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Using Passive Strategies to prevent overheating and promote resilient buildings

LUISA BROTAS[1], FERGUS NICOL[1]

[1]Sir John Cass, Faculty of Art, Architecture and Interior Design, London Metropolitan University, London, UK

ABSTRACT: *Overheating is becoming a problem in buildings in the city centre. This situation is further exacerbated by the Urban Heat Island phenomena and by climate change. High levels of urbanisation and design decisions that compromise the use of passive technologies e.g. opening windows, have resulted in more active systems being used for cooling. This has often led to an increase of energy consumption and compromising the need to achieve nearly zero carbon buildings in the near future. This paper assesses the likelihood of a model dwelling in London overheating in line with climatic predictions for the year 2030, 2050 and 2080. The criteria to assess overheating are based on the Technical Memorandum 52 from CIBSE. A range of passive solutions e.g. natural ventilation, shading and orientation are assessed and discussed in a move towards sustainable buildings that are resilient to global warming.*

Keywords: passive technologies, overheating, resilience, energy, comfort

INTRODUCTION

Climate change means that buildings and cities need to become resilient to more frequent and potentially devastating ‘unpredictable events’ (IPCC, 2014). Trends indicate the growth of urban complexity and population, which is expected to face unprecedented challenges in the near future. Recent economic, social and environmental impacts have raised awareness of the need to seriously address and propose effective solutions. Technological advances, innovation, data availability as well as lessons learned can help to tackle these issues and promote a built environment that is efficient, comfortable and healthy for the population and economically sustainable.

There is a real need to reduce urban carbon emissions to prevent temperatures rising to unprecedented levels (COP21, 2015). This grows in parallel with concerns about the comfort of the occupants and the opportunities available to restore or maintain acceptable environments. The increasing use of air-conditioning systems to provide comfortable spaces has increased the use of energy, usually derived from fossil fuels. Likewise, the need to reduce energy consumption whilst dealing with global climate change is a major challenge for the design of comfortable, low-energy buildings. Passive strategies for heating and cooling are of the primary defence against the effects of climate change (Nicol, 2012; Roaf, 2015). They become even more relevant in scenarios of instability in the energy supply. They are also important taking into account the needs of an ageing population and the problem of fuel poverty even in industrialised countries.

Studies indicate that overheating is already a problem in a prototype tested across different climates in Europe (Brotas and Nicol, 2015). This is further exacerbated under climatic predictions for 2030, 50 and 80. So why are European regulations still mainly addressing the heating season? What low carbon and economically viable solutions can be implemented by which the danger of overheating can be predicted and minimised? A series of passive/hybrid cooling technologies are the basis of a sensitivity analysis based on results obtained from dynamic simulations with EnergyPlus software. The criteria for assessing overheating are based on those presented in CIBSE technical memorandum TM 52 (2013). Good building design can make a difference in reducing the energy demand while maintaining high comfort levels. This paper looks at possible passive solutions that can effectively promote or minimise the use of mechanical systems under future scenarios aiming towards sustainable and more resilient buildings and cities.

THE NEED FOR ACTION

Buildings account for more than 50% of CO_2 emissions in the UK, and similar figures are found across Europe; the energy supply uncertainty (threats of blackouts) and price rises have been a drive to nearly zero carbon buildings (ZCH, 2009). Reducing heating losses (increasing envelope insulation and minimizing infiltration), increasing energy efficiency and adopting renewable energy have been at the front of most EU regulations (EPBD, 2010; EED, 2012). Likewise, climate change involves preventing overheating while providing low energy environments.

Overheating is a key problem in most commercial buildings, even in mild climate cities as London, where for some of the year they can be in cooling mode (Kolokotroni, 2012). While dwellings have been less prone to adopt active systems to deal with temperature rises, there is a growth in sales of air-conditioning units. Unprecedented recent heat waves particularly affecting vulnerable populations, raise awareness to the impact of overheating on people's health (Santamouris, 2015).

Can we still use passive technologies to prevent overheating in buildings now and in the foreseen future? Designers and building stakeholders need to seriously address the whole life cycle and avoid solutions that deal with immediate requirements that often compromise good indoor climate and the environment at future generations.

With climate adaptation, people tend to adapt to new environments up to a certain level. They will also take actions to restore their comfort levels, therefore moulding the spaces to their needs. It has been suggested that people will feel high levels of satisfaction if they are in control of their environment (Leaman 1997). Strategies to prevent overheating in buildings are closely related to the behaviour of the occupant. Opening windows, closing blinds or switching off unnecessary lights or equipment have a major implication for the energy consumption and the quality of the indoor environment. However, important steps towards a well-performing building that fulfils its occupants' needs are due to the initial phases of design. Likewise, the pressure associated with land cost and scarcity of space in cities, (e.g. London has a large shortage of dwellings), has resulted in a more compact urban landscape and less open/green spaces. Immediate implications for the dwellings reveal a reduction of useful floor areas, layouts with deeper rooms, lower ceiling heights, less daylight availability or opportunities for ventilation. Highly insulated and airtight envelopes with the kitchen now often shared with the living space. The advantages of these trends is beyond the scope of this paper but it is relevant to highlight that these factors all aggravate the problem of overheating. This is further exacerbated by global warming and the urban heat island (Santamouris, 2014; Lafuente, 2014; Kolokotroni, 2010).

CLIMATE MODELLING

The climate in cities is strongly influenced by its morphology and urban densification. Previous studies have identified the phenomena of urban heat Island (UHI) and its major impact on the cooling energy use in the summer; to its influence in the way passive technologies such as natural ventilation are viable options to mitigate the impact of climate change in buildings (Kolokotroni, 2006; Santamouris, 2013 & 2014).

Weather data was retrieved from the climate generator predictor from the University of Exeter (Eames, 2011). A high emissions scenario is adopted with a 50th percentile for the potential severity of climate change for a given weather reference. This is assumed as an acceptable indication of the extent of likely future warming. See Figure 1 for Islington in London under these conditions during summer. Initial assumptions adopted the 90% percentile but were deemed to be too extreme and are not presented in this paper.

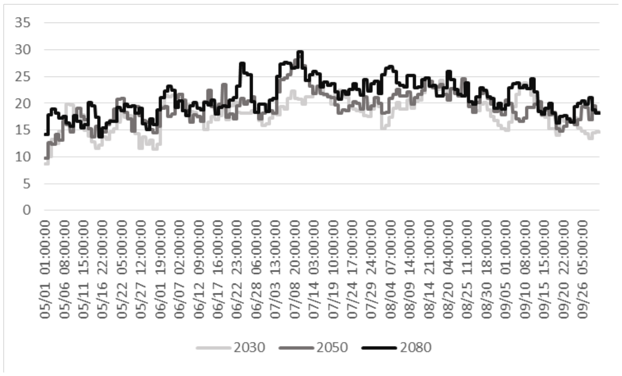

Figure 1 Outside dry bulb temperature for Islington in London for the climatic predictions for the year 2030, 2050 and 2080 with a high CO_2 emission scenario with a 50% percentile of climate change to the reference test year DSY. The period represents the months of May till September inclusive.

Figure 2 shows the heating and cooling load for a prototype for three commonly used weather files in London (Gatwick, Heathrow and Islington). The probabilistic generated weather data for the years 30, 50 and 80 are based on current Test Reference Years (TRY) required for energy analysis and Design Summer Year (DSY) used in overheating analysis. The comparison also includes Gatwick location with the predictions for the years 2020, 50 and 80. These were generated with a different climate model generator from The University of Southampton (CCWorldWeatherGen, 2013).

It is clear from this figure that a major uncertainty in the predictions (or the model chosen) can influence the final quantitative result and care should be taken when overseeing the energy consumption. However, all indicate a clear trend for a reduction of the heating loads and a progressive increase in cooling in the model tested. This tendency is in agreement with other studies that highlight the impact of UHI and climate change in the city of London (Hacker, 2008; Kolokotroni, 2006 & 2010).

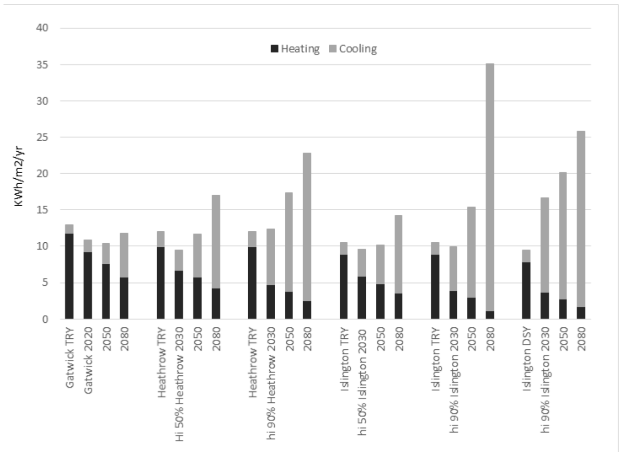

Figure 2: Energy Consumption of a dwelling under different climate predictors for 4 weather locations in London.

Modelling with the Islington 'current' TRY weather (central location) indicates a reduction of 25% in the heating loads and an increase of 60% of the cooling loads compared to a similar model adopting the Gatwick 'current' weather file (outskirts of the city). This is consistent with results given by Kolokotroni et al (2010) indicating that the energy consumption for heating in central London is 65–85% of the heating required outside the Urban Heat Island. Whereas the cooling energy consumption is 32–42% higher than required for the same building outside the UHI.

What is also clear is the tendency towards higher cooling loads, already visible in commercial buildings, may become a norm in dwellings. An increase in hybrid/active systems and its associated aspects in the energy use, their impact in the environment, health and comfort of the occupants, calls for solutions that promote low carbon buildings that are comfortable throughout their life cycle. (Brotas, 2015; Din, 2015)

METHOD

A new approach to the way indoor comfort temperature is strongly related to the running mean of the outdoor temperature was developed in the late seventies by Humphreys and Nicol (1998). This suggested that the temperature that occupants will find uncomfortable changes with the outdoor conditions in a predictable way. This was coined back then as the adaptive comfort method. This approach has been acknowledged and recommended for free-running buildings and implemented in European Standards (BS15251, 2007). In parallel de Dear and Brager (2001) developed a similar approach in the United States that informed the Standard 55-2010 (ASHRAE, 2010).

In the past overheating had been defined in terms of the number of hours over a particular temperature, irrespective of conditions outside the building (CIBSE, 2015). A recent technical memorandum TM52 on Overheating in Europe lays down criteria for assessing the likelihood of a space overheating (TM52, 2013). The first criterion sets a limit of 3% for the number of occupied hours that the operative temperature can exceed a maximum temperature, as defined in BS15251 (2007), during a typical non-heating season (1st May to 30th September). The second criterion deals with the severity of overheating within any one day, which is given in terms of temperature rise and duration and sets a daily limit for acceptability. This weighted exceedance, shall be less than or equal to 6 in any one day. The third criterion sets an absolute maximum acceptable temperature for a room. The absolute maximum value for the indoor operative temperature the value of ΔT shall not exceed 4 K. The criteria are all defined in terms of ΔT the difference between the actual operative temperature in the room at any time and the limiting maximum acceptable temperature (TM52, 2013). A building is likely to overheat if two out of the three criteria is exceeded.

CASE STUDY

The present case study is located in the city of London. A base case model of a mid-storey flat (67m^2) is adopted based on statistics of housing stock broken down by type and in line with a rapid urbanisation of cities.

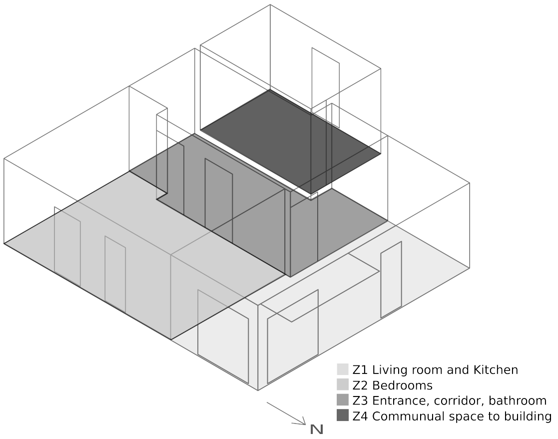

Figure 3 Wireframe model thermal zones. Z1 includes living room and kitchen; Z2 are the bedrooms; Z3 includes entrance, corridor and bathrooms; and Z4 is external to the flat and models a communal space to the building (boundary condition assumed as an interior wall). Zones 1 and 2 have exterior walls and a party wall (modelled as adiabatic) in contact with a flat assumed with the same internal conditions

All the dynamic simulations were made with EnergyPlus software, version 8.4.0. The criteria for the assessment of overheating were compiled in a spreadsheet.

The main façade is oriented east and the secondary faces north (see Figure 3). The thermal characteristics of the envelope comply with the Minimum Fabric Energy Efficient Standard (FEES) for 2016 from UK Part L1A (2013) regulations: external walls (U-value 0.18 W/m^{2}K), party walls (0 W/m^{2}K), semi-exposed wall (0.17 W/m^{2}K) and windows (U-value 1.4 W/m^{2}K and G-value 0.63).

The Aereal heat Capacity, *Km* in *kJ/m^{2}K*, of each surface of the dwelling is calculated according to BS EN ISO 13786 (2007). The overall thermal mass of the dwelling is accounted as the Thermal Mass Parameter (TMP) in *kJ/m^{2}K* according to the UK building regulations compliance tool SAP (2012). This is calculated by multiplying the surface area for each construction element by its *Km*, adding the results and dividing this total by the floor area of the dwelling. SAP assumes an indicative thermal mass of dwellings as *Low* when TMP is 100, *Medium-weight* with 250 and *High* with 450 kJ/m^{2}K.

The layout and further details from the building envelope, ventilation and systems specifications are defined after Zero Carbon Homes (ZCH, 2009; ZCH, 2012). Internal gains from lighting (low energy) and equipment (energy efficient) are assumed equal for all models simulated and data was retrieved from the Guide A from CIBSE (2015). They are assumed to be relatively low in line with the idea that appliances will tend to become more efficient in the near future. The occupancy profile is defined for 3 people in a domestic environment, assuming one person permanently at home. This agrees with future trends towards home-working and an ageing population that may stay indoors most of the time. For assessing the likelihood of overheating a period of occupancy between 8am till 18pm for 7 days in the week between 1st May and 30th September is adopted. This selected period is to account for the hotter period of the day. A 24hr occupancy would tend to dissipate the impact of peak periods over longer hours. Conversely, it should be kept in mind that high density materials commonly found in cities can delay the impact of UHI in buildings for a couple of hours.

Infiltration is specified as 0.3 ac/h as a design level which is modified by temperature difference (indoors minus outdoors) and wind speed. Night cooling ventilation (driven by wind and stack effect) influencing individual rooms is adopted when indoor temperature is above 24°C and the delta differential to the outdoor is less than 2°C. An internal blind with 0.1 visible and solar transmittance and 0.4 visible and solar reflectance is activated when the indoor temperature rises above 24°C and solar radiation incident on the window is above 120 W/m^2. The thermal characteristics of the base model and adopted strategies are already fairly sustainable and energy efficient to a very good standard. This model is presented at table 1 as solution 1: Medium/High thermal mass (TMP 348 kJ/m^{2}K), night single ventilation and interior blind. A series of varying parameters are then tested:

- low thermal mass (TMP 95 kJ/m^{2}K)
- day time ventilation (from 8 till 18pm)
- an high reflective and low transmittance exterior shutter (0.1 visible and solar transmittance and 0.8 visible and solar reflectance)
- cross ventilation (air flow across the different windows and rooms)
- orientation of the building (E, S, W and N)

The second model tests a low thermal mass model with a Thermal Mass Parameter (TMP) of 95 kJ/m^{2}K (BS13786, 2007; SAP, 2012). All other parameters remain the same as the base case (1). As the result for criterion 1 is significantly aggravated the following models return to a Medium/High-weight dwelling. Whilst TM52 (2013) defines 3 criteria and all are equally weighted for the purpose of assessing overheating, it is acknowledged that criterion 1 is the main indicator of a tendency for a space to overheat. This is also in agreement with the method used to estimate overheating in the BS15251 (2007) and its current drafts prEN 16798-1 (2015) and CEN TC156 EN16798-2 (2014).

The third model has the thermal mass of the first model (TMP 348 kJ/m^{2}K) and shifts the single side ventilation to during the day. Ventilation is active between 8 and 18pm when the indoor temperature exceeds 24°C and the delta differential to the outdoor is less than 2°C.

Model four assumes a daytime cross ventilation - air flow network between the zone 1 (living room/kitchen), zone 3 (entrance/corridor/bathrooms) and zone 2 (bedrooms).

The fifth and sixth scenarios model an exterior shutter that has similar visible and solar transmittance characteristics (0.1) but a higher visible and solar reflectance (0.8) than the internal device. The operating profile remains unchanged. The ventilation is single sided night and day, respectively.

The seventh and eighth scenarios model an external shutter with day and night cross ventilation, respectively. This is to benefit from an enhanced air flow due to positive vs negative pressures at different façades.

Finally model ninth models a flat with a low thermal mass (TMP 95 MJ/K.m^2) and characteristics of model 2 except of a external shading device with visible and solar spectrum characteristics as models 5 to 8.

The selection of solutions was based on realistic proposals that would not significantly interfere with land scarcity and high real state value. They could also be adopted in a refurbishment. They were never meant to test all the possible combinations due to space constraints. No restrictions from listed areas were considered in the adoption of external devices.

RESULTS AND DISCUSSION

Table 1 presents results for the three criteria for different solutions tested in the living room of prototype presented in figure 3, placed in the London Borough of Islington.

Criterion 2 presents in brackets the number of days that the criterion is exceeded and criterion 3 shows in brackets the exceedance in hours. Some results seem more aggravated for climate predictions of 2030 than later years. This may be a result of the way the climate data was generated taking into account a particular set of years (see Figure 1 for three climatic years).

Results indicate that a building that complies with current standards and adopts passive strategies e.g. natural ventilation and shading is likely to cope with overheating in line with climate predictions. Differences between the positioning of the shading device are noticeable: external shutters prevent solar radiation from entering the space and therefore are less likely to cause overheating now and in the future. In fact, all the scenarios with external shutters (5,6,7,8 and 9) pass the overheating assessment in all climatic predictions tested. It is therefore assumed the solution with highest impact in preventing overheating. It is worth highlighting that the visible transmittance is quite low (0.1) and may lead to insufficient levels of light and to the switching on of artificial light at times of the day when daylight should be sufficient. Different solutions that obstruct solar radiation, allow view out and light in can be seen in Brotas and Rusovan (2013).

Night-time ventilation associated with higher thermal mass is more effective than day time in preventing overheating (scenario 1 vs 3). Lower outside night-time temperatures create a high temperature differential and promote a better dissipation of the heat and enable cooling of the building fabric to cope with high peaks the following day. However, the urban heat island phenomena may increase the outdoor temperature in the evening even after sunset. This is a result of heavy dense materials found in city buildings and its neighbourhood.

Table 1: Comparison of different solutions in the living room of a prototype with main façade facing East with climate predictions for Islington (London).

	2030	**2050**	**2080**
1 - Mid/High thermal mass, night single ventilation, interior blind			
C1	Fail 4.4%	Pass 0.3%	Pass 2.2%
C2 (a)	Pass	Pass	Pass
C3 (b)	Pass	Pass	Pass
2 - Low thermal mass, night single ventilation, interior blind			
C1	Fail (33.6%)	Fail 16.1%	Fail 25.2%
C2 (a)	Fail (1)	Pass	Pass
C3 (b)	Fail (2)	Pass	Pass
3 - Mid/High thermal mass, day single ventilation, interior blind			
C1	Fail 3.3%	Fail (4.1%)	Fail (14.4%)
C2 (a)	Pass	Fail (1)	Fail (8)
C3 (b)	Pass	Fail (3)	Fail (19)
4 - Mid/High thermal mass, day cross ventilation, interior blind			
C1	Pass 0.0%	Pass 0.1%	Fail (9.8%)
C2 (a)	Pass (0)	Pass	Fail (2)
C3 (b)	Pass (0)	Pass	Fail (3)
5 - Mid/High thermal mass, day single ventilation, exterior shutter			
C1	Pass 0.2%	Pass 0.9%	Fail (5.1%)
C2 (a)	Pass	Pass	Pass
C3 (b)	Pass	Pass	Pass
6 - Mid/High thermal mass, night single ventilation, exterior shutter			
C1	Pass 0.0%	Pass 0.0%	Pass 0.0%
C2 (a)	Pass	Pass	Pass
C3 (b)	Pass	Pass	Pass
7 - Mid/High thermal mass, day cross ventilation, exterior shutter			
C1	Pass 0.0%	Pass 0.0%	Pass 1.4%
C2 (a)	Pass (0)	Pass (0)	Pass (0)
C3 (b)	Pass (0)	Pass (0)	Pass (0)
8 - Mid/High thermal mass, night cross ventilation, exterior shutter			
C1	Pass 0.0%	Pass 0.0%	Pass 0.0%
C2 (a)	Pass (0)	Pass (0)	Pass (0)
C3 (b)	Pass (0)	Pass (0)	Pass (0)
9 - Low thermal mass, night single ventilation, exterior shutter			
C1	Pass 0.0%	Pass 0.0%	Pass 0.0%
C2 (a)	Pass (0)	Pass (0)	Pass (0)
C3 (b)	Pass (0)	Pass (0)	Pass (0)

Model 3 (day single ventilation with internal blind) performs worse than model 4 (day cross ventilation with internal blind) in preventing overheating. This is a result of enhanced air flow due to positive vs negative pressures at different facades. The air flow will also be strongly dependant on the wind speed and direction. However, this particular single side ventilation benefits from high openings which may enhance the stack effect. Models with external shutters, as in scenarios with day single ventilation (5) vs day cross ventilation (7) tend not show significant differences. Scenarios with external shutters and night ventilation: single or cross (6 vs 8) are identical in terms of the overheating criteria. It may be that shading devices by reducing heat from entering the space will work better to minimise problems of overheating during day. However, this does not imply that the operative temperatures experienced at different times of the day are similar for both models. Natural ventilation (stack and cross) are valid options to dissipate heat trapped in the building.

There is an ongoing debate as to whether criteria 2 and 3 are good indicators to easily and consistently apply in the assessment of overheating. In fact, criterion 1 seems to be enough and the driver of a good assessment. It varies from the criteria from CIBSE Guide A (2015) in the adoption of the indoor comfort temperature calculated from the running mean of the outdoor temperature and an acceptable range of temperatures (varying up to ±4K) depending on the building category as defined in BS15251 (2007). Maybe a fixed time frame schedule would reduce the risk of occupancy profiles being chosen to suit (Brotas and Nicol, 2016).

Criterion 2 is seen as difficult to calculate on a daily basis and a weekly analysis may seem more realistic. This would also minimize the extreme peak events occurring on particular hot days on weather files that could be dissipated by heavy weight buildings.

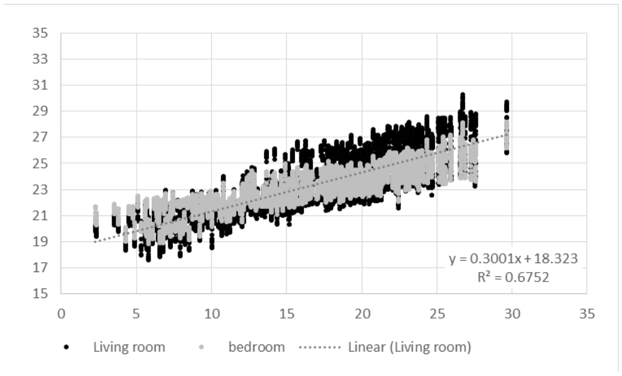

Figure 4 Living room and bedroom operative temperature in a dwelling with main façade oriented south (second façade east) for the climate prediction 2030

Figure 4 presents the relationship between outdoor temperature (x-axis) and the indoors in the living room and bedroom (y-axis). As this scenario models an air flow between the two rooms, similar temperatures seem realistic. However, the bedroom presents a narrow range of temperatures which is consistent with other studies that recommend lower temperatures in bedrooms to promote a good night sleep. (Humphreys, 1979).

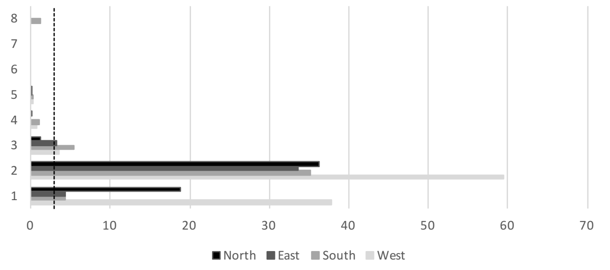

Figure 5 Criterion 1 presented for different models and for the four orientations

Figure 5 presents the percentage of the number of occupied hours that the operative temperature exceeds a calculated maximum temperature (criterion 1) for the scenarios modelled and for different orientations. The threshold of 3% is highlighted. Main orientation facing west (second south) is clearly much more problematic than any other orientation.

External shading (scenarios 5-9) is considered a main factor in preventing overheating. Shading devices are mainly adopted in dwellings in the UK as a privacy issue but could be given more thought in preventing unwanted solar gains. Adopting external shading can affect the aesthetic of the building and may require approval from planning officers. It may be more difficult to implement in refurbishments. Likewise, solutions are required that are resistant to outdoor conditions and may imply higher maintenance issues.

CONCLUSIONS

A clear tendency for higher cooling than heating loads, already visible in commercial buildings, may become a norm in dwellings in London in the future. Climate change means buildings will be more prone to overheating if no preventive solutions are planned and implemented in new buildings and in refurbishments. Buildings will need to adapt to raising temperatures and to mitigate the use of active systems relying on energy derived from fossil fuels. Reducing the energy use whilst promoting comfortable environments will minimize the impact of climate change on the environment and on the health of the populations. This will reduce the levels of mortality, associated with heat stress, will reduce the environmental impact and improve the quality of the buildings reducing the energy use and becoming more resilient to hot events in the future.

Shading systems are fundamental to mitigate solar access to the building on hot periods and where possible should be positioned externally to minimize heat entering the space. This strategy needs to be adopted from early stages of design or refurbishment to address and minimise the impact of its constraints of planning, installation and maintenance.

Night cooling in combination with a thermally medium to heavy-weight building is a good solution to avoiding or minimising the need for mechanical cooling in buildings whilst maintaining thermal comfort. This passive technology can provide comfortable environments for climate predictions up to 2080 for a location in London.

Cross ventilation is preferable to single sided and highlights the importance of promoting dwellings that have more than one façade orientation. This design solution should be a requirement in dwellings with more than one bedroom. Alternatively, provision should be made to the positioning of the windows to allow an enhanced passive stack effect.

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