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Systematic Assessment of Overheating Risk in UK Dwellings by Housing Typology and Climatic Region

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A B S T R A C T

Rising temperatures and frequent extreme heat events are increasing overheating risk within the UK housing stock, much of which was designed for heat retention rather than dissipation. This study investigates the combined influence of regional climate, dwelling typology, construction age and future weather file methodology on overheating risk across representative UK residential archetypes. Dynamic thermal simulations were conducted for mid-terraced, semi-detached and end-terraced dwellings across southern, midland and northern regions under the medium and high emissions pathways, including 50th and 90th percentile climate projections. Overheating was assessed using CIBSE threshold criteria, with results showing a consistent typological hierarchy in which end-terraced dwellings exhibit the highest overheating and mid-terraced dwellings the lowest, reflecting differences in exposed envelope area. Newer, more highly insulated dwellings demonstrate greater overheating risk, highlighting the trade-off between winter efficiency and summer resilience. A clear regional gradient is evident, with southern locations exceeding thresholds under median projections by mid-century. Divergence between morphing-based and stochastic weather files becomes pronounced under extreme scenarios, where overheating is amplified. The findings demonstrate that overheating risk is climate-amplified, exposure-sensitive, and strongly dependent on modelling assumptions, underscoring the need for integrated assessment in future adaptation strategies.

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1. INTRODUCTION

Limiting the increase in global mean temperature to 1.5 °C is now widely regarded as increasingly unattainable, and the United Kingdom is projected to experience some of the largest proportional increases in cooling demand (Miranda et al. 2023). Buildings across the United Kingdom are increasingly exposed to overheating because of rising outdoor temperatures and more frequent extreme heat events driven by climate change. This vulnerability has become increasingly evident in recent years, with 2025 recorded as the warmest year on record and four heatwaves reported by the Met Office (Office 2025). UK homes are particularly susceptible because much of the existing stock was designed to retain heat rather than dissipate it with many dwellings lacking effective passive cooling strategies (Velashjerdi Farahani et al. 2021). Recent studies have

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identified overheating as an emerging public health risk, particularly in lightweight dwellings and highly insulated modern homes, where indoor temperatures can exceed safe thresholds even under current climatic conditions (Vardoulakis et al. 2015; Lomas and Porritt 2017; Lomas 2021). The World Meteorological Organization has reported that over the past five decades, nearly 12,000 extreme weather events have resulted in more than 2 million deaths. Consequently, predicting future overheating risk has become essential for informing building design and climate adaptation policy.

The UK exhibits strong climatic gradients, with warmer and more humid conditions in the South, temperate conditions in the Midlands, and cooler conditions in the North. UK climate projections suggest that these gradients will persist and may widen under higher-emissions futures (Murphy et al. 2018). Despite this, many overheating studies rely heavily on London-based weather files, with comparatively few exploring how regional climatic variation affects overheating risk in different building archetypes (Pathan et al. 2017; Porritt et al. 2012; Li et al. 2019). Older properties are generally found to experience limited overheating, except during extreme heat events. In contrast, newer and more thermally efficient buildings show a higher propensity for overheating because of improved energy performance standards (Tink et al. 2018). As a result, the combined influence of region and future climate uncertainty remains poorly understood. Dwelling form is a well-established determinant of overheating risk. Differences between detached, semi-detached and terraced dwellings lead to distinct thermal responses due to variations in exposed surface area, solar gains and heat exchange with adjacent buildings (Beizaee et al. 2013).

Accordingly, this study does not seek to predict the prevalence of overheating across the entire UK housing stock. Instead, it uses a controlled reference geometry to examine how external exposure configuration, selected construction-period fabric characteristics, climatic region and future-weather generation method influence overheating outcomes when layout, floor area, orientation, glazing and internal gains are held constant. The study therefore addresses three questions:

1. How external envelope exposure effects overheating under otherwise identical conditions,
2. how selected fabric archetypes interact with regional climatic conditions and
3. sensitivity of the results to the future weather generation methods.

2. LITERATURE REVIEW

Existing literature regarding overheating risk in UK dwellings, often spans multiple, disconnected areas of inquiry with a particular focus on four interconnected themes: overheating prevalence and drivers in the housing stock, regional climatic variation and its implications, the role of future weather files in building simulation, and the influence of dwelling age and typology on thermal performance. Together, they provide the foundational understanding of how overheating risk is currently assessed, where methodological and evidential limitations persist, and why an integrated analysis of region, building form and weather-file methodology under future climates is required.

2.1. OVERHEATING IN UK DWELLINGS

Overheating is becoming an increasingly significant issue within the UK housing stock, driven by rising external temperatures, heat-retentive building design, and the limited prevalence of active cooling systems. Research has historically focused on heating-season comfort, leaving summertime thermal performance comparatively underexplored despite increasing exposure to warmer conditions (Velashjerdi Farahani et al. 2021). Numerous monitoring campaigns and modelling studies have documented internal temperatures exceeding recommended thresholds during summer, even under present-day conditions (Pathan et al. 2017; Jones et al. 2016; Ji et al. 2014; Cherian et al. 2025). This is further supported by empirical analyses of UK dwellings, which demonstrate that overheating can occur frequently in naturally ventilated homes and is not always effectively mitigated by occupant behaviour alone (Rodrigues et al. 2015). In response, recent policy and guidance documents, including Building Regulation Part O (HMG 2021) and CIBSE Technical Memorandum 59 (CIBSE 2017) have been introduced to provide a consistent framework for the assessment and mitigation of overheating risk in residential buildings. Key contributors to overheating include high insulation levels (Rodrigues and Gillott 2013), airtightness, large glazing areas, internal heat gains and occupant behaviours.

As building standards have progressively improved, recent dwellings generally exhibit higher internal temperatures. Research indicates that average indoor temperatures can be approximately 1.5 °C warmer in post-1990 homes compared with those constructed before 1919 (Beizaee et al. 2013). Furthermore, reducing external wall U-values from 0.9 W to 0.3 W/m²K has been shown to raise indoor temperatures by 15-17% across multiple climate scenarios (Elsharkawy and Zahiri 2020). While building age provides a broad categorisation of the housing stock, it is complemented by variation in dwelling typology. Common types include terraced, semi-detached, detached and bungalow, along with converted flats and purpose-built low/high-rise flats (Piddington et al. 2020). Terraced and semi-detached homes comprise the largest proportion of the housing stock at 27.4% and 25.0%, respectively, followed by flats (20.9%) and detached dwellings (17.9%), while bungalows account for the smallest share at 8.8% (Piddington et al. 2020). Building typology strongly influences heat retention, solar exposure, and ventilation potential (Beizaee et al. 2013; Mulville et al. 2025). Evidence indicates that flats tend to exhibit the highest summertime temperatures, largely due to the greater solar gains experienced by upper-storey units and in some cases, lower levels of thermal mass (Lomas 2021). Smaller dwellings, such as mid-terrace houses and bungalows, also appear to be at elevated risk (potentially because internal and occupancy gains are distributed over a smaller floor area) resulting in higher heat gains per unit area (kW/m²) (Bugenings and Kamari 2022). Literature further suggests that mid-terrace and semi-detached homes demonstrate broadly comparable thermal behaviour, with end-terrace properties tending to run slightly warmer and detached dwellings generally cooler (Beizaee et al. 2013). Overheating in UK dwellings has been strongly linked to adverse health outcomes, particularly for elderly and vulnerable populations. For example, a London-based study estimated approximately 274 heat-related deaths over a 55-day period during which outdoor temperatures exceeded 24.8 °C (Taylor et al. 2015).

2.2. REGIONAL CLIMATE VARIATION AND IMPLICATIONS FOR OVERHEATING

The UK exhibits considerable climatic diversity, with southern regions generally warmer and subject to more intense heatwaves than northern areas. UKCP18 projections indicate significant warming across all regions, but the magnitude and temporal pattern of change vary geographically especially when considering summer maximums (Murphy et al. 2018). Several studies (Toledo et al. 2025; Lomas et al. 2021; Morgan et al. 2015) have shown that overheating risk varies geographically, with severity consistently higher in southern England (Porritt et al. 2012). As a result, many overheating assessments rely on London weather data as a default, a practice that may lead to systematic under- or overestimation of overheating risk in other regions.

2.3. FUTURE CLIMATE WEATHER FILES FOR BUILDING SIMULATION

Weather files are fundamental inputs to dynamic thermal simulations, and their construction introduces significant variability into overheating outcomes. Conventional weather datasets such as Typical Meteorological Years (TMY) and design-day files remain widely used for building energy modelling, including design, compliance, operation and retrofit assessment (Chan et al. 2006). In a changing climate, this approach is increasingly inadequate, as buildings are sensitive to both future warming trends and short-duration extreme events that drive peak thermal stress and cooling demand (Yan et al. 2025; Hosseini et al. 2021). Future weather assessment is grounded in climate scenario development. Early work relied on the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios, which defined four scenario families and shaped impact research for over a decade. As global socioeconomic and technological pathways diversified, these scenarios became insufficient, prompting the development of Representative Concentration Pathways and their later integration with Shared Socioeconomic Pathways (Zeng et al. 2025). Despite this evolution, many building-performance studies continue to rely on RCP-based datasets due to their availability and embedded use in modelling tools.

Future weather files for buildings are generated using either dynamical or statistical downscaling. Dynamical downscaling applies regional climate models at finer spatial resolution, including topography and urban effects, but remains computationally intensive and limited in availability (Roberts et al. 2018; Feser et al. 2011). Statistical downscaling offers a more accessible alternative by linking large-scale climate outputs to local weather variables, though it assumes the stability of historical climate relationships under future conditions (Giorgi 2008; Ekström et al. 2015). Within this category, commonly used approaches include morphing techniques that modify baseline weather files using climate change signals (Leith and Chandler 2010, Belcher et al. 2005), regression-based methods and stochastic weather generators designed to explore variability and extremes (Wilks and Wilby 1999).

Tools such as CCWorldWeatherGen exemplify the morphing approach and are widely adopted in building simulation studies due to their simplicity and compatibility with standard modelling workflows (Shen et al. 2025). However, CCWorldWeatherGen relies largely on SRES-based projections and applies mean monthly adjustments to historical weather, which limits its ability to represent future extremes, heatwave persistence, and sub-daily variability (Duan et al. 2025). In contrast, PROMETHEUS is based on a stochastic weather generator framework that incorporates probabilistic representations of temperature, solar radiation and persistence of extreme events. This enables PROMETHEUS to produce future weather series that better reflect changes in heatwave frequency, duration and intensity (Eames et al. 2010, UoE). Peer-reviewed comparisons indicate that such methodological differences can lead to substantial divergence in predicted indoor temperatures and cooling demand, particularly for residential buildings under future climates (Liu et al. 2023; Nik et al. 2016).

The methodological distinction between morphing and stochastic generation is particularly important for overheating analysis. Overheating is commonly assessed using threshold-based criteria, in which compliance depends on the number or proportion of occupied hours above a defined temperature. Where indoor conditions remain close to that threshold, relatively small changes in external temperature, nocturnal cooling or heatwave duration can produce disproportionately large changes in exceedance hours. Weather-file methodology may therefore affect not only the magnitude of predicted overheating, but also whether a dwelling passes or fails the selected criterion. A morphing file that primarily represents changes in mean conditions may produce a different risk classification from a probabilistic high-percentile file that incorporates a longer or more intense heat event. This makes weather-file choice a source of methodological uncertainty rather than merely a difference in input format.

2.4. INFLUENCE OF DWELLING AGE AND TYPOLOGY ON OVERHEATING

Within the European Union, the United Kingdom has the highest percent of buildings built pre 1945 with the fewest built post 2000s (Piddington et al. 2020). Analysis of the types of dwellings within the UK literature commonly points at 6 typically identifiable points Pre 1919s, Interwar (1919 to 1944), Post war (1945-1964), Industrial (1965-1980), modern (1980-1990) and post 2002 each with their own construction configuration used:

2.4.1. PRE 1919S

Historically, houses built before the 1919s often utilised frameless construction in which the external façade served as a load-bearing solid wall. These walls were formed from regular masonry units (brick, stone, fired clay, etc.) bound with mortar and were generally constructed as a single leaf (Doran et al. 2014). Although cavity walls existed prior to the 1930s, solid walls were far more prevalent (Li and Densley Tingley 2021; Gori et al. 2021); nearly 70% of pre-1919 dwellings are of solid-wall construction (Seifhashemi and Elkadi 2022). Accordingly, for the purposes of this analysis, all buildings constructed before the 1919s are classified as solid-wall dwellings. As of December 2024, data indicate that only around 10% of homes with solid walls have been fitted with solid wall insulation. Uptake of loft insulation is higher but still incomplete, covering approximately 67% of the housing stock. In contrast, dwellings with cavity walls exhibit substantially greater insulation uptake, with installation rates in the region of 71% (DESNZ 2025). This typology therefore represents the greatest potential for reducing energy demand and associated CO_2 emissions (Kim 2015), particularly given that an estimated one-third of heat loss occurs through external walls (Seifhashemi and Elkadi 2022). A substantial portion of the UK's solid-wall housing stock is located in England, with London and the North-West showing the highest concentrations (Kim 2015). These dwellings are predominantly low-rise, typically two-storey detached, semi-detached or terraced homes (Doran et al. 2014). The thermal implications of this construction are not unidirectional. High U-values increase winter heat loss and may permit more rapid heat exchange with the external environment.

During summer, this can increase heat gains when external temperatures exceed internal temperatures but can also facilitate heat dissipation when outdoor conditions fall overnight. Greater masonry mass may additionally dampen and delay daytime temperature peaks. However, delayed heat release can maintain elevated internal temperatures after sunset and may therefore increase nocturnal overheating, particularly in bedrooms.

2.4.2. 1919-1945

Based on stock data cavity walls began becoming dominant within this period, in stark contrast to the construction used in prior periods (Hamilton et al. 2013; Romero Perez de Tudela et al. 2020). The use of timber as a material within buildings was also becoming more prevalent, mainly for roofs and floors (Liddiard et al. 2021; Romero Perez de Tudela et al. 2020).

2.4.3. 1945-1964

By this period, cavity wall construction had become the dominant external wall form (Hamilton et al. 2013). Formal building regulations were subsequently introduced with the 1965 standards (Romero Perez de Tudela et al. 2020). The 1965 standards introduced the first national controls on fabric heat loss in new buildings. Although explicit performance values were limited, the regulations provided deemed-to-satisfy constructions with associated thermal transmittance criteria, equating to maximum U-values of approximately 1.7 W/m²K for external walls and 1.4 W/m²K for roofs (Ip, 1994, 1965). These values are broadly consistent with findings from other studies assessing the thermal performance of unfilled cavity walls (Raushan et al. 2022). These changes improved winter energy efficiency but introduced more complex implications for summer performance. Reduced thermal transmittance can limit daytime heat transfer through the envelope but can also restrict the dissipation of heat generated by solar radiation, occupants and appliances. Similarly, improved airtightness reduces uncontrolled heat exchange and winter infiltration losses yet may increase overheating where intentional ventilation is limited or windows cannot be opened effectively. Later-period dwellings are therefore not necessarily vulnerable because they are newer, but because their combined fabric, glazing, ventilation and occupancy characteristics may create conditions in which heat is accumulated faster than it can be removed.

2.4.4. 1964-1980

Wall assemblies generally became thinner, while regulatory requirements tightened and materials such as concrete were increasingly incorporated. The 1976 Regulations introduced minimum insulation standards for the first time, reducing permissible heat-loss rates to approximately 1.0 W/m²K for external walls and 0.6 W/m²K for roofs (values that are broadly consistent with findings reported in literature) (Ip, 1994, 1976, Raushan et al. 2022). This prompted advancements in cavity wall construction, with insulation incorporated within the cavity as an effective means of reducing heat loss without increasing overall wall thickness (Mayouf et al. 2022; Bozsaky 2010). Post-war resource shortages also accelerated the adoption of prefabricated construction systems alongside conventional masonry methods (Vagtholm et al. 2023). Although thermal insulation began to appear during this period, its use was not yet widespread or considered standard practice.

2.4.5. 1980-1990

From this period onward, construction practices became closely aligned with successive tightening of building regulations. These changes drove a substantial increase in the use of thermal insulation within external walls and placed growing emphasis on improving airtightness (Vagtholm et al. 2023, Rosser et al. 2019). The 1985 Regulations strengthened thermal performance requirements by further reducing permissible U-values, lowering external wall limits to approximately 0.6 W/m²K and roof limits to around 0.35 W/m²K (1985). Subsequent regulatory revisions continued this reduction, progressively tightening U-value thresholds and promoting greater airtightness to minimise uncontrolled air leakage (Ip 1994). While several studies have assessed overheating within specific dwelling archetypes, comparatively few have evaluated multiple dwelling types under consistent simulation conditions and even fewer have explored how dwelling form interacts with regional climatic variation or alternative future weather datasets. Evidence that post-1990 homes experience higher mean summer temperatures than pre-1919 dwellings supports this concern (Beizaee et al. 2013). However, these comparisons do not isolate insulation from differences in dwelling geometry, glazing area, orientation, ventilation behaviour or internal gains. Attribution of overheating to fabric improvements alone is therefore inappropriate.

Literature consequently presents an apparent trade-off between winter energy efficiency and summer thermal resilience. Higher insulation levels and improved airtightness reduce heating demand but may increase the duration of elevated internal temperatures once heat has entered the building. Studies reporting increased internal temperatures following reductions in wall U-values provide evidence of this effect. Nevertheless, the relationship is conditional rather than universal. Its magnitude depends on solar exposure, thermal mass, external temperature, ventilation availability, internal gains and the timing of heat release. Thermal mass further complicates a simple older-versus-newer distinction. Heavy construction may moderate daytime peaks by absorbing heat, while lightweight construction responds more rapidly to changing external and internal loads. However, stored heat in heavyweight buildings may be released during the evening and night, potentially worsening bedroom overheating. Older construction may therefore appear more resilient when assessed using daytime maximum temperature but less resilient when evaluated using nocturnal exceedance criteria.

2.5. IDENTIFIED GAPS IN THE LITERATURE

Despite substantial progress in understanding overheating risk in UK dwellings, several key gaps remain:

- Most existing studies treat London (south) as a representative (or worst case) UK climate. This leads to a geographical bias that overlooks substantial climatic variation across southern, midland and northern regions. Although the south may be a reasonable way to estimate upper-bound overheating effects, this limits the generalisability of findings. Homes in cities such as the midlands or locations in the north are subject to markedly different thermal conditions, seasonal patterns and projected warming trajectories, which may in turn result in overestimation of future overheating risks.
- While literature acknowledges that future weather files differ depending on the generation method, the implications of these differences remain poorly quantified. Morphing-based tools apply different methodologies and thereby produce different temperature sequences, humidity profiles and extreme heat characteristics. Very few studies evaluate how much these methodological variations affect overheating predictions, or whether the uncertainty introduced by weather-file choice is comparable in magnitude to regional climatic differences.
- Dwelling typology known to strongly influence heat retention and solar exposure is seldom integrated with regional climate or weather-file uncertainty. Detached, semi-detached and mid-terrace dwellings behave very differently thermally, yet most studies examine a single archetype or treat dwelling form as a secondary variable.
- Few studies have systematically examined the combined influence of region, building type and weather-file methodology across multiple future climate scenarios using a unified simulation framework. Existing studies typically vary one factor at a time without analysing how these factors interact.

Together, these gaps create a fragmented evidence base in which overheating risk is difficult to compare across studies and highly sensitive to modelling choices.

3. METHODOLOGY

The reference geometry was derived from a Victorian dwelling located in Watford. The dwelling's original geographical location was not used as a climatic input; instead, the same geometry was exposed to weather files for each selected region. This common geometry was adopted as a controlled analytical baseline rather than as a statistically representative model of the UK housing stock. As discussed, fabric characteristics were inferred using established literature-based archetypes typical of the relevant construction periods. To investigate the influence of dwelling form, three building types were analysed: mid-terrace, semi-detached and end-terraced. The internal layout, floor area and glazing distribution were held constant across all cases to minimise the introduction of additional unknown variables that could complicate results. Dwelling form was differentiated solely by the degree of external exposure. The mid-terrace configuration retained party walls on both sides, the semi-detached configuration included one exposed side wall while the end terrace assumed a similar configuration with no neighbouring building nearby. While it is acknowledged that conventional semi-detached dwellings may exhibit different layouts, configurations or glazing ratios, this controlled approach enables isolation of the effect of exposed surface area on overheating behaviour.

When modelling the mid-terrace, semi-detached and end-terrace dwellings, the presence of exposed external walls and shared party walls was recognised as a potential influence on thermal comfort and the resulting performance metrics. To represent this inter-dwelling heat transfer, adjacent buildings were modelled as single zones with internal loads comparable to the primary dwelling. These neighbouring zones were assigned identical heating schedules and setpoints to the main building, reflecting a typical residential context. To assess the sensitivity of the results on assumptions about neighbouring dwellings, additional scenarios were tested in which adjacent buildings operated with altered heating setpoints: one household at 17 °C during winter and 21 °C during summer, and another running at 19 °C during winter and 23 °C during summer. Across these extreme scenarios, the annual mean internal temperature of the primary dwelling varied by only 0.07 °C. During the summer period, the influence of neighbouring dwellings was further reduced. Under those conditions, the difference in mean internal temperature between the sensitivity scenarios decreased to 0.01 °C. While a maximum temperature difference of up to 0.35 °C was observed at peak conditions. These results indicate that the tested adjacent-zone temperature assumptions had a limited influence on the comparative outcomes. However, the test addresses only this specific boundary condition and should not be interpreted as a comprehensive assessment of occupant or model uncertainty.

The analysis considered multiple construction periods representative of the UK housing stock: dwellings built prior to the 1930s, 1945-1964, 1965-1980 and post 1980-present day. Construction assemblies corresponding to each period were informed by published literature and standard archetype studies, reflecting typical changes in materials, insulation levels and thermal properties over time. A summary of the construction assemblies and associated thermal parameters for each period is provided in Table 1. The dwelling maintained an overall glazing ratio of approximately 25% (24% of glazing located on the south façade and 27% on the north façade). Living spaces and bedrooms were oriented southwards, with glazing restricted to the north and south elevations. These values were maintained across all dwelling forms to ensure consistent solar exposure assumptions, with no adjacent buildings assumed to obstruct solar gains or shade the glazing.

Table 1. Constructions and assumptions.

Building Components	**Materials**	**U-Value (W/m^{2}K)**
Building Time Period: Pre 1919s		
Ground floor	Ground 1. Under floor cavity 2. 100 mm joists ventilated 3. 20 mm timber floor 4. 10 mm carpet	1.19
Wall	1. 300 mm brick 2. 13 mm plaster	1.80
Roof	1. 19 mm clay tiles (ventilated) 2. 25 mm ventilated roof space battens 3. 100 mm ceiling joists 4. 12 mm plasterboard	2.45
Glazing	6 mm clear glass Cavity 6 mm clear glass	3.17 (including frame)
Airtightness	8.7 m^3/h.m^2 @ 50 Pa	-
Building Time Period 1945-1964		
Ground floor	1. 150 mm hard-core layer 2. 150 mm cast concrete 3. 75 mm screed 4. 10 mm carpet	1.49
Wall	1. 105 mm brick 2. 50 mm airspace 3. 105 mm brick 4. 13 mm plaster	1.59
Roof	1. 19 mm Clay tiles (ventilated) 2. 25 mm ventilated roof battens 3. Windtight barrier above rafters 4. 50mm mineral wool between 100 mm ceiling joists 5. 12mm plasterboard	0.68
Airtightness	8.1 m^3/h.m^2 @ 50 Pa	-
Building Time Period: 1965-1979		
Ground floor	1. 150 mm Hard-core layer	0.80

Building Components	**Materials**	**U-Value (W/m^{2}K)**
	2. 150 mm cast concrete	
	3. 20 mm EPS	
	4. 75 mm screed	
	5. 10 mm carpet	
Wall	1. 105 mm brick	0.97
	2. 50 mm airspace	
	3. 100 mm lightweight concrete block	
	4. 13 mm plaster	
Roof	1. 19 mm Clay tiles (ventilated)	0.36
	2. 25 mm ventilated roof battens	
	3. Windtight barrier above rafters	
	4. 100 mm mineral wool between 100 mm ceiling joists	
	5. 12 mm plasterboard	
Airtightness	7.9 m^3/h.m^2 @ 50 Pa	-
Building Time Period: 1980-1990		
Ground floor	1. 150 mm Hard-core layer	0.47
	2. 150 mm cast concrete	
	3. 50 mm EPS	
	4. 75 mm screed	
	5. 10 mm carpet	
Wall	1. 105 mm brick	0.29
	2. 100 mm mineral wool cavity insulation	
	3. 100 mm lightweight concrete block	
	4. 13 mm plaster	
Roof	1. 19 mm Clay tiles (ventilated)	0.19
	2. 50 mm ventilated roof battens	
	3. Windtight barrier above rafters	
	4. 100 mm mineral wool above ceiling joists	
	5. 100 mm mineral wool between 100 mm ceiling joists	
	6. 12 mm plasterboard	
Airtightness	8.6 m^3/h.m^2 @ 50 Pa	-

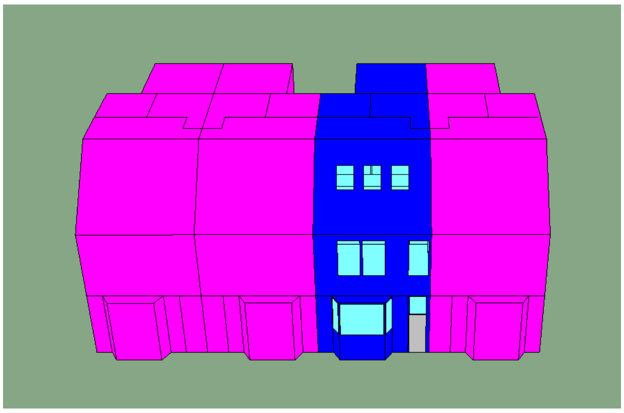

Figure 1. Typical dwelling (highlighted in blue) in a terraced configuration.

The generic dwelling was modelled using Integrated Environmental Solutions Virtual Environment, as shown in Figure 1, a widely used building energy simulation platform. IESVE incorporates the ApacheSim dynamic thermal simulation engine and is accredited by the U.S. Department of Energy for compliance with ASHRAE Standard 140 (Petrou et al. 2017; Qays et al. 2019), with its reliability demonstrated in multiple peer-reviewed studies (Ben and Steemers 2014; Pollock et al. 2009). The models were not calibrated to a specific building, as the results are intended to be indicative and scalable across the different dwelling forms, weather files, and building fabric characteristics considered, rather than to provide highly detailed or site-specific predictions.

3.1. ASSUMPTIONS

CIBSE Technical Memorandum 59 (TM59) provides a standardised methodology for assessing overheating risk in residential buildings using building energy simulation tools (CIBSE 2017). In this study, TM59 profiles (summarised in Table 2) were implemented within a detailed simulation framework to capture the key drivers of overheating. The framework accounted for variations in occupancy patterns and behavioural use to enable realistic assessments of both daytime and nighttime thermal performance. Two occupants were assigned to each double bedroom, while three occupants were assumed for the combined living room and kitchen areas, in accordance with the occupancy schedules and internal gain profiles in Table 2. Appliance and equipment loads were defined using room-specific profiles aligned with TM59 activity assumptions. Window operation was represented using a deterministic binary control that was applied consistently to all simulations. Windows were enabled to open when indoor temperature exceeded 24 °C and were closed when outdoor temperature exceeded 26°C or during the defined winter period. This standardised control was selected to prevent differences in assumed occupant behaviour from confounding comparisons between regions, construction periods and exposure configurations. Space heating was provided by a gas boiler with a setpoint temperature of 18°C, a seasonal efficiency of 0.92 and a corresponding seasonal coefficient of performance of 0.882 kW/kW.

Table 2. Schedules, gains (adapted from (CIBSE 2017)) and Assumptions.

Space	Sensible	Latent	00-08	08-09	09-18	18-20	20-22	22-23	23-24
Double bedroom occupancy	150	110	0.7	1	0.5	0.5	0.5	1	0.7
Double bedroom equipment	80	-	0.13	1	1	1	1	1	0.13
Three bed: living- kitchen occupancy	225	165	0	0	1	1	1	0	0
Living- kitchen equipment	450	-	0.19	0.19	0.24	1	0.44	0.24	0.24
Lighting	2 (W/m^2)		0	0	0	1	1	1	0

3.2. THERMAL COMFORT AND OVERHEATING CRITERIA

Overheating assessments are traditionally based on the number of hours during which indoor temperatures exceed defined comfort thresholds by a specified margin. In accordance with CIBSE Guide A, a space was regarded as 'overheating' when indoor temperatures exceeding 28 °C in living rooms and 26 °C in bedrooms during peak summer conditions (CIBSE 2017; Engineers 2006). Thermal comfort was evaluated using two compliance criteria. Criterion A applies to living rooms, kitchens and bedrooms, requiring that indoor temperatures exceed the relevant comfort threshold by no more than 1 °C for less than 3% of occupied hours between 1 May- 30 September. Criterion B applied to bedrooms only, limiting temperatures above 26 °C between 22:00 - 07:00 to no more than 1% of total annual hours (CIBSE 2017).

3.3. ANALYSIS FRAMEWORK

The analysis is based on a structured scenario matrix that combines regional climatic variation, dwelling form and age, weather-file methodology and future scenarios (as seen in Table 3). Three regions are considered within the UK: South, Midlands and North with Brighton (R1), Birmingham (R2) and Aberdeen (R3). For each region, three representative dwelling archetypes were modelled: a mid-terrace house (B1), a semi-detached house (B2) and end terraced house (B3). In addition, a further set of permutations was considered based on building age, comprising the pre-1919 (A1), 1945-1964 (A2), 1965-1980 (A3), and post-1980 construction periods (A4). Future climate projections were derived using two weather-file methodologies: CCWorldWeatherGen (W1) and PROMETHEUS (W2-W5), applied uniformly across all regions and dwelling typologies. The PROMETHEUS framework includes four projections: a medium emissions 50th percentile scenario (W2), a medium emissions 90th percentile scenario (W3), a high emissions 50th percentile scenario (W4), and a high emissions 90th percentile scenario (W5). Climate change is represented using three time periods: the baseline current-period (T1), and future time slices for the 2050s (T2) and 2080s (T3). Each scenario is uniquely defined by the combination of region (R), building type (B), building age (A), weather method (W) and time slice (T). For example, scenario R1-B2-A2-W1 corresponds to a semi-detached 1945-

1964 dwelling in Brighton simulated with CCWorldWeatherGen weather files. In total, the full scenario matrix comprises 540 distinct simulations.

Table 3. Scenario matrix used in the simulations

Variable	Code	Description
Region (R)	R1, R2, R3	R1: Brighton (South) R2: Birmingham (Midlands) R3: Aberdeen (North)
Building type (B)	B1, B2, B3	B1: Mid-terrace B2: Semi-detached B3: End Terrace
Building age (A)	A1, A2, A3, A4	A1: Pre-1919 A2: 1945-1964 A3: 1965-1980 A4: Post-1980
Weather method (W)	W1, W2, W3, W4, W5	W1: CCWorldWeatherGen W2: Prometheus- Medium 50th Percentile W3: Prometheus- Medium 90th Percentile W4: Prometheus- High 50th Percentile W5: Prometheus- High 90th Percentile
Time slice (T)	T1, T2, T3	T1: Baseline T2: 2050 T3: 2080

4. ANALYSIS AND RESULTS

The model was not calibrated or validated against monitored time-series data from a corresponding dwelling. A limited external plausibility check was instead undertaken by comparing simulated seasonal mean indoor temperatures with ranges reported in large-scale UK monitoring studies. National summer monitoring studies of mid-terrace, end-terrace and semi-detached dwellings report mean indoor temperatures typically between 22.7 and 23.6°C from June to September, with evidence that more recent construction types exhibit a greater tendency to overheat than older stock (Pathan et al. 2017). Similarly, a large-scale study across England identified mean summer temperatures of approximately 21.7 °C during late July and August, rising to around 22.2 °C in southern regions (Beizaee et al. 2013). The simulated seasonal means fall broadly within the ranges reported. For instance, a mid-terraced dwelling constructed between 1965-1989 and modelled in Brighton produced a mean internal temperature of 22.17°C between June and September, consistent with values reported for southern England. However, agreement in seasonal mean temperature does not establish the model's ability to reproduce hourly peaks, diurnal profiles, nocturnal temperatures or threshold-exceedance durations. The comparison should therefore be interpreted as contextual benchmarking.

Across the modelled scenario matrix, climatic region and weather-file severity produced the largest variations in overheating frequency. Dwelling exposure and construction-period fabric modified these climate-driven outcomes, but their influence was generally smaller under median future-weather projections. Typological and age-related differences became more pronounced as climatic severity increased, indicating that building characteristics acted primarily as modifiers or amplifiers of external heat stress rather than as independent dominant drivers. The following sections therefore examine not only the direction of each pattern, but also its magnitude, consistency across scenarios and practical importance.

4.1. BUILDING TYPE

Figure 2 compares overheating in south and north-facing bedrooms across dwelling typologies (B1: mid-terraced, B2: semi-detached and B3: end-terraced). A consistent ordering was observed, with B3 generally recording the highest overheating, followed by B2 and B1. However, the magnitude of the difference varied considerably according to the weather scenario and future time slice. Under the medium scenario, the separation between dwelling configurations was relatively small and was frequently below one percentage point. However, this separation becomes more pronounced under elevated percentile scenarios and in the later time slices. By 2080, under the medium 90th percentile scenario, overheating increases progressively from mid-terraced to end-terraced dwellings, with B3 consistently recording the highest exceedance. This divergence widens further under the high 90th percentile scenario, where overheating approaches 30% in B3, exceeding corresponding B1 values by 3.2 percentage points. While the 2050 results exhibit the same ordering, absolute magnitudes are lower, indicating that both climatic progression and percentile severity amplify typological differences.

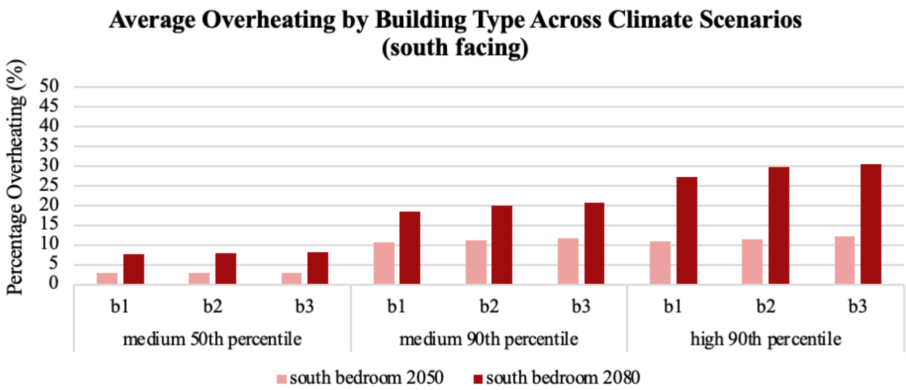

Figure 2. Average overheating values across building type across weather file scenarios (south bedroom). Where B1: Mid terrace, B2: Semi-detached and B3: End Terrace.

A similar hierarchy is evident in north-facing bedrooms, although the magnitude of differences is slightly reduced under the medium scenario. Under the medium 90th percentile projection in 2080, overheating increases substantially across all typologies, with end-terraced dwellings again exhibiting the highest values. This pattern intensifies under the high 90th percentile scenario, where overheating in B3 approaches 30%, clearly exceeding mid-terraced values. The persistence of this hierarchy in north-facing rooms, where direct solar gains are limited, indicates that typological differences are not solely attributable to orientation-driven solar exposure. Rather, the increased external envelope area associated with end-terraced dwellings likely contributes to greater sensitivity to elevated ambient temperatures and external heat transfer. Across both room orientations, a non-linear escalation in overheating is evident between scenarios.

4.2. BUILDING AGE

Across all regions and rooms, a consistent age-related trend emerged: overheating increased progressively from A1 (pre-1919) to A4 (1980-1990). In both 2050 and 2080 projections, newer dwellings (A3 and A4) recorded higher overheating percentages than older stock (A1 and A2). This pattern was most pronounced in south-facing bedrooms. As seen in Figure 3, in Brighton (R1) south bedroom overheating in 2080 increased from 13.9% (A1) to 15.5% (A4). Birmingham (R2) showed a similar progression, from 8.1% (A1) to 10.5% (A4). Even in Aberdeen (R3), where absolute overheating values remained below 1%, the relative increase with construction age persisted (0.4% in A1 rising to 0.9% in A4), however this is within margin of error. North-facing bedrooms and living rooms followed the same trajectory, though with smaller absolute magnitudes. The consistency of this progression across regions indicates that construction age exerts a systematic influence on overheating risk. The only notable deviation from the general age-related trend was observed in the north-facing bedroom and in some instances, the living room, where A1 recorded slightly higher overheating than A2 and A3. This can be attributed to the differing wall constructions. A1 comprises 300 mm solid brick walls, whereas A2 and A3 utilise cavity constructions with lighter internal blocks and improved insulation levels. The solid masonry in A1 provides greater thermal mass, resulting in higher heat storage capacity and a slower diurnal thermal response. In north-facing rooms, where direct solar gains are limited, internal gains and heat transfer from adjacent spaces become the dominant contributors to overheating. Given that bedrooms are assessed against a 26 °C threshold and are particularly sensitive to elevated nocturnal temperatures, this delayed heat release can increase cumulative exceedance hours. By contrast, the lighter cavity constructions in A2 and A3 are likely to cool more rapidly once external temperatures decline, thereby reducing night-time overheating duration.

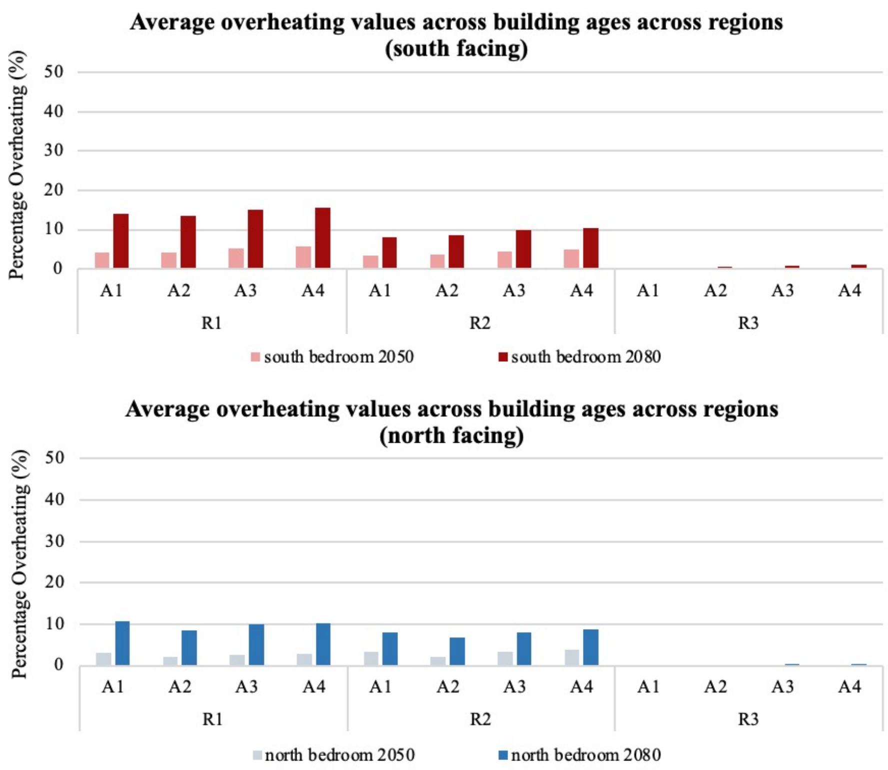

Figure 3. Average overheating values across building age across regions Where A1: Pre 1919, A2: 1945-1964, A3: 1965-1980 and A4: Post-1980.

The increasing overheating from A1-A4 corresponds directly with improvements in thermal fabric performance. Wall U-values reduce from 1.80 W/m²K (A1) to 0.29 W/m²K (A4) and roof U-values from 2.45 W/m²K to 0.19 W/m²K over the same period. While these improvements reduce winter heat losses, they also increase heat retention during summer. Airtightness values vary only marginally between age bands (7.9-8.7 m³/h·m² @50 Pa), suggesting that the dominant driver of age-related variation is insulation level rather than infiltration. The results therefore reinforce the established trade-off between winter efficiency and summer resilience in progressively better-insulated dwellings. Although the age-related trend was consistent, its magnitude varied by region. The increase from A1-A4 was greatest in Brighton, moderate in Birmingham and smallest in Aberdeen. This indicates that warmer climates amplify the overheating penalty associated with improved envelope performance. In cooler climates, while the relative pattern remains, the absolute impact is significantly dampened due to lower external temperature stress.

4.3. REGION

Although the three regions are situated within the same national context, the UK's geographical extent results in distinct climate profiles, with measurable variation in solar exposure, ambient temperature profiles, and diurnal ranges from north to south. Although the analysis of individual cities does not constitute a stock-level assessment of housing across the country, it provides valuable insight into how buildings perform under different regional climatic conditions and whether overheating represents a significant concern in each location. This study therefore evaluated multiple future weather files alongside variations in dwelling age bands and typologies to determine whether overheating constitutes a systemic regional issue on average, rather than being driven by a particular building type or construction period within the domestic stock. The objective was to isolate climatic influence while controlling for archetype-specific characteristics, thereby avoiding bias toward any single segment of the housing landscape. When comparing regions R1 and R2 against R3, a consistent upward trend in overheating frequency is observed across all weather files (as seen in Figure 4). The largest reductions are seen in R3, where reductions in overheating exceed 20% relative to R1. R2 overheating values remain broadly comparable to R1, with only minor deviations across the assessed building spaces. By 2080, the average reduction associated with R2 is approximately 4%.

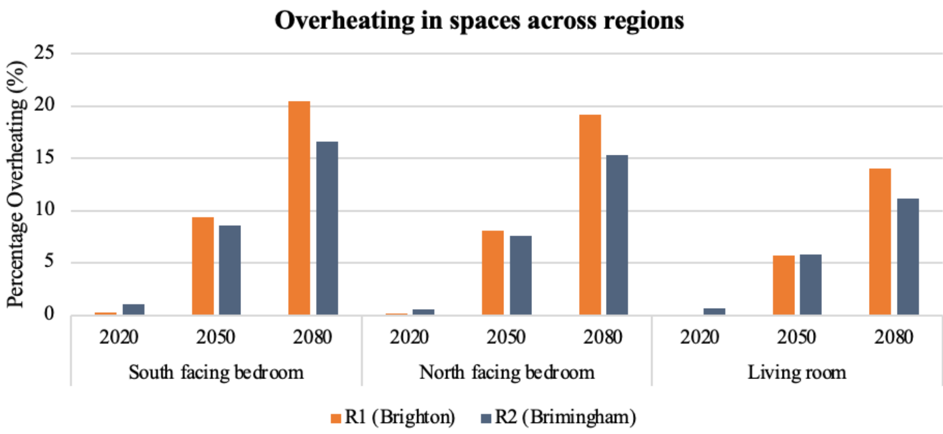

Figure 4. Average overheating values across building type and age when compared against R1 (Brighton).

Regional comparison across the three case study locations confirmed the expected climatic gradient, with overheating risk decreasing progressively towards the north. The southern location (Brighton) consistently exhibited the highest overheating frequencies, while Aberdeen recorded the lowest values across all dwelling typologies and age bands. More notably, under 50th percentile projections, including both medium and high emissions scenarios (W2 and W4) as well as the CCWorldWeatherGen datasets (W1), the northern location did not exceed CIBSE overheating criteria, even when projected into 2080, suggesting under median climate projections future overheating risk in northern regions remains limited. Overheating in the north emerged primarily under the 90th percentile weather files, which represent near-extreme or heatwave conditions. However, even under these more severe projections, exceedance above comfort thresholds was limited, with operative temperatures surpassing the comfort limit by approximately 0.6% under medium emissions and 4% under high emissions (as seen in Figure 5). This indicates that while extreme events introduce some risk, the magnitude of thermal discomfort in northern regions remains comparatively constrained relative to southern counterparts. The north-facing bedroom exhibited patterns consistent with south facing bedroom, though operating at lower overheating percentage points. Consequently, under median climate projections to 2080, north-facing bedrooms are unlikely to present significant overheating risk, with vulnerability emerging primarily under near-worst-case climate scenarios. As illustrated in Figure 5, overheating risk in the Brighton and Birmingham is substantial and warrants concern. Under the medium emissions 50th percentile projections, CIBSE overheating criteria are exceeded as early as 2050, with the magnitude of exceedance increasing progressively towards 2080. The 90th percentile weather files present a more severe outlook. Under the medium emissions pathway, overheating reaches up to 30%, while the high emissions scenario produces values approaching 45%.

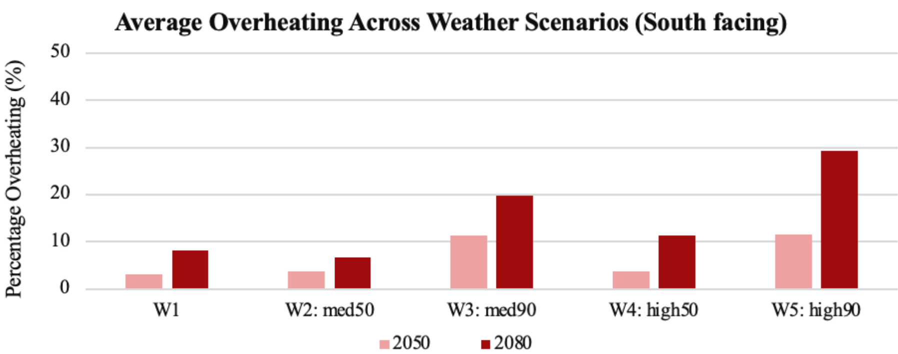

Figure 5. Average overheating for buildings (all typologies and ages) across regions and weather scenarios (south facing bedroom).

4.4. WEATHER FILE USED

Future weather files inherently carry substantial uncertainty due to their reliance on emissions scenarios, climate model projections and downscaling methodologies. The speculative nature of long-term climate forecasting introduces variability that must be acknowledged when interpreting simulation outputs. Consequently, comparative evaluation of different future weather generators is essential to assess robustness in overheating projections. The W5 high emissions scenario at the 90th percentile produced the most severe overheating outcomes across the dataset. By 2080, overheating approached 30% (as seen in Figure 6), representing a substantial exceedance of comfort thresholds. The medium emissions scenario at the 90th percentile also demonstrated markedly elevated risk, with overheating values reaching approximately 20%. Importantly, exceedance of recommended overheating limits was not confined to extreme percentile files. Across all weather datasets, including lower percentile projections, every dwelling typology and age band surpassed the acceptable thresholds defined under CIBSE guidance. Comparable patterns were also observed within the north-facing bedrooms and living rooms, the latter of which was assessed using the higher 28°C overheating criterion (as seen in Figure 7).

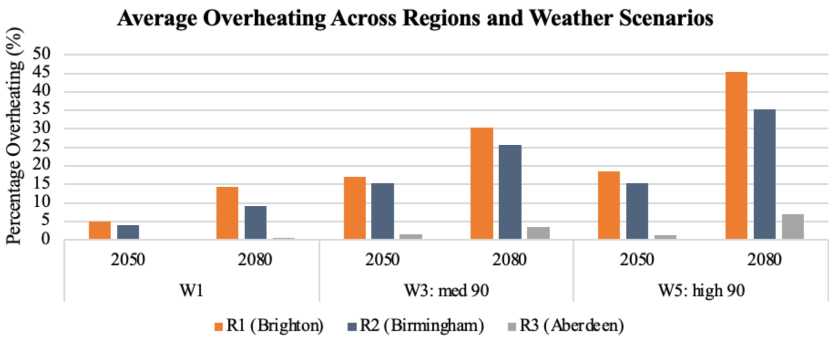

Figure 6. Average Overheating Across Weather Scenarios for All Building Types, Ages and Regions (South Facing).

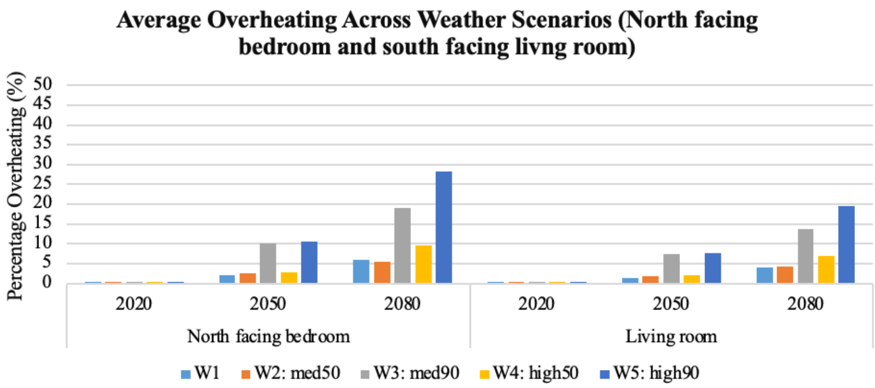

Figure 7. Average Overheating Across Weather Scenarios for All Building Types, Ages and Regions (North facing bedroom and living room).

Across the full matrix of model permutations, including dwelling age bands, typologies and UK regions, the CCWorldWeatherGen datasets demonstrated strong alignment with the Prometheus medium (50th percentile) scenarios. This similarity was particularly evident in overheating metrics derived from dynamic thermal simulation. When aggregating results across all spaces, regions and configurations, the mean difference in overheating frequency between the two datasets ranged ±0.5 percentage point, indicating negligible divergence due to it being within margin of error. Regional analysis revealed that discrepancies were smallest in northern locations. However, this convergence should be interpreted in context, as absolute overheating frequencies in northern regions were substantially lower than those observed in southern climates. The high-emissions (50th percentile) scenario produces similar overall overheating trends but consistently yields higher overheating than CCWorldWeatherGen. On average, overheating is approximately 3.1% greater under the high-emissions dataset. This divergence is primarily driven by results in the Midlands, where the discrepancy becomes more pronounced. In south-facing rooms, overheating frequencies are nearly 7% higher compared to those generated using CCWorldWeatherGen. North-facing rooms also exhibit elevated overheating under the high-emissions scenario, with increases of approximately 6.5% in the Birmingham and 4.1% in Brighton. The 90th percentile weather files, which are interpreted as near-extreme or heatwave conditions within both medium and high emissions pathways, produced substantially elevated overheating across all building typologies and regions. These datasets amplify peak dry-bulb temperatures, reduce nocturnal cooling potential and increase the persistence of consecutive hot days, thereby compounding internal heat accumulation in highly insulated dwellings. Under the medium emissions pathway, overheating exceeded those derived from CCWorldWeatherGen by more than 17% by 2080. The divergence was even more pronounced under the high emissions scenario, where overheating increased by up to 31%. Although 90th percentile files are not typically used to represent "expected" annual performance and therefore may overstate overheating risk in probabilistic terms, they serve an important analytical function. Specifically, they provide insight into system resilience under extreme climatic stress and enable evaluation of passive survivability limits. From a risk-based design perspective, these scenarios are valuable for stress-testing retrofit strategies and identifying thresholds beyond which mechanical cooling becomes unavoidable.

5. DISCUSSION

The results indicate a hierarchy in the factors affecting overheating within the modelled scenario space. Climatic region and weather-file severity produced the largest changes in overheating frequency. Construction-period fabric and external exposure modified these climate-driven outcomes, but their influence was generally smaller under median weather projections. Exposure-related differences became more pronounced under high-percentile conditions, indicating that dwelling form operates primarily as an amplifier of external heat stress rather than as an independent dominant driver. Across all regions and weather scenarios, a clear and consistent typological hierarchy was observed, with end-terraced dwellings (B3) exhibiting the highest overheating, followed by semi-detached (B2) and mid-terraced dwellings (B1) consistently demonstrating the lowest values. This ordering aligns directly with differences in exposed external envelope area. Under moderate climate projections (medium scenario), the typological effect is present but relatively small. However, under 90th percentile scenarios (particularly the high emissions pathway) the divergence between typologies increases substantially. This indicates that typological vulnerability is climate amplified. As external heat stress intensifies, exposed forms disproportionately accumulate and retain heat, resulting in higher exceedance hours.

The comparison does not establish that one future-weather method is universally superior. CCWorldWeatherGen preserves the temporal structure of a historical baseline while applying projected climatic changes, making it useful for assessing the implications of central warming trends under a familiar weather sequence. PROMETHEUS instead generates probabilistic weather years that represent a distribution of possible future conditions. Its 50th-percentile files are more comparable with central projections, whereas the 90th-percentile files are intended to represent relatively severe conditions within the projected distribution. These high-percentile files should therefore be interpreted as resilience stress tests rather than as predictions of typical annual performance. Their greater overheating estimates do not by themselves demonstrate greater predictive accuracy; instead, they reveal vulnerabilities that are not apparent when only central or morphing-based projections are considered.

Another key finding is the non-linear increase in overheating under medium 90th and high 90th percentile scenarios. For example, in Brighton (R1), south-facing bedrooms in 2080 recorded overheating levels of 14.0-14.9% under the medium scenario, increasing to 28.5-31.6% under the medium 90th percentile scenario and rising further to 42.1-47.4% under the high 90th percentile scenario. The escalation between percentile files is not incremental but nonlinear in behaviour. This reflects the threshold-based nature of overheating metrics. The large increase between the 50th- and 90th-percentile weather files reflects both greater climatic severity and the threshold-based form of the overheating metric. When indoor temperatures remain comfortably below 26°C or 28°C, a modest increase in outdoor temperature may have little effect on the calculated exceedance frequency. Once indoor conditions approach those limits, however, a similarly sized temperature increase can shift many additional occupied hours above the threshold. The resulting increase in overheating percentage is therefore non-linear. This helps explain why relatively modest typological differences under the median files became much larger under the high-percentile conditions. The extreme weather files moved the dwellings closer to, or beyond, the point at which small differences in heat gain and heat retention produced disproportionately large changes in exceedance hours.

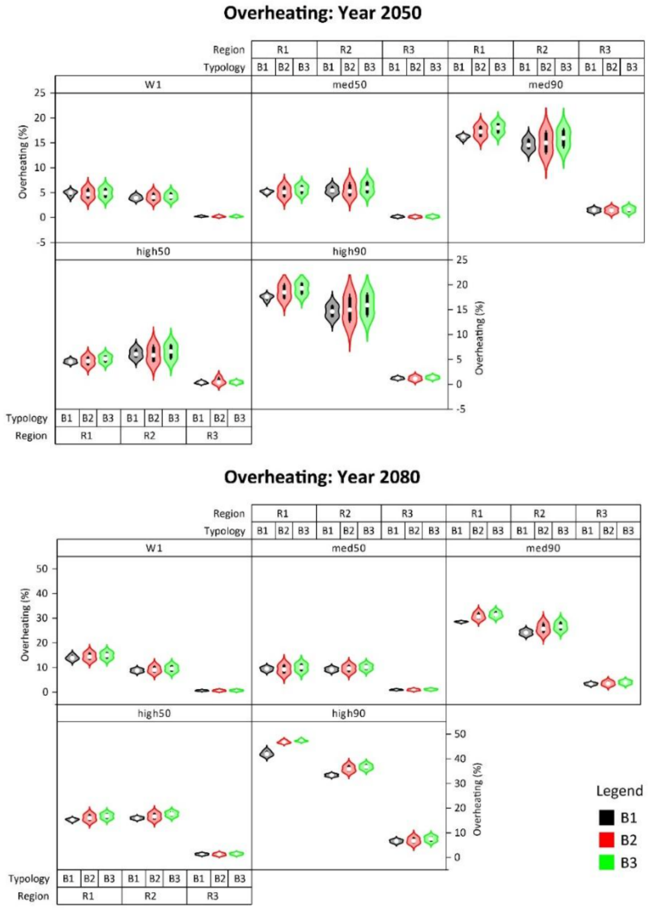

Figure 8. Typology Sensitivity to overheating for the South Bedroom (2050 and 2080) across regions and emission scenarios.

The regional results indicate that the timing and urgency of adaptation are unlikely to be uniform across the selected locations. In Brighton and Birmingham, overheating emerged under median future projections, suggesting that adaptation may be required under expected as well as extreme conditions. In Aberdeen, substantial overheating was largely confined to the high-percentile files, indicating a lower central risk but continuing vulnerability during severe events- 8% for north bedrooms and below 4% for living rooms. The typological ordering persists, but the magnitude remains small. This suggests that typological optimisation becomes more critical in warmer southern climates, whereas in cooler regions, climatic buffering reduces the significance of form-driven overheating risk. The typological effect is most pronounced in south-facing bedrooms, where solar gains are dominant. North-facing bedrooms also exhibit typological differentiation, though slightly reduced in magnitude. Living rooms consistently show lower overheating percentages, due to the laxer 28°C criterion. Importantly, under extreme scenarios, north bedrooms in exposed typologies (B3) approach or exceed 40% overheating in Brighton, demonstrating that envelope exposure interacts with prolonged elevated night-time temperatures. The results also indicate potential interaction effects between construction age and dwelling typology. More highly insulated envelopes (A3/A4), when combined with increased external exposure as seen in end-terraced forms (B3), may compound overheating risk. This highlights an inherent tension within retrofit and regulatory approaches: while enhanced insulation effectively reduces winter heat loss, greater exposed surface area increases susceptibility to summer heat gains. In combination, these factors may unintentionally amplify overheating unless offset by appropriate shading, ventilation or other passive cooling strategies.

The results suggest that climate severity should be considered before differences between dwelling forms or construction periods are used to prioritise adaptation. In the selected southern and midland locations, exposed forms and later-period fabric packages may warrant particular attention because their relative disadvantage increased under severe conditions. In the northern case, the lower median risk should not be interpreted as an absence of vulnerability, as high-percentile events still produced overheating. Because shading and alternative ventilation strategies were not simulated, the study cannot determine which intervention would be most effective. The results instead identify the conditions and dwelling configurations in which mitigation assessment is most necessary. External shading, secure night ventilation and other passive measures should therefore be investigated in subsequent work rather than presented as demonstrated solutions.

Several limitations should be acknowledged and addressed in future research. The findings should be interpreted in relation to the controlled comparative purpose of the study. All cases were derived from a common reference geometry. This enables isolation of external exposure, selected fabric characteristics and climatic inputs, but does not represent the diversity of UK dwelling layouts, orientations, glazing ratios, thermal mass, occupancy patterns or retrofit histories. The regional results therefore describe how the reference geometry responds to different climatic conditions rather than the prevalence of overheating within each regional housing stock. Second, the simulation model was not calibrated against monitored data. A summer monitoring campaign measuring internal temperatures, environmental conditions, and occupant behaviour would provide an empirical basis for model calibration and help corroborate the predicted overheating outcomes. Finally, the analysis was based on a limited number of building archetypes. The UK housing stock varies substantially in terms of glazing ratios, orientation, construction characteristics, geometry, and occupancy patterns. Future research should therefore assess a broader and more representative sample of dwellings and analyse aggregated or mean performance across the sample. This would improve the robustness and generalisability of the findings. Third, the model employed a simplified binary window-opening logic to maintain methodological clarity and avoid introducing excessive behavioural complexity. However, occupant window operation is rarely linear or uniform. Windows may remain closed during warm periods because of external noise, insects, security concerns, air pollution, or personal preferences. Future studies should therefore incorporate more realistic, probabilistic, or occupant-responsive ventilation models.

6. CONCLUSION

This study evaluated overheating risk across representative UK residential archetypes by systematically examining the influence of building typology, construction age, regional climate, and alternative future weather file methodologies. The findings confirm that overheating risk is governed by an interaction between climatic severity and built form characteristics. Building typology exerts a consistent and measurable influence, with end-terraced dwellings exhibiting the highest overheating frequencies, followed by semi-detached and mid-terraced forms. This hierarchy reflects differences in exposed envelope area and associated solar and conductive heat gains, with shared party walls providing inherent thermal buffering in mid-terraced dwellings. While typological differences are modest under median climate projections, they widen substantially under 90th percentile scenarios, indicating that exposure-driven vulnerability is amplified under extreme climatic stress. Construction age also demonstrates a systematic effect. Newer dwellings (characterised by lower U-values and improved thermal performance) consistently recorded higher overheating than older stock. This reinforces the established trade-off between winter efficiency and summer resilience: enhanced insulation reduces heat loss during colder periods but increases heat retention during warm conditions. The magnitude of this effect varies regionally, with southern climates amplifying overheating penalties associated with improved envelope performance, while cooler northern climates moderate absolute impacts. Regional comparisons confirm a pronounced climatic gradient. Brighton consistently exhibits the highest overheating risk, Birmingham shows moderate but increasing exceedance, and Aberdeen remains comparatively resilient under median projections. However, even in northern regions, near-extreme (90th percentile) scenarios introduce measurable overheating risk, highlighting the importance of evaluating both median and stress-test conditions. In southern England, exceedance of CIBSE thresholds emerges as early as 2050 under median emissions pathways and intensifies markedly by 2080, with extreme scenarios producing overheating frequencies exceeding 40% in certain configurations.

Weather file methodology further influences projected magnitude. Although CCWorldWeatherGen and PROMETHEUS medium (50th percentile) projections show strong agreement overall, the two approaches differ fundamentally in their treatment of future climate. CCWorldWeatherGen applies a morphing-based method, modifying historical weather records according to projected climatic shifts while preserving historical variability. In contrast, PROMETHEUS assumes that future weather will be statistically distinct, particularly in the frequency, intensity, and persistence of extreme events. This distinction is critical for overheating assessment, as overheating is driven primarily by short-duration extreme heat events rather than long-term mean conditions. Morphing-based approaches may therefore suppress extremes, whereas stochastic weather generators are more likely to predict higher peak indoor temperatures and prolonged overheating episodes. The 90th percentile weather files illustrate this divergence clearly, producing substantial non-linear increases in overheating across typologies and regions. While such projections may not represent typical annual performance, they are essential for evaluating resilience, passive survivability, and the limits of envelope-based mitigation strategies. Overall, the results demonstrate that future overheating risk in UK housing is climate-amplified and exposure-sensitive. Highly insulated dwellings and externally exposed typologies, particularly in southern regions, are projected to experience the most significant escalation in overheating under future climates. Without integrated passive design measures, including shading, adaptive ventilation and careful envelope optimisation, compliance with comfort criteria will become increasingly difficult. These findings have direct implications for retrofit policy, regulatory frameworks such as Part O, and long-term climate resilience planning within the UK residential sector.

AUTHOR CONTRIBUTIONS

Benjamin Abraham Cherian: Conceptualisation: Developed the overarching themes and objectives of the review. Methodology: Designed the review framework and criteria for literature selection. Writing – Original Draft: Wrote the initial manuscript draft, including key sections. **Serik Tokbolat**: Writing – Review & Editing: Contributed to the revision of the manuscript, focusing on clarity and coherence. Supervision – Supervised the study. **Lucelia Rodrigues**: Writing – Review & Editing: Assisted in editing and refining the final manuscript, ensuring accuracy and completeness. Supervision – Supervised the study. All authors have read and approved the final version of the manuscript.

COMPETING INTERESTS

There are no competing interests.

DATA ACCESSIBILITY

The simulation models, input schedules, construction assumptions and processed output data supporting the findings are available from the corresponding author upon reasonable request.

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