

Combined impacts of extreme climate events and pandemic on future energy use in low-income households in Greater London

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Abstract. The impact of the COVID-19 pandemic on building energy use has been studied across various countries. However, with the growing trend toward flexible working and the rising frequency of climate-induced extreme weather events, the combined effects of these factors on future energy use remain largely unexplored. This study develops a methodology to investigate the resilience of the UK's low-income housing sector in response to the combined impacts of climate change and pandemics. Energy use of 7 residential archetypes (Bungalow, Converted flat, Detached, Semi-detached, Mid-terrace, End-terrace, and Low-rise buildings) under 13 future climate scenarios for the year 2050 and using detailed pandemic occupancy profiles is simulated. Specific thermo-physical properties and construction details of the archetypes (e.g., U-values, building envelope, HVAC system characteristics, boundary conditions, etc.) are obtained from English Housing Survey (EHS) data to develop a multi-zone model using the EnergyPlus software. The aim is to simulate hourly energy use (heating & hot water, electricity, and cooling) considering future climate scenarios (for the year 2050 as extreme warm and extreme cold) and pandemic measures for (1) Standard Retrofitting Scenario (SRS) and (2) Deep Retrofitting Scenario (DRS) for different housing archetypes. The results show that the increase in cooling during the extreme warm year (EWY) - and under the extended 14-hour to 24-hour potential pandemic occupancy schedule - is significantly greater than the rise in heat consumption during the extreme cold year (ECY) but varies across the housing archetypes. Furthermore, the results show retrofitting can result in higher cooling requirements. Across the three retrofitting scenarios, energy use for cooling is highest under the DRS, while the base case scenario (BCS), no retrofitting, shows the lowest energy use for cooling. Implementing passive cooling measures, such as shading, ventilation, and using cool/green roofs, may offset the increase in cooling demand caused by retrofitting.

Keyword: Pandemic, cooling energy demand, extreme climate events, low-income housing



1. Introduction

In response to the impacts of climate change on residential energy consumption, the UK government has committed to achieving net-zero carbon emissions by 2050 [1]. The government has introduced policies aimed at improving the energy efficiency of residential buildings to help lower greenhouse gas emissions. As existing homes are expected to make up around 70–80% of the UK's building stock by the 2050s [2], retrofitting current residential buildings, considering future climate, is essential [3]. This is especially important for fuel-poor households, who spend a significant portion of their income to keep their homes at a safe temperature [4]. As UK temperatures rise due to climate change, it is also essential to include cooling needs in the definition of fuel poverty. Furthermore, daily routines and individual behaviours has changed significantly after the pandemic. Time spent at home has increased especially among people over 65, as well as among low-income families [5]. In addition, many employees and students shifted to working or studying from home, often leading to greater use of computers and tablets in households [6]. As a result, people spent more time at home, which brought notable changes to daily habits, contributing to higher residential heating and electricity use—and consequently, increased carbon dioxide emissions in many countries [7, 8, 9].

While flexible working has become increasingly prevalent (partly due to the pandemic), and climate-induced extreme weather events grow more frequent, the combined impact of these trends on future energy use remains largely unexplored. Addressing the combined effects of these factors on energy use is crucial for guiding future energy planning and policy development, as it captures the complex interactions between extreme events—such as extreme climate events, possible future pandemic and fuel poverty—that disproportionately impact low-income households. The main aim of the present study is to develop a methodology to quantify the resilience of the UK's low-income housing sector in response to the combined impacts of climate change and pandemics. We aim to analyse the impacts of possible pandemic measures on the energy use (electricity, heating & hot water and cooling) for 7 UK housing archetypes, namely Bungalow (floor area, 70 m²), Converted flat (floor area, 72.28 m²), as well as Detached (floor area, 70.96 m²), Semi-detached (floor area, 51.59 m²), Mid-terrace (floor area, 45 m²), End-terrace (floor area, 45 m²), and Low-rise buildings (floor area, 51.8 m²). The focus is on changes in residential occupant density (usable area per person) and occupancy schedules for different confinement scenarios; a typical full-time worker (14hr at home); normal occupancy schedule with no covid-19, partial lockdown level 1 (18hr at home), partial lockdown level 2 (21hr at home), and full lockdown level 3 (24hr at home). The aims are to simulate hourly energy use (heating & hot water and electricity and cooling) considering both future climate scenarios (typical year 2050, extreme warm and extreme cold) and pandemic measures for (1) normal retrofitting scenario and (2) deep retrofitting scenario for different housing archetypes.

2. Data and method

2.1 Data

We use data from the English Housing Survey (EHS) [10] to provide comprehensive details on two main aspects:

- The geometric characteristics of various residential building types, including footprint, number of floors, height, and volume.
- Thermal properties of construction layers such as roof, floor, windows, and walls, including U-values, presence of cavity or solid walls, material properties, thickness (m), and conductivity (W/mK) [9].

Our analysis focuses specifically on low-income homes within the EHS sample of Greater London, comprising 337 homes out of nearly 2000 sampled. Energy consumption simulations were conducted using a typical meteorological year (TMY) weather file for Greater London under base-case (pre-Covid) occupancy schedules, people stay at home 14 hrs per day [9]. Furthermore, simulations were performed using weather data specific to Greater London in 2020, considering three different occupancy schedules

(18 hrs, 21 hrs, and 24 hrs) [9]. Weather files were sourced from Meteonorm version 8 for these simulations. We defined three Covid-19-related occupancy profiles, alongside a base case (no Covid), to assess the impact of changed occupancy patterns on residential energy use. Each profile detailed activities across micro-environments (living room, kitchen, bedroom, etc.), including (i) hours of operation for systems and appliances (heating, lighting, cooking, TV, laptop, fridge, exhaust fan) in winter and summer, (ii) internal heat gains from occupants' activities, and (iii) heat losses through window openings. The confinement scenarios are: (i) a base-case with occupants' home for 14 hours/day (typical full-time worker schedule); (ii) and (iii) partial lockdowns with 18 and 21 hours/day at home, respectively; and (iv) a full lockdown with 24 hours/day occupancy. Activity patterns during lockdown were informed by survey data [11]. We modelled a gas boiler heating system with a 21°C setpoint for heating [12], 26°C for cooling, and natural ventilation when outdoor temperatures were between 21–24°C. Boiler flow temperature was set to 65°C following UK guidelines primarily because the boiler requires this temperature to maintain the indoor setpoint of 21°C. However, the supply temperature is lower for retrofitting scenarios due to a minor modification implemented to enhance system efficiency, in line with UK guidelines. Heating was assumed to be off between May 1 and September 30 (although the simulations were run for the entire year), with systems operating as needed to maintain thermal comfort based on outdoor temperature and occupancy schedules [9]. For the HVAC system, the primary reason for selecting a gas boiler was to represent a moderate or standard renovation approach that prioritizes cost-effectiveness. Replacing the entire heating system—such as installing a heat pump—would involve a significantly higher financial investment. Retaining the gas boiler in these scenarios reflects a more typical, incremental upgrade pathway. In contrast, the deep retrofit scenario illustrates a deep renovation strategy, where the adoption of a heat pump aligns with a more comprehensive level of intervention. This setup also provides a consistent framework for comparing the performance and impact of deep retrofit (DRS) against that of a reasonably well-performing, airtight building that retains an enhanced but conventional heating system. Finally, annual energy simulation results [9] were validated against measured domestic gas and electricity data from the National Energy Efficiency Data-Framework (NEED) [13].

2.2. Energy use simulation using EnergyPlus

Multi-zone 3D models of the residential building archetypes were developed in Grasshopper. Hourly energy consumption profiles were simulated using the EnergyPlus engine via the Ladybug Tools plugin, with all modelling and simulation carried out within Grasshopper. The analysis focused on the effects of residential occupant density (usable area per person) and daily occupancy schedules under different confinement scenarios. Energy use (heating & hot water and electricity and cooling) of 7 residential archetypes (Figure 1) under 13 future climate scenarios for the period of 2040-2069 targeting the year 2050, using detailed occupancy profiles, is simulated. For the future climate, three sets of representative weather data are synthesized and adopted for Greater London based on a method developed by Nik [14], namely Typical Downscaled Year (TDY), Extreme Warm Year (EWY), and Extreme Cold Year (ECY). TDY represents a year with the most typical monthly temperatures across 390 years (13 scenarios over 30 years). Similarly, ECY and EWY capture the coldest and warmest months, respectively (Figure 1). The application of this method has been extensively assessed and shown to accurately capture probable future conditions, including extremes, while significantly reducing the number of simulations needed [15-17].

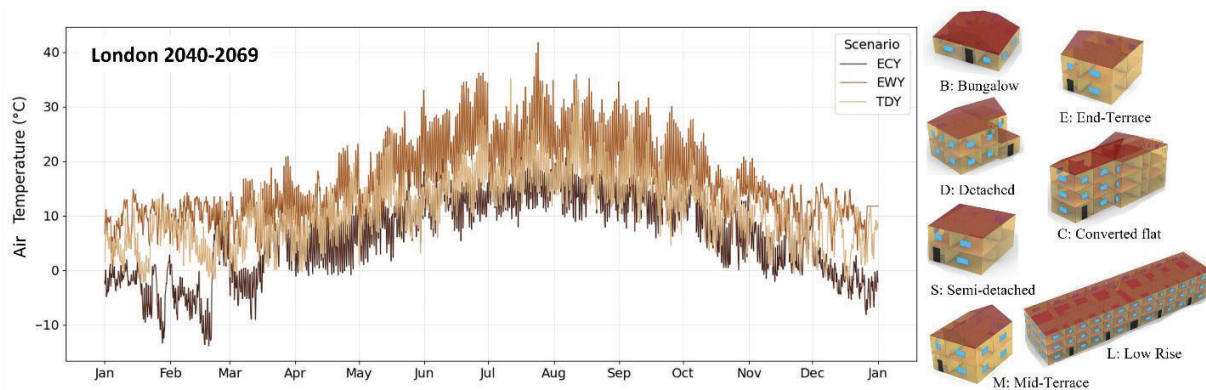


Figure 1. Hourly distribution of ECY, TDY, and EWF future weather data (2040–2069) in Greater London (left). Severn multi-zone residential archetypes in Greater London (right).

2.3 Energy retrofit scenario

To assess how energy efficiency interventions may impact the future energy use, we simulate hourly energy consumption under (i) based-case scenario, BCS, (no retrofitting) and (ii) and (iii) two detailed retrofitting strategies for net-zero emissions.

Table 1. The Energy efficiency target values for existing building elements for different retrofit scenarios for the year 2050 [19–20]. We used auto sizing in OpenStudio to determine the system capacity, based on heating and cooling design days.

	Base-Case Scenario (BCS) (no retrofitting) -2050	Standard Retrofit Scenario (SRS) - 2050	Deep Retrofit Scenario (DRS) - 2050
Cavity wall U-value (W/m ² K)	1.57	0.7	0.55
External wall U-value (W/m ² K)	2	0.7	0.3
Internal Walls U-value (W/m ² K)	2	0.7	0.3
Pitched Roof - Ceiling Level U-value (W/m ² K)	0.61	0.35	0.16
Pitched Roof - Rafter Level U-value (W/m ² K)	0.61	0.35	0.16
Flat Roof U-value (W/m ² K)	0.61	0.35	0.16
Ground floor U-value (W/m ² K)	1.99	0.7	0.25
Internal Floors	0.21	0.8	0.35
Glazing U-value (W/m ² K)	3.19	1.8	1.2
Glazing Type	Double glazing	Double glazing	Triple glazing
Permeability (m ³ /h m ² @ 50Pa)	n/a	n/a	8.0 m ³ / (h.m ²)
External shading	No	No	Yes
HVAC System	Gas boiler	Gas boiler	Heat pump
System Efficiency	0.63	0.86	COP3
Supply Temperature	65	55	Air-based
Energy recovery system	No	No	at least 70%

The two retrofitting scenarios includes standard retrofit scenario (SRS) and deep retrofit scenario (DRS). Home energy retrofits were implemented by upgrading the thermal performance of windows, external walls, floors, and roofs for each dwelling archetype. U-values for these elements were sourced from the English Building Regulations Approved Document L [18–19], which provides target efficiency standards for existing dwellings (see Table 2). For DRS, we apply the standards designated for building extensions, which involve adding new spaces to existing buildings. These standards are more affordable compared to those for new buildings, aligning with the focus of our study on low-income households, where complete replacement of homes is unlikely. However, for roofs, we adopt the standards set for new buildings.

4. Results

4.1 Energy consumptions simulation results for the 2050 extreme warm year (EWY)

Figure 2 shows the results for the 2050 extreme warm year, presenting the predicted household energy use for heating & hot water, cooling and electricity in kWh/m²/year. The prediction includes the (i) base-case scenario, BCS, (no retrofitting), (ii) standard retrofit scenario (SRS) and (iii) deep retrofit scenario (DRS), for the three different confinement occupancy levels (18hr, 21hr, 24hr) as well as for the normal occupancy schedule (14hr) for each housing archetype. Figure 2 indicates the cooling demand is significantly higher than that for heating & hot water and electricity for nearly all archetypes across all retrofitting scenarios. For the three retrofitting scenarios, energy use for heating and hot water is lowest under the SRS and DRS, while the BCS (no retrofitting) shows the highest consumption. This difference is driven by both climatic factors and the energy efficiency improvements achieved through retrofitting measures such as upgraded glazing and insulation. An opposite trend is observed for cooling, where retrofitting can result in higher cooling requirements. Across the three retrofitting scenarios, energy use for cooling is highest under the DRS (and under the extended 14-hour to 24-hour potential pandemic occupancy schedule), while the BCS (no retrofitting) shows the lowest energy use for cooling. Implementing passive cooling measures, such as shading, ventilation, and using cool/green roofs, may offset the increase in cooling demand caused by retrofitting. Bungalow and Mid-Terrace indicate the highest energy use for cooling, while the End-Terrace and Detached archetypes have the lowest cooling. The reasons may be partly related to building geometry, floor area, building age, and surface-to-volume ratio of each archetype as well as to the occupancy profiles – these will be explored further as this study continues. Regarding occupancy levels during a potential pandemic in future, cooling demand increases as the schedule shifts from 14 hours to 24 hours at home.

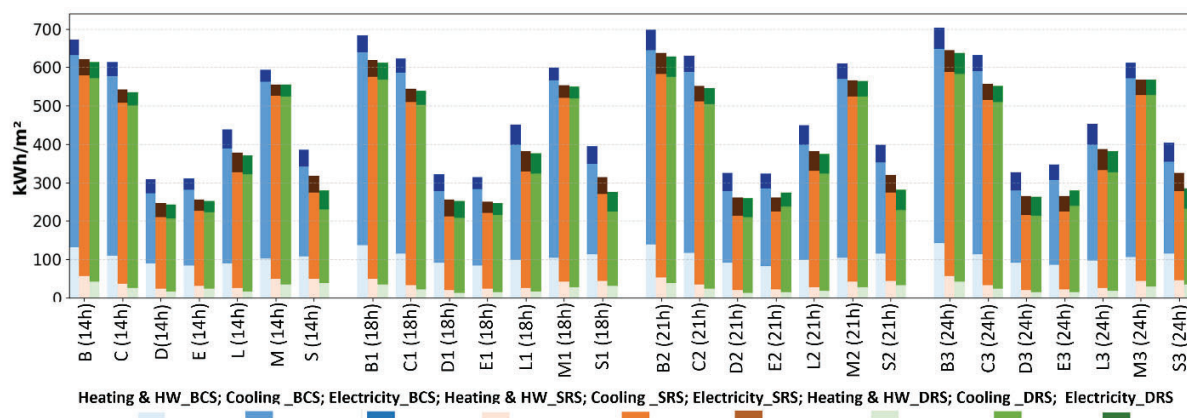


Figure 2. Prediction of energy use for heating & hot water, kWh/m²/year, total electricity, kWh/m²/year (equipment and lighting), and cooling for the 2050 extreme warm year (EWY) and for the (i) base-case scenario, BCS, no retrofitting, (ii) standard retrofit scenario (SRS) and (iii) deep retrofit scenario (DRS), and for the normal occupancy schedule (14 hr at home) and three confinement occupancy schedules: level 1 (18 hr at home), level 2 (21 hr at home), level 3 (24 hr at home). B: Bungalow; C: Converted flat; D: Detached; E: End Terrace; L: Low Rise; M: Mid Terrace; S: Semi-detached.

4.2 Energy consumptions simulation results for the 2050 extreme cold year (ECY)

The results, for the 2050 extreme cold year, show the predicted household energy use kWh/m²/year (heating & hot water, electricity) and cooling kWh/m²/year. Figure 3 indicates energy use for heating & hot water is significantly higher than that for cooling and electricity for all archetypes across all retrofitting scenarios. Across the three retrofitting scenarios, energy use for heating and hot water is lowest under the DRS, while

the BCS (no retrofitting) shows the highest. This difference is certainly driven by the energy efficiency improvements which could possibly achieved through retrofitting measures such as upgraded glazing and insulation. Furthermore, energy use for heating & hot water increases for BCS (no retrofitting) under the extended 14-hour to 24-hour potential pandemic occupancy schedule, while reduces for DRS and SRS from 14-hour to 24-hour and among the archetypes except for low-rise archetype. Across the three retrofitting scenarios, energy use for cooling is very low due to the climate condition. Bungalow and Mid-Terrace indicate an overheating (highest heating consumption), while the End-Terrace archetype has relatively the lowest heating consumption.

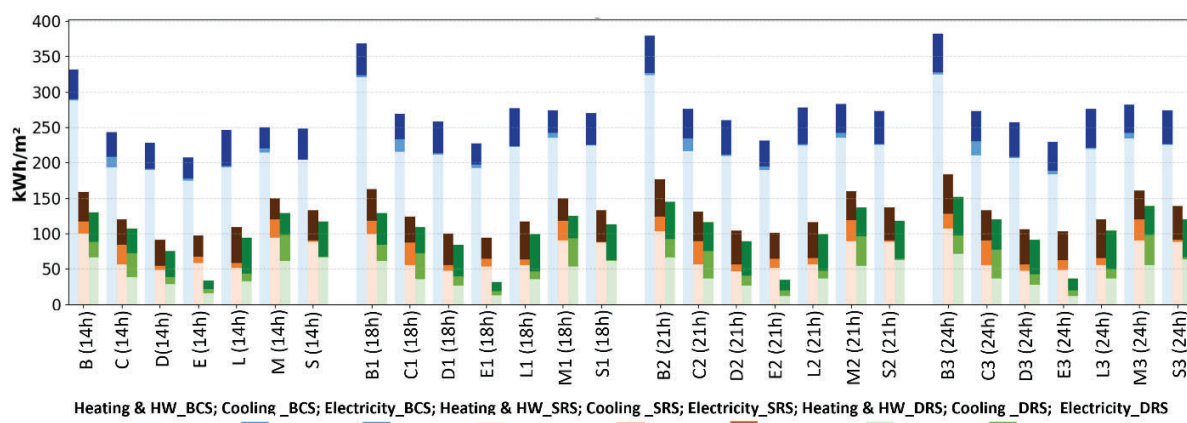


Figure 3. Prediction of energy use for heating & hot water, kWh/m²/year, total electricity, kWh/m²/year (equipment and lighting), and cooling for the 2050 extreme cold year (EWY) and for the (i) base-case scenario (BCS), no retrofitting, (ii) standard retrofit scenario (SRS) and (iii) deep retrofit scenario (DRS), and for the normal occupancy schedule (14 hr at home) and three confinement occupancy schedules: level 1 (18 hr at home), level 2 (21 hr at home), level 3 (24 hr at home). B: Bungalow; C: Converted flat; D: Detached; E: End Terrace; L: Low Rise; M: Mid Terrace; S: Semi-detached.

5. Conclusion and future work

Considering future climate scenarios (2040-2069), this study simulates hourly energy use of 7 residential archetypes, for extreme heat year and extreme cold year, and for different occupancy schedules of potential pandemic, and 2 retrofitting scenarios for net-zero emission buildings. The findings show that the increase in energy use for cooling during the EWY is significantly greater than the rise in energy use for heating during the ECY. This highlights the growing importance of domestic cooling needs and the limited discussion around the strategies households employ to cope with overheating events particularly under the extended 14-hour to 24-hour potential pandemic occupancy schedules. The preliminary results indicate that the risk increases under potential pandemic occupancy schedules, especially when combined with the effects of anticipated future weather conditions. By analysing residential clusters and the distribution of building archetypes in Greater London, the research extends from the building level to a city-scale framework, with a particular emphasis on low-income households. This approach is essential for guiding future energy planning and policy, as it captures the complex interactions between extreme events—such as extreme climate events, possible future pandemic and fuel poverty—that disproportionately impact low-income households. Such insights are critical for achieving the energy and climate goals set for 2050.

References

- [1] Government, H., The Climate Change Act 2008 (2050 Target Amendment) Order 2019, HM Government, London, 2019.
- [2] B. Boardman, Home truths: A low? carbon strategy to reduce UK housing emissions by 80% 2050, A Research report for the Co-operative Bank and, Energy saving in Friends of the Earth (2007 1 June 2023). Available from: <http://www.eci.ox.ac.uk/research/energy/downloads/boardman07-hometruths.pdf>.
- [3] Y Wang, G Petrou, et al., 2025. Investigating the impacts of home energy retrofit on the indoor environment through co-simulation: A UK case study. *Journal of Building Engineering* 100, 111794
- [4] Hinson, S., & Bolton, P. (2022). Fuel Poverty. *The House of Commons Library: London, UK*. <https://researchbriefings.files.parliament.uk/documents/CBP-8730/CBP-8730.pdf>
- [5] S. Saadat, D. Rawtani, C.M. Hussain. 2020. Environmental perspective of COVID-19. *Science of The Total Environment*, 728 (2020), Article 138870, 10.1016/j.scitotenv.2020.138870.
- [6] T. Cuervo-Vilches, M.Á. Navas-Martín, S. March, I. Oteiza. 2021. *Adequacy of telework spaces in homes during the lockdown in Madrid, according to socioeconomic factors and home features* *Sustainable Cities and Society*, 75, DOI: 103262, 10.1016/j.scs.2021.103262
- [7] V. Todeschi, K. et al., 2022. “Impact of the COVID-19 Pandemic on the Energy Performance of Residential Neighborhoods and Their Occupancy Behavior.” *Sustainable Cities and Society* 82: 103896.
- [8] M.A. Khalil, and M. R. Fatmi. 2022. *How Residential Energy Consumption Has Changed Due to COVID-19 Pandemic? An Agent-Based Model.* *Sustainable Cities and Society* 81:103832.
- [9] N. Mohajeri, K Javanroodi, L Fergusson, J Zhou, et al., 2023. Quantifying the impact of Covid-19 on the energy consumption in the low-income housing in Greater London. *Journal of Physics: Conference Series* 2600 (13), 132002.
- [10] DCLG, 2011. *English Housing Survey 2010-2011*.
- [11] G.M. Huebner, et al., 2021. *Survey study on energy use in UK homes during Covid-19. Buildings and Cities*, 2(1), pp. 952–969. DOI: <https://doi.org/10.5334/bc.162>.
- [12] R.V. Jones et al., 2016. *Space heating preferences in UK social housing: A socio-technical household survey combined with building audits*. *Energy and Buildings* 127, 382-398.
- [13] National Energy Efficiency Data Framework (NEED), 2011. *Summary of Analysis using the National Energy Efficiency Data-Framework Part I Domestic Energy Consumption*, Department of Energy & Climate Change, UK.
- [14] VM Nik. Making energy simulation easier for future climate – Synthesizing typical and extreme weather data sets out of regional climate models (RCMs). *Applied Energy* 177, 204–226.
- [15] A.T.D. Perera et al., 2021. *Climate resilient interconnected infrastructure: Co-optimization of energy systems and urban morphology*. *Applied Energy* 285, 116430.
- [16] Y. Yang et al., 2021. *Climate change and energy performance of European residential building stocks – A comprehensive impact assessment using climate big data from the coordinated regional climate downscaling experiment*. *Applied Energy* 298, 117246.
- [17] M. Hosseini et al., 2022. *High-resolution impact assessment of climate change on building energy performance considering extreme weather events and microclimate – Investigating variations in indoor thermal comfort and degree-days*. *Sustainable Cities and Society*, 103634.
- [18] HM Government. (2021). *The Building Regulations 2010: Conservation of fuel and power and overheating*. Approved Document L and O.
- [19] Ministry of Housing, Communities and Local Government. 2021. *The Future Homes Standard: 2019 Consultation on changes to Part L (conservation of fuel and power) and Part F (ventilation) of the Building Regulations for new dwellings*.