WHO guidelines in six homes, five of which were constructed post-1995, with the two highest findings in 1998 built homes. Although there are currently no current WHO guidelines for VOC's, by applying those developed elsewhere, Coward et al found these guidelines to be exceeded in 5 homes. These were again the most modern homes, with the most extreme values found in 1998 built homes. Crump (2004), suggests that consideration of formaldehyde and VOC pollutants, especially where guidelines for tighter level of ventilation control are being suggested in new homes, must be a consideration for future iterations of the buildings regulations.

Sources of indoor air pollutants also include processes being undertaken in the building including cooking and combustion as well as sources of heat and gas cookers (Mant & Muir Gray, 1986). Exposure to smoke and nitrogen dioxide, through the poor ventilation of combustion devices, has significant health impacts on occupants, especially in terms of asthma symptoms. This includes the use of gas in cooking and heating as well as the use of open fires and the combustion of other fuels (including biomass) where adequate ventilation and appropriately designed and installed flues are not present. Coward et al (2001), have found that 25% of homes they studied exceeded the WHO annual guideline for NO_2 in the kitchen. The presence of extractor fans in the kitchen did not significantly alter these findings for the kitchen but did lower findings in the bedrooms of the homes. Furthermore, within the homes studied, the NO_2 guidelines were only exceeded in homes with gas cooking. The type of heating and cooking system has a definitive link with occupant health (Hwang et al, 1999), where the use of gas fuel in a home is associated with carbon monoxide poisoning.

3.2.2.2.3.2 Neighbourhood: Exposure to air pollution

Sources of indoor air pollutants also include the soil beneath the building (Mant & Muir Gray, 1986). Air quality as a result of construction of a home on an area exposed to radon can cause significant health risks, with a potential link to lung cancers, as has been shown in the case of uranium miners (Hwang et al, 1999). The air pollution sources associated with location have been considered earlier as an aspect of source or hazard.

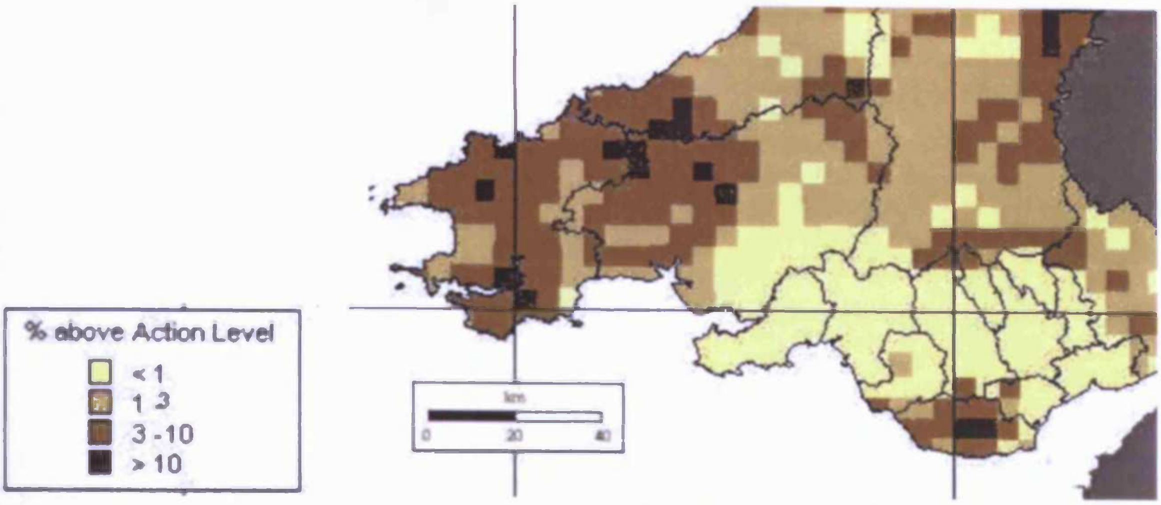


Figure 62: Radon Exposure Map for South Wales (Lomas & et al 1998 - www.hpa.org.uk)

3.2.2.2.4 Inadequate Ventilation: Pathway Factors

The Housing Pathway / Exposure variables that influence the occupant health and comfort risk system for inadequate ventilation are therefore:

- **Housing**
  - Ventilation
    - Background e.g. trickle vents / air bricks
    - Flushing: e.g. open-able windows and doors
    - Extraction e.g. extract fans / cooker hoods
  - Internal Air Pollutants
- **Neighbourhood**
  - Exposure to Wind
  - Exposure to Air Pollution

3.2.2.3 Receptor

The receptor factors in relation to the occupant health and comfort risk system for inadequate ventilation are defined as those aspects of the receptor that influence their vulnerability to the risks described above.

3.2.2.3.1 Socio Economic: Status

It is hypothesised that the socio-economic status of the occupants may influence their ability to maintain the building and thus influence the performance of the building's ventilation and or services. For example, lack of maintenance or replacement of extractor fans or kitchen extract hoods may lead to increased build up of internal air pollutants. Please see section 3.2.3 for links to internal damp and mould. Further to this affordability issues may also lead to inadequate servicing of gas appliances which may again place the occupants at increased vulnerability due to internal build up of NO_2 or other internal pollutants.

3.2.2.3.2 *Existing Health: Presence of Long Standing Illness*

The presence of existing illness, especially those relating to the respiratory tract such as asthma, is likely to influence the vulnerability of housing occupants to inadequate ventilation. The reader is also referred to section 3.2.1.3.2. where the complex inter-relationship between existing health and access to housing as well as vulnerability to risks being considered was explored in depth.

3.2.2.3.3 *Existing Health: Source of Internal Air Pollution*

The presence of occupants that smoke in their home are the key source of air pollution from occupants. Occupants can also cause air pollution as a cause of odours, such as those due to sweat and flatulence, although, unless at a very high level these are unlikely to have health and comfort implications.

3.2.2.3.4 *Inadequate Ventilation: Receptor Factors*

The Occupant Receptor / Vulnerability variables that influence the occupant health and comfort risk system for inadequate ventilation are therefore:

- Socio-economic:
    - Status
- Existing health
    - Presence of Long Standing Illness
    - Source of indoor air pollutants

3.2.2.3.5 *Receptor-Pathway Interaction: Behaviour*

Many sources of indoor air pollutants are the result of decisions by the occupants themselves. These include the selection of furnishing and fittings which often include particle board (as used in much modern furniture) which is a source of formaldehyde as well as, processes being undertaken in the building, including: cooking and cleaning, combustion including smoking as well as the human and animal occupants themselves (Mant & Muir Gray, 1986, Ranson, 1991). Of all environmental health factors the relationship between smoking (and passive smoking) and health has probably received the most attention in terms of research and media coverage. The health impacts of tobacco smoke are now widely understood, including asthma, pulmonary function, lung cancer, bronchitis, pneumonia, and low birth weight among new born babies, together with less well known impacts such as hydrosyproline / creatinine ratios and middle ear infections in children. The causal links for this air quality factor are considered strong (Hwang et al, 1999, Garne et al, 2005).

Although research has not been carried out to date in the domestic setting it may be surmised that control problems may occur in terms ventilation controls in the domestic environment. For example, the use of ventilation sources such as windows, wall vents and trickle vents, may not be as the designers intended, while the presence of an extract hood in the kitchen, to minimise internal air pollution, does not ensure the use of the ventilation system by the occupant. While the density of occupation together with inadequate ventilation can also impact on increased interior moisture (Lowry, 1989b, Marsh et al, 1999, Krieger & Higgins, 2002), an issue that will be considered in section 3.2.3.

3.2.2.4 Current Risk

The current risk to occupant health and comfort as a result of inadequate ventilation can be described in the following problem map. As was the case with risk due to inadequate heat, the relationship between the source and pathway is again influenced by the microclimate around the home; while the interaction between the receptor and the pathway is again non linear, with the occupant's socio-economic status potentially affecting affordability of housing and therefore tenure, and occupant behaviour again influencing the performance of the pathway.

In this case the presence of external air pollution sources introduces a further factor into the problem system, where the presence of external air pollution may influence occupant behaviour in relation to the use of ventilation systems. Additionally, the occupants themselves, through their behaviour, are to a varying extent a source of air pollutant, thereby influencing the indoor air quality and need for increased levels of ventilation.

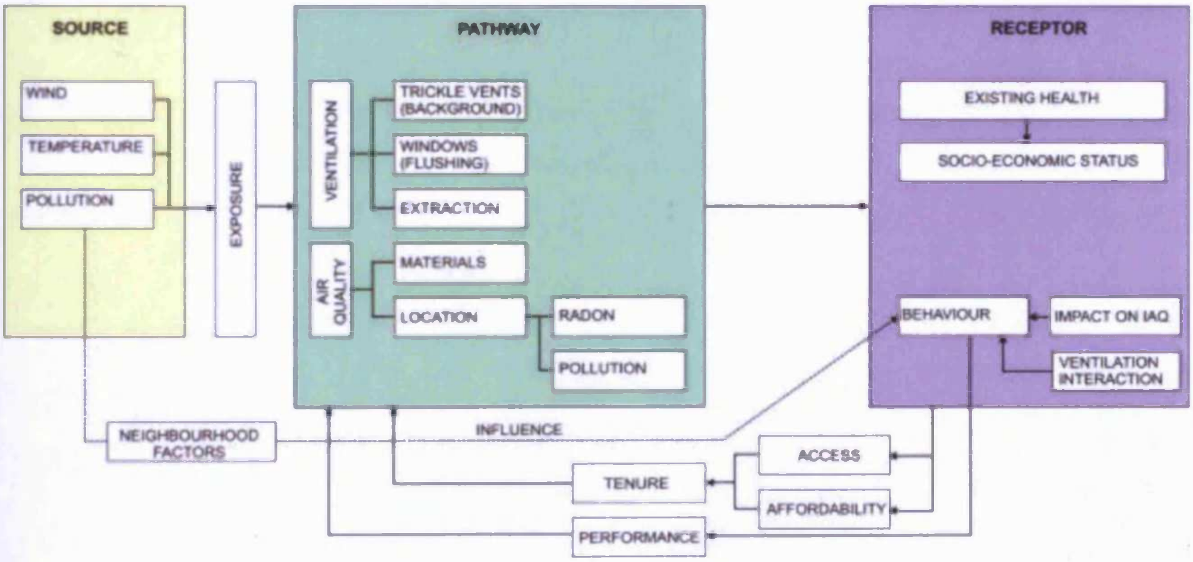


Figure 63: Problem Map for Occupant Health & Comfort Risk Factor: Winter – Inadequate Ventilation

3.2.2.5 Future Risk

Having identified the current risk due to inadequate ventilation for housing occupants in south Wales, it is now necessary to identify the potential for change over the coming decades. In relation to changes in the source, this will be undertaken through reference to section 3.2, where a summary of climate change in NPT under the current UKCIP 02 scenarios was provided. In relation to the pathway and receptor, likely change to these two over the same period will be considered, relating where possible to current government policy.

Likely Change in Source

Climatic Variable	Climate Change Scenario	Scale of Change	Impact on Internal Environment
Daily Average Temperature	Increase	+1.5 – 3°C	Negative
Daily Average Wind	Increase	+5-7%	Positive
Air Pollution (Winter Smog)	Decrease	Unknown	Neutral

The increase in daily average temperature will result in a decrease in temperature differential between the inside of homes, (likely to remain constant as this is related to thermal comfort) and that outside. This will result in a decrease in ventilation rates due to infiltration. The increase in average wind is likely to compensate this decrease to some extent, however, this will be moderated by microclimatic exposure factors in built up areas. Finally any decrease in winter air pollution due to smog (as suggested by the DoH study, 2001) is unlikely to influence occupant behaviour, as the use of flushing ventilation is driven by internal air pollution.

Graves & Phillipson (2000) consider it likely that ventilation rates in winter will decrease and therefore, despite a complex relationship with the source, it is suggested that the change in climate is likely to have a negative impact on the internal environment in relation to ventilation, reducing the background rate of ventilation achieved in homes during the winter.

Anticipated total influence of Source on Occupant Health and Comfort:	Negative

Likely Change in Pathway

Current Government support towards energy efficiency n the domestic environment, as discussed previously (section 3.2.1.5) is likely to alter the pathway significantly in relation to this risk. Further to this the current building regulations part F require upgrading of replacement windows to provide integral background ventilation. This suggests a positive impact on background ventilation rates. In some cases where these changes are implemented this may serve to negate some of the reduction due to climatic change. However, if the trend for poor air quality, as identified by Coward et al, (2001), in new homes continues, this will have a negative impact on indoor air quality. Overall the pathway is likely to remain unchanged.

Anticipated total influence of Pathway on Occupant Health and Comfort:	Neutral

Likely Change in Vulnerability or Receptor

The recent introduction of the smoking ban in Wales from April 2nd 2007 may have an influence over the coming years on occupant smoking. Unfortunately it is not known whether this will be a positive impact, encouraging people to stop smoking altogether, or negative, increasing occupant smoking in the freedom of their own homes. A second source of internal air pollution, influenced directly by occupants, is furnishings. There is an increasing trend for frequent replacement of furnishings (AMA Research, 2000) and if this continues, internal air pollutants from this source will also continue to rise. There is also a continuing rise in the incidence of asthma in the population and the aging population is likely to have an increased vulnerability to inadequate ventilation and poor indoor air quality.

Some of the direct health consequences of unfit housing have been dealt with al to damp and inadequate heating, however, material and structural damag material and structural damage can also be seen to have an influence on o These health risks derive from the close inter-relationship between the pres health with both housing (on many levels) and with socio-economic factors whe of housing has in turn been associated with mental health. The presence of po both negatively influences the accessibility and availability of good housing a impacted on and exacerbated by the presence of poor housing (McCarthy et 1989, Smith et al, 1992, Kearns et al, 1993, Conway, 1995, Ambrose, 200 estimated that approximately 15% of the UK community are subject to c disorders.

The existence of financial strain was found to be a predictor for future psyc (Weich & Lewis, 1998, Robinson, 2004). While Hopton & Hunt, (1996), als occupants of inadequate housing are more prone to day-to-day stress and sig both children and adults. Indeed they go further to suggest that this may result i by viral and bacterial infections. It is hypothesised here that the need for hou maintenance may be a significant source of financial strain, for example as a r to property by storms, especially where property insurance and or contents ins place to cover resultant damage,

• Mental Health [1]	• Future Psychiatric morbidity [2] • Increased vulnerability to bacterial anc

Source:
[1] McCarthy et al, 1985, Kellet, 1989, Smith et al, 1992, Kearns et al, 1993, Conway, 1995,
[2] Weich & Lewis, 1998, Robinson, 2004
[3] Hopton & Hunt, 1996

Table 33: Potential Health Impacts Due to Internal Enviro

3.2.3.1 Source

The hazards in relation to the occupant health and comfort risk system fc structural damage are defined as those climatic variables that influence the above.

3.2.3.1.1 *Wind*

The UK is one of the windiest countries in the world (Troen And Petersen, 1989) and approximately 250,000 buildings and structures are damaged by wind every year. However, being largely free from the devastating tornadoes and cyclones experienced elsewhere this damage is largely due to cyclonic and frontal depressions as well as extreme and smaller scale wind systems. Due to the scale of wind hazard in the UK wind loading forms a major element of the loading calculations for building regulations. The current British Standard, BSI 1972, on wind loading, to which most buildings in the past thirty years have been built is based on the current 50 year return period and vary for location.

***Figure 64: UK Wind Load Map** (Source: Building Regulations Part A: Structure, 2000)*

An example of damage due to windstorms can be taken from analysis of the damage caused by the 1987 hazard event. Severe winds caused structural damage and 19 people were killed by falling trees and debris. Insurance claims for property damage were in excess of £1.2 billion. Nearly 30% of all housing that was damaged in this storm was subject to wind speeds above the 50 year return period, while 80% of these were above the 200 year return period level. The threshold speeds for major or minor damage can be seen to be similar, with higher thresholds recorded in the north of the UK (+5m/s). However, much damage occurs at wind speeds below the design speeds (Ranson, 1991, Johns & Fedeski, 1994). Suggested reasons for this include:

- Buildings not built to standards have not previously experienced these winds and consequently following proper repair (to adequate standards) would not be damaged by similar extreme wind occurrences.
- Successive storms have caused weakening of the building fabric.

3.2.3.1.2 *Precipitation*

Hailstones with a diameter greater than 10mm can cause damage in the built environment, including broken glazing and impact dents in aluminium and other roofing materials. Under current climate stones up to 75mm have occurred during localised storms, mostly in the south of the UK (Johns & Fedeski, 1994). Hailstorms capable of causing damage to property occur approximately 3 times a year in Wales, usually between May and September. The hailstones in these storms are expected to be approximately 10mm in diameter. Furthermore, under the current climate hailstorms with stones of up to 75mm in diameter are anticipated once every 5 years. The Bristol Channel is one of the 'hotspots' for such destructive storms for the UK and therefore it is likely that both Cardiff and Neath and Port Talbot would be subject to such damaging storms.

Flooding can also occur as a result of coastal and fluvial flood events as well as as a result of extreme rainfall events causing direct and localised flash flooding such as the event in Boscastle, Cornwall in 2005. It should be noted that the wider health impacts of flooding are beyond the scope of this research. It should be noted that the potential for health impacts rising from polluted water and the subsequent psychological distress caused by flooding are considered to be beyond the scope of this work and the reader is referred to FHRC, 1999, where these issues are dealt with. Over 1.7 million properties are at risk of flooding in Wales and England (Evans et al, 2003).

Figure 65: Environment Agency Wales Flood Map for Neath Port Tabot Area (http://maps.environment-agency.gov.uk)

3.2.3.1.3 *Materials and Structural Damage: Source Factors*

The climatic hazard variables that influence occupant health and comfort risk system for inadequate materials and structural damage are therefore:

- Wind
- Precipitation including:
    - Rainfall
    - Hail

3.2.3.2 Pathway

The pathway factors in relation to the occupant health and comfort risk system for material and structural damage are defined as those aspects of the pathway that influence the risks described previously. Common failures of housing due to the impact of wind and hail include roof or chimney damage or failure, structural failure and increased maintenance regimes. The following building elements are vulnerable to damage by the hazard or source considered here (Ranson, 1991, Johns & Fedeski, 1994):

Tiled / Slate roofs
Chimneys
Gables
Windows
Guttering

Also external elements:
- Fencing
- Sheds
- Doors / Gates

Further to this, secondary damage may occur, such as that caused by flying debris and trees, especially during tornadoes. Falling trees can cause significant structural damage or even structural failure in extreme instances (Johns & Fedeski, 1994). While flood risks can lead to damage of structure, fabric or materials as well as personal possessions and services (Evans et al, 2003, Lancaster, 2004).

3.2.3.2.1 Housing: Age of Property

Properties built prior to the introduction of the current British Standard, BSI 1972, on wind loading may be more vulnerable than those built after its introduction. In addition, increasing age of a property may also increase its vulnerability, as building materials begin to fail, potentially weakened by previous exposure (Johns & Fedeski, 1994).

3.2.3.2.2 Housing: State of Repair

The presence of damage due to a previous event or damage from another source, left unattended, can result in increased venerability to a subsequent hazard event (Johns & Fedeski, 1994). For example, where a slipped slate is left un-repaired and is subjected to a second wind event, greater damage is likely to occur than would have occurred if the first damage had been promptly repaired. This suggests a relationship between existing state of repair or maintenance regime and consequent damage due to a hazard event. It should be noted that the tenure of a property, owner occupied, or rented, either by a registered social or private landlord may also have a relationship with the maintenance regime. For example, the responsibility for carrying out maintenance may be likely to be retained by the owner in all cases, although the responsibility for identification of maintenance needs may remain with the occupier. This illustrates a clear relationship between receptor and pathway. The state of repair of a property also increases its vulnerability to flood damage, where existing structural and fabric cracks and gaps can enable water entry to a building (Lancaster & Marshall, 2004, Fedeski & Gwilliam, 2007).

3.2.3.2.3 Housing: Construction Type

Flood events can have a significant impact on the materials and structure of a building, for details of which the reader is referred to Lancaster & Marshall, 2004. The materials from which a property is constructed will affect the resulting damage due to flooding. The reader is referred to Lancaster & Marshall, 2004 and Fedeski & Gwilliam, 2007 for further information relating to the impact of flood on building materials, which can be summarised as those permeable to water typically being the most vulnerable. While the use of elemental roofing materials including slate and tiles, rather than sheet materials, can present an increased vulnerability to damage during extreme wind events and together with large glazing units are vulnerable to hail events.

In relation to wind the incidence of dominant opening on a windward side results in increased loading on the leeward side of approximately 2 times, potentially resulting in rising internal pressures with loading on the building concentrated on the leeward wall (Johns & Fedeski, 1994).

3.2.3.2.4 Neighbourhood: Exposure to Flood, Rain and Wind

The topography of the neighbourhood can influence both a building's specific exposure to flood, through proximity to streams, rivers and ponds, as well as adequacy of drainage provision to deal with flash flood events. Topography can also influence the immediate wind regime around a building. For example, certain urban landscapes such as "canyons" between buildings and locations in close proximity to the foot of very tall buildings can be exposed to an enhanced wind regime. Wind in rural, suburban and urban locations will be influenced by the surrounding topography (Nikolopoulou (ed), 2004, p7-11)

3.2.3.2.5 Materials and Structural Damage: Pathway Factors

The pathway variables that influence the occupant health and comfort risk system for materials and structural damage are therefore:

- Housing:
    - Building Age
    - State of Repair
    - Construction Type
- Neighbourhood:
    - Exposure to Wind
    - Exposure to Rain
    - Exposure to Flood

3.2.3.3 Receptor

The receptor factors in relation to the occupant health and comfort risk system for material and structural damage are defined as those aspects of the receptor that influence their vulnerability to the associated risks.

3.2.3.3.1 Socio-Economic Status

An often over-riding relationship exists between socio-economic status and health (Hwang et al, 1999). The impacts of housing on health are therefore to some extent likely to mitigated or exacerbated due to the socio economic status of the occupants, where both higher incomes and levels of education are found to be related to better levels of health. Further to this socio-economic status, (as previously described), is directly associated with access to housing and its quality, where it is suggested that long-term or intermittent ill-health is likely to lead to low earning capacity. This can lead to loss of choice in the housing market where quality of the accommodation is likely to be lower (Conway 1995). Further to this there is an association between poverty and unemployment with the duration and maintenance of common mental disorders (Weich & Lewis, 1998, Robinson, 2004). However, the mediating effects of psychosocial resources available to an occupant should not be overlooked (Bisschop et al, 2004, Shields & Price, 2005).

3.2.3.3.2 Existing Illness: Long Standing Illness

In relation to mental health risks, many further factors must be considered, increasing the complexity of the relationship between mental health, housing and socio-economics. For example, the presence of mental health may be brought on by the presence of chronic disease in an occupant (Verhaak, 2004, Schnittker, 2005).

3.2.3.3.3 Materials and Structural Damage: Receptor Factors

The receptor variables that influence the occupant health and comfort risk system for materials and structural damage are therefore:

- Socio-Economic:
    - Status
- Existing Illness:
    - Presence of Long Standing Illness

3.2.3.3.4 Receptor-Pathway Interaction: Behaviour

Occupant behaviour is likely to be influenced by occupant age where it is hypothesised here that age may be associated with the ability of an occupant to deal with simple maintenance issues in their home, leading to a complex linkage with pathway or exposure to this hazard. In addition, the presence of existing or long term illness may influence the ability to maintain a property or to identify and report maintenance requirements that may be inaccessible or not visible for the occupant.

3.2.3.4 Current Risk

The current risk to occupant health and comfort as a result of material and structural damage can be described in the following problem map, figure 66. As was the case with risk due to inadequate heat and ventilation, the relationship between the source and pathway should be considered to be influenced by the microclimate around the home. The interaction between the receptor and the pathway is again non-linear, with the occupant's socio-economic status potentially affecting affordability of housing and therefore tenure, and occupant behaviour again influencing the performance of the pathway.

In this case the tenure of a property has a further relationship with the maintenance regime, where the responsibility for upkeep of the structure of the property remains with the owner whether or not he or she is the occupier as well as where the property is rented, either by a private landlord or registered social landlord (RSL).

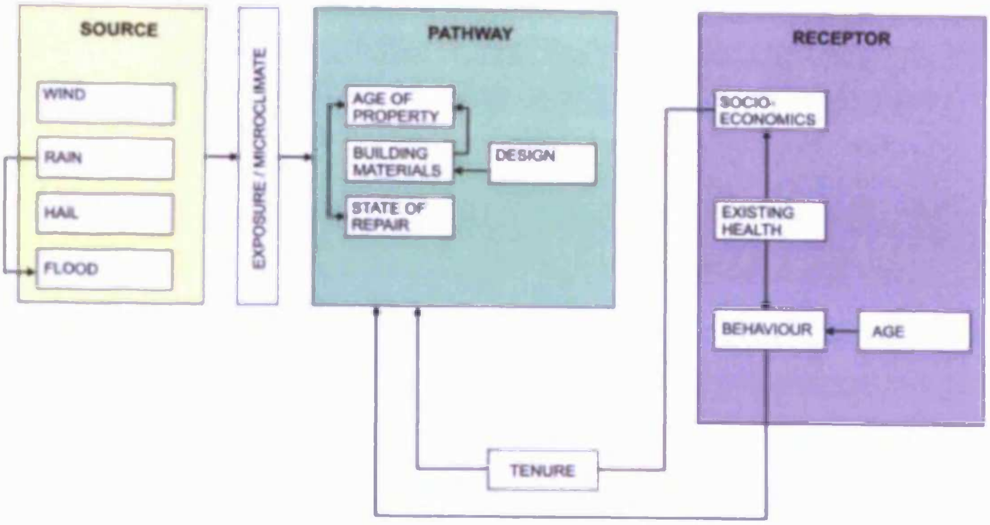


Figure 66: Problem Map for Occupant Health & Comfort Risk Factor: Material & Structural Damage

3.2.3.5 Future Risk

Having identified the current risk system due to material and structural damage for housing occupants in south Wales, it is now necessary to identify the potential for change over the coming decades. In relation to changes in the source, this will be undertaken through reference to section 3.2, where a summary of climate change in NPT under the current UKCIP 02 scenarios was provided. In relation to the pathway and receptor, likely change to these over the same period will be considered, relating where possible to current government policy.

Likely Change in Source

Climatic Variable		Climate Change Scenario	Scale of Change	Impact on Internal Environment
Extreme Wind *		Increase	+2-4%	Negative
Precipitation	% Change in Extreme **	Increase	+15 to + 25%	Negative
	Hail	Unknown	Unknown	Neutral

*% Change in Daily Wind Speed 2 years return period
** % Change in Rainfall During a 2 Year Return Event

The increase in wind regime would be likely to result in an increase in damage to property as would the increase in extreme rainfall, which would be likely to lead to increase in flood events. While the absence of data for changes to the regime of hailstorm events is considered to have a neutral influence on future risk. Cumulatively, the influence of the changing climate on occupant health will be negative, leading to an increase in damage events for the pathway.

Anticipated total influence of Source on Occupant Health: Negative

Likely Change in Pathway

The general governmental support for housing renewal is likely to have some influence on the general state of repair of properties, however, this does not relate to the general maintenance regimes in place for properties, where the author is not aware of any current governmental policies. This suggests that the future changes to the pathway are neither positive nor negative.

Anticipated total influence of Pathway on Occupant Health: Neutral

Likely Change in Vulnerability or Receptor

An increasingly aging population, in combination with the high rate of owner occupation of homes, may combine to result in an increasingly poorly maintained housing stock. The current trend for rising interest rates, resulting in a decrease in disposable income may also negatively influence future maintenance of properties as well as increase the stress and mental illness associated with financial strain. This strain would be enhanced by the possibility of a withdrawal from flood risk insurance by UK buildings insurers (Crichton, 2001). It is suggested that if these current trends continue, the likely change in vulnerability or receptor will result in a negative influence on this health risk system.

Anticipated total Influence of Receptor on Occupant Health: Negative

Likely Change in Occupant Risk

In combination it is expected that the occupant health and comfort risk due to material and structural damage will be increased as a result of climate change and other changes over the coming century.

Anticipated total Future Change in Risk on Occupant Health: Negative

3.2.4 *Risk Factor: Damp & Mould*

The presence of damp, *"prejudicial to the health of occupants"* is one of the factors in identifying unfit homes, where the legal concept of unfitness (as set out in Section 604 of the Housing Act 1985, and amended by Schedule 9 of the Local Government and Housing Act 1989) is applied. The risks to occupant comfort and health associated with damp and mould can be identified from literature as follows:

Comfort:

There are no associated impacts of damp and mould for occupant comfort.

Health

The connection between dampness and / or mould and health symptoms has been the subject of much recent research, as summarised by Hopton & Hunt (1996), Peat et al (1998), Hwang et al, (1999), Collins, (2000) and Bornehag et al (2004). Current research suggests possible causal links between damp, cold and mould. Although significant levels of work have been undertaken, conclusive causal links are yet to be proven for health impacts (Platt, 1989, Martin, 1991, Peat et al, 1998, Hwang et al, 1999, Park, 2004).

- Cough, wheeze
- Asthma
- Rhinitis
- Alveolitis
- Eczema

- Respiratory Symptoms
- Respiratory tract infections
  Psychological distress
- Aches and pains

- Headaches
- Diarrhoea
- Rheumatic fever
- Depression in women

Source
Hopton & Hunt (1996), Peat et al (1998), Hwang et al, (1999), Collins, 2000 and Bornehag et al (2004)

Table 34: Potential Health Impacts Associated with Internal Damp & Mould

Asthma has a complex genesis, as described in section 3.2.2.1.2 and both the development and risk factors for triggering symptoms have been found in a wide variety of housing factors including internal damp (Becklake, 1997, Peden et al, 2004). Further to these health impacts Hopton & Hunt, 1996, also suggest that illness may occur due to the viruses and bacteria which also flourish in damp conditions, where 1% of thepopulation displays allergic reaction to mould and 5% show less severe symptoms as a result of exposure to mould (Mant & Muir Gray 1986, Krieger & Higgins, 2002). A study in Glasgow, reported by Krieger & Higgins (2002), also found a significant link between a reduction in damp and a reduction in mental health.

3.2.4.1 Source

The hazards in relation to the occupant health and comfort risk system for damp and mould are defined as those climatic variables that influence the risks described above.

3.2.4.1.1 Driving Rain

Buildings are not generally vulnerable to damage by the rainfall of the scale experienced on a day to day basis. However, where wind and rain combines the resultant driving rain can cause damp in building materials as well as within buildings. The incidence of driving rain in the UK is considered within the building regulations part C (2004) and it can be seen below that NPT is located in an area categorised as either severe or very severe and is therefore considered to be exposed to this hazard. It should be noted here that local microclimate should also be considered to influence this climatic variable, as a site on an exposed mountainside may be very different to one in the centre of a built up area, although both types are located within the "very severe" mapping contained in the figure below.

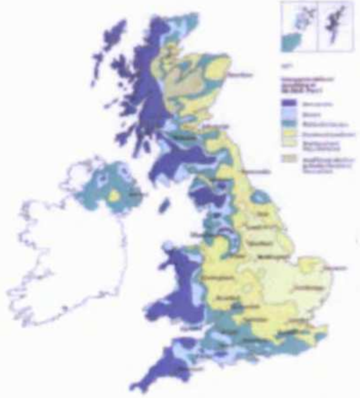


Figure 67: UK Wind Driven Rain Map *(Source: www.archifacts.co.uk/html/rain_resistance1c.htm)*

3.2.4.1.2 Humidity

Humidity, neither specific nor relative, as a background climatic hazard has no significant impact in terms of damage to the external materials or structures in the built environment. However, rapid changes in relative humidity can cause heavy temporary condensation on structures especially those of heavyweight materials. Where high humidity is found inside homes, damp and mould are more likely to occur, for example, where higher ambient humidity is already present. It should be noted, however, that internal damp and mould may have a more significant relationship with the occurrence of condensation, rising damp, low ventilation rates and damp penetration due to structural faults than it has to do with climatic humidity (BRE, 2001). Mould growth requires a relative humidity (RH) greater than 70% (Oreszczyn & Pretlove, 2000). It should be noted that due to the relationship between internal damp and mould and levels, humidity and rates of ventilation, temperature and air pollution must also be considered as secondary sources for internal damp and mould (ref section 3.2.2.1.3).

3.2.4.1.3 Flooding

Flooding has a direct and significant influence on the incidence of damp and mould in affected housing. The reader is referred to section 3.2.3.1.3. where flooding is also considered in relation to material and structural damage.

3.2.4.1.4 Damp & Mould: Source Factors

The climatic hazard variables that influence the occupant health and comfort risk system for damp and mould are therefore:

- Wind & rain leading to driving rain
- Rain leading to floods
- Humidity

3.2.4.2 Pathway

In the 2001 WHCS 17% of all homes were identified as suffering from damp. This was identified as part of the review of the causal factors for unfit homes. It can be seen below that the distribution of dampness in homes is associated with tenure and age of property.

Tenure	Owner Occupied		Social Housing		Privately Rented		All	
Suffering from Damp in Wales	12,100	19%	1,100	5%	3,800	26%	17,000	**17%**
Total	63,000		20,300		14,900		98,200	

Tenure	Pre 1919		1919 – 1944		1945 - 1964		Post 1964		All	
Suffering from Damp in Wales	13,800	25%	1,400	9%	900	5%	1,000	11%	17,000	17%
Total	55,100		14,900		18,900		9,300		98,200	

Table 35: Reasons for Unfitness by Tenure, date of construction for Wales *(Source: WHCS, 1998)*

Unfitness can be seen to be related to age of property and the tenure, where properties built prior to 1919 and those in private rented and owner occupied were more likely to suffer from damp. Further to this Conway, 1995, found that there is evidence that the building forms of the post war period mid-1950's through to the 1970's are prone to internal damp, especially where the built form is high rise (Conway, 1995). Damp in housing can have numerous causes related to the structure and materials of buildings. These could include water penetration including as a result of roof failure or flash flooding, rising damp and condensation on walls or windows.

Penetrating Damp

Penetrating damp can be caused by a number of factors. Firstly, a build up of ground level adjacent to walls can cause direct penetration of damp from the ground through the walls, where these walls have not been designed to resist this, associated with behavioural factors. Secondly, driving rain may cause moisture to penetrate walls, association with exposure to wind and rain. Damp may also penetrate walls or floors as a result of damaged drainage, guttering and burst pipes, permeability of material or incorrect design / construction as a result of construction type and or state of repair. Severe rainfall may result in ponding on flat roofs and inadequate drainage capacity for guttering can result in damp penetration through walls. While storms can result in direct roof failure, for example, through damage to slates and tiles, also related to state of repair.

Buildings with solid wall construction or where cavities are filled with insulation are particularly vulnerable to this hazard. Ensuring permeable materials such as bricks and certain types of stone are protected where this hazard is frequent, together with ensuing cavities are only part filled, helps to minimise the possibility of damage from driving rain. The potential for rain penetration of cavity walls has been the subject of research by the BRE (Pountney et al 1988). This work followed an unusually high incidence of driving rain penetration in the winter of 1983 – 1984. It was found that this high incidence was spatially coincident with locations that were subject to severe wind and rain during this winter. However, both site exposure and building defects were found to be a factor in many cases. Furthermore, there was found to be close relationship with the incorrect installation of cavity wall insulation.

Finally, where rain falls to produce flash floods (or contributes to other flooding events), the resultant extreme hazard event can produce significant damage. It must also be considered that where the building fabric has already been subject to damage, rain penetration into the internal environment is likely to further damage plasterwork and other internal finishes as well as contribute to internal damp and mould growth.

Therefore penetrating damp can be seen to be related to the housing factors of construction type and state of repair together with neighbourhood factors of exposure to wind, rain and flood. Occupant behavioural factors are also inter-related with this pathway variable.

Rising Damp

Rising damp occurs where moisture rises up the through the walls and floor of a property as a result of capillary action through the permeable materials from which the walls are constructed. As detailed in section, 3.2.1.2, properties built prior to 1965 may not have a damp proof course or damp proof membrane and as a result may suffer from damp. However, according to the Society for Protection of Ancient Buildings (SPAB), (Thomas et al, 1992), the vast majority of damp in older properties is due to inappropriate renovation to a structure that was intended to be permeable and breathe allowing moisture to penetrate but also to escape from the walls and floors of properties. The identification of rising damp also requires careful consideration, as damp due to other causes may present similar impacts. The provision of a damp proof course is a frequent remedial action where ground source damp is present. However, this may be inappropriate for certain construction types (Thomas et al, 1992).

Therefore rising damp can also be seen to be related to the housing factors of construction type and state of repair as well as occupant behavioural factors.

Condensation

The presence of condensation is likely to promote damp and consequently the growth of mould. Condensation is most frequently found where single glazed windows are present, where solid walls that have been prevented from breathing are present (for example where modern cement renders and or vinyl paints have been introduced) or where there is inadequate provision for ventilation (Handisyde et al, 1970, Handisyde et al 1971, Croome & Sherratt, 1972, Markus, 1993). Further possible causes relating to the pathway include, inadequate ventilation (relating to section 3.2.2), construction issues such as inappropriate detailing of vapour barriers, and areas of low insulation such as cold water cisterns, pipework and junctions in construction (Handisyde et al, 1970, Handisyde et al 1971, Croome & Sherratt, 1972).

The current building regulations are designed to minimise the risk of condensation through the requirement to specify double-glazing and to avoid thermal bridges (where un-insulated connections occur between internal and external environment) in construction design. Homes built prior to 1965, and where un-insulated cavities, solid walls and single glazed windows are present will be most vulnerable to condensation damp considerations. Further to this, the replacement of single glazed draughty windows with more airtight double glazed windows (where no additional ventilation method is provided) is likely to result in increased internal humidity, especially where clothes are dried internally (Howieson & Lawson, 2000)).

Therefore condensation can again be seen to be related to the housing factors of construction type and state of repair as well as occupant behavioural factors. While the persistence of condensational and the presence of mould is also dependent on ventilation levels.

3.2.4.2.1 Damp & Mould: Pathway Factors

The housing pathway variables that influence the occupant health and comfort risk system for damp and mould are therefore:

- Housing Factors:
    - Age of Property
    - Construction Type
    - State of Repair
    - Ventilation
- Neighbourhood:
    - Exposure to Wind
    - Exposure to Rain
    - Exposure to Flood

increase vulnerability of occupants to damp and mould.

3.2.4.3.2 Socio-Economic: Status

Damp and condensation can be reduced and / or eradicated through adequa although this is often not possible for the poorest members of society (Conway 1995 this heating just one room thus setting up temperature differentials between rooms certain forms of heating such as calor gas heaters (more common to poorer house produce moisture that can exacerbate the problem (Conway 1995). This is only on the inter-relationship between wider socio-economic considerations such as p unemployment, with both direct and indirect health impact factors (Ambrose, 1997, K Lowry, 1989c, Lowry, 1991, Lynch, 2000, Ambrose, 2002). In addition, higher level of occupation in combination with inadequate ventilation can also impact on increa moisture, leading to risk of damp and mould (Lowry, 1989b, Marsh et al, 1999 Higgins, 2002).

3.2.4.3.3 Damp & Mould: Receptor Factors

The receptor variables that influence the occupant health and comfort risk system fo mould are therefore:

- Socio-Economic:
    - Status
- Existing Illness:
    - Presence of Long Standing Illness

3.2.4.3.4 Receptor-Pathway Interaction: Behaviour

Occupant behaviour can have a significant influence on internal damp and mould, relationship with ventilation, as described in section 3.2.2, moisture production ar action in the face of damp or mould.

Possible causes of internal damp associated with occupant behaviour include, ventilation following the production of high humidity in a room, such as bathing cooking and the drying of clothes inside (Handisyde et al, 1970, Handisyde et al 19

& Sherratt, 1972). Lowry 1989 and Ranson, 1991 also suggest that dampness in homes may to some extent be associated with occupant behaviour, such as household size, drying clothes indoors, washing, cooking and the blocking of vents, rather than being purely the result of housing design. However, it may be further argued that the design of homes should be robust enough to ensure that such, relatively innocuous, occupant behaviour would not be detrimental to the internal environment.

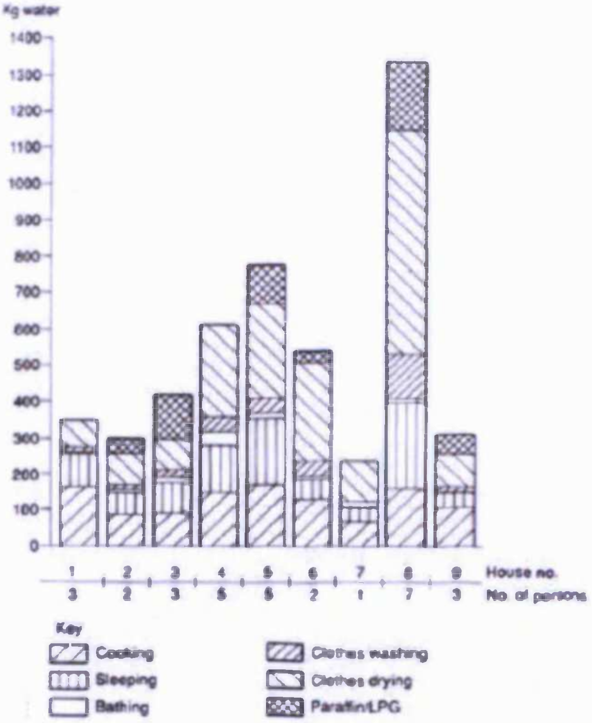


Figure 68: Moisture production over a 13-week period (Source: Burridge & Ormandy, 1993)

Through consideration of the above graph taken from Burridge and Ormandy it can be seen that in this study there was a relationship between number of occupants and level of moisture production. Lowry, 1989b, Marsh et al, 1999, Krieger & Higgins, 2002 agree that the density of occupation, together with inadequate ventilation, can also impact on increased interior moisture. In addition, occupant behaviour in the presence of damp and mould can also mitigate the health impacts. Pasanen, 1997 considered the control of mould growth in terms of both the control of relative humidity inside properties as well as through the application of disinfectants and detergent biocides. This study found that the application of biocides to a series of wallpaper samples with a variety of micro-organisms could not alone prevent growth of the organism. Effectiveness was increased on metal surfaces, but it was suggested that the neutral pH of building materials, including wallpaper, reduce the effectiveness of the biocides.

Finally, long-term occupant behaviour, in relation to property maintenance and "improvements" such as the installation of new glazing systems and blockage of chimneys, altering the ventilation in the property as well as identification and appropriate action in the presence of maintenance needs are likely to influence the presence of damp in a property.

3.2.4.4 Current Risk

The current risk due to the occupant health and comfort risk factor of inadequate heat is illustrated in the following problem map. As was the case with risk due to inadequate heat the relationship between the source and pathway is again influenced by the microclimate around the home and, in addition, in the presence of a flooding hazard. Topography also represents a mediating factor between source and pathway. The interaction between the receptor and the pathway is again non-linear, with the occupant's socio-economic status potentially affecting affordability of housing and therefore tenure, and occupant behaviour again influencing the performance of the pathway, in relation to ventilation, moisture production and through influence on or direct action relating to the maintenance regime.

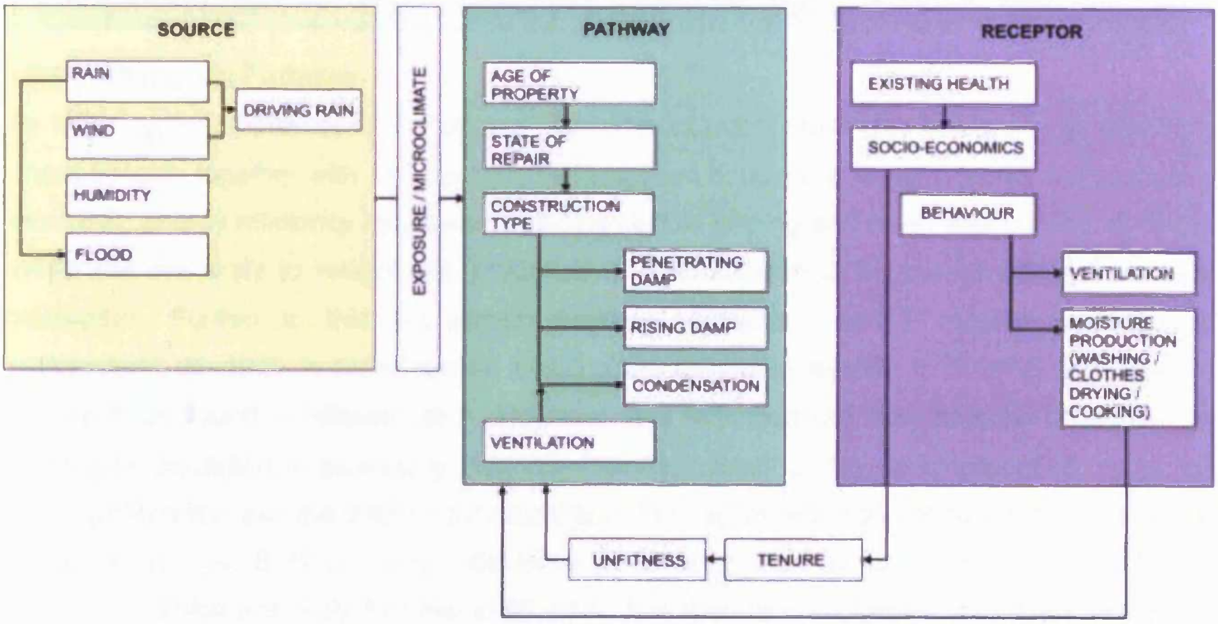


Figure 69: Problem Map for Occupant Health & Comfort Risk Factor: Winter: Damp and Mould

3.2.4.5 Future Risk

Having identified the current risk due to damp and mould for housing occupants in south Wales, it is now necessary to identify the potential for change over the coming decades. Again changes in the source relate to the summary of UKCIP02 scenarios as provided in section 3.2, while other governmental policy changes are highlighted which may influence the pathway or receptor in the system being studied.

Likely Change in Source

Climatic Variable		Climate Change Scenario	Scale of Change	Impact on Internal Environment
Rain	Average	Increase	+15 – 25%	Negative
	Extreme*	Increase	+15 – 25%	Negative
Daily Average Wind		Increase	+5-7%	Negative
Relative Humidity		Decrease	-3%	Neutral

% change in 2 year return period event.

The increase in both average and extreme rainfall is likely to result in higher incidence and greater levels of driving rain. This will have a negative influence on penetrating damp. While the increase in extreme rainfall events is anticipated to increase the incidence of flooding (including flash flooding), also resulting in greater incidence of damp due to this cause. Despite a fall in RH, levels of moisture in the air (absolute humidity) are expected to rise, resulting in greater availability of moisture in the air, with the potential to cause greater levels of condensation, leading to an increased incidence of associated damp and mould. This is combined with the decreased level of background ventilation identified in section 3.2.2.5. It is therefore suggested that the incidence of damp and mould is likely to be increased as a result of climate change.

Anticipated total influence of Source on Occupant Health and Comfort: Negative

Likely Change in Pathway

As was suggested previously the current Government policy relating to home energy efficiency improvements together with he associated widespread housing renovation grants are producing increased energy efficiency measures including double glazing and cavity wall insulation. These influences are likely to reduce the incidence of condensation in homes benefiting from such installation. Further to this the current building regulations part F require upgrading of replacement windows to meet current building regulations in relation to thermal performance and on background ventilation rates. However, it is hypothesised here that the installation of cavity wall insulation in previously clear cavities may result in the development of routes for damp penetration into the internal structural leaf. This action will also not reach the 13,800 pre-1919 built homes, 81% of homes identified as suffering from damp in the 2001 WHCS, the majority of which are likely to have solid walls. It is therefore suggested that there will be no overall change in pathway over the coming century.

Anticipated total influence of Pathway on Occupant Health and Comfort: Neutral

Likely Change in Vulnerability or Receptor

The continuing rise in the incidence of asthma in the population, together with an aging population, is likely to result in an increased vulnerability to damp and mould in the internal environment. In addition, the socio-economic arguments for a future stable level of affordability of heating and associated fuel poverty levels, means that this route for eradication of damp is not likely to be achieved. However, the current trend for lower occupancy density, together with a reduction in lengthy home cooking with the move towards "ready meals" will result in decreasing occupant moisture production. Therefore, on average, occupant vulnerability may be likely to remain stable to this risk.

Anticipated total influence of Receptor on Occupant Health and Comfort: Neutral

Likely Change in Occupant Risk

In combination it is expected that the occupant health and comfort risk due to damp and mould will be increased as a result of climate change.

Anticipated total Future Change in Risk on Occupant Health and Comfort: Negative

3.3 Summer Risk

Each of the risk factors identified as part of the summer occupant health and comfort risk family will now be described and explored using the structure highlighted in the previous section. In order to provide a framework for this risk assessment in relation to the major driver for change in the system, climate change, a summary of current climate change scenarios for the summer in south Wales has been produced. This is included here in order to prevent the need for repetition below as well as to place the risk assessment in an appropriate context. The data is summarised using data from the HADCM3 grid box no 370 from the UKCIP02 dataset, corresponding to Neath and Port Talbot County Borough Council (NPT), the spatial focus for this work. The summer climate anticipated under the UKCIP02 scenarios (Hulme, 2002) can be summarised as follows:

In relation to the future scenarios for temperature in south Wales:

- An annual warming by the 2080s of between 2°C and 4°C.
- It is expected that greater warming in will occur in summer and autumn rather than in winter and spring.

The following graph illustrates the mean temperature change in south Wales for both annual and summer means for 2020s, 2050s and 2080s scenarios as well as for the four emissions scenarios illustrated by UKCIP02, low, medium-low, medium-high and high (Hulme, 2002, p28 – 32). For reference to uncertainty margins and relative uncertainties for the variables reported below please refer to section 3.2.

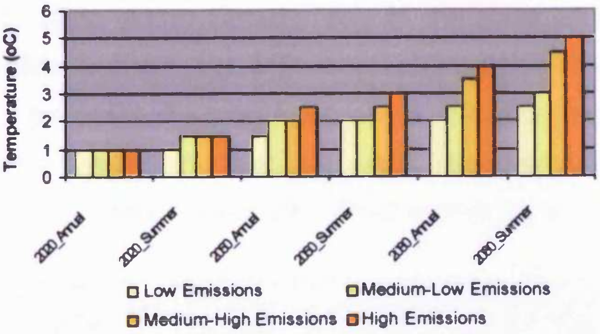


Figure 70: Mean Temperature Change for South Wales (^{o}C)

(Derived from UKCIP02 Data (Hulme, 2002, pp29 - 32)

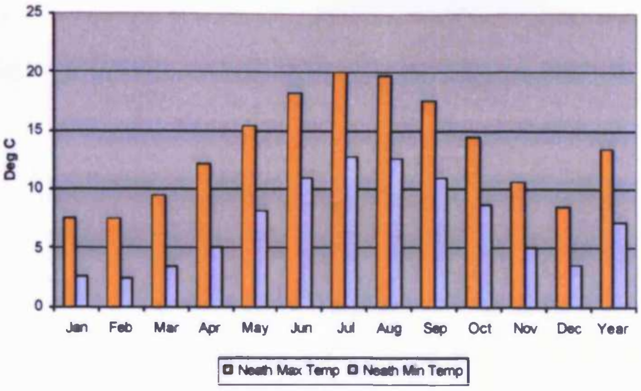


Figure 71: Monthly Average temperatures for Neath for the baseline climate 1961 – 1990 *(www.met-office.gov.uk, 2003)*

The cloud cover is expected to reduce under climate change and as a result of an associated increase in insolation of the order of 10 – 30 w/m^2 would be expected in the summer (Hulme, 2002, p44). It can be seen that during the summer a greater than annual average reduction in cloud cover is expected for south Wales.

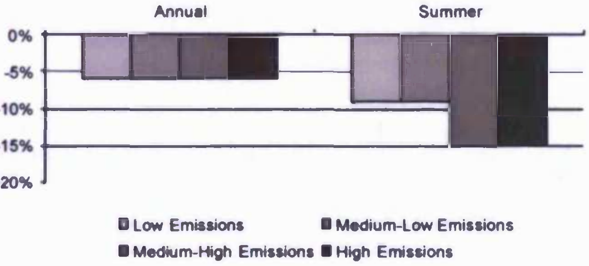


Figure 72: Mean Change in Annual & Summer % Cloud Cover for South Wales (2080s only) *(Derived from UKCIP02 Data (Hulme, 2002, p46)*

52o N	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Year
Possible sunshine hours	8.3	9.9	11.8	13.8	15.6	16.6	16.1	14.6	12.6	10.6	8.8	7.8	12.2

Table 36: Possible Sunshine Hours on the 15th Day of the Month for Cardiff *(www.met-office.gov.uk)*

Summer diurnal ranges are expected to increase by up to 1°C by the 2080's (Hulme, 2002, p43). Days are anticipated to warm more than nights during summer due to the anticipated decrease in cloud cover. The scenarios project milder summer evenings, an example of which is found under the high emissions scenario, where temperatures found at present at 7.00pm are expected to be found at 11.00pm by 2080, resulting in a shift in the diurnal cycle. The change in annual and summer diurnal temperature range in south Wales under UKCIP0-2 scenarios is:

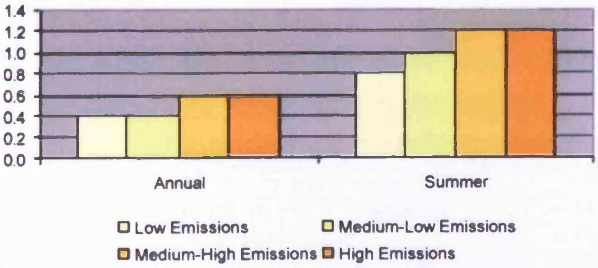


Figure 73: Change in Annual & Summer Diurnal Temperature Range Change for South Wales (2080s only) – Derived from UKCIP02 Data (Hulme, 2002, p45).

In addition to this the frequency of occurrence of extreme temperatures for south Wales by the 2080s is anticipated to rise. The relative confidence for this anticipated change is high. (Hulme, 2002, p71):

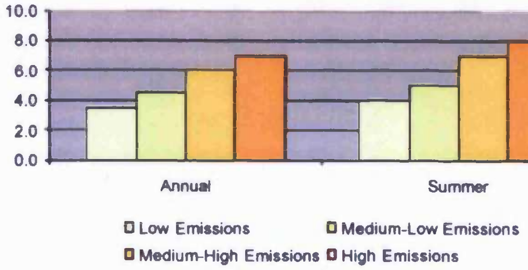


Figure 74: Change by the 2080s in the daily-Average Temperature Threshold which Constitutes an "Extremely" Warm (90th Percentile Day (°C) for South Wales. *(Derived from UKCIP02 Data (Hulme, 2002, p63))*

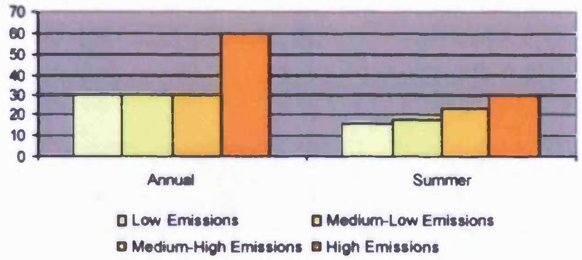


Figure 75: Change by the 2080s in the Average Number of "Extremely" Warm days per season (defined as the 90th Percentile threshold temperature for the periods 1961 – 1990) for South Wales *(Derived from UKCIP02 Data (Hulme, 2002, p64))*

One measure of the impact of this on the built environment can be seen in the commonly applied derived unit of "Cooling Degree Days" (CDD), which, although not currently in widespread use in the UK domestic environment is widely applied elsewhere in the building services industry.

CDD = **Tmean** – base temperature

Where ***Tmean*** is estimated as the average of the min and max temperatures for each day.

An officially designated base temperature already exists for the UK for the corresponding heating degree days for HDD's, but an equivalent has yet to be defined for CDD's. Within the UKCIP02 research, this has been set at 22°C on the basis of current building energy management practice (Hulme, 2002, p70). This measure provides an indication of changes to the summer thermal environment and is widely used in warmer climes. The yearly figure for CDD's represents the sum of these figures for all days in a year, discounting negative values.

Currently a baseline average year in the south of England has approximately 310-330 CDD's and Scotland has in the region of 20-50 CDD's (Hulme, 2002, p70). The table below illustrates the possible changes in CDD regime for the four UKCIP02 2080's scenarios, where it can be seen that south Wales is subject to an increase of between 60 to 100 CDD's by this period.

Low Emissions	**+ 60**
Medium-Low Emissions	**+ 60**
Medium-High Emissions	**+ 100**
High Emissions	**+ 100**

Table 37: South Wales CDD's under current Climate Change Scenarios for 2080s. *(Derived form UKCIP02 Data (Hulme, 2002, p70))*

In relation to average precipitation the main conclusions from current scenarios are for drier summers, by up to 50 % by the 2080's (Hulme, 2002, p53):

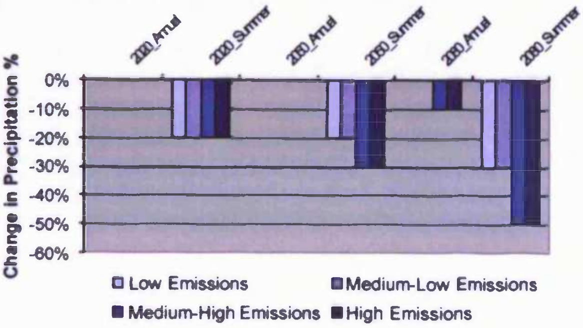


***Figure 76:* Mean % Change in Annual & Summer Precipitation for South Wales (2080s only)**
(Derived form UKCIP02 Data (Hulme, 2002, pp 33 – 36))

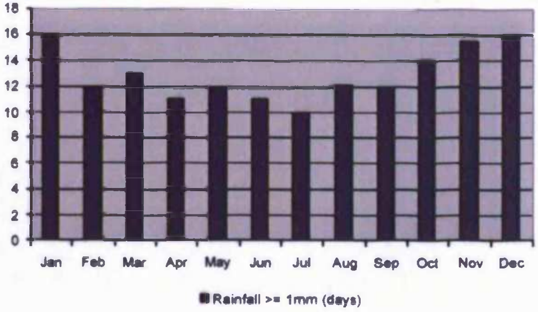


***Figure 77:* Neath Monthly Average Precipitation for period 1961-1990.**
***N.B.* Neath yearly Average 1267mm** *(www.met-office.gov.uk)*

While for extreme precipitation events the main conclusions from current scenarios, both associated with high relative confidence (Hulme, 2002, p71) are illustrated below:

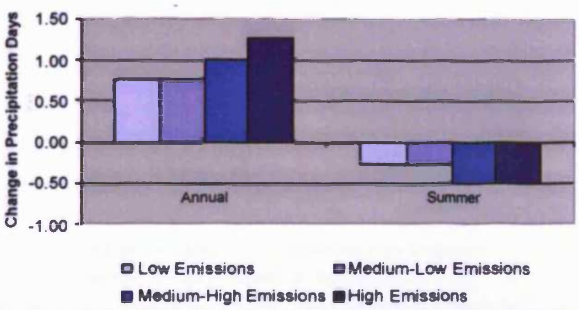


***Figure 78:* Change in Number of Intense Precipitation Days Annually & Summer for South Wales (2080s only)**
(Derived from UKCIP02 Data (Hulme, 2002, p57))

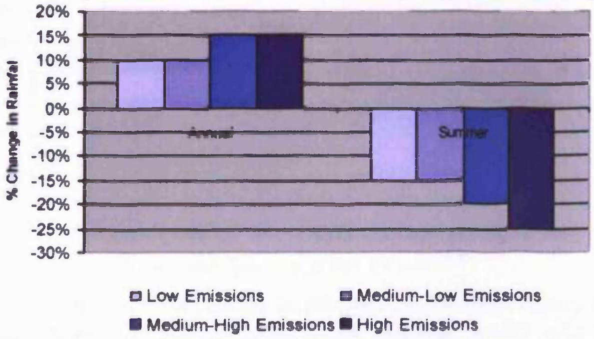


***Figure 79:* % Change in Rainfall During a 2 Year Return Precipitation Event, Annually & Summer for South Wales (2080s only)** *(Derived from UKCIP02 Data (Hulme, 2002, p59))*

A reduction in RH of up to 10% may occur in some parts of Wales during the summer. As for the winter no scenarios are available for the diurnal variation of this climatic variable, although the implicit association of this variable to diurnal temperature range suggest that the diurnal variation will increase due to the associated increased diurnal variation in temperature. The change in RH suggested by the current scenarios is illustrated below:

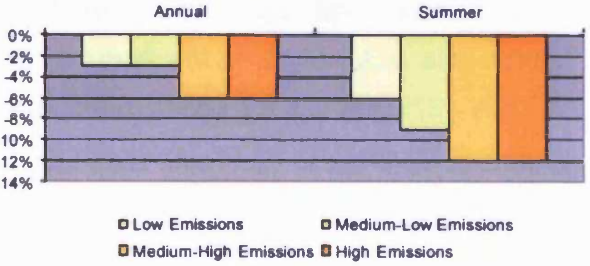


Figure 80: Mean % Change in Annual & Summer Average Relative Humidity for South Wales (2080s only) *(Derived from UKCIP02 Data (Hulme, 2002, p47))*

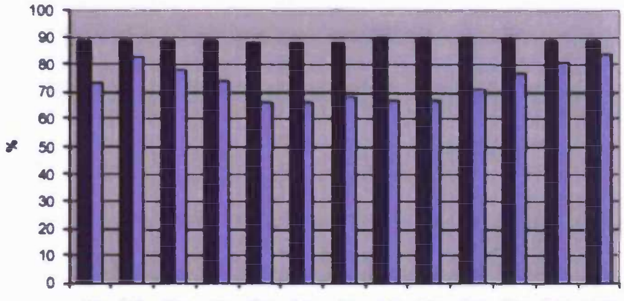


Figure 81: Cardiff Monthly Average relative Humidity 1961-1990 *(www.met-office.gov.uk)*

The mean daily wind speed in south Wales is expected to increase slightly both annually and in the summer by the 2080s (UKCIP02, p48, p44).

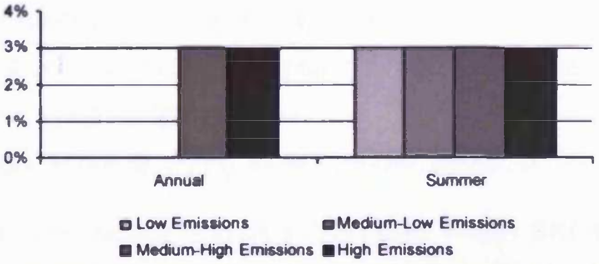


Figure 82: % Change in Annual & Summer Daily mean Wind Speed for South Wales (2080s only) *(Derived from UKCIP02 Data (Hulme, 2002, p48))*

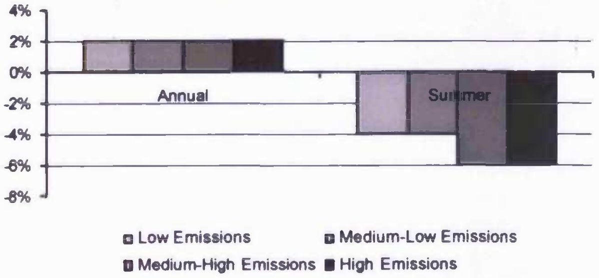


Figure 83: % Change in Annual & Summer Daily Wind Speed which can be Expected on Average every 2 years for South Wales (2080s only) *(Derived form UKCIP02 Data (Hulme, 2002, p68))*

No information exists for the seasonal variation in atmospheric pollution and for changes to this variable readers should refer to section 3.2. However, a study carried out in the USA by Roberts (2004) of deaths related to particulate pollution, suggested that there was an interaction between PM_{10} levels and temperature, where hot days with a temperature in the region of 30°C, were associated with increases in the region of 15% in related deaths. It was suggested that both physiological stress due to the heat as well as people being more lkely to open their windows and/or be outside, would place them at greater risk from increased PM_{10} concentrations. The occurrence of low level ozone, a significant air pollutant, is also related to raised solar radiation and temperatures (Kovats et al, 1999, p1683, DoH, 2001, 219 - 250).

Changes in soil moisture during the summer can also have an impact in the built environment. The following changes both annually and during the summer season are anticipated under current climate change scenarios.

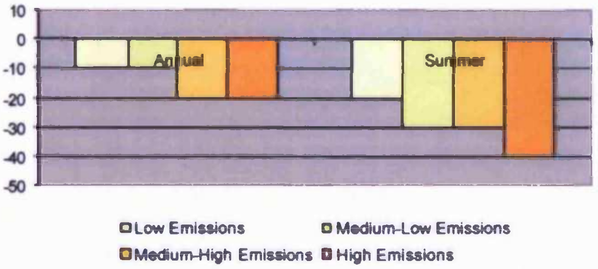


Figure 84: % Change in Soil Moisture Content (2080s only) *(Derived form UKCIP02 Data (Hulme, 2002, p50))*

The uncertainty discussed earlier in relation to the extent of future climatic change should be reiterated here, where observed changes in climate to date, including:

- The frequency of occurrence of very hot days, where the maximum temperature exceeds 25°C has increased throughout the 20th Century.
- The frequency of heatwaves, where the maximum temperature exceeds 22°C for 5 consecutive days increased in the 20th Century particularly in May and July.
- There have been no long term trends found in annual precipitation, although a trend towards drier summers has been indicated. (Hulme, 2002, p8-11).
- 10 of the 16 warmest years in the CET record (since 1659) have occurred since1981.

Having established the current scenarios for summer climate change in the south Wales UKCIP grid box, no 370, the occupant health and comfort systems associated to the summer risk family identified previously will now be explored, namely:

1. Thermal – excess heat
2. Noise
3. Pests & vermin
4. Ventilation & air pollution
5. Material & structural damage

It should be noted that there are significant interconnections between these risk factors which are made explicit in the figure below. Following the primary risk factor during the summer, excess heat, the noise and pest and vermin risk factors are explored initially, as they are likely to be influenced by and also influence occupant behaviour in relation to risks due to excess heat and inadequate ventilation. To expand this notion, noise in the built environment is derived internally and externally. During hot weather, the use of external spaces is likely to be more widespread, leading to increased noise levels externally, which may in turn prevent occupant use of windows to allow ventilation. While, an alternative view may be that as a result of the greater use of open windows to promote ventilation, (in order to mediate excess heat), this may also result in greater noise pollution, as the inside of homes becomes the source of noise to the external environment. The risks associated with pests and vermin has a similar complex relationship with the two risk factors of ventilation and excess heat while being influenced by the presence of damp and mould, which is in turn related to material and structural damage.

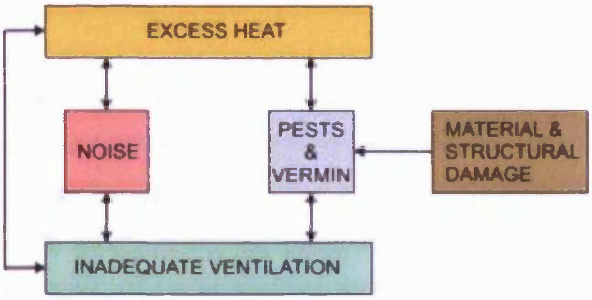


Figure 85: Inter-Relationships Between Summer Family of Risk Factors.

3.3.1 *Risk Factor: Thermal - Excess Heat*

The first risk factor to be considered here is excess heat. The risks to occupant comfort and health associated with this risk factor can be identified from literature as:

Discomfort

Where a home is too hot for its occupants to consider themselves comfortable, discomfort can be considered to occur (The reader is referred to section 3.2.1). As was the case with thermal discomfort due to cold the adaptive comfort model is adopted for this work and it is assumed that occupants will become active in order to achieve thermal comfort, through conscious behavioural actions including those described earlier in section 3.1.1. Additionally, in the short-term heat loss is promoted by the body through its thermoregulatory system, where: vasodilation, directs more blood to the surface of the skin, increases skin temperature and promotes radiant heat loss to the surrounding environment and convective heat loss to the air, as well as reducing metabolic heat production; sensible perspiration, promotes latent heat loss through evaporation of moisture and latent heat is also lost through evaporation of water by respiration. Conscious adaptation and short-term unconscious adaptation are combined with unconscious longer term changes to physiological set points at the control of unconscious adaptation, including: shivering, skin blood flow, sweating, body fluid levels and salt loss (ASHRAE, 2001).

Discomfort can also occur at night, where high bedroom temperatures can relate to poor sleep quality and associated poor performance on the following day at work (Candas et al 1979, Hacker et al, 2005).

Health

Excessive indoor temperatures have been found to be linked with or induce the following illnesses:

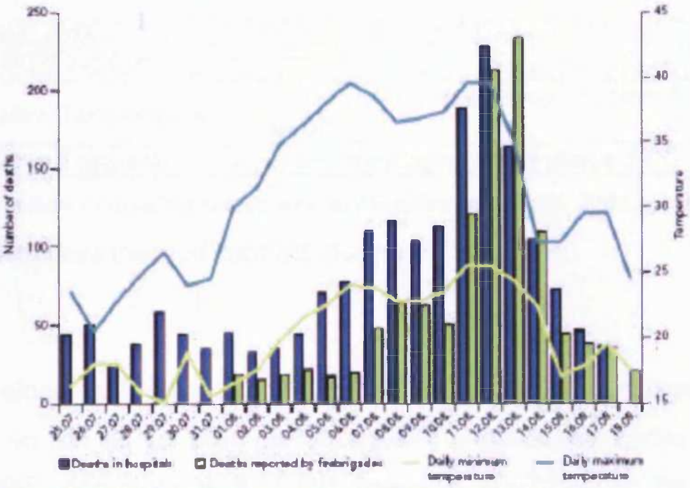
- Skin eruptions [1]
- Heat fatigue [1]
- Heat cramps [1]
- Heat syncope [1]
- Heat exhaustion [1]
- Heat stroke [1,2]
- Respiratory tract infections [2]
- Mortality [2]
- Cardiac events [2]
- Irritability & social intolerance [3]

Sources:

[1] World Health Organisation – Europe, 2003,
[2] Hwang et al, 1999
[3] Krieger & Higgins, 2002

The majority of these illnesses are the result of a failure in the body's thermoregulatory system to varying severities. Where heat stroke occurs and the body's temperature is not relieved from its extreme temperature (above 40.5°C) the result can be damage to the cellular structure as well as the thermoregulatory system. This can lead to death. It is suggested that deaths due to this cause may be severely underreported due to the similarity in symptoms to those of coronary or central thrombosis (Collins, 1993, WHO-Europe, 2003).

According to Mant & Muir Gray (1986), where air temperature exceeds 25°C, mortality begins to increase. Further to this a heatwave, (a prolonged period of hot days), tends to cause a similar increase in excess mortality. For example, during the heatwave of the summer of 2003, summer excess deaths, totalling several thousand, were recorded in France and the UK. Additionally, heatwaves are considered to be particularly hazardous to health when they occur in conjunction with air pollution episodes such as low level ozone (WHO, 2004).



Notes: Reported deaths (bars on left axis), temperature (lines, right axis).

Figure 86: Number of reported deaths and minimum and maximum temperature in Paris during the heatwave of summer 2003 *(Reproduced from EEA, 2004)*

The occurrence of heatwaves is also associated with non-fatal incidence of skin eruptions, heat fatigue, heat cramps, heat syncope, heat stroke and heat exhaustion (WHO-Europe, 2003a, 2003b).

Until the heatwave of August 2003, there had been little consideration of the health impacts of heatwaves in the UK other than an estimation of increases in heat related mortality as a result of climate change (DoH, 2001). In the UK Kovats et al (2003) reported 2045 excess deaths as a result of this heatwave, representing an increase of 16% over expected numbers for that time period, and more than 14,000 in France.

This risk is influenced by the hazard, exposure and vulnerability regime for an individual occupant. The factors associated with this occupant health and comfort risk will now be explored and a problem map produced for this risk factor.

3.3.1.1 Source

The hazards in relation to the occupant health and comfort risk system for excess heat, are defined as those climatic variables that influence the risks described above.

3.3.1.1.1 Comfort

The main environmental factors that affect thermal comfort were previously identified in 3.2.1.1, as were a number of adaptive comfort equations. These equations are applicable both in winter and summer seasons. However, t is appropriate to introduce here the equivalent CIBSE benchmarks for peak and overheating criteria.

Room Type	Benchmark Summer Peak Temperature (°C)	Overheating Criterion
Living Area	28°C	1% Annual Occupied hours over 28°C Operative Temperature
Bedrooms	26°C	1% Annual Occupied hours over 26°C Operative Temperature

***Table 38: Benchmark summer peak temperatures and overheating criteria** (Adapted from Race, 2006, p18)*

Together with the following indoor comfort temperatures:

Room Type	Indoor Summer Comfort Temperature (°C)	Notes
Living Area	25°C Operative Temperature	Assuming warm summer conditions in UK
Bedrooms	23°C Operative Temperature	Sleep may be impaired above 24°C

***Table 39: General summer domestic indoor comfort temperatures** (Adapted from Race, 2006, p21)*

In relation to the other factors that affect occupant thermal comfort, during hot weather:

Relative Humidity (RH):

Although humidity does not have a significant impact on thermal comfort at average temperatures in UK domestic properties, an RH above 80% can feel sticky and uncomfortable (Race, 2006, p11). Guidance from CIBSE recommends that RH between 40–70% can be considered good practice.

Mean Radiant Temperature (MRT) of the Surroundings:

Solar radiation received into a space can be a source of excessive radiative heat, particularly when it affects only one side of the body, for example as a result of being transmitted through a window. This imbalance, even where the ambient temperature is comfortable, can lead to thermal discomfort (Race, 2006, p12). Further than identifying solar radiation as a hazard factor of the occupant comfort system, MRT will be considered further within the exposure section.

Air Movement:

Air movement in the range of 0.1 – 0.3 m/s is considered to be good practice by CIBSE (Race, 2006, p12). However, higher rates of air movement are generally more acceptable during warmer weather and especially where the direction of the air movement varies, for example when this is due to natural ventilation. Air movement during the summer can be influenced and driven by the wind as windows are more likely to be opened to promote ventilation and cooling.

3.3.1.1.2 Health

In relation to health, the concept of a heatwave is the main hazard for occupant risk. A heatwave, unfortunately, is not a precisely defined meteorological term, however, a definition widely applied is *"a period during which average weekly temps at midday exceed 25°C"* (Collins, 1993). The majority of research considering the impact of heat and heatwaves on population health has been carried out in the USA. Under current climate conditions, heatwaves already cause excess deaths and research relating to this relationship can be considered more widely in the light of climate change. For example, the numbers of deaths have been found to rise steeply in a number of cities, where external temperature exceeds 30°C. Further to this, the impact from heatwaves is most notable where average climate and expected summer temperature is lower, as the excess summer deaths are less numerous where the population is used to hotter weather (Koppe et al, 2003).

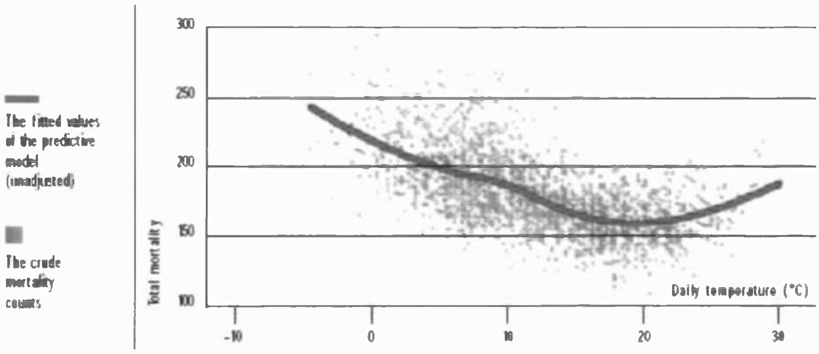


Figure 87: Relationship Between Max. Daily Temperature and Mortality for a European City
(Reproduced from Koppe et al, 2003)

Health impacts due to heatwaves occurring towards the beginning of the summer, are also likely to be associated with acclimatisation during the summer season. Physiological acclimatisation of this sort takes only a few days, however, complete acclimatisation to a new climate may take several years (Koppe et al, 2003).

More detailed analysis of those deaths in France found the majority of those who lost their lives due to the heatwave were over 75 years of age. Kovats et al, 2003, suggest that the unexpected duration and intensity of the heatwave, combined with a lack of preparedness in the health care and social systems, contributed to the loss of life. The relationship between urban areas and increased deaths during heatwaves is reinforced by the case study analysis of heatwaves in the UK over the past two decades in the table below.

Heat Wave	Attributable Mortality
1976	9.7% increase for England and Wales & 15.4% increase for Greater London. Almost two-fold increase in mortality rate in geriatric hospital inpatients (but not outpatients).
1995	8.9% increase in all-cause mortality (768) in England and Wales and 15.4% increase (184) in Greater London.
2003	16% increase in all-cause mortality (2045) for UK

Table 40: Mortality attributable to heatwaves in the UK 1976-2003 (WHO – Europe, 2003a)

As a direct result of the 2003 heatwave the 'Heatwave Plan for England' was produced (DoH, 2004). The plan provides a 'heat-health watch' that is intended to run from 1st June to 15th September each year. The plan can be seen to derive from those already in existence around the world, such as those in Philadelphia, Lisbon and other European countries, (Kalkstein, 1995, Koppe et al, 2003) and although there is the intention to adopt a plan for Wales, this has not as yet been adopted. The English plan provides definitions of 4 levels of response:

- **Level 1: Awareness**
  The minimum state of awareness that is maintained until thresholds are exceeded.
- **Level 2: Alert**
  Triggered as soon as the Met Office forecasts threshold temperatures will be exceeded in any region for at least 3 days ahead, or for 2 consecutive days of extremely high temperatures.
- **Level 3: Heatwave**
  triggered as soon as threshold temperatures are reached in any region.
- **Level 4: Emergency**
  Reached when a heatwave is so severe that the effects threaten the integrity of, or extend beyond, the health and social care systems.

The threshold temperatures for these levels vary by area of the country and are reproduced in the table below:

Region	Day (Max)	Night (Min)
London	32°C	18°C
SE	31°C	16°C
SW	30°C	15°C
Eastern	30°C	15°C
West Midlands	30°C	15°C
North West	30°C	15°C
Yorkshire/Humberside	29°C	15°C
NE	28°C	15°C

Table 41: Threshold Day and Night Temperatures by Region *(Source: DoH, 2004)*

In addition to temperature, the internal thermal environment is influenced by solar gain into a property which is a function of available solar radiation and cloud cover.

3.3.1.1.3 Excess Heat: Source Factors

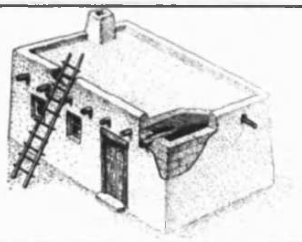
The climatic hazard variables that influence occupant health and comfort risk system for excess heat are therefore:

- Temperature:
    - Monthly mean average temperature

  - Heatwaves defined as *"a period during which average weekly temps at midday exceed 25°C".*
  - Day and night time peak temperatures
- Relative Humidity
- Wind
- Solar Radiation
- Cloud Cover

3.3.1.2 Pathway

The exposure factors in relation to the occupant health and comfort risk system for excess heat, are defined as those aspects of the pathway that influence the risks described above. The thermal environment in a home during the summer is influenced by the heat balance between energy received and released by the property. This is a result of the building fabric, the building layout and the building services. Occupant behaviour completes this cycle and is considered in section 3.3.1.3. Through consideration of vernacular housing in extreme hot regions of the world, strategies to promote thermal comfort in extreme heat conditions can be seen clearly. In hot and dry regions the following design strategies are common:

Climate	***Winter & Summer – Little to No Seasonal Variation***	
Temperature	Hot days Cold nights Intense solar heat and light	 ***Figure 88: Mud House (Traditional Moroccan)***
Precipitation	Little rain	
Humidity	Low humidity	
Available Materials	• Mud, wood	
Appropriate Form	• High heat capacity roof and walls • Maximise shade • Minimise ventilation • Permeable solid load bearing mud masonry walls • Roofs: mud cement on wattle / palm trunk for rafters	

The heavy thermal mass of these buildings together with the small windows are common to the vernacular stone cottages of Wales. However, the thermal mass of the roof is rarely present in Wales, allowing heat to penetrate into the property during the daytime. Ventilation is also minimised due to the limited and small scale of the traditional openings. In hot and humid regions, the following building form and materials are employed:

Climate	***Winter & Summer – Very Little Seasonal Variation***	
Temperature	Hot days Warm nights Intense solar light and heat	 ***Figure89: Raised Hut (Traditional Malaysian)***
Precipitation	Heavy rainfall	
Humidity	High humidity	

Available Materials	- Timber, reeds, thatch (palm fronds), occasionally bamboo
Appropriate Form	- Low heat capacity roof and walls - Maximise shade - Maximise ventilation - Skeletal frame - Thatched roof & walls - Sloping parasol roof - Stilted floors

Although these two examples relate to extreme climates they explain clearly strategies to promote thermal comfort in Welsh housing during the summer. They also serve to confirm the mediating role or pathway that the home has between the climatic hazard and the occupant receptor.

The Welsh housing stock includes examples of both lightweight and heavy weight construction and through consideration of the above worldwide strategies the performance of these strategies can be qualitatively considered for the UK. For example, a modern, light weight building such as a modern timber framed house, may seem to be an appropriate built form for providing comfort during extreme summer weather where both the evenings and nights are warm. The low thermal mass does not store heat from the day and the vernacular designs allow for maximisation of ventilation throughout the day. However, the level of cross ventilation achieved in modern British housing is very low in comparison to that achieved by the vernacular designs of hot humid regions. Therefore the modern UK housing is unlikely to provide a comfortable internal environment within these conditions. It must also be considered that the frequency of warm nights versus cold nights during the summer months together with a medium, rather than high level of humidity, may suggest that the UK current extreme summer climate, may be more similar to the hot and dry regions.

This would suggest that heavy mass buildings would be more appropriate, where the thermal mass can defend from the heat of the day and re-radiate the heat at night to temper the colder night temperatures. However, warm nights are often dealt with through occupant adaptation, for example by sleeping outside, often on the roof, which are not likely to be acceptable in the UK. Therefore the appropriate combination of orientation, thermal mass, ventilation and solar shading through carefully considered architectural design can be seen to be one of the key challenges for designers of the built environment in the light of climate change. There are a number of significant bodies of research in this area (Olgyay, 1963, Jones, 1998, Hawkes & Forster, 2002) and it is not necessary to reproduce this work here. However, in summary the following aspects of passive design can be considered significant to any study of the internal thermal environment of existing domestic properties in the UK. Furthermore, additional exploration would be required in order to explore the potential application of these key concepts in adaptation of existing properties to climate change, as well as in their application to the appropriate design of new build housing.

3.3.1.2.1 Housing: Construction Type

The thermal mass of a building must be considered as it can be used to control thermal peaks in the internal environment. Thermal mass reduces the thermal swings due to daytime warming and night time cooling, and lessens the need for fuel or electricity to regulate temperature. For example, where a property has a high thermal mass, internal peaks in temperature can be reduced by up to 3°C (Hacker et al, 2005). In addition, exposed thermal mass can also provide radiative cooling, improving occupant thermal comfort.

Further to this Hacker (2005) suggests that a significant improvement in comfort can be achieved in the internal environment of the living rooms of new build houses, used during the day and evening, where increased thermal mass was present. The contrary was found to be true for bedrooms where lower thermal mass enabled the building to respond more quickly to the cooler and more comfortable temperatures of the night. These findings reflect the thermal capacity and the thermal resistance of the material in question. For example, the conduction of heat through a dense masonry wall may take up 12 hours.

3.3.1.2.2 Housing: Ventilation

As was the case for the winter, the appropriate design of ventilation is necessary in enabling the achievement of a comfortable internal environment. Again the control of ventilation in the domestic environment is generally achieved through natural ventilation and a combination of trickle vents, air bricks and openable windows. However, it is increasingly common for occupants to utilise mechanical ventilation in the form of fans to improve ventilation rates and airflow in the internal environment during periods of excess heat. Building integrated mechanical ventilation is generally only available where humidity is high, such as in kitchens and bathrooms, and the increased ventilation rates such as these extract fans can provide are now required by building regulations in these locations (ODPM, 2000). Hacker (2005) suggests however, that benefit to occupant comfort is only likely to occur where internal temperature is 3°C higher than external and that natural ventilation should be limited where external temperatures exceed 30°C.

In addition, the domestic market is becoming increasingly targeted by the air conditioning industry, being seen as a potential new and expanding market for their products (Graves and Phillipson, 2000). This is supported by a trend for sales of single room air conditioning units being increasingly accessible to the domestic market through high street electrical stores and DIY chains.

3.3.1.2.3 Housing: Insulation

The provision of adequate thermal insulation in the built environment helps to control heat gain to a building during the summer months. However, thermal insulation can also result in heat being trapped in a building, where adequate ventilation is not provided to flush the heat from the building.

3.3.1.2.4 Housing: Orientation

As was acknowledged in section 3.2.1.2.5, solar gain in a home is related to its orientation, especially in relation to most frequently occupied rooms. However, where the risk is due to excess heat, the objective is to minimise solar gain into a property. Therefore, where a space is subject to solar gain during the summer period it may be necessary to provide solar shading to prevent excessive solar gains to the living areas. This can be achieved in a number of ways including roof overhang, fixed shades, blinds, shutters or louvres, moveable shading or vegetation.

3.3.1.2.5 Neighbourhood: Access to External Space

Access to external space, including private gardens, parks, countryside or beaches, can contribute to thermal comfort during periods of excess heat. This is a direct association with adaptation strategies characterised within the theory of adaptive thermal comfort. Proximity and physical access to external space can be characterised through measures of distance to public space as well as ownership or access to private gardens or balconies.

3.3.1.2.6 Excess Heat: Pathway Factors

The housing pathway variables that influence the occupant health and comfort risk system for excess heat are therefore:

- Housing:
    - Construction Type
        - Thermal Mass
    - Ventilation
        - Facility for natural ventilation
        - Facility for mechanical ventilation.
    - Insulation
    - Orientation
        - Solar Gain
        - Solar Shading
- Neighbourhood:
    - Access to External Space

3.3.1.3 Receptor

The exposure factors in relation to the occupant health and comfort risk system for excess heat are defined as those aspects of the receptor that influence their vulnerability to the risks described above. It should be noted here that much less information is available concerning receptor behaviour and vulnerability in relation to excess heat in comparison to the situation for inadequate heat.

3.3.1.3.1 Age

As was the case for inadequate heat, the age of housing occupants has a significant bearing on their vulnerability to the health and comfort risks associated with excess heat, being especially valid for elderly occupants as well as other more vulnerable populations such the very young (Burridge & Ormandy, 1993, Keatinge & Donaldson, 2000, Collins, 2000, Krieger & Higgins, 2002). The elderly and the very young both have reduced tolerance to temperature extremes and are therefore at greater risk from this hazard (Collins, 1993, WHO-Europe, 2003). For example, this was the case in 2003, where elderly and vulnerable occupants of Paris and London were particularly at risk to the effects of a summer heatwave (WHO – Europe, 2003)

3.3.1.3.2 Socio-economic Status

Further to the wider influence of socio-economics status on occupant health, access to external space, including private gardens, parks, countryside or beaches, can contribute to thermal comfort during periods of excess heat. Due to associated transport requirements and accessibility these may be limited by socio-economic status.

3.3.1.3.3 Socio-Economic: Household Composition

As was the case for inadequate heat, further complication in the achievement of thermal comfort in the home may be disagreement between housing occupants, where anecdotal evidence may suggest similar disagreement between the sexes with regards thermal comfort. While overcrowding remains a valid concern and health risk for housing occupants during periods of excess heat. Indeed heat gain due to higher occupancy rates will directly contribute to the problem, where heat gain from an occupant would be in the region of 40 - 200 Wm^{-2}, depending on activity levels (CIBSE, 2006, p1.6).

3.3.1.3.4 Existing Health: Presence of Long Standing Illness

The presence of long standing illnesses also has an influence on the vulnerability of an occupant to the risks associated with excess heat (Collins, 1993, p135, DoH 2004, p4) and again its relationship with mental health and access to housing remains valid (McCarthy et al, 1985, Smith et al, 1992, Sturm & Gresenz, 2002). It should be noted here that the wider relationship between health and housing remains valid for all aspects considered in this chapter.

Those vulnerable to death from the cold are similarly at risk during heatwaves, where the health based confounding variables are considered to be influenza and other respiratory infections (WHO-Europe, 2003a, 2003b). It should also be noted that few of the deaths are attributed directly to heat. The majority of the increases in mortality are in the most vulnerable proportions of the population and are due to respiratory disease, heart attacks, cardiovascular problems, strokes and cerebrovascular disease (WHO-Europe, 2003a, 2003b).

3.3.1.3.5 Inadequate Heat: Receptor Factors

The occupant receptor variables that influence the occupant health and comfort risk system for inadequate heat are therefore:

- Age:
    - including the very young and very old
- Socio economic:
    - Status
    - Household composition:
        including occupant sex and occupant density / overcrowding
- Existing health:
    - Presence of long standing illness

3.3.1.3.6 Receptor-Pathway Interaction: Behaviour

As was the case for thermal comfort in relation to inadequate heat, occupant behaviour in relation to clothing level, activity level and an individual's acclimatisation to a given environment, will influence their thermal comfort level for a given situation of excess heat. In addition an occupant's behaviour in relation to the use of spaces in the home may influence occupant thermal comfort during periods of excess heat. For example, retiring to rooms on the northerly aspect of a property, where the rooms are likely to be cooler would result in increased thermal comfort. This is often limited by fixed purposes for spaces such as kitchens, bedrooms and living rooms, and especially in smaller homes.

It should be noted here that occupant interaction with ventilation in the home during both day and night is highly significant in relation to the internal thermal environment achieved within homes with the potential to alter the thermal performance of a home. It is suggested by Hacker et al, (2005) that opening windows is counter productive where the external temperature exceeds or is approaching internal temperatures. For example, during modelling, Hacker et al employed an algorithm to their maximise the cooling potential from ventilation, whereby a ventilation rate of 6ACH was applied to a space only when the room was occupied and the internal temperature was more than 3°C higher than external air temperature. However, during the summer, opening windows is likely to be the natural reaction of building occupants in order to freshen the internal environment. Such contradictions between actions and the actual achievement of a comfortable environment must be acknowledged.

The use of night time ventilation of buildings to flush away heat gains from the day time, allowing the fabric of the building to cool, may be impractical where security issues may prohibit such actions; while the same issues related to neighbourhood factors may further influence the use of natural ventilation for cooling during the day. Physical insecurity can also impact negatively on health in relation to housing. The occupant perception of safety and security in the home as a result of the threat of human intruders, physical assault, burglary and theft are a further health threat to housing occupants (Ranson, 1991).

Finally, an occupant's application of solar shading, such as through the use of curtains, blinds, shutters or awnings in a home, can have an influence in reducing thermal gain to the internal environment of a home.

3.3.1.4 Current Risk

The current risk to occupant health and comfort as a result of excess heat can be described in the following problem map. As was the case with risk in previously described systems the relationship between the source and pathway should be considered to be influenced by the microclimate around the home. The interaction between the receptor and the pathway is again non-linear, with the occupant's socio-economic status potentially affecting affordability of housing and therefore tenure, and occupant behaviour again influencing the performance of the pathway. It should be noted here that this problem map also includes wider influence on ventilation behaviour due to the central relationship between occupant comfort and health when at risk of excess heat as described

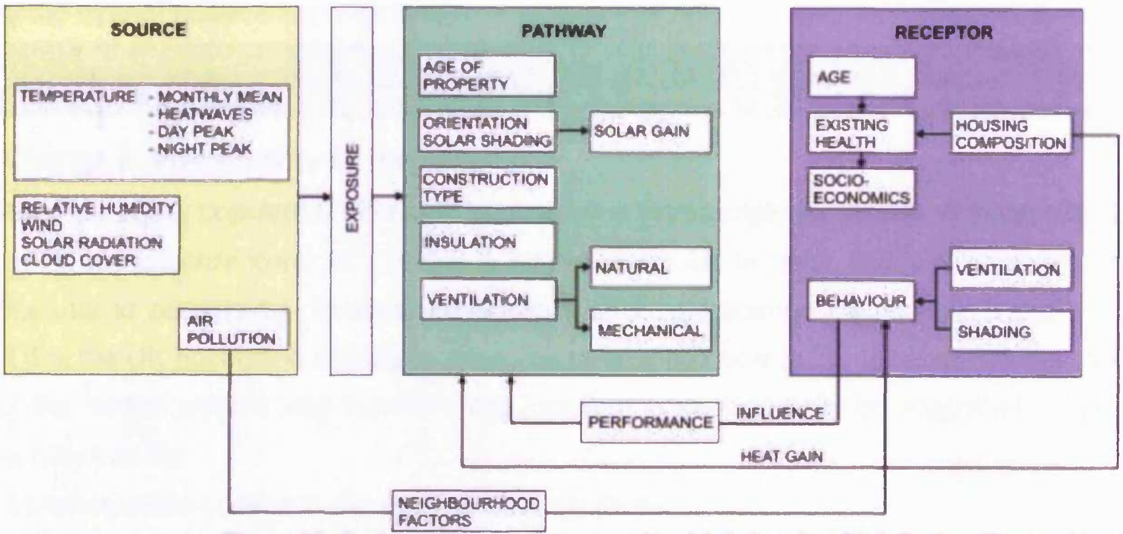


Figure 90: Problem Map for Occupant Health & Comfort Risk Factor: Excess Heat

3.3.1.5 Future Risk

Having identified the current risk system due to excess heat for housing occupants in south Wales, it is now necessary to identify the potential for change over the coming decades in relation to UKCIP02 climate change scenarios and likely drivers for change to the pathway and or receptor.

Likely Change in Source

Climatic Variable		Climate Change Scenario	Scale of Change	Impact on Risk
Temperature	Daily Average	Increase	2.5 – 5°C	Negative
	Daytime Max	Increase	Days Warm More than Nights	Negative
	Night-time Max	Increase		Negative
Heatwaves		Increase	No Data	Negative
Relative Humidity		Decrease	-6 to 12%	Positive
Daily Average Wind		Increase	+3%	Positive
Cloud Cover		Decrease	- 8 to -15%	Negative

The increase in incidence of heatwaves together with the increase in average, daytime maximum and night-time maximum temperatures, together with a decrease in cloud cover, will result in an increased incidence of excess heat. However, the slight increase in wind regime will mediate this to some extent. This would be mitigated by exposure due to microclimatic influences, such as urban or suburban locations. Cumulatively it is certain that the likely influence of climate change on occupant health and comfort will be negative, leading as is would to an increase in internal temperatures.

Anticipated total influence of Source on Occupant Health & Comfort: Negative

---

Likely Change in Pathway

The installation of insulation in both roofs and walls will have some influence in preventing heat gain to properties, however as suggested by Hacker et al, 2005, this will have limited influence on thermal comfort during excess heat events. No other influences on the pathway relevant to risks due to excess heat have been identified. This suggests that the future changes to the pathway are neither positive nor negative.

Anticipated total influence of Pathway on Occupant Health & Comfort: Neutral

---

Likely Change in Vulnerability or Receptor

An increasingly aging population will result in occupants increasingly vulnerable to excess heat, however, trends towards lower occupancy densities will result in lower levels of heat gain in properties due to occupancy. Broader implications of climate change relating to excess heat suggest that the UK population is likely to spend more time outdoors in the summer months as a result of the 'better' climate and therefore this increase in exposure will be magnified. These changes may include:

- Lunches eaten outside in the peak of UVB exposure
- Clothing that exposes more of the body
- Increase in outdoor leisure activities
- Increase in sunbathing

The health effects of this increased exposure could include: skin cancers, ocular cataracts and the impairment of immune functioning (DoH, 2001 & de Gruijl, 2000). This could lead to an increase of up to 5000 cases of skin cancer per-year (DoH, 2001). Although it is acknowledged that the current heatwave plan also defines the responsibilities of the relevant health and social services bodies, including surveillance and reporting of heat-related illnesses, provision and notification of three day forecasts in relation to thresholds and duration of heatwaves, as well as issuing of advice to the public and to health and social service professionals in affected regions (DoH, 2004). It is therefore suggested that if current trends continue, the likely change in vulnerability or receptor will result in increased occupant vulnerability, mainly due to health impacts from increased use of external spaces. .

Anticipated total influence of Receptor on Occupant Health & Comfort:	Negative

Likely Change in Occupant Risk

In combination it is expected that the occupant health and comfort risk due to excess heat will be increased as a result of climate change and other changes over the coming century.

Anticipated total Future Change in Risk on Occupant Health & Comfort:	Negative

3.3.2 Risk Factor: Noise

The risk factor to be considered here is noise in the built environment, where noise is defined as any unwanted sound (Race, 2005). The risks to occupant comfort and health associated with this risk factor can be identified from literature as:

Discomfort

Where ambient noise levels are perceived to be excessive and / or uncontrollable, perceived thermal comfort levels will be lower (Mant & Muir Gray, 1986). Noise at night can also result in sleeplessness and therefore tiredness the next day (Krieger & Higgins, 2002). Noise is a significant causal factor in the perception of human comfort in a location, including that found within a domestic setting. A UK national survey found that nearly one third of housing occupants reported environmental noise spoiling their home life to some extent, with road traffic noise being the most significant noise source. While approximately 18% of respondents to the Survey of Public Attitudes to Quality of Life and to the Environment stated that they regularly closed their windows due to excessive noise (National Statistics, 2002).

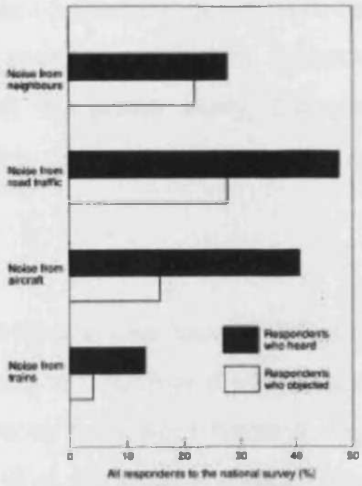


Figure 91: Percentage of Respondents to the National Noise Attitude Survey Who Heard and Objected to the Main Categories of Noise

Grimwood (1993) identified three levels of noise that he characterised as enjoyed, acceptable or unacceptable.

Typical reaction to the noise	Types of Environmental Noise
Enjoyed, appreciated or welcomed	• Birds, children, laughter • A degree of noise from neighbours providing a sense of human contact (some respondents only)
Accepted or tolerated (Unlikely to result in significantly adverse reaction)	• A degree of road traffic, occasional parties • Lawn-mowing or DIY at reasonable hours • Dog barking for a short time (unless the dog sounds maltreated) • Deliveries of post, milk, newspapers
Unacceptable (Likely to result in adverse reaction)	• Loud continuous noises which will apparently go on indefinitely, e.g. heavy traffic noise throughout the day and night • Noises thought to be unnecessary or due to inconsiderate acts, e.g. loud music (especially at night), car engines revving up, shouting, doors slamming • Noises of unknown duration or which have gone on longer than expected, e.g. building work with no foreseeable completion date, burglar/car alarms left operating • Noises with uncertain cause or source, e.g. hums, whines, rattles, unusual animal noises, unexpected noises outside (especially at night) • Emotive or frightening noises, e.g. children crying or screaming, neighbours arguing or shouting, and particularly, violent domestic rows.

Table 42: Typical Reactions to Environmental Noise (Source: Grimwood, 1993)

The reactions to noise are mostly emotional and can range from annoyance, anger, anxiety to resentment. The consequences in the home as a result of environmental noise include disruptions to normal activities including sleeping, resting and listening to TV and radio (Grimwood, 1993).

Further to this, there has been found that an interrelationship exists between noise and thermal comfort (Clausen et al, 1993, Gunnarsen & Santos, 1998, Pellarin & Candas, 2003, Horrie et al, 1985). These findings contradict earlier findings by Fanger et al, (1977), that reported there was no impact on thermal comfort as a result of noise or colour. The interrelationship appears to be complex, whereby acoustic unpleasantness is heightened when thermal comfort or thermo-neutrality is achieved (Pellarin & Candas, 2004). Additionally, in the same study, thermal discomfort was found to be heightened under higher levels of noise, approximate equivalence being given as 1°C for 2.6dBA - 2.9dBA.

Health

Noise has been classified as an environmental pollutant by the WHO and can have significant physical effects on occupants, where physical damage to ears occurs at 130dB and permanent hearing loss can occur where 75dB or more is experienced for more than eight hours a day (Mant & Muir Gray, 1986, Lowry, 1989b, Ranson, 1991, Stansfield et al, 2000). It is unlikely that a housing occupant would experience this sound level regularly in their own home. The literature also suggests that excessive noise, below these thresholds can result in increased blood pressure and heart rate.

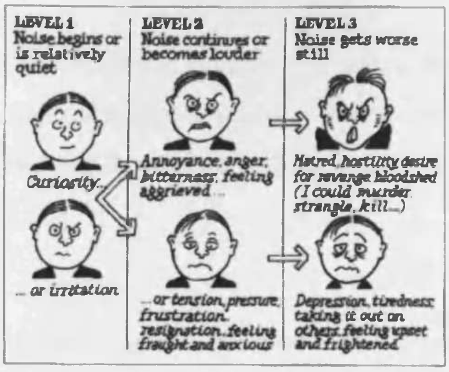


Figure 92: The Noise Reaction Process (Grimwood 1993).

Noise has also been associated with *"sleep deprivation, leading to psychological stress and activation of the hypothalamic-pituitary-adrenal axis and sympathetic nervous system" (Krieger & Higgins, 2002)*. Krieger and Higgins also report that this may lead to stress and strain, or wear and tear to the body, known as allostatic load, as a result of natural response to noise as an environmental stressor. In summary the health impacts of noise in the built environment include:

- Hearing loss[1]
- Increased blood pressure / heart rate[1]
- Cardiovascular disease[4]
- Depression[2]
- Psychological stress[3]
- Psychiatric disorder[4]

Sources:
[1] Mant & Muir Gray, 1986, Lowry, 1989b, Ranson, 1991, Stansfield et al, 2000,
[2] Grimwood, 1993
[3] Krieger & Higgins, 2002
[4] IEH, 1997a.

3.3.2.1 Source

The hazards in relation to the occupant health and comfort risk system for noise are defined as those climatic variables that influence the risks described above. Source and level of noise during the summer months is only indirectly influenced by climate, where hotter temperatures and higher levels of solar gain influence the internal thermal environment, leading to a need to deliver increased levels of ventilation to improve thermal comfort. This is combined with an increased use of external spaces for recreation. Therefore it is suggested that the source or hazard variables are those identified for excess heat as identified in section 3.2.1.

3.3.2.1.1 Noise: Source Factors

The climatic hazard variables that influence the occupant health and comfort risk system for noise are therefore:

- Temperature:
  - Monthly mean average temperature
  - Heatwaves defined as *"a period during which average weekly temps at midday exceed 25°C"*
  - Day and night time peak temperatures
- Relative Humidity
- Wind
- Solar Radiation
- Cloud Cover

3.3.2.2 Pathway

The exposure factors in relation to the occupant health and comfort risk system for noise are defined as those aspects of the pathway that influence the risks described above. These are related to the design and construction of properties as well as neighbourhood factors including: built density, urbanicity and traffic.

3.3.2.2.1 Housing: Type of Property

It has also been found that housing type can be considered an indicator for exposure to noise, where occupants of flats are more exposed to the health and comfort risks from noise, both airborne and impact, than are occupants of houses. Occupants of semi detached houses are lest likely to bothered by or hear noises from their neighbours (Langdon & Buller, 1977). Further to this, the careful design of housing internal layouts, such as using circulation spaces, halls and staircases as buffer zones between homes can also help to minimise noise transmission into occupied zones.

3.3.2.2.2 Housing: Age of Property & Construction Type

Surveys carried out of occupants of post-1947 dwellings with party walls resulted in 7.5% reporting having been bothered by noise from their neighbours. For homes built post-1980 this figure rises to 18% seriously bothered (Mant & Muir Gray 1986). Mant & Muir Gray also noted that noise insulation regulations were at this time modest by international standards. This potentially indicates a considerable impact from noise on housing occupants in the UK. The introduction of minimum noise ratings for both impact and airborne noise transmission for new build homes in the recent Part E of the buildings regulations (ODPM, 2006, p17) is likely to improve this situation in the future, as is the introduction of robust standard details (RSDs) for construction.

3.3.2.2.3 Neighbourhood: Exposure to Noise

One of the central objectives for the planning system is to control noise levels (WAG, 2002, p147, WAG, 1997, Rydin, et al, 2004) as there are a wide range of noise sources in the built environment that can best be controlled at source through appropriate planning of neighbourhoods. This is especially important in more built up areas, such as urban and sub-urban areas where sources of noise are more widespread.

Noise from traffic can be controlled through the installation of traffic calming measures such as roundabouts and low speed limits in urban and suburban areas, while aviation noise sources, a major source of noise pollution in Wales (WWF & Stockholm Environment Institute, 2005) can be controlled by appropriate flight paths (Lowe, 2001). Lowe also suggests that improved public transport can assist through reducing levels of traffic on roads. The appropriate location of play areas, (especially those for older children) can also help to prevent noise pollution (WAG, 1997, p8).

Where these measures of source control are inadequate, barriers between noise sources and the domestic built environment can be introduced. The planting of shelter belts can provide considerable levels of noise control, both attenuating noise by as much as 30 dB per 100 metres and filtering air pollution from motor vehicles, for example by removing sulphur dioxide and reducing particulates by up to 75% (TCPA & Urbed, 2004, Fan & Ling, 2005).

Urbanicity has a wide-spread impact on occupant health, including, elevated intentional injury, poor birth outcomes, cardiovascular disease, HIV, gonorrhoea, tuberculosis, depression, physical inactivity and all cause mortality, in neighbourhoods of lower socio-economic status (Krieger & Higgins, 2002, Nordstrom, 2004, Ross, 2004). It may be that physical features of the neighbourhoods influence this, such as poor air quality due to close proximity to polluting major roads or other sources of pollutants. Additionally, higher levels of noise (see previous consideration under comfort) and improper waste disposal (Joseph, 2004) are widely considered as potential impacts on health. Improvements to neighbourhoods that can increase health include provision of green space and recreational sites and the location of facilities including schools, shops and work within walking distance of homes.

3.3.2.2.4 Noise: Pathway Factors

The exposure variables that influence the occupant health and comfort risk system for noise are therefore:

- Housing:
    - Age of property
    - Building type
    - Construction type
- Neighbourhood
    - Exposure to Noise

3.3.2.3 Receptor

The exposure factors in relation to the occupant health and comfort risk system for noise are defined as those aspects of the receptor that influence their vulnerability to the risks described above. As indicated earlier, occupant behaviour in the face of risks due to noise is also inter-related to their behaviour in relation to excess heat. In addition, Grimwood (1993), identified that people's reaction to noise is dependent on their age, sex, working status, lifestyle and personality.

3.3.2.3.1 Age

Stansfield (2000, p8) reported that (Utley & Keighley, 1989) found that demographic variables including age may be associated with the likelihood of disturbance by noise derived from a neighbour. Utley & Keighley found that adults aged between 25 & 34 are most likely to be disturbed by peoples' voices, radio/TV/hifi, animals and vehicles and occupants aged over 65 least likely to be disturbed by such neighbourhood noises.

3.3.2.3.2 Socio-economic Status

Stansfield (2000) also suggested that incompatibility in terms of lifestyle may influence peoples likelihood to be disturbed by their neighbourhoods. For example, young neighbours with a penchant for loud music may be more likely to disturb elderly neighbours than they would neighbours of the same age or lifestyle. Therefore where occupants share similar lifestyles, they are less likely to be disturbed by noise from this source (Stansfield, 2000, p46). It may be further hypothesised that work status is also likely to influence this relationship, for instance, students and working families may be incompatible in terms of noise based disturbance.

3.3.2.3.3 Other

Sex:

Males are more likely to have reactions to noise which are outwardly aggressive, directed towards the source of noise, describing their feelings as annoyance, anger, and aggravation, while women are more likely have an internalised reaction to noise, which can be characterised by phrases such as tense, pressured and anxious (Grimwood, 1993).

Locus of Control

The locus of control is a personality construct which has been found to be related to reaction and vulnerability to external noise sources. Stansfield (2000, p11), reports a breadth of literature which finds that those occupants with an external locus, who attribute the actions of others to chance or fate, are more likely to express annoyance as a result of noise. A second factor in relation to occupant vulnerability to noise is related to their expectations for the auditory environment. For example, Cinderby & Forrester (2005) found that although comparable noise levels existed in two locations, an inner city location and in a park, people were more likely to accept the noise level in the city centre, where higher levels of noise may be expected than they were to accept this level in a park. This is associated to the findings reported in section 3.2.2, where the reaction to a type of noise was related to its frequency and longevity.

3.3.2.3.4 Noise: Receptor Factors

The exposure variables that influence occupant health and comfort risk system for noise are therefore:

- Age
- Socio-economic
    - Status
- Other
    - including sex, personality and expectation

3.3.2.3.5 Receptor-Pathway Interaction: Behaviour

With reference to section 3.2.1 and 3.2.2.1, it has been suggested that occupant behaviour in the face of noise is likely to be inter-related with the thermal environment, where occupants may be less likely to open their windows in the presence of uncomfortable noise environment, thus influencing the thermal environment in a property. Occupants are more likely to occupy the external environment, potentially increasing environmental noise sources. In addition, occupant opening of windows may increase the noise pollution in the external environment, as homes would become a greater source of environmental noise.

3.3.2.4 Current Risk

The current risk to occupant health and comfort as a result of noise is expressed in the following problem map. In this risk system, the relationship between the risk factor of noise and the source factors is secondary, influencing as it does the internal and external thermal environment. This in turn influences occupant behaviour in relation to use of external spaces as well as in terms of interaction with the ventilation system in the home, for example opening windows and doors. The relationship between the receptor and the pathway is then again two way, where the use of ventilation affects the performance of the pathway to mitigate impact and airborne noise and the pathway influences the receptors exposure to the noise related risks.

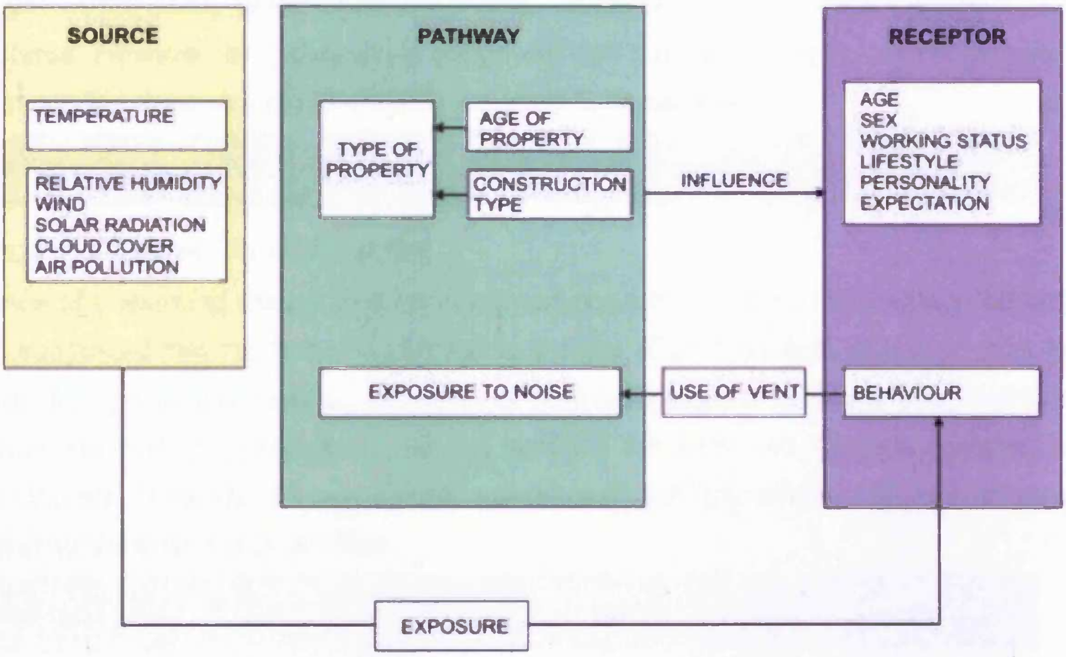


Figure 93: Problem Map for Occupant Health & Comfort Risk Factor: Noise

It must be noted here that although noise is also present as a risk factor for occupant comfort and health during the winter months, it has not been considered here as a separate risk to health in the winter as it is unlikely that the associated health and comfort risks due to noise during this period would be influenced by the changing climate.

3.3.2.5 Future Risk

Having identified the current risk system due to noise for housing occupants in south Wales, it is now necessary to identify the potential for change over the coming decades in relation to UKCIP02 climate change scenarios and likely drivers for change to the pathway and/or receptor.

Likely Change in Source

As per excess heat:

Anticipated total influence of Source on Occupant Health & Comfort: Negative

Likely Change in Pathway

Although new housing is being designed with greater consideration of noise transmission, existing properties will continue to form the majority of homes in Wales, many of which have poor performance in terms of noise. Further to this, the current trend for personal transport and car use does not show signs of abating and therefore traffic noise is unlikely to reduce. In addition, new housing construction is being focussed on brownfield, inner city and urban locations, with associated higher external noise levels, which may be further enhanced by the move towards 24 hour use of city centres as well as the extended house of pub and restaurant licenses (Lowe 2001). The government's 'Quality of Life' indicators include: No. 7: Tackling Community Safety: including drug-related crime and noise nuisance (www.audit-commission.gov.uk/pis/quality-of-life-indicators.shtml), suggesting an acknowledgement for action in this area. However, on balance it is suggested that the future changes to the pathway for health and comfort risks as a result of noise are likely to be negative.

Anticipated total influence of Pathway on Occupant Health & Comfort: Negative

Likely Change in Vulnerability or Receptor

In the presence of a warming climate and an enhanced need for ventilation to promote thermal comfort, it is suggested that the likely trend towards the use of gardens and outside spaces as outside rooms during summer months, will result in increased external noise source. Together with noise from the internal environment, this will increase the likely level of noise pollution in the built environment. However, an increasingly aging population may result in less annoyance as a result of environmental noise pollution.

Anticipated total influence of Receptor on Occupant Health & Comfort: Negative

Likely Change in Occupant Risk

In combination it is expected that the occupant health and comfort risk due to noise will be increased as a result of climate change and other changes over the coming century.

Anticipated total Future Change in Risk on Occupant Health & Comfort: Negative

3.3.3 Risk Factor: Pests & Vermin

The risk factor to be considered here is that resulting from pests and vermin in the built environment. The risks to occupant comfort and health associated with this risk factor can be identified from literature as follows.

Comfort

A number of insect pests, including mosquitoes, wasps and bees, are only likely to enter the home by accident, to shelter or to forage for food (Ranson, 1991, Howard, 1993). They are unlikely to pose any significant health threat to housing occupants, although their presence may result in discomfort, especially where insect bites occur as a result.

Health

Intrusion of health vectors, such as cockroaches, rats and mice, can be a major health impact on poor or badly designed housing (Krieger & Higgins, 2002). Homes provide an ideal environment for a wide variety of pests including insects and vertebrates (Ranson, 1991, Howard, 1993). The health risks that these pose to the human occupants are also broad, including direct health effects (such as blood parasites), indirect effects (vectors for diseases) and finally through causing damage to the environment (food, furniture, clothing and building structure).

Cockroaches and house flies are found in UK homes due to the attraction of human food. They pose direct health risks, mainly as a result of their attraction to food as well as waste products and sewage. They are therefore both the vectors of micro-organisms that cause food poisoning and the transmission of other human diseases. For example, 29 pathogens have been found to be spread by cockroaches that are known causal factors for food poisoning, wound infections, gas gangrene, typhoid, dysentery, pneumonia and leprosy (Howard, 1993). The relationships between cockroaches and the spread of these diseases have not been conclusively proven, however, it is suggested that epidiemiological evidence does reinforce the vector potential of cockroaches. Further to this, both Howard (1993) and Hwang et al (1999) report that literature has linked cockroaches with allergic reaction, ranging form mild hay-fever like symptoms through to anaphylactic shock as well as respiratory tract infections and asthma, with a strong to definitive casual link.

The health impacts of rats include roundworm, tapeworm, possible food contamination (and resultant food poisoning) as well as leptospirosis (Weils disease) from contact with their urine (Ranson, 1991, Arblaster & Hawtin, 1993, Howard, 1993). Rats are also secondary vectors of tropical rat fleas that are in turn vectors of plague between rats and humans (Howard, 1993). The potential of mice as disease vectors is similar to that of rats.

House dust mites have a strong or definitive causal association with asthma (Hwang et al, 1999). 1% of population displays allergic reaction to both and 5% show less severe symptoms as a result of exposure to house dust mites (Mant & Muir Gray 1986, Krieger & Higgins, 2002). Pests and vermin that can thrive in homes and their associated health risks include:

Lice	Human clothing or body louse Human head louse Crab louse	• Allergic reactions • Vectors of exanthematic typhus and trench fever
Bedbugs		• Allergic reactions

Fleas	Human flea	• Allergic reactions
	Dog flea	• Vectors of plague and murine typhus
House Flies		• Food poisoning
Cockroaches		• 29 pathogens including those for food poisoning, wound infections, gas gangrene, typhoid, dysentery, pneumonia and leprosy • Allergic reaction • Respiratory tract infections • Asthma
Rats & Mice		• Roundworm, tapeworm, possible food contamination (& resultant food poisoning) • Leptospirosis (Weils disease)
House Dust Mites		• Asthma

It is also possible that stress may be induced as a result of vermin infestation either directly or indirectly. Indirect impact may result from noise caused by death watch beetle or rodents may be loud or disturbing enough to disrupt sleep, although no reference to this as a health risk has been found. In addition, a number of mites, spiders and ticks have health consequences for humans. However, they are not usually considered to be related to housing and are therefore not considered herein.

3.3.3.1 Source

The hazards in relation to the occupant health and comfort risk system for pests and vermin are defined as those climatic variables that influence the risks described above.

3.3.3.1.1 Relative Humidity

Oreszczyn & Pretlove, (2000) suggest that house dust mites require an immediate environment with an RH of 75-80% while elsewhere an association with ambient RH levels of above 50% is suggested (Arlian, 1992, Hwang et al, 1999, Clarke et al, 1999, Howieson & Lawson, 2000, Pretlove et al, 2001, Bornehag, et al, 2003, Sheikh & Hurwitz, 2004).

3.3.3.1.2 Ambient Temperature

House dust mite proliferation is related to temperatures in the range of 17°C-25°C (Arlian, 1992, Hwang et al, 1999, Clarke et al, 1999, Howieson & Lawson, 2000, Pretlove et al, 2001, Bornehag, et al, 2003, Sheikh & Hurwitz, 2004).

3.3.3.1.3 Pests and Vermin: Source Factors

In addition to RH and temperature identified above it is suggested that all variables associated with excess heat and inadequate ventilation should also be considered to be associated with pests and vermin as access to the home for many of the flying insects is enhanced where windows are left open in order to provide ventilation or relief from excess heat. The climatic hazard variables that influence occupant health and comfort risk system for pests and vermin are therefore:

- Temperature:
    - Monthly mean average temperature

    - Heatwaves defined as *"a period during which average weekly temps at midday exceed 25°C"*
    - Day and night time peak temperatures
- Relative humidity
- Wind
- Solar radiation
- Cloud cover

3.3.3.2 Pathway

The exposure factors in relation to the occupant health and comfort risk system for pests and vermin are defined as those aspects of the pathway that influence the risks described above. These are related to the housing design as well as those associated with the neighbourhood.

3.3.3.2.1 Housing: Age of Property & State of Repair

Cockroaches prefer warm and damp conditions to inhabit and it has been found that post-WWII housing is most likely to provide appropriate conditions (Arblaster & Hawtin, 1993). The presence of condensation is likely to promote the presence of dust mites (Mant & Muir Gray 1986, Krieger & Higgins, 2002). This suggests that consideration of those factors relating to damp and mould in a property should be taken into account here. Structural defects can also increase the likelihood of intrusion by vertebrate pests including rats and mice, with their associated health risks. A consideration of those pathway factors identified for material and structural damage (Howard, 1993).

3.3.3.2.2 Neighbourhood: Exposure to Water & Pollution

Neighbourhood factors associated with pests and vermin are considered here to relate to the presence of breeding or nesting grounds in proximity to homes, which would allow access into housing. These are defined here as bodies of slow moving or stagnant water, breeding grounds for many insects, as well as adequate refuse storage, rubbish tips and scrub land, where small mammals may be able to nest and breed. Neighbouring land use and the surface configurations of freshwater should therefore be considered in this relationship. At a domestic scale ponds and water butts as well as compost bins and bins for other waste may provide appropriate habitats. For example, the presence of rats is frequently related to the presence of poor facilities and or bad practice in relation to food storage, together with incorrect disposal of rubbish (Ranson, 1991, Arblaster & Hawtin, 1993, Howard, 1993). The prevention of house fly and cockroach vector transfer of disease, as well as their presence, is also closely linked to good refuse control and storage (Arblaster & Hawtin, 1993).

3.3.3.2.3 Pests and Vermin - Pathway Factors

The exposure variables that influence the occupant health and comfort risk system for pests and vermin are therefore:

- Housing:
    - Age of property
    - State of repair
    - Construction Type
- Neighbourhood factors
    - Exposure to Wind
    - Exposure to Water / Pollution

Proximity of potential breeding / nesting grounds for pests and vermin

3.3.3.3 Receptor

The exposure factors in relation to the occupant health and comfort risk system for pests and vermin are defined as those aspects of the receptor that influence their vulnerability to the risks described above. As indicated earlier, occupant behaviour in the face of risks due to pests and vermin are inter-related to their behaviour in relation to excess heat and inadequate ventilation.

3.3.3.3.1 Existing Health: Presence of Long Standing Illness

Allergens in the environment (including the presence of house dust mites) can trigger asthma attacks as well as allergic response in sensitive individuals.

3.3.3.3.2 Socio-economic: Status

Howard (1993) reported that hypersensitivity to cockroach infestation has been found to be inversely related to socio-economic status.

3.3.3.3.3 Pests and Vermin: Receptor Factors

The exposure variables that influence occupant health and comfort risk system for pests and vermin are therefore:

- Socio-economic:
    - Status
- Existing Health:
    - Presence of Long Standing Illness

3.3.3.3.4 Receptor-Pathway Interaction: Behaviour

Prevention of house fly and cockroach vector transfer of disease, as well as their presence, is also closely linked good hygiene, through preparation, storage and disposal of food (Arblaster & Hawtin, 1993). House dust mite proliferation is often concentrated in mattresses, upholstered furniture and carpets, where frequent vacuum cleaning has been found to reduce exposure levels (Arlian, 1992, Hwang et al, 1999, Clarke et al, 1999, Howieson & Lawson, 2000, Pretlove et al, 2001, Bornehag, et al, 2003, Sheikh & Hurwitz, 2004). The removal of carpets and installation of solid flooring can remove this breeding ground. It has also been found that indirect health impacts can occur as a result of the pesticides used to eradicate infestations, as well as from the stress and inconvenience caused by their identification (Arblaster & Hawtin, 1993, Hwang et al, 1999). This will be influenced by occupant behaviour in the hours following treatment, where vacating a property for a period of time following treatment can prevent such impacts. In addition, as was stated previously the relationship to factors associated with material and structural damage as well as damp and mould should not be omitted.

3.3.3.4 Current Risk

The current risk to occupant health and comfort as a result of pests and vermin is illustrated by the following problem map. In this risk system, the relationship between the risk factor of noise and the source factors is both primary and secondary, where RH and ambient temperature influences the presence of some pests, while other factors influence behaviour in relation to use of ventilation. The relationship between the receptor and the pathway is then again two way, where the use of ventilation affects the performance of the pathway to prevent intrusions by pests and vermin, while pathway factors influence the receptors exposure to the pest and vermin related risks.

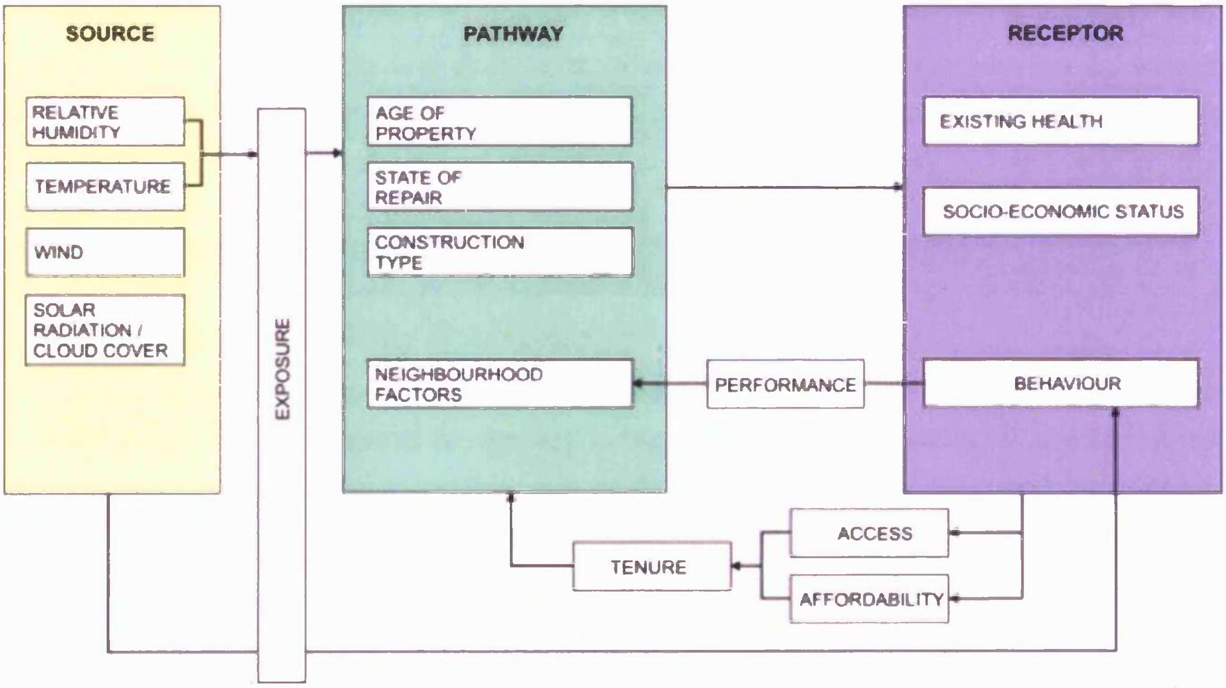


Figure 94: Problem Map for Occupant Health & Comfort Risk Factor: Pests & Vermin

It must be noted here that, as was the case for risk due to noise, pests and vermin are also present as a risk factor for occupant comfort and health during the winter months. Again they have again been considered here as a separate risk to health in the winter as it is considered less likely that the associated health and comfort risks due to pests and vermin during this period would be influenced by the changing climate.

3.3.3.5 Future Risk

Having identified the current risk system due to pests and vermin for housing occupants in south Wales, it is now necessary to identify the potential for change over the coming decades in relation to UKCIP02 climate change scenarios and likely drivers for change to the pathway and or receptor.

It should be noted initially that the presence and increased number of nuisance mosquitoes, flies, midges and fleas together with the potential for increased spread of Weil's disease, should be considered likely in the light of climate change (DoH, 2001). While the existing presence of ideal conditions for their breeding and proliferation, (warmth and humidity) is unlikely to be altered significantly under climatic change. At present it is considered that climate change will also cause an increase in localised incidence of tick borne diseases and malaria in the UK, although their impact on public health is likely to be small (DoH, 2001).

Likely Change in Source

As per excess heat:

Anticipated total influence of Source on Occupant Health & Comfort: Negative

Likely Change in Pathway

The author is not aware of any changes in legislation that are likely to alter the pathway for this vector, although current debate over changes to waste collection from weekly to fortnightly rates due to alternate weekly recycling collections, driven by the need comply with the EU Landfill directive, may serve to provide increased habitat and food for pets and vermin in the domestic environment. It is therefore suggested that future changes to the pathway for health and comfort risks as a result of pests and vermin are likely to be negative.

Anticipated total influence of Pathway on Occupant Health & Comfort: Negative

Likely Change in Vulnerability or Receptor

The presence of a warming climate and an enhanced need for ventilation to promote thermal comfort may result in increased access to the home for pests and vermin. In addition, it has been suggested that a move towards outside living, which may be facilitated by improved summer weather, may also increase the pathway for pest and vermin interaction with food stuffs, increasing health risks due to pests and vermin, as well as food poisoning from inadequately stored meat and fish products for outdoor cooking (DoH, 2001). It is therefore again suggested that changes in behaviour may also increase the risk due to pests and vermin.

Anticipated total influence of Receptor on Occupant Health & Comfort: Negative

Likely Change in Occupant Risk

In combination it is expected that the occupant health and comfort risk due to pests and vermin will be increased as a result of climate change and other changes over the coming century.

Anticipated total Future Change in Risk on Occupant Health & Comfort: Negative

Much research has been undertaken to establish whether the distribution of a number of vector borne diseases, currently absent from the UK, will be altered as a result of climate change (Marten P, 1999, DoH, 2001). The distribution of vector borne disease is influenced by both land use and the prevailing climate. Changes in land use, such as increased irrigation, agricultural land laid to rest (vector refugia) and deforestation, the introduction of new crops and invasive species, can alter the places in which vectors can live and breed. Meanwhile, the changes anticipated under climate change (wind, humidity, temperature and rainfall) are likely to further affect the distribution of these vectors and therefore their associated disease distribution. The current distribution of a number of these diseases is described below.

Disease	*Classification*	*Vulnerable Regions*
Malaria	Formerly widespread	Mediterranean, former USSR, Turkey
Leishmaniasis	Locally endemic	Southern France, Spain, Portugal, Italy
Tick Borne Encephalitis	Locally endemic	Former USSR, Eastern Europe, Southern Scandinavian coastlines
Lyme Disease	Emergent	Northern Europe
Dengue	Emergent	Southern Europe, Italy, Balkans

Table 43: Vector Borne Disease in Europe (Source: DoH, 2001)

At present the climate, frequently the cold winters, represent an upper limit on distribution of some diseases and therefore increasing average temperatures and milder winters will allow redistribution of both vector and disease in parts of Europe hitherto unaffected (Marten P, 1999). More specifically, those vector borne diseases distributed by mosquitoes and ticks (i.e. those distributed by blood feeding vectors and caused by parasites, bacteria and viruses) are most likely to increase their distribution in European countries. However, it is not at present considered likely that these diseases would become widespread in the UK. There is the potential for Vivax malaria to become re-established in the UK by approximately 2050, although this is not likely to be a significant cause of public health risk. Rather a localised risk and most likely in low-lying salt marsh areas. The global increase in malarial distribution may result in an increase in P. *falciparum* in travellers (DoH, 2001).

3.3.4 Risk Factor: Inadequate Ventilation

As was the case for risks due to inadequate ventilation during the winter, ventilation during the summer has the purpose of delivering fresh air to occupants for the purposes of respiration, providing oxygen and diluting CO_2, as well as for the removal of contaminants and to deliver a feeling of freshness. The risks to occupant comfort and health associated with inadequate ventilation were identified from literature in section 3.2.1. In addition to those identified previously, inadequate ventilation poses the following additional risks during the summer:

Comfort

During the summer the higher rates of ventilation and air speeds associated with draughts during the winter are more likely to be considered comfortable during the summer (Race, 2005, p5). This is due to the relationship between air movement and its promotion of cooling through evaporation. This can only occur where there is capacity for moisture uptake into the air, for example in the presence of lower levels of relative humidity.

Health

No additional health risks have been identified due to inadequate ventilation than were identified previously, either in section 3.2.2 in relation to risks due to inadequate ventilation in the winter, or through association to those risks identified in section 3.3.1 where risks associated with excess heat were identified. It should be noted here that the occurrence of low level ozone pollution is more frequent during summer months as a result of its close association with solar radiation. They are therefore more likely to occur during the summer leading (as they can) to increased incidence of eye irritation, respiratory tract irritation, reduced exercise capacity and exacerbation of respiratory disease (Kovats, Ebi, Menne, 2003). In addition to this, the level and frequency of natural air pollution sources, mainly due to pollen in the air from flowering plants, is also more extensive during the warmer seasons, resulting in health risks previously identified in section 3.1.2 including the exacerbation of allergic rhinitis, asthma and other atopic diseases (IPCC, 2001b). Both the onset and aggravation of asthma, in particular, have been found to have a strong relationship with external air pollution including natural sources such as pollens (COMEAP, 1995a, COMEAP, 1998, Peden, 2004, O'Connor et al, 2004).

The factors associated with the occupant health and comfort risks due to inadequate ventilation and indoor air quality risks will now be explored and a problem map produced for this risk factor.

3.3.4.1 Source

The hazards in relation to the occupant health and comfort risk system for inadequate ventilation in summer are as those identified for the winter, being climatic variables that influence the risks described.

Climate and weather exert a profound effect on air quality, with the worst episodes of pollution frequently under anticyclonic conditions and or heatwaves where stagnant air occurs (IPCC, 2001b, DoH, 2001). For example, large slow moving anti cyclones can cover an area for a prolonged period of time, which allows a building up of heat and pollutants, particularly where episodes of ozone pollution are particularly prevalent (COMEAP, 1998, Kovats et al, 1999, IPCC, 2001b). This was found during the 2003 heatwave in August 2003, where levels of ozone were recorded to be particularly high, especially in urban locations such as London (Kovats et al, 2003) where it was suggested that air pollution could be blamed for 750 deaths during the episode (The Independent, 2004). The stratospheric depletion of ozone, another human global impact, leads directly to its increase at a low level, where the increase of UVB sunlight reaching the surface (that is normally filtered by stratospheric ozone), plays a major role in the photochemical process that creates the low level pollutant ozone. The prevailing weather conditions can also influence biogenic and anthropogenic air pollutants, for example, through increased pollen production and energy demand (IPCC, 2001b). The air pollutants can have a direct impact on the use of ventilation by as occupants was suggested in sections 3.2.1 and 3.2.2.

The main air pollutants associated with health impacts in the UK are: ozone, sulphur dioxide, acid aerosols, natural particulates (aero allergens - spores and moulds) and man-made particulates, as well as oxides of nitrogen. For example, the pollen counts from birch trees, one of the main causes of seasonal allergies in northern Europe, have been found to increase with rising temperatures (Emberlin, 1997, Ahlholm *et al.*, 1998, in IPCC, 2001b). Episodes of pollution can be divided into three main types (DoH, 2001):

Type 1: Summer Smog	Pollution with the main or indicator pollutant being ozone
Type 2: Vehicle Smog	Pollution with the main or indicator pollutant being oxides of nitrogen
Type 3: Winter Smog	The indicator or main pollutant being sulphur dioxide

Elevated concentrations of particulates may occur during any of the above pollution episodes.

Photochemical air pollution is formed through a simple process whereby sunlight falls on precursor pollutants such as hydrocarbons and nitrogen oxides produced from many sources in the human environment, including road traffic. Conditions that are particularly favourable to this process include: summer months with anticyclonic conditions, long hours of strong sunlight, high temperatures and stagnant air that permits the build up of pollutants and derived photochemical products (DoH, 2001).

3.3.4.1.1 Inadequate Ventilation: Source Factors

The climatic hazard variables that influence the occupant health and comfort risk system for inadequate ventilation in the summer are therefore relative humidity and solar radiation in addition to those factors identified as winter source factors :

- Temperature
- Wind
- Air pollution
- Anticyclones
- Relative humidity
- Solar radiation (cloud cover)

3.3.4.2 Pathway

The pathway factors in relation to the occupant health and comfort risk system for inadequate ventilation during the summer, as those defined for winter in section 3.2.1.2, can again be divided into two factor groupings relating to the ventilation sources and air pollution sources. In addition to those identified for the winter the following pathway factors should be included:

3.3.4.2.1 Housing: Ventilation

The availability of natural ventilation is again limited by building form in relation to the promotion of stack and cross ventilation as well as by neighbourhood factors affecting exposure to wind to drive cross ventilation as well as exposure to air pollution, especially due to local sources such as traffic and local industry as well as natural sources.

During the summer, additional rates of ventilation are often required to achieve thermal comfort and these can be achieved through the use of ceiling, wall or otherwise mounted electrical fans. It has not been possible to establish the breadth of use of fans to enhance ventilation in the domestic environment in the UK, however, availability is widespread through high street and DIY stores across the UK and it may therefore be assumed that their use is similarly broad.

Other forms of mechanical ventilation are not widespread in the domestic environment, other than in the extract applications previously described in section 3.2.1.2. in relation to domestic ventilation legislation and in section 3.3.1.2.2. in relation to the application of ventilation to promote cooling in the face of risks due to excess heat. The application of air conditioning to promote ventilation is also considered briefly in section 3.3.1.2.2.

3.3.4.2.2 Housing: Internal Air Pollution

Air pollution sources in the home are as described in section 3.2.2. In addition it should be noted that release of formaldehyde from the internal environment of homes has been found to be higher during the summer and autumn than in the spring and winter. This was particularly found in rooms with particleboard flooring (Raw et al, 2002).

3.3.4.2.3 Inadequate Ventilation: Pathway Factors

The housing pathway variables that influence the occupant health and comfort risk system for inadequate ventilation during the summer are closely allied to those identified for the winter and can be summarised as:

- Housing:
  - Construction type
  - Ventilation
  - Internal air pollution
- Neighbourhood:
  - Exposure to Pollution
  - Exposure to Wind

3.3.4.3 Receptor

The receptor factors in relation to the occupant health and comfort risk system for inadequate ventilation during the summer are as identified for the winter (refer to 3.2.1.3), as well as those referred to in section 3.3.1.3., especially in relation to use of ventilation (3.3.1.3.5.) in respect to excess heat. No additional receptor factors have been identified.

3.3.4.3.1 Inadequate Ventilation - Receptor Factors

The occupant receptor variables that influence the occupant health and comfort risk system for inadequate ventilation in the summer are as those identified in section 3.2.2.3. and can be summarised as:

- Socio-economic:
  - Status
- Existing health
  - Presence of Long Standing Illness
  - Source of indoor air pollutants

3.3.4.4 Current Risk

The current risk to occupant health and comfort as a result of inadequate ventilation in the summer can be described in the following problem map. As was the case with risk due to excess heat the relationship between the source and pathway is again influenced by the microclimate around the home; while the interaction between the receptor and the pathway is again non linear, with the occupant's socio-economic status potentially affecting affordability of housing and therefore tenure, and occupant behaviour again influencing the performance of the pathway. It can be seen that the interactions between the source, pathway and receptor are closely allied with those identified for both inadequate ventilation during the winter and excess heat during the summer.

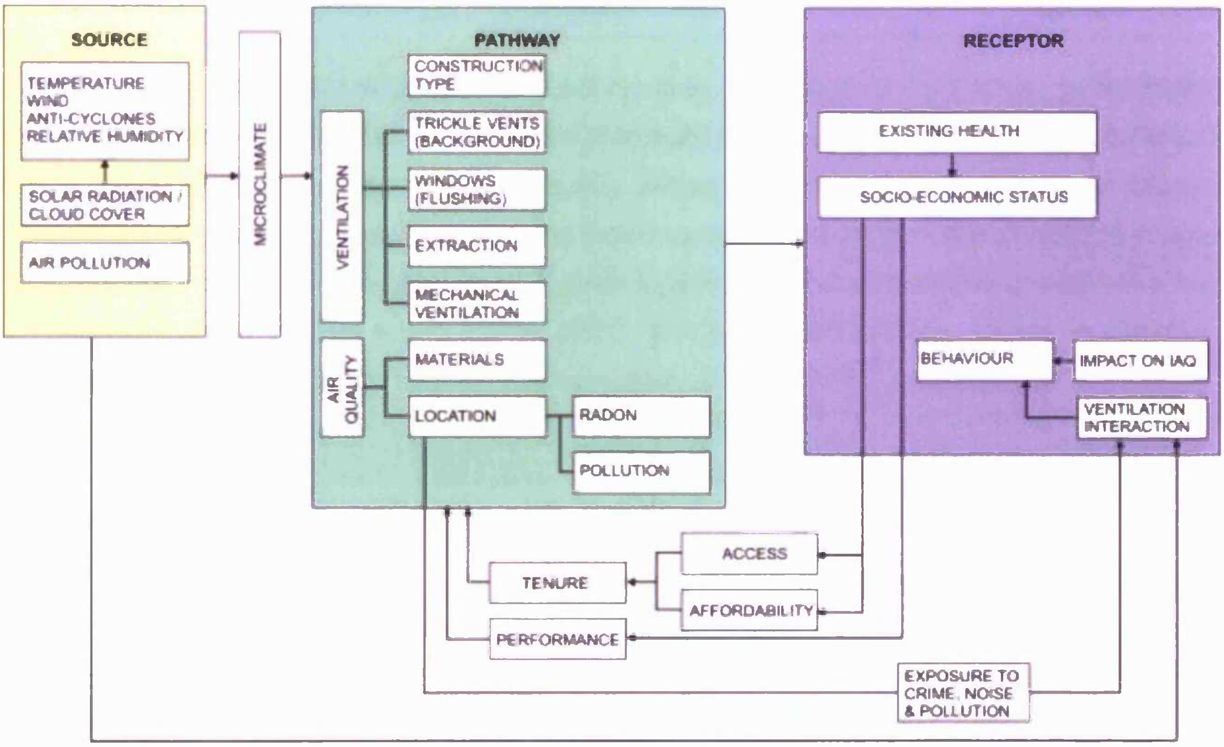


Figure 95: Problem Map for Occupant Health & Comfort Risk Factor: Summer - Inadequate Ventilation

3.3.4.5 Future Risk

Having identified the current risk due to inadequate ventilation for housing occupants in south Wales during the summer, it is now necessary to identify the potential for change over the coming decades. This is undertaken through consideration of the potential changes in the source pathway and receptor. For the source this will be undertaken through reference to section 3.2, where a summary of climate change in NPT under the current UKCIP 02 scenarios is provided. While, in relation to the pathway and receptor, likely change to these over the same period will be considered, relating where possible to current government policy.

Likely Change in Source

Climatic Variable	Climate Change Scenario	Scale of Change	Impact on Internal Environment
Daily Average Temperature	Increase	+2.5 – 5°C	Negative
Daily Average Wind	Increase	+3%	Positive
Air Pollution (Summer Smog)	Increase	Unknown	Negative
Anticyclones	Unknown	Unknown	Neutral
Relative Humidity	Decrease	- 6 to -12%	Positive
Solar Radiation / Cloud Cover	Decrease	- 9 to -15%	Negative

The increase in daily average temperature will result in an increased requirement for ventilation to provide cooling, which is to some extent promoted by the small increase in average wind speed, while the decrease in relative humidity will increase the cooling capacity of the air, promoting evaporative cooling. However, the increase in solar radiation will increase the internal temperatures further through solar gain. Further to this, anticipated increase in summer smog will decrease the overall air quality (DoH, 2001). It is suggested that the change in climate is likely to have a negative impact on the internal environment in relation to ventilation.

Anticipated total influence of Source on Occupant Health and Comfort:	Negative

Likely Change in Pathway

Of particular importance to the built environment is the possibility that climate change may influence and increase radon concentrations in the lower atmosphere. Where ventilation levels may also be affected by global climate change this may significantly impact increased exposure to radon in vulnerable homes (Cuculeanu & Lorgulescu, 1994, in IPCC, 2001b). Meanwhile, increased incidence of thermal discomfort could lead to the increased use of energy in the summer, due to the possibility of increased application of air conditioning plant in the UK, especially in the domestic sector, where air conditioning is currently rarely applied. This adoption of mechanical ventilation and air conditioning technology may be most likely where occupants strive to adhere to the more strictly controlled environments experienced in many controlled office environments, rather than the wider adaptive, socially and culturally constructed notion that exists at present (Chappels & Shove, 2003, Sanders & Phillipson, 2003). It is not anticipated that this would be significantly widespread, especially not in new build homes where energy use for cooling would negatively influence performance to meet Part L. SAP calculations for current new build homes also pay lip service to ensuring thermal comfort due to summer heat. t is not known, how effective this will be in promoting thermal comfort in new homes. Beyond these issues it is not considered likely that there will be any major change in pathway overall.

Anticipated total influence of Pathway on Occupant Health and Comfort: Neutral

Likely Change in Vulnerability or Receptor

No further influences on receptor beyond those referred to in relation to winter inadequate ventilation have been identified. These were in relation to occupant smoking behaviour, internal air pollution due to furnishings and the increasing incidence of asthma in the population. As was the case for the winter these are likely to combine to result in an increasing vulnerability to inadequate ventilation and poor indoor air quality.

Anticipated total influence of Receptor on Occupant Health and Comfort: Negative

Likely Change in Occupant Risk

In combination it is expected that the occupant health and comfort risk due to inadequate ventilation in the summer will be increased as a result of climate change.

Anticipated total Future Change in Risk on Occupant Health and Comfort: Negative

3.3.5 Risk Factor: Material & Structural Damage

Health and comfort risks due to material and structural damage to the home during the winter were discussed during section 3.2.3 and included mental health, future psychiatric morbidity and increased vulnerability to bacterial and viral infection. No further risks have been identified through literature review in relation to this risk factor during the summer.

3.3.5.1 Source

The hazards in relation to the occupant health and comfort risk system for material and structural damage during the summer are however broader than those identified for the winter, namely wind, rainfall and hail. Research has also identified solar radiation (and by association cloud cover) as a further source factor in this health and comfort risk system.

3.3.5.1.1 Soil Moisture

Soil moisture is associated with structural and material damage to homes in the summer due to its relationship with the occurrence of subsidence in buildings.

3.3.5.1.2 Solar Radiation & Cloud Cover

The UV content in solar radiation has the potential to cause damage and deterioration in the built environment (Johns & Fedeski, 1994, Graves & Phillipson, 2000), while the amount of solar radiation incident on a surface is related to both the latitude of the location as well as the level of cloud cover and the orientation and horizontal angle of the surface.

3.3.5.1.3 Materials and Structural Damage: Source Factors

The climatic hazard variables that influence occupant health and comfort risk system for material and structural damage are therefore:

- Wind
- Precipitation
    - Rainfall
    - Hail
- Solar radiation & cloud cover

3.3.5.2 Pathway

The pathway factors in relation to the occupant health and comfort risk system for material and structural damage are defined as those aspects of the pathway that influence the risks described previously. In addition to those factors identified for the winter risk system, building age, building materials, state of repair, neighbourhood and for material and structural damage, the impact and influence of solar radiation, UV and subsidence have been identified as further pathway factors.

3.3.5.2.1 Housing: Age of Property

Subsidence due to drought is usually brought about through the shrinkage of clay soils. Heave, as a result of expansion of soils, can also cause similar damage. The vulnerability of any building to the hazard of subsidence is complex and is related to the age of the building, through a relationship to depth and standard of foundations. In general, the older the property, the less likely it is that there would be foundations in place to withstand subsidence due to shrinkage (Forster & Culshaw, 2004, p64)

3.3.5.2.2 Housing: Construction Type

The impact of solar radiation and UV is to increase the rate of deterioration of certain materials vulnerable to exposure. Materials such as un-plasticised polyvinyl chloride (uPVC), used in windows, replacement fascias and guttering can be degraded by UV and become discoloured or brittle. Timber can also be vulnerable to UV exposure if not adequately protected (Johns & Fedeski, 1994, Graves & Phillipson, 2000).

3.3.5.2.3 Neighbourhood: Exposure to Wind, Rain & Flood

In addition to those factors relating to wind, rain and flooding identified previously in section 3.2.3.2.4, the type of soil beneath the property together with the age, type and proximity of trees and large shrubs close to the property may also influence the vulnerability to and incidence of subsidence.

3.3.5.2.4 Materials and Structural Damage: Pathway Factors

The pathway variables that influence the occupant health and comfort risk system for materials and structural damage during the summer are therefore:

- Housing:
    - Age of property
    - State of repair

    - Construction type
- Neighbourhood:
    - Exposure to wind
    - Exposure to rain
    - Exposure to flood
    - Other:
        Proximity of planting

3.3.5.3 Receptor

The receptor factors in relation to the occupant health and comfort risk system for summer material and structural damage are those previously identified for the winter in section 3.2.3.

3.3.5.3.1 Materials and Structural Damage: Receptor Factors

The receptor variables that influence the occupant health and comfort risk system for materials and structural damage are therefore:

- Socio-Economic:
    - Status
- Existing Illness:
    - Presence of Long Standing Illness

3.3.5.4 Current Risk

The current risk to occupant health and comfort as a result of material and structural damage can be described in the following problem map. The relationships between source, pathway and receptor are as described for risks due to material and structural damage during the winter.

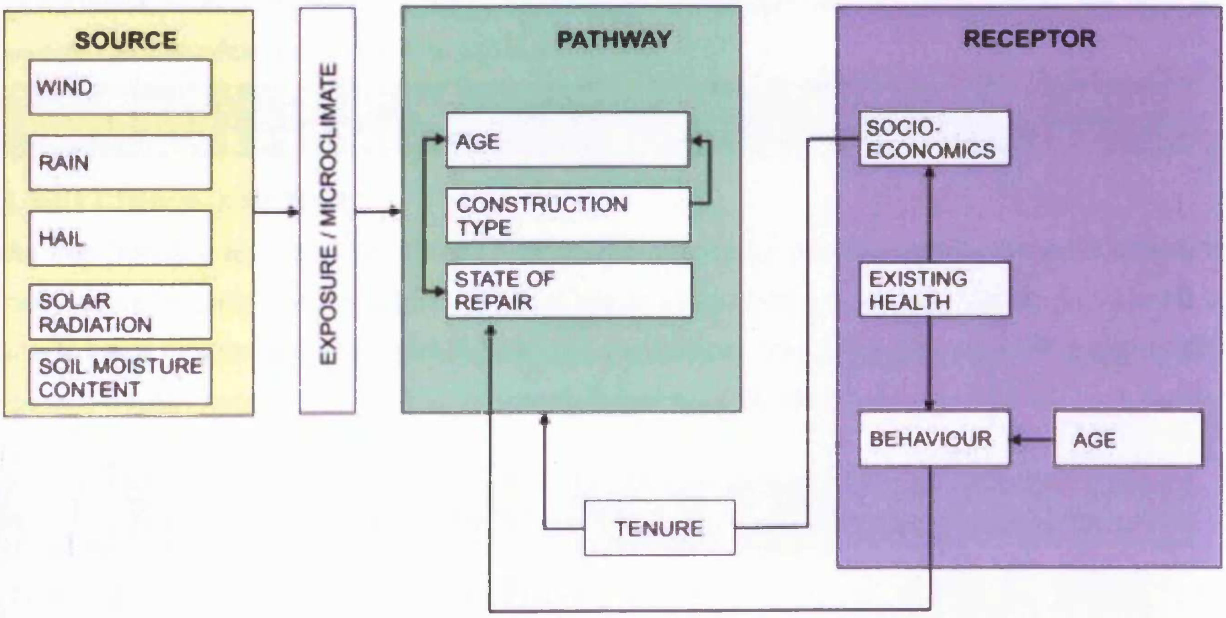


Figure 96: Problem Map for Occupant Health & Comfort Risk Factor: Material & Structural Damage

3.3.5.5 Future Risk

The potential change to the current risk system due to material and structural damage for housing occupants in south Wales during the summer will now be explored.

Likely Change in Source

Climatic Variable		**Climate Change Scenario**	**Scale of Change**	**Impact on Internal Environment**
Wind	**Extreme***	**Decrease**	**-4 to -6%**	**Positive**
Precipitation	**Extreme ****	**Decrease**	**-15 to -25%**	**Positive**
	Hail	**Unknown**	**Unknown**	**Neutral**
Solar Radiation / Cloud Cover		**Decrease**	**-9 to -15%**	**Negative**
Soil Moisture Content		**Decrease**	**-20 to -40%**	**Negative**

**** % Change in Daily Wind Speed 2 years return period***

***** % Change in Rainfall During a 2 Year Return Event***

The decrease in wind regime would be likely to result in a decrease in damage to property, while in the absence of data for changes to the regime of hailstorm events, as was the case for the winter scenarios, no change is assumed for this hazard factor. However, despite the unchanging relationship between latitude and magnitude of solar radiation, increases in solar radiation are anticipated under current climate change scenarios due to decreases in cloud cover in the summer. These changes are likely to result in increased deterioration rates of the material types affected. The frequency, as well as the spatial distribution, of subsidence may be subject to increase as a result of the substantial decrease in soil moisture content described in current climate change scenarios (Forster, A. & Culshaw, M., 2004).

No quantification of these changes is available and therefore for the purposes of this work an overall neutral influence on the risk system is anticipated

Anticipated total influence of Source on Occupant Health: Neutral

Likely Change in Pathway

As was the case for the winter, the general governmental support for housing renewal is likely to have some influence on the general state of repair of properties, however, this does not relate to the general maintenance regimes in place for properties, where the author is not aware of any current governmental policies. This suggests that the future changes to the pathway are neither positive nor negative.

Anticipated total influence of Pathway on Occupant Health: Neutral

Likely Change in Vulnerability or Receptor

As was the case for the winter risks system due to material and structural damage, the presence of an increasingly aging population, in combination with the high rate of owner occupation of homes, may combine to result in an increasingly poorly maintained housing stock.

As suggested before the current rising trend for interest rates, may increase the stress and mental illness associated with financial strain. It is suggested that if these current trends continue, the likely change in vulnerability or receptor will result in a negative influence on the overall risk system.

Anticipated total Influence of Receptor on Occupant Health: Negative

---

Likely Change in Occupant Risk

In combination it is expected that the occupant health and comfort risk due to material and structural damage may be increased over the coming century, although this risk is not considered to be influenced by climatic influences during the summer but by increases in receptor vulnerability within this risk system.

Anticipated total Future Change in Risk on Occupant Health: Negative

---

3.4 Summary

Through application of the logical framework established earlier for the health and comfort risk system in housing, a literature review and logical analysis has been undertaken within this chapter to establish both the current risk system and likely future changes to that system as a result of changes to external drivers including climate change. Through consideration in turn of each of the individual risk factors such as excess and inadequate heat, the related occupant health and comfort risk system have been established. This has included identification of the associated source, pathway and receptor variables. Through logical analysis of the relationships within these health and comfort risk systems, illustrated through the application of problem maps, changes to the drivers have been established to identify the likely change in risk over the coming century. No attempt has been made to quantify the change in risk, simply an assessment of the likely direction of change. Given the complexity of the systems being considered, further drivers, such as future governmental policy, may be introduced into the system to alter the impact of climate change itself, however, given the transparency of the method applied herein an alteration in policy can simply be incorporated into the logical framework to consider the potential influence on future risk.

The following matrix therefore illustrates the changes to risk considered likely under the current climate change scenarios as described by Hulme, 2002 and other drivers identified in the future risk sections for each risk factor considered above. The change in variable illustrates the direction of change in the climatic variable currently anticipated under climate change scenarios.

The following legend is provided to enable interpretation of the following matrices:

Likely Direction of Change in Source	
↓	Decrease
↑	Increase
-	No Change
n/a	Not applicable
?	Unknown change

Influence on Risk	
-	Negative influence on risk
|	Neutral influence on risk
+	Positive influence on risk

Cumulative Influence on Risk	
-	Negative influence
|	Neutral influence
+	Positive influence

Chapter 4 - A Combined Methodology

4.1 Introduction

Having established a framework for the current occupant health and comfort risk systems as well as a direction of change in risk due to climate change, a methodology will now be established to undertake primary research to evaluate the distribution of vulnerability, exposure and risk in the housing stock of south Wales as currently experienced during extreme climatic conditions. The following chapter describes the combined methodology developed to carry out this research, bringing together the strengths of available data and methodologies. In brief, this is comprised of two randomly sampled, cross-sectional surveys of housing occupants in the Neath and Port Talbot area of south Wales. The second aspect of the methodology consists of the monitoring of a case study home in Cardiff. The creation and design of these complimentary aspects of the method are discussed below, including the selection of appropriate study populations, approaches to sampling and detailed methodological design.

4.2 Methodology Design

The study design must consider a number of interrelated factors including the availability of appropriate data, the definition and identification of the study population, availability of resources and the selection of data collection methods that can enable the gathering of appropriate housing and occupant variables, as identified for each risk factor considered in chapter 3. Expert judgement has been found to be appropriate for scoping or initial studies, where the breadth of the study and areas of interest may need to be identified, for example, in the areas of health and climate change (DOH, 2001, IPCC(b), 2002), comfort and climate change, (Graves & Phillipson 2000, Hacker et al 2005), and the built environment and climate change (Fedeski & Johns 2004, Levermore et al, 2004, Graves & Phillipson, 2000). This research proposes a first order quantitative study, and while the method of expert judgement can be used to establish quantitative factors, disagreement between experts as well as identification and access to appropriate experts may limit the application of this method within this work (Mumpower & Stewart, 1996).

The application of modelling or the use of climate chamber type methods, both of which could be considered as traditional experimental methodologies, may also been applied to achieve similar research objectives in relation to climate change impacts and risk For example, research undertaken to establish comfort factors has been undertaken using the controlled environment of climate chambers that provide controlled conditions and full measurements (Markus & Morris, p38-40), Fanger, 1970. The results from these, although accurate, could also be interpreted as artificial, relying as they do on occupant response in an artificial environment in which they may not have an understanding, are unlikely to have a purpose, such as job to do or an emotional attachment as they may have at home. Hacker et al, 2005, applied computer simulation to consider the direct impact of climate change scenarios on the thermal environmental in the built environment. It should be reiterated here that the interaction of occupants with their environment has been identified as a key factor in the performance of the built environment in relation to the risks being considered herein and therefore the methodology selected must be able to collate data in relation to this. The methodologies appropriate to achieve this study's third objective must therefore enable data collection in relation to this aspect of the risk system. Therefore it is stated here explicitly that it is not the aim of this work to study the direct impact of current climate change scenarios on the internal environment of the domestic built environment.

Field work, the second approach to research adopted in the field of thermal comfort, undertaken in the "real", uncontrolled environment and familiar surroundings, (real buildings as well as normal behaviour) such as is reported by Nicol 1993 and deDear & Brager 1997 may therefore be considered to be a more appropriate methodological approach. This type of research is likely to collect occupant thermal comfort relevant to the "real world", although it can be argued that the measurement can lack the precision achieved under controlled experimental conditions of the climate chambers. It is not the objective of the study to explore the internal environment of housing under explicit climate change scenarios. Rather it is to study the complexity of the occupant health and comfort system in housing during current extreme conditions, as an approximate analogy for future climate conditions. The application of survey and monitoring type methodologies are therefore considered most appropriate for this work. The specifics of these approaches will now be considered, before the detailed methodological approach for this work is established.

4.2.1 Interview and Questionnaire Surveys

Interviews and questionnaires have been applied widely as research tools in the built environment, especially where the research is centred on the interaction between the environment and its occupants. Post occupancy evaluations (Such as those carried out under the PROBE study (Post occupancy Evaluation of Buildings and their Engineering), housing standard surveys (WAG, 1998), occupant comfort (reports of many can be found on the Network for Comfort and Energy Use in Buildings website: www.nceub.org.uk), occupant health and sick building syndrome (for which questionnaires can be found on the Question Bank website: http://qb.soc.surrey.ac.uk/), are examples of research areas described within the literature that frequently apply survey methods, both questionnaires and interviews. They would therefore seem appropriate to this research. Within this work the use of surveys is intended to capture a snapshot of occupant perception and behaviour under current conditions, social, economic and physical including climatic, as such future adaptation to changes in climate and broader drivers cannot be assessed.

The application of a survey methodology could be designed to enable the consideration of a form of climatic analogue. That is to say that respondents could be requested to consider current summer climatic extreme, very hot (extreme) summer weather, as well as mild or average winter that they have experienced in their homes, referred to here as a "temporal" analogue to future climate scenarios, such as those illustrated in Hulme, 2002. These could be seen to approach a possible approximate of future conditions and would minimise the reported negative effects associated with previous use of spatial analogue climates, for example, where the future climate of the UK is compared to that of current Mediterranean countries. These analogies bring with them limitations associated with differing length of daylight hours, culture and built environment which would not be affected during the use of temporal analogue. This temporal analogy, where current extreme climatic conditions are considered to approximate future average conditions, would also be appropriate for this initial scoping study, where the extent and manner in which homes may be affected is not yet fully understood. Therefore, although this method cannot simulate climatic change, the resulting exploration of potential vulnerability, exposure and risk in housing may have a longer period of validity, due to its independence from specific climate change scenarios. This may be seen as especially appropriate considering the current frequency of climate change scenario development, approximately 4-5 year intervals.

It must be acknowledged at this point that the data collected through the application of analogues in this manner will be subject to error in relation to recall of all factors. For example, all participants are unlikely to recall the same period of hot weather. These inherent errors in the data are not considered to negate its value, but must be acknowledged during each phase of its design, administration, collection and analysis.

Survey methodologies require a number of stages to enable their implementation:

1. *Selection of the study population*

   Data availability for the study population may influence this selection. Neath Port Talbot is considered an appropriate location and scale for this study as well as the availability of existing data relating to the every domestic property in the county.
2. *Selection of interview or questionnaire methodology*

   This decision would primarily be influenced by time and resource availability as well as the scale of data collection requirements.
3. *Selection of a sample*

   The sample selected would be influenced by the method selected, together with wider consideration, such as resource management, including: time, finance, manpower and likely response rates.

4. *Design*

   The design and/or selection of timing of survey and questions, together with the design and formatting of the survey instrument, must then be considered, in order to maximise potential response rates and ensure appropriate collection of data.

5. *Pilot & conduct of survey*

   The approach to piloting and conducting of the survey would be directly influenced by previous decisions, but where possible, best practice would be followed.

Where a representative sample is required it is necessary to identify the study population through the application of a detailed population dataset. This data would enable a random sample to be selected and would be the only input data requirement for a survey methodology. It is possible to access housing address data through local authorities or through the use of GIS based OS mapping, however, many of these methods have associated costs, that may be prohibitive to use in this project. A more detailed dataset is available to this study, that for NPT, that includes characteristics such as housing age and energy consumption, previously mapped using GIS. This data enables the development of a stratified approach to sampling where appropriate (for example using housing age, location or other factors to target the sample). Wider datasets, including the Census, Local Health Authority data, 'Townsend scores', a measure of socio-economic level, as well as the Welsh House Condition Survey (described previously), are also available to broaden this base population dataset.

In contrast to computer simulation and climate chamber methods, discounted above, this methodological approach can be seen to access information from occupants about the environment and their behaviour in their own homes as well as providing the potential to consider the actual health and comfort implications of homes on their occupants. That is to say the actual health and comfort impacts together with social, housing and building standards for each respondent could be considered during analysis. It must be noted here that the limitation of this methodology in relation to consideration of both occupant behaviour and resulting risk would be likely to be influenced by the adaptation of population to a more frequent experience of extreme climatic situations being considered here.

A survey methodology would be applicable to any location, however, were housing data to be required to select a representative sample, the data collection period for this information may be prohibitively costly to reproduce for any future application of this method. It has recently been proposed that a similar dataset be compiled for the entire UK domestic housing stock (Boardman et al, 2005), that would facilitate broader application of the method. Furthermore, a method for remote estimation of building age using a GIS based methodology is currently under development at the Welsh School of Architecture, that would significantly reduce the resources required to gather this data (Lannon, 2004).

Surveys can be seen to offer a broad methodology able to consider the wide range of variables related to buildings and their occupants that influence health and comfort in housing, as identified in chapter 3 for each risk factor to be explored. Through careful and appropriate design and administration they are capable of offering a method that enables the consideration of a representative sample of housing and their occupants. However, there is a likelihood of differentiation between respondents in terms of temporal analogy of climate being considered and a need for a detailed population dataset, from which to draw a sample.

4.2.2 Monitoring

Monitoring is also used widely in research in the built environment to establish quantitative factors such as temperature, relative humidity, noise levels, air pollutants and air movement or ventilation levels in the internal environment, for example through the use of logging equipment. It has been established that the risk systems for health and comfort in the domestic environment are associated with a number of these quantifiable variables, and therefore monitoring should also be considered to be an appropriate methodology for this work. Further to this, and with access to appropriate equipment, monitoring could be applied to behavioural aspects in the built environment such as automated monitoring of window and ventilation usage. However, with increasing complexity of the monitoring equipment would come greater financial cost of the research method, which in turn is likely to be inversely related to the scale of the sample to which the method can be applied.

A further aspect of monitoring research methodology should be acknowledged at this point that of observation. Within a domestic environment, however, this is not considered to be an appropriate methodology at present. Observation requires the researcher to observe the behaviour of the subject of study within the environment of interest. However, the physical presence of the researcher is often considered to have an influence on the behaviour of the subject. This limitation is likely to be considerable within the confines of a home and therefore has been discounted as a methodology for this research. It may be that as video and other monitoring technology improves the possibilities to consider this approach to research will also develop. For example, webcam type devices logging behaviour within a home are widely used within the television media and may become accessible for research. Monitoring can also, in a sense, be self administered in relation to behaviour, where occupants are requested to maintain diaries of behaviour of interest to the research. Reliance on subjects to undertake this type of data collection has been considered by many researchers to be unreliable and a source of both error and “drop out”, although compensation of subjects can assist in this (Edwards et al, 2002). For example, Jenkins (2002) considers that the monitoring of homes is costly and time consuming for both the researcher and the occupants with rates of attrition in participants being high, thus causing wastage of both time and resources.

Survey methodologies require a number of stages to enable their implementation:

1. *Selection of the study population*

   Data availability for the study population may again influence this selection although this is more likely to be influenced by willingness to participate in the study.
2. *Selection of monitoring methodology*

   This decision would again primarily be influenced by time and resource availability as well as the scale of data collection requirements.
3. *Selection of a sample*

   The sample selected would be influenced by the method selected, together with wider consideration, such as resource management, including: time, finance, manpower and likely response rates.
4. *Design*

   The design and/or selection of timing of monitoring would be at the mercy of the Welsh weather. The objective, to consider current extremes as a temporal analogy of future climate change scenarios, being the limiting factor as to the timing of such a study.
5. *Pilot & Conduct of survey*

   The approach to piloting and conducting of monitoring would be directly influenced by detailed decisions as to the method, but where possible, best practice would be followed.

The results from a monitoring study would be quantitative in nature, where exceedance of thresholds could be interpreted for their potential implications on occupant health and comfort. As such this could be combined with a survey methodology to collate data relating to the breadth of variables identified as relevant to the risk systems to be considered. As stated, data relating to occupant behaviour coud be recorded via diaries in real time, representing a considerable improvement over the survey methodology alone as both quantitative data, relating to the internal performance of a home and occupant behaviour, as well as qualitative data, relating to the occupant perception of the performance, could be collated. In addition, data could be collected for the same analogous climatic experience for all study homes. The limitations to both time and resources available to this research would however, necessitate a relatively small number of subjects to be considered within a study applying this method, when compared to one applying a survey type methodology. It may therefore not be possible to aggregate the results to the wider Neath Port Talbot County Housing population. A further and perhaps more important consideration for this study is the need for data collection during appropriate temporal analogous climatic conditions, extremely hot summer and average or mild winter conditions. A major limitation for a time limited piece of work would be reliance on delivery of this by the unpredictable nature of the weather.

4.2.3 A Combined Methodology

As a result of this analysis of the strengths and weaknesses in both the surveying and monitoring methods, it was considered appropriate that a combined methodology be developed, capable of embracing both potential data sources to achieve the objectives of the research. The application of a combined methodology would also enable emphasis to be placed on the strengths of each method, while preventing any reliance on the weaker aspects of each methodological approach.

The use of survey methods was selected to enable an overview of vulnerability, exposure and risk to occupant health and comfort in housing capable of extrapolation to the case study location of Neath Port Talbot County borough. Survey methods also allow consideration of occupant interaction with their homes to achieve comfortable and/or healthy conditions. These surveys can allow both quantitative and qualitative variables to be collated for both extremes of climate. In summary, the data gathered through these surveys could be designed to fulfil the objective of this primary research, to establish the extent to which vulnerability and exposure is currently distributed during extreme weather conditions to enable an approximation of the extent of future risk in south Wales housing.

It was decided to limit the application of monitoring of the internal environment, together with diary records and occupant questionnaires, to a single case study house representative of current building practice. The house selected was a semi-detached house built in the year 2000 located in Cardiff (the author's home). The case study represents current new build homes enabling these results to be of direct application to proposals for potential adaptations for example regulations governing building form and construction for new build housing. The data collected from monitoring can be explored in order to consider the quantitative thermal environment experienced within a case study home. This data will be analysed in terms of existing thermal comfort standards together with analysis of occupant behaviour in the light of climate. The limited application of monitoring within this work, despite its apparent considerable benefits over survey methods alone, is associated with the inherent time limitations associated with a PhD study. That is to say, were the entire methodology of the study to be reliant on the delivery of appropriate summer and winter weather by the British climate, it is likely that considerable risk of failure would have been attached to the method.

Having established a combined methodological approach to this research, it is necessary to explain the development and detailed design of both elements of the study design. Firstly, the detailed method selection, design and implementation of the survey method will be described. This will be followed by the monitoring aspect of the methodology.

4.3 Survey

The key stages in the carrying out of any survey are as follows:

1. Scope
2. Selection of a study design
3. Defining the study variables
4. Selection of a study population
5. Selection of a method: interview or questionnaire
6. Selection of a sample: random / non-random / mixed
7. Design of survey method: formulating & formatting the questions
8. Piloting of the method
9. Conducting the survey
10. Data cleaning and analysis of the results

4.3.1 Scope

This survey will aim to assess the distribution of vulnerability and exposure to health and comfort risk in the housing stock of south Wales as currently experienced during extreme summer and average winter climate conditions as a temporal analogy of future health and comfort risk in the domestic environment. The results of these surveys will be analysed to establish the distribution of homes and occupant behaviours that may contribute to risk in combination with changes in climatic elements. The wider scope of this aspect of the study is to consider occupant behaviour in the light of extreme weather. The risk systems studied in relation to existing literature in chapter 3 have established those aspects of the climate, home and behaviour that are likely to influence health and comfort. These factors can be established in the homes of participants through the survey. It is not the aim of this survey to establish or support any casual relationship between the factors being studied, but to rely on those relationships already established elsewhere in the literature, between health, comfort and housing.

The strength of this aspect of the study is considered to be its ability to provide a well founded estimate of the future risk to occupant health and comfort problems in the domestic internal environment during average climatic conditions towards the end of the 21st century. This is to be achieved through analysis and consideration of the breadth of factors identified in chapter 3 which combine to influence the risk systems being studied here. In relation to pathway these can be considered to be associated with neighbourhood and building factors and in relation to the receptor occupant health, socio-economic status, well being and behavioural factors. As described in the problem maps these factors combine in a non-linear manner to provide actual risk in the built environment.

4.3.2 Study Design Selection

Studies relating to health and housing usually follow one of five categories of study design, namely: descriptive, case control, longitudinal, intervention or extrapolative. The selection of an appropriate study design can broadly be undertaken through response to the following series of simple questions below (Mant, 1993, Hwang et al, 1999):

Is the study reporting direct observation of the housing environment? The scope for this work has established that the health and comfort of current occupants under current extreme weather is of interest in order to respond to the third objective for this work. Therefore the study design must consider the current observed situation, under specified conditions previously defined as a temporal analogue for future average climate. As the focus of the study is on observation an *extrapolative study*, is inappropriate.

Does the study start with ill people or houses? In the case of this research it is neither possible nor appropriate to consider only those homes that contain ill people. The scope of the study does not aim to consider one type of illness. Although the main focus of this research is the health and comfort of occupants, the influence of all factors, climatic, architectural and people can be considered to be the starting point. Therefore a case control study is not appropriate.

Does the study attempt to change any factors? As has previously been described it is neither possible nor appropriate, as would be the case in a climate chamber, to effect a change in the climate nor would it be appropriate to consider climate change through controlled experiment in homes. Therefore it is not appropriate to undertake an intervention type study.

Does this study attempt to follow people over time? A longitudinal study would be considered most appropriate, were it to be considered necessary to study the same subjects, (housing occupants) over time. While a descriptive or cross sectional study design would enable the evaluation of health and comfort risk for a selected point in time. The description of the scope of this survey method identifies the need for information to be collected relating to both extremes of climate, summer and winter. This could suggest a temporal aspect to the scope of the study and would indicate that it may be appropriate to select a longitudinal study design, where the same cohort of respondents are approached to consider the factors of interest to the study both in the winter and summer. In relation to the design of a longitudinal study, the selection of the cohort and loss to follow-up are of particular concern. The cohort must be representative and feasible, where their interest and commitment to the research is of particular importance, as these factors can in turn influence the loss to follow-up. The question of selection of either descriptive or longitudinal study design should, among other factors, be concerned with the necessity to consider the same cohort of population for both summer and winter situations.

Were a longitudinal study design selected for this study a single cohort would be approached twice to consider the environment in their home in relation to both summer and winter conditions as well as their behaviour. The benefits of the application of such a study design would be the collection of a single set of socio-economic data, housing, neighbourhood and other variables, reducing the time required for data collection, cleaning and analysis. However, the loss of or drop out of participants between data collection points as well as conditioning of responses due to previous participation, together with the potential change in status, may negate the benefits of this approach. Also, as the data collection is to be undertaken to represent the distribution of risk in the study population and not to consider longitudinal variation in health and comfort in case study homes, the risks associated with this approach may outweigh the benefits.
An alternative could be to undertake two descriptive studies, tandem descriptive study design, using dfferent samples, one in the winter and one in the summer. This method would negate problems due to loss of participants and conditioning, although the scale of data input, cleaning and analysis would be increased by comparison. There is, however, no explicit need to consider the actions of the same participants in summer and winter, as this element of the research aims to achieve a description of future average risk and therefore a representative sample is of more significance to the work.

It was suggested that the most significant reasons for not undertaking monitoring work as a major component of the combined methodology was the reliance this would place on the delivery of appropriate climatic conditions by the unpredictable climate. This would suggest that a single descriptive study design could be undertaken here, involving the collection of all information relating to both summer and winter situations at one time. This approach would have the additional benefit of reducing man-power and costs in terms of administration of the survey, however, it could be argued that the information may be subject to bias due to recall, dependent on the time of year that it was undertaken. Therefore, although a survey methodology is not as directly dependent on the climate, it is considered likely that the process of surveying during the appropriate season would have a beneficial influence on the subjects' recall of the performance of their home.

It must be acknowledged at this point that all three methodologies would be subject to error to some extent in relation to recall of comfort and actions. For example, it has already been considered that it will be necessary to request the participants to recall their experiences in their home during a very hot summer. It cannot be relied upon that the time at which they undertake the survey will correlate well to the climate they are requested to consider. Further to this, error is likely to occur in recall as well as between participants, as they will not necessarily recall the same hot summer. However, it is perhaps more appropriate to request recall of a hot summer or a mild winter during or immediately after the equivalent time of year, in order that recall can benefit from actions over the past season. As was suggested earlier, these inherent errors in the data are not considered to negate its value, but must be acknowledged during each phase of its design, administration, collection and analysis.

Following this consideration of available study designs it was decided that administration of two descriptive or cross-sectional studies, during or immediately following the summer and winter seasons, would serve the purposes of the third object of this study most closely. This study design will assist the recall of participants to the internal environment in their homes in the two seasons of interest, while avoiding the unnecessary selection of a single cohort and the significant possibility of loss to follow-up, (a risk where longitudinal design is undertaken). Longitudinal study designs are of particular value where changes over time are of interest. In this case he study is not considering change but is interested in achieving a 'snap shot' description of health and comfort in housing during the two extreme seasons as a temporal analogy of future average risk to occupant health and comfort. It is therefore considered that the risks associated with the selection of a single cohort do not outweigh the benefits in terms of data collection and analysis.

4.3.3 Study Variable Definition

It is now necessary to formally define the information that must be collected from the participants in the survey. The risk systems associated with the internal environment likely to be affected by climate change have been described for both the summer and winter seasons in the literature review. The resulting summary matrix also represents the potential change in risk as a result of climate change. During the literature review, the risk factors associated with the pathway and receptor would be capable of having a significant effect in relation to each of these risk factors (Ed. Burridge & Ormandy, 1993).

The distribution of the following risks are to be evaluated through administration of these surveys, as previously summarised in the table below:

Winter Risk Factors	**Risk to Occupant Health and Comfort due to:**
Inadequate Ventilation	inappropriately low or high levels of ventilation during a mild winter.
Inadequate Heat	cold temperatures during a mild winter.
Material & Structural Damage	structural or material damage of the home during a mild winter.
Damp & Mould	the presence of damp and or mould in their homes during a mild winter.

***Summer* Risk Factor**	**Definition**
Excess Heat	high temperatures during a very hot summer.
Noise	levels of noise during a very hot summer.
Pests & vermin	levels of pests & vermin during a very hot summer.
Inadequate Ventilation	inappropriately low levels of ventilation during a very hot summer.
Material & Structural Damage	structural or material damage of the home during a very hot summer.

Table 44: Health and Comfort Risk Factors in Housing During Mild Winters (above) and Very Hot Summers

The study variables of significance to this research and identified thorough literature review can be collated into the following groups from the description of risks systems undertaken in chapter 3. These factor groupings will be considered in turn, relating to the pathway and receptor elements of the associated risk systems:

- Pathway Factors
    - Housing
    - Neighbourhood
- Receptor Factors
    - Social economic factors
    - Existing health factors
    - Behavioural factors

4.3.3.1 Pathway Factors: Housing

The housing factors of relevance to this research can be summarised from chapter 3 as follows. The definitions are provided as measurable interpretations of each factor:

Housing Factor	Definition
Age of Property	Five age group categories: Pre-1919 / 1919 - 1944 / 1945 - 1964 / 1965 -1980 / Post-1980
Type of Property	Six house type categories: Detached / Semi-detached / Terraced / Maisonette / Bungalow / Flat
State of Repair	Presence of structural faults or need of maintenance work.
Construction Type	Heavy, medium or lightweight construction: to be interpreted through measure of wall construction and age of property. Including presence of "cold" flooring materials such as stone, tiles and laminate flooring.
Windows and Ventilation	Frame materials: uPVC, timber or metal and state of repair and window to wall proportion. Presence of draught stripping and double glazing. Ventilation in terms of presence of trickle vents, air vents, and extractor fans.
Internal Sources of Air Pollution	Presence of gas or solid fuel as cooking and or heating fuel.
Heating Type*	Presence and type of central heating or fires.
Insulation	Standard Assessment Procedure (SAP), measure of energy usage, estimated within existing NPT data. 0 to 120, the higher the score the better the rating. Comparison of this with presence of measures of insulation, loft, wall, double glazing, draught stripping and hot water tank.
Orientation	To be measured in relation to access to sun.

Table 45: Housing Factors Present within Health and Comfort Risk Systems
** Only considered in relation to winter risk systems*

4.3.3.2 Pathway Factors: Neighbourhood

The neighbourhood factors of relevance to this research can be summarised from chapter 3 as follows. The definitions are provided as measurable interpretations of each factor:

Neighbourhood Factor		Definition
Access to External Space*		Access to park, beach and / or own garden.
Exposure	**Air Pollution**	Proximity of industry, roads, refuse sites and self reported measure.
	Noise*	Self-reported measure of noise as well as proximity to industry and roads.
	Wind	Self-reported exposure to wind.
	Rain	Self-reported exposure to driving rain.
	Flood	Self-reported exposure to flooding as well as previous occurrence of flood, proximity to water sources and drainage problems.
	Water*	Self-reported proximity to water.
	Crime*	Self-reported prevalence of crime in the neighbourhood.

Table 46: Neighbourhood Factors Present within Health and Comfort Risk Systems
** Only considered in relation to summer risk systems*

4.3.3.3 Receptor Factors: Social Economic Factors

The socio-economic factors of relevance to this research can be summarised from chapter 3 as follows. The definitions are provided as measurable interpretations of each factor:

Social Complexity	Definition
Socio–Economic Status	Application of NS -Sec measure of socio-economic status.
Education Level	*As defined within the Census, 6 groups: No Qualifications / Level 1 / Level 2 / Level 3 / Level 4/5 / Unknown level.*
Housing Tenure	*Owner Occupied / Council Tenant / Housing Association Tenant / Private Tenant*
Maintenance	*Responsibility for and undertaking of maintenance*
Household Composition	Number, age and sex of occupants of household. Associated with property size to consider overcrowding, in relation to self declared status and bedroom standard, measured in number of bedrooms, in comparison to number of occupants.
Length of Time in the Home*	Period of time household has occupied the home

Table 47: Social Economic Factors Present within Health and Comfort Risk Systems
* This has been included to ensure experience of range of seasonal climate and resultant internal thermal environments

4.3.3.4 Receptor Factors: Existing Health Factors

The Existing Health factors of relevance to this research can be summarised from chapter 3 as follows. The definitions are provided as measurable interpretations of each factor:

Social Complexity	Definition
Presence of Long-Standing Illness	Self-reported presence of long standing physical or mental health condition.
Internal Sources of Air Pollution	Presence of smokers within household & those that smoke in the home.

Table 48: Existing Health Factors Present within Health and Comfort Risk Systems

4.3.3.5 Receptor Factors: Behavioural Factors

The behavioural factors of relevance to this research can be summarised from chapter 3 as follows. The definitions are provided as measurable interpretations of each factor:

Winter Behavioural Factors	Definition
Use and control of heating	Presence of varying level of control for heating, TRVs, thermostat, timer, on / off switch. Period of use of heating.
Introduction of moisture	Drying clothes inside, showering, bathing and cooking.
Control of ventilation	Use of windows and mechanical sources such as vents and extract fans to provide ventilation.
Clothing levels	Level of clothing worn inside during winter
Maintenance	Frequency of regime and outstanding maintenance requirements.
Summer Behavioural Factors	**Definition**
Control of ventilation	Control of ventilation through the use of windows, fans, extracts and air conditioning
Use of shade	Use of shading devices such as planting, blinds, curtains, awnings and shutters.
Seeking cooler conditions	Use of cooler more comfortable spaces such as air conditioned shops or public building, the garden or other outside space and north facing rooms during periods of excess heat.

Table 49: Behavioural Factors Present within Health and Comfort Risk Systems

4.3.3.6 Summary

In order to evaluate the extent to which vulnerability and exposure is currently distributed during extreme weather conditions and undertake an approximation of the extent of future risk in south Wales Housing it is necessary to establish the distribution of the measures of pathway and receptor factors identified above. Each of these factors has been previously identified through literature review within chapter 3 as part of the associated risk systems.

4.3.4 Study Population Selection

The area of Neath Port Talbot, south Wales, has been selected for this research due to accessibility of housing data for this population that is readily available to the study. Data is available in relation to the health of occupants in NPT at a borough level from the Welsh Household Interview Survey WAG, 1998, Welsh Health Survey, GSS,1999, while their socio-economic status as measured through the Townsend score is available at ward level (ONS, 2001a).

Information as to the general health status of the population of NPT is provided by the WHS, that applied the SF-36 (comprised of 36 health status questions) to gather this data. These questions consider the self perception of the respondent in terms of their own mental and physical health. This standard form has been developed in order to enable analysis of these questions thus allowing the production of scores relating to 8 factors. These in turn can be combined to produce two component summary scores as illustrated below:

1. Physical functioning 2. Role-physical 3. Bodily pain 4. General health	Physical Component Score (PCS)
5. Vitality 6. Social functioning 7. Role-emotional 8. Mental health	Mental Component Score (MCS)

Scores for these measures can range between 0 (the worst possible case) through to 100 (the best possible state of health), while in practice they are found to range between 30 and 60, with higher scores representing better health (NAW, 1998). In interpretation of these findings a minimum difference of one unit is considered to be statistically significant. Therefore the PCS component for NPT can be considered to be lower than that found in Wales as a nation.

	Physical Functioning	Role Physical	Bodily Pain	General Health	Vitality	Social Functioning	Role Emotional	Mental Health
NPT	71.0	70.0	64.8	64.5	54.6	73.3	78.7	70.7
Wales	76.5	74.2	69.1	66.5	56.6	76.8	80.4	72.0

Area	PCS	MCS	Base
NPT	46.3	49.5	1,047
Wales	48.2	49.5	22,483
Range	45.9 – 49.4	47.4 – 51.8	-

Table 50: MCS & PCS Scores for Wales & NPT *(Source: WHS data, GSS, 1999)*

As a rule of thumb, a difference in score of one unit (for example, 47.2 and 48.2) is likely to be statistically significant. Differences of less than 0.5 are unlikely to be meaningful.

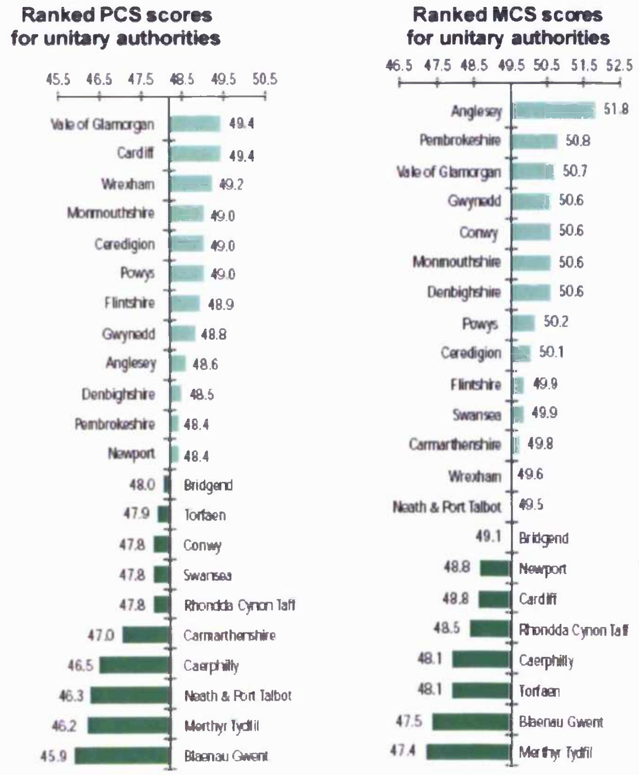


Figure 98: Physical and mental component summary scores: by unitary authority, adults aged 18+ *(GSS, 1999)*

As has been described previously, the study population consists of the 55,148 homes for which data has been collected in the EEP dataset (Jones et al, 1996).

4.3.5 Method Selection: Interview or Questionnaire

The selection of either an interview or questionnaire methodology is related to a number of factors, including: the nature of the investigation, the geographic distribution of the study population, the nature of the study population, the study design and the analytical techniques to be employed. Further to this, in general, interviews are capable of eliciting more information from the participants than are questionnaires. However, the information may be less structured, and it is likely that the sample would be smaller owing to the increased time required to undertake interviews in relation to questionnaires. Further to this, it may not be appropriate for a lone person to undertake interviews in homes, due to associated personal safety implications. It was therefore not considered possible to undertake an interview methodology within the framework of this research. A questionnaire methodology was selected by default.

The nature of the data to be collected, the wide spatial distribution of the population and the possibility of 'interviewer effect', may also have influenced the methodological selection. Some data to be collected, such as that related to health and socio-economic factors, may be considered to be personal and may not be solicited easily by a stranger, in person, in an interview situation. 'Interviewer effect' may occur where the interviewer influences responses to questions, with their own values, opinions or enthusiasms. This may be especially likely where the interviewer is also the principal investigator (Fink, 1989).

The possibility of bias, from the point of view of the housing occupant, must also be considered. Mant (1993) suggests that, *'achieving an unbiased answer from those occupying poor housing, either about housing conditions or their health status, is even more difficult as they are invariably aware that their answer may influence what happens'.* The conduct of an anonymous questionnaire may however help to reduce this prospect as no link will be apparent between response to the questionnaire and individual occupants.

Questionnaire methods available include face-to-face and telephone surveys, researcher administered questionnaires, postal and / or web-based surveys and self-administered questionnaires. The researcher administered methods were not available to this research because the names of individual occupants were not available to the research, nor was access to the telephone numbers of households. It was not considered appropriate to conduct a web-based questionnaire as access to the web is not as yet universal and non-response bias due to inaccessibility to the technology would have been likely to be high. A postal distribution, self-administered method was therefore selected. This method was applicable as access to postal contact details was available. The method also enables affordable access to large numbers of people and no limitation due to geographical distribution. Self-selection or non-response bias as well as the potential for a low response rate likely where postal questionnaires are conducted must be acknowledged during analysis of the results.

4.3.6 Sample Selection

This research is primarily being considered from the perspective of the built environment and as a result a sample that ensures coverage of the breadth of housing types is required. A random sample is appropriate in order that the information may be extrapolated in some manner to the wider population of NPT. However, if a random sample were to be taken from the population, a bias would be likely in the age distribution of homes included in the survey. This is due to the larger distributions within the pre-1919 and 1945-1964 housing age categories. Further to this, the location of homes, either rural or urban, is also of interest, where issues relating to built density as well as exposure to climate are to be considered.

Age	Pre-1919	1919-1944	1945-1964	1965-1980	Post-1980	TOTAL
EEP Dataset	**19,317**	**7,022**	**14,868**	**9,773** **13,941**	**4,168**	**55,148**
WHCS Dataset	18,900	10,100	14,700	13,200		56,900
Difference	-417	**3,078**	-168	-741		**1,752**

Table 51: EEP Datasets by Date of Construction

For the survey samples, it was decided to select them using a stratification relating to both location (urban or rural) and age of the home. This was seen to be most appropriate as the changes to building methods and size of homes over the decades can be seen to have potentially important relationships with the pathway factors identified earlier. For example, higher thermal mass and larger rooms traditionally found in older homes may help to keep these homes cooler in a warming summer climate, in comparison with the smaller and lighter mass homes being built today. The solid wall construction common at the end of the 19th century may also result in a higher incidence of internal damp. The stratification of the sample would therefore enable similar response rates to be achieved throughout each of the strata, reducing non-coverage bias.

Date of Construction	Location	Strata No.	Date of Construction	Location	Strata No.
Pre-1919	Rural	1	Pre-1919	Urban	2
1919 - 1944	Rural	3	1919 - 1944	Urban	4
1945 - 1964	Rural	5	1945 - 1964	Urban	6
1965 - 1980	Rural	7	1965 - 1980	Urban	8
Post-1980	Rural	9	Post-1980	Urban	10

Table 52: Survey Sample Strata

Having selected the method of sampling it was then necessary to select the sample size. The scale of the study must be considered to be limited by both time and financial factors. Two important factors must be employed within the calculation for a minimum sample size. These are: the likely response rates, together with numbers required for statistical analysis within and between groups. A response rate of approximately 20% - 30% was considered likely from an unsolicited postal survey. A number of factors including, pre-contact, length of questionnaire, provision or pre-paid response envelopes, stamped envelopes and follow-up contact can influence the response rate (Edwards et al, 2002). It is also considered likely that questionnaires derived from academic institutions as opposed to commercial or marketing sources are likely to produce heightened response rates. This response rate was estimated from literature as well as discussions with experienced colleagues.

From consideration of the data analysis to be undertaken, 20 responses per strata was considered to be a minimum to enable meaningful analysis of the responses. It was therefore suggested that a sample of 100 per strata per survey would be required (20% of 100 = 20). The application of more complex sample sizing methodologies was not considered possible due to the exploratory or scoping nature of the study. For example, methods that employ an estimation of the proportion of the population are not appropriate as it is not possible at this stage to estimate the proportion of the population likely to suffer from these housing risks prior to the undertaking of the study. An example application of such a method for homes likely to be too cold for comfort in the winter could be taken from previous studies considered earlier. The figure of 10%, equal to those considered to be in fuel poverty, could be used as an estimation of the population proportion.

Estimated proportion (P) = 10%

Desired precision (d) = 0.5

Standard Error associated with 95% Confidence Interval ($Z_{(1-\alpha/2)}$) = 1.96

Required sample size (n) = $\frac{Z_{(1-\alpha/2)} P (1 - P)}{d^2}$ = 71

This is similar to that suggested for each strata, 100, although consideration of complex sampling methods including the stratification employed in this study is not considered. It was therefore concluded that two independent, stratified, random samples of 1000 homes would be required to undertake the two surveys.

4.3.7 Questionnaire Design

The process of questionnaire design and the formulating and formatting of questions has been considered widely and it is beyond the scope of this work to reproduce the full process required (Sudman & Bradburn, 1983, Oppenheim, 1992, Aday, 1996, Jackson & Furnham, 1999, Saw & Ng, 2001). However, it is necessary to consider here the decisions that were made as to the overall design of the questionnaire, as well as its content, including the detailed design of questions and the breadth of sources available for existing questions. The final winter and summer surveys are reproduced in Appendix F and Appendix G respectively.

4.3.7.1 Questionnaire Structure

The to be collected through survey, relating to pathway and receptor factors have been established in section 4.3.3, however, these can be divided further between those relating to the household as a whole and those relating to individual occupants.

Household Level	**Occupant Level**
○ Socio-economic	○ Health
○ Housing	○ Comfort
○ Neighbourhood	○ Behaviour

It was therefore decided that the questionnaire should be divided into sections to enable a single collection of household factors, to be completed by any adult occupant of the household, as well as a male and female section. This division was selected due to the division in responses to comfort questions by male and female occupants in previous comfort research. Previous research has not found any significant difference between male and female occupant comfort in office environments, where differences in clothing levels and comfort levels have been found, as well as social and cultural factors. However, it is suggested that these factors may differ in the home environment, where control of the environment is likely to be more directly in the hands of the occupants, and comfort expectations may be enhanced as a result. The use of colour coding was selected to differentiate between these different sections. The use of colour in postal questionnaires has been linked to increased response rates and therefore this may have a secondary benefit (Edwards et al, 2002).

Both of the questionnaires were then devised using a clear layout with three sections: 'General', which considered issues related to the location, construction and household composition (among others) or household level factors and separate 'Male' and 'Female' sections, where questions that related to occupant level were to be concentrated. The male and female question sets were otherwise identical.

The length of time the occupants had been living in the home was identified at this stage as a filter variable for the sample. In order that occupants may respond to the survey accurately, it was important to ensure that they had a full understanding of the internal environment provided within their home. Therefore, to avoid collecting erroneous data, a filter question was included on the front page of both surveys. This requested that those recipients of the survey who had been resident for less than one year should return the questionnaire unanswered. This would enable them to be replaced in the sample and reduce non-response bias.

4.3.7.2 Question Selection & Design

The detailed design of survey questions is of particular relevance where there is no interviewer present. It is vital that straightforward plain language is used and that where complex concepts are to be considered, they must be thought of as a sum of parts as opposed to the use of complex phrasing. The words, phrases and sentences from which questions are derived must therefore be considered very carefully, to ensure that clarity of the research aim and meaning are understood by the respondent (Oppenheim, 1992). Further to this, when words are combined into phrases within questions it is vital that the responses are not likely to be weighted or loaded due to the question. Phrases such as 'Do you agree that.....', for example, may be more likely to elicit a positive response in agreement than the question, 'Do you agree or disagree that...?' (Aday, 1996). It is also important that both sides of an argument are presented and that only one question is asked at any one time. Again this ensures clarity and removes complexity from the question.

The ability to control the type of response from questions, through the use of open-ended or closed-ended questions, is another factor to consider in the development and selection of appropriate questions. Closed-ended questions provide a fixed range of responses. It is therefore important that the categories provided for response incorporate the full breadth of possible responses. Open-ended questions are of particular value at the pilot stage of research, where they can inform the creation of categories for closed-ended versions of the same questions. This enables the researcher to gain confidence in the categories provided in the final question format. Where open-ended questions are utilised in final surveys, the responses gained have the quality of allowing the respondent free rein to talk about the topic. However, coding of these responses is often complex and greatly more time consuming than that required for closed-end questions. The selection of response method, as well as the consideration of language utilised in questions, of particular relevance in postal questionnaires, was therefore of great importance at this stage.

The compilation of the questions to be included in the survey was to be a combination of the use of existing standard question sets (CASS - The Questionnaire Bank), such as those used to gauge mental health (GHQ_{12} - Bowling, 1997) and NS-SEC (National Statistics Website) occupation coding, through to those created specifically for these questionnaires. The utilisation of existing questions and questions response formats greatly eases the development of appropriate questions. The following sources and methods were used to ensure clarity and appropriateness in questions to be utilised in this study:

Source	**Application**
The Question Bank (**QB**): (QB, 2002)	Source of social surveys and questions from large scale; benchmark; professionally designed; quality assured; conducted after 1991.
National Standard Socio-Economic Classification: **(NSS-EC)** (ONS, 2002)	Set of questions to evaluate socio-economic status
British Household Panel Survey: **(BHP)** (Taylor et al, 2000)	Housing questions
General Household Survey: **(GHS)** (QB, 2002)	Housing and neighbourhood questions
Welsh Health Survey: **(WHS)** (GSS, 1999)	Evaluation of existing occupant health status
Housing Attitudes Survey: **(HAS)** (QB, 2002)	Housing and neighbourhood attitudinal questions
General Health Questionnaire: **(GHQ_{12})** (Bowling, 1997)	Evaluation of existing occupant health status

Table 53: Sources of Survey Questions and their Application

The General Health Questionnaire (GHQ) is a self-administered screening test which has been designed to identify short-term changes in mental health, including: depression, anxiety, social dysfunction and somatic symptoms. It is a pure state measure, responding to how much a subject feels that their present state 'over the past few weeks' is unlike their usual state. This measure does not attempt to make clinical diagnoses and as such should not be used to measure long-standing attributes. It is relevant to employ this measure within this study as it is appropriate to consider current mental status as a confounding variable that may otherwise bias responses to the questionnaire in terms of health and comfort in the internal environment. Discontent with current health status or housing environment may also influence mental health. For example, a study into the relationship between chronic illness and mental distress carried out by Verhaak et al (2004), employed the general health questionnaire, GHQ_{12}, to assess mental disorder. The health survey for England also employs the GHQ_{12} in order to assess levels of depression, anxiety, sleep disturbance and happiness in the population (DoH, 1999).

The rational and standard method for investigating how the indoor environment is perceived in existing buildings is to use questionnaires and to ask people to judge the indoor climate. It was not considered appropriate to employ standard comfort questions, such as those directly based on the ASHRAE or Fanger scales, within this study, as both the winter and summer questionnaires are particularly focussed on comfort in extreme climate, those relating to climate change. That is to say that during the summer, it was of particular interest to consider the health and comfort implications and behaviour related to heat in the internal environment and conversely of cold during the winter. The questions relating to comfort were therefore designed for this research to enable consideration of comfort where and when discomfort due to heat or coolth is experienced in the appropriate season.

Both the questions and the questionnaires were then evaluated through a series of rigorous development stages, including general comprehension tests with members of the general public, external to the academic field, as well as expert review of the questionnaire, wording, layout and questions themselves. As the surveys were to be conducted by post this process was critical to the success of the survey. As has been suggested, the use of this method is beneficial in terms of costs and time pressures, nevertheless, with no researcher present to help the interpretation of the questions, they must be easily intelligible, written in plain and simple English, and the response method must be as intuitive as possible. The detailed distribution of questions and their sources for both the summer and winter questionnaires are reproduced in Appendix 1.

4.3.8 Pilot of the Method

The process of administering a questionnaire is well documented and has in itself been the subject of much research (Aday 1996, Edwards et al, 2002). As such this will not be considered in detail here. It has already been suggested that piloting of questions can enable the creation of appropriate categories which can enhance the application of closed questions. This in turn can reduce data entry and analysis required. The piloting of questionnaires can assist in the identification of problems in the format and understanding of questions that may not have been identified during the developmental stages. The pilot also enables testing of the process designed to administer the questionnaires, as well as give an indication of likely response rates. In order to assist in these factors, two pilot surveys were carried out, one for the summer survey in August / September, 2002, and for the winter survey in November / December, 2002. Samples were selected from housing outside the Neath Port Talbot locality to prevent prior introduction of the research to the area to be studied. A random sample of 50 homes in Cardiff, stratified by age group only, was used. The process employed to administer the first summer pilot questionnaires involved three stages described below:

1. The research was introduced to each of the sample households via an introductory letter. This method of research introduction, rather than the first contact being the questionnaire itself, is described as 'warm contact' and is said to help increase response rates. A postcard was included with the letter to enable those who had not been resident for one year, or those who did not wish to take part, to respond.
2. After one week the questionnaire was sent with an accompanying letter.
3. After three weeks a polite reminder postcard was then posted to those who had not yet responded.

To enable tracking of responses and to link data collected from the questionnaire with home and household data already collected, a reference number was included on all questionnaires. This enabled the two datasets to be linked. A short note should be made of the importance to adhere to data protection regulations, where personal information should not be kept in the same database as data collected in confidence. This was achieved through the use of a linking reference, whereby household contact details were never kept in the same database as data collected through either the existing EEP database or this research. Further to this, the names of the respondents remained unknown to the research, only household addresses were utilised in the administration of the questionnaires, and occupants were referred to as 'the Householder'. This also helped adherence to data protection and consideration of research ethics through ensured anonymity for the respondents to the questionnaires (www.informationcommissioner.gov.uk)

A response rate of 34% was achieved for both the summer and winter pilot surveys, slightly exceeding the estimated response rate employed in the sample selection method. In terms of survey administration no problems were perceived in the administration methods, although the provision of a response postcard with the initial letter was pronounced unnecessary as no responses were received at this stage. A basic analysis was carried out on the results of each of these surveys to identify which questions had been found to be unclear, and therefore required rewording, and which had produced similar responses from the respondents and as a result were found to be redundant.

Problem Description	**Action**
Confusion had been caused due to unclear application of 'Yes / No' response categories.	Creation of more appropriate response categories. OR Re-write as open question.
Written response to 'Yes / No' response categories – Don't know	Inclusion of *'Don't Know'* response category.
Construction of external walls question failed to identify timber frame construction.	Include further question relating to timber frame construction.
Where the question asked the respondent to *'Please tick the appropriate boxes'* they had not responded to all questions.	Change action request to *'Please tick one box on each line.'*
Analysis of separate questions referring to sunlight in questions asked to each sex.	Move to general section.
Four questions referring to use of external spaces all soliciting similar responses.	Questions redundant – merge into one.
Written responses referring to discomfort at night not solicited by existing questions.	Include question referring to night-time comfort.

Table 54: Examples of Changes Required to Questions Following Piloting

Where questions either required alteration or new questions were introduced, these were then informally piloted by members of the public and within the academic colleagues to ensure clarity, as previously undertaken for the full questionnaire. A second full scale pilot was not considered to be necessary to test these questions further. The format and design of the questionnaires were finalised following this process.

4.3.9 Conducting the Surveys

The final surveys were then conducted in September / October, 2002, for the summer and February / March, 2003, for the winter. The summer survey may be considered to have been undertaken late in the year to reflect summer time behaviour, however, the summer of 2002 was relatively hot and long-lived, and as a result it is hoped that the responses would not be unduly affected by this delay. It was considered that a further delay (until the following summer) in data collection would be unacceptable.

It was hoped that a response rate akin to that achieved during the pilot would be achieved and in order to assist this a further stage in the administration of the survey was included. This entailed tabulating the postal response rates for individual strata, and where strata were considered to be responding at a level below that of other strata or where the level of 25% was not reached, a final reminder letter and copy of the questionnaire were also posted. This additional stage in the questionnaire administration was derived from results of postal questionnaire response rates reported by Edwards et al (2002). It was also considered appropriate to contact respondents further where significant proportions of the questionnaire were returned incomplete, this was considered especially appropriate where one or other sex of occupant was present but had not competed the appropriate section of the questionnaire.

4.3.10 Data Input and Analysis of the Results

'there is a limit to which disentanglement is possible and common sense must be applied before complex statistics' (Source: Mant, 1993)

The data input, coding, cleaning and analysis that should be undertaken in order to report the results of a questionnaire survey is a significant undertaking. All aspects of which must be considered prior to the undertaking of the surveys in order to ensure that the data gathered through survey will address the research questions. The stages of data processing and analysis that must be undertaken are summarised below:

- Data Input Cleaning & Coding
- Data Analysis
    - Sample Analysis
    - Descriptive Statistics
- Application to Climate Change Housing Risks
    - Summer Survey
    - Winter Survey

4.3.10.3 Data Coding & Cleaning

Data coding, input and cleaning form the initial stages in enabling analysis of results from questionnaire surveys. The process differs for open and closed-ended question types, however, the initial process is common to all. The data must be coded in order that it can be inputted into the analysis tool, which in the case of this work was SPSS. SPSS was selected due to its accessibility as well as its capabilities in terms of data analysis (Oppenheim, 1992, Aday, 1996, WHCS, 1995, Burns, 2000).

Data coding can initially be eased through the application of edge coding to the questionnaire itself and creation of data input files in the SPSS statistical package. Further to this, a code book must be created in order to enable the coding of open-ended questions or 'other responses' to otherwise closed-ended questions. The coding of these responses can either be considered prior to responses or through the analysis of responses received through the research. It was suggested that due to the explorative nature of this research, the latter method should be adopted and coding of all open-ended questions would be undertaken through qualitative content analysis.

Where responses were either 'not applicable' or 'missing', the following codes were used:

999	for missing information
888	for responses that were not applicable

Further to this, it was considered appropriate to include the subsequent variables coded as follows, relating to information regarding the overall questionnaire response:

Variable name: ***Valid***

This variable was to be added to the SPSS data input files in order to include refusals and incomplete datasets, this helped in chasing data as well as enabling sample response calculations.

M	Missing data
One	Less than one year occupation of home
R	Refused
Y	Returned complete data

Variable name: ***Nodata***

This variable was to be added to the SPSS data input files in order to code response types as well as the data collected for homes.

1	Female data missing
2	Male data missing
3	Not complete
4	No female in house
5	No male in house
6	Refused
7	Less than one year
8	No missing data

Once the data has been input into the SPSS file it is necessary to carry out a check of the accuracy of the data input. Data cleaning methodologies can be carried out, such as range and contingency checks, where range checks ensure that the response lies within the expected range and contingency considers the comparison between related questions. It is not necessary to rely on such checks entirely in this sample, as it is relatively small. Therefore a check to ensure the accuracy of the data input was undertaken through re-verification of all questionnaire datasets after input. It is then proposed that a final 10% random sample check of datasets is undertaken. It is considered that this level of quality control of the data input process will ensure a minimised level of systematic errors from this source.

With regards to missing data it is here suggested that decisions as to the appropriate course of action, whether deductive, cold-deck, hot-deck, statistical or multiple imputation methods, or exclusion of the cases, should be considered on an individual variable level. These gaps in data can in themselves be a source of systematic error or bias, due to the characteristics of the missing cases. It is therefore stated here that where imputation has been undertaken the method and scale of imputation will be included in the report of the results of the research (Aday, 1996).

4.3.10.4 Data Analysis

In order to enable the analysis of the data collected through these two surveys measurement matrices were developed for the variables to be gathered in each. These matrices include question numbers, the concept that it is applicable to and the level of measurement at which it is to be collected: nominal, ordinal, interval or ratio. These matrices are reproduced in Appendix 1. The analysis of this data is then to be undertaken though statistical analysis.

The first stage of the analysis should involve the collation of uni-variate or descriptive statistics of the results for individual variables collected through the two surveys. These results are reproduced in full in Appendix I for the winter variables and Appendix J for summer variables. These statistics are to be produced to enable a summary of the findings from the surveys. Uni-variate statistics are to be used at this stage, such as the frequencies and percentages of all valid responses. Further descriptive statistics are reproduced where appropriate within the following results chapter. The table below illustrates those uni-variate statistics appropriate to levels of measurement.

		Levels of Measurement		
		Nominal	**Ordinal**	**Interval or Ratio**
Frequencies		✓	✓	✓
Measures of Central Tendency	**Mode**	✓	✓	✓
	Median	N/A	✓	✓
	Mean (Average)	N/A	N/A	✓
Measures of Dispersion	**Range**	N/A	N/A	✓
	Variance	N/A	N/A	✓
	Standard Deviation	N/A	N/A	✓

Table 55: Uni-variate Statistics to be Applied During the Initial Data Analysis

At this stage it is then necessary to calculate combined variables from those measured directly through survey. For example, analysis and calculation must be undertaken to enable interpretation of the responses to the twelve GHQ questions, where a score of 4 or more has been defined as a threshold to identify respondents with high levels of psychological distress (DoH, 1999). Coding of the NSSEC socio-economic level must also be undertaken following interpretation of the responses received. Further to this, combined measures must be created from the variables collected that interpret the health and comfort status, as well as factors relating to housing and neighbourhood. These combinations are illustrated in the measurement matrices reproduced in Appendix D. These matrices illustrate those questions that are to be considered in combination and may be applied to create measures of these complex notions of housing satisfaction, state of repair, health, comfort in relation to cold or overheating and wider socio-economic factors. At this initial stage it is also appropriate to analyse the sample in relation to the known population distributions. This may enable the identification of possible bias in the sample that may in turn be applied to influence the weightings of results, where they are to be aggregated to the population level.

The second stage of data analysis is to test relationships between variables using bi-variate statistics. These statistical tests enable the analysis of the differences between subgroups of variables related to the principal objectives of this work. In the case of this work, appropriate groups would include socio-economic status, housing status and nature and / or age of home.

Where such tests are undertaken the selection is expounded further as appropriate in chapter 5. It can be noted that the selection of parametric or non-parametric tests is dependent on the following three factors:

- The data can be treated as interval (it must be noted that attitude scales are often considered to fulfil this assumption)
- (Close to) normal distribution
- Homogeneity of variance

Finally, where appropriate, the data gathered from the surveys can be extrapolated to the Neath Port Talbot population scale. The distribution at sample and population scale must be carefully considered where this is undertaken, as well as the broad sources of error that are likely to be present.

During the process of designing and administering postal questionnaires, a number of sources of errors are likely to be introduced. The sources appropriate to this methodology include coverage, sampling and measurement, together with non-response bias (Openheim, 1992, Aday, 1996). A final source of error, identified by Sudman & Bradburn (1983), relates to the characteristics of the survey instrument, questionnaire, the respondent themselves and their potential interaction. All sources of error must be considered during the analysis of the data, where possible through their quantification, or through verbal consideration and acceptance of their likely existence and impact on the reported results.

4.3.11 Summary

The complexities of the relationships between health, comfort and housing that are to be evaluated through this survey have been considered and the development of two appropriate survey instruments have been illustrated. Throughout this process it has been important to ensure that it is possible to make certain that the breadth of the pathway and receptor factors identified within each of the risk systems being considered can be taken into account during data analysis. It was therefore necessary to guarantee that all relevant vulnerability and exposure variables were collected through survey or that they were already available to the research, as was the case of the postcode level Townsend scores. Where appropriate, the survey has strived to achieve objectivity through the use of factually based questions. However, many factors to be explored through survey are, by their nature, subjective concepts, such as the concepts of comfort and health.

It is necessary to reaffirm here that responses to questionnaires such as these may be biased due to the emotive subject being considered, that of the home. Where respondents may consider that their responses to a questionnaire may result in beneficial changes to their environment bias may occur. It is hoped that the academic nature of the research, with no connection to policy or government at any level, may reduce this potential source of response error.

The consideration of the potential health impacts of climate change are to be inferred through application of already established causal links as described during the literature review, and with direct reference to the risk systems illustrated in chapter 3 for each of the risk factors to be evaluated. Further to this, the study is considered to be descriptive in nature with application of group comparison tests to establish possible patterns in relation to factors including: pathway and receptor factor families.

4.4 Monitoring

The application of monitoring to a case study home, representative of current building practice research, is considered appropriate to enable consideration of appropriate adaptation to current building practice, a key requirement in developing healthy and comfortable domestic environment for the future climate. The key stages in the development of the monitoring methodology is illustrated here are as follows:

- Scope for Monitoring in the Built Environment
- Selection of Study Design
- Selection of Case Study
- Design of Method
- Piloting of Method
- Conducting the Monitoring
- Analysis of the Results

4.4.1 Scope for Monitoring in the Built Environment

The scope for the monitoring aspect of this work must include empirical measurement of the internal environment as experienced in the case study home under current climate conditions. Data has been widely collected for internal temperatures experienced and achieved within homes in the winter season, for homes in England, within the English House Condition Survey (Boardman et al, 2005). To date this work has, however, been focused on the consideration of fuel poverty and winter cold. It can be seen from this widely available data that the quality of homes, as well as socio-economic status of the occupants, are associated with fuel poverty and internal cold in the home environment during the winter. However, equivalent work has not as yet been undertaken for the summer season, which, by contrast, has not been associated with health or comfort implications for housing occupants.

It is therefore considered appropriate that this research explores the internal environment experienced within homes during the winter and summer seasons in order to enable consideration of this factor.

4.4.2 Selection of Study Design

The method to be selected to enable monitoring of the internal environment is, by necessity, constrained by the availability of monitoring equipment, together with the time scale within which the research is to be undertaken. Finally, the availability of willing and reliable housing occupants in appropriate case study homes must also be considered. Were this to have been undertaken using a representative sample of housing in Neath Port Talbot, consideration of housing tenure, age of property, efficiency of the heating system, housing heat-loss characteristics, housing SAP rating, occupant income, fuel cost, indoor and outdoor temperatures, would be required in combination with a record of occupant behaviour for each home. It can be seen that this would require a large resource, unavailable to this PhD study. Therefore the method design selected was to employ a single case study home, representative of current house building and design.

4.4.3 Selection of Case Study

The case study home selected was that of the author. A summary of the home's characteristics, together with those of its occupants, is provided below:

Year of Construction	2000
Built Form	3 Bedrooms / Semi-detached
Construction	Traditional masonry construction
Heating Method	Conventional gas boiler with radiator central heating.
SAP Rating	81
Occupancy	1 Adult Female: PhD Student @ home 3-4 days a week 1 Adult Male: Employed full time

This case study was selected for a number of reasons. The construction, scale and form is representative of current mass-house building in the UK and as such represents an appropriate case study of the performance of current housing. A conventional gas boiler central heating system with radiators throughout the home also conforms to a widespread standard in such homes. The low level of occupancy reflects current national trends towards smaller households. The relatively comfortable economic status of the occupants ensures that the results of the monitoring will not be influenced due to the affects of fuel poverty. Finally, the onerous requirement of a detailed record of occupant behaviour throughout the period of monitoring would be likely to result in missing data or loss to follow-up were a longitudinal multi-location methodology to have been adopted. The monitoring of the home of the researcher is unlikely to suffer from significant levels of missing or lost data due to the inherent motivation likely to be present for participation.

4.4.4 Design of Monitoring Method

The methodology to be implemented in the monitoring of the home has been developed from that created to undertake SBS research as described in Jones et al (1995), in consultation with Huw Jenkins of the Welsh School of Architecture (Jenkins, 2002). Monitoring was undertaken for the period of a year, from 1st January 2003 to the 31st December 2003 using miniature temperature and RH data loggers (Gemini Data Loggers, 2000). The seasons being defined thus: December, January, February as Winter; March, April, May as Spring; June, July, August as Summer and September, October, November as Autumn (Levermore et al, 2004).

Manufacturer	Ref	Purpose	Range
Gemini Data Loggers	RS Tinytalk II: 196-7386	Miniature Temperature Logger	-40°C to + 75°C
Gemini Data Loggers	RS Tinytalk II: 196-7386	Miniature RH Data Logger	0 to 90% RH

Table 56: Details of Data Loggers to be Employed in Case Study Home Monitoring

The data loggers were carefully located in each living room, ensuring that they were not to be exposed to direct sunlight nor subject to excess ventilation or draughts. Data loggers should also not be directly exposed to radiators or other sources of heat, such as concealed hot water pipes. It was also good practice to ensure they were not located where they were likely to be disturbed or moved during normal day-to-day household activities. They were programmed to take a reading every 15 minutes. This interval ensured a record of fast moving influences on the internal environment, such as showering or changes in ventilation.

Household activity and relevant occupant behaviour was recorded through a written diary, where detailed behaviour, such as the use of heating, opening windows or other window vents for ventilation, drying clothes, cooking and showering were to be recorded. A copy of the diary sheet developed for this purpose is provided in Appendix H The data required includes the duration of the activity and, for the heating, the use and setting of timers and thermostats.

It can be seen that up to now this methodology does not allow for detailed consideration or measurement of the ventilation rates within the case study home. Equipment was not available to this research to monitor air flow or ventilation rates continually throughout the year long monitoring period. Furthermore, it would be difficult to select appropriate locations in which to measure this without causing disruption to the day to day activities. A more appropriate method to apply for approximate measurement of the air change rates likely to be experienced within the home is to undertake a fan pressurisation test (CIBSE, 2000).

This technique actually measures the Air Leakage Index or air permeability of the building, the volume flow per hour ($m^3 h^{-1}$) of air supplied to the space by the air-moving equipment, per square metre (m^2) of building envelope area for a specified internal to external pressure difference of 50Pa, for example, $10m^3h^{-1}m^{-2}$ at 50Pa (CIBSE, 2000). The difference between these two measures lies within their definition of the building envelope, wherein the Air Leakage

Index does not include the solid ground floor in the calculation. The air permeability test is selected here for reporting of this test, as this has been selected to be included in both the UK building regulations and the European Standard EN13829.

Figure 99: Typical Fan Pressurisation Equipment for Domestic Scale Air Leakage Tests

The detailed methodology required to be undertaken to enable calculation of the air permeability index is described in CIBSE, 2000, and will not be reproduced here. The fan pressurisation test can then be combined with methods to identify leakage such as smoke visualisation or thermography tests. In order to enable comparison of the results with best practice appropriate standards have been reproduced in table below from CIBSE, 2000. It should be noted that these indexes are not a direct measure of infiltration, as the pressure difference of 50Pa is much higher that would normally be experienced. However, an air infiltration rate can be calculated from the air leakage index through the application of a simple rule of thumb, derived from a large number of measurements (CIBSE, 2000). The air infiltration rate measured in air changes per hour, is approximately 1/20 of the 50Pa air leakage rate (Q_{50}/V). Where Q_{50} is the Air Leakage Index and V is the internal volume of the building.

	Air Leakage Index ($m^3 h^{-1} m^{-2}$) @ 50Pa		**Air Permeability ($m^3 h^{-1} m^{-2}$) @ 50Pa**	
	Good Practice	**Best Practice**	**Good Practice**	**Best Practice**
Dwellings	15.0	8.0	10.0	5.0
Dwelling (with balanced whole house mechanical ventilation)	8.0	4.0	5.0	3.0

***Table 57: Air Leakage Standards** (Reproduced from CIBSE, 2000)*

A final method to be applied during the monitoring of the house involves assessment of the insulation throughout the building. That is to say it is appropriate to ensure that the building was constructed to the thermally insulative standards expected. A thermography survey can be undertaken whereby an infra-red camera records the locations and intensities of localised heating of the building fabric. This survey must be undertaken on a cool, calm day when the temperature differential between the inside and outside can be maximised by heating the building internally (Jenkins, 2002). The camera is then used to scan the surfaces of the building for locations of relatively inadequate insulation or significant air leakage.

4.4.5 Pilot of the Method

The pilot of the monitoring methodology involved the calibration and testing of the monitoring equipment. In relation to the pressure test equipment and infra red camera, these pieces of equipment are of a specialist nature and have been calibrated in manufacture. They are tested regularly for their accuracy and precision by qualified staff at the WSA The data loggers are also calibrated during manufacture, however, the logging equipment made available to this work had been stored for a number of months and it was therefore considered appropriate to test their accuracy. This was undertaken through the placement of the probes in standard and extreme conditions for periods of time in order to test their response to a wide variety of conditions, as follows:

Test 1:	Exposed to the conditions in a single location in the home
Test 2:	Conditions in a sealed box
Test 3:	Extreme cold and hot conditions each for a 24 hour period
Test 4:	Sudden changes in temperature

The following graphs illustrate the findings from the final test conditions. The relative humidity loggers were exposed to a space at ambient humidity which was then exposed to increased humidity, through the running of a shower, and then allowed to regain ambient conditions. The temperature loggers were placed together in a tray and firstly exposed to the heat in an airing cupboard (to represent extreme heat) and then the fridge compartment (to simulate the cold extreme). In each case one logger had been independently calibrated in order to ensure the overall accuracy of the readings.

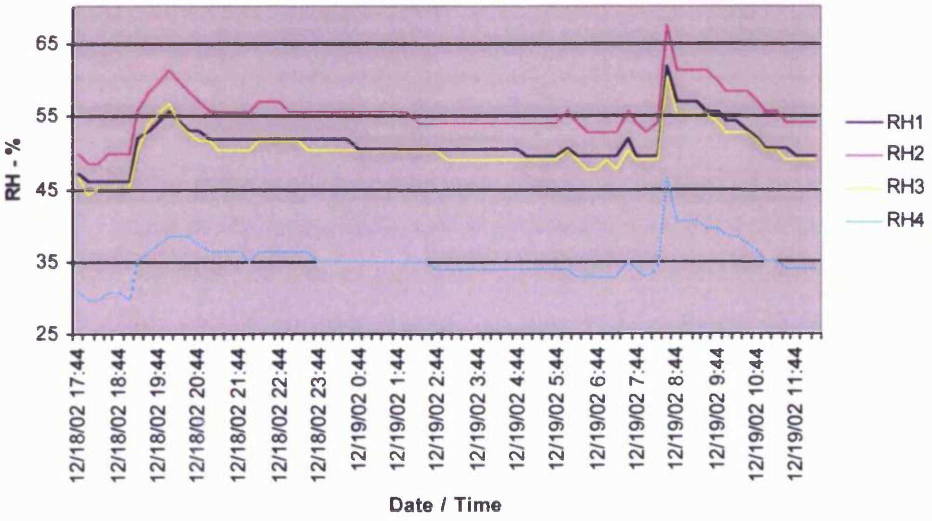


Figure 100: Results from Test 4 of the Relative Humidity Data Loggers

Calibration to Logger RH1		
RH2	RH3	RH4
+ 4 %	- 1 %	- 16 %

Table 58: Calibration of Relative Humidity Data Loggers to Independently Verified Logger RH1

It can be seen that the four relative humidity loggers read consistently differently. Unfortunately, no other logging equipment was available to the project and therefore these differentials were calculated and recorded in order that they may be applied to the final results of the monitoring. RH1 represents the independently calibrated logger. The loggers were again calibrated following the year long logging and were found to have retained a consistent level of differential (+ / - 1%).

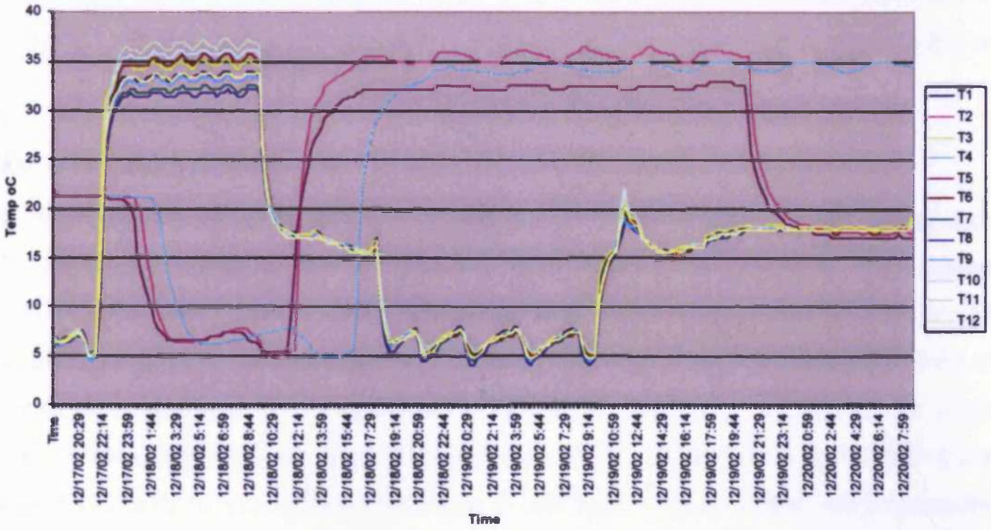


Figure 101: Results from Test 4 of the Temperature Data Loggers

	Calibration at 30°C - 35°C			Calibration at 5°C - 25°C	
	Logger Ref	Average Error		Logger Ref	Average Error
+4	T11	3.11	+3	T11	0.04
+3	T10	2.24	+2	T10	0.01
+2	T6	1.55	+1	T3	0.03
+1	T3	1.19	0	T1	0.00
0	T1	0.00	-1	T12	-0.22
-1	T12	-0.06	-2	T9	-0.20
-2	T9	-0.39	-3	T6	-0.27
-3	T7	-1.29	-4	T8	-0.38
-4	T8	-1.82	-5	T7	-0.47

Table 59: Calibration of Temperature Data Loggers at Hot and Cold Extremes

For the temperature loggers the final test was of particular significance as it highlighted an error within three loggers that had not previously been detected. Loggers T2, T4 and T5 displayed an unusual delay in their response to changes in temperature which rendered them unusable for the monitoring. This had not been detected in previous work where the loggers had only been subject to gradual temperature changes. It can also be seen that their accuracy is less at higher temperatures, 32°C - 36°C, close to their +40°C extreme, as well as during sudden changes in temperature. A range of readings of approximately 5°C was experienced at the higher extreme and approximately 4°C where temperatures changed suddenly. Again, access to monitoring equipment was limited, eliminating the possibility of replacement. The error could not be rectified and it was decided that the results of the monitoring should therefore be analysed taking into account this identified measurement error.

Through analysis of the readings at hot and cold extremes it can be seen that although the scale of the error does not remain constant at different temperatures the order in which the loggers read erroneously did remain relatively constant, where only data logger T6 altered its position significantly in the ranking. The calibration tests undertaken at 5°C - 7°C using a refrigerator and between 20°C - 25°C, during a period of thermostatic heating control also suggested that readings within the lower temperature ranges were within the stated accuracy of the loggers +/- 0.5°C. Where the larger errors are present for the higher temperatures these calibration factors can be applied as corrections to the readings where necessary.

4.4.6 Conducting the Monitoring

The case study monitoring was undertaken for a period of 12 months, from 21st December, 2002, until 25th December, 2003, where temperature and relative humidity data was logged every 15 minutes for the entire period. Data download was required approximately every 20 days due to the storage capacity of the loggers. However, this also enabled frequent checks of the loggers to ensure minimisation of loss of data through breakdown of equipment or more simply as a result of low battery power. Data loss was limited to a maximum of one reading per download through the ability to swiftly download and re-set logging equipment via a computer located in the building.

The locations of the data loggers throughout the case study were as follows:

Logger Name	Type	Location
T1	Temperature	Kitchen
T3	Temperature	Lounge
T6	Temperature	Hallway
T8	Temperature	Main Bed (Bed 2)
T9	Temperature	Small Bed (Bed 3)
T10	Temperature	Office (Bed 1)
T11	Temperature	Bathroom
T12	Temperature	Attic
RH1	Relative Humidity	Bathroom
RH2	Relative Humidity	Main Bed (Bed 2)
RH3	Relative Humidity	Kitchen
RH4*	Relative Humidity	Lounge

**NB Very Low readings*

Table 60: Data Logger Locations in Case Study Home *(Highlighting indicates independently calibrated loggers)*

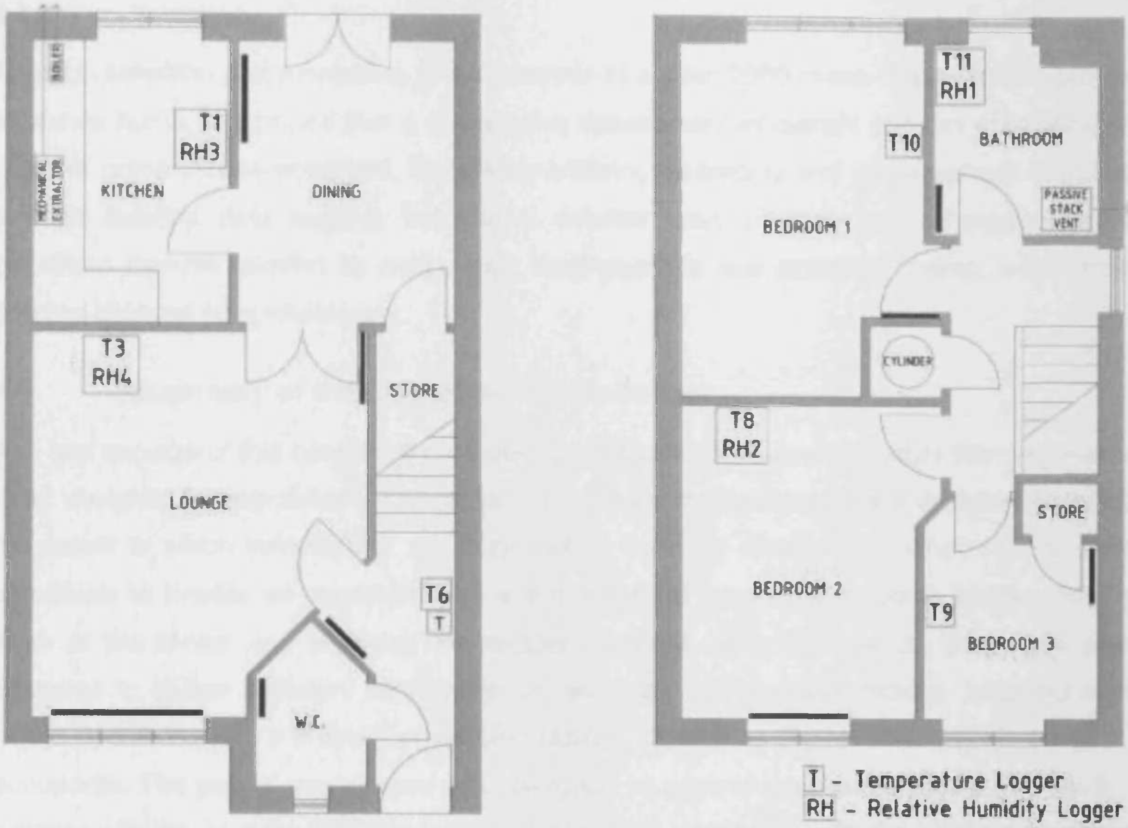


Figure 102: Floor Plans Showing Locations of Temperature and RH Loggers in House

The infrared thermography test was undertaken on 14th March, 2003, in consultation with Huw Jenkins of the Welsh School of Architecture, and the pressure test was undertaken on 21st October, 2003, with guidance from Huw Jenkins and Simon Lannon, both of the Welsh School of Architecture.

4.4.7 Analysis of the Results

The results of the monitoring process will be analysed in comparison with the principals of adaptive comfort, as well as through the application of previously applied comfort standards such as those considered by Hacker et al, 2005. Periods when either of these two types of comfort standards are exceeded will therefore be measured. Consideration will be taken during this analysis as to occupant behaviour, with attention to control of ventilation, heating, and the internal production and extraction of moisture and related humidity levels. Analysis will focus on the two extreme seasons of winter and summer.

The analysis of the thermography test will involve detailed study of the video, in consultation with experts at the Welsh School of Architecture, in order to consider any significant problems with insulation levels in the building that may influence the internal environment in the case study home. The analysis of the pressure test will be undertaken through application of the analysis procedure as outlined in the guidance document, CIBSE, 2000.

4.4.8 Summary

Through selection and monitoring of an example of a year 2000 mass house-builder built semi-detached home, it is hoped that a quantitative assessment of current comfort conditions in this types of home can be assessed. Detailed monitoring, recording and measurement of the home through detailed data logging, keeping a detailed diary of occupant behaviour, record of perceived thermal comfort by occupants, thermography and pressure testing, will produce a detailed data set for a whole year.

4.5 Summary of the Combined Methodology

The two aspects of this combined methodology that are to be applied within this research have been designed to compliment each other. The survey methodologies are designed to establish the extent to which vulnerability and exposure is currently distributed during extreme weather conditions to enable an approximation of the extent of future risk in south Wales housing for each of the winter and summer risk factors explored within chapter 3 They have also be designed to gather sufficient information on pathway and receptor factors, including existing health conditions and a breadth of housing factors, as well as the socio-economic status of the occupants. The pair of surveys are also designed to explore occupant behaviour in the light of extreme climate, in order that the impact of occupant interaction with the housing environment can also be considered. Meanwhile, the monitoring aspect of the methodology has been incorporated in order that quantitative data as to the internal environment of homes currently being built can be assessed.

Chapter 5 - Results

The results from the summer and winter surveys together with those from the monitoring are described in the following sections.

5.1 Winter Survey Results

The winter survey received 250 responses, representing a response rate of 25% (anticipated response rate was 20 – 30%). Ninety-nine replacement questionnaires were sent out in addition to the initial sample of 1000, required due to inadequate addresses, as well as those households deemed non-eligible due to residency of less than one year. A fairly even spread across the ten strata was received, with the lowest distribution for the 1965 - 1980 / rural and 1919 – 1944 / urban strata and highest in the pre-1919 / urban stratum.

Age	**Location**	**Total**	**Response Valid**	**% of Valid**
Pre-1919	**Rural**	30	**23**	9.2%
	Urban	44	**31**	12.0%
1919-1944	**Rural**	38	**30**	10.4%
	Urban	29	**24**	8.0%
1945 - 1964	**Rural**	38	**30**	11.2%
	Urban	39	**29**	10.0%
1965 -1980	**Rural**	25	**21**	8.0%
	Urban	35	**28**	10.4%
Post-1980	**Rural**	32	**29**	10.0%
	Urban	37	**26**	10.0%
Respondent Removed Reference		1	**1**	0.8%
	TOTALS	**349**	**272**	**100%**

Table 61: Summary of Response Rates to Winter Survey

Those responses that were received, but were not fully complete were, also a significant proportion and must be considered here, due to their implications for the analysis of the data. Of those responses received 60% of the responses were fully complete (with responses from both male and female occupants); 33% were complete as appropriate to their household composition, where either no female or no male occupants were present and the remaining incomplete responses, 7% had either male or female response datasets incomplete or missing and 1% were more substantially incomplete. Where the respondents had indicated that they were willing to receive further communication this missing information was requested.

	Frequency	**Percent**
Fully Complete	162	**59.6%**
Female Data Missing	4	**1.5%**
Male Data Missing	15	**5.5%**
Not Complete	2	**0.7%**
No Female in Household	29	**10.7%**
No Male in Household	60	**22.1%**
Total	272	**100.0%**

Table 62: Distribution of Response Cases with Incomplete Datasets

The responses to the winter survey will now be analysed following the methodology described previously, while a summary of appropriate descriptive statistics for each variable gathered is reproduced in Appendix I. Initially these responses have been analysed in terms of the pathway and receptor factors. Where analysis has been undertaken to compare the sample with the population, appropriate weighting has been applied to counteract the effect of the stratified sampling method, through the application of weighting factors. A table of weighting calculations is reproduced in Appendix J. Finally, analysis was undertaken to evaluate the distribution of health and comfort risks in the home environment that have earlier been identified as likely to be influenced by climate change.

5.1.1 Pathway Factors

The winter survey collated information on the following pathway factors:

Pathway Factors: Housing

- Age of property*
- Type of property
- State of repair
- Construction type
- Ventilation
- Internal air pollution
- Heating type
- Insulation
- Orientation

Pathway Factors: Neighbourhood

- Exposure to air pollution
- Exposure to wind
- Exposure to rain
- Exposure to flood

* It is reiterated here that the age of the property formed part of the sample stratification and the distribution of this pathway factor has therefore been considered in section 5.2.

In addition to this data, relevant factors from the HANAH EEP datasets for Neath Port Talbot will be reproduced.

5.1.1.1 Pathway Factor: Type of Property

The distribution of housing built form for the winter survey is illustrated in table below. A contingency table analysis was conducted to determine whether there was an association between age of property and built form. A significant relationship was present (chi square = 145.141, df = 16, p<0.001) and the effect size of 0.596 indicates a medium large effect. It can be seen that pre-1919 properties in the sample are most likely to be terraces, or semi-detached, those built between 1919 & 1980 are more likely to be semi-detached and those built post-1980 detached or bungalows. This distribution does not differ significantly from that found for the summer survey (chi square = 5.659, df = 4, p=0.226, n.s.) nor that found in the population. The number of storeys of the properties follows a logical distribution where the majority of homes are two-storey, except the majority of flats, maisonettes and bungalows. There are 3 three-storey terraced properties within the respondents' homes.

	Age of Property					
	Pre-1919	**1919 – 1944**	**1945 – 1964**	**1965 – 1980**	**Post-1980**	**Total**
Detached House	4	3	3	15	19	44
Semi-Detached House	20	32	45	17	9	123
Terraced House	28	10	1	3	2	44
Flat / Maisonette	1	1	6	4	5	17
Bungalow	1	7	3	10	19	40
Total	54	53	58	49	54	268

Table 63: Cross-tabulation Showing Age of Property and Built Form

5.1.1.2 *Pathway Factor: State of Repair*

The measures of state of repair of the respondents' homes relate to existing structural and maintenance problems. It was found that 5% of respondents' properties had structural faults, ranging from cracks in the walls, settlement and damp issues as a result of external land drainage problems.

		Pre 1919	1919 - 1944	1945 - 1964	1965 - 1980	Post 1980	Total
Housing Faults	**No**	50	48	49	47	51	**245**
	Yes	3	5	9	1	2	**20**
	Total	**53**	**53**	**58**	**48**	**53**	**265**

Table 64: Presence of Structural and Maintenance Faults by Age of Property

A simple additive measure of housing faults was created, where homes were found to either have faults or not. It was found that the distribution of homes with structural faults did not differ significantly from the expected distribution of unfit homes, (chi square = 1.214, df = 1, p=0.270, n.s.).

5.1.1.3 *Pathway Factor: Construction Type*

The construction typology of the respondents' homes can be summarised through analysis of information relating to the construction of the external walls, the presence of timber framing and the age of the property. Through combination of reported wall construction materials, presence of timber frame construction methods and age of property, a combined measure of weight of construction has been estimated. The distribution of this measure for the survey respondents is illustrated below.

		Pre 1919	1919 - 1944	1945 - 1964	1965 - 1980	Post 1980	Total
External Wall Construction	**Light Weight**	1		4	1	7	**13**
	Medium Weight		1	1	48	48	**98**
	Heavy Weight	53	53	54			**160**
	Total	**54**	**54**	**59**	**49**	**55**	**271**

Table 65: Comparison of External Wall Construction Weight by Age of Property

One factor that can influence perception of comfort in a home is the flooring throughout the property. For example, laminate flooring, feels relatively cold in comparison to carpet, while stripped floorboards on the ground floor of an older property may result in an increase in draughts. In order to consider this factor, occupants were requested to state the flooring type in their main living room.

	Frequency	%
Fitted Carpets	228	84.8
Exposed Wooden Floorboards	8	2.8
Laminate Flooring / Wood Block	30	11.0
OTHER	4	1.4
Total	**269**	**100.0**

Table 66: Frequency of Flooring Types in Respondents Main Living Rooms

5.1.1.4 *Pathway Factor: Ventilation*

The ventilation afforded by respondents' homes can be considered in terms of type and state of repair of windows, together with the presence of alternative and additional ventilation methods, including, extractor fans in the bathroom and kitchen, trickle vents and wall vents. An initial summary of window types present in the sample is illustrated below. A contingency table analysis for age of property and type of window found no significant correlation.

	Count	%
Wood	37	13.9%
uPVC	224	83.9%
Metal	6	2.2%
Total	268	100.0

Table 67: Window types in the Sample

Of the respondents, 14% required replacement windows. Of these, 30% required these in one room, 52% in more than one room and 18% required new windows throughout their property. The distribution of these homes was not significantly associated with the type of window in place, the age of the property, nor with the regime of maintenance, which for timber or metal windows, ranged from every year to once every 10 years. Overall, 31% of the respondents reported that there was draught stripping in their properties. This statistic seems particularly low in comparison to that expected from the WHCS. It is likely that where replacement doors have been installed at the same time as windows, these doors would have draught stripping installed, as would uPVC double glazing. The proportion may therefore be closer to the 84% distribution for prevalence of this glazing type.

The presence of air vents, either in the wall (airbricks) or within window frames (trickle vents) in the respondents main bedroom, main living rooms and bathroom was found to be 40%, 57% and 34% respectively. The distribution of these by age of property was found to be non-linear. Analysis was therefore undertaken through the use of Confidence Intervals (CI). It was found that for main bedrooms, properties built between 1965 and 1980 were significantly less likely to have fixed vents than those built during any other period. A contingency table analysis of the relationship between total presence of air vents in these rooms and age of property, identified a non-linear relationship. An analysis of 95% confidence intervals for the distribution in 1919 – 1964 properties found a significant difference between the presence of air vents in these properties and those built at any other time; where the occupants of these properties were more likely to be aware of the air vents.

	Pre 1919	1919 - 1964	Post 1964	Total
No Vents	19 (35.8%)	25 (22.7%)	40 (41.7%)	**84 (32.4%)**
Air Vents	34 (64.2%)	85 (77.3%)	56 (58.3%)	**175 (67.6%)**
Total Count	**53**	**110**	**96**	**259**

Table 68: Comparison between Age of Property and Combined Presence of Air Vents

In relation to extract ventilation, 43% of respondents' households had an extractor fan in their kitchen and 25% in their bathroom. A contingency table analysis was conducted to determine whether an association exists between presence of kitchen extractor fan and age of property. A significant relationship was present with chi square = 20.281, df = 4, p<0.001. The effect size of -0.244, indicates a low effect, and it can be seen that kitchen extraction is most likely to be present for this sample in properties built post-1965.

			Pre 1919	1919 - 1944	1945 - 1964	1965 - 1980	Post 1980	Total
Extract Fan in Kitchen	**Yes**	**Count**	22	17	15	29	32	**115**
		%	41.5%	32.7%	25.9%	59.2%	59.3%	**43.2%**
	No	**Count**	31	35	43	20	22	**151**
		%	58.5%	67.3%	74.1%	40.8%	40.7%	**56.8%**
Total		**Count**	**53**	**52**	**58**	**49**	**54**	**266**

Table 69: Cross-tabulation of Housing Age and Presence of Kitchen Extraction

A further contingency table analysis was conducted to determine whether an association exists between presence of bathroom extractor fans and age of property. A significant relationship was again present with chi square = 19.321, df = 4, $p<0.001$. The effect size of -0.249 also indicates a low effect, where properties built post-1980 are again more likely to have a bathroom extractor fan than are properties built at any other time period. These distributions are not significantly different from those found in the summer survey (section 5.2.1.4).

			Pre 1919	1919 - 1944	1945 - 1964	1965 - 1980	Post 1980	Total
Extract Fan in Bathroom	**Yes**	**Count**	13	10	10	9	26	**68**
		%	24.1%	18.9%	17.2%	18.4%	48.1%	**25.4%**
	No	**Count**	41	43	48	40	28	**200**
		%	75.9%	81.1%	82.8%	81.6%	51.9%	**74.6%**
Total		**Count**	**54**	**53**	**58**	**49**	**54**	**268**

Table 70: Cross-tabulation of Housing Age and Presence of Bathroom Extraction

5.1.1.5 Pathway Factor: Internal Air Pollution

Internal air pollution sources in the home being considered here relate to gas combustion due to heating and cooking sources. Of households in this survey, 59% cook on the hob in the kitchen with gas. While 87.5% of the respondents have gas fired central heating and 1 respondent reported a gas fire in their main living room. Further details as to the use of gas in relation to heating is reported within 5.2.1.7.

5.1.1.6 Pathway Factor: Heating Type

Of the winter survey respondents' households, 98% have central heating. The remaining 2% have no central heating, equating to five cases. One of these households has a gas fire in their main lounge and a further case has an electric fire in their lounge. The remainder have a combination of electric, gas and oil heaters in various rooms. The distribution for central heating provision differs significantly from the 94.8% found in the population (chi square = 5.996, df = 1, $p<0.05$).

It was found that 7% of respondents considered that there was a problem with their heating system. Problems reported in order of prevalence were: general problems with the system "as a whole," problems with specific radiator(s), needing further radiators and problems with control of the system. Further to this, an equivalent of 16% of respondents' households agreed with the statement their *'heating system needs to be replaced'.* Following appropriate weighting of the responses to control for the stratified sample, this equates to an 18% proportion of all NPT households (95% CI: 13.3 – 22.7).

Following a contingency table analysis to determine whether there was an association between the distribution of households that consider they need a new heating system and the age of property, a non-linear association was identified. A further contingency table analysis was undertaken identifying a significant association between housing tenure and attitude towards the statement *'my heating system needs to be replaced'* (chi square = 6.223, df = 2, $p<0.05$), meaning that for this sample, occupants of rented properties are more likely to consider that they require a new heating system. An effect size of 0.367 indicates a low effect.

	Heating Fuel		**Boiler Type**			**Age of Boiler**		
	Count	**%**		**Count**	**%**		**Count**	**%**
Gas	225	87.5%	**Standard**	154	62.9%	**< 5 years**	50	21.3%
Electricity	15	5.8%	**Combi**	74	30.2%	**< 10 years**	53	22.6%
Oil	9	3.5%	**Economy 7**	12	4.9%	**> 10 years**	120	51.1%
Coal	8	3.1%	**Back Boiler**	5	2.0%	**Don't Know**	12	5.1%
Total	**257**		**Total**	**245**		**Total**	**235**	

Table 71: Proportions of Heating Fuel, Boiler Type and Boiler Age for the Winter Respondents' Homes

No significant association exists between housing age and any of these factors relating to central heating, nor do significant associations exist with housing tenure. There is a significant relationship between rural or urban location and fuel used for central heating, (rho – 0.206, df – 250, $p<0.001$), whereby, homes located in rural locations are more likely to use coal or oil for their central heating fuel. A summary of the distribution of central heating control distributions in the respondents' homes is given in the table below.

		Response		
	Yes	**No**	**Don't Know**	**Count**
On / Off Switch	99%	1%	-	207
Thermostat	80%	18%	2%	216
Timer	95%	4%	1%	232
TRV's	59%	39%	2%	185

Table 72: Distribution of Central Heating Controls in the Winter Survey Respondent's Homes

No significant associations exist between those control factors and age of property or age of boiler, except that between boiler age and presence of Thermostatic Radiator Valves (TRV's), where chi square = 15.790, df = 2, $p<0.001$. An effect size of 0.501 indicates a medium effect.

			Boiler Age			
			< 5 years	**< 10 years**	**> 10 years**	**Total**
Central Heating TRV's	**Yes**	**Count**	29	27	39	**95**
		%	74.4%	77.1%	44.8%	**59.0%**
	No	**Count**	10	8	48	**66**
		%	25.6%	22.9%	55.2%	**41.0%**
	Total	**Count**	**39**	**35**	**87**	**161**

Table 73: Contingency Table Showing Relationship Between Boiler Age and Presence of TRV's

5.1.1.7 Pathway Factor: Insulation

As described elsewhere, the SAP rating for a property is related to property size, areas of walls, areas of windows, types and scale of insulation and types and fuel of heating system. This varies significantly with the age of property. The distribution of SAP ratings for this sample are illustrated below.

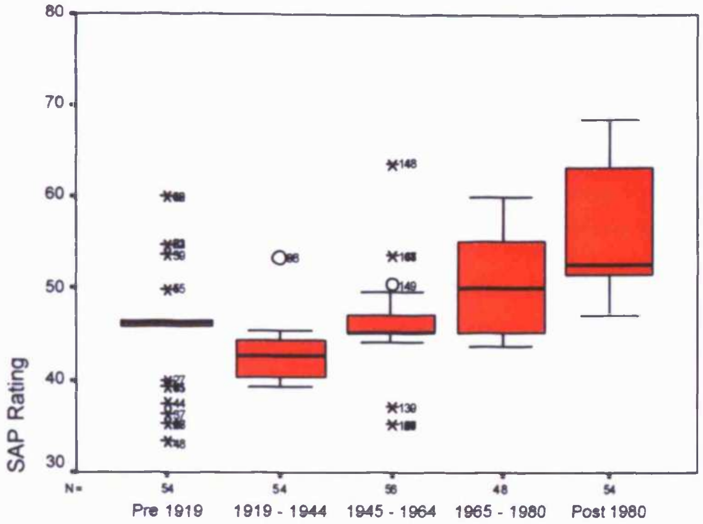


Figure 103: Box Plot Illustrating Median, Quartiles & Extreme Values for SAP Ratings by Age Categories

Loft insulation is evenly distributed through property age strata and contingency table analysis found no significant relationship exists between these variables.

		Pre 1919	1919 - 1944	1945 - 1964	1965 - 1980	Post 1980	Total
Loft Insulation	**Yes**	46	47	43	45	48	**229**
	No / Don't Know	6	2	10	2	5	**25**
		52	**49**	**53**	**47**	**53**	**254**

Table 74: Comparison of Presence of Loft Insulation by Age of Property

A 2 x 5 contingency table analysis was conducted to determine whether there was an association between the presence of cavity wall insulation and age of property. A significant relationship was present with chi square = 14.841, df = 4, p<0.01, meaning that older the property, the less likely the presence of cavity wall insulation. The effect size of -0.359 indicates a low effect. It should be noted that the reporting of this variable may be less reliable that that of loft insulation as it is not readily visible to the occupant. This is suggested the enhanced frequency of responses of *'don't know'* in both the summer and winter survey when compared to those regarding loft insulation.

			Pre 1919	1919 - 1944	1945 - 1964	1965 - 1980	Post 1980	Total
Wall Insulation	**Yes**	**Count**	5	13	14	12	27	**71**
		%	16.1%	41.9%	43.8%	37.5%	60.0%	**41.5%**
	No / Don't Know	**Count**	26	18	18	20	18	**100**
		%	83.9%	58.1%	56.3%	62.5%	40.0%	**58.5%**
			31	**31**	**32**	**32**	**45**	**171**

Table 75: Comparison of Presence of Cavity Wall Insulation by Age of Property

A further 2 x 5 contingency table analysis was conducted to determine whether there was an association between the presence of double glazing and age of property. A non-linear relationship was present (p=0.823). However, visual inspection of the distribution in the contingency table suggest that for this sample it is more likely that double glazing will be present in older properties, built prior to 1919 than in newer properties built post-1980. This is perhaps contrary to expected results.

			Pre 1919	1919 - 1944	1945 - 1964	1965 - 1980	Post 1980	Total
Double Glazing	**Yes**	**Count**	47	42	40	46	48	**223**
		%	92.2%	91.3%	83.3%	97.9%	90.6%	**91.0%**
	No / Don't Know	**Count**	4	4	8	1	5	**22**
		%	7.8%	8.7%	16.7%	2.1%	9.4%	**9.0%**
			51	**46**	**48**	**47**	**53**	**245**

Table 76: Comparison of Presence of Double Glazed Windows by Age of Property

Double glazing was least likely to be present in properties built between 1945 & 1964. The relationship that the presence of double glazing has with housing tenure was not found to be significant for this sample. Further to this, the distribution found for this sample is significantly different from that found for the summer survey (chi-square – 7.472, df = 1, $p<0.01$). It is suggested that a regime of window replacement may have been put in place between the timeframes of these two surveys and that this difference represents a true change in the situation in the population. Verification of this hypothesis has not been possible at the individual household scale, although it is known that refurbishment of council properties has been undertaken in NPT during this period.

			Owner Occupied	Rental Property	Total
Double Glazing	**Yes**	**Count**	181	39	**220**
		%	92.3%	84.8%	**90.9%**
	No / Don't Know	**Count**	15	7	**22**
		%	7.7%	15.2%	**9.1%**
			196	**46**	**242**

Table 77: Comparison of Presence of Double Glazed Windows by Housing Tenure

It was found that 75% of properties in this sample were found to have a hot water tank, 91% of which were insulated. A contingency table analysis (2 x 5) was conducted to determine whether there was an association between the presence of hot water tank insulation and age of property. A non-linear relationship was present ($p=0.923$). However, visual inspection of the distribution in the contingency table suggests that for this sample it is more likely that the hot water tank is not insulated in properties built between 1945 and 1964.

			Pre 1919	1919 - 1944	1945 - 1964	1965 - 1980	Post 1980	Total
Insulated Hot Water Tank	**Yes**	**Count**	34	40	38	32	29	**173**
		%	94.4%	93.0%	80.9%	91.4%	96.7%	**90.6%**
	No / Don't Know	**Count**	2	3	9	3	1	**18**
		%	5.6%	7.0%	19.1%	8.6%	3.3%	**9.4%**
			36	**43**	**47**	**35**	**30**	**191**

Table 78: Comparison of Presence of Double Glazed Windows by Age of Property

A combined measure of the five types of insulation considered in the WHCS, loft, wall and hot water tank insulation, double glazing and draught stripping, was prepared and cross-tabulated against age categories. For the purposes of this combined measure, those properties that do not have hot water tanks due to the presence of 'combi' boilers, were considered to have insulated hot water tanks. It can be seen that, as was the case with the summer survey sample, a non-linear relationship exists between these factors, where homes built between 1945 and 1964 are less likely to have more than one measure of insulation than homes built at any other period. Goodness of fit chi square tests were conducted and identified a significant difference between the distribution of the combined measure of insulation for the winter sample and the summer sample, with chi square = 24.496, df = 1, p<0.001, whereas no significant difference was found between the winter sample and the population chi square = 3.584, df = 1, p = 0.167 (n.s.).

	Pre-1919	1919-1944	1945-1964	1965-1980	Post 1980	Total
0-1 Insulation Measures	2 (3.7%)	4 (7.5%)	12 (20.3%)	5 (10.2%)	1 (1.9%)	**24 (8.9%)**
2+ Insulation Measures	52 (96.3%)	49 (92.5%)	47 (79.7%)	44 (89.8%)	53 (98.1%)	**245 (91.1%)**
Total	**54**	**53**	**59**	**49**	**54**	**269**

Table 79: Comparison of Presence of Insulation Measures by Age of Property

Further goodness of fit chi square tests were conducted to compare the distribution of loft insulation, cavity wall insulation, double glazing, draught stripping and hot water tank insulation with that found in the population.

	Chi Square	df	p	Effect Size
Loft Insulation	5.387	1	0.05	0.02 (V. Low)
Cavity Wall Insulation	24.279	1	<0.001	0.14 (V. Low)
Double Glazing	64.414	1	<0.001	0.26 (Low)
Draught Stripping	6.019	1	=0.01	0.05 (V. Low)
Hot Water Tank Insulation	3.354	1	=0.067 (ns)	-

Table 80: Results from Goodness of Fit Chi-square Tests to Compare the Distribution of Insulations Measures with Distributions Found in the Population

It can be seen that all of the distributions, except hot water tank insulation, differ significantly from that found in the population. Higher distributions of loft, wall insulation and double glazing, and reduced distributions of draught stripping, were found in the sample. It may be that the reduced distribution of draught stripping and increased distribution of double glazing, reflect a true change in the population distribution between the WHCS of 1998 and this survey, 2002, where double glazing has been installed in an increasing proportion of properties. The finding in relation to hot water tanks, where the distribution has been controlled for 'combi' boilers, which was not possible for the summer survey, may help to strengthen the hypothesis that the lower distribution of hot water tanks in the summer survey was affected by the presence of 'combi' boilers, that had not been identified in this survey. The installation of cavity wall insulation appears to have been increasing, possibly due to the availability of government subsidies.

5.1.1.8 Pathway Factor: Orientation

The results from the winter survey, as for the summer survey, provide simple orientation information for the main bathroom, main living room, main bedroom and the kitchen of the respondents' homes. This information indicates when the rooms receive direct sunlight.

5.1.1.9 Pathway Factor: Exposure to Air Pollution

Male and female respondents considered separately whether their homes were exposed to air pollution. A significant positive relationship exists between the male and female responses (r=0.649, df=136, p<0.001). A combined measure of exposure for each household was then created, taking the average of the male and female occupants' responses, where appropriate. The distribution of this is reproduced below, controlled for sample stratification.

	Count	%	95% CI
Extremely exposed	11	4.4	1.8 - 7.0
Very exposed	20	8.0	4.6 - 11.4
Exposed	42	17.1	12.4 - 21.8
Slightly exposed	59	24.1	18.7 - 29.5
Not at all exposed	97	39.6	33.5 - 45.7
Don't know	17	6.8	2.9 - 8.7
Total	**245**	**100.0**	

Table 81: Household Level Measure of Perceived Exposure to Air Pollution

5.1.1.10 Pathway Factor: Exposure to Wind

Male and female respondents considered separately whether their homes were exposed to strong winds. A significant positive relationship exists between the male and female responses to this question (r = 0.596, df = 154, p<0.001). A combined measure of exposure for each household has been created taking the average of the responses, the distribution of which is reproduced below:

	Count	%	95% CI
Extremely exposed	15	5.8	2.9 - 8.7
Very exposed	18	7.3	4.1 - 10.5
Exposed	64	25.1	19.8 - 30.4
Slightly exposed	106	41.8	35.7 - 47.9
Not at all exposed	45	17.9	13.2 - 22.6
Don't know	5	2.0	0.3 - 3.7
Total	**253**	**100.0**	

Table 82: Household Level Measure of Perceived Exposure to Strong Winds

17.4% of household respondents reported that their home had previously been damaged in a winter storm, equating to 19% of households in NPT (95% CI: 14.2 – 24.8). Of these, 56% reported that the damage was to roof tiles or slates. Other damage included that to flat roofs, general roof damage, soffit boards, guttering, chimneys and greenhouses. A contingency table analysis establish that significant positive correlation was present, between perceived exposure to strong winds and previous storm damage, with chi square = 23.056, df = 4, p<0.001, where those homes that were perceived to be exposed to strong winds were more likely to have been previously damaged by winter storms.

5.1.1.11 Pathway Factor: Exposure to Rain

The response to questions regarding driving rain were analysed as those for strong winds previously. A significant positive relationship exists between the male and female responses (r = 0.712, df = 148, p<0.001). The combined measure illustrated below was created in the same manner.

	Count	%	95% CI
Extremely exposed	13	5.2	2.4 - 8.0
Very exposed	19	7.8	4.4 - 11.2
Exposed	64	25.9	20.4 - 31.4
Slightly exposed	99	40.2	34.1 - 46.3
Not at all exposed	47	19.0	14.1 - 23.9
Don't know	4	1.8	0.1 - 3.5
Total	**246**	**100.0**	

Table 83: Household Level Measure of Perceived Exposure to Driving Rain

5.1.1.12 Pathway Factor: Exposure to Flood

As for wind, pollution and driving rain, male and female respondents considered separately whether their homes were exposed to strong winds. A significant positive relationship exists between the male and female responses (r = 0.578, df = 137, p<0.001). A combined measure of exposure for each household has been created, taking the average of the responses, the distribution of which is reproduced below:

	Count	%	95% CI
Extremely exposed	-	-	-
Very exposed	6	2.4	0.5 - 4.3
Exposed	13	5.3	2.5 - 8.1
Slightly exposed	20	8.2	4.8 - 11.6
Not at all exposed	199	81.9	77.1 - 86.7
Don't know	5	2.2	0.4 - 4.0
Total	**243**	**100.0**	

Table 84: Household Level Measure of Perceived Exposure to Flood

It was found that 2% of household respondents reported that their home had previously been damaged in a winter storm, equating to 2.5% of households in NPT (95% CI: 0.6 – 4.4). Of these, two cases were as a result of culverts becoming blocked, two as a result of drainage failure following torrential rain and the final case was due to a nearby stream bursting its banks. All of those households that had previously experienced flooding considered themselves to be exposed to future flooding.

5.1.2 Receptor Factors

The winter survey collated information on the following receptor factors:

Receptor Factors: Socio Economic

- Occupant Age
- Socio–economic status
  - *Education level*
  - *Housing tenure*
  - *Maintenance*
- Household composition
- Length of time in the home

Receptor Factors: Existing Health

- Presence of long standing illness
- Sources of internal air pollution

While the behavioural receptor factors are dealt with in section 5.1.3. in direct relationship with the risk systems for winter. In addition to this data, relevant factors from the EEP NPT datasets will be considered, including Townsend scores.

5.1.2.1 Receptor Factor: Age

The ages of male and female respondents were gathered within the winter survey and descriptive statistics for their distributions are reproduced below:

	Female Respondents	Male Respondents
N	234	192
Mean	56.19	56.90
Mode	45	54
Std. Deviation	16.021	14.500
Range	73	79
Minimum	17	21
Maximum	90	100

Table 85: Summary of Descriptive Statistics for Winter Survey Respondent's Ages

5.1.2.2 Receptor Factor: Socio-Economic Status

The socio-economic status of the respondents can be considered through a number of measures collected through survey as well as through the postcode level Townsend score from the EEP NPT dataset. The distribution of the Townsend scores for the sample is illustrated below and appears to differ from that found in the population, whereby the distribution seems 'flatter', with a more even distribution over the breadth of Townsend scores.

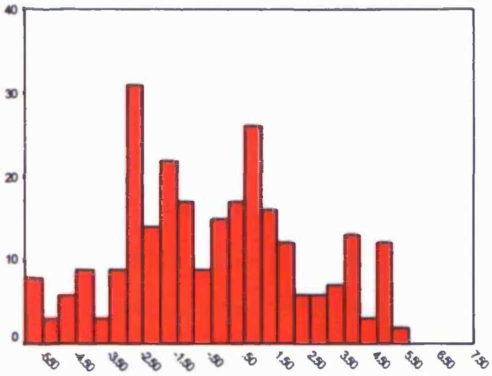


Figure 104: Distribution of Postcode Level Townsend Scores for Winter Survey Sample

The distribution of economic activity illustrates that 42% of the total respondents were in employment.

	Male	Female	Total	%
Employed	87	90	177	**41.8**
Unemployed and seeking work	8	3	11	**2.6**
Looking after home and or children full time	2	28	30	**7.1**
Full time student / at school		5	5	**1.2**
Retired from paid work	76	83	159	**37.6**
Long-term carer	1	4	5	**1.2**
Permanently unable to work due to illness or disability	17	19	36	**8.5**
Total	**191**	**232**	**423**	**100.0**

Table 86: Employment Status for All Adult Respondents

Goodness of fit chi square tests were conducted to determine whether the male, female and combined distribution of employment status differed from that found in the population. Statistically significant differences were found for all three, female (chi square = 50.853, df = 5, $p<0.001$), male (chi square=287.119, df = 5, $p<0.001$), and household level (chi square = 135.705, df = 5, $p<0.001$). The largest deviation from the expected distribution was that for retired occupants, for all three distributions, with a second largest residual being a reduced number of employed respondents. This bias in the sample may therefore be explained by a bias in response, in favour of retired occupants, as described in section 5.2.2.1 for the summer survey.

Although the questionnaire was not formally directed at the heads of the household, the respondents are placed in that role for the purposes of data analysis. The analysis of self-coded NSSEC status for the respondents is illustrated below.

	Female		Male		Household	
	Count	%	Count	%	Count	%
Managerial and Professional Occupations	51	23.4	60	31.9	94	34.6
Intermediate Occupations	69	31.7	22	11.7	64	23.5
Small Employers and Own Account Workers	5	2.3	16	8.5	9	3.3
Lower Supervisory and Technical Occupations	16	7.3	46	24.5	28	10.3
Semi-routine and Routine Occupations	73	33.5	44	23.4	58	21.3
Never in Paid Employment	4	1.8	-	-	-	-
Total	**218**	**100.0**	188	100.0	253	93.0

Table 87: Male Female and Household NSSEC Self-Coded Classification

Goodness of fit chi square tests were conducted to determine whether the male, female and combined distribution of NSSEC status differed from that found in the population, as calculated form the 2001 Census. Statistically significant differences were found for all three: for female (chi square = 90.308, df = 5, p<0.001), where higher numbers of responses were received from respondents from intermediate occupations and fewer from all other categories, for male (chi square = 30.877, df = 4, p<0.001), where a higher number of responses were received from managerial and small employers than would be expected, and at a household level (chi square = 65.223, df = 5, p<0.001), where representation from managerial and intermediate occupations was also higher. Where these responses were weighted to control for the effect of sampling strata and response bias, these associations weakened: female (chi square = 30.877, df = 4, p<0.001), male (chi square = 30.877, df = 4, p<0.001) and household (chi square = 30.877, df = 4, p<0.001). All still differed significantly from distributions found in the population. No further control is proposed for these differences, and therefore this distribution is hereby acknowledged in analysis and during extrapolation to the population.

The final measure of socio-economic status gathered within the survey relates to self-reported measure of financial status, gathered using a Likert-type scale. The distribution of this for the sample, below, represents a significant positive relationship between households' NSSEC classification and self-declared financial status, where rho = 0.235, df = 244, p<0.001.

	Count	%
Living comfortably	56	21.5
Doing alright	96	36.8
Just about getting by	109	41.8
Total	261	100.0

Table 88: Self-reported Economic Status (Illustrated using a Collapsed Scale from 5 Categories to 3)

In order to consider those households that may find themselves in fuel poverty, the respondents were asked to provide the cost of fuels used by their households for heating, hot water and electricity. These costs were aggregated to provide a total cost for a year to the household, which was found to range from £115 to £1,600 per year. No significant association was found between total fuel cost and size of house as measured by heated floor area (rho = 0.101, df = 235, p = 0.121 (n.s.), nor was there a significant association between fuel costs and sap rating (rho = 0.094, df = 235, p = 0.151 (n.s).

A significant relationship does, however, exist between self-reported financial status, on a Likert-type scale ranging from living comfortably, to finding it very difficult to make ends meet (rho = 0.158, df = 235, p <0.05). A contingency table analysis of a categorical measure of annual cost of fuel found a further significant association with chi square = 15.308, df = 6, $p<0.05$, meaning that those occupants with higher fuel bills were also more likely to consider their household to be in a less comfortable financial state or *'just about getting by'.* An effect size of 0.195 indicates a low effect.

	<£300	£300<£500	>=£500	Total
Living comfortably	15 (20.8%)	25 (28.4%)	10 (13.2%)	**50** (21.2%
Doing alright	34 (47.2%)	29 (33.0%)	24 (31.6%)	**87** (36.9%)
Just about getting by	23 (31.9%)	34 (38.6%)	42 (55.3%)	**99** (41.9%)
	72	**88**	**76**	**236**

Table 89: Comparison of Self-Declared Financial Status and Annual Fuel Costs

5.1.2.2.1 Receptor Factor: Education Level

The highest educational levels attained by respondents to the survey, both male and female were analysed with respect to the distribution found in the population through the application of goodness of fit chi square tests. There were found to be significant statistical differences between the observed and population distributions for all three groups, female (chi square = 30.606, df = 5, $p<0.001$), male, (chi square = 67.640, df = 5, $p<0.001$) and combined (chi square = 80.010, df = 5, $p<0.001$). Notably a greater frequency of respondents with Level 2 qualifications (GCSE, O level or equivalent) and above existed in the sample than would be expected from the population distribution.

	Observed N	Expected N	Residual
No Educational Qualifications	151	164.3	-13.3
Level 1	18	69.5	-51.5
Level 2	90	77.7	12.3
Level 3	31	21.7	9.3
Level 4 / 5	64	54.1	9.9
Other - Level Unknown	67	33.6	33.4
Total	**421**		

Table 90: Results of Rank Correlation Test of Highest Educational Level Against Population Distribution

5.1.2.2.2 Receptor Factor: Housing Tenure

It was found that 79% of the respondents were owner occupiers, 15% council tenants, 5% housing association tenants and the remaining respondents private tenants. In relation to property age, the majority of council properties in the sample were built between 1945 and 1964, while housing association properties were mostly constructed post-1980. A goodness of fit chi square was conducted to compare the sample distribution with that found in the population. The sample housing tenure distribution did not differ significantly (chi square = 5.819, df = 2, p=n.s.).

		Pre 1919	1919 - 1944	1945 - 1964	1965 - 1980	Post 1980	Total Count
Housing Tenure	**Owner Occupied**	47	46	33	41	42	**209**
	Rented Property	6	7	25	8	10	**56**
	Total	**53**	**53**	**58**	**49**	**52**	**265**

Table 91: Cross-tabulation showing Housing Tenure against Age of Property

5.1.2.2.3 Receptor Factor: Maintenance

The measures of maintenance regimes and responsibility for the maintenance of the property, where cost of repair, apathy and the fact that the situation was stable were the most frequently given reasons for repair not having taken place. It was found that 4% of respondents had outstanding maintenance work on their homes, including issues relating to the roof, guttering, windows and rendering. Structural faults were more likely to remain outstanding for 5 or more years. Of the respondents, 21% were not responsible for maintenance of their home.

5.1.2.3 Receptor Factor: Household Composition

The respondents' household composition can be described in terms of the number of occupants, and their ages. The distribution of household sizes for the winter survey respondents' households is illustrated below. A goodness of fit chi square test was conducted to determine whether the sample distribution of household sizes was different from that expected within the population. The distribution was found to differ significantly from that found in the population (chi square = 22.817, df = 5, $p<0.001$). It can be seen that the residuals experienced for the winter sample are smaller than those experienced for the summer sample, with a distribution that appears more closely associated with that found in the population. This is confirmed through comparison of the average household size, where for the population this is 2.46, for the summer survey this is, 2.04 and for the winter survey 2.24. Again there is a prevalence of smaller sized households in the sample.

	1	2	3	4	5	6
Count	73	115	35	33	4	7
Observed %	26.2	44.3	13.3	11.2	2.0	2.7
Residuals	6	21	-12	-9	-10	4

Table 92: Distribution of Households Size in Winter Survey Respondent's Households

The size of a home can be considered through the self-declared Likert-type measure of overcrowding included in the survey, heated floor area of each home measured in m^2 provided by the EEP NPT dataset and the estimated bedroom standard, calculated from the number of bedrooms and the age, sex and number of occupants. These measures of size and overcrowding will now be considered for the winter sample.

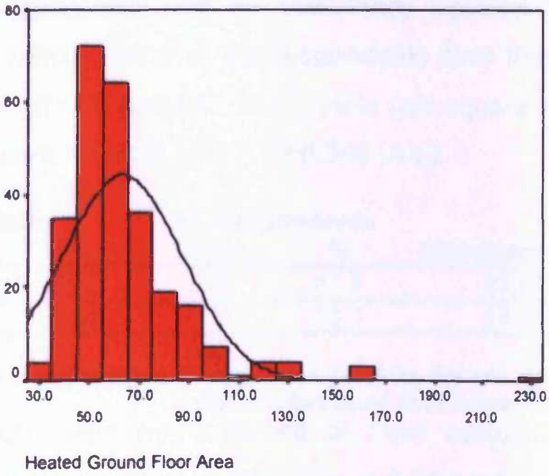


Figure 105: Histogram of Heated floor Area *(Data Source: EEP NPT Dataset)*

The distribution of self declared perception of the space in the respondents' homes is as follows:

	Frequency	Valid Percent
Crowded	20	7.5%
Just About Right	220	82.1%
Too large	28	10.4%
Total	268	100.0%

Table 93: Distribution of Self-Declared perception of Space

The bedroom standard for the respondents' households was estimated from the distribution of adult and child occupants. A goodness of fit chi square was conducted to determine whether the distribution of the bedrooms standard in the sample differed from that found in the population, as reported in the WHS. A statistically significant difference was found (chi square = 8.452, df = 2, $p<0.05$). This suggests that the two distributions do differ, where higher than expected number of responses were received from households with a bedroom standard of greater than one, where the home is larger than required by the standard. A significant association was also found between the self-reported estimate of overcrowding and calculated bedroom standard, where rho = 0.383 df = 264, $p<0.001$.

	Observed N	Expected N	Residual
Not Overcrowded	212	190.7	**21.3**
Equal	47	66.5	**-19.5**
Overcrowded	7	8.8	**-1.8**
Total	266		

Table 94: Comparison of Calculated Distribution of Sample Bedroom Standard Against Population Value

5.1.2.4 Receptor Factor: Length of Time in the Home

Of the respondent households, 82% have been occupant in their home for over 5 years, while 18% have been occupant for between 1 and 5 years.

5.1.2.5 Receptor Factor: Presence of Long Standing Illness

The existing health status of the respondents was considered through the use of a set of questions relating to overall health, existing respiratory and long terms illnesses as well as the GHQ_{12}. A goodness of fit chi square test was conducted and no statistically significant difference was found between that of the general health status of the respondents from that found in the population: female (chi square = 0.012, df = 1, p=0.912 (n.s.), male (chi square = 1.611, df = 1, p=0.204 (n.s.), all respondents (chi square = 0.889, df = 1, p=0.346 (n.s.).

	Female		Male		All Respondents		
	Count	%	Count	%	Count	%	Population
Good	195	83.8	162	79.7	356	81.9	**83.6%**
Poor	38	16.2	41	20.3	79	18.1	**16.4%**
Total	**232**		**203**		**435**		

Table 95: Comparison of the Distribution of Self-Reported Health Status for Male, Female, All, Respondents and the Population

It was found that 29% of households in the sample were home to one or more occupant suffering from a long term illness including: 2 children, 38 adults of working age and 53 adults of retirement age, equating to 15% (95%CI: 12.5 – 18.3) of the total occupants. The Census reported a statistic of 29.4% of NPT population with a long-term illness, while the WHS estimated 36%. This sample differs significantly from both of these values. The distribution of occupants with long-term illness is significantly lower than that found in the population. As is the case with the summer survey, it is known that a number of occupants refused to take part in the survey due to ill health and this is therefore likely to be a source of response bias in the survey. Long-term illness included: angina (6 cases), arthritis (40 cases), back problems (7 cases), diabetes (14 cases), heart problems (12 cases), mental conditions (9 cases), and various other physical conditions (27 cases). The cases of reported respiratory disease were also significantly lower than proportion found in the population, 12.1% (95%CI: 9.5 – 14.7) of total respondents household occupants, against 25% reported in the WHS. Reported respiratory illnesses included: asthma (58 cases), bronchitis (10 cases), emphysema (4 cases), pleurisy (2 case), and other breathing illness (8 cases).

The final measure of illness gathered through the summer survey was the GHQ_{12}, a measure of short term changes in mental health. It was found that 23% of female and 23% of male respondents scored 4 or more on the GHQ_{12} measurement scale, the indicator level for presence of mental health symptoms at the time of completing the form, with 31% of households occupied by one or more person subject to changes in symptoms of short-term anxiety or depression.

5.1.2.6 Receptor Factor: Sources of Internal Air Pollution

Internal air pollution sources related to the receptor evaluated through this survey were limited to tobacco smoke. Of households in this survey, 36% of households have one or more occupants that smoke, although respondents from only 29% of homes actually smoked in their homes. The population statistic for smoking in NPT borough is 25.5% and this figure does not differ significantly from the proportion of male and female smokers in the respondents to this survey, 23% (95%Ci: 21.3 – 32.7) and 27% (95% CI: 17.2 – 28.8) respectively.

5.1.3 Risks Systems in Winter

The distribution of the pathway and receptor factors for the respondents' households, have now been established, enabling them to be considered during the next stage of data analysis. This stage will involve establishing the extent to which current average winter climate currently poses a risk to the health and comfort of occupants in housing in NPT, south Wales, as a temporal analogy for future climatic change. It will be possible to establish the distribution of these risks in the population together with a related 95% confidence interval. To calculate these proportions it will be necessary to apply weighting factors to the sample in order to counteract distribution bias in the sample due to stratified sampling, as well as response bias due to the significantly higher response rates fom retired households. A schedule of the weights applied is reproduced in Appendix K.

This analysis will begin with the consideration of the responses to a question posed to both male and female occupants, relating to satisfaction with their home environment during the winter. Analysis revealed that 9% of male occupants and 10% of female occupants in the population would be dissatisfied with the internal environment of their homes during the winter.

When a combined statistic was calculated, 87% (95%CI: 83.4 – 91.4) of households in NPT would be likely to be satisfied and 13% (95% CI: 8.6 - 16.6) would be likely to be dissatisfied with the internal environment of their homes during the winter.

	Female %	Male %	Household %	 95% CI
V Satisifed	43.9	54.6	39.2	33.3 - 45.1
Satisifed	46.6	36.2	48.3	42.3 - 54.3
Dissatisifed	9.5	9.1	12.6	8.6 - 16.6
Total Count	**231**	**201**	**264**	

Table 96: Male, Female and Household Level Satisfaction with the Internal Environment of their Homes During the Winter

The age of the properties in which dissatisfied households were resident were then analysed and a significant difference (chi square = 25.594, df = 8, $p<0.001$) from the population distribution was found. Analysis of the contingency table highlights that those homes built between 1945 and 1964 were more likely to provide unsatisfactory environments under these conditions. An effect size of 0.298 indicates a low effect. This distribution of dissatisfaction and uncomfortable internal environments will now be analysed further in terms of ventilation and stuffiness, draughts, humidity, damp, mould and condensation, material structure and the cold. The attention of the reader is referred to Figure 97 in Chapter 3 illustrating the potential relationships that will now be analysed further.

	Pre 1919	1919-1944	1945-1964	1965-1980	Post 1980	
Very Satisfied	34 (37.0%)	13 (40.6%)	16 (25.4%)	25 (49.0%)	15 (62.5%)	103 (39.3%)
Satisfied	49 (53.3%)	17 (53.1%)	30 (47.6%)	22 (43.1%)	9 (37.5%)	127 (48.5%)
Dissatisfied	9 (9.8%)	2 (6.3%)	17 (27.0%)	4 (7.8%)		32 (12.2%)
	92	32	63	51	24	262

Table 97: Contingency Table Illustrating the Relationship Between Property Age and Satisfaction with Internal Environment During the Winter

5.1.3.1 Inadequate Ventilation

The ventilation systems available to occupants were explored previously in section 5.1.1.5, where the distribution of air vents and extractor fans for the sample was identified. It is now necessary to investigate the interaction of occupants with their environment, together with their opinions on the environment that their home provides to them in terms of ventilation. Firstly this section will consider occupant interaction with the ventilation systems available to them in their home including air vents, extraction and windows, considering actions during the day and night as well as during periods while their heating is working. The environment provided by their homes in general as well as in specific rooms will also be considered. Analysis will finally be undertaken to identify those interactions with the environment, as well as those housing factors that may interact to produce uncomfortable conditions, in relation to ventilation during the winter. Ventilation refers to controllable air flow, while draughts as an aspect of uncontrolled air flow are considered in section 5.1.3.2 due to their association with the cold.

5.1.3.1.1 Behavioural Factors in Ventilation

In relation to permanent air vents, of those occupants who had reported that there were air vents in their home, 9% usually block those in the main bedroom in the winter, while 8% block those in the main living room and 8% in the main bathroom. The reasons given were related to prevention of draughts and to prevent cold air entering the room, or keep the rooms warmer. It was not possible to undertake further statistical analysis due to the small sub-sample.

The presence of kitchen and bathroom extract fans has already been considered. It is now appropriate to consider occupant use of these extracts as well as opening windows in their lieu. A significant association was found between male and female use of the kitchen extract or window for ventilation when cooking (rho = 0.735 df = 162, p<0.001), which was 52.0% (95% CI: 45.7 – 58.3) for female occupants and 43.2% (95% CI: 36.1 – 50.3) for male occupants. Further to this, contingency table analyses determined that positive associations exist between presence of kitchen extraction and use of ventilation when cooking for both male (table size, 2 x 4, chi square = 14.695, df = 3, p<0.01, effect size – 0.305, low) and female occupants (table size, 2 x 4, chi square = 32.652, df = 3, p<0.001, effect size – 0.611, medium large).

In relation to bathroom extraction, a further significant association was found between male and female use of the bathroom extractors or windows for ventilation (r=0.653, df=151, p<0.001), where 37.7% (95% CI: 31.3 – 44.1) of female occupants and 29.4% (95% CI: 22.8 – 36.0) of male occupants always use a form of ventilation when in the bathroom. In comparison to those distributions found for the summer, male winter usage of ventilation in the bathroom is significantly lower at the 5% level. Further to this, contingency table analyses determined that a positive association exists between presence of bathroom extraction and use of ventilation while using the bathroom for female occupants (table size, 2 x 5, chi square = 31.931, df = 4, p<0.001, effect size – 0.466, medium), while this association is not significant for male occupants (table size, 2 x 5, chi square = 9.238, df = 5, p=0.06 (n.s.). In order to enable analysis of the impacts of these occupant interactions with the internal environment, a combined household level measure of extract and / or window usage when cooking and when bathing was also created for all households. The distributions for these factors are reproduced in the table below. It can be seen that in comparison with the summer distributions, the household level usage of the bathroom extract is significantly different, where fewer households use the extract every time they use the bathroom, during the winter, than in the summer.

	Kitchen Extract		Bathroom Extract	
	%	**95% CI**	**%**	**95% CI**
Every time	40.1	34.2 - 46.0	26.3	20.9 - 31.7
Sometimes	54.3	48.3 - 60.3	61.0	55 - 67
Never	5.7	2.9 - 8.5	12.7	8.6 - 16.8
Total Count	**259**		**252**	

Table 98: Combined Household Measure of Ventilation Usage in the Kitchen and Bathroom

Further to this, 17.0% of females and 13.7% of males, equating to 10.5% of households in NPT (95% CI: 6.7 – 14.3), agreed that *'they often open the windows of their homes because it is so stuffy in the winter'*. While, 66.4% females (95% CI: 60.2 – 72.6) and 72.5% of males (95% CI: 65.9 – 79.1), equating to 70.0% of households (95% CI: 64.4 – 75.6), disagreed. No statistical relationships with housing age or other relevant factors were found for this distribution.

Respondents were asked whether they *'ever open the windows in their home when the heating is on'*. A 4 x 4 contingency table analysis was undertaken and found statistically significant association between male and female responses to this statement, with chi square = 64.870, df = 9, p<0.001. An effect size of 0.490 indicates a medium effect. A summary of the distribution of responses to this statement for female and male occupants as well as a combined measure equating to response at a NPT household level is reproduced below.

	Female Occupants	**Male Occupants**	**Households**	
	%	**%**	**%**	**95% CI**
Yes-often	18.4	13.9	20.9	16.0 – 25.8
Yes - sometimes	39.1	36.2	37.4	31.6 – 43.2
Yes - rarely	22.8	29.7	26.5	21.2 – 31.8
No - never	19.6	20.1	15.1	10.8 – 19.4
Total Count	**232**	**189**	263	

Table 99: Distribution of Occupants Responses to Question: 'In the Winter, Do You Open the Windows in Your Home When the Heating is On?'

Occupants were also asked to provide the reasons for opening their windows while their heating was on. The combined distribution of responses for both male and female occupants is reproduced below:

	Combined Respondents		**Male**	**Female**
	Valid Percent	**Rank Order**	**Rank Order**	**Rank Order**
Fresh Air	48.7%	1	1	1
Cooking	9.0%	2	4	2
Too Hot	8.5%	3	2	5
Kitchen & Bathroom	8.1%	4	3	4
Combination of Reasons	7.8%	5	5	3
Stuffy	4.4%	6	6	6
Condensation	2.5%	7	7	12
Smoking	2.3%	8	9	11
Bedroom	2.3%	9	10	9
Washing clothes	2.1%	10	11	7
Bathroom	1.8%	11	8	13
Mild Weather	1.5%	12	12	8
Other	0.9%	13	12	10
Total Count	**324**		**144**	**180**

Table 100: Respondents' Reported reasons for Opening Windows while using their Heating System

A 3 x 4 contingency table analysis was undertaken to determine whether there was an association between household level responses to these two questions. A significant relationship was found between perceived stuffiness in the home and opening windows when the heating is on (chi square = 19.653, df = 6, p<0.01.

		It is often stuffy in our home....				
		Yes-Often	**Yes-Sometimes**	**Yes-Rarely**	**No-Never**	
'In the winter we often open the windows in our home because it is so stuffy'	**Agree**	10 (18.2%)	13 (13.4%)	3 (4.4%)	1 (2.8%)	**27 (10.5%)**
	Neither Agree nor Disagree	16 (29.1%)	20 (20.6%)	10 (14.7%)	3 (8.3%)	**49 (19.1%)**
	Disagree	29 (52.7%)	64 (66.0%)	55 (80.9%)	32 (88.9%)	**180 (70.3%)**
	Total Count	**55**	**97**	**68**	**36**	**256**

Table 101: Contingency Table - Relationship Between behaviour in Relation to Window Opening in the Winter

Where occupants perceived their homes to be stuffy in the winter, action taken to remedy the situation were collated and are summarised below. It can be seen that turning down heating, ventilating, or a combination of these two actions were the most frequently cited of actions.

	Valid Percent	95%CI
Ventilation	24.8%	15.3 - 34.3
Turn Down Heating	43.6%	32.7 - 54.5
Ventilation & Turn Down Heating	22.6%	13.4 - 31.8
Internal Ventilation	5.5%	0.5 - 10.5
Other	3.3%	0 - 5.4
Total Count	**80**	

Table 102: Actions in the Presence of Stuffiness

5.1.3.1.2 Perceived Ventilation Deficiencies

In relation to stuffiness in the home during the winter, 20.9% female occupants (95% CI: 15.5 – 26.3) and 17.6% of males (95% CI: 12.1 – 23.1), equating to 17.9% of households in NPT (95% CI: 13.2 – 22.6), agreed that *'When the heating is on my home often becomes stuffy and airless'.* While, 60.4% females (95% CI: 53.9 – 66.9) and 55.7% of males (95% CI: 48.5 – 62.9), equating to 57.5% of households in NPT (95% CI: 51.4 – 63.6), disagreed.

Statistical tests for association between household level response to this statement and previously considered behavioural factors were than undertaken. Following a 3 x 3 contingency table analysis, a significant positive relationship was found between agreement with the statement *'when the heating is on my home often becomes stuffy and airless'* and opening windows because it is stuffy, with chi square = 120.590, df = 4, p<0.001 and effect size = 0.759, large. No significant relationships were found between stuffiness while heating is on in the winter and age of property, presence of double glazing or age of occupant.

Occupants were also individually asked to report as to where and when their home is stuffy during the winter. The distribution of stuffiness as reported for specific rooms in the winter was much lower than that found reported for housing in NPT in the summer, with 11.1% of households (95% CI: 7.3 – 14.9) reporting their main bedroom (summer survey: 30.1%) and 12.6% (95% CI: 8.6 – 16.6) their main living room (summer survey: 44.1%). A combined measure of number of rooms considered to be stuffy was therefore created at a male, female and household level, where overall 30% (95% CI: 24.5 – 35.5) of households in NPT consider one or more room in their house to be stuffy. Within this sample 12% consider their home to be stuffy during the day, 72% at night and 16% during both times.

	Female Occupants	Male Occupants	Household Measure	
	%	%	%	95%CI
No Rooms	77.3	79.6	69.9	64.4 – 75.4
One Room	19.3	19.0	26.0	20.8 – 31.2
More than One Room	3.4	1.4	4.0	1.7 – 6.3
Total Count	**196**	**236**	**269**	

Table 103: Distribution of Number of Rooms Perceived to be Stuffy or Airless during the Winter

No significant associations were found to be present between these distributions and house age, presence of double glazing or household SAP level. However, the household level measure of presence of one or more stuffy rooms, was found to have a significant association with occupants age, as considered through the consideration of pensioner and non-pensioner households (chi square = 9.567, df = 1, p<0.01, effect size = 0.460, medium).

5.1.3.2 Inadequate Heat

Having established the interaction of occupants' behaviour with ventilation and resultant stuffiness in homes, it is now possible to consider health and comfort risks further in relation to cold, in the context of these previous results. As was the case with ventilation, occupant behaviour that may influence the perception of cold in the home environment will be considered first. The subjective perception of cold in the home as a whole, and then in relation to specific rooms in the home, will be considered.

5.1.3.2.1 Behavioural Factors in Cold

The subjective perception of cold can be seen to be influenced by occupant behaviour in terms of the control of heating in a space and the financial affordability of this, the level of clothing worn, ventilation as well as other actions in the home, all of which are embraced within the adaptive theory of comfort. Respondents to the winter survey were asked to consider the actions they take to make rooms that are perceived to be too cold more comfortable. Their responses to questions relating to the control of their heating and attitudinal responses to clothing levels and affordability of heating will be considered here. Actions taken by occupants that currently experience cold in their homes are also considered.

In relation to the controllability of heating, 75.4% of female respondents and 75.7% of male respondents equating to 74.1% of NPT households (95%CI: 68.7 – 79.5) agree that *'The temperature of my home is very easy to control'.* While, 15.6% of female respondents and 14.1% of male respondents, equating to 13.3% of households in NPT (95% CI: 9.1 – 17.5), disagree with this statement. Occupants were more likely to perceive their heating as *'very easy to control'* if they owned their home (chi square = 10.709, df = 2, $p<0.01$, effect size = 0.243). A significant relationship was also found with presence of insulation (rho = 0.170, df = 241, $p<0.01$), an on / off switch for heating (rho = 0.200, df = 201, $p<0.01$) and TRV's (rho = 0.177, df = 176, $p<0.05$). A significant association was also found where those who disagreed with this statement were more likely to experience damp in their homes (rho = -0.162, df = 173, $p<0.05$).

Where households stated that there was a thermostatic control (95%CI: 69.2 – 80.2% in NPT) for their central heating, the location and temperature at which it as set were reported. The locations of thermostats were also reported and were found in the airing cupboard, on the boiler, in bedrooms, bathrooms, living rooms, dining rooms, kitchens and hallways, while the reported thermostat temperature ranged from 10°C to 60°C. It has been assumed that where thermostatic set temperatures of over 30°C have been reported these refer to water temperatures and have been excluded from further analysis. These temperatures were then grouped into <18°C, 18°C -21°C and >21°C; while locations have been divided into four categories, those associated with living areas embracing bedrooms, living rooms and dining rooms, non living areas including kitchens and bathrooms, circulation spaces hallways and landings, and other, including the boiler and the airing cupboard. No significant association was found between location of thermostat and thermostat set temperature, nor was there an association between thermostat set temperature and self declared financial status.

		Thermostatic Temp			Total
		<18	18<21	>21	
Thermostat Location	Living Area	6 (35.3%)	13 (27.1%)	19 (42.2%)	**38 (34.5%)**
	Non Living Area	-	10 (20.8%)	4 (8.9%)	**14 (12.7%)**
	Circulation	9 (52.9%)	22 (45.8%)	18 (40.0%)	**49 (44.5%)**
	Other	2 (11.8%)	3 (6.3%)	4 (8.9%)	**9 (8.2%)**
Total Count		**17**	**48**	**45**	**110**

Table 104: Relationship Between Thermostatic Set Temperature and Location for Winter Survey Respondents' Households

Where households stated that there was a timer control for their central heating (95% CI: 92.2 – 97.8%) the periodic usage of the heating was considered. Of those households in NPT that have a timer control for their central heating, 16% (95%CI: 11.1 – 20.9) do not use this and control their heating system manually, either by the use of the thermostat or on / off switch. A contingency table analysis of categorical measure of hours of heating usage in respondents' households indicates a significant positive association exists between hours of usage in the morning and evening (chi square = 91.077, df = 9, p<0.001, effect size = 0.601), where the level of usage hours in the morning is positively associated with those in the evening.

		HEATING PM				Total
		< 5 hours	5 < 6 hours	6 < 9 hours	> 9 hours	
HEATING AM	< 2 hours	9 (26.5%)	5 (20.8%)	12 (17.6%)	-	**26 (15.2%)**
	2< 3 hours	17 (50.0%)	11 (45.8%)	24 (35.3%)	1 (2.2%)	**53 (31.0%)**
	3< 5 hours	7 (20.6%)	6 (25.0%)	25 (36.8%)	10 (22.2%)	**48 (28.1%)**
	>5 hours	1 (2.9%)	2 (8.3%)	7 10.3%)	34 (75.6%)	**44 (25.7%)**
	Total Count	**34**	**24**	**68**	**45**	**171**

Table 105: Association Between AM and PM Heating Usage, Also Illustrating Distribution of Heating Usage Hours for These Periods

The total hours of heating usage for the respondents' homes ranges from 2 to 24 hours, the distribution of which is illustrated below. No significant association was found to be present between total hours of heating usage and occupant age.

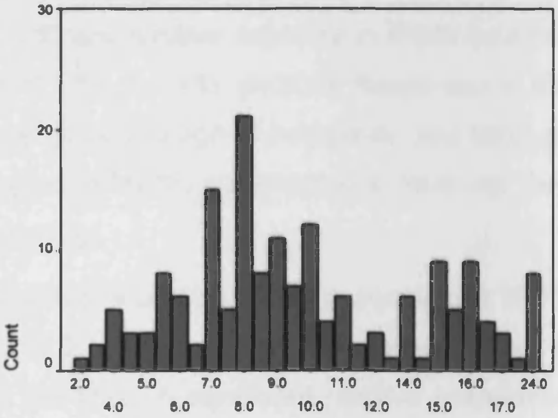


Figure 106: Distribution of Total Number of Heated Hours for Respondents' Homes in NPT

The clothing level adopted by housing occupants can significantly influence subjective perception of comfort. The winter survey therefore asked male and female occupants separately for attitudinal responses to two statements relating to their preference for clothing levels in their homes. It was found that 72.0% of female respondents and 78.9% of male respondents, equating to 75.2% of households in Neath and Port Talbot (95% CI: 68.9 – 80.5), agreed that on a winter's day they *'like to be warm enough to be able to wear light clothing inside their homes'* and 15.9% of female respondents and 13.1% of male respondents, equating to 10.1% of households in Neath and Port Talbot (95% CI: 6.4 – 13.8), disagreed with this statement. A significant positive association exists between male and female responses to this statement (rho = 0.403, df = 152, p<0.001). While it was found that 27.1% of female respondents and 15.1% of male respondents, equating to 18.1% of households in Neath and Port Talbot (95% CI: 13.3 – 22.9), agreed they *'usually wrap up warm – wear warm clothes, when they are in their house in the winter'* and 55.1% of female respondents and 71.7% of male respondents, equating to 62.4% of households in Neath and Port Talbot (95% CI: 56.4 – 68.4), disagreed with this statement. A significant positive association exists between male and female responses to this statement (rho = 0.344, df = 185, p<0.001).

Significant negative associations were found to exist between responses to these two statements for females (rho = -0.242, df = 216, p<0.001) and for male respondents (rho = -0.296, df = 183, p<0.001). A contingency table analysis was undertaken to determine whether there was an association between attitudinal responses to these questions at a household level. A significant association was found between response to these questions (chi square = 21.331, df = 4, p<0.001). An effect size of -0.427 indicates a medium effect. While no relationship was found between responses to these questions and occupant age or with property age, presence of insulation, SAP rating or self-declared financial status.

The concept of fuel poverty (or more explicitly the situation where occupants cannot afford to heat their home) can have a significant impact on internal comfort during the winter in the UK. The winter survey therefore asked male and female occupants separately for attitudinal responses to two statements relating to their use of heating and its relationship to affordability. It was found that 5.5% of female respondents and 6.0% of male respondents, equating to 3.7% of households in Neath and Port Talbot (95% CI: 1.4 – 6.0), agreed that on a winter's day they *'usually only heat the room that they are in'*. A significant positive association exists between male and female responses to this statement (rho =0.178, df = 153, p<0.05). Responses to this statement at a household level were not found to be related to age of occupants, and although not significant, seven of the nine households that agreed with this statement also described their household financial status as low or *'just about getting by'*.

Further to this 13.7% of female respondents and 12.6% of male respondents, equating to 17.7% of households in Neath and Port Talbot (95% CI: 13.0 – 22.4), agreed they *'cannot afford to heat my house to a comfortable temperature all the time'*. A significant positive association exists between male and female responses to this statement (rho = 0.562, df = 152, p<0.001). A contingency table analysis was undertaken to determine whether a relationship existed between response to this statement and financial situation of the household. A significant negative association was found between their resposes (chi square = 59.318, df = 4, p<0.001). An effect size of -0.793, indicates a large effect. Further to this, a significant positive association also exists between responses to these two statements, for example at the household level rho = 0.320, df = 237, p<0.001, indicating that affordability of heating and the decision to heat only one room are linked, although 3 households that indicated that they only heat the room they are in, do not agree that they cannot afford to heat their whole home.

Where occupants of homes experience rooms that are too cold and or draughty, respondents were requested to consider what action they currently take to rectify the situation. The table below summarises these actions. It can be seen that physically blocking draughts and additional heating, or turning up heating were the most frequently cited actions.

	%	95%CI
Block Draught	28.1%	20.0 - 36.2
Additional Heating	21.1%	13.7 - 28.5
Turn Up/On Heating	19.8%	12.6 - 27.0
Various	13.5%	7.3 - 19.7
Nothing	10.3%	4.8 - 15.8
Building Work	6.1%	1.8 - 10.4
Encourage Heat Flow From Other Rooms	0.9%	0 - 2.6
Clothing	0.3%	0 - 1.3
Total Count	**118**	

Table 106: Actions in Response to Cold Rooms

5.1.3.2.2 Perceived Heating Deficiencies

During comfort studies in offices, it has been found that male and female occupant comfort levels do not differ significantly, however, as a result of analysis of the results from the winter survey, this does not seem to hold true within a home environment for occupants of housing in NPT. The respondents to the winter survey were asked whether *'the male and female occupants of their home often disagree about the temperature'*, where 45.3% of female respondents and 48.1% of male respondents agreed with the statement. This corresponds to male and female occupants disagreeing about the temperature in their homes in 48.9% of households in NPT (95% CI: 41.5 – 56.3), with 33.8% of households disagreeing with this statement. A contingency table analysis determined that a significant relationship exists between male and female attitudinal responses to this statement (chi square = 102.960, df = 4, $p<0.001$, effect size = 0.830, large).

It was found that 25.6% of female respondents and 24.6% of male respondents agreed with the statement that *'on a winter's day: there are rooms in my home that are never a comfortable temperature'*. This corresponds to 25.6% of households in NPT (95% CI: 20.2 – 31.0). A significant relationship exists between male and female attitudinal responses to this statement (rho = 0.373, df = 153, $p<0.001$). Analysis was undertaken of the potential associations between household level response to this statement and age of occupant, age of property, insulation levels, self-declared heating problems, financial status of household and housing tenure. The following significant associations were found to be present:

- Significant positive association with presence of insulation (rho = 0.201, df = 239, $p<0.01$), indicating that presence of increased levels of insulation are associated with disagreement with this statement.
- Significant negative association with heating problems (rho = -0.231, df = 235, $p<0.001$), indicating that presence of heating problems are associated with agreement with this

statement.

- Significant negative association with self declared financial status (rho = -0.231, df = 250, p<0.001), indicating that concern over financial state of household is associated with agreement with this statement.
- Significant positive association with agreement with statement that household cannot afford to heat the whole house (chi square = 37.755, df = 4, p<0.001 and effect size = 0.595, medium).
- Significant negative association with housing tenure (rho = 0.267, df = 252, p<0.001). Where those in rented accommodations were more likely to agree with this statement.
- Significant negative association with perceived ease of control of heating (chi square = 39.837, df = 4, p<0.001 and effect size = 0.532, medium).

A further contingency table analysis was undertaken to determine whether an association existed between response to this statement and overall household level satisfaction with the home. A strong, significant negative association was found to be present (chi square = 76.118, df = 4, p<0.001, effect size = -0.726, large), indicating that agreement with this factor is also strongly associated with dissatisfaction with the home in general.

Further to this, respondents were asked to respond to the statement that *'on a winter's day: when the heating is on, it is always the same temperature in all of the rooms of my home'.* It was found that 50.0% of female respondents and 39.5% of male respondents agreed with this statement, corresponding to 38.2% of households in NPT (95% CI: 32.4 – 44.2). While 41.5% of female respondents and 42.2% of male respondents disagreed with this statement, corresponding to 40.6% of households in NPT (95% CI: 34.6 – 46.6). A significant relationship exists between male and female attitudinal responses to this statement (rho = 0.386, df = 152, p<0.001) and, as may be expected, negative relationships exist between attitudinal responses to these two statements where for all three groups significant associations of a medium strength are present: female respondents (chi square = 30.769, df = 4, p<0.001, effect size = -0.475, medium), male respondents (chi square = 33.533, df = 4, p<0.001, effect size = -0.566, medium) and for households (chi square = 39.914, df = 4, p<0.001, effect size = -0.478, medium). Significant associations were found between attitudinal responses to this statement and levels of insulation in the home (rho = -0.134, df = 234, p<0.05), indicating that lower levels of insulation were associated with disagreement with this statement and reported presence of condensation in the home (rho = -0.143, df = 229, p<0.05), indicating that presence of condensation in a home is associated with disagreement with this statement.

It was further found that 25.9% of female respondents and 23.2% of male respondents, equating to 28.6% of households in Neath Port Talbot (95% CI: 23.1 – 34.1), agree that their *'home takes a long period of time to heat up again, if left with no heating for a day or more'.* While, 61.2% of female respondents and 59.5% of male respondents, equating to 57.3% of households in Neath and Port Talbot (95% CI: 51.2 – 63.4), disagree with this statement. A significant relationship exists between male and female attitudinal responses to this statement (rho = 0.561, df = 154, p<0.001). The following significant associations were found to exist between heating up time for their home as perceived by the household:

- A significant negative association was found with insulation levels (rho = 0.160, df = 236, p<0.05), indicating that housing that is less well insulated will take longer to heat up.
- A significant association is also present between housing age and the heating response time (chi square = 18.348, df = 8, p<0.05, effect size = 0.260, low) indicating that older properties are perceived to be slower to respond to heating.
- While neither housing size nor storey height, as a proxy for ceiling height, are significantly associated with this factor.

	Pre 1919	**1919 - 1944**	**1945 - 1964**	**1965 - 1980**	**Post 1980**	
Agree	35 (38.9%)	6 (18.8%)	21 (35.6%)	7 (13.7%)	4 (18.2%)	**73 (28.7%)**
Neither Agree nor Disagree	9 (10.0%)	6 (18.8%)	9 (15.3%)	5 (9.8%)	5 (22.7%)	**34 (13.4%)**
Disagree	46 (51.1%)	20 (62.5%)	29 (49.2%)	39 (76.5%)	13 (59.1%)	**147 (57.9%)**
Total Count	**90**	**32**	**59**	**51**	**22**	**254**

Table 107: Contingency Table Illustrating Association Between Housing Age and Perceived Heating response Time

Further to this, a partial correlation was computed between housing tenure and household response to this statement, holding property age constant. The partial correlation of 0.194 indicates that the two associations are independent.

It was found that 31.4% of female respondents and 28.6% of male respondents agreed with the statement that their *'home looses heat rapidly if the heating is turned off'*. This corresponds to 30.6% of households in NPT (95% CI: 25.0 – 36.2). A significant relationship exists between male and female attitudinal responses to this statement (rho = 0.603, df = 152, p<0.001). Analysis was undertaken of the potential associations between household level response to this statement and age of property, and insulation levels. The following significant associations were found to be present:

- Property age was found to be significantly associated with the perceived speed at which the property looses heat (chi square = 34.409, df = 9, p<0.001, effect size = 0.345), whereby properties built between 1945 – 1964 are perceived by their occupants to loose heat rapidly.

	Pre-1919	**1919 - 1944**	**1945 - 1964**	**1965 - 1980**	**Post-1980**	**Total**
Agree	19 (20.9%)	9 (30.0%)	35 (57.4%)	11 (22.0%)	4 (17.4%)	**78 (30.6%)**
Neither Agree nor Disagree	17 (18.7%)	7 (23.3%)	2 (3.3%)	6 (12.0%)	6 (26.1%)	**38 (14.9%)**
Disagree	55 (60.4%)	14 (46.7%)	24 (39.3%)	33 (66.0%)	13 (56.5%)	**139 (54.5%)**
Total Count	**91**	**30**	**61**	**50**	**23**	**255**

Table 108: Contingency Table Illustrating Association Between Housing Age and Perceived Speed at Which Property Looses Heat

- The presence of insulation was also found to have significant associations with the perceived speed at which heat is lost:
  - Loft insulation (chi square= 14.771, df = 2, p<0.001, effect size = -0.478).
  - Double glazing (chi square – 26.458, df = 2, p<0.001, effect size = -0.777).

  - Higher SAP rating (rho = 160, df = 236, p<0.05).
  - And combined measure of insulation measures (chi square = 15.677, df = 2, p<0.001 and effect size = 0.512).
- The perceived speed with which a home heats up and cools down are also significantly related, with a positive association (rho = 0.573, df = 239, p<0.001).

In relation to draughts in the home, 10.9% of female respondents and 10.4% of male respondents consider that their *'home is very draughty in the winter'*. This equates to 14.1% of households in NPT (95%CI: 9.8 – 18.4). A significant relationship exists between male and female attitudinal responses to this statement (rho = 0.468, df = 150, p<0.001). Through the application of contingency table analysis the perceived draughtiness of a property was found to be significantly related to the need for replacement windows (chi square = 14.370, df = 2, p<0.001, effect size = 0.414, medium). Draught in properties was also found to be significantly negatively associated with the presence of double glazing (rho = -0.319, df = 226, p<0.001) and positively associated with perceived exposure of the property to wind (rho = 0.155, df = 230, p<0.05). Further to this, a large significant correlation was found between the perception that a property looses heat rapidly after the heating is turned off and the perception that a property is draughty (chi square = 56.910, df = 4, p<0.001 and effect size = 0.691, large).

Discomfort at night can have an impact on quality of sleep. It was found that 4.1% of female respondents and 4.4% of male respondents, equating to a distribution of 5.8% of NPT households (95% CI: 2.9 – 8.7), agreed that *'on a cold winter's night it is often too cold in their home to be able to sleep well'*. A significant relationship exists between male and female attitudinal responses to this statement (rho = 0.592, df = 151, p<0.001). Asignificant association was found between general health level and response to this statement (rho = -0.237, df = 228, p<0.001). Further to this, perception of a home being too cold to be able to sleep well is also significantly associated with:

- Low levels of insulation (rho = 0.287, df = 237, p<0.001)
- Rented properties (rho = -0.284, df = 234, p<0.001)
- Properties that are perceived to loose their heat rapidly (rho = 0.392, df = 237, p<0.001)

No significant association was found between housing age and perception of a home being too cold to sleep at night, although eight of the 13 households that agreed with this statement occupied homes that were built between 1945 – 1964.

Occupants were also asked to report as to where and when they perceive their home to be too cold or draughty during the winter. As was the case for the summer survey, these questions were designed to request the male and female occupants to separately consider rooms in their home. Their responses were very closely correlated (rho = 0.760, df =50, p<0.001) and therefore a summary of those rooms which occupants jointly perceived to be too cold or too draughty at a household level was compiled and is reproduced below. At one period or more throughout the day and night, 49.1% of homes experience no rooms that are too cold or too draughty (95% CI: 43.1 – 55.1), 27.8% of homes experience one room that is too cold or too draughty (95% CI: 22.5 – 33.1), while 22.2% of homes experience two or more rooms that are too cold or too draughty (95% CI: 17.3 – 27.1).

		Too Cold	Too Draughty	Too Cold & Too Draughty	
Where the Property is Perceived to Be Too Cold and / or Too Draughty	**1 Room – Not Living Room**	23 (34.8%)	5 (31.3%)	5 (16.1%)	**33 (29.2%)**
	1 Living room	18 (27.3%)	9 (56.3%)	4 (12.9%)	**31 (27.4%)**
	More Than One Room - Not Living Room	5 (7.6%)	-	4 (12.9%)	**9 (8.0%)**
	More Than One Room - Inc Living Room	17 (25.8%)	1 (6.3%)	16 (51.6%)	**34 (30.1%)**
	Most or All Rooms	3 (4.5%)	1 (6.3%)	2 (6.5%)	**6 (5.3%)**
	Total Count	**66**	**16**	**31**	**113**

Table 109: Distribution of Number of Rooms Perceived to be Too Cold or Too Draughty During the Winter

Respondents were also asked to consider *when* these rooms were too cold and or too draughty. Of those households that perceived one or more rooms to be too cold or too draughty, 26.0% experienced discomfort during the daytime (95% CI: 18.4 – 33.6), 16.1% during the evening or night time (95% Ct 9.7 – 22.5) and 58.0% throughout the day and night (95% Ci: 49.4 – 66.6).

A series of contingency table analyses were undertaken to determine whether associations were present between a number of social risk and housing factors and presence of one or more rooms perceived to be too cold or too draughty by housing occupants. The following table summarises the associations found.

Factor		Meaning for NPT Housing / Occupants
Age of Occupant	Chi square = 9.416, df = 2, p<0.01 effect size = 0.459	Older occupants are less likely to perceive rooms in their home to be too cold or too draughty.
Housing Age	Chi square = 16.415, df = 8, p<0.05 effect size = 0.240	Housing built between 1965 and 1980 is most likely to experience rooms that are too cold or too draughty, followed by those built between 1919 and 1944,
Combined Measure of Insulation	Chi square = 14.106, df = 2, p<0.001 effect size = -0.498	Increased presence of insulation measures is inversely associated with perception of rooms that are too cold or too draughty.
Condensation	Chi square = 13.305, df = 4, p<0.01 effect size = -0.229	For all of these factors, presence of rooms that are too cold or too draughty are positively associated with their presence in the home.
Damp	Chi square = 10.547, df = 2, p<0.01 effect size = -0.402	
Mould	Chi square = 8.663, df = 2, p<0.05, effect size = -0.193	
Self-Declared Financial Status	Chi square = 8.797, df = 4, p=0.07 (n.s.)	N/A
Annual Cost of Fuel	Chi square = 14.033, df = 4, p<0.01 effect size = 0.234	The greater the annual fuel costs, the more likely the presence of rooms that are too cold or too draughty in the home.
Presence of central Heating	Chi square = 1.220, df = 2, p-0.543 (n.s.)	N/A
Perceived Exposure to Wind	Chi square = 19.988, df = 8, p<0.01, effect size = 0.272	Where homes are perceived to be exposed to wind, the more likely the presence of rooms that are considered to be too cold or draughty.
Perception of Draughts in winter	Chi square = 46.335 df = 4, p<0.001, effect size = -0.653	A test correlation statistic with overall consideration of draughtiness in home.
Presence of Rooms that are never Comfortable	Chi square = 85.647, df = 4, p<0.001, effect size = -0.717	A test correlation statistic with overall consideration of rooms that are never comfortable in home.

Table 110: Summary of Associations in Relation to Cold and / or Draughty Rooms in NPT Housing

A further significant association was found between the presence of one or more rooms perceived to be too cold or too draughty by its occupants in relation to overall satisfaction with the home environment in the winter (chi square = 59.201, df = 4, p<0.001, effect size – 0.575). Where there is a presence of rooms that are considered to be too cold or too draughty during the winter, their occupants are more likely to be dissatisfied with the environment during the winter. The distribution of this association is described below.

		V Satisfied	Satisfied	Dissatisfied	
Where the Property is Perceived to Be Too Cold and / or Too Draughty	**No Rooms**	68 (65.4%)	55 (43.3%)	5 (15.2%)	**128 (48.5%)**
	1 Room	31 (29.8%)	39 (30.7%)	6 (18.2%)	**76 (28.8%)**
	More than One Room	5 (4.8%)	33 (26.0%)	22 (66.7%)	**60 (22.7%)**
	Total Count	**104**	**127**	**33**	**264**

Table 111: Distribution of Number of Rooms Perceived to be Too Cold or Too Draughty compared to Housing Satisfaction During the Winter

5.1.3.3 Damp & Mould

The internal humidity of a property can be influenced by ventilation together with actions of occupants to introduce and expel humidity, such as drying clothes cooking and bathing. The methods by which occupants dry their clothes described below. Cooking and bathing moisture are examined through the use of ventilation, considered previously in section 5.1.3.1.1.

	Count	%	95% CI
Outside	53	19.9	15.1 – 24.7
Inside	82	30.7	25.2 – 36.2
Dryer	83	31.0	25.5 – 36.5
Combination Including Inside	49	18.4	13.8 – 23.0
Total	267	0	

Table 112: Methods of Drying Clothes in the Winter, including 95% Confidence Intervals

5.1.3.3.1 Incidence of Condensation

35.3% of female occupants and 26.7% of males, equating to 29.7% of households in NPT (95% CI: 24.1 – 35.3), agreed that *'On a winter's day: there is often condensation on the windows of my home in the morning'.* While, 56.7% females (95% CI: 50.2 – 63.2) and 63.0% of males (95% CI: 56.0 – 70.0), equating to 57.1% of households in NPT (95% CI: 51.0 – 63.2), disagreed. A significant positive association exists between male and female responses (rho = 0.731, df = 154, p<0.001).

A 3 x 2 contingency table analysis was undertaken to determine whether an association existed between reported condensation on windows and presence of double glazing. A significant negative association was present with chi square = 15.721, df = 2, p<0.001, meaning that where double glazing was present there is less likelihood of the presence of condensation. However, this is not a perfect correlation and a number of double glazed homes experience condensation, while some single glazed homes have no experience of condensation.

	Double Glazing	Single Glazing	Total
Agree	55	13	**68**
Neither Agree nor Disagree	28	3	**31**
Disagree	135	4	**139**
	218	**20**	**238**

Table 113: Contingency Table Showing Association Between Glazing Types and Response to Statement: 'There is often condensation on the windows of my home in the morning'

In relation to self-reported presence of condensation in the main bedroom, main living room, main bathroom and kitchen of the respondents' homes, 29.8% of homes in NPT have no condensation in any of these rooms (95%CI: 24.1 – 35.5), while the remaining 70.2% (95%CI: 64.5 – 75.9), report condensation in one of more of these rooms. The frequency of condensation experienced in these four main rooms, is illustrated in the table below.

	Always		**Sometimes**		**Never**		**Total**
	%	**95% CI**	**%**	**95% CI**	**%**	**95% CI**	
Main Bedroom	11.3	7.2 – 15.4	29.9	24.0 – 35.8	58.8	52.5 – 65.1	**234**
Main Living Room	4.8	2.0 – 7.6	14.0	9.5 – 18.5	81.2	76.1 – 86.3	**226**
Kitchen	8.6	5.0 – 12.2	39.7	33.5 – 45.9	51.6	45.2 – 58.0	**236**
Main Bathroom	9.7	6.1 – 13.5	41.2	35.2 - 47.2	49.1	43.0 – 55.2	**258**

Table 114: Condensation as Experienced in Four Rooms in Homes in the NPT Housing Population

A number of contingency table analyses were undertaken to investigate potential relationships between presence of condensation and clothes drying method, presence air vents, presence and use of extractors, overcrowding, housing age and double glazing. Significant associations were found between the presence of double glazing and prevalence of condensation in all four rooms: in the main bedroom (chi square = 17.796, df = 1, $p<0.001$, effect size = -0.860), in the main living room (chi square = 6.998, df = 1, $p<0.01$, effect size = -0.661), in the kitchen (chi square = 8.859, df = 1, $p<0.01$, effect size = -0.860) and in the main bathroom (chi square = 5.169, df = 1, $p<0.05$, effect size = -0.540). Additionally, a significant association was found between the household measure of use of bathroom extract and presence of condensation in the bathroom (chi square = 8.204, df = 2, $p<0.05$, effect size = -0.205).

Further to this, non-significant associations were present for this sample in each room with the self-declared measure of overcrowding. This factor was therefore considered in relation to the household measure of condensation, where a significant association was found with chi square = 20.448, df = 4, $p<0.001$, effect size = 0.443. No association was found between presence of condensation and housing age, however, for this sample condensation was most likely to be present in bedrooms in housing built post-1980, in living rooms in housing built between 1965 - 1980 and in kitchens built prior to 1964. Actions taken to remedy condensation are summarised below.

	Count	**%**
Open Window (s)	113	63.1%
Wipe	34	18.9%
Wipe and Open Window (s)	13	7.2%
Other	10	5.8%
No Action	6	3.2%
De-humidifier	3	1.9%
Total	**180**	

Table 115: Action Taken in the Winter in the Presence of Condensation

5.1.3.3.2 Incidence of Damp & Mould

The winter survey also requested that the respondents report the presence of damp and / or mould in their main bedroom, main living room, main bathroom and kitchen. Of the homes in NPT, 81.6 % have no damp in any of these rooms (95%CI: 75.9 – 87.3), while the remaining, 18.3% (95%CI: 12.6 – 24.0), reported damp in one of more of these four rooms. The frequency of damp experienced in the four main rooms under consideration, are illustrated below:

	Always		Sometimes		Never		Total
	%	95% CI	%	95% CI	%	95% CI	
Main Bedroom	4.7	1.6 - 7.8	9.5	5.1 - 13.9	85.8	80.6 - 91.0	174
Main Living Room	2.1	0.0 - 4.2	7.3	3.4 -11.2	90.6	86.2 - 95.0	172
Kitchen	4.2	1.2 - 7.2	6.2	2.6 - 9.8	89.6	85.0 - 94.2	170
Main Bathroom	3.5	0.7 - 6.3	15.3	9.9 - 20.7	81.2	75.3 - 87.1	169

Table 116: Damp as Experienced in Four Main Rooms in Homes in NPT

The low numbers of households that indicated the presence of damp in their homes prevent further statistical analysis of these results at the room scale. In order to enable further analysis of the distribution of damp in the NPT housing population a household level measure was created, indicating the presence of one or more rooms with damp. It was found that significant associations existed between this measure and housing tenure (chi square = 5.015, df = 1, $p<0.05$, effect size – 0.429, medium low), where rented properties are more likely to experience damp and exposure to driving rain during the winter (rho = 0.177, df = 168, $p<0.05$), where perceived exposure to driving rain is positively associated with presence of damp.

	Always		Sometimes		Never		Total
	%	95% CI	%	95% CI	%	95% CI	
Main Bedroom	2.9	0.5 - 5.3	6.1	2.7 - 9.5	90.9	86.8 - 95.0	188
Main Living Room	1.8	0.0 - 3.7	6.9	3.3 - 10.5	91.3	87.2 - 95.4	186
Kitchen	2.9	0.5 - 5.3	3.1	0.6 - 5.6	94.0	90.6 - 97.4	184
Main Bathroom	2.7	0.4 - 5.0	3.7	1.0 - 6.4	93.7	90.2 - 97.2	187

Table 117: Mould Growth as Experienced in Four Main Rooms in Homes in NPT

Relatively strong and significant statistical relationships have been found between the distribution of damp and mould growth in the respondents homes: for the bedroom, (rho = 0.409, df = 171, $p<0.001$), for the living room (rho = 0.300, df = 167, $p<0.001$), for the kitchen (rho = 0.463, df = 165, $p<0.001$) and for the bathroom (rho = 0.288, df = 162, $p<0.001$). As was the case for damp, the low distribution of households reporting mould prevents further statistical analysis of these results at the room scale. A household level measure was therefore created. No significant associations were found in relation to the distribution of mould in housing in NPT in the winter. Actions taken to remedy damp and mould are summarised below.

	Count	%
Wipe	48	17.6%
Re-Decorate	10	3.7%
Heat	1	0.4%
Wipe and Open Window	4	1.5%

	Count	%
Ventilate	2	0.7%
Nothing	1	0.4%
Other	9	3.3%
Total	272	

Table 118: Action Taken in the Winter in the Presence of Damp and or Mould

5.1.3.4 Material & Structural Damage

In relation to concern over the structure of their homes during violent storms, male and female responses to this question were significantly correlated, with a strong association (rho = 0.699, df = 151, $p<0.001$). The distribution of concern for the structure of homes is reproduced below, where it can be seen that 22.8% of households are concerned about the structure of their homes during a storm. The 95% Confidence Intervals (CI) for the distributions in the NPT population are also reproduced in the table below. The responses to this question and respondents perceived exposure to strong winds displayed statistically significant associations for female occupants (rho = 0.328 df = 220, p<0.001), male occupants, (rho = 0.363, df = 180, p<0.001) and at a household level (rho = 0.311, df = 247, p<0.001).

	Female (%)	**Male** (%)	**Household % (95% CI)**	
Concerned	22.8	23.1	22.8	(17.7 - 27.9)
Slightly concerned	27.8	27.4	26.0	(20.7 - 31.4)
Not at all concerned	38.5	37.6	42.3	(36.3 - 48.3)
Not considered	11.0	11.8	8.9	(5.4 - 12.4)
Total Count	**224**	**186**	**258**	

Table 119: Distribution of Concern Over the Structure of Homes During Violent Storms

In relation to concern over the structures in their gardens during violent storms male and female responses to this question were again significantly correlated, with a strong association (rho = 0.631, df = 154, p<0.001). The distribution of this factor is reproduced below, where it can be seen that 25.0% of households are concerned about the structures in their gardens during a storm. The responses to this question and respondents perceived exposure to strong winds displayed statistically significant associations for female occupants (rho = 0.280, df = 201, p<0.001), male occupants (rho = 0.451, df = 176, p<0.001) and at a household level (rho = 0.320, df = 226, p<0.001).

	Female	**Male**	**Household**	
	%	**%**	**%**	**95% CI**
Concerned	30.2	28.2	25.1	19.7 - 30.5
Slightly concerned	25.6	27.8	29.3	23.6 - 35.0
Not at all concerned	37.2	34.9	40.1	34.0 - 46.3
Not considered	7.0	9.1	5.5	2.7 - 8.4
Total Count	**212**	**181**	**244**	

Table 120: Distribution of Concern Over the Garden Structures During Violent Storms

In relation to concern with respect to the potential increase in frequency of flooding as a result of global warming, male and female responses to this question were significantly correlated, with a strong association (rho = 0.630, df = 153, p<0.001). The distribution of this factor is reproduced below, where it can be seen that 19.1% of households expressed concern over flooding. Again, 95% Confidence Intervals (CI) for the distributions in the NPT population are included. The responses to this question and respondents perceived exposure to flooding displayed statistically significant associations: for female occupants (rho = 0.543, df = 199, p<0.001), male occupants (rho = 0.451, df = 169, p<0.001) and at a household level (rho = 0.527, df = 231, p<0.001). Less strong associations were also present in relation to those properties that had previously been flooded: for female occupants (rho = 0.241, df = 201, p=0.001), male occupants (rho = 0.152, df = 177, p<0.05.) and at a household level (rho = 0.241, df = 201, p<0.01).

	Female	**Male**	**Household**	
	%	**%**	**%**	**95% CI**
Concerned	22.7	22.1	19.1	14.3 - 24.0
Slightly concerned	11.4	13.6	16.0	11.5 - 20.5
Not at all concerned	44.7	45.8	52.1	46.0 - 58.3
Not considered	21.3	18.4	12.7	8.6 - 15.8
Total Count	**220**	**184**	**254**	

Table 121: Distribution of Concern Over the Possibility of More Frequent Flooding in Neighbourhood, Due to Global Warming

5.1.4 Summary of Winter Survey Results

In order to carry out the analysis of the winter survey results it was firstly necessary to consider the distribution of the sample in relation to known distributions in the NPT population in terms of housing and social complexity factors. This has helped to ensure that any bias in the sample could be considered in the analysis of the results, ensuring that a significant bias in the sample (at the 5% level), that of response bias towards retired households, was identified and could be controlled for, where appropriate, through the application of a weight to responses from pensioner and non-pensioner households. It was important that this factor be controlled for, as older occupants are likely to have different comfort thresholds, and therefore where distributions are to be extrapolated to the population this bias should be considered. A summary of the results for the winter survey are now presented. The 95% Confidence Interval (95% CI – highlighted blue) is provided for all population level proportions.

Risk Factor	**NPT Household Proportion**	
	Proportion	**95% CI**
Inadequate Ventilation	10.5% often open the windows of their homes because it is so stuffy in the winter. No statistical explanation for this distribution was found.	6.7 – 14.3
	20.9% often open their windows when their heating system is in use and a further 27.4% sometimes open their windows at this time. A significant association exists between this factor and those occupants that consider their home to be stuffy. The most frequent reason stated by occupants for this action was to provide fresh air.	16.0–25.8; 31.6 – 43.2
	17.9% consider that '*when the heating is on their home often becomes stuffy and airless*' (57.5% disagreed).	13.2 – 22.6 (51.4–63.6)
	A significant association was found between those occupants that consider their home to be stuffy and those that open their windows because it is so stuffy.	
	11.1% consider their main bedroom to be stuffy at one period of time or more.	7.3 – 14.9
	12.6% consider their main living room to be stuffy at one period of time or more.	8.6 – 16.6
	30.0% consider that one of more of these rooms are stuffy during the winter. This distribution was found to be significantly associated with household age, where older occupants were more likely to perceive that one or more room as stuffy during the winter.	24.5 – 35.5

Risk Factor	**NPT Household Proportion**	
	Proportion	**95% CI**
Inadequate Heat	74.1% consider the temperature of their home to be very easy to control in the winter (13.3% disagree). Those homes where the temperature is considered easy to control are more likely to be owner occupied, have higher levels of insulation and TRV's. Presence of damp is negatively associated with this factor.	**68.7 – 79.5** **(9.1–17.5)**
	3.7% agreed that on a winter's day they usually only heat the room that they are in.	**1.4 – 6.0**
	17.7% agreed that they *'cannot afford to heat their homes to a comfortable temperature all the time'.* Response to this statement was significantly associated with self-declared financial status. Response to these two statements was positively and significantly associated.	**13.0 – 22.4**
	48.9% agree that the male and female occupants of their home often disagree about the temperature in their home. (33.8% disagree).	**41.5 - 56.3** (27.1–40.5)
	25.6% agree that *'on a winter's day: there are rooms in my home that are never a comfortable temperature'.* Agreement with this statement was significantly associated with low levels of insulation, presence of heating problems, low financial status, rented properties, heating that is difficult to control and low overall satisfaction with the environment provided by the home in the winter.	**20.2 – 31**
	38.2% agree that *'on a winter's day: when the heating is on, it is always the same temperature in all of the rooms of my home'* (40.6% disagree). A negative association was found between response to this statement and response to the previous statement. Further associations were found between occurrence of condensation (negative association) and levels of insulation (positive association).	**32.4 - 44.2** (34.6- 46.6)
	28.6% agree that their home *'takes a long period of time to heat up again, if left with no heating for a day or more'* (57.3% disagree).	**23.1 – 34.1** (51.2-63.4)
	Associations were found between this statement and insulation levels (higher levels, quicker the response), housing tenure (rental properties associated with slower responses) and age of property (older properties associated with slower response rates).	

Risk Factor	NPT Household Proportion	
	Proportion	95% CI
Inadequate Heat (Continued)	30.6% agree that their home *'looses heat rapidly if the heating is turned off'*. Response to this and the previous statement were positively associated. Significant associations were also found to be present for insulation levels, and age of property (1945 – 1964 perceived to loose heat most rapidly).	25.0 – 36.2
	14.1% perceive their home to be very draughty in the winter.	9.8 – 18.4
	Significant associations were found with presence of double glazing (negative) and exposure to wind (positive).	
	5.8% agreed that on a cold winter's night it is often too cold in their home to be able to sleep well. Significant associations were found with presence of insulation levels (negative) and housing tenure (occupants of rental properties were more likely to agree with this statement).	2.9 – 8.7
	49.1% consider no rooms in their home to be too cold or draughty at any time.	43.1 – 55.1
	27.8% consider one room in their home to be too cold or draughty at some time of the day or night.	22.5 – 33.1
	22.2% consider two or more rooms in their home to be too cold or draughty at some time of the day or night. The distribution of rooms that are considered to be too cold or too draughty by their occupants was found to be associated with: age of occupant; age of property; combined measure of insulation; presence of condensation, damp and or mould; annual cost of fuel; perceived exposure to wind; and overall satisfaction with the home environment in the winter.	17.3 – 27.1
Damp & Mould	29.7% consider that *'on a winter's day: there is often condensation on the windows of their home in the morning'* (57.1% disagree). A significant negative association was found between occurrence of condensation in the mornings and presence of double glazing associated.	24.1 – 35.3 (51.0–63.2)
	70.2% report condensation in one of more of the following four rooms: main bedroom, main living room, main bathroom and kitchen (29.8% disagree). For all rooms, the presence of double glazing was again found to be negatively associated with the occurrence of condensation. Additionally, for the bathroom the prevalence of use of bathroom extraction or other ventilation was also negatively associated.	64.5 – 75.9 (24.1–35.5)

Risk Factor	NPT Household Proportion Proportion	95% CI
Damp & Mould	Overcrowding in a home is positively associated with occurrence of condensation at a household level.	
(Continued)	Statistical associations exist between the presence of mould and the presence of damp for all four rooms considered herein.	
	18.3% have damp in one or more of the four rooms considered (81.6% disagree).	12.6 – 24.0 (75.9–87.3)
	Rented properties were more likely than owner occupied to experience occurrence of damp. The experience of damp was also positively associated with perceived exposure to driven rain.	
	26.1% have damp in one or more of the four rooms considered (74.0% disagree). No statistical explanation for this distribution was found.	19.9 – 32.3 (67.8–80.2)
	Mould growth was found to be statistically more prevalent in the kitchen during the winter than during the summer. No other statistical differences were found in the other three rooms considered.	
Material & Structural Damage	22.8%: Concerned over structure of their home during a violent storm (42.3% disagree). Significant associations were found between the attitudes to this statement and perceived exposure of home to wind.	17.7 – 27.9 (36.3–48.3)
	25.1%: Concerned over structures in their gardens during a violent storm (40.1% disagree). Significant associations were found between the attitudes to this statement and perceived exposure of home to wind.	19.7 – 30.5 (34.0-46.3)
	19.1%: Concerned over the potential increase in frequency of flooding as a result of global warming (52.1% disagree). Significant associations were found between the attitudes to this statement and perceived exposure of home to flood and homes that have previously flooded.	14.3 – 24.0 (46.0-58.3)

An open ended question ended the winter survey, allowed the male and female respondents to consider what they would do to improve the internal environment in their home during the winter. The table below provides a summary of the responses to this question.

Action	
Improve Heating System	15%
Change Windows and / or Doors	9%
Improve Ventilation inc. Extract Fans	5%
Improve Insulation	5%
Improve Control of Heating System	4%
Building Work	3%
Control Draughts	3%
Control Condensation, Damp and or Mould	2%
Control External Noise or Pollution	1%
No Changes	53%

Table 122: Summary of respondents' desired actions to improve the internal environment of their homes in a cold winter

5.2 Summer Survey Results

The summer survey received 307 responses, representing a response rate of just over 31%. This exceeded that anticipated during the survey design. Seventy replacement questionnaires were sent out in addition to the initial sample of 1000, for those reasons identified for the winter questionnaire. It can be seen that there is a fairly even spread across the ten strata, where the distribution was lowest for the pre-1919 / rural stratum and highest in the 1945-64 / rural stratum.

Age	Location		Response	
		Total	Valid	% of Valid
Pre 1919	Rural	34	26	8.5%
	Urban	33	27	8.8%
1919-1944	Rural	35	32	10.4%
	Urban	33	27	8.8%
1945 - 1964	Rural	45	34	11.1%
	Urban	37	32	10.4%
1965 -1980	Rural	46	39	12.7%
	Urban	40	29	9.4%
Post 1980	Rural	36	30	9.8%
	Urban	40	29	9.4%
Respondent Removed Reference		2	2	0.7%
	TOTALS	381	307	100%

Table 123: Summary of Response Rates to Summer Survey

Those responses that were received and were not fully complete were again a significant proportion and must be considered here due to their implications for the analysis of the data. Of the responses, 50% were fully complete, with responses from both male and female occupants. In addition, 38% of the returned questionnaires were complete as appropriate to their household composition. Of the 12% incomplete responses, 10% had either male or female response datasets incomplete or missing, and 2% were more substantially incomplete. Where the respondents had indicated that they were willing to receive further communication this missing information was requested.

	Frequency	Percent
Fully Complete	152	49.5
Female Data Missing	13	4.2
Male Data Missing	20	6.5
Not Complete	4	1.3
No Female in Household	41	13.4
No Male in Household	77	25.1
Total	307	100.0

Table 124: Distribution of Response Cases with Incomplete Datasets

The responses to the summer survey will now be analysed according to the methodology described previously. A summary of appropriate descriptive statistics for each variable gathered is reproduced in Appendix J. As was the case for the winter questionnaire, these responses will initially be analysed in terms of pathway and receptor factors. Where analysis has been undertaken to compare the sample with the population, appropriate weighting has been applied to counteract the effect of the stratified sampling method, through application of weighting factors. A table of weighting calculations is reproduced in Appendix K. Finally, further analysis will be undertaken to examine the interrelationship between these factors and potential risks for occupants in the internal home environment that have been identified as likely to be influenced by climate change.

5.2.1 Pathway Factors

The summer survey collated information on the following pathway factors:

Pathway Factors: Housing

- Age of property*
- Type of property
- State of repair
- Construction type
- Ventilation
- Internal air pollution
- Insulation
- Orientation

Pathway Factors: Neighbourhood

- Access to external space
- Exposure to pollution
- Exposure to noise
- Exposure to wind
- Exposure to rain
- Exposure to flood
- Exposure to water
- Exposure to crime

* It is reiterated here that the age of the property formed part of the sample stratification and the distribution of this pathway factor has therefore been considered in section 5.2.

In addition to this data, relevant factors from the HANAH EEP datasets for Neath Port Talbot will also be reproduced.

5.2.1.1 Pathway Factor: Type of Property

The survey identified built form in six categories: detached house, semi-detached house, terraced house, maisonette, bungalow and flat. Further to this, the EEP NPT dataset provides information regarding the number of storeys. The distribution of housing built form is illustrated in the table below. The number of storeys of the properties follows a logical distribution where the majority of homes are two-storey, except the vast majority of flats, maisonettes and bungalows. There is only one three-storey terraced property within the respondents. A contingency table analysis was conducted to determine whether there was an association between age of property and built form. A significant relationship was present (chi square = 160.303, df = 16, p<0.01) and the effect size of 0.587 indicates a medium effect. It can be seen that pre-1919 properties in the sample are more likely to be terraces, those built between 1919 & 1980 are more likely to be semi-detached and those built after 1980 are more likely to be detached or flats. This distribution mirrors that found in the previously reported Welsh Housing Condition Survey, and does not differ significantly from the population distribution.

	Age of Property					
	Pre-1919	**1919-1944**	**1945-1964**	**1965-1980**	**Post-1980**	**Total**
Detached House	6	7	4	18	18	53
Semi-Detached House	13	**36**	**46**	**23**	4	**122**
Terraced House	**32**	12	9	6	5	64
Flat / Maisonette	1	3	2	16	**21**	43
Bungalow	1	1	5	5	11	23
Total	53	59	66	68	59	305

Table 125: Cross Tabulation Showing Age of Property and Built Form

5.2.1.2 Pathway Factor: State of Repair

The measures of state of repair of the respondents' homes relate to structural state of repair. It was found that 9% of respondents' properties had structural faults, ranging from cracks in rendering, to subsidence and cavity wall tie corrosion. Cost of repair and the responsibility of the council were the most frequently given reasons for repair not having taken place, while the fact that the fault was minor or recurring were also stated reasons. Of these structural faults, 39% had been present for longer than five years.

	Pre 1919	1919-1944	1945-1964	1965-1980	Post 1980	
Structural Fault	4	4	5	2	6	21
Maintenance fault	2	3	3		3	11
Both Faults	0	2	3	2	0	7
No Housing Faults	47	50	55	62	50	264
	53	**59**	**66**	**66**	**59**	**303**

Table 126: Presence of Structural and Maintenance Faults by Age of Property

Contingency table analysis found no significant relationship between housing age and the presence of structural or maintenance type faults in the respondents' housing, nor between household responsibility for this work and presence of faults. A simple additive measure of housing faults was created following this analysis, where homes were found to either have housing faults or not. It was found that the distribution of homes with structural faults did not differ significantly from the expected distribution of unfit homes, neither by proportion in the population nor by age of property.

5.2.1.3 Pathway Factor: Construction Type

The construction type of the respondent's homes can be summarised through analysis of information relating to the construction of the external walls, the presence of timber framing and the age of the property. Through combination of reported wall construction materials, presence of timber frame construction methods and age of property, a combined measure of weight of construction has been estimated. The distribution of this measure for the survey respondents is illustrated below:

		Pre 1919	1919 - 1944	1945 - 1964	1965 - 1980	Post 1980	Total
External Wall Construction	**Light Weight**		3	4	2	8	17
	Medium Weight			4	64	51	119
	Heavy Weight	53	55	56			164
	Total	53	58	64	66	59	300

Table 127: Comparison of External Wall Construction Weight by Age of Property

5.2.1.4 Pathway Factor: Ventilation

The windows and ventilation present in respondents' homes can be considered in terms of type and state of repair of windows, together with the presence of alternative and additional ventilation methods, including trickle and wall vents, as well as bathroom and kitchen extractor fans. no significant correlation was found through analysis of age of property and type of window. An initial summary of window types present in the sample is illustrated in the following table:

	Count	%
Wood	35	12%
Metal	7	2%
uPVC	255	84%
uPVC and Timber Mix	7	2%

Table 128: Window Types in the Sample

Of the respondents, 12% required replacement windows in their homes mostly due to rotten, damaged or defective windows, where 39% required replacement in one room, 46% required more than one room and 15% required new windows throughout their property. The distribution of these homes was not significantly associated with the type of window in place, the age of the property, nor with the regime of maintenance, which ranged from every year to every 10 years.

The proportion of glazing in the façade is also of interest to this study as this may influence solar gain to the property. A goodness of fit chi square was conducted to determine whether the sample distribution differed from that found in the population for window to wall ratio. There was no statistical difference between the expected and observed frequencies (chi square = 0.94, df = 2, ns). The data available to the study, gathered within the EEP NPT dataset has been calculated from inspection of the front façade of the properties, however, the ranks of the proportions are likely to be similar for each façade, despite differences in actual values for front, side and rear facades. As was shown in the analysis of the population data, there is an association between age of property and window to wall ratio.

		Pre 1919	1919-1964	Post 1964	Total
Window to wall Scale	**<17.5%**	52.8%	24.0%	35.4%	33.8%
	17.5<22.5%	30.2%	41.6%	23.6%	32.1%
	>22.5%	17.0%	34.4%	40.9%	34.1%
	Total Count	**53**	**125**	**127**	**305**

Table 129: Comparison of Window to Wall Scale (%) and Age of Property

It was found that 2% of the responses considered there to be problem with air flow or ventilation. All six of these properties had uPVC windows and the properties were built pre-1919 (5 total) and post-1980 (1 total). All of the problems were long standing (over 2 years). This sub-sample is too small to undertake meaningful statistical analysis, although the potential sealing of previously less airtight windows with uPVC double glazing could be considered a potential risk factor for 5 out of 6 of the properties. Overall 24% of the respondents reported that there was draught stripping in their properties. As was the case for the winter survey this statistic may again be erroneous due to the likely relationship between double glazing and draught stripping. The proportion is therefore likely to be closer to the 84% distribution of double glazing.

The presence of air vents, either in the wall (airbricks) or within window frames (trickle vents), in the respondents' main bedroom and main living rooms was found to be 39% and 57% respectively. The distribution of these by age of property was not found to be significant, although the distribution did seem to show a greater presence of air vents in properties built between 1919 and 1964.

		Pre 1919	1919-1964	Post 1964	Total
No Vents	**Count**	19	27	58	**104**
% within Age Scale		*36.5*	*21.8*	*46.4*	***34.6***
Air Vent(s)	**Count**	33	97	67	**197**
% within Age Scale		*63.5*	*78.2*	*53.6*	***65.4***
	Total	**52**	**124**	**125**	**301**

Table 130: Comparison between Age of Property and Presence of Air Vents

Further to this, 46% of respondents' households had an extractor fan in their kitchen and 22% in their bathroom. A contingency table analysis was conducted to determine whether an association exists between presence of kitchen extractor fan and age of property. A significant relationship was present with chi square= 11.105, df = 4, $p<0.05$, however, the test of linear association was not significant, indicating that the association is not linear (p-0.196). This non-linearity is most clear on visual inspection of the cross-tabulation, see below, where it can be seen that extraction fans are least widely distributed in the property age group 1945 – 1964.

			Pre-1919	1919 - 1944	1945 - 1964	1965 - 1980	Post-1980	Total
Extract Fan in Kitchen	**Yes**	**Count**	24	27	19	36	32	**138**
		%	45.3%	46.6%	28 8%	53.7%	54.2%	**45.5%**
	No	**Count**	29	31	47	31	27	**165**
		%	54.7%	53.4%	71 2%	46.3%	45.8%	**54.5%**
Total		**Count**	**53**	**58**	66	**67**	**59**	**303**

Table 131: Cross-tabulation of Housing Age and Presence of Kitchen Extraction

A further contingency table analysis was conducted to determine whether an association exists between presence of bathroom extractor fan and age of property. A significant relationship was again present with chi square = 28.540, df = 4, $p<0.001$, effect size = -0.258. The contingency table appears to indicate that bathroom extractor fans are more likely to be present in post-1980 properties.

			Pre-1919	1919 - 1944	1945 - 1964	1965 - 1980	Post 1980	Total
Extract Fan in Bathroom	**Yes**	**Count**	12	9	11	8	28	**68**
		%	22.6%	15.3%	16.7%	11.9%	47 5%	**22.4%**
	No	**Count**	41	50	55	59	31	**236**
		%	77.4%	84.7%	83.3%	88.1%	52.5%	**77.6%**
Total		**Count**	**53**	**59**	**66**	**67**	59	**304**

Table 132: Cross-tabulation of Housing Age and Presence of Bathroom Extraction

5.2.1.5 Pathway Factor: Internal Air Pollution

Internal air pollution sources in the home include gas combustion as a result of gas hobs, heating and fires. It was found that 68% of households in this survey cook using a gas hob in the kitchen. Data was not gathered in relation to furnishings as a source of pollution, nor in relation to heating energy type (although this information was gathered for the winter survey). The presence of mould, a further source of indoor pollution is considered in section 5.2.3.4.4.

5.2.1.6 Pathway Factor: Insulation

As described elsewhere, the SAP rating for a property is related to property size, area of walls, area of windows, type and scale of insulation and type and fuel of heating system. The SAP rating was estimated within the EEP NPT dataset, having been created from standard estimation of insulation properties for each home. An ANOVA comparison of means test was carried out in order to consider the relationship between age of property and its SAP rating. The relationship between the two was significant (F (4, 301) 45.973, $p<0.001$) and the effect size was relatively high, 0.616, indicating that SAP ratings do vary with age of property. The box plot below illustrates this relationship.

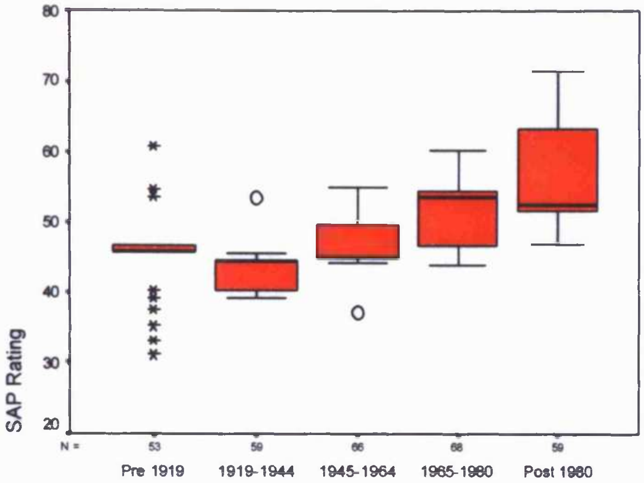


Figure 107: Box Plot Illustrating Median, Quartiles, and Extreme Values for SAP Ratings by Age Categories

Loft insulation is evenly distributed through property age strata and contingency table analysis found no significant relationship can be found between these variables.

		Pre 1919	1919 - 1944	1945 - 1964	1965 - 1980	Post 1980	Total
Loft Insulation	Yes	47	53	52	59	51	262
	No / Don't know	6	6	13	8	8	41
	Total	53	59	65	67	59	303

Table 133: Comparison of Presence of Loft Insulation by Age of Property

A 2 x 5 contingency table analysis was conducted to determine whether there was an association between the presence of cavity wall insulation and age of property. A significant relationship was present with chi square = 21.77, df = 4, $p<0.001$ meaning that the older the property, the less likely the presence of cavity wall insulation, as would be expected. The effect size of -0.423 indicates a medium effect. It should be noted that for cavity wall insulation, the reporting of this variable may be less reliable that that of loft insulation as it is not readily visible to the occupant.

		Pre 1919	1919 - 1944	1945 - 1964	1965 - 1980	Post 1980	Total
Cavity Wall Insulation	Yes	5	15	19	22	26	87
	No / Don't know	48	44	47	44	33	216
	Total	53	59	66	66	59	303

Table 134: Comparison of Presence of Cavity Wall Insulation by Age of Property

A further 2 x 5 contingency table analysis was conducted to determine whether there was an association between the presence of double glazing and age of property. A non-linear relationship was present ($p=0.196$). However, visual inspection of the distribution in the contingency table suggests that for this sample it is more likely that double glazing will be present in older properties, built prior to 1919 than in newer properties built post-1980. This is perhaps contrary to expected results.

		Pre 1919	1919 - 1944	1945 - 1964	1965 - 1980	Post 1980	Total
Double	**Yes**	90.6%	91.5%	72.3%	86.6%	82.8%	84.4%
Glazed	**No / Don't know**	9.4%	8.5%	27.7%	13.4%	17.2%	15.6%
Windows	**Total (count)**	53	59	65	67	58	302

***Table 135:** Comparison of Presence of Double Glazed Windows by Age of Property*

Double glazing is least likely to be present in properties built between 1945 & 1964. It was considered appropriate to examine the relationship that the presence of double glazing may hold with housing tenure. It was found that a significant relationship exists between housing tenure and double glazing, with chi square 40.534, df = 1, p<0.001. The effect size of 0.765 indicates a high effect, where rented properties are less likely to have double glazing.

		Owner Occupied	Rental Property	Total
Double	**Yes**	221 (91.3%)	35 (58.3%)	**256 (84.8%)**
Glazing	**No / Don't Know**	21 (8.7%)	25 (41.7%)	**46 (15.2%)**
		242	**60**	**302**

***Table 136:** Comparison of Presence of Double Glazed Windows by Housing Tenure*

A combined measure of these three types of insulation was prepared and cross-tabulated against age categories. It can be seen that a non-linear relationship exists between these factors, where for this sample homes built between 1945 and 1964 are less likely to have more than one measure of insulation than homes built at any other period. It is again possible that the high prevalence of rented properties in this tenure may be of influence on this finding.

	Pre 1919	1919 - 1944	1945 - 1964	1965 - 1980	Post 1980	Total
0-1 Measures of Insulation	17.0%	15.3%	36.9%	16.4%	19.0%	21.2%
2 or more Measures of Insulation	83.0%	84.7%	63.1%	83.6%	81.0%	78.8%
Total (count)	**53**	**59**	**65**	**67**	**58**	**302**

***Table 137:** Comparison of Presence of Insulation Measures by Age of Property*

Goodness of fit chi square were conducted to compare the distribution of loft insulation, cavity wall insulation, double glazing, draught stripping and hot water tank insulation with that found in the population.

	Chi Square	df	p	Effect Size
Loft Insulation	1.98	1	0.160	-
Cavity Wall Insulation	8.257	1	<0.01	0.03 (V. Low)
Double Glazing	34.00	1	<0.001	0.12 (V. Low)
Draught Stripping	46.25	1	<0.001	0.16 (V. Low)
Hot Water Tank Insulation	154.026	1	<0.001	0.54 (Medium)
Combined Measures	78.565	2	<0.001	0.13 (V. Low)

***Table 138:** Results from Goodness of Fit Chi-square Tests to Compare the Distribution of Insulation Measures with Distributions found in the Population*

It can be seen that all of the distributions, except that of loft insulation, differ significantly from that found in the population. Higher distributions of wall insulation and double glazing and reduced distributions of draught stripping and water tank insulation were found in the sample. It may be that the reduced distribution of draught stripping and increased distribution of double glazing reflect a true change in the population distribution between the WHCS of 1998 and this survey, 2002, where double glazing has been installed in an increasing proportion of properties. It is further possible that the reduction in insulated hot water tanks may also reflect a wider distribution of combi-boilers, where no hot water tank is required. This information was not gathered through this survey and may represent an error in the data. The installation of cavity wall insulation has also been increasing, due to the availability of government subsidies (such as those resulting from the HECA, 1995). The final comparison of the combined numbers of measures of insulation represented an increase in numbers of homes with all insulation measures and a decrease in those with some or no measures.

	Observed N	Expected N	Residual
No Insulation	5	14.3	-9.3
Some Insulation	273	275.0	-2.0
All Insulation	13	1.7	11.3
Total	**291**		

Table 139: Comparison of Distribution of Insulation Measures Between Sample and Population

5.2.1.7 Pathway Factor: Orientation

The results from the survey provide orientation information for the main bathroom, main living room, main bedroom and the kitchen. The information indicates when the rooms receive direct sunlight and when they are shaded from direct sun. Detailed analysis of this information is not appropriate here but orientation is likely to influence potential overheating and therefore orientation is an important factor in the analysis. An example of the data available for the analysis is reproduced below.

		Direction from which Bedroom is Shaded							
		East	**South East**	**South**	**South West**	**West**	**North**	**Not Shade**	**Total**
Bedroom Orientation	**East**	3		37	30	45		7	**122**
	South East				1	15		2	**18**
	South	34	1	5		12	5	12	**69**
	South West	18						2	**20**
	West	22	10	1				2	**35**
	North			1		1			**2**
	No Direct Sun	1		4		1			**6**
	Total	**78**	**11**	**48**	**31**	**74**	**5**	**25**	**F**

Table 140: Comparison of Bedroom Orientation and External Shading

5.2.1.8 Pathway Factor: Access to External Space

The access to external space, either a private garden or a public space such as a park or a beach, was considered through questions relating to ownership gardens and proximity to public open space, where 93% of the respondents had access to their own garden and 85% live within walking distance of a public open space. This can also be considered in relation to the rural or urban location of the property through application of the relevant EEP NPT data. When garden ownership and access to public open space was analysed in relation to location, it was found that rural occupants were significantly ($p<0.05$) less likely to have a public open space within walking distance, 80% (strong association Gamma = 0.576) yet they were more likely to have their own garden, 97% (Gamma = -0.358). Only four respondents neither had access to a garden nor lived within walking distance of a public open space, all four of whom were occupants of flats.

5.2.1.9 Pathway Factor: Exposure to Pollution

Sources of pollution at the neighbourhood scale are widespread and this variable cannot therefore be considered in its entirety, except through detailed measurement on site. This survey has therefore attempted to measure this variable qualitatively through consideration of proximity to pollution sources. The proximity of respondents' households to sources of air pollution, busy or dual carriageway roads, heavy and light industry and rubbish tips, were all measured through this survey. It was found that 43% of cases considered their home to be very close to a busy road, 7% to heavy industry, 5% to light industry and 1% to a municipal rubbish dump. These figures rise to 70%, 16%, 25% and 4% respectively for sources within 1 mile.

It was found that 31% of households in NPT consider air pollution to be a problem in their neighbourhood (95%CI: 25.5 – 36.5). Further to this, 34% of female occupants (95%CI: 28 - 40) and 33% of male occupants (95%CI: 26.4 – 39.6) considered their homes to be exposed to air pollution. The correlation between male and female responses, measured using the rank correlation procedure, showed a significant association ($r = 0.672$, $df = 151$, $p<0.001$), reflecting a strong association between responses. Correlation between the household and neighbourhood measures of exposure to pollution also showed a strong and significant association, with a Spearman's rho value of ($r = 0.607$, $df = 257$, $p<0.001$).

A series of 2 x 3 contingency table analyses were conducted to determine whether there was an association between the presence of sources of air pollution: busy roads, industry and rubbish tips within one mile of a home and householders' perception of air pollution both at a neighbourhood and home scale. It was found that at a neighbourhood scale significant associations exist where busy roads (chi square = 21.188, df = 2, $p<0.001$, effect size = 0.633 medium high), heavy industry (chi square = 78.958, df = 2, $p<0.001$, effect size = 0.850, high) and light industry (chi square = 14.467, df = 2, $p = 0.001$, effect size = 0.422, medium) are located within one mile of the household.

The low number of homes located in proximity to rubbish tips did not enable the same analysis but a significant association with low effect was found ($r = 0.198$, $df = 272$, $p<0.01$). These associations were lower where exposure of the home itself was considered by the households: busy roads (chi square = 11.360, df = 2, $p<0.01$, effect size = 0.377, medium low), heavy industry (chi square = 57.606, df = 2, $p<0.001$, effect size = 0.771, high), and light industry (chi square = 11.641, df = 2, $p<0.01$, effect size = 0.371, medium low). Again for rubbish tips the distribution did not enable the same analysis but a very low yet significant association was found ($r = 0.135$, $df = 265$, $p<0.05$). It can be seen that the presence of heavy industry in close proximity to the home has the strongest impact on perception of air pollution at both neighbourhood and home scale. This is followed by the presence of busy roads.

5.2.1.10 *Pathway Factor: Exposure to Noise*

Approximately 16% of respondents considered noise to be a fairly big or very big problem in their neighbourhood, while 51% would consider it to be at least a minor problem. For these respondents, 31% cited road traffic noise as the source, with children, neighbours, animals, local industry and various additional sources being cited as other sources of the noise in their neighbourhood. Three contingency table analysis tests were undertaken to consider the relationship between the proximity of roads, light and heavy industry to homes, the results of which are reproduced below. All were found to be positively and significantly associated with noise problems.

	Chi Square	df	p	Effect Size
Noise as a Problem & Busy Roads	42.025	4	<0.001	0.541 (Medium)
Noise as a Problem & Heavy Industry	12.580	6	=0.05	0.278 (Low)
Noise as a Problem & Light Industry	18.023	4	=0.001	0.385 (Low)

Table 141: Results from Contingency Table Analysis Tests Between 'Noise as a Problem' and Industrial Sites & Busy Roads

5.2.1.11 *Pathway Factor: Exposure to Wind*

Male and female respondents each considered whether their homes were exposed to strong winds. A significant positive relationship exists between the male and female responses to this question (r = 0.75, df = 148, p<0.001). A combined measure of exposure for each household was created, taking the average of the responses, the distribution of which is reproduced below.

	Frequency	Valid Percent	Cumulative Percent
Extremely Exposed	17	5.8%	**5.8%**
Very Exposed	25	8.6%	**14.4%**
Exposed	70	24.0%	**38.4%**
Slightly Exposed	133	45.5%	**83.9%**
Not at all exposed	47	16.1%	**100.0%**
Total	**292**	**100.0%**	

Table 142: Combined Measure of Perceived Exposure to Strong Winds

5.2.1.12 *Pathway Factor: Exposure to Rain*

The responses to questions regarding driving rain were analysed as for those regarding strong winds. A significant positive relationship exists between the male and female responses to this question (r = 0.70, df = 150, p<0.001). The combined measure illustrated below was created in the same manner.

	Frequency	Valid Percent	Cumulative Percent
Extremely Exposed	16	5.7%	**5.7%**
Very Exposed	16	5.7%	**11.3%**
Exposed	75	26.5%	**37.8%**
Slightly Exposed	132	46.6%	**84.5%**
Not at all exposed	44	15.5%	**100.0%**
Total Count	**283**	**100.0%**	

Table 143: Combined Measure of Perceived Exposure to Driving Rain

5.2.1.13 Pathway Factor: Exposure to Flood

Of the respondents' homes, 6% had previously flooded and 6% had experienced drainage problems of some sort. Where combined a total of 9% had experienced problems relating to flooding or drainage. In relation to this 19% of respondents' properties, 29 cases, were located in close proximity to a natural body of water, river, stream, lake or pond. Following measurement of the association between these two factors, no significant association was found, although 16% of respondents were both located in proximity to a natural body of water and had experienced flooding or drainage problems. The problems experienced by these properties included failures in mains drainage, 28%, surface water problems, 40%, stream or river overtopping, 20%, internal drainage failures, 4%, and other problems 8%.

The perceived exposure to flooding was measured for both male and female occupants and through correlation a significant positive relationship was found to exist between the male and female responses to this question (r = 0.71, df = 145, p<0.001). A combined measure was then created for each household and the association between this and the experience of previous flood (contingency coefficient 0.370), drainage (0.156) or both problems (0.251).was found to be significant (p<0.01), although the associations were relatively weak.

			Exposed	Not At All Exposed	Total
Previously Experience of Flooding	**Yes**	%	46.2%	4.1%	**6.1%**
	No	%	53.8%	95.9%	**93.9%**
	Total Count		**13**	**267**	**280**

Table 144: Association between Perceived Exposure to Flooding and Previous Experience of Flooding

5.2.1.14 Pathway Factor: Exposure to Water

The survey enabled the presence of static or running water, including water butts, garden ponds (with or without running water), streams, rivers, lakes and ponds in the garden or in close proximity to respondents' homes to be established. A 2 x 2 contingency table analysis was conducted to determine whether there was an association between rural and urban location and proximity to water. A significant association was present with chi square = 6.708, df = 1, p = 0.01, meaning that homes in a rural location are more likely to be located in proximity to water. However, an effect size of 0.151 indicates a very low effect.

	Frequency	%
No Water	169	56.7%
Running Water	63	21.1%
Static Water	55	18.5%
Both Types	11	3.7%
Total	**298**	**100.0%**

Table 145: Frequency of Static and Running Water Bodies Either in Respondents' Gardens or in close Proximity to their Homes

5.2.1.15 Pathway Factor: Exposure to Crime

It was found that 5% of the male respondents and 6% of the female respondents that took part in this survey indicated that they had personally been a victim of crime in the past year. Taken as an indicator this suggests that 8% of the households had been affected by crime. In total 29 crimes were reported in the survey, 11 car crimes, 1 financial, 5 garden, 5 violent or criminal damage, 4 theft or burglaries and 5 further undefined crimes. Further to this, 13% of households considered burglary and theft to a 'big' problem in their neighbourhood. Following a contingency table analysis no significant association was found between status as victim of crime and perception of crime in the neighbourhood.

	Frequency	Valid Percent	Cumulative Percent
Very Big Problem	13	4.5%	**4.5%**
Fairly Big Problem	24	8.4%	**12.9%**
Minor Problem	132	46.0%	**58.9%**
Not at all a Problem	97	33.8%	**92.7%**
Don't Know	21	7.3%	**100.0%**
Total	**287**	**100.0%**	

Table 146: Burglary and Theft as a Problem in Respondents Neighbourhood

A further measure of perception of safety that may embrace perception of crime was a question relating to 'feeling safe' in the home. Significant negative relationships exist between perception of neighbourhood level crime and feeling of safety in the home both for female occupants ($r = -0.157$, $df = 236$, $p<0.05$), male occupants ($r = -0.204$, $df = 187$, $p<0.05$) and at a combined household level ($r = -0.194$, $df = 283$, $p<0.001$). The low strengths of these associations suggest that perceived neighbourhood crime level is just one of many variables that influence the concept of feeling safe for housing occupants.

	Female	Male	Household
Completely safe	57.7%	60.0%	49.4%
Fairly safe	38.3%	37.3%	47.2%
Not very safe	4.0%	2.2%	3.0%
Not at all safe	0.0%	0.5%	0.4%
Total Count	**250**	**204**	**304**

Table 147: Comparison of Female, Male and Household Perceived Safety in Their Home

5.2.2 Receptor Factors

The summer survey collated information on the following receptor factors:

Receptor Factors: Socio Economic

- Occupant Age
- Socio–economic status
    - *Education level*
    - *Housing tenure*
    - *Maintenance*
- Household composition
- Length of time in the home

Receptor Factors: Existing Health

- Presence of long standing illness
- Sources of internal air pollution

While the behavioural receptor factors are dealt with in section 5.2.3, considering their direct relationship with the risk systems for summer. In addition to this data, relevant factors from the EEP NPT datasets will be considered including Townsend scores.

5.2.2.1 Receptor Factor: Age

The only data collected in terms of age of occupants identifies those households occupied by those that have retired from paid employment. A goodness of fit chi square test to determine whether the distribution of retired households in the sample differed from the population distribution found a statistically significant difference between these observed and expected frequencies (chi square = 3.095, df = 1, p<0.001). A residual of 43 from a total observed number, or sample of 303. It is here suggested that this may be a significant source of bias in the sample and should be controlled for where appropriate.

5.2.2.2 Receptor Factor: Socio-Economic Status

The socio-economic status of the respondents can be considered through a number of measures collected through survey as well as through the postcode level Townsend score. The distribution of the Townsend scores for the sample is illustrated below and can be seen to be similar to that found in the population, as illustrated below.

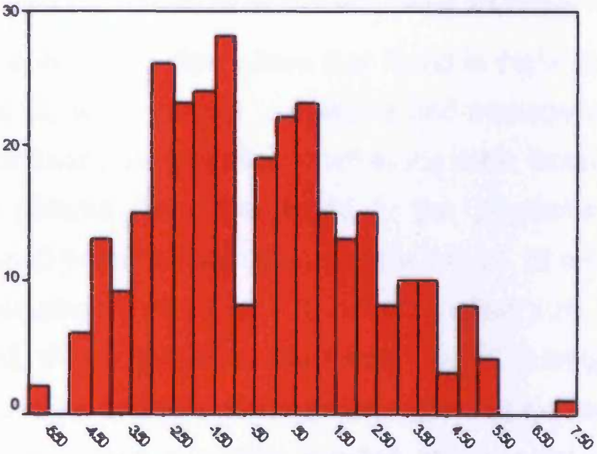


Figure 108: Distribution of Postcode Level Townsend Scores for Summer Survey Sample

The distribution of economic activity illustrates 37% of the total respondents were in employment.

	Male	Female	Total	%
Employed	88	82	170	**37.4%**
Unemployed and seeking work	4	1	5	**1.1%**
Looking after home and or children full time	27	4	31	**6.8%**
Retired from paid work	103	80	183	**40.3%**
Long term carer	4	7	11	**2.4%**
Permanently unable to work due to illness or disability	23	31	54	**11.9%**
Total	**249**	**205**	**454**	**100.0%**

Table 148: Employment Status for All Adult Respondents

Goodness of fit chi square tests were conducted to determine whether the male, female and combined distribution of employment status differed from that found in the population. Statistically significant differences were found for all three, female (chi square = 85.461, df = 4, p<0.001, effect size = 0.087 [v.low]), male (chi square = 102.431, df = 4, p<0.001, effect size = 0.129 [v. low]), and household level (chi square = 200.59, df = 4, p<0.001, effect size = 0.078 [v. low]). The largest deviation from expected distribution was that for retired occupants, for all three distributions. Analysis was undertaken of these households it was revealed that the majority had not provided previous employment statistics, but were currently retired. This bias in the sample may therefore be explained by the previously explored bias in response, in favour of retired occupants.

Although the questionnaire was not formally directed at the heads of the household, the respondents are placed in that role for the purposes of data analysis. The analysis of self-coded NSSEC status for the respondents is illustrated below.

;	Female		Male		Household	
	Count	%	Count	%	Count	%
Managerial and Professional Occupations	70	27.8	67	32.5	117	**38.5**
Intermediate Occupations	58	23.0	11	5.3	46	**15.1**
Small Employers and Own Account Workers	7	2.8	12	5.8	14	**4.6**
Lower Supervisory and Technical Occupations	17	6.7	49	23.8	44	**14.5**
Semi Routine and Routine Occupations	75	29.8	51	24.8	65	**21.4**
Never in Paid Employment	8	3.2	4	1.9	6	**2.0**
Not Classifiable	17	6.7	12	5.8	12	**3.9**
Total	**252**		**206**		**304**	

Table 149: Male Female and Household NSSEC Self-Coded Classification

As was the case for the winter survey, this distribution also differs from that found in the wider population. The most notable differences appear to lie in the not classifiable and managerial sectors. Goodness of fit chi square tests were conducted to determine whether the male, female and combined distribution of NSSEC status differed from that found in the population. Statistically significant differences were found for all three, female (chi square = 141.01, df = 6, $p<0.001$, effect size = 0.096 [v.low]), male (chi square = 119.24, df = 6, $p<0.001$, effect size = 0.010 [v.low]) and combined (chi square = 5.232, df = 5, $p<0.001$, effect size = 0.021 [v.low]). The observed, expected and residual results from the analysis of combined male and female responses are reproduced below. It can be seen that a greater number of managerial, intermediate and lower supervisory level respondents were received than would be expected from the population distribution. Semi-routine, the self employed and those in the population that had never been in paid employment are seen to be under-represented in the sample.

	Observed N	Expected N	Residual
Managerial and Professional Occupations	117	74	**43**
Intermediate Occupations	46	33	**13**
Small Employers and Own Account Workers	14	19	**-5**
Lower Supervisory and Technical Occupations	46	36	**10**
Semi Routine and Routine Occupations	59	105	**-46**
Never Worked	4	19	**-15**
Total	**286**		

Table 150: Results of Rank Correlation Test of Household NSSEC Against Population Distribution

The final measure of economic status gathered within the survey was a self-reported measure of financial status using a Likert-type scale. The distribution of this for the sample is reproduced below. A 3 x 2 contingency table analysis was conducted to determine whether there was an association between self-reported economic status and household NSSEC. A significant relationship was found to be present where chi square = 12.683, df = 4, $p<0.05$. The effect size of 0.20 indicates a low effect.

	Frequency	%
Living Comfortably	67	22.1%
Doing Alright	96	31.7%
Just About Getting By	140	46.2%
Total	**303**	**100.0%**

Table 151: Self-reported Economic Status

5.2.2.2.1 Receptor Factor: Education Level

The highest educational level attained by respondents to the survey, both male and female, were analysed with respect to the distribution found in the population, through the application of goodness of fit chi square test. There were found to be significant statistical differences between the observed and the population distributions for all three groups, female (chi square = 218.911, df = 5, p<0.001, effect size = 0.058 [v.low]), male (chi square = 112.367, df = 5, p<0.001, effect size = 0.024 [v.low]), and combined (chi square = 77.071, df = 5 p<0.001, effect size = 0.011 [low]). Notably, a greater frequency of respondents with Level 2 qualifications (GCSE, O level or equivalent) and above existed in the sample than would be expected from the population distribution.

	Observed N	Expected N	Residual
No Educational Qualifications	173	173	**0**
Level 1	15	73	**-58**
Level 2	91	82	**9**
Level 3	40	23	**17**
Level 4 / 5	66	57	**9**
Other Qualification - Level Unknown	59	35	**24**
Total	**444**		

Table 152: Results of Rank Correlation Test of All Respondents Highest Educational Level Against Population Distribution

A significant positive association was found between male and female occupant's highest level of education (rho = 0.373, df=151, p<0.01). Population split between sexes is not available, however, similar significant differences were found between both individual distributions and the overall population distribution.

	Female		Male		Population
	Count	%	Count	%	Distribution
No Educational Qualifications	92	37.2%	79	39.3%	**39.0%**
Level 1	9	3.6%	10	5.0%	**16.5%**
Level 2	56	22.7%	35	17.4%	**18.5%**
Level 3	25	10.1%	14	7.0%	**5.2%**
Level 4 / 5	38	15.4%	32	15.9%	**12.9%**
Other Qualification - Level Unknown	27	10.9%	31	15.4%	**8.0%**
Total	**247**	100.0%	**201**	100.0%	**100.0%**

Table 153: Highest Education Qualification Achieved for Male and Female Respondents with Overall Population Distribution for Comparison

5.2.2.2.2 Receptor Factor: Housing Tenure

The survey identified housing type in terms of housing tenure: owner occupied, council tenant, housing association tenant, private tenant. It was found that 79% of the respondents were owner occupiers, 14% were council tenants, 4% housing association tenants and the remaining respondents were private tenants, while one respondent resided rent free in a property owned by a family member. In relation to property age the majority of council properties in the sample were built between 1945 and 1980, while housing association properties were mostly constructed post-1980. A goodness of fit chi square was conducted to compare the sample distribution with that found in the population. The sample housing tenure distribution differs significantly (chi square = 8.892, df = 2, $p<0.01$). However, the associated effect size of 0.015 shows the deviation from expected was low, where higher than expected responses were received from owner occupied properties.

5.2.2.2.3 Receptor Factor: Maintenance

The responsibility for the maintenance of the property lay with 84% of the respondents. Where 6% of respondents had outstanding maintenance work on their homes. This included issues relating to the roof, cosmetic factors and rendering. The reasons for the work remaining outstanding were similar to those reported for structural faults.

5.2.2.3 Receptor Factor: Household Composition

The respondents' household composition can be described in terms of the number of occupants, their ages and their ethnicity. The distribution of household sizes is illustrated below. Goodness of fit chi square was conducted to determine whether the sample distribution of household sizes was different from that expected within the population. The distribution was found to differ significantly from that found in the population (chi square = 51.512, df = 5, $p<0.001$), with greater than expected smaller households present in the sample.

	1	2	3	4	5	6
Count	110	118	47	13	14	3
Residuals	42	10.	-9	-41	-2	-1
%	35.8	38.5	15.4	4.3	4.5	0.9
Expected	24.6	34.6	17.4	15.5	5.1	1.1

Table 154: Distribution of Households Size in Summer Survey Respondent's Households

The objective measurement of size of a home is provided by the EEP NPT dataset and indicates heated floor area of each home measured in m^2. Further to this, the appropriate size of a home in relation to its occupants can be derived through the application of the bedroom standard, through consideration of the number of bedrooms and the age, sex and number of occupants. This has been estimated from data gathered through survey. Further to this measure, a self-declared, Likert-type measure of overcrowding was also gathered and these two measures of overcrowding, together with the objective measure, will now be considered for the sample.

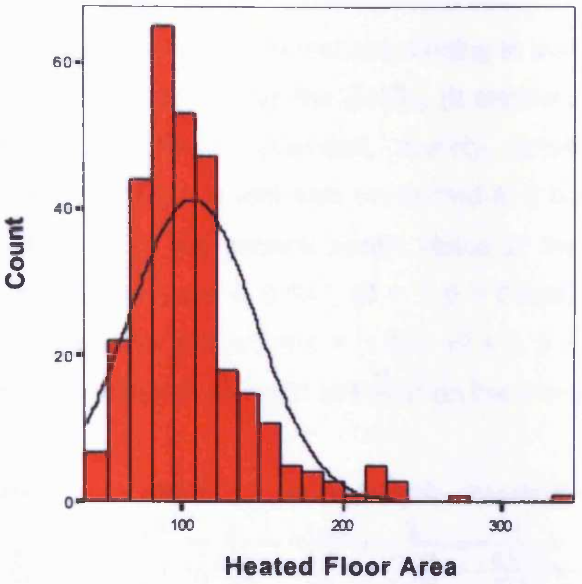


***Figure 108: Histogram of Heated Floor Area** (Data Source: EEP NPT Dataset)*

The distribution of self declared perception of the space in the respondents' homes is as follows:

	Frequency	Valid Percent
Crowded	39	12.8%
Just About Right	230	74.7%
Too Large	38	12.4%
Total	308	100.0%

Table 155: Distribution of Self-Declared Perception of Space

The bedroom standard for the respondents' households was estimated from the distribution of adult and child occupants. A goodness of fit chi square was conducted to determine whether the distribution of the bedrooms standard in the sample differed from that found in the population, as reported in the WHIS. A statistically significant difference was found (chi square = 16.742, df = 2, p<0.001). This suggests that the two distributions do differ, where a higher than expected number of responses were received from households with a bedroom standard of greater than one (where the home is larger than required by the standard). A significant association was also found between the self reported estimate of overcrowding and calculated bedroom standard, where rho = 0.457, df – 286, p<0.001.

	Observed N	Expected N	Residual
Not Overcrowded	237	205.8	31.2
Equal	44	71.8	-27.8
Overcrowded	6	9.5	-3.5
Total	287		

Table 156: Comparison of Calculated Distribution of Sample Bedroom Standard Against Population Value

5.2.2.4 Receptor Factor: Length of Time in the Home

It was found that 82% of the respondent households have been occupant in their home for over 5 years, while 18% have been occupant for between 1 and 5 years. Those occupant for a longer period of time are more likely to have experienced a hotter summer in this home and therefore may provide more reliable responses to questions relating to overheating than those occupant for between 1 and 5 years. However, very hot summers have occurred during the last 5 years, so this potential source of bias may not influence responses unduly.

5.2.2.5 *Receptor Factor: Existing Health and Illness*

The existing health status of the respondents was considered through questions relating to their overall health, existing respiratory and long terms illnesses as well as the GHQ_{12} (a standard measure of short-term changes in mental health including depression, anxiety, social dysfunction and somatic symptoms). A goodness of fit chi square test was conducted and no statistically significant difference was found between that of the general health status of the respondents and that found in the population, female (chi square = 0.537, df = 1, p = 0.464), male (chi square = 0.992, df = 1, p = 0.319), all respondents (chi square = 1.604, df = 1, p = 0.302), with 82% of the population describing their general health as good or better on the scale provided and 18% as poor or worse.

	Female		Male		All Respondents		Population
	Count	%	Count	%	Count	%	%
Good	201	82.0%	154	78.2%	355	81.8%	83.6%
Poor	44	18.0%	43	21.8%	67	18.2%	16.4%
Total	245		197		442		

Table 157: Comparison of the Distribution of Self Reported Health Status for Male, Female, All, Household respondents and the Population

Of households in the sample, 39% were home to one or more occupant suffering from a long term illness, including 6 children, 58 adults of working age and 70 of retirement age; equating to a distribution of 20% (95%CI: 16.9 – 23.2) of the total occupants of the respondents' homes. The Census reported a statistic of 29.4% of NPT population with a long term illness, while the WHS estimated 36%. This sample differs significantly from both of these values. The distribution of occupants with long terms illness is therefore significantly lower than that found in the population. As was he case for the winter survey, t is known that a number of occupants refused to take part in the survey due to ill health and this is therefore likely to be a source of response bias in the survey. Long-term illness included: angina (4 cases), arthritis (22 cases), back problems (14 cases), diabetes (8 cases), heart problems (25 cases), mental conditions (10 cases), and various other physical conditions (26 cases).

The cases of reported respiratory disease were also significantly lower than proportion found in the population, 12.8% (95%CI: 10.2 – 14.4) of total respondents household occupants, against 25% in WHS. Reported respiratory illnesses included: asthma, 35 cases; bronchitis, 3 cases; emphysema, 3 cases; pleurisy, 1 case; other breathing illness, 6 cases.

It must be noted that it was not possible to consider the impact of the age distribution of the housing occupants within the sample analysis in relation to illness and therefore this may be an influential factor in these low distributions when compared to expected values in the population.

The final measure of illness gathered through the summer survey was the GHQ12, a measure of short term changes in mental health. It was found that 20% of female and 12% of male respondents scored 4 or more on the GHQ12 measurement scale, the indicator level for presence of mental health symptoms at the time of completing the form, with 25% of households occupied by one or more person subject to changes in symptoms of short term anxiety or depression. Through application of rank correlation tests, these distributions were found to be significantly different (female, with chi square = 6.551, df = 1, p<0.05 and male with chi square = 4.303, df = 1, p<0.05) from the WHS figure of 14% of NPT population suffering from mental health illness. The GHQ_{12} is not an appropriate method of testing for forms of long-term and on-going mental health of which the WHS statistic is a measure. Therefore, it was likely that these figures would not correlate.

5.2.2.6 *Receptor Factor: Internal Air Pollution Sources*

Internal air pollution sources in the home include tobacco smoke, cooking and gas combustion, such as gas hobs and fires as well as moisture from sources including drying clothes. It was found that 68% of households in this survey cook using a gas hob in the kitchen, while 27% of households have one or more occupants that smoke, although only 24% of respondents stated that they personally smoked in their homes. The population statistic for distribution of smoking in NPT borough is 25.5% and this figure does not differ significantly from the proportion of male and female smokers in the respondents to this survey, 23% and 24% respectively.

This was tested through goodness of fit tests, where for female distribution (chi square = 0.524, df = 1, p=0.469) and male (chi square = 1.025, df = 1, p=0.311). However, the actual proportion of smokers in the households as a whole is 103 out of a total reported respondents of 541, resulting in a total proportion of smokers of 19%, significantly lower (p<0.01) than the population distribution. It is proposed that the proportion of homes that are occupied by smokers that smoke in their own home will be applied when this form of air pollution is to be considered. While self-declared smoking should be applied where health impacts of smoking are of interest.

The internal humidity of a property can be influenced by ventilation together with actions of occupants to introduce and expel humidity, such as drying clothes cooking and bathing. The methods by which occupants dry their clothes is reproduced in the table below.

	Count	%	95% CI
Outside	268	89.8	86.4 - 93.2
Inside	6	2.2	0.6 - 3.8
Dryer	14	2.7	0.9 - 4.5
Combination including Inside	17	5.4	2.9 - 7.9
Total Count	305		

Table 158: Methods of Drying Clothes in the Summer, including 95% Confidence Intervals

5.2.3 Risks to Health and Comfort in Housing

Having established the pathway and receptor factors for the respondents households, it is now possible to evaluate the distribution of risk to occupant health and comfort identified due to excess heat, noise, pests and vermin, inadequate ventilation and material and structural damage; collectively the summer risk family identified in section 3.3. It will be possible to establish the distribution of these risks (together with a related 95% confidence interval) in the population, housing in NPT. In order to be able to calculate these proportions it will be necessary to apply weighting factors to the sample in order to counteract distribution bias in the sample due to stratified sampling as well as response bias due to the identified higher response rates from retired households. A schedule of the weights applied is reproduced in Appendix K.

First of all, it is possible to describe occupant satisfaction with the environment in their homes during a hot summer, through analysis of the response to a question asked of both male and female occupants, with a Likert-type six point scale response (extremely satisfied through to extremely dissatisfied). Analysis using a collapsed three point scale revealed that 10% of male occupants and 10% of female occupants in the population would be dissatisfied with the internal environment of their homes on a hot summers' day. When a combined statistic was calculated, 89% (+/- 3.5%: 95% CI) of households in NPT would be likely to be satisfied and 11% (+/- 4.0%: 95% CI) would be likely to be dissatisfied with the internal environment of their homes on a hot summers' day.

	Female		**Male**		**Household**	
	%	**95%CI**	**%**	**95%CI**	**%**	**95%CI**
Very Satisfied	**41%**	7%	**40%**	8%	**33%**	6%
Satisifed	**49%**	7%	**50%**	8%	**56%**	6%
Dissatisifed	**10%**	4%	**10%**	5%	**11%**	4%
Sample (n)	**204**		**160**		**240**	

Table 159: Male, Female and Household Level Satisfaction with the Internal Environment of their Homes on a Hot Summer's Day

The age of the properties in which occupants were dissatisfied with their internal environment on a hot summers day were then analysed and a significant difference (chi square = 18.914, df = 8, p<0.05, effect size = 0.243, low) from the population distribution was found. That is to say, homes built during the period 1945 to 1964, followed by properties built post-1980, are more likely to provide unsatisfactory environments under these conditions. This distribution of dissatisfaction and uncomfortable internal environments will now be analysed further in terms of ventilation and stuffiness, pests, air pollution, noise, security, humidity, damp, mould and condensation, material and structure and overheating.

	Pre 1919	**1919-1944**	**1945-1964**	**1965-1980**	**Post 1980**	
Very Satisfied	32 (30.5%)	16 (41.0%)	17 (21.8%)	28 (50.0%)	9 (37.5%)	102 (33.8%)
Satisfied	66 (62.9%)	19 (48.7%)	47 (60.3%)	25 (44.6%)	12 (50.0%)	169 (56.0%)
Dissatisfied	7 (6.7%)	4 (10.3%)	14 (17.9%)	3 (5.4%)	3 (12.5%)	31 (10.3%)
	105	39	78	56	24	302

Table 160: Contingency Table Illustrating the Relationship Between Property Age and Satisfaction with Internal Environment during a Hot Summer

5.2.3.1 Excess Heat

The potential for overheating in the home has been identified as one of the most significant risks for housing and occupants as a result of climate change. As was the case for the risks during the winter, occupant behaviour that may influence the perception of this risk will be considered first. The perception of overheating in the home as a whole and then in relation to four specific rooms in the home will be considered. The potential relationships between this risk and pathway and receptor factors will also be considered where appropriate.

5.2.3.1.1 Behavioural Factors in Overheating

The experience of overheating in homes is closely related to levels of ventilation in the home, considered in section 5.2.3.4, however, actions embraced within the adaptive theory of comfort can also be considered, such as the use of shading as well as moving to a more comfortable location. Respondents to the summer survey were asked to consider the actions they take to make rooms that are perceived to have overheated more comfortable. Their attitudinal responses to the use of curtains to provide shade, as well as the use of outdoor spaces on a hot summer's day, were also considered. Actions taken by occupants of homes that currently experience overheating are also considered.

The use of curtains or blinds to shade homes from potential solar gain is an example of a simple measure of occupant behaviour that can provide a reduction in solar gain. It was found that 44.3% of female respondents and 35.0% of male respondents, equating to 38.9% of households in Neath and Port Talbot (95% CI: 38.9 – 44.5) agree that *'it is best to keep all of the curtains closed on the sunny side of* {their} *homes to keep it cool'.* While, 41.8% of female respondents and 47.5% of male respondents, equating to 42.2% of households in Neath and Port Talbot (95% CI: 36.6 – 47.8) disagree with this statement. Explanations of these distributions were sought through statistical analysis in terms of pathway and receptor factors, however, no significant relationships were found.

The use of external spaces, including gardens and parks, has been cited as a potential adaptation to the changes in climate suggested by current climate change scenarios. It was found that 80.8 % of female respondents and 80.9% of male respondents, equating to 79.3% of households in Neath and Port Talbot (95% CI: 74.7 – 83.9), agreed that on a hot summer's day *'their household often uses the garden and / or visits the park, beach or other open space'.* While, 9.4% of female respondents and 9.3% of male respondents, equating to 9.7% of households in Neath and Port Talbot (95% CI: 6.3 – 13.1), disagreed with this statement.

A 3 x 3 contingency table analysis was conducted to determine whether there was an association between the ease of access to public open space and response to this question. A significant association was present, with chi square = 24.94, df = 4, p<0.001. The effect size of 0.475, indicates a medium size effect. A further low strength significant positive association was found between household access to its own garden and response to this statement (rho = 0.213, df = 284, p<0.001).

	Very close - Just Around the Corner	**A Short Walk Away**	**A Drive / Bus Journey Away**	**Total**
Agree	90.4%	78.7%	61.1%	80.3%
Neither Agree nor Disagree	6.4%	12.1%	8.3%	9.9%
Disagree	3.2%	9.2%	30.6%	9.9%
Total Count	**94**	**174**	**36**	**304**

Table 161: Correlation Between proximity of Public Open Space & Attitudinal Response to the Statement: 'On a hot summer's day: my household often uses the garden and/or visits the park, beach or other open space'

Where occupants of homes experience overheating, respondents were requested to consider what action they currently take to rectify the situation. The table below summarises these actions. It can be seen that opening windows, doors and other forms of passive ventilation were the most frequently cited form of action.

Action	%	95% CI
Open Windows	25.5	20.6 - 30.24
Close Curtains / Blinds	1.8	0.3 - 3.3
Turn on Fan	2.8	0.9 - 4.7
Combination Inc Fan	12.8	9.0 - 16.6
Combination Other	5.4	28 - 8.0
No Action Given	14.4	10.4 - 18.4
N/A	37.4	31.9 - 42.9
Total Count	**287**	

Table 162: Actions in Response to Overheating

5.2.3.1.2 Perceived Overheating

It was found that 84.7% of female respondents and 82.7% of male respondents agreed with the statement that *'on a hot summer's day there is always somewhere inside my home that stays cool'*. This corresponds to 83.8% of households in NPT (95% CI: 79.6 – 88.0). Contingency table analysis determined that a significant relationship exists between housing tenure and response to this question at a household level, with chi square = 24.833, df = 2, p<0.001, effect size = 0.636, medium high. Occupants of rented properties were more likely to disagree with this statement, all of whom were council tenants. Due to the low number of households to disagree with this statement, further statistical analysis of these responses is limited, however, further inspection of these respondents found that they were more likely to occupy homes built between 1945 and 1964 than at any other period of time, 47% of those that disagreed (95% confidence confirmed through analysis of proportional confidence intervals). Further to this, 70% (12 of 17) of these households considered themselves to be 'just about getting by' in terms of household economics and 41% (7 of 17) were generally dissatisfied with the environment that their home provided during a hot summer.

It was found that 8.9% of female respondents and 6.1% of male respondents agreed with the statement that *'on a hot summer's day there is nowhere in my home that remains a comfortable temperature'*. This corresponds to 7.3% of households in NPT (95% CI: 4.3 – 10.3). As would be expected, negative relationships exist between attitudinal responses to these two statements, where for all three groups these are significant associations of a low to medium strength: female respondents (rho = -0.282, df = 232, p<0.001), male respondents, (rho = -0.434 df = 188, p<0.001) and for households in NPT (rho = -0.356, df = 279, p<0.001). A contingency table analysis was undertaken to determine whether there was an association between response to this statement and housing tenure. A significant association was found (chi square = 8.854 df = 2, p<0.05 effect size = 0.402, a medium effect size), whereby occupants of rented properties are more likely to agree with this statement.

A contingency table analysis determined that a significant association exits between self-reported general health at a household level and response to this question, where those with poor health are more likely to agree that on a hot summer's day there is nowhere in their home that remains a comfortable temperature (chi square = 9.690, df = 2, p<0.01, effect size = -0.417). Further to this, an association was found between combined influences on occupant controlled ventilation and this variable, whereby presence of a negative influence on ventilation (as defined in section 5.2.3.4) increases the likelihood of agreement that *'on a hot summer's day there is nowhere in my home that remains a comfortable temperature'* (chi square = 42.211, df = 2, p<0.001, effect size = -0.707).

It was found that 32.1 % of female respondents and 33.5% of male respondents, equating to 31.5% of households in Neath and Port Talbot (95% CI: 26.2 – 36.8), agree that on a hot summer's day *'it is most comfortable outside / in the garden'*. While, 42.1% of female respondents and 35.5% of male respondents, equating to 40.1% of households in Neath and Port Talbot (95% CI: 34.5 – 45.7), disagree with this statement. Significant associations were found to exist between household responses to this statement and attitudes towards internal comfort.

During a hot summer's evening, 33.3% of female respondents and 37.1% of male respondents consider that *'it is often too hot to be comfortable upstairs in their homes'*. This equates to 34.7% of households in NPT (95%CI: 28.6 = 40.8). No relationship was found between the distribution of attitudinal responses to this statement and age of property or construction type, heavy, medium or light weight. A 2 x 3 contingency table analysis was undertaken to ascertain whether an association existed between general health level and attitudinal response to this statement. A medium-low strength significant association was found to exist, with chi square = 9.986, df = 2, p<0.01, effect size = -0.393.

During hot summer weather, the heat at night can have an impact on comfort during sleeping. It was found that 49.8% of female respondents and 47.7% of male respondents, equating to a distribution of 48.1% of NPT households (95% CI: 42.5 – 53.7), agreed that *'on a hot summer's night it is often too hot to allow them to sleep'*. Again, a significant association was found between general health level and response to this statement (chi square = 11.621, df = 2, p<0.01, effect size = -0.315). A non-linear association is present between housing age and the distribution of responses to this statement. For this sample the proportion of households that agreed with the statement, who occupy homes built between 1945 and 1964 was 66.7%, against, 40.7%, 42.9%, 40.6% and 40.2% for other groups of housing by age of construction. This distribution of proportions is not significantly different at the 95% level.

Further to this, an association was found between combined influences on occupant controlled ventilation and this variable, whereby presence of a negative influence on ventilation increases the likelihood of agreement that *'on a hot summer's night it is often too hot to allow sleep'* (chi square = 22.183, df = 2, p<0.001, effect size = 0.465). The prevention of leaving windows open at night due to concerns over security is also significantly associated with this variable (chi square = 12.531, df = 4, p<0.05, effect size = 0.239). However, a contingency analysis did not find a significant association between the opening of windows to increase comfort on a hot summer's night and attitudinal response to this statement *'on a hot summer's night it is often too hot to allow sleep'* (chi square = 3.188, df = 4, p = 0.527 (ns). A very strong association exists between perception of the environment in the home being stuffy and hot on a hot summer's night (chi square = 286.808, df = 4, p<0.001 and effect size = 0.877).

Occupants were also asked to report as to where and when their home is too hot during a hot summer. Questions were designed to request the male and female occupants to separately consider their main bedroom, main living room main bathroom and kitchen. As for the reported stuffiness in these rooms, for all rooms significant associations were determined between male and female responses and therefore household level responses will be considered in the further analysis of these rooms in relation to overheating. Correlation of responses: rho= 0.586, df = 144, p<0.001 for the main bedroom, rho= 0.564, df = 141, p<0.001 for the main living room, rho= 0.452, df = 139, p<0.001 for the main bathroom and rho= 0.403, df = 136, p<0.001 for the kitchen.

The following proportions were found for the distribution of overheating in these rooms for the NPT population. It can be seen that 52% consider their main bedroom overheats at one period of time or more (95%CI: 46.3 – 57.7), 40.6% their main living room (95%CI: 35.0 – 46.2), 42.4% their kitchen (95%CI: 36.7 – 48.1) and 24.6% their main bathroom (95%CI: 19.6 – 29.6). Overall, 59% of households in NPT consider that one of more of these rooms currently overheat during a hot summer's day or night (95%CI: 53.5 – 64.5).

	Day		**Night**		**Both Day &**		**Never**		
	%	**95% CI**	**%**	**95% CI**	**%**	**95% CI**	**%**	**95% CI**	**Total Count**
Main Bedroom	12.7	8.9 - 16.5	29.2	24.0 - 34.4	10.1	6.7 - 13.5	48.0	42.3 - 53.7	**297**
Main Living Room	21.9	17.2 - 26.6	10.2	6.7 - 13.7	8.3	5.1 - 11.5	59.6	54.0 - 65.2	**294**
Kitchen	26.9	21.8 - 32.0	9.7	6.3 - 13.1	5.8	3.1 - 8.5	57.6	51.9 - 63.3	**290**
Main Bathroom	15.4	11.2 - 19.6	5.6	2.9 - 8.3	3.7	1.5 - 5.9	75.4	70.4 - 80.4	**288**

Table 163: Time of Day at Which Respondents Homes are Perceived to be Too Hot: At a Household Level

Following a series of contingency table analyses, no significant relationships were found between overheating in specific rooms and the presence of air vents: for the main bedroom (chi square = 1.647, df = 1, p=ns) and living room (chi square = 0.297, df = 1, p=ns), or extraction fans for the bathroom (chi square = 0.114, df = 1, p=ns) and kitchen (chi square = 7.328, df = 1, p=ns). Analysis to consider the proportions of overheating rooms and their orientation for this sample found fewer incidences of perceived overheating where the kitchen and bathroom were orientated to the north, although this distribution is not significantly different at the 95% level.

A series of contingency table analyses were then undertaken to determine whether associations were present between a number of social risk and housing factors and presence of one or more rooms perceived by housing occupants to overheat during a hot summer. The following table summarises the associations found:

Factor		Meaning for NPT Housing / Occupants
Housing Age	Chi square = 6.997, df = 2, p<0.05 effect size = 0.288	Housing built post-1980 is least likely to experience rooms that overheat during a hot summer.

	Pre1980	Post 1980	Total
No Rooms Overheat	83 (34.6%)	31 (52.5%)	**114 (38.1%)**
1 Room Overheats	48 (20.0%)	9 (15.3%)	**57 (19.1%)**
Two or More Rooms Overheat	109 (45.4%)	19 (32.2%)	**128 (42.8%)**
	240	**59**	**299**

Table 164: Distribution of Number of Rooms Considered by their Occupants to Overheat Compared to Housing Age During the Summer

Age of Occupant	Chi square = 2.788, df = 2, p<0.01 effect size = 0.459	Older occupants are less likely to perceive rooms in their home to be too hot.
Occupant Health	Chi square = 10.899, df = 2, p<0.01 effect size = 0.388	Presence of occupants with poor health is associated with increased perception of rooms that overheat in a home.
Household Financial Status	Chi square = 9.991, df = 4, p<0.05 effect size = 0.250	Households with low self-declared financial status are more likely to have considered rooms to overheat in their home.
Combined Measure of Influence on Ventilation (see section 5.2.3.4)	Chi square = 6.239, df = 2, p<0.05 effect size = 0.244	Increased presence of influence on ventilation, such as pollution and noise is associated with perception of rooms that overheat.
Combined Measure of Insulation	Chi square = 0.345, df = 2, p=0.862 (n.s.)	N/A

Factor		Meaning for NPT Housing / Occupants
Condensation	Chi square = 0.616, df = 2, p=0.735 (n.s.)	N/A
Damp	Chi square = 2.036, df = 2, p=0.361 (n.s.)	
Mould	Chi square = 1.676, df = 2, p=0.433 (n.s.)	
Perception of Overall Discomfort	Chi square = 18.372, df = 4, p<0.001, effect size = -0.468	*A test with overall consideration of those that consider there to be nowhere in their home that remains a comfortable temperature.*
Presence of Rooms that Always Stay Cool	Chi square = 13.926, df = 4, p<0.01, effect size = 0.359	*A test with overall consideration of rooms that always remain cool.*
Satisfaction with Home Environment in the Summer	Chi square = 26.319, df = 4, p<0.001, effect size = -.392	Where there is a presence of rooms that are considered to overheat during a hot summer, housing occupants are more likely to be dissatisfied with the home. The distribution of which is described in the table below.

		V Satisfied	Satisfied	Dissatisfied	
Where the Property is Perceived to Overheat	**No Rooms**	52 (48.1%)	59 (37.1%)	4 (12.5%)	**115 (38.5%)**
	1 Room	25 (23.1%)	24 (15.1%)	7 (21.9%)	**56 (18.7%)**
	More than One Room	31 (28.7%)	76 (47.8%)	21 (65.6%)	**128 (42.8%)**
	Total Count	**108**	**159**	**32**	**299**

Table 165: Distribution of Number of Rooms Considered by their Occupants to Overheat Compared to Housing Satisfaction During the Summer

Having been asked to consider their current behaviour in relation to overheating in their home, the respondents were asked to consider the passive and active methods to promote a cooler internal environment. For a passive method the use of shutters was proffered and air conditioning was considered as an active methods.

It was found that 19.8% of female respondents and 19.4% of male respondents, equating to 21.2% of households in Neath and Port Talbot (95% CI: 16.6 – 25.8), agreed that on a hot summer's day *'shutters on the windows of my home would help to keep it more comfortable'*. While, 46.1% of female respondents and 43.5% of male respondents, equating to 45.4% of households in Neath and Port Talbot (95% CI: 6.3 – 13.1), disagreed with this statement.

Regarding air conditioning, 27.5% of female respondents and 32.3% of male respondents agreed that they would like to have air conditioning to keep their home a comfortable temperature on a hot summer's day. This is equivalent to 32.1% of households in Neath and Port Talbot (95% CI: 26.8 – 37.4). While 52.0% of female and 44.0% of male respondents did not want to have air conditioning in their homes, equating to 50.4% of households (95% CI: 44.7 – 56.1). Significant associations were found between male, female and household level responses to this statement and the presence of overheating in homes.

	Number of Rooms Overheating (Maximum Considered = 4)			
	3-4 Rooms	**1-2 Rooms**	**No Rooms**	**Total**
Agree	50.5%	33.3%	16.7%	32.4%
Neither Agree nor Disagree	18.3%	15.2%	18.4%	17.3%
Disagree	31.2%	51.5%	64.9%	50.3%
Total Count	**93**	**99**	**114**	**306**

Table 166: Correlation at Household Level Between Number of Rooms Overheating & Response to the Statement: 'I would like to have air conditioning to keep my home a comfortable temperature'

A further question within the summer survey asked for attitudinal responses to the statement, *'air conditioning would be a waste of energy in the UK'*, to which, 38.1% of female respondents and 36.4% of male respondents replied that they agreed with this assertion, equating to 37.8% households in NPT (95% CI: 32.4 – 43.2). Contingency table analyses were undertaken which determines a significant negative associations between respondents' attitudes to these two statements, for female respondents (chi square = 76.386, df = 4, p<0.001, effect size = -0.612, medium high), male (chi square = 59.159, df = 4, p<0.001, effect size = -0.540, medium) and household (chi square = 89.565, df = 4, p<0.001, effect size = -0.569, medium) level responses. It should be noted that 5% of respondents agreed with both statements suggesting that they would like air conditioning, but that thought it a waste of energy in the UK.

5.2.3.2 Noise

In section 3.2.2 it was suggested that the use of ventilation through opening windows may be limited as a result of noise from external sources as well as through a householder's preference for privacy. Through this survey it was found that 9% (95% CI: 5.4 – 12.6) of female occupants, 13% (95% CI: 8.4 – 17.6) of male occupants, equating to 12% (95% CI: 8.3 – 15.7) of households, do not open their windows on a hot summers' day due to the noise outside. A significant, positive and strong correlation was found between male and female responses to this question (r = 0.767, df = 144, p<0.001). Further significant associations were found between household level opening of windows, in relation to noise, and:

- the reporting of noise as a problem in the neighbourhood, where a positive association was found (table size: 3 x 3, chi square = 37.803, df = 4, $p<0.001$, effect size = 0.592, medium high).
- location, either rural or urban, where urban locations were found to be more bothered by noise (table size: 3 x 2, chi square = 10.172, df = 2, $p<0.01$, effect size = 0.330, medium low).
- proximity to roads, where busy or dual carriageways either about or closer that one mile to the home would increase the likelihood that households would keep their windows closed (table size: 3 x 2, chi square = 7.892, df = 2, $p<0.05$, effect size = 0.390, medium low).
- house type, where occupants of detached and semi-detached properties were less likely to be affected than those occupying flats, maisonettes or terraced properties (table size: 3 x 2, chi square = 22.694, df = 2, $p<0.001$, effect size = 0.537, medium).

In relation to occupant privacy, 7% (95% CI: 3.8 – 10.2) of female occupants, 4% (95% CI: 1.3 – 6.7) of male occupants, equating to 6% (95% CI: 3.3 – 8.7) of households in NPT do not open their windows on a hot summers day, although they would like to, because they prefer privacy. An association between this distribution and house types was found to be statistically significant following a contingency table analysis (table size: 3 x 2, chi square = 8.174, df = 2, $p<0.05$, effect size = 0.353, low). Again occupants of semi-detached and detached properties were less likely to be troubled by this than those occupying flats, maisonettes or terraced properties.

5.2.3.3 Pests & Vermin

It was found that 45% of respondents' households considered that flying insects bother them in the summer in their home, which, following appropriate weighting of the sample, provides a distribution in the NPT population of 49% (95%CI: 43.3 – 54.7). The presence of many flying insects, such as gnats and mosquitoes, is more likely in moist, damp conditions and therefore proximity to water is likely to be linked. A 3 x 2 contingency table analysis was therefore undertaken in order to explore whether there was an association between presence of static or running water, including water butts, garden ponds (with or without running water), streams, rivers, lakes and ponds and the presence of the problem of flying insects. A significant relationship was present (chi square = 4.078, df = 1, $p<0.05$), although the effect was relatively low, 0.235.

			No Water	Running Water	Static Water	Total
Are Flying insects a Problem?	**Yes**	%	43.6%	54.2%	59.1%	**49.2%**
	No	%	56.4%	45.8%	40.9%	**50.8%**
	Total	**Count**	**172**	**59**	**66**	**297**

Table 167: Association between Perceived Problem of Flying Insects and Presence of Bodies of Water

The survey also asked respondents to consider when they were bothered by flying insects in their homes. The categorised responses to this question are reproduced below.

	Frequency	%	95% CI
Afternoon	3	2.2%	2.5%
Evening / Night	20	14.8%	6.0%
All Day	43	31.9%	7.9%
All Day & Night	15	10.4%	5.1%
Hot Weather	51	37.0%	8.1%
Rarely	5	3.7%	3.2%
Total	**135**		

Table 168: Responses to Question – 'When are Flying Insects a Problem in your Home?'

The presence and concern over flying insects in the home can also influence the opening of windows which can in turn have a detrimental impact on internal health and comfort. It was found that 22% of female occupants (95%CI: 16.8–27.2), 23% of male occupants (95%CI: 17.2 – 28.8) and 21% of households (95%CI: 16.4 - 25.6) in NPT agree that on a hot summers day they do not open windows in order to keep flying insects out of their homes. Following a 2 x 3 contingency table analysis a statistically significant association (chi square = 18.831, df = 2, $p<0.01$) was found between flying insects bothering the occupants and their refraining from using windows in order to keep insects out of the house on a hot summer's day. An effect size of 0.421 suggests a medium effect.

5.2.3.4 Inadequate Ventilation

The ventilation systems available to occupants were explored previously in section 5.2.1.4., where the distribution of air vents and extractor fans for the sample was identified. It is now necessary to investigate the interaction of occupants with their environment, together with their opinions on the environment that their home provides to them in terms of ventilation. Firstly this section will look at occupant interaction with the ventilation systems available to them in their home, including air vents, mechanical extraction and windows, finally the distribution of condensation damp and mould will be described. General interaction throughout a hot summer period, during a hot summer's day and a hot summer's night will now be considered. The environment provided by their homes in general, as well as in specific rooms during a hot summers day, evening and night will then be considered. Finally, analysis will be undertaken to identify those interactions with the environment as well as those pathway factors that may interact to produce stuffy internal home environments during a hot summer.

5.2.3.4.1 Behavioural Factors in Ventilation

The relationship between security risks and ventilation through the opening of windows may also influence the ventilation strategy employed in homes. It was found that 22% (95% CI: 16.8 – 27.2) of female occupants, 20% (95% CI: 14.5 – 25.5) of male occupants, equating to 22% (95% CI: 17.3 – 26.7) of households, *"do not open their windows on a hot summers day, although they would like to, due to the security risks".* A 3 x 3 contingency table analysis was conducted to determine whether there was an association between household perception of crime, burglary and theft in the neighbourhood and household window usage in relation to security. A positive significant relationship was present, with chi square = 17.585, df = 4, p=0.01, where higher level of perceived crime in the neighbourhood was found to be associated with windows being kept closed for security reasons on a hot summers day. The effect size of 0.333 indicates a low effect.

	Female	Male	Household
Agree	22.0%	19.8%	21.5%
Neither Agree no Disagree	13.8%	16.5%	15.9%
Disagree	64.2%	63.7%	62.7%
Total Count	**242**	**199**	**297**

Table 169: Total Distribution of Responses to: 'On a Hot Summer's Day: I Would Like to Open My Windows Downstairs but I Don't Because of Security Risks'

This relationship is strengthened at night, where 33% (95% CI: 27.1 – 38.9) of female occupants, 30% (95% CI: 23.6 – 36.4) of male occupants, equating to 32% (95% CI: 26.7 – 27.3) of households, do not open their windows on a hot summers night, although they would like to, due to the security risks. A similar contingency table analysis (described previously for window usage in relation to crime in the day) was carried out for window usage at night. However, no statistically significant relationship was found to be present for window usage at night, chi square = 3.405, df = 4, p=0.493. Night time security considerations in relation to window ventilation, was not associated with perceptions of neighbourhood crime.

	Female	Male	Household
Agree	32.5%	30.3%	31.5%
Neither Agree no Disagree	15.0%	13.9%	14.6%
Disagree	52.5%	55.9%	53.9%
Total Count	**240**	**200**	**297**

Table 170: Total Distribution of Responses to: 'On a Hot Summer's Night: I Would Like to Leave My Windows Open but I Don't Because of Security Risks'

The household's perception of exposure to air pollution may also influence their use of open windows to affect ventilation. It was found that 10% of female occupants (95%CI: 6.3 – 13.7), 13% of male occupants (95%CI: 8.6 – 17.4) and 10% of households (95%CI: 6.6 – 13.4) agree that *"on a hot summers day they would like to open their windows but do not because of air pollution"*. Following a series of contingency table analyses, statistically significant associations were found between perceived exposure to air pollution (as defined in section 5.2.1.9) and refraining from using windows in order to keep pollution from the house on a hot summer's day, for female occupants roads (table: 2 x 2, chi square = 11.099, df = 2, p<0.01, effect size = 0.446, medium), male occupants roads (table: 2 x 2, chi square = 17.637, df = 2, p<0.001, effect size = 0.531, medium) and at a household level roads (table: 3 x 2, chi square = 39.005, df = 4, p<0.001, effect size = 0.499, medium).

There is also a relatively strong significant association between a combined measure of proximity of sources of air pollution and household use of windows to prevent the ingress of air pollution (table: 3 x 3, chi square = 39.005, df = 4, p<0.001, effect size = 0.0499, medium). However, contingency table analysis did not reveal significant associations between male, female or household measures of use of windows in relation to air pollution and the proximity of individual potential sources of air pollution, roads, heavy and light industry. This may be due to the apparent non-linear relationships that can be seen in the cross-tabulations, an example of which is reproduced below. It can however, be seen that where heavy industry is located very close to a home, less than a mile away, 26% (95% CI: 20.7 – 31.3) of male respondents agreed that they refrained from opening the windows due to pollution, this contrast with just 9% (95% CI: 5.5 – 12.5) where heavy industry was greater than a mile away.

		Location of Heavy Industry			
	On a Hot Summer's Day:	**> one mile away**	**Quite Close (c. mile)**	**Very Close**	**Total**
I Would Like to Open My Windows but I Don't Because of the Air Pollution.	**Agree**	19 (8.7%)	1 (5.6%)	7 (25.9%)	**27 (10.2%)**
	Neither Agree nor Disagree	32 (14.6%)		8 (29.6%)	**40 (15.2%)**
	Disagree	168 (76.7%)	17 (94.4%)	12 (44.4%)	**197 (74.6%)**
	Total	**219**	**18**	**27**	**264**

Table 171: Contingency Analysis Table Showing Correlation Between Male Responses to 'Opening window in the Presence of air Pollution' and Proximity of Heavy Industry

Where occupants had reported that there were air vents in their living room and main bedroom, only three cases had blocked those in the living room and one in the bedroom. The reasons given were *'permanently blocked to prevent heat loss in the winter time'* and *'to reduce noise levels'*. All three of these properties were built prior to 1944, and the property that cited noise as the reason, considered road traffic noise to be a fairly big problem. No further analysis is possible of this data due to the small sub-sample.

The presence of kitchen and bathroom extract fans has already been considered. It is now appropriate to consider occupant use of these extracts as well as opening windows in their lieu. A significant association was found between male and female use of the kitchen extract (or window) for ventilation when cooking (r = 0.529, df = 248, p<0.001), where 46.9% (95% CI: 40 – 53.8) of female occupants and 55.6% (95% CI: 49.4 – 61.8) of male occupants always use a form of ventilation when cooking. Further to this, contingency table analyses determined that a positive association exists between presence of kitchen extraction and use of ventilation when cooking for both male (table size, 2 x 4, chi square = 36.993, df = 3, p<0.001, effect size – 0.573, medium high) and female occupants (table size, 2 x 4, chi square = 23.705, df = 3, p<0.001, effect size – 0.472, medium).

In relation to bathroom extraction, a further significant association was found between male and female use of the bathroom extractors or windows for ventilation (r=0.517, df=157, p<0.001), where 45.6% (95% CI:39.5 – 51.7) of female occupants and 44.7% (95% CI: 37.9 – 51.5) of male occupants always use a form of ventilation when in the bathroom. Further to this, contingency table analyses determined that no association exists between presence of bathroom extraction and use of ventilation when bathing for either male or female occupants. In order to enable analysis of the impacts of these occupant interactions with the internal environment, a combined household level measure of extract and / or window usage, when cooking and when bathing, was also created for all households. This is reproduced in the table below:

	Kitchen Extract			Bathroom Extract		
	Count	**%**	**95% CI**	**Count**	**%**	**95% CI**
Every Time	134	45.7%	40 - 51.4%	113	38.6%	33 - 44.1%
Sometimes	138	47.1%	41.4 - 52.8%	152	51.9%	45.2 - 57.6%
Never	21	7.2%	4.2 - 10.1%	28	9.6%	6.2 - 12.9%
Total Count	**293**			**293**		

Table 172: Combined Household Measure of Ventilation Usage in the Kitchen and Bathroom

Having considered the occupant behaviour with respect to air vents and extraction in the bathroom and kitchen, it is now appropriate to consider general attitudes to ventilation in relation to occupants' homes. As has been identified in sections 5.1.5.1 to 5.1.4.4 associations exist between external factors, including pests, air pollution, noise and security, as well as the household internal factor of privacy on the use of ventilation. A combined measure was created, through the application of an additive method, to represent the impact of those factors that have been identified to influence ventilation in households. The distribution of this new factor is illustrated below.

	Female		Male		Household	
	Count	**%**	**Count**	**%**	**Count**	**%**
None	147	57.1%	126	56.3%	192	59.9%
1 or 2	55	38.1%	48	36.0%	57	33.6%
3 or More	33	4.9%	19	7.7%	36	6.4%
	248		**205**		**303**	

Table 173: Combined Factor to Represent External and Behavioural Influences on Daytime Ventilation Usage
(Including, the influence of pests, air pollution, noise, privacy and security)

In relation to general ventilation levels in respondents' households, 91.9% of females (95% CI: 87.9 – 94.9) and 88.7% of males (95% CI: 84.7 – 93.3), equating to 91.4% of households (95% CI: 88.3 – 94.7), agreed that they always open windows to encourage air flow or ventilation on a hot summers day. While, 3.9% females (95% CI: 1.5 – 6.3) and 3.9% of males (95% CI: 1.1 – 6.7), equating to 3.3% of households (95% CI: 1.2 – 5.4), disagreed. There is a weak yet significant relationship between combined household response to this statement and the combined factor of influences on ventilation usage for households (rho = 0.160, df = 303, $p<0.01$). Analysis of these results through visual inspection of a cross tabulation suggests that those households exposed to one or more external factors influential on ventilation behaviour were more likely to disagree with this statement.

Further to this, 77.8% of females (95% CI: 70.6 – 81.2) and 75.7% of males (95% CI: 69.8 – 81.6), equating to 74.0% of households (95% CI: 69.1 – 78.9), agreed that the more ventilation or air flow, the more comfortable their home is on a hot summer's day. While 9.7% females (95% CI: 6.0 – 13.4) and 11.0% of males (95% CI: 6.7 – 15.3), equating to 8.5% of households (95% CI: 5.4 – 11.6), disagreed. No significant relationships were found to be present between either male, female or household responses to this statement and the combined factor of influences on ventilation usage for households. No statistical explanation for this distribution was found.

A further question relating to overall measures of attitudinal and behavioural influences on ventilation 5.7% of female respondents (95% CI: 2.3 – 7.7) and 3.5% of male respondents (95%

CI: 2.2 – 8.4), equating to 5.0% of households (95% CI: 2.5 – 7.5), agreed that they never open their downstairs windows. Weak yet significant positive relationships exist between combined household response to this statement and the combined factor of influences on ventilation usage for female respondents (rho = 0.289, df = 236, p<0.001), male respondents (rho = 0.238, df = 191, p<0.001) and at a household level (rho = 0.248, df = 285, p<0.001). Analysis of this results through visual inspection of a cross tabulation suggests that those households exposed to one or more external factors influential on ventilation behaviour were more likely to agree with this statement.

Having considered both overarching behaviour and that specific to the daytime behaviour it is also important to consider occupant behaviour at night, when leaving windows open will encourage both ventilation and night purging of the home. It was found that 67.1% of females (95% CI: 61.2 – 73.0) and 64.5% of males (95% CI: 57.9 – 71.1), equating to 60.4% of households (95% CI: 60.4 – 71.2), agreed that they usually leave the windows open on a hot summers night as it helps to make their home more comfortable. While, 24.0% females (95% CI: 18.7 – 29.3) and 19.1% of males (95% CI: 13.7 – 24.5), equating to 21.8% of households (95% CI: 17.1 – 26.5), disagreed.

Contingency table analyses were carried out to determine whether relationships existed between responses to this statement and concern for leaving windows open at night (I would like to leave windows open at night but I don't because of security risks'). A significant relationship was found for female occupants (table = 3 x 2, chi square, 67.639, df = 4, p<0.001, effect size = -0.702, high), male occupants (table = 3 x 2, chi square, 31.407, df = 4, p<0.001, effect size = -0.534, medium) and at a household level (table = 3 x 2, chi square, 62.442, df = 4, p<0.001, effect size = -0.638, medium high). Analysis of these results through visual inspection of cross tabulation suggests that where occupants expressed concern for leaving windows open at night for security reasons, they are statistically less likely to do so. Where stuffiness was present in a home, respondents were requested to consider what action they would take to rectify the situation. The following table summarises these actions. It can be seen that opening windows, doors and other forms of passive ventilation were the most frequently cited of actions.

	%	95% CI
Open Windows	23.8	19.0 - 28.6
Use Fan	3.5	1.4 - 5.6
Open Windows & Use Fan	6.8	4.0 - 9.6
No Action Given	18.7	14.3 - 23.1
None of the Rooms Considered Overheat	47.3	41.7 - 52.9
Total Count	**307**	

Table 174: Actions in the Presence of Stuffiness

5.2.3.4.2 Perceived Ventilation Deficiencies

Six respondent households reported problems with the ventilation in their homes, equating to a distribution of 3.2% of the homes in NPT (95% CI: 0.4 – 3.6). However, in relation to stuffiness in the home during the daytime and at night this distribution is found to be much more widespread. It was found that 15.8% of female occupants (95% CI: 11.2 – 20.4) and 20.7% of males (95% CI: 15.1 - 26.3), equating to 16.5% of households in NPT (95% CI: 12.3 – 20.7), agreed that *'it often gets stuffy in their home on a hot summer's day'.* While, 68.0% females (95% CI: 62.2 – 73.8) and 63.9% of males (95% CI: 56.2 – 69.6), equating to 66.9% of households in NPT (95% CI: 61.6 – 72.2), disagreed. Although the female responses to this statement appear to differ from that of male respondents, where on visual inspection males seem more likely to agree that their home is often stuffy, a goodness of fit chi square test found no statistical difference between the observed male and female responses, with chi square = 2.718, df = 2, p=0.257.

Statistical tests for association between household level response to this statement and previously considered behavioural factors were than undertaken. A significant relationship was found between agreement with the statement *'it often gets stuffy in my home'* and never opening downstairs windows (rho = 0.175, df = 297, p=0.01). A 2 x 3 contingency table analysis also identified a significant association between the combined measure of external influences on ventilation behaviour and internal stuffiness, with chi square = 10.055, df = 2, p<0.001. An effect size of 0.338 indicates a low effect. A further significant negative association was found between stuffiness and response to the statement that *'I always open some windows to encourage ventilation'* (rho = -0.136, df = 299, p<0.05). No significant relationship was found between household responses to the over-riding statement that *'the more ventilation the more comfortable my home is on a hot day',* and the experience of stuffiness (rho = 0.105, 300, p=0.068).A contingency table analysis was then undertaken to determine whether a relationship existed between the age of property and perceived stuffiness. The relationship was found to be non-linear (linear by linear association = 0.120, df = 1, p=0.729).

	Pre 1919	**1919-1944**	**1945-1964**	**1965-1980**	**Post1980**	**Total**
Agree	11 (10.5%)	7 (18.4%)	22 (27.5%)	8 (14.3%)	3 (12.5%)	**51 (16.8%)**
Neither Agree nor Disagree	11 (10.5%)	9 (23.7%)	15 (18.8%)	12 (21.4%)	3 (12.5%)	**50 (16.5%)**
Disagree	83 (79.0%)	22 (57.9%)	43 (53.8%)	36 (64.3%)	18 (75.0%)	**202 (66.7%)**
Total Count	**105**	**38**	**80**	**56**	**24**	**303**

Table 175: Household Level Perception of Stuffiness Compared Against Age of Property

It can be seen that for this sample, householders occupying homes built between 1945 and 1964 are most likely to agree that their homes are stuffy during a hot summer's day. On inspection, this was found to be a non-significant difference, due to the small sample. For this sample, it also appears that occupants of pre-1919 and post-1980 households are most likely to disagree with this statement. With both proportions differing significantly from responses from occupants of homes built between 1919 and 1964, however, these differences are again non-significant.

Further analysis can be undertaken to consider the distribution of stuffiness in homes on a hot summer's night. Analysis of the distributions of responses to the statement, *'it is often too stuffy on a hot summer's night to allow me to sleep well',* found that 51.0% of females (95% CI: 44.7 – 57.3) and 43.3% of males (95% CI: 36.4 – 50.2), equating to 46.1% of households in NPT (95% CI: 40.5 – 51.7), agreed. While, 29.5% females (95% CI: 23.8 – 33.2) and 35.0% of males (95%

CI: 28.4 – 41.6), equating to 29.1% of households (95% CI: 24.0 – 34.2), disagreed. A significant association was found between male and female responses with chi square = 60.648, df = 4, p<0.001, effect size = 0.623, medium high. Response to this statement was found to be significantly associated with concern over security and not leaving windows open, with chi square = 21.621, df = 4, p<0.001, effect size = 0.376, medium low. This association indicates that one factor that may impact on stuffiness at night is concern over security which discourages the night-time opening of windows. A 2 x 3 contingency table analysis was undertaken to consider whether a relationship was present between age of occupant, using pensioner households as a proxy measure and household response to this statement. A further significant relationship was found, with chi square = 13.769, df = 2, p<0.01. An effect size of 0.307 indicates a high effect, where pensioner's householders are more likely to agree with this statement.

As was the case with the overall consideration of stuffiness in the home, it is appropriate to determine whether an association exists between response to this statement and age of property occupied. A 2 x 3 contingency table analysis was again undertaken that identified a non-linear association, linear by linear association = 0.398, df = 1, p = 0.528. It was found that for this sample householders occupying homes built between 1945 and 1964 are most likely to agree that their homes are too stuffy during a hot summer's night. Again through application of 95% CI to these proportions, this difference is not significant at the 95% level.

Occupants were also asked to report as to where and when their home is stuffy during a hot summer. Questions were designed to request the male and female occupants to separately consider their main bedroom, main living room, main bathroom and kitchen. For all rooms significant associations were determined between male and female responses and therefore household level responses will be considered in the further analyses of these rooms in relation to stuffiness. The responses were: rho= 0.577, df = 138, p<0.001 for the main bedroom, rho= 0.606, df = 138, p<0.001 for the main living room, rho= 0.475, df = 136, p<0.001 for the main bathroom and rho= 0.418, df = 134, p<0.001 for the kitchen.

The following proportions were found for the distribution of stuffiness in these rooms for the NPT population. It can be seen that 44.4% consider their main bedroom to be stuffy at one period of time or more (95%CI: 38.7 – 50.1), 30.1% their main living room (95%CI: 24.8 – 35.4), 29.6% their kitchen (95%CI: 24.3 – 34.9) and 18.6% their main bathroom (95%CI: 14.1 – 23.4). Overall 54% of households in NPT consider that one of more of these rooms are currently stuffy during a hot summer's day or night (95%CI: 48.8 – 60.0).

	Day		Night		Both Day & Night		Never		Total
	%	95% CI	%	95% CI	%	95% CI	%	95% CI	Count
Main Bedroom	7.7	4.6 - 10.8	25.6	20.6 - 30.6	11.1	7.5 - 14.7	55.6	49.9 - 61.3	**292**
Main Living Room	17.4	13.0 - 21.8	4.5	2.1 - 6.9	8.7	5.4 - 12.0	69.9	64.6 - 75.2	**287**
Kitchen	17.8	13.4 - 22.2	7.1	4.1 - 10.1	4.8	2.3 - 7.3	70.4	65.1 - 75.7	**284**
Main Bathroom	8.9	5.6 - 12.2	5.2	2.6 - 7.8	4.6	2.2 - 7.0	81.4	76.9 - 85.9	**283**

Table 176: Time of Day at Which Respondents Homes are Perceived to be Stuffy: At a Household Level

The following actions were taken by occupants to alleviate stuffiness in these rooms. The samples for these proportions were low and therefore the 95% CI for each are relatively wide. Care should therefore be taken when applying these to the NPT population.

	Ventilate		Use Fan		Venitlate & Use Fan		Nothing		Total
	%	95% CI	%	95% CI	%	95% CI	%	95% CI	Count
Main Bedroom	72.0	62.0 - 82.0	10.5	3.7 - 17.3	17.6	9.1 - 26.1	0.0	-	**78 (124)**
Main Living Room	72.1	60.4 - 83.8	11.4	3.1 - 19.7	14.4	5.2 - 23.6	2.0	0 - 5.7	**56 (83)**
Kitchen	83.1	72.3 - 93.9	5.2	0 - 11.6	11.7	2.4 - 21.0	0.0	-	**46 (81)**
Main Bathroom	97.9	91.5 - 100	2.1	0 - 8.5	0.0	-	0.0	-	**19 (49)**

Table 177: Action by Respondents When Homes are Perceived to be Stuffy: At a Household Level
(Total count: figures outside brackets correspond to number of responses, bracketed figures correspond to number of rooms considered to be stuffy)

Following a series of contingency table analyses, no significant relationships were found between stuffiness in specific rooms and the presence of air vents, for the main bedroom (chi square = 2.401, df = 1, p=ns) and living room (chi square = 3.045, df = 1, p=ns) or extraction fans for the bathroom (chi square = 0.939, df = 1, p=ns) and kitchen (chi square = 0.110, df = 1, p=ns). Analysis to consider the proportions of stuffy rooms in relation to orientation did not find significant associations, although for this sample bedrooms with a southerly or westerly orientation were more likely to be perceived to be stuffy than those orientated to the east or north.

The summer survey requested that the respondents report the presence of condensation in their main bedroom, main living room, main bathroom and kitchen. It was found that 42.3% of homes in NPT have no condensation in any of these rooms (95%CI: 36.4 – 48.2), while the remaining 47.6% (95%CI: 41.6 – 53.6) report condensation in one of more of these four rooms. The frequency of condensation experienced in the four main rooms considered herein, as experienced in homes in NPT, is illustrated in the table below.

	Always		Sometimes		Never		
	%	95% CI	%	95% CI	%	95% CI	Total Count
Main Bedroom	2.0	0.3 - 3.7	24.0	18.9 - 29.1	74.0	68.8 - 79.2	**273**
Main Living Room	0.8	0 - 1.9	12.4	8.5 - 16.3	86.8	82.8 - 90.8	**270**
Kitchen	4.3	1.9 - 6.7	36.0	30.3 - 41.7	59.6	53.7 - 65.5	**270**
Main Bathroom	8.0	4.8 - 11.2	39.2	33.4 - 45.0	51.8	45.9 - 57.7	**273**

Table 178: Condensation as Experienced in Four Rooms in Homes in NPT

No significant associations were found between presence of condensation and double glazing in the properties, nor were there statistically significant associations between the presence of condensation and stuffiness, overcrowding, housing age, the drying of clothes inside, nor any measure of occupant behavioural influence on ventilation. Further to this, no statistical associations between housing factors, such as presence of air vents or extractor fans, were found to explain the distribution of condensation in the home. Actions taken to remedy condensation include ventilation, wiping or cleaning, opening windows to increase ventilation, the installation of de-humidifiers as well as no action.

Goodness of fit chi square tests were undertaken to consider whether the distribution in proportions for presence of condensation in homes in winter differs from that found in summer.

A statistically significant difference was observed, where condensation is more prevalent in the winter, between condensation presence in the main bedrooms, main living rooms and kitchens for the NPT housing population: for the main bedroom (chi square = 32.388, df = 1, $p<0.001$), for the main living room (chi square = 10.095, df = 1, $p=0.001$) and for the kitchen (chi square = 8.714, df = 1, $p<0.01$), while for the bathroom the difference between the distributions between summer and winter was not significant (chi square = 1.074, df = 1, $p = 0.300$).

The summer survey also requested that the respondents report the presence of damp and or mould in their main bedroom, main living room, main bathroom and kitchen. It was found that 87.2 % of homes in NPT have no damp in any of these rooms (95%CI: 82.9 – 91.5), while the remaining 12.8% (95%CI: 8.5 – 17.1) reported damp in one of more of these four rooms. The frequency of damp experienced in the four main rooms considered herein, as experienced in homes in NPT, is illustrated in the table below.

	Always		**Sometimes**		**Never**		
	%	**95% CI**	**%**	**95% CI**	**%**	**95% CI**	**Total Count**
Main Bedroom	1.1	0 - 2.5	6.1	3.0 - 9.2	92.8	89.4 - 96.2	**227**
Main Living Room	0.6	0 - 1.6	8.2	4.6 - 11.8	91.1	87.4 - 94.8	**222**
Kitchen	1.2	0 - 2.6	6.1	3.0 - 9.2	92.7	89.3 - 96.1	**224**
Main Bathroom	1.7	0 - 3.4	7.8	4.3 - 11.3	90.5	86.7 - 94.3	**224**

Table 179: Damp as Experienced in Four Main Rooms in Homes in NPT

The low numbers of households that indicated the presence of damp in their homes prevent further statistical analysis of these results at the room scale. Although a significant association was determined between the absence of bathroom extract and the presence of mould (rho = 0.166, df = 212, $p<0.05$). A household level measure was created to indicate the presence of one or more rooms with damp, in order to enable further analysis of this data. It was found that significant associations existed between this measure and financial status (chi square = 12.530, df = 2, $p<0.05$, effect size – 0.623, medium high), where 22 of the 29 households that experience damp considered themselves to be 'just about getting by', as well as with age of property (chi square = 9.826, df = 4, $p<0.05$, effect size – 0.273, low), where 17 of the 29 properties were built prior to 1919 and 6 of the 29 properties were built between 1965 and 1980.

It was found that 73.9 % of homes in NPT have no mould growth in any of these rooms (95%CI: 68.3 – 79.5), while the remaining 26.1% (95%CI: 20.51 – 31.7) reported mould growth in one of more of these four rooms. The frequency of mould growth experienced in the four main rooms considered herein, as experienced in homes in NPT, is illustrated in the table below.

	Always		**Sometimes**		**Never**		
	%	**95% CI**	**%**	**95% CI**	**%**	**95% CI**	**Total Count**
Main Bedroom	1.7	0 - 3.4	9.0	5.3 - 12.7	88.8	84.7 - 92.9	**229**
Main Living Room	0.3	0 - 1.0	7.3	3.9 - 10.7	92.4	88.9 - 95.9	**223**
Kitchen	1.6	0.0 - 3.3	5.3	2.3 - 8.3	93.1	89.8 - 96.4	**221**
Main Bathroom	1.9	0.1 - 3.7	15.3	10.6 - 20.0	82.8	77.9 - 87.7	**228**

Table 180: Mould Growth as Experienced in Four Main Rooms in Homes in NPT

Relatively strong and significant statistical relationships have been found between the distribution of damp and mould in the respondents homes: for the bedroom (rho = 0.680, df = 210, $p<0.001$), for the living room (rho = 0.620, df = 211, $p<0.001$), for the kitchen (rho = 0.552, df = 209, p<0.001) and for the bathroom (rho = 0.533, df = 210, p<0.001). No statistical associations between housing and behavioural factors were found to explain the distribution of mould in these homes at the individual room level. A household level measure was therefore created to indicate the presence of one or more rooms with mould, in order to enable further analysis of this data. Significant associations were found between this measure and: financial status (chi square = 9.838, df = 2, p<0.01, effect size – 0.367, medium low), where 39 of the 61 households that experience mould growth considered themselves to be 'just about getting by' as well as with age of property (chi square = 17.354, df = 4, p<0.01, effect size – 0.305, low), where 33 of the 61 properties experiencing mould growth were built prior to 1919.

Actions taken to remedy damp and mould growth include wiping or cleaning it (such as with anti-fungal treatment), ventilation, location of source with associated appropriate remedial works and reporting its presence to a landlord.

Goodness of fit chi square tests were undertaken to consider whether the distribution in proportions for presence of damp and mould in homes in winter differs from that found in summer. The distribution was not found to differ significantly from that found in the summer survey. Of the homes in NPT, 74.0 % have no mould growth in any of these rooms (95%CI: 67.8 – 80.2), while the remaining 26.1% (95%CI: 19.9 – 32.3), reported mould growth in one of more of these four rooms. The frequency of mould growth experienced in the four main rooms under consideration, are illustrated in Table 180. Goodness of fit chi square tests were undertaken to consider whether the distribution in proportions for presence of mould in homes in winter differs from that found in summer. A statistically significant difference was observed between mould presence in the kitchen for the NPT housing population (chi square = 4.405, df = 1, p<0.05) between summer and winter, while for the main bedroom, main living room and bathroom, the difference between the distributions between summer and winter was not significant.

5.2.3.5 Material and Structural Damage

The respondents were asked to consider the extent to which they were concerned over the structure of their home and the structures in their gardens during violent storms and the possibility of increased flooding due to Global Warming. In relation to concern over the structure of their homes during violent storms, male and female responses to this question were significantly correlated, with a strong association (rho = 0.585, df = 146, p<0.001). The distribution of concern for the structure of homes is reproduced below, where it can be seen that 22.8% of households are concerned about the structure of their homes during a storm (95% confidence intervals for the distributions in the NPT population are also reproduced in the table below. The responses to this question and respondents perceived exposure to strong winds displayed statistically significant associations for: female occupants (rho = 0.362, df = 232, p<0.001), male occupants, (rho = 0.509, df = 189, p<0.001) and at a household level, (rho = 0.434, df = 278, p<0.001).

	Female		Male		Household	
	%	95% CI	%	95% CI	%	95% CI
Concerned	25.6	20.2 - 31.0	24.7	18.8 - 30.6	22.8	18.0 - 27.6
Slightly Concerned	30.0	24.3 - 35.7	35.1	28.5 - 41.7	39.8	34.3 - 45.3
Not at all Concerned	34.3	28.4 - 40.2	32.8	26.3 - 39.3	30.8	25.6 - 36.0
Not Considered	10.2	6.4 - 14.0	7.4	3.8 - 11.0	6.6	3.8 - 9.4
	247		**203**		**299**	

Table 181: Distribution of Concern Over the Structure of Homes During Violent Storms

In relation to concern over the structures in their gardens during violent storms, male and female responses to this question were significantly correlated, with a strong association (rho = 0.628, df = 146, p<0.001). The distribution of this factor is reproduced below, where it can be seen that 23.0% of households are concerned about the structures in their gardens during a storm. 95% confidence intervals for the distributions in the NPT population are also reproduced in the following table. The responses to this question and respondents perceived exposure to strong winds displayed statistically significant associations for: female occupants, (rho = 0.291, df = 230, p<0.001); male occupants (rho = 0.404, df = 188, p<0.001); and at a household level (rho = 0.409, df = 277, p<0.001).

	Female		Male		Household	
	%	95% CI	%	95% CI	%	95% CI
Concerned	26.3	20.8 - 31.9	25.0	19.0 - 31.0	23.0	18.2 - 27.8
Slightly Concerned	27.7	22.1 - 33.3	25.2	19.2 - 31.2	35.7	30.2 - 41.2
Not at all Concerned	35.8	29.8 - 41.8	39.5	32.7 - 46.3	34.0	28.6 - 39.4
Not Considered	10.2	6.4 - 14.0	10.2	6.0 - 14.4	7.3	4.3 - 10.3
	244		**200**		**295**	

Table 182: Distribution of Concern Over Garden Structures During Violent Storms

In relation to concern with respect to the potential increase in frequency of flooding as a result of global warming, male and female responses to this question were significantly correlated, with a strong association (rho = 0.323, df = 141, p<0.001). The distribution of this factor is reproduced in the table below, where it can be seen that 18.8% of households expressed concern over flooding (again 95% confidence intervals for the distributions in the NPT population are included). The responses to this question and respondents perceived exposure to flooding displayed statistically significant associations for: female occupants (rho = 0.519, df = 223, p<0.001), male occupants (rho = 0.443, df = 180, p<0.001) and at a household level (rho = 0.530, df = 265, p<0.001). Less strong, and for the case of male occupants not significant associations were also present in relation to those properties that had previously been flooded: female occupants (rho = 0158, df = 223, p<0.05) male occupants (rho = 0.094, df = 186, p=n.s.) and at a household level (rho = 0.173, df = 265, p<0.001).

	Female		Male		Household	
	%	95% CI	%	95% CI	%	95% CI
Concerned	20.5	15.4 - 25.6	15.3	10.3 - 20.3	18.8	14.3 0 23.3
Slightly Concerned	22.0	16.8 - 27.2	22.7	16.9 - 28.5	27.4	22.3 - 32.5
Not at all Concerned	39.0	32.9 0 45.1	44.8	37.9 - 51.7	40.0	34.4 - 45.6
Not Considered	18.5	13.6 - 23.4	17.1	11.8 - 22.4	13.8	9.9 - 17.7
	243		**197**		**293**	

Table 183: Distribution of Concern Over the Possibility of More Frequent Flooding in Neighbourhood, Due to Global Warming

5.2.4 Summary of Summer Survey Results

It was firstly necessary to consider the distribution of the sample in relation with known distributions in the NPT population in terms of housing and social complexity factors. This has helped to ensure that the response bias towards retired households was identified and could be controlled for, where appropriate, through the application of a weighting to responses from pensioner and non-pensioner households. It was important that this factor be controlled as older occupants are likely to have different comfort thresholds and therefore, where distributions are to be extrapolated to the population, this bias should be considered.

It was considered that the difference from the population in relation to insulation measures was likely to be due to actual changes in the population and therefore this factor was not controlled for. The statistically significant higher response rates from those households where household NSSEC was considered to be from Class 1 = managerial or professional, were also not controlled for where data was to be considered at the NPT population level. The effect size of these associations was low and it was therefore considered unnecessary to control for this factor.

A summary of the findings from the summer survey is presented below. The 95% Confidence Interval (95% CI – highlighted blue) is provided for all population level proportions.

Risk Factor	**NPT Household Proportion**	
	Proportion	**95% CI**
Excess Heat	38.9% think that keeping all curtains closed on the sunny side of the home, helps to keep it cool (42.2% disagree).	**38.9 – 44.5** (36.6– 7.8)
	No significant association for this distribution were identified.	**43.3 – 54.7**
	79.3% think that on a hot summer's day, the household often uses the garden and / or visits the park, beach or other open space (9.7% disagree).	**74.7 – 83.9** (6.3 – 13.1)
	Ease of access to public open spaces, as well as access to the household's own garden, were both significantly associated with response to this statement.	**25.5 – 36.5**
	83.8% think that on a hot summer's day there is always somewhere in their home that stays cool (5.5% disagree).	**79.6 – 88.0** (3.3 – 8.7)
	Housing tenure was significantly associated with response to this statement, where council tenants were most likely to disagree. Low self declared financial status and occupation of housing built between 1945 and 1964 were also significantly associated with disagreement with this statement.	**37.2 – 51.2**

Risk Factor	**NPT Household Proportion** **Proportion**	**95% CI**
Excess Heat (Continued)	7.3% think that on a hot summer's day there is nowhere in their home that remains a comfortable temperature (77.3% disagree).	**4.3 - 10.3** (72.5–82.1)
	A significant association exists between response to this statement and occupation of rented property, as well as presence of poor health. A further significant association was found with those occupants that agreed that noise, air pollution, crime and pests influenced their use of windows for ventilation.	**8.3 – 17.7**
	31.5% think that on a hot summer's day *'it is most comfortable outside / in the garden'* (40.1% disagree).	**26.2 – 36.8** (34.5– 5.7)
	A negative association was found between responses to this statement and those to *'on a hot summer's day there is always somewhere inside my home that stays cool'*, while a positive significant association was found with those to *'on a hot summer's day there is nowhere in my home that remains a comfortable temperature'*.	**88.3 – 94.7**
	34.7% think that *'on a hot summer's evening it is often too hot to be comfortable upstairs in the home'*.	**28.6 – 40.8**
	A negative association was found between this statement and general health status.	**69.1 – 78.9**
	48.1% think that *'on a hot summer's night it is often too hot to allow them to sleep'*.	**42.5 – 53.7**
	A negative association was found between this statement and general health status. Additionally associations with age of property where occupants of those built between 1945 & 1964 are more likely to agree than occupants of any other housing age as well as with those occupants that agreed that external factors influenced their use of windows for ventilation.	
	52.0% consider their main bedroom overheats at one period of time or more.	**46.3 – 57.7**
	40.6% consider their main living room overheats at one period of time or more.	**35.0 – 46.2**
	42.4% consider their kitchen overheats at one period of time or more.	**36.7 – 48.1**

Risk Factor	NPT Household Proportion	
	Proportion	95% CI
Excess Heat (Continued)	24.6% consider their main bathroom overheats at one period of time or more.	19.6 – 29.6
	38.5% consider that no room in their home currently overheats during a hot summer's day or night.	33.0 – 44.0
	15.7% consider that one room in their home currently overheats during a hot summer's day or night.	11.6 – 19.8
	42.8% consider that two or more rooms in their home currently overheat during a hot summer's day or night.	37.2 – 48.8
	The distribution of rooms that are considered to overheat by their occupants was found to be associated with: age of property, age of occupant, occupant health, household financial status, combined measure of influence on ventilation, and overall satisfaction with the home environment in the summer.	
Shutters	21.2% think that on a hot summer's day shutters on the windows of my home would help to keep it more comfortable (45.4% disagree).	16.6 – 25.8 (6.3 – 13.1)
Air Conditioning	32.1% would like to have air conditioning to keep their home a comfortable temperature on a hot summer's day (50.4% disagree).	26.8 – 37.4 (44.7–56.1)
	Significant associations were found between responses to this statement and the presence of overheating in homes.	
	37.8% think that on a hot summer's day: air conditioning would be a waste of energy in the UK (33.9% disagree).	32.4 – 43.2 (28.6–39.2)
Noise	44.2% think noise is a problem in their neighbourhood.	37.2 – 51.2
	Proximity to heavy and light industry and busy roads was found to have a significant association with perception of noise as a problem, where an urban location, occupation of a flat, maisonette or terraced house were all also found to be associated. This factor was found to have a significant impact on occupant use of windows for ventilation on a hot summer's day.	
Pests	49% consider themselves bothered by flying insects	43.3 – 54.7
	Flying insects bother them in the summer in their home where the presence of water in proximity to the home was found to have a significant association. This factor was also found to have a significant impact on occupant use of windows for ventilation on a hot summer's day.	

Risk Factor	NPT Household Proportion	
	Proportion	95% CI
Ventilation	94% always open windows to encourage air flow or ventilation on a hot summer's day. A significant association exists between this factor and those occupants that agreed that noise, air pollution, crime and pests influenced their use of windows for ventilation.	88.3 – 94.7
	74.0% think that the more ventilation or air flow, the more comfortable their home is on a hot summer's day.	69.1 – 78.9
	5.0% never open their downstairs windows A significant association exists between this factor and those occupants that agreed that noise, air pollution, crime and pests influenced their use of windows for ventilation.	2.5 – 7.5
	60.4% usually leave the windows open on a hot summers night as it helps to make their home more comfortable (21.8% disagree). A significant association exists between this factor and those occupants whose concerns over security prevent them leaving windows open at night.	60.4 – 71.2 (17.1–26.5)
	16.5% think that on a hot summer's day, it often gets stuffy in their home (66.9% disagree). Significant associations exist between this factor and never opening downstairs windows, those occupants that agreed that noise, air pollution, crime and pests influenced their use of windows for ventilation, as well as those that agreed that on a hot summer's day they always open some windows to encourage ventilation.	12.3 – 20.7 (61.6–72.2)
	Age of property and stuffiness on a hot summer's day:	
	Occupants of property built between 1919 and 1964 in this sample are most likely to indicate that their homes are often stuffy on a hot summer's day, while occupants of property built between prior to 1919 and post 1980 are most likely to disagree.	
	46.1% think that on a hot summer's night it is often too stuffy to allow occupants to sleep well (29.1% disagree). Pensioner households in NPT are significantly more likely to agree with this statement. Occupants of property built between 1945 and 1964 in this sample are more likely to indicate that their homes are too stuffy to sleep on a hot summer's night, while occupants of property built between prior to 1945 and post 1980 are most likely to disagree.	40.5 – 51.7 (24.0–34.2)

Risk Factor	NPT Household Proportion	
	Proportion	95% CI
Ventilation (Continued)	44.4% consider their main bedroom to be stuffy at one period of time or more.	38.7 – 50.1
	30.1% consider their main living room to be stuffy at one period of time or more.	24.8 – 35.4
	29.6% consider their kitchen to be stuffy at one period of time or more.	24.3 – 34.9
	18.6% consider their main bathroom to be stuffy at one period of time or more.	14.1 – 23.4
	54% consider that one of more of these rooms are currently stuffy during a hot summer's day or night.	48.8 – 60.0
Crime	13% think crime is a problem in their neighbourhood. Occupants of urban locations were more likely to consider that crime, burglary and theft is a problem in their neighbourhood. This factor was also found to have a significant impact on occupant use of windows for ventilation on a hot summer's day. This significant association was not present at night, although greater proportion of households agreed that they did not leave their windows open at night due to security concerns.	8.3 – 17.7
Air Pollution	31% think air pollution is a problem in their neighbourhood. Proximity to heavy and light industry and busy roads was found to have a significant association with perception of exposure to air pollution. This factor was also found to have a significant impact on occupant use of windows for ventilation on a hot summer's day.	25.5 – 36.5
Damp & Mould	47.6% experience condensation in one or more of the four rooms considered herein (42.3% disagree). No significant association for this distribution were identified.	41.6 – 53.6 (36.4–48.2)
	Condensation was more prevalent in the winter than in the summer for all but the bathroom, where the distribution was not statistically different.	
	Statistical associations exist between the presence of mould and the presence of damp for all four rooms considered herein.	
	12.8% have damp in one or more of the four rooms considered (87.2 % disagree). For bathrooms the presence of a bathroom extract was significantly associated with levels of damp. Presence of damp in one or more rooms was also significantly associated with self declared financial status, and was statistically more likely to be present in homes built prior to 1919 or between 1965 and 1980.	82.9 – 91.5 (8.5 – 17)

Risk Factor	NPT Household Proportion	
	Proportion	95% CI
Damp & Mould (continued)	12.8% have damp in one or more of the four rooms considered (87.2 % disagree).	**82.9 – 91.5** (8.5 – 17)
	For bathrooms the presence of a bathroom extract was significantly associated with levels of damp. Presence of damp in one or more rooms was also significantly associated with self declared financial status, and was statistically more likely to be present in homes built prior to 1919 or between 1965 and 1980.	
	26.1% have mould growth in one of more of the 4 main rooms.	**20.5– 31.7** (68.3– 9.5)
	Presence of mould growth in one or more rooms was also significantly associated with self-declared financial status, and was statistically more likely to be present in homes built prior to 1919.	
	No statistical difference was found for prevalence of damp in winter and summer.	
Material & Structural Damage	22.8% are concerned about the structure of their home during a violent storm (30.6% disagree).	**18.0 – 27.6** (25.6-36.0)
	Significant associations were found between the attitudes to this statement and perceived exposure of home to wind.	
	23.0% are concerned about structures in their gardens during a violent storm (30.6% disagree).	**18.2 – 27.8** (28.6-39.4)
	Significant associations were found between the attitudes to this statement and perceived exposure of home to wind.	
	18.8% are concerned about the potential increase in frequency of flooding as a result of Global Warming (40.0% disagree).	**14.3 – 23.3** (34.3-45.6)
	Significant associations were found between the attitudes to this statement and perceived exposure of home to flood.	

An open-ended question ended the summer survey, allowing the male and female respondents to consider what they would do to improve the internal environment in their home on a hot summer's day. The following table provides a summary of the responses to this question.

Action	
Install air conditioning	11%
Ventilation including installing fans	10%
Prevention of noise	2%
Prevention of insects	2%
Prevention of pollution	2%
Provide shading	2%
Increase security	2%
Undertake building works	10%
Changes to garden	4%
Changes to heating system	2%
No changes	54%

Table 184: Summary of respondents' desired actions to improve the internal environment of their homes in a hot summer

5.3 Case Study Monitoring Results

The case study home was monitored using Gemini 'Tinytag' data loggers from 01.01.03 to 31.12.03, as described in the methodology. The data collected is continuous, apart from relatively brief periods of missing data that occurred during logging due to battery failure. Summaries of the whole monitored dataset are reproduced in Appendix M. The loggers were located as follows in the case study home:

Logger Name	Type	Location
T1	Temperature	Kitchen
T3	Temperature	Lounge
T6	Temperature	Hallway
T8	Temperature	Main Bed (Bed 2)
T9	Temperature	Small Bed (Bed 3)
T10	Temperature	Office (Bed 1)
T11	Temperature	Bathroom
T12	Temperature	Attic
RH1	Relative Humidity	Bathroom
RH2	Relative Humidity	Main Bed (Bed 2)
RH3	Relative Humidity	Kitchen
RH4*	Relative Humidity	Lounge

**NB Very Low readings*

Table 185: Logger Location Schedule

Figure 110: Logger Location Plan in Case Study Home

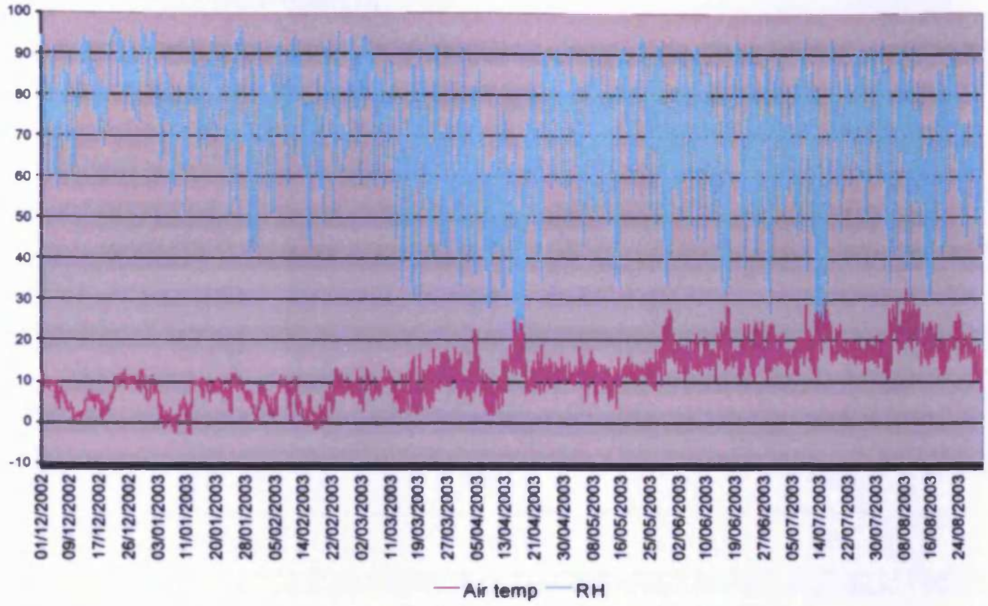


***Figure 111: 2003 Winter, Spring and Summer Climate: Air Temperature and Relative Humidity for Cardiff Central** (WSA Weather Station)*

The year 2003 was found to be the fifth hottest year in the UK since records began in 1659, with the mean CET being 10.82°C, 1.09°C above the long-term average and the summer average of 17.3°C, the fourth warmest on record (Met Office website, December 2003). The summer weather experienced during the monitoring period was found to be of particular interest to this study, providing in itself a temporal analogue for future average summers, as described in Chapter 2, and found in the current UKCIP02 scenarios. The following analysis of the results will therefore focus on the summer season, which for the purposes of this analysis, is defined as the 12 week period 7th June - 27th August. Results from the winter and spring periods will be described briefly for the purposes of completeness.

Week	Dates			
Week 1	*7th*	-	*13th*	*June*
Week 2	*14th*	-	*20th*	*June*
Week 3	*21st*	-	*27th*	*June*
Week 4	*28th*	-	*4th*	*July*
Week 5	*5th*	-	*11th*	*July*
Week 6	*12th*	-	*18th*	*July*
Week 7	*19th*	-	*25th*	*July*
Week 8	*26th*	-	*1st*	*August*
Week 9	*2nd*	-	*8th*	*August*
Week 10	*10th*	-	*15th*	*August*
Week 11	*16th*	-	*22nd*	*August*
Week12	*23rd*	-	*29th*	*August*

Table 186: Summer Period Dates of 12 Week Period

The findings from these 12 weeks of monitoring will firstly be described in relation to the external climate, occupant perceived comfort and occupant behaviour. This will be followed by analysis of the internal environment found in the monitored rooms during this period, in relation to comfort standards. Firstly, however, it is appropriate to consider the results of the pressurisation and thermography tests undertaken to examine the construction of the case study home. These tests enable consideration of the actual construction in comparison with that anticipated by building regulations and specifications.

5.3.1 Results from the Pressurisation Test

The pressurisation test for the case study home was carried out on the 21st October, 2003. Three tests were undertaken, one with trickle vents closed and two with trickle vents open. The results from these tests are reproduced below.

	Air Leakage Index ($m^3 h^{-1} m^{-2}$) @ 50Pa	Air Permeability ($m^3 h^{-1} m^{-2}$) @ 50Pa	Air Infiltration Rate (Air Changes per Hour - ACH)
Dwellings Good Practice	15.0	10.0	(1-4)*
Dwellings Best Practice	8.0	5.0	-
Case Study – Trickle Vents Closed	13.4	11.0	0.58
Case Study – Trickle Vents Open (1)	(17.4)	(14.2)	0.76
Case Study – Trickle Vents Open (1)	(17.6)	(14.4)	0.76

* Where 1 ACH = minimum for whole house ventilation, 2 ACH= Minimum ventilation rate to avoid odours & stuffiness and 4 ACH = minimum ventilation rate to avoid condensation (Evans, 1980, Jones et al, 1997)

Table 187: Results of Air Leakage Tests for the Case study Home

It can be seen that the case study home does not meet the good practice standards for the air leakage index, or the air permeability index, the chosen measure for this study. Following smoke tests undertaken during pressurisation, faults were discovered in the seals surrounding the patio doors and loft hatch, allowing air infiltration at these points. It is interesting to consider further, that with trickle vents open the property does not achieve a level of 1 ACH, considered by Evans (1980) and Jones et al (1997), to be a minimum background ventilation rate required to achieve comfort in domestic buildings.

5.3.2 Results from the Thermography Survey

The thermography survey of the case study home was undertaken on the 14th March 2003, at 20:00, following a cool bright winter's day. The heating was turned on to full capacity two hours prior to the test to enable a large temperature differential to be achieved between internal and external environments. This was undertaken to help ensure that failures in insulation and ait tightness sealing can be identified clearly.

Figure 112: Thermography Survey - North Façade

Figure 113: Thermography Survey - Front Door

Simple interpretation of the recording provided by the thermography survey can be undertaken, whereby lighter areas are hotter than darker areas. From an external standpoint, those areas that are lighter can be interpreted as providing lower levels of insulation, while from an internal standpoint, darker areas are cooler and therefore provide lower levels of insulation. This phenomenon is known as 'thermal bridging' to the external environment.

Externally no gaps in the insulation were apparent, although hot air could be seen to be emitted from the loft area. Further to this, the windows could be clearly identified as providing the lowest level of insulation. The glazing in the front door can be identified from the image as providing a lower level of insulation than other glazing in the home, although the steel front door itself is well insulated.

Figure 114: Thermography Survey – Dining Room West Wall

Figure 115: Thermography Survey – Lounge – North Facing Wall and Party Wall

Internally, an interesting phenomenon was identified as a result of the 'dot and dab' construction method for dry lining. Where the adhesive plaster had been applied to the walls to which the plasterboard was affixed, cold bridging appeared to occur. This appeared throughout the property on the external walls and seemed particularly apparent in corners (for example the corner illustrated above right, between the north facing wall of the lounge and the party wall). It was also identified that the insulation in the front porch roof was of a lower standard than that in the main roof.

The final image reproduced here from the filmed thermography survey illustrates cold air infiltrating through a downstairs window. The reverse was identified for upstairs windows, where hot air was seen escaping, illustrating the 'stack' effect in action in the property.

Figure 116: Thermography Survey – Lounge Open Trickle Vents

5.3.3 Analysis of Winter Monitoring

The environment provided by the case study home during the winter period, was found to be well controlled, with temperatures dropping below those perceived to be comfortable only during unoccupied periods. Peak temperatures seen on this graph occurred where the heating system's capability was being tested as well as in order to enable the thermography survey. The average internal temperature was found to be 18.6°C (+/-0.5°C) with upstairs average temperatures of 19.3°C (+/-0.5°C) and downstairs of 17.7°C (+/-0.5°C). The average external temperature for this winter period in Cardiff was 6.4°C, with a maximum of 13.7°C and minimum of 1 °C.

Problems associated with thermal comfort perceived by the occupants during the winter were limited to cold in the hallway and downstairs toilet. This was likely to be caused by the lower level insulation in the porch roof as well as 'stack' effect, where heat rises to the upstairs landing and beyond. The difference in heating between downstairs and upstairs was also perceptible by occupants, especially during the mornings, following an unheated night. However, it was not considered by the occupants to be difficult to achieve a comfort temperature throughout the property, with all rooms capable of being heated to comfort levels and the cost of achieving this being low, where annual gas fuel bills of £216 per year, including heating, hot water and cooking.

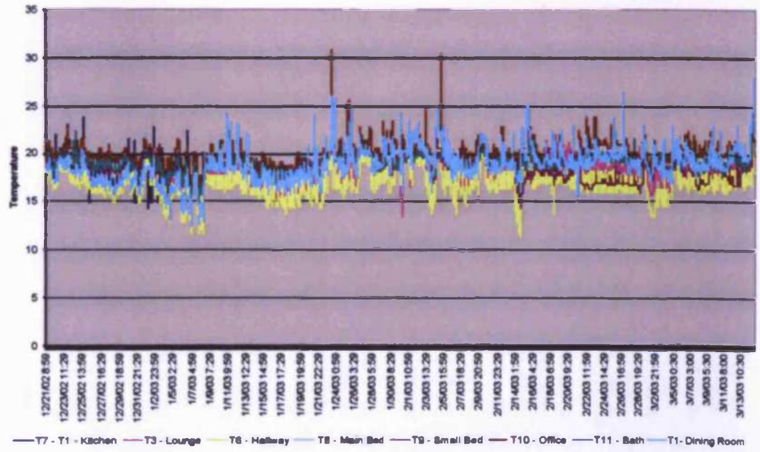


Figure 117: Summary of Winter Temperature Monitoring Results (Accuracy +/-0.5 °C)

The relative humidity in the property during the winter was influenced by cooking, washing and the drying of clothes and lay between 26% and 100%. The peaks in the bathroom resulted in condensation on the walls and small levels of mould growth were sometimes present on the grouting. This was treated through the use of a proprietary mould removal spray. The atmosphere in the living areas of the case study home was frequently perceived as dry and stuffy by the occupants during the winter.

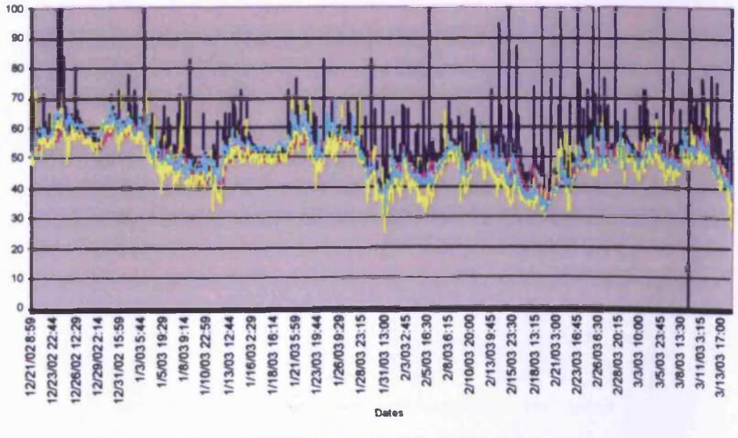


Figure 118: Summary of Winter Relative Humidity Monitoring Results

5.3.4 Analysis of Spring Monitoring

The environment provided by the case study home during the spring period, was also easily controlled, with temperatures dropping below those perceived to be comfortable only during unoccupied periods. The average internal temperature was found to be 19.7°C (+/-0.5°C) with upstairs average temperatures of 20.5°C (+/-0.5°C) and downstairs of 18.7°C (+/-0.5°C). The average external temperature for this winter period in Cardiff was 11.8°C, with a maximum of 27.4°C and a minimum of 1.7°C.

Problems perceived by the occupants during both the spring and autumn were as those for the winter, with the difference in heating between downstairs and upstairs still perceptible by occupants. Regular peaks in temperature perceived during this monitoring period mostly illustrate cooking, although the prolonged periods of hotter temperatures during April and May illustrate two periods of hotter springtime weather.

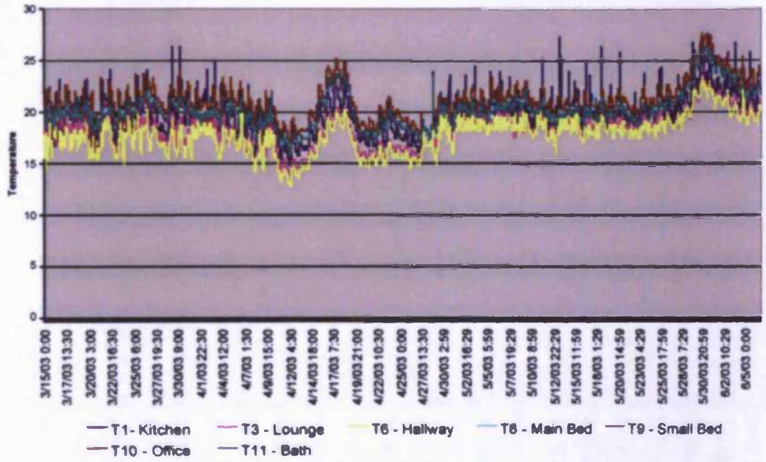


Figure 119: Summary of Spring Temperature Monitoring Results (Accuracy +/-0.5 °C)

The relative humidity in the property during the spring was influenced mainly by cooking, washing and the drying of clothes and lay between 27% and 100%. The atmosphere in the case study home during the springtime was also perceived as uncomfortably dry by the occupants when the central heating was on.

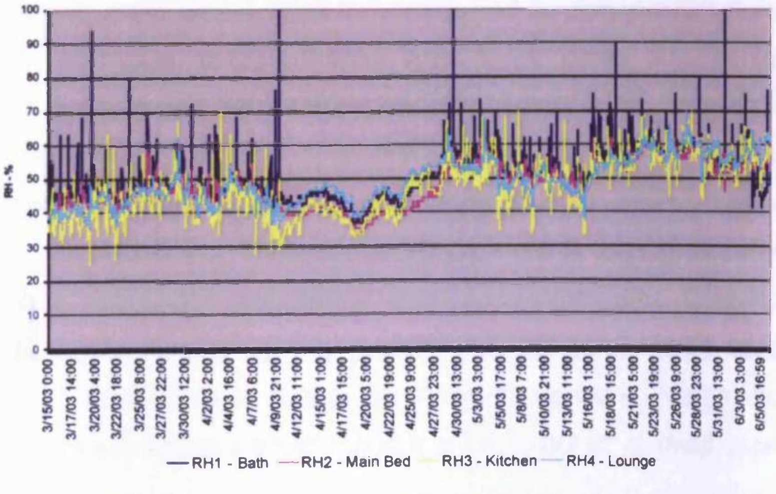


Figure 120: Summary of Spring Relative Humidity Monitoring Results

It was not deemed necessary to consider results of the autumn monitoring period herein, as the results are similar to those found in the spring.

5.3.5 Analysis of Summer Monitoring

The internal temperature in the case study property ranged from a maximum of 31.4°C to a minimum of 18.4°C during the summer monitoring periods. The average internal temperature was 23.5°C, with 24.2°C upstairs and 22.6°C downstairs. The average external temperature for this twelve week period in Cardiff was 18.4°C, with a maximum of 34.5°C and a minimum of 10.2°C. The graph below summarises the monitoring results for the period, where the three sudden dips indicate periods of error in the data logging.

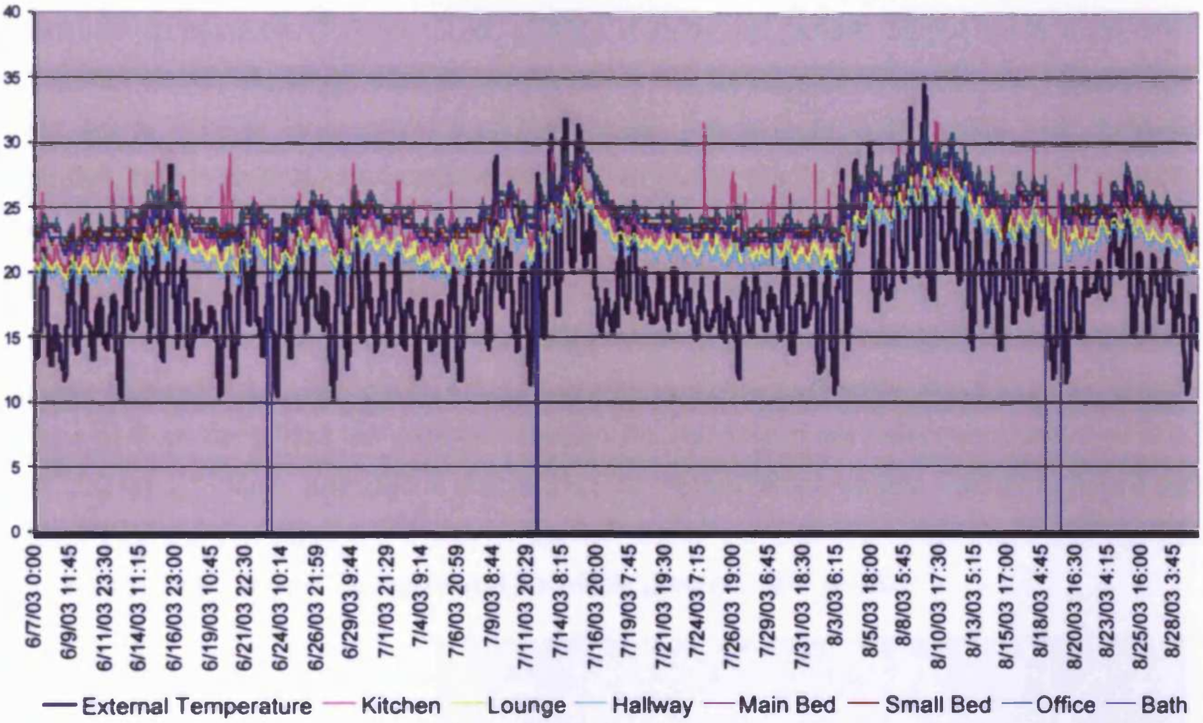


Figure 121: Summary of Summer Monitoring Results with External Temperature

Occupant behaviour to be highlighted during this analysis includes where occupants were present or absent, where cooking or bathing has had influence on the monitoring and flushing ventilation periods (where windows or patio doors have been opened to provide increased ventilation). Throughout the period, all trickle ventilators were open in all rooms, the kitchen extract should be assumed to have been used when cooking and the passive stack vent in the bathroom was automatically activated during periods of increased humidity. Further to this, increased ventilation was used throughout the property when occupied, through open windows in the main bedroom (bed 2) and office (bed 1). The internal temperature is also likely to be influenced by the use of the following appliances (see below) in terms of heat gains. Constant use of those in bold should be assumed throughout this period, while all others were used intermittently throughout the day. The Boilermate is a 'thermal store' that ensures instant hot water at any time, through the constant storage of a small amount of hot water in a small upper chamber.

Room	Appliance
Kitchen	○ **Fridge freezer** ○ **Boiler** ○ Washing machine
Lounge	○ Television ○ Stereo
Office (Bed 1)	○ Desktop computer ○ Stereo
Airing Cupboard	○ **Boilermate**

5.3.5.1 Week 1: 7th – 13th June 2003

The average temperature for this week was 15.8°C, with a minimum of 10.2°C and a maximum of 21.8°C. Occupancy of the property was relatively constant throughout the week, although 4 visitors were present on 7th June 10:30 – 16:30. Unoccupied periods do not seem to influence the internal temperatures greatly. It can be seen that throughout the week the hallway and lounge are of a lower temperature than the kitchen, this is likely to be due to their northerly orientation, where peak temperatures in the kitchen during the day on the 7th and 12th June are mostly due to solar gain. Other peak temperatures in the kitchen are due to cooking gains.

It can also be seen that in comparison to the external temperature, the internal temperatures are 'flattened', where the internal environment of the home is protected from the evening and night-time lows of temperature and internal temperatures very rarely fall below those found externally. The use of flush ventilation, for example through the opening of the patio doors between 14:00 and 17:30 on 12th June, provided a visible drop in internal temperatures. Further to this, it can be seen that the temperatures found in the loft follow the external temperature closely. For clarity these values will not be reproduced on other graphs in this section.

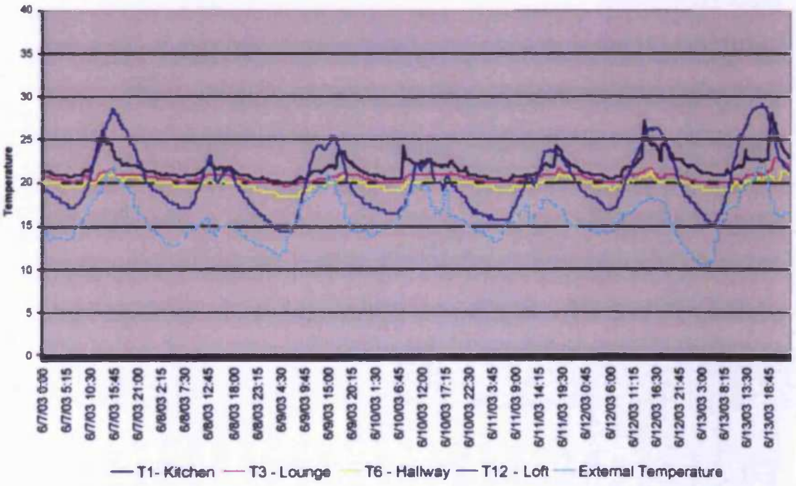


Figure 122: Summer Period - Week 1, Downstairs Temperatures

The upstairs temperatures for this week are also relatively constant with those in the office (Bed 1) remaining constantly higher than those elsewhere upstairs. Again orientation is likely to have influenced this internal temperature where large windows on the south façade in the office admit solar gain throughout the day. During the night the main bedroom (Bed 2) achieves internal temperatures equal to those in the office. This is likely to be due to occupancy as this space had 2 occupants during this period, while the office had none.

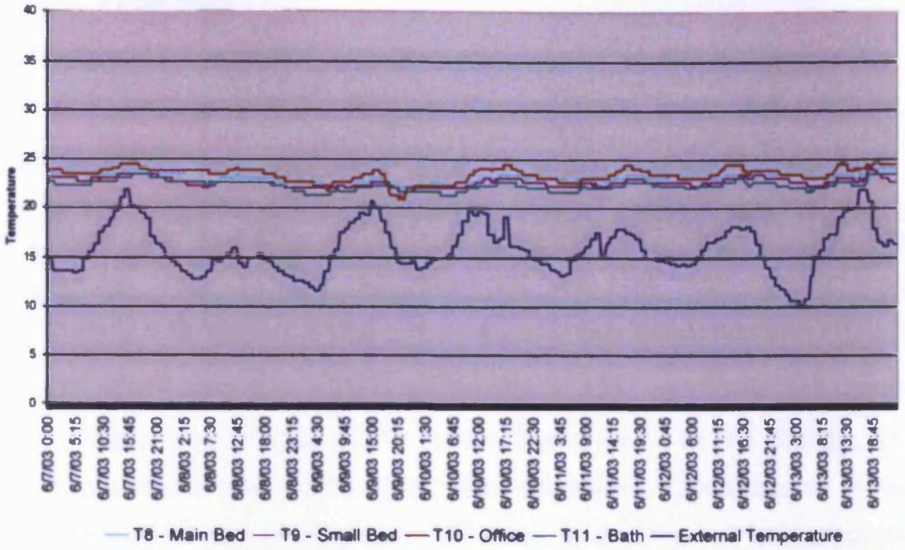


Figure 123: Summer Period - Week 1, Upstairs Temperatures

The internal and climatic relative humidity during this period is illustrated below. It can be seen that the internal RH remains relatively constant, due to its relationship to the constant internal temperatures, while the external RH rises during the night as external temperatures fall, and lowers during the day in line with increasing external temperatures. Peaks in RH for each room follow occupation closely, where cooking and bathing produce the largest peaks in internal RH. It can also be seen that static occupation also causes increased RH for the period of occupation. This pattern of external and internal RH is relatively similar throughout the 12 week summer period and will not therefore be illustrated for all twelve weeks. The mean, maximum and minimum RH values in the climate, and for all four loggers, is reproduced in the table below. This information will be presented for the remaining 11 weeks to provide references.

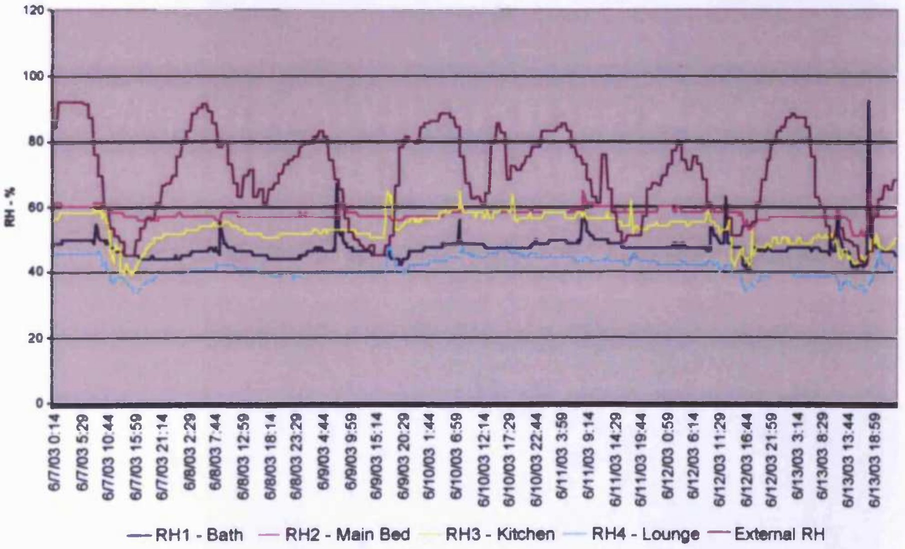


Figure 124: Relative Humidity, Internally and Externally for Week 1

		Climate			RH1 - Bath			RH2 - Bed 2			RH3 - Kitchen			RH4 - Lounge		
		Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min
Week	1	69	92	42	47	92	40	58	64	40	58	64	51	53	64	49

Table 188: Summary of Relative Humidity, Internally and Externally for Week 1

5.3.5.2 Week 2: 14th – 20th June 2003

The average temperature for this week was 17.5°C, with a minimum of 10.4°C and a maximum of 28.2°C. Both minimum and average climatic RH are lower for this week, reflecting the increased temperatures experienced.

		Climate			RH1 - Bath			RH2 - Bed 2			RH3 - Kitchen			RH4 - Lounge		
		Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min
Week	2	68	93	31	45	80	34	55	64	43	51	70	32	39	30	48

Table 189: Summary of Relative Humidity, Internally and Externally for Week 2

The internal temperatures downstairs rose above 25°C, again due to cooking, despite the use of extraction. Solar gain is also a prominent factor of the temperatures found in the kitchen, the only south facing room to be monitored downstairs. Internal temperatures remain above those found externally, apart from the hottest day of the week, 16th June, where internal temperatures are lower than those experienced at midday externally. The upstairs temperatures follow a similar pattern to those found in week one, with the increased occupation during the nights of the 14th and 15th of June, (+2 adults) reflected through night-time temperatures in the office remaining constantly higher than those elsewhere upstairs. With increased occupation the temperatures upstairs fluctuated around 25°C. Night-time ventilation was provided throughout the period through the use of trickle ventilators.

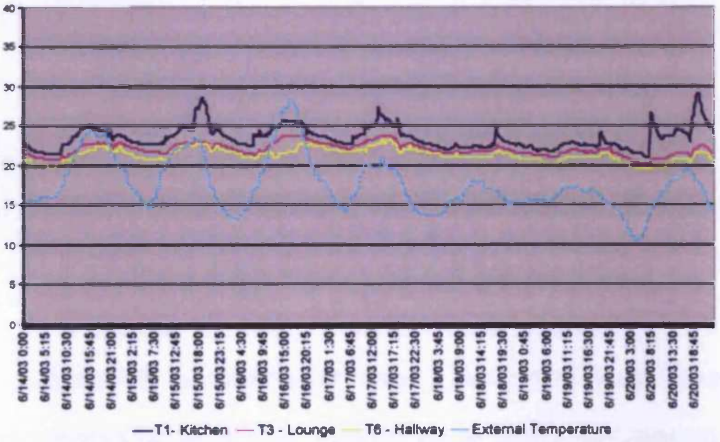


Figure 125: Summer Period - Week 2, Downstairs Temperatures

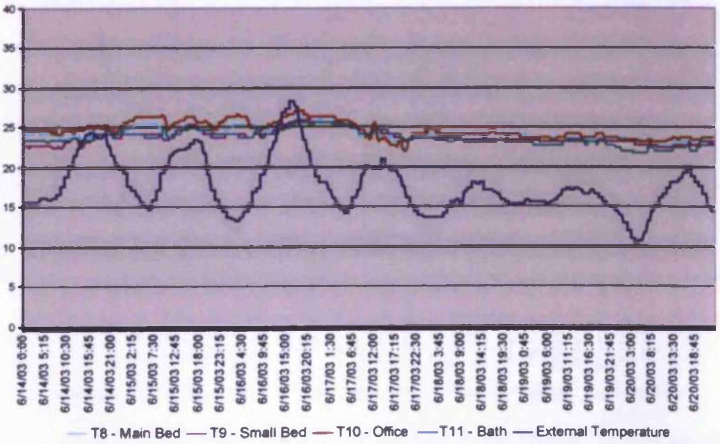


Figure 126: Summer Period - Week 2, Upstairs Temperatures

5.3.5.3 Week 3: 21st – 27th June 203

The average temperature for this week was 17.6°C, with a minimum of 10.4°C and a maximum of 24.6°C. Climatic relative humidity reflects this slightly cooler week. Internal relative humidity is found to be higher this week. This reflects the drying of washing inside due to inclement external weather.

	Climate			RH1 - Bath			RH2 - Bed 2			RH3 - Kitchen			RH4 - Lounge		
	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min
Week 3	67	92	38	49	62	42	56	66	48	53	69	44	40	50	32

Table 190: Summary of Relative Humidity, Internally and Externally for Week 3

Internal downstairs temperatures follow a similar range again with peaks of temperatures following the expected patterns of cooking and solar gain. Upstairs temperatures are again very constant. The particularly constant period towards the end of the week reflects a period of low occupancy, where both occupants were absent throughout the day and night. Again, throughout the week internal temperatures are higher than those found externally, apart from the hottest time of the day, where the hallway and lounge are consistently cooler than outside.

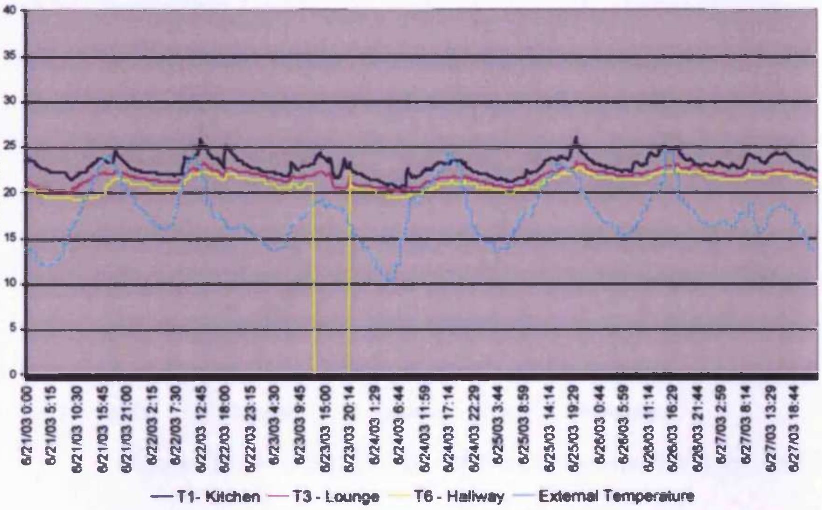


Figure 127: Summer Period - Week 3, Downstairs Temperatures

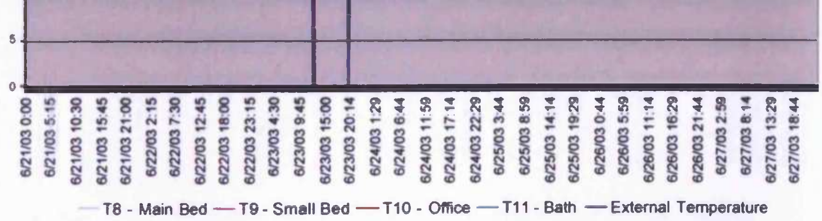


Figure 128: Summer Period - Week 3, Upstairs Temperatures

5.3.5.4 Week 4: 28th June - 4th July 2003

The average temperature for this week was 17.0°C, with a minimum of 10.3°C and a maximum of 24.2°C, reflecting a very similar external thermal climate to the previous week. Throughout the week relative humidity was found to be lower than the previous three weeks.

		Climate			RH1 - Bath			RH2 - Bed 2			RH3 - Kitchen			RH4 - Lounge		
		Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min
Week	4	66	90	27	49	66	46	56	60	51	51	67	43	38	31	43

Table 191: Summary of Relative Humidity, Internally and Externally for Week 4

The property was unoccupied until the evening of the 28th June and from the morning of the 3rd July. These periods can be seen to be reflected in the monitored data where internal temperatures display fewer fluctuations in temperature, particularly the kitchen.

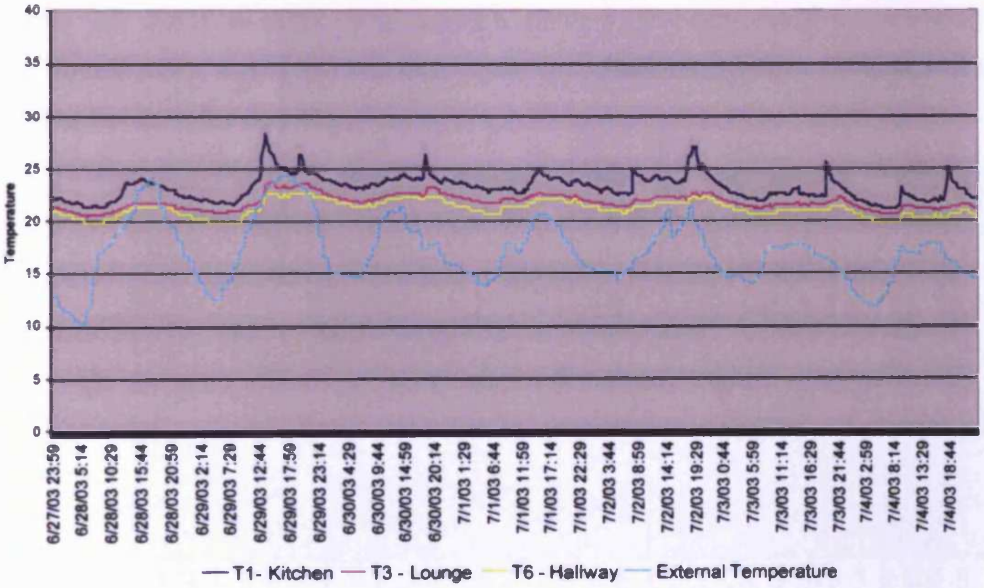


Figure 129: Summer Period - Week 4, Downstairs Temperatures

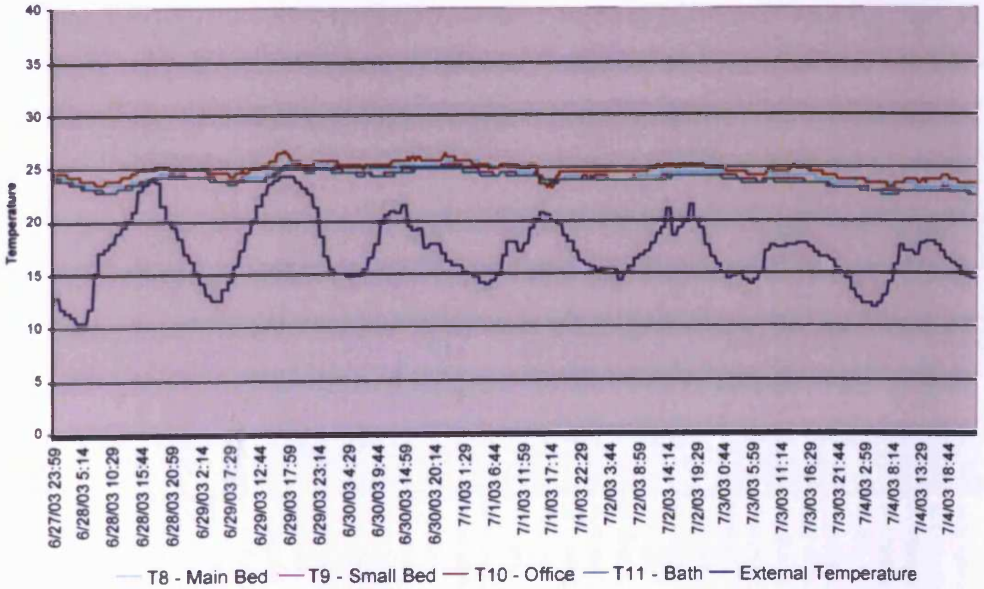


Figure 130: Summer Period - Week 4, Upstairs Temperatures

5.3.5.5 Week 5: 5th – 11th July 2003

The average temperature for this week was 17.7°C, with a minimum of 11.6°C and a maximum of 28.9°C. Higher relative humidity for all three measures,(average, maximum and minimum) was experienced this week.

	Climate			RH1 - Bath			RH2 - Bed 2			RH3 - Kitchen			RH4 - Lounge		
	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min
Week 5	70	94	37	49	100	38	50	60	37	50	64	29	35	43	21

Table 192: Summary of Relative Humidity, Internally and Externally for Week 5

The temperature internally increased slowly throughout this week, reflecting the increasing external temperatures, particularly those experienced at night. This higher ambient internal temperature was retained until the 11th July, despite cooler external temperatures on the 10th July. Higher night-time ventilation rates were experienced on the night of the 11th July, as a bedroom window was left open all night. This can be seen in the upstairs and downstairs temperatures that reduced more swiftly on this night than on others. Night-time ventilation was limited due to occupant concern for security.

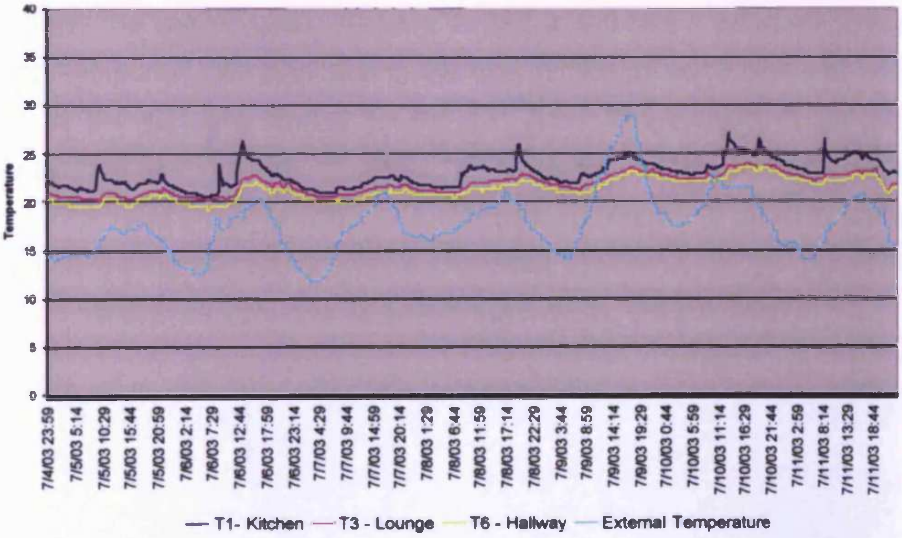


Figure 131: Summer Period - Week 5, Downstairs Temperatures

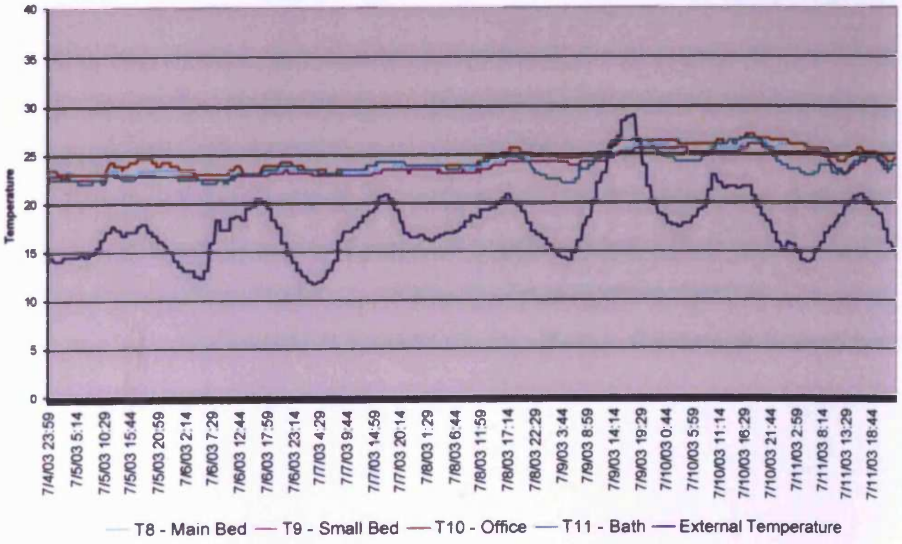


Figure 132: Summer Period - Week 5, Upstairs Temperatures

5.3.5.6 *Week 6: 12th – 18th July 2003*

The average temperature for this week was 21.0°C, with a minimum of 11.3°C and a maximum of 31.7°C. This week is therefore the hottest so far for this monitoring period and as a result both the lowest average and minimum relative humidities were also experienced.

		Climate			RH1 - Bath			RH2 - Bed 2			RH3 - Kitchen			RH4 - Lounge		
		Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min
Week	6	60	93	25	48	75	37	50	60	37	50	64	29	35	21	43

Table 193: Summary of Relative Humidity, Internally and Externally for Week 6

The external temperatures during the middle of the day exceeded those inside on the 12th – 15th July 2003, with peak temperatures exceeding 30°C for the first time during this monitoring period. During this week the internal temperatures throughout the home increased until they remained over 25°C from midday on the 15th June until the 17th June, downstairs and upstairs, from midday on the 13th to late afternoon of the 17th June. The difference in temperatures between south and north facing rooms can be seen to be particularly pronounced during this warmer period.

Night-time ventilation, through the use of open windows in bed 2 and bed 1 were employed throughout the night during this period, although during the day, additional ventilation was only possible on the afternoon of the 12th and all day on the 13th June. The benefits of flushing ventilation are particularly evident on the afternoon of the 13th July where solar gain in the office and cooking gains in the kitchen were flushed through increased ventilation. At all other times the house was unoccupied during the day and therefore increased ventilation was not possible, due to security implications, until the property was occupied again during the evenings.

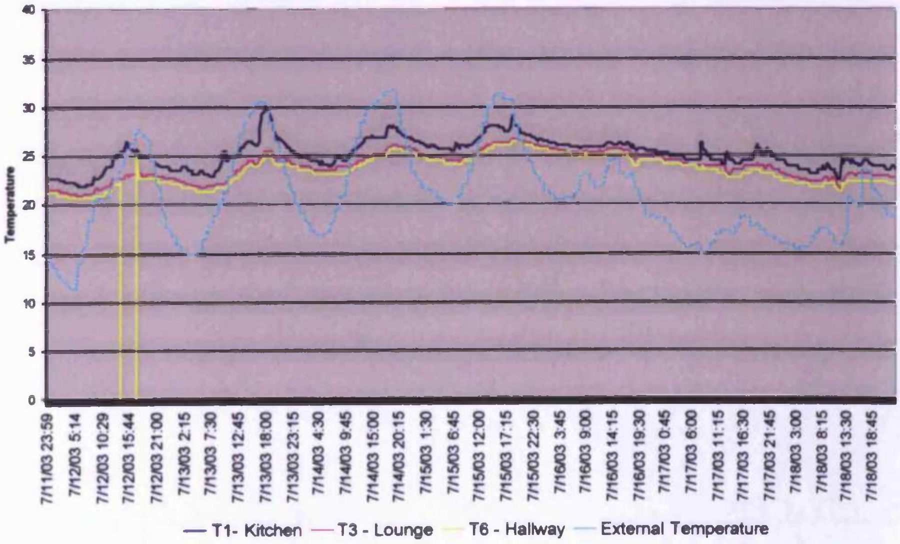


Figure 133: Summer Period - Week 6, Downstairs Temperatures

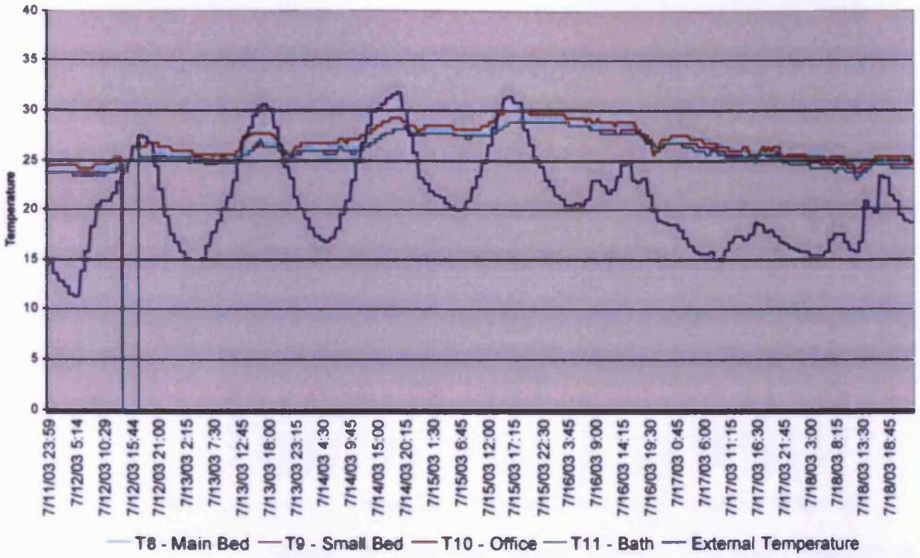


Figure 134: Summer Period - Week 6, Upstairs Temperatures

5.3.5.7 Week 7: 19th - 25th July 2003

The average temperature for this week was 17.8°C, with a minimum of 14.7°C and a maximum of 24.0°C. A much cooler week is reflected in higher relative humidity levels.

		Climate			RH1 - Bath			RH2 - Bed 2			RH3 - Kitchen			RH4 - Lounge		
		Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min
Week	7	75	91	46	56	72	52	58	66	54	57	66	46	41	46	37

Table 194: Summary of Relative Humidity, Internally and Externally for Week 7

Internal temperatures exceed those experienced externally throughout the week. The house was unoccupied for the weekend of the 19th and 20th July which is reflected in fewer fluctuations in internal temperatures.

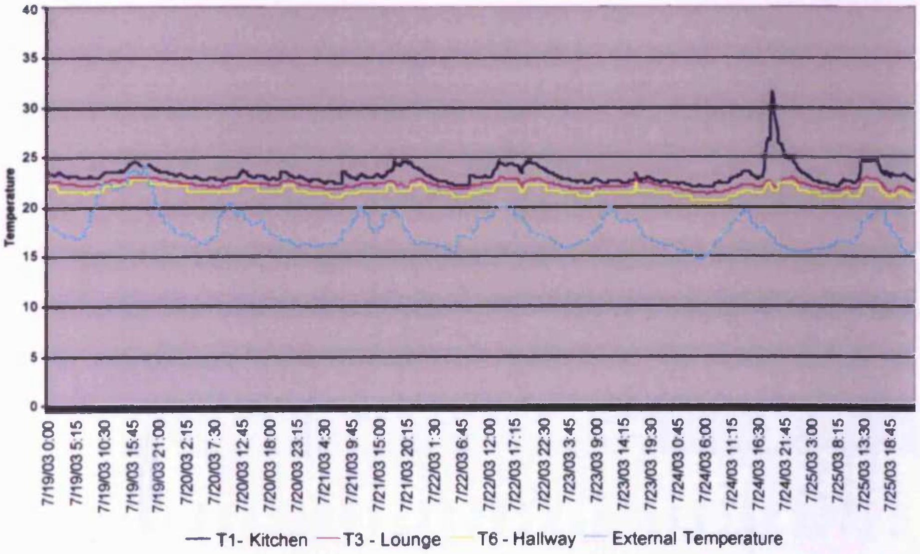


Figure 135: Summer Period - Week 7, Downstairs Temperatures

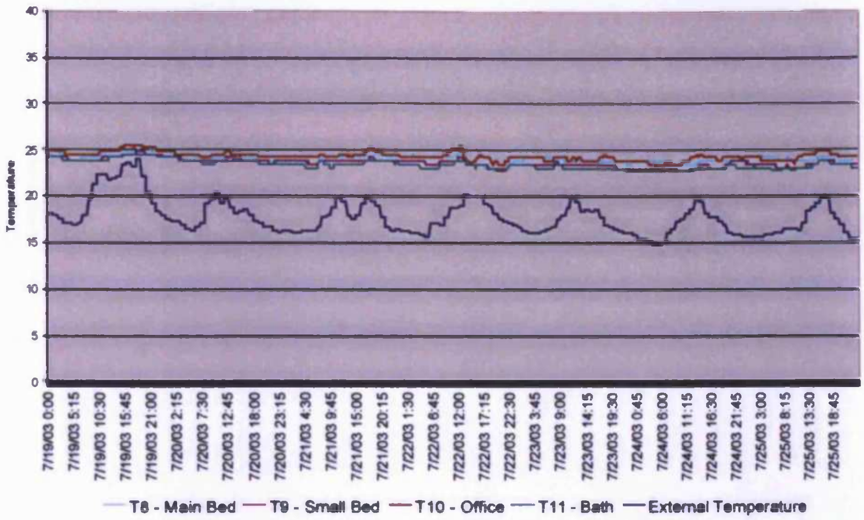


Figure 136: Summer Period - Week 7, Upstairs Temperatures

5.3.5.8 Week 8: 26th July – 1st August 2003

The average temperature for this week was 16.9°C, with a minimum of 11.7°C and a maximum of 21.3°C, while relative humidity levels were again higher.

		Climate			RH1 - Bath			RH2 - Bed 2			RH3 - Kitchen			RH4 - Lounge		
		Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min
Week	8	77	93	49	60	100	49	62	71	51	59	80	43	44	64	33

Table 195: Summary of Relative Humidity, Internally and Externally for Week 8

Overnight temperatures upstairs were elevated on the 26th July due to 2 adult guests occupying the office. The impact of increased occupation is also evident in the lounge, where evening temperatures for the 26th are also higher than would be anticipated. No explanation can be given from the diary record for the reduction in temperature experienced in the office on the afternoon of the 29th of July, flushing ventilation is suggested as an explanation for this rapid heat loss.

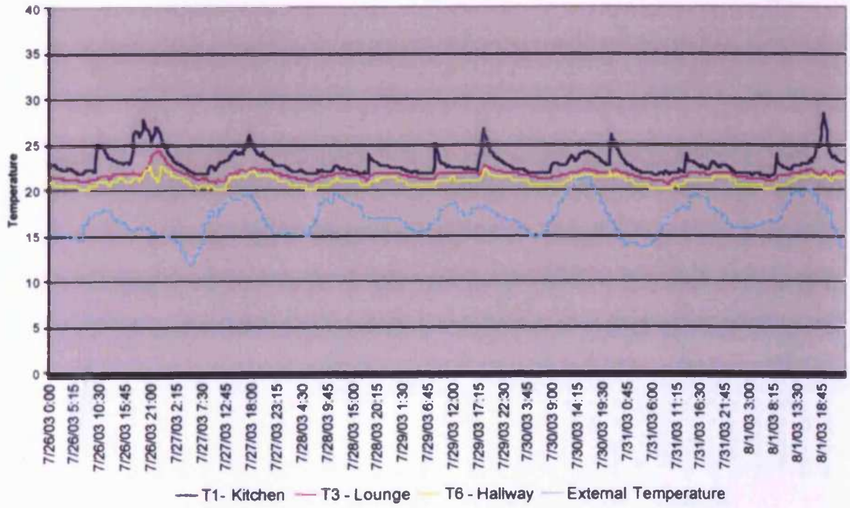


Figure 137: Summer Period - Week 8, Downstairs Temperatures

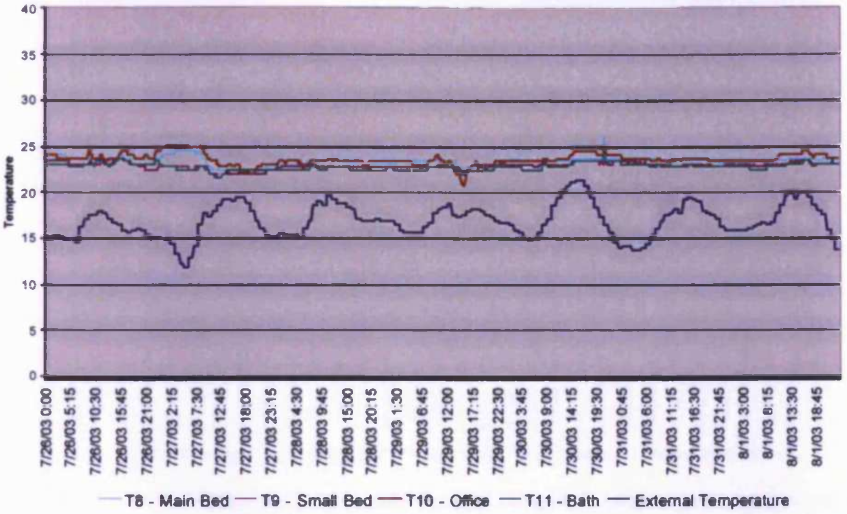


Figure138: Summer Period - Week 8, Upstairs Temperatures

5.3.5.9 Week 9: 2nd – 8th August 2003

The average temperature for this week was 21.3°C, with a minimum of 10.6°C and a maximum of 32.7°C. This increased temperature is reflected in lowered relative humidity levels.

		Climate			RH1 - Bath			RH2 - Bed 2			RH3 - Kitchen			RH4 - Lounge		
		Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min
Week	9	66	91	34	56	67	49	59	67	50	55	79	43	42	34	50

Table 196: Summary of Relative Humidity, Internally and Externally for Week 9

Internal temperatures throughout the property rose throughout this week, despite the use of increased ventilation throughout the day and night (where night-time ventilation was used in the main bedroom during this week despite the perceived potential security implications), with ground floor temperatures in the lounge rising from just above 20°C at the start of the week to above 25 °C at the end of the week. Upstairs the temperatures also rose by a similar 5°C throughout the week, reaching 27°C-30°C by the end of the week.

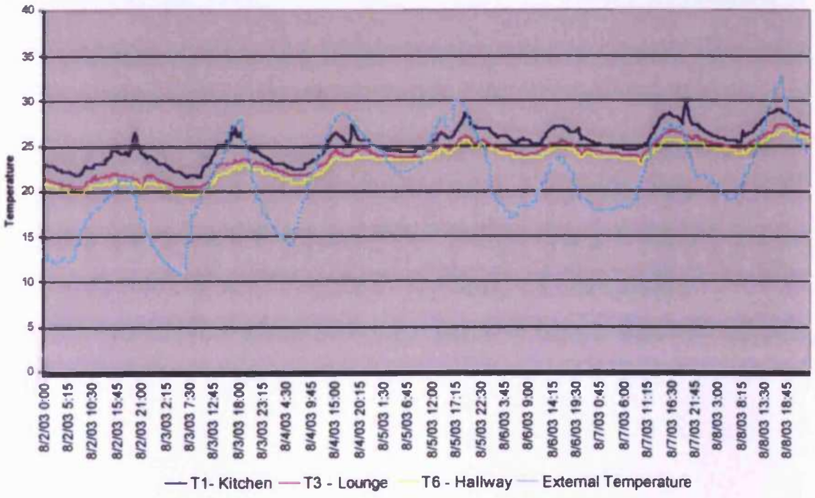


Figure 139: Summer Period - Week 9, Downstairs Temperatures

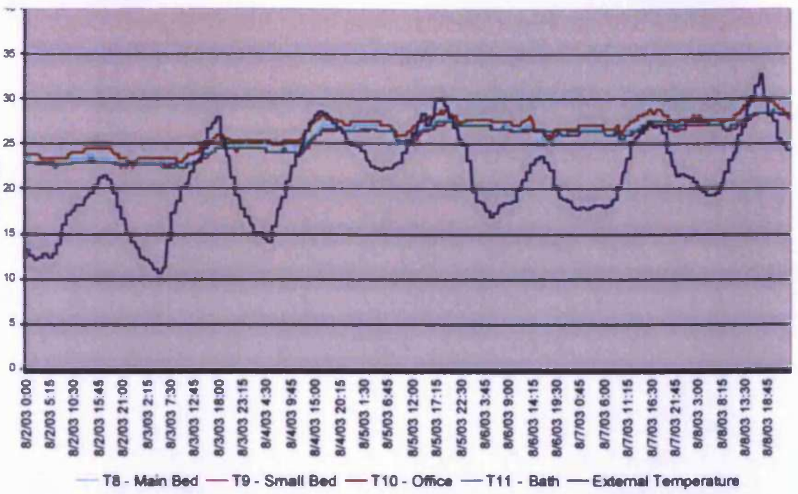


Figure 140: Summer Period - Week 9, Upstairs Temperatures

5.3.5.10 Week 10: 9th – 15th August 2003

The average temperature for this week was 21.8°C, with a minimum of 13.9°C and a maximum of 34.5°C (the peak temperature recorded by the WSA weather station for Cardiff for the summer of 2003), and was accompanied by lower relative humidity.

		Climate			RH1 - Bath			RH2 - Bed 2			RH3 - Kitchen			RH4 - Lounge		
		Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min
Week	10	61	92	30	50	62	34	54	36	66	51	62	34	38	48	25

Table 197: Summary of Relative Humidity, Internally and Externally for Week 10

The peak external temperature was associated with internal temperatures exceeding 30°C in the kitchen and throughout the upstairs of the property. As external temperatures dropped slowly throughout the week the internal temperatures reduced in line.

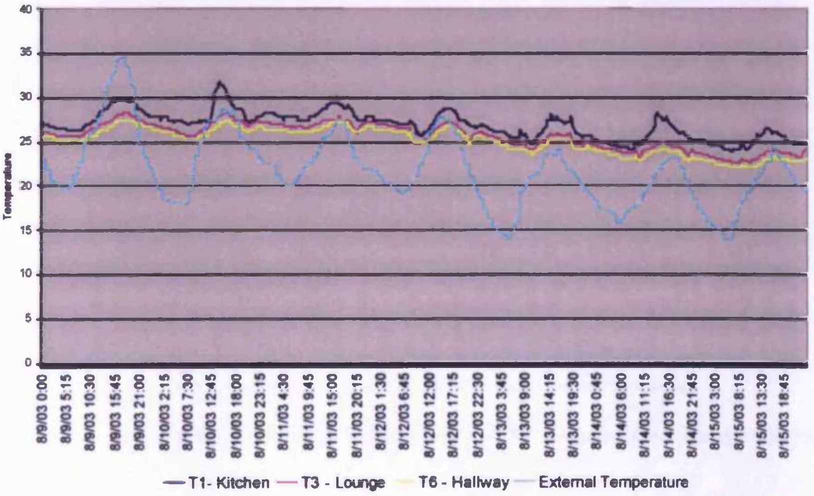


Figure 141: Summer Period - Week 10, Downstairs Temperatures

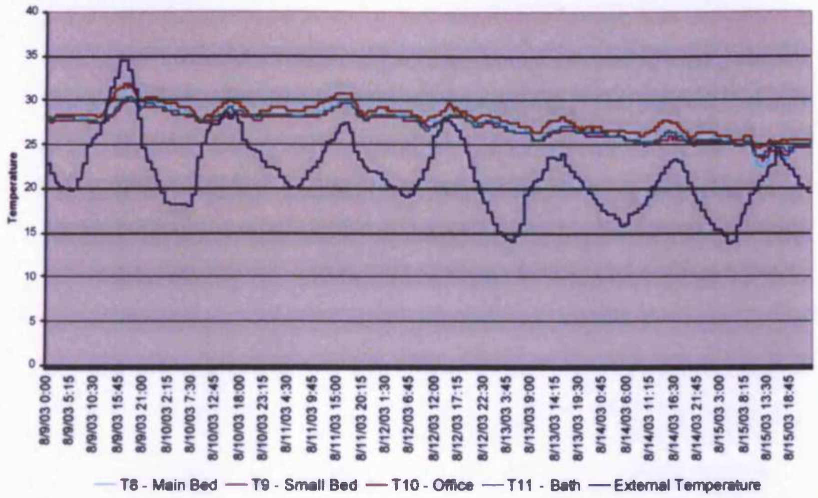


Figure 142: Summer Period - Week 10, Upstairs Temperatures

5.3.5.11 Week 11: 16th – 22nd August 2003

The average temperature for this week was 18.1°C, with a minimum of 11.5°C and a maximum of 24.2°C. Relative humidity levels increased in line with the decrease in temperatures.

		Climate			RH1 - Bath			RH2 - Bed 2			RH3 - Kitchen			RH4 - Lounge		
		Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min
Week	11	68	89	36	47	66	41	49	64	43	50	70	39	35	51	29

Table 198: Summary of Relative Humidity, Internally and Externally for Week 11

Temperatures throughout the property fluctuated around 25°C for the majority of the week, with upstairs temperatures continuing to exceed those experienced downstairs.

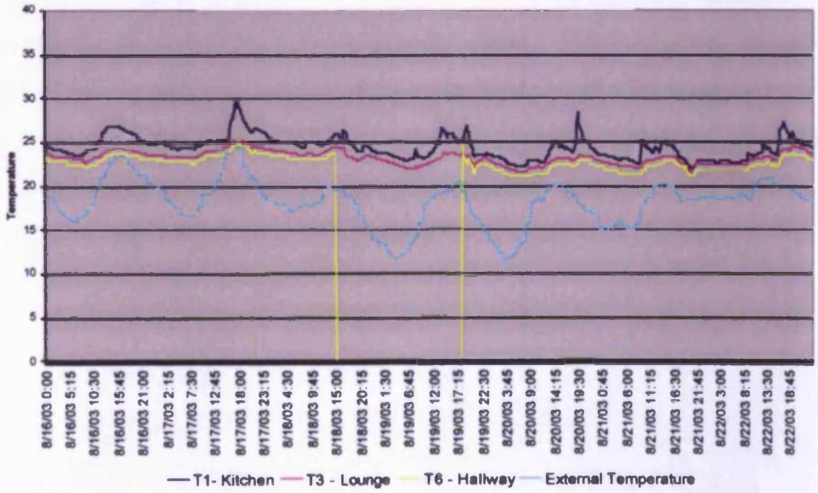


Figure 143: Summer Period - Week 11, Downstairs Temperatures

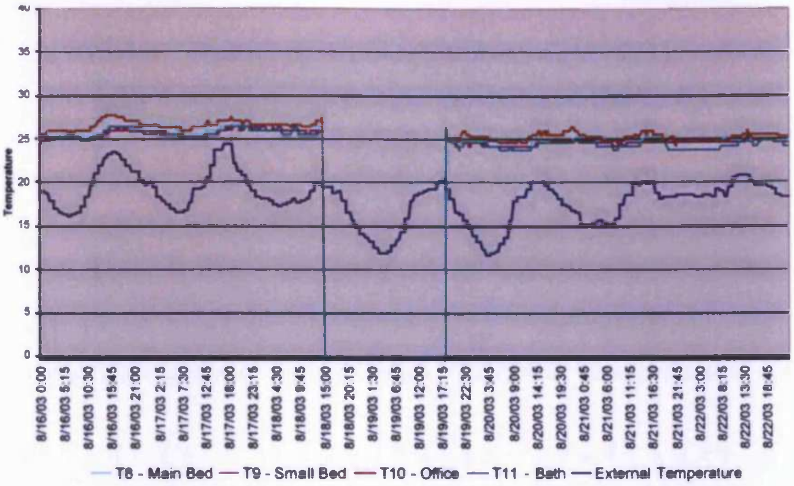


Figure 144: Summer Period - Week 11, Upstairs Temperatures

5.3.5.12 Week 12: 23rd – 29th August 2003

The average temperature for this week was 18.6°C, with a minimum of 10.5°C and a maximum of 26.2°C, while relative humidity levels had again increased in line with this reduction in temperatures.

	Climate			RH1 - Bath			RH2 - Bed 2			RH3 - Kitchen			RH4 - Lounge		
	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min
Week 12	66	91	45	49	63	41	54	63	48	53	66	44	38	48	33

Table 199: Summary of Relative Humidity, Internally and Externally for Week 12

As external temperatures decreased, so too did internal temperatures. This week the property was left unoccupied throughout and reflects a steady state, with no influence from occupants. The effect of solar gain on temperatures in the kitchen is clearly seen. Temperatures upstairs fluctuated slightly more widely than when the home was occupied, perhaps reflecting the influence of ventilation from open windows that would be closed for security reasons during this time. Further to this, heat gain due to hot water usage and related use of the boiler and Boilermate are also much reduced during an unoccupied period.

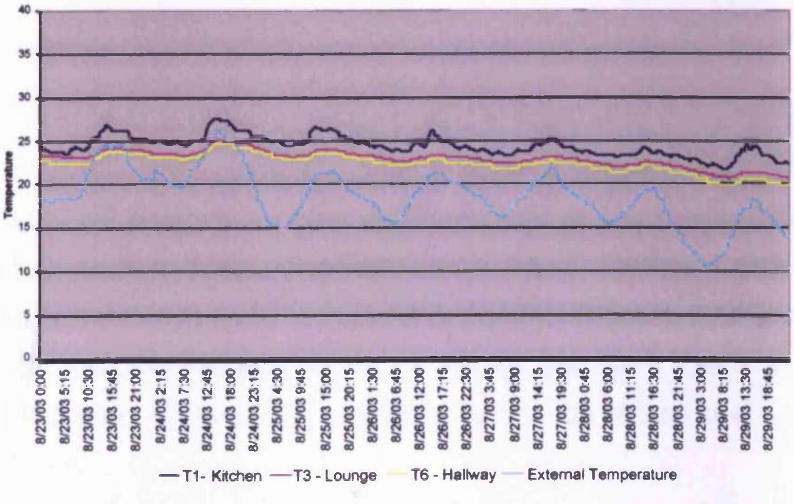


Figure 145: Summer Period - Week 12, Downstairs Temperatures

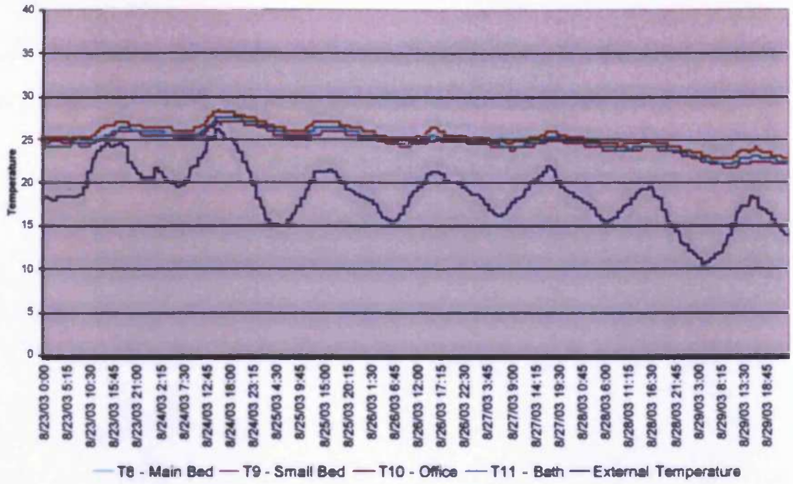


Figure 146: Summer Period - Week 12, Upstairs Temperatures

5.3.5.13 Summary

In summary it can be seen that temperatures experienced upstairs in the property are consistently 2°C-4°C higher than those downstairs. Further to this, those rooms with a southerly aspect are also consistently warmer than those facing north, as a result of solar gain. Both of these findings would be expected from first principles. In addition to this, occupation of the property has a significant influence on internal temperatures where higher numbers of occupants affect internal temperatures, specifically those experienced at night-time. Occupant interaction with the internal environment, through the use of hot water, ventilation, cooking and bathing also influences the internal thermal environment. The results of the monitoring for the summer, as well as other data not reproduced herein, suggest that the property is well insulated, with a high level of heat retention throughout the cooler night-time periods. This, despite shortcomings in the detailing of the construction highlighted by the thermography tests. However, it may be seen that this heat retention is not beneficial where night-time temperatures exceed those considered to be comfortable. Analysis to consider this monitored data in relation to thermal comfort for the seven monitored rooms follows.

5.3.6 Thermal Comfort Analysis

Having analysed the internal environment over the summer period in relation to the external temperature and occupant behaviour, it is now appropriate to consider the environment in terms of comfort. Three comfort standards will be applied to the monitored data in order to interpret occupant comfort in a quantitative manner: firstly, the European Adopted Thermal Comfort Standard for summer internal environment (as applied by Levermore et al, 2004, and Hacker et al, 2005) (European); secondly, the Adaptive Method (H&N) (Humphreys and Nicol, 1995); and finally, the ASHRAE Standard 55 Adaptive Method (ASHRAE). The calculation of the thresholds for these standards is explained below.

European Adopted Standard *(Levermore et al, 2004, Hacker et al 2005)*	**Warm threshold:** 25°C for more than 5% of the occupied time **Hot Threshold:** 28 °C for more than 1% of the occupied time.

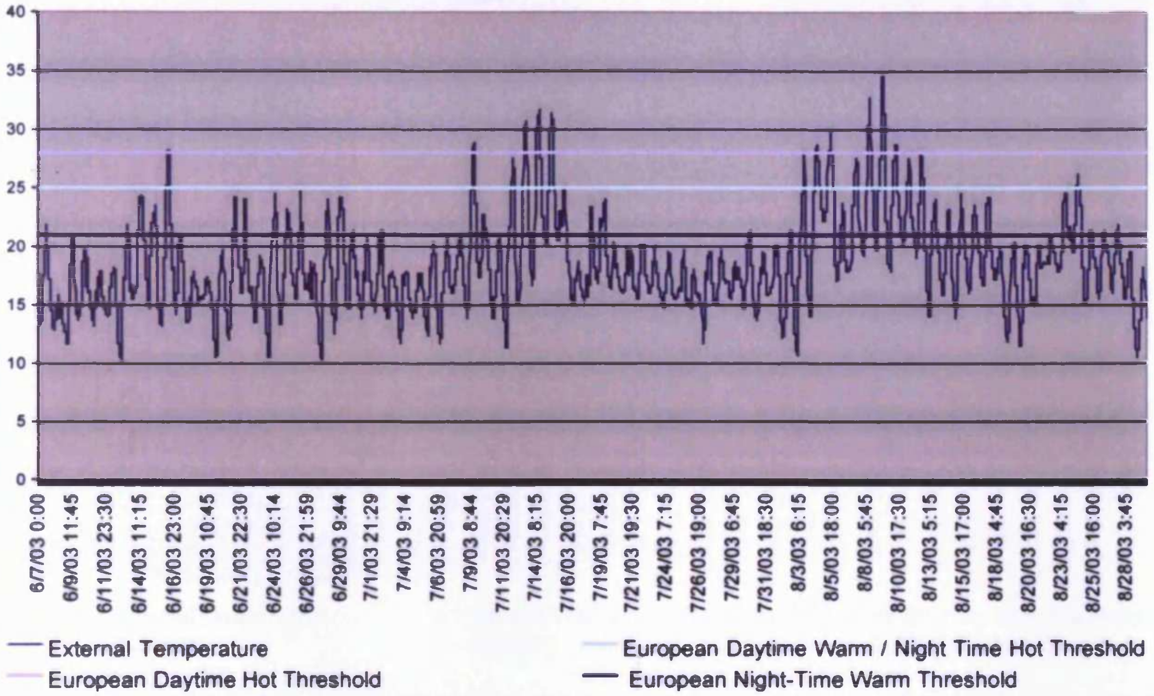


Figure 1476: European Adopted Summer Comfort Standards in the Context of the External Temperature for the 2003 Summer Monitoring Period

Adaptive Method *(Humphreys & Nicol, 1995)*	$T_{it} = 0.534\ T_o + 12.9$ (°C) T_{it} = Indoor Target Temperature T_o = Exponentially Weighted Running Mean of the Outdoor Temperature (The estimated comfort temperature can then be calculated to a standard error of 1.0°C for free running buildings)

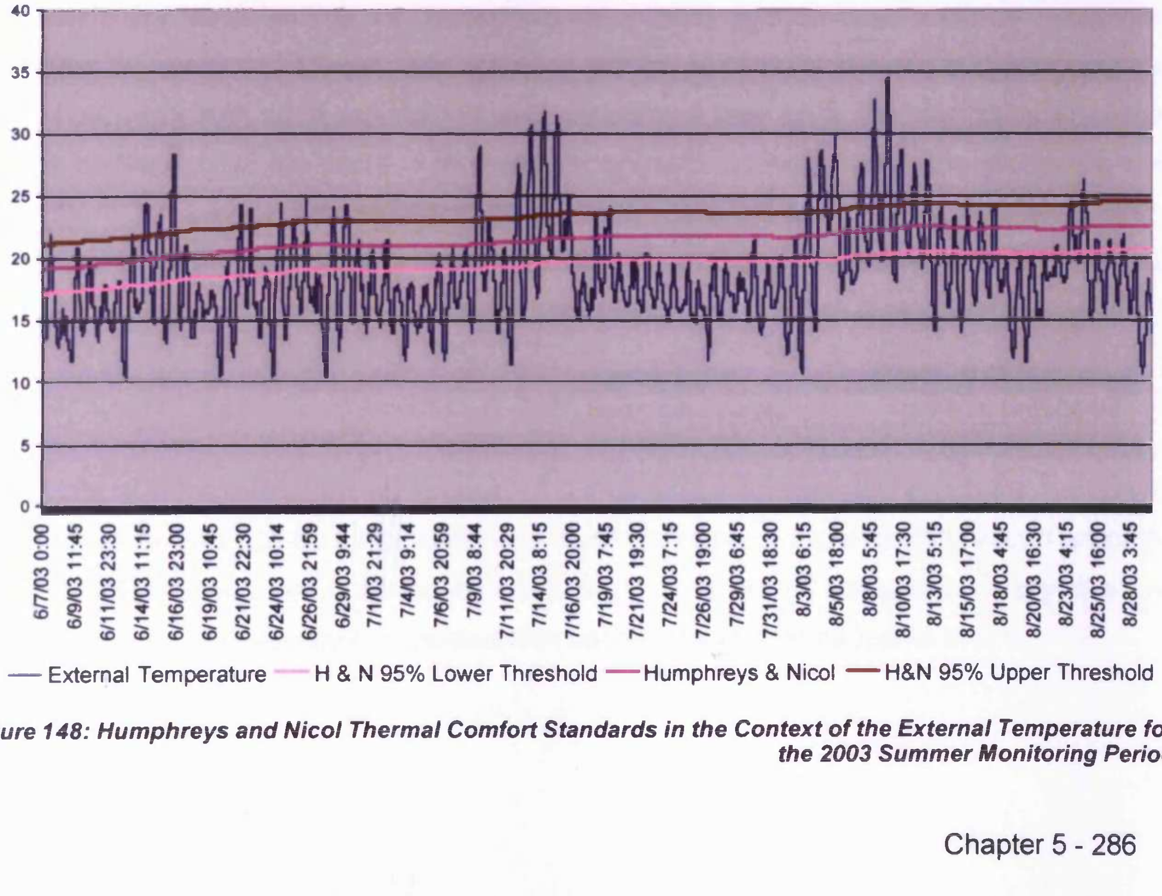


Figure 148: Humphreys and Nicol Thermal Comfort Standards in the Context of the External Temperature for the 2003 Summer Monitoring Period

Adaptive Method – ASHRAE Standard 55 *(ASHRAE 55 Rev, 2003)*	$T_{comf} = 0.31\,T_o + 17.8$ (°C) T_{comf} = Optimum Comfort Temperature T_o = Mean of the Outdoor Dry Bulb Temperature With a range of: 5(°C) for 90% thermal acceptability and 7(°C) for 80% thermal acceptability.

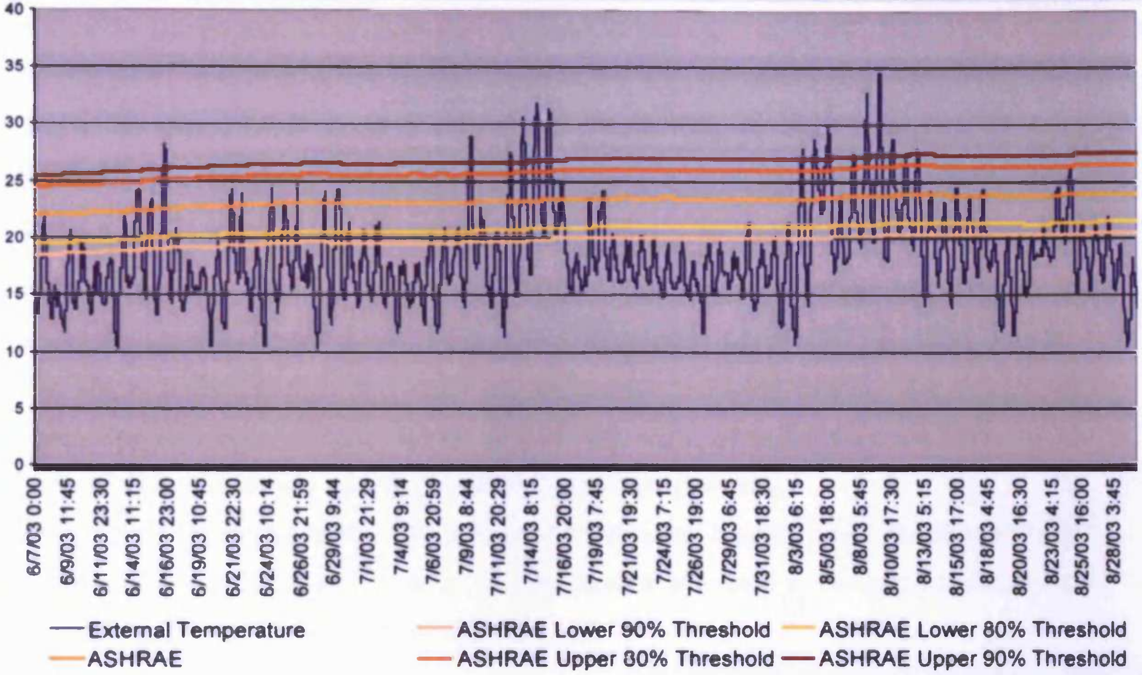


Figure 149: ASHRAE Standard 55 Thermal Comfort Standard in the Context of the External Temperature for the 2003 Summer Monitoring Period

In order to quantify comfort in the case study home it is also necessary to consider occupancy periods. The following have been defined for sleeping areas and other living areas. These can only be interpreted as broad estimates, as occupancy of homes varies from week to week within the same household and greatly between households. It should be noted that a three bedroom home would be considered to be appropriate for a family and as such continual occupation throughout the week would seem appropriate to ensure comfort for children and their carers at home. Further to this, each standard is also considered here on a 24 hour basis to enable broader application of the results, for example unusual working hours, the elderly or sick. Furthermore, the comfort standards for one bedroom space are to be shown as a 'living' space and as a 'bedroom' space. This is in order to consider changing use patterns for homes, such as home working and home offices, a use to which this space was put during the monitoring.

Space Type	Hours of Occupancy
Bedroom Spaces	20:00 until 08:00
Living Spaces	07:00 until 23:00

The accuracy of the monitoring equipment (+/- 0.5°C) will be considered through the inclusion of Confidence Intervals (CI) for each value. The comfort levels, as experienced through exposure to the external climate, are provided for comparison. This will be followed by analysis of the comfort levels experienced by occupants within each of the monitored rooms in turn.

5.3.6.1 Climate

This section is included in order to provide a comparison against which the internal environment within the case study home can be considered. The periods of exceedance of the thresholds for the three comfort standards to be considered here are provided for the external climate, as experienced for the twelve week summer monitoring period. The lower thresholds included for both the ASHRAE and the H&N standards indicate the percentage of occupancy hours for which the minimum comfort level is exceeded. These figures must therefore be interpreted differently from others in the table. For example:

- The figure highlighted in the table below in blue indicates that for the occupancy period for living spaces, 07:00 until 23:00, 90% of occupants are likely to be uncomfortable (too cold) during 61% of this occupancy period (100% - 39% = 61%).
- The figure highlighted in the table below in red indicates that for the occupancy period for bedroom spaces, 20:00 until 08:00, 95% of occupants are likely to be uncomfortable (too hot) during 3% of this occupancy period.
- The figure highlighted in the table in green indicates that for the occupancy period for bedroom spaces, 20:00 until 08:00, occupants are likely to be uncomfortable (too hot) during 2% of this occupancy period.

			Climate		
			Living Spaces	**Bedroom Spaces**	**24 hours**
ASHRAE Standard 55		**- 3.5°C: (90% Satisfied)**	39%	13%	29%
		- 2.5°C: (80% Satisfied)	30%	9%	22%
		Central Value	15%	3%	11%
		+ 2.5°C : (80% Satisfied)	8%	1%	5%
		+ 3.5°C: (90% Satisfied)	5%	1%	4%
Humphreys & Nicol		**95% Lower Threshold**	44%	14%	32%
		Central Value	26%	7%	19%
		95% Upper Threshold	15%	3%	10%
European Standard	**Day Time**	**Warm Threshold**	9%	-	21%
		Hot Threshold	3%	-	6%
	Night Time	**Warm Threshold**	-	9%	6%
		Hot Threshold	-	2%	2%

Table 200: % of Occupancy Periods during which Standard Thresholds are exceeded by the External Climate

Interpretation guidelines for the European Standards indicate that 'Warm' thresholds should not be exceeded for more than 5% of the occupancy period and 'Hot' thresholds should not be exceeded for 1% of the occupancy period. No similar interpretative guidelines are available for the ASHRAE of H&N thresholds. These figures therefore indicate that for all three comfort standards, the external climate exceeds acceptable standards.

5.3.6.2 Kitchen

The weekly analysis of internal climate identified the kitchen as frequently providing the hottest environment in the case study home. It can be seen that the ASHRAE 90% threshold is exceeded for 8% of the kitchen occupancy period (the accuracy interval for the monitoring equipment is indicated by the upper and lower bounds, in this case 5%-12%). In the case of the H&N 95% Comfort Threshold, this is exceeded for 66% of the time (54%-78%). The European

'Warm' threshold is exceeded for 28% of the time (20%-34%) and the European 'Hot' threshold is exceeded for 4% of the time (2%-6%), both of which exceed the summer comfort standards. However, despite this quantitative analysis of the thermal environment, the occupant interpretation of comfort for this space is less damming. Although during this period the occupants would consider this space to be uncomfortably hot the relatively short duration of occupancy duration does limit the impact of this discomfort.

			Kitchen					
			07.45 - 23.00 Living Room			24 hours		
			Lower	Central	Upper	Lower	Central	Upper
ASHRAE		- 3.5°C: (90% Satisfied)	100%	100%	100%	100%	100%	100%
		- 2.5°C: (80% Satisfied)	99%	100%	100%	98%	100%	100%
		Central Value	52%	65%	77%	44%	62%	69%
		+ 2.5°C : (80% Satisfied)	12%	17%	23%	10%	14%	19%
		+ 3.5°C: (90% Satisfied)	5%	8%	12%	4%	6%	10%
Humphreys & Nicol		95% Lower Threshold	100%	100%	100%	100%	100%	100%
		Central Value	95%	99%	100%	92%	98%	100%
		95% Upper Threshold	54%	66%	78%	45%	57%	70%
European Standard	Day Time	Warm Threshold	20%	28%	34%	17%	96%	29%
		Hot Threshold	2%	4%	6%	1%	23%	4%
	Night Time	Warm Threshold	-	-	-	91%	23%	98%
		Hot Threshold	-	-	-	17%	3%	29%

Table 201: % of Occupancy Periods during which Comfort Standard Thresholds are exceeded in the Kitchen

5.3.6.3 Lounge

During the weekly analysis of internal climate, the lounge and hallway were seen to be consistently cooler than the kitchen. This is reflected in a significant reduction in the periods of time in which the comfort standards are exceeded. For the ASHRAE 90% threshold, this is found to be exceeded for 1% of the living room occupancy period (0%-3%). In the case of the H&N 95% comfort threshold, this is exceeded for 26% of the time (18%-40%). The European 'Warm' threshold is exceeded for 10% of the tme (7%-13%), leading to failure to meet this standard although the European 'Hot' threshold is not exceeded for more than 1% of the time (0-1%). This quantitative interpretation of the thermal environment is in line with occupant interpretation of comfort within this space. Very rarely would the occupants perceive this space to be too hot. Greater levels of occupancy, for example when visitors are present would increase this problem, as would heat gains due to cooking.

			Lounge					
			07.45 - 23.00 Living Room			24 hours		
			Lower	Central	Upper	Lower	Central	Upper
ASHRAE		- 3.5°C: (90% Satisfied)	99%	100%	100%	99%	100%	100%
		- 2.5°C: (80% Satisfied)	89%	96%	99%	85%	95%	99%
		Central Value	18%	27%	37%	16%	24%	33%
		+ 2.5°C : (80% Satisfied)	3%	5%	7%	2%	4%	6%
		+ 3.5°C: (90% Satisfied)	0%	1%	3%	0%	1%	2%
Humphreys & Nicol		95% Lower Threshold	99%	100%	100%	99%	100%	100%
		Central Value	72%	87%	95%	79%	83%	94%
		95% Upper Threshold	18%	26%	40%	16%	23%	34%
European Standard	Day Time	Warm Threshold	7%	10%	13%	6%	9%	12%
		Hot Threshold	0%	0%	1%	0%	0%	0%
	Night Time	Warm Threshold	-	-	-	69%	83%	91%
		Hot Threshold	-	-	-	6%	9%	12%

Table 202: % of Occupancy Periods during which Comfort Standard Thresholds are exceeded in the Lounge

5.3.6.4 Hallway

The hallway is found to be more comfortable than the lounge, with the ASHRAE 90% threshold rarely exceeded (0%-1%) throughout the day. In the case of the H&N 95% comfort threshold this is exceeded for 15% of the day (11%-22%). The European 'Warm' day time threshold is not exceeded, while the European 'Hot' daytime threshold is exceeded for 8% of the time (4%-9%). Occupancy is transient in this space, however, it was always perceived as comfortable and mostly comfortably cool by the occupants, which is reasonably reflected in this quantitative interpretation of comfort, although the H&N comfort standard does not appear to reflect this.

			Hallway					
			07.45 - 23.00 Living Room			24 hours		
			Lower	Central	Upper	Lower	Central	Upper
ASHRAE		- 3.5°C: (90% Satisfied)	94%	98%	100%	90%	96%	98%
		- 2.5°C: (80% Satisfied)	67%	83%	94%	61%	77%	90%
		Central Value	13%	17%	27%	12%	16%	24%
		+ 2.5°C : (80% Satisfie	1%	3%	5%	1%	2%	4%
		+ 3.5°C: (90% Satisfied	0%	0%	1%	0%	0%	1%
Humphreys & Nicol		95% Lower Threshold	98%	99%	100%	96%	97%	98%
		Central Value	51%	67%	83%	45%	61%	77%
		95% Upper Threshold	13%	17%	25%	11%	15%	22%
European Standard	Day Time	Warm Threshold	5%	8%	10%	4%	8%	9%
		Hot Threshold	0%	0%	0%	0%	0%	0%
	Night Time	Warm Threshold	-	-	-	53%	63%	82%
		Hot Threshold	-	-	-	4%	8%	9%

Table 203: % of Occupancy Periods during which Comfort Standard Thresholds are exceeded in the Hallway

5.3.6.5 Bathroom

The internal environment in the bathroom exceeds all three thermal comfort standards. The ASHRAE 90% threshold is exceeded for 9% of the "living room" occupancy period (7%-13%), while in the case of the H&N 95% Comfort Threshold, this is exceeded for 73% of the day (62%-84%). Furthermore, both European Summer Comfort Standards are exceeded. For the 'Warm' day time threshold this is exceeded during 29% of the "living room" occupancy period (21%-33%) and for the European 'Hot' daytime threshold is exceeded for 5% of the time (2%-7%). As was the case for the kitchen, the relatively short duration of occupancy within this space is not reflected in this quantitative comfort interpretation. It should also be noted that where the occupancy is for a relatively long period of time, clothing levels are zero and as such it is likely that higher temperatures would be perceived as comfortable. The thermal environment in this space was perceived to be warm to hot by the occupants, but this did not influence the function of this space, which remained fit for purpose.

			Bathroom					
			07.45 - 23.00 Living Room			24 hours		
			Lower	Central	Upper	Lower	Central	Upper
ASHRAE		- 3.5°C: (90% Satisfied)	100%	100%	100%	100%	100%	100%
		- 2.5°C: (80% Satisfied)	100%	100%	100%	100%	100%	100%
		Central Value	58%	16%	89%	57%	70%	86%
		+ 2.5°C : (80% Satisfied)	13%	17%	24%	12%	17%	23%
		+ 3.5°C: (90% Satisfied)	7%	9%	13%	7%	9%	12%
Humphreys & Nicol		95% Lower Threshold	100%	100%	100%	100%	100%	100%
		Central Value	98%	99%	100%	99%	99%	100%
		95% Upper Threshold	62%	73%	84%	60%	72%	83%
European Standard	Day Time	Warm Threshold	21%	29%	33%	20%	28%	32%
		Hot Threshold	2%	5%	7%	2%	5%	7%
	Night Time	Warm Threshold	-	-	-	98%	98%	98%
		Hot Threshold	-	-	-	20%	28%	32%

Table 204: % of Occupancy Periods during which Comfort Standard Thresholds are exceeded in the Bathroom

5.3.6.6 *Bedroom 1*

Bedroom 1 was consistently found to be the hottest room in the case study house. The following analysis of thermal comfort standards, considers both living room and bedroom occupation hours, as this space is used for both purposes, reflecting the need for flexibility in the use of space in homes. In relation to the living room occupation period, all three thermal comfort standards are exceeded: ASHRAE 90% threshold 16% of the time (12%-22%), H&N 95% threshold 93% of the time (82%-97%) and the European 'Warm' threshold 46% of the tme (31%-53%) and 'Hot' day time threshold 10% of the time (6%-12%). In relation to the bedroom occupation period, all three standards are again exceeded: ASHRAE 90% threshold 14% of the time (9%-20%), H&N 95% threshold 79% of the time (91%-97%), the European 'Warm' threshold 100% of the time and the 'Hot' day time threshold 43% of the time (30%-52%). It can be seen that this room exceeds all comfort thresholds for significant periods of time, and throughout the day. This space was frequently perceived by the occupants to be too hot for comfort during the day, while being used as an office as well as by guests, when being used as a bedroom during the night. Achieving comfort through use of night time ventilation was also problematic, due to discomfort from cold air as well as night time noise from neighbours and concerns for security.

			Bedroom 1								
			07.45 - 23.00 Living Room			20:00 - 08.00 Bedroom			24 hours		
			Lower	Central	Upper	Lower	Central	Upper	Lower	Central	Upper
ASHRAE		- 3.5°C: (90% Satisfied)	100%	100%	100%	100%	100%	100%	100%	100%	100%
		- 2.5°C: (80% Satisfied)	100%	100%	100%	100%	100%	100%	100%	100%	100%
		Central Value	85%	92%	98%	82%	90%	99%	83%	91%	98%
		+ 2.5°C : (80% Satisfied)	22%	28%	41%	20%	26%	37%	21%	27%	40%
		+ 3.5°C: (90% Satisfied)	12%	16%	22%	9%	14%	20%	11%	16%	21%
Humphreys & Nicol		95% Lower Threshold	100%	100%	100%	100%	100%	100%	100%	100%	100%
		Central Value	99%	100%	100%	99%	100%	100%	99%	100%	100%
		95% Upper Threshold	82%	93%	97%	79%	91%	97%	81%	92%	97%
European Standard	Day Time	Warm Threshold	31%	46%	53%	-	-	-	30%	45%	52%
		Hot Threshold	6%	10%	12%	-	-	-	6%	9%	12%
	Night Time	Warm Threshold	-	-	-	100%	100%	100%	100%	100%	100%
		Hot Threshold	-	-	-	30%	43%	52%	30%	45%	52%

Table 205: % of Occupancy Periods during which Comfort Standard Thresholds are exceeded in the Bedroom

5.3.6.7 Bedroom 2

Bedroom 2 also exceeds all thermal comfort thresholds being considered here, despite its northerly orientation. In relation to the bedroom occupation period: ASHRAE 90% threshold is exceeded for 11% of the time (8%-15%), H&N 95% threshold for 73% of the time (91%-95%), the European 'Warm' threshold for 100% of the time and the 'Hot' day time threshold 38% of the time (25%-45%). The perception of thermal comfort by occupants of this space at night was comfortably warm to too hot during the hotter periods of this monitoring period. Efforts to achieve thermal comfort at night included the use of fans and open windows and doors throughout the property to promote the flow of air. The relative lower levels of discomfort predicted by the comfort standards in relation to bedroom 1 are in line with perceived occupant thermal comfort, although the frequency of standard exceedance appears to be higher than occupant experience.

			Bedroom 2					
			20:00 - 08.00 Bedroom			24 hours		
			Lower	Central	Upper	Lower	Central	Upper
ASHRAE		- 3.5°C: (90% Satisfied)	100%	100%	100%	100%	100%	100%
		- 2.5°C: (80% Satisfied)	100%	100%	100%	100%	100%	100%
		Central Value	79%	89%	98%	75%	87%	97%
		+ 2.5°C : (80% Satisfied)	15%	23%	33%	15%	21%	31%
		+ 3.5°C: (90% Satisfied)	8%	11%	15%	7%	10%	15%
Humphreys & Nicol		95% Lower Threshold	75%	100%	100%	100%	100%	100%
		Central Value	99%	99%	100%	99%	99%	100%
		95% Upper Threshold	73%	91%	95%	71%	89%	95%
European Standard	Day Time	Warm Threshold	-	-	-	24%	36%	43%
		Hot Threshold	-	-	-	2%	6%	9%
	Night Time	Warm Threshold	100%	100%	100%	100%	100%	100%
		Hot Threshold	25%	38%	45%	24%	36%	43%

Table 206: % of Occupancy Periods during which Comfort Standard Thresholds are exceeded in Bedroom 2

5.3.6.8 Bedroom 3

Bedroom 3 is cooler than the other bedrooms but is also found to exceed all thermal comfort thresholds being considered here, despite its northerly orientation. In relation to the bedroom occupation period: ASHRAE 90% threshold is exceeded for 7% of the time (6%-11%), Humphreys and Nicol 95% Threshold for 78% of the time (63%–86%), the European 'Warm' threshold for 100% of the time and 'Hot' day time threshold 30% of the time (19%-34%). Occupancy of this space during the night was zero and therefore, no perceived occupant comfort levels are available. In addition there were to occupancy gains to this space during this period, which would have provided greater thermal gain to the space.

			Bedroom 3					
			20:00 - 08.00 Bedroom			24 hours		
			Lower	Central	Upper	Lower	Central	Upper
ASHRAE		- 3.5°C: (90% Satisfied)	100%	100%	100%	100%	100%	100%
		- 2.5°C: (80% Satisfied)	100%	100%	100%	100%	100%	100%
		Central Value	62%	73%	91%	62%	74%	91%
		+ 2.5°C : (80% Satisfiec	11%	16%	25%	11%	16%	24%
		+ 3.5°C: (90% Satisfied	6%	7%	11%	6%	8%	11%
Humphreys & Nicol		95% Lower Threshold	100%	100%	100%	100%	100%	100%
		Central Value	99%	99%	99%	98%	99%	99%
		95% Upper Threshold	63%	78%	86%	63%	76%	86%
European Standard	Day Time	Warm Threshold	-	-	-	19%	30%	34%
		Hot Threshold	-	-	-	2%	5%	7%
	Night Time	Warm Threshold	100%	100%	100%	100%	100%	100%
		Hot Threshold	19%	30%	34%	19%	30%	34%

Table 207: % of Occupancy Periods During which Comfort Standard Thresholds are Exceeded in Bedroom 3

5.3.7 Summary

It was found that all monitored rooms in the case study home exceeded at least two of the three thermal comfort thresholds being considered herein during the 12 week summer monitoring period. The monitored rooms located upstairs in the property were less comfortable than rooms downstairs, while night-time discomfort levels can be seen to exceed day-time discomfort for all bedrooms. It should be noted that all three thermal comfort standards together with the occupancy periods applied to the bathroom and kitchen appear to exaggerate the thermal discomfort experienced by occupants. This is likely to be due to the relatively short duration of occupation of both spaces as well as the absence of clothing during longer periods of occupation, specifically in the bathroom. However, it can be suggested that health and comfort risk due to excess heat is substantial under current climate. It follows therefore that future risk, where the source variables for excess heat identified in section 3.3.1.1.3 of temperature, relative humidity, wind, solar radiation and solar cloud cover are likely to contribute to the risk system to negatively influence future risk.

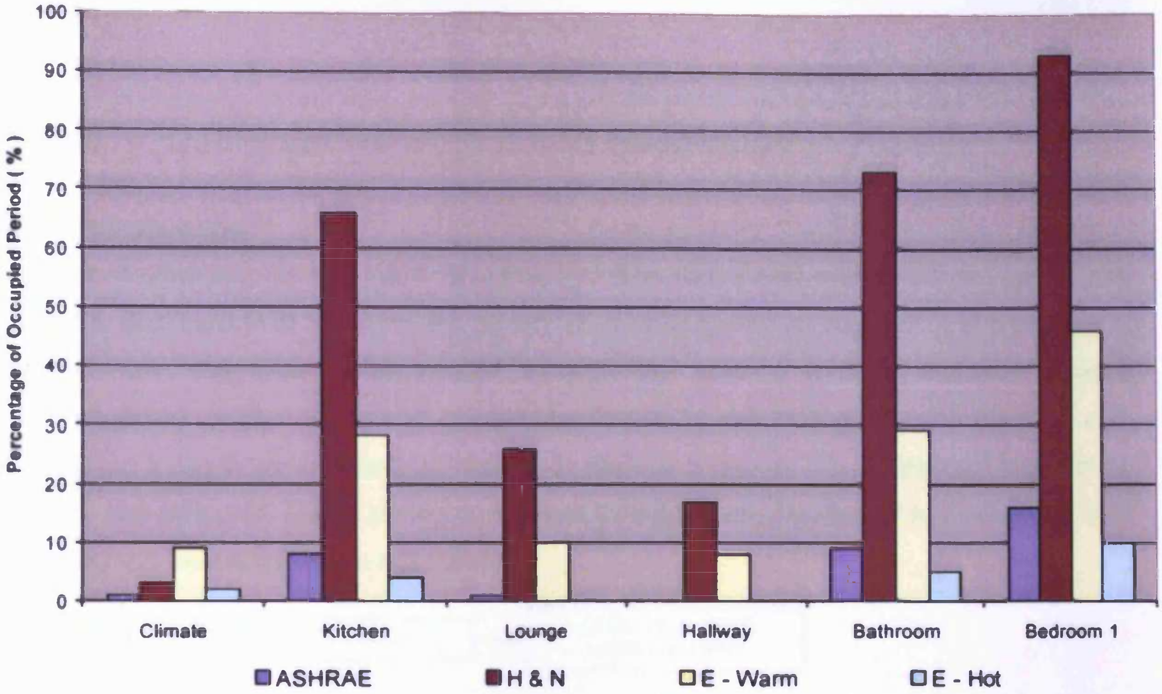


Figure 150: Summary of the Proportion of Time Living Rooms Exceeded the ASHRAE, H&N and European Thermal Comfort Standards During Periods of Occupation for the Summer Monitoring Period

It can be seen that the H&N thermal comfort standard suggests thermal discomfort is likely during a significant proportion of the time in each of the spaces considered, while the ASHRAE, and European "hot" predict a significantly lower proportion of time as uncomfortable. From interpretation of occupancy comfort during this period it is considered that the ASHRAE standard reflects most closely occupant comfort during the monitoring period.

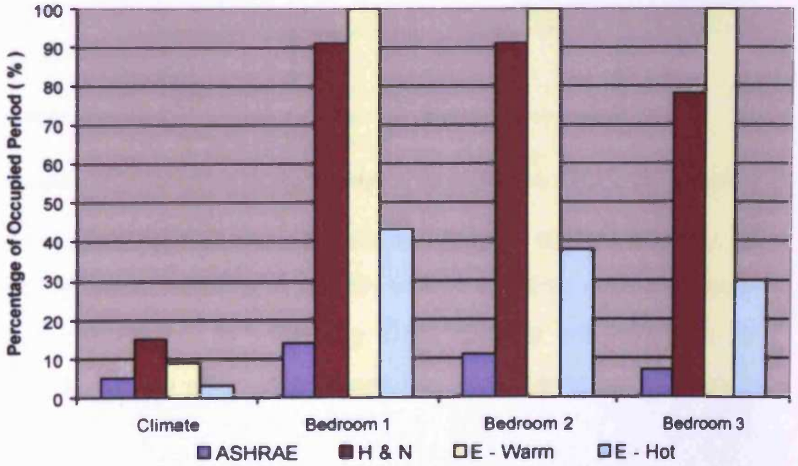


Figure 151: Summary of the Proportion of Time Bedrooms Exceeded the ASHRAE, H&N and European Thermal Comfort Standards During Periods of Occupation for the Summer Monitoring Period

For the bedrooms, it can be seen that the European "warm" threshold is exceeded for 100% of the period and the ASHRAE standard is again reflects most closely the proportion of time during which the occupants perceived discomfort during the monitoring period.

Chapter 6 - Occupant Behaviour and Adaptation

6.1 Introduction

Risks due to a changing climate within the risk systems associated with occupant health and comfort in the domestic built environment health have been identified as a result of a number of factors. However, the systems expressed through the source, pathway receptor models explicitly defined in chapter 3 and the current distribution of risk during extreme summer and winter identified through surveys and monitoring in chapter 5 can be altered through changes to the pathway and receptor. These changes, if made through consideration of and response to a potential risk, can be described as adaptation.

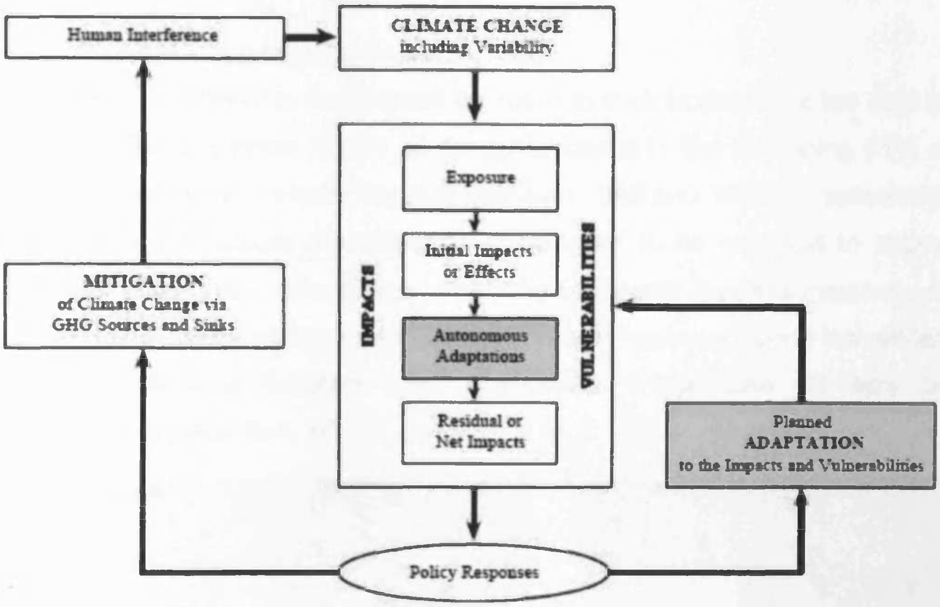


Figure 152: Places of Adaptation in the Climate Change Issue (IPCC, 2001b, p881)

Through further analysis of health and comfort risk, appropriate adaptation measures may be established to ensure continued occupant comfort and health within existing and new-build housing under global climate change during the 21st Century. This chapter will now identify appropriate adaptation responses which can be seen to address the risks being considered in this work.

Broadly, the adaptations discussed below will address housing, neighbourhood and behavioural factors identified as influencing the risk systems being considered in this study; while, housing and neighbourhood factors will consider the potential for adaptation both for the existing built environment as well as providing potential for adaptation to new build homes. Adaptation opportunities for each risk factor will be considered in turn, within the context of the risk problem map created in chapter 3. Firstly, opportunities relating to the pathway, including neighbourhood and building scale adaptation, will be considered in relation to both existing and new build properties. Finally, behavioural adaptation will be considered in the context of current behaviour, as established through survey and reported in chapter 5.

6.2 Winter

Appropriate adaptation, to enable alleviation of risk to occupant health and comfort as a result of the following winter risk factors, will now be considered:

- Thermal: Inadequate Heat
- Ventilation & Air Pollution
- Incidence of Condensation, Damp & Mould
- Material & Structural Damage

6.2.1 Risk Factor: Thermal – Inadequate Heat

It was found that 49% of NPT households considered no room in their home to be too cold or draughty during the winter. The presence of cold or draughty rooms in the remaining 51% of properties was found to be most likely in properties built between 1945 and 1980, in households with higher annual fuel costs and where property was considered to be exposed to strong winds. Through analysis of current literature it was considered probable that the incidence of excessive cold would decrease, while incidence of draughts would increase during the winter. Through reference to the following problem map, appropriate adaptations will now be considered for the risk due to inadequate heat.

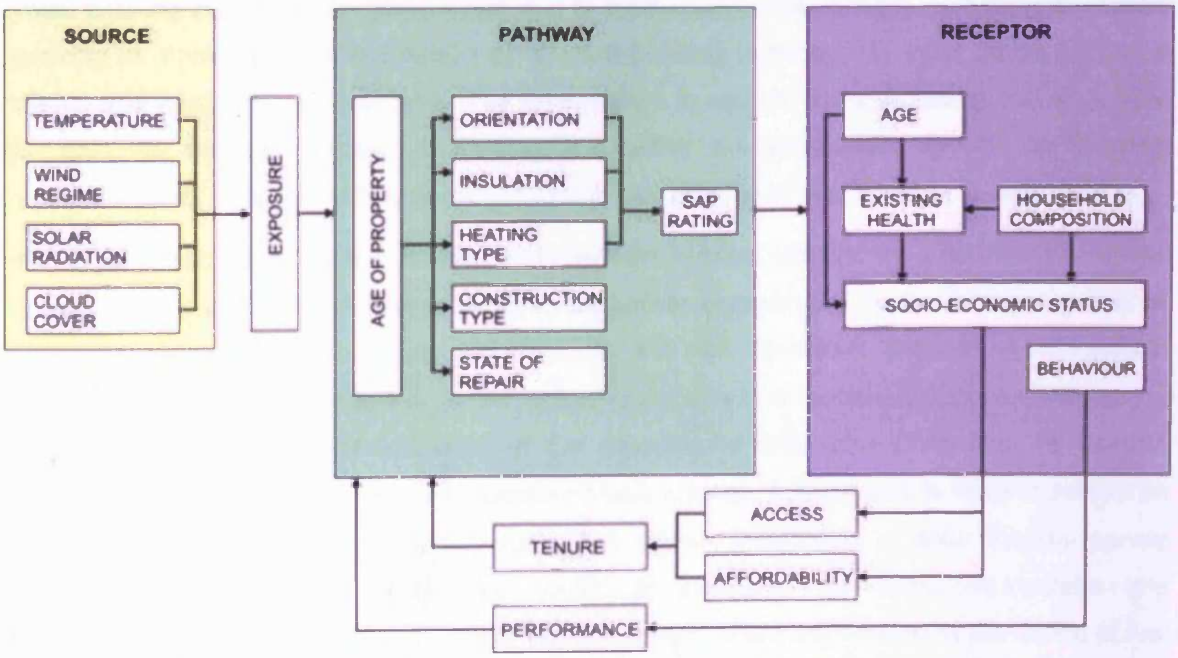


Figure 153: Simple Problem Map for Occupant Health & Comfort Risk Factor: Thermal – Inadequate Heat

6.2.1.1 *Inadequate Heat: Pathway Factors*

Adaptation to achieve a reduction in occupant health and comfort risk due to climate change, reflects the widespread aim for lowering carbon emissions from the built environment, together with the eradication of fuel poverty. As a result it is not considered appropriate to reproduce in detail the low and zero carbon design principles necessary to achieve this objective in this study. Rather to reinforce the dual necessity of retention of heat, through insulation and air tight construction as well as efficient delivery of heat through building services. The installation of loft insulation is likely to be widely acceptable in almost all properties, however, the installation of cavity wall insulation, internal lining or external cladding, may not be possible in all properties due to their construction (Thomas et al, 1992). The alteration of air tightness in older properties should only be considered where this is not likely to be detrimental to their intended mode of performance, in relation to breath-ability (Thomas et al, 1992). An example of efficient building services could be a more widespread application of mechanical ventilation with heat recovery (MVHR) which in combination with increased air tightness could provide an efficient method for heating properties (this heating method is more widespread in Europe). Finally, the use of low and zero carbon energy sources can be incorporated into buildings to further achievement of this objective.

The introduction of Home Information Packs (HIPS) and energy performance certification for existing properties, in partial fulfilment of the European Energy Performance of Buildings Directive, will go some way to encourage homeowners to decrease carbon emissions from their homes. Existing buildings can reduce risk due to inadequate heat through increasing insulation, improving air tightness and installation of efficient building services, (in most cases boilers).In addition, at a neighbourhood scale it may be possible to reduce overshadowing and so enable solar gain, for example through pollarding or pruning tall vegetation, as well as reducing exposure to wind, which may be achieved through the planting of lower height shelter belts.

It should be noted here that the relationship between heating affordability and climate change, discussed in the literature review, is likely to be further complicated by the increasing cost of traditional energy sources, including grid electricity and gas. Therefore, despite the increases in external temperatures, the potential for rising fuel costs due to oil price inflation, may negate the savings made as a result of reduction in the amounts of fuel required to achieve thermal comfort. It is therefore suggested that despite climate change, fuel poverty is likely to remain as a factor in relation to thermal comfort during the winter. Installation of solar thermal panels delivering “free” hot water for those in fuel poverty, in association with increased insulation and air tightness, would seem to be an appropriate adaptation to ensure continued alleviation of fuel poverty within the framework of increasing energy costs. For new build homes all of the pathway factors identified above should be addressed at the design stages to enable optimisation of building design for low carbon and thermally comfortable homes.

6.2.1.2 Inadequate Heat: Receptor Factors

During the winter, the control of heating was found to be associated with achievement of thermal comfort in households, where the presence of TRV's and a greater number of insulation measures were associated with increased controllability of heating systems. Although timers and / or thermostats were present in the majority of homes, their presence was not found to be significantly associated with controllability of central heating. Despite the presence of these controls, many households used the on / off switch (or the thermostat in this manner) or simply opened windows to control the internal environment. The development and more widespread application of finer heating controls would therefore seem to be an important factor in achieving more widespread thermal comfort during the winter. Current campaigns regarding energy efficiency suggest significant savings to energy bills could be achieved if domestic thermostat set points were reduced by one degree. However, if housing occupants do not currently use these finer control methods (such as thermostats and timers) for their heating, these campaigns are not likely to deliver widespread energy savings in line with the energy efficiency gains required to achieve current climate change mitigation targets. The results of this work do, however, suggest that further increases in levels of insulation are considered likely to help to alleviate perceived household heating problems in NPT.

For the case study property, thermal comfort levels were consistently achieved throughout the property during the winter. The heating system in this property was controlled by means of timer, thermostat and radiator TRV's throughout the monitoring period. It was found that despite the presence of fine controls for the heating system, persistent differences were present between the upstairs and downstairs temperatures, particularly in the mornings, following a period of little or no heating through the night.

In relation to building services it is therefore important that these are easily controllable and the widespread installation of TRV's and the possible zoning of heating systems to enable consideration of building orientation and buoyancy of hot air (the 'stack' effect) may help to ensure delivery of thermal comfort throughout a home. For example, in the case of the monitored home, it was difficult to control temperatures, despite the presence of TRVs on all radiators, and deliver comfort on both the lower and upper floor due to internal gains from the thermal store located upstairs. This may have been considered likely due to the buoyancy of hot air. Furthermore, the education of occupants as to the appropriate use of existing heating controls together with more intuitive design of building services controls are likely to assist in delivery of a decrease in risk due to inadequate heat. Finally the interaction of occupants with their home can have a significant influence on the actual passive thermal gains achieved in a property due to the sun. Where occupants do not interact with curtains or blinds to optimise thermal gain, opening curtains in the day and closing them at night, potential solar gain can result in a net loss through glazing.

The presence of widespread disagreement between the sexes in the domestic setting in relation to thermal comfort levels in 38% of NPT households, is of further interest. Previous studies of thermal comfort, many of which have concentrated on office and laboratory controlled environments, have suggested that no difference exists between the sexes in relation to objective comfort levels. However, this finding suggests that differences may occur in the domestic setting. No further rationalisation of this result is appropriate from this sample. It is therefore suggested that further research to consider the influence factors such as activity level, clothing, existing health status, fitness and (perhaps) expectation, would be required to explore this relationship further. The level of clothing being worn by each occupant may have an influence on this factor; where a greater level of clothing will enable thermal comfort to be achieved at lower temperatures.

6.2.1.3 Inadequate Heat: Adaptation

The pathway & receptor adaptation that may help to reduce occupant health and comfort due to inadequate heat can be summarised as:

Housing Adaptation	
Existing	Increase insulation* Increase air tightness* Efficient building services Controllability of heating system Building integrated renewables (e.g. solar hot water, PV, wind turbines)
New Build	Low to zero carbon design
Neighbourhood Adaptation	
Existing & New Build	Shelter from wind Enable solar gain
Behavioural Adaptation	
Existing & New Build	Appropriate control of heating Enable net solar gain Appropriate clothing levels

** This is unlikely to be an appropriate adaptation for all properties.*

6.2.2 Risk Factor: Inadequate Ventilation

During the winter, 11% of NPT households considered that their home becomes stuffy, while 30% of households during the winter considered one or more rooms in their homes to be too stuffy at one or more times of the day. Housing built during the 1945 – 1964 period was most likely to be perceived as being too stuffy by its occupants. Through analysis of current literature it was considered probable that ventilation levels would be likely to decrease during both seasons due to climatic change (3.2.2.5). It can therefore be hypothesised that the above distribution would be likely to increase.

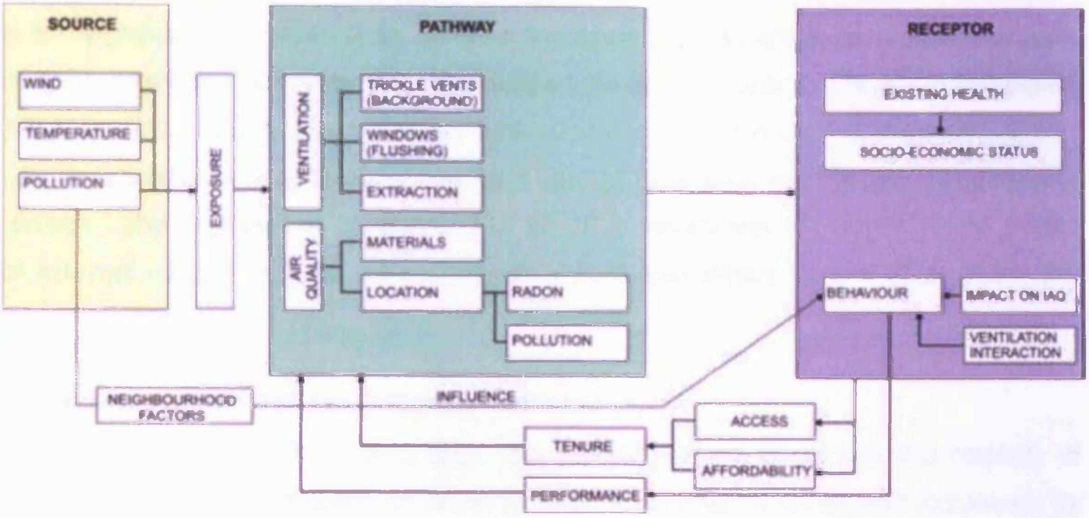


Figure 154: Simple Problem Map for Occupant Health & Comfort Risk Factor: Inadequate Ventilation

6.2.2.1 *Inadequate Ventilation: Pathway Factors*

The design of naturally ventilated buildings, including the majority of homes, generally anticipates that ventilation during the winter is mainly through infiltration, with localised use of extraction in spaces with higher humidity levels, such as bathrooms and kitchens. This helps to ensure minimisation of heat loss through unnecessary ventilation. During the winter, a solution to the dichotomy between the need to preserve heat, in line with aims of climate change mitigation and eradication of fuel poverty, while relieving any perceived stuffiness, must be achieved. The control of infiltration, through increases to the air tightness of properties (as described in section 6.2.2.1) should be considered to enable controlled background ventilation provision and reduce draughts. The installation of extractor fans in kitchens and bathrooms would enable the provision of enhanced levels of ventilation where required. This would also reduce internal air pollution due to cooking sources. This is required, through regulation, in new build properties and should be encouraged in existing homes. The control of other internal air pollution sources, such as those derived from building materials and furnishings, would require legislation to set and enforce safe pollutant levels for the internal environment of homes.

Further to these adaptation opportunities, whole house ventilation systems, where ventilation can be provided at the same time as control of humidity and the use of heat exchangers to minimise heat loss, could be considered. This method would also ensure adequate ventilation while reducing the incidence of condensation, damp and mould growth (see section 62.3.). However, the anecdotal evidence gathered in this research does suggest that this method may not provide the 'fresh air' that many householders seek through the opening of windows. The author suggests that the concept of 'fresh air' may have as much to do with the contrast in air temperature as with the perceived alleviation of internal stuffiness.

In relation to neighbourhood adaptation, as was the case for adaptation to reduce risk from inadequate heat, promotion of shelter from the wind would enable control of levels of ventilation, reducing the influence of the wind on internal ventilation levels. The control of external pollutant sources can be achieved either through planning control to ensure appropriate separation of pollution sources and housing, or by filtration of air. The installation of MVHR would enable filtration of external air and may be an appropriate adaptation, where control at source is not possible.

6.2.2.2 Inadequate Ventilation: Receptor Factors

It was found that during the winter and while the central heating is on that the majority of households also open their windows in order to fulfil a number of ventilation purposes: for example, to provide fresh air and to alleviate or prevent stuffiness, to remove cooking and / or bathing smells and steam, and also because it has become too hot in the home. In relation to the mitigation of climate change these actions are likely to result in significant loss of heat energy during the winter. However, some respondents considered that a need for fresh air in the property was more important to them than preservation of heat: *'Warmth is important but so is freshness', 'I love the fresh air especially in bedrooms, at the same time I feel the radiators need to be on to keep the house warm'.* It would seem that the resolution of these two factors, the need for fresh air and the preservation of heat energy, would require the altering of widespread perceptions as to the *'need for fresh air'* during the winter months. No relationships with housing, social or neighbourhood factors were found to explain the distribution of perceived stuffiness in the home for the winter. Education may assist in achieving behavioural adaptation to reduce the use of over-ventilation to achieve "fresh air", increase the application and use of extract ventilation where it is required in the bathroom and kitchen, as well as about the various sources of air pollution in the home and their health impacts.

The author has not been able to identify existing research about the notion of fresh air, however, this concept may be key to understanding some aspects of domestic occupant behaviour relation to ventilation, which may in turn have significant implications for the delivery of a low carbon future in this sector.

6.2.2.3 *Inadequate Ventilation: Adaptation*

The pathway & receptor adaptation that may help to reduce occupant health and comfort due to inadequate ventilation can be summarised as:

Housing Adaptation	
Existing	Installation of extract units in kitchen and bathrooms. Increase air tightness.*
New Build	Increase air tightness.
Existing & New Build	Control internal air pollutant sources.
Neighbourhood Adaptation	
Existing & New Build	Shelter from wind. Control / reduce / prevent air pollutants at source.
Behavioural Adaptation	
Existing & New Build	Educate / raise awareness about: - energy implications of over-ventilation. - benefits of regular use of extractors fans. - air pollutant sources in home.

** This is unlikely to be an appropriate adaptation for all properties.*

6.2.3 Risk Factor: Material & Structural Damage

23% of households were found to be concerned over the structure of their home during a violent storm, while 25.1% were concerned over structures in their gardens during a violent storm. It was found that both of these attitudes were associated with perceived exposure to the wind. 19% were concerned over the potential increase in frequency of flooding as a result of global warming. Those who had this concern were likely to have previous experience of flooding in their current home, or perceived their home to exposed to flood hazard.

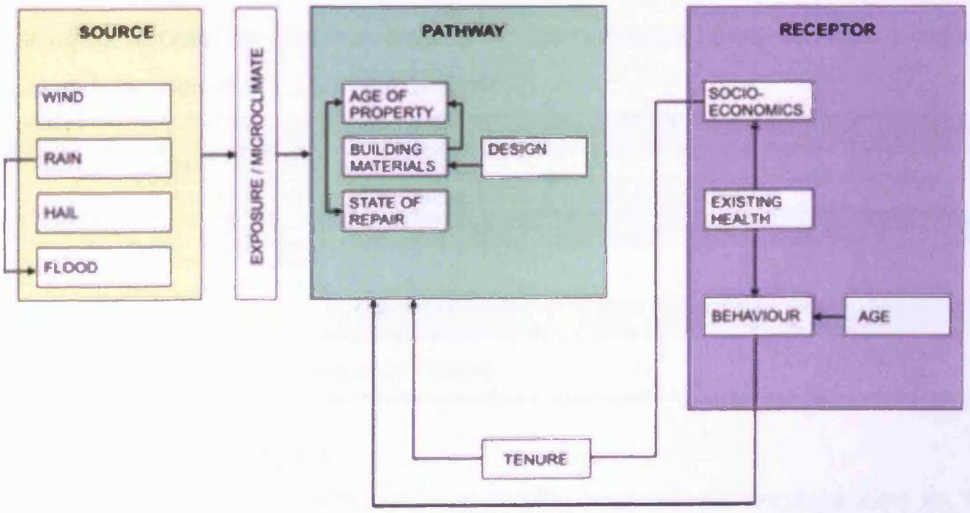


Figure 155: Simple Problem Map for Occupant Health & Comfort Risk Factor: Material & Structural Damage

6.2.3.1 *Materials and Structural Damage: Pathway Factors*

Adaptation relating to material and structural damage can be achieved through the application of resilient reinstatement of building elements following damage (Johns & Fedeski, 1994), thereby, facilitating the renewal of the property to a standard appropriate to withstand any change in wind and rain regime anticipated under climate change. For new build properties, consideration should be given to climate change scenarios and where appropriate more resilient solutions should be selected than currently required by regulation, to take into account potential alterations to wind and rain regimes over the coming century.

Where adaptation is required to reduce the health and comfort risks as a result of flood exposure, the reader is referred to work undertaken by Lancaster et al (2004) that considers appropriate adaptation methods for this hazard at a building scale through resilient reinstatement methods.

Adaptation at a neighbourhood scale to reduce risk from material and structural damage would again involve the reduction of exposure to wind and rain, for example through the planting of shelter belts. Exposure to flooding from any source can be controlled at a building, neighbourhood and river catchment scale (Evans et al, 2003) and should be considered on an individual case by case basis.

6.2.3.2 *Materials and Structural Damage: Receptor Factors*

Behavioural adaptation relating to material and structural damage can be achieved through the application of a frequent and prompt maintenance regime (Johns & Fedeski, 1994). The ability to achieve this may be impaired by socio-economic status and perhaps by age of occupant.

6.2.3.3 *Materials and Structural Damage: Adaptation*

The pathway & receptor adaptation that may help to reduce occupant health and comfort due to material and structural damage can be summarised as:

Housing Adaptation	
Existing	Resilient reinstatement following damage
New Build	Resilient construction, taking into account climate change scenarios
Neighbourhood Adaptation	
Existing & New Build	Shelter from wind and rain Promote defence from flood
Behavioural Adaptation	
Existing & New Build	Frequent and prompt maintenance regime

6.2.4 Risk Factor: Damp & Mould

It was found that during the winter, 30% of households experienced condensation on the windows of their homes in the morning. Further to this, during the winter, 70% of NPT households reported condensation in one or more rooms. The distribution of damp and mould for households in NPT being 26% and 18% respectively. Damp in the winter was found to be more likely in rented homes as well as in those homes that were considered by their occupants to be exposed to driving rain. The presence of damp, mould and condensation in households during the winter was also associated with the presence of rooms perceived to be too cold or too draughty. Through analysis of current literature it was considered likely that the incidence of damp and mould would be likely to increase during the winter due to climate change (section 3.2.4.5). It can therefore be hypothesised that this distribution would be likely to increase.

During the winter, the presence of double glazing was found to reduce, but not to eradicate the likelihood of condensation. In bathrooms the incidence of condensation was found to be associated with less frequent use of an extractor fan or the opening of windows. Throughout the home overcrowding was also found to be significantly associated with incidence of condensation. The distribution of damp was found to be associated with perceived exposure to driving rain, while the presence of mould in housing in NPT was not found to be associated with any housing, neighbourhood or socio-economic factor. It can be suggested that the self-reporting of mould may be subject to non-reporting bias due to associated perceived stigma (Patterson, 2005), which may in turn have influenced the identification of statistical associations.

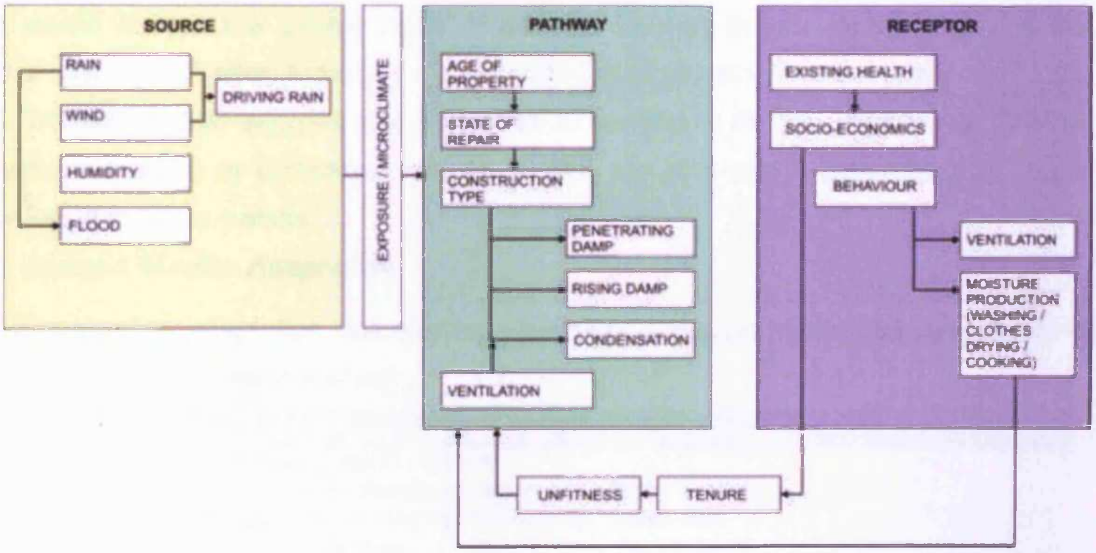


Figure 156: Simple Problem Map for Occupant Health & Comfort Risk Factor: Winter: Damp and Mould

6.2.4.1 *Damp & Mould: Pathway Factors*

Adaptation in existing buildings to reduce the occupant health and comfort risk due to damp and mould requires the consideration of each source of damp and mould in turn. In relation to penetrating damp, causal factors of raised ground level and maintenance problems such as damaged guttering or holes in the fabric allowing direct migration of water into the internal environment, must be considered. In relation to rising damp, this must first be identified correctly. It has been suggested that many cases of rising damp are wrongly identified as such by companies with a financial interest in the supply of damp proofing. The SPAB suggest that many cases of damp, identified as rising damp are in fact a result of condensation, penetrating damp or inadequate ventilation of structures constructed as "breathable" and subsequently modernised (Thomas et al, 1992). The subsequent removal of inappropriate modernisation can reduce damp, mould and condensation in such properties. The incidence of condensation is found to be associated with occurrence of damp, cold, draught and single glazing. Installation of double glazing can reduce but not eradicate condensation, as can the provision of adequate forms of ventilation in areas of high humidity, including the bathroom and kitchen (refer to section 6.2.2.2).

The detailed design of new build properties should pay careful attention to cold bridging, as presence of cold bridging presents opportunity for condensation in homes.

Adaptation at a neighbourhood scale to reduce risk from damp and mould would again involve the reduction of exposure to flood, wind and rain, as described in sections 6.2.2 & 6.2.3.

6.2.4.2 Damp & Mould: Receptor Factors

The behavioural factors which may offer an appropriate adaptation response to the incidence of damp and mould include the prompt repair of damage causing internal damp problems, the installation of extract ventilation in bathrooms and kitchens together with appropriate use of this ventilation. The SPAB also suggest that education is needed to ensure appropriate "DIY" in older properties designed as breathable structures. This can also help to prevent damp, mould and condensation in these homes.

6.2.4.3 Damp & Mould: Adaptation

The pathway & receptor adaptation that may help to reduce occupant health and comfort due to damp and mould can be summarised as:

Housing Adaptation	
Existing	Removal of adjacent ground build up. Regular maintenance of damaged guttering or holes in fabric. Removal of inappropriate renovations to older properties. Installation of double glazing. Installation of appropriate extract ventilation.
New Build	Careful attention to cold bridging in detail design.
Neighbourhood Adaptation	
Existing & New Build	Shelter from wind and rain Promote defence from flood.
Behavioural Adaptation	
Existing	Education for appropriate DIY and renovation of older properties.
Existing & New Build	Prompt maintenance regimes. Use of extract ventilation systems.

6.3 Summer Risk

Appropriate adaptation, to enable alleviation of risk to occupant health and comfort, as a result of the following summer risk factors will now be considered:

- Thermal: Excess Heat
- Noise

- Pests & Vermin
- Ventilation & Air Pollution
- Material & Structural Damage

6.3.1 Risk Factor: Thermal - Excess Heat

During hot summers, 39% of households considered that no room in their home currently overheats during hot summers. The presence of overheating rooms in the remaining 61% of NPT properties was found to be more likely in those built prior to 1980, those occupied by non-pensioner households and those with occupants in poor health.

During the summer, the presence of overheating in homes was influenced by the presence of external influences on ventilation including external noise and concern for security. In relation to thermal comfort during a hot summer's night, it was found that 48% of households considered that on a hot summer's night it is often too hot to allow sleep. This was again found to be associated with housing built between 1945 and 1964 and the presence of external influences on ventilation. Neither the presence of measures of insulation, nor the estimated 'weight' of construction (see section 3.3.1.2.1.) was found to be related to increased thermal comfort during the summer. Similarly, the influence of orientation and shading on overheating was not ascertained through this study, although from first principals these factors would be considered likely to influence overheating during the summer. It may be that the affect of external influences was greater than the anticipated benefits offered by higher levels of thermal mass or the various influence of orientation and ventilation levels. These results were also reflected in the findings from the summer monitoring of the case study property, where comfort thresholds were exceeded in many rooms of the property during the summer of 2003.

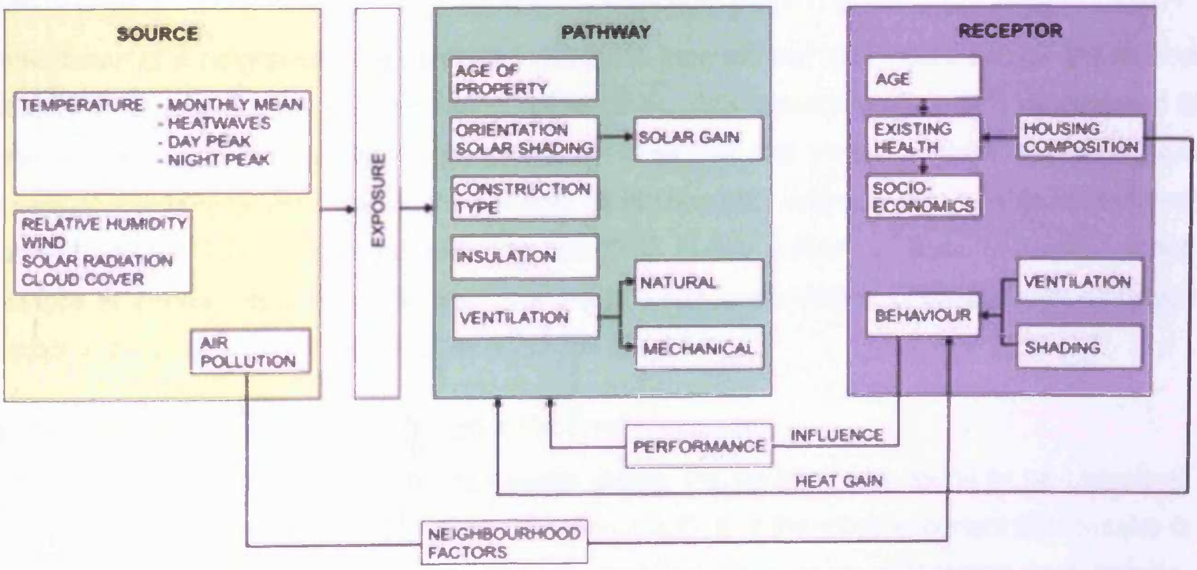


Figure 157: Simple Problem Map for Occupant Health & Comfort Risk Factor: Excess Heat

6.3.1.1 *Excess Heat: Pathway Factors*

In relation to the control of overheating in summer in existing properties, the installation of mechanisms for the delivery of secure night-time or purge ventilation may offer increased levels of thermal comfort during periods of excess heat. The benefits of this would be maximised if this was combined with externally exposed thermal mass and increased insulation levels to prevent ingress of heat to the property. Further to this, the widespread use of shading devices such as awnings, shutters or planting of vines (or other quick growing and deciduous vegetation) could reduce solar gain to properties, thus increasing thermal comfort.

In new build properties careful consideration of these factors, (ventilation and shading, as well as orientation) at the design stage could promote thermal comfort in heatwave conditions, without the recourse of mechanical cooling.

The introduction of air conditioning in the domestic environment is an adaptation that may be perceived by occupants as the simplest 'quick fix' to perceived problems in the internal environment of homes during the summer. Indeed, 32% of households in NPT considered that they would like air conditioning to keep their home comfortable on a hot summer's day, while 11% stated installing air conditioning as their preferred action to improve the internal environment in a hot summer. The energy consumption of heating and cooling systems is a subject beyond the scope of this research, but it is logical to suggest here that *any* reduction in domestic energy usage, whether it be through reduced heating or the avoidance or 'active' cooling, would be a mitigating factor for climate change. The adaptation of occupant behaviour, the careful detailed design of new homes, as well as the appropriate, considered renovation of existing properties should be capable of negating the need for 'active' cooling to achieve thermal comfort.

Adaptation at a neighbourhood scale to reduce risk from excess heat would involve the ease of access to external space for use during hot weather. This space should in turn be designed to offer a range of facilities, including the promotion of air flow and breeze, together with a range of levels of shade provision. Design to promote ventilation with orientation to enable utilisation of wind driven air flow through homes may also help in the delivery of thermal comfort during periods of excess heat. However this may be in direct contradiction of neighbourhood design objectives for the winter (See sections 6.2.1.3 & 6.2.2.3).

6.3.1.2 *Inadequate Heat: Receptor Factors*

The perception of excess heat by occupants during the summer was found to be associated with a wide range of health implications (Section 3.3.1). It is therefore important that passive or low energy solutions, as descried above, providing appropriate adaptation and reducing potential for comfort and health risks are sought.

Occupant behaviour can also be adapted to promote thermal comfort during heatwaves through a number of behavioural changes. For example, use of ventilation should be limited to those periods where the external temperature is 3°C lower than internal temperatures (Hacker et al, 2005). This may require occupant education, as promotion of ventilation is a natural reaction to excess heat in the UK. In addition, the use of shading to reduce the impact of solar gain may also be counter-intuitive to UK housing occupants who may at present enjoy promoting the access of sun into their homes. Further to these adaptations, changes in lifestyle may also be suggested such as withdrawing to more comfortable spaces, for example, the outside or a north orientated or sheltered space in the home and adoption of social practices such as siestas common in hotter regions of Europe. This behavioural adaptation is supported by the data from the case study homes for which the north facing lounge in the monitored case study home remained a comfortable temperature throughout the day and night, while south facing rooms, such as the kitchen, as well as all rooms upstairs, consistently exceeded comfort thresholds both at night and day.

It should be noted here that where passive opportunities for adaptation are not taken up, the issue of fuel poverty may be exacerbated during summer heatwaves. Where the cost of energy to provide cooling through the use of mechanical systems including portable air conditioning units may prevent access to adequate summer cooling and thermal comfort for those already considered to be in what may be termed "traditional" fuel poverty.

The use of external spaces during hot weather was widespread, with 32% of respondents considering that outside was the most comfortable place to be, reflecting one of the concepts of adaptive comfort. This method of adaptation to hotter weather may increase, with the potential to raise external noise where use of outside spaces, including gardens and outside spaces, rises. Use of public spaces, such as parks, beaches and outside sports and leisure facilities, often separated from residential districts, may therefore increase.

6.3.1.3 Excess Heat: Adaptation

The pathway & receptor adaptation that may help to reduce occupant health and comfort due to excess heat can be summarised as:

Housing Adaptation	
Existing	Exposure / introduction of internal exposed thermal mass as well as increased external insulation. Promotion of secure night-time / purge ventilation. Installation of devices to provide shading on east / south / west orientations
New Build	Consideration of summer thermal comfort during design stages.
Neighbourhood Adaptation	
Existing & New Build	Design and alteration to promote: - Ventilation / air flow driven by wind. - Shading.

Behavioural Adaptation	
Existing & New Build	Appropriate use of ventilation. Use of solar shading Appropriate adaptive use of cooler spaces in the home. Increased use of external space. Social and cultural changes – e.g. the adoption of siestas.

6.3.2 Risk Factor: Noise

During a hot summer, 44% of households in NPT consider that noise is a problem in their neighbourhood, where proximity to heavy and light industry and busy roads, as well as an urban location, occupation of a flat, maisonette or terraced house were found to have a significant association with perception of noise as a problem.

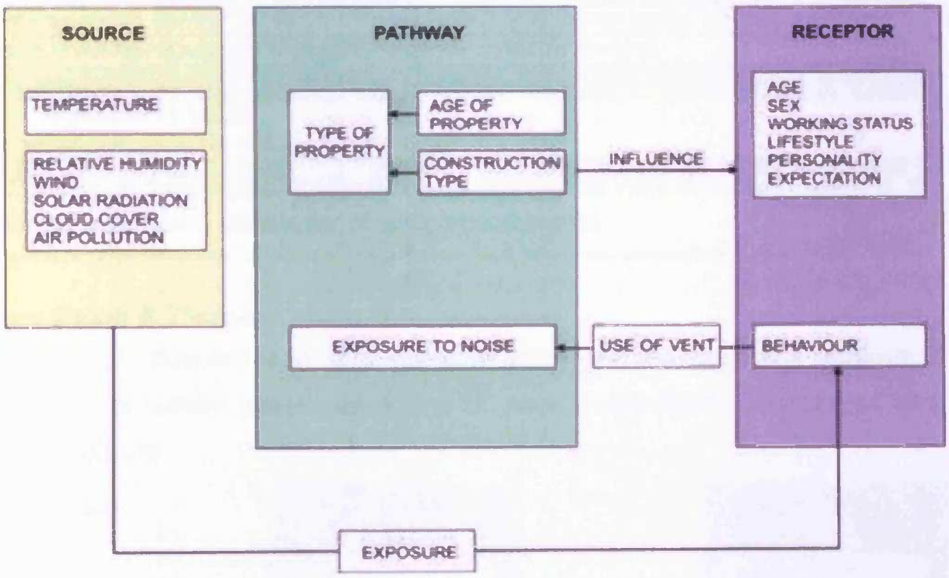


Figure 158: Simple Problem Map for Occupant Health & Comfort Risk Factor: Noise

6.3.2.1 *Noise: Pathway Factors*

Adaptation at a building scale for existing structures would involve the introduction of acoustic control measures to a property to reduce impact and air-borne sound transmission. This is of particular relevance for more densely occupied and adjoining structures such as flats, maisonettes and terraced housing. New build properties should adhere to current building regulations and testing should be encouraged to ensure that transmission levels are minimal. In addition, the introduction of planting and structures to control external noise sources such as roads can help to mitigate the impact of noise as an issue. This can be considered as appropriate adaptation at both scales: individual property and neighbourhood.

Finally, the planning system should be employed to ensure the appropriate siting of developments sensitive to noise. Housing should be located at an appropriate distance from developments such can be considered as a source of noise including roads, public spaces, commercial and entertainment development and industry.

6.3.2.2 *Noise: Receptor Factors*

Occupant adaptation to noise as a risk to health and comfort during a hot summer can be seen to be associated with the provision of ventilation. However, sensitive use of outside spaces so as not to cause nuisance to neighbours must be considered to ensure comfort for all.

6.3.2.3 *Noise: Adaptation*

The pathway & receptor adaptation that may help to reduce occupant health and comfort due to noise can be summarised as:

Housing Adaptation	
Existing	Introduce acoustic control measures for air borne and transmission sound.
New Build	Adhere to existing regulation including tests for acoustic control.
Neighbourhood Adaptation	
Existing & New Build	Consider exposure to noise. Where necessary provide noise control.
Behavioural Adaptation	
Existing & New Build	Use external space with respect for neighbourhood impact.

6.3.3 Risk Factor: Pests & Vermin

During a hot summer, 49% of households in NPT consider that flying insects are a problem in their neighbourhood, where proximity water was found to have a significant association with perception of pests as a problem.

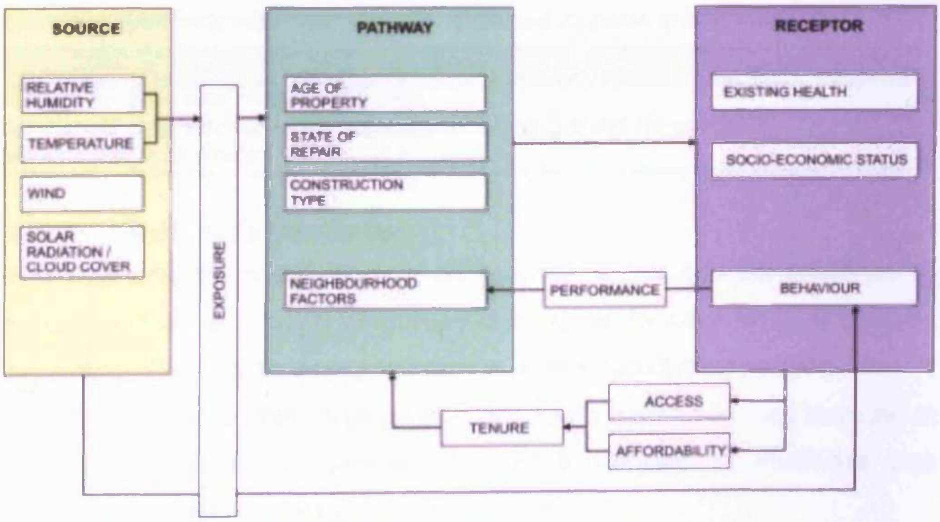


Figure 159: Simple Problem Map for Occupant Health & Comfort Risk Factor: Pests & Vermin

6.3.3.1 *Pests & Vermin - Pathway Factors*

At an individual scale installation of inset screens may become a necessary adaptation to enable ventilation, while ensuring protection from the ingress of pests and vermin into the home. This would be appropriate in both new build and exiting homes. While at a neighbourhood scale the control of environmental sources of pests and vermin, together with appropriate land use planning, would need to be employed to enable adaptation to any increase in pests and vermin likely to occur as a result of climate change.

6.3.3.2 Pests & Vermin: Receptor Factors

Occupant behaviour can be adapted to minimise exposure to pests and vermin. Through reduction in availability of appropriate breeding sites for pests, such as stagnant water for mosquitoes, as well as through the use of insect screens and mosquito nets, the impact and risk due to pests and vermin in the home can be minimised. Water butts and ponds in gardens may provide breeding grounds, although their value in promoting water conservation and supporting biodiversity in gardens may be considered to outweigh any negative influence. Appropriate storage and production of waste can also influence exposure to rodent pests.

6.3.3.3 Pests & Vermin: Adaptation

The pathway & receptor adaptation that may help to reduce occupant health and comfort due to pests and vermin can be summarised as:

Housing Adaptation	
Existing & New Build	Installation of insect screens.
Neighbourhood Adaptation	
Existing & New Build	Utilise planning system to minimise domestic exposure to pests and vermin,
Behavioural Adaptation	
Existing & New Build	Use of insect screens and or mosquito nets. Consideration of stagnant water as potential breeding ground for pests. Appropriate storage of waste.

6.3.4 Risk Factor: Inadequate Ventilation

It is considered probable that external noise sources, air pollution levels and the presence of flying insects are likely to increase as a result of climate change, while concern over security may increase where occupants feel the necessity to open windows to achieve comfort. Then it may be hypothesised that the influence exerted by all four factors on ventilation may increase in the light of climate change, resulting in more widespread experience of stuffiness and airlessness in the domestic internal environment.

During the summer 17% of NPT households considered that their home becomes stuffy. Further to this, 54% of households considered one or more rooms in their homes to be too stuffy at one or more times of the day during the summer. Housing built during the 1945 – 1964 period was most likely to be perceived as being too stuffy by its occupants. Through analysis of current literature it was considered probable that ventilation levels would be likely to decrease during both seasons due to climatic change (See section 3.3.4.5). It can therefore be hypothesised that the above distribution would be likely to increase.

For the summer season, solutions to the perceived stuffiness, would need to consider factors relating to the home itself, as well as methods to control the wider influencing factors of concern: security, pests, noise and air pollution. In order to alleviate the ventilation problems present, while adhering to the need to mitigate further climate change, passive and low energy solutions must be sought.

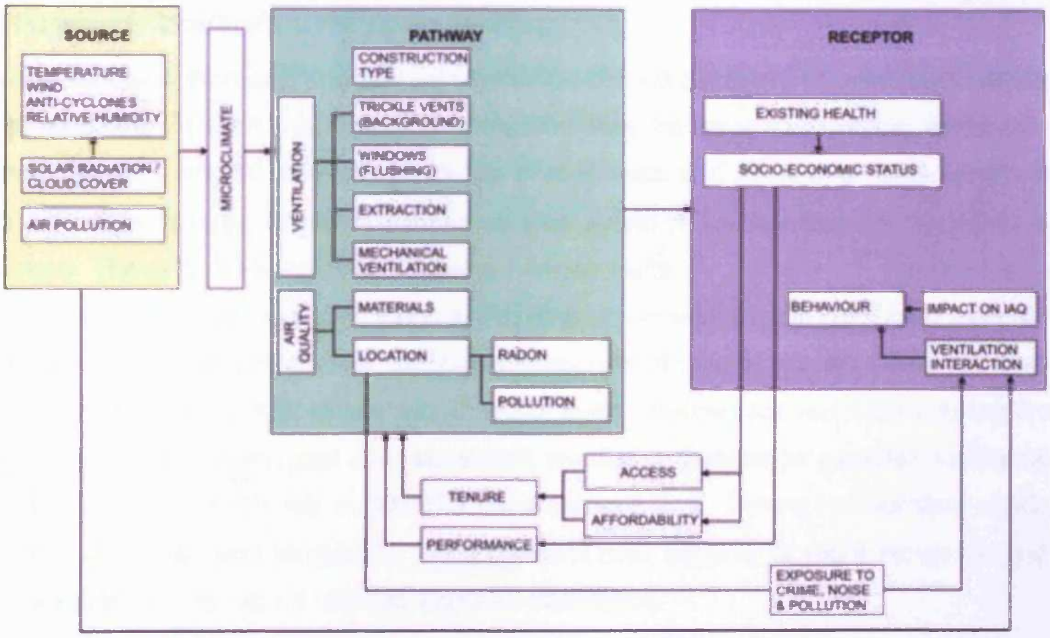


Figure 160: Simple Problem Map for Occupant Health & Comfort Risk Factor: Summer - Inadequate Ventilation

6.3.4.1 Inadequate Ventilation: Pathway Factors

For existing properties, appropriate adaptation to promote adequate ventilation during hot summer weather would correlate closely with those adaptation measures suggested in section 6.3.1.1 in relation to excess heat. However, in relation to ventilation, the provision of night time purge ventilation in combination with exposed thermal mass would be further enhanced through the support of cross and stack ventilation opportunities, where possible. Where security concerns currently prevent the use of ventilation, installation of vents, shutters, screens or windows, to allow ventilation while ensuring security, would be appropriate. Issues relating to internal sources of air pollution, as considered in section 6.2.2 relating to inadequate ventilation in the winter, are also valid here. For new build properties, consideration should be given to the delivery of appropriate levels of night-time (purge) ventilation to ensure appropriate levels of ventilation during hot weather.

Adaptation at a neighbourhood scale to reduce risk from excess heat would involve the reduction in exposure to air pollution and noise, as well as a reduction in the concern for security implications in relation to the use of ventilation. Adaptation could be provided through control of pollution, both noise and air, through an increase of planning controls on sources in proximity to housing. The design of neighbourhoods to promote air flow due to wind would also be beneficial although this may be contrary to the needs for wind control during the winter (see sections 6.2.1.3 & 6.2.2.3).

6.3.4.2 *Inadequate Ventilation: Receptor Factors*

During the summer, it is anticipated that natural ventilation can be achieved through the opening of appropriate windows. In addition, fans and extraction may be used to increase ventilation levels. However, for NPT households, the presence of stuffiness and the use of open windows and doors to provide increased levels of ventilation was found to be significantly related to a number of factors. These factors included perceived exposure to air pollution, the presence of external noise and flying insect pests in the neighbourhood, as well as concern over security risks and the possibility of intruders. The perceived presence of one or more of these factors was found to be significantly related to a reduced use of open windows for ventilation during the summer. This was despite agreement that increased ventilation helped to alleviate stuffiness and overheating in the occupant's home during a hot summer's day. During hot summer nights the distribution of stuffiness was increased, while concern over security at night increased the likelihood that windows would not be used to increase ventilation.

The external influence on the application of adequate levels of ventilation are therefore mostly influenced by external factors and little alteration and adaptation in occupant use of ventilation is likely where these factors remain. However, as was suggested in section 6.3.1.2, ventilation is only appropriate to promote ventilation where the temperature differential is greater than 3°C and, as suggested before, education to promote understanding of this counterintuitive factor may be necessary to promote passive comfort in hot summer weather.

6.3.4.3 *Inadequate Ventilation: Adaptation*

The pathway & receptor adaptation that may help to reduce occupant health and comfort due to inadequate ventilation can be summarised as:

Housing Adaptation	
Existing	Promotion of secure night-time / purge ventilation Installation of extract units in kitchen and bathrooms. Increase air tightness.*
New Build	Consideration of summer ventilation strategies during design stages. Increase air tightness.
Existing & New Build	Control internal air pollutant sources.

Neighbourhood Adaptation	
Existing & New Build	Design and neighbourhood alteration to promote ventilation / air flow driven by wind.
Behavioural Adaptation	
Existing & New Build	Appropriate use of ventilation. Educate / raise awareness about: - benefits of regular use of extractors fans. - air pollutant sources in home.

** This is unlikely to be an appropriate adaptation for all properties.*

6.3.5 Risk Factor: Material & Structural Damage

It was found that 23% of households were found to be concerned over the structure of their home during a violent storm and the same proportion were concerned over structures in their gardens during a violent storm. It was found that both of these attitudes were associated with perceived exposure to the wind. In addition, 19% were concerned over the potential increase in frequency of flooding as a result of climate change. Those who had this concern were likely to have pervious experience of flooding in their current home, or perceived their home to exposed to flood hazard.

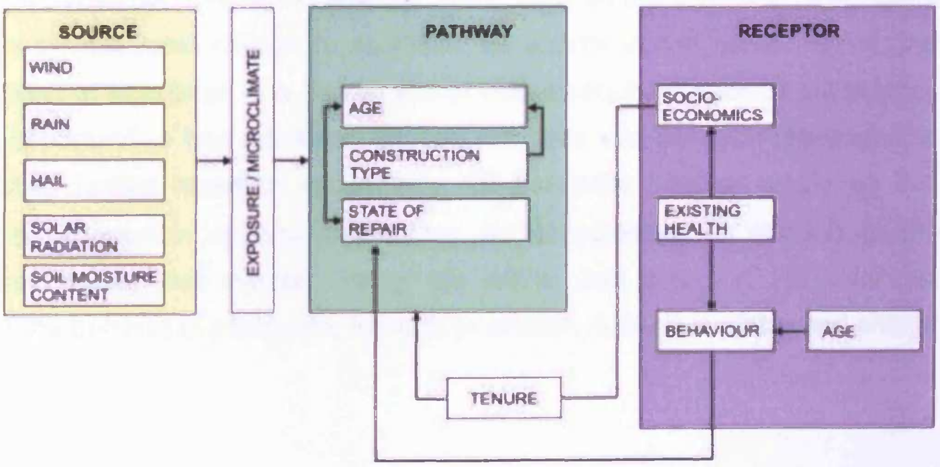


Figure 161: Simple Problem Map for Occupant Health & Comfort Risk Factor: Material & Structural Damage

6.3.5.1 Materials and Structural Damage: Pathway Factors

Appropriate pathway adaptation would be as found for winter risks due to material and structural damage (see section 6.2.3.1).

6.3.5.2 Materials and Structural Damage: Receptor Factors

Appropriate receptor adaptation would be as found for winter risks due to material and structural damage (see section 6.2.3.2).

6.3.5.3 Materials and Structural Damage: Adaptation

The pathway & receptor adaptation that may help to reduce occupant health and comfort due to materials and structural damage can be summarised as:

Housing Adaptation	
Existing	Resilient reinstatement following damage.
New Build	Resilient construction, taking into account climate change scenarios.
Neighbourhood Adaptation	
Existing & New Build	Shelter from wind and rain Promote defence from flood.
Behavioural Adaptation	
Existing & New Build	Frequent and prompt maintenance regime

6.4 Summary

Through the application of the logical frameworks and associated problem maps established earlier for each of the health and comfort risk systems in housing, appropriate adaptations have been identified at housing, neighbourhood and occupant levels, as well as for existing and new-build properties. Where adaptation has been identified which involves the alteration of occupant behaviour, these may be the most difficult to establish, as activity in the home cannot and should not be the subject of legislation in a democratic environment. Evaluation of the efficacy of these adaptation opportunities has not been undertaken here and as such represents a relevant and interesting further research opportunity. Of particular interest would be the consideration of those adaptation options which may be contradictory in relation to the promotion of occupant health and comfort during the winter and summer. For example, orientation to optimise the benefits of solar gain, through promotion during the winter and shelter during the summer.

Chapter 7 - Conclusions & Discussion

7.1 Introduction

This chapter presents conclusions to the objectives outlined in chapter one. These objectives were developed in order to address the main aim of this thesis: *'to explore the potential risk due to global climate change for the health and comfort of occupants in the domestic built environment in south Wales'*. Each objective is considered in turn and a final concluding statement is presented in relation to the main aims of this research. The final section of this chapter includes discussion of the aspects of the thesis where further work could be undertaken.

7.2 Conclusions

The following objectives were developed:

- Through literature review, establish those current risks to health and comfort in the built environment that are likely to be influenced by a changing climate. **(7.2.1)**
- Through analysis of the literature, evaluate the potential change in current risk due to climate change through analysis of the factors that constitute occupant health and comfort risk. **(7.2.2)**
- Through primary research, establish the extent to which vulnerability, exposure and risk are currently distributed during extreme weather conditions, enabling an approximation of the extent of future risk in south Wales housing. **(7.2.3)**
- Through further analysis of health and comfort risk, establish appropriate adaptation measures to ensure continued occupant comfort and health within existing and new-build housing under global climate change during the 21st Century. **(7.2.4)**

A separate conclusion is presented for each objective. For clarity each is presented in a separate section according to the order above.

7.2.1 Current Risk to Health and Comfort in the Domestic Built Environment

The presence of occupant health and comfort risk was established through the application of the source-pathway-receptor model as a logical framework during the existing summer and winter seasons. The constituent factors of the risk system were identified through reference to literature. The following table illustrates the source, pathway and receptor factors identified:

	Winter		Summer	
Source Factor				
	Air Pollution		Anticylcones	
	Precipitation	Average	Air Pollution	
		Extreme	Extreme Precipitation	
		Hail	Hail	
	Relative Humidity		Relative Humidity	
	Cloud Cover (Solar Radiation)		Soil Moisture Content	
	Daily Average Temperature		Cloud Cover (Solar Radiation)	
	Daily Min Temperature		Temperature	Daily Average
	Wind	Average		Daily Max
		Extreme		Night Max
				Heatwaves
			Wind	Average
				Extreme
Pathway Factor				
Housing	Age of Property		Age of Property	
	Type of Property		Type of Property	
	State of Repair		State of Repair	
	Construction Type		Construction Type	
	ventilation		ventilation	
	Internal Air Pollution		Internal Air Pollution	
	Heating Type		Insulation	
	Insulation		Orientation	
	Orientation			
Neighbourhood	Exposure to Air Pollution		Access to External Space	
	Exposure to Wind		Exposure to Pollution	
	Exposure to Rain		Exposure to Noise	
	Exposure to Flood		Exposure to Wind	
			Exposure to Rain	
			Exposure to Flood	
			Exposure to Water	
			Exposure to Crime	
Receptor Factor				
	Age		Age	
Socio-Economic	Status		Status	
	Household Composition		Household Composition	
Existing Health	Presence of Long Standing Illness		Presence of Long Standing Illness	
	Sources of Air Pollution		Sources of Air Pollution	

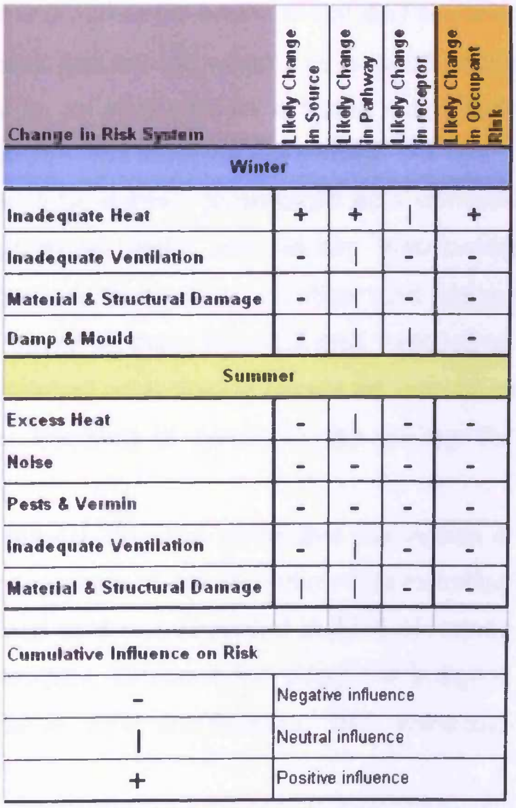
Table 208: Source, Pathway and Receptor Factors of the Risk Systems Studied

In addition to these factors, problem maps were created for each risk system providing a visual illustration of the risk systems and interactions between the factors, especially where exposure to the source may be mitigated by neighbourhood and receptor behaviour and may influence the performance of the pathway or home.

In conclusion, during the winter, the risk systems influenced by climate have been identified as those due to inadequate ventilation, inadequate heat, material & structural damage and damp & mould; while during the summer the health and comfort risk family are as a result of excess heat, noise, pests & vermin, inadequate ventilation and material & structural damage.

7.2.2 The Potential Change in Current Risk Due to Climate Change

The effect of the changing climate on the internal environment of buildings as a result of the changes in global climate over the 21st century was also established through literature review. The climate was found to be a key driving force in the development of vernacular built form that evolved over time to control daylight, temperature, ventilation, rain penetration, wind, humidity and solar gain, providing an internal environment closely influenced by the surrounding climate. This relationship has been diminished throughout the 20th century with a trend towards mass housing, standardised materials and the widespread use of central heating and other environmental controls. However, it was established that the internal environment of most homes continues to be closely influenced by the surrounding climate throughout the year. It was also established that the changes in climate anticipated over the 21st century are therefore likely to be significant in driving modifications in internal environment. The following table illustrates the anticipated change in risk due to alterations in climate, as anticipated under current climate change scenarios (UKCIP02) as well as due to other drivers (likely to influence the pathway or receptor) identified in chapter 3.



Change in Risk System	Likely Change in Source	Likely Change in Pathway	Likely Change in receptor	Likely Change in Occupant Risk
Winter				
Inadequate Heat	+	+	|	+
Inadequate Ventilation	-	|	-	-
Material & Structural Damage	-	|	-	-
Damp & Mould	-	|	|	-
Summer				
Excess Heat	-	|	-	-
Noise	-	-	-	-
Pests & Vermin	-	-	-	-
Inadequate Ventilation	-	|	-	-
Material & Structural Damage	|	|	-	-

Cumulative Influence on Risk	
-	Negative influence
|	Neutral influence
+	Positive influence

Table 209: Likely Changes in the Risk Systems Studied

In conclusion, the changes in climate anticipated under climatic change are likely to result in alterations in the internal environment throughout the year. These alterations are likely to include: an increase in occurrence of overheating during the summer months,

with annual cooling degree days (CDD) increasing by up to 200 to approximately 500 CDD by the 2080's; a decrease in extreme cold during winter months, with annual heating degree days (HDD) decreasing by up to 40-45% by the 2080's from approximately 3300 HDD currently; a decrease in ventilation rates in the summer; a decrease in ventilation rates coupled with an increase in draughts during the winter; increase in the incidence of damp and mould; a negative impact on material and structural damage in both seasons and an increase in the health and comfort risks for occupants due to noise, pests and vermin during the summer. It should be re-iterated here that a cooling scenario, as would occur with a slowing down or shutting off of the Gulf Stream has been discounted within this.

7.2.3 Current Distribution of Risk during Extreme Weather Conditions in South Wales Housing

Having established health and comfort risk factors likely to be influenced by the changing climate, the distribution of their presence in housing in south Wales was then established through survey and monitoring. Conclusions for climatic analogues for future winter and summer seasons, derived from primary survey research are presented below, where, as a result of the warming climate, a current average winter is employed as an analogue for a future cold winter and a hot summer is employed as an analogue for future average summer conditions.

In conclusion, it was found that during a current average winter, (employed as a climatic analogue for future winter climate), health and comfort risks are widely distributed throughout housing in south Wales. Perceived exposure to extreme weather and limited control of the internal environment of the home in terms of both thermal and ventilation requirements were found to be most strongly associated with lower levels of occupant comfort and the presence of health risk factors in housing in south Wales during the winter.

Health and comfort risks considered during the winter survey included subjective perception of low levels of ventilation present in 30% of homes. The presence of condensation was recorded in 70% of homes, damp in 18%, mould in 26%. Perceived cold was recorded in 28% of homes while 14% of homes were considered to be very draughty. Concern for structural integrity, including garden structures was recorded in 25%, the home, 23%, and flooding, 19%, were also widespread.

As for the winter season, it can also be concluded that during a current extreme summer, (employed as a climatic analogue for future average summer climate), health and comfort risks were again found to be widely distributed throughout housing in south Wales.

Health and comfort risk factors for the summer considered herein included the subjective perception of low levels of ventilation present in 17% of homes during the day and 46.1% of homes during the night. The presence of condensation was recorded in 48% of homes, damp in 13%, mould in 26%, and overheating of homes was presented in one of more rooms during the day in 62% of properties and 48% of homes during the night.

The results of the monitoring of a case study year 2000 built semi-detached property in Cardiff were also reported, providing quantitative data for the internal environment of homes under the current climate. The monitoring, undertaken during the summer of 2003, provides case study data with which to consider current comfort conditions in relation to three widely applied comfort standards or thresholds: ASHRAE Standard 55, Humphreys and Nicol adaptive standard and European threshold day time and night time standards. The summer of 2003 was the fifth hottest summer on record and temperatures recorded by Cardiff weather station exceeded 30°C on a number of occasions. It is therefore considered that this year provides a relatively close analogue to a future average summer conditions.

It can be concluded that the case study home failed to meet comfort conditions, as defined by three widely applied comfort standards during the summer of 2003. During the monitoring period of summer 2003, the living spaces exceeded comfort conditions on average up to 44% of the time and the bedroom spaces up to 14% of the time. In both cases rooms orientated to the south experienced greater frequency of discomfort than those oriented either to the west or north. During the hottest period of monitoring, occupants were frequently uncomfortable at night. The south orientated rooms, were particularly uncomfortable, while rooms orientated to the north remained more comfortable throughout the day. This case study home, was selected as representative of current new build homes and as such this monitoring data represents a valuable representation of the average future conditions in new build properties, were summer comfort to continue not to be considered as a factor during the design housing.

7.2.4 Appropriate Adaptation Measures to Ensure Continued Occupant Health and Comfort

The possible alterations in occupant behaviour that could significantly reduce the negative effects of identified changes in the internal environment have been identified through the consideration of potential adaptation to pathway and receptor factors of the health and comfort risk systems. The identification of measures that could be taken to ensure continued occupant comfort and health within existing and new-build housing were identified through literature review as well as being influenced by analysis of survey responses.

During the summer, these behavioural factors include the use of shading, (including curtains), ventilation, (including the use of fans), and the use of more active adaptations such as seeking comfort in other parts of the home and in outside spaces. During the winter, adaptations that can be undertaken include the control of ventilation, including windows, extract fans and the management of heating systems through use of controls including thermostatic radiator valves (TRV's), timers and thermostats. Adaptive measures taken in winter include the use of additional heat sources, including fires, (similar to the notion of seeking cool locations in summer) and the use of warmer clothing.

It can be concluded that occupant behaviour throughout the year was found to be influenced by the desire to achieve thermal comfort. However, occupant ability to achieve this aim was affected by influences on behaviour due to external or neighbourhood factors, including the presence of noise, pollution, pests and security concerns; an understanding, facility and ability to control the internal environment through the application of shading, ventilation as well as control of heating systems; and during the winter, a need to achieve "freshness" through ventilation, despite the direct impact on the internal thermal environment.

In conclusion, it was found that adaptation in both existing and new building housing must concentrate on the following four areas:

- **The development of intuitive control of central heating or other heating methods.**
- **The application of adaptation methods to passively control overheating in summer.**
- **The development of appropriate ventilation methods and control during both summer and winter seasons (especially in relation to locations where external factors are likely to influence occupant behaviour).**
- **Control of external influences on occupant behaviour including sources of noise, pollution and pests together with causal factors in security concerns.**

7.2.5 The Potential Risk Due to Global Climate Change for the Health and Comfort of Occupants in the Domestic Built Environment in South Wales

The central aim of this work as defined in the first chapter of this dissertation, was potential risk due to global climate change for the health and comfort of occupants in the domestic built environment in south Wales. The results of both surveys and the case study monitoring have combined to suggest that occupant behaviour, as well as attributes relating to the pathway, both housing and neighbourhood factors, can influence occupant health and comfort, both currently and in the light of a changing climate.

In conclusion, the overall findings of this work suggest that the distribution of the risks to health and comfort currently present in housing in south Wales in summer and winter, as identified through the literature review, are already widespread. Furthermore, without

appropriate changes to the building fabric, including the provision of shading, insulation and increased exposed thermal mass, alterations in occupant behaviour and / or widespread new build of appropriately designed and constructed homes, a significant proportion of the housing in south Wales will not be capable of providing comfortable, healthy homes for their occupants in the light of climate change, especially during average to extreme summer weather.

7.3 Recommendations for Further Study

'All research work is incomplete – whether it be observational or experimental. All scientific work is liable to be upset or modified by advancing knowledge. That does not confer upon us a freedom to ignore the knowledge we already have or to postpone the action that it appears to demand at a given time'. *(Bradford Hill, 1965)*

This research has provided a descriptive overview of the potential health and comfort implications of climate change in housing in south Wales. The following considers a number of further research considerations that have resulted from this study.

The relationship of the distribution of these risks to the age of property has been considered. Properties built between 1945 and 1965 have been identified as presenting the most risk to occupant health and comfort in this study. This category of housing may therefore represent the most appropriate group for further study. However, the minorities in other age categories, in relation to all risks, have also been proved to provide uncomfortable or unhealthy environments. For example, although housing built prior to 1980 is most likely to overheat, where 45% of these homes indicated that 2 or more rooms overheat, 32% of homes built post-1980 also overheat to the same extent. The case study home, a member of this latter category, was found to overheat significantly during a hot summer and would therefore be representative of this minority. It is considered appropriate to develop methodologies to consider further the impact of construction and design on the internal environment of a wide range of case study homes, in order to gather quantitative data as to the performance of housing in hot summers in south Wales. This would compliment the qualitative results of the surveys described here and expand on the dataset begun through the monitoring undertaken of the case study home.

The current ongoing reviews of Part L of the Building Regulations, regarding energy efficiency, are likely to introduce consideration of reduced air leakage rates in their future iterations. It is entirely appropriate in relation to energy saving that infiltration is minimised in order that ventilation can be controlled. However, the perception of internal environments as stuffy by their occupants must also be considered if the energy savings made due to the benefits of controlled ventilation are not to be lost due to the increased opening of windows at the same time as heating in order to alleviate perceived stuffiness.

It is also considered that building orientation and the provision of external shading could be studied further in relation to both new-build and existing housing, to establish the potential for these passive methods to alleviate summer overheating. It is considered that a thermal model of the case study property could be created to undertake study in this vein. In addition, such a model could be applied in relation to climate change scenarios, occupant behaviour as well as the consideration of changes in the detailed construction, layout and design of the property. For example, through the application of future climate change scenarios to the meteorological file of a computer thermal model, the resultant internal environment could be considered. In conjunction with the monitored data, the likely variance of the model from those conditions actually experienced can also be considered.

Installation of air conditioning is becoming more commonplace in 'executive' housing and apartments, action that is encouraged by articles such as "The Independent" newspaper's, 'The Ten Best Air Conditioners' (The Independent, 2003), aimed at design conscious householders, suggesting that it is possible that 'active' cooling technology is becoming more accepted by the public. This is also suggested by the responses to the summer survey from the sample of occupants of homes in NPT. Hacker et al (2005) have reported that in some instances a method of cooling is already employed in many UK domestic properties, and this need is certainly likely to rise in the future. However, if energy usage is likely to be reduced in line with UK Kyoto targets, it is vital that energy use is minimised, both for heating and cooling. It is suggested here that further research into both 'active' and 'passive' methods of cooling should be conducted in order to assess the effectiveness and energy implications of the various systems available.

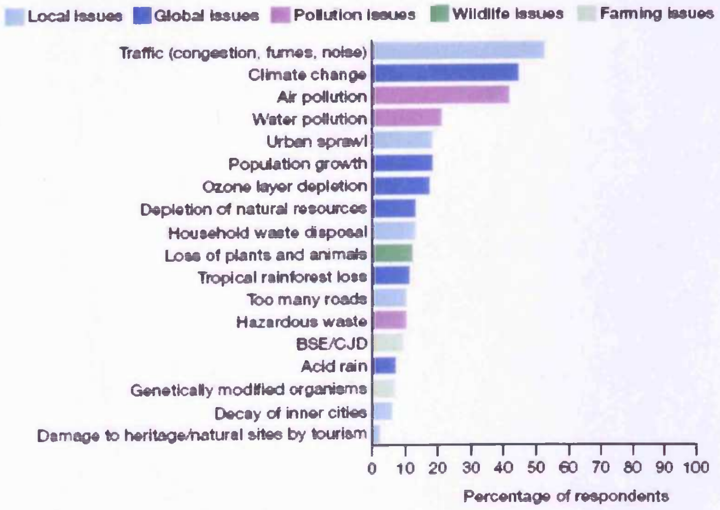


Figure 161: Respondents to the Survey of Public Attitudes to Quality of Life and to the Environment in 2001 were asked what environmental trends or issues they thought would cause the most concern in 20 years time (National Statistics, 2002)

UK Concern over climate change has recently been measured by Greenpeace in an opinion poll that found that 78% of people are concerned over its potential impact in the UK (Blair, 2005). In Wales, public concern over climate change was found to be similarly distributed, with 66% of respondents stating that they were fairly or very concerned (generally) over climate change in a joint Friends of the Earth, Welsh Consumer Council and Countryside Council for Wales survey (WCC, 2004). Concern over the impact of climate change on occupants' homes and their personal health were considered within this research and similar statistics were found for the population of Neath Port Talbot. Of those that had considered the potential impact of climate change, 62% were concerned about the potential impact on their homes and 75% were concerned about the potential impact on their health. It is possible, therefore, that this widespread public concern could be harnessed, to achieve both appropriate adaptations to the changes in climate, as well as mitigation of climate change.

Bibliography

A

A.B.I., (2004). A Changing Climate for Insurance A Summary Report for Chief Executives and Policymakers. Published by the ABI June 2004.

Aday, L. A., (1996). Designing and Conducting Health Surveys. Jossey Bass Pub, San Francisco.

Adger, W. N., Et Al, (2002). Adaptation to Climate Change: Setting The Agenda For Development Policy And Research. Working Paper 16, Tyndall Centre For Climate Change Research.

Adger, W. N., (2001). Social Capital And Climate Change - Working Paper No. 8. Tyndall Centre For Climate Change Research, Norwich

Advisory Group On The Medical Aspects Of Air Pollution Episodes, (1991). First Report: Ozone. HMSO, London.

Agbaje, G. I., (1999). Global Environmental Change And Human Health. Presented at Conference - Setting An Agenda For Research On Health And The Environment: Mona, Jamaica, Nov 12 – 14 1999.

Aldrich, R et al, (2003). Using Socioeconomic Evidence in Clinical Practice Guidelines. BMJ, Vol. 327, 29 Nov 2003.

Alexander, D., K., (1997). HTB2: A Model for the Thermal Environment of Buildings in Operation: Release 2. User Manual. Welsh School of Architecture, Wales.

Allen, M. R, et al, (2000). Quantifying the Uncertainty in Forecasts of Anthropogenic Change. Nature, Vol. 407, 5th October 2000, www.nature.com.

AMA Research, (2000). AM20010 AMA Upholstered Furniture & Beds Market January 2000, AMA Research, http://www.amaresearch.co.uk/

Ambrose, P., (1997). Better Housing as Preventative Medicine. Housing Review. Vol. 46. No.3. May-June 1997.

Aron, J. L., (1999). Conceptual And Methodological Approaches For The Study Of Climate/Health Linkages. Presented At Conference - Setting An Agenda For Research On Health And The Environment: Mona, Jamaica, Nov 12 – 14 (1999).

Andersson, K, Fagerlund, I, Bodin, L, & Ydreborg, B., (1988). Questionnaires as an Instrument When Evaluating Indoor Climate. Healthy Buildings '88, Vol. 3, pp 139-145.

Antikainen, H., (1999). Spatial Aspects Of Health, Individual-Level Behaviour Patterns, And Public Health Policy. Presented At Conference - Setting An Agenda For Research On Health And The Environment: Mona, Jamaica, Nov 12 – 14 1999.

Arblaster, L. & Hawtin, M., (1993). Health Housing and Social Policy. Socialist Health Association, London.

Arian, L. G., (1992). Water Balance and Humidity Requirements of House Dust Mites. Experimental and Applied Archaeology, 16 (1992) 15-35.

Aron, J. L. & Patz, J. A., (Ed), (2001). Ecosystem Change & Public Health - A Global Perspective. John Hopkins University Press, London & Baltimore.

Auliciems, A., (1981). Towards a Psycho-Physiological Model of thermal Perception. International Journal of Biometeorology. 1981, Vol. 25, Number 2, pp. 109-122.

ASHRAE, (2001). ASHRAE Fundamentals Handbook, ASHRAE, Atlanta.

ASHRAE, (2003). ASHRAE Standard 62 – 2001-rev.Venitlation for acceptable Air Quality. ASHRAE, Atlanta.

ASHRAE, (2004). Thermal Environmental Conditions for Human Occupancy: ASHRAE Standard 55. ASHRAE, Atlanta, GA.

B

Baker, N., (1996). The Irritable Occupant: Recent Developments in Thermal Comfort Theory. Arq, Vol. 2: Winter 1996, pp. 84 – 90.

Barker, T., (2001). Representing The Integrated Assessment Of Climate Change, Adaptation And Mitigation - Working Paper 11. Tyndall Centre for Climate Change Research

Barnett, J., (2001). Security And Climate Change - Working Paper 7. Tyndall Centre for Climate Change Research

Barrow M & Bachan, R., (1997). The cost of Neglect. RICS, London.

Basu, D., (1969). An Essay On The Logical Foundations Of Survey Sampling, Part 1, Pp. 203-242. Foundations Of Statistical Inference, Toronto: Holt, Rinehart And Winston.

BBC – Website, (2001). Climate Change Outstrips Forecasts. Monday, 22 January, 2001.

BBC – Website, (2001). Climate Change 'Could Kill Thousands'. Friday, 9 February, 2001

Beer, T, (2001). Air Quality as a Meteorological Hazard. Natural Hazards, 23, 157-169, 2001, Kluwer.

Belcher, S.E., Hacker, J. L. & Powell, D. S., (2005). Constructing Design Weather Data for Future Climates. Building Serv. Eng. Res. Technol. 26, 1, (2005) pp.49-61.

Bellhouse D.R. & Stafford, J.E. (2001). Local Polynomial Regression Techniques. Complex Surveys. Survey Methodology, 27, 197-2003.

Belson, W. A., (1982). The Design and Understanding of Survey Questions, Gower Publishing, Aldershot.

Ben-Shclomo, Y. & Davey-Smith, G., (1999). Commentary: Socioeconomic Position Should be Measured Accurately. BMJ, Vol. 318., 27 March 1999.

Bentham & Langford, (1995). Climate Change And The Incidence Of Food Poisoning. England and Wales International Journal Of Biometeorology, 39, Pages 81 - 86.

Berkhout, F., Hertin, J. & Jordan, A., (2001). Socio-Economic Futures. Climate Change Impact Assessment: Using Scenarios As 'Learning Machines' - Working Paper 3, Tyndall Centre For Climate Change Research

Bernstein, J. A., ed., (2004). Health Effects of Air Pollution. Environment and Occupational Respiratory Disorders, August , 2004.

Bisschop M. I., Kriegsman D. M. W, Beekman A. T. F. & Deeg D. J. H., (2004). Chronic Diseases and Depression: the Modifying Role of Psychosocial Resources. Social Science & Medicine 59 (2004) 721–733.Elsevier.

Black, D., et Al, (1999). Better Benefits For Health: Plan To Implement The Central Recommendation Of The Acheson Report. BMJ Volume 318 13 March 1999. www.Bmj.Com

Blyth, A., (1995). Towards Sustainable Design. The AJ, 3 August 1995, Pages 38 – 39.

Boardman, B., (1991). Fuel Poverty: from Cold Homes to Affordable Warmth. Belhaven Press, London.

Boardman, B., et al, (2005). 40% House. ECI, University of Oxford, Oxford.

Bolam, B., Murphy, S., & Gleeson, K., (2004). Individualisation and Inequalities in Health: a Qualitative Study of class Identity and Health. Social Science and Medicine 59 (2004) 1355-1365. Elsevier.

Bordass, B. & Leaman, A., (1997). Design for Manageability. Building Research & Information. 25 (3), 148-157.

Bornehag, C. G., Sundell, J., Bonini, S., Custovic, A., Malmberg, P., Skerfving, S., Sigsgaard, T. & Verhoeff, A., (2004). Dampness in Buildings as a Risk Factor for Health Effects. EUROEXPO: A Multidisciplinary Review of the Literature (1998–2000) on Dampness and Mite Exposure in Buildings and Health Effects. Indoor Air 2004; 14; 243-257, Blackwell Munksgaard.

Bosma, H., Schrijvers, C., & Mackenbach, J. P., (1999). Socioeconomic Inequalities In Mortality And Importance Of Perceived Control: Cohort Study. BMJ Volume 319, 4 December 1999, www.bmj.com, p. 469

Bowling, A., (1995). Measuring Disease - A Review Of Disease-Specific Quality Of Life Measurement Scales. Open University Press, Buckingham.

Bowling, A., (1997). Measuring Health - A Review Of Quality Of Life Measurement Scales. Open University Press, Buckingham, 2nd Edition.

Bradford Hill, A., (1965). The Environment and Disease: Association or Causation? Proceedings of the Royal Society of Medicine, 58, pp295-300.

Brasche, S., Bullinger, M., Norield, M., Gebhardt, H. J., & Bischop, W., (2001). Why do Women Suffer from Sick Building Syndrome More Often Than Men? – Subjective Higher Sensitivity Versus Objective Causes. Indoor Air, 2001; 11; 217-222.

BRECSU, (1996). General Information Report No. 40: Heating Systems and Their Control. Energy Efficiency Best Practice Programme, DETR,

Brewer, K.R.W. & Mellor, R.W. (1973). The Effect Of Sample Structure On Analytical Surveys. Australian Journal Of Statistics, 15, 145-152.

Brewster, D. H., Et Al, (2001). Relation Between Socioeconomic Status And Tumour Stage In Patients With Breast, Colorectal, Ovarian, And Lung Cancer: Results From Four National, Population Based Studies - On Behalf Of The Scottish Cancer Therapy Network. BMJ Volume 322 7 April 2001 Bmj.Com

Briedt, F.J. & Opsomer, J.D., (2000). Local Polynomial Regression Estimators In Survey Sampling. Annals Of Statistics, 28, 1026-1053.

Broecker, W.S. et al, (1988). The Chronology of the Last De-Glaciation: Implications to the Cause of the Younger Dryas Event. Palaeoceanog, 3, pp. 1-19.

Brooks N. (2003) Vulnerability, risk and adaptation: A Conceptual framework, *Tyndall Centre*, University of East Anglia, 16p

Brooks, N. & Adger, W.N., (2003a). Country Level Risk Measures Of Climate-Related Natural Disasters And Implications For Adaptation To Climate Change - Working Paper 26. Tyndall Centre For Climate Change Research

Burberry, P., (1991). Saving Energy. The AJ 13 Feb 1991, Pages 55 - 59

Burns, R. B., (2000). Introduction To Research Methods. Sage Publications International, London, 4th Ed.

Burridge, R & Ormandy, D., (Eds), (1993). Unhealthy Housing, Research, Remedies and reform. E & FN Spon, Bury St Edmunds.

Byrne, D. & Keithley, J., (1993). Housing and the Health of the Community. In Unhealthy Housing: Research Remedies and Reform. Burridge, R & Ormandy, D. (ed.s). E & FN Spon. pp.41 – 66.

C

Campbell-Lendrum, D. H., Wilkinson, P., Kuhn, K., Kovats, R., S., Haines, A., Menne, B., & Parr, T.W., (2002). Monitoring the Health Impacts of Global Climate Change. In Martens, P., & McMichael, A. J., (2002). Environment Change, Climate and Health: Issues and research methods. Cambridge University Press, Cambridge.

Candas, V. J. P, Libert, J. J., Ehrhart, J. & Muzet, A., (1979). Body Temperature During Sleep Under Different Thermal Conditions. In: Indoor Climate Effect on Human Comfort, Performance and Health, edited by P. O Fanger & O. Valbjorn. Copenhagen: Danish Building Research Institute. 1979, p. 763 – 775.

Carter, T.R., M.L. Parry, H. Harasawa, and S. Nishioka. 1994. IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations. London: Department of Geography, University College London

CEN, (1998). CR1752 Ventilation for Buildings: Design Criteria for the Indoor Environment. CEN, Brussels.

Chalmers, J., & Capewell, S., (2001). Deprivation, Disease, and Death in Scotland: Graphical Display of Survival of a Cohort. BMJ Volume 323 27 October 2001 Bmj.Com P967

Chambers, R.L., And Skinner, C.J., (Eds.), (2003). Analysis Of Survey Data. Chichester: Wiley.

Chan, D. W. T., Burnett, J., de Dear R. J. & Ng, S. C. H., (1998). A Large Scale Survey of Thermal Comfort in Office Premises in Hong Kong. ASHRAE Transactions. 104 (1).

Chapman, J., (1991). Data Accuracy and Model Reliability. Presented at BEPAC Canterbury Conference, 1991.

Chappels, H. & Shove, E., (2003). The Environment and the Home. Draft Paper for Environment and Human Behaviour Seminar, 23rd June 2003, Policy Studies Institute, London.

Chappels, H. & Shove, E., (2005). Debating the Future of Comfort: Environmental Sustainability, Energy Consumption and the Indoor Environment. Building Research & Information (Jan-Feb) 33(1), 32-40.

Charles, K. E., (2003), Fanger's Thermal Comfort and Draught Models. IRC research report RR-162 – October 10, 2003.

Chen, K, McAneney, J, Blong, R, Leigh, R, Huner L and Magill, C (2004). Defining area at risk and its effect in catastrophe loss estimation a dasymatric approach *Applied Geography* 24 97-117

Chow, D. H. C., & Levermore, G., (2005). Climate Weather Change Data and Effects on UK Office Buildings. Presentation at CIB W 108 15 April, 2005. CSTB, Paris.

CIBSE, (2000). Testing Buildings for Air Leakage. CIBSE Technical Memoranda TM23:2000. CIBSE, London.

CIBSE, (2002). Weather, Solar and Illuminance Data: CIBSE Guide J. London, Chartered Institute of Building Services Engineers.

CIBSE (2005). Climate change and the indoor environment: impacts and adaptation. TM36. CIBSE, London.

CIBSE, (2006). CIBSE Guide A:Environmental Design. CIBSE Publications, London.

Cinderby, S. & Forrester, J. (2005). Facilitating the local governance of air pollution using GIS for participation. Applied Geography 25 (2005) 143–158 157.

Clarke, J. A., Johnstone, C. M., Kelly, N. J., Mclean, R.C., & Nakhi, A. E., (Unknown). Development for a Simulation Tool for Mould Growth Prediction in Buildings. Unknown. Energy Systems research Unit, University of Strathclyde.

Clarke, J. A., Johnstone, C. M., Kelly, N. J., Mclean, R.C., Anderson, J.A., Rowan, N. J., & Smith, J.E., (1999). A Technique for the Prediction of the Conditions Leading to Mould Growth in Buildings. Building and Environment, 34, 1999, pp. 515 – 521.

Clausen, G., Garrick M. L., Fanger, P. O., Kim, S.W., Poulsen, T and Rindel, J. H., (1993). A Comparative Study of Discomfort Caused by Indoor Air Pollution, Thermal Load and Noise, indoor Air, 3, 255-262.

Colhoun, H. M., Et Al, (2000). Cross Sectional Study of Differences in Coronary Artery Calcification By Socioeconomic Status. BMJ Volume 321 18 November 2000 Bmj.Com, P1262.

Collins, KJ; Easton, JC; Belfield-Smith, H; Exton Smith, AN & Pluck, RA (1985), 'Effects of age on body temperature and blood pressure in cold environments, Clinical Science, 69, 465-470

Collins, K., (1993). Cold and heat related Illnesses in the Indoor Environment. In Unhealthy Housing: research Remedies and Reform. Burridge, R & Ormandy, D., (eds), (1993). E & FN Spon. pp.117 - 140.

Collins, K., (2000). Cold, Cold Housing and Respiratory Illnesses. In Cutting the Cost of Cold, Ed, Rudge, J. & Nicol, F. (2000), E & F Spon, pp 36 - 47.

COMEAP - Committee On The Medical Aspects Of Air Pollutants, (1995a). Asthma And Outdoor Air Pollution. HMSO.

COMEAP - Committee On The Medical Aspects Of Air Pollutants, (1995b). Non-Biological Particles And Health. HMSO.

COMEAP - Committee On The Medical Effects Of Air Pollutants, (1998). Report: The Quantification Of The Effects Of Air Pollution On Health. In The United Kingdom, HMSO.

Confalonieri, U., E., C., (1999). Conceptual And Methodological Approaches For The Study of Climate/Health Linkages. Presented at Conference - Setting An Agenda For Research On Health And The Environment: Mona, Jamaica, Nov 12 – 14 (1999).

Connor, C., (2001). Thinking Ahead, Socio-Economic Scenarios For Climate Change Impact Assessment. UKCIP, UK.

Conway, J., (1995). Housing as an instrument of Health Care. Health and Social Care in the Community, 3, 141-150, Blackwell Science Ltd.

Courage, C., & Duarte-Davidson, R., (1999). Medical Research Council, Institute for Environment And Health. IEH Report On Benzene In The Environment: An Evaluation Of Exposure Of The UK General Population And Possible Diverse Health Effects, Report R12, Institute for Environment And Health, Norwich.

Cova T.J. (1999). GIS in Emergency management in Longley et al eds. Geographical information systems: principles, techniques, applications, Vol.2 : Management issues and applications, Chapter 60, p845 – 858.

Coward S. K. D., et al., (2001). Indoor Air Quality in Homes in England. BRE, Watford & DEFRA, London.

Cranmer, D., (1998). Fundamental Statistics for Social Research. Duncan, Routledge, London.

Crichton D. (2001) The implication of climate change for the insurance industry – an update and outlook to 2020. *Published by the building research establishment*, Watford, England.

Croome, D. J., & Sherratt, A. F. C., (1972). Condensation in Buildings. Applied Science Publishers, London.

Crump, D., (2004). Ventilation and Indoor Air Quality in New Homes. IEH Web Report W15, posted January 2004 at http://www.le.ac.uk/ieh

D

Danesch, J., Gault, S., Semmence, J., Appleby, P. & Peto, R., (1999). Postcodes as Useful Markers of Social Class: Population Based Study in 26,000 British Households. BMJ, Vol 318, 27 March 1999.

De Dear, R., (1998). A Global Database of Thermal Comfort Field Experiments. ASHRAE Transactions 104 (1).

deDear, R. & Brager, G., (1998). Developing an Adaptive Model for Thermal Comfort and Preference. ASHRAE Transactions 104 (1).

de Gruijl, F. R., (200_) Health effects of the Sun's Ultraviolet Radiation & Ozone as a Stratospheric Sunscreen. Global Change and Human Health Vol. 1, Issue, Pages 26 – 40.

Danesh, J., et Al, (1999), Postcodes As Useful Markers Of Social Class: Population Based Study In 26 000 British Households, BMJ Volume 318 27 March 1999 Www.Bmj.Com

Davies, G., (2004). Too Hot to Handle. In Building 6 August 2004.

Dessai, S., et Al, (2003). Defining And Experiencing Dangerous Climate Change, - Working Paper 28, Tyndall Centre For Climate Change Research

Department for Communities and Local Government (2006). Review of Sustainability of Existing Buidings: The Energy Efficiency of Dwellings – Initial Analysis. November 2006. DCLG.

Department for Environment, Food and Rural Affairs, (DEFRA), (2001). Literature review of the implications of climate change for species, habitats and the wider UK countryside, 13 February 2001 - http://www.defra.gov.uk/wildlife-countryside/ewd/rrrpac/lreview/04.htm

Department For The Environment Transport And The Regions, (D.E.T.R.), (2000). Climate Change The UK Programme, DETR, UK

DETR, Environment Agency, Institute for Environment and Health, (2000). Guidelines for environmental risk assessment and management, The Stationery Office, London.

Department of The Environment, (1992). Questionnaire And Corresponding Literature Of The Housing Attitudes Survey 1992

DoE (Department of The Environment) & The Welsh Office, (1994). Designated Defective Housing: Housing Booklet Number 18. HMSO, London.

Department of Health, (DoH), (1999). The Health Survey for England, HMSO.

Department of Health, (DoH), (2001). Health Effects Of Climate Change In The UK - An Expert Review For Comment, UK Department Of Health.

Department Of Health (DoH), (2004). The Heatwave plan for England.UK Department Of Health.

Diamond, I. & Jefferies, J., (2001). Beginning Statistics, An Introduction For Social Scientists, Sage Publications, London.

Dobson, R., (1999). Death Rates Higher In Wales, BMJ Volume 318 2 January 1999 www.bmj.com P12.

Dobson, R., (1999). News Extra, Report Reveals Health Inequalities In Wales. BMJ 1999;319:806, 25 September 1999

Dobson, R., (2001). News Roundup: Funding Formula Based On Health Needs Planned For Wales. BMJ 2001;323:69 (14 July)

Dorling, D., et al, (2000). The Ghost of Christmas Past: health Effects of Poverty in London in 1896 & 1991. BMJ Colume 321, 23-30 Dec 2000. www.bmj.com

Douglas, C., Higgins, A., Dabbs, C. & Walbank, M., (2004). Health Impact Assessment or the Sustainable futures of Salford. Journal of Epidemiology and Community Health, Vol. 58.

Douglas, M., (1991). 'The Idea of a Home: A Kind of Space', Social Research, 58 (1): 287–307.

Douglas, M. J., Conway, L., Gorman, D., Gavin, S. & Hanlon, P., (2001). Developing Principles for Health Impact Assessment. Journal of Public Health Medicine. 23:2.

DTI. (2001). Digest of UK energy statistics, 2001. Department of Trade and Industry. The Stationery Office, London, UK, 2001.

Dumouchel, W.H. & Duncan, G.J., (1983). Using Sample Survey Weights In Multiple Regression Analysis Of Stratified Samples. Journal Of The American Statistical Association, 78, 535-548.

Dupuis, A. & Thorns, D.C., (1996). Meaning of home for home owners, Housing Studies, 11 (4): 485–501.

E

Ecologist, The (2001). The Ecologist Report – Climate Change, Time to Act: The latest on the Problem and the Solutions. The Ecologist, Volume 31, No 9, November 2001.

Edwards, P., et Al (2002). Papers: Increasing Response Rates To Postal Questionnaires: Systematic Review. BMJ Volume 324 18 May 2002 Bmj.Com

Elkins, P., (1999). Household Heat Is Fuelling Global Warming. Town And Country Planning, Page 187, June 1999.

Emeny, J. & Shuker, L., (Ed.), (2000). MRC Institute For Environment And Health Joint Research Programmes On Outdoor And Indoor Air Pollution A Review Of Progress. Institute For Environment And Health, Norwich.

Entchev, E., et al, (2004). Micro-Generation Technology Assessment for Housing Technology. Energy and Buildings 36 (2004) 925-931. Elsevier.

Environment, Transport and Regional Affairs Committee, (1999). UK Climate Change Programme – Minutes of Evidence. Wednesday 14th April 1999, House of Commons, London, The Stationary Office.

Eppel, H. & Lomas, K J., (199_). Empirical Validation of three Thermal Simulation Programs Using Data from a Passive Solar Building. Unknown Publication.

ESRC Research Centre On Micro-Social Change, (1994). British Household Panel Survey (BHPS) & British Household Panel Survey User Manual, Questionnaire & Additional Elements (e.g. Show cards etc) University Of Essex.

European Commission Architect's Council of Europe, Energy Research Group, Softech, Suomen Arkkirehtiliito, (1999). A Green Vitruvius : Principles and Practice of Sustainable Architectural Design. James and James, London.

European Environment Agency, (2004). Impacts of Europe's Changing Climate – An Indicator Based Assessment. EEA report No 2/2004.

Evans, B., (1995). Making Buildings Healthier. AJ, 14 September 1995, Page 57-8

Evans, B., (1996). Weather Forecasts For The Future. AJ, 15/22 August 1996, Page 37

Evans, E P, Penning-Rowsell, E C,& Hall, J W., (2003). Foresight Flood and Coastal Defence Project, Office of Science & Technology, London.

Evans, E., Ashley, R., Hall, J., Penning-Rowsell, E., Sayers, P., Thorne, C. & Watkinson, A., (2004). Foresight. Future Flooding. Scientific Summary: Volumes I Future Risks and Their Drivers & II Managing Future Risks. Office of Science and Technology, London.

F

Fang, C.F., & Ling, D.L., (2005). Guidance for noise reduction provided by tree belts, Landscape and Urban Planning 71 (2005) 29–34

Fangar, P. O., Breum, N. O. & Jerking, E., (1977). Can Colour and Noise Influence Man's Thermal Comfort? Ergonomics, 20, pp11-18.

Fangar, P. O., (1970). Thermal Comfort. Florida, Robert E. Krieger Publishing Company.

Farrar. J. F. & Vaze. P., (2000). Wales: Changing Climate, Challenging Choices- A Scoping Study Of Climate Change Impacts In Wales. Prepared For The National Assembly For Wales, Institute Of Environmental Science, University Of Wales, Bangor

Fedeski, M. H. and Gwilliam J. A. Urban sustainability in the presence of flood and geological hazards: the development of a GIS-based vulnerability and risk assessment methodology. Planning and Landscape Journal, 2007, submitted.

Ferriman, A., (2001). Excess Winter Deaths Linked To Temperatures In Cold Homes. BMJ Volume 323 24 November 2001. www.bmj.Com

Freeman, H., (1993). Mental Heath and High Rise Housing. In Unhealthy Housing: Research Remedies and Reform. Burridge, R & Ormandy, D. (eds). E & FN Spon. Pp 168 - 190

Firth, D & Bennet, K. E., (1998). Robust Models In Probability Sampling. Journal Of The Royal Statistical Society, B, 60, pp.3-21.

Fishman, D & Pimbert S, (1982). The Thermal Environment in Offices. Energy and Buildings. 5: pp.109-116.

Forster, A., & Culshaw, M., (2004). Implications of climate change for hazardous
ground conditions in the UK. Geology Today, Vol. 20, No. 2, March.April 2004. Blackwell Publishing Ltd,

Fuller, W.A. (1975). Regression Analysis For Sample Surveys. Sankhya C, 37, pp.117-132.

G

Gabe, J. & Williams, P., (1993). Women, Crowding and Mental Health. In Unhealthy Housing: research Remedies and Reform. Burridge, R & Ormandy, D. (eds). E & FN Spon. Pp 191 - 208

Gaffin, S. R., Rosenaweig, C., Xing, X & Yetman, G., (2003). Downscaling and Geo-Spatial Gridding of Socioeconomic Projections from the IPCC Special Report on Emissions Scenarios (SRES). Global Environmental Change 14 (2004) 105–123, Elsevier.

Garne, D., Watson, M., Chapman, S. & Byrne, F., (2005). Environmental Tobacco Smoke Research Published in the Journal Indoor and Built Environment and Associations with the Tobacco Industry. Lancet, 2005; 365:804-09.

Gatrell, A. C., & Guptill, S. C., (1999). GIS In Public And Environmental Health: Visualisation, Exploration and Modelling, , Presented At Conference - Setting An Agenda For Research On Health And The Environment: Mona, Jamaica, Nov 12 – 14 1999

Gemini Data Loggers, (2000). Data Logger Manual. Gemini Data Loggers. pdf. publication. http://www.geminidataloggers.com

Ghadames, L., Ealiwa, M. A., Taki, A. H., Howarth, A. T. & Seden, M. R., (1999). Field investigation of thermal comfort in both Naturally and mechanically ventilated buildings. The Leicester School of Architecture, de Montfort university, Leicester, LE1 9PH, UK. Indoor Air 99, Vol. 2, Pg 166.

Githeko, A. K., (1999). Health And Climate Variability- Exploring The Future, Presented At Conference - Setting An Agenda For Research On Health And The Environment: Mona, Jamaica, Nov 12 – 14 (1999).

London School Of Hygiene And Tropical Medicine, (2001). Globalisation Environmental Change And Health; Evidence, Estimation And Response - 28 March 2001, London. Seminar Attended At London School Of Hygiene And Tropical Medicine.

Godambe, V.P. & Thompson, M.E., (1986). Parameters of Super Populations And Survey Population: Their Relationship And Estimation. International Statistical Review, 54, 37-59.

Goodess, C. M., Hulme, M. & Osborn, T. J., (2001). The Identification And Evaluation Of Suitable Scenario Development Methods For The Estimation Of Future Probabilities Of Extreme Weather Events - Working Paper 6., Tyndall Centre For Climate Change Research

Goodwin, J., (2000). Cold Stress, Circulatory Illness and the Elderly. In Cutting the Cost of Cold, Ed, Rudge, J. & Nicol, F. (2000), E & F Spon, pp 49 - 61.

Gossett, J.M., Simpson, P., Parker, J.G. & Simon, W.L., (Unknown). How Complex Can Complex Survey Analysis Be With SAS? University Of Arkansas For Medical Sciences, Little Rock, AR, Sugi 27 Statistics And Data Analysis, pp.266-27.

Government Statistical Service, (1999). The National Assembly for Wales Welsh Health Survey 1998. HMSO, Norwich.

Granger K. (2001) Geohazards risk to urban communities in Australia, CCOP technical bulletin Volume 30, *Australian Geological survey organisation*, p 165-174.

Graves, H. M. & Phillipson, M. C., (2000). Potential Implications of Climate Change in the Built Environment. FBE Report 2.

Green, E. & Short, S., (1998). Medical Research Council, Institute For Environment and Health, IEH Assessment On Indoor Air Quality In The Home (2): Carbon Monoxide, Assessment A5, Institute For Environment And Health, Norwich.

Green, E., (2000). Health And Well-Being: Does Our Environment Matter? A Report Of An Open Seminar Organised By The MRC Institute For Environment And Health And Held At The NSPCC National Training Centre, Leicester, On 28 November 2000, IEH, Norwich.

Grimwood, C. J., (1993). Effects of Environmental Noise on People at Home. BRE Infomation Paper 11/92 C75 28938. BRE, Watford.

De Groot, N., (1999). Climate Change Or Climate Variability? Presented At Conference - Setting An Agenda For Research On Health And The Environment: Mona, Jamaica, Nov 12 – 14 (1999).

De Gruijl, F. R., (2000). Health Effects From The Sun's Ultraviolet Radiation & Ozone As A Stratospheric Sunscreen. Global Change and Human Health Vol. 1, Issue, Pages 26 – 40.

GSS (The Government Statistical Service), (1999). Welsh Health Survey 1998. National Assembly For Wales.

Gunnersen, L & Santos, A., M. B., (1998). Relative Importance of Temperature, Draft, Noise and Window Area in Offices. In: Proceedings of EPIC'98, European Conference on Energy, Performance and Indoor Climate in Buildings, Lyon, 862-867.

H

Hacker, et al, (2005). Climate Change and the Internal Environment. CIBSE, RIBA & DTI, TM36: 2005.

Hacker, J & Twinn, C, (2005). UK Housing & Climate Change. Heavyweight vs Lightweight, Arup research, Bill Dunster Architects, London.

Hadley Centre, The, (2001). The Hadley Centre Regional Climate Modeling System. PRECIS (Providing Regional Climates For Impacts Studies), Met Office Hadley Centre, Bracknell Berkshire.

Hadley Centre, The, (2001). Climate Change Science - Some Recent Results From The Hadley Centre. Met Office Hadley Centre, Bracknell Berkshire.

Hadley Centre, The, (2002a). The Hadley Centre Regional Climate Modeling System PRECIS: Update 2002, Providing Regional Climates for Impacts Studies Met Office Hadley Centre, Bracknell Berkshire.

Hadley Centre, The, (2002b). Stabilisation and Commitment to Future Climate Change - Scientific Results from the Hadley Centre, Met Office Hadley Centre, Bracknell Berkshire.

Haines, A., & McMichael, A. J., (1999). Climate Change and Human Health. Science in Society, A Discussion Meeting Held at the Royal Society on Tuesday 20 October 1998, Pub
The Royal Society, London.

Haines, A., Epstein, P.R. & McMichael, A.J., (2000). Global Change and Health, CMAJ.

Haines, A. & Kammen, D., (2000). Sustainable Energy and Health. Global Change and Human Health 2000; 1; 85-87 Kluwer Academic Publishers.

Hales, S., (1999). Health and Climate Variability – Exploring the Past. Presented at Conference, Setting an Agenda for Research on Health and the Environment: Mona, Jamaica, Nov 12 – 14 (1999).

Halliday, S., (1997). Using the Problem to Provide the Solution. Refrigeration and Air Conditioning, October 1997.

Handisyde C. C., et al, (1970). Condensation in Dwellings, Part 1 – A design Guide. Ministry of Public Buildings and Works, HMSO, London.

Handisyde, C. C., et al, (1971). Condensation in Dwellings, - Part 2 Remedial Measures. Department of The Environment HMSO, London.

Hartley H. O. & Sielken, R. L., Jr., (1975). A "Super-Population Viewpoint" for Finite Population Sampling. Biometrics, 31, 411-22.

Hawkes, D & Forster, W., (2002). Architecture, engineering and environment. London : Laurence King.

Hedge, A., (1996). Addressing the Psychological Aspects of Indoor Air Quality. Paper Presented at the 1st Asian Indoor Air Quality Seminar Sponsored by Bat, Urumqi, China, Sept. 22-23, 1996

Hendrick, J., (Unknown). The Impact of Weights on Standard Errors. Management Studies Group, Wageningen , The Netherlands

Hensen, J. L. M., (1990). Literature Review on Thermal Comfort in Transient Conditions. Building and Environment, Vol. 25, no. 4, pp. 309-316.

Heron, J., Et Al, (2002). Avon Longitudinal Study of Parents and Children, the Relationship Between Noise in the Home and the Health, Behaviour & Development of Children up to Age 7. End Of Study Report, University Of Bristol, Division Of Child Health.

Hippisley-Cox, J., et al, (2002). Cross Sectional Survey of Socioeconomic Variations in Severity and Mechanism of Childhood Injuries. In Trent 1992-7. BMJ Volume 324 11 May 2002 Bmj.Com

Holerie, G., Sakurai, Y., Nogushi, T. & Matsubara, N., (1985). Synthesized Evaluation of Noise, Lighting and Thermal Conditions in a Room. In Proceedings of Noise Control 85, International Conference on Noise Control Engineering, Krakow, 491-496.

Holmes, P., And Tuckett, C., (2000). MRC Institute For Environment and Health, Airborne Particles: Exposure in the Home and Health Effects. Institute for Environment and Health, Norwich.

Hopton, J. & Hunt, S., (1996). The Health Effects of Improvements to Housing: A Longitudinal study. Unknown, Journals Oxford Ltd.

Houghton, J. T., (ed), (1996). Climate Change 1995 : The Science of Climate Change, Cambridge : Cambridge University Press for the Intergovernmental Panel on Climate Change, 1996

Howard, M. (1993). The Effects on Human Health of Pest Infestations in Houses. In Unhealthy Housing: Research Remedies and Reform. Burridge, R & Ormandy, D. (ed.s). E & FN Spon. Pp 191 - 208

Howard, R. & Critchley, R., (2000). Treating Cold, Damp and Asthma with Affordable Warmth. In

Cutting the Cost of Cold, Ed, Rudge, J. & Nicol, F. (2000), E & F Spon, pp 166 - 175

Howieson, S. & Lawson, A., (2000). Dust Mite Allergen, Indoor Humidity and Asthma. In Cutting the Cost of Cold, Ed, Rudge, J. & Nicol, F. (2000), E & F Spon, pp 62 - 77

Hulme, M. And Barrow, A., (1997). Climates of the British Isles, Present, Past and Future. Routledge, London.

Hulme, M & Parry, M, (1998). Adapt or Mitigate? Responding for Climate Change. Town and Country Planning, March 1998.

Hulme, M., (2003). Abrupt Climate Change: Can Society Cope? Tyndall Centre Working Paper No. 30 Tyndall Centre For Climate Change Research

Hulme, M., et al, (2002). Climate Change Scenarios for the United Kingdom: The UKCIP02 Scientific Report, Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia, Norwich, UK.

Hulme, M., (2001). Integrated Assessment Models - Working Paper 2 Tyndall Centre for Climate Change Research, Norwich.

Hulme, M. & Jenkins, G. J., (1998). Climate Change Scenarios for the United Kingdom, Scientific Report, UKCIP Technical Report No 1, Climatic Research Unit, Norwich, 80pp.

Humfrey. C., Shuker, L., & Harrison, P., (1996). Medical Research Council, Institute for Environment and Health, IEH Assessment On Indoor Air Quality In The Home: Nitrogen Dioxide, Formaldehyde, Volatile Organic Compounds, House Dust Mites, Fungi and Bacteria. Assessment A2, Institute for Environment and Health, Norwich.

Humfrey, C., Taylor, M., & Amaning, K., (1997). Medical Research Council, Institute For Environment And Health, IEH Report On Health Effects Of Waste Combustion Products. Report R7, Institute for Environment and Health, Norwich.

Humphreys, M. & Nicol, J. F., (1995). An Adaptive Guideline for UK Office temperatures. In Standards for Thermal Comfort, Nicol, F., Humphreys, M. A., Sykes, O. & Roaf, S. eds., pp 190-195. London: E & FN Spon (Chapman & Hall)

Humphreys, M. & Nicol, J. F., (1998a). Understanding the Adaptive Approach to Thermal Comfort. ASHRAE Technical Data Bulletin 104(1);-14.

Humphreys, M. & Nicol, J. F., (1998b). Effects of Measurement and Formulation Error on Thermal Comfort Indices in the ASHRAE Database of Field Studies. ASHRAE technical Data bulletin 106(2).

Humphreys, M. & Nicol, J. F., (1998c). Outdoor Temperature and Indoor Thermal Comfort: Raising the Precision of the Relationship. For the 1998 ASHRAE Database of Field Studies. ASHRAE technical Data bulletin 106(2).

Humphreys, M.A., Oseland, N.A., (1994). Trends in Thermal Comfort Research. (BRE, London.)

Humphreys, M.A., (1978). Outdoor Temperatures and Comfort Indoors CP53/78, (BRE, London.)

Hunt, D. R. G. & Gidman, M. I., (1982). A National Field Survey of House Temperatures. Building and Environment Vol. 17, No 2, pp107 0 124, 1982.

Hurrell, J. W., (1995). Decadal Trends in the North Atlantic Oscillation: Regional Temperatures and Precipitation. Science August 4, 1995 v269 n5224 p676(4)

Hwang, S., et al, (1999). Housing and Population Health: A Review of the Literature. Centre for Applied Research, Faculty of Social Work, University of Toronto, May 1999

I

IEH, (Institute for Environment and Health), (2000). Volatile Organic Compounds (Including Formaldehyde) in the Home. www.le.ac.uk/ieh/

I.E.H., (1994). IEH Report On Air Pollution And Respiratory Disease: UK Research Priorities. This Publication is Based on a Workshop Held In Leicester 28 February 1994, Report R2, Institute for Environment and Health, Norwich.

I.E.H., (1997), Medical Research Council Institute For Environment And Health, IEH Report On The Non-Auditory Effects of Noise, Report R10, Institute for Environment and Health, Norwich.

IEH, (1997a). The Non-Auditory Effects of Noise – R10. www.le.ac.uk/ieh/

IEH, (1997b). Health Effects of Waste Combustion Products – R7. www.le.ac.uk/ieh/

IEH, (2001). Indoor Air Quality in the Home: Final Report on DETR Contract EPG 1/5/12 (Web Report W7). Institute for Environment and Health, Leicester, UK. (http://www.le.ac.uk/ieh/publications/publications.html posted November 2001)

IEH, (2001), Indoor Air Quality In The Home: Final Report On DETR Contract Epg 1/5/12 (Web Report W7), Leicester, UK, Institute For Environment And Health
(At Http://Www.Le.Ac.Uk/Ieh/Publications/Publications.Html Posted November 2001)

IEH, (2002), Sixth Annual UK Review Meeting On Outdoor And Indoor Air Pollution Research 15th–16th April 2002 (Web Report W12), Leicester, UK, MRC Institute For Environment And Health, Available At Http://Www.Le.Ac.Uk/Ieh/

IEH, (2002a). Sixth Annual UK Review Meeting on Outdoor and Indoor Air Pollution Research 5th–16th April 2002 (Web Report W12). MRC Institute for Environment and Health, Leicester, UK.

(http://www.le.ac.uk/ieh/)

Independent, The, (1997). A Climate for Change. 25 Jun 1997 / (1096), Andrew Marr.

Independent, The, (2002). Ten Day Heatwave May Have Led to 2,000 Deaths. Paul Peachey, The Independent, Saturday 4th October 2002.

Independent, The, (2003). The Ten Best Air Conditioners.pp23 -24, Mon. 8th September

Independent, The, (2004). Air Pollution Blamed for 750 Deaths in Heatwave. Steven Carrell, The Independent, 22nd August 2004.

IPCC, (1995). Contributions of Working Group II to the IPCC Second Assessment Report. IPCC-XI/Doc. 4. IPCC Geneva.

IPCC, (2002a). Summary for Policymakers. A Report of Working Group I of the Intergovernmental Panel on Climate Change – Third Assessment Report Pub IPCC.

IPCC, (2002b). Summary for Policymakers. A Report of Working Group 2 of the Intergovernmental Panel on Climate Change – Third Assessment Report Pub IPCC.

IPCC, (2002c). Summary for Policymakers. A Report of Working Group 3 of the Intergovernmental Panel on Climate Change – Third Assessment Report Pub IPCC.

IPCC, (2002d). IPCC Workshop on Changes in Extreme Weather and Climate Events. Beijing, China, 11 – 13 June, 2002 workshop Report.

IPCC, (2003). An Introduction to the Intergovernmental Panel on Climate Change. IPCC, Feb 2003.

IPCC-TGCIA, (1999) Guidelines on the Use of Scenario Data for Climate Impact and Adaptation Assessment. Version 1. Prepared By Carter, T.R., M. Hulme, and M. Lal. Intergovernmental Panel on Climate Change, Task Group on Scenarios for Climate Impact Assessment, 69pp.

IPCC-TGCIA, (2001). Climate Change 2001: Impacts, Adaptation and Vulnerability. Edited by McCarthy J J, et al. Intergovernmental Panel on Climate Change, Cambridge University Press.

J

Jackson, C. & Furnham, A., (1999), Designing And Analysing Questionnaires & Surveys. Missing.

Jenkins, G. J., Mitchell, J. F. B. & Folland C. K., (199_). The Greenhouse Effect and Climate Change - A Review. Hadley Centre For Climate Prediction And Research

Jenkins, G., & Lowe, J., (2003). Handling uncertainties in the UKCIP02 scenarios of climate change. Hadley Centre Technical Note 44. Hadley Centre For Climate Prediction And Research, Berkshire, 20 November 2003

Jenkins, H., (2002). Personal Communication.

Jenkins, P., Scheim, C., Wans, J. T., Reed, R. & Green, A., (2004). Assessment of Coverage Rates and Bias Using Double Sampling Method. Journal of Clinical Epidemiology 57, (2004) 123-130. Elsevier.

Jepa, C. J., & Munasinghe, M., (1998). Climate Change Policy, Facts Issues and Analyses. Cambridge University Press, Cambridge.

Jeryl, L. M. & Stewart, T. R., (1996). Expert Judgement and Expert Disagreement. Thinking and Reasoning, 1996, 2 (2/3), 191–211

Jitkhajornwanich, K., Pitts, A. C., Malama, A. & Sharples, S., (1998). Thermal Comfort in Transitional Spaces in the Cool Season of Bangkok. ASHRAE Transactions, 104 (1).

Johns, J., & Fedeski, M., (2001). Assessing the Impacts of Climate Change on the Building Stick of a Region: Identifying an Appropriate Methodology. In Brunet India M. & Lopez Bonillo, D. (Eds) Detecting and Modelling Regional Climate Change, Springer & Verlag, Berlin, 2001.

Johns, T.C., et al, (2001). Anthropogenic Climate Change for 1860 to 2100 Simulated With the HadCM3 model Under Updated Emissions Scenarios. Hadley Centre Technical Note No. 22. Met Office, Hadley Centre for Climate Prediction and Research, Bracknell, 24 Jan 2001.

Johns Hopkins University (2001), Climate Change and Human Health - The Potential Consequences Of Climate Variability And Change: A Report Of The National Health Assessment Group For The U.S. Global Change Research Program. Johns Hopkins University, Bloomberg School Of Public Health & Department Of Environmental Health Sciences, Baltimore.

Jones, D.L. (1998). Architecture and the environment : bioclimatic building design. London : Laurence King.

Jones, J., (2001). UK Seeks To Prevent 50 000 Winter Deaths From "Fuel Poverty". BMJ 2001; 322: 510 (3 March)

Jones, P. J., Alexander, D. K. & Rahman, A. M., (Unknown). Evaluation of the Thermal Performance of Low-Cost Tropical Housing. Published: Unknown.

Jones, P. J., Lannon, S., Sutcliffe, A. & Vaughan, A., (1996). An Energy and Environmental Prediction Tool for Planning Sustainability in Cities. Proceedings of the 4th European Conference on Architecture, Solar Energy in Architecture and Urban Planning, Bedford.

Jones, P. J., Vaughan, N. D., Grajewski, T & Jenkins, H. G., (1995). New Guidelines for the Design of Healthy Office Environments, March 1995, Reference: GR/H38645, Findings from the investigation of eight buildings carried out by the Welsh School of Architecture and the Bartlett School of Architecture for the SERC and DTI through the LINK initiative.

Jones, R.J., Lim, B. and Burton, I. (submitted) Coping ranges and climate risk assessment: a new approach to vulnerability and adaptation. Climatic Change.

Joos, F., Ramirez-Rojas, A., Stone, J. M. R. & Zillman, J., Eds., (2001). Technical Summary of the Working Group I Report, IPCC, Web.

Joseph, J. (2004). Perception or Reality – Waste, Landfill and the Environment. Geology Today, Vol. 20, No 3. May – June 2004.

K

Kalkstein, L. S., (1995). Lessons from a Very Hot Summer. The Lancet, Vol. 346, September 30 1995

Kalton, G. (1983). Models in the Practice of Survey Sampling. International Statistical Review, 51, 175-188.

Kawachi, I & Berkham, L., (2003). Neighbourhoods and Health. Oxford University Press.

Kearns, A. R., Smith, C. J., & Abbott, M. W., (1993). Housing Stressors and Persons with Serious Mental Helath Problems. Health and Social Care; 1; 263 – 275.

Keatinge, W. R. & Donaldson, G. C., (2000). Cold Weather, Cold Homes and Winter Mortality. In Cutting the Cost of Cold, Ed, Rudge, J. & Nicol, F. (2000), E & F Spon, pp 17 – 29..

Kellett, J., (1989). Paper Title Missing. Journal of Psychosomatic Research. Vol33. No 3. pp255-268, 1989. Maxwell Pergamon Macmillan plc.

Kish, L. & Frankel, M. R., (1974). Inference from Complex Samples (with Discussion). Journal of the Royal Statistical Society B, 36, 1-37.

Knutt, E., (1996). Climate Change Prompts Design Alert. Building July 1996 Page 10.

Koppe, C., Kovats, S., Jendritzky, G., & Menne, B., (2003). Heat-Waves: Risks and Responses. Health and Global Environmental Change Series, No2. WHO, Europe.

Korn, E.L. & Graubard, B.I., (1995). Analysis of Large Health Surveys: Accounting for the Sampling Designs. Journal of the Royal Statistical Society A, 158, 263-295.

Korn, E.L. & Graubard, B.I., (1995). Examples of Differing Weighted and Unweighted Estimates from a Sample Survey. The American Statistician, 49, 291-295.

Korn, E.L. & Graubard, B.I., (1999). Analysis oOf Health Surveys. New York: Wiley.

Kovats, S., (1999). Climate Variability: Daily Temperature Extremes Presented at Conference - Setting An Agenda For Research On Health And The Environment. Mona, Jamaica, Nov 12 – 14 (1999).

Kovats, R. S., et al, (1999). Climate Change and Human Health in Europe. BMJ Volume 318 19 June 1999 www.bmj.com, pp 1682 – 1685.

Kovats, R.S., et al, (2000). Climate Change and Human Health: Impact And Adaptation, WHO.

Kovats R. S., Jales S. & Woodward A, (2000). What El Nino Can Tell Us About Human Health and Climate Change. Global Change and Human Health, 2000, 1; 66-77 Kluwer Academic Publishers

Kovats, S., Wolf, T., & Menne, B., (2003). Heatwave of August 2003 in Europe: Provisional Estimates of the Impact on Mortality. Web.- www.lshtm.ac.uk.

Kovats, S., Ebi, K., L., & Menne, B., (2003). Methods of Assessing Human Health Vulnerability and Public Health. Adaptation to climate Change Health and Global Environmental Change Series, No1. WHO, Europe.

Krieger, J. & Higgins D. L., (2002). Housing and Health: Time Again for Public Health Action. American Journal for Public Health; May 2002; 92,5; ABI/INFORM Global Pg758.

Kriz, B., (1999). Climatic Variability, Extreme Weather Events and Health. Presented at Conference - Setting an Agenda for Research on Health and the Environment: Mona, Jamaica, Nov 12 – 14 (1999).

Kuhn, K., G., (1999). Conceptual and Methodological Approaches for the Study of Climate/Health Linkages. Presented at Conference - Setting an Agenda for Research on Health and the Environment: Mona, Jamaica, Nov 12 – 14 (1999).

Kumar, R., (1999). Research Methodology – A step by Step Guide for Beginners, Sage Publications, London.

Kunzli, N, et al, (2000). Public Health Impact Of Outdoor and Traffic-Related Air Pollution. A European Assessment. Lancet 2000; 356: 795-801.

Kwok, A. G., (1998). Thermal Comfort in Tropical Classrooms. ASHRAE Transactions, 104(1).

L

Lacy, R.E., (1977). Climate and Building in Britain: A Review of Meteorological Information Suitable for Use in the Planning, Design, Construction and Operation of Buildings. London : H.M.S.O.

Lam, J. C. , Tsang, C. L., Yang, L. & Li, D. H. W., (2004). Weather Data Analysis and Design Implications for Different Climatic Zones in China. Building and Environment 40 (2005) 277–296. Elsevier.

Lancaster J W, Preene, M & Marshall, C T.,(2004).Development and flood risk guidance for the construction industry CIRIA C624 London, 2004

Lannon, S. (2004). Personal Communication with the Author.

Lechyd Morgannwg Health, (2000), The Health Improvement Programme for Morgannwg for 2000 – 2005. Lechyd Morgannwg Health & Local Health Groups for Swansea, Neath Port Talbot and Bridgend.

Levermore, G., Chow, D., Jones, P. & Lister, D., (2004). Accuracy of Modeled Extremes of Temperature and Climate Change and its Implications for the Built Environment in the UK. Tyndall Centre for Climate Change research Technical Report 14.

Lewis, J., (1993). Building for Global Warming. The AJ, 16 June 1993 PES 54 - 55

Lewis, P. T. & Alexander, D. K., (1990). HTB2: A Flexible Model for Dynamic Building Simulation. Building and Environment, Vol. 25, No. 1, pp. 7-16.

Liao Z, Swainson M and Dexter A L. (2005). On the Control of Heating Systems in the UK. Buildings and Environment 40 (2005) 341 349. Elsevier.

Lindsay, S. & Joyce, A., (2000). Climate Change and the Disappearance of Malaria from England. Global Change & Human Health, Volume 1, No. 2 (2000). Kluwer Academic Publishers P 184 – 196.

Lindsay, S. W. & Thomas, C. J., (2001). Global Warming and Risk of Vivax Malaria in Great Britain. Global Change & Human Health, Volume 2, No. 1 (2001) Kluwer Academic Publishers, P 80 – 84.

Little, R. J. A., (1991). Inference with Survey Weights. Journal Of Official Statistics, 7, 405-424.

Little, R. J. A., (2003). To Model or Not to Model? Competing Modes of Inference for Finite Population Sampling. Technical Report, Department Of Statistics, University Of Michigan.

Lomas P R, Green B M R and Miles J C H (1998). Radon in Dwellings in Wales: Atlas and 1998 Review, Health Protection Agency, London.

Lorch, R., (1990) Energy and Global Responsibility. Richard Lorch, RIBA Journal March 1990, Pages 50 – 51.

Lowe, R., (2001). A Review of Recent and Current Initiatives on Climate Change and its Impact on the Built Environment: Impact, Effectiveness and Recommendations. CEBE Report No 10, Centre For The Built Environment, Leeds Metropolitan University, ISSN 1358-0558

Lowry, S., (1989a). Indoor Air Quality. BMJ, Vol. 299, 02 Dec 1989.

Lowry, S., (1989b). Housing and Health: Temperature and Humidity. British medical Journal, 1989; 299; 1326-8(25.November)

Lowry, S., (1989c). An Introduction to Housing and Health. British Medical Journal, 1989; 299; 1261-2(18.November)

Lowry, S., (1991). Housing and Health. British Medical Journal, London.

Lynch, J W., et al, (2000). Income Inequality and Mortality: Importance to Health of Individual Income. Psychosocial Environment, or Material Conditions. BMJ Volume 320 29 April 2000 Bmj.Com

M

Macintosh, A. & Steemers, K., (2005). Ventilation Strategies for Urban Housing: Lessons from a PoE Case Study. Building Research & Information (Jan-Feb). 33(1), 17-31.

Macintyre, K., (2000). Relation Between Socioeconomic Deprivation and Death from a First Myocardial Infarction. In Scotland: Population Based Analysis, National Heart Foundation Of Australia.

Macintyre, S., Maciver, S. & Sooman, A., (1993). Area, Class and Health: Should We be Focusing on Places or People. Journal of Social Policy, Volume 22, 2, 213-234.Cambridge University Press.

Macintyre, S., et al, (2001). Using Evidence to Inform Health Policy: Case Study, BMJ Volume 322 27 January 2001 www.bmj.com.

Macintyre, S., McKay, L., & Ellaway, A., (2005). Are Rich People or Poor People More Likely to be Ill? Lay Perceptions, by Social Class and Neighbourhood, or Inequalities in Health. Social Science & medicine, 60, (2005), pp 313 – 317.

Malama, A., Sharpless, S., & Pitts, A., (1998). An Investigation of the Thermal Comfort Adaptive Model in a Tropical Upland Climate. ASHRAE Transactions 104 (1).

Mallet, S., (2004). Understanding Home: A Critical Review of the Literature. The Sociological Review, Volume 52 Issue 1 Page 62 - February 2004, Blackwell, London.

Malmesbury, J. J., (2001). UK Seeks To Prevent 50 000 Winter Deaths from "Fuel Poverty". BMJ 2001;322:510 (3 March)

Manabe, S, & Stouffer, R. J., (2000). Study of abrupt climate change by a coupled ocean-atmosphere model Quaternary ScienceR eviews 19 (2000)2 85-299

Manning, M. & Nobre, C., Eds., (2001). Technical Summary, Climate Change 2001, Impacts Adaptation And Vulnerability: A Report Of Working Group II Of The Intergovernmental Panel On Climate Change. IPCC, Web.

Mant, D.C. & Muir Gray J.A., (1986). Building Regulation and Health, (BRE, UK.)

Mant, D., (1993). Understanding the Problems of Health and Housing Research. In Unhealthy Housing: Research Remedies and Reform. Burridge, R & Ormandy, D. (ed.s). E & FN Spon. Pp 3 -

Markov, D., (Unknown). Standards of thermal Comfort. Web based publication.

Markus T. A. & Morris, E., N., (1980). Buildings, Climate and Energy. Pitman.

Markus, T. A., (1993). Cold, Condensation and Housing Poverty. In Unhealthy Housing: Research Remedies and Reform. Burridge, R & Ormandy, D. (ed.s). E & FN Spon. Pp 141-167.

Marmot, M. & Wilkinson, R. G., (2001). Psychosocial and Material Pathways in the Relation Between Income and Health: A Response To Lynch et al. BMJ Volume 322 19 May 2001 www.bmj.com.

Marsh, A., Gordon, D., Pantazis, C. & Heslop, P., (1999). Home Sweet Home?: The Impact of Poor Housing on Health. The University of Bristol & The Policy Press, Bristol.

Martens, P (1999). Climate Change Impacts on Vector Borne Disease Transmission in Europe. Pages 45 – 53 in Haines, A., And McMichael, A. J., (1999), Climate Change And Human Health. Science In Society, - A Discussion Meeting Held At The Royal Society On Tuesday 20 October 1998, Pub. The Royal Society, London.

Martin, P. H., (1999), Health and Climate Variability - The Stakeholders Approach. Presented At Conference - Setting An Agenda For Research On Health And The Environment: Mona, Jamaica, Nov 12 – 14 (1999).

Martens, P. & McMichael, A. J., (2002). Environment Change, Climate and Health: Issues and Research Methods. Cambridge University Press, Cambridge.

Martens, W. J. M., (1998). Health and Climate Change: Modelling the Impacts of Global Warming and Ozone Depletion. London, Earthscan.

Martin, C. (1991). Damp Homes Make You Ill. Housing, March, 1991. pp31 – 33.

McCarthy, P., Byrne, D., Harrison, S. & Keithlry, J., (1985). Housing Type, Housing Location and Mental Health. Social Psychiatry, 1985, 20; 125-130.

McCartney, K., (ed), (2001). Moving Thermal Comfort Standards into the 21st Century, Conference held at Cumberland Lodge, Windsor, UK, 5th – 8tth April 2001, Conference Proceedings. Organised by Oxford Centre for Sustainable Development & Loughborough University. Oxford Brookes University, Oxford.

McCormack, C., (1994). Bad Housing = Bad Health. World Health. 47th year, No 6. Nov-Dec 1994.

McCulloch, A., (2001), Social Environments and Health: Cross Sectional National Survey. BMJ Volume 323 28 July 2001 Bmj.Com P208.

McEvoy, D., Handley, J. F., Cavan, G., Aylen, J., Lindley, S., McMorrow, J. and Glynn, S. (2006). Climate Change and the Visitor Economy: the challenges and opportunities for Northwest, Sustainability Northwest (Manchester) and UKCIP (Oxford).

McGregor, G. R., (1999). Climatic Variability, Extreme Weather Events and Health, Presented at Setting an Agenda for Research on Health and the Environment: Mona, Jamaica, Nov 12 – 14 (1999).

McIlveen, J. F. R., (1992). Fundamentals of Weather and Climate. London: Chapman & Hall.

McKenzie-Hedger, Merylyn et al (Eds), (2000), Climate Change – Assessing the Impacts – Identifying Responses – The first three years of the UK Climate Impacts Programme. UKCIP Technical Report, UKCIP & DETR, Oxford.

McMichael, A. J., et al, (2000). Human Health In: Methodological And Technological Issues In Technology Transfer, IPCC, Ed. S Metz B. Et Al, Cup.

McMichael, A. J., & Kovats R. S., (2000). Climate Change and Climate Variability: Adaptations to Reduce Adverse Health Impacts, Environmental Monitoring and Assessment, 2000, 61, 49 – 64

McMichael, A. J. & Kovats R. S., (2000). Global Environmental Change and Health: Approaches to Assessing Risks. Ecosystem Health, 2000, 6, 59-66.

McMichael, A.J., & Kovats, R.S.M., (2001). Strategies for Assessing Health Impacts of Global Environmental Change. In Crabbe P, Westra L, Holland A (Eds) Implementing Ecological Integrity: Restoring Regional and Global Environmental and Human Health, Dordrecht: Kluwer Academic Publishing.

McMichael, A. J., (2001). Global Environmental Change in the Coming Century: How Sustainable are Recent Health Gains? In Pimentel D, Westra L, Noss R (Eds) Ecological Integrity In The Worlds Environment And Health. Washington Dc: Island Press.

McMichael, A. J., (2001). Human Frontiers, Environments and Disease, Cambridge University Press, Cambridge.

McNiece, R. & Majeed, A., (1999). General Practice: Socioeconomic Differences in General Practice Consultation Rates In Patients Aged 65 And Over: Prospective Cohort Study, BMJ Volume 319 3 July 1999 www.bmj.com, P26.

Meehl Et Al., Bams, 2000, 81, 413-416 www.clivar.org

Meyer, W. B., (2002). Why Indoor Climates Change: A Case Study. Climatic Change 55: 395-407, 2002.

Milbank N., (1989). Building Design and Use - Response To Climate Change. The AJ 2 August 1989, Pages 59 - 63.

Mood, E., W. (1993). Fundamentals of Healthful Housing: Their application in the 21st Century. In:

Unhealthy Housing: Research Remedies and Reform. Burridge, R & Ormandy, D. (ed.s). E & FN Spon. pp. 303 – 337.

Moore, C. G. & Guptill, S. C., (1999). Methods and Data for Vector-Borne and Zoonotic Diseases. Presented at Conference - Setting an Agenda for Research on Health and the Environment: Mona, Jamaica, Nov 12 – 14 1999

Mountis, A., Natarajan, S. & Levermore, G., (2005). Climate Change and indoor Comfort. Presentation at CIB W 108 15 April, 2005. CSTB, Paris.

Morgannwg LHA, (2000). Health Improvement Programme for Morgannwg 2000-2005. Morgannwg Local Health Authority.

MRC Institute for Environment and Health, (2003). 10th Anniversary Open Seminar: Climate Change in the UK, Impact on Environment and health, 16th September 2003, University of Leicester, UK.

Muller, A., (2002). Education, Income Inequality and Mortality: A Multiple Regression Analysis. BMJ Volume 324 5 January 2002 Bmj.Com

N

National House Building Council, (2000). How Your Home was Constructed – A guide to Your New Home. NHBC, UK.

National Statistics, (2002), The Environment in your pocket. DEFRA.

Newcombe, R. G., Lyons, R. A., Jones, S. J. & Patterson, J., (2005). Home Injuries and Built Form: Methodological Issues and Developments in Database Linkage. BMC Health Services Research, 2005, 5:12.

New Zealand Climate Change Office, Ministry for the Environment, (2004). Climate change effects and Impacts Assessment, A guidance manual for Local Government in New Zealand, Wellington, p140.

Nicol, F., Humphreys, M., Sykes, O & Roaf, S. (ed.s) (1995). Standards for Thermal Comfort. Indoor Air temperature Standards for the 21st century. E & FN Spon.

Marialene Nikolopoulou (ed), (2004). Designing Urban Spaces in the Urban Environment. CRES Department of Buildings.

NOP Survey Group, (1997/8), Welsh Heath Survey – Questionnaire & Technical Report, NOP.

Nordstrom, C. K., Diez Roux, A. V., Jackson, S. A. & Gardin, J. M., (2004). The Association of Personal and Neighbourhood Socio-Economic Indicators with Sub-Clinical Cardiovascular Disease in an Elderly Cohort. The Cardiovascular Health Study. Social Science and Medicine. Vol. 59 (2004) 2139 – 2147.

North Devon Journal, (2002), Termite Invaders Face A 12-Year Wipe Out Plan

Norusis, M. J., (1987), The SPSS Guide to Data Analysis for SPSS, SPPS Inc, Chicago.

O

O'Connor, G. T., et al, (2004). Airborne Fungi in the Homes of Children with Asthma in Low Income Urban Communities: The Inner City Asthma Study. Environment and Occupation Respiratory Disorders. 20th August 2004 Article in Press.

Office of the Deputy Prime Minister (2002). Approved Document E – Resistance to the Passage of Sound. The Building Regulations, 2000. NBS, London.

Office of the Deputy Prime Minister (2006). Approved Document F – Ventilation. The Building Regulations, 2000. NBS, London.

Office of the Deputy Prime Minister (2006). Approved Document L1A: Conservation of fuel and power (New dwellings) (2006 edition). NBS, London.

Office of the Deputy Prime Minister (2006). Approved Document L1B Conservation of fuel and power (Existing dwellings) (2006 edition). NBS, London.

Olivier, D., (1999). Air Leakage Sandards. AECB, UK.

ONS (Office for National Statistics), (2002). The National Statistics Socio-Economic Classification User Manual, National Statistics / Her Majesty's Stationery Office (HMSO), London

ONS, (2003a). Census 2001: Key Statistics for Local Authorities in Wales. HMSO, London.

ONS, (2003b). Census 2001, Key Statistics for Local Authorities in England and Wales. HMSO, London.

ONS, (2003c). News release: Census 2001. Wales, HMSO, London.

ONS, (2003d), News release: Census 2001 - New Detailed View includes Picture of Children's Backgrounds. HMSO, London.

ONS, (2003e). Census 2001, National Report For England and Wales. HMSO, London.

Olgyay, V., (1963). Design with Climate: A Bioclimatic Approach to Architectural Regionalism. Princeton University Press, new Jersey.

Olesen, B. W., (2004). International Standards for the Indoor Environment. Indoor Air, 2004;14 (suppl. 7); 18-26.

O'Marde, D., E., (1999). Health, Climate Change and Climate Variability – Exploring the Future.

Presented at Conference - Setting an Agenda for Research on Health and the Environment: Mona, Jamaica, Nov 12 – 14 (1999).

Oppenheim, A., (1992). Questionnaire Design and Attitude Measurement. Pinter Publishers, London.

Oppenheim, A. N., (1992). Questionnaire Design, Interviewing and Attitude Measurement. Pinter Publishers, London.

Oppenheimer, M. & Alley, R. B., (2004). The West Antarctic Ice Sheet and Long Term Climate Policy: an Editorial Comment. Climatic Change 64: 1–10, 2004.

Oremus M & Wolfson C, (2004). Female Specialists were more likely to respond to postal questionnaire about drug treatments for Alzheimer disease. Journal of Epidemiology 57 (2004 620-623.

Oreszczyn, T. & Pretlove, S., (2000). Mould Index. In Cutting the Cost of Cold, Ed, Rudge, J. & Nicol, F. (2000), E & F Spon, pp 122 – 133.

Osborn, T.J. & Hulme, M., (2002). Evidence for Trends in Heavy Rainfall Events Over the United Kingdom. Philosophical Transactions of the Royal Society of London Series, A360, pp. 1313-1325 (Doi:10.1098/Rsta.2002.1002).

Oseland, N. A., (199_). Acceptable Temperature Ranges in Naturally Ventilated and Air Conditioned Offices. ASHRAE Transactions, 104 (1).

P

Pachauri, R., Ed., (2001). Technical Summary - Climate Change 2001: Mitigation, A Report of Working Group III of the Intergovernmental Panel On Climate Change. IPCC, Web.

Page, R.C.J., (199_). Reducing the Cost of Subsidence Damage Despite Global Warming. Structural Survey, Vol16 No 2 Pp 67 – 75

Park, J. H., Schleiff, P. L., Attfiedl, M. D., Cox-Ganser, J. M., & Kreiss, K., (2004). Building-Related Respiratory Symptoms can be Predicted with Semi-Quantitative Indices of Exposure to Dampness and Mold. Indoor Air, 2004, 14; 425 – 433.

Parker, D. & Horton, B., (2004). Uncertainties in the Central England Temperature series 1878-2003 and Some Changes to the Maximum and Minimum Series. Hadley Centre, Met Office, Exeter, United Kingdom August 2004.

Parliamentary Office of Science and Technology (POST), (2004). Postnote Number 232 - UK Health Impacts of Climate Change. P.O.S.T, November 2004.

Parry M. & Parry C., (1991). Preparing for Climatic Change. Town & Country Planning, June 1991, pp184 – 185

Parry, M., & Carter, T., (1998). Climate Impact and Adaptation Assessment: A Guide to the IPCC Approach. Earthscan Publications, London.

Parry, M., (Ed.), (2000). Assessment of Potential Effects and Adaptations for Climate Change in Europe. The Europe Acacia Project. University Of East Anglia, Norwich, UK,

Pasanen, P., Kalliokoski, P. & Pasanen, A. L., (1997). The Effectiveness of Some Disinfectants and Detergents Against Microbial Activity. Building and Environment, Vol. 32, No. 3, pp 281 – 287.

Patterson, J. (2005). Personal Communcation wit the author.

Patz, J., (1999). Health, Climate Change and Climate Variability - Exploring the Future. Presented At Conference - Setting An Agenda For Research On Health And The Environment: Mona, Jamaica, Nov 12 – 14 (1999).

Pearson, D., (1991). The Natural House Book, Creating Healthy, Harmonious and Ecologically Sound Homes. Conran Octopus, London.

Peat, J.K., Dickerson, J., & Li, J., (1998). Effects of Damp and Mould in the Home on Respiratory Health: A Review of Literature. Allergy, 53(2), 120-128.

Peden, D. B., (2004). The Epidemiology and Genetics of Asthma Risk Associated with Air Pollution. American Academy of Allergy, Asthma and Immunology, 2004, 12.

Peen, J. & Dekker, J., (2004). Is Urbanicity and Environmental Risk-Factor for Psychiatric Disorders. Letter in the Lancet, Vol., 363, June 19, 2004.pp 2012 - 13

Pershagen, G., (1999). Research Priorities In Environmental Health - We Need to Be Sure That Improving the Environment Does Not Harm Health. BMJ Volume 318 19 June 1999

Pfeffermann, D. (1993). The Role of Sampling Weights when Modelling Survey Data. International Statistical Review, 61, 317-337.

Pfeffermann, D. (1996). The Use Of Sampling Weights for Survey Data Analysis. Statistical Methods In Medical Research, 5, 239-62.

Platt, S. D., Martin, C. J., Hunt, S. M., & Lewis, C. W., (1989). Damp Housing, Mould Growth and Symptomatic Health State. BMJ, Vol. 298, 24.06.89.pp1673 – 1678.

Pope, V.D., Pamment, J.A., Jackson, D. R. & Slingo, A., (2000). The Representation of Water Vapour and its Dependence on Vertical Resolution in the Hadley Centre Climate Model. Technical Advice Note 28. Hadley Centre for Climate prediction and Research, The Met Office, Bracknell.

Porteous, C. & Sharpe, T., (1999). Building health in Glasgow (Exhibition catalogue), MEARU, August 1999.

Pountney, M. T., Maxwell, R. & Butler, A.J., (1988). Rain Penetration of Cavity Walls: Report of a Survey of Properties in England and Wales. BRE Information Paper, Watford.

Poveda, G., (1999), Health and Environmental Effects Associated wWith ENSO In Colombia. Presented At Conference - Setting An Agenda For Research On Health And The Environment: Mona, Jamaica, Nov 12 – 14 (1999).

Pretlove, S. E. C., Ridley, I., Horwood, J. A., Leung, B., Cox, P., Thomson, D., Baker, N., Crowther, D. & Oresczcyn, T., (2001). A Combined Transient Hygrothermal and Population Model of House Dust Mites in Beds. Presented at IAQ, 2001: Moisture, Microbes and Health Effects: Indoor Air Quality and Moisture in Buildings, ASHRAE, San Francisco, USA, Nov. 4 – 7, 2001.

Pye, S., et al, (2001). Further Analysis of NO_2 and PM_{10} Air Pollution and Social Deprivation. A Report Produced for the Department for Environment, Food and Rural Affairs (Ref: Aeat/Env/R/0865), The National Assembly for Wales and Department of the Environment in Northern Ireland.

Q

Qian, B. & Saunders, M. A., (2003). Seasonal Predictability of Wintertime Storminess over the North Atlantic. Geophysical Research Letters, Vol. 30 No 13 1698.

R

Ranson, R., (1991). Healthy Housing: A Practical Guide. E & FN Spon & the Wold Health Organisation, London.

Rao, J.N.K. & Bellhouse, D.R., (1990). History and Development of the Theoretical Foundations of Survey Based Estimation and Analysis. Survey Methodology, 16, 3-25

Raw, G. J., et al, (2000). A Risk Assessment Procedure for Health and Safety in Buildings. DETR, BRE, Garston, Watford.

Raw GJ, Coward SKD, Llewellyn JW, Brown VM, Crump DR & Ross DI (2002). 3.13 Indoor air quality in English homes. In the Proceedings of the Sixth Annual UK Review Meeting on Outdoor and Indoor Air Pollution Research 15th–16th April 2002, Leicester, UK.

Richards, H. M., et al, (2002). Socioeconomic Variations in Response tTo Chest Pain: A Qualitative Study. BMJ Volume 324 1 June 2002 Bmj.Com

Roaf, S., (2001). Standards for Sustainability. Paper. P. 1-18 in proceedings of "Moving Thermal Comfort Standards into the 21st century", Cumbernauld Lodge, Windsor, UK 5th – 8th April 2001.

Robinson, K.L., Mcbeth, J., & Macfarlane, G.J., (2004). Psychological Distress and Premature Mortality in the General Population: A Prospective Study. AEP, Vol. 14, No 7, August 2004, pp467 – 472.

Roberts, G., & Binder, D. A., (Unknown). Analysis Issues for data from Complex Surveys. Data Analysis Resource Centre, Canada - Binddav@Statcan.Ca

Roberts, J., Fedeski, M., Johns, J. & Eggleton, A., (1994). An Investigation of the Response of Building Fabric Performance to Projected Climatic Changes in the UK. Volume 1: Main Text. Volume 2: Appendices. The Welsh School of Architecture, University of Wales, College of Cardiff, for the Building Research Establishment, Under Contract Reference No. F3/2/463.

Roderick, P., Victor, C. & Connelly, J., (1991). Is housing a Public Helath issue? A survey of Directors of Public Health. BMJ, Vol. 302, 19 Jan. 1991.

Rogerson, R. J., (1995). Environment and Health Related Quality Of Life: Conceptual and Methodological Similarities. Soc.Sci. Med. Vol. 41 No 10pp 1373- 1382, Elsevier Science, GB.

Ross, N. A., Tremblay, S., & Graham, K., (2004). Neighbourhood Influences on Health in Montreal, Canada. Social Science and Medicine. Vol. 59, (2004) pp 1485-1494.

Rudge, J. & Nicol, F. (Ed.s), (2000). Cutting the Cost of Cold: Affordable Warmth for Healthier Homes. E & FN Spon, London.

Rydin, Y, Livesey, H & Purvis, B, (2004). LSE & ERM *New Horizons Project* for ODPM Planning, Sustainability And Environmental Risks Final Report 25th May 2004, Centre For Environmental Policy And Governance, LSE, London.

S

Sadler, R., & Ward, K, (1992). Owner Occupiers' Attitudes to House Repairs and Maintenance. The Stationery Office. ISBN 0117530115

Santamouris, M., (1999). Energy and climate in the Urban Built Environment. London, James & James

Santana, W., (2002). Income Inequality and Population Health - Evidence Favouring A Negative Correlation Between Income Inequality and Life Expectancy has Disappeared, BMJ Volume 324 5 January 2002 Bmj.Com

Saw, S. M., & Ng, T. P., (2001). The Design and Assessment of Questionnaires. In Clinical Research, Singapore Med J 2001 Vol. 42(3) : 131-135

Schar, C. & Jendritzky, G., (2004). Hot News from Summer 2003. Nature, Vol. 432, 2 Dec 2004.

Schnittker J., (2005). Chronic Illness and Depressive Symptoms in Later life. Social Science &

Medicine 60 (2005) 13-23.

Sexton, D. M. H., Parker, D. E. & Folland, C. K., (2003). Natural and human influences on Central England Temperature. Hadley Centre, Met Office, Bracknell, U.K.

Seymour, J., (1991). Science on Your Doorstep: Does Damp Housing Make You Ill? Working With Community Groups, Scientists Are Pioneering A New Way Of Doing Research. New Scientist - 132/17984700 07 December 1991.

Shackley, S. And Gough, C., (2002). The Use of Integrated Assessment: An Institutional Analysis Perspective. Working Paper 14, Tyndall Centre For Climate Change Research

Sheikh, A. & Hurwitz, B., (2004). House Dust Mite Avoidance: measure for Perennial Allergic Rhinitis (Review). The Cochrane Collaboration, John Wiley & Sons.

Sherriff, A., Farrow, A., Henderson, J., Golding, J. & The ALSPAC Study Team A, (2002). Frequent Use of Chemical Household Products is Associated with Wheeze in Pre-School Age Children. Presented in IEH (2002) Sixth Annual UK Review Meeting on Outdoor and Indoor Air Pollution Research 15th–16th April 2002 (Web Report W12), Leicester, UK, MRC Institute for Environment and Health, available at http://www.le.ac.uk/ieh/

Shields, M.A., & Wheatley Price, S., (2005). Exploring the Economic and Social Determinants of Psychological Well-Being and Perceived Support in England. Journal of the Royal Statistical Society A. (2005). Vol. 168; Part 3 pp 513 – 537.

Short, S., (2001), The Issues And Implications Of Setting And Applying Indoor Air Quality Guidelines. A Report of an Open Seminar Organised by the MRC Institute for Environment and Health and Held at the University Of Leicester on 6 April 2001,Medical Research Council & Institute for Environment and Health, UK.

Skinner, C. J., Holt, D. & Smith, T.M.F. (Eds.), (1989). Analysis of Complex Surveys. Chichester: Wiley.

Smith, C. J., Kearns, R. A., & Abbott, M. W., (1992). Housing and Mental Health: Exploring the Relationship in Urban New Zealand. Community Mental Health in New Zealand. Vol. 6, No 2. August 1992.

Smith P., (1991), Carbon Trouble Building Design Prof. Peter Smith, March 15 1991, 24-25.

Smith, J.B. 1997. Setting priorities for adapting to climate change. Global Environmental Change 7, 251-264.

Smith, T.M.F. (1976). The Foundations of Survey Sampling: A Review (with Discussion). Journal Of The Royal Statistical Society A, 139, 183-204.

Spence, R., Fawcett, W., Brown, A. & Coburn, A., (unknown). The Windstorm Vulnerability of the UK Building Stock. www.cambridge.ac.uk

Soebarto, V.I., (2000). Dynamic Comfort: Engaging the Occupants in Low Energy House, Architecture, City, Environment. Proceedings of PLEA 2000, Cambridge July 2000, Pages 642-643, James and James (Science) Publishers.

Sorrell, S., (2001). Making The Link: Climate Policy and the Reform of the UK Construction Industry - Electronic Working Paper Series - Paper No. 67, Science and Technology Policy Research, Brighton.

Steemers, K., (2003). Establishing Research Directions in Sustainable Building Design. Tyndall Centre for Climate Change Research: Technical Report 5, September 2003.

Stern, N, (2006). Stern Review on the Economics of Climate change. Cambirdge Univiersty Press, Cambirdge, UK.

Stansfield, S., et al (2000). The Development of a Standardised Interview To Assess Domestic Noise Complaints and Their Effects. (Science) - Final Report. Department Of Psychiatry, St Bartholomew's and the Royal London School of Medicine and Dentistry, Queen Mary and Westfield College.

Stokols, D., (1972). On the Distinction Between Density and Overcrowding: Some Implications for Future Research. Psychological Review, 79, 275-277.

Stoneham, J. & Kendle, T., (eds), (1996). Plants and Human Well Being, Proceedings of a conference held at the University of Reading, 18th – 19th September 1996, Organised by the Sensory Trust and Horticulture for all. The Sensory Trust, Bath.

Stroud District Council Riverside Energy Project (2000). NEA/Riverside Stroud: Keep Warm Keep Well Project - Evaluation Report, NEA MEB Bid Proposals.Doc 20/02/01

Sturm, R. & Gresenz, C. R., (2002). Relations of Income Inequality and Family Income to Chronic Medical Conditions and Mental Health Disorders. National Survey, BMJ Volume 324 5 January 2002 Bmj.Com

Sudman, S. & Bradburn, N. M., (1983). Asking Questions, A Practial Guide to Questionnaire Design. Jossey Bass Publishers, London.

The Sunday Times, (2000). North Pole Icecap Melts. 20 August 2000, News Home News, P.30 Jonathan Leake, Environment Editor.

The Sunday Times, (2000). Scientists Claim Nothing will Stop Climate Change. Home News, 12 November 2000, P.4 Jonathan Leake And Guy Dennis.

The Sunday Times, (2000). Rich Towns To Get Flood Money First. Home News, 10 December 2000, P.10, Jonathan Leake, Environment Editor.

The Sunday Times, (2000). Climate Beyond Control. Letters To The Editor 03 December 2000, P.20 Professor Philip Stott

The Sunday Times, (2002). Watch out for the Alligators in Everglades. Britain, 14th April 2002 Article by Tim Robbins.

Sundell, J. (2004). On the History of Indoor Air Quality and Health. Indoor Air, 2004, 14 (Suppl. 7); 51-58.

Sundquist, K., Frank, G., & Sundquist, G., (2004). Urbanisation and Incidence of Psychosis and Depression: Follow up Study of 4.4 Million Women and Mmen in Sweden. British Journal of Psychiatry, 2004, 184, 293 – 98.

Swart, R.J. & Vellinga, P., (1994). The 'Ultimate objective' of the Framework Convention on Climate Change Requires a New Approach in Climate Change Research. Climatic Change 26, 343-349.

T

Taylor, M. F., (ed), Brice, J., Buck, N., & Prentice-Lane, E., (2000). British Household Panel Survey User Manual Volume A: Introduction, Technical Report and Appendices Introduction & Volume B: Codebook. Colchester: University of Essex.

TCPA & Urbed (2004). Biodiversity by design: A guide for sustainable communities, TCPA, London.

Theuray, N, Lindley, S, Handley, J & ASCCUE Project team (2004). ASCCUE: Research framework and proposed risk assessment methodologies. CURE, Manchester University.

The Times, (2000). Canals To Carry Drinking Water. Home News 28 June 2000, P.9 Nick Nuttall Environment Correspondent.

The Times, (2000). After The Storm, Regular Fight Against Floods 'Is Part Of Britain's Future'. Home News 01 November 2000, The Times, P.7, Craig Clarke

The Times, (2000). Heat Deaths To Rise. 2 November 2000, P.15, Home News Politics

The Times, (2000). Floods Were A Global Warming Wake-Up Call. Home News Politics, 2 November 2000, P.15,, Nick Nuttall In The Hague.

The Times, (2000), Ozone Hole Will Heal In 50 Years. Say Scientists - Home News 4 December 2000, P.9, Mark Henderson.

The Times, (2000). Floods Will Double In Our Children's Lifetime. Home News 4 December 2000, P.11, Nick Nuttall Environment Correspondent.

The Times, (2000). Why Greens Are Not Tickled Pink. Features City Law 12 December 2000, P.11 Edward Fennell

Thomas, A, Williams, G., and Ashurst, N., (1992). The Control of Damp in Old Buildings: Technical Davice Note . Society for Protection of Ancient Buidlings, London.

Thomson, H., Petticrew, M. & Morrison, D., (2001), Health Effects of Housing Improvement: Systematic Review of Intervention Studies. BMJ Volume 323 28 July 2001 Bmj.Com

Toftum, J., (2002). Human Responses to combined Indoor Environment Exposures, Energy Buildings, 34, 601-606.

Toftum, J., Langkilde, G. & Fanger, P. O., (2003). New Indoor Environment Chambers and Field Experiment Offices for Research on Human Comfort, Health and Productivity at Moderate Energy and Expenditure. Energy and Buildings, 36 (2004) 899-903. Elsevier.

Tompkins, E.L. & Adger, W.N., (2002). Building Resilience to Climate Change Through Adaptive Management of Natural Resources. Paper Presented to the UNDP Expert Group Meeting - Integrating Disaster Reduction and Adaptation to Climate Change, June 17-19, 2002, Havana Cuba. UNDP Cuba.

Town And Country Planning, Planning To Avert Climate Change, Town And Country Planning May 1993 Pages108 - 110.

Town and Country Planning, (1991). Preparing For Climate Change. Town and Country Planning, June 1991, Pages 184 - 186

Townsend, P., Simpson, D. & Beattie, A., (1988). Health and Deprivation: Inequality and the North. Croom Helm, London.

Troen, I & Petersen, E. L., (1991). European Wind Atlas. Risoe National Laboratory, Denmark.

Tyndall Centre, (2002). Proceedings of the Tyndall/CIB, International Conference on Climate Change and the Built Environment. UMIST, Manchester April 8th – 9th 2002.

U

UKCIP, (2001). Socio-Economic Scenarios for Climate Change Impact Assessment: A Guide to their Use in the UK Climate Impacts Programme. UKCIP, Oxford.

UKCIP, (2002a). Climate Change Scenarios for the United Kingdom (UKCIP02). Tyndall Centre, Norwich.

UKCIP, (2002b). Climate Change Impacts on Buildings, Briefing Note. UKCIP, Oxford.

V

Vandenberg, J. J., (2005). The Role of Air Quality Management in Improving Public Health: A Brief Synopsis. Journal of Clinical Immunology. Vol. 115, No. 2.

Vellinga, M., Wood, R. A., (2001). Global Climatic Impacts of a Collapse of the Atlantic Thermohaline Circulation. Hadley Centre Technical Note 26. Met Office, Hadley Centre for Climate Prediction and Research, Berkshire, United Kingdom, 20 February 2001.

Verhaak, O. F. M., Heijmans. J. W. M., Peters, L. & Rijken, M., (2005). Chronic Disease and Mental Disorder. Social Science and Medicine 60 (2005). Pp. 789 – 797.

W

Walker, A., Maher, J., Coulthard, M., Goddard, E. & Thomas, M., (2001). Living In Britain - Results from the 2000/01 General Household Survey. HMSO & The Office for National Statistics.

Warsco, K., (1992). Explaining Housing Related Illness: A decade of Analysis of Emerging Paradigms. Housing and Society, Vol. 19, No. 3, 1992.

Wathan, J., Holdsworth, C. & Leeser, R., (Unknown). A Rule-Based Definition for Census Family and Household Reference Persons: Choices And Impacts. CCSR Occasional Paper No. 2.

Watson, R.T. & McMichael, A.J., (2001), Global Climate Change: The Latest Assessment: Does Global Warming Warrant A Health Warning? Global Change & Human Health, Volume 2, No. 1 (2001) Kluwer Academic Publishers, P 64 – 75.

Weakliem, D. & Villemez, W. J., (2004). Public Attitudes Toward the Census: Influences and Trends. Social Science Quarterly Volume 85, Number 4, December 2004.

Weaver, A. J, & Zweirs, F. W., (2000), Uncertainty in Climate Change. Nature, Vol 407, 5th October 2000, www.nature.com.

Weich, S., & Lewis, G., (1998). Poverty, Unemployment, and Common Mental Disorders: Population Based Cohort Study. BMJ Volume 317 11 July 1998 www.bmj.com, 115.

Welsh Assembly Government, (1998). Planning Guidance (Wales), Technical Advice Note (Wales) 11, Noise - October 1997. National Assembly for Wales.

Welsh Assembly Government, (1998). Welsh House Condition Survey 1998 – National Assembly for Wales.

Welsh Assembly Government, (2000). Better Homes For People In Wales. The National Assembly For Wales' Proposals for a National Housing Strategy, National Strategy Branch, National Assembly For Wales, Cardiff (Website: Http://www.wales.gov.uk)

Welsh Assembly Government, (2001). Climate Change Wales: Learning To Live Differently. Air And Environment Quality Branch Environmental Protection Division, National Assembly For Wales.

Welsh Assembly Government, (2002). Planning Policy Wales. National Assembly For Wales.

White, A., Freeth, S., & Martin, J., (2001), Evaluation Of Survey Data Quality Using Matched Census Survey Records, SMB 49 7/01

Wilkinson, P., Landon, M. & Stevenson, S., (2000). Housing and Winter Death: Epidemiological Evidence. In Cutting the Cost of Cold, Ed, Rudge, J. & Nicol, F. (2000), E & F Spon, pp 30 - 35.

Willows, R.I. and Connell, R.K. (Eds.). (2003). *Climate adaptation: Risk, uncertainty and decision-* UKCIP Technical Report. UKCIP, Oxford.

World Health Organization (WHO), (1996), Climate Change And Human Health, World health Organisation.

WHO, (1999). Environment and Health: Europe's Partnerships Can Be a Model. BMJ Volume 318 19 June 1999 www.bmj.com

WHO - Europe, (2003a). The Health Impacts of 2003 Summer Heat Waves: Briefing Note for the Delegation of the Fifty-Third Session of the WHO Regional Committee for Europe. Vienna, Austria, 8-11 September 2003.

World Health Organisation - Europe, (2003b). Extreme Weather Events: Health Effects and Public Health Measures, Fact Sheet EURO/04/03. Copenhagen, Rome 29 September 2003

World Health Organization (2003c) Climate change and human health : risks and responses. Summary. World Health Organization, Switzerland.

WWF, Cymru & Stockholm Environment Institute (2005). York Reducing Wales environmental footprint, March 2005. WWF Cymru, Cardiff.

X -

Y

Yamazaki, K., Nomoto, S. Yokota, Y & Murai, T., (1998). The Effects of Temperature, Light, and Sound on Perceived Work Environment. ASHRAE Transactions, 104.

Yamey, G., (1999). Report Finds Persisting Poverty and Social Exclusion. BMJ Volume 319 11 December 1999 www.bmj.com – 1522

Z

Zimmerman, R. H., (1999). Health and Climate variability - The Stakeholders Approach. Presented at conference - Setting An Agenda for Research on Health and the Environment: Mona, Jamaica, Nov. 12 – 14 (1999).

Zureik, M., et el, (2002). Sensitisation to Airborne Moulds and Severity of Asthma: Cross Sectional Study from European Community. Respiratory Health Survey on Behalf of the European Community Respiratory Health Survey, BMJ Volume 325 24 August 2002 Bmj.Com

Websites

A Air Pollution: What It Means for your Health, The Public Information Service, Department for Environment, Food & Rural Affairs in Partnership with the Department of Health, The Scottish Executive and the Department of the Environment in Northern Ireland. Department of Health Publications Centre, Wetherby, Internet: http://www.open.gov.uk/doh/hef/airpol/airpolh

B BBC News Website - http://news.bbc.co.uk
BETWIXT: http://www.cru.uea.ac.uk/cru/projects/betwixt/cruwg_daily/
British Atmospheric Data Centre: http://badc.nerc.ac.uk/data/surface/
Bartlett, University College London Carbon Monoxide Concentrations and Ventilation Strategies in Dwellings (1996-1998) & Mould and Dampness Index:
http://www.bartlett.ucl.ac.uk/research/environment/overview.htm
Building Knowledge for Changing Climate (BKCC),
http://www.art.man.ac.uk/PLANNING/cure/bkcc/projects/projects.html

C Census (2001) - www.statistics.gov.uk/census
Climate and Health Research Program, Department of Earth and Atmospheric Sciences, University of Alberta: http://www.ualberta.ca/~ksmoyer/grtframe.htm
Centre for Integrated Study of the Human Dimension of Global Change, Department of Engineering and Public Policy, Carnegie Mellon University: http://hdgc.epp.cmu.edu
Climate Impacts Link Project – www.cru.uea.ac.uk/link/
Climatic Research Unit, University of East Anglia – www.cru.uea.ac.uk/

D Department of Health www.doh.gov.uk
Data Distribution Centre - http://ipcc-ddc.cru.uea.ac.uk/
Department of Health - Statistics & Surveys: http://www.doh.gov.uk/public/stats1.htm
Department of Health - Neighbourhood Statistics –
http://www.statistics.gov.uk/census2001/profiles/uk.asp

E Environmental Air Pollutant Measurement - Groeswen Hospital, Margam Road, Port Talbot, OS Grid Reference: Ss780882, Site Type: Urban Background, Start Date: 09/01/97 Pollutants Measured: O3, Co, So2, Pm10, Nox. Website - http://www.stanger.co.uk

F Fuel Poverty Strategy - www.environment.detr.gov.uk/consult/fuelpov/index.htm
Friends of the Earth - www.foe.org

G Greenpeace - www.greenpeace.org

H The Hadley Centre for Climate Prediction and Research, Met Office –
www.metoffice.com/research/hadleycentre/index.html
HANAH (Housing and Neighbourhoods and Health): http://www.hanahproject.com/
Home Energy Conseration Act – HECA:
http://www.defra.gov.uk/environment/energy/heca95/index.htm
HTB2 website: http://www.cardiff.ac.uk/archi/school/resources/envlab/htb2_2.html

I International Centre For Integrative Studies (ICIS), University Of Maastricht
http://www.icis.unimaas.ni
The Intergovernmental Panel on Climate Change (IPCC) - www.ipcc.ch
The IPCC Data Distribution Centre (DDC) – www.ipcc-ddc.cru.ues.ac.uk/
The IPCC Special report on Emissions Scenarios (SRES) www.sres.ciesin.org/index.html

J John Hopkins University - http://www.jhu.edu/~climate/

K -

L Landfill Sites -www.detr.gov.uk
The LARS Weather Generator – www.iacr.bbsrc.ac.uk/mas-models/larswg.html
London School Of Hygiene And Tropical
Medicinehttp://www.lshtm.ac.uk/research/research.htm

M The Meteorological Office: www.met-office.gov.uk
MIMAS – Surveys Website www.mimas.ac.uk/surveys/
Morgannwg Local Health Authority – www.morgannwg-ha.wales.nhs.uk

N Neath Port Talbot Local Health Board –
www.wales.nhs.uk/sites3/home.cfm?origid=245&redirect=yes
Network for Comfort and Energy Use in Buildings
www.nceub.org.uk
NHS Public Health Network – www.avon.nhs.uk/phnet/Methods/townsend.htm
NSSEC (National Statistics Socio-Economic Classification Self Coded Method):
http://www.statistics.gov.uk/methods_quality/ns_sec/ns_sec_self_coded_method.asp

O -

P Pollution Inventory Sites – www.detr.gov.uk
Physical Geography.net: http://www.physicalgeography.net

Q QCA – The National Qualfications Framework – www.qca.org.uk
The Quarterly Review - A Publication Of The Centre For Health And The Global Environment
At Harvard Medical School - www.med.harvard.edu/chge/review.html
The Question Bank - http://qb.soc.surrey.ac.uk/

R River Quality - – www.detr.gov.uk

S Society for the Protection of Ancient Buildings – www.spab.org.uk
Square One research – Environmental Design Website
- http://www.squ1.com/site.html
Synoptic Climatology Laboratory, University Of
Delaware: http://www.udel.edu/synclim/scl.html

T Tyndall Centre - www.tyndall.ac.uk
Tyndall Working Papers – available at www.tyndall.ac.uk/publications
/working_papers/working_papers.shtml

U http://www.ecu.ox.ac.uk/ukcip.htm
UK Climate Impacts Programme – (UKCIP) – www.ukcip.org.uk
UKCIP02 Climate Scenario Data – www.ukcip.org.uk/scenarios/
UNFCCC - http://www.unfccc.int/
UNEP - http://www.unep.org/
UK Data Archive - www.data-archive.ac.uk

V -

W Welsh Health Statistics: http://www.wales.nhs.uk
Welsh School of Architecture (WSA): - http://www.cf.ac.uk/archi/research
Danish Wind Industry Association. http://www.windpower.org/en/tour/wres/wndsprac.htm
WSA – HTB2: http://www.cf.ac.uk/archi/research/envlab/htb2_1.html
WSA – Weather Centre: http://cf.ac.uk/archi/research/met/index.html
World Health Organisation – Definition of Health:
http://www.who.int/aboutwho/en/definition.html
Climate & health: Http://www.who.int/peh/climate/climate_and_health.htm
World Monetary Organisation - http://www.wmo.ch/

X -

Y -

Z -

Notes: