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Thermal comfort in UK retrofit practice: the practitioners' perspective

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ABSTRACT

This study explores the role of thermal comfort in UK retrofit practices through the perspectives of practitioners. A survey of 29 professionals, including engineers, architects, and policy consultants, was conducted to gather data on their priorities, methods, and challenges. The survey included multiple-choice and open-ended questions, analysed using descriptive statistics and thematic analysis.

Results indicate that energy efficiency and thermal comfort are top priorities for practitioners, but there is an identified gap between these priorities and their practical implementation. Challenges include cost-effectiveness, resident engagement, and balancing heritage conservation with energy efficiency. The study highlights the need for implementation of standards and methodologies to better integrate thermal comfort into retrofit practices. Addressing the identified gaps in practice requires a holistic approach, incorporating user perspectives and adaptive comfort principles to enhance retrofit outcomes and occupant well-being to better support the practitioners.

The study's findings could have significant implications for policy and practice in the UK retrofit sector. For policymakers, the results provide evidence for the need for comprehensive standards or process design for thermal comfort within energy efficiency interventions and other criteria that practitioners have recognised as important.

1. Introduction

The climate crisis is one of the most important challenges of our time, demanding an immediate societal transformation in how we adapt buildings and manage energy use for the future climate conditions. In Europe, buildings are responsible for 36 % of the GHG emissions [1]. In the UK, they are the second largest source of emissions. As part of its mitigation strategy, the UK government has prioritised energy retrofitting to achieve an 80 % reduction in carbon emissions by 2050 [2]. The Committee for Climate Change estimates that there are still 29 million homes that require retrofitting [3]. However, the current retrofitting rate (less than 1 % of the existing building stock) is insufficient to meet net-zero targets [4]. To make a significant impact and reach these goals, retrofitting efforts must be amplified tenfold [5]. Upscaling retrofit efforts should involve not only increasing the number of retrofitted buildings but also improving the quality and standards of those retrofits [6].

While it is crucial to emphasize the quality of retrofits to minimise the 'performance gap' between design and energy performance and achieve the necessary reductions in energy and carbon emissions [7–9], it is equally important to acknowledge that previous retrofit measures have primarily focused on energy reduction. This narrow focus often results in the neglect of other essential aspects, such as users' needs, health, comfort, and heritage values.

Interventions for energy efficiency alter the entire balance of a building, including its envelope, services, and the way users interact with it. While retrofitting is considered essential, studies have uncovered several unexpected outcomes linked to these interventions. Some outcomes are positive, such as noise reduction and improved acoustics. However, other interventions have led to undesirable consequences that can pose risks to the health and quality of life of occupants [10]. For instance, a national funding retrofit scheme in Caerau, Wales, left residents in worse conditions than before, with issues such as structural damage, mould growth, and poor thermal comfort levels, requiring additional funding for remediation [11]. Incorrect interventions, such as the use of incompatible materials, can disrupt the balance of a building, leading to moisture-related problems. Excessive humidity levels can cause mould growth, which not only damages the building fabric but also poses health risks to occupants. Moisture problems and the associated risk of mould growth can extend to neighbouring homes.

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Traditional retrofit strategies can sometimes prove even counter effective, leading to increased energy consumption. The expected energy savings from enhancing building energy efficiency are often diminished or entirely negated by changes in occupant behaviour or other systemic responses, a phenomenon known as the Rebound Effect [12]. This can be attributed to incorrect or unrealistic initial assumptions, such as assuming the pre-retrofit home was already comfortable, which leads to underestimating the anticipated energy use. The last years, in the UK, PAS 2035, a Specification for whole house retrofit was introduced, to improve the quality in energy efficiency measures in buildings and tackle the performance gap [13].

The difference between expected and observed energy use (the performance gap) can be as high as 35 %, attributed to the adoption of a rigid techno-economic approach to retrofitting and the application of the limiting international standards for thermal comfort. The common assumption that occupants will use the dwelling, and the technologies as 'intended' after the retrofit, although dominant in practice, has been proven false [14]. Additionally, documented differences in the understandings of thermal comfort between experts, such as building engineers, architects, and government regulators and users, have contributed to the energy performance gap [15]. Focusing on these differences, researchers argue that a 'one-size-fits-all' approach to thermal comfort potentially underestimates other critical motivations, such as domestic well-being, health, control, familiarity, tradition, costs, and beauty, which influence energy demand and daily energy practices [16,17]. In recent years, researchers have suggested that energy retrofits should not be considered solely as interventions to the building envelope but should also account for thermal comfort practices [18]. Therefore, more research is needed to understand how thermal comfort practices change pre and post retrofit projects and how professionals currently integrate thermal comfort into retrofit design.

However, the incorporation of user experience becomes more challenging, as recent research has identified significant information asymmetries between households, professionals, and policymakers, which hinder effective decision-making and user engagement in retrofit projects. These gaps often result in mismatched expectations, reduced trust, and suboptimal outcomes [19]. In response, participatory models and tools (technical or not) such as Building Information Modelling (BIM), co-design strategies, and improved communication channels have been proposed to support early-stage identification of user needs and values [20]. For example, evidence from higher education building retrofits further supports this approach, showing that involving end users in the design and evaluation process enhances satisfaction, usability, and long-term performance of retrofit interventions [20]. These inclusive strategies not only enhance the social value of retrofits but also help bridge the persistent performance gap between design intentions and real-world outcomes.

In some specific settings, such as retrofitting for residents experiencing fuel poverty, specific aspects like thermal comfort becomes even more critical. The widely adopted cost-effective methodology for energy retrofitting, which calculates cost effective levels of minimum energy performance requirements for buildings and their elements, has been proven ineffective in addressing the needs of fuel poor households. This methodology typically determines the optimum retrofit package for each case and is often combined with deep and large-scale retrofit solutions. However, when multiple factors, such as occupant behaviour and environmental indicators, are considered, the optimal solutions identified with this methodology change considerably. To address this limitation, an alternative methodology was developed by Vilches et al. [21]specifically for social housing. In this approach, thermal comfort is prioritised as the primary criterion, with the budget for monthly energy bills as the secondary consideration.

Supporting this argument, Desvallées [22] emphasises the need to distinguish thermal comfort practices that come from cultural norms and those resulting from financial deprivation. They suggest conducting in situ pre-retrofit assessments of user consumption profiles, including thermal comfort, monthly expenses, and the fulfilment of social needs. These assessments can establish context-based indicators of energy poverty situations, which can inform the design and evaluation of retrofitting policies based on real user profiles, helping prevent issues like the rebound effect.

UK retrofit efforts have mainly focused on the social housing sector [23]. Social housing residents are more vulnerable to fuel poverty and thermal comfort stress (indoor cold strain) than those in other sectors. However, typical retrofit design assumptions are not directly applicable to social housing retrofits. Teli et al. [24]have shown that typical indoor thermal conditions used in building energy modelling do not represent the conditions in social housing. Moreover, they argue that even if targets for CO_2 reduction are not achieved through retrofitting, the social impact of these retrofits could be much greater and more critical than assumed. In addition, other researchers have argued that direct incentives for retrofit schemes in social housing have great social and health benefits. Improved indoor comfort conditions positively affect individuals' health and social life and can be translated into economic relief for the National Healthcare Service [25]. Similarly, thermal comfort is critical in the energy retrofit of care homes, as older adults are particularly vulnerable to thermal and relative humidity conditions and are more prone to temperature-related illnesses. In this context, thermal comfort should be considered not only as an indicator of retrofit success but also associated with health.

Focusing on retrofit practitioners is essential for the success of large-scale energy efficiency interventions. These professionals, such as architects, engineers, coordinators, installers and consultants, are the ones who translate national climate policies into practical, on-the-ground actions. Their decisions directly shape retrofit outcomes, influencing not only energy performance but also occupant comfort, health, and satisfaction. The development of the UK Government's Warm Homes Skills Programme is evidencing the critical role of retrofit professionals by investing in their training to expand the sector's capacity and ensure high-quality, standards-aligned retrofit delivery [26]. Despite this pivotal role, their perspectives are often underrepresented in retrofit policy and research [4]. Recent research has begun to address this gap by exploring the capabilities of practitioners in domestic retrofits [27], the barriers and opportunities they face [28], and their motivations for integrating energy efficiency into routine maintenance and repair work [29]. These insights reveal that practitioners are not just implementers but also key decision-makers who must navigate complex trade-offs between cost, heritage preservation, user needs, and technical feasibility. Moreover, international research shows that even when professionals recognise the value of new tools, adoption is often hindered by institutional and policy limitations [30]. Understanding and supporting the role of practitioners is therefore critical to closing the performance gap, improving retrofit quality, and ensuring that retrofit strategies are both scalable and user-centred.

Building on the outcomes of those studies, this paper aims to explore how retrofit practices consider thermal comfort, using the UK context as a starting point to illustrate broader trends and challenges in retrofit projects. The study presents the practitioners' priorities, key outcomes, retrofit assessment criteria and methods, as well as the concerns and challenges that retrofit practitioners face. The insights from this paper could be used to deepen our understanding of how retrofit professionals operate, identify potential points of intervention, and a good base to develop tools to support their work, based on their own needs. This paper offers the professional perspective. Including the perspective of practitioners in a broader conversation with researchers, building users, and policymakers could help identify points of alignment and misalignment, as well as opportunities to upscale the retrofit process.

2. Methodology

To understand the role of thermal comfort in retrofit practice in the UK context, an online survey was created using Opinio software [31].

The focus, the questions and the possible answers given to the participants were based on relevant literature, which included policy and strategy national documents, standards and frameworks, academic research papers on retrofit practice and professionals, as well as professional reports, described in more details in the Table 2.1 below:

A survey was chosen as a research method, as it provides a consistent way to ask questions, ensuring that all respondents are given the same information and options. In addition, it can offer participants anonymity, which can lead to more honest and accurate responses, and it is important as our sample is consisted of professionals [40].

2.1. Survey description

The survey employed a mixed-methods approach, incorporating both quantitative and qualitative question formats. As detailed in Appendix A, it included multiple-choice items, Likert-scale questions, and open-ended questions. A five-point Likert scale was adopted to enhance respondent engagement and reduce measurement error by offering a neutral midpoint, consistent with established methodological recommendations [41,42].

The survey first gathered demographic and professional background information, including participants' educational qualifications, professional certifications, current roles in retrofit projects, and specific interests in the field. To assess experience, respondents were asked to indicate the number of retrofit projects they had undertaken and the years of their involvement in the sector. Further questions explored the typology of buildings retrofitted and the geographical distribution of these projects across the UK.

Open-ended questions were also included in the survey, where participants could elaborate on their responses, introduce additional perspectives, and incorporate their own priorities, success indicators, and perceived challenges.

Finally, technical and supply chain issues that were identified during the literature review, they weren't considered in the survey, as they have been explored in detail in other research studies [43,44].

Table 2.1
Key UK Retrofit Policies, Frameworks, and Academic Contributions.

Title/Source	Description/Focus
National Retrofit Strategy [32]	It describes a 20-year plan for UK home retrofit, policy pillars, skills, priorities, finance, quality, and leadership
Heat and Buildings Strategy [33]	National policy on decarbonizing heat, funding mechanisms, and retrofit targets
Net Zero Whole Life Carbon Roadmap [34]	Sector roadmap for net zero, retrofit targets, success metrics (EPC, bills, emissions)
Future Homes Standard 2025 [35]	Upcoming low-carbon heating/building standards
PAS 2035/2030 Retrofit Standards Framework [13]	UK technical retrofit standard: whole-house approach, occupant comfort, heritage, safety, risks and compliance
TrustMark Quality Framework [36]	Mandatory quality assurance for government-funded retrofits
Whole House Retrofit Framework [37]	Holistic, risk-based, fabric-first, system-wide approach on four pillars considering building, occupants, context, services
Residential retrofit in the climate emergency: the role of metrics [38]	Metrics for retrofit success: energy savings, occupant well-being, trade-offs
Opportunities and barriers to business engagement in the UK domestic retrofit sector: an industry perspective [28]	Barriers: supply chain fragmentation, skills, finance; business perspectives
Retrofit Revealed [39]	Analysis of 37 retrofit projects, referencing success factors: engagement, airtightness, cost, CO_2 reduction

Table 3.1
Table of Participants Characteristics: Role, Education level, number of retrofit projects, years of experience.

Role	Education	Number of Projects	Years of Experience
RC = Retrofit Coordinator	Ms = MSc, MEng	a = 1–2 projects	N= Number of years of experience
RD = Retrofit Designer	Ph= PhD	b = 2–5 projects	
R = Researcher	Ri = Riba 2, 3	c = more than 5 projects	
H= Heritage	PC=Professional Certification		
SR= Standards, Regulations			
0= Other			

2.2. Survey distribution & sample size

Participants were recruited through emails with a snowball sampling method, whereby existing participants recommended others. This is an approach commonly used in socio-technical studies on retrofitting and energy efficiency perceptions [45,46]. The sample consisted of professionals such as engineers, architects, policy consultants, and heritage specialists, all of whom had documented experience in the UK retrofit sector. The final sample size of 29 includes professionals engaged in various aspects of retrofitting across the UK, from research and design to implementation, scaling, and heritage building guidelines.

Due to the focus on professionals, the study prioritised qualitative depth, employing a mixed-methods questionnaire that included multiple-choice, scale-based, and open-ended questions. Optional comment sections in all questions allowed participants to elaborate on their responses, enriching the qualitative data. The sample size was anticipated due to the professional capacities of the participants and aligns with comparable studies in the field [27,28,47,48]. Due to snowball sampling method, only six incomplete responses were observed, which were excluded from the analysis.

2.3. Survey analysis

Quantitative data from multiple choice questions and scales were analysed using descriptive statistical methods. The data were presented based on mean values and the spread of the answers was included too as it provided additional information (Table 3.2). Additionally, cross-tabulation (Table 3.3) was conducted to understand the relationship between the role of the participant and their priorities.

Comments and open-ended questions have provided vast qualitative data. They were also presented in the results and analysed thematically to support the quantitative data. In the open-end questions, participants expressed their sentiments, concerns, perspectives and experiences.

The results of this study, when compared with the existing literature, enable an overview of the current practices and challenges in retrofitting in the UK context. This comparison can help identify gaps in policy or research and highlight opportunities for future improvements in retrofit strategies.

3. Results

3.1. Practitioners' background and personal interest to retrofit

Figs. 3.1 and 3.2 presents the respondents' roles, experiences in the built environment and the retrofit sector and educational background and certification. In general, the participants' responses are diverse, reflecting a combination of personal values and professional motivations. The participants' experience and qualifications varied widely, reflecting a diverse range of backgrounds, expertise, and roles. Most participants are highly qualified, with the vast majority of the

Table 3.2
Overview of the survey results with a chart and heat map for the prevalence of answers.

Prevalence of Answers
More than 20 Participants
Between 11-19 Participants
Less than 11

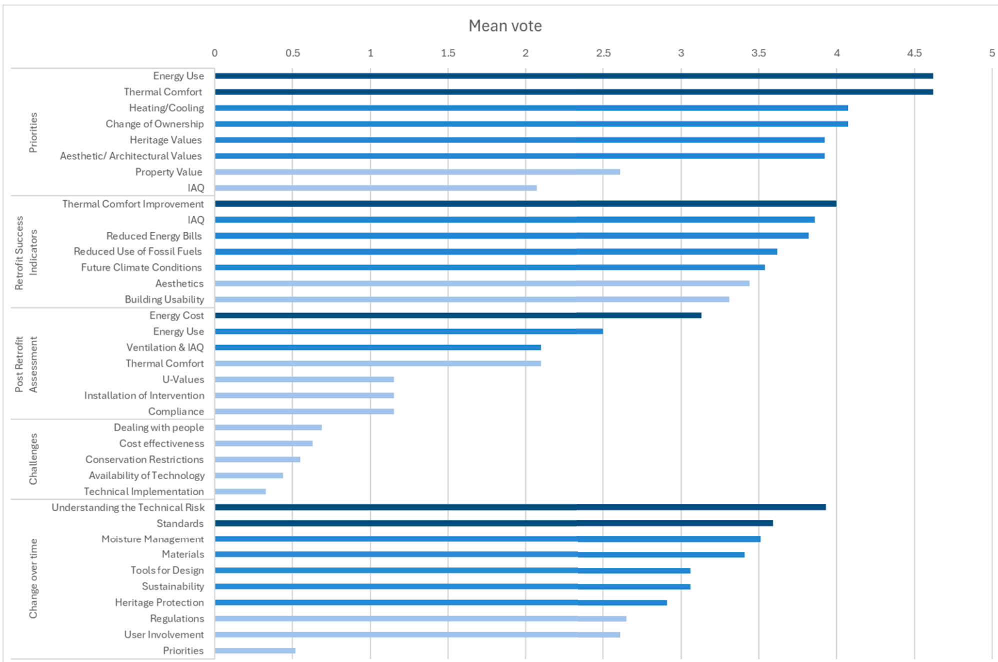

Table 3.3
Mean thermal comfort priority for each professional role.

Professional Role	(1–5)	Comment analysis per role
Retrofit Coordinator	4.55 [4,4,4,4,5,5,5,5,5]	Generally focused on energy efficiency and environmental concerns.
Retrofit Designer	4.16 [3,4,4,4,5,5]	Some mention thermal comfort as a top priority, and some do not.
Researcher	4.8 [4,5,5,5,5]	Focused on performance gap and comfort.
Heritage	5 [5,5]	Strong emphasis on preserving vernacular, ecological, and traditional features. Comfort is also mentioned as a top priority.
Standards/ Regulations	5 [5,5]	Emphasis on compliance and quality, including comfort and heritage.
Other	4.8 [4,5,5,5,5]	–

practitioners to have considerable practical experience. In detail, six participants (20.68 %) mentioned having over 15 years of extensive experience in the field. Respondents have held various roles and possessed formal qualifications such as PhDs, MSc or MEng in fields like architecture, civil engineering, or environmental design. Additionally, eleven participants hold professional certifications, including from: Chartered Institution of Building Services Engineers (CIBSE) [49], Chartered Engineer (CEng) [50], International Performance Measurement and Verification Protocol Certification (IPMVP Certification) [51], Building Research Establishment Environmental Assessment Method (BREEAM) Certification [52], Standard Assessment Procedure (SAP) [53], Royal Institute of British Architects (RIBA part 2 and part 3) [54], and Passivhaus certification [55].

Fig. 3.1. Schematic Overview of Participants Characteristics: role and experience in retrofit projects.

Table 3.1 outlines a coding system used to link participants' attributed characteristics to their corresponding quotations.

In the case of special interests in retrofitting, respondents' motivations can be grouped into three main areas: environmental impact, social values and improving retrofit.

The most common reason cited for working in the retrofit sector was related to its environmental benefits (n = 8, 27.59 %). Respondents mentioned ecological concerns including the reduction of carbon emissions and the improvement of energy efficiency. For instance, one participant, who worked as a retrofit coordinator expressed their personal interest in the positive impact of buildings retrofitting, stating:

[RCRiPCc] 'Global energy efficiency and reduction of CO_2 emissions'.

The social value of retrofitting emerged as another key area of interest (n = 6, 20.68 %). Participants highlighted issues such addressing energy poverty, improving the housing stock, and improving residents' living conditions as primary motivation for retrofitting buildings. This was particularly significant for retrofit coordinators working in architectural practices, who often have roles as designers and/or researchers.

Some participants expressed a specific interest in improving the retrofit process and expanding knowledge in this field (n = 4, 13.79 %). The interest ranged from practical, everyday improvements to more institutional level changes.

[RPhCPhc] 'My focus work is measuring buildings performance to inform and validate retrofit'.

[RPh45] 'Set up and led the … Group, with a particular emphasis on energy utilisation in existing buildings and communities'.

This emphasis on retrofit quality can be attributed to extensive experience of most participants and their roles in the retrofit process,

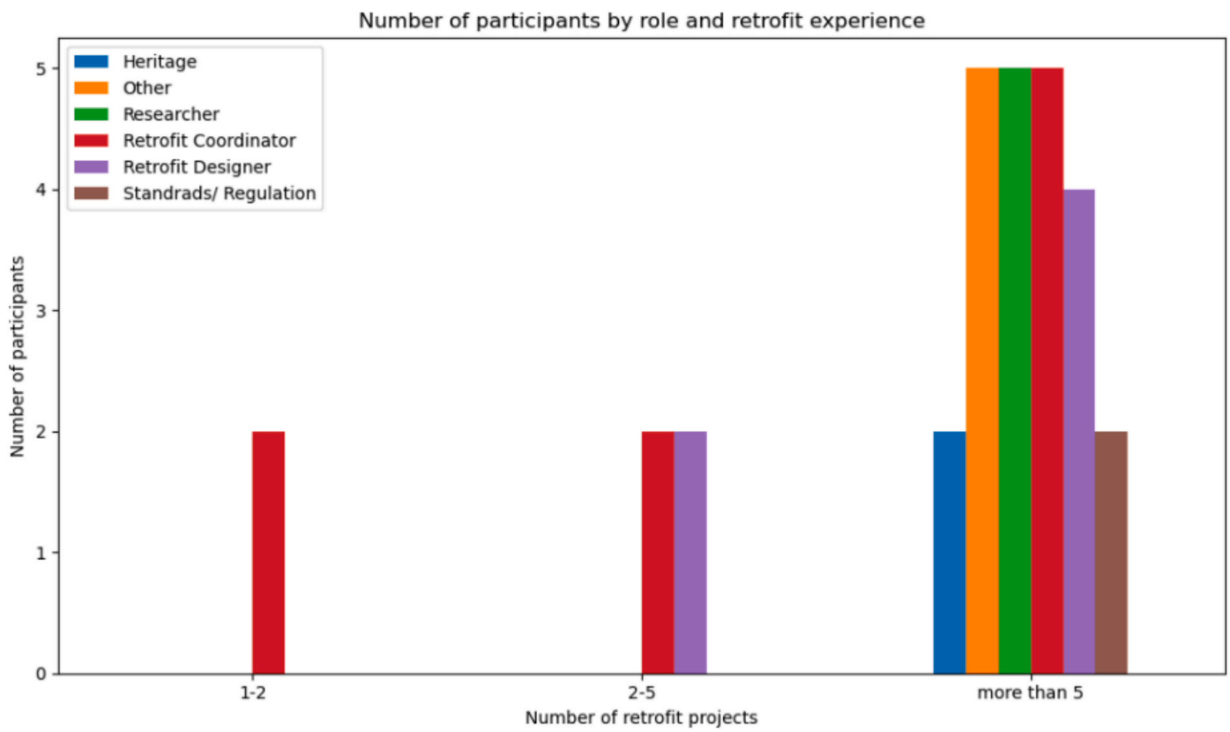

Fig. 3.1. Schematic Overview of Participants Characteristics: role and experience in retrofit projects.

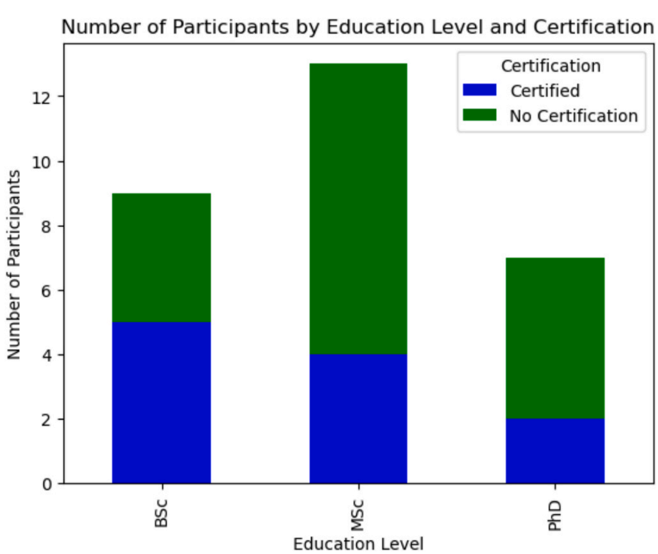

Fig. 3.2. Schematic Overview of participants education level and professional certification.

including designers, coordinators, consultants, and researchers. This focus was particularly relevant to those involved in policy-related retrofitting or the heritage sector, where expanding the definition of retrofit was seen as crucial. For instance, participants mentioned:

[SR20] 'Improving quality and knowledge'.

[HPh15] 'Widening the definition of retrofit beyond the fabric first mantra'.

The "Fabric first" approach, which prioritises improving the thermal performance of the building envelope, has been widely implemented in retrofit practices. However, its continued relevance has been questioned by researchers [56]. Since 2012, heritage professionals have published reports challenging the fabric first approach in the context of a historic environment [57], advocating for a more responsible and context-sensitive retrofit strategy.

3.2. Overview of the results

As can be seen in Table 3.1, the most important priorities in retrofitting, were '*energy use*' and '*thermal comfort*'. Additionally, the most important indicators of retrofit success were identified as '*reduced energy bills', 'improved thermal comfort'* and *'indoor air quality'*. However, when assessing-post retrofit assessment outcomes, the most common criterion was '*energy cost*'. In contracts, air quality and ventilation were considered as having medium importance, and thermal comfort was ranked even lower.

3.3. Priorities, success indicators and challenges

3.3.1. Priorities

The results revealed that energy use and thermal comfort for occupants were generally rated as very important (mean = 4.62), reflecting the primary goal of retrofit professionals to improve energy efficiency while ensuring occupant comfort. Cooling and heating savings and change of ownership were also rated as important (mean = 4.08 for both). The rating for heritage and aesthetic values varied (mean = 3.92), suggesting differing perspectives on the importance of preserving original building features and maintaining aesthetic value during retrofitting. These differences seem to depend on the expertise and special interests of the professionals.

[RCPCc] 'For me retrofit is about energy efficiency and carbon reduction. Everything else is refurbishment or renovation'.

In contrast, a participant specialising in heritage expressed a different view on energy efficiency, emphasising the importance original elements in traditional buildings, such as vernacular characteristics.

[HPh15] 'The natural low-energy features of buildings, especially of traditional construction. These should be understood in the retrofit design, but they rarely are!'.

Increasing the property value (mean = 2.61) and indoor air quality (IAQ) (mean = 2.07) were rated as less important by participants.

Table 3.3 above reveals that all professional roles rated thermal comfort as a high priority. Researchers and heritage professionals placed the highest emphasis on thermal comfort (mean = 4.8 and 5 respectively), often linking it to performance gaps and the preservation of traditional building features in the comments. In contrast, retrofit designers showed more variability in their responses, suggesting that while thermal comfort is important, it may be balanced against other design considerations in their practice.

In addition to the main factors, respondents also introduced several other considerations, such as the importance of local building regulations, the availability of skilled labour, and the impact of retrofitting on the functionality of the building. Their answers can be summarised into three main topics: a) sustainability and energy efficiency, b) policy and financial incentives and c) practical considerations and client personal motivations.

Participants also mentioned the health of residents, futureproofing, property durability and the importance of maintenance. While policy makers and retrofit coordinators mentioned practical and financial factors as central to retrofitting, such as government funding schemes, space upgrades and the disruption of resident daily life.

3.3.2. *Retrofit success indicators*

Participants also assessed the importance of retrofit outcomes. Among these, improvement to thermal comfort was rated as the most important indicator of success (mean = 4). This aligns with the retrofit priorities discussed in the previous section. As one researcher mentioned, achieving occupant comfort is key for a successful retrofit, alongside implementing effective measures:

[R20] ‘Renovations that fail. Renovations that don’t achieve desired values because of comfort claw back or changes in occupant behaviour or a lack of robustness in the renovation measures’.

Reduced energy bills (mean = 3,82) and indoor air quality (mean = 3,86) were also ranked as important factors. Medium importance was given to the reduction of fossil fuels use and future climate conditions, while slightly lower importance was given to aesthetic parameters (mean = 3,44), building usability (mean = 3,31) and historic preservation (mean = 3,44). The three success indicators with the highest mean from the participants are thermal comfort, reduced energy bills, and indoor air quality. Other outcomes, such as *reduction of fossil fuels*, addressing *future climate conditions*, *building usability* and *historic preservation* were rated as less important on average. These results highlight the complexity of the retrofit process, which involves balancing multiple desired outcomes.

In the comments, participants also introduced additional parameters, such as *client satisfaction* and *financial savings, as essential* for the success of the retrofit projects and the advancement of retrofitting practices. Participants expressed:

[RCRiPCc] ‘Unless the Clients/ Occupants feel that the retrofitting exercise was worthwhile, then they will not help “spread the word “ to others.’.

[RPhc] ‘Outcomes not as important as costs. Why retrofit if it never pays back? Too expensive’.

These comments emphasise the various factors that determine the success of retrofit projections on a larger scale. Success depends not only the technical aspects of building practices but also on client satisfaction and financial returns from retrofits. Participants emphasised that these parameters are crucial for advancing the retrofit industry.

A retrofit coordinator (**RCPCc**) introduced additional factors, highlighting ‘reduced water use’ in addition to energy use key considerations. Similarly, they commented about the future of retrofit, mentioning factors such as ‘building Longevity’, ‘Ease of deconstruction’, ‘Embodied and Sequestered carbon’ and ‘Ease of maintenance. A Retrofit Designer (**RDPCc**) also mentioned the ‘Longevity of building’.

These factors contribute to the sustainability, financial viability, and user satisfaction of retrofit projects, making them essential for the future of retrofitting. This feedback aligns with the broader findings, highlighting the need for a holistic approach to retrofitting that goes beyond energy efficiency.

3.3.3. *Challenges*

Participants were asked to select the most important challenges in the retrofit process. The most selected challenge was dealing with people (0.69). For instance, one participant highlighted the practical challenges faced during retrofit projects:

[RDMsPCc] ‘Disruption to residents is one of the hardest things to overcome. We might need to pay them to move out!’.

However, engaging with residents was also viewed as a valuable opportunity for gaining insights into retrofitting design.

[HPh15] ‘Challenges are opportunities, when it comes to dealing with the householder! Where are the problems? How do they use their building? My approach to retrofit is ’people-first’, definitely NOT “fabric first’’!’.

The roles and responsibilities of participants significantly influenced their perspective, particularly among professional in retrofit design and heritage areas. Disruption to residents, especially in social housing, is well-documented as a major barrier to retrofitting in the UK [58]. On the other hand, residents of historic buildings often engage in energy efficient conscious behaviours [59]. These different contexts may explain the contrast of viewpoints of viewpoints on residents’ engagements in retrofits: dealing with residents as a challenge for the completion of retrofit or residents as an opportunity for knowledge exchange.

Cost effectiveness was another frequently mentioned challenge (0.63). Financial concerns were a recurring theme in the survey responses. Some participants mentioned additional costs, such as remediation costs implemented before any intervention, while others highlighted broader issues financial savings and the need to explore no economic incentives for retrofitting, health benefits. This is especially relevant in fuel poverty retrofits, where incentives are more focused on residents’ health and wellbeing than on direct financial gains.

[RPhc] ‘Existing homes need thousands of pounds of remedial make good works before you can do anything. Too much damp, obstructions, access issues, uncovering problems. Cost of these things can be as much as the actual retrofit.’.

[RPhc] ‘Demand, no one wants to retrofit. Why should they? It doesn’t make economic sense’.

Another highly rated challenge was conservation restrictions (0.55). A few participants felt compelled to balance heritage conservation requirements against energy efficient conservation (n = 3). This balancing act between heritage preservation and energy efficiency in retrofit of historic buildings was recurring in their case, showing the potential need to broader discussions and potential solutions, or conservation guidelines aimed at heritage professionals.

[RCPCc] ‘We had to reduce energy efficiency measures to meet heritage/ conservation requirements in many of our retrofit projects’.

[SR20] ‘The protection of historic fabric is essential and must be considered to ensure there is no over-optimisation that leads to decay and degradation of the building’.

[R20] ‘The detailed requirements of both proper retrofit and good quality ventilation need to be part of the National conversation’.

Other challenges relate to the implementation process and technical problems when designing retrofitting solution, particularly in the context of ventilation systems, external wall insulation and window replacements:

[RCc] ‘Normally (the challenge is) around EWI, so having options that reduce carbon whilst employing other measures than EWI’.

[OMsc] ‘External wall insulation and window replacements are the main challenges’.

The lack of suitable contractors and industry skills was also introduced by participants in the comments as a challenge in the industry in general.

3.4. Retrofit assessment

Regarding the information participants gather before the retrofit to inform or assess the design of projects, several aspects were mentioned. The most common cited aspects were the history of the building and known problems, which were often identified through visual inspections and discussions with the clients. Additionally, infrared (IR) thermography was widely used. For some, like one architect, understanding building before retrofitting was crucial, as each case is unique.

[SR20] 'It is important to capture the true context of a building before deciding on the intended outcomes or energy reduction'.

In terms of retrofit monitoring spot measurements of temperature and relative humidity were the most common (n = 6, 20.68 %), with a few participants also measuring carbon dioxide (CO2) (n = 2, 6.9 %). However, comments highlighted a recognised need for long-term monitoring. While spot measurements and specific tests are important, there is a need within the industry to complement them with long-term monitoring to better assess the success of the retrofit and building performance over time. Regarding methods of assessment, 35 % of participants were aware of Building Performance Evaluation, (n = 7). Researchers and performance evaluators mentioned additional methods like air pressure testing for airtightness and measuring moisture content in existing materials, which are often conducted for research purposes.

3.4.1. Retrofit process regarding thermal comfort

Thermal comfort emerged as one of the most critical priorities and success indicators of retrofit. Nearly half of participants (48.27 %) mentioned using thermal comfort approaches, guidance or standards, with air (dry bulb) temperature being the most measured parameter. (n = 5, 17.24 %). Alternatively, some participants adopt the Passivhaus approach (n = 3, 10.34 %) to inform their projects, while others incorporate user perception by asking about their thermal preferences (n = 3, 10.34 %). Passivhaus approach was explicitly mentioned by three participants, who highlighted the use of PHPP energy calculations to set comfort conditions based on air temperature and to align them with energy bills.

[RDMsPCc] 'We use PHPP energy calculations to inform choices. Typically calibrated against existing energy bills by adjusting the internal temperature assumptions'.

On the contrary, several practitioners emphasised the link between user comfort and behaviour, noting efforts to *'understand the users' patterns'*. The subjectivity of thermal comfort was acknowledged twice through a theoretical and a more practical perspective:

[SR20] 'Building comfort is subjective, so it's important to understand the users and their preferences'.

***[R20*]** 'I tend to accept the clients own subjective view on comfort. In terms of usability, I would consider the access and functionality based on measured survey, followed by probing interview'.

Incorporating subjective thermal comfort assessments has been mentioned as a strategy to lower the rebound effect in specific contexts, such as social housing. However, there is sometimes a difference between the priorities of the client (owner, housing association, council) and the user (resident, employee), which can significantly affect the user's subjective assessment of thermal comfort. For instance, clients such as housing association may prioritise cost-effectiveness and energy efficiency, leading to retrofit decisions that do not align with the user's comfort preferences. If users find the post-retrofit environment too cold or too hot, it can lead to thermal discomfort and an unsatisfying indoor environment, even if the retrofit achieves its energy-saving goals. This shows the need for effective communication between retrofit designers, clients, and users to balance energy efficiency, cost, and user thermal comfort. Notably, 75 % of the retrofit designers and coordinators mentioned that they communicate with clients/users during a retrofit project. However, there is an opportunity to study this communication in greater depth to identify what information can be extracted and utilised to enhance the retrofit design and outcomes.

3.4.2. Post retrofit assessment & post occupancy evaluation

The results showed that energy costs (mean = 3.13) were the most frequently assessed parameter, whilst thermal comfort was less often assessed (mean = 2.40) mainly by researchers, heritage professionals and other roles involved in retrofitting projects. While retrofit designers and coordinators assessed those parameters differently, reporting energy costs (mean = 2.5) and thermal comfort (mean = 1.8). These findings highlight the contradictions between retrofit priorities, success indicators and the practical assessment of retrofit practices.

Three retrofit coordinators mentioned the importance of compliance with Energy Performance Certificates (EPC) and energy bills. While another mentioned the need for evidence in practice:

[RCMs10] 'lightweight, informal resident interview, energy bills'.

[RCPhPCc] 'the lack of measured performance'.

Other mentioned assessment techniques including thermal imaging or thermographic surveys and air pressure tests:

[R20] 'Air pressure testing is a great indicator of quality of works. It should be integrated into the project works phase and the contract.'.

The results indicate that while post occupancy is considered a common practice, they are not consistently conducted after every retrofit project (mean = 1.15). When they are performed, only the BUS Survey is applied. On the other hand, one designer mentioned using consultations with the client as good practice:

[RCRiPcc] 'One-to-one conversation, questions based on experience of Client/ Occupant'.

3.5. Changes in retrofit practice over time & retrofit standards

This section examines the evolving landscape of retrofit practices, focusing on aspects such as regulations, tools for design, understanding technical risk, new materials, priorities, user's involvement. The participants, many of whom have over 20 years of experience in the field, noted a significant shift in their approaches to technical challenges, including fire safety and moisture quality assurance in retrofit processes. These challenges are largely a response to catastrophic failures such as the Preston Green Deal [11,57] and Grenfell Tower [60]. Among the participants, understanding technical risk (mean = 3.93) and the development of standards (mean = 3.59) were identified as the biggest changes in the retrofit practices in recent years. Big progress on topics such as moisture management (mean = 3.51) and the development of new materials (mean = 3.41) were also mentioned. However, regulations (mean = 2.65) and user/community engagement (mean = 2.61) were viewed areas experiencing less changes, suggesting opportunities for further investigation, particularly regarding user involvement, which showed considerable variation in responses. As one participant stated, there is already progress on the subject.

[HPh15] 'All of these have always been of great concern, but my thinking on the people side of things has developed over the years.'.

This statement reveals the dynamic nature of retrofit practices, and the growing recognition of the role users play in retrofit success. It also reinforces the need for further research into how user involvement can be effectively incorporated into retrofit design and implementation to ensure the best outcomes. This is particularly relevant given the wide range of responses on this subject, indicating diverse viewpoints and practices within the field.

User participation is frequently emphasised in sustainability practices, spanning areas like planning and housing development. This emphasis could be even more pronounced in retrofit projects, given that it is identified as one of the two main challenges. An important observation from this study is that, according to practitioners, the priorities in retrofitting have remained largely consistent over the years, with an average rating of 0.52 indicating minimal change. In the comments, one retrofit designer summarised all the above with the following statement:

[RDRic30]. 'Ecological and user-friendly design has always been our priority. Learning through experiment and experience has meant we have always led change on all the above categories. We've developed through this learning over 30 years or more'.

Retrofit practices have significantly changed during the last decade [61], as explained by an experienced retrofit designer. Throughout their professional career, they have engaged in numerous experiments and learned valuable lessons. Despite these advancements and changes in methodologies, the core values and priorities of professional have remained consistent.

3.5.1. Standards and guidance

Despite the advancements in retrofit standards over the years, their adoption remains limited, with only 41.3 % (12 out of 29) of participants reporting their use. When excluding participants from research, standards, and heritage sectors – roles that may not necessarily require adherence to these standards – the responses from retrofit coordinators and designers become particularly noteworthy. Among this more focused group of coordinators, designers, and other specialists (20 in total), the rate of standard adoption is similar at 40 % (8 out of 20). These figures provide an insight into the extent of standard incorporation in the retrofit field.

PAS2035 (UK National Standard for retrofit process) was mentioned as the most used standard in the industry. On one hand coordinators recognise the importance of the PAS2035 for the retrofit process, on the other they question its applicability given its recent introduction into the industry. PAS2025 will require a transition period before is fully adopted:

[RCc] 'PAS2035 will be a game changer if it is applied correctly'.

[RDc] 'I have been undertaking sustainability 'audits' for decades and use this knowledge. Now starting to use PAS'.

Additionally, two designers indicated that they rely heavily on their past experiences when developing retrofits plans, although this reliance would have been greater in the past. It is important to consider that the mandatory implementation of PAS2035 in publicly funded domestic schemes could have significantly influenced these findings. Costs also play a pivotal role, as the decision to use or not a standard like PAS2035 can be influenced by the need for numerous expert roles, which may increase the budget of a project. As one participant explained:

[RDPhc] 'The management of retrofit through PAS2035 is new and only applies to public funded domestic schemes. it seems a good basis for all retrofit projects, if clients can afford the various roles required'.

These observations suggest that there is potential for greater adoption of retrofit standards in the coming years and for the application of these standards beyond domestic retrofit. Practitioners also mentioned using other guides such as CIBSE guidelines, Building Regulations, and Best Practice guidelines, further highlighting the diverse framework supporting retrofit practices.

4. Discussion

As mentioned in the introduction, the priorities for retrofitting can vary based on the specific context and settings, such as social housing, fuel poverty initiatives, and care homes. Given the current pressing need to enhance both the scale and quality of energy-efficient retrofits to achieve carbon targets, it is important to include the perspectives of practitioners in the field, as we can develop a deeper understanding beyond the policies and the standards around factors that form the current retrofit practices. This study has shed light on their priorities, key outcomes, and factors influencing retrofit assessments. The participants, who have long experience and have worked on diverse projects across the UK (including heritage buildings, offices, residential properties, and social housing), provide valuable insights into retrofit practice.

The findings reveal the complexity around understanding the current retrofit practices and decisions-making processes. Practitioners primarily prioritise energy efficiency and the thermal comfort of occupants. The urgency of prioritising thermal comfort in retrofit research and practice, to safeguard user health, and well-being, has been increasingly emphasised by researchers in recent years [21,62,63]. Medal et al. [64] emphasize the importance of energy efficiency in retrofit projects, highlighting its role in enhancing occupant comfort. Van Moeseke et al. [65] provide insights into achieving thermal comfort sufficiency, demonstrating significant energy savings through adaptive heating practices. Collectively, these studies underscore the critical need for practitioners to integrate energy efficiency and occupant comfort into their retrofit strategies. However, they also consider other important factors, such as the heritage and aesthetic value of the building, and potential changes in ownership. Piderit et al. [66] have also proven the need to balance heritage preservation with energy efficiency, particularly in vulnerable contexts.

Participants' comments analysis showed the need to incorporate less frequently used criteria into future sustainability assessments. These criteria include future-proofing buildings, considering the impact of climate change, and accounting for embodied carbon. Such factors are known to the researcher for the role to sustainability [7,67,68]. Integrating sustainability criteria into building retrofits is crucial for enhancing long-term sustainability. Georgiadou et al. [7] emphasize the importance of future-proofing and climate change resilience in retrofit projects, highlighting their role in achieving sustainable outcomes. Juliardi et al. [67] further underscore the environmental, social, and economic benefits of incorporating green building components into renovations. Additionally, Vijayan et al. [68] demonstrate the significant environmental advantages of considering embodied carbon in retrofit projects. It is encouraging that practitioners in this paper recognize the growing importance of these aspects. Researchers can learn from these priorities and develop methods and tools to help practitioners integrate sustainability into their retrofit designs and decisions.

One significant insight from the analysis of the results is that priorities, success indicators, and retrofit assessment criteria do not always align. Energy savings is the common thread, serving as a primary consideration in retrofit practices, a key success indicator, and an incorporated assessment criterion. In contrast, while thermal comfort is recognised by practitioners as an essential retrofit goal, there is notable discrepancy between its documented importance and how effectively it is considered in practice. The design and retrofit assessment practices of descripted in this study often lack a thorough investigation into thermal comfort. Although a user-centric approach is adopted by some participants, and it is reflected in their responses, it could be argued that this aspect is not fully integrated into their overall practice and work philosophy. This interesting finding highlights a gap in the current practices and calls for further research into how thermal comfort can be adequately incorporated into retrofit assessments.

This gap aligns with findings from current research advocating for the role indoor environmental quality in the net zero era to safeguard the user comfort, health, and well-being [21,62,63]. Thermal comfort as one of main components of indoor environmental quality is critically important. The findings of this survey suggest that thermal comfort could be the link for further integrating indoor environmental quality into retrofit practices, given its recognition as both priority and a success indicator. While other indoor Environmental Quality parameters, such as indoor air quality, were mentioned as success indicator, they received lower priority from participants. This highlights an opportunity for greater emphasis on indoor environmental quality in future in pre and post retrofit assessments, aligning with specific retrofit goals and success indicators.

Additionally, occupants' health is a concern raised by participants. However, there is currently no direct connection to retrofit design parameters or performance indicators, although the connection between indoor environmental quality factors and health aspects have been established [69]. Implementing specific criteria for indoor environmental quality and particularly regarding thermal comfort and indoor air quality could be a possible way to address this concern, although further research on the subject is needed.

Participants identified cost effectiveness as a challenge, noting it as one of the primary obstacles to advancing retrofit practices. This finding could indicate the need to explore different comfort and health incentives in retrofit projects. Another big challenge is the relationship with users and clients. While the technical aspects and risks associated with retrofitting have shown considerable progress in recent years, they remain among the lowest rated challenges. These current challenges highlight areas where research and policy could concentrate efforts to gather knowledge and provide guidance through the retrofit process. Even though, there isn't a consensus on challenges, technical challenges potentially have been overcome, and the current retrofit challenges are of socioeconomical nature. The results in this study could suggest the need for new tools and methods such a sociotechnical approach to retrofit design to address such challenges. In fields like planning and housing, users are increasingly recognised as key stakeholders through engaged research and policy tools [70,71]. This acknowledgment could serve as a potential next step for the retrofit practice. In this context, investigating thermal comfort perception could serve as a potential links between the practitioners' priorities and user engagement. In the field of thermal comfort research, there is an ongoing discussion about transitioning towards the inclusion of adaptive comfort principles in retrofit design practices [72,73]. This shift recognises the dynamic nature of comfort preferences and the need to incorporate the user and personalized comfort to effectively tackle the challenges posed by climate change.

Retrofit challenges identified in this study-such as cost-effectiveness, resident engagement, and the tension between heritage conservation and energy efficiency-are closely aligned with those found in the wider European context. Similar studies employing surveys, workshops, and interviews with retrofit professionals across Europe consistently reveal the need for holistic, whole-building approaches and highlight the benefits of industrialized solutions, such as prefabrication, which can improve quality and reduce costs and disruption for occupants. Across Europe, retrofit efforts are hindered by high upfront costs, limited access to affordable financing, and fragmented supply chains, which collectively slow the pace and scale of deep retrofit [4,38,74]. Technical barriers, including a shortage of skilled professionals and the need for tailored solutions for historic or multi-unit buildings, are also reported [7]. The last point is also re-affirmed by this study.

However, this UK-focused study adds a unique dimension to these studies, the gap between practitioners' prioritisation of thermal comfort and the practical realisation of these outcomes, particularly in the social housing sector. While European literature emphasizes the need for user-centered approaches and adaptive comfort principles [17,18], the present findings showcase the difficulties practitioners face in integrating these principles within existing regulatory and funding frameworks. Furthermore, the study's results for resident engagement and the performance gap between design intentions and real-world outcomes echoes concerns raised in European research about information asymmetries and the limitations of techno-economic approaches [4,47]. Overall, while the structural challenges are similar across Europe, the UK's focus on practitioner-led priorities and the integration of thermal comfort into retrofit practice provides potentially a first step for developing more user-centered retrofit strategies continent-wide.

Retrofit practices and approaches have continuously evolved in response to environmental and societal needs, new materials, and technologies. It is noteworthy that certain areas and approaches, such as retrofit priorities have remained the same. However, the implementation of standards, specifically PAS2035, has provided participants with a deeper understanding of the technical risks associated with retrofitting. This development is documented in this study as a milestone and a paradigm shift in the industry.

One of the most intriguing points highlighted in this study is the breadth of topics, viewpoints, and the depth of participant responses. Some participants reflected on the scale of a retrofit project, while others reflected on the needs of the industry, introducing ideas at a more theoretical level. This diversity can be attributed to the extensive experience and the diverse roles of most participants. This variability became especially evident when exploring retrofit assessments and the different performance evaluation methods applied. In parallel, an aspect to consider is the variability in respondents' interpretations of the term "retrofit." This term may be understood differently by various practitioners, which can influence their responses. Some participants might prioritize energy use and efficiency because they interpret "retrofit" primarily in terms of energy savings and carbon reduction. On the contrary, others might have a broader understanding that combines various aspects of sustainability, such as thermal comfort, health, and well-being. This variation in interpretation could affect the consistency and comparability of the responses but could be also evidence for the interdisciplinary nature of retrofit. Recognizing the interdisciplinary nature of the subject and these differences is crucial for accurately assessing the priorities and practices of retrofit practitioners in the future.

One significant limitation of this study is the potential variability in respondents' interpretations of the term "retrofit." The term may be understood differently by different practitioners, which could influence their responses. Some participants might prioritize energy use and efficiency because they interpret "retrofit" primarily in terms of energy savings and carbon reduction. In contrast, others might have a broader understanding that includes various aspects of sustainability, such as thermal comfort, health, and well-being. This variation in interpretation could affect the consistency and comparability of the responses, potentially impacting the study's results.

Finally, a specific aspect that was evident throughout the survey is the conflicting nature of energy savings and the heritage preservation. The results highlighted a different approach to retrofit from heritage practitioners, who expressed a need for a specific retrofit solutions and criteria tailored to historic buildings. The percentage of heritage professionals inside the sample was small, however, their answers varied significantly. This can indicate a need for further investigation for deeper understanding of the complexities surrounding the balance between energy retrofit and heritage preservation.

5. Conclusions

The urgency of prioritising thermal comfort in retrofit research and practice, to safeguard user health, and well-being, has been increasingly emphasised by researchers in recent years. The accelerating effects of climate change pose new challenges and expectations for indoor environmental quality among residents. The upscaling of retrofit must be reflected both in the quantity and quality of the measures. To date, retrofit practices have primarily been driven by energy efficiency and financial considerations, a trend evident in policy, research, and practice.

The results of this study, a survey of 29 retrofit practitioners in the UK, support this observation. While practitioners acknowledge the significance of comfortable and healthier homes, this recognition is not consistently reflected in their practices. For example, although they are aware of health risks linked to excessive moisture and its impact on thermal comfort, they report a lack of technical tools to prevent such problems. Despite the introduction of a standard that aims to ensure that energy retrofit projects deliver measurable improvements in building performance, while protecting occupant health and building fabric (PAS2035), the need for appropriate and detailed ventilation design remains one aspect that has yet to be resolved. Interestingly, less than half of the practitioners reported using regulations and guidance in their practice. This study has identified a need for a more practical consideration of research and standards. A broader application of standards and a development of new tools for professionals, could manage this misalignment between the priorities and values of professionals and their current constraints to apply them. Financial restrictions also have risen as one important limiting factor.

Finally, this research has shown that energy retrofit is an interdisciplinary and multi-layered topic. Besides energy savings, other parameters are also found to be considered in practice. Thermal comfort is recognised as one of the two main priorities for energy retrofitting besides energy efficiency. Both are regarded as the most important indicators of a successful retrofit process. However, thermal comfort assessment is not yet a common practice. Some practitioners advocate for even broader considerations of sustainability beyond energy efficiency. An important finding is that the role of the practitioner is a critical factor in their priorities and in general their perspective. This reaffirms the mantra ''not one solution fits all'' for retrofit approaches and argues for tailored methodologies regarding building type, use and context. A special consideration to historic buildings as retrofitting in such cases requires a sensitive balance between improving energy performance and preserving heritage value. This can mean added consideration in the design such as solutions that respect original materials, construction techniques, and architectural character, or reversible measures. In general, this paper contributes to the deeper understanding of retrofit practices and decision-making criteria in the retrofit process. Future work will investigate methodologies to include the user comfort perception and perspective in the retrofit design.

In future studies, the needs and priorities from users, in this case residents, will be explored to understand the similarities and differences between professionals and users in energy retrofit. In parallel, the current research landscape about retrofit priorities could be explored, to understand the It's critical to understand in depth all the different agents that contribute to retrofit success to plan more effectively for the future.

Data accessibility

The data gathered from the survey have not yet been made publicly available. The data may be available under certain conditions, however, so please contact the authors.

CRediT authorship contribution statement

Athina Petsou: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Hector Altamirano:** Writing – review & editing, Supervision, Validation, Conceptualization, Funding acquisition. **Sung-Min Hong:** Writing – review & editing. **Valentina Marincioni:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.enbuild.2025.116288.

Data availability

Data will be made available on request.

References

[1] European Union, Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings, Off. J. Eur. Union. L 153 (2010) pp13–35.

[2] Element Energy, Analysis of a Net Zero 2030 Target for Greater London, Greater London Authority, London, UK, 2022. [Online]. Available: https://www.london.gov.uk/sites/default/files/nz2030_element_energy.pdf.

[3] Committee on Climate Change, UK Housing: Fit for the Future?, London, UK, 2019. [Online]. Available: https://www.theccc.org.uk/wp-content/uploads/2019/02/UK-housing-Fit-for-the-future-CCC-2019.pdf.

[4] F. Wade, H. Visscher, Retrofit at scale: accelerating capabilities for domestic building stocks, Build. Cities 2 (1) (2021), https://doi.org/10.5334/bc.158.

[5] Bankers for Net Zero, Tooling Up the Green Homes Industry, London, UK, 2022. [Online]. Available: https://www.bankersfornetzero.co.uk/wp-content/uploads/2022/05/Tooling-up-the-Green-Homes-Industry_FINAL.pdf.

[6] D. Bjelland, J. Brozovsky, B.D. Hrynyszyn, Systematic review: upscaling energy retrofitting to the multi-building level, Renew. Sustain. Energy Rev. 198 (2024) 114402, https://doi.org/10.1016/j.rser.2024.114402.

[7] M.C. Georgiadou, T. Hacking, P. Guthrie, A conceptual framework for future-proofing the energy performance of buildings, Energy Policy 47 (2012) 145–155, https://doi.org/10.1016/j.enpol.2012.04.039.

[8] L.V. Madsen, K. Gram-Hanssen, Understanding comfort and senses in social practice theory: Insights from a Danish field study, Energy Res. Soc. Sci. 29 (2017) 86–94, https://doi.org/10.1016/j.erss.2017.05.013.

[9] T. Sharpe, et al., Hab-Lab: development a light-touch BPE methodology for retrofit, in: Proc. PLEA 2018 Conf., Hong Kong, China, 2018. [Online]. Available: https://pure.strath.ac.uk/ws/portalfiles/portal/100008694/Sharpe_etal_PLEA2018_Hab_Lab_development_light_touch_BPE_methodology_for_retrofit.pdf.

[10] C. Shrubsole, A. Macmillan, M. Davies, N. May, 100 unintended consequences of policies to improve the energy efficiency of the UK housing stock, Indoor Built Environ. 23 (3) (2014) 340–352, https://doi.org/10.1177/1420326X14524586.

[11] K. de Selincourt, Disastrous Preston retrofit scheme remains unresolved, Passive House Plus (2018). [Online]. Available: https://passivehouseplus.ie/news/health/disastrous-preston-retrofit-scheme-remains-unresolved (accessed 30 May 2025).

[12] R. Galvin, A. Gubernat, The rebound effect and Schatzki's social theory: reassessing the socio-materiality of energy consumption via a German case study, Energy Res. Soc. Sci. 22 (2016) 183–191, https://doi.org/10.1016/j.erss.2016.08.024.

[13] British Standards Institution, PAS 2035:2023 – Retrofitting dwellings for improved energy efficiency – Specification and guidance, BSI Standards Limited, London, UK, 2023. [Online]. Available: https://retrofitacademy.org/wp-content/uploads/2023/10/PAS2035_2023.pdf.

[14] R. Macrorie, Reconstructing low-energy housing using 'systems of practice', PhD Thesis, University of East Anglia, Norwich, UK, 2016. [Online]. Available: https://ueaeprints.uea.ac.uk/id/eprint/58553/1/MACRORIE_FINAL_PHD_MARCH16.pdf.

[15] E. Hinton, Review of the literature relating to comfort practices and socio-technical systems, Environ. Polit. Dev. Work. Pap. Ser. 35, King's College London, London, UK, 2010.

[16] C. Cherry, C. Hopfe, B. MacGillivray, N. Pidgeon, Homes as machines: exploring expert and public imaginaries of low carbon housing futures in the United Kingdom, Energy Res. Soc. Sci. 23 (2017) 36–45, https://doi.org/10.1016/j.erss.2016.10.011.

[17] G. Van Moeseke, D. De Grave, A. Anciaux, J. Sobczak, G. Wallenborn, New insights into thermal comfort sufficiency in dwellings, Build. Cities 5 (1) (2024), https://doi.org/10.5334/bc.444.

[18] F.J. de Feijter, B.J.M. van Vliet, Housing retrofit as an intervention in thermal comfort practices: Chinese and Dutch householder perspectives, Energ. Effi. 14 (1) (2021), https://doi.org/10.1007/s12053-020-09919-8.

[19] J. Alabid, A. Bennadji, M. Seddiki, A review on the energy retrofit policies and improvements of the UK existing buildings, challenges and benefits, Renew. Sustain. Energy Rev. 159 (2022) 112161, https://doi.org/10.1016/j.rser.2022.112161.

[20] H. Elsharkawy, P. Rutherford, Energy-efficient retrofit of social housing in the UK: lessons learned from a Community Energy Saving Programme (CESP) in Nottingham, Energy Build. 172 (2018) 295–306, https://doi.org/10.1016/j.enbuild.2018.04.067.

[21] A. Vilches, Á. Barrios Padura, M. Molina Huelva, Retrofitting of homes for people in fuel poverty: approach based on household thermal comfort, Energy Policy 100 (2017) 283–291, https://doi.org/10.1016/j.enpol.2016.10.016.

[22] L. Desvallées, Low-carbon retrofits in social housing: energy efficiency, multidimensional energy poverty, and domestic comfort strategies in southern Europe, Energy Res. Soc. Sci. 85 (2022) 102413, https://doi.org/10.1016/j.erss.2021.102413.

[23] E. Elsharkawy, P. Rutherford, Retrofitting social housing in the UK: home energy use and performance in a pre-Community Energy Saving Programme (CESP), Energy Build. 88 (2015) 25–33, https://doi.org/10.1016/j.enbuild.2014.11.045.

[24] D. Teli, T. Dimitriou, P.A.B. James, A.S. Bahaj, L. Ellison, A. Waggott, Fuel poverty-induced "prebound effect" in achieving the anticipated carbon savings from social housing retrofit, Build. Serv. Eng. Res. Technol. 37 (2) (2016) 123–138, https://doi.org/10.1177/0143624415621028.

[25] M. Avanzini, M.D. Pinheiro, R. Gomes, C. Rolim, Energy retrofit as an answer to public health costs of fuel poverty in Lisbon social housing, Energy Policy 160 (2022) 112658, https://doi.org/10.1016/j.enpol.2021.112658.

[26] Department for Energy Security & Net Zero, Warm Homes Skills Fund: Competition Guidance, UK Government, London, UK, 2025. [Online]. Available: https://assets.

publishing.service.gov.uk/media/68358a198bb692c0b0b4bd71/warm-homes-skills-fund-competition-guidance.pdf.
[27] K. Simpson, N. Murtagh, A. Owen, Domestic retrofit: understanding capabilities of micro-enterprise building practitioners, Build. Cities 2 (1) (2021) 449–466, https://doi.org/10.5334/bc.106.
[28] B. Butt, R.V. Jones, A. Fuertes, Opportunities and barriers to business engagement in the UK domestic retrofit sector: an industry perspective, Build. Serv. Eng. Res. Technol. 42 (3) (2021) 293–305, https://doi.org/10.1177/0143624420975640.
[29] N. Murtagh, A.M. Owen, K. Simpson, What motivates building repair-maintenance practitioners to include or avoid energy efficiency measures? Evidence from three studies in the United Kingdom, Energy Res. Soc. Sci. 73 (2021) 101943, https://doi.org/10.1016/j.erss.2021.101943.
[30] M. Tehami, M. Seddiki, *Investigation toward the adoption of Building Information Modelling in Algeria from architects' perspective*, J. Constr. Dev. Ctries. 28 (2023) 329–352, https://doi.org/10.21315/jcdc-08-22-0148.
[31] ObjectPlanet, *Opinio survey software* [software], ObjectPlanet, 2025. https://www.objectplanet.com/opinio/.
[32] Construction Leadership Council, *National Retrofit Strategy: Version 2* [online], Construction Leadership Council, 2021. https://www.constructionleadershipcouncil.co.uk/wp-content/uploads/2021/05/Construction-Leadership-Council-National-Retrofit-Strategy-Version-2.pdf [Accessed 20 May 2025].
[33] UK Government, *Heat and Buildings Strategy* [online], Department for Energy Security and Net Zero, 2021. https://www.gov.uk/government/publications/heat-and-buildings-strategy [Accessed 20 May 2025].
[34] UK Green Building Council (UKGBC), *Net Zero Whole Life Carbon Roadmap: Technical Report* [online], UKGBC, 2021. https://ukgbc.org/wp-content/uploads/2021/11/UKGBC-Whole-Life-Carbon-Roadmap-Technical-Report.pdf [Accessed 20 May 2025].
[35] UK Government, *The Future Homes Standard: Changes to Part L and Part F of the Building Regulations for New Dwellings* [online], Ministry of Housing, Communities & Local Government, 2021. https://www.gov.uk/government/consultations/the-future-homes-standard-changes-to-part-l-and-part-f-of-the-building-regulations-for-new-dwellings [Accessed 20 May 2025].
[36] TrustMark, *TrustMark Quality Assurance Guidance for Government-Funded Schemes* [online], TrustMark, 2024. https://www.trustmark.org.uk/tradespeople/quality-assurance-guidance-government-funded-schemes [Accessed 20 May 2025].
[37] STBA, *EPCs & The Whole House Approach* [online], Sustainable Traditional Buildings Alliance, 2018. https://stbauk.org/wp-content/uploads/2020/08/EPCs-The-Whole-House-Approach.pdf [Accessed 20 May 2025].
[38] T. Fawcett, M. Topouzi, *Residential retrofit in the climate emergency: the role of metrics*, Build. Cities 1 (2020) 475–490, https://doi.org/10.5334/bc.37.
[39] Technology Strategy Board, *Retrofit Revealed: The Retrofit for the Future projects – Data analysis report* [online], Technology Strategy Board, 2018. https://assets.publishing.service.gov.uk/media/5a81c336ed915d74e6233fb0/Retrofit_Revealed_-The_Retrofit_for_the_Future_projects-_data_analysis_report.pdf [Accessed 20 May 2025].
[40] K. Kelley, B. Clark, V. Brown, J. Sitzia, *Good practice in the conduct and reporting of survey research*, Int. J. Qual. Health Care 15 (2003) 261–266, https://doi.org/10.1093/intqhc/mzg031.
[41] G.W.K. Ho, *Examining perceptions and attitudes: a review of Likert-type scales versus Q-methodology*, West. J. Nurs. Res. 39 (2017) 674–689, https://doi.org/10.1177/0193945916661302.
[42] H. Taherdoost, *What is the best response scale for survey and questionnaire design: Review of different lengths of rating scale / attitude scale / Likert scale*, Int. J. Acad. Res. Manag. 8 (2019) 1–10.
[43] F. Brocklehurst, E. Morgan, K. Greer, J. Wade, G. Killip, Domestic retrofit supply chain initiatives and business innovations: an international review, Build. Cities 2 (2021) 472–489, https://doi.org/10.5334/bc.95.
[44] A. Genovese, S.C.L. Koh, A. Acquaye, Energy efficiency retrofitting services supply chains: evidence about stakeholders and configurations from the Yorkshire and Humber region case, Int. J. Prod. Econ. 144 (1) (2013) 20–43, https://doi.org/10.1016/j.ijpe.2012.12.019.
[45] R. Atkinson, J. Flint, Accessing hidden and hard-to-reach populations: snowball research strategies, Soc. Res. Update. 33 (2001). https://sru.soc.surrey.ac.uk/SRU33.html.
[46] K. Fouseki, D. Newton, K.S. Murillo Camacho, S. Nandi, T. Koukou, Energy efficiency, thermal comfort, and heritage conservation in residential historic buildings as dynamic and systemic socio-cultural practices, Atmos. 11 (2020) 604, https://doi.org/10.3390/atmos11060604.
[47] F. Wise, A. Gillich, P. Palmer, Retrofit information challenges and potential solutions: perspectives of households, retrofit professionals and local policy makers in the United Kingdom, Energy Res. Soc. Sci. 119 (2025) 103866, https://doi.org/10.1016/j.erss.2024.103866.
[48] D. Brown, L. Middlemiss, M. Davis, R. Bookbinder, I. Cairns, M. Hannon, G. Mininni, M.C. Brisbois, A. Owen, S. Hall, Rethinking retrofit: relational insights for the design of residential energy efficiency policy, Energy Res. Soc. Sci. 120 (2025) 103863, https://doi.org/10.1016/j.erss.2024.103863.
[49] CIBSE, 2025. Chartered Institution of Building Services Engineers [online]. https://www.cibse.org/[Accessed 30 May 2025].
[50] Engineering Council, 2025. Chartered Engineer (CEng) [online]. https://www.engc.org.uk/ceng [Accessed 30 May 2025].
[51] Efficiency Valuation Organization (EVO), 2025. International Performance Measurement and Verification Protocol (IPMVP) [online]. https://evo-world.org/en/products-services-mainmenu-en/protocols/ipmvp [Accessed 30 May 2025].
[52] BREEAM, 2025. BREEAM – Sustainable Building Certification [online]. https://breeam.com/ [Accessed 30 May 2025].
[53] UK Government, 2025. Standard Assessment Procedure (SAP) [online]. https://www.gov.uk/guidance/standard-assessment-procedure [Accessed 30 May 2025].
[54] RIBA, 2025. RIBA Part 3 – Advanced Diploma in Professional Practice in Architecture [online]. https://www.architecture.com/education-cpd-and-careers/studying-architecture/riba-part-3 [Accessed 30 May 2025].
[55] Passivhaus Trust, 2025. *Certification.* [online] Available at: https://www.passivhaustrust.org.uk/certification.php [Accessed 30 May 2025].
[56] N. Eyre, T. Fawcett, M. Topouzi, G. Killip, T. Oreszczyn, K. Jenkinson, J. Rosenow, Fabric first: is it still the right approach? Build. Cities 4 (1) (2023) https://doi.org/10.5334/bc.388.
[57] Historic England, 2021. *When retrofit goes wrong.* [online] Available at: https://historicengland.org.uk/research/heritage-counts/heritage-and-environment/introduction-to-retrofitting/when-retrofit-goes-wrong/ [Accessed 30 May 2025].
[58] D.J. Morgan, C.A. Maddock, C.B.A. Musselwhite, These are tenants not guinea pigs: barriers and facilitators of retrofit in Wales, United Kingdom, Energy Res. Social Sci. 111 (2024) 103462, https://doi.org/10.1016/j.erss.2024.103462.
[59] F. Wise, D. Jones, A. Moncaster, Reducing carbon from heritage buildings: the importance of residents' views, values and behaviours, J. Arch. Conserv. 27 (1–2) (2021) 74–91, https://doi.org/10.1080/13556207.2021.1933342.
[60] Voutsadakis, E. and Gonzalez, C., 2018. Grenfell Tower fire: the importance of ethics and professionalism for the procurement of safe buildings and infrastructure in the construction industry. In: *International Conference on Professionalism and Ethics in Construction*, London, UK, 21–22 November 2018.
[61] F. Liu, C.J. Anumba, A.K. Jallow, P. Carrillo, Integrated change and knowledge management approach for energy retrofits, J. Archit. Eng. 26 (1) (2020) 0000380, https://doi.org/10.1061/(ASCE)AE.1943-5568.0000380.
[62] O. McGinley, P. Moran, J. Goggins, An assessment of the key performance indicators (KPIs) of energy efficient retrofits to existing residential buildings, Energies. 15 (1) (2022) 10334, https://doi.org/10.3390/en15010334.
[63] S. Roumi, F. Zhang, R.A. Stewart, M. Santamouris, Weighting of indoor environment quality parameters for occupant satisfaction and energy efficiency, Build. Environ. 228 (2023) 109898, https://doi.org/10.1016/j.buildenv.2022.109898.
[64] L.A. Medal, Y. Sunitiyoso, A.A. Kim, Prioritizing decision factors of energy efficiency retrofit for facilities portfolio management, J. Manag. Eng. 37 (2) (2021) 0000878, https://doi.org/10.1061/(ASCE)ME.1943-5479.0000878.
[65] G. Van Moeseke, D. De Grave, A. Anciaux, J. Sobczak, G. Wallenborn, New insights into thermal comfort sufficiency in dwellings, Build. Cities 5 (1) (2024) 444, https://doi.org/10.5334/bc.444.
[66] M.B. Piderit, F. Vivanco, G. Van Moeseke, S. Attia, Net zero buildings—a framework for an integrated policy in Chile, Sustainability. 11 (5) (2019) 1494, https://doi.org/10.3390/su11051494.
[67] R.D. Juliardi, M.S. Misnan, A.G. Khalid, L. Haron, Recognizing of building components to achieve green performance for renovation and retrofitting works, IOP Conf. Ser.: Earth Environ. Sci. 353 (2019) 012017, https://doi.org/10.1088/1755-1315/353/1/012017.
[68] D.S. Vijayan, P. Devarajan, A. Sivasuriyan, A. Stefańska, E. Koda, A. Jakimiuk, M. D. Vaverková, J. Winkler, C.C. Duarte, N.D. Corticos, A state of review on instigating resources and technological sustainable approaches in green construction, Sustainability. 15 (2023) 6751, https://doi.org/10.3390/su15086751.
[69] Y. Al Horr, M. Arif, M. Katafygiotou, A. Mazroei, A. Kaushik, E. Elsarrag, Impact of indoor environmental quality on occupant well-being and comfort: a review of the literature, Int. J. Sustain. Built Environ. 5 (1) (2016) 1–11, https://doi.org/10.1016/j.ijsbe.2016.03.006.
[70] H.A.M. Hamdan, P.H. Andersen, L. de Boer, Stakeholder collaboration in sustainable neighborhood projects—a review and research agenda, Sustain. Cities Soc. 68 (2021) 102776, https://doi.org/10.1016/j.scs.2021.102776.
[71] J. Hoffman, Enhancing community engagement in scenario-based urban planning and policy development using experiential futures, J. Urbanism. (2024), https://doi.org/10.1080/17549175.2024.2307049.
[72] A. Albatayneh, M. Jaradat, M.B. Alkhatib, R. Abdallah, A. Juaidi, F. Manzano-Agugliaro, The significance of the adaptive thermal comfort practice over the structure retrofits to sustain indoor thermal comfort, Energies. 14 (10) (2021) 2946, https://doi.org/10.3390/en14102946.
[73] R. Yao, S. Zhang, C. Du, M. Schweiker, S. Hodder, B.W. Olesen, J. Toftum, F. R. d'Ambrosio, H. Gebhardt, S. Zhou, F. Yuan, B. Li, Evolution and performance analysis of adaptive thermal comfort models—a comprehensive literature review, Build. Environ. 217 (2022) 109020, https://doi.org/10.1016/j.buildenv.2022.109020.
[74] Odyssee-Mure. Energy renovation of buildings in Spain and the EU. Odyssee-Mure Policy Brief. 2021. Available at: https://www.odyssee-mure.eu/publications/policy-brief/building-renovation-spain-eu.html (accessed 30 May 2025).