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ScienceDirect

Energy Procedia 122 (2017) 21–26

Energy Procedia

www.elsevier.com/locate/procedia

CISBAT 2017 International Conference – Future Buildings & Districts – Energy Efficiency from Nano to Urban Scale, CISBAT 2017 6-8 September 2017, Lausanne, Switzerland

Assessment of climate change on UK dwelling indoor comfort

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Abstract

The effect of future climate change may reduce heating load but will significantly increase overheating on a largely naturally cooled dwelling stock in the UK. Thermal mass significantly reduces the need for active cooling to be used. The air conditioning installation date for a range of building characteristics is presented with the amount of overheating occurring in a heat wave.
The future weather file for 2080 with 90th percentile data show a large increase in overheating events and is considered too extreme. The need for active cooling in bedrooms is expected to occur around 2035 and is independent of a heat wave. Results for living rooms are more variable with thermal mass mitigating the adoption of active cooling by 40 years and 25% of the overheating in a heat wave event. Designers need to think about thermal mass usage in living rooms to cater for extreme temperature events rather than the whole of the cooling season to delay the adoption of active cooling.

Peer-review under responsibility of the scientific committee of the CISBAT 2017 International Conference – Future Buildings & Districts – Energy Efficiency from Nano to Urban Scale

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 [1] to establish overheating in buildings are not easily understood by designers. The onset of climate change has increased the risk of overheating in the UK to both new and existing dwellings which have no active cooling systems. This has led to an increasing need to design buildings for robustness over the

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Peer-review under responsibility of the scientific committee of the CISBAT 2017 International Conference – Future Buildings & Districts – Energy Efficiency from Nano to Urban Scale
10.1016/j.egypro.2017.07.296

proposed design lifespan of buildings rather than using current regulations which assess designs using historic weather data. Heat wave risks are not explicitly covered by CIBSE TM52 and requires user guidance to be established on the significance and impact of heat waves within the current framework.

To assess overheating in buildings and its resilience to heat waves it is important to estimate the date in which active cooling is required. This leads to a marked increase in future electrical demand The cooling demand increases approximately 3 fold in a future climate in which the heating demand drops by 14% by the year 2080. See Din and Brotas [2] for further details.

The study aims to assess factors inputted into simulation software (Energy Plus v8.2.10) to create the parameters of CIBSE TM52 in a range of values in the normal operation of building design specifications. In particular a full range of future climate weather files [3] covering medium and high climate change scenarios is used to determine the significance of thermal mass parameters. In the evaluation of the criteria for the identification of heat wave scenarios the significance on TM52 protocol for a cooling season is established. This requires the investigation of current definitions of heat waves and the identification of warm periods applied to available weather files.

The paper demonstrates the effect of material and design choices by quantifying their effects against a baseline building physics model, to determine the overheating significance of a cooling season and a heat wave event.

2. Background

The evaluation of the robustness of building designs needs to be considered on how climate change will affect the built environment. Previous studies have established probabilistic weather data for future years on established CP09 models [3]. A 60 year lifespan would require a building to be in operation until 2077 which determines the 2080 weather file used in this study to evaluate heat wave periods. Given the slow rate of progress of the global tackling of climate change a high scenario (a1fi under IPCC modeling) was used to determine year of air conditioning install across all future dates. The Design Summer Year (DSY) weather files that use 20 years of the peak summer condition to weight the data has been specified in TM52 and is used as the basis of the analysis in this paper.

The resilience of domestic buildings based on the projected future climate is required to reduce the risk of the building not being fit for purpose over its lifespan [4] requires a change to the specification of building designs. Although thermal mass influence on overheating has been investigated [5] its specification, density or its quantity in a dwelling has not.

Overheating has previously been assessed for living rooms and bedrooms but only on historic weather data using BS EN 15251 criteria [6], this assumes a smaller range of factors than used in TM52. The impact of overheating variables was analysed by Mavrogianni et al [7] but there was no clear statement of the significance of factors under the BS EN 15251 overheating criteria chosen. CIBSE TM36 [8] publication covers a range of future climate scenarios and although a sensitivity study is presented in a range of graphs, there are no distinct outcomes or conclusions on the importance of inputs or design features therefore is of little use in the building design process.

The evaluation of overheating are defined by the proportion of uncomfortable conditions that is experienced by the occupants of a building. This is defined by CIBSE TM52 which establishes a methodology for naturally ventilated building, this is an update when a set internal temperature that is exceeded the basis of previous BS EN 15251 guidance. CIBSE TM52 takes into consideration 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 amount of degree hours above 1K over the limiting comfort temperature must be below 3% of occupied hours. Assessed from 1st May to 30th September.
2. The higher the temperature the more significant the effect. This 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.

CIBSE TM52 does not deal directly with more sensitive environments but categories have been stated on the grade of sensitivity of the environment assessed. In a previous study the sleeping comfort temperature has been stated as 2K lower than other occupied spaces [2] with a higher class of sensitivity (class I) under CIBSE TM52.

Heat wave weather periods have been established to have a direct relationship to mortality events [9] with many major urban centres have a trigger temperature when an increased emergency services plan is to be put in place [10]. Studies have been conducted to classify inhabitants by location and social demographic to identify their venerability to heat wave events [11] which has a trigger temperature of 28ºC. Heat wave definitions vary depending on geographic locations ranging in peak daytime temperatures from 26ºC to 40ºC (Scandinavia to Australia respectively) and varying 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. Previous heat wave studies show actual observed data from a historic viewpoint [12] 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.

3. Methodology

A 2 bed flat in a typical apartment layout was modeled in EnergyPlus simulation software. There are two main exposed walls with a U value of 0.15W/m^{2}K, the main living space to the south and bedrooms to the north see Fig 1. The construction is airtight to 1m^3/m^2/hr. A midpoint entry on one of the flanking sides provides a dual facing apartment. 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.

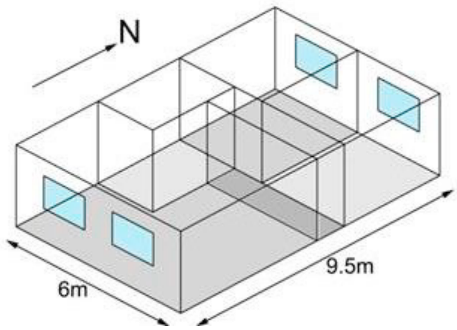

Fig. 1. Two bed Flat configuration and dimensions

The first part of the study evaluates thermal mass variables within the living area over a range of weather files using CIBSE TM52 outputs. Thermal mass has been previously validated in the EnergyPlus software [13]. Model A uses a plasterboard lining for a lightweight construction, Model B a dense block work/concrete at 2400kg/m3, Model C a 15mm cement board, Model D a 40mm cement board. The next set of parameters assesses the orientation of the thermal mass with Model E for a concrete floor only, Model F a concrete ceiling only, Model G a block work wall only with other areas plasterboard. Model H and J deal with density of materials being 1500kg/m^3 in line with aerated concrete and 3000kg/m^3 for a super dense construction at the limits of current specifications.

The second part of the study evaluates when overheating occurs using a high scenario weather file with 50% probability cross over points were established for when two criteria in CIBSE TM52 were not met to determine the year air conditioning would be installed for both living and bedrooms. The main model parameters explored are broadly classified into the groups in table 1.

The heat wave effect is assessed in London for a 32ºC day temperature when the proceeding night exceeded a temperature of 18ºC [14] used to highlight heat wave events across all climate files. The same models (1-15) in Table 1 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.

Model 1,4 and 8 are duplicates to aid comparison by feature with other variables shown to have a minimal effect [2] in a previous study.

Table 1. model categories and variables explored

model	category	variable
1	air velocity	0.2 m/s
2	air velocity	0.4 m/s
3	air velocity	1.6m/s
4	solar shading	none
5	solar shading	horizontal window width 1.5m deep
6	solar shading	horizontal facade width 1.5m deep
7	solar shading	horiz window with vertical fins 1.5m deep
8	thermal mass	plasterboard
9	thermal mass	0.015m cement board
10	thermal mass	0.04m cement board
11	thermal mass	0.1m dense concrete
12	dg window	4 number 0.25 m^2 windows
13	dg window	4 number 0.5 m^2 windows
14	dg window	4 number 1.5 m^2 windows
15	dg window	4 number 4.05 m^2 windows,

4. Results

The results in Table 2 show inconsistencies in weather files (10, 50 and 90 refer to the percentile probabilistic future climate source weather files [3]) but there is less overheating depending on the density and amount of thermal mass used within the model. The even distribution of mass is better than discrete features with all models overheating in both 2080 scenarios. The lightweight 650kg/m^3 (model A) overheats the most, the wall and ceiling concrete models have almost identical results despite furniture areas being discounted from both models to give a realistic amount of thermal mass to achieve heat exchange.

Table 2. Thermal mass TM52 sensitivity with medium and high future weather files

		2010	2030 med			2030 high			2050 med			2050 high			2080 med			2080 high		
model	cond		10	50	90	10	50	90	10	50	90	10	50	90	10	50	90	10	50	90
A	1	0%	0%	1%	17%	0%	2%	28%	0%	8%	35%	1%	13%	35%	0%	17%	98%	1%	30%	189%
	2	0	0	0	16	0	0	41	0	7	37	0	10	41	0	11	170	0	25	281
	3	0	0	0	0	0	0	8	0	0	0	0	0	9	0	2	99	0	6	167
B	1	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%	0%	0%	43%	0%	3%	94%
	2	0	0	0	0	0	0	0	0	0	0	0	0	24	0	0	98	0	14	108
	3	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	74	0	2	138
C	1	0%	0%	0%	4%	0%	0%	18%	0%	5%	16%	0%	9%	17%	0%	3%	81%	0%	10%	169%
	2	0	0	0	1	0	0	19	0	5	6	0	6	32	0	5	143	16	54	190
	3	0	0	0	0	0	0	4	0	0	0	0	0	8	0	0	86	2	133	142
D	1	0%	0%	0%	0%	0%	0%	5%	0%	0%	3%	0%	4%	6%	0%	2%	56%	0%	6%	116%
	2	0	0	0	0	0	0	2	0	0	1	0	1	27	0	0	106	3	26	103
	3	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	74	0	11	138
E	1	0%	0%	0%	2%	0%	0%	15%	0%	4%	12%	0%	10%	14%	0%	2%	81%	0%	9%	166%
	2	0	0	0	0	0	0	16	0	4	6	0	6	26	0	2	116	0	14	165
	3	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	81	0	0	140
F	1	0%	0%	0%	0%	0%	0%	9%	0%	1%	4%	0%	5%	6%	0%	2%	60%	0%	7%	132%
	2	0	0	0	0	0	0	3	0	0	1	0	2	23	0	0	105	0	7	122
	3	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	74	0	0	138
G	1	0%	0%	0%	0%	0%	0%	8%	0%	1%	5%	0%	4%	6%	0%	2%	60%	0%	7%	132%
	2	0	0	0	0	0	0	3	0	0	2	0	1	23	0	0	103	0	7	115
	3	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	74	0	0	138
H	1	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	5%	0%	0%	52%	0%	4%	97%
	2	0	0	0	0	0	0	0	0	0	0	0	0	25	0	0	76	0	20	104
	3	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	54	0	4	138
J	1	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%	0%	0%	42%	0%	0%	90%
	2	0	0	0	0	0	0	0	0	0	0	0	0	23	0	0	114	0	0	103
	3	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	74	0	0	138

In Fig 2a living rooms are shown to be more susceptible to overheating than bedrooms which are not influenced by solar gain. If solar conditions or internal conditions dominate then condition 1 is broken. Bedrooms areas are largely consistently fail condition 2 and 3 of CIBSE TM52 and will require cooling around the year2035. Although an increase of the air velocity with the use of a ceiling fan will reduce the need for active cooling by 15 years. There is a 50-year difference in living rooms between heavyweight and lightweight constructions with larger windows contributing to air conditioning being installed 20 years earlier, however there is a tradeoff between day lighting, ventilation and overheating. The use of ceiling fans in living rooms delays air conditioning by 10 years and solar shading by 20 years both being effective mitigating strategies to minimise overheating.

A

	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	2010				2032			
5	2018				2032			
6	2032				2032			
7	2030				2032			
8	2010				2032			
9	2010				2035			
10	2035				2035			
11	2060				2035			
12	2030				2035			
13	2032				2035			
14	2018				2035			
15	2010				2028			

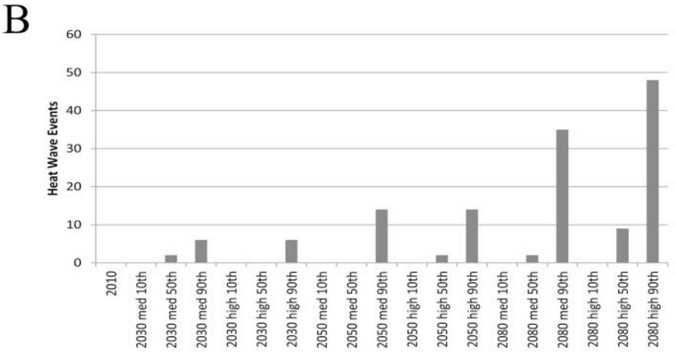

Fig. 2. (a) showing when active cooling is required and (b) heat wave occurrences across future weather files

Fig 2b shows a higher number of heat wave events in the future while there are none today it should be noted that each bar accounts for 20 years of data and a heat wave would have to occur every year to register on this graph. Realistically we will have a 20 fold increase in heat wave events in 2080 with heat waves becoming frequent as early as 2020.

Fig 3a shows the heat wave of 4th to 9th July 2080 is used as the specific EnergyPlus interval modeled. With high levels of mitigation such as thermal mass and shading the heat wave is responsible for a large proportion of heat stress effects (condition 3) in living rooms and accounts for around 20% of conditions 1 and 2 of overheating and higher proportions of condition 3. The same measures in the cooling season are applicable in a heat wave event.

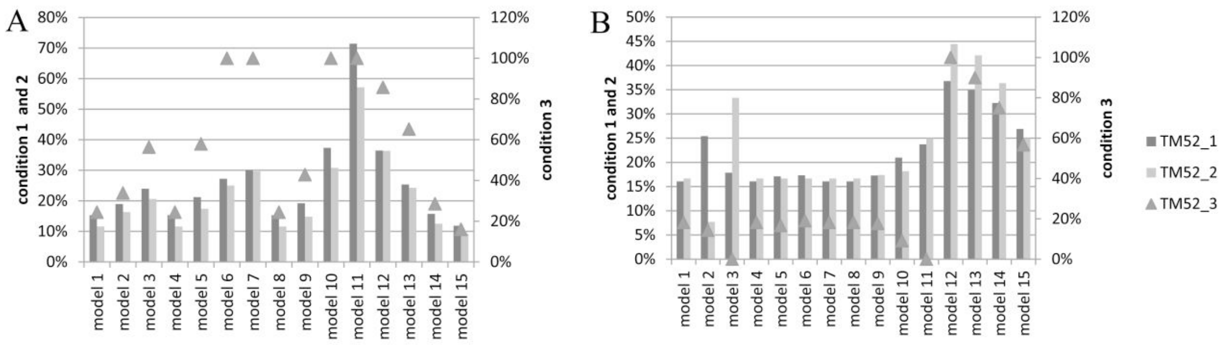

Fig. 3. (a) living rooms in heat wave (b) bedrooms in heat wave

In Fig. 3b the bedroom results show that the variation is smaller between models and the heat wave event only covers 15% of the cooling season. This indicates that the bedrooms are less susceptible to heat waves though the mitigation strategies result in a higher proportion of overheating in the case of high air velocities, thermal mass and low window to wall ratios as these are more susceptible to abnormal overheating periods.

Future implementation

This paper could be used to predict the thermal energy demand in the future dependant on building featues. A daily dynamic tool could establish demand on the electricity grid leading to summer cooling loads determining infrastructure sizing with the date of air conditioning install providing a good proxy for the amount of energy used. More sensitivity testing is required around threshold temperatures to increase robustness in line with historical events and to get a granularity of a single year rather than 20 year intervals.

5. Conclusions

Designers need to consider passive building design strategies as shading, thermal mass and internal air movement to mitigate overheating and postpone the use of active systems. Window wall ratios should be kept as low as possible but there is a compromise to achieve good daylight levels. Some mitigation strategies can be retrofitted namely ceiling fans but only if ceiling heights are high enough to allow their operation. Other aspects such as thermal mass need consideration on the outset of building design, which have structural implications, with robust reasons to justify the exclusion of high density materials.

Thermal mass has been shown to be the most advantageous in reducing overheating in buildings in their designs with a partial deployment providing some advantage. The climate files for a high 90th percentile highlight an excessive increase in the prediction of overheating incidences and should not be used as a realistic future scenario as they would adversely skew the design decisions made regarding the predictions on cooling demand and energy used.

The air conditioning install date provides a good proxy for the energy buildings will use in the future and could be the basis of further development. Buildings have a realistic 20 fold susceptibility of increased heat wave effects at the end of a 60 year life and these factors should be considered at the design stage as an important upgrade strategy to ensure future fitness of purpose of buildings.

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