MC2024
PEOPLE & BUILDINGS
Proceedings of 13th Masters Conference:
London, 16th September 2024

Network for Comfort &
Energy Use in Buildings
http://www.nceub.org.uk

# Climate change mitigation and adaptation of UK complex-to-decarbonise homes: building fabric vs. systems upgrade approaches

**Maimai Prayongrat**[1]

[1] MSc Environmental Design and Engineering, University of London, UK, maimai.prayongrat.22@ucl.ac.uk

**Abstract:** Buildings account for 31% of the global final energy demand, 70% from residential sector. Complex-to-decarbonise dwellings emit 25% of the residential sector's $CO_2$ emissions. While decarbonising can be challenging, effective retrofit solutions are required to reduce energy consumption and overheating risks. This paper identifies solutions and challenges to retrofit complex-to-decarbonise homes, focusing on two case studies: a pre-1919 Victorian mid-terrace house in Battersea, London, and a 1966 social housing high-rise flat in Southsea, Portsmouth. IES VE simulation assessed the impact of different retrofit packages in current and future (UKCP09) climate conditions, including heating system upgrades, passive heating and cooling strategies, and their combination. Results show that combining passive measures with electric heat pumps provides optimal outcomes, reducing energy consumption by 74.2% and 75.6% in the house and flat, respectively, while mitigating overheating. Additional measures are necessary to achieve net-zero and TM59 targets in the future, considering technical and financial feasibility.

**Keywords:** Complex-to-decarbonise homes, building retrofit, climate change, building energy consumption, overheating risks

## 1. Introduction

Climate change presents severe challenges globally, demanding urgent reduction of greenhouse gas emissions to slow global warming (IPCC, 2023). In 2022, the UK recorded its hottest year, exceeding 40°C (Climate Change Committee, 2022). Buildings account for 31% of global final energy demand, with 70% from the residential sector (Cabeza *et al.*, 2022). Achieving the net-zero target by 2050 requires reducing emissions, including retrofitting 15 million UK homes by 2030 (Friedler and Kumar, 2019). Climate change adaptation is also crucial, as 4.5 million UK homes face overheating risks in cool summer (Committee on Climate Change, 2019). Complex-to-decarbonise (CTD) homes, responsible for 25% of residential $CO_2$ emissions, have often been overlooked (Raslan and Ambrose, 2022; Houghton *et al.*, 2023).

This study focuses on two UK CTD homes: a pre-1919 mid-terrace in London and a 1960s high-rise flat in Portsmouth. It aims to assess the effectiveness of climate change mitigation and adaptation measures, including building fabric-first and systems upgrade approaches, in the context of retrofitting CTD homes in the UK.

## 2. Literature review

CTD homes are defined by unique physical, locational, and occupant-related factors that make decarbonisation costly and complex, including multi-occupancy buildings, heritage properties, and homes with space constraints or vulnerable occupants such as low-income or older individuals (Raslan, 2022; Raslan and Ambrose, 2022; Houghton *et al.*, 2023).

Mitigating emissions from CTD homes is urgent and crucial, as 60%-80% of CTD homes have poor EPC ratings (F-G) compared to the UK average of D, with high energy costs impacting vulnerable groups (Raslan, 2022; Raslan and Ambrose, 2022). Retrofitting CTD homes faces significant technical and financial challenges, including limited financing, inadequate regulations, and insufficient expertise. Skill gaps among suppliers, especially for heritage features or vulnerable residents, add complexity. Additionally, there is a lack of data and representation of these homes in building stock models (Raslan, 2022). Moreover, a holistic retrofit approach can mitigate unintended consequences but requires substantial funding, while less costly non-holistic methods are less comprehensive (Charles, 2012). Building fabric retrofit approaches, particularly deep retrofits, face barriers such as high costs, disruption, and skill shortages (Eyre, 2023). System upgrades like heat pumps also present challenges related to costs, space needs, and noise issues (Gaur, Fitiwi and Curtis, 2019; Crownhart, 2023). Lastly, retrofit strategies must consider future climate uncertainties, as some measures may lose effectiveness if climate conditions change (Liu *et al.*, 2023; Liyanage *et al.*, 2024).

## 3. Case studies description

This study focuses on two CTD homes, selected based on locational, occupant, and physical criteria of CTD homes, ensuring available data for analysis and modelling.

### 3.1 Case study one (CS1): Pre-1919 Victorian mid-terraced house in Battersea, London

The two-bedroom Victorian house was built between 1872 and 1877, and is located in the Shaftesbury Park Estate conservation area in Battersea, London. The house is CTD due to its location in a conservation area, restricting façade alterations, and as an owner-occupier property, its retrofit feasibility depends on the owner’s finances (Behar, 2010).

### 3.2 Case study two (CS2): 1966 high-rise flat for retirees in Portsmouth

Tipton House is a 1966 high-rise social housing block in Southsea, Portsmouth, housing retirees aged 55 and above. It is classified as CTD due to its height, which requires costly scaffolding to retrofit, its vulnerable occupants and its funding depending on the government (Aragon, Teli and James, 2018). The study focuses on a top-floor two-bedroom flat, which faces higher overheating risks (Mavrogianni *et al.*, 2012).

## 4. Research methodology

### 4.1 Tools and Approaches

IES VE is used for the modelling and simulation process (IES, no date). Python (JupyterLab) and Microsoft Excel are employed for data analysis, processing, and creating visual graphs (Jupyter, no date; Microsoft, no date). CIBSE Guide A and TM59 are used to evaluate heating setpoints and assess overheating risks, respectively (CIBSE, 2015, 2017). Additional guidelines provide further overheating risk categorisation to TM59: Pass (Criteria A: not more than 3%, Criteria B: not more than 32 hours), Moderate fail (Criteria A: 3-6%, Criteria B: 32-64 hours), Severe fail (Criteria A: 6-15%, Criteria B: 64-160 hours), Extreme fail (Criteria A: over 15%, Criteria B: over 160 hours) (Arup, 2022).

### 4.2 Simulation Inputs and Retrofit Packages

This study employs dynamic simulation using IES VE to assess strategies for reducing energy consumption and overheating risks in the case studies under various climate conditions. The data for these case studies, such as the U-value of building elements, has been gathered from previous research and referenced in the RdSAP document when data is unavailable (BRE, 2012). The simulation inputs assumed variables, such as occupancy patterns and heating schedules, according to the UK's National Calculation Method (UKNCM) (Department for

Communities and Local Government, 2021). Adjustments were made to reflect occupant behaviour, such as an earlier bedtime for the older occupants in CS2.

Figure 1. CS1 view from the front and back façade and floor plan

Figure 2. CS2 building and floor plan

Weather files from the PROMETHEUS project, according to UK Climate Projections 2009 (UKCP09), were used (Eames, Kershaw and Coley, 2011). In CS1, weather files from an inner London location (Islington) were used so as to factor in London's urban heat island effects. In CS2, Portsmouth weather files were used. Both current and future climate scenarios (2030s to 2080s) under medium and high emissions scenarios were employed.

The modelling scenarios include: **Baseline model** is existing building conditions with a worst-case orientation to assess potential overheating. The following retrofit strategies will be added to the baseline model by considering retrofitting the whole building in case study one while retrofitting flat-by-flat in case study two. **Fabric first strategy** is split into three scenarios, including **passive heating**: mineral fibre insulation, double and secondary glazing, and reduced window opening areas, **passive cooling:** shading options, low-E glazing, and nighttime ventilation, with additional measures like enhancing stack ventilation through chimney, green roofs, and overhangs and **combined passive strategies:** passive heating and cooling integration. **System upgrade strategy** is split into improving heating efficiency and replacing existing system with air source heat pumps. **Combined fabric and system upgrades** improve both building fabric and heating system.

In each climate scenario, the baseline model and twelve retrofit packages for CS1 are simulated, and the baseline model and nine retrofit packages are simulated for CS2. Therefore, there are 182 simulations for CS1 and 140 total simulations for CS2.

## 5. Results and analysis

### 5.1 Energy Performance

In CS1, the baseline model's annual energy consumption is 162.8 kWh/m² for gas and 18.5 kWh/m² for electricity. Retrofitting with passive heating and an electric heat pump results in the lowest energy consumption, 76.5% from the baseline. Replacing the boiler with a heat pump is more efficient than passive heating alone, which reduces energy use by 65.6% and 40.5%, respectively. In future climate scenarios, energy consumption will gradually drop due to warmer temperatures, with a significant drop between the current and 2030s climates.

In CS2, the baseline annual consumption is 343.2 kWh/m². Passive heating with an electric heat pump retrofit reduces maximum energy use by 79.5%, while combined passive measures with an electric heat pump also achieve significant reductions. Future scenarios show a 15.4% reduction in energy consumption by the 2030s. Nevertheless, despite these improvements, no retrofit package in both case studies meets the 2030 target of 35 kWh/m²/year (RIBA, 2021).

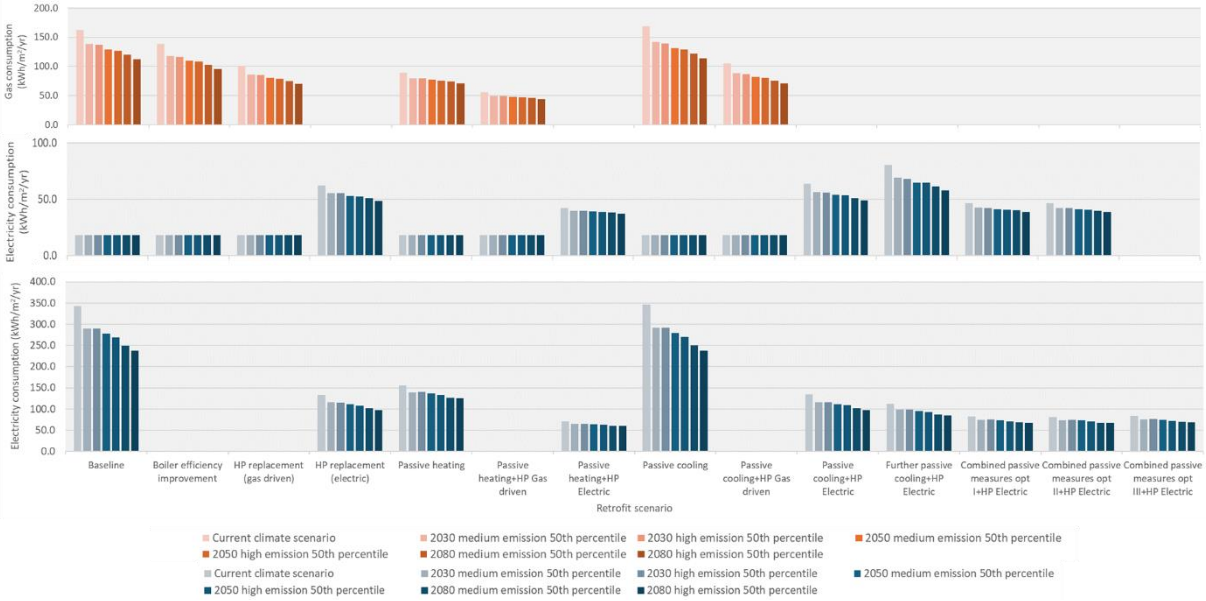

Figure 3. Annual energy consumption in different climate scenarios from top to bottom: gas consumption (CS1), electric consumption (CS1), electric consumption (CS2)

### 5.2 Indoor Environmental Quality

In CS1, overheating risks are assessed using ARUP's criteria based on CIBSE TM59. In the current climate, all retrofit scenarios pass both TM59 criteria. For future climates, further passive cooling performs best in mitigating overheating risks. The passive heating only approach fails significantly in managing overheating.

In CS2, most retrofit scenarios meet TM59 criteria in the current climate except for passive heating. However, all packages fail to meet the criteria in the 2080s high emissions scenario. Combined passive measures option III is the most effective for managing overheating risks in all key rooms, while combined passive measures option I perform best in managing bedroom temperature.

### 5.3 Comparative Analysis

In CS1, combined passive measures option I with internal shutters offer the best overall performance, achieving a 74.2% reduction in energy consumption and effectively managing overheating risks across various climates. In CS2, combined passive measures option III is optimal, providing a 75.6% reduction in energy consumption and effectively addressing overheating risks. The combined passive measures option I include the implementation of internal shutters, nighttime cooling, improved glazing, insulation, and a heat pump. Option III contains a green roof, overhang, internal shutters, and similar measures. Therefore, additional strategies are needed to enhance energy reduction and manage overheating risks, as the current retrofit options do not meet TM59 criteria or achieve the 2030 energy targets.

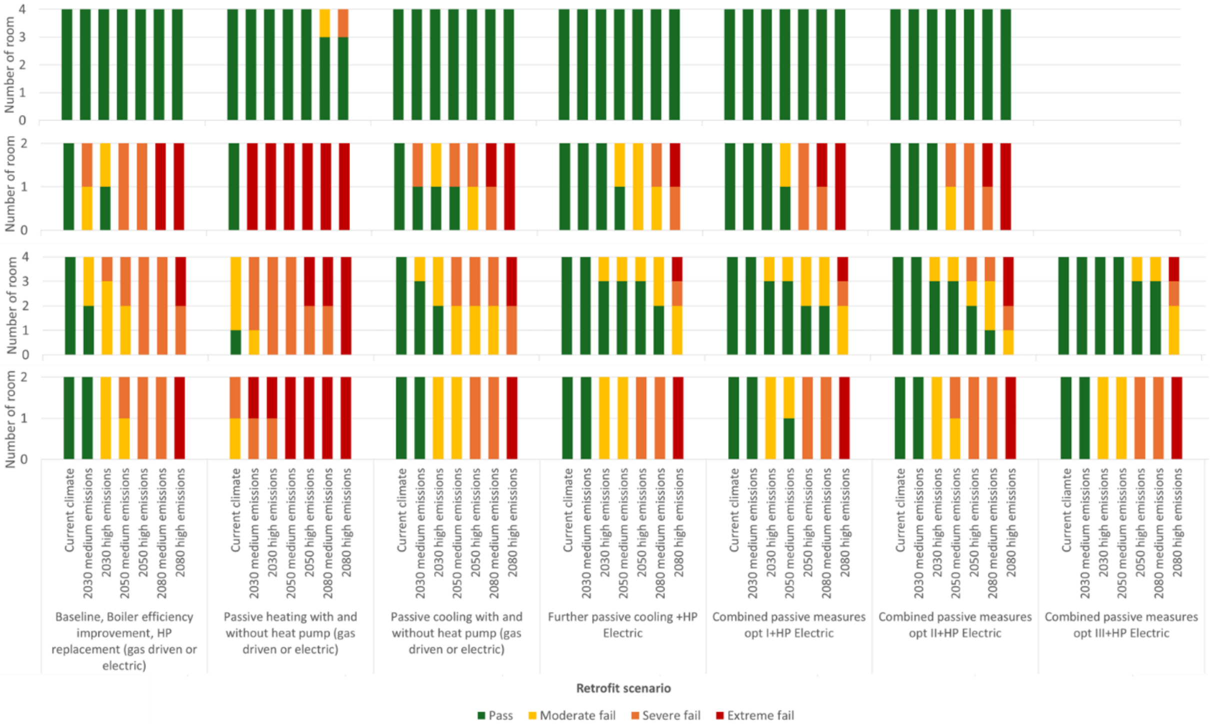

Figure 4. TM59 results from top to bottom criteria A (CS1), criteria B (CS1), criteria A (CS2), criteria B (CS2)

## 6. Discussion

Combining passive measures with electric heat pumps is needed for mitigating and adapting to climate change in CTD homes by reducing energy consumption and overheating risks across current and future climates. However, potential unintended consequences such as moisture trapping, thermal bridging, and increased overheating risk from glazing improvement will need to be considered, alongside challenges related to skill gaps and space constraints during installation.

Study limitations include focusing on only two specific case studies, not including active cooling systems, and potential uncertainties related to climate and other modelling input data, such as building construction materials. Factors such as building orientation, and the impact of the local microclimates, were not fully addressed. Future research should explore enhanced building fabric strategies, natural materials, additional cooling options, and financial and technical aspects of retrofitting. Addressing unintended consequences and scaling findings to varied contexts will be necessary.

This study has implications for homeowners, tenants, landlords, local authorities, designers, retrofit providers and building services engineers. Taking the study findings into account, it is recommended that passive heating, cooling, and heat pump retrofits are combined for optimal results.

## 7. Conclusion

This study evaluated retrofit options for CTD homes in the UK. Combining passive heating and cooling measures with electric heat pumps was found to be the most effective option, reducing energy use by up to 75.6% and mitigating overheating risks under the current climate. However, none of the retrofit options met 2030 net-zero targets or TM59 criteria by 2080s. Limitations include focusing on two case studies, weather data, and occupant behaviour uncertainties. Future research should explore additional measures, active cooling systems, and scaling while addressing skill gaps.

## 8. References

Aragon, V., Teli, D. and James, P. (2018) 'Evaluation of Retrofit Approaches for Two Social Housing Tower Blocks in Portsmouth, UK', *Future Cities and Environment*, 4(1).

Behar, C. (2010) *THE PEABODY LOW-ENERGY RETROFIT; A Case Study of a Victorian Terraced House in Battersea*.

BRE (2012) *Appendix S: Reduced Data SAP for existing dwellings*.

Cabeza, L.F. *et al.* (2022) 'Buildings', in *IPCC, 2022: Climate Change 2022 - Mitigation of Climate Change*. Cambridge University Press, pp. 953–1048.

Charles, A. (2012) *Factors affecting the transformation of existing (no-fines concrete) dwellings to low carbon homes*. Glasgow Caledonian University.

CIBSE (2015) *Environmental design: CIBSE guide A*.

CIBSE (2017) *Design methodology for the assessment of overheating risk in homes: TM59*. Chartered Institution of Building Services Engineers.

Climate Change Committee (2022) 'Risks to health, wellbeing and productivity from overheating in buildings'.

Committee on Climate Change (2019) *UK housing: Fit for the future?*

Crownhart, C. (2023) *Everything you need to know about the wild world of heat pumps | MIT Technology Review*, *MITTechnologyReview*.

Department for Communities and Local Government (2021) *National Calculation Methodology (NCM) modelling guide (for buildings other than dwellings in England)*.

Eames, M., Kershaw, T. and Coley, D. (2011) 'On the creation of future probabilistic design weather years from UKCP09', *Building Serv. Eng. Res. Technol.*, 32, pp. 127–142.

Eyre, N. (2023) 'Fabric first: is it still the right approach?'

Friedler, C. and Kumar, C. (2019) *Reinventing retrofit How to scale up home energy efficiency in the UK*, *Green Alliance*.

Gaur, A.S., Fitiwi, D.Z. and Curtis, J.A. (2019) 'Heat pumps and their role in decarbonising heating sector: A comprehensive review Standard-Nutzungsbedingungen: Heat Pumps and Their Role in Decarbonising Heating Sector: A Comprehensive Review'.

Houghton, E. *et al.* (2023) *Defining and identifying complex-to-decarbonise homes and retrofit solutions: research report*.

IES (no date) *IES Virtual Environment | The Leading Integrated Suite for Accurate Whole Building Performance Simulation*.

IPCC (2023) '2023: Sections', in *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Geneva, Switzerland: IPCC, pp. 35–115.

Jupyter (no date) *Project Jupyter*.

Liu, S. *et al.* (2023) 'How does future climatic uncertainty affect multi-objective building energy retrofit decisions? Evidence from residential buildings in subtropical Hong Kong', *Sustainable Cities and Society*, 92, p. 104482.

Liyanage, D.R. *et al.* (2024) 'Climate adaptation of existing buildings: A critical review on planning energy retrofit strategies for future climate', *Renewable and Sustainable Energy Reviews*, 199, p. 114476.

Mavrogianni, A. *et al.* (2012) 'Building characteristics as determinants of propensity to high indoor summer temperatures in London dwellings', *Building and Environment*, 55, pp. 117–130.

Microsoft (no date) *Microsoft Excel | Microsoft 365*.

Raslan, R. (2022) *Analysis: One in four homes is 'hard to decarbonise'*, *UCL News*.

Raslan, R. and Ambrose, A. (2022) 'Solving the difficult problem of hard to decarbonize homes'.

RIBA (2021) *RIBA 2030 CLIMATE CHALLENGE*.