The evaluation of the variables of overheating under TM52 and its impact on Life Cycle calculations of buildings:
A strategy tool for designers

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ABSTRACT:
Overheating and its influencing factors in buildings are not understood by designers with both overheating and construction has a direct influence when air condition is adopted under future UK climate. Using TM52 the sensitivity of variables is studied to determine when air conditioning would be installed for various constructions. Air velocity, thermal mass and shading are the most influential mitigation factors against overheating but care is required to use realistic values within designs. Occupancy, Thermal insulation values and internal heat gains show a low amount of variance to the overheating result. TM52 criterion 1 matches closely the solar, construction and internal ventilation control influencing living room overheating incidents. Criteria 2 and 3 are influenced by the outdoor environment and determine when air conditioning is required for bedrooms. Designers should understand the implications of design choices for the lifespan of the building considered.
Keywords: overheating mitigation, TM52, future climate, life cycle

INTRODUCTION

The sensitivity of the formulae in the Chartered Institute of Service Engineers (CIBSE) Technical Memorandum 52, TM52 [1] is used to establish overheating in buildings are not intended for use on proposed concept stage designs. There is a need to design buildings for robustness over the proposed design lifespan with the construction industry currently assessing a buildings annual energy using historic weather data. Elements such as room usage are not covered by TM52 and require user guidance.

Domestic active cooling energy may become the dominant energy load under current climate change predictions. Previous studies have established passive cooling mitigation strategies but these have been ranked with little explanation of how the results were obtained or the inputs used for each of the variables. Some criteria in the standards are not readily assessed using simulation software and such shortcomings require highlighting.

The Embodied Carbon (EC) can be established for differing buildings but overheating results may disregard heavyweight buildings which have a lower susceptibility to overheating as shown by Hacker et al [2] The decisions made at the design stage is investigated as a trade-off between EC compared to carbon saving during the building operation

AIMS

The main part of the study assesses the range of factors for input in simulation software (Energy Plus v8.2.10) varying the parameters of TM52 within a normal range of building design specifications. By assessing the factors inputted into simulation software the sensitivity of key inputs to TM52 results is found. The date of air conditioning adoption and subsequent Green House Gas (GHG) emission determines the effectiveness of mitigation measures to potentially reduce the use of active cooling for buildings. This gives an indication of important factors when designing for future climates.

BACKGROUND

The evaluation of the robustness of building designs at a future date needs the consideration of how climate changes affect the built environment. Previous studies have established probabilistic weather for the future on established climate change models [3]. The lifespan of a building from the Building Research Establishment life cycle analysis of 60 years [4] was used with the resultant end date of the building being in operation until 2076 matching the 2080 weather file used in this study. Given the slow rate of progress of tackling climate change a high global warming prediction on weather (a1fi under International Panel of Climate Change modelling) was used with a 50th percentile profile. As the Design Summer Year (DSY) file has been specified in TM52 these are used for the basis of analysis in this paper.

CIBSE TM 52 2013

The evaluation of overheating is defined by the proportion of uncomfortable conditions that is experienced by building occupants. A naturally ventilated building cannot be assessed simply on when a set internal temperature is exceeded used in superseded BS EN 15251 [5] overheating guidance. TM52 has more of a relationship between the outside temperature, behaviour and adaptive opportunities which affect comfort. Overheating in the standard is defined in three distinct criteria:

1. The amount 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 criteria are not met. TM52 does not deal directly with room usage but categories have been stated on the grade of temperature sensitivity in the building. Previously definitions of a sleeping comfort temperature has been stated as 2K lower than other occupied spaces [5]. Given the criteria above further investigation is conducted to the sensitivity of bedroom temperature.

Overheating

The resilience of domestic buildings needs to be assessed to reduce the risk of the building not being fit for purpose over its lifespan [6]. Assessing the performance under future climate influences the specification of current building designs. Overheating has previously been studied for living rooms and bedrooms but only on 2007 weather data using BS EN 15251 criteria [7], as previously stated this is inferior to the range of factors used in the TM52 specification of overheating.

Current designer guidance for mitigation has been provided by The Zero Carbon Hub [8] but this is presented as a simplistic bar chart showing the reduction in overheating 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 [9] but there is no clear statement of the significance of factors under the BS EN 15251 overheating criteria chosen. CIBSE Technical Memorandum 36 [10] has dealt with overheating in buildings but covers a range of future climate scenarios, the study documents a range of graphs with no distinct conclusions on the importance of inputs as such it is of little use to building designers.

Carbon Calculation

Considering the life cycle of the building overheating influences the carbon expended in operation as shown in a Passivhaus case study [11] . When used in combination with EC (cradle to gate data) a more accurate indication of the carbon implications of overheating in relation to the construction specification. Climate change influences the adoption of air conditioning, the impact of overheating mitigation needs assessment in terms of the building life cycle with of the length of time a design solution does not require active systems for cooling. Models assessing these decisions are important to increase the resilience of proposed designs.

Once air conditioning has been installed the building is no longer subject to TM52 to compensate for a more closely controlled environment, and the increased carbon expenditure that results, the cooling hours calculation for 2080 is used as a basis of the Green House Gas (GHG) calculation for cooling energy expended. The change in electrical grid carbon at current rate has been slow to decarbonise as has been shown in latest UK governmental reports [12] as this is subject to electrical power generation methods. For the basis of the study current electrical grid GHG has been used [13].

METHOD

A 2 bed flat in a typical apartment layout (fig1) was modelled in EnergyPlus (v8.2.10) 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 with the other being a party wall provides a dual facing apartment. Double glazed argon filled windows of the same size for each habitable room are representative in terms of size for natural lighting and ventilation for this size of flat. The model is located in Islington, London UK matching the weather file used.

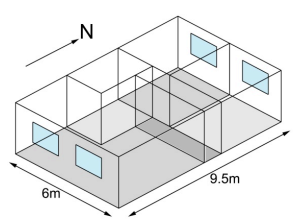

Figure 1. Two bed Flat configuration and dimensions

To simplify the comparison default values were established for each of the parameters investigated. The weather file chosen, as previously stated, is 2080, high scenario using 50th percentile data. The main parameters explored these broadly classified into the following groups illustrated in table 1:

Table 1. model categories and variables explored

model category		variable
1	occupancy	2 adults, 1child at home
2	occupancy	1 adult work, 1 adult, 1 child at home
3	occupancy	2 adult work (1 part time), 1 child at school
4	occupancy	2 adult work, child out during working hours
5	window control	open during occupied hours
6	window control	closed when outside 2.5K higher
7	window control	closed when outside 5K higher
8	window control	closed all the time
9	fabric insulation	U= 0.1W/m^{2}K zero heating
10	fabric insulation	U= 0.15W/m^{2}K Passivhaus
11	fabric insulation	UK building regulations 2014
12	fabric insulation	solid wall (no thermal mass)
13	internal heat gain	none
14	internal heat gain	EU A rated appliances induction hob, LED lighting
15	internal heat gain	EU C rated appliances ceramic hob, fluorescent lights
16	internal heat gain	EU D rated appliances electric hob, halogen lighting
17	internal air velocity	0.2ms^{-1} by natural ventilation
18	internal air velocity	0.4ms^{-1}
19	internal air velocity	1.6ms^{-1}
20	internal air velocity	3.2ms^{-1}
21	solar shading	none
22	solar shading	horiz window width 1.5m deep
23	solar shading	horiz facade width 1.5m deep
24	solar shading	horizontal shade window width with vertical fins 1.5m
25	thermal mass	plasterboard
26	thermal mass	15mm cement board
27	thermal mass	40mm cement board
28	thermal mass	100mm dense concrete block

The first set of variables are directly derived from the building usage and material characteristics. The occupancy profile evaluates the control of windows and internal heat gain from occupants. The level of ventilation control of windows determines when windows are closed comparing interior to external temperatures. The transmission of external heat determined by the level of insulation and the Internal Heat Gain (IHG) influences overheating criteria in relation to occupancy with the efficiency of cooking, lighting and domestic appliances are determined by appropriate wattages for each appliance by occupancy.

The next range of variables considered were mitigation characteristics. The first of these is the fixing of internal ceiling fans increasing the internal air velocity applied to the model. The operation of the increased velocity was only used when occupied in line with TM52 guidance. The shading on the south elevation is fixed to reduce the risk of being operated incorrectly. The use of high density materials (thermal mass) reduces peak temperatures when applied to the internal face, the density of thermal mass used in this section was 2200kg/m^3 in line with CIBSE recommendations [14].

The base case results in duplication (models 2, 7, 10, 15, 17, 21 and 25 have identical specifications) to allow the evaluation the results into distinct groups of variables. TM52 was used as a basis of the evaluation modifying criterion 1 reporting overheating events rather than the percentage of occupied overheating. All events reported are during occupied hours. The use of the 2080 file allows conclusions to be drawn with the amount of overheating events being higher than current weather files. Each of these results is compared to the base case, this is not a full Monte Carlo analysis but establishes individual variables over threshold values, rather that of cumulative overheating.

As stated bedrooms have a different set of comfort criteria 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. The third variation reduces this by a further 2K and is in line with the threshold stated in BS EN 15251, this was the methodology used in the previous models to differentiate the living room specification from that of the bedroom. The fourth case reduces again by a further 2K and increases the time schedule of reporting on criteria 2 of TM52 from a day interval to a week in which the 6K value is broken for every day in that week.

Mitigation strategies in models 17-28 are re-evaluated for a full range of future weather data (current, 2030, 2050, 2080) to determine when air conditioning would be installed. This is done by graphing all values to plot when two of the criteria of TM52 are broken.

Each of the models has their EC quantified using Environmental Performance Declarations (EPD) from suppliers verified by third parties to ensure robustness of input data. The resultant GHG figure, in $kgCO_2e$, to align with International Panel on Climate Change reporting recommendations. For ceiling fans a steel composition was assumed and for shading a support structure of 25x50mm metal box section was used to fix a flexible opaque fabric shade between.

In determining the amount of cooling energy used (converted to GHG) was then combined with the EC to provide the carbon balance for each scenario. In addition a replacement factor of 20 years life is assigned to each air conditioning unit and is factored into the calculation.

RESULTS

Consistency was important in the model and results were evaluated continuously to ensure robustness. The living area was modelled over the 28 scenarios (including duplicates) showing the variance from the base model (model 2) with negative effects being worse and a positive effect resulting in less overheating.

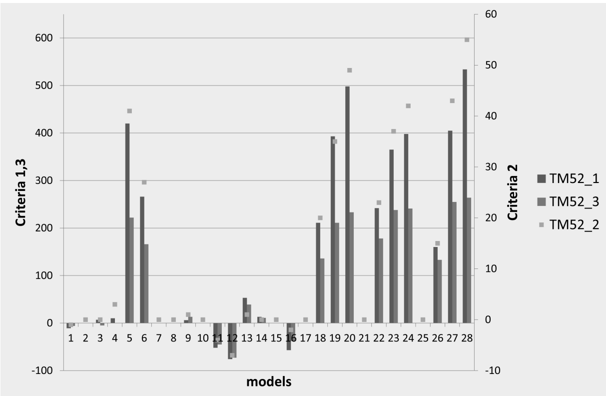

Figure 2. Living room overheating events by category and model

In Figure 2 a high variance exists for 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 with increased security/ noise concerns. Similarly air velocity (17-20), results had to be recalculated as EnergyPlus does not take into account air velocity. Once the error was recognised the results were calculated within a spreadsheet using the graph within TM52 for inside operative temperatures. Shading (21-24) and thermal mass (25-28) have high influence. These results should be considered realistically in terms of comfort for as well as nuisance factors (blowing papers for increased internal air velocity), psychological issues regarding seeing the sun, passive solar gain in winter (fixed shading of windows) and structural issues which is particularly important for the placement of thermal mass.

It is worth noting that model 8 (building fully closed) had extremely high results that were omitted not to skew results. Figure 2 indicates high incidents of conditions 1 and 3 with condition 2 of TM52 being 10 times lower.

For bedrooms (Fig 3) using a base temperature of 4K 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. The incidents of conditions 2 and 3 being significantly higher than when condition 1 of TM52 is broken.

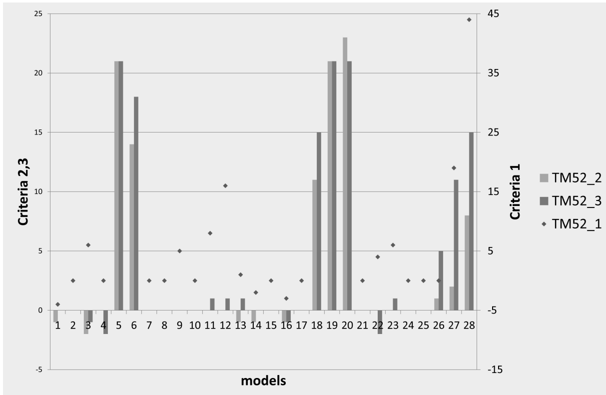

Figure 3. Bedroom overheating (2 occupants) by TM52 category

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.

When the base temperature for overheating of the bedrooms (fig 4) uses the same conditions as the living room (bar 1, below) in TM52 a very low number of overheating incidences exist.

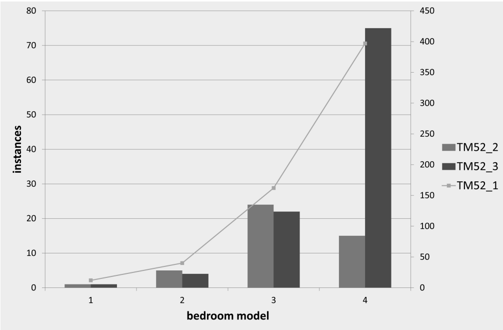

Figure 4. Bedroom variation of TM52 criteria

For each reduction of 2K, of the upper comfort temperature, the relationship of criteria 1 increases exponentially and the values for criteria 2 and 3 resulting in a close relationship. In bar 4 the time period of reporting for criteria 2 is increased to 7 days hence its vastly reduced value which indicates if longer term outside conditions are used a correction factor is required to correlate with criteria 3, however this would need to be tested by thermal comfort surveys to indicate what factor should be used to match participant comfort levels.

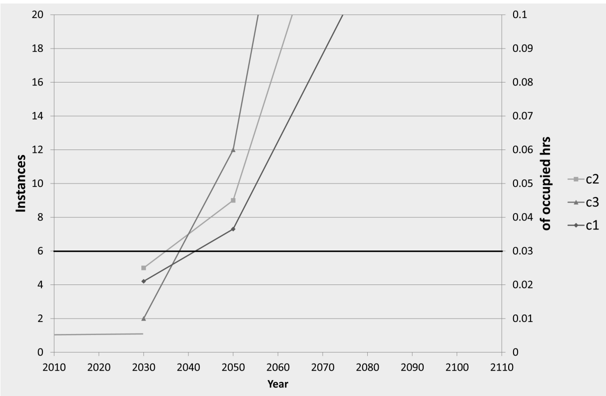

Figure 5. Overheating incidents and percentage for living room model 19

For each of the mitigation models both the living room and bedroom were evaluated using a graph similar to Fig 5, determining the year two conditions are broken, in this case criteria 2 and 3 are broken before the 3% threshold of criteria 1 is reached. This results in air conditioning being installed in 2021.

Table 2. Overheating determination date for all mitigation models

	living				bedroom			
model	o/h year	cond 1	cond 2	cond 3	o/h year	cond 1	cond 2	cond 3
17	2010				2032			
18	2018				2035			
19	2021				2050			
20	2055				2065			
21	2010				2032			
22	2018				2032			
23	2032				2032			
24	2030				2032			
25	2010				2032			
26	2010				2035			
27	2035				2035			
28	2060				2035			

Table 2 shows the date of air condition installation and which criteria in TM52 were broken. Whilst the living room criteria are mixed, bedrooms are consistently broken on criteria 2 and 3 of TM52.

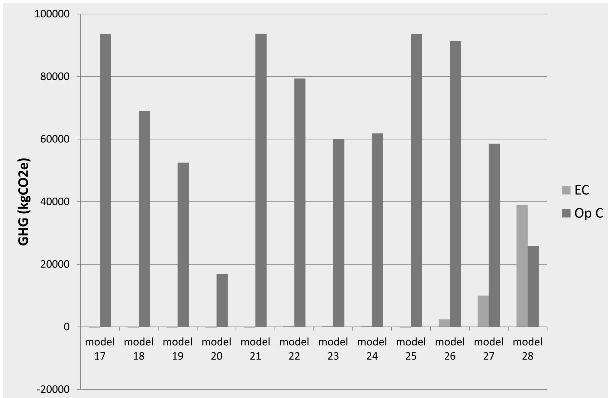

Figure 6. EC and cooling carbon breakdown

When the EC for each construction was determined Fig 6 shows that most of the GHG is occupied by cooling energy carbon over a 60 year building lifespan with the exception of the thermal mass models.

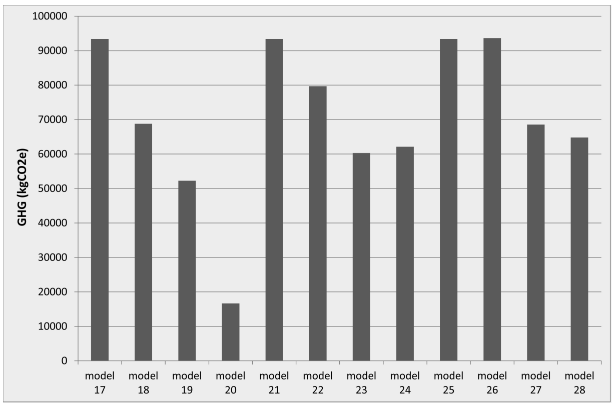

Figure 7. Overall GHG balance

The overall balance in Fig 7 shows a high degree of variance with higher levels of each of the mitigation variables reducing the overall GHG. It should be noted that the high air velocity in model 20 is unacceptable and likely to produce uncomfortable internal conditions.

FUTURE IMPLEMENTATION

Further work could include the modification of criteria 2 of TM52, with recommendations for a future revision of technical standard. In using more accurate iterations of future climate files, if available, would allow a closer determination on the year that air conditioning would be adopted and by consequence a more accurate result on the cooling energy carbon over the building lifespan.

Heating is not critical factor in summer but by providing the overall annual carbon balance would help in creating a holistic comparator. The modelling would have to take closer consideration of the ventilation strategy used.

CONCLUSIONS

Designers need to consider the building design in the order of shading, thermal mass, internal air movement, ventilation set points and availability of ventilation. Some aspects of mitigation could be retrofitted such as ceiling fans. 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 in future building designs.

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. Many of the variants explored in the study are linear in their results, within realistic specification boundaries having 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 4K reduction to the sensitivity of sleeping occupants is a realistic recommendation as this creates a similar amount of overheating events at night compared to the living room. As part of this a new benchmark should be created and evaluated against real life thermal comfort surveys to check the findings in this paper.

TM52 criteria 1 matches closely the solar, construction and internal ventilation control heavily influencing living room overheating incidents. Criteria 2 and 3 are highly influenced by the outdoor environment which bedrooms consistently fail under. Bedroom overheating occurs after living room air conditioning adoption date with the exception of high thermal mass models with the consistency of the year of overheating in bedrooms is in a small band of years and is not influenced by thermal mass.

Findings in the life cycle study reflect the conclusions in overheating but the advantage of using thermal mass is highly reduced. The results are largely linear giving clear guidance to designers on the reduction of carbon and overheating in future buildings.

REFERENCES

1 CIBSE (2013). The limits of thermal comfort: avoiding overheating in European buildings. TM52. Chartered Institute of British Service Engineers

2 Hacker, J.N., De Saulles, T.P., Minson, A.J., Holmes, M.J. (2008). Embodied and operational carbon dioxide emissions from housing: A case study on the effects of thermal mass and climate change. Energy and Buildings 40, 375–384. doi:10.1016/j.enbuild.2007.03.005

3 Eames, M., Kershaw, T., Coley, D.(2012). The appropriate spatial resolution of future weather files for building simulation. Journal of Building Performance Simulation vol5, Issue 6, DOI:10.1080/19401493.2011.608133

4 http://www.bre.co.uk/greenguide/podpage.jsp?id=2126 (assessed Feb 2016

5 BSi (2007) Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics, BS EN 15251:2007, British standards institute

6 Jenkins, D.P., Ingram, V., Simpson, S.A., Patidar, S. (2013). Methods for assessing domestic overheating for future building regulation compliance. Energy Policy 56, 684–692. doi:10.1016/j.enpol.2013.01.030

7 Beizaee, A., Lomas, K.J., Firth, S.K. (2013). National survey of summertime temperatures and overheating risk in English homes. Building and Environment 65, 1–17. doi:10.1016/j.buildenv.2013.03.011

8 Zero Carbon Hub (2012). Overheating in New Homes: A review of the evidence. NHBC Foundation. NF46. BRE Press. UK

9 Mavrogianni, A., Davies, M., Taylor, J., Chalabi, Z., Biddulph, P., Oikonomou, E., Das, P., Jones, B. (2014). The impact of occupancy patterns, occupant-controlled ventilation and shading on indoor overheating risk in domestic environments. Building and Environment 78, 183–198. doi:10.1016/j.buildenv.2014.04.008

10 CIBSE (2005), Climate change and the indoor environment: impacts and adaptation, TM36, Chartered Institute of British Service Engineers

11 Din, A., Brotas, L. (2016). Exploration of life cycle data calculation: Lessons from a Passivhaus case study. Energy and Buildings 118, 82–92. doi:10.1016/j.enbuild.2016.02.032

12 DECC, 2011 Decarbonisation and Carbon Capture and Storage Progress, HMSO

13 http://www.carbon-calculator.org.uk/ (accessed Feb 2016)

14 CIBSE (2007). Guide A Environmental design. Chartered Institute of British Service Engineers