Regulating for climate change related overheating risk in dwellings

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Abstract

There is broad scientific consensus supporting the link between CO_2 emissions and climate change. In cool and temperate climates such change is predicted to result in (among other impacts) warming ambient temperatures. As in recent years buildings in such locations have been increasingly optimised for heat retention (through regulations and standards), a warming climate has the potential to have a significant impact on the built environment and there is already evidence of overheating in new and recently constructed buildings.

Regulations in the built environment are largely designed to address issues of health and safety. In recent times however, such regulations have increasingly sought to incorporate issues related to energy efficiency while being used to implement national carbon reduction targets at the building scale. Arguably, building regulations remain focused on the 'point of handover' or near term performance, which given the uncertainty associated with predictions (such as climate change, occupant behaviour or technological change) is understandable. Such an approach however, in a situation where the current existing stock is seen as a major barrier to carbon reduction, risks buildings delivered today becoming prematurely obsolete due to the impacts of climate change.

Current overheating risk assessments in building regulations may not be appropriate as they are largely based on historic climate data. There remains a role however for regulations and standards that take account of the potential impacts of climate change. Building upon earlier research by the authors that demonstrates the potential magnitude of the overheating risk for UK dwellings, this paper suggests a risk based regulatory approach to overheating assessment based on climate change predictions while incorporating a requirement for adaptation planning. The approach put forward is based on semi-detached dwellings, built to new and emerging standards and regulations and aims to ensure that short term efficiency is not compromised for long term performance and comfort, thus minimising the potential for premature obsolescence related to overheating.

Keywords: Adaptation planning, Building regulations, Climate change, Dwellings, Overheating risk

1. Introduction

The built environment is responsible for a large proportion of global energy use and corresponding CO_2 emissions, with the residential sector using 18% of energy in 2011 (U.S. Energy Information Administration, 2015). In that context and with the drive to reduce such CO_2 emissions and thus mitigate against climate change, there has in recent years been a drive to make our dwellings more energy efficient. Building regulations have set increasingly ambitious energy reduction targets while other standards and assessment methods have emerged which go beyond the minimums of the building regulations (such as the Passivhaus standard). In cool and temperate climates increasing efficiency largely means optimising buildings for heat retention, with increasing levels of insulation and air tightness significantly reducing energy consumption.

Although the drive to improve efficiency, reduce emissions and minimise the potential for climate change is well founded, as noted by the IPCC (2007) a certain amount of warming is now inevitable. In cool and temperate climates there is evidence that this change may result in overheating (for example Jenkins et al., 2014a and Dodoo et al., 2014). Adaptations to alleviate overheating (Porritt et al., 2012) may help reduce the risk, however such adaptations may result in costs that some sectors of society cannot afford (Hills, 2012). In this context there is a need for building regulations to consider the impacts of predicted climate change. Furthermore, as ambient temperatures warm it is likely that occupant behaviour may become an increasingly important factor where clothing, work and lifestyle patterns may have to adjust.

This paper, which builds upon an earlier publication by the authors that sought to understand the magnitude of the potential for climate change related overheating (Mulville and Stravoravdis, 2016), presents a risk based approach for dealing with such overheating. Such as approach could form part of a regulatory framework that considers the potential impacts of climate change. The proposed approach aims to ensure that short term efficiency does not result in an unacceptably high overheating risk in the long term, thus attempting to take account of the lifetime performance of the building.

2. Literature Review

Roaf et al. (2015) suggest that the long life of buildings presents a challenge in developing *'fit for purpose'* regulations and standards in the context of climate change.

Most studies that seek to explore overheating related to climate change in dwellings do so using predictive building simulation models, considering how building specification, building type and/or location can impact on the magnitude of the overheating (for example see Peacock et al., 2010 and McLeod et al., 2013). Some studies consider the potential benefit of technical building adaptations to reduce overheating (such as Porritt et al., 2012) while others also consider the role of occupant adaptations linked to behaviour (such as Mavrogianni et al., 2014). In this context the review that follows focuses on the evidence for current and predicted overheating, how this may be avoided, how the current overheating assessment methods may contribute to this and what alternative approaches may be of benefit.

2.1 Evidence of overheating

There is evidence that new, recently constructed and well insulated dwellings may already be experiencing overheating, especially during warm summers (Dengel and Swainson, 2012). In support of this McLeod et al. (2012) suggest that highly insulated buildings in the UK, Ireland and Northern Europe may be at risk of overheating, arguably as they have been optimised for heat retention.

Going forward, the frequencies of such problems are predicted to increase. Jenkins et al. (2014a) suggest that by the 2030s, 76% of flats and 29% of detached dwellings in the UK could be at risk of overheating. Furthermore, Dodoo et al. (2014) in a study considering the potential impact of climate change on overheating risk for ‘conventional’ and ‘Passive House’ dwellings in Sweden, predicted significant increases in cooling demand by 2050 (reductions in heating load were also predicted). The research predicted a proportionately greater increase in cooling demand for the highly insulated Passive House building. In support of this Orme and Palmer (cited in Dengel and Swainson, 2012) note that increasing levels of insulation can result in increasing overheating risk. De Wilde and Tian (2012) suggest that buildings may be more resilient to climate change than expected due to the relatively short life expectancy of systems, presence of additional capacity in those systems and opportunities to install new systems. However, Peacock et al. (2010) note that an increase in installed air conditioning could result in occupant behaviour that accentuates energy consuming behaviour. A challenge in how to deal with overheating risk remains.

It has been suggested that raised temperatures in bedrooms overnight is a particular risk (Naughton et al., 2002 as cited in Peacock et al., 2010), where temperatures above 24°C have been linked to impaired sleep and health implications (Dengel and Swainson, 2012). In this context Peacock et al. (2010) suggest that where high bedroom temperatures overnight are problematic, the use of a ‘cooling nights’ metric may be of benefit.

2.2 Overheating assessment methods

Given the evidence of overheating in new and recently constructed buildings it can be argued that the current approach to overheating risk assessment may not be fit for purpose. In regulations, assessments related to overheating risk are often made using relatively simplistic steady state tools (such as SAP UK (Department of Energy and Climate Change [DECC], 2014). This may be due to the complexity and resource needed to conduct, potentially more accurate, dynamic simulation based assessments (Jenkins et al. 2013). It has been argued that the current approach cannot account for the potential impacts of a warming climate as much of the climate data used is historic (de Wilde and Coley, 2012). Furthermore, it has been suggested that the current approach to overheating risk assessment may also allow for unrealistic user adaptations, such as window opening (Mulville and Stravoravdis, 2016).

Peacock et al. (2010) note that there remains a role for policy in addressing elevated temperatures in dwellings. Jenkins et al. (2013) suggest that using an alternative approach based on overheating frequency curves derived from regression analysis of a range of climate predictions and analysed using dynamic simulation for specific buildings, may improve predictions and allow for the consideration of risk. Expanding on the proposed overheating risk curves (Jenkins et al., 2014b), it is suggested that potential user adaptations, such as opening windows and technical intervention (such as shading and the reduction of internal gains) could be included in the assessment. The approach does still require significant knowledge of the building operation and building characteristics, however it greatly reduces the amount of simulation required and may help designers to contextualise the problem (Jenkins et al., 2013). Jenkins et al. (2013) argue that any methodology used to assess overheating should be industry focused and able to include a range of building types, glazing ratios, building characteristics and locations.

2.3 Reducing overheating risk

McLeod et al. (2013) found that in highly insulated dwellings, external shading followed by adjustments to south-facing glazing ratios had the greatest potential to reduce overheating risk. Supporting this, Porritt et al. (2012) suggest that the control of solar gains (shading, shutters, glazing specification), solar reflective coatings and insulation (the study was based on dwellings with low levels of existing insulation) could also help reduce overheating risk. Furthermore, increased ventilation (Porritt et al., 2012) and higher levels of thermal mass (Gupta and Gregg, 2012) have also been shown to be of benefit although in both cases there are potential limitations. Peacock et al. (2010) note that although during the day time thermal mass would appear to have significant advantages, overnight the measured benefits may reduce as stored heat from day-time heat gains is radiated back into the spaces. This is supported by McLeod et al. (2013) who found that although overall temperatures in high thermal mass buildings were lower than in others, bedrooms in light weight buildings cooled more rapidly (in the 2080s). Where raised temperatures in bedrooms have been shown to be problematic (Dengel and Swainson, 2012) this potentially presents a risk and the perceived benefits of thermal mass in dwellings may be questionable.

Window opening may help to reduce overheating risk. However, Mavrogianni et al. (2015) suggest that window opening in urban centres may have negative health impacts, with Tong et al. (2016) highlighting the link between raised indoor air pollution and proximity to roads. This is supported by Peacock et al. (2010) who note that window opening is likely to be limited by noise, pollution and security in urban areas. In addition to the discussion about window opening behaviour there is evidence that in the future the benefits of such window opening may reduce. Peacock et al. (2010) found that although increased ventilation still had benefits this was not enough to overcome the overheating issues predicted for London in the 2030s.

Gupta and Gregg (2012) note that adaptations to reduce overheating risk could result in some increase in heating demand and suggest that phased adaptations over the lifetime of the building may be of benefit. In this context Jones et al. (2015) set out an approach to adaptation planning related to the predicted impacts of climate change. Although based on a non-domestic building, the approach suggested that where future problems were identified an adaptation plan could be developed to enable the building to be altered on a cost-effective basis when required. Where interventions in the future may prove prohibitively expensive, but predicted risk is high, enabling works to allow the future adaptation could be incorporated into the initial construction phase.

3. Methodology

As detailed in the earlier paper associated with this research (Mulville and Stravoravdis, 2016), and summarised here, this study used dynamic simulation modelling for a ‘typical’ (UK) semi-detached dwelling coupled with climate change predictions to understand the level of overheating risk. To understand how the heat retention parameters of the fabric impact upon the potential overheating risk, five standards were chosen and associated construction specifications developed to reflect these construction standards (UK Part L 2006 and 2010, ‘Good Fabric’, ‘Advanced Fabric’ and the Passivhaus standard). The construction system used was also varied to reflect a range of potential levels of thermal mass (low, medium and high options). For the purposes of this paper the analysis and results presented are based on a North-South orientation only.

3.1 Simulation approach

The ‘typical’ building was modelled using Ecotect® software (Marsh, 1996) which was then exported to Heat Transfer in Buildings 2 (HTB2) software (Lewis & Alexander, 1990) for the purpose of dynamic simulation and analysis. The models were then ‘run’ for the summer months using a range of current and probabilistic future reference years (climate files) based around the prediction of the UKCP09 weather generator and developed as part of the PROMETHEUS project at the University of Exeter (as detailed by Eames et al., 2011). For the purposes of this work the 50th percentile medium scenario predictions were chosen. The results presented in this paper are based on Design Summer Years (DSYs) representing near extreme scenarios. In addition a range of possible window opening positions, where included in the modelling.

3.2 Overheating assessment approach

The adaptive comfort approach to predicting overheating as detailed by Nicol and Spires (2013) was used to determine when overheating may have occurred and to gauge the magnitude of the overheating identified. This is represented by three overheating criteria. Criteria one was based on the comfort threshold being exceeded, criteria two considered the severity of the overheating in a given day and criteria three set an absolute maximum allowable temperature. In each case the temperatures were related to a running mean of outdoor temperature and were analysed based on the outputs of the preceding modelling approach. Exceedance of any two of these three criteria, as detailed by Nicol and Spires (2013), was then considered to represent an unacceptable level of overheating. As noted in the preceding research to this paper (Mulville and Stravoravdis, 2016), there remains a debate about the most appropriate metrics to be used. As a result, additional analysis was carried out based on exceedance of specific temperatures.

4. Overheating Risk

This research sought to consider the potential impact of a warming climate on dwellings. In this case a ‘typical’ semi-detached dwelling was chosen and analysed using dynamic building simulation and probabilistic climate scenarios for a southern UK climate.

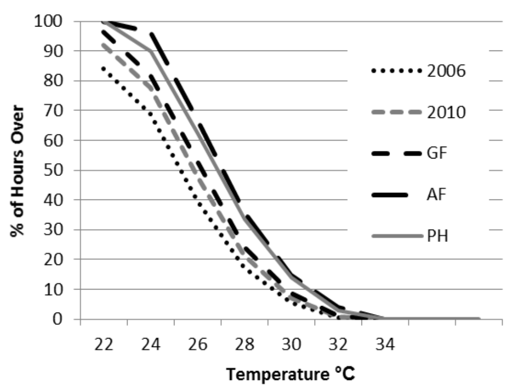

Figure 1: Temp. frequency curve – Across standards

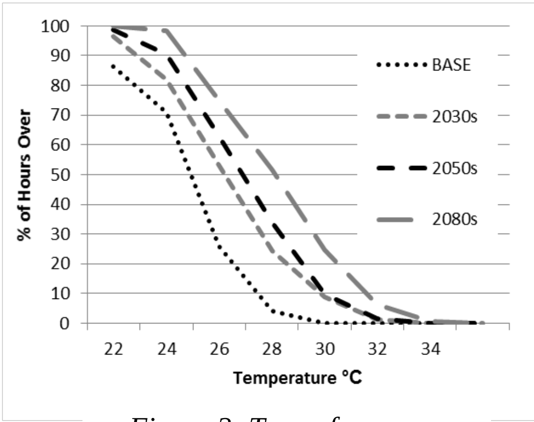

Figure 2: Temp. frequency curve – Overtime

4.1 Predicted overheating patterns

Figures 1 and 2 are based on scenarios where windows are able to be opened to the ‘slightly opened’ position (triggered by internal temperatures thresholds and appropriate outdoor temperatures to aid cooling) which represents one air change per hour and a medium thermal mass construction. As can be seen in Figures 1 and 2 there is a general increase in temperatures and therefore overheating risk as fabric heat retention criteria increase (insulation levels, air tightness, glazing specification etc.) and the climate warms. This was also reflected in the wider analysis across all thermal mass and window opening scenarios. The Passive House standard did appear to offer some protection from overheating when compared with the ‘Advanced Fabric’ building, with 6.6% reductions in the 2030s, 6.8% in the 2050s and 7.2% in the 2080s observed in certain scenarios (see Mulville and Stravoravdis, 2016). This is arguably due to the greater emphasis on solar protection required by the Passive House standard and possibly a more robust overheating assessment. Thermal mass was also found to offer benefits in reducing levels of overheating with reductions of 15% observed in the 2030s, however the benefit for highly insulated options (Advanced Fabric and Passive House) may reduce between

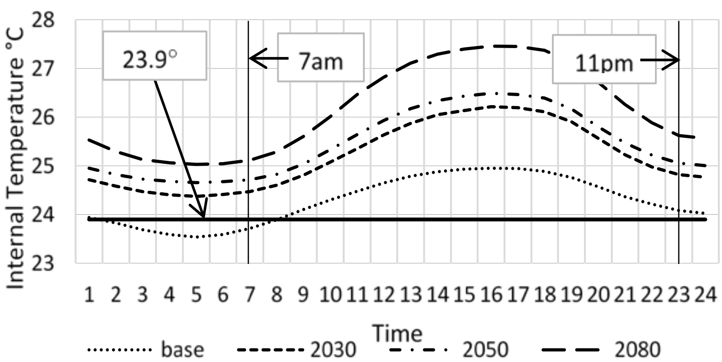

Figure 3: Daily temperature profile (HTM, Good Fabric)

the 2050s and 2080s. This could be related to a reduction in internal to external temperature differences over time, with for instance a reduction in the mean internal to external temperature difference for the Advanced Fabric building of 3.36°C observed between the base case and the 2080s. This in turn reduces the ability of ventilation air to cool the building fabric. As demonstrated in Figure 3, which is based on slightly open windows, as the temperature warms due to the impacts of climate change, night-time bedroom temperatures frequently exceed the 23.9°C threshold (as noted by Peacock et al, (2010) this is the temperature at which bedroom occupants at night may begin to feel uncomfortable and may seek to change the conditions) during peak summer. This does reduce where windows can be opened further (see Figure 4, based on 'half open' windows in the 2030s), but the issue remains. Exploring this in more detail it is found that although thermal mass can, as noted above, reduce overall levels of overheating (measured against the adaptive comfort criteria), temperatures are higher overnight for the high thermal mass solution compared to the low thermal mass solution (see Figure 4). This can be related back to the suggestion by McLeod et al. (2013) that heavy weight buildings may contribute to raised temperatures in bedrooms overnight due to the re-admittance of stored gains into the space. As demonstrated by comparing Figures 3 and 4 window opening to increase ventilation offers benefits, although as previously noted such benefits may reduce over time and concerns regarding air pollution, noise and security remain.

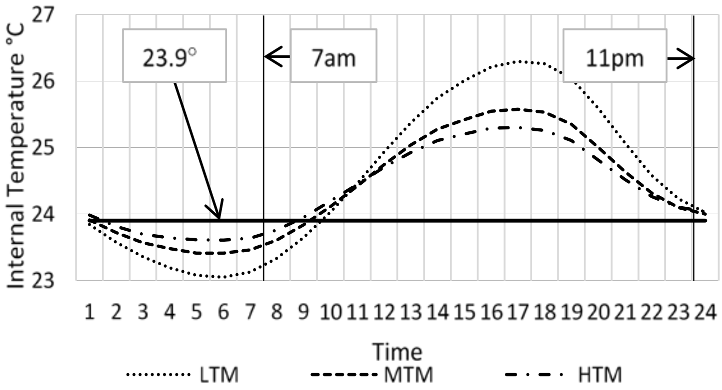

Figure 4: Daily temperature profile (Good Fabric – 2030s)

In the context of the analysis presented here, it can be argued that there is a need for more robust building regulations that take a longer term view in relation to overheating risk assessment. There is also a need to explore overheating metrics in relation to overnight bedroom temperatures.

4.2 Building overheating risk categorisation criteria

Based on the preceding discussion (and findings of the previous research to this paper (Mulville and Stravoravdis, 2016)) it can be argued that the main risk criteria related to overheating in dwellings are overall fabric heat retention parameters (insulation levels, air tightness, window specification), thermal storage parameters (mass) and opportunities for occupant adaptation (window opening). There remains questions around both thermal mass and window opening in relation to long term benefits, overnight temperatures and urban environments. In addition, building on the findings from previous studies, building configuration (semi-detached, terraced, flat etc. and orientation (including shading)) and insulation position (which could be included in the 'heat retention parameters') are also risk categories. This study did not seek to rank the relevant importance of these risk categories, but instead considered how the potential combinations of these criteria are likely to contribute to overall overheating risk (see Figure 6).

4.3 Proposed risk based assessment approach

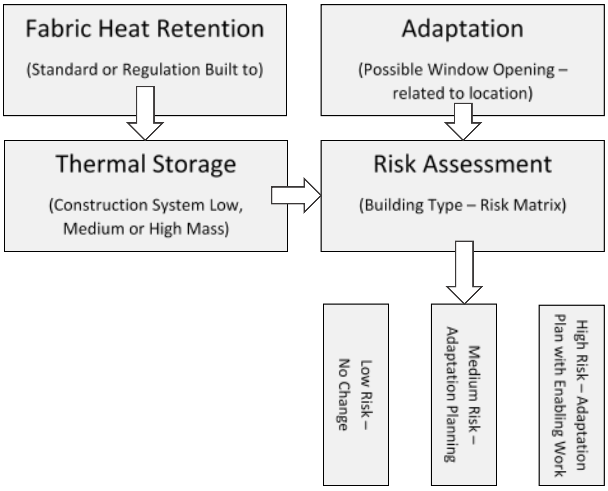

Figure 5: Proposed Approach – Flow Chart

As noted by BJM (2009) cited in de Wilde and Tian (2012) a risk can generally be stated as 'probability x consequence'. In this case the probability is that overheating risk derived from dynamic building simulation and the consequence is the impacts of that overheating. In any risk assessment the weightings of parameters used should reflect their relative importance. In this case exceedance of the adaptive comfort criteria is used to determine the level of risk. This is based on the relevant running mean of acceptable temperatures. As raised bedroom temperatures at night time have been shown to be problematic and as the benefits of thermal mass in reducing overheating during the day may reverse overnight, a debate remains regarding the most appropriate metrics to use. If raised temperatures in bedrooms overnight (above 23.9°C) was used as the overheating metric in this study the risk matrix presented in Figure 6 would be significantly different. The adaptive comfort criteria as described, coupled with the risk criteria previously noted (fabric heat retention parameters, thermal storage parameters, adaptation options and building configuration) are combined to create the risk matrix displayed in Figure 6. A flow chart of the assessment process is presented in Figure 5, detailing the steps taken to reach the appropriate point on the risk matrix. One of the key input criteria for the proposed approach is the possible window opening position. Permissible window opening positions must be linked to the location of the building and a decision made based on exposure to pollution and noise along with an assessment of potential security concerns. The risk matrix as presented considers the 2030s only, arguably a weighted matrix could also include predictions for the 2050s and 2080s. However, as noted by de Wilde and Tian (2012) longer term predictions become increasingly uncertain due to the range of assumptions association with maintenance, systems and renovations etc. As a result, in this case a shorter term assessment is presented, although longer term predictions may also have merit where the level of uncertainty can be taken into account.

As noted by Gupta and Gregg (2012) interventions made now could result in increased heating demand. In this context regulations dealing with overheating should aim to optimise lifetime building performance while minimising the risk of future overheating. An approach integrated with adaptation planning and backcasting/forecasting (Jones et al., 2015) could help to deliver whole life performance. Therefore, the output of the proposed approach is requirements for adaptation planning, adaptation planning with enabling works or a change in the approach taken based on the level of risk identified. As an example, taking a dwelling in an urban area where only slightly open windows may be possible. If built to the ‘Good Fabric’ condition with low thermal mass, this dwelling would be at high risk of overheating (see Figure 6) and would require an adaptation plan with enabling works to allow for future adaptations (such as preparations for the installation of shading). As this is likely to add cost, it may be that the designer/ developer would choose to avoid such a scenario. In that case, a change in construction system to a medium thermal mass level has the effect of reducing the risk and removing the requirement for enabling works, while a high thermal mass solution would move the building into a low risk scenario. This approach must be considered in the context of the previous comments about the potential impact of thermal mass on overnight temperatures in bedrooms. However, if appropriate overheating metrics could be assigned, the approach outlined could help to ensure that current performance is not compromised to avoid longer term overheating. The approach, as such, incentivises the designer/developer to favour a low risk scenario while accounting for a range of building characteristics (as suggested by Jenkins et al., 2013) and favouring phased adaptations (as suggested by Gupta and Gregg, 2012).

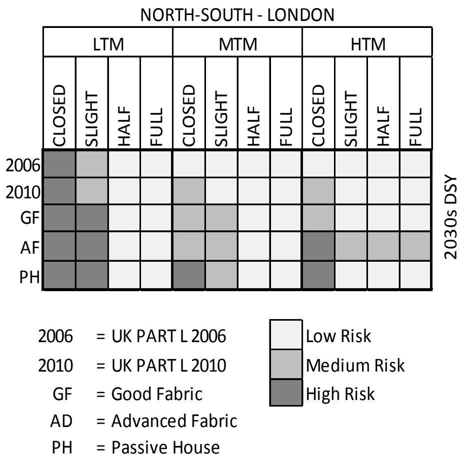

Figure 6: Risk Matrix (adapted from – Mulville and Stravoravdis, 2016)

5. Discussion & Conclusion

The overall installed capacity of artificial cooling in UK dwellings remains low (Hulme et al., 2011). However, if the potential increase in overheating as predicted is realised the installed capacity could increase significantly (Peacock et al., 2010). Although there is likely to be a corresponding reduction in heating demand (Dodoo et al., 2014) and with technological change the overall increase in carbon emissions may be minimal, increased use of artificial cooling could have a negative impact on the energy use behaviour of occupants (Peacock et al., 2010). Furthermore, if the overheating risk is not addressed a shift from winter to summer time fuel poverty could be observed, with corresponding health, wellbeing and societal impacts. As discussed, the current approach to overheating risk assessment may not be fit for purpose as it does not take account of climate change projections and may assume unrealistic adaptations.

The proposed approach to overheating risk assessment utilises the increased accuracy of dynamic building simulation modelling (when compared to steady state assessments) (Jenkins et al., 2013), while reducing the amount of resource required and presents an approach that could be applied by industry. If risk matrices for a range of building types, in a range of locations could be developed a large proportion of the ‘typical’ new stock could be represented. The requirement for adaptation planning based on the level of risk identified would help to ensure that pathways focused on long term performance can be developed for the dwellings in question. This approach could be tied to the likely major refurbishment points for the building, such as when windows etc. have reached the end of their useful life.

The findings of this research demonstrate that, by using risk based assessments implemented through the building regulations, it may be possible to take account of the potential impacts of climate change (in this case overheating) while considering the inherent uncertainty of such predictions. The implications for building regulations is a shift from a *‘point of handover’* approach towards a forecasting role. Such forecasting must be approached with caution and an appreciation of risk and probability to avoid unintended consequences. Arguably, given the potential impacts of overheating on occupants, this refocuses on the traditional health and safety role of the building regulations while accounting for energy performance on a whole of life basis.

As noted, the metric used can have a significant impact on the level of risk identified. This is particularly true in relation to temperatures in bedrooms overnight, where issues related to the relevant benefit and drawbacks of thermal mass may also be important. Further research in relation to developing overheating metrics in dwellings that takes these issues into account would be of benefit. In addition, as the research demonstrated, window opening to increase ventilation can have a significant impact on reducing overheating risk. However, in some scenarios presumed window opening behaviour may be unrealistic or may result in negative health impacts related to pollution. Further research into window opening behaviour in dwellings, particularly in urban areas subject to noise, pollution and security issues would be of benefit.

6. Limitations

The approach taken in this study must be considered in relation to a number of limitations. A medium level, 50th percentile prediction was used and a wider consideration of potential climate scenarios may add depth to the assessment. In addition the building simulation approach used includes a number of assumptions related to internal gains and occupancy patterns that cannot be easily predicted. Although a range of ‘typical’ buildings could be addressed if this approach was expanded to include other configurations, the criteria that define ‘typical’ would need to be carefully developed. A range of dwellings that cannot be easily categorised would remain and these would require more resource intensive building specific assessments.

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