ENHANCING THERMAL COMFORT IN CONVERTED DWELLINGS THROUGH PASSIVE DESIGN STRATEGIES.

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ABSTRACT

Poorly ventilated dwellings, new winter-focused insulation standards, and the increasing global temperatures are factors that aggravate the overheating during hot spells. The number of dwellings that experience overheating are exponentially rising, and simultaneously are the number of deaths. Overheating is currently of a major concern for many UK dwellings particularly in urban areas. The projected alarming temperature rise of 4 °C in the next 50 years in addition to more frequent heatwaves also contributes to the need of urgency to address this issue. This paper investigates the effects of passive design strategies, including natural ventilation, solar shading, and optimised window sizes and openings, on thermal comfort in a case study residential building in London. Dynamic thermal simulation in IES(VE) was conducted and CIBSE TM59 was used for the assessments. The results show significant improvement in thermal comfort particularly when a combination of these strategies was considered.

Keywords: Overheating, Thermal Comfort, Passive Design.

INTRODUCTION

Overheating has become a major concern in dwellings as a result of climate change during the past two decades (ZCH, 2015). The UK Climate Change Projection (UKCP, 2009) has estimated that all the regions in the UK will manifest warmer summers, especially in the South of England where it is estimated that the temperature will rise by 4.2 degrees by the end of the century. The majority of the UK population lives in urban areas, where the outdoor temperatures are at its highest due to the effect of the Urban Heat Island (UBI) (Mavrogianni et. al.,2016). Moreover, according to the Building Research Establishment (BRE), apartments located within the urban boundary are most prone to overheating and thermal discomfort. The Energy Performance of Building Directive recommends using strategies such as solar shading and natural ventilation to reduce risks of overheating. A report from the UK Green Building Council (UKGBC, 2017), states that in the last 30 years, carbon emissions by the building sector have reduced (Table 1); however, data shows that domestic buildings still contribute to 30% of the total carbon emissions in the UK.

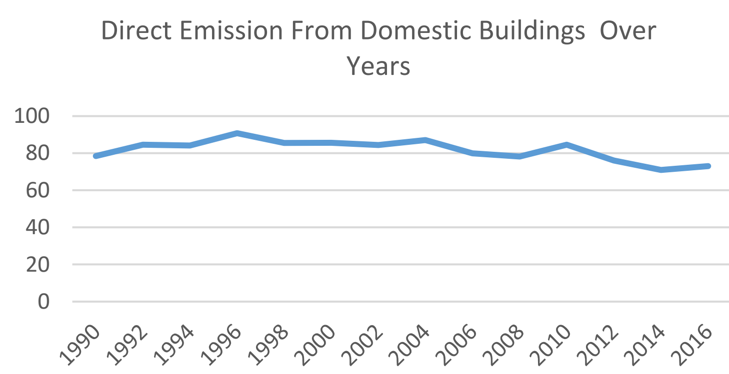

Figure 1: Direct emission from fuel use in domestic buildings (UKGBC,2017)

The Existing housing and Climate Change Report (2007) has set actions which will help to decrease carbon emissions. This can be achieved by refurbishing dwellings which present weak thermal insulation, improving cladding's thermal transmission, thermal bridge, and airtightness; assisting to reduce the carbon footprint by 60% by 2050. In addition, the Code for Sustainable Homes (CSH) in 2006, aimed at reducing the emission by creating more sustainable Zero Energy homes. The CSH has now been replaced with BREEAM, an assessment method that values the sustainable performance of buildings, starting from the choice of materials, the construction of the building and its environmental impact. The UK has currently no policies to reduce the effects of UHI on dwellings and nonetheless policies to help existing and new dwellings adapt to high temperatures (Committee on Climate Change, 2016).

A study by Wright et. al. (2005) aimed to explore the relation between the internal and external temperatures measured during the summertime and if the overheating risk is related to the type of construction and its thermal capacity, in four dwellings in Manchester and five dwellings in London, during a heatwave in August that lasted 9 days. In Manchester, the upper storey was more likely to be warmer than the lower storey, due to the structure and its thermal mass; however, in London, the indoor temperatures were much higher on both day- and night-time. The results of the above research coincide with the research by Beizaee et. al. 2013) in July-August 2007 to assess temperature ranges in bedrooms and living rooms in 207 dwellings in England. The findings showed that dwellings built before 1919, which present solid walls and high thermal mass, are notably cooler than dwellings built afterwards, which generally present cavity walls. It was argued that flats and dwellings positioned at higher storeys tend to have a warmer indoor temperature. The authors argued that relatively modern dwellings, built after 1990, are prone to higher risk of overheating as the amount of insulation used is mainly aimed at reducing energy consumption during winter, but does not take into consideration overheating during summer. Lomas and Porritt (2016), affirm that the urbanisation and the housing crisis led to an increase in high-rise buildings. Those dwellings, for most of the time, present prefabricated modules or thermally lightweight materials that may have a good insulating standard; however, they lack on thermal mass that is essential to absorb excessive heat and overcome overheating risk. Dengel and Swainson (2012) also assert that overheating risk is more likely to occur in new build dwellings and highly insulated houses in contrast with the general assumption where older buildings are at more risk due to their lack on insulation. Another study conducted by Lomas and Kane (2012) in 268 dwellings in Leicester during summer of 2009, concludes that dwellings with solid walls and especially those built before 1919 generally tend to have cooler indoor temperatures compared to dwellings that present a cavity wall; yet dwellings built after 1980s had a slightly warmer living rooms than bedrooms, and dwellings built before 80s present the opposite pattern. The authors justifies the outcomes by arguing the insulated roofs can decrease solar gains hence improving the conditions. Several studies other studies, including a report by Zero Carbon Hub (2015) and Building research Establishment (2014), state that even modern dwellings with high insulation and great airtightness are exposed to risk of overheating during the hot periods (Tink, Porritt, Allison and Loveday, 2018). Poorly ventilated dwellings, new insulation standards (imposed by the Building Regulations, which aim is to reduce heat loss during winter) and the increasing global temperatures are factors that aggravate the overheating during hot spells. The number of dwellings that experience overheating and disruption of thermal comfort are exponentially rising, and simultaneously the number of deaths. To this end, the aim of this research paper is to investigate suitable sustainable design strategies that can be applied to existing dwellings, further, to recommend and help occupants to improve the indoor thermal comfort by applying those strategies.

RESEARCH AIM AND METHODOLOGY

Case Study Building

The selected case study building is a typical naturally ventilated converted terrace house built in 1890s in London (Fig.2). The research was carried out on the top floor where occupants have experienced thermal discomfort during summertime. The building consists of solid walls made of red bricks; therefore, no cavity wall insulation is present; the roof however has been upgraded with a 300mm fibreglass insulation. The flat has an approximate floor area of 46 sqm with three different thermal zones: open plan kitchen and living room, bedroom 1 and Bedroom 2 (Fig.2). The flat has large, double-glazed windows, facing North, in bedroom 1 and in the living room, and rooflights (facing South) in the kitchen, bathroom and Bedroom 2. The large top hung window panels, facing North, cannot be fully opened due to safety reasons and noise pollution as a rail network runs very close to the building. This reduces the ability to enhance indoor natural ventilation. Table 1 shows the construction elements and U-values.

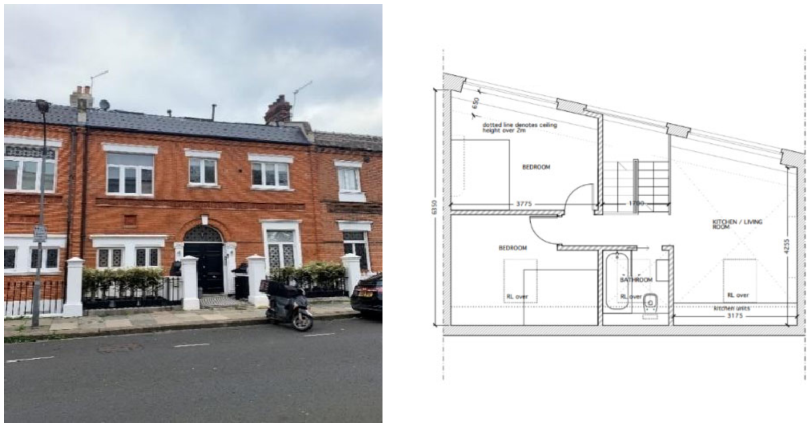

Figure 2: Front elevation of the case study building facing South (left); Floor plan of the case study building (right) (Hammersmith and Fulham Council)

Table 1: Summary of construction build up and approximate u-value.

Building Component	Construction Build Up	U-Value (W/m2K)
External Wall	X2 Brickwork 4mm Render 12.5mm posterboard	1.7
Party walls	X2 Brickwork 50mm Cavity	0.6
Internal Partitional Wall	Solid Brick covered with 12.5mm plasterboard	2.1
Roof	4mm Synthetic Slate tiles 6mm Vapour Barrier 300mm Fiberglass insulation	0.13
Windows	Double Glazed with uPVC frame	1.3
Roof Light	Double Glazed with uPVC frame	1.3
Intermediate Floor	Uninsulated suspended timber	0.84
Doors	Timber	1.3

Simulation Procedure

Simulations are conducted in IES(VE) aiming to assess compliance with CIBSE TM59 (CIBSE TM59, 2017) for thermal comfort. TM59, stats that when assessing overheating, Design Summer Years (DSY) should be used, therefore in the following simulations, as the case study is situated in London, the London DSY is used.

Table 2: Window and Doors Openings

Thermal Zone	*C. Degrees*	*Period*
Living Room & Kitchen	Exceeds 22C	Open between 9am- 22pm
Doors		
Internal Doors		Closed Between 22pm-9am
External Door		All Day Closed

Table 3: Occupancy profile and internal gains

Thermal Zone	*Period*	*Maximum*
Bedrooms	Occupied all day	22pm-9am
Living & Kitchen		9am-22pm

Internal gains such as lighting and equipment are following the TM59 guidelines and vary between thermal zone depending on the occupancy. Heating and cooling are set off continuously, throughout the whole simulation period 1 May-30 September. Conforming to TM59, dwellings that are primarily naturally ventilated, must satisfy the two criteria imposed, A and B.

Criterion A states that the number of hours, in bedrooms, lounges, living rooms and kitchens, which ΔT is greater than or equal to one degree shall not be more than 3% of occupied hours for the period between May and September (CIBSE TM59,2017). Criterion B is applied for bedrooms only and it state that the operative temperature of the room between the hours 22:00 and 07:00 must not exceed 26 °C for more than 1% of annual hours, which corresponds to 32 hours, 33 or more hours in exceedance will fail the simulation. This is to assure comfort during the sleeping schedule (CIBSE TM59,2017).

SIMULATION RESULTS AND DISCUSSION

The case study building has been simulated formulating different scenario alternatives (Table 4); follows, therefore, a discussion of the outcome of the simulation which will talk through the various data gathered.

Table 4: Summary of different scenario alternatives used in the simulation

Variables	Alternatives
Occupancy	Following TM59 standard (Living and Kitchen 09:00 to 22:00, Bedroom 24/7 with peak between 22:00 and 09:00).
Windows operation	Always open; Always closed; Open at night; TM59(when the temperature of the occupied room exceeds 22 °C)
Shading system	No shading; 500, 750, 1000mm
Openable windows	As built (9m2); Increased (12m2)

Simulation was conducted to assess the situation for the following as the base case scenario: windows and doors closed permanently, occupancy of 100%, and lastly no shading. The results (Table 5) show a very high risk of overheating. Despite extreme outcomes, this will be used to assess how the implementations of the various alternatives would affect comfort. The south facing zones including Bedroom 2 and Living room/Kitchen are more likely to experience overheating.

Table 5: Outcome of the worst-case scenario

Thermal Zone	Maximum Temperature	TM 59 Criteria A&B Pass/Fail
Bedroom 1	37	Fail
Bedroom 2	48	Fail
Living room and Kitchen	46	Fail

Additional simulation was conducted with the following criteria according to the TM59 occupancy and control profiles explained in Table 2 and Table 3. The results (Table 6) show a clear reduction of the overall temperatures, especially of Bedroom 1 where window is facing North, however Bedroom 2 fails TM59 criterion A, where the number of hours between 22:00 and 07:00 from May to September, ΔT exceeds 3% of the occupied hours; yet, both bedrooms fail to meet criterion B however the situation is significantly worse in Bedroom 2. The results suggest that natural could reduce the overheating risk, however excessive solar gain could deteriorate the conditions for the south facing rooms.

Table 6: Outcome of the simulation implementing TM59 criteria

Thermal Zone	Maximum Temperature	Criterion (a)	Criterion a Percentage	Criterion (b)	Criterion b hours	TM59 Pass/fail
Bedroom 1	32	Pass	0.9	Fail	33	Fail
Bedroom 2	33	Fail	4.4	Fail	119	Fail
Living Room and Kitchen	30	Pass	0.4	--		Pass

Considering the above results, a 1000mm shading device was considered on the south facing windows. Windows were fully open during the whole day and the openable area increased from 9 sqm to 12 sqm to improve natural ventilation. The occupancy period was considered as set by the TM59. The results of the simulation show significant improvement with all three zones meeting both TM59 criteria. It should be noted that although increase openable area improves ventilation, it needs to be combined with solar shading to avoid excessive solar gain. Yet, more research is required to assess the effects of larger glazing on heat-losses during winter.

The effects of natural ventilation were further investigated by considering four different schedules: a) always open, b) always closed, c) TM59 schedule and lastly d) open at night (opened between 18:00 and 07:00 and closed between 07:00 and 18:00). Occupancy periods remained as defined by TM59. The results are summarised in Table 7. The results indicate that thermal comfort was achieved for the windows "always open" and" open at night". For the "always open" scenario, the best outcome was achieved however this may not always be feasible due to noise, pollution or for security reasons especially for the flats on the ground floor.

Table 7: Effects of natural ventilation on thermal comfort

Thermal Zones	Maximum Temperature`	Criterion (a)	Criterion a Percentage	Criterion (b)	Criterion b hours
Windows always open					
Bedroom 1	31	Pass	0.1	Pass	0
Bedroom 2	30	Pass	0.1	Pass	1
Living room and Kitchen	30	Pass	0.0	---	
Windows always closed					
Bedroom 1	31	Fail	5.0	Fail	87
Bedroom 2	30	Fail	16.9	Fail	264
Living room and Kitchen	32	Fail	13.0	---	

TM59 profile					
Bedroom 1	35	Pass	0.9	Fail	33
Bedroom 2	37	Fail	4.4	Fail	119
Living Room and Kitchen	36	Pass	0.4	--	
Windows open at night					
Bedroom 1	30	Pass	0.1	Pass	1
Bedroom 2	31	Pass	0.8	Pass	3
Living room and Kitchen	31	Pass	0.8	---	

The effects of solar shading were also investigated by considering 500mm, 750mm and 1000mm overhangs applied to south facing windows. As expected, the outcome of the simulation shows a clear reduction of annual solar heat gain by over 30% from 1.75 to 1.22 MWh for no shading scenario compared to 1000mm overhang, respectively. Table 8 summarises thermal comfort conditions when shading was applied. According to the results (table 8), all zones meet the requirements of Criterion A; however, Bedroom 2 does not mee the requirements set by Criterion B.

Table 8: Outcome of simulation for shading

Thermal Zone with 500mm shading	Maximum Temperature`	Criterion (a)	Criterion a Percentage	Criterion (b)	Criterion b hours
Bedroom 1	31	Pass	0.2	Pass	10
Bedroom 2	32	Pass	0.9	Fail	50
Living room and Kitchen	29	Pass	0.0	---	
Thermal Zone with 750mm shading					
C	30	Pass	0.2	Pass	9
Bedroom 2	31	Pass	0.7	Fail	41
Living room and Kitchen	29	Pass	0.0	---	
Thermal Zone with 1000mm shading					
Bedroom 1	30	Pass	0.2	Pass	8
Bedroom 2	31	Pass	0.5	Fail	33
Living room and Kitchen	28	Pass	0.0	---	

Figures 3 and 4, extracted from IES(VE), also illustrate indoor conditions when opening areas increased from 9 m^2 to12 m^2. The red colour is the time when the temperature exceeded 26 C (considered as overheating) for the duration of simulations (May 1 to September 30) for all rooms. Comparing the results, it is evident that the number of hours when the temperature exceeds 26 C has significantly decreased in all rooms indicating reduced risk of overheating thanks to improved natural ventilation.

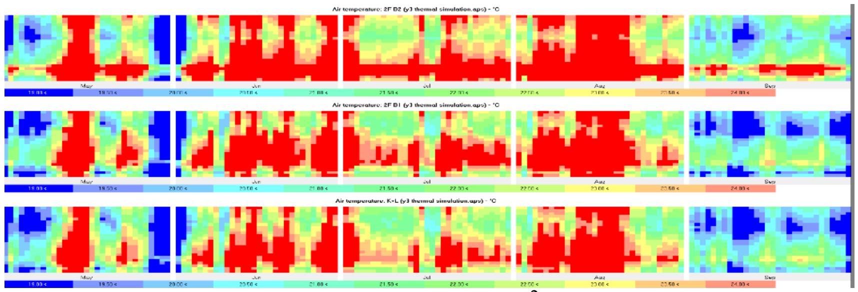

Figure 3: opening areas 9 m^2, “as built”

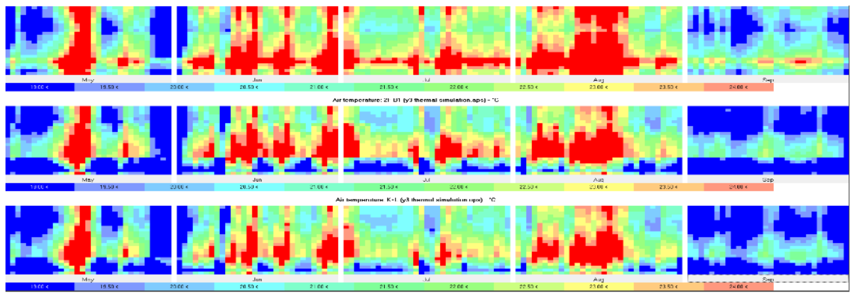

Figure 4: opening areas 12 m^2

Figure 4 shows the outcomes of the simulation for the combination of the most effective strategies, namely opening time and sizes combined with 1000mm solar shading. The results show a clear reduction of overheating (red colour) when temperature exceeds 26 C. The yellow and light green colours indicate temperatures between 20 and 23 C. All zones have passed both TM59 criteria (Table 8) indicating a significant reduction in risk of overheating in the flat during summer.

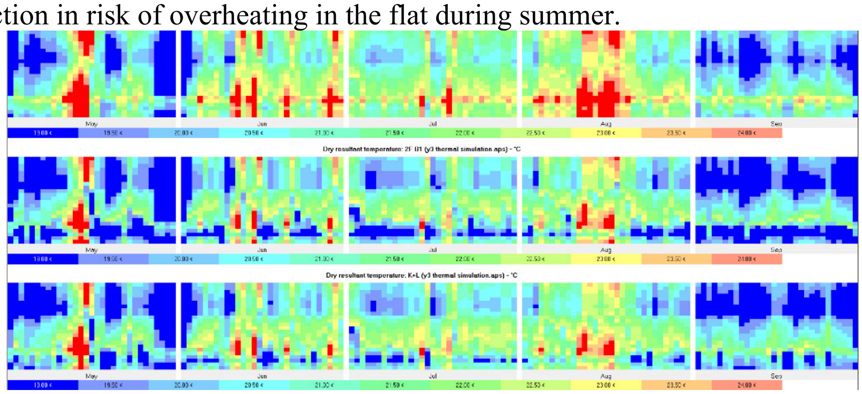

Figure 5: Outcome of the simulation with all strategies implemented

Table 9: Outcome of simulation with multiple strategies applied

Thermal Zone	Maximum Temperature`	Criterion (a)	Criterion a Percentage	Criterion (b)	Criterion b hours
Bedroom 1	27	Pass	0.2	Pass	0
Bedroom 2	27	Pass	0.6	Pass	0
Living room and Kitchen	27	Pass	0.0	---	

CONCLUSION

The predicted rising temperature combined with heat weaves and acute weather events in the UK have raised the question as to whether the new and existing dwellings can adapt to the consequences of climate change including acute overheating. The aim of this research to investigate and enhance thermal comfort in a typical case study building by implementing sustainable passive strategies. The results show that such strategies could significantly improve the conditions. The implementation of a combination of passive design strategies, including natural ventilation, solar shading, and thermal mass, in early stages of design could effectively address these issues in buildings mitigating the risk of overheating and thermal discomfort for occupants of buildings. This would not only improve the health and wellbeing of the occupants but would also reduce the need for mechanical ventilation that could contribute to more energy consumption and CO2 emissions. This said, rising temperatures in moderate and cold climates may also reduce the need for heating during the wintertime. More investigation is required to understand the overall effects of global warming on the energy performance of residential building in such climatic conditions.

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