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# The evaluation of the variables of domestic overheating in the UK under TM52 using a future climate model- Guidance for designers

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## Abstract

The variables of the formulae used in TM52 (CIBSE, 2013) are not understood by designers who cannot evaluate potential overheating within concept stage designs. Guidance on how TM52 relates to usage and heat wave effects is lacking in current documentation. The paper evaluates occupancy profiles, level of control, level of insulation and Internal Heat Gains on overheating criteria. The base point temperature for bedroom usage is discussed and how TM52 can be modified to accommodate this condition. Previous studies have established overheating mitigation measures (ZCH, 2014) and within the study these have been evaluated on their effectiveness for the UK future climate.
Using available weather files a heat wave criterion is established and its significance on the TM52 protocol is explored. Simulation software is used to investigate sensitivity of key parameters within realistic bounds. Shading, thermal mass, air velocity and ventilation availability are the most important factors in the reduction of overheating events. Heat waves cannot be definitively categorised given current weather files and other factors require consideration. Overheating in bedrooms is mainly caused by heat wave instances. Buildings should consider overheating aspects at the design stage to ensure buildings are fit for purpose at the end of their lifespan.

Keywords: TM52, Future Climate, Overheating, Heat Wave

## 1 Introduction

The mechanics and the sensitivity of the formulae used in the Chartered Institute of Service Engineers (CIBSE) Technical Memorandum TM52 (2013) used to establish overheating in buildings are not understood by designers who cannot evaluate overheating effects within proposed concept stage designs. There is an increasing need to design buildings for robustness over the proposed design lifespan of buildings rather than using current regulations which assess designs with historic weather data. Some elements such as the different usages of rooms and heat wave risks are not covered by TM52 but requires user guidance and an investigation to the relative sensitivity to be established within the current framework.

BSEN 15251 (BSi, 2007), now interpreted by TM52, and provides operative thresholds and does establish such aspects as the weighted mean temperature overheating effects or heat stress definitions. TM52 uses adaptive cooling methodology based on acclimatisation to previous weather patterns. Using this methodology these standards are not accessible to designers requiring a range of specifications not normally considered at an early stage of building design.

Previous studies have established passive mitigation strategies but these have been crudely ranked with little explanation of how the results were obtained, the sensitivity of results or the inputs used for each of the variables. Aspects of the standards are not readily assessed using simulation software and such shortcomings require highlighting. TM52 has its boundaries and it is important to establish instances when it should not be used in its current format as a reliable measure of comfort levels in buildings.

## 2 Research aims

The main part of the study assesses the range of factors inputted to simulation software (Energy Plus v8.2.10) in varying the parameters of TM52 including sensitivity of occupation, passive ventilation control, construction specification and Internal Heat gains (IHG) within a range in the normal operation of building design specifications. The paper does not investigate personal variables such as clothing, activity and age of the domestic building occupants.

In the evaluation of the criteria for the identification of heat wave scenarios the significance of the TM52 protocol for a cooling season can be established. This requires the investigation of current definitions of heat waves and the identification of warm periods applied to available weather files.

The paper derives a ranking to identifying the factors along with the significance of previously used mitigation measures by quantifying their effects against a baseline building physics model.

## 3 Background

The evaluation of the robustness of building designs at a future date needs the consideration of how climate change will affect the built environment. Previous studies have established probabilistic weather for future years on established climate change models (Eames et al, 2012). Establishing the lifespan of a building taken from the Building Research Establishment life cycle analysis of a building being 60 years (BRE, 2014). The resultant end date of the building being in operation until 2076 and as a result a 2080 weather file used in this study. Given the slow rate of progress of the global tackling of climate change a high scenario (a1fi under IPCC modelling) was used with a 50% probability profile.

The climate output files are available in two forms of future weather files. Test Reference Year (TRY) which uses averages from the previous 20 years of data to produce a weather file and Design Summer Year (DSY) which uses 20 years of the peak summer condition to weight the weather file. As DSY data has been specified in TM52 as the file to be used in the assessment, these weather files were used for the basis of analysis in this paper.

### 3.1 CIBSE TM 52 2013

The evaluation of overheating is defined by the proportion of uncomfortable conditions that is experienced by building occupants. This is defined by TM52 which establishes a methodology to assess a naturally ventilated building which cannot be assessed simply on when a set internal temperature is exceeded and updates previous BS EN 15251 guidance. TM52 has more of a relationship between the outside temperature, the occupant’s behaviour, activity and adaptive opportunities which affect comfort. Overheating in the standard is defined in three distinct criteria which has some interdependency in their calculation method:

1. The proportion of degree hours above 1K over the limiting comfort temperature. Assessed from 1st May to 30th September must be below 3% of occupied hours.
2. The higher the temperature the more significant the effect. This test quantifies the severity of temperature on a daily basis. Where the weighted excess of temperature must be less than 6K on any one day for comfort to be achieved.
3. Reports heat stress events 4K above the limiting comfort temperature.

Occupants are likely to experience overheating if two or more of these conditions are not met.

TM52 does not deal directly with more sensitive environments but categories have been stated on the grade of sensitivity in the building. Previous definitions of a sleeping comfort temperature have been stated as 2K lower than other occupied spaces (BSi 2007). Given the criteria above further investigation is conducted to the sensitivity of this temperature as a realistic update of the guidance given in TM52.

### 3.2 Overheating

The resilience of domestic buildings is in question and should be based on projected future climate to reduce the risk of the building not being fit for purpose over its lifespan (Jenkins et al, 2012). Rather than defining thermal comfort of occupants when buildings have been completed, under traditional post occupancy thermal comfort surveys, there should be a bias towards a future performance leading the specification of building designs.

Overheating has previously been assessed for living rooms and bedrooms but only on 2007 weather data using BS EN 15251 criteria (Beizaee et al, 2013). To some extent this only adopts part of the TM52 specifications to assess overheating. A PassivHaus single dwelling has also been previously assessed against the overheating criteria used in building regulation methodology (McLeod et al, 2013). However, this study is limited to a crude overheating assessment. Moreover, this regulatory tool assesses the building against historic climate, not its fitness for purpose in the future.

Current designer guidance for mitigation has been provided by The Zero Carbon Hub (2012) but this is presented as a simplistic bar chart showing the reduction in overheating percentage for a notional house with no explanation of the quantification or specification of factors. The impact of the significant overheating variables has been analysed by Mavrogianni et al (2014) but there is no clear statement of the significance of factors under the BS EN 15251 overheating criteria chosen. TM36 (CIBSE, 2005) is a large scenario based document covering a range of future climate scenarios. Whilst a good sensitivity study, it documents a range of graphs with no distinct outcomes or conclusions on the importance of inputs. This is of little use in the building design process.

### 3.3 Heat waves

Heat wave weather periods have been established to have a direct relationship to mortality events (Zhang et al, 2013). Many major urban centres have a trigger temperature when an increased emergency services plan is to be put in place (Diaz et al, 2015). Studies have been conducted to classify Inhabitants by location and social demographic to identify their venerability to heat wave events (Wolf and McGregor, 2012) for a trigger temperature of 28$^{o}$C. Heat wave definitions vary depending on geographic locations ranging in peak daytime temperatures from 26°C to 40°C (Scandinavia to Australia respectively). They also vary as a result of the duration these temperatures are experienced from a daytime single event to averaged over seven consecutive days. Other heat wave definitions include night time temperatures as part of the assessment occurring before or after the daytime threshold level to be classified as a heat wave.

Dense built up areas cause Heat Island Effect in major urban cities resulting in an average rise of night time temperatures (Lemonsu et al, 2014). This is the basis of the current heat wave plan for England (NHS, 2015) with a set point temperature for the day on condition that the night before breaks a specified differing threshold temperature. Previous heat wave studies show actual observed data from a historic viewpoint (Porritt et al, 2012). As heat waves are defined as extreme random events, historical data is currently the only methodology of analysing such events with no studies defining heat wave effects using future climate files.

## 4 Methodology

A 2 bed flat in a typical apartment layout was modelled in EnergyPlus simulation software. There are two main exposed walls south to the main living space and to the north for bedrooms, a midpoint entry on one of the flanking sides provides a dual facing apartment (see figure 1). Double glazed argon filled windows are of the same size for each habitable room and is representative in terms of size for natural lighting and ventilation. The model was placed in Islington a short distance from Central London UK to match the weather file used.

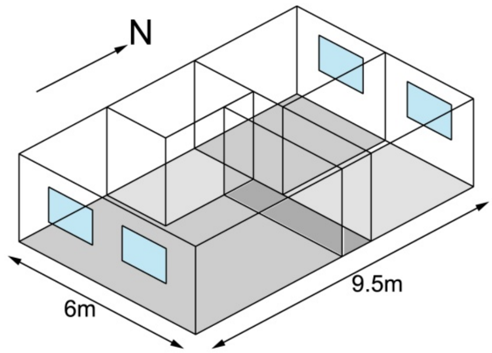


Figure 1. Two bed Flat configuration and dimensions

To simplify the comparison, default values were established for each of the parameters investigated. The weather file chosen is that for 2080, high scenario with 50% probability. Of the main parameters explored were broadly classified into the following groups:

The evaluation of the occupancy profile, including: full occupancy (model 1), one adult working with a child at home with other parent (model 2), one adult working and other part time with child at school (model 3), both parents working and occupying house only in evenings (model 4).

In order to establish the level of ventilation control by windows in the model, variants included: open all the time (model 5), completely closed (model 8) and two intermediates when the temperature outside is 2.5K higher than inside temperature (model 6) and 5K higher (model 7) before windows are closed as an upper limit to ventilation control.

The construction composition and heat transfer in the envelope is mainly determined by the level of insulation. In the model a zero heating U value the equivalent of 300mm of insulation was used (model 9), subsequently the specification of a PassivHaus: U value equivalent of 0.15 $W/m^2K$ (model 10), current UK building regulations (model 11) and a minimal insulated building the lightweight equivalent to a solid wall building, such that no thermal mass effects were applied (model 12).

Internal Heat Gain (IHG) occurs from people and appliances which influences overheating criteria in relation to the efficiency of cooking, lighting and domestic appliances and are broadly aligned to zero internal load (model 13) A rated EU appliance labelling classification (induction hob LED lighting model 14), C rated (ceramic hob, compact fluorescent lighting, model 15) and D rated bands (electric resistance hob, halogen lighting, model 16) with appropriate wattages and usage determined for each appliance on occupancy.

The next range of variables considered mitigation approaches. The first is the fixing of internal ceiling fans with increasing internal air velocity applied to the model. The default value for the air velocity in the dwelling is $0.2ms^{-1}$ (model 17). This is raised in subsequent models to $0.4ms^{-1}$ (model 18), $1.6ms^{-1}$ (model 19) and an unrealistically high velocity of $3.2ms^{-1}$ (model 20). A sensitivity analysis of increasing air velocity was undertaken for a given operation profile when the dwelling was occupied, in line with TM52 guidance.

The shading on the south elevation was increased from a default of no shading (model 21) to a horizontal shade 1.5m deep for the width of window. This value was chosen as the maximum realistic structural depth not requiring excessive fixing details and shades mid day sun throughout the cooling season (model 22). This was subsequently increased to a full horizontal shade for the width of the facade (model 23) which over shades each side of the openings and a local horizontal shade with 1.5m deep vertical fins for the two windows on the south façade (model 24). Fixed shading is chosen rather than a bespoke user operated device which has a high risk of being operated incorrectly or an unrealistic number of user options determined within the building physics model.

A high thermal capacitance, through the use of high density materials (thermal mass) reduces peak temperatures within the building and dissipates the heat energy (Hacker, 2008) over a longer period of time when applied to the internal face. The density of material used was $2200kg/m^3$, in line with CIBSE recommendations. The default value of plasterboard (model 25) was increased to 12.5mm cement board (model 26). This was further increased to a realistic value a timber/steel structural wall could support at 40mm thick (model 27). Model 28 would require a different construction system with 100mm of concrete structure directly exposed as an internal face of the external walls.

A base case scenario is duplicated in some models (models 2, 7, 10, 15, 17, 21 and 25 have identical specifications) to facilitate the evaluation of results into distinct groups of variables. TM52 was used as a basis of the evaluation with the number of overheating events logged as overheating. This modifies criterion 1 reporting overheating events rather than the percentage of overheating. All events reported are during occupied hours. The use of a future weather file allows conclusions to be drawn as the amount of overheating events is higher than current or historic weather files. Each of these results was compared to the base case to evaluate if overheating is taking place. This is not a full Monte Carlo analysis but establishes individual events over threshold values rather than cumulative effects of overheating.

As stated bedrooms have a different set of comfort criteria which is not covered in TM52. An analysis was conducted in changing the variables in TM52. The first case being no change taken place. The second variation is that of the reduction of the sensitivity to a higher class (from level II to level I) reducing the upper temperature before overheating is perceived, this was the methodology used in the previous models to differentiate the living room specification from that of the bedroom. The third variation reduces this by a further 2K and is in line with the threshold stated in BS EN 15251. The fourth case reduces again by a further 2K and increases the time schedule of reporting on criteria 2 from a day interval to a week in which the 6K value is broken for each day in that week.

For establishing a heat wave effect, a 32$^{o}$C day temperature with a night temperature of 18$^{o}$C is used. The daytime temperature was varied to create a significant and realistic result. This was used on an Islington and Heathrow weather file for a historic value (Eames et al, 2012), the 2010 DSY data (CIBSE) and then the 2080 DSY data (Eames et al, 2012) in each case. This is to establish the influence of heat island effect on the results obtained.

The same models (1-25) are conducted for a heat wave period identified in July in the 2080 Islington data and the results evaluated against the proportion of overheating events for the whole cooling season.

## 5 Results

Consistency was important in the model and results were evaluated continuously to ensure robustness. The Heathrow weather file was used as an error control to compare different scenarios, as the weather station is 30km away, providing a realistic variance for the amount of overheating experienced.

### 5.1 Cooling Season

The living area was modelled over the 28 scenarios (including duplicates) showing the variance from the base model (model 2). See figure 2. Negative effects are aggravated solutions to overheating and higher the positive effects. The occupancy (models 1-4), thermal insulation values (9-12) and internal heat gains (13-16) show a low amount of variance to the overheating result.

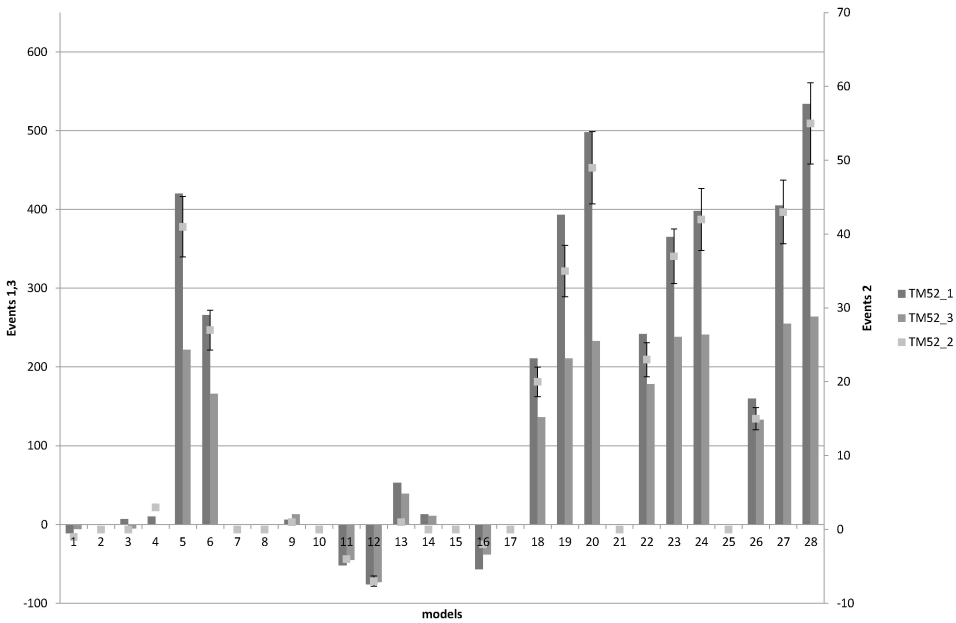


Figure 2. Living room overheating events by category and model

There is a high variance of the ventilation control options (models 5-8) with the best results obtained when windows are left open but this may cause discomfort due to low night time temperatures and also security/ noise concerns. Similarly, air velocity (17-20), results had to be recalculated as EnergyPlus under BS 15251 does not take into account air velocity. Once the error was recognised the results had to be calculated within a spreadsheet using the graph within TM52 for inside operative temperatures. Shading (21-24) and thermal mass (25-28) have a high influence. Again these should be considered realistic in terms of comfort for internal air velocity as well as nuisance factors (blowing papers), psychological issues regarding seeing the sun with passive solar gain in winter for the fixed shading of windows and structural issues for building mass.

It is worth noting that model 8 (building fully closed) had extremely high results that were omitted from the graph otherwise the other results would be dwarfed. As presented the results allow some conclusions to be drawn.

For bedrooms using a base temperature of 2K lower than the living rooms a similar pattern emerges during occupied night hours. Ventilation, velocity and thermal mass have high influences but unsurprisingly shading, being north facing rooms, had no influence on the night time overheating results.

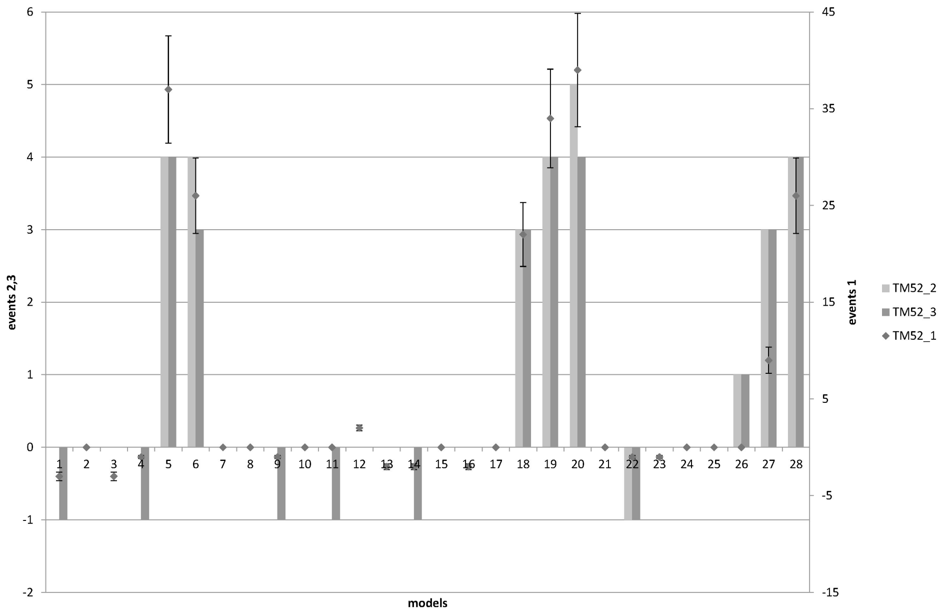


Figure 3. Bedroom overheating (2 occupants) by TM52 category

The relationships between criteria 1,2 and 3 is less consistent for the bedrooms than that of a living room with many cases criteria 2 and 3 being very similar indicating a direct relationship to outside temperature. Also Criteria 1, in the bedroom, is roughly a tenth the value in most cases compared to the living room overheating events. Again model 8 results led to excessively high overheating event values and were excluded from the graph. See figure 3.

When the base temperature for overheating of the bedrooms uses the same conditions as the living room (bar 1, in figure 4) a very low number of overheating incidences exist.

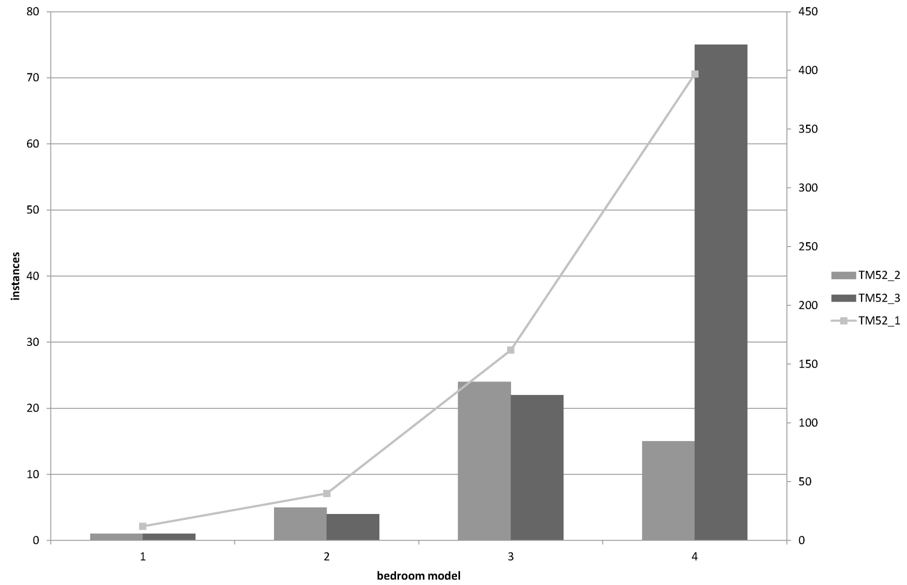


Figure 4. Bedroom variation of TM52 criteria

For each reduction of 2K the relationship for criterion 1 increases exponentially and the values for criteria 2 and 3 are fairly similar. In bar 4 the time period of reporting for criterion 2 is increased to 7 days, hence its significantly reduced value. This suggests that if longer term outside conditions are used, a correction factor is required to correlate with condition 3. However, this would need to be tested through physical thermal comfort surveys to indicate what factor should be used to match comfort levels.

## 5.2 Heat wave

A range of base point temperatures were used to check the sensitivity on the amount of heat wave events experienced. Realistic results were achieved with a 30$^{o}$C daytime and 18$^{o}$C night time temperature recording any day with a preceding warm night. The base points used pick up historical heat waves of 2007 and 2010 in the dates that were reported by the press. This compares to the NHS (2015) London trigger levels of 32$^{o}$C during the day and 18$^{o}$C at night.

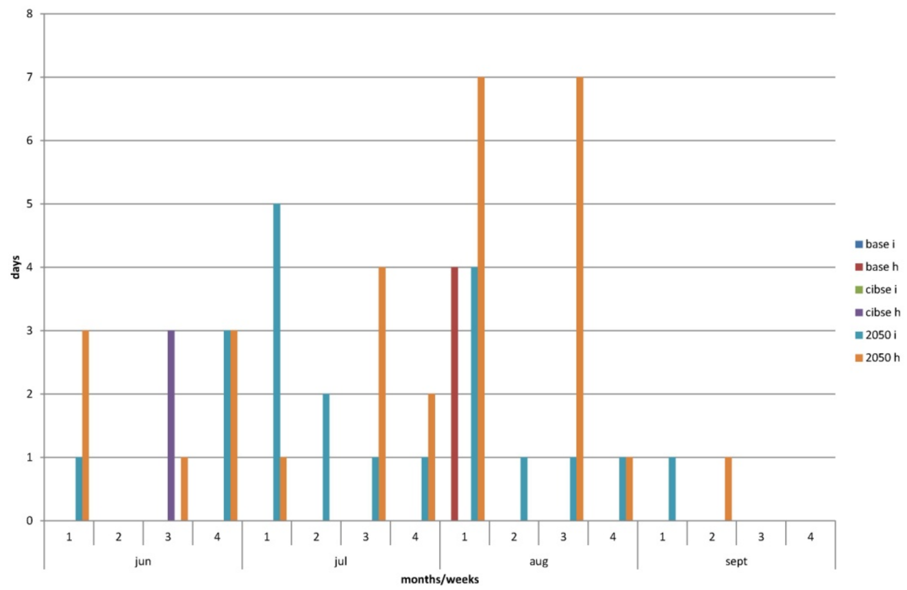


Figure 5. Time periods of heat waves

These air temperatures show that there is no account of heat island effect with Heathrow (h) bars being consistently higher than Islington (i) files. See figure 5. In all cases a day threshold had a corresponding preceding night threshold trigger of 18$^{o}$C. This may indicate that a sensitivity analysis is required on the night time trigger temperature against a physical comfort survey data to evaluate the discomfort experienced.

To evaluate the heat wave effect on the living room previous model scenarios were used and proportionally evaluated against the whole cooling season. The heat wave in 2080 of 4th to 9th July was used as the specific building physics model time interval modelled.

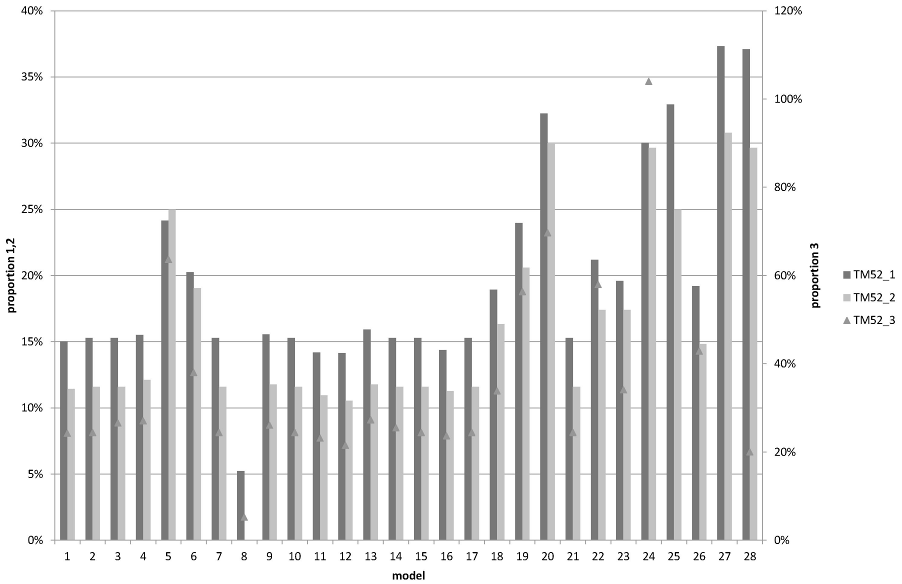


Figure 6. Living room proportion of overheating events over cooling season

With high levels of mitigation such as air movement and shading the heat wave is responsible for a large proportion of heat stress effects (condition 3) in living rooms (figure 6) and accounts for around 20% of occupied hours of overheating and daily weighted averages. Largely the same measures in the cooling season are applicable in a heat wave event.

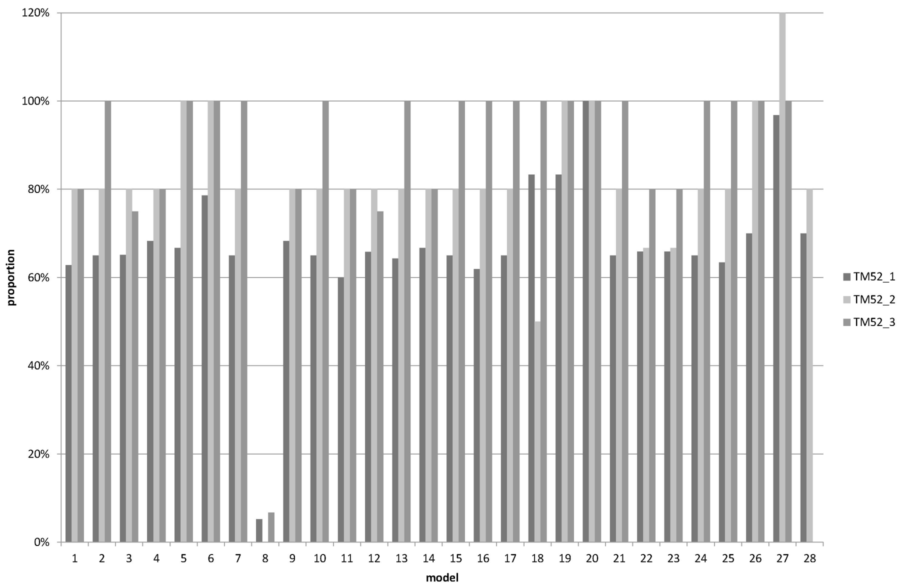


Figure 7. Bedroom proportion of overheating events over cooling season

Looking at the bedroom situation (figure 7) low figures are obtained from model 8. This is due to extremely high figures assumed in this scenario, that result in a reduced number of overheating events during this confined period of time.

The results show that the variation is lower between models and the heat wave event picks up most overheating incidents ranging from 60-100% of the cooling season. This indicates that bedrooms are more susceptible to heat waves, although mitigation strategies are limited due to highly consistent results across all model types. As the shading models report higher figures than the cooling season this was further investigated.

For models 23 (horizontal shading across windows) and 28 (high thermal mass model) the data was taken from those specific dates from the cooling season data (part of the data from earlier tests) demonstrating some variation exists.

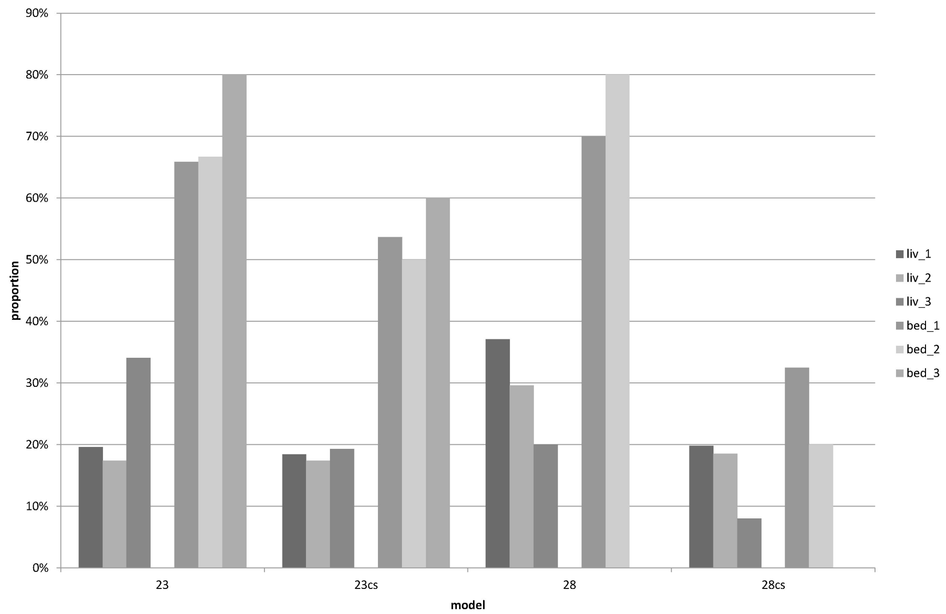


Figure 8. variation of EnergyPlus models given different run times

The results in figure 8 show the proportion of heating season for living rooms and bedrooms with 'cs' stating part data from the cooling season models, as the previous set of results. The part data (the heat wave) is consistently lower with marked changes in condition 3 (heat stress) in living rooms. This shows that the building physics model is highly influenced by the small number of days modelled and the 'warm up days' used to stabilise the internal temperatures in the model. For more accurate results, part data should be used as comparison whether the errors experienced would be consistent across all the models. This is still inconclusive given the results obtained.

## 6 Conclusion

Designers need to consider the building design in the order of shading, thermal mass, internal air movement, ventilation set points and availability. Some aspects of mitigation could be retrofitted such as ceiling fans but it is unclear whether given the choice, occupants would choose this solution due to the discomfort and inconvenience experienced in operation. Other aspects such as thermal mass need consideration on the outset of building design with regards to structural issues. If disregarded robust reasons should justify the exclusion of high density materials.

Many of the variants explored in the study are linear in their results, they achieve realistic specification boundaries and have little overlap between the factors considered, although this can only truly be established in a full Monte Carlo analysis. There is not enough data in survey modelling to suggest that the time constant for criteria 2 of TM52 to be changed but a 2K reduction and a classification to the sensitivity of sleeping occupants is a realistic recommendation for the overheating experienced in bedrooms. This is a 4K reduction in the limiting temperature which creates a similar number of overheating events at night compared to the living room during heat wave events. As part of this a new benchmark should be created and evaluated against thermal comfort surveys to check people's experiences match the findings in this paper.

Current weather data on heat waves is insufficient to assess extreme events. This should be a bespoke extreme data file for air temperature to include humidity and radiant effects to clearly demonstrate the influence of heat island of the results. This could be a synthetic data transformation based on the statistical risk from existing weather files. The differences between Heathrow and Islington data leads to questions on the reliability of future weather files and the significance of consistently hotter longer periods evidenced in the Heathrow projected data.

Bedrooms are at more risk of heat waves due to high night time air temperatures which result in the majority of overheating events in a cooling season. In living rooms this is around a third although the same mitigation strategies are applicable for both cooling overheating events in a cooling season and in a heat wave for living spaces.

Buildings have a realistic 10-fold susceptibility of increased heat wave effects at the end of a 60-year life and these should be considered by designers as an important upgrade strategy to ensure future fitness of purpose of buildings currently at design stage.

## 7 Further work

This paper could be expanded to include the lifespan of buildings should be evaluated against the mitigation measures used as major mitigation may not be necessary if a building is to last less than a certain number of years, each mitigation has its limit relating to the lifespan of the design building in question. A more comprehensive design guide is required showing the exact variables in EnergyPlus changed so that they can be scrutinised and peer reviewed for their realism with results replicated by others. More work would be beneficial on the influence of microclimate around a building that can influence overheating events and increase the reliability of the design tool.

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