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Impact of standard construction specification on thermal comfort in UK dwellings

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Abstract. The quest for enhanced thermal comfort for dwellings encompasses the holistic utilization of improved building fabric, impact of weather variation and amongst passive cooling design consideration the provision of appropriate ventilation and shading strategy. Whilst thermal comfort is prime to dwellings considerations, limited research has been done in this area with the attention focused mostly on non-dwellings. This paper examines the current and future thermal comfort implications of four different standard construction specifications which show a progressive increase in thermal mass and airtightness and is underpinned by the newly developed CIBSE adaptive thermal comfort method for assessing the risk of overheating in naturally ventilated dwellings. Interactive investigation on the impact of building fabric variation, natural ventilation scenarios, external shading and varying occupants' characteristics to analyse dwellings thermal comfort based on non-heating season of current and future weather patterns of London and Birmingham is conducted. The overheating analysis focus on the whole building and individual zones. The findings from the thermal analysis simulation are illustrated graphically coupled with statistical analysis of data collected from the simulation. The results indicate that, judicious integrated approach of improved design options could substantially reduce the operating temperatures in dwellings and enhance thermal comfort.

Keywords: buildings; thermal comfort; CIBSE overheating criteria; future weather; sustainability

1. Introduction

Evidence of global temperature increase as a result of climate change (IPCC 2013), (CIBSE TM36 2005) and the tightening of Building Regulation requirements to mitigate carbon dioxide emissions and its emphasis on energy efficiency coupled with the creation of thermally comfortable dwellings currently confront the built environment. United Kingdom Building Regulation Part L 2013 with its inclusion of fabric energy efficiency (FEE) standards will be in operation by April 2014 in England (DCLG 2013). In addition, all newly built dwellings are earmarked to be zero-carbon by 2016 (CLG 2007). Applying the axiom 'fabric first' with its increase insulation, high glazing standards, improved thermal mass and airtightness, modern building professionals have sought to improve building standards which have inadvertently led to

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the retention of unwanted heat gains in buildings during summer, offsetting one of the primary objectives in buildings; the provision of thermal comfort (Bessoudo *et al*. 2010). Thermal comfort in newly built dwellings will thus be impacted by these changes as many UK dwellings are designed to be free-running naturally ventilated buildings during the non-heating season (Hacker *et al*. 2008).

In general, there is a lack of research in thermal comfort analysis in dwellings (Peeters *et al*. 2009). Moreover, many of the thermal comfort investigations have been based on non-domestic buildings (DCLG, AECOM 2012) during the day whereas night serves as a significant motivation for domestic cooling in the urban environment where there is the existence of less air movement and urban heat island effect (CIBSE TM52 2013).

Studies of the impact of improved building construction standards and mode of operation have been presented in many recent publications and these studies point to how the variance in climatic patterns and passive design techniques have a remarkable impact on building thermal performance. Kolokotroni (2001) evaluated night cooling strategies using natural ventilation in office building. Gan (2001) analysed the impact of varying window shapes and dimensions on thermal comfort. Kim *et al*. (2007) using computational fluid dynamics models and genetic algorithms considered design strategies for indoor thermal environment. Stravrakakis *et al*. (2008) experimentally examined the effect of cross-ventilation at non-symmetrical locations on indoor thermal environment. Lomas and Ji (2009) identified the essence of area of ventilation opening in determining internal temperatures and from their investigation on single-sided and advanced ventilation in hospital wards noted the difficulty in predicting the performance of single-side natural ventilation. Haase *et al*. (2009) evaluated energy savings in different ventilated facades and in 2010, Bessoudo *et al*. (2010) conducted experimental study to investigate indoor thermal environment in winter using a glass façade with different modes of shading. The effects of fenestration have also been investigated by Tzempelikos *et al*. (2010). Zanghirella *et al*. (2011) used a developed numerical model to simulate the thermal performance of mechanically ventilated facades. In 2012, Barclays *et al*. (2012) carried out work on the repercussion of future natural ventilation strategies on non-domestic buildings. Stegou-Sagia *et al*. (2007) investigated the impact of glazing thermal properties on energy consumption and comfort. Palmer *et al*. (2005) provided evidence of the intended effect of the use of thermal mass to reduce overheating in buildings during summer. Hacker *et al*. (2008) in 2008 published their findings on the relationship between thermal mass and overheating risk in buildings using the medium-high emission climate change scenario. In 2010, Jenkins *et al*. (2010) and Patidar *et al*. (2011), in separate studies employed statistical methods to evaluate the effect of climatic change on thermal performance of UK dwellings. Ali and Ahmed (2012) explored how different shading devices affect thermal performance of dwellings and Kamal (2012) in the same year evaluated the relationship between passive cooling techniques and thermal comfort. Amoako-Attah and B-Jahromi (2013) using thermal analysis simulation investigated the impact of varying climatic patterns on five building performance indicators and indicated how improve building energy efficiency will challenge future innovative design and adapted technological process. Anh-Tuan and Reiter (2014) used simulation approach to investigate the design, operation and thermal comfort of low-cost dwellings and Taleghani *et al*. (2014) using thermal simulation investigated heat mitigation strategies using vegetation and ponds.

Studies of thermal comfort performance metrics have also been presented in many publications which have led to the development of thermal comfort models and standards. Beginning in 1970, Fanger (1970) through steady-state experimentation in a controlled climate chamber developed a heat balance comfort model and further stipulated the predicted mean vote. In 1998, de Dear and Brager (1998) using the concept of adaptation developed their adaptive model which later formed part of the American adaptive model ASHRAE 55. In 2002, Nicol and Humphreys (2002) developed an adaptive model which together with Fanger comfort model was later incorporated in the European standard EN 15251 in 2007. Another acceptable thermal comfort standard, the ISO 7730 was developed in 2005. This standard seeks to specify varying stages of thermal comfort and takes into cognisance the predictive mean vote (PMV) index and the predicted percentage of dissatisfied (PPD). The ASHRAE 55, whilst using the PMV and PPD in the model also accounts for local thermal discomfort and dynamic effects (ANSI/ASHRAE 55, 2004) and the improved standard of 2010 accounts for mechanically conditioned buildings (ASHRAE 2010). In 2005, CIBSE TM36 (2005) outlined thermal performance risk using the UKCIP02 medium-high emission scenarios on selected dwellings and non-dwellings in different UK locations. The criteria for assessment were the comfort threshold temperatures of 25°C and 28°C earmarked in the Fanger model (CIBSE 2005, Hacker *et al*. 2005). In 2009, Chen reviewed ventilation performance predictive tools. In 2009, Yao *et al*. (2009) conceptualized the adaptive predictive mean vote and in that same year, Toftum *et al*. (2009), in determining acceptable thermal conditions applied the adaptive thermal comfort mode. In 2010, the Zero Carbon Hub (ZCH 2010) re-examined the CIBSE TM36 (2010) overheating assessment methods and metrics. In 2013, CIBSE (2013) offered the most updated assessment of thermal comfort performance based on current knowledge and this is an integration of the methodology and recommendation outline in BS EN 15251 (BSI 2007) and additional factors to assess the overheating in naturally ventilated dwellings (CIBSE TM52 2013). Carlucci *et al*. (2014) analysed various thermal comfort methods used as tools for predicting overheating but did not include the newly developed CIBSE overheating criteria in their work.

Prior to the advent of the new CIBSE overheating criteria, the Zero Carbon Hub in conclusion after their work on overheating on a range of UK dwelling type indicated the need of a more robust tool for assessing overheating in buildings (ZCH 2012). No research to the authors' view has been done using the new CIBSE overheating criteria to holistically assess the thermal comfort of detached dwellings in the UK. This paper therefore employs integrated passive cooling strategies of enhanced thermal mass, ventilation scenarios, different building locations and external shading, and a methodology that combines thermal analysis modelling and simulation coupled with the application of the newly developed CIBSE overheating criteria to investigate the thermal comfort in detached dwellings in the UK using the CIBSE high design summer year (DSY) emission scenarios for the current and future (2020's, 2050's and 2080's) climatic change projections.

2. Methodology

2.1 Background

The goal is to verify through a series of simulation using the UK Charted Institution of Building Services Engineers CIBSE Design Summer Year (DSY) of current and future weather data which incorporates the UKCIP02 projections to verify if the optimization of thermal comfort performance depends on variable climatic conditions, enhanced thermal mass, building orientation and location, ventilation strategy, external shading and varying occupant characteristics using the newly developed CIBE overheating criteria (CIBSE TM52 2013) as an assessment tool on detached dwelling stock in the United Kingdom.

TAS software version 9.2.1.6 (build) is used as a dynamic simulation modeller to model and simulate the thermal mass of the prototype building taking London and Birmingham as locations. The TAS software was developed by EDSL. The TAS software has the capability to overcome the challenge of applying the 'vast quantity of data to assess the probabilistic performance of buildings in the future' (Williams *et al*. 2011) and the new version of TAS has now incorporated the CIBSE TM52 adaptive overheating criteria for building zones analysis. Moreover, it offers complete solution as a powerful modelling and simulation in the optimisation of building environment, energy performance and occupant comfort. The SAP software a "surrogate design tool" which uses monthly average in determining overheating risk (DCLG, AECOM 2012) was not used in this work. As noted in the Department of communities and Local Government (DCLG) and AECOM report in July 2012 "SAP tool is intended to be used for a compliance assessment rather than as a design tool." Since the work on the progressive variation of the thermal mass and other construction specifications were design based, TAS was selected as appropriate software. However, while TAS offers an excellent means to evaluate the respective zones overheating based on the CIBSE TM52 adaptive overheating criteria, the analysis and graphical representation of the whole building was observed to be only weather based and do not truly reflect the indoor operating temperatures as defined in the CIBSE TM52. TAS uses variation of the external temperatures instead of the indoor operative temperature. Thus TAS graphical representation of the CIBSE adaptive overheating criteria is based on the external dry bulb and external running mean temperature. The authors therefore developed an Excel program for the analysis of the whole building scenario as stipulated in the CIBSE TM52 to reflect the variation of the indoor operating temperature for clear assessment of the dwelling thermal comfort. Data from the TAS simulation was fed into the Excel program for this analysis.

Four typical energy efficient standard construction specification previously identified as part of the core standard construction specifications in the work of the Zero Caron Homes practise (ZCH 2009) were used. These standard construction specifications used are underpinned by the fabric energy efficiency standards on dwellings which was developed by an Industry Task Group led by the Zero Carbon Hub in 2009 (ZCH 2009) whose work was based on well recognized energy efficient design standards. The 'Baseline' specification was set based on current building practise (ZCH 2009) and conforms to the 2010 Building Regulations Part L compliant for dwelling. The 'Fabric Energy Efficiency Standard' (FEES) specification is based on the Energy Saving Trust Best Practice Energy Efficiency (EST BPEE) Standard. The third specification; 'Beyond Fabric Energy Efficiency Standard' is based on the Energy Saving Trust Advanced Practice Energy Efficiency (EST APEE) Standard and the fourth specification is equivalent to the PassivHaus Standard. Table 1 stipulates the summary of the four construction specification as indicated in the Zero Carbon Homes report (ZCH 2009) and their equivalent as the results of the modelling and simulation of this work.

2.2 Thermal Analysis Simulation (TAS) 3D modelling

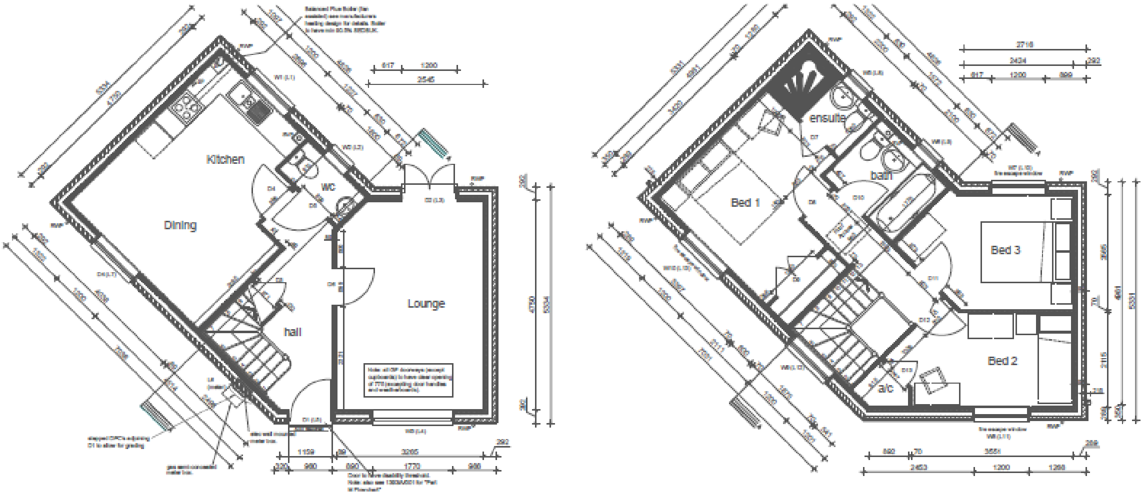
The data used, are the AutoCAD two-storey residential detached buildings drawings of Persimmon South East Ltd Sheppey General Hospital. The building drawings consisted of the front elevation, rear and side elevation, a section through the elevation, ground floor plan, first floor plan and the roof arrangement plan. Figs. 1(a)-(d) below indicate the architectural plan of the selected houses, the drawing data for 0712 House Type G Pri used in this work.

Table 1 Standard construction specifications and modelling assumptions zero carbon homes and TAS results

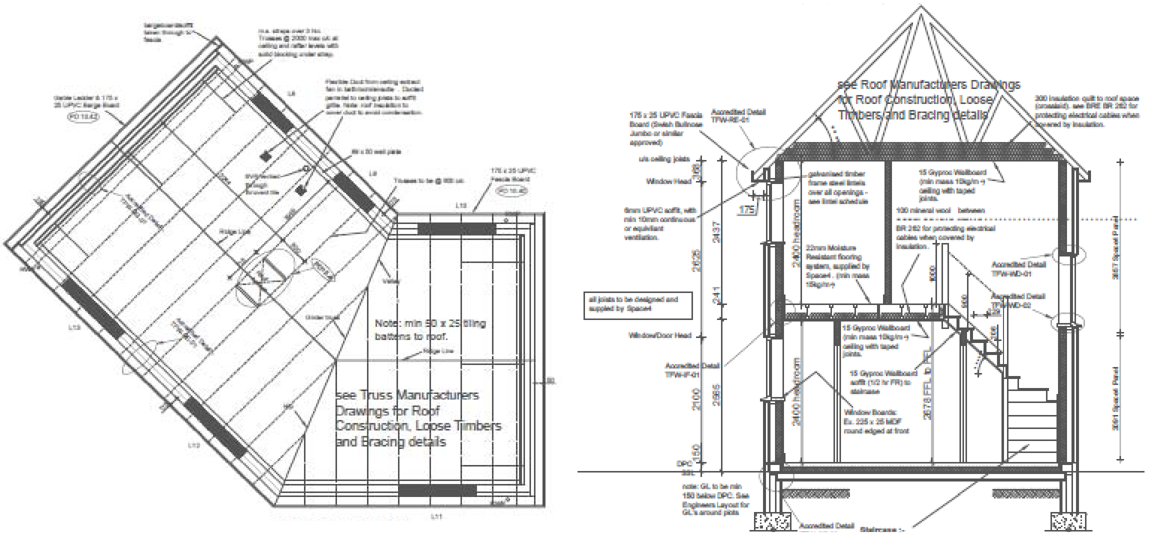
		Standard construction specifications and modelling assumptions (ZCH 2009)				Equivalent standard construction specifications and modelling assumptions (TAS results)			
		Baseline	FEES / EST BPEE	Beyond FEES / EST APEE	PassivHaus Equivalent	Baseline	FEES / EST BPEE	Beyond FEES / EST APEE	PassivHaus Equivalent
U-value (W/m^{2}K)	Wall	0.28	0.18	0.15	0.1-0.15	0.25	0.16	0.15	0.1
	Party wall	0.5	0	0	0	0.5	0	0	0
	Floor	0.2	0.18	0.15	0.1-0.15	0.16	0.15	0.13	0.09
	Roof	0.16	0.13	0.11	0.1	0.14	0.12	0.1	0.09
	Windows	1.8	1.4	0.8	0.8-1.0	1.8	1.4	1	1
	Doors	1.6	1.2	1	0.8	1.7	1.24	1.24	1.24
	Air permeability (m^3/hr/m^2)	5	3	1	0.41-0.5	5	3	1	0.5
	Thermal bridging (W/m^{2}K)	0.08	0.05	0.04	0.04	0.8	0.05	0.4	0.04
	Ventilation	Natural (extract fans)	Natural (extract fans)	MVHR	MVHR	Natural (extract fans)	Natural (extract fans)	Mechanical	Mechanical
	Low energy lighting	100%	100%	100%	100%	100%	100%	100%	100%
	MVHR spec (where used)	-	-	SFP = 1 W/l/s	SFP = 1 W/l/s	-	-	SFP = 1.0 W/l/s	SFP = 1 W/l/s
	Orientation (max glazed area)	East	East	East	East	East	East	East	East
	Gas boiler efficiency	90%	90%	90%	90%	90%	90%	90%	90%
	DHW storage	200 Litres	200 Litres	200 Litres	200 Litres	200 Litres	200 Litres	200 Litres	200 Litres

2.3 Modelling process

Measurements of floors, doors and windows dimensions were taken from the AutoCAD elevations drawings. The floor level was measured from the ground plane at datum 0.0 m. The default wall heights dimensions were measured from the floor finish to directly below the floor finishing of the upper floor. The respective zones on the ground floor and first floor plans were



(a) Ground floor plan (b) First floor plan



(c) Roof arrangement (d) Building section

Fig. 1 Architectural plan

noted and further grouped into Bedrooms, Circulation, Toilet and Miscellaneous.

To aid in the shadow calculations in the 3D Modeller, the orientation of the north angle was changed to 135 degrees clockwise to the North and the latitude, longitude and time zone changed to 51.5 degrees North, –0.4 degrees East and UTC +0.0 respectively to reflect the geographical and time parameters of London and 52.45 degrees North, –1.74 degrees East and UTC +0.0 respectively to also reflect the geographical and time parameters of Birmingham. The flow charts in Figs. 2-4 below illustrate the drawing files preparation for the 3D modelling process and the modelling of the ground floor, first floor and the roof arrangement respectively.

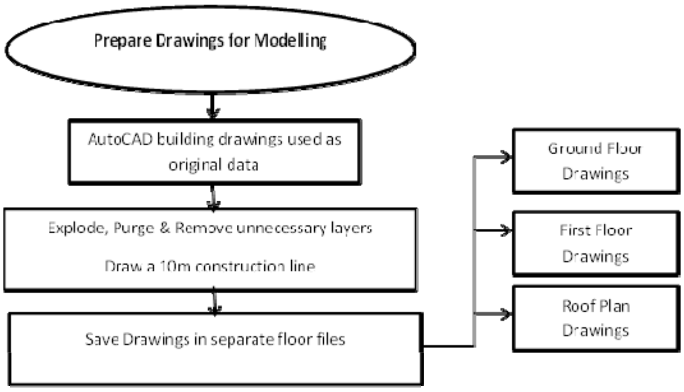


Fig. 2 Prepare drawings for modelling

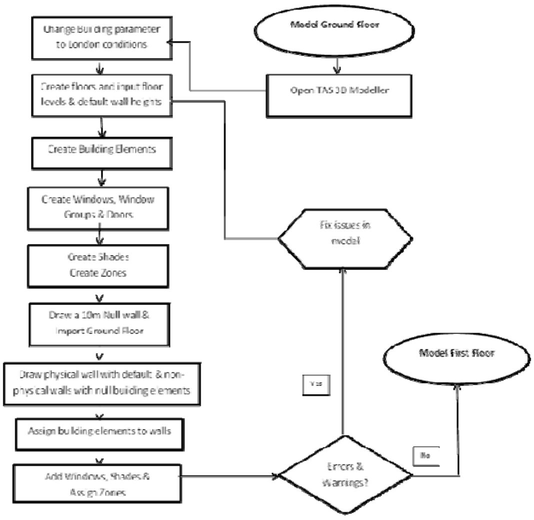


Fig. 3 Ground floor modelling process

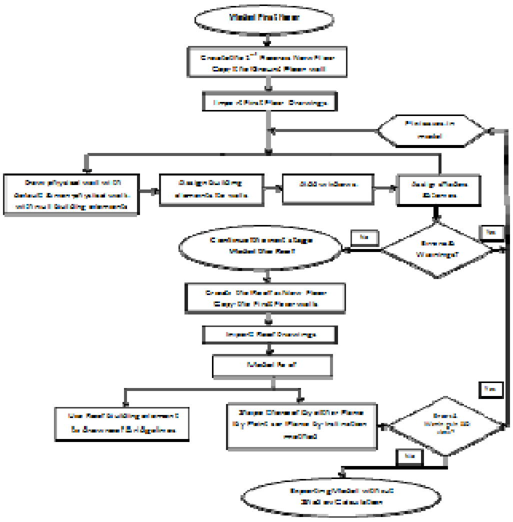


Fig. 4 First floor/roof modelling process

2.4 Simulation process

TAS as a dynamic simulation modeller models the thermal mass of a building. Building performance simulation requires the appropriate selection of modelling parameters and assumptions. The various construction elements thermal mass as specified by the Zero Carbon Hub Work Group were design in the TAS software to reflect the standard construction specifications for the 'Baseline', 'Fabric Energy Efficiency Standard' (FEES) / Energy Saving Trust Best Practice Energy Efficiency (EST BPEE) Standard, 'Beyond Fabric Energy Efficiency Standard'/ Energy Saving Trust Advanced Practice Energy Efficiency Standard and the PassivHaus Standard as outlined in Table 1. Figs. (5) and (6) show an example in the case of the PassivHaus Equivalent Standard external wall with totalling width of 515.5 mm of 13 mm plaster internal finish, 100 mm 4 N/mm^2 ACC block work, full-fill 300 mm glass wool insulation and 102.5 mm external leaf brick work.

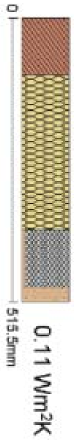
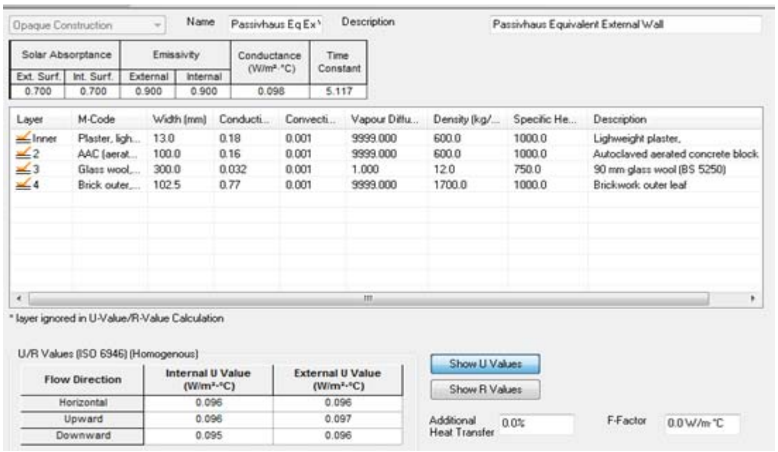


Fig. 5 ZCH (2009) PassiHaus external wall specification



Name: Passivhaus Eq Ex
Description: Passivhaus Equivalent External Wall

Solar Absorptance		Emissivity		Conductance (W/m²·°C)	Time Constant
Ext. Surf.	Int. Surf.	External	Internal		
0.700	0.700	0.900	0.900	0.098	5.117

Layer	M-Code	Width (mm)	Conducti...	Convecti...	Vapour Diffu...	Density (kg/...	Specific He...	Description
Inner	Plaster, ligh...	13.0	0.18	0.001	9999.000	600.0	1000.0	Lighweight plaster,
2	AAC (aerat...	100.0	0.16	0.001	9999.000	600.0	1000.0	Autoclaved aerated concrete block
3	Glass wool,...	300.0	0.032	0.001	1.000	12.0	750.0	90 mm glass wool (BS 5250)
4	Brick outer,...	102.5	0.77	0.001	9999.000	1700.0	1000.0	Brickwork outer leaf

* layer ignored in U-Value/R-Value Calculation

U/R Values (ISO 6946) (Homogenous)

Flow Direction	Internal U Value (W/m²·°C)	External U Value (W/m²·°C)
Horizontal	0.096	0.096
Upward	0.096	0.097
Downward	0.095	0.096

Additional Heat Transfer: 0.0%
F-Factor: 0.0 W/m·°C

Fig. 6 Equivalent PassiHaus external specification as design for TAS simulation

Table 2 Internal conditions specification for simulation

Construction data base	NCM construction - v4.1.tcd	
Occupancy levels	Bath	0.01873684 pers/m^2. 150 Lux
People density	Bed	0.01873684 pers/m^2. 100 Lux
Lux level	Circulation areas	0.02293877 pers/m^2. 100 Lux
	Dining	0.0169163 pers/m^2. 150 Lux
	Kitchen	0.0237037 pers/m^2. 300 Lux
	Lounge	0.0187563 pers/m^2. 150 Lux
	Toilet	0.02431718 pers/m^2. 100 Lux
Calendar	NCM standard	
Fuel source	Natural gas	CO_2 Factor - 0.198 Kg/kWh
	Grid electricity	CO_2 Factor - 0.517 Kg/kWh

The other simulation parameters of Building Summary, Calendar, Weather, Zones, Internal conditions, Schedule, and Aperture Types were populated to simulate the building for it to reflect the construction design criteria specified by the CIBSE Guide A (2006) and TAS for dwellings. These are shown in Table 2. Fig. 7 is a flow chart which shows the thermal simulation process with its associated modelling and simulation parameters in Tables 1 and 2.

2.5 UK building regulation studio

The UK Building Regulations Studio used by the TAS EDSL 9.2.1.6 software is based on 2010 regulations. It adheres to the National Calculation for Methodology (NCM) for the Energy Performance of Building Directive (DCLG). The UK Building Regulations Studio is systematically worked through by appropriately selecting various parameters and circuit configuration leading to the generation of series of building reports of which data based on the external temperature, the

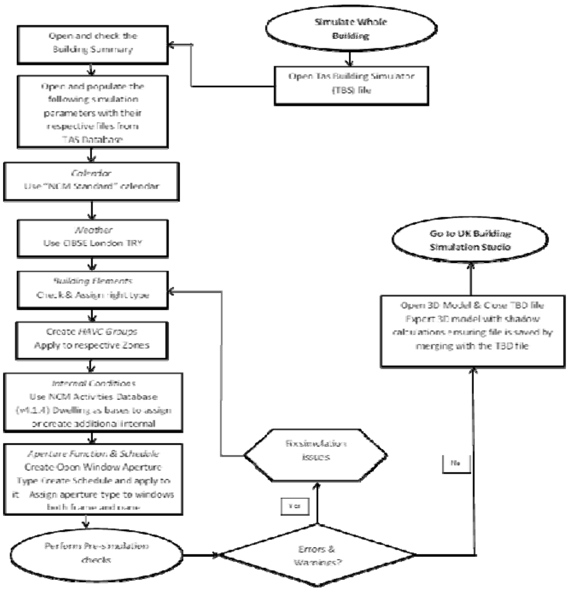


Fig. 7 Thermal simulation process

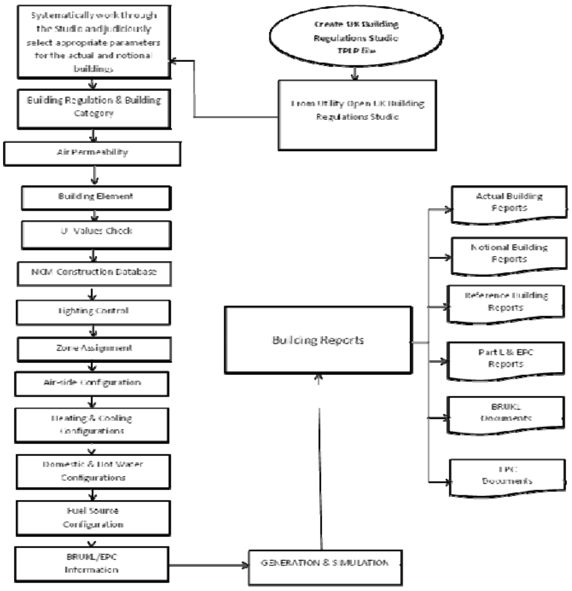


Fig. 8 UK building regulation studio simulation

dry bulb temperature and the mean radiant temperatures are extracted and sent to the developed Excel program for CIBSE TM52 whole building overheating analysis. The CIBSE TM52 overheating analysis is carried out in TAS report generator. Fig. 8 illustrates the flow chart of simulation processes in the UK building regulation studio.

2.6 Future weather data simulation process and mitigation scenarios

The various modelling and simulation parameters of Building Summary, Calendar, Building Elements, Zones, Internal conditions (which include thermostat set up, infiltration and ventilation, occupancy, lighting and equipment details), Schedule, and Aperture Types which were used to populated and simulate each building are maintained with the only variant being the weather data.

A series of scenarios based on the current and the future climate variables at different time lines of 2020s, 2050s and 2080s with their respective high design summer year (DSY) as the worst case analysis carbon scenarios are simulated. Most existing buildings in the UK are naturally ventilated during the day, thus the methodology begins with this design consideration seeing its advantages of reduced carbon dioxide emissions when compared with mechanical ventilation. The modelling and simulation processes were followed through for the mitigation scenarios of night ventilation and night ventilation with external shading. External shading was used as it is observed to be most effective shading strategy for provision of passive cooling in buildings (DCLG, AECOM 2012). The shading was a combination of both vertical and horizontal shades. Windows were opened 50% at all times in all scenarios.

2.7 CIBSE TM52 criteria as an overheating assessment tool

Thermal comfort (indoor operative temperature) depends on four basic environmental factors of air temperature, the mean radiant temperature, the relative air velocity and relative humidity. One of the main functions of residential buildings is to provide healthy and comfortable environments to the occupants. Buildings must therefore be designed and built by taking cognisance of the physiological reactions of the occupants due to temperature and humidity tolerance of occupants.

CIBSE TM52 (2013) provides guidelines for general indoor overheating for naturally ventilated dwellings which replaces the criterion set out in CIBSE Guide A (2006). The guideline specifies three criteria of 'Hours of Exceedance', 'Weighted Exceedance' and 'Upper Temperature Limit' as first, second and third criteria respectively. A dwelling would be considered overheated if any two of the three criteria are exceeded (CIBSE TM52 2013).

The CIBSE TM52 criteria are underpinned by the Category II in BS EN 15251 (BSI 2007) which earmark a maximum acceptable temperature of three degrees above the comfort temperature for naturally ventilated buildings. The BS EN 15251 Eq. for comfort temperature is given as

$$T_{comf} = 0.33T_{rm} + 18.8 \tag{1}$$

Where, T_{comf} is the comfort temperature and T_{rm} is the exponentially weighted running mean of the daily mean outdoor air temperature.

The general equation of the exponentially weighted running mean temperature for any day is given as

$$T_{rm} = (1-\alpha)(T_{od-1} + \alpha T_{od-2} + T_{od-3} \ldots) \tag{2}$$

Where α is a constant less than one and $T_{od\text{-}1}$, $T_{od\text{-}2}$, $T_{od\text{-}3}$, etc. are the daily mean outdoor temperatures for yesterday, the day before, and so on.

The simplified equation of the exponentially weighted running mean is given as

$$T_{rm} = (1-\alpha)T_{od-1} + \alpha T_{rm-1} \tag{3}$$

In situations of lack of extensive run of days, the BS EN 12521 (BSI 2007) specifies Eq. (4) as an approximated method for computing the exponentially weight running mean using the outdoor mean temperatures for the last seven days with the 'α' value equal to 0.8.

$$T_{rm} = (T_{od-1} + 0.8T_{od-2} + 0.6T_{od-3} + 0.5T_{od-4} + 0.4T_{od-5} + 0.3T_{od-6} + 0.2T_{od-7})/3.8 \tag{4}$$

With known value for the exponentially weighted running mean, T_{rm}, the limiting maximum acceptable temperature can be calculated using Eq. (5).

$$T_{\max} = 0.33T_{rm} + 21.8 \tag{5}$$

All the CIBSE TM52 criteria are governed by the difference between the actual operative temperature in the room (T_{op}) and the limiting maximum acceptable temperature, $T_{\max}$ and it is given by Eq. (6) as

$$\Delta T = T_{op} - T_{\max} \tag{6}$$

The exponentially weighted running means Eq. (4), the limiting maximum acceptable temperature Eq. (5) and the difference between the actual operative temperature and the limiting

(a) Front elevation

(b) Rear and side elevation (c) Rear and side elevation

Fig. 9 Modelling results

maximum acceptable temperature Eq. (6) were used by the authors in developing the Excel program used for the whole building overheating analysis.

The hours of exceedance criterion, stipulates the number of hours during which the operative temperature can exceed the limiting maximum acceptable temperature by one degree or more during a non-heating season of 1 May to 30 September (CIBSE TM52 2013). The daily weighted exceeding criterion stipulates a daily limit of severity (a function of temperature increase and duration) above which overheating can be classified (CIBSE TM52 2013). The upper limit earmarks a set temperature value for the difference between the indoor operative temperature and limiting maximum acceptable temperature to be not more than four degrees (CIBSE TM52 2013).

3. Results and discussion

The analysis of building prototype - Persimmon South East Ltd. Sheppey General Hospital dwelling 0712 House Type G Private - two-storey residential detached building is presented below. Figs. 9(a)-(c) represent the outcome of the modelling process.

Figs. (10)-(13) and (14)-(17) show the Excel whole building analysis results for London and Birmingham respectively, of all the simulation scenarios of progressive improvement of thermal

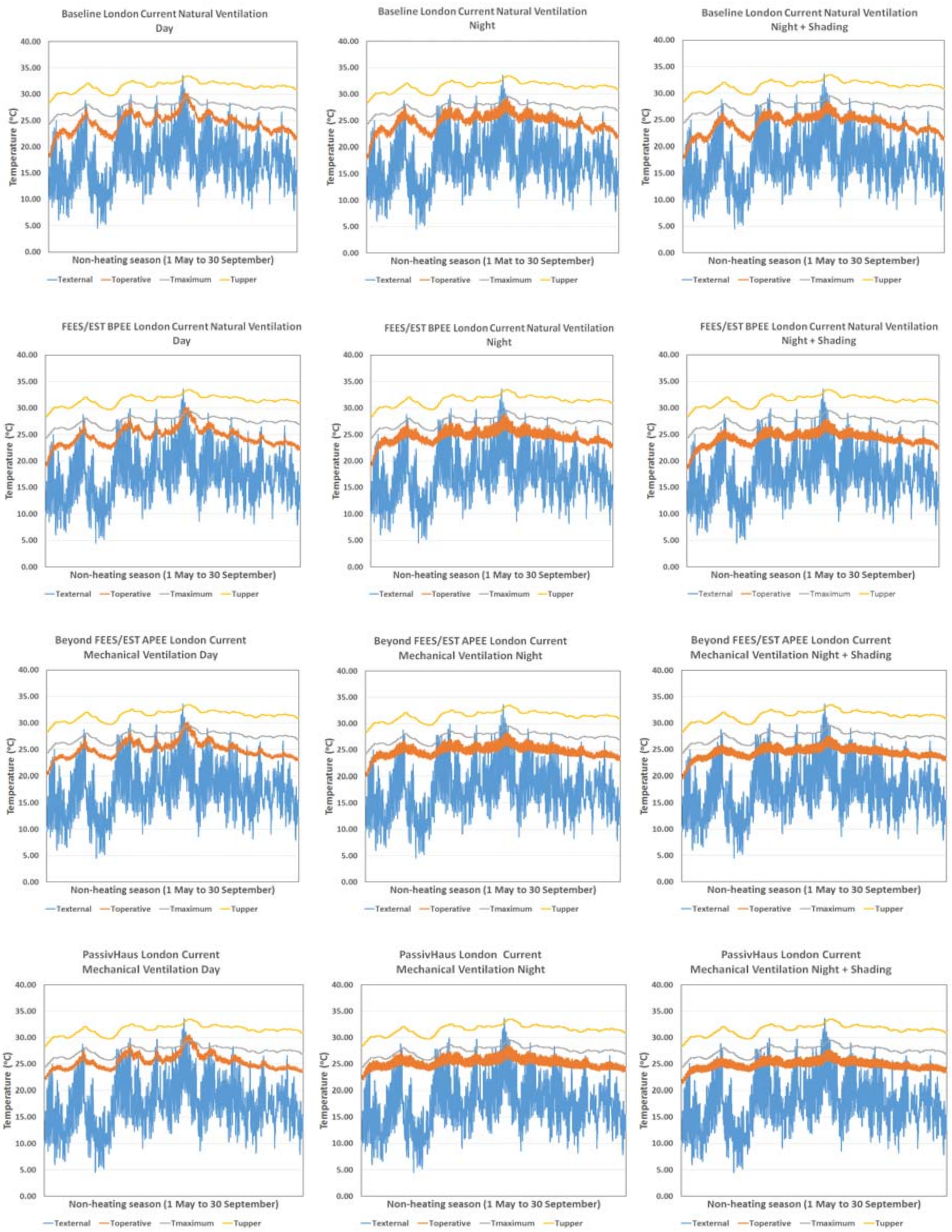
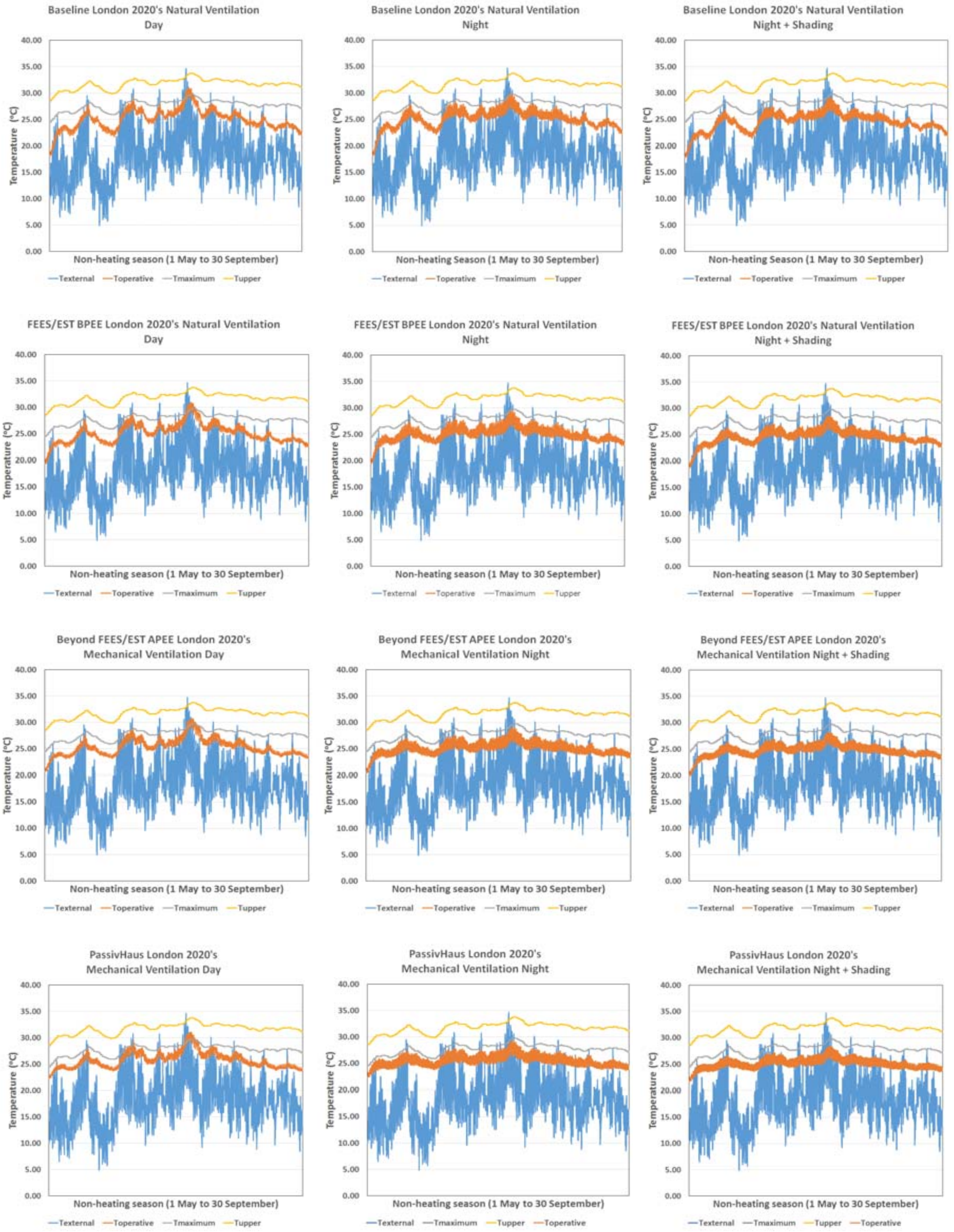


Fig. 10 London current weather whole building analysis



Baseline London 2020's Natural Ventilation Day

Baseline London 2020's Natural Ventilation Night

Baseline London 2020's Natural Ventilation Night + Shading

FEES/EST BPEE London 2020's Natural Ventilation Day

FEES/EST BPEE London 2020's Natural Ventilation Night

FEES/EST BPEE London 2020's Natural Ventilation Night + Shading

Beyond FEES/EST APEE London 2020's Mechanical Ventilation Day

Beyond FEES/EST APEE London 2020's Mechanical Ventilation Night

Beyond FEES/EST APEE London 2020's Mechanical Ventilation Night + Shading

PassivHaus London 2020's Mechanical Ventilation Day

PassivHaus London 2020's Mechanical Ventilation Night

PassivHaus London 2020's Mechanical Ventilation Night + Shading

Fig. 11 London 2020’s weather whole building analysis

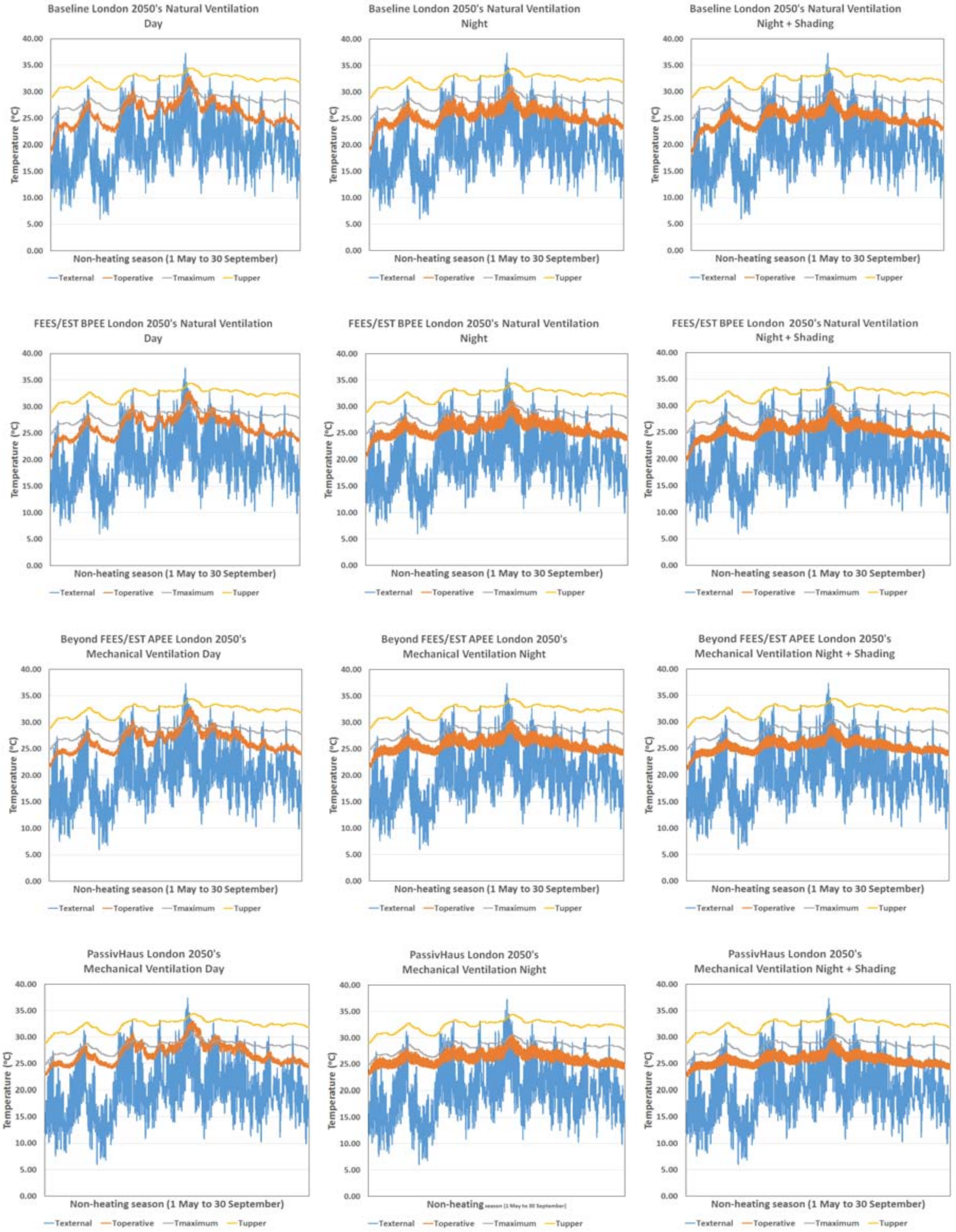


Fig. 12 London 2050's weather whole building analysis

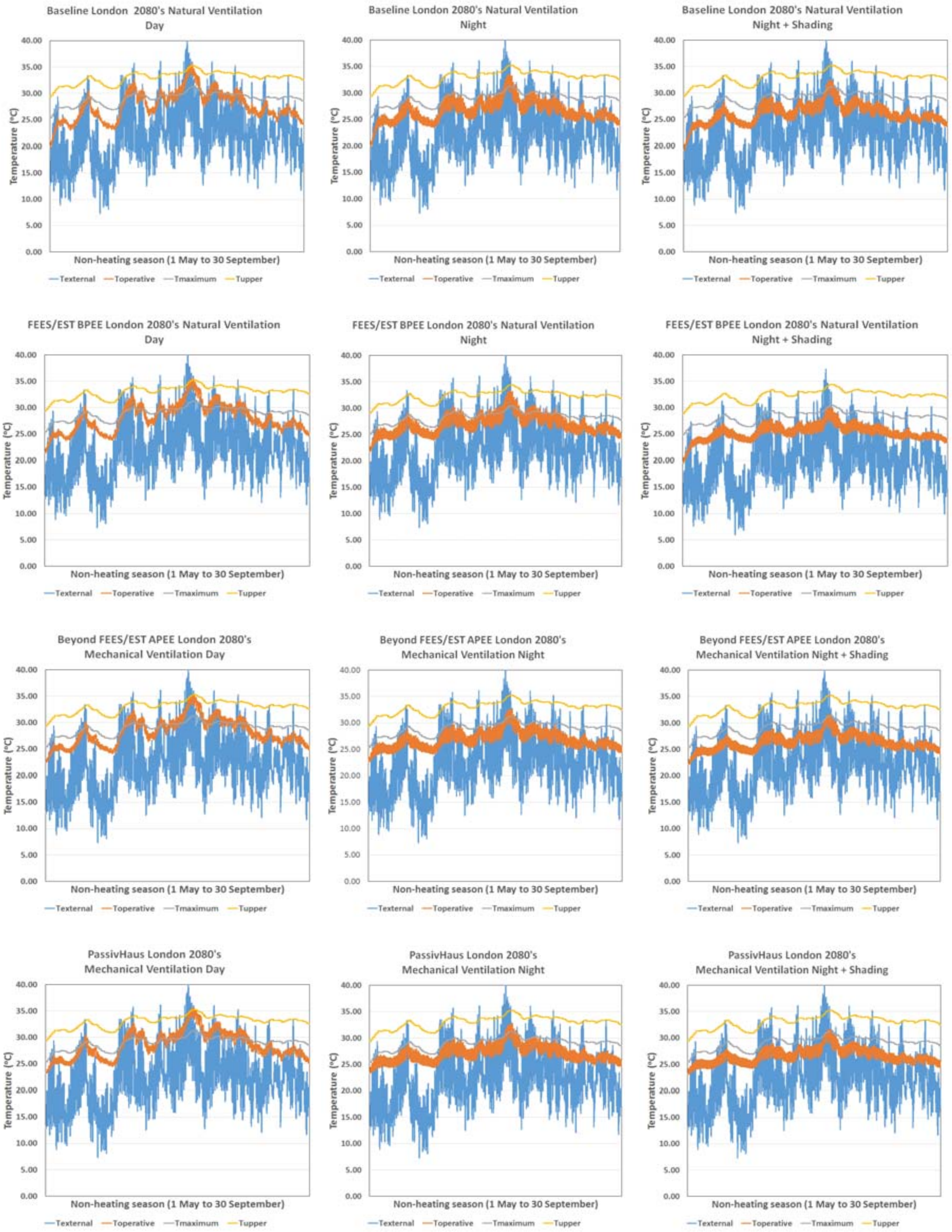
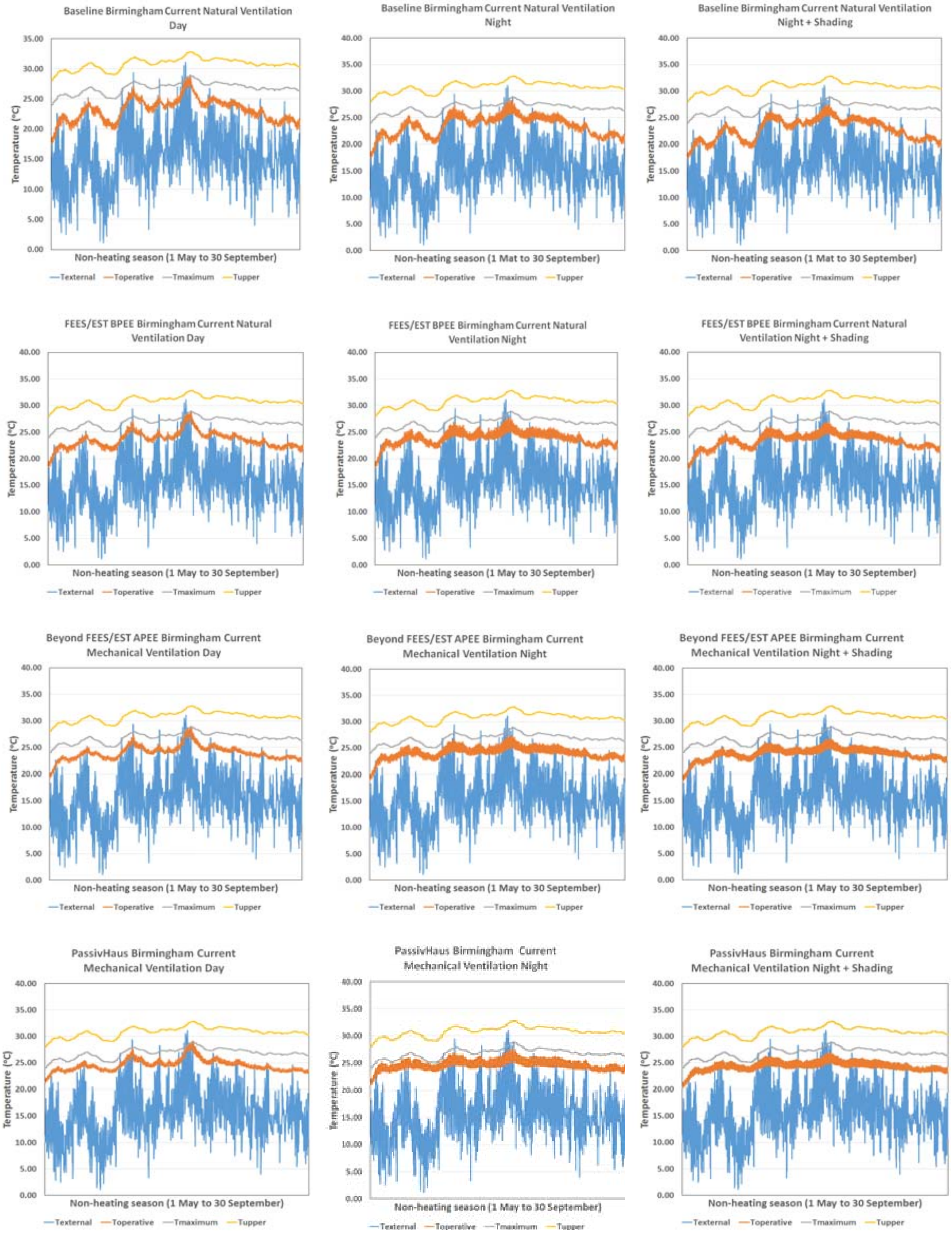


Fig. 13 London 2080's weather whole building analysis



Baseline Birmingham Current Natural Ventilation Day

Baseline Birmingham Current Natural Ventilation Night

Baseline Birmingham Current Natural Ventilation Night + Shading

FEES/EST BPEE Birmingham Current Natural Ventilation Day

FEES/EST BPEE Birmingham Current Natural Ventilation Night

FEES/EST BPEE Birmingham Current Natural Ventilation Night + Shading

Beyond FEES/EST APEE Birmingham Current Mechanical Ventilation Day

Beyond FEES/EST APEE Birmingham Current Mechanical Ventilation Night

Beyond FEES/EST APEE Birmingham Current Mechanical Ventilation Night + Shading

PassivHaus Birmingham Current Mechanical Ventilation Day

PassivHaus Birmingham Current Mechanical Ventilation Night

PassivHaus Birmingham Current Mechanical Ventilation Night + Shading

Fig. 14 Birmingham current weather whole building analysis

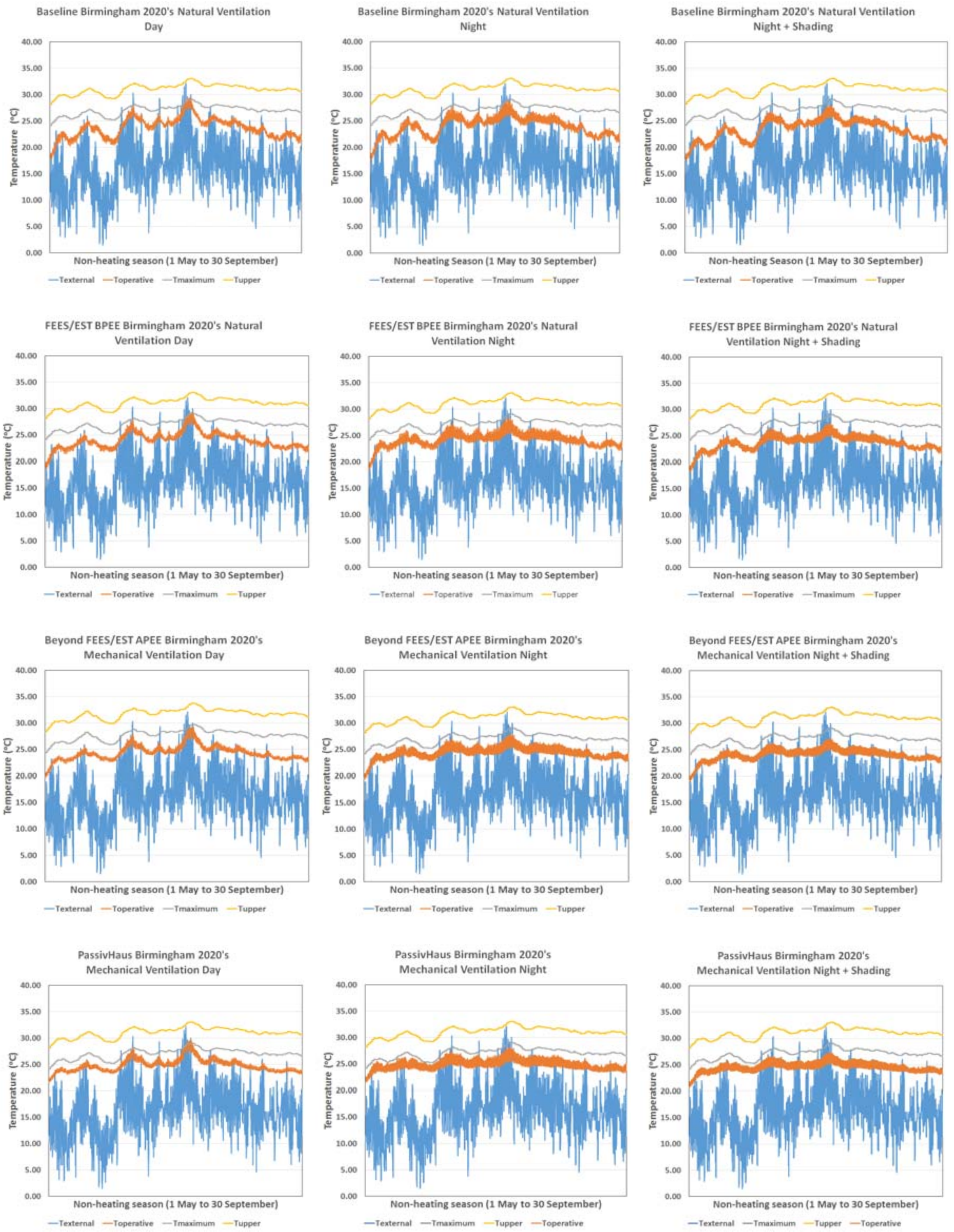


Fig. 15 Birmingham 2020’s weather whole building analysis

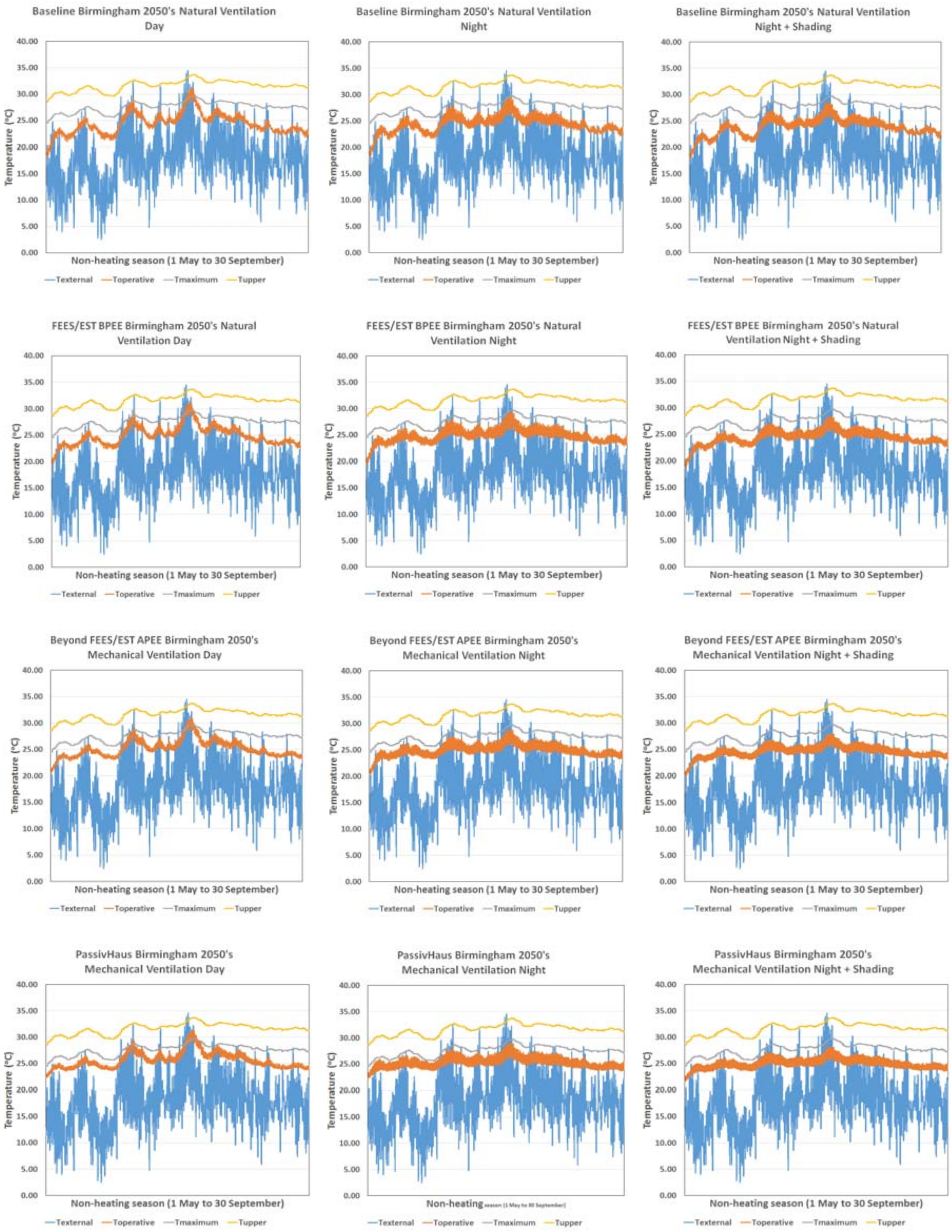
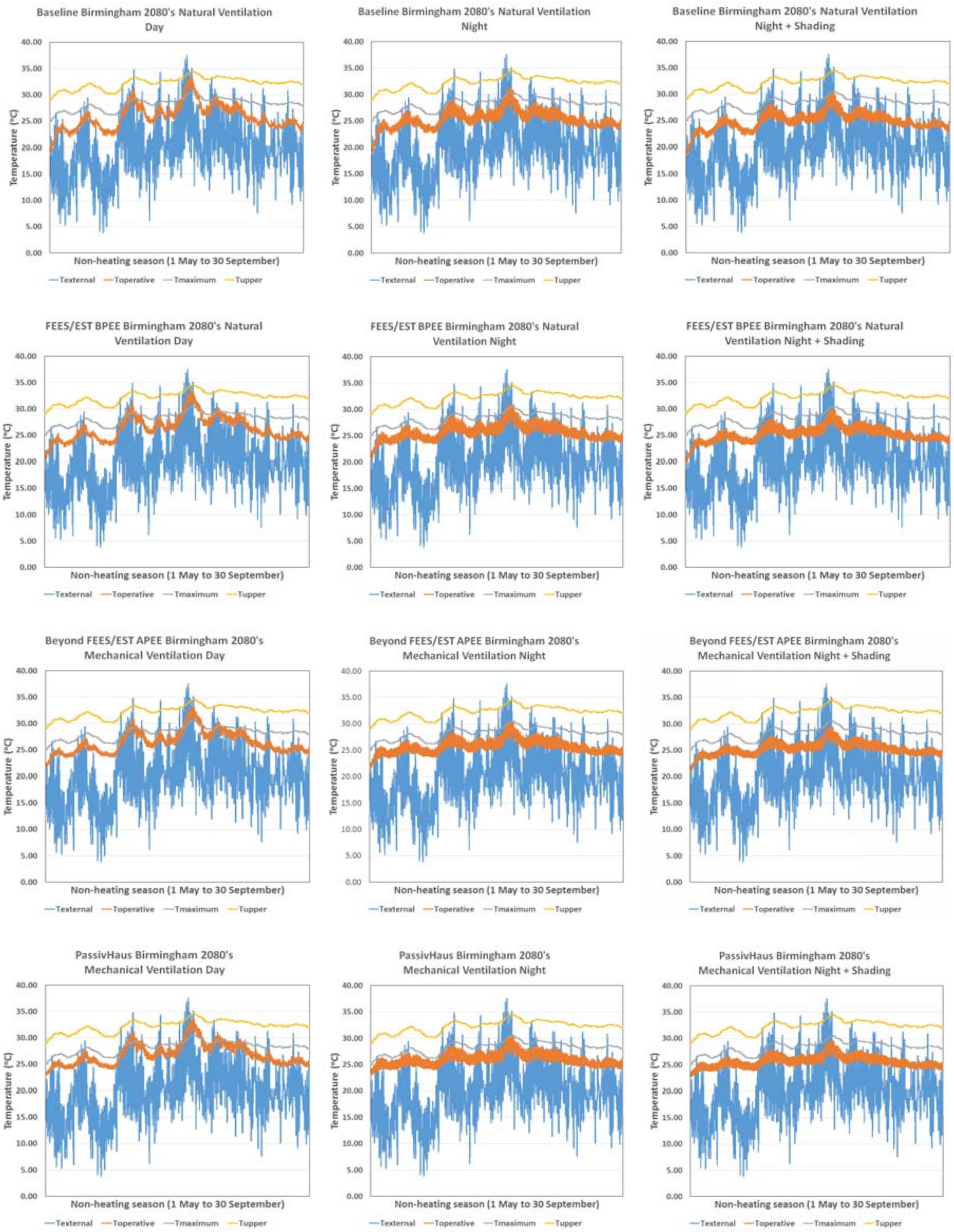


Fig. 16 Birmingham 2050's weather whole building analysis


Baseline Birmingham 2080's Natural Ventilation Day

Baseline Birmingham 2080's Natural Ventilation Night

Baseline Birmingham 2080's Natural Ventilation Night + Shading

FEES/EST BPEE Birmingham 2080's Natural Ventilation Day

FEES/EST BPEE Birmingham 2080's Natural Ventilation Night

FEES/EST BPEE Birmingham 2080's Natural Ventilation Night + Shading

Beyond FEES/EST APEE Birmingham 2080's Mechanical Ventilation Day

Beyond FEES/EST APEE Birmingham 2080's Mechanical Ventilation Night

Beyond FEES/EST APEE Birmingham 2080's Mechanical Ventilation Night + Shading

PassivHaus Birmingham 2080's Mechanical Ventilation Day

PassivHaus Birmingham 2080's Mechanical Ventilation Night

PassivHaus Birmingham 2080's Mechanical Ventilation Night + Shading

Fig. 17 Birmingham 2080’s weather whole building analysis

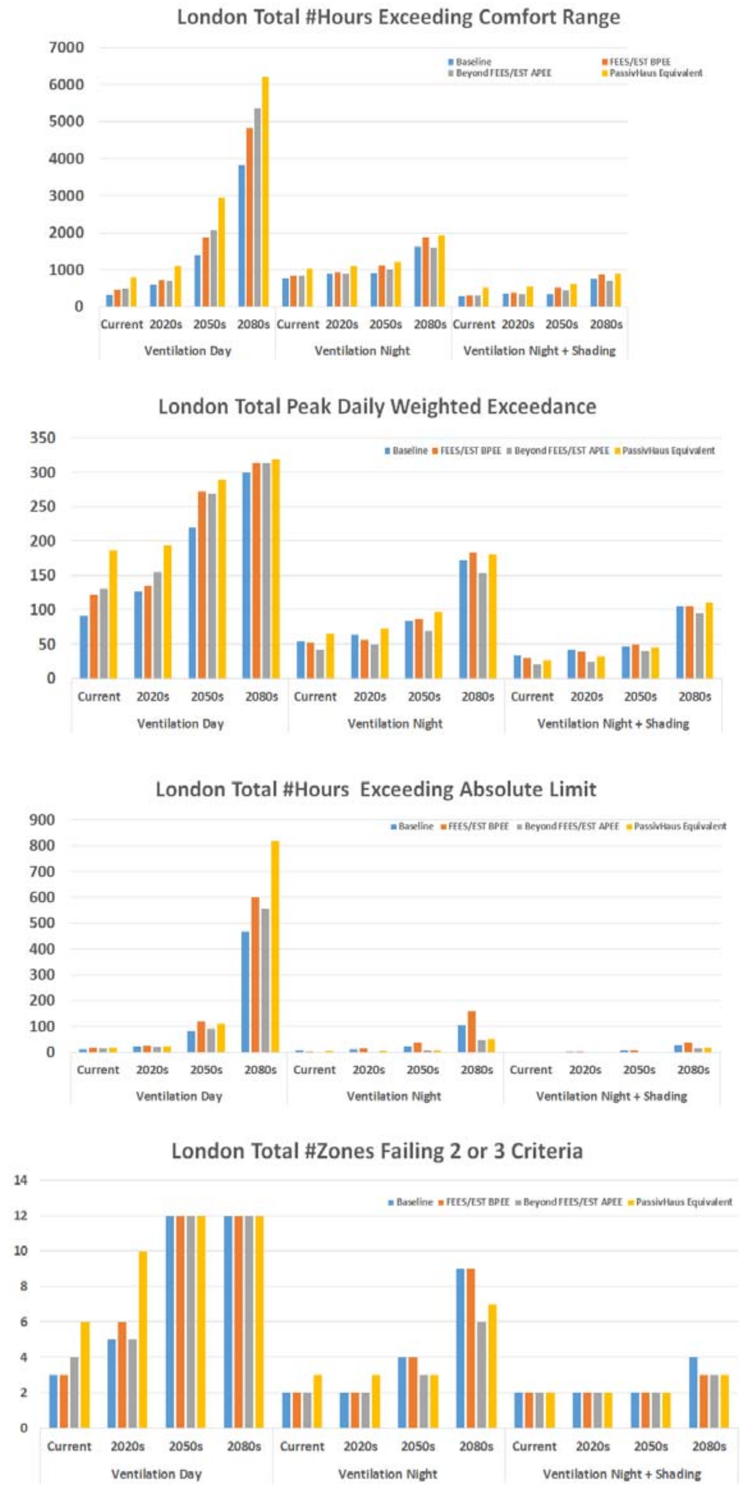


Fig. 18 London CIBSE TM52 analysis

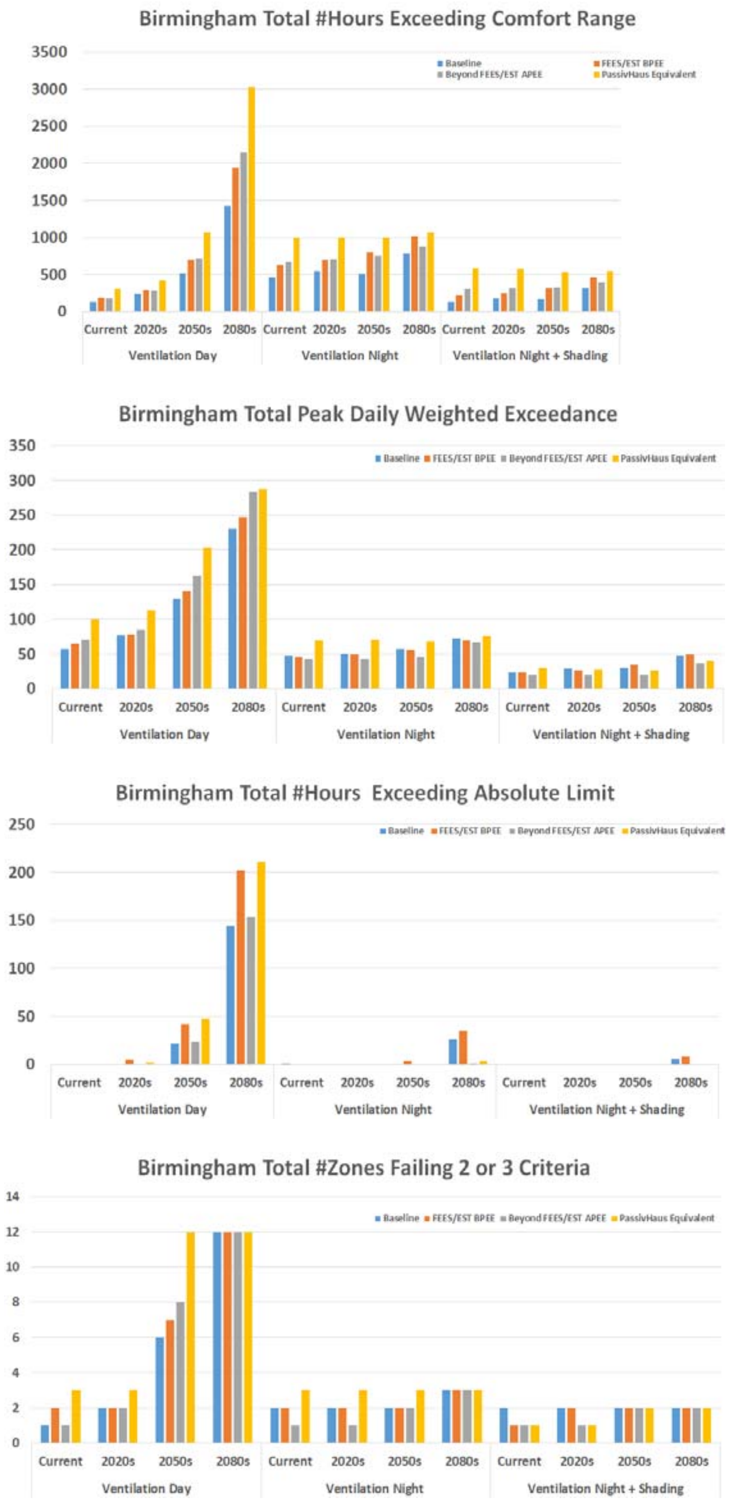


Fig. 19 Birmingham CIBSE TM52 analysis

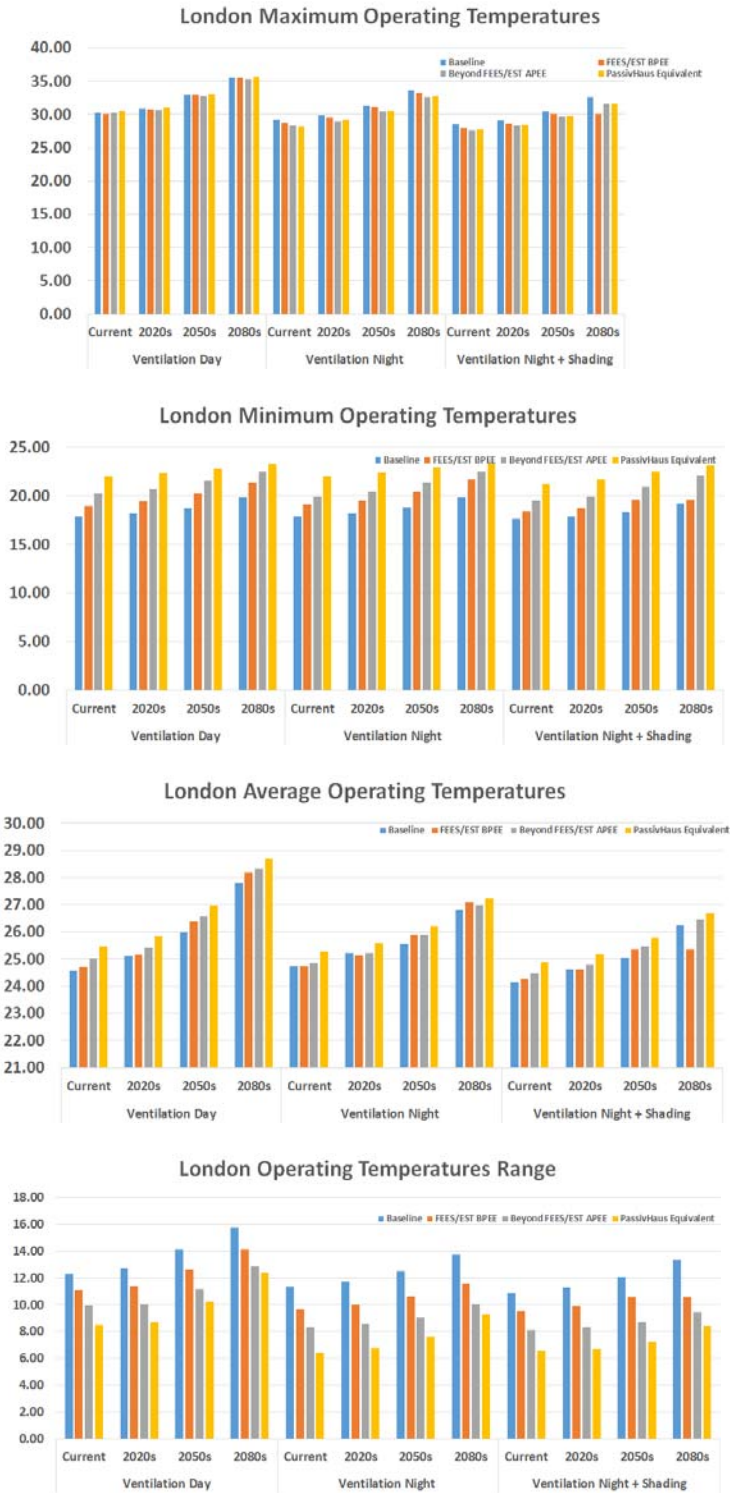
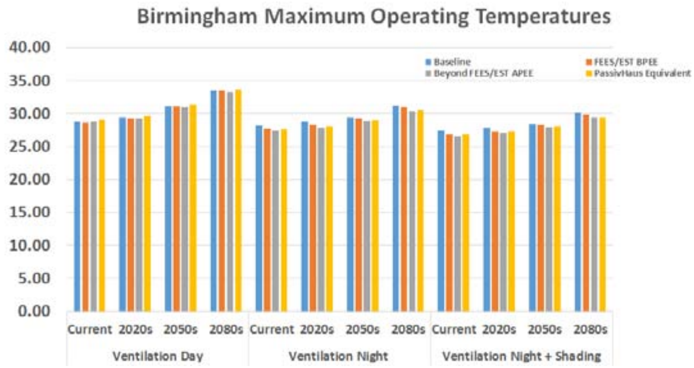
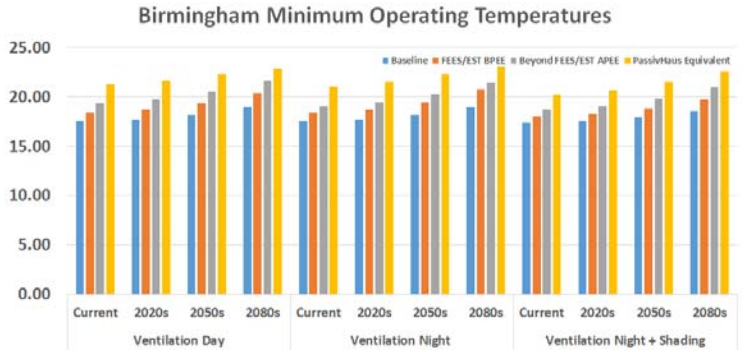
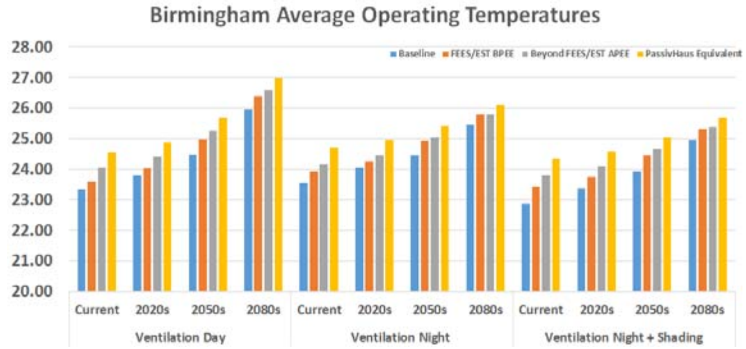


Fig. 20 London operative temperature analysis







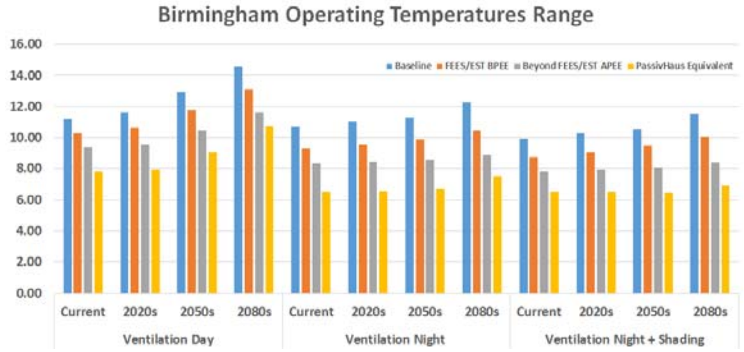


Fig. 21 Birmingham operative temperature analysis

mass, change of building location, different ventilation strategies, provision of external shading and variable occupant behaviour earmarked to optimized thermal comfort, the set goal for the study.

Figs. 18-21 show analysis of operative temperatures in respective zones analysis results for London and Birmingham respectively based on the CIBSE TM52 results.

3.1 Impact of weather and location

The whole building simulation scenarios for London and Birmingham results over the current and the three future high Design summer year (DSY) weather data set show a consistence increase in indoor operative temperatures. The prime factor for the variation of indoor operative temperatures is the variability of climatic patterns. The analysis of the average indoor operating temperature in Figs. (20) and (21) all show a consistent increase variability of operative temperatures for all the current and future weather data set scenarios. This pattern is also observed in the increase in respective maximum and minimum temperatures analysis. This observed increases is in consonance with the range of annual average temperature change predicted by the GCM based on the IPCC scenarios (IPCC 2001) which generally shows an increase in ambient temperature over stipulated time lines.

The results in Figs. (20) and (21) also shows that London is likely to experience more risk of thermal discomfort than Birmingham over the time period for the analysis. The total number of zones failing two (2) or three (3) CIBSE TM52 overheating criteria is more in London than in Birmingham as shown in Figs. (18) and (19). There are observable evidence of all zones in London failing the day ventilation scenarios of all the standard construction specification considered under the CIBSE TM52 assessment criteria in the 2050’s and 2080’s but this trend is observed only in the 2080’s in the case of Birmingham.

3.2 Effects of thermal mass

The role of thermal mass in provision of thermal comfort is to absorb the internal heat gains during daytime in summer and progressively release it in the night when external temperatures decrease. Its use is more effective when there is marked difference between night and day temperatures. The whole building simulation scenarios for London and Birmingham results show that the progressive increase in thermal mass for the current and three future high Design summer year (DSY) weather data set decreases the adaptive thermal comfort temperature amplitudes over the non-heating season. The optimum thermal mass design sufficiently de-couples and lessens the heat transfer between the external environment and the building interior. The London and Birmingham operating temperature range analysis presented in Figs. (20) and (21) provide evidence that thermal mass improvement effectively reduces and stabilizes the large varying indoor temperature swings and thus leads to the enhancing of thermal comfort over the period. However, it was observed that increasing in thermal mass although provided the advantage of reducing indoor temperature swings led to the progressive increase in indoor operating temperature over the current and future weather data scenarios. Increasing thermal mass must be augmented with other effective passive design strategies which will cool the building by removing excessive internal heat gains.

3.3 Ventilation and shading as mitigation strategies

Openable windows significantly contribute to the provision of thermal comfort in dwellings.

Effective ventilation dissipates the release internal heat gain by enhanced thermal mass design during the day into the external environment. The daytime ventilation scenario was seen not to be an effective way of mitigating internal heat gains in dwellings. There are noticeable progressive increases in the variability of indoor thermal temperatures from the current to the 2080’s weather data scenarios. The alternative night time ventilation strategy offers some improvement in the reduction of indoor operative temperatures. However, the strategic effect of the implementation of night ventilation would only be realised with a good variation in diurnal temperature which facilitate the flow of internal heat gains to the external environment. Moreover, whilst night ventilation may present security risk, appropriate windows design options could be sought for the implementation of night ventilation strategy. The night ventilation coupled with shading strategy offered the best effective mitigation strategy in reducing indoor operative temperatures. Shading decreases the amount of radiant heat penetration during the daytime. Furthermore, since occupant control of windows was used as the means of controlling the indoor temperature it is imperative that variable occupant behaviour should be given more attention in considering the ventilation strategy.

3.4 Zones analysis

It was observed in the zone overheating assessment of both London and Birmingham that most zone failures under the CIBSE TM52 overheating assessment criteria occurred in the kitchen, lounge and the first floor stairs area. The kitchen area generally experience high internal heat gains because of heating activities related to cooking. The provision of thermal mass in this work was uniformly distributed throughout the building. An uneven distribution of thermal mass with focus on areas most likely to experienced more internal heat gains may improve the cycle of heat storage. It was observed that there was no openable window associated with the first floor stair area leading to unwanted accumulation of internal heat gains with the resulting increase in operative temperatures in the zone. The lounge has only one single sided north-east facing window. This might have contributed to the observed indoor overheating in this zone due to low summer sun angles. Cross-ventilation is more effective in large areas like lounges. A north-south window orientation is also preferable as it has limited solar penetration during the non-heating season. In addition, the fixed external shading instead of being adjustable might have contributed to the effectiveness of the shading strategy.

PassiHaus night ventilation with shading scenario presented the most stable short range of adaptive thermal comfort temperature variation over the non-heating season. The variability of the indoor operating temperatures in all-weather scenarios in Figs. (10) to 17 tend to flatten indicating that this design strategy currently offers the most effective means in this work considerations to enhance thermal comfort.

4. Conclusions

The study investigated the impact of four standard construction specifications which give a progressive improved thermal mass coupled with passive cooling strategies to optimize the thermal comfort in detached dwellings in London and Birmingham using the CIBSE TM52 criteria for assessing adaptive overheating in free-running dwellings. The CIBSE TM52 criteria proved to be an effective and credible assessment tool as the results obtained in this work are in consonance with what is presented in literature.

Generally, in all scenarios, the indoor temperatures were observed to vary with external temperatures which in turn are related to change in climatic conditions. The findings from the various simulation scenarios coupled with the statistical analysis of the data collected from the simulation present a strong positive correlation between improved building fabric, strategic ventilation scenarios with external shading and indoor adaptive overheating thermal performance. This integrated approach has been verified to result in substantial reduction in indoor operating temperatures leading to enhance thermal comfort environment. However, the effect of the variability of climate change was clearly observe to impact operating temperature in the 2050's and 2080's in the case of London and 2080's in Birmingham as the future frequency and intensity of heat waves increases. These increases are in consonance with the range of annual average temperature change predicted by the GCM based on the IPCC scenarios which generally shows an increase in temperature over stipulated time lines.

The variability of the indoor operative temperature across the progressive increase in thermal mass in the whole building consideration is clearly seen as the swing of the operative temperatures during the non-heating reduces. The PassiHaus standard construction specification with the incorporation of passive cooling strategies of improved night ventilation with shading offers the best case scenario analysis of the optimization of indoor operative temperatures with relatively decrease in the fluctuations of operative temperature during the observed period. However, the progressive increase in thermal mass resulting in the increase indoor temperatures might necessitate the inclusion of mechanical room conditioning systems in the strategic mixed to keep the indoor temperatures at specified levels to provide heat balance or thermal comfort in the future. As heating, ventilation and air conditioning (HVAC) systems have high energy consumption, an alternative strategy could also be the utilization of improved natural ventilation systems.

This work has indicated that thermal comfort in dwellings can be enhanced by analysis of future climatic patterns, improved building fabric and provision of passive design consideration of improved ventilation and shading. It also affirms that the utilization of appropriate mitigation strategies to enhance thermal comfort could contribute to the reduction of the environmental implications to the built environment and facilitates the drive towards the attainment of future sustainability requirements. The focus on how to provide enhance thermal comfort will challenge future innovative design and adapted technological process as Building Regulations continuously seek strategies to mitigate carbon dioxide emissions and improve dwelling energy efficiency. The measures would include planning and design options sensitive to varying climatic conditions and resilient building design which incorporates improved and better façade and building envelope and passive design technologies with the aim to eventually reduce future total energy demands in dwellings and at the same time enhance thermal comfort.

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