Department for Communities and Local Government

Investigation into Overheating in Homes

Literature Review

AECOM

July 2012

The findings and recommendations in this report are those of the consultant authors and do not necessarily represent the views or proposed policies of the Department for Communities and Local Government.

A separate report titled *Investigation into Overheating in Homes: Analysis of gaps and Recommendations* has also been published by the same consultants and has been published separately by the Department for Communities and Local Government.

This document/publication is also available on our website at www.communities.gov.uk

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Table of contents

Executive Summary

1. This project investigates overheating in residential buildings for our client the Department of Communities and Local Government (DCLG). AECOM have led the investigations supported by the London School of Hygiene and Tropical Medicine (LSHTM) and University College London (UCL). AECOM have project managed and integrated the work, whilst also reviewing the definitions and policy aspects and carrying out stakeholder interviews. LSHTM bring particular expertise on health issues and UCL have expertise in building modelling and data.

2. DCLG has interests in building standards and energy efficiency as well as health and safety. The Department also has responsibility for the framework of the land-use planning system. With regard to specific building sectors, DCLG is responsible for housing and other buildings where people live. Other departments will be responsible for considering the risks and implications of overheating for the buildings in the sector for which they responsible. This work has its main interest in dwellings and health impacts, and in particular whether there are defined internal temperatures which are likely to be detrimental to the peoples' health, including the vulnerable. Comfort as well as health has been included to a limited extent where possible. There is also a blurring between comfort and health where impacts such as sleep loss can be significant to health, either to the health of the individual or to others due to the consequences of a lack of concentration/falling asleep.

3. There are three main areas of interest:

   - Whether overheating is occurring in new dwellings as a result of higher insulation standards and improved air tightness?
   - Whether overheating is currently occurring in existing dwellings?
   - Whether retrofitting/refurbishing existing dwellings is likely to increase the risk of overheating or not?

   These questions are posed in the context of the current climate and predicted future external conditions in the UK arising as a result of climate change.

4. This report considers the following:

   - What is the impact on health of temperature, other internal conditions and potential cumulative impacts?
   - How do dwellings modify the external conditions?
   - How does the behaviour of individuals affect the risk of overheating?
   - How is overheating defined, and by whom? What might be done via Government policy to address the risks of overheating?
   - What can current research tell us (i.e. projects which are not yet featuring in a literature review)?
   - What is the range of possible technical (not policy-based) interventions?
   - What do stakeholders think?
   - What are the future research needs?

5. The study consists primarily of a literature review. We have also considered current research and conducted some telephone interviews with stakeholders, but the scope did not involve any new research. In summary , the report addresses:

    - What is clearly known and from what sources?
    - What is known anecdotally?
    - The views of relevant stakeholders
    - Areas of current research activity
    - Significant areas where new or further work is needed.

6. A second output from this project is complementary report, published by DCLG alongside this document, titled Overheating in Homes: Analysis of Gaps and Recommendations, which identifies the main gaps in the literature, and areas where further work would be of most value.

Health studies

7. Overheating in dwellings is identified as a significant health problem, but it is on a smaller scale to that due to cold dwellings in winter. Although clearly dependent on the summer weather, studies suggest that there may be typically around 2,000 deaths brought forward per year due to heat, compared to around 25,000 due to cold. However climate change projections suggest the heat related deaths could rise to around 5,000 per year in the 2080s if action is not taken.

8. Epidemiological studies show that high temperatures result in excess deaths, hospital admissions and other adverse health outcomes, and their evidence allows predictions to be made of the effect of any future heat wave. However such evidence is based on the link between external temperatures and health effects, and it is reasonable to assume there will be a wide distribution of indoor temperatures at any given outdoor temperature. **There is only very limited and indirect epidemiological evidence about the conditions of indoor temperature exposure that give rise to adverse health effects, and at present it is insufficient for a clear definition of the indoor temperature that represents an overheating threshold for health risk.** Modelling studies linked to epidemiological data could however provide some evidence relevant to this question.

9. Use of physiological evidence and modelling is an alternative approach for defining overheating. However, it is often unclear how measured physiological responses relate to the risk of adverse health events especially in vulnerable individuals. Definitions of overheating are also made more complex if based on continuous physiological response functions. The temperature that limits the ability to carry out pre-specified levels of physical activity is one possible way of defining overheating, but there are many alternatives, and judgements are required to define acceptable thresholds. Those thresholds may vary from person to person and be modified by arrange of environmental and other factors. There is substantial data on the direct health effects of different temperatures on different groups of people and much of the health evidence relating to overheating risk has been summarised well in an NHBC Foundation report on overheating in highly insulated homes; due for publication 2012.

10. Whilst there is very substantial literature on the impact of the thermal environment on comfort this topic is not the main concern of this study. The effect of different aspects of the thermal environment on health is not as easy to formulate because it is not possible (ethical) to carry out controlled experiments.

Building studies

11. There are many factors that will determine indoor summer temperatures in UK dwellings. These factors include:

    - The external climate (which will vary with location in the UK)
    - Location
    - Dwelling orientation
    - Room type
    - Time of day
    - Building fabric characteristics
    - Occupant behaviour

    This review was carried out between September and December 2011 (with the exception of references to the National Planning Policy Statement and the Green Deal, which were updated in 2012 following policy announcements from DCLG and DECC respectively) and reports on relevant published work relating to such factors.

12. **The literature describing the current knowledge as to how UK dwellings modify external temperatures is dominated by modelling studies and published measured data is scarce.** There have been a large number of modelling studies examining the impact of climate change on homes, the effect of the urban heat island and how different building construction affects overheating. There are also studies on the different interventions that could be made and what difference they might make.

13. There is limited published information on measured indoor temperatures in homes. However there are several current projects gathering data, and so this position should improve over the next 1 - 2 years.

14. A recent review of the UK's preparations to adapt to climate change by the Committee on Climate Change noted the importance of designing and refurbishing properties so that they are suited to current and projected future temperatures. The review reported that UK buildings are already vulnerable to overheating and that this is likely to get worse as temperatures increase.

15. Current evidence suggests that the South of the UK is likely to face the largest risk of indoor overheating.

16. A recent study undertaken as part of the LUCID project explored the relative importance of the urban heat island vs. building thermal quality. Whilst location does play a part in potential overheating, the effects of built form and other dwelling characteristics appear to be more important determinants of variation in high indoor temperatures than the location of a dwelling within London's urban heat island.

17. **A number of studies have identified that an unintended consequence of high insulation and air tightness standards of newly built and retrofitted houses may be overheating.** It has been suggested that changing the positioning of insulation, i.e. external rather than internal, may minimise the risk of extreme temperatures during the summer. Generally thermal mass coupled with night cooling through ventilation has been identified as a relatively effective measure to combat domestic overheating.

18. Another key finding with significant implications for design and operation is that natural ventilation may become a 'double-edged sword' in the future. As ambient temperatures are projected to increase, daytime ventilation may not be beneficial for the mitigation of overheating as the incoming air will be at a high temperature. In addition, night purge ventilation will be effective only if the diurnal temperature variation is significant enough to flush away the heat stored in the building. However, this is also likely to change under current climate change projections.

19. **The CREW research project** which has just been completed (December 2011) **reviewed the effectiveness of different passive cooling strategies as a function of occupancy schedules, type of room and time of day, looking at existing dwellings.** When the overheating assessment was carried out for a house occupied by a working couple with children at school, external wall insulation, followed by internal wall insulation, was shown to be the most effective measure for both the living room and the bedroom. In contrast, the internal wall insulation was found to increase overheating in the living room of an elderly couple with increased number of occupied hours during the daytime, as unwanted solar and internal heat gains were trapped within the building envelope. The project recognises the importance of improving thermal insulation in order to contribute to climate change mitigation, but it suggests that solar and internal heat gains need to be limited to minimise the risk of overheating. Thus 'switch-off' solar protection strategies, e.g. external shading and shutters, are likely to offer benefits for rooms that tend to be heavily occupied during the daytime.

20. **A relationship exists between dwelling construction age and overheating risk, owing to the potential correlation between age and parameters such as morphology, glazing levels, size, insulation, air tightness etc.** A common finding is that dwellings built around the 1960s and small top-floor purpose-built flats appear to be considerably more prone to overheating. This is attributed to the low solar thermal protection offered by the top floor of poorly insulated flats. In contrast, concrete ground floors were found to have a significant cooling effect. **The studies looking at which dwelling types (detached, semi-detached and terraced) are characterised by the highest cooling loads do not always identify the same ranking because the findings depend on the way the house types are characterised and this has not been made standard.**

21. **Another important finding is that not only older but also recently built dwellings will experience increased cooling loads by the 2080s.** Whilst newly constructed houses are characterised by reduced heat losses and, hence, increased thermal efficiency during winter, they may not be suitably designed to cope with extreme heat events.

22. **Published summer thermal monitoring data from housing is rather limited owing,** in part at least, to the fact that until recently overheating was not a major concern in the

heating dominated climate of the UK. The findings from the known monitored studies are noted, together with a list of on-going monitored schemes which should produce data in the next year or so.

23. The relevant literature is dominated by modelling studies and published measured data is scarce. However, the key mechanisms associated with overheating at an individual building level have been identified. For an individual dwelling, if sufficient data are available to characterise the thermal properties and occupant behaviour, it is possible to make some assessment of the vulnerability of the occupants to overheating and also make some projections as to the impact of a range of energy efficiency interventions. The challenge here is two-fold – firstly to develop a robust decision analysis framework to enable the assessment of individual dwellings, and secondly to ensure that adequate data are available to drive that framework.

24. The existing literature provides some useful indication of the potential scale of the problem based on modelled or monitored data. Building thermal simulation models are sophisticated tools that are able to accurately represent the physics associated with overheating. However, as with all modelled data, their value is determined by the quality of the input data. At the stock level there is much uncertainty associated with these inputs with regard to occupant behaviour and a detailed knowledge of the thermal properties of the dwelling. Relevant monitored data is currently scarce and generally only available for small samples of the housing stock. Large-scale measurement and data gathering campaigns are required in order to reduce the uncertainties associated with our current understanding of overheating at the stock level. Such work will allow the vulnerability of the overall UK stock to be better understood – both in its current state and in a 'low-carbon' future state.

25. The table below summarises some key messages identified in the currently available published literature on the scale of indoor overheating and points the reader to the relevant passages in Chapter 3.

Summary of published evidence

	Summary of published evidence on the extent of overheating risk problem	**Commentary on available published evidence**
Scale of problem for the existing building stock	Several monitoring studies have indicated that there could be a substantial problem of overheating in the existing stock *(paragraphs 3.34-36)*. This is in accordance with modelling work that has indicated that the overheating risk currently faced by UK dwellings during extreme heat events could be exacerbated in the future under various climate change scenarios *(paragraphs 3.8-10, 3.12-16, 3.27-28)*. Messages that emerge from the literature include the fact that large variations in internal temperatures between various	There have been relatively few monitoring studies. Whilst valuable information has been provided by such work, the sample size of these studies is generally too small to allow the application of the findings to the entire UK housing stock. Modelling work in this area provides useful insights but must be interpreted cautiously due

	dwelling types were observed during the 2006 heat wave. Purpose-built, usually top-floor, flats and end terraces, as well as houses built after 1990, were found to be more prone to overheating. Overheating appears to be more of an issue in bedrooms *(paragraphs 3.32-38)*.	to the uncertainties involved.
Scale of problem for low-energy, refurbished and recently built dwellings	In certain cases, dwellings that were recently built or refurbished to high efficiency standards have the potential to face a significant risk of summer overheating. Internal temperatures above the external and/or peaking above CIBSE overheating criteria, as well as higher cooling loads in air conditioned dwellings have been recorded during the summer in small samples of energy efficient dwellings *(paragraphs 21, 19, 24, 37-38)*. If applied appropriately, energy efficiency interventions can be beneficial for the abatement of overheating. Nevertheless, overheating risk has the potential to increase following inappropriate interventions. It has been suggested that lightweight structures, as well as internally insulated heavyweight structures may be at higher risk of overheating in the future *(paragraphs 8-12, 25-30)*. Current modelling based evidence suggests that the south of the UK is likely to face the largest risk of indoor overheating.	Concerns about the unintended consequences of increased levels of insulation have been highlighted by modelling studies. However, the relevant empirical data currently available is limited.

Behaviour

26. The section on behaviour sets out a general framework for consideration of occupant behaviour in relation to overheating of buildings (primarily residential buildings). Some evidence is cited but the more important purpose of the framework is to ensure that the range of possible influences is considered in policy development, and that any need for further evidence can be defined by reference to the framework. This is because at the time the work was commissioned the primary focus was what, if any, action DCLG could take to mitigate overheating through the Building Regulations and other policy interventions, rather than investigating fully the role of occupant behaviour.

27. Although there is limited empirical evidence, it is clear that the behaviour of the occupants in a building can impact significantly on the temperatures in the home. It is

not possible to regulate for this, but behaviour needs to be considered when planning interventions.

28. Three distinct aspects of user behaviour are considered:

- Behaviour causing (or exacerbating) overheating or the risk of overheating;
- Behaviour responding (or not) to actual or anticipated overheating, with the intention of averting or reducing risks;
- Overheating having an adverse effect on behaviour (e.g. through increasing accident risk or impairing cognitive performance).

These are interdependent because, logically, the behaviours that increase overheating should generally be the opposite of those taken to reduce overheating. In practice, behaviour may not always be logical and actions taken with the intention of averting risk may actually increase it. The risk of counter-adaptive behaviour may itself increase as a result overheating causing cognitive impairment.

29. It is important to establish whether specific behaviours (in practice – not just in principle) either lead to overheating or increase the risk of overheating. Supplementary to this is the question of whether/how these behaviours differ by factors such as building type/characteristics/orientation, occupant type, location and housing tenure. Overheating would result from some combination of:

- The thermal environment (air temperature, radiant temperature, humidity and air velocity/turbulence);
- Insulation of the body (by clothing, bedding, etc.);
- Metabolic rate, hence physical activity and thermoregulatory capacity, both of which may depend on age and state of health.[1]

30. Behaviour increasing the risk of overheating may act on any one of these three factors. The thermal environment is most directly related to the building characteristics while the other factors are more relevant to the question of which occupant types are at greatest risk. In all three cases, inability to detect overheating (e.g. because of a deficient thermoregulatory system or cognitive impairment) would increase the risk. Alternatively, the thermal environment might be seen as the primary risk factor (particularly in the context of DCLG's interests) whereas the other two factors relate to the secondary risk of an adverse thermal environment actually causing harm. Either way, all three need to be considered.

31. There is a question regarding whether specific behaviours (in practice – not just in principle) contribute to the reduction in (or avoidance of) overheating. Supplementary to this is the question of how such behaviours might be encouraged or facilitated. As in the case of behaviours leading to overheating, behaviours to mitigate overheating would act through some combination of the thermal environment, insulation of the body, and metabolic rate.

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[1] Age and health are also relevant to the person's ability to cope with the physiological and mental change brought about by the combination of the three factors leading to overheating.

32. It is important to understand and model the behaviour of occupants in buildings and how this behaviour impacts energy use and comfort. Although health, rather than comfort, is the key concern in this review, behaviour is likely to be driven by comfort and the indoor environmental consequences of that behaviour can affect health. It is similarly important to understand how a building's design affects occupant comfort, occupant behaviour and ultimately the energy used in the operation of the building. A behavioural algorithm for window opening developed from field survey data has been implemented in a dynamic simulation tool. The adaptive algorithm is shown to provide insights not available using non-adaptive simulation methods and can assist in achieving more comfortable and lower energy buildings.

33. The design of a building and its services can determine what adaptive behaviours are possible and influence the occupants' selection from possible behaviours. Behaviour is therefore not a separate issue from building design but a consequence of that design. While there are many other influences on behaviour (e.g, personal knowledge and preferences, the social context and economic resources), building design is important. Buildings should be designed with knowledge of how people actually behave (as distinct from how the designer would like them to behave) so as to promote adaptive behaviour that mitigates the impact of high outdoor temperatures. In similar fashion, the urban environment (e.g, the availability of cool outdoor or indoor spaces) should also be planned with a view to promoting adaptive behaviour. These provisions would be persistent in their beneficial effects whereas providing direct social support to households is likely to be an ongoing requirement.

34. Occupant behaviour in terms of movement around the zones of the dwelling is important with regard to possible exposure to heat, combined with how the occupants choose to operate the ventilation systems. In general, occupant behaviour has the potential to impact significantly on overheating. A Department of Health (DoH) report gives advice as to how reducing risks to health can be achieved through adaptation of behaviour, for example:

    - Ensuring that windows can be opened
    - Shading windows from direct sunshine, for example by outside shutters
    - If shading is impractical, using thick curtains to reduce heating of the indoor environment
    - Opening windows in the early morning, and shutting them if the outdoor temperature rises above the indoor temperature.

35. Behaviour in emergency conditions (heat waves) may be expected to be different to normal, and so advice at these times may be taken more seriously. The Heatwave Plan for England is mainly focussed on behavioural changes.

Definitions

36. There are many documents that refer to overheating and these give different definitions. Whilst it is clear that some building sectors have different needs, there may be a place for rationalising the number of standards.

37. Most standards refer to comfort, rather than health effects. The exception is the Heatwave Plan, which links to external temperatures.

38. It is conjectured that the SAP Appendix P definition is the mostly widely used for new dwellings. This is a simplistic assessment tool rather than a detailed design tool. The use of SAP Appendix P was mentioned by some of the stakeholders who were interviewed.

39. The CIBSE Guide A definition may also be reasonably widely applied. For example, English Partnerships, the forerunner to the Homes and Communities Agency, developed a Quality Standard governing peak temperatures and overheating, which stated:

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

40. CIBSE Guide A also provides general summer indoor comfort temperatures for non-air conditioned dwellings. These are that living areas should be at an operative temperature of 25ºC and bedrooms at an operative temperature 23ºC, noting that sleep may be impaired above an operative temperature of 24ºC.

41. The Zero Carbon Hub has considered likely overheating in housing under future climate change projections. Their modelling included dynamic thermal modelling, SAP Appendix P and the Passivhaus Planning Package to test a range of dwelling types against High and Low Emissions scenarios for climate change in the 2020s, 2050s and 2080s. Regarding *SAP Appendix P* they commented:

    "We also know that the current method of compliance in SAP, Appendix P, substantially depends upon night cooling, but can hardly be described as robust – simply leaving windows open '50% of the time' appears to cure most overheating problems, but is a questionable assumption in the light of perceived home security considerations and variables of dwelling occupancy."

    From their study the Zero Carbon Hub concluded:

    "Immediate action is required to gain a better understanding of overheating in dwellings; a point of concern for current and more recently built homes, not just future designs. A suitable model for determining overheating of new homes needs to be validated or identified and a combination of desk research and practical testing is necessary. Such is the dearth of test data from UK homes that activity this summer is likely to be required. This will enable the opportunity to develop an improved simplified tool for assessing overheating; a critical step which determines the direction of the subsequent development of the carbon compliance tool."

42. Within Chapter 5, we have reviewed other definitions and the current policy instruments and potential policy options to address overheating in buildings.

Current research activities

43. There are a number of relevant research projects and activities underway that are producing new information, but this is not all yet published. The largest group of studies is funded by the EPSRC (Engineering and Physical Sciences Research Council) through the ARCC group of projects (Adaptation and Resilience to a Changing Climate). The Programme Managers have been asked to state how their research projects can contribute to addressing DCLG's overheating concerns and their responses have been included. Of particular note is the CREW project which has developed a retrofit toolkit. Some conclusions from CREW are reported here:

- Solar gain is the most significant cause of overheating. External shutters consistently rank as the most effective measure and should be integrated in future window design and installed systematically at the time of window replacement. The only exception is Victorian terraced homes with solid walls facilitating inward transmission of solar heat. External insulation with light-coloured rendering is most effective. This should be combined with external shutters for windows.
- External insulation consistently outperforms the internal insulation in all building types, occupancy patterns and orientations examined. Therefore external insulation should be encouraged.
- More advice could be given to councils to ensure that the most vulnerable are not housed in the worst dwellings for overheating – e.g avoid putting elderly residents in top floor flats. Top floor 1960s flats can experience over 6 times the overheating of ground floor flats, depending on orientation, and almost 9 times that of Victorian terraced houses. Importantly, modern detached houses are found to present the second worst overheating exposure. The CREW retrofit advice web tool could be used to assess the overheating exposures of councils' housing stocks.
- It is possible to substantially reduce overheating and energy use at moderate cost. For example it would cost about £3,000 to reduce overheating by 85% for a 3-bed 1930s semi-detached house, and £10,000 for 97% reduction, with reduction in winter heating too in both cases (10% and 30% respectively). There is generally diminishing return in both heating and cooling performance as costs go up.
- The CREW results demonstrate the value of behavioural (zero cost) adaptations including window opening, night ventilation and closing curtains during the day. More advice could be given when hot weather is forecast, in addition to the heat wave plan.
- Designers and relevant staff in Registered Housing Providers should be encouraged to use tools such as the CREW retrofit advice web tool to plan refurbishment strategies because the most appropriate adaptation interventions are influenced by factors including building type, orientation, and occupancy. The web tool would help navigation through the options.
- Last, but not least, integrating adaptation and mitigation in retrofit design is essential. This is important whether the retrofit was initially for mitigation or adaptation, and it is important for both performance and keeping costs to a minimum. Subsequent retrofit to correct overheating resulting from retrofits which address only mitigation/carbon reduction would incur extra cost, and could defeat the original mitigation aim (e.g. if

air conditioning is installed as happened often). Likewise, retrofits that only consider adapting to future hotter summers may require further corrective retrofit to resolve extra carbon emissions in heating season. The corrective retrofits, if carried out in the same approach that separates adaptation and mitigation, could result in a vicious circle.

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44. We have also noted the work which CIBSE is undertaking, reviewing the current overheating criteria in *CIBSE Guide A*.

Interventions

45. Interventions to reduce risks due to overheating could be made at each of the following levels:

    a) Urban realm measures
    b) Building measures
    c) Equipment changes
    d) Behaviour changes
    e) Health interventions

46. These levels of interventions may be driven by different actors; only some are relevant to the Building Regulations for which DCLG has responsibility in England. Many of the potential interventions interact with each other, such that the impact of each is complex to predict. Experimental evidence of the effectiveness of each is limited, but more is beginning to emerge.

47. The potential solutions are summarised in the table below, grouped into the levels at which they apply. Note that several blur across the boundaries, for example are shutters building or equipment? This is an AECOM-prepared table (rather than one identified in the literature review) for further consideration and discussion.

Urban	Building	Equipment	Behaviour	Health
Avoid canyons	Cavity wall insulation	Circulation fans	Window opening, if external temps less than internal temps	Drink water, eat cool food
Create blue areas	Chimneys/ passive stack ventilation	Curtains	Night ventilation	Sit in the shade
Change building form	External fixed shading	Internal blinds	Reduce bedclothes	Avoid exercise in sun
City albedo	External shutters	Air conditioning if renewable electricity is available at an appropriate time	Reduce clothing	Monitor temperatures for vulnerable people
City ventilation	External wall insulation	Cross ventilation provision	Curtain / blind usage	Follow *Heatwave Plan* intervention levels
Electric vehicles (low noise)	Glazing areas	Grow plants, especially trees	Place vulnerable people with thought – not top floor flats	Obtain ice / cool water supplies
Create green roofs	Internal wall insulation	Ensure mech. vent heat recovery units are correctly operated in summer	Ensure vulnerable people have access to cool / shady areas	Monitor vulnerable people regularly
Tree planting	Low e triple glazing		Turn off lights and non-essential equipment	Take cool showers
Zero energy city	Orientation			
	Solar reflective roof			
	Solar reflective walls			
	Thermal mass			
	Avoid single aspect flats			
	Do not add car parks at expense of green space			
	Consider heating & potential overheating issues in the same package of works			

48. Other, non-technical measures, include:

- Adopting a regionally differentiated approach to solutions
- Improving overheating models
- Using decision-making tools when developing refurbishment strategies
- Advice to small builders and designers
- Advice to residents/carers, care home staff and healthcare professionals.

Stakeholder input

49. A limited stakeholder consultation exercise with 20 people involved in managing or building homes (out of 54 contacted) has raised a number of issues that should be explored further.

50. Most consider overheating to be a problem now (16 out of 20 respondents); with 5 organisations saying they had received formal complaints.

51. Relatively newly built flats, constructed post 2000, were perceived as the dwellings most likely to overheat. The strongest single message is that overheating is occurring as a result of community/district heating systems in apartment buildings, where unintended heat losses due to a lack of insulation is resulting in problems in some parts of some buildings, especially corridors. This is of particular interest because it has not been identified at all in the literature review.

52. Other factors quoted were south-facing, single-aspect dwellings, difficulties in achieving "night-time purge" ventilation in ground floor flats and concern about problems generated through retrofit. The urban heat island effect was also mentioned.

53. Also noted as contributing factors were restrictions on corridor ventilation, for fire and/or health and safety reasons, and restrictions on window opening – due to health & safety concerns (say in high-rise dwellings) and external conditions (air pollution).

54. Several respondents highlighted their uncertainty over what can be defined as overheating, believing that humidity and ventilation may need to be considered as well as temperature.

55. When asked about tools to assess the risk, respondents mentioned SAP – which was regarded as not really suitable, being a steady state model and a compliance tool not a design tool – and dynamic simulation models such as SBEM, IES and TAS. 9 out of 18 respondents said the tools are not adequate.

56. When asked about any remediation measures which had been adopted, correct use of mechanical ventilation with heat recovery (MVHR) was quoted, as was occupant behaviour and reducing solar gain through the selection of the glazing. Another suggestion was fully understanding the risk at the design stage and taking appropriate measures then.

57. When asked if overheating is a significant concern to their organisation or not, 11 out of 17 confirmed that it is.

58. All respondents were happy to take part in further investigations/discussions and this opportunity should be taken up.

Going forward

59. Identifying areas for potential further work is the purpose of our subsequent report (March 2012), but some initial thoughts are presented in the final chapter.

1. Introduction

1.1 This project investigates overheating in residential buildings for our client the Department of Communities and Local Government (DCLG). AECOM have led the investigations supported by the London School of Hygiene and Tropical Medicine (LSHTM) and University College London (UCL). AECOM have project managed and integrated the work, whilst also reviewing the definitions and policy aspects. LSHTM bring particular expertise on health issues and UCL have expertise in building modelling and data.

1.2 DCLG has interests in building standards and energy efficiency as well as health and safety. The Department also has responsibility for the framework of the land-use planning system. With regard to specific building sectors, DCLG is responsible for housing and other buildings where people live. Other departments will be responsible for considering the risks and implications of overheating for the buildings in the sector for which they responsible. This work has its main interest in dwellings and health impacts, and in particular whether there are defined internal temperatures which are likely to be detrimental to peoples' health, including the vulnerable. Comfort as well as health has been included to a limited extent where possible. There is also a blurring between comfort and health where impacts such as sleep loss can be significant to health, either to the health of the individual or to others due to the consequences of a lack of concentration/falling asleep.

1.3 There are three main areas of interest:

- Whether overheating is occurring in new dwellings as a result of higher insulation standards and improved air tightness?
- Whether overheating is currently occurring in existing dwellings?
- Whether retrofitting/refurbishing existing dwellings is likely to increase the risk of overheating or not?

1.4 These questions are posed in the context of the current climate and future external conditions in the UK arising as a result of climate change. A recent review of the UK's preparations to adapt to climate change noted the importance of designing and refurbishing properties so that they are suited to current and projected future temperatures (Committee on Climate Change, CCC ASC, 2010). The review reported that UK buildings are already vulnerable to overheating and that this is likely to get worse as temperatures increase.

1.5 The particular remit is therefore to assist DCLG to answer the following key questions:

- How exactly do we define the issue of overheating?
- What exactly causes overheating?
- Which sectors of society are most vulnerable from overheating and what exactly is the scale of the problem?
- Given how the nature of policy-making is changing what would be the best way to address overheating if it were found to be a serious problem?
- What are the costs/benefits associated with possible solutions?

1.6 This report considers the following:

- What is the impact on health of temperature, other internal conditions and potential cumulative impacts?
- How do dwellings modify the external conditions?
- How does the behaviour of individuals affect the risk of overheating?
- How is overheating defined, and by whom? What might be done via Government policy to address the risks of overheating?
- What can current research tell us (i.e. projects which are not yet featuring in a literature review)?
- What is the range of possible technical (not policy-based) interventions?
- What do stakeholders think?
- What are the future research needs?

1.7 The study consists primarily of a literature review. We have also considered current research and conducted some stakeholder telephone interviews, but this first phase does not involve any new research. In summary it addressees:

- What is clearly known and from what sources
- What is known anecdotally
- The views of relevant stakeholders
- Areas of current research activity
- Significant areas where new or further work is needed.

1.8 A second output from this project will identify the main gaps in the literature, and areas where further work would be of most value. This will be published separately by DCLG.

2. Impact on health of temperature

Epidemiological evidence relating to high ambient temperatures and its relation to overheating in buildings.

2.1 Much of the health evidence relating to overheating risk has been summarised well in an NHBC Foundation report on overheating in highly insulated homes; due for publication in 2012. This section does not repeat that summary, but attempts to explain how it might be used for a definition of indoor overheating using largely epidemiological evidence.

Impact of temperature on health

2.2 Currently in the UK, heat-related adverse health impacts are a far smaller burden than that of cold-related health impacts (by almost an order of magnitude). As a broad figure, there are around 2,000 heat-related deaths in a typical year.[1 2] However, if summer temperatures increase, as they are expected to do under climate change, the burden can be expected to grow appreciably unless there are additional protection/adaptation measures (whether planned or unplanned). The probability of a heat wave similar to that experienced across much of Western Europe in 2003 with substantial excess mortality, remains low, but some climate change scenarios suggest that similar summer temperatures could become common by mid century. Adaptations to help reduce indoor temperatures during periods of heat will be an important part of any adaptation strategy as the indoor environment is the potential refuge from outdoor heat.

2.3 Nearly all the evidence on the relationship between temperature and health effects (mortality and morbidity) derives from studies where daily or weekly counts of health events have been related to temperatures measured at one or a few weather monitoring stations in time-series analyses.[3] Such studies focus not on indoor temperature but on outdoor temperature and how it influences day to day variations in the frequency of health events for a whole city or other aggregate population. If the analysis of time-series makes allowance for time-varying risk factors such as outdoor air pollution, influenza and other seasonal infections, it can provide fairly robust evidence of association with temperature as, in effect, the same population is being compared with itself from one day to the next. Thus, if there is an increase in health events on one day compared with another it is very unlikely to be attributable over the short term to differences in population composition. Instead, the influence of some external agent such as temperature can be assumed. Outdoor temperature has one of the strongest, most definable relationships with variations in mortality and morbidity.

2.4 Through various methodological developments, it has been possible to characterise the temperature-mortality/morbidity functions fairly precisely for many populations [4 5 6 7 8 9 10 11 12 13 14] including those of the regions of England and Wales.[1] For London, for example, epidemiological studies have shown that mortality begins to rise above a heat threshold of around 24.7°C maximum daily temperature (at a short time lag of zero or one day) and that the shape of the function curves upwards slightly (approximately quadratic) above this temperature, although it can reasonably, and more simply, be approximated by a straight line (**Figure 1**)[1] This curve indicates that mortality on a day with maximum outdoor temperature of 35 Celsius is around 1.9 times that on a day with a maximum temperature of around 20 Celsius (i.e. a 90% increase). The shape of the curve suggests a gradual steepening of mortality risk with increasing temperature, which may suggest that the risks are particularly high at temperatures at, and above, the upper end of the current temperature distribution.

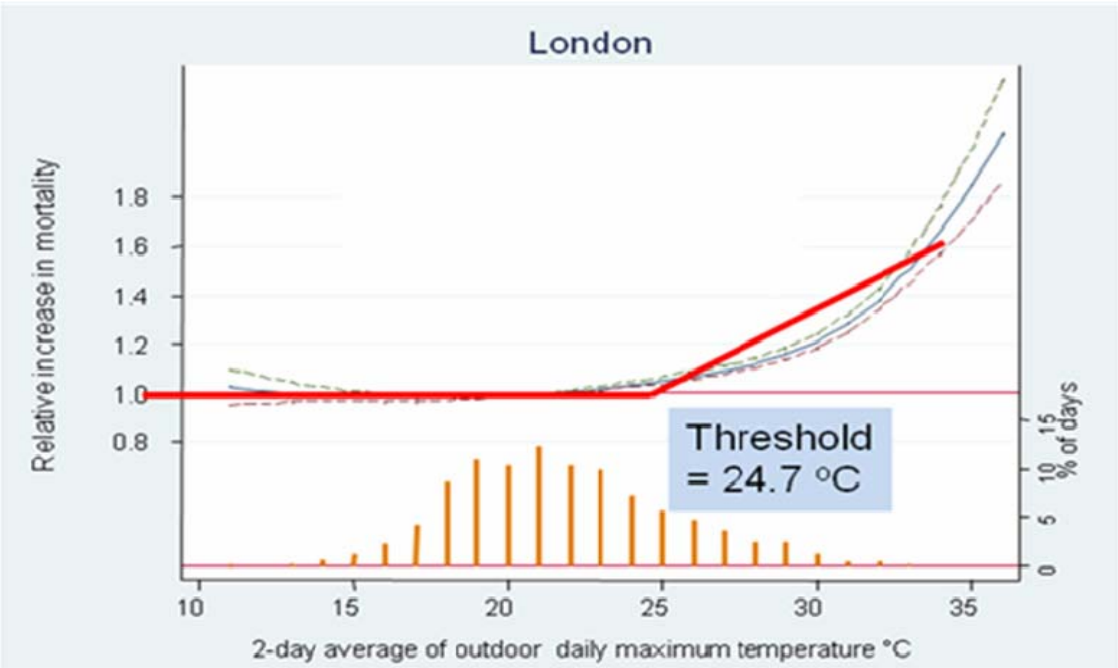
2.5 This type of epidemiological evidence relates to the association of mortality/morbidity with outdoor temperature. The results cannot be directly extrapolated to indoor temperatures.

2.6 The nature of this relationship is such that, given the daily temperature, it is possible to predict the expected number of excess deaths fairly accurately.[14] In simple terms, the number of people who die of heat is directly related to how high the temperatures are and the number of days of high temperature. (Note, however, that the evidence is still inconclusive whether runs of hot days, such as may occur during a heat wave, have greater effect on mortality than that predicted by the effect of the temperatures on each of the individual days;[15] there is also some evidence that early season heat waves have greater impact than those occurring later in the summer). It should be noted that in most epidemiological analyses to date, weather variables other than temperature appear to have relatively limited predictive power for mortality or morbidity, and do not therefore contribute much to the assessment of health risks beyond the use of temperature alone.

2.7 However, it should be noted that certain air pollutants, especially ozone, may rise during heat waves as a consequence of atmospheric conditions, and may account for a proportion of the adverse health impacts. Night-time (minimum) temperatures appear to contribute little additional predictive value in models of heat-related risk once (the highly correlated) maximum day time temperature is taken into account.

2.8 However, physiological considerations suggest that attention should also be given to humidity and other factors, whose joint effects are typically represented in a composite index. One of the most commonly applied composite measures is the apparent temperature, which (ignoring wind effects) can be estimated as $-1.3 + 0.92T + 2.2P$, where T is ambient air temperature in degrees Celsius, and P the vapour pressure of water in kPa. However, any theoretical gain in predictive ability from the use of such measures has to be weighed against the loss of transparency compared with simple air temperature measure (as reported in public weather forecasts). For most practical purposes, the untransformed daily maximum temperature, or possibly the daily mean or minimum, appears reasonable for epidemiological analyses.

Figure 1: Relative risk for summer temperature-related mortality in London



Notes: The results are based on analysis of mortality in relation to two-day mean of the maximum daily temperature (Tmax), after adjusting for season and time-varying risk factors. The red lines indicate the fit of a simpler linear-threshold (hockey stick) model. *Source:* Armstrong et al. 2009.[1]

2.9 The body of evidence on heat-related morbidity, as reflected by hospital admissions,[16 17 18] general practice consultations, ambulance calls,[19 20 21 20] and communication with the health service,[22] is less extensive than for mortality, but it shows broadly similar patterns (though some analyses suggest that hospital admissions have a weaker association with high temperature than mortality).[23 18] There is also some evidence that high (outdoor) temperatures may increase falls (e.g. from open windows)[24] and other accidents,[25 26] and even suicide.[27]

2.10 There is some data to suggest that the strength of the association between outdoor temperature and mortality/morbidity has been getting weaker over decades,[28] presumably in large measure due to the influence of improvements in environmental conditions, health care and population health, but as yet there is insufficient evidence to conclude whether warning systems have had a measurable impact to reduce the adverse health effects of heat waves in the UK.

Variation within population groups

2.11 It should be noted that the risk of death from heat rises very steeply with age but is otherwise fairly widely distributed in the population,[2] so that it is difficult to identify in advance all those who are likely to succumb during a period of heat. Deaths in nearly all major cause-of-death groups increase with temperature, suggesting that many people with a wide range of different underlying medical conditions are at potential risk.[2] But the principal identified risk factors for heat death include age, limiting health conditions (e.g. being confined to bed, not leaving home daily, being unable to care for oneself), and pre-existing psychiatric, cardiovascular, pulmonary and other illness, and these may offer some basis for targeted actions.[29 30 31 32 33] Social, behavioural, demographic and clinical factors mean that the temperature that is a serious health threat for a person with vulnerability factors may not represent such a significant health threat for another person, but with increasing temperatures an increasingly large proportion of the population becomes at potential risk, especially if levels of physical activity are taken into account. Under very high temperatures even relatively fit young people may succumb to heat if they have to be physically active.

2.12 It is also worth noting that deaths from heat are not confined to 'heat waves', however defined. In fact, the evidence for the UK indicates that more people die of heat on days that are not part of a defined heat wave than during heat waves.[1]

Evidence for impact of indoor temperatures

2.13 Although the relationship between mortality and outdoor temperature is well-characterised, crucially for the current brief, it is not clear how this translates into the health risks of indoor temperature. The epidemiological evidence merely indicates that at a certain outdoor temperature, mortality begins to rise. But at any outdoor temperature there will be a range of indoor temperatures – both higher and lower that the recorded outdoor maximum – and it is not possible to say with any certainty what level of indoor temperature presents a risk to health. Indeed, there is even debate whether it is exposure to the indoor temperatures or exposure while outdoors that carries the greater risk to health, although it is reasonable to assume that indoor temperatures are important because the majority of the most vulnerable population group (the elderly) spend most of their time at home and indoors.

2.14 As yet, therefore, it is not possible to define a safe or a definitely unsafe indoor temperature purely on the basis of epidemiological evidence, even though the outdoor temperature-mortality/morbidity relationship is well-defined for populations throughout England and Wales. It should also be remembered that susceptibility to high ambient temperature is likely to vary from one individual to another, which makes the assessment of the role of dwelling-related factors more problematic for defining overheating risk on health criteria.

Evidence of impact of buildings on health

2.15 There is very little direct epidemiological evidence about housing characteristics as independent risk factors, except that air conditioning has repeatedly been shown to be protective [6 34 35 36] and that residents of nursing homes may be particularly at risk,[37 31 33] although the latter is not a universal finding,[38] and is likely to relate more to the characteristics of individuals and their circumstances of care than to the condition of the (indoor) environment. Low socio-economic status may also be a determinant of vulnerability.[36 39 14 31 35 40 41] The reason for vulnerability in groups of low socio-economic status is not fully understood, but might relate to a range of factors, including quality of housing, access to cooler (air conditioned) environments, intrinsic health status, or understanding of how best to protect oneself against high temperatures. The topic of air conditioning is addressed further in the next chapter, but the evidence is fairly clear and unsurprising that air conditioning is protective against heat risks (assuming it is functioning and affordable).

Using epidemiological evidence to define health risks in relation to indoor temperatures

2.16 Given current epidemiological evidence, no clear health-based definition of dwelling- or building-related overheating can be made other than by reference to evidence on physiological responses or thermal comfort (see the following section). However, an approximate indirect measure of health risk in relation to indoor temperature is potentially feasible using the very few studies that have yielded evidence about housing characteristics as risk factors for heat death.

2.17 **Table 2.1** below shows results from Vandentorren et al, 2006, from the most detailed study about the role of housing in the 2003 Paris heat wave,[35] which used a case-control method to compare the relative rise in risk of death during heat in relation to dwelling, area and other characteristics.[35,42] This study design was possible in relation to the 2003 Paris heat wave because of the very large excess of deaths during the heat wave period, when around 80% of deaths on the peak mortality days were heat attributable. The proportion is much smaller for past heat wave events in the UK.

Table 2.1 Housing conditions and environmental characteristics as risk factors for all-cause mortality[a]. Odds ratios are unadjusted for other factors listed in the table.

	Number of pairs	Cases No.	Cases (%)	Controls No.	Controls (%)	Odds ratio	Confidence interval (95%)
Building	258						
Single family house		31	(12.0)	33	(12.7)	1	
Multiple dwelling unit		227	(87.6)	225	(86.9)	1.19	0.62–2.27
Construction date	259						
After 1975		37	(14.3)	62	(23.9)	1	
Before 1975		222	(85.7)	197	(76.1)	1.83	1.14–2.92
Proportion of housing with toilets	177					0.24	0.08–0.74
Dwelling unit							
Floor (storey)[b]	142					1.12	1.00–1.25
Lives on the top floor							
No	207	160	(61.8)	184	(71.0)		
Yes		47	(18.1)	23	(8.9)	2.33	1.33–4.09
Thermal insulation[c]	250						
Very bad insulation		112	(43.2)	74	(28.6)	1	
Bad insulation		22	(8.5)	20	(7.7)	0.80	0.39–1.68
Average insulation		49	(18.9)	59	(22.8)	0.48	0.28–0.83
Good insulation		67	(25.9)	97	(37.5)	0.42	0.26–0.67

	Number of pairs	Cases No.	Cases (%)	Controls No.	Controls (%)	Odds ratio	Confidence interval (95%)
Number of rooms	254					0.85	0.72–0.99
Number of windows/50 m^2	203					1.19	1.03–1.37
Draughts feasible							
Yes	259	200	(77.2)	212	(81.9)	1	
No		59	(22.8)	47	(18.1)	1.25	0.80–1.93
Air conditioner in home							
No	257	253	(97.7)	249	(96.1)		
Yes		4	(1.5)	8	(3.1)	0.49	0.14–1.67
Room[d]							
Bedroom under the roof							
No	248	208	(80.3)	230	(88.8)		
Yes		40	(15.4)	18	(6.9)	2.16	1.26–3.69
Duration of sunlight in bedroom (hours)	243					1.07	1.01–1.13
Window coverings in bedroom							
Yes	203	164	(63.3)	168	(64.9)		
No		39	(15.1)	35	(13.5)	1.06	0.64–1.76
Environmental factors							
Vegetation index (200 m radius)[e]	257					0.37	0.13–1.06
Temperature index in °C (200 m radius)[f]	257					1.21	1.04–1.43

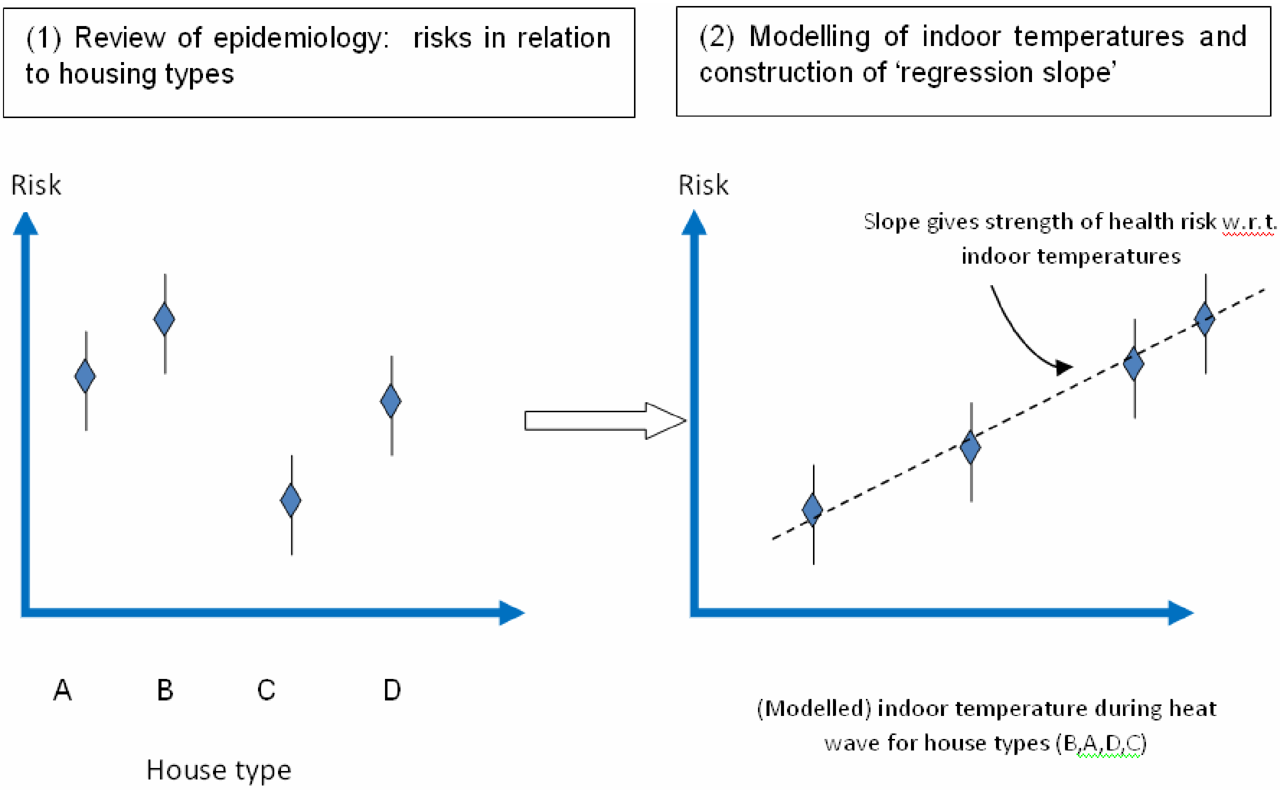
Notes: a: For each variable, the denominator is based on the number of pairs with no missing data. All results are adjusted for age. For quantitative variables, OR was calculated for an increase of one unit of the corresponding variable
b: Upper floors excluded
c: Insulation was built from three other variables: building date, work on improvement of the heat insulation for the building and for the housing
d: Results about the room were similar in the day- and night-time
e: The normalised difference vegetation index
f: The mean surface temperature in a 200 m radius (°C)

More detail can be found in: S. Vandentorren, P. Bretin, A Zeghnoun, L. Mandereau-Bruno, A. Croisier, C. Cochet, J. Ribéron, I. Siberan, B. Declercq and M. Ledrans August 2003 Heat Wave in France: Risk Factors for Death of Elderly People Living at Home *European Journal of Public Health* (2006) **16(6)**:583-591[35]

2.18 These results indicate fairly large variations in risk in relation to specific dwelling characteristics, and suggest heat-related mortality is increased for example in top-floor flats, older dwellings, and in those without ‘good’ insulation. The odds ratios in this table indicate the degree to which the risk of heat death is multiplied if the relevant factor is present, with the confidence intervals providing a measure of the uncertainty in the estimate (final column). These figures are unadjusted for the effect of other risk factors except age. For example, someone living in a top floor flat is 2.33 times as likely to die of heat as someone living in other forms of accommodation (penultimate column, 12th row of data). The odds ratios ('relative risks') can be multiplied together to give the overall relative risk for different combinations of housing characteristics. They could also be combined with evidence on individual-level risk factors if desired.

2.19 The key to quantifying the relationship between heat-related mortality/morbidity and indoor temperature is to translate these dwelling characteristics into indoor temperatures during the weather conditions prevailing at the time of the 2003 Paris heat wave. If these indoor temperatures can be estimated using building physics models then, in theory, a 'regression slope' (of risk against estimated indoor temperature) would give an indirect indication of the strength of the health hazard at different indoor temperatures. This is illustrated schematically in **Figure 2**. Such an approach is unlikely to be able to define a heat threshold for adverse health effects – i.e to identify the point at which there is a change in slope of the temperature-mortality/morbidity function. It is also unclear which measure of indoor temperature (daily maximum, minimum, threshold exceedance, period average etc) is the most appropriate to analyse. Indeed, different measures might be appropriate under different weather conditions. But linking existing epidemiological evidence to building physics models could yield quantification of how heat-related health risks are influenced by indoor temperatures.

Figure 2: Principle for deriving an approximate relationship between indoor temperature and risk of heat-related mortality/morbidity



Notes: Arbitrary labels A to D are intended to signify different housing types but carry no significance in relation to particular housing types or built forms.

2.20 Although the results in **Table 2.1** are French data, there aren't equivalent data for the UK and relationships between indoor temperature and mortality/morbidity are likely to be very similar in the two settings as they reflect biological responses in populations of very similar genetic stock. (Although some element of physiological habituation to heat is likely in those living in warmer climates, the degree of impact on the exposure-response relationship is likely to be small, especially if comparing London and Paris which have quite similar weather patterns. The greater influence on variations in epidemiological temperature thresholds for adverse health effects between different populations is likely to be related to infrastructure and behavioural factors.) The fact that the housing stock differs between the UK and France is relevant only to the task of modelling indoor temperatures, and is much less relevant to the nature of the underlying (biological) temperature-mortality/morbidity relationship. Thus, the epidemiological studies of heat-deaths in Paris could provide broad estimates of health risks in relation to indoor temperature which are relevant to the UK, even if dwelling characteristics are different in the two settings.

2.21 The absolute level of risk to health will also of course depend on individual-level vulnerability, behaviours (especially activity levels) and other factors. But this does not detract from the basis of the quantification which would provide population average relative risks against indoor temperature – i.e. the degree to which a particular indoor temperature level multiples the risk of an adverse health event. If desired, such estimates could be combined with evidence on how temperature risks vary with individual characteristics to provide aggregated estimates of heat-related health risk for specific target groups, such as the elderly.

2.22 It is important to emphasize that, to our knowledge, no analysis of this kind has yet been attempted, and to do so would entail some developmental work. There are variants on the approach that might be directly applied to the UK housing stock. Over the next three years, it is expected that the AWESOME project (Air pollution and Weather-related health impacts: methodological Study Of Multi-pollutant Exposures) funded under the NERC-coordinated Environmental Exposure and Health Initiative (EEHI), will provide new empirical evidence on the degree to which housing characteristics modify the health impacts of high ambient temperatures and from this some estimates of their influence on variation in heat-related risks. But this evidence will still be a step removed from the characterisation of the risks of adverse health events at specific indoor temperatures.

An alternative: use of physiological evidence

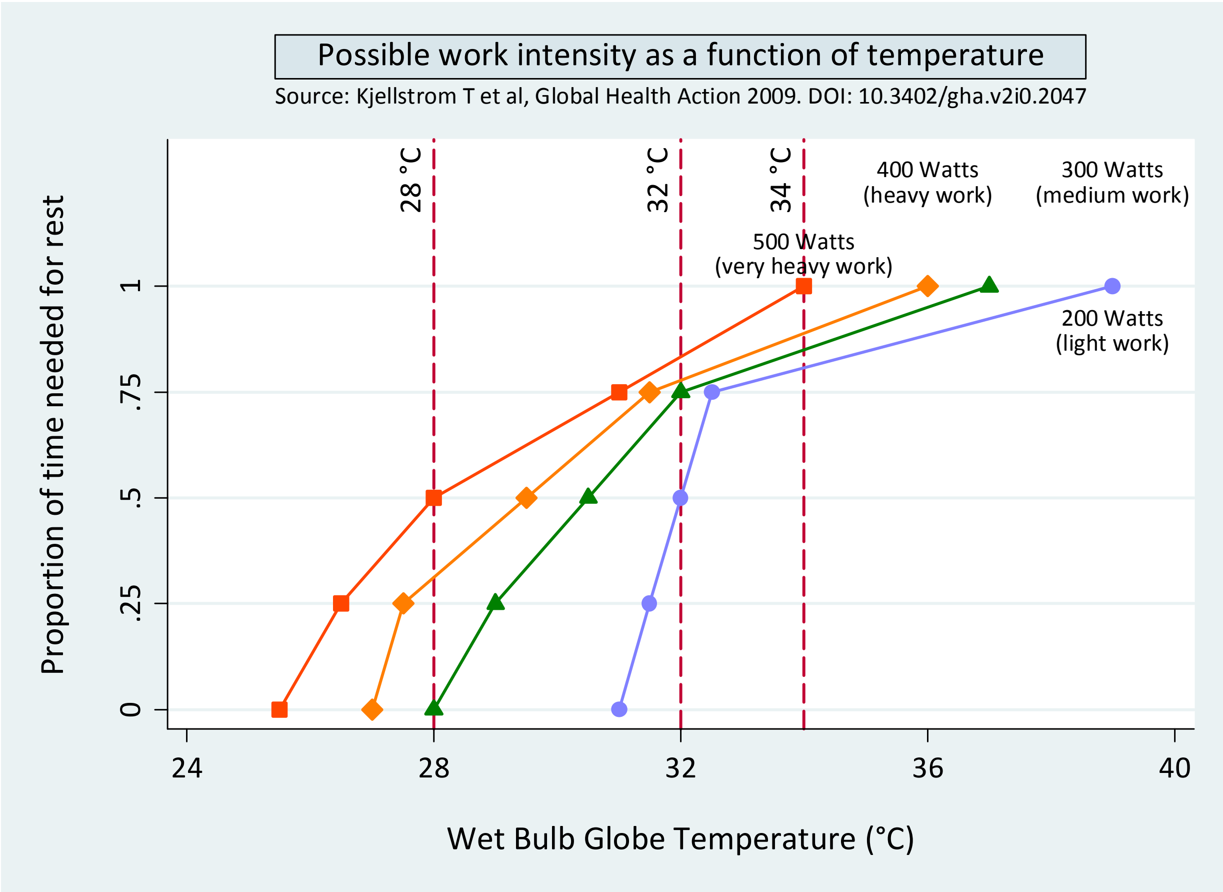
2.23 An alternative approach to the use of epidemiology for defining overheating is to use physiological evidence. This is a fundamentally different approach as physiology relates to the measurement or modelling of (mainly normal) bodily responses, typically in fairly fit individuals, usually under laboratory conditions. Its evidence can fairly readily be applied to the consideration of responses at individual level. Epidemiological studies, in contrast, are based on direct observation of the (aggregate) risk of adverse heat events occurring in the population at large or in susceptible subgroups defined on the basis of age, disease status or similar parameter. Within the population there will be considerable variation from individual to individual in activity levels, local environments (including indoor temperatures), as well as in personal vulnerability. An epidemiologically-defined heat threshold reflects the point at which some individuals under some circumstances within the population begin to succumb to heat. It is reasonable to assume that there will be a fairly wide distribution of indoor temperatures at a given outdoor temperature, and experienced by people of varying vulnerability. But the specific circumstances of those who are adversely affected are not generally known. Physiological evidence on the other hand can provide indication of responses to specified temperatures for an individual, yet the relationship between physiological response and adverse health events is often unclear. This has bearing on the fundamental basis for defining overheating. An implicit assumption of the discussion of this section is that the parameter most relevant to the health-related definition of overheating is the temperature at which clear adverse health effects occur, rather than the (continuous function) of thermal comfort.

2.24 However, much is now known about the physiological response to heat.[43] Sophisticated mathematical models have been developed to simulate it, and physiological evidence has been used to set occupational standards for protection against heat stress.[44] There is also increasing understanding of how physiological responses vary with age, one of the key factors determining susceptibility to heat.[45] Furthermore, there is some evidence about variations in responses in relation to disease status and other vulnerability factors (see for example chapter 9 of Parsons, 2003 [43]). It should be noted, however, that air temperature alone is not the only factor that defines the thermal environment for human health and well-being: radiant temperature, humidity, and air movement are also important, as are the level of physical activity (metabolic rate) of the individual and the thermal characteristics of his/her clothing. Thus, from a physiological perspective, it is simplistic to define over-heating on the basis of air temperature alone.

2.25 The fact that physiological responses are almost always continuous functions adds to the complexity of defining specific thresholds. It is also common that researchers of thermal stress use derived measures of temperature in preference to simple air temperature in order to take account of the effects of humidity, radiant energy and other parameters mentioned above. Many different approaches could be used to characterise the response to the thermal environment – thermal comfort, behavioural responses, physiological disturbances etc. But here we take one example which could be argued to provide a useful basis for defining overheating, namely the temperatures that limit the ability to perform daily activities (physical work). This has been an area of increasing interest, particularly in the context of climate change.[46 47]. **Figure 3**, derived from data reported by Kjellstrom et al 2011,[46] graphs the relationship between ambient temperature (measured as Wet Bulb Globe Temperature (WBGT)) and the need for periods of rest and at differing levels of physical activity. The WGBT is used because it takes into account effects other than simple shade temperature. It is a weighted average of three forms of temperature measurement: the so-called black globe thermometer temperature (Tg), which represents the integrated effects of radiation and wind; the natural wet-bulb temperature (Tnwb), which represents the effect of humidity, wind and radiation; and the (shade) air temperature (Ta).[49] For indoor conditions where solar radiation is negligible, the formula for WBGT reduces to 0.7Tnwb + 0.3Tg.

2.26 The curves of **Figure 3** indicate (in broad terms) the proportion of worked hours during which an average worker would need to take rest in order to avoid his/her core temperature exceeding 38°C.[46] Their evidence could be used to construct a definition of overheating based on a temperature that allows a specified level of activity (say light work) without interruption or at an acceptable specified need for periodic rest (say 25%). What these specifications should be is a matter of judgement, of course, and is as much a social consideration as one of health.

Figure 3: Approximate functions indicating limitation to work intensity as a function of Wet Bulb Globe Temperature.



Notes: Each line indicates a different work intensity with indicative (very approximate) metabolic rates in Watts.

2.27 As the figure shows, continuous light work is possible for an average person at a WBGT of around 31°C. Very approximately, at 50% relative humidity the WBGT of 31°C corresponds to an air temperature of around 29°C, although this is an approximation that includes assumptions about sunshine and wind speed. Clearly, the physiological impact also depends on the individual, and refinements would be needed to translate this evidence to something more appropriate for an older population active in their homes. In passing it is worth noting that the maximum daily outdoor temperature at which mortality increases in London, at 24.7 °C, is several degrees Celsius lower than the 'continuous light activity' threshold implied by the graph above.

2.28 Other measures of response or thermal comfort[48] could be used instead of productivity. It should also be noted that more sophisticated heat balance methods are preferred to the use of WBGT for assessing thermal stress.[49] But a fundamental issue for a definition of overheating is difference in the nature of evidence provided by physiological and epidemiological studies.

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3. How do UK dwellings modify the external conditions?

Introduction

3.1 There are many factors that will determine indoor summer temperatures in UK dwellings. These factors include:

- The external climate (which will vary with location in the UK)
- Location
- Dwelling orientation
- Room type
- Time of day
- Building fabric characteristics
- Occupant behaviour

3.2 This review reports on relevant published work that has been undertaken with regard to such factors. The main discussion of occupant behaviour is deferred to the next chapter. The majority of overheating studies to date for the UK residential building stock are modelling exercises rather than monitoring surveys. Crump et al. (2009), for example, noted that there is very little real data as to the actual extent of overheating. The outputs from the few published monitoring campaigns - including those since 2009 - are noted but the review that follows is inevitably dominated by modelling studies. A brief overview of currently ongoing monitoring campaigns is also provided.

3.3 A separate section introducing some of the findings from the limited stakeholder engagement undertaken by AECOM as part of this project has also been included at the end of the chapter. The exercise is fully reported in Chapter 8.

Modelling studies

3.4 Section 3.5 provides an overview of the range of relevant projects that have been undertaken. Further detail is provided in sections 3.19 – 3.2.5 which draws together findings from the published literature relating to these projects.

Overview

3.5 A considerable number of UK focussed thermal modelling studies have been published in recent years, which have investigated the impact of climate change on indoor overheating levels. A common feature of these studies is the use of dynamic thermal simulation packages which are able to explore the transient effects related to indoor overheating at a fine temporal resolution i.e hourly or even sub-hourly time steps. Whilst these studies usually examine a limited number of dwelling archetypes, most authors have made an attempt to use archetypes that are broadly representative of the UK housing stock or the parts of the stock in the region under examination. However, the lack of standardisation of these input parameters across the various studies does not allow the direct comparison of their results.

3.6 Until recently, these impact assessment studies commonly adopted a deterministic approach. This was achieved by representing the future climate through ranges of projected changes in the central estimates of environmental variables without any probabilities assigned to each range. The majority of the studies reviewed here have applied a simple methodology devised by Belcher et al. (2005) for transforming historic weather files into future weather years according to various climate change scenarios produced for the UK by the UK Climate Impacts Programme (UKCIP). The first version of these scenarios was published in 2002 (UKCIP02, UKCIP 2002), and provided deterministic predictions of the future climate for three future time slices (the 2020s, 2050s and 2080s) and four SRES carbon emissions scenarios (Low, Medium-Low, Medium-High and High) derived from the Special Report on Emissions Scenarios (SRES).

3.7 In the years that followed, there has been a gradual recognition of the need to express and quantify uncertainty assigned to future climate projection. The second generation of climate change projections for the UK climate were published in 2009 (UKCIP 2009) and adopted a probabilistic approach. The key differences between the weather files for building simulation based on UKCIP02 and on UKCP09 are that the latter are (a) provided at a finer spatial resolution; and (b) include distribution ranges rather than single estimates, allowing the uncertainty in the predictions to be considered.

3.8 Four different research projects under the Adaptation and Resilience in a Changing Climate Coordination Network umbrella (ARCC ACN 2011) have set out to develop protocols for the conversion of the UKCP09 data in a format suitable for building simulation:

(a) ‘Coincident probabilistic climate change weather data for a sustainable built environment’ (COPSE 2011);
(b) ‘Low Carbon Futures: Decision support for building adaptation in a low carbon climate change future’ (Low Carbon Futures 2011);
(c) ‘The use of probabilistic climate scenarios in building environmental performance simulation’ (PROCLIMATION 2011);
(d) ‘The use of probabilistic climate data to future proof design decisions in the buildings sector’ (PROMETHEUS 2011).

CIBSE have also recently provided relevant advice and data via Technical Memorandum (TM) 48 (CIBSE 2009) and TM 49 (CIBSE 2011).

3.9 One of the earliest, most extensive and influential modelling exercises on the impact of the external climate on indoor thermal performance across a wide range of typical UK buildings was published in CIBSE TM 36 ‘Climate change and the indoor environment: Impacts and adaptation’ (CIBSE 2005, Hacker et al. 2005). A key aim of the study was to assess the potential limitations of passive cooling strategies to alleviate overheating across a range of naturally ventilated building types. It quantified the overheating risk under the UKCIP02 Medium-High emissions scenario of four dwelling archetypes (a 19th century house, a newly-built house, a 1960s flat and a newly-built flat) and seven non-domestic building archetypes (offices and schools) for three locations (London, Manchester, and Edinburgh) for the 2020s, 2050s and 2080s time slices. The dwelling types were selected in such a way so as to represent typical UK types or particular approaches to design.

3.10 An additional set of studies built on the initial piece of work noted above but focused on specific aspects of building construction and, in particular, the role of thermal mass with regard to overheating risk. Two studies set out to assess the impact of thermal mass on overheating levels in houses under a Medium-High emissions climate change scenario (Arup Research + Development and Bill Dunster Architects 2005, Hacker et al. 2008). Both studies examined the thermal behaviour of a single built form archetype with different levels of thermal mass (a four-bedroom detached house and a two-bedroom semi-detached house respectively). Hacker et al. carried out a thermal performance assessment in conjunction with embodied energy calculations of the modelled materials. A similar study by Capon and Hacker (2009), despite being limited to the modelling of two dwelling archetypes (a 1930s-1950s two-storey semi-detached house and a 1960s-1970s medium-rise purpose-built block of flats) also included indicative costings associated with adaptation measures.

3.11 The form of the thermal response function in a large number of buildings for a given range of predictions of future climate has also been investigated by Coley and Kershaw (2010). They modelled 400 different variants of non-air conditioned buildings comprising of four building archetypes (a house, a purpose-built flat, an office and a school) and combinations of future weather, morphology (building form), ventilation strategy, ventilation type (natural, mechanical and buoyancy driven stack ventilation), thermal mass characteristics, glazing ratio, insulation levels and building type.

3.12 The unintended consequences of domestic energy efficient improvements, such as increased levels of fabric insulation and air tightness, on indoor overheating have also been a key concern of built environment professionals and policy makers. Another series of early modelling studies (Orme and Palmer 2003, Orme et al. 2003) focused on the overheating risk of super-insulated houses by modelling four housing archetypes (a top-floor flat, a town house, a semi-detached house and a detached house), representative of existing and future built forms.

3.13 More recently, within the context of the Community Resilience to Extreme Weather (CREW 2011) research project, Porritt et al. (2010a, 2010b, 2011, 2012) conducted a modelling exercise aiming to rank the effectiveness of selected adaptations for reducing overheating during heat waves. Although the authors have now expanded the study to a range of UK dwelling types, published papers report results obtained from the thermal modelling of typical mid-terrace and end-terraced houses. Models were run for two occupancy types: a family and an elderly couple. Another example of recently published work is an indoor overheating assessment study by Gupta et al. (2012) with a particular emphasis on dwelling archetypes found in suburban settings (a detached, a semi-detached and a mid-terraced house and a purpose built flat), as part of the Suburban Neighbourhood Adaptation for a Changing Climate (SNACC).

3.14 In addition to future climate projections, a study by Peacock et al. (2010), carried out as part of the Tarbase project, also took into account a potential future increase in electrical consumption in UK households due to a rise in the ownership of energy intensive appliances and its impact on indoor overheating. The thermal performance of three construction variants of a detached dwelling (1988 timber frame construction, 2002 twin leaf insulated masonry construction, and pre-1900 solid wall construction) for two scenarios of electrical consumption was investigated. Existing databases were analysed in order to generate a set of occupancy profiles and their linked appliance ownership levels and hourly usage profiles.

3.15 Also of interest are a set of studies that explored the potential uptake of domestic air conditioning market penetration and its associated energy and carbon toll. A UCL study carried out for the EPSRC[2]-funded 'Domestic Air Conditioning - Occupant Use and Operational Efficiency Project' assessed the future impact of a warming climate on the potential uptake of domestic air conditioning in the South East of England and the consequent impacts of a rise in cooling energy needs for the national carbon reduction targets (He et al. 2005, Young et al. 2007, Pathan et al. 2008). A modelling study was initially carried out by He et al. (2005) for a theoretical stock of air-conditioned houses based on 9 dwelling archetypes weighted according to their prevalence in the entire stock and the associated levels of air conditioning ownership in South East England. Similar to the above-mentioned studies, the UKCIP02 emissions scenarios for the 2050s were used. A later study by Collins et al. (2010) explored the climate change impact on heating and cooling needs of UK dwellings up to 2080s, assuming a widespread uptake of cooling systems. Initial modelling involved seven dwelling archetypes but only results obtained for the semi-detached type were presented.

3.16 A more recent example of a climate change impact assessment study for UK dwellings is the Zero Carbon Hub inter-model comparison report (2010). The study sought to review the methods used to assess overheating in CIBSE TM 36 both in terms of future climate predictions as well as overheating metrics. Simulations of UK dwelling archetypes for time periods and locations similar to the TM 36 were repeated through the use of a variety of steady-state and dynamic modelling packages. As UKCP09 data was not available at the time of the study, UKCIP02 projections were used with an aim to substitute them in the future.

3.17 Following the release of the UKCP09 projections, a set of studies emerged from the Low Carbon Futures and PROMETHEUS projects, showcasing methods to translate the probabilistic climate data for use in building thermal simulation (Jenkins et al. 2010, Patidar et al. 2010, Eames et al. 2010). Work by the Low Carbon Futures team (Jenkins et al. 2010, Patidar et al. 2010) involved a model that relies on established statistical methods in order to assess climate change effects on the indoor thermal performance of UK dwellings. Although the analysis has only included one dwelling archetype (a three-bedroom two-storey detached house), the authors plan to expand it to include a variety of building variants. Finally, de Wilde et al. (2008) offer a detailed account of inherent uncertainties of thermal comfort modelling studies.

3.18 Chappels and Shove (2003, 2005) have noted that a significant shift of cultural norms in thermal comfort has taken place in the five decades since the 1960s. On the one hand, there has been a trend of demand temperatures increasingly falling within narrow ranges specified by engineered comfort models based on thermal chamber studies. Consequently, occupants may require internal temperatures to remain almost constant throughout the year in the future. It is possible that this saturation limit will converge around the world towards 'Western' standards of comfort. In the UK, under a business-as-usual scenario, this temperature is expected to be within the range of

[2] EPSRC – Engineering and Physical Sciences Research Council

19-20ºC according to Utley and Shorrock (2003) and 22-23ºC according to Darby and White (2005). According to current projections, air-conditioning will be installed in half of all homes in England and Wales by 2050 (Darby and White, 2005). On the other hand, many authors (Darby and White, 2005, Chappels and Shove, 2005) claim that there is still a significant potential for behavioural change. In their extensive review of theories and future trajectories of thermal comfort, Chappels and Shove (2005) argue that if the notion of thermal comfort is viewed as a socio-cultural construct, social norms could perhaps be reconfigured towards more sustainable practices in the future.

Findings on overheating risk by location

By location in the UK

3.19 Current modelling based evidence suggests that the South of the UK is likely to face the largest risk of indoor overheating. It was suggested that comfort targets will not be met in naturally ventilated buildings in London by the middle of the century without some form of mechanical cooling unless some additional adaptation measures are carried out (CIBSE 2005). In contrast, it was estimated that Manchester and Edinburgh buildings will only encounter minor overheating problems within the same time frame.

3.20 Similar results were presented in the more recent study by Peacock et al. (2010) where, for the dwelling variants examined, increased levels of insulation had a positive impact on the abatement of overheating in Edinburgh houses due to the low levels of solar gains. However, it was found that a super-insulated dwelling in London would present a considerable overheating risk due to the higher levels of solar gains in that location that are eventually retained in the interior.

By location in a city

3.21 A recent study by Oikonomou et al. [50], undertaken as part of the LUCID (2011) project, explored the relative importance of the urban heat island vs. building thermal quality. Whilst location does play a part in potential overheating, the effects of built form and other dwelling characteristics appear to be more important determinants of variation in high indoor temperatures than the location of a dwelling within London's urban heat island.

Findings on overheating risk by room type and time of day

3.22 Based on the CIBSE overheating criteria, modelled bedrooms have consistently been reported to perform relatively poorly especially in newly built flats (Arup Research + Development and Bill Dunster Architects 2005, CIBSE 2005b, Hacker et al. 2005). It has also been estimated that the modelled cooling loads required to maintain the temperature of the main sleeping areas at around 22oC are approximately double that of living areas (He et al. 2005). Note that the use of cooling loads is sometimes used as a way of representing the amount of overheating taking place, and does not mean that it is actually provided. In addition, lower average switch-on temperatures and longer operation periods have been monitored in sleeping spaces: an average switch-on temperature of 23.9°C and an average operation of 9 hours were recorded in bedrooms compared to 25.0°C and 5 hours respectively in sitting rooms (Young et al. 2007, Pathan et al. 2008). However, this might simply be an indication of increased occupied hours in bedrooms for particular demographic groups in the studies examined, or a preference for lower temperatures for sleeping whilst retaining bedclothes.

3.23 Porritt et al. (2010a, 2010b, 2011, 2012) quantified the difference in the effectiveness of the passive cooling strategies as a function of occupancy schedules, type of room and time of day. In particular, when the overheating assessment was carried out for a house occupied by a working couple with children at school, external wall insulation, followed by internal wall insulation was shown to be the most effective measure for both the living room and the bedroom. In that scenario, both spaces are occupied later in the day and, thus, benefit from the time lag in the heat release. In contrast, the internal wall insulation was found to increase overheating in the living room of an elderly couple with increased number of occupied hours during the daytime, as unwanted solar and internal heat gains were trapped within the building envelope. It was, therefore, suggested that 'switch-off' solar protection strategies, e.g. external shading and shutters, are likely to offer more immediate benefits for rooms that tend to be heavily occupied during the daytime. Clearly, other spaces that are dominated by high internal heat gains, such as kitchens, are also likely to overheat (Orme et al. 2003).

Findings on overheating risk by construction age and built form type

3.24 A relationship exists between dwelling construction age and overheating risk, owing to the potential correlation between age and parameters such as morphology, glazing levels, size, insulation, air tightness etc. A common finding in the studies explored here is that dwellings built around the 1960s and small top-floor purpose-built flats appear to be considerably more prone to overheating (Orme and Palmer 2003, Orme et al. 2003, CIBSE 2005, Hacker et al. 2005, Capon and Hacker 2009). This is attributed to the low solar thermal protection offered by the top floor of poorly insulated flats. In contrast, concrete ground floors were found to have a significant cooling effect (Capon and Hacker 2009). It was also shown that, among houses, the detached archetypes are characterised by the highest cooling loads, followed by semi-detached and mid-terrace types but similar values were obtained when loads were normalised per floor space area unit (He et al. 2005). Another study, however, found that the detached house was the least efficient building on the basis of cooling loads per floor space area unit (Collins et al. 2010). These findings depend of course on the way the house types are characterised, and this has not been made standard, and so other studies may give different results.

3.25 Another important finding is that not only older but also recently built dwellings will require increased cooling loads by the 2080s (Collins et al. 2010). Whilst newly constructed houses are characterised by reduced heat losses and, hence, increased thermal efficiency during winter, they may not be suitably designed to cope with extreme heat events. This leads in to the next section which focuses on the variation in overheating risk by fabric characteristics and operation, including ventilation strategy.

Findings on overheating risk as a function of building fabric characteristics and operation

3.26 An unintended consequence of high insulation and air tightness standards of newly built and retrofitted houses may be overheating (Zero Carbon Hub 2010). Newly constructed highly insulated houses were found to have the potential to be at higher risk of overheating than older, less well insulated houses (Young et al. 2007, Pathan et al. 2008). It has often been suggested that changing the positioning of insulation, i.e. external rather than internal, may minimise the risk of extreme temperatures during the summer. This will also vary as a function of the amount of heat retained in the structure (Peacock et al. 2010). Mavrogianni et al. (2012) stress that careful consideration of insulation options needs to be made in the future in the context of energy efficiency retrofit strategies as part of national carbon reduction targets such as the UK Government's 'Green Deal' retrofitting initiative. It is recommended that the specification of thermal upgrade solutions should not only evaluate the overall year-round benefits of various insulation measures but also preferably tailor these solutions to specific occupancy patterns.

3.27 Another key finding, which emerged from the TM 36 study, with significant implications for design and operation is that natural ventilation may become a 'double-edged sword' in the future (CIBSE 2005). As ambient temperatures are projected to increase, daytime ventilation may not be beneficial for the mitigation of overheating as the incoming air will be at a high temperature. In addition, night purge ventilation will be effective only if the diurnal temperature variation is significant enough to flush away the heat stored in the building. However, this is also likely to change under current climate change projections. Whilst window opening significantly reduces internal temperatures in London houses, it does not appear to fully eliminate overheating problems by the 2030s (Peacock et al. 2010).

3.28 On the other hand, simulation work by Porritt et al. (2011, 2012) demonstrated that living room temperatures could be maintained below the CIBSE overheating thresholds in 19th century terraced houses in the 2080s, assuming a Medium-High emissions scenario, as a result of a combination of intervention measures that include external wall insulation, external surface albedo reduction (e.g. solar reflective paint), shading (e.g. external shutters) and intelligent ventilation regimes. The effectiveness ranking of interventions is broadly in agreement with the study by Gupta et al. (2012). Nevertheless, Gupta et al. found that whilst these measures are effective in reducing indoor temperatures to a certain extent, indoor overheating risk in the wider group of suburban dwelling archetypes examined is not completely eliminated by the 2080s under future climate change scenarios.

3.29 The SCORCHIO research project (see Chapter 6) refers to the possibility that there may be future renewable energy surplus capacity in the summer, which could favour increased use of air conditioning to avoid overheating and adverse health effects. However this surplus will not necessarily be at the right times to match peak electrical loads required by air conditioning equipment and his capacity could quite feasibly run behind the rise in air conditioning unless there are some restrictions on the use of installations.

3.30 Furthermore, once people have air conditioning available, they tend to use it more than is necessary to avoid dangerous overheating, and without regard to whether there is surplus electricity capacity at the time or not. Unless air conditioning is restricted remotely through the use of smart meters, the net effect of air conditioning could easily be an increase in CO2 emissions. Thus, as a mitigation method for overheating, it needs to be considered carefully.

3.31 Thermal mass coupled with night-time ventilative cooling has been identified as a relatively effective measure to combat domestic overheating. This was confirmed by comparative analyses of indoor thermal performance of lightweight vs. heavyweight structures (Arup Research + Development and Bill Dunster Architects 2005, Coley and Kershaw 2010). In the heavyweight houses, the heat that was built up during the daytime was reradiated back during the night, thus resulting in both a time lag in heat release and lower daily peak temperatures. This is important given that increases in the amount of exposed thermal mass may delay the installation of mechanical cooling in newly built dwellings (Hacker et al. 2008). Dwellings with low thermal mass are characterised by higher ‘climate change amplification coefficients’, or steeper slopes of the linear regression between internal and external temperature (Coley and Kershaw 2010). These buildings may not be able to successfully respond to a warming external environment due to the rapid overheating of their interiors.

3.32 However, it is essential that adequate levels of night ventilation are provided in heavyweight structures as thermal mass alone is not likely to reduce overheating (Orme and Palmer 2003). Night time purging ventilation, combined with fans that increase air circulation and internal blinds during the daytime were found to reduce the cooling loads of one of the modelled flats by more than 50% (Capon and Hacker 2009). Night ventilation may prove beneficial even in lightweight structures (Orme and Palmer 2003). Solar control, such as shading, was found to reduce overheating as long as daylighting is less critical during the daytime (Capon and Hacker 2009, Porritt et al. 2011, 2012).

3.33 As noted in Chapter 4, occupant behaviour in terms of movement around the zones of the dwelling is important with regard to possible exposure to heat. However, it is clear from the discussion above that how the occupants choose to operate the ventilation systems is also key. In general, occupant behaviour has the potential to impact significantly on overheating and this was recognised, for example, in a DoH report (DoH 2008). The report gives advice as to how reducing risks to health can be achieved through adaptation of behaviour, for example:

- Ensure that windows can be opened
- Shade windows from direct sunshine, for example by outside shutters
- If shading is impractical, the use of thick curtains can reduce heating of the indoor environment
- Windows should be opened in the early morning, and shut if the outdoor temperature rises above indoor temperature.

Monitoring studies

3.34 Published summer thermal monitoring data from housing is rather limited owing, in part at least, to the fact that, until recently, overheating was not a major concern in the heating dominated climate of the UK. Six recent such studies are; the analysis of temperature measurements from five houses in London and four houses in

Manchester during the 2003 heat wave (Wright et al. 2005); 15 low energy houses in Milton Keynes (Summerfield et al. 2007); four houses in Stamford Brook in 2006 (Wingfield et al. 2008); 62 houses in Leicester during the 2006 heat wave (Firth et al. 2007); 36 houses (from a total of 110 dwellings in the overall study) in London in 2009 (Mavrogianni et al. 2010); and a large monitoring campaign involving 224 nationally representative houses across the UK during July and August 2007 (Firth and Wright 2008).

3.35 Some of the monitoring findings from the above published studies accord with the modelling outcomes presented in the previous sections. For instance, monitored bedrooms across the UK were shown to be more prone to overheating (Firth and Wright 2008): The mean indoor temperature peaks were higher in sleeping spaces for all dwelling types apart from purpose-built flats and temporary dwellings (such as caravans or other mobile or temporary structures). Across the whole sample, the average daily maximum living room temperatures was 25.9°C, compared to 26.6°C in the bedrooms. A higher range of temperatures is also observed in bedrooms (from 18.1°C to 26.6°C) compared to living rooms (from 18.5°C to 25.9°C). A higher average percentage of hours with temperatures exceeding 25°C was also observed in bedrooms of (4.6% compared to 3.2% in living rooms). In the Leicester 2006 monitoring study that comprised mostly of Victorian cavity or solid masonry walled properties, overheating also appeared to be more of an issue in bedrooms (Firth et al. 2007). In the smaller 2003 study, slightly lower temperatures were measured in London bedrooms, unlike Manchester (Wright et al. 2005).

3.36 With regard to building morphology and construction age, purpose-built flats and end terraces, as well as houses built after 1990, were at highest risk of overheating (Firth and Wright 2008). Temperatures above 25°C were measured in the bedrooms in post-1990 dwellings for 7.1% of the monitored period. Overheated bedrooms, in particular, were more common in temporary accommodation and purpose-built flats.

3.37 Firth et al. (2007) also highlighted the large variation in internal temperatures between various dwellings during the 2006 heat wave (up to 5oC difference in half hourly temperatures).

3.38 The analysis of diurnal conditions within monitored houses demonstrated that internal temperatures were highest during the evening and lowest in the early morning (Firth and Wright 2008). It was also found that in the small dwelling sample monitored during the extreme heat event of 2003 in London and Manchester, internal spaces in general maintained an approximately 5°C higher temperature than the external (Wright et al. 2005). This could perhaps be an indication of poor night-time ventilation as a result of occupant behaviour.

3.39 Summertime indoor overheating has been reported in ‘low energy’ dwellings. A monitoring study of 15 houses in Milton Keynes that were built in the 1980s to good energy performance standards is analysed by Summerfield et al. (2007). It was found that both the living room and bedroom temperature were generally maintained at temperatures above the external during both the heating and cooling season. This indicated the possibility of summertime indoor overheating risk although the monitored properties are not representative of UK dwellings and the sample is too small to generalise these findings. Internal temperatures peaking above 30ºC were also reported in the four masonry dwellings monitored by Wingfield et al. (2008) that were built according to high fabric efficiency and air tightness standards. The authors suggested that increasing risks of summer overheating are likely in the future in new housing developments, especially in lightweight structures, as well as heavyweight structures that have been internally insulated. Moderate overheating levels were reported in the Camden Low Energy Victorian House when external temperatures rose above 26ºC, which could potentially be attributed to internally insulated walls (Makrodimitri and Ridley 2010, Makrodimitri 2010).

3.40 Data obtained from a more recent pilot monitoring study is reported by Mavrogianni et al. (2010). The data relate to a subset of 36 dwellings (from a total of 110 dwellings in the overall study) across London during the summer of 2009. The results illustrated the need to quantify the net impacts of individual building characteristics and the location of each dwelling within the London heat island. During a hot period, 15 out of 36 monitored bedrooms failed the recommended CIBSE overheating criteria during the night time, i.e. indoor temperature rose above 26ºC. There was some indication of purpose-built or top-floor flats being more prone to overheating but the sample is too small to allow the generalisation of conclusions.

3.41 In addition to the above-mentioned studies, results are expected from the following large-scale monitoring campaigns:

- As part of the annual English Housing Survey commissioned by DCLG, a follow-up monitoring survey of heating and temperature patterns of a sub-sample of the surveyed stock is currently ongoing (DECC 2011).
- As part of the EPSRC-funded 'Measurement, Modelling, Mapping and Management' (4M) project, temperature data has been monitored in more than 300 houses across Leicester between July 2009 and February 2010 (4M 2011).
- As part of the Technology Strategy Board funded 'Retrofit for the Future' initiative, (TSB 2011) monitoring data from over 120 retrofitted properties located across the UK is currently being gathered with the involvement of Building Services Research and Information Association (BSRIA 2011) and Energy Saving Trust (EST). This information includes energy use and internal condition data (temperature, relative humidity), the analysis of which is currently being undertaken as part of the European Energy Development Fund (ERDP) / Institute for Sustainability's (IfS) FLASH project (IfS 2011).
- As part of the FutureFit project (Affinity Sutton 2011) that focuses on the social housing sector, the energy use and thermal conditions will be monitored in 102 retrofitted properties for the period from May 2011 to June 2012.
- The Welsh Government has initiated a project to measure the in-use performance of developments built to Code for Sustainable Homes levels 4 and 5, covering about 360 homes in 16 schemes from all across Wales. The main focus is on energy use, but data on internal and external temperatures is being collected for some homes. Sample dwellings will be monitored via the Low Carbon Research Institute (LRCI). The LCRI was set up to unite and promote energy research in Wales to help deliver a low carbon future, and is led by the Welsh School of Architecture.
- Separately, we are aware that an organisation (RPA) is undertaking work for the NHBC Foundation looking at practical issues around overheating with the intention of identifying the pitfalls for smaller builders and designers (October 2011).
- The development for Scottish and Southern Energy at Greenwatt Way, Slough was constructed to deliver zero carbon housing to Level 6 of the Code for

Sustainable Homes and it is intended to trial a range of renewable energy technologies supplying district heating to 10 low energy homes. Half of the homes have been constructed using masonry and the other half are timber-framed; all are occupied. The development is being monitored for 2 years.

3.42 The extent to which the summertime performance of the monitored dwellings will form part of the analysis of all of these datasets is not yet clear.

3.43 A body of other projects funded through the Technology Strategy Board 'Building Performance Evaluation' programme are also likely to produce useful relevant datasets. For example, at UCL, three long-term (two-year) monitoring projects in new build dwellings are underway. All dwellings are relatively air tight and fitted with Mechanical Ventilation and Heat Recovery (MVHR) and are built to PassivHaus, Code for Sustainable Homes level 4 and Fabric Energy Efficiency Standards (FEES). During the two monitored summers the data will be evaluated to assess the risk of overheating. The three projects are:

- Rowner Development, Portsmouth: Partnership with Zero Carbon Hub. 24 apartments, 12 built to FEES standard (utility data from 24 dwellings, detailed monitoring - including window opening - in 8 apartments).
- One Brighton Development, Brighton: Partnership with Bio Regional Quintain. Development of 170 apartments (6 apartments being monitored in detail).
- Ranulf Road Passiv house in London: Partnership with Bere Architects.

3.44 The Energy Technologies Institute (ETI 2011) has also funded a two-year research project to explore pathways for the refurbishment of the UK housing stock. It aims to identify the most energy efficient and cost effective solutions at the building stock level and address the challenges for the supply chain and regulatory framework. The work will also involve consideration of potential unintended consequences of retrofit, such as increased summertime indoor temperatures.

Summary

3.45 **Table 3.1** below summarises some key messages identified in the currently available published literature on the scale of indoor overheating and points the reader to the relevant passages in the text above.

Table 3.1 Summary of published evidence

	Summary of published evidence on the extent of overheating risk problem	**Commentary on available published evidence**
Scale of problem for the existing building stock	Several monitoring studies have indicated that there could be a substantial problem of overheating in the existing stock *(paragraphs 3.34-36)*. This is in accordance with modelling work that has indicated that the overheating risk currently faced by UK dwellings during extreme heat events could be exacerbated in the future under various climate change scenarios *(paragraphs 3.8-10, 3.12-16, 3.27-28)*. Messages that emerge from the literature include the fact that large variations in internal temperatures between various dwelling types were observed during the 2006 heat wave. Purpose-built, usually top-floor, flats and end terraces, as well as houses built after 1990, were found to be more prone to overheating. Overheating appears to be more of an issue in bedrooms *(paragraphs 3.32-38)*.	There have been relatively few monitoring studies. Whilst valuable information has been provided by such work, the sample size of these studies is generally too small to allow the application of the findings to the entire UK housing stock. Modelling work in this area provides useful insights but must be interpreted cautiously due to the uncertainties involved.
Scale of problem for low-energy, refurbished and recently built dwellings	In certain cases, dwellings that were recently built or refurbished to high efficiency standards have the potential to face a significant risk of summer overheating. Internal temperatures above the external and/or peaking above CIBSE overheating criteria, as well as higher cooling loads in air conditioned dwellings have been recorded during the summer in small samples of energy efficient dwellings *(paragraphs 3.21,3.19, 3.24,3.37-38)*. If applied appropriately, energy efficiency interventions can be beneficial for the abatement of overheating. Nevertheless, overheating risk has the potential to increase following inappropriate interventions. It has been suggested that lightweight structures, as well as internally insulated heavyweight structures may be at higher risk of overheating in the future *(paragraphs3.8-12, 3.25-30)*. Current modelling based evidence suggests that the south of the UK is likely to face the largest risk of indoor overheating.	Concerns about the unintended consequences of increased levels of insulation have been highlighted by modelling studies. However, the relevant empirical data currently available is limited.

Conclusion

3.46 This review has summarised the current published literature relating to how UK dwellings modify external temperatures. The relevant literature is dominated by modelling studies and published measured data is scarce.

3.47 However, the key mechanisms associated with overheating at an individual building level have been identified. For an individual dwelling, if sufficient data are available to characterise the thermal properties and occupant behaviour, it is possible to make some assessment of the vulnerability of the occupants to overheating and also make some projections as to the impact of a range of energy efficiency interventions. The challenge here is two-fold – firstly to develop a robust decision analysis framework to enable the assessment of individual dwellings, and secondly to ensure that adequate data are available to drive that framework.

3.48 The existing literature provides some useful indication of the potential scale of the problem based on modelled or monitored data. Building thermal simulation models are sophisticated tools that are able to accurately represent the physics associated with overheating. However, as with all modelled data, their value is determined by the quality of the input data. At the stock level there is much uncertainty associated with these inputs with regard to occupant behaviour and a detailed knowledge of the thermal properties of the dwelling. Relevant monitored data is currently scarce and generally only available for small samples of the housing stock. Large-scale measurement and data gathering campaigns are required in order to reduce the uncertainties associated with our current understanding of overheating at the stock level. Such work will allow the vulnerability of the overall UK stock to be better understood – both in its current state and in a 'low-carbon' future state.

Stakeholder engagement

3.49 As part of this project, and as an additional activity to the literature review, AECOM undertook a limited amount of stakeholder engagement, the findings from which are reported in Chapter 8 in detail. Some highlights are reported below:

- Most consider overheating to be a problem now (16 out of 20 respondents); with 5 organisations saying they had received formal complaints.
- Relatively newly built flats, post 2000, were perceived as the dwellings most likely to overheat. The strongest single message is that overheating is occurring as a result of community / district heating systems in apartment buildings, where unintended heat losses due to a lack of insulation are resulting in problems in some parts of some buildings, especially corridors. This is of particular interest because it has not been identified at all in the literature review.
- Other factors quoted were south-facing, single-aspect dwellings, difficulties in achieving "night-time purge" ventilation in ground floor flats and concern about problems generated through retrofit. The urban heat island effect was also mentioned.
- Also noted as contributing factors were restrictions on corridor ventilation, for fire and/or health and safety reasons, and restrictions on window opening – due to health & safety concerns (say in high-rise dwellings) and external conditions (air pollution).

- Several respondents highlighted their uncertainty over what can be defined as overheating, believing that humidity and ventilation may need to be considered as well as temperature.
- When asked about tools to assess the risk, respondents mentioned SAP – which was regarded as not really suitable, being a steady state model and a compliance tool not a design tool – and dynamic simulation models. 9 out of 18 respondents said the tools are not adequate.
- A question was posed regarding any remediation measures which had been adopted, and correct use of mechanical ventilation with heat recovery (MVHR) was quoted, as was occupant behaviour and reducing solar gain through the selection of the glazing. Another suggestion was fully understanding the risk at the design stage and taking appropriate measures then.
- Finally when asked if overheating is a significant concern to their organisation or not, 11 out of 17 confirmed that it is.

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4. Behaviour

How does the behaviour of building occupants affect overheating risk?

Introduction

4.1 The literature on overheating, as reviewed elsewhere in this report, is clear that occupant behaviour plays a key role in determining the risk of overheating. It is also clear that there is little empirical evidence about which behavioural factors are most important, or quantification of their effects. This chapter therefore sets out a general framework for consideration of occupant behaviour in relation to overheating of buildings (primarily residential buildings). Some evidence is cited but the more important purpose of the framework is to ensure that the range of possible influences is considered in policy development, and that any needs for further evidence can be defined by reference to the framework.

4.2 The definition of overheating has yet to be agreed in precise terms. The qualitative definition adopted here is “the existence of a thermal environment that is too warm, to the extent that it creates a risk of harm to people as a result of being (or having been) in that environment”. The definition of user behaviour is restricted to the behaviour of the usual building occupants and – where applicable – their carers (as distinct from other visitors) while they are resident (i.e. excluding the behaviour of choosing a suitable home).

4.3 Three distinct aspects of user behaviour are considered:

- behaviour causing (or exacerbating) overheating or the risk of overheating;
- behaviour responding (or not) to actual or anticipated overheating, with the intention of averting or reducing risks;
- overheating having an adverse effect on behaviour (e.g. through increasing accident risk or impairing cognitive performance).

4.4 These are interdependent because, logically, the behaviours that increase overheating should generally be the opposite of those taken to reduce overheating. In practice, behaviour may not always be logical and actions taken with the intention of averting risk may actually increase it. The risk of counter-adaptive behaviour may itself increase as a result overheating causing cognitive impairment.

Causing (or exacerbating) overheating or the risk of overheating

4.5 The question here is whether specific behaviours (in practice – not just in principle) either lead to overheating or increase the risk of overheating. Supplementary to this is the question of whether/how these behaviours differ by factors such as building type/characteristics/orientation, occupant type, location and housing tenure.

4.6 Overheating would result from some combination of:

- the thermal environment (air temperature, radiant temperature, humidity and air velocity/turbulence);
- insulation of the body (by clothing, bedding, etc.);
- metabolic rate, hence physical activity and thermoregulatory capacity, both of which may depend on age and state of health.[3]

4.7 Behaviour increasing the risk of overheating may act on any one of these three factors. The thermal environment is most directly related to the building characteristics while the other factors are more relevant to the question of which occupant types are at greatest risk. In all three cases, inability to detect overheating (e.g. because of a deficient thermoregulatory system or cognitive impairment) would increase the risk. Alternatively, the thermal environment might be seen as the primary risk factor (particularly in the context of DCLG's interests) whereas the other two factors relate to the secondary risk of an adverse thermal environment actually causing harm. Either way, all three need to be considered.

4.8 Depending on the main external source(s) of risk (high air temperature, high radiant temperature, high humidity or low air velocity/turbulence), any or all of the following may increase the risk of overheating because of the thermal environment in a building:

- Closing windows/doors/other ventilation openings in non-air-conditioned spaces. The possible reasons for doing this are many, including:
  - external noise;
  - external air pollution/odours, natural (e.g. pollen) or caused by human activity (e.g. smoke, fumes) – this is particularly relevant to people with respiratory or cardiovascular illness;
  - wind or precipitation (rain, snow, etc.);
  - concerns over security or privacy;
  - concerns over the safety of young children or people with a confused mental state;
  - keeping pets in;
  - keeping animals/insects/pests out;
  - practical/ergonomic difficulties in opening the window (e.g. jammed catches, the window being difficult to reach or there being no way of fixing the window in a narrowly open position);
  - habit or the lack of a specific reason for opening the windows.

- Opening windows in air-conditioned spaces. The risk of this would be greater where (a) the building is designed in such a way that it is dependent on air conditioning to keep cool (e.g. lightweight fabric and large south-facing windows) or (b) the air conditioning is automatically switched off if a window is opened. Reasons for doing this might include:
  - to keep cool (even though it could have the opposite effect);
  - to avoid condensation;
  - for fresh air / to prevent odour;
  - to talk to someone or hear what is happening outside;

[3] Age and health are also relevant to the person's ability to cope with the physiological and mental change brought about by the combination of the three factors leading to overheating.

    - habit / preference for no particular reason.

- Opening windows in other spaces where the building characteristics (e.g. shading, thermal mass) would otherwise keep the building cooler than the outdoor air (after adjusting for the cooling effect of air movement). Possible reasons for doing this are listed at the previous bullet point.
- Opening doors onto common parts of buildings (e.g. corridors, atria) that are warmer than the home (e.g. because of glazing or hot water pipes running through them). This might be done, for example, in the hope of achieving cross-ventilation and/or secure ventilation (or in residential care facilities so that staff can see and maintain care of residents).
- Switching off air conditioning or mechanical ventilation with heat recovery (e.g. because of localised draughts, noise or concern over energy costs).
- Leaving curtains/shutters open at windows with direct incident solar radiation.
- Removal of shading devices.
- Purchase/use of heat-producing appliances (e.g. cookers, washing machines, tumble driers, air conditioners) without external discharge of heat.
- High occupant density.
- Being at home during the hottest part of the day (e.g. because it is "too warm" outside or because of lack of mobility).
- Using warmer parts of the home (e.g. upper floors)[4].
- Sharing a bed.

4.9 Hence there are connections to noise, ventilation, space/layout in the home, security, fear of crime, safety and urban/transport planning – not just the thermal provisions of buildings.

4.10 In many cases, the cost of these actions to decrease the risk of overheating is low or zero but the actual cost will depend on the exact circumstances. Opening a window may appear to be a zero cost action but it may have a cost if, for example, additional security measures have to be taken as a result, insurance premiums are raised or insurance is denied.

4.11 The potential impact of these is not trivial. The CREW study (described in more detail in Appendix 3), for example, alludes to the "window rule" whereby building users should refrain from opening windows when the outside temperature is higher than that indoors. Li Shao (personal communication to DCLG) estimates from the models used in CREW that this single action could result in a 30% reduction of "overheating exposure during a heatwave period". Useful though such modelled outcomes are, they do not cover all the potentially relevant actions and, more importantly, they do not tell us what people actually do in heatwave conditions.

4.12 While the evidence on what people actually do in response to overheating (or the prospect of overheating) is limited, there is some long-established knowledge of domestic ventilation behaviour in general. IEA Annex 8 (Dubrul 1987) was a substantial international investigation of the UK and other temperate climates. It revealed different patterns in different types of room:

[4] The specific risks of sleeping on the top floor are reviewed in Chapters 2 and 3 but this is something that people may feel they have little control over.

- “Lived in” (i.e. living rooms), characterised by low constant window-opening at all times of day. Airings are kept to a minimum and the percentage of windows that are never opened is highest for these rooms.
- “Functional” (e.g. kitchens and bathrooms), characterised by frequent short-term ventilation on an “as needed” basis (e.g. when cooking).
- “Sleeping” rooms, where windows are opened three or four times more than in other rooms (increasing overnight and then a peak in the morning). Variation in behaviour (between households) was also greatest in these rooms.

4.13 The main reasons given for opening windows were related to air quality (removing smells or condensation, “airing the room”) and maintaining contact with the street or garden (e.g. to supervise children or talk to someone outside) rather than controlling temperature. In contrast, windows were closed to control temperature (also to keep out rain, pollution, noise or draughts, and for privacy or security); this has also long been seen in other research (e.g. Dick & Thomas 1951, Brundrett 1977, Davies & Davies 1987, Erhorn 1988) and is more to do with keeping warm than keeping cool. The fact that there are characteristic daily patterns of behaviour also indicates that habitual behaviour is relevant.

4.14 Hence, while we can say that (at least some) people open windows to keep cool at night, at least some of the time it is more difficult to say how many would do this during heatwaves. Logically it should become more common but more evidence is needed on the actual behavioural response and the effects of barriers such as noise and concerns about security.

4.15 IEA Annex 8 found that behaviour did depend on the characteristics of the dwelling itself – windows were less likely to be opened:

- in flats, and to be opened less widely (e.g. because of higher winds on upper floors or privacy issues with windows being close to neighbours’ windows);
- if the dwelling is older, has sliding sash windows or has open fireplaces;
- if the dwelling is more airtight (which is counterintuitive);
- where there is central heating;
- if the windows are side-hung;
- in non-south-facing rooms.

The specific details are of tangential interest because they do not relate to circumstances of overheating; the key point is that there can be connections between design and behaviour.

4.16 Perhaps equally important, having mechanical ventilation made little difference to window opening, again suggesting a key role of habit. It is also likely that the air flow rates and air movement (in the room) achievable with mechanical ventilation alone are typically not sufficient for cooling under extreme high temperature conditions.

4.17 A more focused interview survey of small new homes in England and Scotland (Grey & Raw 1990) largely confirmed the Annex 8 findings except that bedroom windows were more likely to be opened during the day than at night, and security was the most common reason for keeping windows closed. This study was conducted in winter but it is nevertheless interesting that the reason “Because the room is too warm” was given for opening windows by 8.9% of respondents but only 3.8% used other ventilation devices for this reason. Importantly, there was little effect of socioeconomic and demographic variables.

4.18 A follow-up analysis of the same data (Roys et al 1990) looked at regional differences between London, the South of England, the North of England and Scotland. While the findings have to be seen in the context that this was a winter survey, therefore having limited direct relevance to overheating, the reasons given for opening and closing windows did vary with region and this may be a consideration in policy development.

4.19 Moving on to the behaviour that would increase risk through over-insulation (of the body), in a sense the relevant behaviour is obvious: wearing too much clothing or using too much bedding. However, the reasons for such behaviour are likely to be more complex to understand, being related to:

- culture (e.g. a minimum level or style of clothing that is considered socially acceptable for reasons of decency or self-image);
- availability of alternative clothing;
- understanding of what clothing is good for keeping cool;
- physical/mental ability to change;
- sleeping during the day;
- habit or inertia.

4.20 It is therefore difficult to predict how much people as a whole, or particular groups, would make adaptive use of lighter clothing and/or bedding. The effect is, however, potentially large as may be seen by using modelled heat stress, as discussed in Chapter 2.[5] As an example, consider a man weighing 80 kg with a surface area of 2 m^2 under the following conditions:

- wearing underpants, vest, calf-length socks, slippers, long-sleeve shirt and long trousers (a clothing ensemble of about 0.75 Clo);
- doing general housework (cleaning, tidying) for an hour;
- air temperature = radiant temperature = 35°C;
- 50% relative humidity;
- air velocity = 0.1 ms-1.

Changing clothing to just underpants, shorts and T-shirt (Clo ≈ 0.2) would be the equivalent of reducing the air and radiant temperatures to 27°C.

4.21 Similarly, while behaviour that increases metabolic rate may seem obvious (i.e. principally greater physical activity), the reasons behind it are more complex. In particular, there may be positive feedback loops such as warm weather leading to increased activity (e.g. sport or "spring cleaning"); even if the activity is outdoors, the raised metabolic rate may persist indoors. Stress (e.g. about overheating) and illness are also potential risk factors.

4.22 As with clothing, the actual behaviour of people is difficult to predict but the potential impact is large. In the above example, if the man were to sit and read instead of doing housework, this would again be the equivalent of reducing the air and radiant temperatures to 27°C. Combining resting with reduced clothing would be the equivalent of reducing the air and radiant temperatures to 23°C. Using a fan to create

[5] Calculations performed using online algorithm's set up by Richard de Dear, an authority on thermal comfort at the University of Sydney. http://sydney.edu.au/architecture/staff/homepage/richarddedear.shtml

a moderate increase in air movement (velocity = 0.2 ms-1) would have the effect of approximately a further 1°C of cooling.

4.23 Use of antiperspirants reduces the ability of the body to keep cool.

4.24 In addition to the above, there is an overriding consideration of the extent to which people want to avoid overheating. In a culture where cold is seen as bad, warm is good, and sauna is especially healthy, the desire to keep cool may sometimes be lacking. At work, keeping cool is important in order to be able to concentrate and/or maintain physical effort. At home, heat may be seen as a benefit to relaxation and not something to be avoided.

Responding to overheating, with the intention of averting or reducing risks

4.25 The question here is whether specific behaviours (in practice – not just in principle) contribute to the reduction in (or avoidance of) overheating. Supplementary to this is the question of how such behaviours might be encouraged or facilitated.

4.26 As in the case of behaviours leading to overheating, behaviours to mitigate overheating would act through some combination of the thermal environment, insulation of the body and metabolic rate. Depending on the main external source(s) of risk, any or all of the following may reduce the risk of overheating arising from the thermal environment in a building.

- Opening windows/doors/other ventilation openings in non-air-conditioned spaces. This may be done explicitly to reduce air temperature or humidity or to increase air movement, but is likely to be described more as “getting fresh air”. It could also be motivated by other factors such as removing odours or simply habit.
- Closing windows in air-conditioned spaces, especially where (a) the building is designed in such a way that it is dependent on air conditioning to keep cool or (b) the air conditioning is automatically switched off if a window is opened.
- Closing windows in other spaces where the building characteristics keep the building cooler than the outdoor air (after adjusting for the cooling effect of air movement).
- Switching on air conditioning or mechanical ventilation.
- Fitting/closing curtains/shutters at windows with direct incident solar radiation, and avoiding exposure to direct solar radiation.
- Creating air movement with a fan.[6]
- Switching off heat-producing appliances (e.g. cookers, washing machines, tumble driers, air conditioners) without external discharge of extracted heat.
- Using cooler parts of the home (e.g. lower floors on the north side of the building).
- Leaving the home to spend time in a cooler indoor or outdoor place (e.g. on hot days or during the hottest part of the day). This could bring major health and comfort benefits but clearly depends on having the physical ability to leave the home and there being a suitable space available within reasonably easy reach.[7] There may also be alternative health consequences if the place chosen for respite is a pub.

[6] Except at extreme high temperatures, where air movement serves only to create a “fan oven” effect.

[7] For example, in the Chicago heatwave of 1995 (Semenza 1996), people who lived in apartments without air conditioning had a lower risk of death if they had access to an air-conditioned lobby.

4.27 Hence there are connections to ventilation, local facilities and urban planning – not just the thermal provisions of buildings. In particular, the ability of users to respond to raised temperatures will depend on the actual level of user control provided and the extent to which the users understand and are physically able to operate the controls. Controls are generally less likely to benefit users if they are unnecessarily complex or require good eyesight and manual dexterity to operate.

4.28 Some behaviours, such as opening windows in the evening, can be used retrospectively (i.e. after it has become too hot) while others would require anticipation to prevent overheating (e.g. drawing curtains before leaving for work in the morning).

4.29 Removing clothing/bedding to keep cool is an obvious strategy and this may be encouraged – in some social groups – as much by style as by the need to avoid overheating. Cold drinks and social acceptance of sweating can also be effective. Cool showers, or just application of cool sprays or cloths can also assist cooling.

4.30 Keeping still and avoiding stress will tend to reduce metabolic rate. Antipyretic medicines could also be used but this is not a medically recommended strategy.

Overheating having an adverse effect on behaviour

4.31 There is perhaps a fine distinction between harm caused by overheating and behavioural mediating factors for harm. For example, consider this possible sequence involving accidental injury as a result of overheating.[8]

Heat → Mental/physical fatigue → Fall on stairs → Fractured femur
→ Immobility → Pneumonia → Death

4.32 Which steps in the chain should be seen as behaviours (e.g. falling, being immobile) and which as harms? Rather than debate terminology, the important thing is to consider the whole causal chain. Other examples of possible behavioural mediators of health effects might be eating less, drinking more alcohol or failing to take medicines. Similarly, while loss of sleep may be considered a harm in its own right, it might also have behavioural consequences within the home (e.g. domestic accidents) and outside the home (e.g. accidents at work or on the road). Sleep loss, and its consequences, may be worse for people who need to sleep during the day (e.g. night workers, people who are ill, babies and their carers).

4.33 As noted earlier, some behavioural effects may themselves impair a person's ability or motivation to engage in positively adaptive behaviour.

4.34 It is important to understand and model the behaviour of occupants in buildings and how this behaviour impacts energy use and comfort. Although health, rather than comfort, is the key concern in this review, behaviour is likely to be driven by comfort and the indoor environmental consequences of that behaviour can affect health.

4.35 It is similarly important to understand how a building's design affects occupant comfort, therefore occupant behaviour and ultimately the energy used in the operation

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[8] Overheating increasing accident risk is a well established mechanism – see Koppe *et al* (2004). While the Building Regulations are clearly concerned with accidental injury, this has generally not been explored in relation to indoor temperature.

of the building and overheating risk. In the work by Tuohy et al (2007), a behavioural algorithm for window opening developed from field survey data has been implemented in a dynamic simulation tool. The algorithm is in alignment with the proposed CEN standard for adaptive thermal comfort. The algorithm is first compared to the field study data then used to illustrate the impact of adaptive behaviour on summer indoor temperatures and heating energy. The simulation model is also used to illustrate the sensitivity of the occupant adaptive behaviour to building design parameters such as solar shading and thermal mass and the resulting impact on energy use and comfort. The results are compared to those from other approaches to model window opening behaviour. The adaptive algorithm is shown to provide insights not available using non adaptive simulation methods and can assist in achieving more comfortable and lower energy buildings. The key point is that the study shows an alternative way of modelling although the adaptive algorithm effectively treats behaviour as a "black box" and models the overall effect of the box, not its contents.

4.36 In conclusion, the design of a building and its services can determine what adaptive behaviours are possible and influence the occupants' selection from possible behaviours. Behaviour is therefore not a separate issue from building design but a consequence of that design. While there are many other influences on behaviour (e.g. personal knowledge and preferences, the social context and economic resources), building design is important.

4.37 Two distinct points follow from this:

- Buildings should be designed with knowledge of how people actually behave (as distinct from how the designer would like them to behave) so as to promote adaptive behaviour that mitigates the impact of high outdoor temperatures.
- In similar fashion, the urban environment (e.g., the availability of cool outdoor or indoor spaces) should also be planned with a view to promoting adaptive behaviour.

These provisions would be persistent in their beneficial effects whereas providing direct social support to households is likely to be an ongoing requirement.

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5. Definitions of overheating and current policy instruments

Definitions of Overheating for Vulnerable Populations

5.1 For vulnerable populations, in general there are three types of definitions of overheating that are relevant. These cover overheating definitions that are applicable:

a) during short term extreme heatwaves, focusing on acute health issues
b) on a seasonal basis, focusing on thermal comfort
c) generic definitions that apply to all population groups, principally the working population.

These are reported below.

Health-related definitions

5.2 The Heatwave Plan for England (NHS, 2011) defines forecast regional external day and night temperature thresholds that trigger four escalating action levels. In connection with this, a 'Heat-Health Watch' system operates in England from 1st June to 15th September each year. The Plan gives the following explanation of the thresholds:

> *"Although excess seasonal deaths start to occur at approximately 25°C [outdoors], for practical reasons the health heatwave alert system is based upon temperature thresholds where the odds ratio is above 1.15 – 1.2 (a 15 – 20% increased risk). The different trigger temperatures are summarised [below], with regional variations due to the relative adaptation to heat. However, a significant proportion of excess summer deaths occur before the health heatwave alert is triggered, which emphasises the importance of long-term planning actions by local authorities and the health sector."*

Region	Day	Night
London	32ºC	18ºC
South East	31ºC	16ºC
South West	30ºC	15ºC
Eastern	30ºC	15ºC
West Midlands	30ºC	15ºC
East Midlands	30ºC	15ºC
North West	30ºC	15ºC
Yorkshire and Humber	29ºC	15ºC
North East	28ºC	15ºC

5.3 NHS heatwave guidance for care home managers and staff (NHS, 2010b) advises:

"Create cool rooms or cool areas. High risk groups that are vulnerable to the effects of heat are physiologically unable to cool themselves efficiently once temperatures rise above 26ºC. Therefore, every care, nursing and residential home should be able to provide a room or area that maintains a temperature at 26ºC or below."

5.4 This guidance forms part of the implementation of the national Heatwave Plan for England. (See Appendix 1 also.)

Definitions related to thermal comfort

5.5 This section principally considers definitions usually applied at design stage.

5.6 Concerning perceived thermal comfort, 'predicted mean vote' (PMV) and 'percentage people dissatisfied' (PPD) were originally defined by Fanger (1970). More recent development include the use of 'adaptive' thermal comfort, defined in BS EN 15251 (2007) and ASHRAE Standard 55 (ANSI-ASHRAE, 2004). Adaptive thermal comfort theory assumes that given a long enough period of time (typically days or weeks), people will adjust their own clothing levels, behaviour and environment to suit external thermal conditions and therefore they are able to tolerate a wider range of conditions than would be suggested by, for example, Fanger's original work. A number of other temperature metrics relevant to overheating have also been defined that take into account not only air temperature but also humidity or air speed (see for instance, ASHRAE, 2009).

5.7 SAP Appendix P 'Assessment of Internal Temperature in Summer' (DECC, 2009) is applicable for new dwellings. This is a self-contained simplified calculation of the whole dwelling average peak internal temperature for a proposed design. It takes into account regional variations in climate during summer months. It is stated (in DECC, 2009) that '[the Appendix P] procedure is not integral to SAP and does not affect the calculated SAP rating or CO2 emissions'. SAP Appendix P also refers users to an Energy Saving Trust (EST) guide CE 129 'Reducing overheating – a designer's guide' (EEBPH, 2005, after Orme and Palmer 2003), which in turn is based on the use of overheating degree-hours above 27ºC.

5.8 Software used for SAP assessments must be tested and approved (BRE, 2011b). At least one of the approved packages widely used by industry, 'NHER Plan Assessor', contains an implementation of SAP Appendix P. Furthermore, this particular software package can include results calculated according to the Appendix P procedure as part of the overall SAP results. Moreover, if a SAP assessment does not include such an overheating calculation or if one is carried out and does not meet the Appendix P overheating criterion, it is understood the overall SAP rating presented by this software is erroneously shown as 'fail'. From this it is inferred that for new developments in England a significant number of SAP Appendix P results are being presented to Building Control bodies. It is, however, uncertain whether design teams are acting on such results or whether they are being treated as de facto submissions for Building Regulations approval.

5.9 For dwellings, CIBSE Guide A (2006) advises the following criteria for overheating should be met, calculated based on the CIBSE Design Summer Years:

Living areas - 1% annual occupied hours over operative temperature of 28ºC.

Bedrooms - 1% annual occupied hours over operative temperature of 26ºC.

5.10 As well as the above overheating criteria, CIBSE Guide A also provides general summer indoor comfort temperatures for non-air conditioned dwellings. These are that living areas should be at an operative temperature of 25ºC and bedrooms at an operative temperature 23ºC, noting that sleep may be impaired above an operative temperature of 24ºC. It is necessary to use dynamic thermal simulation software to assess a design against the CIBSE Guide A criteria.

5.11 The CIBSE Guide A standards are not mandatory for housing. They are typically only applied by developers when they are required for new housing by client contractual specifications.

5.12 Care Quality Commission guidance for service users (CQC, 2011a) mentions they should be able to control temperature, but does not set limits. For the design of new healthcare buildings, Health Technical Memorandum 03-01 (DH, 2007) (HTM03-01) states:

> *"Calculations and thermal modelling should be undertaken to ensure that, during the summertime, internal temperatures in patient areas do not exceed 28ºC (dry bulb) for more than 50 hours per year."*

5.13 No weather data are specified as a basis for the calculations in HTM 03-01. It is necessary to use dynamic thermal simulation software to assess a design against this criterion. The requirements of HTM 03-01 are believed to be widely fulfilled at design stage for new healthcare buildings. It is understood that prior to its introduction, previous HTM guidance did not necessarily ensure satisfactory outcomes with a number of new hospital buildings experiencing overheating problems. Also, beyond forming the client's requirements for new design, the Health Technical Memoranda series have gained legal status through case law.

5.14 Although it is unknown how widely they have been adopted, the Housing Learning & Improvement Network has published Design principles for Extra Care developments (HLIN, 2008), which include the following:

> *"Passive design features may include orientation to maximise solar gain and daylighting, winter gardens to warm air before it enters the building, cooling and ventilation of communal areas though natural stack effect and exposed thermal mass, and through openable windows in individual dwellings. The menu of energy efficiency measures that should be considered is likely to include high levels of insulation and window specification to achieve low U-values, low-energy light fittings and efficient heating and ventilation systems. As the effects of climate change are felt now and in the future, avoiding overheating is becoming a critical issue."*

5.15 The BREEAM Thermal Comfort issue, Hea 03, (BRE, 2011a) for new non-domestic buildings includes the following partial requirement towards achieving the Hea 03 credit:

> *"The building complies with any requirement, in terms of 'time out of range' (TOR) metric, from the appropriate industry standard (as above) OR where there is no appropriate industry standard available or TOR recommendation made, the*

building services engineer confirms that the TOR is acceptable for the purpose and function of the building."

5.16 It is not compulsory to achieve this credit, so not all schemes assessed under BREEAM will be designed to achieve it. Moreover, within the same BREEAM issue, specific 'time out of range' metrics are identified for certain building types:

> *"Pre-schools, schools and sixth form colleges - Internal summer temperatures are significantly better than the recommendations of Building Bulletin 101 [DfE, 2006] e.g. there are fewer than 60 hours a year where temperatures rise above 28°C.*
>
> *Health buildings - Thermal comfort levels in patient and clinical areas are in accordance with the requirements set out in Health Technical Memorandum 03-01, Appendix 2. In particular, internal summer temperatures do not exceed 28°C dry bulb for more than 50 hours per year as defined in Health Technical Memorandum 03-01. Other occupied spaces are in accordance with CIBSE Guide A Environmental Design [CIBSE, 2006]; as identified in point 2 of the first credit above."*

5.17 Concerning overheating, the defunct English Partnerships Quality Standards (EP, 2007) stated:

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

The Homes and Communities Agency are understood to have used the English Partnerships' Quality Standards for legacy projects inherited from them.

5.18 A certification criterion set by the International Passive House Association (iPHA, 2011) requires that the indoor temperature should exceed 25°C for no more than 10% of the hours each year. This should be demonstrated at design stage using the Passive House Planning Package software.

5.19 Thermal comfort design standards in terms of limits on calculated air temperature exceedances for new school buildings are presented in Building Bulletin 101 (DfE, 2006) and may be applied to early years or nursery settings. To assess whether a design meets the stated criteria, it is necessary to use either dynamic thermal simulation or the simplified tool ClassCool may be used for classrooms. Building Bulletin 101 advises that CIBSE Test Reference Years are used for overheating calculations.

Other definitions

5.20 This section principally considers definitions usually first applied at design stage and then later checked during building operation.

5.21 A significant proportion of the population vulnerable to overheating live in care homes or are hospitalised, places which are also workplaces for their carers hence workplace requirements have also been noted.

5.22 The Workplace (Health, Safety and Welfare) Regulations 1992 as Amended, HSE guidance for managers has been provided (HSE, 2007):

> *"Workplaces need to be adequately ventilated. Fresh, clean air should be drawn from a source outside the workplace, uncontaminated by discharges from flues, chimneys or other process outlets, and be circulated through the workrooms.*
>
> *Ventilation should also remove and dilute warm, humid air and provide air movement which gives a sense of freshness without causing a draught. If the workplace contains process or heating equipment or other sources of dust, fumes or vapours, more fresh air will be needed to provide adequate ventilation.*
>
> *Windows or other openings may provide sufficient ventilation but, where necessary, mechanical ventilation systems should be provided and regularly maintained."*

5.23 HSE give the following guidance on estimating and calculating thermal comfort (HSE, 2011):

> *"A simple way of estimating the level of thermal comfort in your workplace is to ask the workers or their workplace representatives (such as Unions or employee associations), if the percentage of workers dissatisfied with the thermal environment is above a certain level, you will need to take action. See the five steps to risk assessment for more details for more details.*
> *…*
> *Calculating thermal comfort*
> *In most instances, the guidance given on this website will be sufficient to enable you to improve thermal comfort in your workplace. However, you may wish to measure the factors contributing to thermal comfort more accurately. The predicted mean vote (PMV) and percentage people dissatisfied (PPD) index and use of BS EN ISO 7730 and BS EN ISO 10551 British standards are recommended.*
>
> *The PMV / PPD index predicts the thermal comfort of people working in a given environment. It uses the six basic factors, and has become the most widely used index in recent years. It has been adopted as a British and European and International standard."*

5.24 DCLG have a published expectation for dwelling temperatures, (DCLG 2008):

> *"It is recommended that indoor operative temperatures (taken as a mean of air and radiant temperatures) should not exceed 26ºC when RH is 30% or 24ºC at RH 60%."*

It is unclear if this has been widely used.

Conclusion

5.25 It is likely that the CIBSE Guide A definition is the mostly widely used in terms of peak temperatures and the avoidance of overheating. CIBSE also provides general summer indoor comfort temperatures for non-air conditioned dwellings. Although SAP is a domestic compliance tool rather than a design tool, it includes a means of demonstrating, in a simplistic manner, whether the Building Regulations overheating criteria is met or not. SAP Appendix P provides a more detailed means of assessment. The use of SAP is referred to by some of the stakeholders who were interviewed – See Section 8.

Current policy instruments and potential options

5.26 This section considers current policy instruments to address overheating in buildings, what others have said about current policy instruments, and international experiences. It is divided into:

- Current policy instruments
  - Non-behavioural building-related measures
  - Non-behavioural community scale measures
  - Measures during heat waves
  - Climate change impacts
- What others have said about current policy instruments
- International experiences.

Current policy landscape instruments - buildings related measures

5.27 Recent DCLG statistics show that in the year to the end of September 2011 construction has started on 96,070 new homes in England, of which 75,600 are private sector. Many of these are likely to be built according to the previous 2006 edition of Approved Document L1A (ODPM, 2006), rather than the most recent 2010 edition (DCLG, 2010a). During the same period, construction on 14,620 new homes has started in London, of which 8,980 are private sector.

5.28 Part L (Conservation of Heat and Power) of the Building Regulations 2010 does not require overheating to be limited, but, for new dwellings the guidance in Approved Document L1A (DCLG, 2010a), forming statutory guidance to the Building Regulations 2010, states reasonable provision would be to assess overheating according to SAP Appendix P (DECC, 2009):

> *"SAP 2009 Appendix P contains a procedure enabling designers to check whether solar gains are excessive. Reasonable provision would be achieved if the SAP assessment indicates that the dwelling will not have a high risk of high internal temperatures. This assessment should be done regardless of whether or not the dwelling has mechanical cooling. If the dwelling has mechanical cooling, the assessment should be based on the design without the cooling system operating, but with an appropriate assumption about effective air change rate through openable windows.*
> *Designers may wish to go beyond the requirements in the current Building Regulations to consider the impacts of future global warming on the risks of higher internal temperatures occurring more often. CIBSE TM 36 Climate*

Change and the Indoor Environment [CIBSE, 2005] gives guidance on this issue. "

5.29 SAP 2009 (DECC, 2009) also includes a separate assessment of cooling energy demand, which is taken into account in the overall rating based on regional climate data. This was not included in earlier editions of SAP.

5.30 For new buildings other than dwellings, Approved Document L2A (DCLG, 2010c) does not give a requirement except in terms of limiting solar gains and it indicates the client and design teams should agree what the target should be:

> *"Criterion 3 - Limiting the Effects of Solar Gains in Summer*
> *…*
> *4.43 If the [limiting solar gains] criterion set out below is satisfied in the context of a naturally ventilated building, this is NOT evidence that the internal environment of the building will be satisfactory, since many factors that are not covered by the compliance assessment procedure will have a bearing on the incidence of overheating (incidental gains, thermal capacity, ventilation provisions, etc.)*
>
> *Therefore the developer should work with the design team to specify what constitutes an acceptable indoor environment in the particular case, and carry out the necessary design solutions that meet the agreed brief. Some ways of assessing overheating risk are given in CIBSE TM37 and, for education buildings, in BB101."*

5.31 The Housing Health and Safety Rating System (England) Regulations 2005 (enacted by the Housing Act 2004) identify excess heat as a hazard, but no quantitative threshold is stated. Operating guidance (DCLG, 2006a) and guidance for landlords (DCLG, 2006b) have been produced to support these regulations. The operating guidance does however advise on inspections and assessment of hazards.

5.32 The Lifetime Homes Design Criterion 15 (LTH, 2010) states:

> "*Glazing and window handle heights: Windows in the principal living space (typically the living room), should allow people to see out when seated. In addition, at least one opening light in each habitable room should be approachable and usable by a wide range of people – including those with restricted movement and reach.*"

5.33 Under the 2011-15 Affordable Housing Programme, the Homes and Communities Agency requires that new social housing meets at least Code for Sustainable Homes level 3 as part of their design standards (HC, 2007). Also, the 'New Interim Funding Design and Sustainability Standards for London' (HCA, 2011) states:

> "*Development proposals must demonstrate how the design of dwellings will avoid overheating during summer months without reliance on energy intensive mechanical cooling systems."* It continues*, "Deemed compliance with this criterion will be met by a commitment to achieving Code Level 4 status."*

5.34 However, the Code for Sustainable Homes (DCLG, 2010f) does not presently include overheating as a design issue to be considered. It is also noted the English Partnerships' Quality Standards (EP, 2007) were used by the Homes and

Communities Agency for legacy projects inherited from English Partnerships. These required the CIBSE overheating criteria for housing to be met by modelling at design stage (CIBSE, 2006).

5.35 The Interim London Housing Design Guide (Design for London, 2010) states:

> *"5.5 Daylight and Sunlight. Sunlight can have a significant impact on thermal comfort and energy consumption. In winter it can make an important contribution to heating, but excessive solar gain can cause discomfort in summer. In general the best control of sunlight is achieved through the careful positioning and sizing of windows according to the function of spaces and their orientation. Fixed projections above windows, including balconies, can be designed to screen high summer sun while admitting low winter sun and deciduous trees also provide useful seasonal shading.*
>
> *6.3 Overheating. In accordance with the London Plan Sustainable Design and Construction SPG this guide promotes dual aspect dwellings, which help to make natural ventilation more effective in hot weather (see section 5.2). Designers should also consider controlling solar gain in summer by using fixed or adjustable shading devices and planting deciduous trees to achieve shading in the summer.*
>
> *6.3.1 Standards. Development proposals should demonstrate how the design of dwellings will avoid overheating during summer months without reliance on energy intensive mechanical cooling systems."*

5.36 The Greater London Authority (GLA) has indicated that, "All housing built on London Development Agency land is expected to meet these [London Housing Design Guide] standards. The standards will also start to be applied to housing schemes applying for funding from the London Homes and Communities Agency from April 2011." The London Homes and Communities Agency became part of the GLA IN April 2012.

5.37 DfL (2010) also advises "The final guide will be issued following the finalisation of the Homes and Communities Agency's (HCA) consultation on its Proposed Core Housing Design and Sustainability Standards and the draft replacement London Plan Examination in Public, incorporating any necessary changes arising from these processes to ensure all design guidance is in alignment."

5.38 The Heatwave Plan for England (NHS, 2011) includes long term planning summary guidance covering the indoor environment, including:

- *Reflective paint*
- *Loft and wall insulation*
- *Reduce internal energy and heat*

Conclusions about thermal comfort and current policy instruments for buildings

5.39 SAP Appendix P provides a simplified means of overheating assessment for dwellings. (The use of SAP Appendix P was mentioned by some of the stakeholders who were interviewed – see Section 8.) Further, reference is made to it in Building

Regulations Approved Document L1A. In a significant number of cases it is likely that Appendix P results are being presented to Building Control bodies alongside Building Regulations submissions for new dwellings, due to possibly incorrect interpretation of its legal status.

5.40 Also for dwellings, it is likely that the CIBSE Guide A criteria have been reasonably widely used in the design of dwellings built in accordance with English Partnerships Quality Standards.

5.41 For new, publicly funded, healthcare buildings, pre-schools and schools, most will have been designed according to Health Technical Memorandum 03-01 or Building Bulletin 101 criteria as appropriate. Of these, some will have been designed to substantially exceed the minimum standards in order to achieve BREEAM Thermal Comfort credits.

Current policy instruments - community scale measures

5.42 The National Planning Policy Framework (DCLG, 2012) states that:

Local planning authorities should adopt proactive strategies to mitigate and adapt to climate change, taking full account of flood risk, coastal change and water supply and demand considerations.

5.43 The Framework also states:

Local Plans should take account of climate change over the longer term, including factors such as flood risk, coastal change, water supply and changes to biodiversity and landscape. New development should be planned to avoid increased vulnerability to the range of impacts arising from climate change. When new development is brought forward in areas which are vulnerable, care should be taken to ensure that risks can be managed through suitable adaptation measures, including through the planning of green infrastructure.

5.44 The Heatwave Plan for England (NHS, 2011) includes long term planning summary guidance covering the outdoor environment and identifies the following as desirable:

Increase trees and green spaces
External shading
Water features

5.45 Draft Supplementary Planning Guidance for The London Plan proposes an 'All London Green Grid' (GLA (2011a). Within this guidance, the role played in overheating management by green infrastructure is recognised. It proposes that the following should be taken into account in making planning decisions:

"Enhancements to London's green infrastructure should be sought from development and where a proposal falls within a regional or metropolitan park deficiency area (broadly corresponding to the areas identified as 'regional park opportunities' on Map 2.8), it should contribute to addressing this need. Development Proposals should: 1. incorporate appropriate elements of green

infrastructure that are integrated into the wider network. 2. encourage the linkage of green infrastructure, including the Blue Ribbon Network, to the wider public realm to improve accessibility for all and development new links, utilising green chains, street trees, and other components of urban greening."

Current policy instruments - measures during heatwaves

5.46 The Essential Standards of Quality and Safety (CQC, 2010) forms guidance relating to The Health and Social Care Act 2008 (Regulated Activities) Regulations 2010. For service users, 'What Standards to Expect from the Regulation of your Care Home' (CQC, 2011a) provides an overview of minimum standards: Users should be able to control temperature, but the guidance does not set limits.

5.47 The Heatwave Plan for England was first published July 2004 and most recently updated in May 2011 (NHS, 2011). Its purpose is to enhance resilience in the event of a heatwave and is a key part of overall emergency planning. In England, local authorities, the emergency services, certain health services, the Environment Agency and the Secretary of State are classed as 'Category 1' responders under The Civil Contingencies Act 2004 and have certain responsibilities identified under The Civil Contingencies Act 2004 (Contingency Planning) Regulations 2005. They would therefore be involved in responding to heatwave-related emergencies.

5.48 In support of the Heatwave Plan, a number of guidance documents have been produced targeted at key groups. These are:

- 'A Guide to Looking After Yourself and Others During Hot Weather' (NHS, 2004),
- 'Supporting Vulnerable People Before and During a Heatwave: Advice for Health and Social Care Professionals' (NHS, 2010a), and
- 'Supporting Vulnerable People Before and During a Heatwave - Advice for Care Home Managers and Staff' (NHS, 2010b).

Current policy instruments - climate change impacts

5.49 As required under the Climate Change Act 2008, a strategy for climate change adaptation for London (GLA 2011b) has now been published:

"The Mayor will work with partners to reduce and manage the impact of hot weather on Londoners through:
- *mapping overheating risk to prioritise actions to target the worst affected areas and most vulnerable people*
- *managing rising temperatures by increasing the amount of green space and vegetation in the city*
- *reducing the risk of overheating and the need for mechanical cooling in new and existing development and infrastructure*
- *ensuring London has a robust heatwave plan."*

5.50 A range of building energy improvements will be within the scope of the Green Deal funding mechanism, being created under the Energy Act 2011 for dwellings and other building types. The following energy improvements that may also impact on summer thermal comfort have been outlined in the list of Green Deal qualifying measures (DECC, 2012):

- *air source heat pumps* [can be designed to also be used in cooling mode]
- *cavity wall insulation* [reduces heat losses or gains]
- *draught proofing* [reduces air infiltration]
- *energy efficient glazing* [reduces heat losses or gains]
- *external wall insulation* [reduces heat losses or gains and also improves performance of thermal mass in storing 'coolth']
- *ground source heat pumps* [can be designed to also be used in cooling mode]
- *high thermal performance external doors* [reduce heat losses or gains]
- *hot water cylinder insulation* [reduces casual gains]
- *internal wall insulation* [reduces heat losses or gains, but also isolates otherwise useable thermal mass]
- *lighting systems, fittings and controls* [efficient systems and good control can reduce casual gains]
- *loft or rafter insulation* [reduces heat losses or gains]
- *mechanical ventilation* with heat recovery [provides a certain level of secure ventilation, but requires summer bypass]
- *roof insulation* [reduces heat losses or gains]
- *room in roof insulation* [reduces heat losses or gains]
- *under-floor insulation* [reduces heat losses or gains]
- *solar blinds, shutters and shading devices* [reduces heat gains]
- *pipe-work insulation* [reduces heat losses or gains]
- *heating ventilation and air-conditioning controls* (including zoning controls) [provide cooling]

What others have said about current policy instruments

5.51 The Housing our Ageing Population: Panel for Innovation (HCA, 2009) have recommended that "homes are energy-efficient and well insulated, but also well ventilated and able to avoid overheating by, for example, passive solar design, the use of native deciduous planting supplemented by external blinds or shutters, easily operated awnings over balconies, green roofs and cooling chimneys".

5.52 Johnson and Bickler (2007) have made a series of recommendations based on an evaluation of the Heatwave Plan for England including suggesting improvements to measures and thresholds, the ‘Heat-Health Watch’ Levels, the care of vulnerable people, and communications. They have also made recommendations for further research concerning the agreement of baselines, and improvement of mortality data and the wider evidence base. In connection with the Heatwave Plan, Abrahamson and Raine (2009) have examined health and social care responses to it. Opinions given by health-care professionals, social services professionals and voluntary workers led the authors to conclude that most participants in the study did not consider heatwaves as a high priority and highlighted the problems associated with identifying and prioritising vulnerable individuals. Additionally, through a number of case studies of climate change adaptation in south-west England and with a major emphasis on heatwaves, Benzie et al (2011) have made recommendations as follows:

- *"develop a broader 'heat strategy' for the UK that builds longer term resilience;*
- *improve the forward looking preparedness of the Heatwave Plan;*
- *share information in order to identify vulnerable people;*
- *evaluate how the Heatwave Plan is monitored at local level;*
- *consider the need for additional resources."*

5.53 Care Quality Commission inspections on nutrition in hospitals, including intake of drinks and hydration, have also identified a significant number of areas for concern (CQC, 2011b):

"Of the 100 checks we made against Outcome 5 [Meeting nutritional needs]:

- *51 hospitals were fully compliant.*
- *32 were compliant but needed to make improvements.*
- *15 were not compliant and had to take action to become compliant.*
- *Two were a cause of major concern and had to take urgent action."*

5.54 In a climate change mitigation study, the 40% House project (Boardman et al, 2005) has looked at how UK housing can achieve a 60% reduction in energy related carbon dioxide emissions by 2050. This has included assumptions about the impact of an increased uptake of mechanical cooling:

> *"The 40% House scenario does not include any air conditioning but allows for some cooling, for example in hard-to-cool dwellings (mostly high density, highly-glazed flats). This might be through absorption cooling from a district chilling network (using the heat from CHP), or heat pumps circulating cold water (or cold air) during the summer."*

5.55 This is a possible technical outcome of a policy of achieving a 60% reduction target in energy-related CO2 emissions by 2050.

5.56 The Zero Carbon Hub has considered likely overheating in housing under future climate change projections (ZCH, 2010). Their modelling included dynamic thermal modelling, SAP Appendix P (DECC, 2009) and the Passivhaus Planning Package (iPHA, 2011) to test a range of dwelling types against High and Low Emissions scenarios for climate change in the 2020s, 2050s and 2080s. Regarding SAP Appendix P they commented:

> *"We also know that the current method of compliance in SAP, Appendix P, substantially depends upon night cooling, but can hardly be described as robust – simply leaving windows open '50% of the time' appears to cure most overheating problems, but is a questionable assumption in the light of perceived home security considerations and variables of dwelling occupancy."*

5.57 From their study, the Zero Carbon Hub concluded:

> *"Immediate action is required to gain a better understanding of overheating in dwellings; a point of concern for current and more recently built homes, not just future designs. A suitable model for determining overheating of new homes*

needs to be validated or identified and a combination of desk research and practical testing is necessary. Such is the dearth of test data from UK homes that activity this summer is likely to be required. This will enable the opportunity to develop an improved simplified tool for assessing overheating; a critical step which determines the direction of the subsequent development of the carbon compliance tool."

5.58 The Adaptation Sub Committee of the UK Climate Change Committee (CCC, ASC 2011) has recently examined the impact of climate change on overheating in housing in South East England. Their analysis has established there would be a net benefit to society of using certain passive measures rather than air conditioning:

> *"We have identified a number of low-regret adaptation measures to reduce overheating in buildings, improve comfort levels for occupants and avoid the need to invest in alternative cooling measures, such as air-conditioning in the South East. They include energy-efficient appliances to reduce waste heat, and increasing shading through use of curtains and tinted window film. These measures are cost-effective when installed at both the new-build stage and as part of a retrofit. In addition improving roof albedo (white roofs) and installing shutters are also cost-effective for new builds.*
> *Our analysis suggests that if air-conditioning was used instead of these low-regret passive cooling measures in both existing and new homes, it would cost society around £2 billion and £400 million respectively, over 15 years given projected future electricity prices."*

5.59 Further, in a study of land use change over the last ten years in several local authorities, the Adaptation Sub-Committee concluded (CCC, 2011), "The area of hard surfacing increased in five of the six urban authorities studied, primarily at the expense of urban green space, which declined in all six authorities. This is likely to exacerbate surface water flooding and the urban heat island effect."

International experiences of overheating

5.60 By means of a case-control study of excess heat related mortality of elderly people in France during the August 2003 heatwave, Vandentorren et al (2006) have identified the most significant risk factors. The important causative factors of excessive mortality they found were:

- *"chronic diseases,*
- *lack of mobility,*
- *lack of thermal insulation,*
- *sleeping on the top floor, and*
- *the temperature around the building."*

5.61 Cooling techniques were determined to be protective factors. On the basis of the study findings, they proposed a range of preventative actions and measures:

- *"Prevention messages should be proposed before heat[wave] periods to [the] elderly suffering from chronic disease and lacking mobility.*

- *Prevention message should suggest [the following] behaviour changes: wearing light clothes, drinking more, increasing showers, opening windows at night, and avoiding living in attic flats.*
- *Environmental measures should advocate for improvement of thermal insulation in old buildings and design green spaces around buildings."*

5.62 Fouillet et al (2008) have conducted a follow up study of the impact of the National Heat Wave Plan for France that was put into effect after the August 2003 heatwave. The preventative measures and new alert system included in the Plan were intended to modify the behaviour of people, health institutions and health authorities with regard to high summer temperatures. They concluded the July 2006 heatwave resulted in a substantial reduction in excess mortality in comparison with predictions made based on long term historical trends.

5.63 WHO (2004) included a survey of heat health warning systems in operation in Europe. The EuroHEAT project (WHO, 2009) has quantified heat-related health effects in Europe and has proposed options for improving health system preparedness and responses. The project identified the following eight core elements of heat–health action plans:

- *"agreement on a lead body (to coordinate a multi-purpose collaborative mechanism between bodies and institutions and to direct the response if an emergency occurs);*
- *accurate and timely alert systems (heat–health warning systems trigger warnings, determine the threshold for action and communicate the risks);*
- *a heat-related health information plan (about what is communicated, to whom and when);*
- *a reduction in indoor heat exposure (medium- and short-term strategies) (advice on how to keep indoor temperatures low during heat episodes);*
- *long-term urban planning (to address building design and energy and transport policies that will ultimately reduce heat exposure);*
- *particular care for vulnerable population groups;*
- *preparedness of the health and social care system (staff training and planning, appropriate health care and the physical environment);*
- *real-time surveillance and evaluation."*

5.64 A national heatwave early warning system (EWS) does not exist for Australia, but certain cities and states have implemented them, including Victoria (SV-DH, 2011), and Perth (GWA-DH, 2010). The EWS in Victoria is based on 'heat health temperature' thresholds for various districts, which in absolute terms are significantly higher than the analogous thresholds for England. However, the overall heatwave framework is qualitatively similar to that in place in England. It is also noted that during heatwaves, otherwise healthy people could become vulnerable to heat-related health issues, for example workers in industrial or warehouse buildings that are not mechanically cooled. Moreover, Perth defines 'non-compensated heatwaves' as those during which the electricity grid fails (and hence electrically driven mechanical ventilation or cooling will not operate).

5.65 In Canada, the Toronto Hot Weather Response Plan (CT, 2011) was introduced in 1999. Annual Toronto Board of Health reports are published concerning the implementation and effectiveness of the Plan. Information about the locations of air conditioned public places is published and during extreme heat alerts, seven dedicated 'cooling centres' are opened. City wide 'heat vulnerability maps' for Toronto are also published (TCHPP, 2011).

5.66 A study by Weisskopf et al (2002) examined whether differences in excess heat alone accounted for the reduction that occurred in heatwave mortality and paramedic emergency medical service (EMS) runs between two heatwaves in Milwaukee, Wisconsin, USA in 1995 and 1999 respectively. It concluded that the reduction was not attributable to this alone and proposed that changes in public health preparedness and response may also have contributed.

5.67 See Appendix 1 for a table outlining current legalisation and statutory guidance relevant to overheating in buildings for vulnerable populations.

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6. Current research activities

Introduction

6.1 There are a number of relevant research projects and activities underway that are producing new information, but this is not all yet published. The largest group of studies is funded by the EPSRC (Engineering and Physical Sciences Research Council) through the ARCC group of projects (Adaptation and Resilience to a Changing Climate). These are introduced first, followed by a number of other relevant studies.

ACN

6.2 The ARCC Coordination Network (ACN) brings together researchers and stakeholders working on 18 projects to help explore how the infrastructure of the UK can best adapt to a changing climate. A brief summary of ARCC project work relating to overheating in UK dwellings is provided in this document. CREW, LUCID and SNACC modelled building performance in relation to overheating and ARCADIA, SCORCHIO and LUCID had a particular focus on urban overheating.

- SNACC (Lead: Katie Williams, University of the West of England (UWE))
  Aim: *The proposed research answers the question: how can existing suburban neighbourhoods be best adapted to reduce further impacts of climate change and withstand ongoing changes?*

- CREW (Lead: Stephen Hallett, Cranfield University)
  Aim: *To develop a set of tools for improving the capacity for resilience of local communities to the impacts of extreme weather events (EWEs).*

- SCORCHIO (Lead: Geoffrey Levermore, University of Manchester)
  Aim: *To develop tools that use the latest forecasts from UKCIP to help planners, designers, engineers and users to adapt urban areas, with a particular emphasis on heat and human comfort.*

- LUCID (Lead: Michael Davies, University College London)
  Aim: *To understand the impact of local climate on energy use, comfort and health.*

- ARCADIA (Lead: Jim Hall, Environmental Change Institute, University of Oxford)
  Aim: *To provide system-scale understanding of the inter-relationships between climate impacts, the urban economy, land use, transport and the built environment and to use this understanding to design cities that are more resilient and adaptable.*

6.3 Two recent ACN events are extremely pertinent and the outputs of the events are summarised below and in Appendix 1 (a summary document prepared by ACN). Appendices 2-5 provide additional information for some of the projects.

Seminar to Address DCLG/Defra Policy Questions on Overheating, 1 December 2010, DCLG, London

6.4 The aim of this seminar was to inform current and future policy decisions on climate change adaptation with a specific focus on overheating. The seminar concluded that:

> *"..there is evidence to show that overheating of the built environment is a serious problem now and it will further intensify in the future, impacting on both health and productivity. Successful and low carbon adaptation of the built environment to future higher temperatures is only possible through the presence of policy and government initiatives, social awareness and training of the building professionals. Further involvement of policy makers in current research can steer research to provide answers to specific policy questions."*

6.5 A copy of the relevant report produced by ACN is already with DCLG.

Meeting to address Overheating in Cities and Neighbourhoods, 6 October 2011, City Hall, London

6.6 This meeting was held between key policy central makers and relevant ACN projects (SNACC, ARCADIA, LUCID, SCORCHIO, CREW) to draw out clear, consistent messages from across the research spectrum to inform decision makers with respect to overheating particularly at the neighbourhood and city level. The key, relevant, bullet points from each project were summarised by ACN and a document has been produced; provided here as Appendix 2.

Follow up to ACN October 2011 meeting

6.7 A follow up request from the project team's Mike Davies for any further information relating to the key questions of DCLG elicited several replies. The responses received by 27 October 2011 are provided in Appendices 3 - 5. Note that additional information from the LUCID project is already included in the main review and so no further LUCID section is provided in the appendices.

Other research activities

Health impacts

6.8 We could not identify ongoing research on the health impacts of overheating.

Modelling of overheating and potential interventions

6.9 These are mainly covered in the ARCC network projects. There is other similar work taking place, including at Exeter University, "The development of an early stage thermal model to protect against uncertainty and morbidity in buildings under predicted climate change", and at Heriott Watt University, "Decision support for building adaptation in a low-carbon climate change future". Related work is also taking place at Reading University, "A simplified mathematical model for urban microclimate simulation", recently published [Yao 2011].

6.10 Another project that looked at modelling interventions based on an urban scale led to the development of the DECoRuM tool. The Domestic Energy, Carbon Counting and Carbon Reduction model (DECoRuM) is a tool developed by Oxford Brookes University that brings together Geographic Information System (GIS) techniques and energy efficiency measures to identify and measure potential strategies to reduce CO2 emissions in housing (RICS 2006, Gupta R 2005). It is able to estimate baseline CO2 emissions from individual dwellings and aggregate these at an urban scale – street, district or city level. This enables the estimate the potential for domestic CO2 reduction emissions from a range of measures on the demand and supply sides (solar technologies). These can be shown graphically. It also assesses the cost benefit of individual CO2 reduction measures.

Measurement studies

6.11 Chapter 3 (paragraphs 3.34-44) included summaries of recent past and ongoing studies of temperatures in homes. These were:

- English Housing Survey (DCLG / DECC)
- Measurement, Modelling, Mapping and Management (4M) project
- Retrofit for the Future programme (TSB)
- Building Performance Evaluation (TSB)
- FutureFit
- Welsh Government's pilot of Code 4 and 5 homes
- Potential NHBC Foundation study, including a search for case studies.
- Monitoring of Greenwatt Way in Slough

CIBSE Overheating Task Force

6.12 The CIBSE Overheating Task Force (OTF) formed in 2007 is developing the Institute's position on overheating and the approaches to addressing it, in response to concerns about the increased risk of overheating arising from the drive for low carbon buildings, concern that there is no legal maximum workplace temperature, and the fact that some PPP/PFI contracts impose penalties if the building overheats. Their focus is on comfort and the work is aiming to develop an improved way to predict, and therefore manage, comfort problems related to overheating, mainly in new buildings.

6.13 The approach being taken includes a more complex approach than the existing standards based on single temperatures, accounting for the different aspects of the thermal environment:

- Task 1: provides advice on what to do when a building overheats – advice for facilities managers and for building users (CIBSE 2010a, CIBSE 2010b).

- Task 2: provides practical guidance on improving summertime comfort – resulting in guide KS16 in the CIBSE knowledge series How to Manage

Overheating in Buildings (CIBSE 2010c). This work includes a review of CIIBSE Guide A (2008) – referred to in Section 6. Whilst the prescribed criteria may seem sensible, there are a number of potential problems:

- Predicting a small number of hours of exceedance of a threshold temperature with any accuracy is difficult as it is very sensitive to the modelling methods used
- There may be a difference between the prediction in the simulation and the actual building's behaviour, due to its actual construction, use and/or climatic conditions
- It has not been proven that the defined standards are acceptable to building occupants.
- There is the potential to adjust the "occupied hours" which will give a different percentage of occupied hours over the threshold temperatures.

So CIBSE are intending to provide the building industry with:

- An appropriate overheating risk criteria
- A standardised calculation method
- Standardised climatic data
- A standardised methodology

To do this they have combined three working groups and they are also working with a number of research programmes.

6.14 CIBSE have therefore devised 3 criteria for assessing the acceptable level of overheating and to replace the existing criterion given in CIBSE Guide A (2006).

- Criteria 1 – Hours of Exceedance (He):
- Criteria 2 – Weighted Exceedance (We)
- Criteria 3 – Threshold/Upper Temperature Limit (Tempup)

The building will be deemed to have overheated if any two of the three criteria are exceeded.

6.15 CIBSE have stated that these should be tested out on real buildings for which there is clear evidence of occupant satisfaction with acceptance levels of overheating as well as buildings where occupants suffer from unacceptable levels of thermal comfort.

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7. Potential technical interventions

Introduction

7.1 This section gives a brief coverage of the literature on potential technical interventions that could be made to reduce the extent of overheating, or its impact on people. These are then the types of intervention that could be implemented through potential policy changes or other interventions. Many of the issues relevant here have already been raised in Chapter 3, in that the causes of overheating tend to lend themselves directly to potential solutions which remove that driver of overheating.

7.2 The potential areas for reducing overheating impacts for people are:

- Urban realm measures
- Building measures
- Equipment changes
- Behaviour changes affecting building performance
- Health interventions

7.3 These areas are not independent; there is some overlap between them, particularly around behaviour and use of e.g. curtains and ventilation. Further the effectiveness of an intervention depends on many other factors, such that each needs to be considered in combination with all of its circumstances, which means that it is not possible generalise about the extent of the benefit that comes with each intervention.

7.4 The different levels of intervention outlined above are developed further in the following sections. However it is also important to recognise that the opportunity to use these interventions typically rests with different actors. Therefore the route to influencing these will also vary between them. Specifically only some of these issues can be addressed through Building Regulations; others are affected by planning, education and health planning, and decisions and actions may need to be taken locally within buildings, or through spatial planning.

Urban realm changes

7.5 The ARCC funded projects described earlier, including LUCID, SCORCHIO and ARCADIA, have all examined the potential impact of climate change and the urban heat island (UHI) effect. These are discussed in Chapter 6 under the research landscape sector. In summary however there is potential for reducing local external temperatures as these are found to vary by around 3-4ºC depending on local building form, surfaces and amount of green space.

7.6 Hence there is potential to reduce impacts for some parts of some cities by major changes to buildings and land use, but this will not be equally effective or possible for all areas. Selected observations are:

- Street ‘canyons’ should be avoided as they increase local temperatures, but they are not as important as we previously thought. A ‘street canyon’ is an urban feature where the closeness and scale of the buildings result in a build-up of heat and pollution in the space between them. A large Manchester canyon recorded a dry bulb temperature 2ºC higher than the nearby Manchester urban area which is 5oC above the rural dry bulb temperature. (SCORCHIO)
- City ventilation (allowing air movement through the city) is important in reducing UHI effect. (SCORCHIO)
- Trees are better than grass for reducing UHI effect and provide shading. “Blue” areas are also important. (SCORCHIO)
- A move to electric vehicles and/or significantly decreased traffic reduces noise to levels at which dwellers feel better able to cool buildings by opening windows rather than using artificial ventilation systems. (ARCADIA)
- A zero-energy London (i.e. no waste heat release from buildings, traffic, people, etc.) would reduce the average summer UHI magnitude by approximately 0.3ºC (15% reduction). (Met Office)
- A double-energy use London would increase average summer UHI magnitude by approximately 0.3ºC (15% increase). (Met Office)
- Doubling green space in London would decrease the average summer UHI by approximately 0.7ºC (35% reduction). (Met Office)
- Changing building form in terms of shape, massing, surfaces has the potential to change the urban heat island up to 1°C when altered at the city-scale. (LUCID)
- Green roofs are demonstrated in cities such as Tokyo to provide a several degree Celsius cooling effect in summer for the local climate, reducing energy use for cooling. (ARCADIA)
- Reflective roof materials should replace absorptive materials to increase the albedo of roof surfaces, reducing the heat island effect. (ARCADIA)

Building and equipment measures

7.7 It is helpful conceptually to separate building related measures into two parts:

- Those that are part of the main 'build', and can only be changed at construction or a major refurbishment (building)
- Those that can be changed relatively easily (equipment).

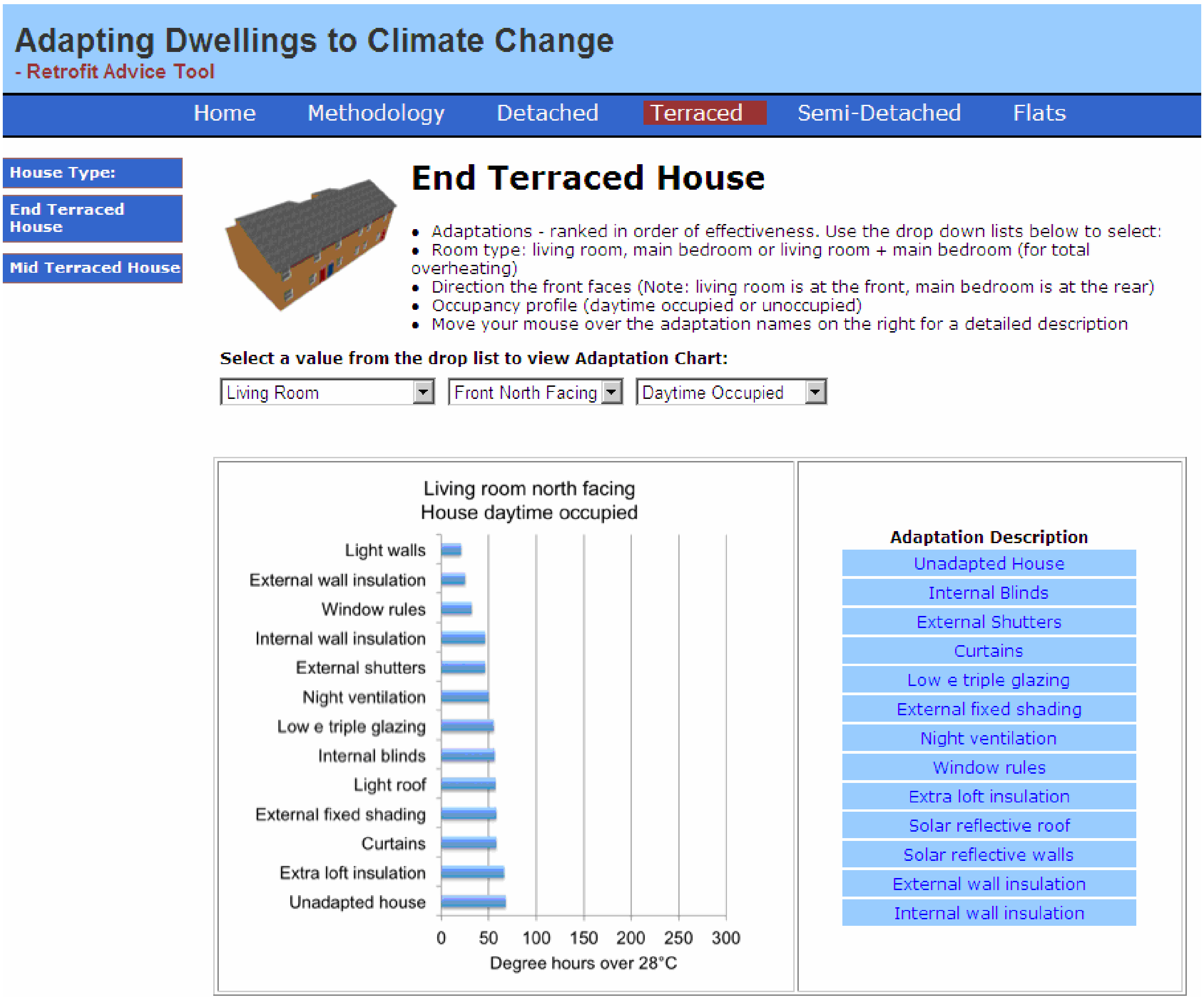
7.8 However the main studies do not separate these, and so the two groups are discussed together here, but split out at the end of the section.

7.9 Helping to advise on improvements to homes is a particular focus of the CREW project, and the project has developed a design tool to help understand the likely impact of different measures, and how they may vary between dwelling types. Their list of potential interventions for existing homes is:

- Internal Blinds
- External Shutters
- Curtains
- Low emissivity coated triple glazing
- External fixed shading
- Night ventilation
- Window rules
- Solar reflective roof
- Solar reflective walls
- External wall insulation
- Internal wall insulation
- Cavity wall insulation

7.10 Their modelling work indicates the relative effectiveness of each of these interventions, depending on the house type and age (hence original levels of insulation and thermal mass), orientation and whether it is occupied in the daytime or not. Their results support the use of external shutters or shading as frequently being the most effective solution. [http://www.iesd.dmu.ac.uk/crew/]

7.11 An example 'snapshot' from their work is shown below. What this indicates is a relative ranking of measures for this dwelling type, using the measure of hours above 28ºC. This is based on the limited data provided to their system, and so the number of hours will change significantly with different systems, as may the ranking of measures.



7.12 In a new build situation there is also the option to change the following, which in general cannot be changed later:

- The orientation
- Glazed areas on different facades
- The amount of and access to thermal mass.

7.13 There is also substantial published literature in this area, although the majority of documents are based on simulation studies, and have been discussed earlier in Chapter 3. These included the following observations:

- Natural ventilation may become a ‘double-edged sword’ in the future (CIBSE 2005b). As ambient temperatures are projected to increase, daytime ventilation may not be beneficial for the mitigation of overheating as the incoming air will be at a high temperature. In addition, night purge ventilation will be effective only if the diurnal temperature variation is significant enough to flush away the heat stored in the building. However, this is also likely to change under current climate change projections. Whilst window opening significantly reduces internal temperatures in London houses, it does not appear to fully eliminate overheating problems by the 2030s (Peacock et al. 2010).

- Thermal mass coupled with night ventilative cooling has been identified as a relatively effective measure to combat domestic overheating. This was confirmed by comparative analyses of indoor thermal performance of lightweight vs. heavyweight structures (Arup Research + Development and Bill Dunster Architects 2005, Coley and Kershaw 2010). In the heavyweight houses, the heat that was built up during the daytime was reradiated back during the night, thus resulting in both a time lag in heat release and lower daily peak temperatures. This is important given that increases in the amount of exposed thermal mass may delay the installation of mechanical cooling (Hacker et al. 2008). Dwellings with low thermal mass are characterised by higher 'climate change amplification coefficients', or steeper slopes of the linear regression between internal and external temperature (Coley and Kershaw 2009). These buildings may not be able to successfully respond to a warming external environment due to the rapid overheating of their interiors.
- It is essential that adequate levels of night ventilation are provided in heavyweight structures as thermal mass alone is not likely to reduce overheating (Orme and Palmer 2003). Night time purging ventilation, combined with fans that increase air circulation, and internal blinds during the daytime were found to reduce the cooling loads of one of the modelled flats by more than 50% (Capon and Hacker 2009). Night ventilation may prove beneficial even in lightweight structures (Orme and Palmer 2003). Solar control, such as shading, was found to reduce overheating as long as daylighting is less critical during the daytime (Capon and Hacker 2009, Porritt et al. 2011).

Behavioural interventions

7.14 The day to day behaviour of occupants can clearly influence, positively or negatively, the extent of overheating in a dwelling. Many of the elements of the building and all of the equipment options are affected by behaviour, particularly relating to the adjustment of:

- Shading (curtains, blinds or shutters)
- Ventilation (windows, fans, vents), and therefore the usefulness of thermal mass and night ventilation strategies
- Clothing (clothing and bedclothes).

7.15 There are also behavioural issues that affect whether people will take more permanent measures such as external wall insulation, but these form part of consideration of how to promote those interventions.

Health interventions

7.16 The policy section (Chapter 4) describes the approaches raised in the Heatwave Plan, and points to a number of guidance documents that have been produced targeted at key groups. These are:

- 'A Guide to Looking After Yourself and Others During Hot Weather' (NHS, 2004)
- 'Supporting Vulnerable People Before and During a Heatwave: Advice for Health and Social Care Professionals' (NHS, 2010a), and

- 'Supporting Vulnerable People Before and During a Heatwave - Advice for Care Home Managers and Staff' (NHS, 2010b).

7.17 These provide approaches to reducing risks to individuals during heatwaves, in a simplified form for householders, but in considerable detail for care home managers. A key part of this for vulnerable groups is knowing who the most vulnerable are, and being prepared to move them to the cooler places, provide them with fluids and keep them under observation.

A detailed extract gives the level of advice given in the Heatwave Plan for England (NHS, 2011):

- Cool rooms or cool areas should be created. High-risk groups who are vulnerable to the effects of heat are physiologically unable to cool themselves efficiently once temperatures rise above 26ºC. Therefore, every care, nursing and residential home should be able to provide a room or area that maintains a temperature of 26ºC or below. Hospitals should aim to ensure that cool areas are created that do not exceed 26ºC, especially in areas with high-risk patients.
- If temperatures exceed 26ºC, high-risk individuals should be moved to a cool area that is 26ºC or below.
- Cool areas can be developed with appropriate indoor and outdoor shading, ventilation, the use of indoor and outdoor plants and, if necessary, air-conditioning.
- During the summer months, sufficient staff must be available so that appropriate action can be taken in the event of a heatwave.
- Due to the additional risk of psychiatric medications affecting thermoregulation and sweating, mental health trusts and teams need to ensure that hospital environments have a cool room (26ºC or below) and that heatwave considerations (see the section on Protective factors on page 18) are included within an individual's Care Programme Approach.

Summary

7.18 The potential solutions identified above are summarised in the table below (Table 7.1), grouped into the levels at which they apply. Note that several blur across the boundaries, for example are shutters building or equipment? This is an AECOM-prepared table (rather than one identified in the literature review) and it will require further consideration and discussion, which is beyond the scope of this report. The ideas suggested by the ACN programme leaders, via correspondence, to a specific question on this topic are also included.

Table 7.1 Potential solutions

Urban	Building	Equipment	Behaviour	Health
Avoid canyons	Cavity wall insulation	Circulation fans	Window opening, if external temps are less than internal temps	Drink water, eat cool food
Create blue areas	Chimneys/ passive stack ventilation	Curtains	Night ventilation	Sit in the shade
Change building form	External fixed shading	Internal blinds	Reduce bedclothes	Avoid exercise in sun
City albedo	External shutters	Air conditioning if renewable electricity is available at right time	Reduce clothing	Monitor temperatures for vulnerable people
City ventilation	External wall insulation	Cross ventilation provision	Curtain / blind usage	Follow heatwave plan intervention levels
Electric vehicles (low noise)	Glazing areas	Grow plants, especially trees	Place vulnerable people with thought – not top floor flats	Obtain ice / cool water supplies
Create green roofs	Internal wall insulation	Ensuring MVHR units are correctly operated in summer	Ensure vulnerable people have access to cool / shady areas	Monitor vulnerable people regularly
Tree planting	Low e triple glazing		Turn off lights and non-essential equipment	Take cool showers
Zero energy city	Orientation			
	Solar reflective roof			
	Solar reflective walls			
	Thermal mass			
	Avoid single aspect flats			
	Do not add car parks at expense of green space			
	Consider heating & potential overheating issues within the same package of works			

7.19 Other, non-technical measures, include:

- Adopting a regionally differentiated approach to solutions
- Improving overheating models
- Using decision-making tools when developing refurbishment strategies
- Advice to small builders and designers
- Advice to residents/carers, care home staff and healthcare professionals

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8. Summary of responses to questionnaire for stakeholders in the house-building and public sectors

Summary of responses to telephone interviews undertaken by AECOM

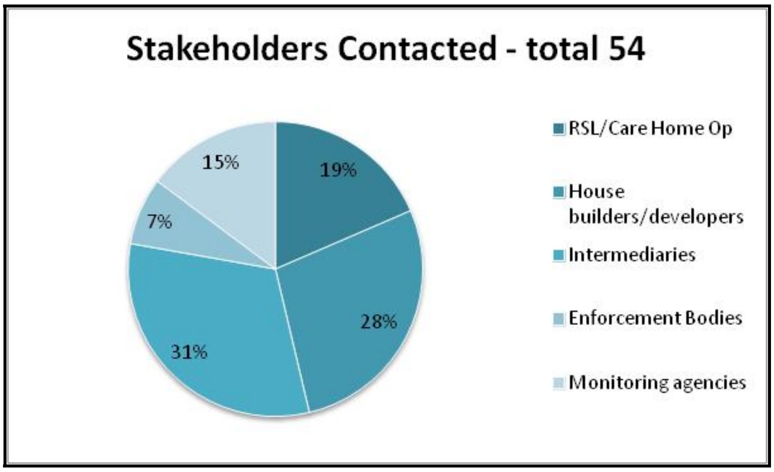
Purpose of discussions

8.1 To understand the extent to which overheating is felt to be a problem in dwellings today AECOM contacted a number of stakeholders in October and November 2011 to ask for their views on the nature and extent of problems related to overheating in dwellings.

Stakeholders Contacted – Q1

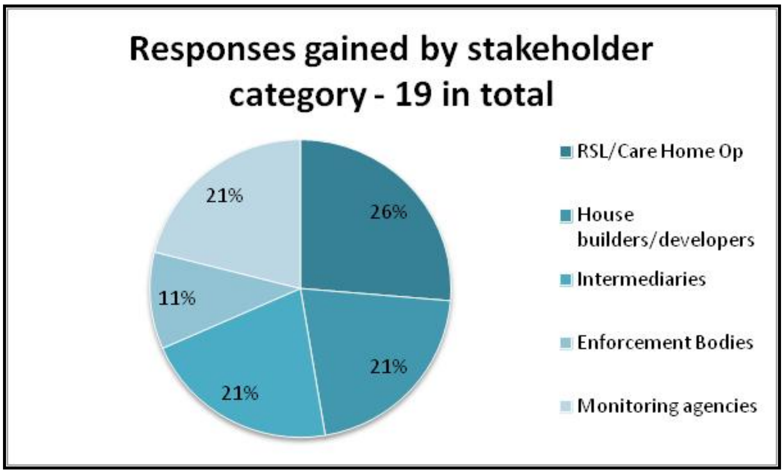
Numbers of stakeholders contacted

- 54 stakeholders were contacted via telephone and e-mail. A breakdown of the sectors that the stakeholders are from is presented below.



Number of stakeholders interviewed

- 20 stakeholders were interviewed; a breakdown of the stakeholders responding sector is presented below.



Of these respondents, how many are actively building properties now and into the future?

- 10

Summary of Responses

Question 2a, b, c and d

2a Have you experienced any instances of overheating in properties or are you aware of any of the buildings in your stock/being built by you being prone to overheating; for example, during recent hot summers?

2b, c and d
Has the respondent received informal (Q2b) or formal (Q2c) complaints and who were they from (Q2d)

Yes – (16)
No – (4)

The supporting comments are summarised below:

Yes
- Within our stock (informal or anecdotal evidence) – (5)
- Within our stock (formal complaints) – (5)
- Not within our stock, but aware of anecdotal evidence or research – (6)

No
- ‘Not in our stock’ *RSL / Care Home Op*
- ‘Not in our district, a small amount of new buildings being built, not many large blocks of flats, generally quite exposed area.’ *Enforcement*
- We generally refurbish existing houses - *House builder/Developer*
- No formal complaints but I am aware of specific issues in different buildings. – *Monitoring agency*

From whom?

- These are from a mixture of sources. Internal staff, internal investigations, external contractors working on properties, occupiers and environmental health officers (EHOs).

Question 3a and b

3a If you have no experience of overheating within your housing stock/developments at present or concerns that it may become a problem, do you have anything else you wish to say on the issue?

3b If you have experience of overheating within your housing stock/developments, do you feel able to tell us about the circumstances?

These questions were generally not required.

Overheating within your housing stock/developments

Question 4

You have said you are aware of some instances of overheating; please can you provide some further information:

Was it an isolated incident or is it annual or a more widespread issue?

You have said you are aware of some instances of overheating; please can you provide some further information:

Was it an isolated incident or is it annual or a more widespread issue?

This question was indirectly covered by respondents and not easily answered. See questions 10 below.

Comments are summarised below

- ‘On the schemes with communal heating we have four with serious problems out of 20 since 2008’ *House builder / developer*
- ‘The extent of the problem? We have had a slow building programme, probably only done 2 or 3 estates so potentially a 100% of these have problems.’ Respondent only had anecdotal evidence of overheating, either it wasn’t a significant issue or occupants were putting up with the conditions. *RSL/Care Home Op*
- ‘Widespread, heard loads about it but not had the chance or need to investigate further.’ *RSL/Care Home Op*
- ‘Yes this is an isolated incident’ – *House Builder/Developer*
- Anecdotal reports really, biggest issues seem to be from RSLs and Local Authorities. They are given substandard homes under Section 106, homes with worst location and largest problem with overheating. They then have to resolve this issue and not the house builder – *Intermediary*
- I concentrate on schools where we are beginning to see evidence of overheating problems. *Intermediary*

- No, it is definitely a trend and from our reports it definitely seems to be in the south. Our new projects that meet the new fabric efficiency standards mean that they may now over heat.' *House builder / developer*

Do you have any sense that some parts of your stock/types of dwellings are more likely than others to suffer from overheating?

Comments are summarised below

- It was stated by three respondents that overheating occurs in all property types, including terraced properties from the 1930s and before. In these properties though occupants can open windows and control the temperature – they are not generally made aware of this sort of overheating. *House builder / developer* and *RSL/Care Home Op*
- All respondents said that they were aware, had seen, received complaints about or were concerned about the possibility of overheating in flats built after 2002 especially those with communal heating systems.
    - Of the possible responses 'Flats built after 2002, 2006, 2010' was selected. 'Flats are the only types of properties that I have heard of at the moment that may be having overheating issues. I think all properties have these problems it is just we don't hear about it.' *House builder / developer*
    - 'The buildings with problems are ones that were finished two or three years ago – mainly an issue in the summer.' *RSL/Care Home Op*
    - 'There is a growing belief that new buildings have an increased chance of overheating.' *Intermediary*
    - 'Flats built after 2002, 2006, 2010' was selected. 'These are the ones we know about, mainly because we are in and out of these properties more often.' *RSL/Care Home Op*
- One respondent mentioned that newly built three-storey town houses may also have an overheating issue. *Intermediary*
- One respondent mentioned that they 'Only deal with new build, the lightweight structures seem to be overheating more.' *House builder / developer*
- Two respondents mentioned the issue of overheating in office blocks in an urban setting and the reliance on mechanical cooling and ventilation and how this could lead to problems as urban heat island effect continues. Would like to see a move towards designing building with a maximum internal temperature without mechanical cooling systems. *Monitoring agencies*

The supporting comments for Common Factors (other than property type/age) are summarised below

- The main factor discussed was the presence of communal heating. It was stated by 14 respondents with experience of overheating that communally heated properties in general have inadequate insulation for the main hot water risers, pipe runs into properties and heat exchangers, heat meters or mechanical ventilation heat recovery equipment. These pipe lengths and equipment were radiating heat into communal areas and dwellings.
    - 'One of the buildings has communal areas overheating because the energy centre is located in the middle of the building and is not properly insulated.' *Monitoring Agencies.*

- It was also noted by all respondents that did not have a housing stock themselves that they were aware that flats with communal heating may have an overheating problem.
- Two respondents highlighted the uncertainty over what can be defined as overheating. They highlighted the role that humidity and ventilation may have alongside temperature.
- It was stated that heat gain is compounded by the restrictions on ventilation in communal areas - due to fire safety regulations - and in dwellings - due to health and safety and outdoor air quality restricting window size and opening.
    - With reference to this, one respondent noted ‘There are buildings that are south facing and can open windows and these still overheat.’ *Monitoring Agencies*
    - ‘There is always overheating in south facing apartments, it is not brand new, what tips the balance is the additional heat from the apartments or from the communal areas.’
    - ‘Exemplar retrofit properties, built really tight; we’re not sure that people understand MVHR and night purging.’ *RSL/Care Home Operator*
- Other factors mentioned were heat gains from orientation and glazed surfaces. This included the preference for single aspect buildings with little or no shading for south faces of the building.
- One respondent mentioned the slightly raised temperatures in London due to the heat island affect and reduced exposure to wind. *RSL/Care Home Operator*
- ‘It is fair to say that we suspect that there will be further issues. Especially considering ground floor properties bearing mind issues with night time purging for ground floor flats.’ *House builder/developer*
- I am aware that the older the building the more heavy weight the building and the more appropriate the glazed area = less risk. *Intermediary*
- The fact that nobody considered it the first time round. It is not appearing on the radar of the designers, the manufacturers, builders. *House builder / developer*
- I have not seen any good solutions; I have seen some pretty poor solutions. Not enough guidance or experience. There could be a skills gap. *House builder / developer*

Are there any problems elsewhere? (corridors, day rooms, other?)

Comments are summarised below

- Those respondents with experience of overheating stated that they had seen, or where aware of, communal areas being affected by heat gain from communal heating systems.
- ‘Particularly where we have communal heating systems. Through pipework in the communal areas as well as in the dwellings...’ *RSL/Care Home Operator*
- ‘There is interesting side benefit; if the pipes are all being run together then the cold water gets hot as well.’ *RSL/Care Home Operator*
- If they have cracked the problem with the distribution network, then the problem moves into the flat in the cupboard where the heat meter is, the hallways of individual flats can turn into little furnaces.’ *RSL/Care Home Operator*
- I have heard that communal heating systems mentioned. We encourage this to be taken up. I am aware of instances of where these have been designed or poorly commissioned. *Monitoring Agencies*

- Only required to look at living areas, tends to be both but bedrooms are slightly worse. *House builder / developer*

Do you have any actual measurements/evidence that indicates overheating is more of a problem in some dwelling types than others?

Yes – (5)
Not yet – (4)
No – (9)

The supporting comments are summarised below
Yes / Not yet

- 'There is a project looking at a refit of a Victorian building.' *RSL/Care Home Operator*
- 'I would like us to collect some information on the communal heating systems so we would have ammunition to show that they don't work.' *RSL/Care Home Operator*
- 'There was one on Vauxhall Bridge road monitored by the BRE. It was modelled and retrofitted. We are undertaking measurement in new build housing and flats and terraces about 10 sites.' *Monitoring agencies*
- 'Monitoring of a range of temperature characteristics.' *Intermediaries*
- 'Yes we have, larger areas in the communal spaces, lift shafts.' *House builder/developer*
- No but we are looking for opportunities. *Monitoring agencies*
- Not here, I have been trying to set up post occupancy monitoring, particularly on some of our schools. Classic problem with POM seems difficult getting everybody onboard. *Monitoring agencies*
- Collecting temperature data. *House builder / developer*

No

- 'No these are just comments, not a large enough number of complaints at the moment to warrant further investigations.' *House builder/developer*
- 'No, but has seen information/research that may be investigated further by Zero Carbon Hub – looking for DCLG support.' *Monitoring agencies*
- 'But we are doing on our retrofit properties, not on our new build. Not having any complaints. If we did then we would look at monitoring.' *Intermediaries*
- We are going to have to start investigating it more - *House builder/developer*

Question 5

Do you have any sense that some of your residents/home owners are more likely than others to suffer from overheating?

The supporting comments are summarised below

- Respondents generally felt that this was not core to the issue. They were aware that some residents/owners may be more at risk from the affects of overheating but this did not affect the cause of overheating.
- Key areas are older people, those in poorer health and those mainly at home during the day. *Monitoring agencies*
- 'We did a workshop in February with BRE with health protection agency – traditionally you think that health issues are based about being over a certain temperature, or

over a certain temperature for a certain amount of time. In reality it is much more complex and health problems are also affected by sleepless nights, levels of activity etc.' *Monitoring agencies*

Question 6

a) Do you/project teams use any tools to assess overheating risk at the design stage? If yes, do you believe they are adequate/appropriate and which tool do you use?

Yes – (5)
No – (3)

Only 6 respondents specifically defined the software used, however 11 respondents had comments on the existing software systems.

The supporting comments are summarised below

- 'To start with, most developers don't want to commission any extra work to look specifically at the issue of overheating. They don't want to spend money on something where they can't see a direct benefit for it.' *Intermediaries*
- 'Instead they rely on the SAP tool specified in Building Regulations – the SAP tool is not good enough when considering overheating.' *Intermediaries*
- 'There should be a push towards a more widespread use of thermal dynamic modelling – RSLs are starting to pick up on this and ask for the use of a dynamic thermal model.' *Intermediaries*
- 'There is an added issue about how you recognise overheating in dwellings – most people use the CIBSE guide which is currently being reviewed.' *RSL/Care Home Operator*
- 'All of these properties (those that are now identified as having overheating problems) passed the SAP overheating requirements. This is rubbish.' *House builder/developer*
- 'They don't help, we have tried, but we don't believe the models! They underestimate the amount of overheating.' *Intermediaries*
- Need thermodynamic modelling. *Intermediaries*
- 'We rely on modelling from outside.' *RSL/Care Home Operator*
- 'All assessed using the SAP calculations, the standard for assessing overheating risks. We install the standard measure to address the risk. SAP is not great.' *RSL/Care Home Operator*
- 'Not come across any other tools.' *House builder/developer*
- 'We have built things and they have passed SAP but we end up with a building that is overheating. The building then has an overheating risk. It may be an appropriate tool but the assumptions used need to be revised to reflect actual environments.' *RSL/Care Home Operator*
- 'Development team will be involved but we have no input into developer design. We do not have technical knowledge.' *RSL/Care Home Operator*
- 'Ask for thermal modelling on south facing. Asking our contractors, our M&E people to show how they are going to stop the communal heating problem. We record the fact that we have these conversations and we can go back to the M&E consultants – not had any cause to do this yet.' *Intermediaries*

- ‘In residences we have used SAP and SBEM, SAP is a waste of time. It is not a design tool it is a compliance tool.’ *House builder/developer*
- ‘IES, TAS, look at the hourly temperature profile of the building, this is why we have problems with the domestic sector because uses a very steady state profile in SAP. SAP is not the right kind of model.’ *Intermediary*
- Only seen the CIBSE modelling tool – the volume A. Not sure that this is up to the job, this is quite an onerous task, they may only want to do one in a development – an average or the best maybe – it is very generic. What is the reality in comparison, it is not on all our developments. Might more likely to find out on social housing. *House builder/developer*

b) If yes, do you believe they are adequate/appropriate and which tool do you use?

Yes – (1)
No – (9)
Don’t know – (7)

The supporting comments are summarised below

- ‘Only just starting to get data so it is difficult to tell if these are working or not.’
- ‘We shouldn’t be using models, don’t think that computer tools are the answer. The computer tools aggravate the situation.’
- ‘People see that they get different results.’
- ‘There are some issues about standard occupation assumptions and older people, people that are home during the day, higher occupancy of the properties.’
- Passive house planning package – address shading and orientation and cooling load at the design stage.

Tools

SAP –

- ‘An ongoing debate on SAP tools, there are a number of assumptions in these tools, are they correct? There are issues related around those elements. Ventilation, when the 2010 AD for Part F came in, it used various sources of anecdotal evidence that are not very helpful – leaves uncertainty around if the ventilation installed is working.’

- ‘We know that there are going to be a lot of older people on our waiting list. They want higher temperatures on a day to day basis and SAP doesn’t really understand this thermal requirement.’

BRE –

- The BRE have been doing the modelling for us. Modelled two different sites and the specifications on overheating – you need to contact BRE for the details of the modelling.

Question 7 and 8

For housing managers/ EHOs only: Do you use the Housing Health & Safety Rating System (HHSRS) to assess overheating risk?

- So far we have had only one response from an EHO and overheating is not a major issue in their area. They do use the Housing Health & Safety Rating System (HHSRS) to assess overheating risk.

Question 9

a) Have you attempted any interventions to prevent/reduce overheating, and if so what were they?

Yes – (9)
No – (9)
N/A – (1)

The supporting comments are summarised below

- Insulation of pipe work. *House builder/developer*
- 'Might start to use smoke ventilation system to provide ventilation.' *RSL/Care Home Operator*
- 'Don't think we have, aware that RSLs and LAs are having to deal with this issue.' *RSL/Care Home Operator*
- 'Deal with it at the early design stages, orientation and shading, night time and lighting.' *RSL/Care Home Operator*
- 'Cross ventilation, more insulation in the heating systems, gold glazing on the front and brise soleil.' *Monitoring agencies*
- 'Mechanical ventilation – we do, that is part of the problem, we have built the properties, with MVHR and created nicely sealed units.' *House builder/developer*
- Occupant behaviour advice – 'it is early days, we do need to educate the residents on the importance of the MVHR if it is located in a bad location.' *House builder/developer*
- 'Insulation on the risers' *House builder/developer*
- Mechanical ventilation – 'we are using MVHR if you use it properly then the air changes don't make a difference, need air changing at over 10 ACH.' *House builder/developer*
- 'Reduced the solar transition of the glazing, reduced the G – value.' *House builder/developer*
- 'Thermostatically controlled Velux window, an automatic control out of a staircase, creates a heat chimney in the staircase.' *House builder / Developer*
- Occupant behaviour advice – 'we did do a very small survey talking to residents in 5 developments. We got some feedback, they want something that they can control themselves that is easy to use and is reliable and doesn't cost them a lot of money.' *RSL/Care Home Operator*
- 'For a fully glazed building, apart from internal blind system, we are going to be a bit stuck for what we can do.' *House builder/developer*
- Looking for mitigation at the design stage. At the moment we are having problems getting the information late on in the design stage which provides other problems. They are looking to remedy this through policy. We have seen some good examples but we are looking for improvements. *Monitoring Agencies*

b). Have these been effective?

Yes – (1)
No - (0)
Don't know – (15)

Question 10

Overall, would you say overheating is a significant concern to your organisation or not?

Yes – (11)
No – (2)
Not sure – (4)

The supporting comments are summarised below

- 'Not so sure, at the moment it is just uncomfortable. People may be putting up with the problem.' *RSL/Care Home Operator*
- 'I think it is, big problem for those suffering the effects of the additional heat, especially when you consider that there are interventions that can be made. Then you must consider increasing heat, and increasing energy efficiency and air tightness standards and the problems becomes more serious.' *Monitoring agencies*
- 'I think it is a growing concern, it is on our radar. Because as a social housing provider we have lots of older people, and those in poor health who may feel the affects more.' *RSL/Care Home Op*
- 'We are very dense and built up Borough. With that urban heat island effect we are concerned at the impact on the Borough.' *Monitoring agencies*
- 'I think that we are kind of in the quantification stage, it is difficult to know how large the problem is. It is an expected issue and it needs a bit of attention. Needs further research and monitoring – need to get a better understanding as we move towards zero carbon.' *Intermediaries*
- 'Very significant, one of the buildings I have talked about has legal action pending.' *Intermediaries*
- 'Yes, it is a significant to us already.' *Intermediaries*
- 'I think that it is but what we find is that new builds are being built with a lot of air conditioning to try and mitigate the problem. However, in urban London, there is the urban heat island effect; most people are using air conditioning which may be increasing the problem – referenced facts from Paris 2003'. *Monitoring agencies*
- 'We are proposing to have a design threshold that the building should not go beyond 28^{o}C and you should not rely on air conditioning.' *Monitoring agencies*
- Not a significant issue for their organisation. The examples that the individual has seen are generally were in newly built flats, with large amounts of glass facing south, without shading, they are going to overheat. 'We try not to depend upon too much technology; prefer to do it through good design, orientation, fabric, ventilation.' *House builder/developer*
- 'I don't think the organisation is yet aware of the size of the problem. More of a problem with the capital cost, MVHR being installed, not installed very well and not being used by the residents.' *RSL/Care Home Op*
- 'Not a high concern, it is an interesting issue. We generally haven't had the customer feedback telling us the building is overheating.' It can be seen as an issue with

traditional style housing which residents deal with and do not complain about. ‘Going forward we are going to have to look at it more, especially with south glazing. We have push and pull, from regulations.’ *House builder/developer*

- ‘Zero carbon is a more pressing issue.’ *House builder/developer*
- ‘In the press at the moment, haven’t had lots of confirmed occurrences of overheating.’ *House builder/developer*
- ‘It is a concern but it isn’t a significant concern to the organisation but it is more of a concern to the development department – we are all aware of it now and ask questions.’ *RSL/Care Home Op*
- This is a significant concern. Those who aren’t concerned should be. Forward from Part L 2010, no testing, need to do more. *House builder/developer*
- No we have been told to drop it and that is what we have done. Very few people have ever understood it. It is too difficult and there is a lack of understanding. Given the new focus on meeting LA criteria I think the issue has now been dropped. *House builder/developer*
- Of course, overheating is now covered in SAP – this may not be good enough to deal with the problem. *House builder/developer*

Question 11

Would you be content to go into more detail at a later date to assist DCLG with their understanding of this issue?

The supporting comments are summarised below

- All respondents were happy to take part in further investigations/discussions.
- It has been requested that DCLG send around a confirmation e-mail saying how this research will be used and confirming the contact should the respondents want to follow up.

Final additional comments

- A further comment was that – ‘Residential is through accredited details and those sort of schemes – where as we tend to use more investigations and testing for commercial properties.’ *House builder/Developer*
- Beginning to see the design performance gap – can we prove the as-built project? Part L must be aware of all the issues that get in the way of making energy efficient buildings. It needs design stages that can be used throughout the building process and used as performance indicators to compare to the as-built finished project. - *Intermediaries*

9. Discussion of future research needs

Introduction

9.1 Identifying areas for potential further work is the purpose of the AECOM-led report: Investigation into Overheating in Homes: Analysis of Gaps and Recommendations, which has been published by DCLG alongside this document.

9.2 Our initial thoughts dating from December 2011 are listed below.

Indoor/outdoor temperatures

9.3 The main evidence of the relationship between health impacts and temperature is for external temperatures and the correlation with deaths/hospital admissions during heat wave events. There is limited or no data on the indoor temperatures associated with the outdoor conditions that drove the health impacts.

9.4 There is therefore a place for a range of studies to understand, through measurements and modelling, which different building types, configurations and operations lead to different thermal conditions, and therefore where the greatest problems lie. This should enable the better targeting of interventions in future.

9.5 The lack of standardisation of input parameters across the various studies does not allow the direct comparison of their results. Standardised house types for both new build dwellings and those which represent the existing dwelling stock should be confirmed for use in modelling to facilitate this comparison.

Analysis of measured data

9.6 There are a number of current studies collecting data on temperatures in dwellings which have been identified in Chapter 3. There will be value in a study across all of these data sets to correlate the findings, and use this to evaluate the temperatures that occur in different buildings under different conditions.

Issues in new homes

9.7 The brief stakeholder survey has indicated that overheating is a perceived as a significant problem by a number of respondents. A particular issue is emerging around poorly installed community heating systems resulting in additional problems. A study to target a number of these schemes, to look at the heat distribution systems in particular, and all the features of low energy homes would help to evaluate this, and target changes that may be needed to address the problem.

9.8 On a broader footing, a review of overheating issues in post Building Regulations 2006 dwellings would be appropriate, to assess if the ongoing enhancement of insulation standards is leading to larger problems than in the past. This may emerge from the general studies underway, but it may require specific studies.

Occupant behaviour

9.9 The general lack of knowledge about behavioural risk factors and mitigation indicates a wide range of research that would be needed to fill the gaps. Given this major need, research would need to be carefully prioritised to address the most important gaps in relation to policy actions that might realistically be taken up and where the risks and/or benefits relating to behaviour are greatest.

9.10 Identification of research priorities is therefore likely to be an iterative process but the following may be considered:

- Identification of the adaptive behaviours that are most effective and most easily communicated and implemented.
- Identification of the most common maladaptive behaviours.
- Specification of the most significant behavioural risks associated with possible physical interventions.
- Determination of the motivational drivers which are most likely to result in adaptive behaviour. Critically, if comfort is the key driver, rather than health (particularly in relation to avoiding future demand for air conditioning), then there is a need to determine whether action based on comfort will also protect health.
- Review of the availability and effectiveness of local support in communities.
- Whether there are particular population groups that are most in need of support to make their behaviour more adaptive.

Regulation review

9.11 The review of regulations indicates that there are very many standards and regulations in place for different building sectors. There may be a need for a review of the potential to simplify this and remove many of them to be replaced smaller number or single approach for all building types.

Opportunities / integration with other policies

9.12 The planned changes to domestic Energy Performance Certificates (EPCs) and the availability of EPCs via the Energy Act may provide any new opportunities to understand existing dwellings and the potential for retrofit measures to counter both heat loss and unwanted heat gains leading to summertime overheating. The Green Deal Framework has been designed to ensure that measures installed are appropriate to the building in question and that any measures are installed to minimise known risks associated with them, including the potential risk of overheating. However, there may be further work to do once a better understanding on the links between energy efficiency upgrades and overheating is established.

9.13 Further work could be appropriate to evaluate the interface with these policy interventions, and to try to direct them to a more successful outcome.

Stakeholder interaction

9.14 All of the telephone interview respondents were happy to take part in further investigations/discussions and this opportunity should be taken up.

9.15 Further liaison is planned with the CIBSE Overheating Task Force to better understand how comfort is being addressed by that group, such that the gap analysis for this study can focus on health impacts.

Appendix 1

Current legalisation and statutory guidance relevant to overheating in buildings for vulnerable populations

Sector	Act	Regulations	Statutory Guidance	Still in force?	Notes	*Are the Workplace (Health, Safety and Welfare) Regulations 1992* as Amended applicable?	*National Heatwave Plan* - relevant sector guidance
Housing - Rented (new)	*Housing Act 2004*	*The Housing Health and Safety Rating System (England) Regulations 2005*	*Housing Health and Safety Rating System Operating Guidance 2006; Housing Health and Safety Rating System Guidance for Landlords and Property Related Professionals 2006*	Yes	- Excess heat identified as a hazard but is not quantified		*A Guide to Looking After Yourself and Others During Hot Weather 2004* *Supporting Vulnerable People Before and During a Heatwave - Advice for Health and Social Care Professionals 2010*
	Building Act 1984	*Building Regulations 2010*	*Approved Document F 2010* *Approved Document L1A 2010* *Approved Document L2A 2010*	Yes	- Purge ventilation is required in each habitable room and should be capable of extracting a minimum of 4 air changes per hour per room directly to outside - SAP 2009 Appendix P overheating calculation	Yes, for common areas if workplace. - Employer's in use thermal comfort risk assessment required based on employee satisfaction survey, upon which action may need to be taken. - Design stage risk assessment required according to *BS 8213 – 1: 2004 Windows, doors and roof lights – Part 1: Design for safety in use and during cleaning of windows, including door-height*	

Sector	Act	Regulations	Statutory Guidance	Still in force?	Notes	*Are the Workplace (Health, Safety and Welfare) Regulations 1992* as Amended applicable?	*National Heatwave Plan* - relevant sector guidance
					required - Solar gains should be limited	*windows and roof windows – code of practice.* This may limit window opening sizes with mechanical restrictors.	
Housing - Rented (existing)	*Housing Act 2004*	*The Housing Health and Safety Rating System (England) Regulations 2005*	*Housing Health and Safety Rating System Operating Guidance 2006; Housing Health and Safety Rating System Guidance for Landlords and Property Related Professionals 2006*	Yes	- Excess heat identified as a hazard but is not quantified		*A Guide to Looking After Yourself and Others During Hot Weather 2004* *Supporting Vulnerable People Before and During a Heatwave - Advice for Health and Social Care Professionals 2010*
	Building Act 1984	*Building Regulations 2010*	*Approved Document F 2010* *Approved Document L1B 2010* *Approved Document L2B 2010*	Yes	- If carrying out major refurbishment work or for extensions - For common areas	Yes, for common areas if workplace. - Employer's in use thermal comfort risk assessment required based on employee satisfaction survey, upon which action may need to be taken.	
Housing -	*Building*	*Building*	*Approved*	Yes	- Purge ventilation		*A Guide to Looking*

Sector	Act	Regulations	Statutory Guidance	Still in force?	Notes	*Are the Workplace (Health, Safety and Welfare) Regulations 1992* as Amended applicable?	*National Heatwave Plan* - relevant sector guidance
Owner Occupied (new)	*Act 1984*	*Regulations 2010*	*Document F 2010* *Approved Document L1A 2010* *Approved Document L2A 2010*		is required in each habitable room and should be capable of extracting a minimum of 4 air changes per hour per room directly to outside - SAP 2009 Appendix P overheating calculation required - For common areas: solar gains should be limited	Yes, for common areas if workplace. - Employer's in use thermal comfort risk assessment required based on employee satisfaction survey, upon which action may need to be taken.	*After Yourself and Others During Hot Weather 2004* *Supporting Vulnerable People Before and During a Heatwave - Advice for Health and Social Care Professionals 2010*
Housing - Owner Occupied (existing)	*Building Act 1984*	*Building Regulations 2010*	*Approved Document F 2010* *Approved Document L1B 2010* *Approved Document L2B 2010*	Yes	- If carrying out major refurbishment work or for extensions - For common areas	Yes, for common areas if workplace. - Employer's in use thermal comfort risk assessment required based on employee satisfaction survey, upon which action may need to be taken.	*A Guide to Looking After Yourself and Others During Hot Weather 2004* *Supporting Vulnerable People Before and During a Heatwave - Advice for Health and Social Care Professionals 2010*
Hospitals (new)	*Health and Social Care Act 2008*	*The Health and Social Care Act 2008 (Regulated*	*Essential Standards of Quality and Safety 2010*	Yes	- People who use the service can make choice about temperature, but this is not	Yes. - Employer's in use thermal comfort risk assessment required based on employee satisfaction survey, upon which action may	*Supporting Vulnerable People Before and During a Heatwave - Advice for Health and Social Care*

Sector	Act	Regulations	Statutory Guidance	Still in force?	Notes	*Are the Workplace (Health, Safety and Welfare) Regulations 1992* as Amended applicable?	*National Heatwave Plan* - relevant sector guidance
		Activities) Regulations 2010			quantified	need to be taken. - Design stage risk assessment required according to *BS 8213 – 1: 2004 Windows, doors and roof lights – Part 1: Design for safety in use and during cleaning of windows, including door-height windows and roof windows – code of practice.* This may limit window opening sizes with mechanical restrictors.	*Professionals 2010*
	Building Act 1984	*Building Regulations 2010*	*Approved Document F 2010* *Approved Document L2A 2010*	Yes	- Solar gains should be limited		
	N/a	*N/a*	*Heating and ventilation systems - Health Technical Memorandum 03-01: Specialised ventilation for Healthcare Premises. Part A: Design and validation 2007 [HTMs may be considered as de facto statutory guidance though case law]*	Yes	- Minimum quantified ventilation and overheating requirements		

Sector	Act	Regulations	Statutory Guidance	Still in force?	Notes	*Are the Workplace (Health, Safety and Welfare) Regulations 1992* as Amended applicable?	*National Heatwave Plan* - relevant sector guidance
Hospitals (existing)	*Health and Social Care Act 2008*	*The Health and Social Care Act 2008 (Regulated Activities) Regulations 2010*	*Essential Standards of Quality and Safety 2010*	Yes	- People who use the service can make choice about temperature, but this is not quantified	Yes. - Employer's in use thermal comfort risk assessment required based on employee satisfaction survey, upon which action may need to be taken.	*Supporting Vulnerable People Before and During a Heatwave - Advice for Health and Social Care Professionals 2010*
	Building Act 1984	*Building Regulations 2010*	*Approved Document F 2010* *Approved Document L2B 2010*	Yes	- If carrying out major refurbishment work or for extensions		
Care Homes (new)	*Health and Social Care Act 2008*	*The Health and Social Care Act 2008 (Regulated Activities) Regulations 2010*	*Essential Standards of Quality and Safety 2010; What Standards to Expect from the Regulation of your Care Home 2011*	Yes	- People who use a service can make choice about temperature, but this is not quantified	Yes. - Employer's in use thermal comfort risk assessment required based on employee satisfaction survey, upon which action may need to be taken. - Design stage risk assessment required according to *BS 8213 – 1: 2004 Windows, doors and roof lights – Part 1: Design for safety in use and during cleaning of windows, including door-height windows and roof windows – code of practice.* This may limit window opening sizes with mechanical restrictors.	*Supporting Vulnerable People Before and During a Heatwave - Advice for Care Home Managers and Staff 2010*
	Building Act 1984	*Building Regulations*	*Approved Document F*	Yes	- Solar gains should be limited		

Sector	Act	Regulations	Statutory Guidance	Still in force?	Notes	*Are the Workplace (Health, Safety and Welfare) Regulations 1992* as Amended applicable?	*National Heatwave Plan* - relevant sector guidance
		2010	*2010 Approved Document L2A 2010*				
Care Homes (existing)	*Health and Social Care Act 2008*	*The Health and Social Care Act 2008 (Regulated Activities) Regulations 2010*	*Essential Standards of Quality and Safety 2010; What Standards to Expect from the Regulation of your Care Home 2011*	Yes	- People who use a service can make choice about temperature, but this is not quantified	Yes. - Employer's in use thermal comfort risk assessment required based on employee satisfaction survey, upon which action may need to be taken.	*Supporting Vulnerable People Before and During a Heatwave - Advice for Care Home Managers and Staff 2010*
	Building Act 1984	*Building Regulations 2010*	*Approved Document F 2010 Approved Document L2B 2010*	Yes	- If carrying out major refurbishment work or for extensions		
Schools (new)	*The Education Act 1996*	*The Education (School Premises) Regulations 1999*	*Building Bulletin 101 2006*	To be superseded by output specifications for new Academies now drafted by Partner-ship for Schools	- Minimum quantified ventilation and overheating requirements	Yes. - Employer's in use thermal comfort risk assessment required based on employee satisfaction survey, upon which action may need to be taken. - Design stage risk assessment required according to *BS 8213 – 1: 2004 Windows, doors and roof lights – Part 1: Design for safety in use and during cleaning of windows, including door-height windows and roof windows –*	*Looking after Schoolchildren and those in Early Years settings during Heatwaves: Guidance for Teachers and Other Professionals 2009* *Looking after Schoolchildren during Heatwaves: Background*

Sector	Act	Regulations	Statutory Guidance	Still in force?	Notes	Are the Workplace (Health, Safety and Welfare) Regulations 1992 as Amended applicable?	National Heatwave Plan - relevant sector guidance
						code of practice. This may limit window opening sizes with mechanical restrictors.	*Information 2009*
	Building Act 1984	*Building Regulations 2010*	*Approved Document F 2010* *Approved Document L2A 2010*	Yes	- Solar gains should be limited		
Schools (existing)	*The Education Act 1996*	*The Education (School Premises) Regulations 1999*	*Building Bulletin 101 2006*	To be superseded by output specifications for new Academies now drafted by Partner-ship for Schools	- Minimum quantified ventilation and overheating requirements - If major refurbishment work	Yes. - Employer's in use thermal comfort risk assessment required based on employee satisfaction survey, upon which action may need to be taken.	*Looking after Schoolchildren and those in Early Years settings during Heatwaves: Guidance for Teachers and Other Professionals 2009* *Looking after Schoolchildren during Heatwaves: Background Information 2009*
	Building Act 1984	*Building Regulations 2010*	*Approved Document F 2010* *Approved Document L2B 2010*	Yes	- If carrying out major refurbishment work or for extensions		

Appendix 2

Document produced by ACN to summarise the key, relevant, bullet points from each project relating to the ACN October 2011 overheating meeting

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ACN meeting: Overheating in cities and neighbourhoods
London City Hall, 6 October 2011

Urban Heat Island effect and health implications

LONDON

- London experiences a significant Urban Heat Island (UHI). Modelling work undertaken in the LUCID project suggests that a UHI intensity of 5°C during the hours after sunset may not be uncommon. (LUCID)
- Temperatures may vary considerably (3-4°C) over relatively short distances (i.e. a kilometre) within urban areas due to the different thermal properties of the land use types, as well as the varying morphology. (LUCID)
- Anthropogenic heat emissions affect local temperatures. For example, within tens of metres of roads, temperatures may increase by a several degrees due to heavy traffic. (LUCID)
- Anthropogenic heating also appears to increase the magnitude of the urban heat island at the city scale – up to 2°C at night. (LUCID)
- The most intense UHI is observed on calm nights with clear skies. Advection of cool rural air changes the urban heat island pattern on windier days and distributes heat within London. (LUCID)
- The current greening in London reduces the night-time temperatures by up to 2–3°C. (LUCID)
- The urban land-surface fractions and its scale and distribution set the urban heat island magnitude and structure. (LUCID)
- The UHI currently has a significant net energy benefit for London. The urban heat island was found to be responsible for a 13% decrease in the average annual household primary fuel space heating load. (LUCID)
- This energy balance will depend critically on future uptake of air conditioning. (LUCID)
- London's dwellings are vulnerable to heat. For example, monitoring of 36 London dwellings during a hot spell demonstrated that night time. (LUCID)
- Urban heat island of London in the summer peaks at night, with an average magnitude of order 2°C. (Met Office)

Urban Heat Island effect and health implications

MANCHESTER

- Even in Manchester there is a UHI effect, summer maximum dry bulb temperature 8°C, winter maximum dry bulb temperature 10°C but much less frequent. (SCORCHIO)
- UHI effect must be included in building, local area design modelling and Design Reference Year and new Design Summer Year possible for simulation. (SCORCHIO)
- Radiant temperature UHI effect (from plane or satellite measurement) about twice as large as DBT UHI effect, implications for condensers. (SCORCHIO)

HEALTH IMPLICATIONS

- Heat-related mortality risk appears to be greater in postcode areas with high average building height. (LUCID)
- It is unclear whether those living in city centres show the same temperature-mortality relationship but if so, the UHI would have substantial impact on the burden of heat-related mortality. (LUCID)

CLIMATE CHANGE PROJECTIONS

- Simulated change in the urban heat island magnitude for London in an ensemble of 11 regional climate models is less than 0.1°C. In other words, all things staying the same London warms at same rate as rural in response to climate change. (Met Office)
- Projected change in mean summer (JJA) temperature by 2050s spans range 1.1 to 5.2°C. Summer daily maximum temperature change 1.2 to 7.3°C (source UKCP09). i.e. uncertainty in climate projections is larger than UHI magnitude. (Met Office)
- ARCADIA weather generator improves representation of extreme events and spatial coherence. (Met Office)
- The higher temperatures in cities mean that exceedence of specific temperature thresholds will increase more rapidly in response to the same rate of warming. i.e. the presence of the UHI will result in more additional heatwave events per degree of warming. (Met Office)

Interventions at building level

- Wall and floor insulation levels appear to be positively correlated with internal temperatures, with wall insulation having the largest impact of all measures. On the other hand, roof insulation was shown to be generally beneficial for the alleviation of overheating. (LUCID)
- There is a significant impact of very local microclimatic effects on internal temperatures. Should we be using more 'local' weather files for compliance purposes? (LUCID)
- It is found that for each 1°C rise in external temperature, the peak cooling load for air conditioning increases approximately by 10%, the chiller power by 14% and fan power for distribution by 30–50% whereas peak heating load for a boiler, radiator heating reduces by about 5% and average loads reduce by about 8%. (COPSE)
- The adoption of adaptive comfort criteria markedly reduces the need for additional cooling capacity and also the cooling energy. Indeed, this move may allow policy makers to mandate design or retrofit measures that do not include the use of mechanical cooling. This is advantageous not only because of reduced investment and emissions, but also because in urban areas less heat will be discharged to the external environment. (COPSE)
- Advanced building designs using computational fluid dynamics can improve the perceived comfort of dwellers even at higher temperatures. (ARCADIA)
- Construction type, occupancy and orientation of dwellings have a significant impact on overheating exposure, where elderly residents in a top floor flat could experience over 8 times the overheating exposure of a family in an end terraced house. (CREW)
- Occupancy is important for choice of intervention too: what works for the average family may not work for the elderly. (CREW)
- Above certain cost levels (£3-£8k for some house types) there is a diminishing return in both overheating performance and energy use reduction. (CREW)
- Passive measures could be sufficient for elimination of overheating. (CREW)
- An interactive presentation tool has been developed to allow rapid and informative interrogation of the research results. (CREW)
- Prototype presentation tool for rapid access to guidance information.
- An interactive presentation tool has been developed to allow rapid and informative interrogation of the research results. (CREW)

Interventions at neighbourhood level

- 86% of England's population lives in suburban areas, hence the suburbs should receive more attention in terms of adaption and mitigation. The focus of much research and policy has been the central area of cities. Suburbs are where the domestic life of the population will be most affected. (SNACC)
- The physical fabric of suburbs: the type of homes, the mix of uses, the proportion of garden and open land and so on needs to be adapted and managed to more livable and to mitigate against future climate change. (SNACC)
- However, the variety of actors responsible for suburban adaptation and mitigation means that implementing change is complex. Suburbs are relatively static environments, although incremental changes can have an impact over time. (SNACC)
- The response capacity of suburbs varies. It is a function of many things including the existing physical characteristics of the suburb, socio-economic conditions, the governance context, differing knowledge of and attitudes to change (and risk), and the cultural context. (SNACC)
- Mitigation and adaptation need to be considered simultaneously: as do all climate-related impacts. An adaptation that is good for heat stress may not be good for flooding or mitigation, for example. If we are adapting built environments we need to 'get it right'. (SNACC)
- We have identified (from a literature and policy review) a large number of adaptations (approx. 100) that could be made to the physical environment – at three scales (home, garden and neighborhood). We are now testing (via modeling, visualization and stakeholder input) which of these adaptations are effective, acceptable and feasible. (SNACC)
- Adapting suburbs is not just a technical 'retrofit' problem: it requires socio-technical knowledge and long-term strategies related to urban design, planning and community development. (SNACC)

Interventions at city level

- Scattered greening cools London at night. (LUCID)
- Street canyons not as important as we previously thought. Here large Manchester canyon dry bulb temperature 2°C higher than nearby Manchester urban area which is 5°C above the rural dry bulb temperature. (SCORCHIO)
- City ventilation important in reducing UHI effect. (SCORCHIO)
- Trees better than grass for reducing UHI effect and trees provide shading. "Blue" areas important. (SCORCHIO)
- A move to electric vehicles and/or significantly decreased traffic reduces noise to levels at which dwellers feel better able to cool buildings by opening windows rather than using artificial ventilation systems. (ARCADIA)
- A zero-energy London (i.e. no waste heat release from buildings, traffic, people, etc.) would reduce average summer UHI magnitude by approximately 0.3°C (15% reduction). (Met Office)
- A double-energy use London would increase average summer UHI magnitude by approximately 0.3°C (15% increase). (Met Office)
- Removal of all green space in London would increase average summer UHI by approximately 0.9°C (45% increase). (Met Office)
- Double green space in London would decrease average summer UHI by approximately 0.7°C (35% reduction). (Met Office)

Interactions between building and city form

- Building form has the potential to change the urban heat island up to 1°C when altered at the city-scale. (LUCID)
- The thermal quality of dwellings seems more important than the location in the UHI in term of influencing internal temperatures. (LUCID)
- Green roofs are demonstrated in cities such as Tokyo to provide a several degree C cooling effect in summer for the local climate, reducing energy use for cooling. (ARCADIA)
- Reflective roof materials should replace absorptive materials to increase the albedo of roof surfaces, reducing the heat island effect. (ARCADIA)

Appendix 3

SNACC project - Prepared by Rajat Gupta

1. How exactly do we define the issue of overheating?

Overheating can range from thermal discomfort to conditions which may cause heat stroke or death. Both SAP and CIBSE quantify the potential for overheating and we have not specifically endorsed any measurement of overheating yet.

2. What exactly causes overheating?

Heat usually moves toward cooler air through both transfer through materials or air infiltration, therefore overheating in a room (for example) can occur in the following scenarios:

a) the heat cannot be transferred through the material because the temperature of the material is warmer on the opposing side
b) heat transfer through the material is slower than heat gain (through such sources as solar gain through windows, equipment/body heat, etc)
c) infiltration cannot displace the heat because the infiltrating air is actually warmer, or
d) the infiltration rate is too slow as opposed to the rate of heat gained in the room.

This overheating is of course relative to the thermal comfort of the occupant.

3. Which sectors of society are most vulnerable from overheating and what exactly is the scale of the problem?

Physically or mentally disabled and those that rely heavily on medication. Those who live in modern purpose built flats(?) We do not know the scale of the problem (yet?)

Flats with mechanical ventilation and heat recovery systems and lack of openable windows.

4. Given how the nature of policy-making is changing what would be the best way to address overheating if it were found to be a serious problem?

Immediate change: incorporate adaptation measures, particularly shading, to the new build and retrofit agenda.

5. What are the costs/benefits of possible solutions?

Refer to the following reports:
http://www.london.gov.uk/trccg/docs/pub1.pdf
http://www.theccc.org.uk/reports/adaptation/2nd-progress-report-2011

Appendix 4

CREW project - Prepared by Li Shao and Stephen Porritt

Points relating to the specific questions:

1) Definition

This has been the subject of quite a few discussions recently. The current heat wave warning thresholds are not adaptive, so may not be suitable as the climate warms. Also, different buildings will have very different indoor temperatures for the same outdoor temperature.

It may be better to consider overheating in terms of heat stress temperatures, which vary for different types of people (lower for the elderly).

2) What causes overheating?

Two most significant causes are solar gains and poor ventilation:

- Poor protection from solar gains, e.g. unshaded south and west-facing windows; and east facing windows for rooms occupied in the morning, such as elderly homes.
- Modern highly insulated and airtight homes without solar protection and adequate ventilation provision

3) Sectors of society and scale of problem

The elderly and infirm are particularly vulnerable as they occupy dwellings during the hottest parts of the day (and lower heat stress tolerance than healthy adults).

Top floor 1960s flats can experience over 6 times the overheating of ground floor flats, depending on orientation, and almost 9 times that of Victorian terraced houses.

4) How to address overheating

Given the coalition Government's desire to reduce regulation it will be difficult to add anything to building regulations for existing dwellings.

External shutters consistently rank as the most effective measure and should be integrated in future window design and installed systematically at the time of window replacement. The only exception is the Victorian Terrace with solid walls transmitting solar heat inwards. External insulation with light rendering is most effective; this should be combined with external shutters for windows.

The CREW results demonstrate the value of behavioural (zero cost) adaptations including window opening, night ventilation and closing curtains during the day. Perhaps more advice could be given when hot weather is forecast, in addition to the heat wave plan - e.g. advice at the end of weather forecasts?

Encourage housing decision-makers to use tools such as the CREW retrofit advice web tool to plan refurbishment strategies (but difficult to make them use it if there is no regulatory pressure for the required change).

More advice could be given to councils to ensure that the most vulnerable are not housed in the worst dwellings for overheating – e.g. avoid putting elderly residents in top floor flats. Again the CREW web tool could be used to assess the overheating risks of councils' housing stock.

5) Costs/benefits

As mentioned in point 4, overheating reduction can be achieved through behavioural change with no cost.

Integrating adaptation and mitigation in retrofit design is essential. This is important whether the retrofit was initially for mitigation or adaptation, and it is important for both performance and keeping costs to a minimum.

Subsequent retrofit to correct overheating resulting from retrofits which address only mitigation/carbon reduction would incur extra cost, and could defeat the original mitigation aim (e.g. if A/C is installed as happened often). Likewise, retrofits that only consider adapting to future hotter summers may require further corrective retrofit to resolve extra carbon emissions in heating season. The corrective retrofits, if carried out in the same approach that separates adaptation and mitigation, could result in a vicious circle.

The CREW web tool allows selection of interventions can also reduce summer overheating as well as annual heating energy use - it is important to consider year round performance when making retrofit decisions.

It is also possible to substantially reduce overheating and energy use at moderate cost. For example it would cost about £3k to reduce overheating by 85% for a 3-bed 1930s semi-detached house, and £10k for 97% reduction, with reduction in winter heating too in both cases (10% and 30% respectively).

Higher cost adaptations produce a diminishing return in both reducing overheating and space heating energy use.

Appendix 5

SCORCHIO project - Prepared by Roger Courtney

How exactly do we define the issue of overheating?

I suggest that we need to define overheating in different ways according to the main area of concern. This means (a) for most non-domestic buildings, in relation to comfort and its implications for the effective discharge of whatever activity is carried out in the building; (b) for housing, having some ‘desirable’ range in relation to comfort but also some more ‘absolute’ criteria which relate to health impacts, and possibly (c) some intermediate approach for hospitals where there are both activity and health dimensions.

It would seem to me that the adaptive comfort algorithms best represent the present state of knowledge in relation to non-domestic buildings, particularly since they allow for different sensitivities of occupants and may therefore cover case (c) above. I am less convinced about their relevance to housing, where night-time temperatures may be more significant, and would then look to whatever conclusions can be drawn from health-related studies as a basis for setting overheating criteria.

Given how the nature of policy-making is changing what would be the best way to address overheating if it were found to be a serious problem?

There are clearly several different policy contexts. For a start, planning, Building Regulations and policy in relation to the current stock, notably aimed at reducing GHG emissions. Hence it would be helpful to classify proposed measures according to the context.

Many technical measures relating to area policies and individual buildings could be promoted through policy changes and the ARCC studies will inform these. Several broader issues should, though, be considered:

a) Some aspects of policy, which previously have been uniform across the country, might now be location-dependent (and thus consistent with the ‘localism’ agenda). I am thinking particularly to Building Regulations. It is clear that overheating risks, even under future climate scenarios, are primarily a matter for the southern half of the UK and a complementary consideration is that heating requirements vary considerably from north to south. So rather than stipulating technical measures (e.g. minimum U values) which are the same across the country we should be stipulating outcomes but at the same time ensuring that all the relevant factors (e.g. location within an urban area) are taken into account when assessing these.
b) In a future where there is likely to be surplus renewable energy supply capacity in summer, modest use of air-conditioning would not increase emissions, nor require extra investment in generating plant. So measures to address overheating need to be set within a plausible supply context, in order to avoid unnecessary investment in reducing summer-time loads.