Adaptive thermal comfort and healthy home metrics among minority households in the United Kingdom

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Abstract. Ethnic minority households in the UK face compounded challenges in maintaining thermally comfortable and healthy indoor environmental conditions. Policy efforts tend to prioritise cost reduction and decarbonisation over indoor health, often assuming that achieving thermal comfort automatically ensures healthy living conditions. This assumption is questionable, especially for vulnerable and minority households who frequently live in cold, damp, and energy-inefficient homes that are Complex-to-decarbonise (CTD). This study explores the current gap between thermal comfort and health metrics based on longitudinal field measurements within one minority group in the UK, to assess whether thermal comfort metrics reflect healthy indoor conditions. Quantitative high-resolution data were collected from eleven minority households using Internet of Things (IoT) sensors recording temperature and relative humidity (RH) in the living areas over a one-year period. When looking at overheated and underheated conditions during annual occupied hours (7:00 am to 10:00 pm), all 11 cases had periods of cold stress, with temperatures below 18°C for up to 72% of annual occupied hours. Periods of overheating were observed in 8 cases, with temperatures over 26°C for up to 11% of the annual occupied hours. A dry living area was observed in one case, for up to 5% of the annual occupied hours. Excessively humid living areas with RH above 60% were identified in all cases, for up to 91% of annual occupied hours. This study applied a practical taxonomy to identify thermal and health stresses that may disproportionately affect minority households. The findings from this study demonstrate that relying on thermal comfort metrics may obscure unhealthy indoor conditions. Therefore, a combined approach linking thermal comfort and health is essential and will be beneficial for architects, academics, practitioners, and policymakers who are concerned with thermal health, inclusive and equitable approaches for home decarbonisation.

Keywords. Adaptive Thermal Comfort (ATC), Healthy Homes, Indoor Environmental Quality (IEQ), Ethnic Minority, Complex-To-Decarbonise (CTD).

1 Introduction

People spend 95% of their time indoors and 66% of their time in their own homes [1]. Therefore, ensuring adequate indoor environmental quality (IEQ) that supports both comfort and health is essential. However, energy performance, cost reduction and decarbonisation are central goals when designing new homes or retrofitting old ones [2,3,4], unlike health, which frequently occupies a secondary indirect position for the management and mitigation of associated health risks.

In the UK, homes are assigned an Energy Performance Certificate (EPC) rating reflecting how efficient the dwelling is. Around 52% of all UK households are living in homes with EPC D or below, these categories generally considered energy inefficient [5]. The average cost to improve those homes to a higher band C is £92.5 billion [5]. In addition, 3.5 million UK households (14%) live in poor quality homes that fail to meet the Decent Homes Standard, 2.1 million households (9%) live in a home with at least one Category I hazard [6], and 1 million households (4%) live in a home with damp [6,7]. The cost to improve non-decent to decent homes is estimated at £32 billion [6].

Households living in energy inefficient and poor-quality homes are at increased health risk of both physical and mental problems [6] and are putting additional burdens on health services. Treating people who are affected by poor housing costs the National Health Service (NHS) £1.4 billion per year, or £18.5 billion if societal costs are included [7].

In the UK, there were 13,400 excess winter deaths in 2021-22 [8], with 21.5% attributable to only cold homes [9]. Though yearly mortality associated with cold homes is substantial, there were also 1,311 deaths linked to the four extreme heat episodes experienced in 2023 [10].

The negative health impacts of poor-quality housing are particularly significant for minority groups [11].

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Balancing thermal comfort and healthy living is increasingly complex for such groups, who are one of the hard-to-reach groups (HtR) and their homes are often categorised as complex-to-decarbonise (CTD) [12,13]. Minority groups tend to live in dwellings with lower thermal quality, damp and cold conditions, which in turn can adversely affect health and increase energy costs [8].

Minority households who are mostly tenants living in rental accommodation [14] may face several structural barriers that amplify the problem of poor-quality homes. They usually face restricted agency in their practices and limited access to support programs to enhance the IEQ of their homes [13], such as their inability to enhance home materiality and the restricted use of spaces and appliances. Also, they may be reluctant to report damp and mould as this could jeopardise their housing security. These compounded uncertainties may contribute to mental stress, poor health outcomes and increased illness [8,15].

Health should be the priority criterion to be achieved to meet the fundamental meaning of home as a shelter that ensures healthy indoor conditions and promotes wellbeing for all at all ages [16]. Although housing is a social determinant of health [15,16], a persistent tension remains between standardised metrics and quality of life. In practice, cost and carbon reduction targets tend to dominate the design and renovation of housing. This emphasis shifts the core purpose of housing away from health to what can be measured and certified, such as thermal comfort.

This raises foundational questions about homes that are fit for purpose [17]: are homes being designed and retrofitted primarily to meet performance standards and achieve thermal comfort, or should their primary purpose shift towards protecting and promoting occupants' health?

This tension is also evident in the way indoor environmental quality (IEQ) is defined and assessed. IEQ focuses on four key environmental material factors (indoor air quality, thermal comfort, lighting and acoustic quality) and their effect on human health. IEQ lacks clear guidance and requirements to deliver a healthy home [18]. Moreover, IEQ neglects the agency of occupants' behaviour and how they interact with building design, systems, and materiality [19].

Over the past decade, growing research on IEQ has examined thermal comfort and health [18]. Nevertheless, further research is required to understand IEQ in domestic settings, particularly among minority households, who remain under-represented in existing studies despite facing greater risks of poor IEQ, reduced thermal comfort, and health implications.

Thermal comfort is used as a proxy for health [20], but it may not necessarily reflect healthy indoor conditions. Research and policy tend to frame healthy homes narrowly as warm homes, mould and cold problems are often overshadowed by a strong focus on achieving warmth [21]. This emphasis risks masking housing-related health hazards that arise even when recommended thermal comfort thresholds are acceptable.

Given the persistent and interrelated challenges associated with both health and thermal comfort in dwellings occupied by minority households. This paper focuses on thermal comfort as a key component of IEQ and its relationship with health.

1.1 Thermal Comfort Models

Thermal comfort can be assessed using mostly two models: the Predicted Mean Vote (PMV) and the Adaptive Thermal Comfort (ATC) Model [22]. The PMV model is based on the heat balance between the human body and the surrounding environment in a mechanically controlled environment [23]. In contrast, UK homes rely on mixed mode ventilation or typically operate as free-running buildings, relying on natural ventilation and having no mechanical means for regulating the environment. Instead, there are a variety of opportunities that are presented to the building's occupants to adapt their local environment or their personal circumstances. Under these adaptive and free-running conditions, the assumption of thermal equilibrium underpinning PMV does not hold. Accordingly, the ATC model is more suitable for UK homes.

1.1.1 Adaptive thermal Comfort (ATC) model

The ATC perception is based on the relation between indoor and outdoor temperatures. This model relates indoor comfort temperature ($T_{comfort}$) to the running mean outdoor temperature (T_{rm}), which is based on the outdoor temperature of the previous 7 days (T_{od-n}) [22]. Both can be calculated using Equations 1 and 2, where α is a constant <1, typically α=0.8:

$$T_{comfort} = 0.33T_{rm} + 18.8 \quad (1)$$

$$T_{rm} = (1-\alpha)\{T_{od-1} + \alpha T_{od-2} + \alpha^2 T_{od-3} + \alpha^3 T_{od-4} + \alpha^4 T_{od-5} + \alpha^5 T_{od-6} + \alpha^6 T_{od-7}\} \quad (2)$$

The tolerable minimum (T_{lower}) and maximum (T_{upper}) temperatures defining the normally acceptable band around the neutral comfort temperature for category II buildings in free-running mode [24] can be calculated as:

$$T_{lower} = T_{comfort} - 4 \quad (3)$$

$$T_{upper} = T_{comfort} + 3 \quad (4)$$

The ATC percentage can be calculated as the percentage of hours within the adaptive comfort band, defined as the temperature range between (T_{lower} and T_{upper}). Indoor temperature should not fall outside this acceptable band for more than 3% of occupied hours at any given running mean value of outdoor temperature [25], as exceeding these thresholds may indicate underheating or overheating stress:

$$\text{Adaptive Comfort } \% = 100 \times (\text{number of comfortable hours} \div \text{total hours or occupied hours}) \quad (5)$$

1.2 Underheating and Overheating Thermal Stress

The UK Chartered Institution of Building Services Engineers (CIBSE) [26] provides an explicit methodology to assess overheating risk. This approach has three criteria that quantify how frequently a dwelling is likely to exceed its comfort range during summer or non-heating season. If two criteria are failed, then overheating stress is proven.

Criterion I assesses the number of hours of exceedance (H_e) that should not exceed 3% of occupied hours, H_e is defined as the proportion of occupied hours during which the temperature difference (ΔT) between indoor operative temperature (T_{op}) and T_{upper} is greater than or equal to 1.

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

Criterion II evaluates the daily weighted exceedance (W_e), which accounts for both the duration and severity of overheating. W_e shall be less than or equal to 6 on any single day. The weighting factor (w_f) is determined by the magnitude of ΔT, and the total of hourly exceedance within each temperature band (h_{ey}), representing the number of hours for which ΔT falls within each temperature band (y):

$$W_e = (\sum h_e) \times w_f = (h_{e0} \times 0) + (h_{e1} \times 1) + (h_{e2} \times 2) + (h_{e3} \times 3) \tag{7}$$

Criterion III sets an absolute maximum temperature where ΔT shall not exceed 4, beyond which overheating is considered unacceptable regardless of duration.

Although recognised guidelines exist for identifying and quantifying overheating risk, there are no equivalent explicit or detailed criteria within international standards for assessing underheating risk. Consequently, the risk of underheating can be evaluated using the lower adaptive temperature limit (T_{lower}) [24] or by applying minimum temperature thresholds derived from building regulations, research evidence, or health-based guidance.

1.3 Health Metrics

Indoor environmental conditions such as temperature and relative humidity (RH) have direct and indirect impacts on public health [15]. Determining the lower and upper indoor temperature for a healthy home is still under study and needs more epidemiological evidence [15]. However, the World Health Organisation (WHO) recommends keeping indoor temperatures of at least 18°C to minimise health risks associated with cold exposure. Cold indoor environments cause respiratory and cardiovascular illness, and poor mental health outcomes.

There is also strong evidence that high indoor temperatures correlate with negative health effects on the respiratory system, diabetes management and core schizophrenia and dementia symptoms [1]. A global systematic review of international literature has identified worsening of respiratory, dementia and schizophrenia symptoms when indoor temperatures exceed 26°C [27,1].

Relative humidity further modifies thermal stress and physiological response. When RH is 40% or higher, the ability of the human body to cool itself through sweating decreases gradually. If the temperature goes above 26°C, the body retains heat, and core temperature can start to rise [19]. Therefore, indoor temperature below approximately 26°C is recommended when RH exceeds 40% for heat stress reduction and physiological safety [28].

Maintaining indoor RH between 40–60% is widely recognised as the optimal range for both health and comfort [29]. When RH falls below 40%, occupants may experience dry skin, irritated eyes, and respiratory discomfort, and airborne viruses can survive longer in drier air. Conversely, RH above 60% encourages condensation and mould growth, contributing to poor indoor air quality and respiratory illnesses such as asthma.

Thus, temperature and RH work together to shape both occupant and building health. When both are kept within appropriate ranges, they limit microbial and viral risks, protect materials, and sustain comfort without unnecessary energy use for heating or dehumidification. Their combined management is therefore fundamental to creating healthy, resilient and energy-efficient homes.

Figure 1 illustrates indoor temperatures between 18°C and 26°C in conjunction with RH between 40 and 60% that form practical and safe thresholds for assessing the thermal IEQ for healthy homes. These thresholds provide a framework that this study interprets as periods of thermal stress and associated health risks among minority households in the UK.

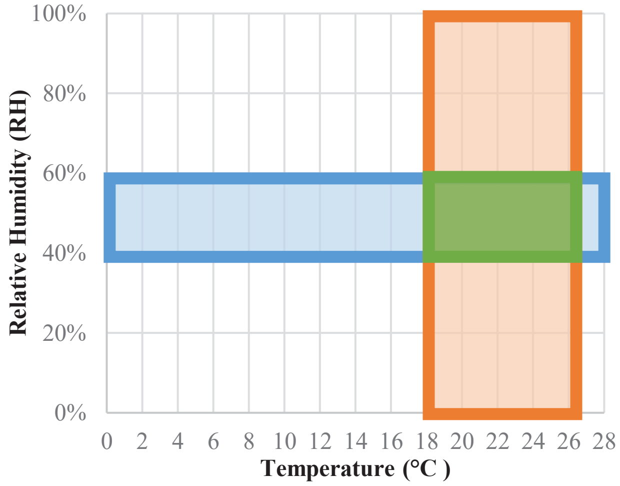

Fig. 1. Practical and safe thresholds in the indoor environment for thermal comfort and health

Therefore, this paper will investigate periods of health risks and thermal discomfort based on data collected for a year. The key question of this paper is whether the ATC model reflects healthy indoor environmental conditions in UK homes. This will be tested by calculating how long a sample of minority households experiences indoor temperatures outside ATC levels and comparing to periods of outside recognised thresholds of temperature and RH for healthy homes.

2 Methods

Indoor environmental conditions of temperature and RH are compared to thermal comfort ranges and health thresholds for eleven minority ethnic households, using hourly data for 366 days, to investigate if the ATC model reflects healthy indoor conditions. Since most of the ethnicity studies focused on black or Asian minority groups, this study focuses on another understudied and underrepresented minority population that is lost under the predefined ethnicity groups.

2.1 Sampling

A purposive sampling strategy was employed to recruit households belonging to the Egyptian minority group living in Sheffield. Recruitment was conducted through community advocates and volunteers during social and cultural events, supplemented by snowballing to recruit the hard-to-reach households.

The research project information sheet and a detailed method guide were provided to the potential participants who expressed interest. The final sample comprised 11 households. In this study, the focus on a hard-to-reach ethnic minority group prioritised depth of understanding by collecting 12 months of longitudinal data. This allowed generating a large within-household dataset (hourly/ daily/ monthly observations), which increases statistical power and allows robust analysis [30].

2.2 Indoor Environmental Monitoring

Real environmental field measurements were taken by UBIBOT WS1 Pro wireless sensors from 1st of March 2023, until 29th of February 2024. Hourly outdoor weather data were obtained for the same period from Weston Park weather station, located within 2 km of Sheffield city centre. The monitored dwellings were situated between 1 and 15 Km away from this weather station. Data from this station were therefore assumed to provide a reasonable representation of the external weather conditions experienced at each dwelling.

The technical specification of the UBIBOT WS1 device ensures its high level of accuracy and precision. Its measurement range is -20°C to 60°C (-4°F to 140°F) and 10% to 90% RH, with accuracy of ±0.3°C for temperature, ±3% for RH. The datasets were automatically and continuously captured by the monitoring equipment every 5 minutes and transmitted to an Internet of Things (IoT) cloud-based data management system every 15 minutes.

One data logger was installed in the main living area of each dwelling to monitor indoor temperature and RH. The living area was selected as it functions as a family hub, characterised by high occupancy and multiple daily activities. Sensors were mounted on an interior wall at a height of 1.5 meters, and a minimum of 1.5 meters away from openings to avoid direct sunlight and air flow. The sensors devices were not placed in a corner or an alcove, or any recessed part of the wall; it was also placed away from heat sources such as radiators, computers, portable heaters and fans.

2.3 Adaptive Thermal Comfort (ATC) Analysis

The ATC percentage is calculated in Microsoft Excel using 8783 hourly datapoints over 366 days for each of the 11 participants during the occupied hours. Occupied hours for the living rooms were assumed to be between 7:00 and 22:00, which is common practice in other studies [31, 19]. Using raw hourly outdoor temperature data from the UK MET office, the daily average outdoor temperature was computed. The neutral comfort temperature ($T_{comfort}$) is calculated from the daily outdoor mean over the previous 7 days (T_{rm}), using *Equations 1 and 2*. The corresponding adaptive thermal comfort range was subsequently determined for each day using *Equations 3 and 4*.

Indoor environmental sensors recorded dry-bulb air temperature and relative humidity (*RH*) at five-minute intervals. These five-minute measurements were averaged to produce hourly mean values of temperature and RH, resulting in 24 data points per day for each dwelling over the monitoring period. The number of occupied hours within the thermal comfort range was assessed for each day separately, then aggregated over the 366 days. The number of hours within the recommended health range for temperature and RH was directly calculated over the annual datasets. Then, out-of-range durations (indoor thermal and health stresses) were assessed accordingly.

Overheating stress was assessed using the CIBSE adaptive overheating criteria. A dwelling was classified as experiencing overheating when two of the defined overheating criteria were exceeded, based on Equations 6 and 7 [26]. The adaptive overheating criteria are based on the operative temperature *(T_{op})* that is approximately assumed to be equal to dry bulb air temperature *(T_{air})* in the monitored dwellings. This assumption is justified [31] as no notable air movement or radiant temperature asymmetry was observed, and the indoor conditions under which the T_{op} closely align with T_{air}.

3 Results

Under Sheffield weather conditions, the thermal comfort range varied across the year, with a minimum T_{lower} of 16°C and maximum T_{upper} of 27°C. This range is slightly wider than the recommended health range (T_{min}=18°C and T_{max}=26°C, when RH_{min}=40% and RH_{max}=60%). However, the ATC range should not be applied uniformly across the year, as daily comfort limits vary in response to changes in the running mean outdoor temperature.

3.1 Adaptive Thermal Comfort Diagnosis

ATC percentage (percentage of hours a household is within the ATC range) was calculated during the occupied hours for the monitoring year. Table 1 shows that five of the eleven households exhibited high levels of thermal comfort, with 88% or more of occupied hours in the ATC range. Another five households experienced moderate comfort, with 63–72% of occupied hours falling within the ATC range. One household experienced low comfort, with only 26% of occupied hours within the ATC range.

Table 1. Adaptive comfort % compared to the duration and % of hourly deviation during annual occupied hours.

Living area		Annual occupied hours (7 am-10 pm) out of range (T_{lower} - T_{upper})			
Case ID	$T_{comfort}$ **%**	**No. of hours below** T_{lower}	**% below** T_{lower} (15°C - 20°C)	**No. of hours above** T_{upper}	**% above** T_{upper} (22°C - 27°C)
P_1	**89%**	570	10%	57	1%
P_2	**88%**	689	12%	0	0%
P_3	**26%**	4309	74%	1	<1%
P_4	**98%**	65	1%	39	1%
P_5	**67%**	1900	32%	52	1%
P_6	**89%**	125	2%	525	9%
P_7	**71%**	1649	28%	44	1%
P_8	**72%**	1184	20%	436	8%
P_9	**68%**	1552	27%	267	5%
P_{10}	**90%**	24	4%	348	6%
P_{11}	**63%**	2187	37%	7	<1%

Although the above Table 1 shows that indoor thermal comfort is highly linked to warm indoor temperatures, it also shows that thermal discomfort due to low temperatures and underheated spaces is more prominent. However, unlike overeating, there is no explicit standardised framework for quantifying underheating stress in cold homes.

With respect to overheating assessment, four out of 11 households had a temperature above T_{upper} for more than 3% of the occupied hours over the year. Table 2 shows that two of them (P_6 and P_9) failed criteria I and II, as the number of hours of exceedance (H_e) when ΔT>0 during summer (June to August) exceeds 3% of occupied hours. Besides, the daily weight of exceedance (W_e) at P_6 and P_9 exceeds 6 in both cases for 15 and 12 days, respectively. This means that they are subjected to overheating stress in the summer season.

The other two cases (P_8 and P_{10}) experience periods of overheating during the heating season, indicating high indoor temperatures associated with increased energy use for space heating and relatively high set-points in winter.

Table 2. Hourly exceedance and daily weight of exceedance at overheated cases.

ID	% of annual occupied hours above T_{upper}	Criterion I	Criterion II
		% of H_e in Summer	**No. of days when W_e > 6**
P_6	9%	17%	15 days
P_8	7%	0%	0
P_9	5%	13%	12 days
P_{10}	6%	0%	0

3.2 Underheating and Overheating Health Stress

Five cases experienced consistent cold (T_{indoor} below T_{min}) for 40% or more of the total annual occupied hours, as in Table 3. The longest duration of cold, when the underheating health risk may occur, was 72% for 271 days on average, for P_3, as shown in Figure 2. The longest period of heat exposure (T_{indoor} above T_{max}) was 11%.

Table 2 shows that two households (P_6 and P_9) failed two overheating criteria. These households also had relatively high percentages of occupied hours above T_{max}. Therefore, Figures 3 and 4 are presented to show the hourly variations in indoor temperature over the summer period for these two households, compared to the upper thermal comfort temperature (T_{upper}) and the maximum health temperature threshold (T_{max}).

Table 3. Annual occupied hours when indoor temperature is out of the recommended health Range (18°C-26°C)

Living area in the dwelling of case ID	Annual occupied hours (7 am-10 pm) out of range (18°C-26°C)			
	No. of hours below 18°C	**% below T_{min}**	**No. of hours above 26°C**	**% above T_{max}**
P_1	1308	22%	111	2%
P_2	1241	22%	5	<1%
P_3	4188	72%	8	<1%
P_4	516	9%	78	1%
P_5	2973	51%	92	2%
P_6	779	13%	621	11%
P_7	2622	45%	108	2%
P_8	840	14%	0	0%
P_9	2352	40%	344	6%
P_{10}	240	4%	54	1%
P_{11}	2797	48%	23	<1%

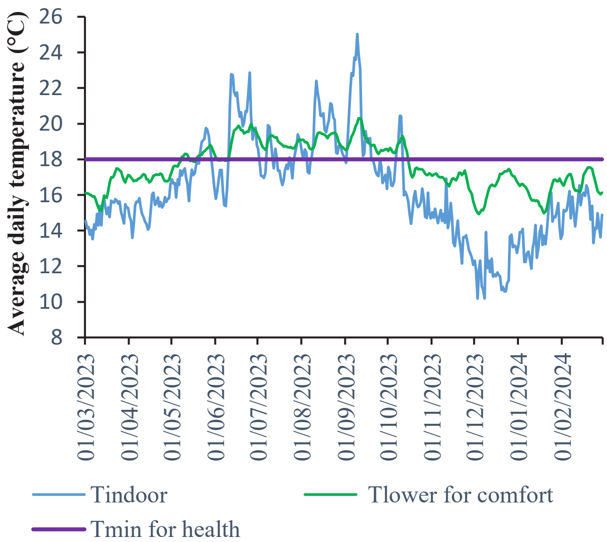

Fig. 2. Average indoor daily temperature at P_3 compared with T_{lower} and T_{min}.

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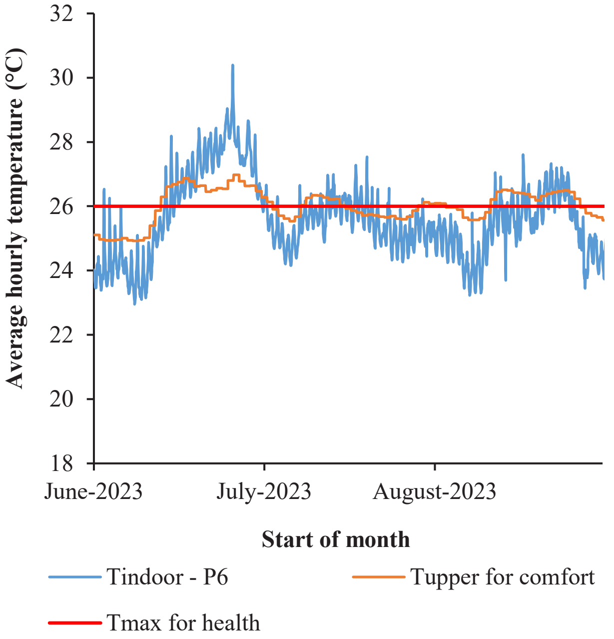

Fig. 3. Hourly indoor temperature for P_6 over the summer period, compared with T_{max} and T_{upper}

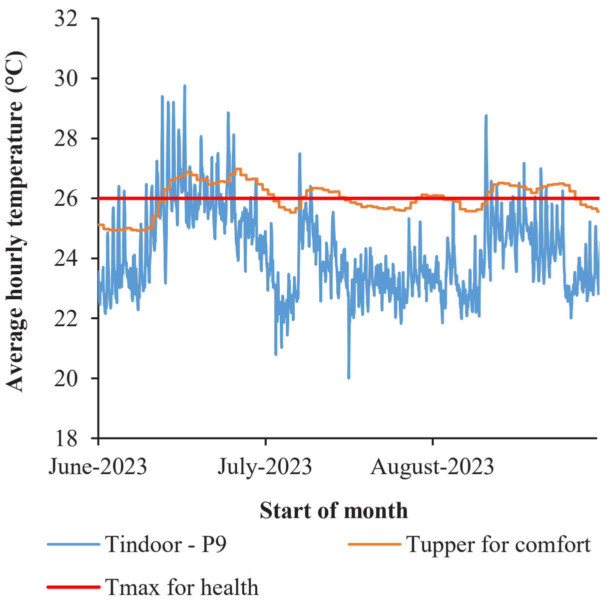

Fig. 4. Hourly indoor temperature for P_9 over the summer period, compared with T_{max} and T_{upper}

3.3 Dryness and Dampness

RH is not explicitly incorporated nor accounted for in the ATC analysis used to assess IEQ. However, it is a key metric for a healthy indoor environment. In Table 4, a relatively dry living area (when indoor RH is below 40%) is shown only in 1 case (P_8), with 5% of annual occupied hours over 17 days (Figure 5). In contrast, consistently humid living areas were observed in most cases during the occupied hours. The most severe and prolonged deviation occurred in P_{10}, where indoor RH exceeded 60% for 91% of annual occupied hours, over 335 days, as in Figure 6.

Table 4. Annual occupied hours when indoor RH is out of the recommended health range (40%-60%)

Living area in the dwelling of case ID	**Annual occupied hours (7 am-10 pm) out of range (40%-60%)**			
	No. of hours below 40%	**% below RH_{min}**	**No. of hours above 60%**	**% above RH_{max}**
P_1	36	<1%	1275	22%
P_2	0	0%	4321	74%
P_3	31	<1%	3881	66%
P_4	120	2%	1222	21%
P_5	10	<1%	2359	40%
P_6	36	<1%	321	6%
P_7	34	<1%	3759	65%
P_8	319	5%	2029	35%
P_9	144	2%	2279	39%
P_{10}	5	0%	5302	91%
P_{11}	12	<1%	4247	73%

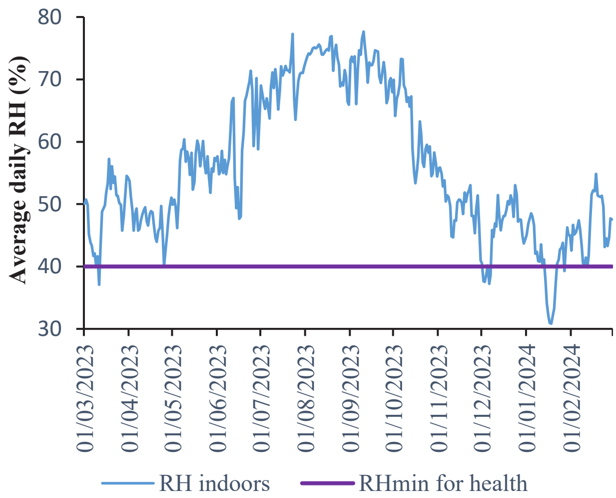

Fig. 5. Average daily RH at P_8 compared with RH_{min}

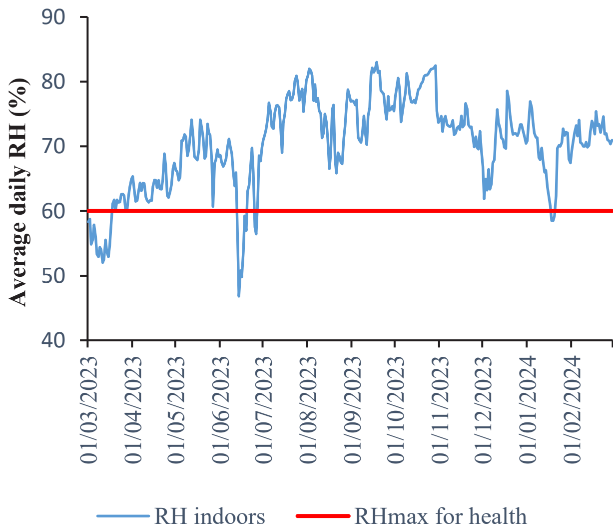

Fig. 6. Average daily RH at P_{10} compared with RH_{max}

4 Discussion

This study explored the current gap between ATC and health metrics, questioning the assumption that meeting thermal comfort standards automatically delivers healthy indoor environments. To address this, high-resolution temperature and RH data were collected over one year in the living spaces of 11 minority households in the UK, allowing comparison between adaptive comfort ranges and recognised health thresholds.

Existing standards [24, 26] define comfort limits, but do not define a thermal health performance classification system based on deviation duration percentages. This study adopts a practical taxonomy to classify the percentage of annual occupied hours that fall outside both the adaptive thermal comfort range and the recommended health thresholds. Table 5 provides a consistent analytical framework for comparison across dwellings.

To achieve an *acceptable* level of thermal comfort, the proportion of occupied hours that fall outside the ATC or health ranges should be less than 3% [24]. When 3–10% of annual occupied hours deviate, conditions are considered marginal comfort, as some discomfort and minor health-related stress may occur, but these conditions *can be acceptable*. If 11–35% of occupied hours deviated, attention is required to address *unacceptable* conditions and mitigate ongoing discomfort and health stress. When more than 35% of occupied hours exceed comfort limits, this indicates very poor IEQ, severe thermal discomfort and persistent health stress, and conditions are *highly unacceptable*.

Table 5. Taxonomy for Interpreting Percentage of Annual Occupied Hours Outside Adaptive Thermal Comfort and Recommended Health Ranges

Out of range comfort % (T_{in}% < T_{lower} or T_{in}% > $T_{upp.}$)	Annual occupied hours out of range					
	T_{in}% < T_{lower}	T_{in}% < 18°C	T_{in}% > $T_{upp.}$	T_{in}% > 26°C	RH_{in}% < 40%	RH_{in}% > 60%
P_1 **11%**	10%	22%	1%	2%	<1%	22%
P_2 **12%**	12%	22%	0%	<1%	0%	74%
P_3 **74%**	74%	72%	<1%	<1%	<1%	66%
P_4 **2%**	1%	9%	1%	1%	2%	21%
P_5 **33%**	32%	51%	1%	2%	<1%	40%
P_6 **11%**	2%	13%	9%	11%	<1%	6%
P_7 **29%**	28%	45%	1%	2%	<1%	65%
P_8 **28%**	20%	14%	8%	0%	5%	35%
P_9 **32%**	27%	40%	5%	6%	2%	39%
P_{10} **10%**	4%	4%	6%	1%	0%	91%
P_{11} **37%**	37%	48%	<1%	<1%	<1%	73%

Fully Accepted (< 3%)
Can be Accepted (3%-10%)
Highly unacceptable (> 35%)
Unacceptable (11%-35%)

Based on the taxonomy above, five out of eleven cases showed highly unacceptable indoor conditions combining cold (<18°C) and damp (>60%) for more than a quarter of annual occupied hours, exceeding both ATC and recommended health ranges. This is likely to affect these households' health, comfort and overall IEQ.

5 Conclusion

Indoor temperature and RH, which constitute a healthy IEQ, must be carefully reconsidered because of their significant direct implications on energy use, running costs and the lifecycle carbon footprint. A combined approach grounded in empirical studies that apply inferential statistical techniques and prioritise epidemiologically validated health metrics as proxies for thermal comfort is highly recommended. Future studies should include larger and more diverse minority samples.

In this study, all 11 homes occupied by minority households encounter a percentage of unacceptable deviation in at least one metric defining thermally healthy conditions. Identifying the duration of deviation is needed to assess the integrated thermal health of occupants and buildings. This study provided a taxonomy to enable a consistent comparative interpretation of results.

Looking at thermal comfort in isolation might mask unhealthy indoor conditions and fail to reflect a true picture of the overall IEQ. The ATC model reflects perceived comfort, not necessarily healthy indoor conditions. For example, ATC can be at acceptable levels while RH is highly unacceptable, such as in case P_{10}. Indoor RH should be incorporated as an important metric to ensure a better IEQ that is free of damp and mould affecting health and wellbeing.

Thermal comfort should not be used as a proxy for a healthy home or healthy occupants. Warm indoor temperatures (above T_{lower}) may be linked to a relatively higher ATC. However, these high percentages may overshadow unacceptable cold (P_5, P_7, P_9) and damp (P_2, P_7, P_9, P_{10}) conditions and therefore not clearly reflect indoor stresses, nor a healthy indoor environment.

The current lack of clear, evidence-based guidance on healthy indoor conditions puts avoidable stress on health services and simultaneously conflicts with the UK's home-decarbonisation agenda. As we design future homes and renovate existing ones, health should be the primary design criterion, rather than a secondary outcome of cost and carbon optimisation. When thermal comfort metrics are explicitly linked to health outcomes, a healthy home pathway emerges to deliver dual benefits: reducing health risks and NHS demand while supporting equitable national home decarbonisation targets.

I acknowledge the support of the Funds for Women Graduates (FfWG), whose grants, bursaries, and fellowships support living costs, enabling women graduates to pursue their research and academic endeavours.

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