Department for Communities and Local Government

Investigation into Overheating in Homes

Analysis of Gaps and Recommendations

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: Literature Review* has also been prepared by the same consultants and has been published separately by the Department for Communities and Local Government.

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Executive Summary

1. A project has been undertaken to investigate the issue of overheating in residential buildings for the Department of Communities and Local Government (DCLG). DCLG is concerned to understand current risks of overheating in existing and new build dwellings; how these risks may increase or decrease following action to mitigate carbon dioxide emissions through better energy efficiency; and how they are likely to change with the move towards zero carbon new homes from 2016. Both current and predicted climatic conditions are included within the project scope. The work has been undertaken by a consortium of AECOM (consulting engineers), London School of Hygiene and Tropical Medicine, and University College London.

2. The first output from the project, published alongside this report and titled Investigation into Overheating in Homes: Literature Review, summarises the relevant published literature and outlines current ongoing research.

3. This report describes the subsequent gap analysis which identifies where there are aspects of the topic which are not sufficiently understood to enable any potential policy decisions to be made with confidence. The following elements of work are included in this report:

    - A description of the ideal world in terms of capability needed to answer the key policy questions (described at the start of Chapter 2)
    - From this, each element is reviewed in terms of whether it is currently fully understood or not; this results in the gap analysis (the main subject of Chapter 2)
    - Building on these gaps, in Chapter 3, the shortfalls are discussed further, and proposals are developed regarding how these could be addressed
    - Whilst the focus of this work is on direct health impacts, comfort is linked to health, and a brief summary of comfort issues is given in Chapter 4
    - Finally Chapter 5 pulls together the findings of Chapter 3 in terms of the potential next projects, and identifies which actors might be best placed to take them forward.

4. The two reports conclude the commissioned work from this consortium.

5. At this point in time there is significant work being undertaken in many of these areas, but there will be benefit from DCLG and DECC becoming involved in steering future work, funded by themselves or others, to address areas that will inform their potential future policy choices.

6. This document sets out two different types of gaps in knowledge and the associated future actions to help to fill these gaps.

7. The first group addresses the substantial gaps in knowledge which would require significant research activity to improve our fundamental understanding of health issues around heat, and the real performance of buildings. These are summarised in the table below.

Gap description	Response
Health	
Lack of understanding of the link between adverse health effects and *indoor temperatures* plus other environmental factors	Extensive measurements or reverse modelling
Lack of link between housing, interventions (technical & behavioural) and health for different climate scenarios	Either large scale study or models based on other work
Behaviour	
Lack of evidence on behaviour within a dwelling to avoid overheating	Studies of behaviour in high temperature episodes **or** opportunistic & targeted research
Building data	
Stock models incomplete	Build on English Housing Survey and use it to test and improve stock models. Undertake large-scale monitoring and data gathering campaigns
Lack of standardised methodology and inconsistent model inputs	Standardised approaches to modelling to enable comparison across research. Study and consultation to agree on model structures and use of climate files
Comprehensive model	
Absence of fully integrated model	When components are ready build linked model of stages of the process
Cost benefit analysis and impact assessment	
Insufficient use of models to establish cost benefit analysis of different measures	Apply best available models onto options, and cost the interventions. Look wider at additional non-climate change/carbon benefits
Guidance	
Guidance for a range of audiences is needed	Advice and guidance targeted at specific audiences

8. The second group encompasses a number of potential activities that could help inform decision making in the near term:

- A structured review with stakeholders of their experience of overheating in existing and new build homes, to help evaluate the extent to which it is a real problem today.
- Integration of current efforts to gather monitored data from homes, and in particular to try to ensure that opportunities to build on and extrapolate from the work of others are not missed. It may prove possible to extend the scope or time period of some projects to enhance their usefulness with respect to information on overheating, rather than simply benefits during the heating season.

- A review of whether specific technologies are causing problems of overheating, such as inappropriate or improper use of mechanical ventilation with heat recovery or poor insulation of district heating distribution pipework.
- Updating of the literature review and learning from other research projects as they emerge.
- Review of whether advice and recommended actions suggested as part of the emerging Green Deal retrofitting initiative in respect of minimising heating energy are at risk of creating overheating problems.
- Development of a simple checklist and a design tool and agreement on future climate data to use in modelling studies.

1. Introduction

1.1 A project has been undertaken to investigate the issue of overheating in buildings for the Department of Communities and Local Government (DCLG). DCLG is concerned to understand current risks of overheating in existing and new build dwellings; how these risks may increase or decrease following action to mitigate carbon dioxide emissions through better energy efficiency; and how they are likely to change with the move towards zero carbon new homes from 2016. Both current and predicted climatic conditions are included within the project scope.

1.2 Because of the concerns over vulnerable groups, particularly the elderly and sick, considering "buildings where people live" includes residential provision beyond homes. The social policy to assist the elderly to remain living in their homes as long as possible is also relevant.

1.3 The ultimate purpose is to inform the action that DCLG might take in respect of minimising overheating risks to health and to identify the areas about which the Department should liaise with other Government Departments and agencies. Such parties would include the Department of Energy and Climate Change (DECC), the Department for Environment, Food and Rural Affairs (Defra), the Department of Health (DoH) and the Health Protection Agency (HPA).

1.4 AECOM (a multi-disciplinary consultancy) were the Project Managers and have co-ordinated a consortium incorporating the London School of Hygiene and Tropical Medicine (LSHTM) and University College London (UCL) to deliver the project. The relevant aspects relating to overheating are listed below, showing which consortium member has led the review:

- The relationship between indoor temperature and health - LSHTM
- Building physics: how buildings modify external conditions, and the relationship between modelled and monitored results - UCL
- Behaviour: how occupants and building managers modify environmental conditions through their behaviour to prevent, reduce or better tolerate overheating (and how this interacts with the characteristics of the building) - AECOM
- Definitions: current definitions of overheating and acceptable conditions - AECOM
- Policy: current policies and applicable regulations – AECOM
- Technical interventions - AECOM
- Stakeholder views: what are the concerns of those involved in building and managing dwellings – AECOM

1.5 Because of the area of DCLG's policy responsibility, the 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. 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. It is also likely that comfort is a key driver of behaviour in buildings, which itself will have consequences for the indoor environment and health.

1.6 The project had two parts:

- A review of the existing literature and ongoing research to identify the available information and the likely forthcoming results arising from current programmes.
- Identification of any gaps in the existing evidence, leading to recommended actions to fill them.

1.7 The first part, titled Investigation into Overheating in Buildings: Literature Review, has been published by DCLG alongside this report DCLG in early 2012. The findings from the literature review are the focus of this report: setting out a vision of perfect information upon which to base any potential policy decisions; identifying the key gaps which mean this perfect information is not currently available; and describing the possible types of research that may be needed to address the gaps. It also discusses the potential routes to carrying out this research, i.e. which elements might be funded by different stakeholders, and which, if any, might logically belong to DCLG. This report concludes the currently commissioned project.

2. Gap analysis

2.1 To produce the gap analysis, building from the literature review, the approach taken was to set out the information that would be available to inform decisions in an ideal world, and to compare this to the findings from the review. The review encompassed published literature and current research, and the concerns which were expressed by stakeholders when interviewed. On the assumption that the information needed is not all available, gaps in knowledge can then be identified. This analysis identifies what action could be taken to fill the gaps and which parts might be appropriate for DCLG to undertake. The work for DCLG has focused on health, but a short section has also been included on comfort and the actions the Chartered Institute of Building Services Engineers (CIBSE) is undertaking, because the comfort of individuals and their overall satisfaction with their homes is also of interest to DCLG.

2.2 This chapter first sets out the overall vision, in paragraph 2.7 the highlighted gaps in knowledge are summarised, then we present more detailed discussions in the following chapter.

What would "perfect information" look like?

2.3 To be able to make interventions and\or policy decisions relating to overheating in places where people live, it would be ideal if all of the following were to be in place:

i. A good understanding of the relationship between health and indoor temperatures (and other relevant environmental conditions).
ii. A good understanding of the impact of behaviour on this relationship (to prevent, modify and/or tolerate the overheating) and the interaction with building characteristics. This should cover a better understanding of how much impact behaviour in its different forms has on overheating, and how it can be influenced.
iii. Validated models (based on good quality measured data) for individual dwellings to understand how buildings modify external environmental conditions for a range of occupancy patterns and behaviour.
iv. Validated dwelling models to understand the variation of internal environmental conditions – impact of orientation, location within a building, local factors (including urban heat island effect) and regional climatic factors.
v. Validated dwelling models to understand the impact of a range of interventions to reduce overheating risks – technical and behavioural interventions and the interaction between the two.
vi. A validated model (based on good quality measured data) of the housing stock (including care homes) to predict indoor environmental conditions across the stock, building on (iii, iv and v) above, for different future climate scenarios (temperatures + other factors).

vii. Agreed definitions (as a set of equations) of the relationship between health events and indoor temperatures.
viii. A combining of the housing stock and health models into a complete model to enable the prediction of the impact on the population's health (vulnerable people and others), energy use and the carbon impacts of a range of interventions (design, retrofit, including mechanical cooling, and behaviour) for different climate scenarios.
ix. Agreed methods to apply costs to benefits and interventions to enable Cost Benefit Analysis (CBA) to inform potential policy and design decisions.
x. A plan for action.

Note, although items iii, iv and v have been described separately, the ideal scenario is that one model that would address all of these issues in an integrated manner.

2.4 Once the evidence base is in place, and CBA has been undertaken, it will be important to determine who should take what action, in terms of interventions of any type. These could include regulation and guidance (targeted at a range of audiences) and consideration should be given to dissemination and communications as well.

Key strategic gaps

2.5 The vision outlined above expresses a set of interlinked tools and knowledge. Drawing on the literature review report and discussions within the project team it is clear that these elements are not all in place, although some are available/advancing and there is understanding to some extent of each.

2.6 Therefore we have identified where knowledge is lacking, and where it may be appropriate for further work to be carried out to support decision making.

2.7 The following issues have been identified as strategic areas where there is a gap:

a) The link between indoor temperatures and health impacts (item i) and a set of definitions/equations to convey this (item vii). There are also the issues of peak day-time temperatures, minimum night-time temperatures and sustained heat events to be considered.
b) Understanding of the significance of other indoor climate factors on health (item i).
c) How behaviour impacts on temperature (and other internal environmental conditions if relevant) and on health outcomes (item ii) and how these relationships depend on the characteristics of the building. These characteristics include the facilities available to control indoor temperature, the location (vertical position) of the dwelling and the local availability of cooler spaces.
d) An agreed set of inputs for modelling and measurement studies, including future climate predictions, to ensure consistency and enable comparison between research findings which focus on different aspects – comparison

between studies looking at the same aspects, as well across aspect areas (item iii - behaviour, item iv – local factors, and item v - interventions).

e) Full confidence in stock models – because of their scale, there is a lack of calibration / validation of these. More data is being collected but there is still a need for large-scale monitoring and data gathering campaigns, so that validation may be more practical (item vi).
f) The availability of a comprehensive model, with stock, occupant information (including health), interventions (technical & behavioural) and climate scenarios enabling analysis (item viii).
g) Cost benefit analysis of the possible interventions, recognising the benefits in terms of reducing overheating risk and other consequences – e.g. better security, reduced daylighting (item ix).
h) The application of impact assessment analysis, taking into account costs and risks (item ix).
i) Overall co-ordination of different components of the analysis and policy making process, and an agreement as to who should lead each activity (a combination of Government policy and solutions from industry), resulting in a plan for action (item x).

2.8 This project has also resulted in some specific topics being identified as areas where more work is needed. These are listed below, with the corresponding item number from section 2.3:

j) There is a no simple tool for predicting overheating: SAP is not appropriate. SAP is the compliance tool for Building Regulations Part L1 to predict energy use and resulting CO2 emissions and to compare this to a target (DER vs TER). However, it has become a surrogate design tool as well. SAP includes a means of determining overheating risks but as a monthly average model, which uses annual energy data, it is not considered to be an adequate tool to assess overheating risk at the design stage and nor is it intended to be (items ii, iv and v).
k) There is a need for a better understanding of the use of mechanical ventilation with heat recovery (MVHR): how well is it working? Generally is there a good understanding amongst designers, specifiers, house builders, housing managers and occupants about what its purpose is, how to use the controls and whether heat exchanger summer bypasses are fitted and used? What are the maintenance issues? (items ii, iii, iv and v).
l) There is a need for a better understanding about community heating and whether its use is inadvertently leading to unwanted summer heat gains within corridors and adjacent accommodation. This issue was raised in the stakeholder discussions rather than appearing in the literature review and it needs to be investigated further to understand the overheating risks from poor design and/or installation, the relationship with ventilation within corridors, and with ventilation onto corridors for single aspect dwellings (item iii).
m) 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. There may be further work to do once a better understanding on the links between energy efficiency upgrades and

overheating is established (items ii, iii, iv and v, and item x). The issues relate to the potential to increase overheating risk as a result of an energy efficiency measure/s; ensuring consideration of ways in which measures to combat overheating can be considered in tandem with measures to reduce heating requirements to provide the best overall outcome for the intervention; the assessments that Green Deal assessors may need to undertake; and the advice the Green Deal assessors can provide to owners and occupiers.

n) There is a need for a better understanding of the extent to which overheating is a problem today, both in new and older homes. There is a lack of evidence of the problems from measurement rather than from anecdote, and further evidence is needed to ensure the correct preventative action can be taken.

3. Discussion of strategic gaps/research requirements

3.1 This chapter builds on the gaps identified in paragraph 2.5 and suggests activities to address the current lack of knowledge or tools.

Health – gaps and recommendations

3.2 There is very little epidemiological evidence on the link between indoor temperature and other variables and the risk of adverse health outcomes, and thus no adequate basis for the definition of overheating in dwellings in terms of the likelihood of the occurrence of heat-attributable mortality and morbidity (gap a and b).

3.3 The primary reason is the lack of data on indoor (as opposed to outdoor) temperatures, which means there are insufficient data to classify, and thus to compare, indoor temperatures on days when people do and do not suffer adverse health events. It is relevant also to note that most heat-attributable health events are not readily identifiable as heat-related from the clinical circumstances. The attribution of heat-related is purely statistical based on the observation that a greater frequency of adverse events occur on days of high temperature compared with days of lower temperature, after controlling for other time-varying risk factors. This means that any epidemiological study cannot readily identify those who suffer an adverse health event because of heat, and so requires analysis of all health events, with evident implications for study size.

3.4 The problem is more complex still because air temperature alone is only one of the factors that determine the heat balance of individuals, the other factors being radiant energy, humidity, air movement, clothing levels, and, crucially, the level of physical activity (metabolic rate) of the individual.

3.5 There is evidence on how thermal comfort and selected physiological responses relate to ambient temperature, but there is no direct translation between these relationships and risk of clinical impact, even though it is reasonable to assume some broad association. Although it would be possible to define overheating in relation to thermal comfort, such a definition would not provide a useful measure of clinical harm or enable costs to health and the health service to be quantified.

How can this evidence gap be filled?

3.6 The “gold standard” would be to have sufficient intensity of indoor temperature monitoring that comparisons could be made of indoor temperatures when individuals do and do not suffer clinically important adverse events. The difficulty is

that hundreds of thousands of homes would have to be monitored as even common adverse events are relatively rare, and thus many dwellings would have to be monitored to ensure capturing enough data when people do suffer adverse events. And, as indicated above, during periods of heat, only a modest proportion of those who suffer adverse events do so because of the heat.

3.7 Given the practical difficulties of monitoring a very large number of homes, an indirect approach might be to attempt to reconstruct indoor temperatures for people who suffer adverse health events using building physics modelling. This also entails considerable challenges to ensure dwelling characteristics are specified with sufficient detail that models can provide reliable classification. Model validation is also needed. Moreover, for any individual dwelling, a critical but usually unknown factor is behaviour: how individuals use a building, for example in relation to window opening, can substantially influence indoor temperatures. This means it is not possible to reconstruct temperatures for any individual dwelling with certainty, but it is in theory possible to model likely average indoor temperatures (under assumptions of typical behaviour), and from this to establish an indoor temperature-health risk relationship.

3.8 A more practical, and arguably more useful, approach is not to attempt to characterise indoor temperature itself, but rather to determine the characteristics of homes that appear to protect against the association between high outdoor temperature and adverse health events. The principle is straightforward, but there are many complexities, which are currently being explored in the NERC-coordinated AWESOME project (Air pollution and WEather-related health impacts: methodological Study Of Multi-pollutant Exposures). The approach is to attempt to classify or rank dwellings according to the degree to which indoor temperatures increase during a period of outdoor heat. This first entails building physics modelling to explore the indoor temperature characteristics of different types and forms of dwelling under different weather (outdoor temperature) conditions. Evidence from such modelling, suitably validated, then needs to be linked to data on actual building stock to which health records can also be linked. With dwellings classified with regard to their ‘overheating potential’, analyses can then be made of the relationship between outdoor temperature and health (mortality, hospital admission etc) to attempt to quantify the degree to which the temperature-related health risks vary by dwelling type. This approach is simpler in many respects as it based on the study of the outdoor temperature-morbidity/mortality relationship examined in relation to the type and characteristics of the dwellings in which people live. No direct measurement or modelling of indoor temperature is entailed, but all dwellings need to be classified according to their likely indoor temperature characteristics. Thus, it would not provide direct evidence about the risks associated with a specific indoor temperature, but it could indicate the degree to which heat-related health risk may be modified by dwelling characteristics – which, in fact, may be more useful for policy development, as it would indicate the variation in risk in relation to particular design and construction characteristics under the usual range of population behaviour. Armed with appropriate model-based evidence about indoor temperatures, it would also be possible to target selected dwellings for measurements of temperature and human responses (in terms of comfort, physiological outcomes). Evidence of this kind is currently being

explored through the NERC-funded AWESOME project, but should be taken further.

3.9 There is almost no direct empirical evidence on the degree to which housing interventions alter the risk of heat-related mortality or morbidity. Knowledge of how heat-related risks may be modified by building adaptations is highly relevant for potential policy and would be more directly useful than simply defining the level of health risk associated with a given indoor temperature (to inform gap f).

3.10 To answer this question directly would require either a (large scale) intervention study/trial or a well-controlled observational study of the effect of a programme of housing adaptations (a 'natural experiment' study). The required study size is a major barrier to such investigation.

3.11 Indirect evidence could be obtained if (i) there were clear evidence on the link between indoor temperature and the risk of adverse health outcomes (gap a) and (ii) models or measurements could establish how building modifications alter indoor temperatures. Step (ii) is relatively feasible, so reasonable understanding of the likely effect of building modifications on health would be possible if gap a) were adequately addressed using approaches outlined above.

Behaviour – gaps and recommendations

3.12 There is a lack of evidence on what residents (and carers) actually do in their homes and to their behaviour to avoid or reduce summer overheating, or how this behaviour is determined by the temperature, the characteristics of the residents and residence, or other factors (gap c).

3.13 Under any given summer outdoor conditions, the environment inside residences will vary widely. This can be attributed partly to differences in building characteristics and facilities. However the behaviour of residents also has a critical role in determining the hygrothermal conditions created in particular premises (e.g. through use of windows and shading) and the impact of those conditions on the residents (e.g. because of choices about clothing, activities, and where to spend periods of high temperature). While the effects of such behaviour on heat stress can be modelled, this can currently be done only by making assumptions about what people actually do. This has three important implications:

- predictions of actual risk of overheating are likely to be in error (in general and as applied to particular groups of people or residences)
- it is not clear what changes in building design would best support more adaptive behaviour (or not promote maladaptive behaviour)
- any guidance given to people on behavioural means of reducing risk may be flawed or inappropriately focused.

3.14 In addition, based on current projections of climate change, there may be a point in the future at which the optimal behavioural response to high outdoor temperatures will shift during some periods of the year, or on particular days. The residents,

carers and the residences need to be prepared for this. Within this area, developing a better understanding of the drivers and barriers to changing behaviour would assist in devising potential interventions to help encourage the optimal behaviour.

How can this evidence gap be filled?

3.15 The challenge of developing a significant improvement of understanding of behaviour with respect of overheating is that although a comprehensive study of behaviour under high outdoor temperature conditions would provide highly valuable data, it would also be time-consuming and expensive. A combination of opportunistic and targeted research is therefore recommended. It is worth noting, however, that an important objective of building design and adaptation should be to minimise heat-related risks to health under a range of different occupant behaviours as it is reasonable to assume that many people will not behave in optimal ways to limit exposure to heat – because they are not able, through lack of knowledge, or simply because they choose not to alter their habits.

3.16 Opportunistic research would take advantage of research conducted for other purposes, and other data collection mechanisms, to collect data on behaviour and the factors which influence that behaviour. For example, studies monitoring the environment in residences could also use a standardised questionnaire and/or diary to monitor behaviour. Other routes for data collection could include a sample of people in the health and social services professions being trained to interview and advise vulnerable residents, and return of data to a central point.

3.17 Targeted research would be guided by critical decisions that need to be made by DCLG or other parties. Modelling, guided by expert risk assessment, would show whether the impact of a particular proposed change (e.g. in building design, urban planning or advice to residents) would depend on the behaviour of residents or carers. In the extreme, the behavioural response might determine whether the proposed change would substantially increase or decrease the overheating risk. For example, external shutters – used appropriately to provide daytime shading – can substantially reduce overheating risk. Used inappropriately (thereby reducing night-time ventilation) they can substantially increase overheating risk. Targeted research would be important in such cases to quantify impact and to understand how to mitigate risks. Targeted research would also be needed to gather knowledge on barriers to changing behaviour, although this could be considered as additional work on top of other studies.

Building data – gaps and recommendations

3.18 There is a need for further development of ‘stock’ models, in relation to input data, validation and recognition of uncertainties (gap e).

(i) Input data

3.19 The quality of the data required to drive overheating stock models of the approximately 25 million UK dwellings is currently inadequate. The required data include not only those relating to occupant behaviour as noted above, but also detailed knowledge of thermal properties, ventilation systems, window designs, etc.

(ii) Validation

3.20 Models of the dwelling stock offer the potential for powerful analysis of the extent of current overheating and also essential scenario modelling. We can think of such models as being composed of two main elements: 'Building Physics' models and 'Stock' models.

3.21 Building Physics' models operate at the scale of the individual building and provide estimates of energy use and indoor environmental quality (temperatures and pollutant concentrations). The physics components of such models have typically been tested and 'validated' using industry standard methods to the point that for a precisely defined and reliable set of input data the outputs are adequately robust.

3.22 However, as noted above, even for one real building, and certainly at the stock level, there is much uncertainty associated with these inputs. 'Stock models' therefore must be appropriately tested and validated and at present there are inadequate data available for this task.

(iii) Uncertainty

3.23 The currently available deterministic methodologies for understanding overheating performance are not sufficient to correctly assess the variations across the stock. In general, the impact of uncertainty of input data is not being adequately addressed in current modelling.

How can this gap be filled?

3.24 Large-scale measurement and data gathering campaigns are required in order to improve the quality of input data for stock models and also act as validation sets against which such models can be tested. We must develop knowledge and tools that support the use of probability based modelling of the stock to ensure that such models give reliable information about the true spectrum of overheating. Note that there are some relevant studies underway already, particularly the English Housing Survey and so it is important to ensure these exercises are as useful as possible for addressing overheating. There may also be potential routes through the domestic energy assessors involved in future Green Deal work, as they may be able to collect suitable information.

3.25 There is a need for a standardised methodology for the modelling of overheating (gap d and part of j).

3.26 At present, many research groups and practitioners are undertaking such modelling. In the development of the models, these teams are forced to develop their own scenarios for ventilation habits ('optimal' and 'sub-optimal' strategies) etc and thus a set of differing methodologies emerge which make direct and meaningful comparison between studies impossible. There is thus a need for a range/set of 'standard' input parameters and the wider development of a standardised methodology regarding the use of thermal simulation models for the assessment of overheating risk. Such a standardised approach would inform any tool that might be used for compliance purposes.

3.27 Furthermore there is not yet agreement on the climate files to use to model potential future climates, such that future overheating risks can be evaluated.

3.28 These tools are also needed in a form that can be used more easily within building design to replace the SAP compliance tools that are currently sometimes used in design but are not felt to be adequate for the purpose.

3.29 It seems sensible to address this issue via a body of work which would involve engagement and consultation with relevant parties – policy makers, industry, academia, professional bodies etc. Following consultation, a suitably endorsed 'industry standard' document and approach could be produced by a Working Group.

Extent of the current problem of overheating (gap n)

3.30 Although modelling studies suggest that overheating is expected to be a problem, and there is anecdotal evidence of where problems occur, the evidence from buildings is limited.

How can this gap be filled?

3.31 The work required to calibrate both stock and detailed models would provide an excellent level of information on the extent of overheating, but this is likely to take a long period of time. In the short term there is a case for a study to collect and collate the experience that a targeted group of stakeholders have of overheating in homes. This could build on the limited study associated with the literature review for this project, but achieve a more balanced range of inputs and a more significant sample size. It may also deliver useful numerical data where stakeholders may be measuring for their own purposes.

3.32 There is a need for a better understanding of some newly mentioned issues (gaps k and l)

3.33 Both MVHR and district heating are becoming more common in new housing, and some concerns have been identified over whether they are being operated in a way that may worsen the overheating risks.

3.34 Further discussions should take place with the stakeholders who have been engaged in this project, and other housing managers, to ensure a full understanding of particular issues which appear to impact on overheating, but about which there is no published literature to date. This should include the use/misuse of MVHR, and the interaction between unwanted heat gains (such as those associated with pipework for community heating), dwelling temperatures, corridor and stairwell ventilation, heat loss reduction and fire risk. Responsibility for undertaking these discussions and any supporting surveys and/or monitoring will need to be assigned, and reviewing these issues in other monitored projects if applicable would also be advisable.

3.35 There is a need for a robust and pragmatic overheating checklist (gap j and m).

3.36 The key mechanisms associated with overheating at an individual building level have been identified and are addressed in the literature. 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. However a robust and pragmatic decision analysis framework (checklist) to enable the assessment of individual dwellings - which could perhaps be used by a Green Deal adviser for example - does not exist.

3.37 A relatively small piece of work would be required to pull together the evidence in the literature, consult appropriately and produce the checklist. This would also contribute to the development of a design tool.

Comprehensive model - gaps and recommendations

3.38 It is recognised that we do not have all of the input data at present in relation to health impacts, behaviour and the way buildings modify external conditions. A role also exists for a comprehensive model that can take these inputs, when available, and produce a range of technical and behavioural interventions. Ideally this model could consider the impact of the local external climate, as a function of location and orientation, and also future climate predictions (gap f).

How can this gap be filled?

3.39 The scale of this model is probably such that it should be prepared by several academic institutions working together, with funding perhaps by a UK research council and/or with EU funding.

Cost benefit analysis and impact assessment – gaps and recommendations

3.40 The balance will need to be determined between the costs of interventions, whether design-stage, retrofit and/or behaviour-based; and the benefits in terms of

reduced health risks and deaths (gap g), and the use of this in impact assessment (gap h). It is likely that comfort and the reduced use of air conditioning will also be taken into account.

How can this gap be filled?

3.41 Information as to the types of intervention measures which may be employed is already available – external shutters, overhangs, exposed thermal mass etc, and these can be costed for typical dwellings, noting the earlier requirement for standardisation of assumptions. Other measures such as facilitating cross-ventilation through avoiding single aspect dwellings are potentially more difficult to quantify, as there may be an overall reduction in the number of dwellings that can be fitted on a development site as a consequence of such a layout. The cost of bringing about a change in behaviour, and the need for repeated advice, may also be harder to estimate, but information should be available from other public awareness raising campaigns. The value of avoided action, such as avoiding the use of air conditioning is difficult to quantify. It should be possible to start to pull together sources of cost and benefit information, whilst other data-gathering exercises occur in parallel. For impact assessment the unintended consequences of actions need to be reviewed, and the differences in appropriate interventions between homes of different types e.g. older top floor flats where insulation is needed to reduce overheating (keep heat out) rather than new homes where extra insulation may be limiting the outward transfer of unwanted summer time heat gains.

Co-ordination and guidance

3.42 Overall co-ordination of different components of the analysis and policy making, and an agreement as to who should lead each activity (a combination of Government policy and solutions from industry), resulting in a plan for action (gap i).

3.43 Once an internal temperature threshold or set of building characteristics likely to trigger overheating have been determined there needs to be a strategy, clear guidance and resulting actions. The ultimate aims are to establish what Government departments and agencies might do and encourage others to do in relation to the risk of overheating in places where people live (gaps h and i).

3.44 Better cross-Government co-ordination and sharing of information relating to the risks of overheating and potential mitigation may be needed.

How can this gap be filled?

3.45 It is recommended that a coherent strategy across Government should be agreed and implemented to reduce the health impacts of overheating on vulnerable populations.

3.46 As well as communications within Government, there will need to be discussions with industry – both professional bodies and solutions providers, see Chapter 4.

3.47 Finally, we recommend that a range of guidance in a suitable format should be produced targeted at the following groups:

- Designers and building modellers
- Health and social service professionals
- Developers
- Planners and policy makers
- Environmental Health Officers
- Contractors
- Housing advisors (tenants and developers)
- Occupants, building managers and carers
- Green Deal advisors
- Third sector groups

4. Comfort

4.1 This study has been focussed on the health related impacts of overheating, in dwellings and other places where people live. The scope has been restricted, not to indicate that the issue of comfort is unimportant, but in response to a particular area of policy responsibility within DCLG relating to Building Regulations which are mainly in place for health protection. Nevertheless, as comfort issues potentially affect the entire UK population, whereas deaths due to heat may amount to about 1,000 per year, the topic of comfort is discussed briefly below, together with comments on planned activities.

4.2 Comfort is clearly important for a number of reasons:

- Comfort issues may be an indicator of overheating problems that may have health effects in extreme conditions or for the vulnerable.
- A response to internal conditions being perceived as uncomfortable may be the use of air conditioning (fixed or portable) with a resulting increase in energy use and contribution to climate change.
- More generally, comfort is likely to be a key driver of behaviour in buildings, which itself can have consequences for the indoor conditions and health.
- Discomfort at home may lead to a lack of sleep and hence increased risk of atypical behaviour and accidents (inside and outside the home).
- Comfort has a direct impact on productivity and hence on the economy.

4.3 Most work on comfort to date has focussed on the non-domestic sector where the productivity issue is the prime consideration. Comfort standards are widely used in building design, as discussed in the literature review for this study. Nevertheless, partly as there is no legal maximum internal temperature for the workplace, despite there being a legal minimum workplace temperature, there is a view that more work is needed in this area.

4.4 CIBSE runs an Overheating Task Force and this is active at present, aiming to update comfort standards in line with current knowledge.

4.5 A key part of the debate is around the adaptive and deterministic approaches to predicting and understanding comfort. The deterministic approach, as set out in EN ISO 7730 based on climate chamber studies, predicts the proportion of people expected to be comfortable under a given set of conditions. It enables the hours of expected comfort to be predicted from thermal models in a relatively easy way; it is coded into models.

4.6 The adaptive model extends the deterministic approach to include an additional and significant factor in human physiology; our capacity to adapt. It has been observed that people will adapt to conditions based on the trend in conditions in general; and in particular, people become accustomed to hot weather and will report higher comfort levels under the same internal conditions after an extended

period of warmer weather. There is also evidence that people are more comfortable where they have control over the conditions within the building they work in.

4.7 CIBSE are working to see if it is practical to incorporate the adaptive model into their comfort standard. This is not straightforward as it requires more complex modelling to take account of additional factors.

4.8 There is also interest within CIBSE and the Zero Carbon Hub to extend comfort considerations to domestic buildings, and to update the approach used in current overheating calculations, as in SAP for example.

4.9 When looking to co-ordinate the action on health risks relating to overheating, Government should be mindful of CIBSE and Zero Carbon Hub's work relating to comfort and ensure co-ordination of research, analysis and conclusions.

5. Potential routes to carrying out this research

5.1 In this chapter we have extracted a short description of the key areas for action that emerge from the gap analysis (as determined in Chapter 3) and made an initial suggestion as to which organisation(s) might best take them forward to inform further work on this important topic. The first group, in the table below, focuses on the more ambitious long term aim of undertaking significant research to inform decisions and action. A number of near term activities that could inform more immediate actions are outlined after this table.

Section	Gap	Gap description	Suggested response	Potential actor
Health				
3.2	a, b	Lack of understanding of the link between adverse health effects and *indoor temps* plus other environmental factors	Extensive measurements or reverse modelling	EPSRC / other Research Council
3.9	f	Lack of link between housing, interventions (technical & behavioural) and health for different climate scenarios	Either large scale study, or models based on other work	[later stage]
Behaviour				
3.12	c	Lack of evidence on behaviour within a dwelling to avoid overheating	Studies of behaviour in high temperature episodes **or** Opportunistic & targeted research	EPSRC / MRC / ESRC / HPA / DCLG / Defra
Building data				
3.18	e	Stock models incomplete	Build on EHS and use to test and improve stock models. Undertake large-scale monitoring and data gathering campaigns	EPSRC / DECC / DCLG
3.25	d, j	Lack of standardised methodology and inconsistent model inputs	Standardised approaches to modelling to enable comparison across research. Study and consultation to agree on model structures and use of climate files	CIBSE / DECC / DCLG / Defra / TSB
Comprehensive model				
3.38	f	Absence of fully integrated model	When components are ready, build linked model of stages of the process	EPSRC

Section	**Gap**	**Gap description**	**Suggested response**	**Potential actor**
Cost benefit analysis and impact assessment				
3.40	g, h	Insufficient use of models to establish cost benefit analysis of different measures	Apply best available models onto options, and cost the interventions. Look wider at additional non-climate change/carbon benefits	DCLG / DECC, but in several years time
Co-ordination and guidance				
3.40	i	Lack of co-ordination across Government & industry Need for clear messages and guidance for a range of audiences.	A coherent strategy across Government, supported by industry to be agreed and implemented to reduce the health impacts of overheating on vulnerable populations. Advice and guidance targeted at specific audiences	DCLG / HPA / DECC/ HMT / Defra

EA Environment Agency
EHS English Housing Survey
EPSRC Engineering and Physical Sciences Research Council
ESRC Economic and Social Research Council
HMT Her Majesty's Treasury Department
HPA Health Protection Agency
MRC Medical Research Council
TSB Technology Strategy Board

Potential shorter term studies

5.2 A study (see 3.31): a broad structured exercise to gather stakeholder experience on overheating in new and existing homes, to help evaluate the extent to which it is a real problem today. This would focus on the extent of overheating, what is felt to cause it, and what can be done about it. As a part of the literature review study we contacted a limited number of stakeholders to understand their perspective on overheating. This approach could usefully be extended to pick up a broader and deeper sample of stakeholders, and a more targeted approach to building and ownership types. There is also potential benefit from one or more workshops with particular target groups to share information and discuss solutions.

5.3 MVHR (see 3.33): Many modern apartments are built with mechanical ventilation with heat recovery, which is mainly intended to reduce winter heating bills through recovering heat from exhaust air and using it to heat the incoming fresh air. MVHR is necessary in dwellings which have been constructed in a very air tight manner and cannot rely on natural ventilation for incoming air. Whether these systems are causing problems in summer, through incorrect use of the summer bypass, is not understood and a limited survey of installations could help identify whether this is a

problem. The recent Zero Carbon Hub / NHBC Foundation report on Mechanical Ventilation with Heat Recovery in New Homes specifically excludes overheating from its study. See http://www.zerocarbonhub.org/news_details.aspx?article=28.

5.4 District heating (see 3.33): similarly there are anecdotal reports that apartments with communal heating can have problems associated with insufficient insulation or ventilation around the heat distribution, meaning that parts of the building overheat. This has not been reviewed to date that we are aware of, and so a preliminary investigation and limited site surveys would bring valuable information to target potential interventions.

5.5 Monitoring data focused on overheating: Integration of current efforts to gather data from homes, and in particular to try to ensure that opportunities to build on the work of others are not missed (such as extending monitoring in the heat season to the summer as well, and conducting occupant surveys to inform research on behaviour). It may prove possible to extend the scope of other projects to enhance their usefulness. In particular the English Housing Survey (DECC), Retrofit for the Future (TSB) and Building Performance Evaluation Programme (TSB) are all collecting data, but a process of checking for compatibility and requesting consistency of reporting could make the data more useful. At the appropriate time these data could be compiled and analysed; this is potentially best in late 2012 / early 2013 when data for summer 2012 should be available.

5.6 Maintaining current information: Updating of the literature review and learning from other research projects as they emerge is recommended. Clearly any literature review is at risk of being out of date as soon as it is issued, as new material is published. A regular update to the literature review would therefore be appropriate to pick up new knowledge as it emerges, especially in light of the ongoing ARCC funded research. (ARCC – Adaptation and Resilience in a Changing Climate).

5.7 Interaction with the Green Deal: Review of whether recommendations and advice delivered as part of the emerging Green Deal are at risk of creating overheating problems. There are potential risks around the placing of insulation and there may be a need to combine measures to reduce the risk. The Green Deal includes a number of mitigation measures, such as requirements on Green Deal providers ensure that installations do not adversely impact on health, Green Deal advisor standards already ensure overheating is taken into consideration by Green Deal advisors and consumer advice will be provided on broader installation risks. Further work is needed to establish the links between energy efficiency upgrades and overheating in order to identify which buildings are most at risk. This could, for example, maybe result in an overheating checklist to be used within the Green Deal.

5.8 Development of an approach to assessing overheating risk in design (see 3.36): SAP includes an assessment (in Appendix P) but the SAP tool is intended to be used for a compliance assessment rather than as a design tool. A design tool is needed which is not too complex to be affordable in housing design. As part of this an agreed approach to the selection of climate data for the future is also needed; CIBSE are working on this at present.

5.9 Agreement on input data: Linked to the design tool issue is the benefit of agreeing on the data to apply to modelling studies, both in terms of climate data for future studies, and the details of standard building types to be included. CIBSE are working on the weather tape issues, but ARCC could co-ordinate the modelling templates.