Challenges to carbon reduction policies upon residential heritage buildings (RHB): a Low Carbon Village study

Fiona Forster[a,*], Kishor T. Zingre[b]

[a]*National Trust, Land amd Estates Department, Heelis, Kemble Drive, Swindon, Wiltshire, SN2 2NA*

[b]*Faculty of Engineering and Environment, Northumbria University, Newcastle upon Tyne, NE1 8ST, UK*

*Correspondence: fiona.forster@nationaltrust.org.uk

Abstract

In the UK, residential heritage buildings (RHB) are facing significant conservation challenges from policies aiming to achieve net zero carbon emissions and associated retrofit recommendations. Currently, most studies are primarily focused on investigating the impact of carbon reduction policies upon non-heritage buildings with limited regard for vernacular conservation principles, emphasising the need for a detailed study to understand policy changes upon RHB. Consequently, this long-term (2007- ongoing) study focuses on specific geographic locale, rather than the generic, considering current policy influence upon a cluster of 12 RHB on the National Trust's Wallington Estate in Northumberland, England. Data was collected using a combination of building measurements and survey observations, alongside assessing tenant behaviours through an interview process. Firstly, case studies emphasised the weaknesses of energy performance certificates (EPC) as a policy tool when considering energy retrofit options to RHB, despite a 53% increase in EPC ratings following retrofit. Furthermore, supporting the recent turnaround on proposed minimum EPC 'C' standards, collected post-refurbishment tenant perspectives highlighted tenant behaviours and the unrealistic policy proposal to increase minimum EPC ratings within the UK's existing housing stock, particularly upon idiosyncratic RHB.

Keywords: Carbon reduction; National Trust; Residential heritage buildings; Conservation; Tenant behaviour.

1. Introduction

Climate change is the largest threat towards conserving RHB, those constructed pre-1919, for future purpose [1] and with around 40% of the UK's overall carbon footprint arising from the built environment [2], the UK Government have implemented a swathe of policies aiming to address this global issue and shape a path to net zero [3]. The Climate Change Act 2008 created a legally binding agenda for reducing greenhouse gas emissions and identified 'research gaps' in quantifying current and future risks to culturally valued structures and the wider historic built environment from climate change [4]. Policies influence the preservation of RHB as demonstrated by the Energy Act 2011 legislation which provided the framework for the now obsolete Green Deal policy and current Minimum Energy Efficiency Standards (MEES) which are still applicable within the private rented sector [5]. Currently, limited studies examine the effectiveness of MEES regulations upon RHB whilst considering the effect of tenant behaviour and consequent impact upon heritage organisations, such as the National Trust, who need to manage the juxtaposition of RHB delivering essential rental income to fund conservation, yet simultaneously not impede progress towards organisational goal of net zero carbon. Ultimately, energy efficiency regulations created within the geopolitical macro-environment, such as MEES, impact upon the micro-environment of heritage organisations.

Whilst the UK Government's Net Zero Strategy contains policies focusing on reducing carbon generated from the use of a property, MEES compliance uses measurements to produce EPCs based upon estimated energy cost per m^2 through the standardised Reduced data Standard Assessment Procedure (RdSAP) modelling tool, creating a conflict between two strategic aims. EPCs derived from RdSAP often influence government policies and funded retrofit programmes, such as the Green Homes Grant [6] and Boiler Upgrade Scheme. Consequently, energy reduction within historic properties can be difficult to achieve due to limited retrofitting capabilities [5], and therefore, fail to achieve carbon reduction goals [7]. As preservation means maintaining the integrity, identity and functional efficiency of a cultural asset [8], multidisciplinary approaches are essential in order to improve active functionality and prevent further decay of built heritage assets from climate change [9]. Whilst this paper provides wider context of policies targeting carbon emission reductions when considering retrofit options, the implementation of mixed methods research created nomological link between theoretical framework with the empirical framework of collected research data [10]. Findings highlighted the need to analyse the future impact of such policies upon RHB and this study assesses twelve case studies within the Trust's care over a time period of over 10 years, evaluating data collected between 2007 – 2010 from an LCV pilot scheme in comparison to data collected in 2022 following MEES refurbishment works, to examine the influence of carbon reduction policies upon RHB.

2. Review of previous studies

Whilst a drastic reduction in carbon emissions would slow climate change, an alteration in climate is already certain [11], creating threats to the long-term survival of tangible built cultural heritage [12]. Thurley [13] asserted that 'the arguments for keeping old buildings will shift from the old ground of historical and architectural value and will increasingly revolve around carbon reduction'. Creating a low-emission society frequently conflicts with the continued use of historic buildings [14], yet as identified in the *Heritage Responds* report [15] decarbonising historic buildings is core to accomplishing net zero emissions by 2050 [16]. The RIBA [17] estimate twenty-five million existing homes will need to be energy-retrofitted over the next 30 years to meet 2050 carbon targets, therefore it is imperative to improve energy efficiency within existing buildings, of which 20% are historic, through the practice of retrofit [18]. Berg [19] argues the cost-effective and resilient retrofit of RHB should follow a 'fabric first' hierarchal procedure where improvement of the thermal envelope precedes installation of energy efficient technology and conversion to renewable energy sources. Yet, 'fabric first' may not be the most suitable approach in the context of a rapidly decarbonising electricity grid [20] and an alternative perspective within the heritage sector is a 'think first' approach which includes time to understand a building, the people and the way a home is used [18].

Interestingly, the most significant durability problems experienced in existing buildings is through high demand for internal building comfort [21] with homes the second largest consumers of energy in the UK after transport, largely due to energy required to heat buildings [22]. Balancing thermal comfort with building preservation is one of the greatest challenges for retrofitting RHB [17]. Empirical evidence reveals significant discrepancy in residential buildings between calculated energy demand and actual measured energy consumption of a household [23], described as the performance gap. As discussed, there is an established conflict between net zero carbon and MEES regulations from the EPC methodology of RdSAP calculating energy efficiency of existing dwellings. Whilst an EPC permits comparisons to be made between different properties as a compliance tool [24], Gram-Hanssen [25] argues EPCs should encourage energy reduction, however, current modelling software often underestimates the thermal performance of historic properties [26] providing an inaccurate picture of actual energy use, thus suggested recommendations for retrofit are often not tailored to a building, nor are resident behaviours and values considered [27]. Research by Wise et al. [7] showed RdSAP overestimated energy use within heritage buildings by an average of 66% and asserted the accuracy of RdSAP tools must be significantly improved to inform correct retrofit decisions on RHB, by combining EPCs with metrics reflecting actual energy use, adding options for assessing physical condition of the building and behavioural tailoring. To achieve energy efficiency targets, tenant behaviours need to be considered throughout energy retrofit process for success [19] as homes do not consume energy but people in homes with different types of practices and different technologies consume energy [25]. Interestingly, energy behaviours in heritage buildings have been shown to differ in some contexts to those in modern buildings [28]. Whilst the environmental benefits of reducing carbon are prominent within research literature, operational energy use is less so [7]. Fouseki and Cassar [29] support this further stating how people use a building is often more important than the type of energy efficiency technologies selected. Historic England [30] suggest future research should undertake an occupant-centric approach as ultimately, buildings don't use energy – people do [31].

In 2015, almost 79% of homes in England had an EPC rating of 'D' or better, compared to 39% in 2005 [32]. Whilst the accuracy of EPCs is debated, fundamentally, EPCs are a compliance tool from Part L of the Building Regulations dealing with energy efficiency requirements [26]. Yet, householders understanding of EPCs are still considerably low, with Amecke [33] stating low relevance attached to EPCs can be attributed to policy circumstances, rather than design, suggesting how increasing importance of EPCs as a decision-making criterion for tenants would produce more valuable energy efficiency regulations. Using EPC ratings to drive lower emissions is unlikely to work in practice as ratings are linked to type of energy and costs [34]. For example, case studies evaluated for research are all off-grid, often using electricity to produce space heating and thus penalised on EPC assessment despite lower rate of emissions produced by electricity. Passivhaus Trust [34] argue how as carbon emissions related to expensive electricity continue to reduce, the EPC rating system will become increasingly inaccurate and suggests space heating demand should be used as primary metric to measure energy efficiency.

Berg et al. [19] states 'further investigations should study interplay between policy instruments for energy saving, heritage and conservation principles, as well as the psychological drivers behind tenant energy behaviour'. The quantity of current research projects concerning energy efficiency within historic buildings is testament to the continuing importance of this subject area [35]. Yet, cultural heritage-specific research challenging climate adaptation efforts to minimise adverse impacts on built heritage are scarce within climate change literature and policy documents [36]. Yarrow [37] presented how application of general policies upon historical buildings causes conflict between legislation promoting preservation of cultural heritage against regulations requiring reduction of energy consumption within buildings, such as MEES Regulations. Consequently, this study evaluated the recent National Trust refurbishment scheme in response to current MEES regulations with data collection focusing on occupant interactions with building fabric and services [38], as although rebound effects are relatively well understood, research on aspects of occupant operational energy use is less reflected upon within carbon reduction research [7]. Additionally, there is a lack of data both prior to and post-retrofit to assess effectiveness of carbon reduction measures through case study research. As suggested by Berg [19], considering the retrofit hierarchal procedure to improve the thermal envelope before installation of energy efficient technology and conversion to renewable energy sources was investigated by using archival LCV project data. Ultimately, the inconsistency of policy regarding energy efficiency in historic buildings leaves a considerable amount of England's existing building stock vulnerable to the impending climate crisis [39], therefore creating a need to reduce number of challenges upon RHB derived from carbon reduction policies.

3. Research methodology

3.1 Selection of Low Carbon Village (LCV)

Low Carbon Villages (LCV) was a 3-year scheme between the National Trust and former energy partner Npower researching low-carbon living through two Trust owned villages of Coleshill in Oxfordshire and Cambo in Northumberland, working with communities to understand tenants' carbon footprint and share practical solutions to reduce carbon and tenant energy bills. After an initial survey, energy efficiency interventions were implemented (e.g. loft insulation) with tenants encouraged to reduce carbon through behaviour changes, such as switching off appliances when not in use. As well as the location for previous LCV scheme, 12 RHB in Cambo (Figure 1) were selected for this research

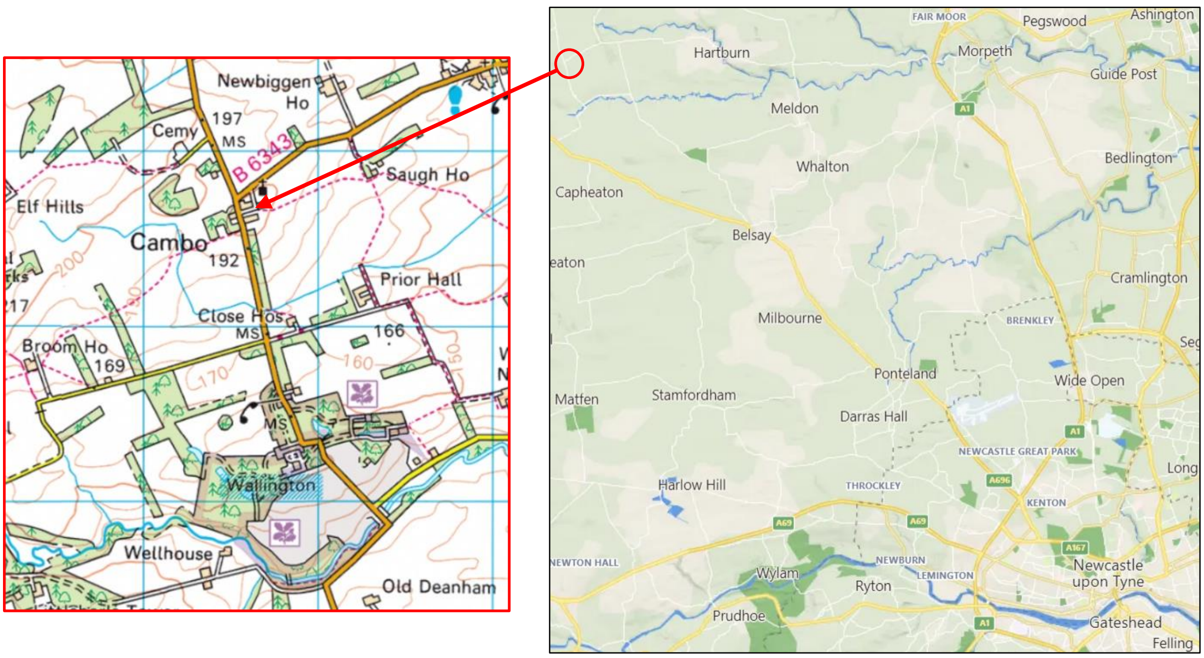

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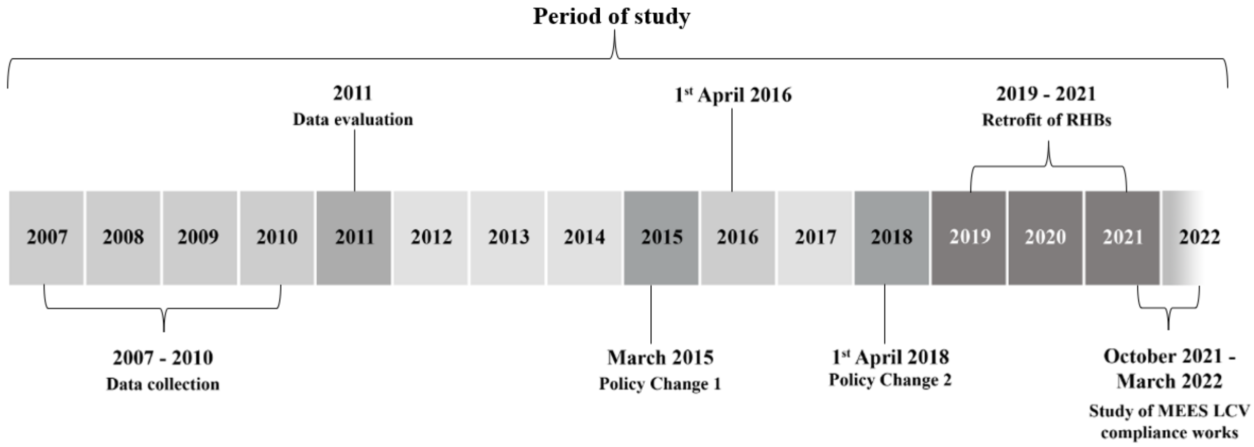
Figure 1 Map showing location of the Low Carbon Village, Combo where RHBs were selected.

study (Table 1) as recent MEES compliance refurbishment works had been completed on the same properties between 2020-22 allowing a longitudinal study to be completed, alongside assessing any behavioural changes from tenants during the period (2007 – ongoing) through semi-structured interviews, as shown in Figure 2.



Period of longitudinal study	**Remarks**
2007 – 2010	Data collection from Low Carbon Villages (LCV).
2011	Data evaluation of LCV scheme.
March 2015	Energy Act 2011 introduces Minimum Energy Efficiency Standards (MEES).
1st April 2016	Minimum EPC rating of ‘E’ required for all residential lets.
1st April 2018	Unlawful to let or renew a residential tenancy with an EPC rating below an ‘E’.
2019 – 2021	Retrofit of RHBs within LCV not meeting minimum EPC rating ‘E’ rating.
October 2021 – March 2022	Study of MEES compliance works completed between 2019 -2021 on 12 RHBs in LCV to assess effectiveness of carbon reduction policies upon RHBs.
March 2022 – ongoing	Ongoing carbon reduction research continues.

Figure 2 Energy efficiency policy changes during study (2007 – ongoing)

Cambo was constructed between 1730 – 40 to rehouse estate workers and comprises of 32 solid stone-built terraced cottages under slate roofs. Importantly, Cambo is out of reach of mains gas, relying on oil, electricity or solid fuel for heating, and with very few exceptions, all cottages only have single-glazed sash windows. In this study, interviewees refer to National Trust staff questioned, whilst interviewed tenants have been anonymised with case study references (e.g. RHB1, etc.), see Table 1.

Table 1 Building characteristics of the selected 12 RHBs.

RHB	Year of construction	Designation*	Description	Building Usage	Heating System 'x' identifies heating system before works whilst '+' highlights heating system after works									
					Mixed fuel fire & back boiler	Oil boiler	Stove	Storage heaters	Electric fire	Some rooms with no heating	Open fire & back boiler	Electric radiators	Biomass	No heating system
1	1840	Not listed	Stone built semi-detached cottage	2 adults, retired	x	+	+							
2	1850	Not listed, but attached to RHB4	End-terraced stone built cottage	2 adults, retired		x +								
3	1875	Not listed	Stone built semi-detached cottage	2 adults, working			x +	x				+		
4	1580	Grade II Listed	Stone built three-storey bastle house	2 adults, retired		x +								
5	1740	Grade II Listed	Two-storey mid-terraced stone cottage	1 adult, retired				x	x	x		+		
6	1750	Not listed	End-terraced two-storeyed stone cottage	1 adult, working	x	+	+							
7	1740	Grade II Listed	Two-storey mid-terraced stone cottage, remodelled c.1880.	1 adult, retired		+	+				x			x
8	1750	Grade II* Listed	Mid-terraced stone cottage within courtyard of Wallington Hall.	1 adult, retired		x							+	
9	1710	Grade II Listed	Semi-detached stone built cottage.	2 adults, working and 2 children		+	+				x			
10	1810	Grade II Listed	Semi-detached stone built cottage.	1 adult, retired		+	+ (x2)				x			
11	1900	Not listed	Semi-detached stone built cottage.	2 adults, retired		+	+				x			
12	1750	Not listed	Mid-terraced cottage with rubble built north wall retained in the late C19th remodelling.	2 adults, 1 working (freelance) and 1 retired		+	+	x						

"*" All RHBs are located within Cambo Conservation Area, it is important to identify designations for each RHB due to the impact on retrofit decisions. Grade 1 is a building of exceptional interest; Grade II* are buildings particularly important, being of more than special interest and Grade II are buildings of special architectural or historic interest.

"+" Indicates the retrofitted element, in some instances a like-for-like option was adopted despite not being best option for EPC grading due to cost and designation restraints.

"x+" Indicates retained heating system with compliance safety checks completed only.

3.2 Interviews for assessing of carbon reduction policies

Research was longitudinal in approach, considering historic information gathered across a fifteen-year period (Figure 2) supported by in-depth semi-structured interviews with tenants of selected RHB over a 6-month period (Table 2). Furthermore, archival transcripts from staff and tenants were utilised together with current National Trust file notes from tenants.

Table 2 Tenant Interview Questionnaire

Research Section	Challenge Area	Questions
Tenant Background	Tenants / Energy	1. Age category. 2. Size of household. 3. Length of tenancy – how long tenant has been resident at property address. 4. Decision to take on a National Trust tenancy, including exploration into positive/negative aspects of living on the Wallington Estate. 5. Do you see yourself as a custodian of the property? 6. A core objective of the National Trust is to make a positive contribution towards tackling climate change, including looking at ways to reduce carbon within the Trust's residential let estate. How well, if at all, do you feel you understand what the National Trust is trying to do to tackle climate change? 7. Do you, if at all, contribute towards reducing carbon emissions within your home?
Property Background	Energy / Compliance	8. Size of property (m^2) – information taken from EPC completed January 2022. 9. Number of rooms within property. 10. Heating source/s for the property – primary and secondary sources of heat. Does the property have an AGA? If so, gather tenant's thoughts on contribution towards property heat energy consumption. 11. Have you made any adaptations to the property to improve energy efficiency? 12. Do you think heritage is a barrier to creating more energy efficiency homes? *Researcher observations of property survey completed under this section during site visit, including notes about recent refurbishment works completed.*
Energy Behaviours	Energy / Tenants / Compliance	13. EPC: do you know what an Energy Performance Certificate is? If yes, does tenant know current EPC rating for home and associated energy saving recommendations listed on the EPC? 14. Importance of utility costs when deciding to take on the tenancy.

		Would increasing future fuel costs and responsibilities of managing energy within a historic property cause you to look for a more energy efficient home? 15. Daily heat settings – what are they? Occupation – length of time at home? 16. Current energy-efficient measures and tenant behaviours concerning lighting and appliances (list provided). 17. Energy expenditure – monthly/annual fuel bill costs? 18. Do you have any non-energy related problems such as damp/condensation issues?
Refurbishment Programme 2020 – 2022	Tenants / Compliance	19. How did you find the refurbishment works process and have there been any positive outcomes so far (e.g. fuel bill reductions, etc.)? 20. Upon completion of refurbishment works, were you shown how to use newly installed appliances/controls/energy efficiency measures? 21. Would you be open to future works and disruption to your home if it meant improving the energy efficiency of the building further, therefore reducing running costs?
Low Carbon Village	Energy / Tenants / Compliance	22. The Low Carbon Village (LCV) Project took place in Cambo between 2007-2011, can you remember this project and what the aims were for this? 23. Reflecting on LCV, how do you feel your energy behaviours have changed, if at all in the last 10 years, towards climate change and carbon reduction (both at home and wider perspective)?

An interview pilot was completed before twelve semi-structured in-depth interviews, ranging from 45 minutes to 2 hours in length, were carried out at selected RHB involving all household members apart from RHB9 where only one resident was available at the time of interview. This allowed tenants to be lead through a pre-determined interview schedule focused on research challenge areas, whilst not necessarily in a rigid order, encouraging tenants to develop their personal reflections further. Observations on the building fabric and interventions were recorded during property visits. Immediately after interviews, the researcher's perspective was captured [40], as the overpowering validity of observation is that it is the most direct way of obtaining data [41]. Data from each respondent was subjected to an editing process before coding, an elementary form of content analysis as a method to examine qualitative data collected through inductive coding by analysing word and sentence structure within interview transcripts to extract themes relevant to core research objectives. Table 3 highlights the research challenge areas and the related data collection method, alongside the sample size obtained for this study.

Table 3 Sampling: data collection and sample size for research parameters			
Research Challenge Area	**Description**	**Data Collection Method**	**Sample Size**
Carbon reduction policies (i.e. EPCs)	Investigate EPCs as policy tool when considering retrofit options.	Quantitative data collection through collation of EPC data for North East portfolio of the National Trust, using Parity Projects software.	188
Tenants	Investigating tenant behaviour amongst National Trust residential tenants.	Semi-structured interviews with 12 selected RHBs tenant to ascertain tenant behaviour and thoughts on retrofit; use of previous LCV case study will add greater depth.	12
Compliance	Policy proposals to increase minimum EPC rating to 'C' and effect on RHBs.	Semi-structured interviews with National Trust colleagues on energy efficiency regulations, participants are from a single organisation therefore homogeneous sampling appropriate (Saunders et. al, 2019).	10

4. Results and analysis

4.1 Challenges to implementing EPCs as a policy tool for retrofit purposes

To investigate EPCs as a retrofit tool derived from carbon reduction policies, Parity Projects, a software programme which assesses energy retrofit options, allowed the analysis of EPC data to establish the current position of the National Trust's let estate. With an average RdSAP of 36.10 (EPC 'F' rating) and only one RHB attaining an EPC rating of 'C' across the Trust's North East residential portfolio the connection between building age and EPC rating was evident, supporting argument for policy clarification on long-term governmental aspiration to achieve minimum EPC 'C' ratings within existing housing stock. Often mechanical and electrical interventions have a significant influence on EPC ratings, whereas sensitive fabric interventions are limited in impact upon total rating. EPC data revealed 68% of the Trust's RHBs in the North East are constructed from solid sandstone walls which are rated 'very poor' within EPC documents. However, carbon reduction policies recommend internal or external solid wall insulation to increase EPC rating to 'C', and yet 'this retrofit option would never be implemented' (Interviewee 1) due to the impact on hygric balance within historic wall structure, thus highlighting differences between energy efficiency regulations and the conservation of RHBs [30]. Whilst EPC data is often fixed to default assumptions, current research exposes need for EPCs to be more appropriate for RHB retrofit [42], for alongside risk to building fabric if modelling is inaccurate, both environmental and financial targets may also not be achieved [43].

Interestingly, the LCV project invested £600,000 into basic fabric upgrades such as draughtproofing and fitting of sheep wool loft insulation on the Wallington estate, yet no investment into heating upgrades. High demand for internal building comfort within existing buildings is the leading durability problem for RHB due to highest proportion of energy use being devoted to heating [21]. Consequently, the National Trust is facing complex decisions around energy production, particularly as secondary data analysis revealed the Trust's national RHB are fuelled primarily by oil (52%). For this study, all RHBs are off-grid requiring higher-cost fuels (Table 1) with only RHB8 fuelled by low carbon biomass energy, benefiting from being located within the courtyard area of Wallington Hall where a communal biomass system has been installed. Whilst the Trust is 'committed to removing oil from properties and creating more sustainable heat energy sources' (Interviewee 2), internal data revealed although aim has been achieved successfully on larger mansion properties, such as above at Wallington, the proposal is more complex for RHBs due to additional challenge from heating levels demanded by tenants. Subsequently, recent refurbishment scheme aimed to extend initial LCV project work by improving thermal envelope of buildings before installation of more energy efficient technologies and considerations for future renewable energy.

In total, 88 RHB required refurbishment works with 38 prioritised due to falling below Decent Homes Standards [44] and not achieving minimum EPC 'E' rating; assessment of selected 38 properties after refurbishment works showed only one renewable energy installation with remaining heating systems updated with same energy source (i.e. oil for oil), despite internal National Trust policy to not install new oil boilers. However, it is important to recognise how EPCs fail to provide a complete energy audit of a building focusing largely on the energy running costs of a building [26] where installation of lower carbon heating systems can reduce EPC scores where fuel is considered more expensive than other forms of fuel. For example, the use of LPG will decrease an EPC score comparative to an oil boiler due to higher fuel costs. Often improving an EPC to current minimum 'E' rating from installing cheaper fossil fuel systems can often take pre-eminence over selecting suitable, long term retrofit measures for RHBs due to methodology causing heating systems to be renewed 'like-for-like creating conflict between organisational goals and carbon reduction aspirations for the Trust' (Interviewee 2). As EPCs inform government funded retrofit programmes [6] it is essential actual energy use, alongside tenant behaviours and values [25] are considered in carbon reduction policy changes to ensure appropriate future recommendations.

4.2 *Challenges of Tenant Energy Behaviours*

To achieve energy efficiency targets, tenant behaviour must be considered [19] as study revealed assumption that tenant's profit from energetic retrofits [45] is often not the case. In this study, 75% of tenants agreed heritage was a barrier to creating a more energy efficient home with heating costs a concern for tenants despite many stating they 'would just adapt to rising fuel costs' (RHB2). Interestingly, increasing fuel costs would only cause 17% of RHB interviewees to consider looking for a more energy efficient home with majority stating location and other benefits were of more importance; 'rising fuel costs would definitely not cause me to consider moving as I love the area' (RHB10). Electric heating had been installed to improve EPC rating at RHB5, yet tenant statement reveals conflicts between EPC carbon reduction measures and the reality of utility costs: My electricity bill for the month of January was £277 – that was with only three radiators working downstairs – so totally unsustainable. Importantly, interviews were held after refurbishment works had taken place yet 9 RHBs had further implemented minor changes to improve energy efficiency, with thick curtains across entrance doors the most common adaptation, followed by draft excluders. One tenant had 'carved wooden wedges to slot around certain window frames in the cottage to stop them rattling as the drafts are horrendous' (RHB1) and RHB5 had installed 'wooden shutters for each window unit to improve temperature control', highlighting how despite an improvement in EPC ratings, a 'whole building approach' had not been considered as tenants were still adjusting weaknesses within historic fabric to reduce heat loss.

Cross analysis of interview transcripts revealed National Trust tenants often have strong loyalties towards the Trust as a landlord, compared to tenants in wider private rented sector where lower levels of satisfaction and landlord loyalties result in shorter tenancy periods [46]. In this study, average tenancy length is 20 years with the longest at 83 years, which is significantly above the UK national average of 4.3 years [42]. Connected to tenancy length, 100% of participants identified as 'a custodian and not merely just a tenant' (RHB11), with RHB1 stating 'I like to think I am looking after the property for future generations.' Consequently, tenants are motivated to contribute to wider estate community and have strong interests in the 'future impacts of climate change' (RHB3).

Heating and comfort behaviours in RHB may differ from those in more modern buildings [28] with interviews highlighting tenant's strong custodian perception: 'it is a privilege to live in a house like this' (RHB4). Consequently, despite a strong desire to look after RHB there was a reluctance to embrace energy efficient appliances and technologies from tenants, particularly those 65 years old and above, with concerns of technology not being suitable for RHB a key theme. Yet, at 5 RHBs where smart meters were installed, tenants were notably more aware of monthly energy costs and impact of certain behaviours on affecting energy usage. Utilising smart meters to understand how much energy is being used can assist in adapting properties against climate change [26].

Occupant behaviour, such as drying washing indoors, are known to have a substantial effect on heat demand [47]. Daily heat setting behaviours were explored within interviews, with 83% reporting related building concerns (Table 4). The issues of damp and condensation were repeatedly mentioned by tenants, yet most expected these issues from living in an older property.

Table 4 Tenant energy behaviours and related building concerns (with tenant comments referenced)

RHB	Tenant Energy Behaviours	Related building concerns (i.e. condensation, repairs, etc.)
1	Wood burner stove only in the evening, oil heating on for 1 hour every morning.	Considerable amount of condensation with some damp above stairs (blocked guttering identified).
2	Set temperature of 20°C, heating programmed for 2 hours use in the morning and in the evening.	Damp mentioned as having 'always been an issue'.
3	Heating on as and when needed as tenants work shift pattern within healthcare.	Some damp, nothing major or cause for concern.
4	23°C every day, set to come on twice a day.	'Always lived in an old house so used to issues that this brings'; no signs of damp, cottage well ventilated.
5	Different temperatures for different rooms; 21°C set throughout, less used areas (i.e. utility) set at 18°C.	Visible damp and condensation issues.
6	Sporadic, no heating settings in place.	Significant damp within hall area (very cold).
7	Wood burner stove on throughout the day, heating on once every morning at 20°C.	No issues to report.
8	Biomass heating system, heats the whole property at a consistent low temperature.	No issues to report.
9	20-22°C average, has on a set programme to keep levels at consistent levels.	Ongoing contractor issues after refurbishment works; plaster snagging to be completed due to damp.
10	Oil heating system on every morning between 7-9am at 20°C, during day only sitting room radiator used.	Damp (efflorescence sited along with white furring on interior walls in specific locations).
11	Heat rooms only in use around 21°C.	Serious condensation (windows).
12	Oil heating on in evenings only (21°C).	Cold bathroom (location) causes condensation.

Only RHB7 and RHB8 reported no other property problems with RHB8 strongly connecting improvements to moisture levels from previous installation of biomass heating system reducing former damp issues: 'biomass boiler is super! I am confident in the biomass system, these houses are cold due to the thick stone walls so it is better to have a consistent low temperature which the biomass can provide', noting the only negative was when the 'biomass does go off it is a bit of a nightmare as it is specialised equipment so it takes time to find a suitable contractor'. Importantly, RHB7 had no heating system before and attributed damp clearing from understairs cupboard due to new heating system and 'change in behaviour in heating house with oil boiler and heat from stove'. Reflecting on site visits, despite new heating systems within properties to improve EPC ratings, if tenants are not utilising heating technologies to greatest effect due to fuel cost concerns or lack of knowledge it makes carbon reduction strategies futile and damages building fabric long term too (e.g. damp penetration to walls).

Figure 3 illustrates energy behaviours of interviewed tenants and overall, there are positive energy actions, particularly when it comes to energy efficient lighting despite RHB4 not considering a change to more energy efficient lighting as they ‘do not like the light emitted from LED lightbulbs’. Interestingly, RHB5 stated they ‘wouldn’t turn the heating off when away as it takes so long to heat the cottage back up when it has been empty for a while’, whilst most tenants would. Many tenants are deciding to heat only parts of the building actively used, alongside not heating bedrooms and consciously lowering heating temperatures. These findings support identification from Wise [11] of spot heating as a strong theme when heating historic homes, particularly as the majority of tenants are retired (Table 1), thus potentially occupying the buildings for lengthier time periods.

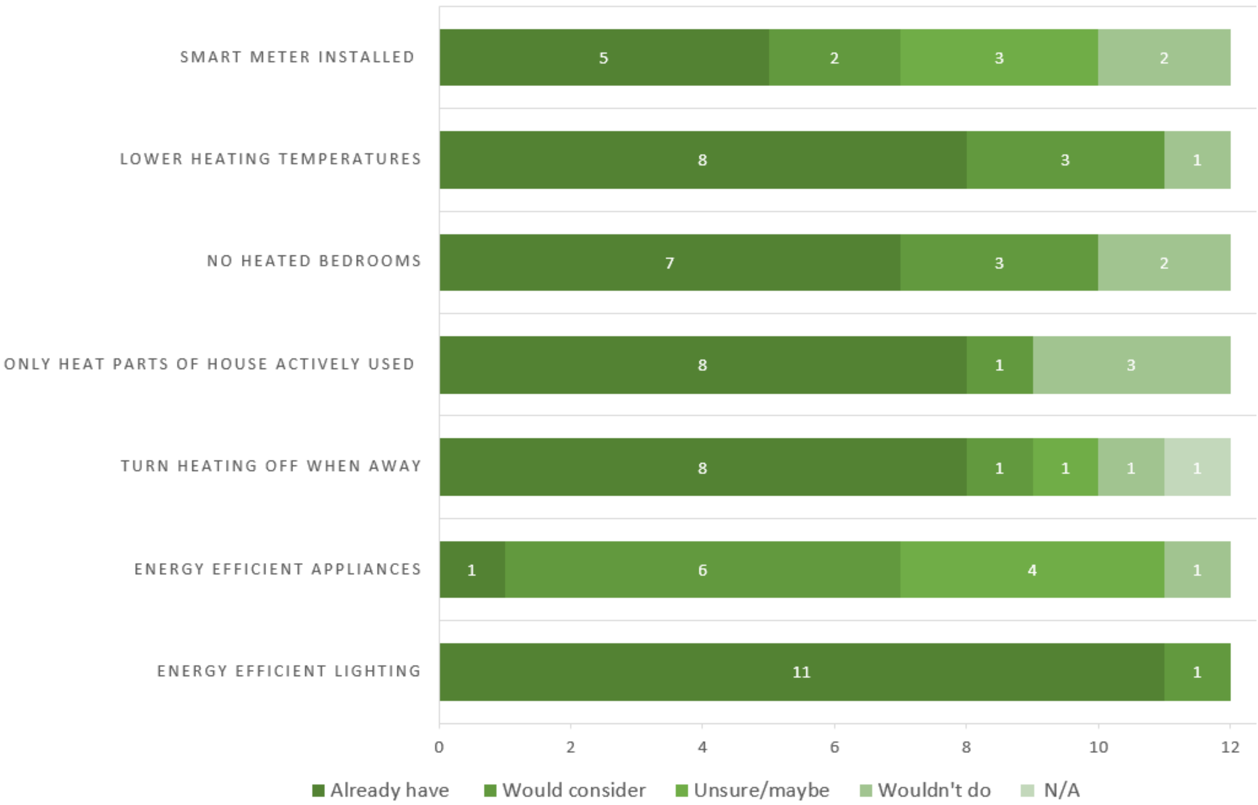


Figure 3 Energy behaviours of RHB case study tenants.

4.3 *Challenges of implementing compliance*

Research showed how increasing the importance of energy efficiency as a decision-making criterion for tenants would produce more valuable carbon reduction policies [33]. Interestingly, only 58% of tenants interviewed knew what an EPC was with none knowing their current rating, RHB3 summarised most tenant perspectives: ‘[I] wouldn’t have a clue, couldn’t guess!’. Furthermore, study revealed practical conflict between net zero carbon targets and MEES compliance, with modelling showing the Trust would have to invest around £98 million to bring all Trust properties to minimum ‘C’ rating through appropriate energy efficiency measures and renewable energy technologies. Consequently, these tensions are causing the Trust to remain in a 'sitting still state whilst clearer government guidance is awaited' (Interviewee 2). To assess further, EPCs were completed for each RHB following refurbishment works with Table 5 identifying EPC result analysis, alongside potential rating advised on EPC if suggested retrofit recommendations were undertaken.

Table 5 EPC analysis for selected RHBs

RHB	**Heating System** (LCV scheme 2007 - 2010)	**Heating System** (after MEES refurbishment works)	**Cost of refurbishment works**	**EPC rating** (before)	**EPC rating** (after)	**EPC Potential Rating** (as listed on Jan 2022 EPC)
1	Mixed fuel fire and back boiler	Oil boiler and radiators, room heaters (secondary) and wood burner stove	£52,330	F (35)	E (50)	B (84)
2	Oil boiler (coming to end of life), wood burner stove	Oil boiler and radiators, wood burner stove	£59,473	F (36)	E (46)	C (79)
3	Storage heaters and stove	Electric radiators and stove	£28,007	E (42)	E (50)	B (82)
4	Oil boiler (coming to end of life)	Oil boiler and radiators, no secondary heating	£30,793	E (49)	E (49)	C (78)
5	Storage heating (2 rooms had no storage heaters)	Electric storage heaters, controls for high heat retention heaters	£141,165	F (22)	D (59)	B (83)
6	Stove and back boiler with radiators	Oil boiler and radiators, duel fuel (mineral and wood) stove	£104,003	E (50)	E (52)	B (82)
7	Open fire and back boiler – no heating throughout property	Oil boiler and radiators, duel fuel (mineral and wood) stove	£64,392	G (19)	D (60)	B (85)
8	Oil boiler supplies both heating and hot water	Biomass boiler (communal and installed separate to MEES refurbishment works)	£98,004	E (45)	C (69)	B (90)
9	Open fire and back boiler (for hot water)	Oil boiler and radiators, duel fuel (mineral and wood) stove	£219,056	F (30)	E (51)	C (79)
10	Open fire and back boiler (for hot water)	Oil boiler and radiators, no secondary heating – wood burner stoves x2	£219,056	F (22)	E (48)	C (79)
11	Open fire and back boiler with radiators (solid fuel)	Oil boiler and radiators, room heaters (secondary) and wood burner stove	£36,169	F (22)	E (53)	B (81)
12	Storage heating	Oil boiler and radiators, dual fuel (mineral and wood) stove	£104,003	E (50)	D (60)	B (85)

Across the 12 RHB, there was an average 53.3% increase in EPC rating following refurbishment works, with a total spend of £1,156,451. After such significant staff and financial investment, analysis must assess if resulting EPC ratings warrant resources employed in achieving often minor energy efficiency improvements, emphasising the uncertainty of MEES regulations on future proposals upon RHB. Clearly, there are cases where EPC ratings have increased significantly reflecting evident retrofit measures, with RHB7 a leading example where ratings have gone from G19 to D60 through the installation of a new heating system, improved insulation and other fabric measures. However, whilst RHB5 improved from F22 to D59, examination of bills at tenant interview revealed that fuel bills were 'totally unsustainable' (RHB5) prompting discussion into suitability of selecting electric storage heating for RHB.

9 RHB improved from 'G' or 'F' EPC ratings to 'E' or above from refurbishment works, whilst remaining 3 RHB had started at 'E' with aim to address compliance issues. RHB4 remained the same (E49) despite heating system control upgrades and RHB6 only increased by two points from E50 to E52 following installation of a new heating system. Potential EPC inconsistencies are further highlighted by comparing RHB6 with the cottage next door (RHB12) as both properties have same floor area and layout, identical heating systems and refurbishment works completed, yet despite matching information on EPC, RHB12 achieved D60 in comparison to E52 for RHB6. RHB8 also started within 'E' rating (E45) increasing to C69, the only property in the North East portfolio to achieve 'C'; substantial change in result derived from prior installation of a communal biomass system at Wallington permitting courtyard cottages to benefit, illustrating type of EPC results that could be achieved through renewable energy heating solutions.

As discussed, installation of lower carbon heating systems can actually reduce EPC score where fuel is considered more expensive. Yet, irrespective of policy inaccuracies, RdSAP is the industry recognised measurement of energy performance and whilst an update in 2025 is imminent there are no plans for a completely new system. The Trust argues 'energy efficiency ratings are an inappropriate way to drive the most effective de-carbonisation solutions and can create perverse incentives where high carbon emitting heating options achieve higher scores because they are cheaper to install and run' (Interviewee 2). This was evidenced within selected RHB where 75% have new oil condensing boilers installed to achieve necessary MEES compliance in preference over more expensive to install, yet low carbon energy sources with potential to reduce tenant bills. Overall, majority of RHB obtained minimum rating of 'E' (8 RHB), followed by 'D' (3 RHB). Figure 4 reinforces current system is not fit for purpose with recommendations on completed EPCs revealing barriers to preservation through inappropriate suggestions for retrofit, such as photovoltaics which 'would not be implemented on RHB due to location within a conservation area and therefore installation of solar panels would not be permitted' (Interviewee 1).

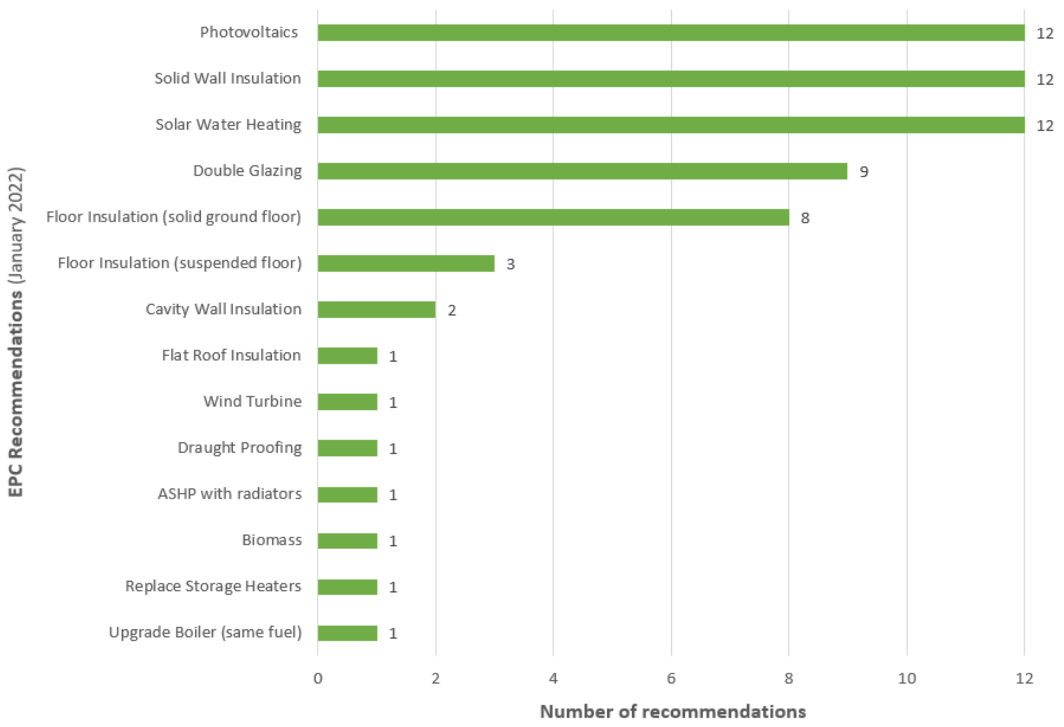


Figure 4 EPC recommendations for selected 12 RHB

Whilst clarification is sought over future UK carbon reduction policy regarding MEES Regulations, landlords such as the National Trust are prevented from planning long-term carbon reduction strategies within their portfolios. Indeed, Interviewee 2 advised the Trust had suggested a new form of EPC specific for RHB to the UK government but 'thinks we'll have to work with what we have and therefore, will need to plan for compliance accordingly'. Figure 5 illustrates case study RHB7 before and after refurbishment works providing insight into the level of compliance works carried out on selected RHB between 2020-22 in response to MEES. During a site visit, the tenant presented researcher with photographs showing the building in use from the early 1900s, revealing family members sitting in the same place in front of a former range cooker where the newly installed wood burner stove was now located. Previously, an open fire was in situ (left image) until 2021 with the tenant using coal as fuel, the highest fuel type for carbon emissions, and significantly, an open fire will typically only be 15% efficient with remaining heat energy escaping up the chimney [48]. This progression of heating systems over time was a stark reminder of the transitory nature of heating systems within RHB as technological innovations develop and the need for the National Trust to lead on creating long term strategies reducing environmental impact upon their let estate. For example, investing in communal renewable heating solutions within their villages and influencing government policy framework in adapting compliance legislation for the historic built environment.

Figure 5 Case study profile of RHB7 before and after recent refurbishment works

Importantly, the EPC rating for RHB7 increased from G19 to D60 due to the installation of a new oil heating system and additional fabric improvements, with the tenant stating how 'bills went up slightly but not by very much'. Furthermore, 50% of participants were positive towards future energy efficiency works 'if it meant reduced fuel bills' (RHB5). For remaining 50% who said no, age of tenant and not wanting any additional disruption after latest refurbishment works were two recurring key factors deterring tenants from further energy upgrades. Additionally, tenants were asked to reflect on recent works to ascertain any positive energy efficiency outcomes, with mixed viewpoints discovered throughout interview process:

> RHB1: Bills are now more expensive due to supply issues to rural location… happy with system, but it is more expensive.
>
> RHB2: Overall, very happy with works, noticed difference since systems have been improved.
>
> RHB3: Would have liked to have seen more energy efficient measures, such as secondary glazing, as drafts are still an issue.

Some tenants (RHB3, RHB4, RHB9, RHB10 and RHB11) felt they 'weren't listened to' (RHB11) as they 'know all of the 'quirks' with the house and where improvements could have been made' (RHB3), stating priority wasn't given to fixing real issues within the building. For example, RHB4 mentioned 'windows are a disaster area' thus emphasising the need to integrate occupiers in decision-making process to deepen understanding of RHB needs [19] and implementing people-centred energy strategies rather than solely reducing energy demand through use of energy-efficient technologies. Interestingly, RHB4 suggested 'long term tenants would invest financially in energy efficient measures', supported by RHB5 where tenant had already installed costly window shutters to control temperature levels as they were 'even wearing a Christmas jumper in summer to try and reduce costs!'. Perhaps the Trust could consider partnership working with long-term tenants when formulating organisational carbon reduction strategies.

4.4 *Recommendations based on lessons learned*

Interestingly, many participants remembered the LCV project without much prompting, particularly the tenant village hall meetings and proposals for installing a biomass unit at Wallington; RHB7 mentioned LCV project without being prompted and felt it had a 'lasting impact' but would have 'liked to have heard more from the Trust with follow up information' on how suggestions could be taken further. Archival research enabled collection of tenants comments from LCV project 15 years ago to enable comparison with feedback from the same tenants when interviewed 15 years later following recent refurbishment works; selected comments highlighted in Table 6.

Table 6 Comparison of tenant comments from LCV Project (2007) to after recent refurbishment works (2022)

RHB	**Then** Tenant comments from LCV project (archival)	**Now** Following refurbishment scheme 2020 – 2022
2	'We're still using the meter (smart) after three years and we reckon it has cut our electricity use by a third. Everyone in the village seems to have heard how much we've saved from turning off the towel rail in the bedroom, we think it was costing £200 a year!'	'We remember [LCV] project and the village hall meetings as part of getting tenants involved; I do think the Trust could sharpen up in putting in more long-term energy efficiency measures in sooner rather than later – it will save them money too'.
7	'Eco-motivation is 90% saving money, 10% doing good. I've cut my electric bill – by half – from turning the TV off and not using things as much. The loft insulation fitted by the project is brilliant and the massive difference from that has made me interested in the draughtproofing too, but I don't want a central heating boiler, I'll manage with just the fire in my sitting room'.	'You [researcher] persuaded me to finally get a central heating system two years ago and I'm now pleased this has been installed. I was concerned at first but I have got used to the heating settings to create a nice temperature balance in the property. There is certainly more heat from the wood burner stove compared to the open fire, so that has been an improvement as well – I'll admit it!'

11	'It just seemed like the most sensible thing to do (referencing the trialling of energy-monitoring meters). It's like another child. We check we've switched things off when we go to bed. We don't leave things on standby. I stopped leaving the cooker on because even the light loses power. And we are always telling our son to turn stuff off'.	'We continue to use a smart meter as it helps us monitor the fuel usage, which we like to be on top of. Now the new system is in place (oil boiler) we heat rooms only that are in use and the wood burner has been a definite improvement compared to the open fire that had been here – we have been surprised by the heat it throws off'.

Many tenants were positive about the scheme and although public awareness and interest in climate change matters have increased in the UK, an individual's behaviour and action against climate concerns may not always translate into more efficient energy use within their home. For example, RHB1 asserted that 'climate change doesn't exist', yet most tenants recognised the need for carbon reduction with RHB6 stating 'climate change is an issue but not sure what can be done with old buildings', whilst some tenants (RHB1, RHB5, RHB8 and RHB12) independently called researcher after reflecting on initial interviews to provide energy bill updates and further comments revealing desire to engage in subject. Essentially, the best use for a building will often be the use for which it was originally designed for [49] and the National Trust recognises the importance of tenants in looking after the Trust's RHB; RHB5 reflected how it was 'nice to think the Trust are looking into sustainability long-term for tenants, as ultimately tenants are preserving properties for the National Trust'.

Whilst Trust tenants were not motivated by utility costs alone, clear confusion around EPCs was evident, alongside desire from tenants to become more energy efficient. The Construction Index [50] argues that 'EPCs are outdated and should be replaced with Building Renovation Passports (BRPs) which set a clear pathway to decarbonise homes.' BRPs would monitor MEES compliance obligations, identify retrofit measures and attract tenants by presenting low carbon standards with low energy bills through proposed 'green rental agreements', thus encouraging building occupiers to have greater concern for personal energy use whilst visualising financial benefits. The Trust as the UK's largest private landowner could influence at policy level to ensure future digital platforms consider the historic built environment. Furthermore, the idea of tenant's contributing financially towards energy efficiency improvements emerged from interview data, for example, RHB4 stated how 'long term tenants would invest in energy efficiency measures', an idea which could be explored further by the Trust. The National Trust could immediately implement the need to collaborate with tenants within future refurbishment programmes as research identified there are many long-term tenants who understand their homes and 'quirks' deeply (RHB3), this could take the form of a tenant questionnaire and property walk through before any retrofit works to understand more about the property and how it is used.

Whilst responsible retrofit improves energy performance of RHB through technical interventions, a 'whole building approach' must be applied for success [27] to ensure heritage assets adapt for continued sustainability rather than proposed 'fabric first' approach suggested by the UK Government.

5 Conclusions

This study aimed at investigating the effectiveness of current carbon reduction policies on achieving net zero carbon emissions for residential heritage buildings (RHB) by performing a long-term study on real scale low carbon village located at Wallington Estate in Northumberland, England It is observed that the current guidelines on energy performance certificate (EPC) are ineffective to reduce carbon emissions with evidence indicating current methodology needs to reflect clearer evaluation of energy use as it is not just a methodology but influences carbon reduction policies, resulting in current EPC tool producing erroneous recommendations for RHB. Tenant interviews sought to provide further depth behind EPC quantitative data results, and as human behaviour, thoughts and feelings are partly determined by their context, it was important to interview tenants within their homes to collect energy behaviour observations, which revealed importance of involving tenants to implement effective retrofit works due to personal knowledge of the property, evident through tenant building alterations both before and after refurbishment works. Whilst EPC awareness was low amongst interviewed tenants, archival documentation showed tenants understanding of energy efficiency had improved over a 10-year period. Furthermore, tenant interviews revealed occupant behaviour and heating controls are highly influenced by draughts that EPCs do not account for, alongside recognition that tenant behaviour has been a neglected area in building energy policies. Collecting actual energy usage data for RHB using energy meters would permit tenant behaviours to be considered within future EPC methodology to generate clearer guidance for appropriate energy efficient retrofits within RHB. Mitigation strategies to confront environmental threats from climate change is essential for the National Trust to protect historic buildings by employing the organisational value of 'think now and for ever'. Ultimately, people and places are intertwined and thus we not only need to sustain and conserve the life of the building but also its custodians, changing current preference for 'fabric first' to 'people first', especially when addressing the challenges of carbon reduction policies upon RHB.

AUTHOR CONTRIBUTIONS

The first author was primarily responsible for data collection, analysis and drafting of the article. The second author substantially contributed by critically revising the article. All authors approved the final version to be published and agree to be accountable for all aspects of the work and to be named as authors.

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Ethical approval was provided by Northumbria University (ethics submission reference: 39699). Participants gave informed consent.

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