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Evaluating Thermal Comfort and Overheating Risks in A Social Housing Prototype - As-Built Versus Retrofit Scenarios

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Abstract

Climate change has highlighted the importance of thermal comfort and its health-related outcomes, particularly for the most vulnerable members of society living in social housing. Due to their vulnerable living conditions, low-income people are more exposed to negative outcomes of overheating and cold indoor temperatures in buildings. Previous studies suggest that there is a significant risk of overheating in retrofitted buildings both for the current and future weather scenarios. The UK government has introduced new building regulations to assess and limit the risk of overheating in new buildings; however, there is still a need to assess and improve conditions for existing and retrofitted properties. This study aims to evaluate the effect of retrofit strategies on thermal comfort and the risk of overheating in social housing under current and future climatic conditions. A typical case study building was simulated in DesignBuilder to assess thermal comfort conditions for upgraded building fabric to Part L of the UK building regulations and Passive House standards. The summer results were analyzed according to CIBSE TM59 while the Predicted Mean Vote index (PMV) was used for winter analysis. Findings revealed that the south-facing bedrooms are most exposed to overheating. Risk of overheating significantly increased for the future weather scenarios by up to 10 times while winter thermal comfort improved for the retrofitted scenarios.

Keywords

Thermal comfort; Climate change; Social housing; Overheating; Retrofit

1. Introduction

It is widely accepted that climate change has exacerbated the risk of acute overheating in residential buildings. South and Southeast of England are particularly exposed to increased temperatures due to global warming. Under the current climate, there is a substantial risk of overheating in London, and if climate change adaptation measures are not incorporated into building regulations, design, and retrofit, occupants' exposure to excessive interior temperatures is likely to significantly increase in the future (Pathan et al., 2017) affecting their health and wellbeing. Recent studies show that climate is undergoing noticeable changes primarily as a result of human activities, particularly due to greenhouse gas emissions, which have reached unprecedented levels in recent times; (IPCC, 2014). These have led to an increase in the duration, intensity, and frequency of heat waves worldwide (Perkins et al., 2012). Other studies suggest that outdoor temperatures may rise even greater than initially estimated (Kala et al., 2016). According to the UK Climate Change Projections 2009 (UKCP09), all UK regions are expected to become warmer, especially during the summer period (DEFRA, 2009), increasing the risk of overheating across the UK (Beizaee et al., 2013; Lomas & Porritt, 2017). Under the medium emissions scenarios, the greatest rise in summer mean temperatures will be in Southern England with up to a 4.2°C average increase by the end of the century (Murphy et al., 2009). It is expected that by the middle of the century, the daytime temperatures in London will exceed 32°C for one-third of June to August (Hall et al., 2009).

There is a strong link between high temperatures and mortality rates. This was reflected in the 2003 and 2006 European heatwaves resulting in substantial damage and disruption to the economy, infrastructure, and transport, as well as a significant increase in the excess heat-related mortality rates especially amongst older people (Fouillet et al., 2006; Fouillet et al., 2008; Kovats & Hajat, 2008). In August 2003, over 30,000 excess deaths were recorded across Western Europe during an exceptional heatwave (Kosatsky, 2005), with a total of 2091 cases in the UK, 616 cases of which were in London (Johnson et al., 2005). Moreover, in cities like London, the risk of overheating is further increased due to the Urban Heat Island (UHI) effect (Santamouris et al., 2015). In 2006, London had the highest rates of heat-related mortality during hot weather (Hajat et al.,2007). According to estimates, the proportion of excessive heat-related mortality in outer London, inner London, and central London that can be attributed to the UHI effect during a warm summer in 2006 was approximately 38%, 47%, and 47%, respectively (Milojevic et al., 2011). The situation is expected to deteriorate increasing the heat-related mortality rates three-fold by 2050 (PHE, 2015). Preventing heat-related mortality is therefore a major public concern in the UK and Europe (Menne & Matthies, 2009; PHE, 2015; WHO, 2004).

The UK was the first country in the world to introduce a long-term, legally binding climate change mitigation framework. According to the Climate Change Act 2008, UK emissions must decrease by at least 80% by 2050 when compared to 1990 levels (UK.Government, 2008). Meanwhile, incorporating energy efficiency regulations may lead to more airtight and highly insulated building envelopes that could lead to trapping heat increasing the risk of acute overheating. Currently around 20% of existing homes in the UK experience overheating (Beizaee et al., 2013; Hulme et al., 2013a; ZCH, 2015b). Defective retrofit (Dengel & Swainson, 2012; Shrubsole et al., 2014) and, in particular, inappropriate energy efficiency measures that are not coupled with suitable passive cooling solutions (Gupta et al., 2015; Hub, 2016; Santamouris & Kolokotsa, 2013) could increase risk of overheating. Frequent overheating may lead to increased use of mechanical cooling systems that in turn result in higher carbon emissions that will contribute further to climate change (Hulme et al., 2013b). Passive design solutions (e.g. the use of natural ventilation, thermal mass, solar shading, glazing type/area, and building orientation) are widely recognized as the most environmentally friendly techniques to mitigate the risk of overheating and improve occupants' thermal comfort, and health, (Gupta et al., 2015; Hub, 2016; Kolokotroniet al., 2010; Lafuente & Brotas, 2014; Santamouris & Kolokotsa, 2013; Santamouris et al., 2007).

Investigations have demonstrated that dwelling style (Baborska-Narozny et al., 2016; Firth et al., 2007; Firth & Wright, 2008; Lomas & Kane, 2013; Mavrogianni et al., 2015; Wright, Young, & Natarajan, 2005), construction age, and building fabric (Beizaee et al., 2013; Firth & Wright, 2008; Hulme et al., 2013a; Mavrogianni et al., 2015) are important factors contributing to indoor overheating. It has been shown that homes built in the 1960s, 1970s, and after 1990 tend to be most at risk of overheating. There is evidence that highly energy-efficient homes, whether newly constructed or modified, may be susceptible to summer overheating, especially those designed to Passivhaus standards (Morgan et al., 2015; Sameni et al., 2015; Mitchell & Natarajan, 2019). In order to minimize the negative effects on occupants' health and well-being, the UK government has been advised by the Committee on Climate Change (CCC) Adaptation Sub-Committee that "more action is needed" to limit overheating hazards of buildings (CCC 2014, 2017). Although there have been concerns about the risk of overheating in UK terraced homes and apartments for some time (Ministry of Housing, Communities & Local Government, 2012; Alliance, 2014; ZCH, 2015b), the issue is still largely underreported in the literature (Gupta & Gregg, 2016).

Improving buildings' energy performance will reduce energy bills and CO_2 emissions of domestic buildings (Owen et al., 2014; DECC, 2012); however, there is still a need to assess the effects of building fabric upgrades on the risk of overheating for the current and future climate scenario in order to develop future-proof retrofit strategies to not only improve energy performance but also avoid the 'unintended' effects of such strategies on indoor environments and health and wellbeing of building occupants. To this end, this study evaluates the effects of energy-efficient retrofit strategies (with a focus on building fabric upgrades) on the energy and thermal performances of an end-terraced house located in London.

2. Methodology

This study is undertaken in three phases, as shown in Figure 1: the first phase identifies the current thermal performance of the base case scenario, using the DesignBuilder software. The second phase includes the creation of different modelling scenarios; for a) the built era (BRE, 2019), b) Approved Document L for improved existing elements in existing dwellings (Department for Levelling Up, 2023), and c) Passivhaus standards (PassiveHouseInstitute, 2015; Trust, 2023), as shown in Table 1. Relevant U-values, G-values, and airtightness rates are assigned to each scenario (Table 1). The third phase assesses occupants' thermal comfort for the future climate scenario using CIBSE Weather Files for 2050.

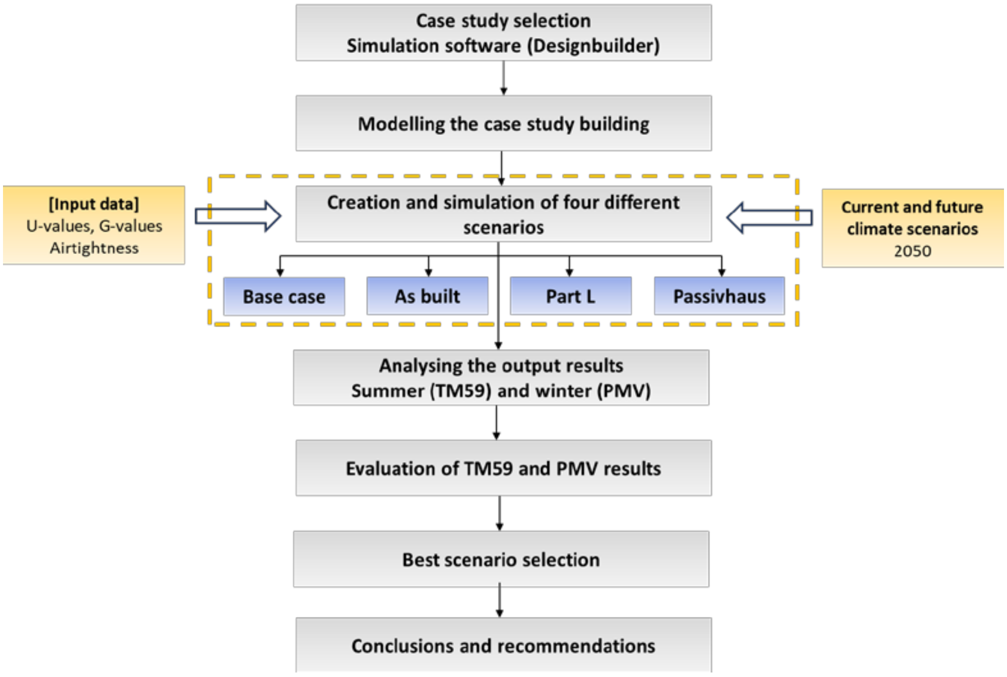

Figure 1: Methodology of analysis.

2.1. DesignBuilder Software

DesignBuilder is a software that provides accurate environmental performance, such as thermal comfort, energy consumption, and carbon emissions at annual, monthly, daily, hourly, and sub-hourly intervals. It integrates EnergyPlus as a powerful simulation engine that provides advanced dynamic thermal simulation at sub-hourly timesteps (DesignBuilder, 2023b). CIBCE TM59 templates were adopted for predicting overheating risk. Due to the large amount of simulated data, the results charts were exported using the DesignBuilder Results Viewer 4.0 application (DesignBuilder, 2023a).

2.2. The Case Study and Modelling Parameters

A typical terraced house constructed during the 1930s-1949s (selected from lists of social houses identified by the research partners) was modeled to assess occupants' thermal comfort. The case study is a two-story, end-terraced house with three exposed external surfaces, located in Greenwich, London (Figure 2) occupied by a low-income family of three. The walls are Solid Brick: as Built, and the windows are double-glazed installed in 2002 or later. Due to the limited information about the building construction, typical 1940s building construction materials (Raushan et al., 2022) and U-values (BRE, 2019) were adopted (Table 2). The adjacent house was considered as Adiabatic for the purpose of simulations, as shown in Figure 2. b.

Figure 2: (a) a picture of the case study house. (b) the 3D model of the case study house. (c) Ground floor plan. (d) First floor plan (by the Author).

The Design Summer Year (DSY) weather files were used as required for thermal comfort assessments. Four scenarios were simulated; the base case which refers to (1) the built-era specifications, (2) as-built, which represents the actual available data, (3) Part L recommendations, and (4) Passivhaus standards as shown in Table 1. The house has three bedrooms, two bathrooms, a kitchen, and a living room. For the ground floor, the living room is facing the North direction. It is important to highlight that it has a large window opening area with no shading. The kitchen is south-facing and has large openings with no shading. Regarding the first floor, the main bedroom is south-facing with a small opening; the single bedroom is relatively small and has two exposed external surfaces (North and East directions) with a small opening facing south; and the double bedroom is north-facing, similar to the living room. The roof overhangs play a role in providing some shading for the top floor zones.

Table 1: The assigned u-values and airtightness for all four case study scenarios

3D Model simulation scenarios	U-Values (W/ m^2 K)				Airtightness
	Roof	**Wall**	**Floor**	**Window**	**(m^3/h. m^2 @ 50 Pa)**
Scenario 1: Base case (typical 1930s/1949s house)	2.3	1.7	1.2	2.8	15
Scenario 2: As-built	2.3	1.7	1.2	2	15
Scenario 3: Building regulation, Approved Document (Part L)	0.16	0.3	0.25	1.4	10

Scenario 4: Passivhaus Standard	0.15	0.15	0.15	0.78 (triple with argon)	0.6

The internal gains profiles (occupancy, equipment, and heat gain) and natural ventilation set points for opening/closing windows followed TM 59 (CIBSE, 2017). Table 2 illustrates detailed information on opening types along with the percentage of openable areas. Heating set points, temperatures, and clothing levels for winter simulations followed the CIBSE guidelines (CIBSE, 2017), (e.g. dwellings' living rooms at 22–23 °C while bedrooms and kitchens at 17–19 °C).

Simulation results were conducted for the summer period (May-September) according to CIBSE TM59 criteria as follows: a) Criterion A: for bedrooms, kitchens, and living room, number of exceedance should not be over 3% of the occupied hours; Criterion B: for bedrooms only, the operating temperature between 10 pm and 7 am should not rise above 26 °C for more than 1% of the hours in a year (CIBSE 2015, CIBSE 2017).

Table 2: Opening sizes and types.

Zones	**Window type**	**Glazing area open (%)**	**Total Window area (m2)**
Living room (Two windows divided into four parts each)	Two tops hung Two parallel hung	38	2.352
Kitchen (Two windows divided into four parts each)	Two tops hung Two parallel hung	38	2.328
Main bedroom (one window divided into four parts)	Top hung parallel hung	39	1.164
Single bed (one window divided into four parts)	Top hung parallel hung	39	1.164
Double bedroom (Two windows divided into four parts each)	Two tops hung Two parallel hung	38	2.328
WC (one window)	bottom hung	50	0.22
Bathroom (one window divided into two parts)	Bottom hung	22	0.423
Corridor_ Ground level (one window)	Parallel hung	75	0.7
Corridor_ First level (one window on the second floor divided into four parts)	Top hung parallel hung	39	1.164

For winter assessment, the simulations were conducted from October to March representing the cold/heated seasons in the UK. The Predicted Mean Vote index (PMV) (Fanger & Toftum, 2002) was used following the thermal comfort limits (CIBSE, 2013), as included in Table 3. All the reported results are for the occupied periods.

Table 3: Thermal comfort indicators.

ASHRAE comfort scale		**Bedford comfort scale**
+3	Hot	Much too hot
+2	Warm	Too warm
+1	Slightly warm	Comfortably warm
0	Neutral	Comfortable
-1	Slightly cool	Comfortably cool
-2	Cool	Too cold
-3	cold	Much too cold

3. Results

3.1. Summer thermal comfort conditions

An internal layer of insulation was considered in order to reach the assigned U-Values for the case study scenarios, as shown in Table 4. The external wall layers included solid brick, internal insulation, and plaster.

Table 2: the assigned insulation material type and thickness for all the case study scenarios.

	U-Values ($W/ m^2 K$)	Total wall thickness (m)	Insulation material	Insulation thickness (m)
Base case/As-built	1.7	0.2	N/A	N/A
Part L	0.3	0.37	Foam – urea-formaldehyde resin	0.151
Passivhaus	0.15	0.552	Foam – urea-formaldehyde resin	0.332

Summer simulation results (Table 5), showed that for the "base case", only the living room and the kitchen passed the summer assessment for the current weather scenario. For the 2050 scenario, none of the zones passed the thermal comfort criteria. For the "as-built", there was a slight improvement in the total number of discomfort hours for all the bedrooms compared to the base case scenario; however, the test didn't pass Criterion B. Both the living room and kitchen passed the requirements for the current weather, whereas, for the future weather scenario, only the living room achieved the requirements. Regarding "Part L", both the main- and single-bedroom failed while for the future weather scenario, all bedrooms failed and only the kitchen and living room passed the tests. For the "Passivhaus", all the zones passed the thermal comfort requirements for the current climate while for the future weather conditions, all bedrooms dramatically failed revealing the significant risk of overheating and possible negative health outcomes. When comparing the current and future weather scenarios, the risk of overheating is increasing by around 10 times for the base case and by nearly 7.5 times over the acceptable recommended CIBSE limits.

Table 3: Summer simulation pass/fail test results for current and future climate scenarios (Criterion A (%), Criterion B (hr)).

Zones/current	**Base case**	**As-built**	**Part L**	**Passivhaus**
Main bedroom	Fail (52 h)	Fail (48 h)	Fail (37 h)	Pass (22 h)
Double bedroom	Fail (34 h)	Fail (33.5 h)	Pass (16 h)	Pass (10.5 h)
Single bedroom	Fail (62 h)	Fail (48.5 h)	Fail (33 h)	Pass (25 h)
Living room	Pass (0.29%)	Pass (0.26%)	Pass (0.18%)	Pass (0%)
Kitchen	Pass (1.53%)	Pass (1.09%)	Pass (0.42%)	Pass (0.31%)
Zones / 2050	**Base case**	**As-built**	**Part L**	**Passivhaus**
Main bedroom	Fail (414 h)	Fail (391.5 h)	Fail (307 h)	Fail (241.5 h)
Double bedroom	Fail (301 h)	Fail (284.5 h)	Fail (190 h)	Fail (156.5 h)
Single bedroom	Fail (374 h)	Fail (367.5 h)	Fail (260.5 h)	Fail (218.5 h)
Living room	Fail (3.01 %)	Pass (2.43%)	Pass (2%)	Pass (1.64%)
Kitchen	Fail (6.5%)	Fail (4.88%)	Pass (2.88%)	Pass (1.72%)

3.2. Winter thermal comfort conditions

For the base case scenario, for the current climate, no major overheating was observed except for the main bedroom (Figure 3) reaching its maximum on October 31 with a value of PMV +1.25. For the future weather scenario, it marginally failed the comfort range except during December and reached a maximum value of +1.39 on October 5. The major issue was identified as cold conditions in all other rooms except for the living room which remained within the threshold.

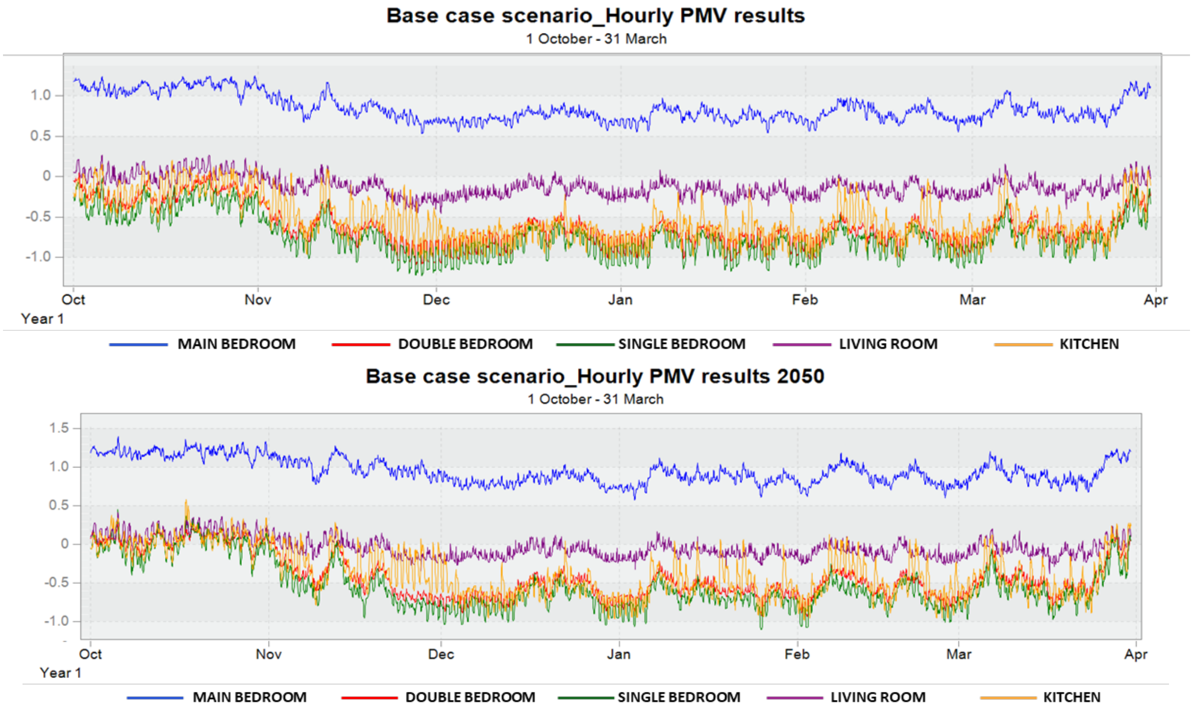

Figure 3: Base case scenario, hourly PMV results for the current and future climate scenarios.

Similar to the above, for the “as-built” scenario, the main bedroom experienced a warmer environment reaching a Max. PMV values of +1.25 and +1.39 as the maximum PMV values for current and future climates respectively. Concerning the double bedroom, values were in the comfort range with -0.97 as the minimum PMV recorded in the current climate in November (figure 4), whereas the situation improved slightly for the 2050 case. The single bedroom experienced a cooler environment reaching -1.20 as a minimum value, which was improved in 2050 reaching -1.04. Overall, the comfort conditions were rather similar to the base case in all rooms for both current and future weather scenarios.

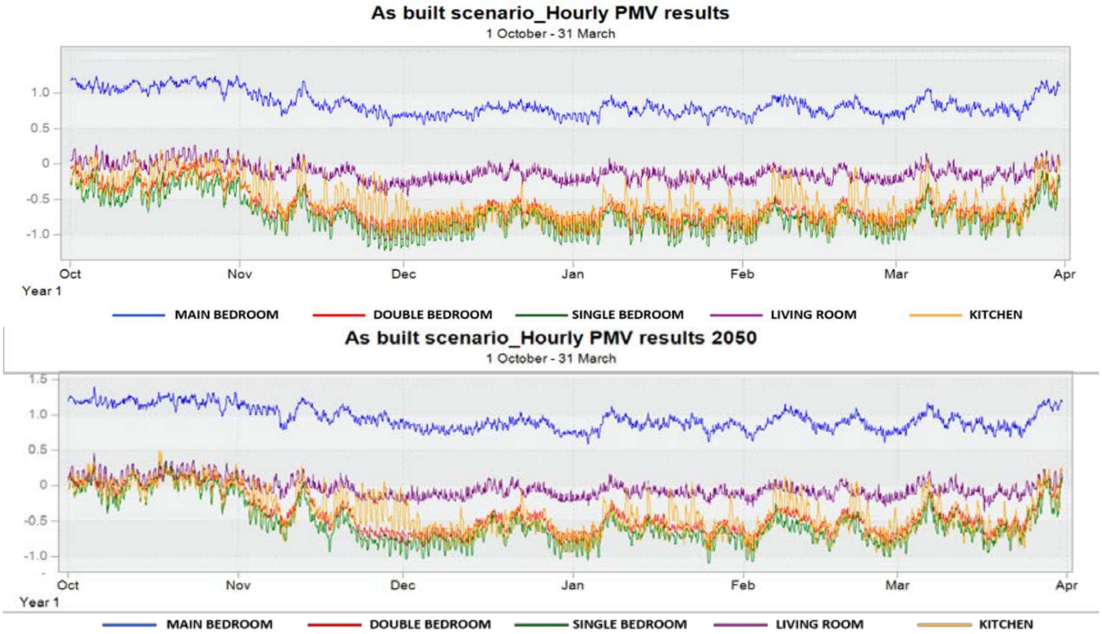

Figure 4: As-built scenario, hourly PMV results for the current and future climate scenarios.

Regarding, the Part L scenario for the current climate, similar conditions were observed for the main bedroom experiencing overheating while other zones, except the living room, experienced cold conditions, particularly during December/March (Figure 5). For the future scenario, the cold conditions were improved for all zones while the main bedroom experienced more overheating reaching a PMV value of +1.41 for 2050.

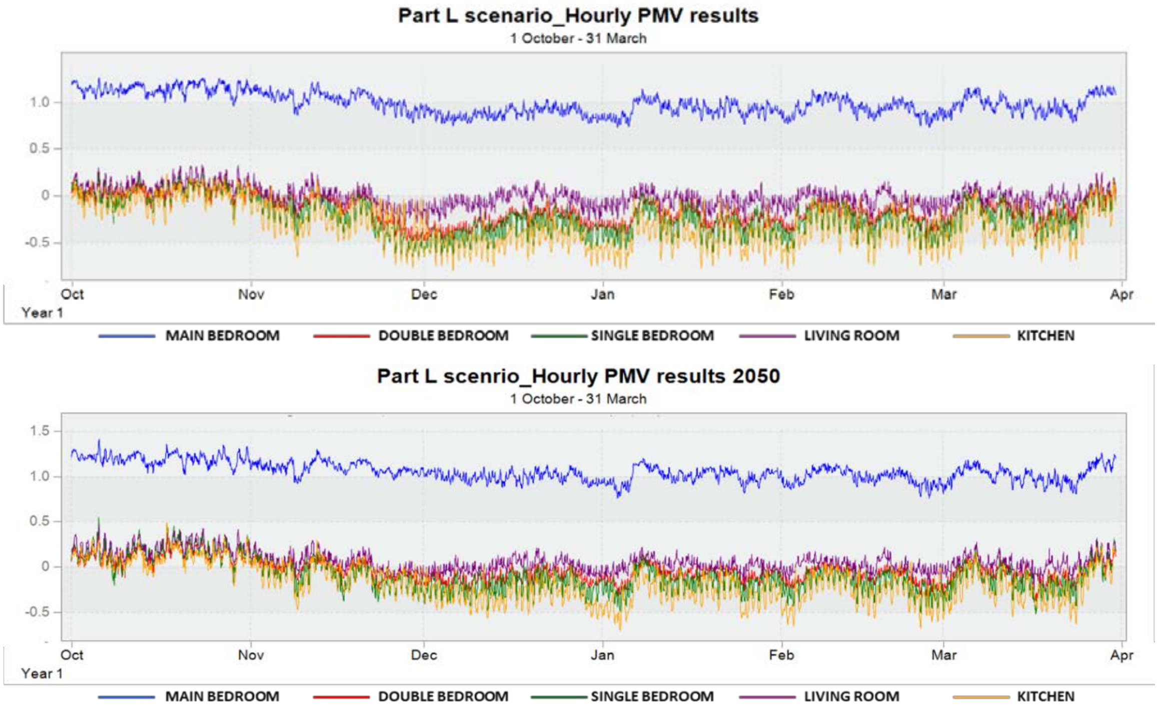

Figure 5: Part L scenario, hourly PMV results for the current and future climate scenarios.

For the Passivhaus scenario, all zones were in the comfortable range except for the main bedroom reporting PMV ratings of +1.30 and +1.41 for the current and the future weather scenarios, respectively (Figure 6). Similar to Part L, the cold conditions significantly improved for all rooms while the main bedroom experienced consistent overheating; however, overall, the building fabric upgrades did not significantly increase the risk of overheating during winter.

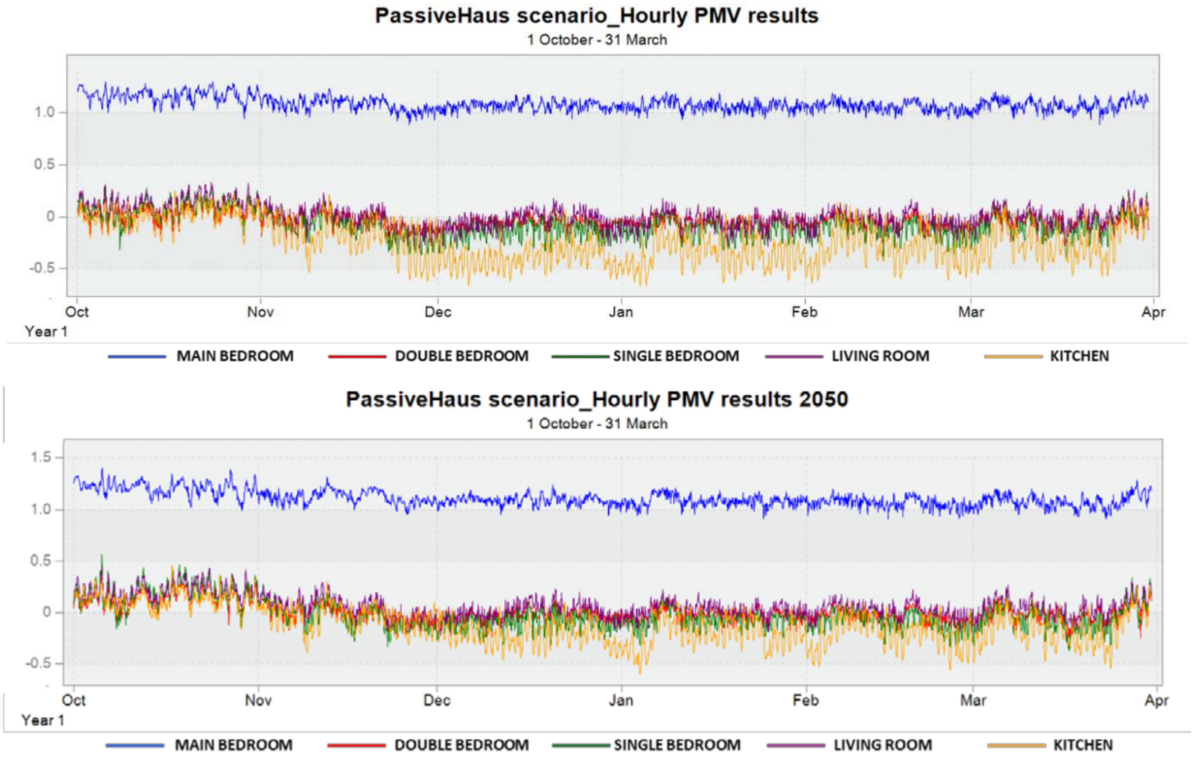

Figure 6: Passivhaus scenario, hourly PMV results for the current and the future climate scenario

4. Conclusions

This paper investigated the thermal comfort and risk of overheating in a social housing case study building. Different scenarios were analyzed to assess and select the optimum option to avoid overheating in summer while improving thermal comfort by reducing cold conditions during winter. For the current weather conditions, both in the base case and the as-built scenarios, the living room and the kitchen were in the acceptable range for summer and winter assessments, while for the Part L scenario, three zones (double room, living room, and kitchen) met the requirements. For the Passivhaus scenario, all the zones were within the acceptable ranges except for the main bedroom which experienced some overheating during winter. Generally, for the retrofitted options, the situation improved for all the zones apart from the main bedroom which experienced a warmer environment. For future weather conditions, bedrooms experience a risk of overheating during both summer and winter seasons. The situation significantly improved for the Passivhaus compared to the other scenarios. Yet, the results revealed that only the living room and kitchen met the requirements for both summer and winter assessments, while bedrooms were in the comfortable range for winter assessments (except for the south-facing main bedroom).

In summary, south-facing bedrooms expose a high risk of overheating and should be considered with more cases for retrofitting. The Passivhaus scenario passed the summer test for the current climate but failed for the 2050 scenario. This agrees with the previous findings highlighting bedrooms as the most exposed to overheating for future climate scenarios during summer (Beasley et al., 2014,). It should be noted that even though the bedrooms failed the test, there were improvements in the total number of discomfort hours in comparison to other case study scenarios. Building orientation, window opening areas, and insulation strategies combined could lead to overheating particularly during summer. Therefore, further adjustments, such as shading and/or lower G-values, should be considered to reduce the heat gains through the windows for the south-oriented rooms. Finally, more investigation is required to assess the effect of other factors including occupant behavior, natural and mechanical ventilation strategies, thermal mass, construction methods and materials, and other passive design strategies on thermal comfort in buildings.

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Ethics approval

The authors have received ethics approval from the ethics committee of the University of East London, for the interviews and surveys that were conducted by the authors.

Conflict of interest

The authors declare that there is no competing interest.

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