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The Impacts of Overheating Mitigation within the Life Cycle Carbon of Dwellings under UK Future Climate

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Abstract

Overheating factors are not understood by designers at early design stage both the operation and construction of buildings directly influence when air condition is adopted in dwellings, using TM52 the sensitivity of variables is studied to mitigate overheating events to achieve comfortable buildings. Air velocity, thermal mass and shading are the most influential mitigation factors against overheating but realistic values are required to understand the implications of design choices made. Glazing in the normal range has a low effect on overheating outcome but shading features are required for larger glazed areas to stop excessive solar gain and uncomfortable conditions during occupied hours.

Peer-review under responsibility of the organizing committee of SBE16.

Keywords: Overheating; TM52; Future Climate; Life cycle

1. Introduction

The sensitivity of the formulae used in, the Chartered Institute of Service Engineers (CIBSE) Technical Memorandum, TM52[1] to establish overheating in buildings but is not intended for use by designers on proposed concept stage designs. There is a need to design buildings for robustness over their proposed design lifespan with the construction industry currently assessing annual building energy using historic weather data.

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 how the inputs used for each of the variables was derived. Some of

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the variables used in the overheating assessment cannot be directly quantified using simulation software and such shortcomings need highlighting.

The Embodied Carbon (EC) carbon data in this paper differs from the Annex 57 definition[2] taking into account only the 'Cradle to Gate' stages this has the highest impact on climate change due to the short period of time rather than relying on the inaccuracy of other future life cycle stage scenarios. The EC can be established for differing buildings but results may disregard heavyweight buildings which have a lower susceptibility to overheating[3]. The decisions made at the design stage is investigated as a trade-off between EC compared to carbon saving during the building operation from cooling and the reduction of heating due to climate change. Figures are converted to Green House Gas (GHG) emissions to show impact on climate change in line with the International Panel on Climate Change (IPCC) proceedures[4].

The main part of the study assesses the range of factors input to simulation software (Energy Plus v8.2.10) in varying the parameters of TM52 within a range quantified in the normal operation of building design specifications. By assessing the range of factors inputted into simulation software the sensitivity of key inputs to TM52 results is found. The date of air conditioning adoption and subsequent GHG emission allows the assessment of the effectiveness of mitigation measures on the amount of carbon used in the building. This gives an indication of the important factors when designing for future climates.

2. 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[5]. The lifespan of a building is taken from the Building Research Establishment life cycle analysis of a building being 60 years[6] such that the resultant end date of the building being in operation until 2076 matching the 2080 weather file used in this study to indicate the weather experienced by the building at the end of its useful life. Given the slow rate of progress of tackling climate change a high scenario (a1fi under IPCC modeling) was used with a 50th percentile profile.

As the Design Summer Year (DSY) weather file has been specified in TM52 these are used for the basis of analysis in this paper and for the life cycle building calculations during operation.

The evaluation of overheating is defined in CIBSE TM52 by the proportion of uncomfortable conditions that is experienced by the building occupants. A naturally ventilated building cannot be assessed simply on when a set internal temperature is exceeded, updating previous BS EN 15251[7] 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 that must be below 3% of occupied hours.
2. The significance of the uncomfortable temperature. 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 the heat stress events in which a 4K above the limiting comfort temperature is exceeded.

Occupants are likely to experience overheating if two or more of these criteria 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 has been stated as 2K lower than other occupied spaces[5]. From a previous study[8] a 4K reduction for sleeping areas, based upon an additional 2K reduction, moving the sensitivity category of the bed spaces according to TM52 in addition to previous guidance.

The resilience of domestic buildings needs to be assessed to reduce the risk of the building not being fit for purpose over its lifespan[9]. Using the performance under future climate influences the specification of current building designs. Design guidance for mitigation has been provided by The Zero Carbon Hub[10] but this is presented as a simplistic bar chart showing overheating reduction for a notional house with no explanation of the quantification or specification of factors. The impact of major overheating variables has been analysed by Mavrogianni et al[11] but there is no clear statement of the significance of factors under the BS EN 15251 overheating criteria chosen. TM36[12] 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 different inputs, as such it is of little use to building designers.

The occupancy, thermal insulation values and internal heat gains show a low amount of variance to overheating as shown from previous studies[8] and are determined within default values for this study within normal building design ranges.

In the life cycle of a building, overheating influences the carbon expended in operation. When used in combination with EC GHG, this has been assessed previously for a passive house[13], a more accurate indication of the GHG implications of overheating in relation to the building's construction specification can be obtained[14]. Climate change influences the adoption of air conditioning with the predicted rise in temperatures, the impact of overheating mitigation needs assessment in terms of the building life cycle, with of the length of time the building does not require active systems for cooling in combination with assessing the space heating requirements- other factors such as hot water consumption is dependent on occupation and act independently to the building fabric specification. Assessing these decisions is important to increase the resilience of proposed designs. Heating and air conditioning loads are calculated using future climate files available[5] using an end date of 2080.

The GHG loading of grid has remained stable[15] with little progress to decarbonise the grid power generation of electricity. For the basis of the study current grid GHG for the UK[16] has been used for future scenarios.

3. Method

A 2 bed flat in a typical apartment layout was modeled 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 the other being a party wall provides a dual facing apartment.

To simplify the comparison default values were established for each of the parameters investigated. A default double glazed argon filled timber windows of the same size for each habitable room are representative in terms of size for natural lighting and ventilation. They are used for the base case model but were varied later in the study. The model is located in Islington, London UK matching the weather file used. The base model is occupied with one parent working with a child at home with the other parent. Window ventilation availability is limited with ventilation closed when external temperatures are greater than 2.5K above the indoor temperature to reduce the cooling burden through air transmittance. The insulation and air tightness of the building follows a minimum PassivHaus standard although this is not true for the window specification.

The internal heat gains use modern LED lighting loads, appliances are similarly EU A rated appliances with appropriate wattages and usage determined by room occupancy.

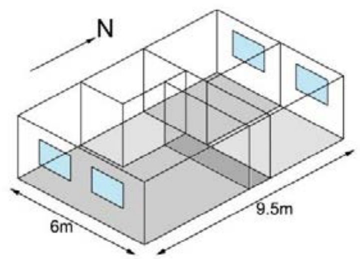


Fig 1. Two bed Flat configuration and dimensions.

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:

To investigate increasing internal air velocity the fixing of internal ceiling fans is applied to the model. The default value for this in a dwelling is $0.2ms^{-1}$ (model 1) and is raised in subsequent models to $0.4ms^{-1}$ (model 2), $1.6ms^{-1}$ (model 3) and an unrealistic high velocity of $3.2ms^{-1}$ (model 4) to gain an understanding of the sensitivity.

The operation of the increased velocity was only used when occupied in line with TM52 guidance.

The shading on the south elevation was increased from a default of no shading (model 5) to a horizontal shade 1.5m deep for width of window, the maximum not requiring excessive fixing details, shading mid-day sun throughout the cooling season (model 6). This was increased to a full horizontal shade for the width of the facade (model 7) and a local horizontal shade with 1.5m deep vertical fins for the two windows on the south facade (model 8). Fixed shading is chosen rather than user operated device which has a high risk of incorrect operation.

The use of high density materials (thermal mass) reduces peak temperatures within the building and dissipates the heat energy[3] over a longer period of time when applied to the internal face. The density of thermal mass used in this section was 2200kg/m^3 in line with CIBSE recommendations[17]. The default value of plasterboard (model 9) was used and increased to 12.5mm cement board (model 10). This was further increased to a maximum realistic value a timber structural wall could support at 40mm thick (model 11). Model 12 would require a different construction system with 100mm of dense concrete directly exposed to the internal face of the building.

The base case results in duplication (models 1, 5, 9 have identical specifications) to allow the evaluation the results into distinct groups of variables.

The next sets of variables are concerned with windows and glazing ratios. These differ from the default with the introduction of a low emissivity (low-e) coat to face 3 on double glazing and on face 3 and 5 on triple glazed units. This allows infrared radiation to be retained in the building beneficial for passive solar gain. Model 13 uses four double glazed windows each with an area of 0.25m^2 (0.5m x 0.5m). Subsequently this is increased to 0.5m^2 (1m x 0.5m) for model 14, 1.5m^2 (1.5m x 1m) for model 15 in line with default window size and then 4.05m^2 (2.5m x 1.5m) for model 16. Models 17- 20 follow the same window sizes for triple glazed units.

TM52 was used as a basis of the evaluation of when all criteria were broken, this modifies criteria 1, reporting events rather than the percentage of occupied hours when uncomfortable conditions were experienced with all events reported are during occupied hours. The use of the 2080 file allows conclusions to be drawn with the number 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 than the cumulative effects of overheating.

By the evaluation of future weather files namely: current, 2030, 2050, 2080 year files. The overheating conditions for each of the TM52 criteria is plotted on a graph for both living rooms and bedrooms allowing the assessment of when two of the conditions are broken leading to overheating and the year of installation of an air conditioning unit.

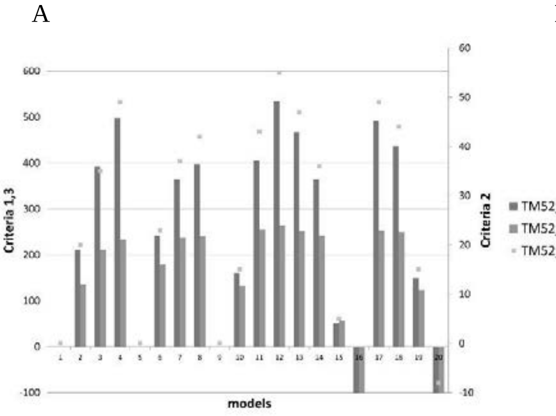
Each of the models has their EC quantified in GHG using Environmental Performance Declarations (EPD) from suppliers verified by third parties to ensure the robustness of the input data[18] the exception to this was the glazing which used Institute of Chartered Engineers' (ICE) carbon data[19] as there was insufficient EPD data given the range of variations explored. For ceiling fans a steel composition was assumed and for shading a support structure of 25 x 50mm metal box section was used to fix a ETFE shade between.

In considering the lifespan of appliances a 20 year life is set for heating, air conditioning and fan units and is factored into the calculation but other material replacement factors were not calculated as they would be similar for each of the cases. Given current technology a Coefficient of Performance (COP) for the air conditioning was set at 3 and on the heating system at 2. Heat recovery on winter ventilation was set at 70% with an internal set point of 20^{o}C. In the study the overall construction build ups allowed the GHG to be assessed per square meter including fixings and ties. Within this calculation a factor from Waste Resources and Action Program (WRAP)[20] was added to account for wastage in coordination and site processes.

In determining the amount of heating and cooling energy used and its conversion to GHG, was then combined with the EC to provide the carbon balance for each scenario.

4. Results

Consistency was important in the model and results were evaluated continuously to ensure robustness. The living area was modelled over the 20 scenarios (including duplicates) showing the variance from the base case (model 1) with negative effects being worse and a positive effects resulting in less overheating.



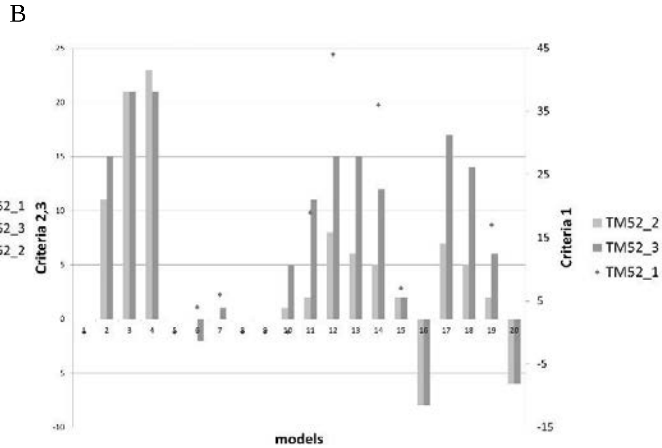


Fig 2. Living and bedroom overheating events by TM52 category.

Air velocity (1-4) results were erroneous as EnergyPlus which does not take into account air velocity in this simplified algorithm. These results were calculated within a spreadsheet using the graph within TM52 for inside operative temperatures. In addition Fig 2A shows Shading (5-8) and thermal mass (9-12) have high influence on TM52 comfort criteria. Glazing figures show that smaller window apertures create less overheating by eliminating solar gain. Large window apertures increase solar gain and therefore result in highly negative values due to there being more overheating (models 16, 20).

These results should be considered realistically in terms of comfort and nuisance factors (for instance disturbance of papers by increased internal air velocity). Fig 2A shows high incidents of criteria 1 and 3 with conditions of criteria 2 being 10 times lower in value. This indicates heat stress build ups and overheating is highly aligned to occupancy and internal factors rather than outside temperature.

For bedrooms in Fig 2B, a similar pattern occurs during occupied night hours. Ventilation, velocity and thermal mass have high influences but unsurprisingly shading, being north facing rooms, have no influence on the night time overheating results. The instances of conditions 2 and 3 being significantly higher when condition 1 of TM52 is broken. No pattern is in evidence for models 5-8 but may have something to do with heat transference from the living zone during the day. Criterion 1, in the bedroom, is 10 times smaller in value in most cases compared to the living room overheating events. Again models 16 and 20 illustrate that even for non occupied times overheating is occurs due to heat transfer from other zones.

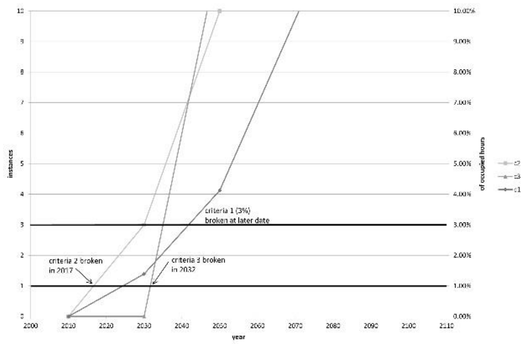


Fig 3. Overheating incidents and percentage for living room model 7.

To evaluate when overheating occurs a graph similar to Fig 3 was adopted. This determines the year two conditions are broken, the process is repeated for both the living room and bedrooms taking into account different comfort criteria. In this case instance one occurs when criterion 2 is broken in year 2017 and then criterion 3 is broken in 2032 before the 3% threshold of criterion 1 is reached, reverting back to TM52 stipulations. This results in air conditioning being installed in 2032.

Table 1. 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
1	2010				2032			
2	2018				2035			
3	2021				2050			
4	2055				2065			
5	2010				2032			
6	2018				2032			
7	2032				2032			
8	2030				2032			
9	2010				2032			
10	2010				2035			
11	2035				2035			
12	2060				2035			
13	2030				2035			
14	2032				2035			
15	2025				2035			
16	2010				2028			
17	2035				2035			
18	2035				2035			
19	2018				2032			
20	2010				2028			

Table 1 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. The Living room variation is due to range of factors including solar heat gain (low passive solar gain results in 2, 3 criteria failure and in unshaded conditions 1, 3), internal heat gain and fabric weight, where lightweight constructions fail under criteria 1, 3 and heavyweight constructions under 1, 2 being influenced more by external temperature.

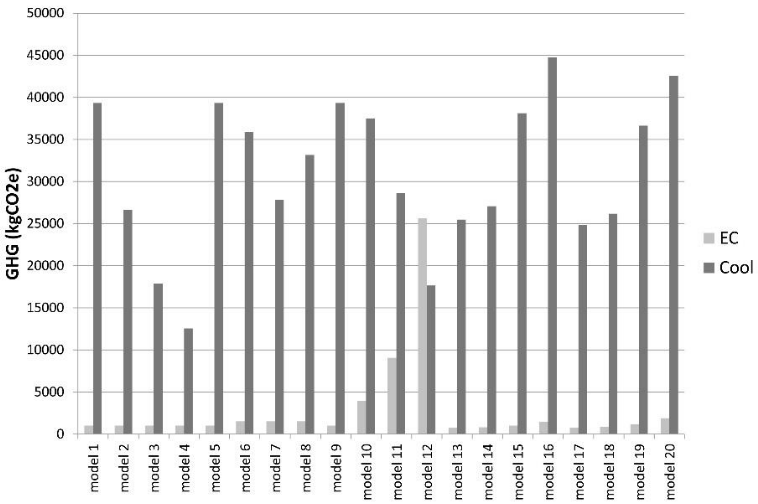


Fig 4. Breakdown of EC/Cooling and GHG balance.

When the EC for each construction was determined Fig 4 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. The EC ranges from 3-10% in other cases having a low contribution on the overall figure. Models 1-12 show a trend that higher values (or more shading) result in lower cooling loads although there is an exception with model 8 where the side shades result in unexpected results that will need to be explored in more incremental depth to understand its cause. It should be noted that model 4 is an unrealistically high parameter for air velocity but graphs in TM52 show that air velocity effectiveness largely levels off after 3 ms^{-1} velocity.

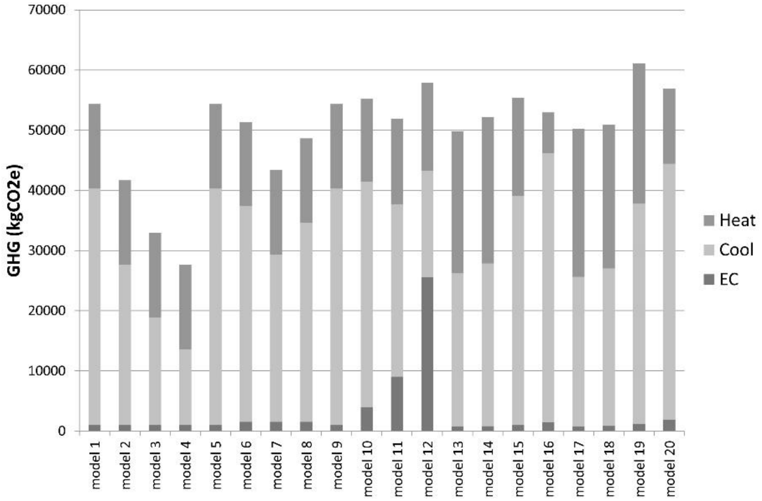


Fig 5. breakdown of GHG balance

Fig 5 shows a large variation on overall GHG of 3200-6000kgCO_2e. Most of the results (models 5-20) are within a band of 5000-6000kgCO_2e.Interestingly models 13-16 peak and ten fall away perhaps indicating that this parameter can be optimised within the building design. The overall balance in Fig 5 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.

The energy under future climate is cooling dominated given the COP values of commercially available equipment used for this scale of application. The EC and recurring GHG from heating and cooling plant is a small proportion from model 1 this represents less than 5% of the total while on the 100mm thermal mass this is 44%.

Models 1-12 have similar heating values, this being a function related to passive solar gain. Interestingly thermal mass does not lead to a reduction in heating load but provides more stable internal temperatures this characteristic has been found in a previous study[21].

Model 16 shows a clear reduction in heating compared to smaller window models. Models 17-20 have considerably more heating load compared to their double glazing counter parts as there is a much reduced passive solar gain due to the insolation value and the inclusion of an addition low-e coat on the glazing system

5. Further Implementation

Further work could include the modification of criterion 2 of TM52 with recommendations for a future revision of technical standard. In using more accurate iterations of future climate files with a finer grain of data would establish patterns that are non linear in nature to understand the determining characteristics on when air conditioning would be adopted and by consequence a more accurate result on the cooling energy GHG over the building lifespan.

In winter a more accurate representation of fan, pump and hot water loads could establish the regulated load requirements within the building and a comparison made with current UK building regulations.

6. Conclusions

TM52 criterion 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 in which bedrooms consistently fail under. Significant variation occurs between living and bedroom characteristics exist within the 2080 overheating results, with bedroom criteria being 5% of the living room values. Bedroom overheating occurs after living room air conditioning adoption date with the exception of high thermal mass models. 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 the use of thermal mass is highly reduced which highly influences the EC GHG value. Heating GHG is largely consistent in the models unless where large areas of glazing are present given the buildings are well insulated and airtight. The cumulative GHG results are in a band apart from the air velocity which is under utilised as a mitigation measure in the UK.

Designers need to consider building design in the order of internal air movement, shading, thermal mass and minimised window ratios (but still satisfy daylighting and ventilation requirements) to reduce overheating in buildings. 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 all mitigation measures in future building designs. For the overall GHG balance air velocity and shading are the most significant factors. The results obtained in this study are largely linear giving clear guidance to designers on the reduction of GHG and overheating in future building design.

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