Energy, Cost and Carbon Performance of Retrofit

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Introduction

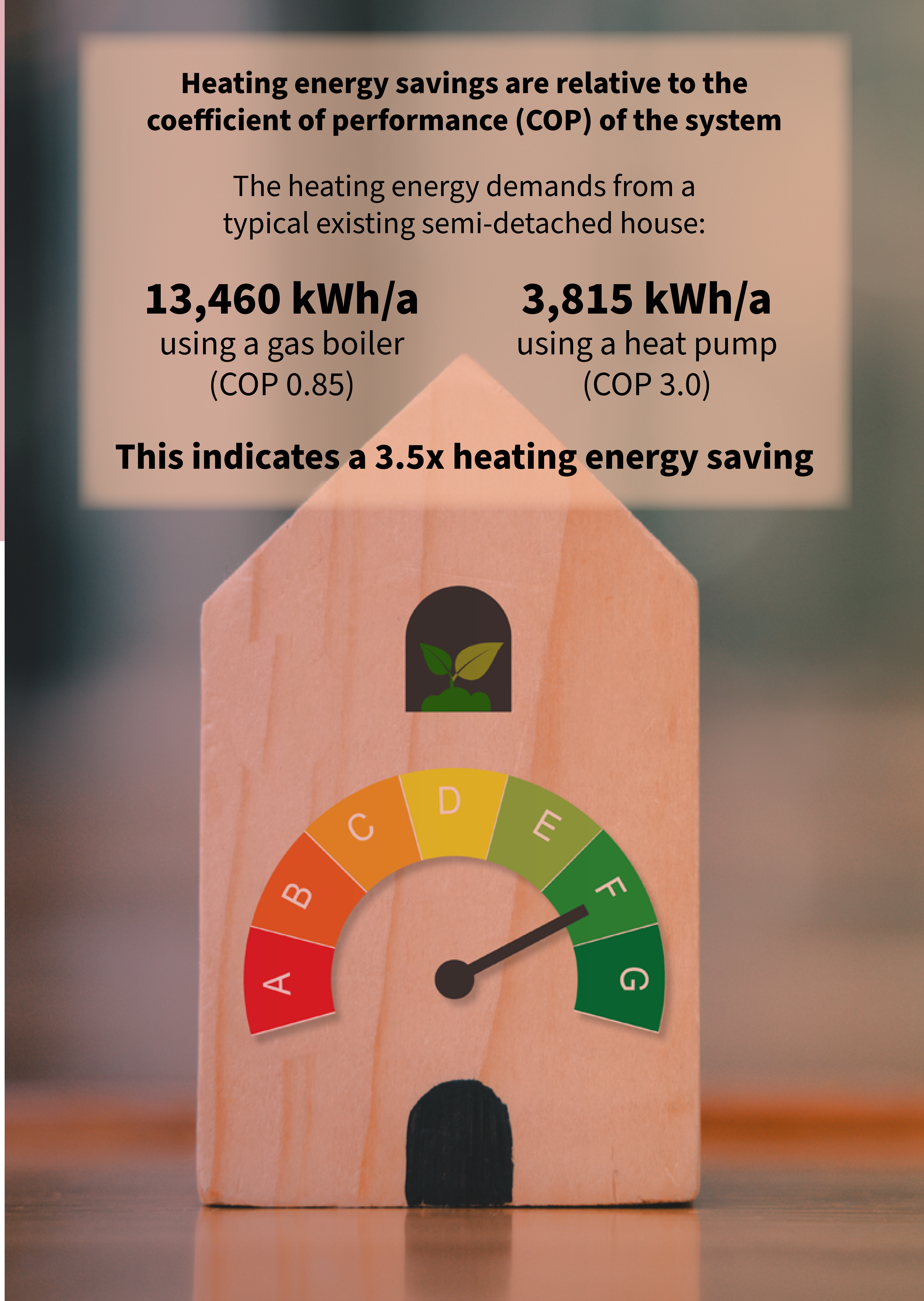
Implementing different decarbonisation strategies, such as building fabric and systems retrofit, in parallel with grid decarbonisation, aims to reduce domestic carbon emissions, improve housing quality, and tackle fuel poverty. However, many retrofit schemes and policies have not been oriented to achieve a net-zero target[1], and there is a lack of data that informs the relative change between energy demands, energy cost and carbon performance of different retrofit scenarios across various building typologies against their existing condition.

Focusing on South Yorkshire's climate context, our research investigates the effectiveness of different retrofit measures on fourteen low-rise housing archetypes and their contribution to net-zero retrofit.

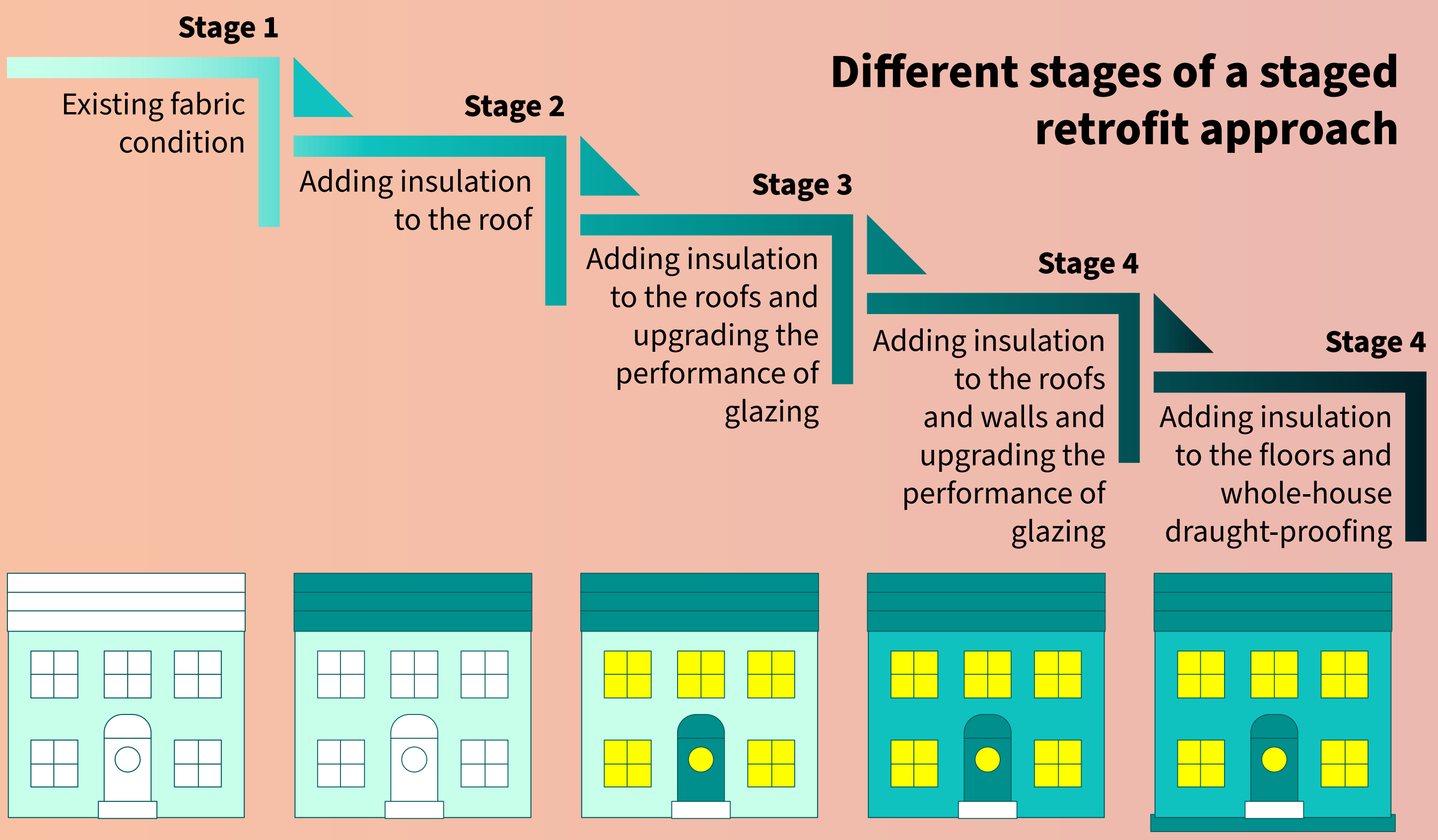
Fabric-first and system-first retrofit

Heating energy savings of a system-only retrofit i.e. switching a gas boiler to a heat pump are relative to the coefficient of performance (COP) of the system. For instance, the heating energy demands from a typical existing semi-detached house with a gas boiler were 13,460 kWh/a, and this could change to 3,815 kWh/a by switching from a gas boiler (COP 0.85) to a heat pump (COP 3.0), indicating 3.5 times heating energy savings. Despite heat pumps being more efficient and using less energy, the overall household energy bills are likely to increase in the system-only retrofit scenario due to electricity being more expensive than natural gas (i.e. in 2025 the electricity tariff was 3.9 times higher than the gas tariff). If the heat pump is 3 times higher, our research found that once the requirements for cooling and ventilation were accounted for, there was an average increase of 10% in energy bills across all different housing types. However, this could be remedied by adding a fabric-retrofit first, reducing the energy demands of the building. In a whole-house retrofit scenario, an average of 85% of the heating energy cost savings can be achieved across all housing types. As illustrated in Case Study "Retrofit for Net-Zero and Healthy Buildings in a Warming World", it is also important to ensure adequate ventilation and cooling are provided, which, if mechanical rather than passive, will result in additional energy use.

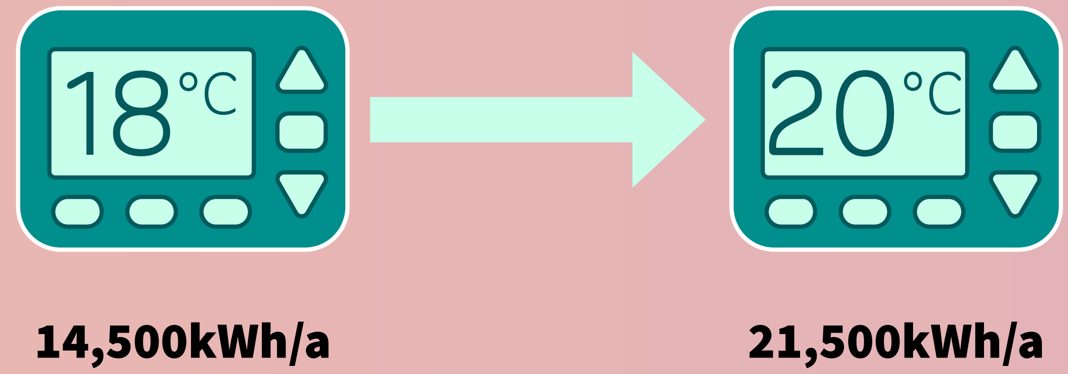
1 Alabid, J., Bennadji, A. and Seddiki, M. (2022), A Review on the Energy Retrofit Policies and Improvements of the UK Existing Buildings, Challenges and Benefits. Renewable and Sustainable Energy Reviews, 159(1), p.112161.



Different stages of a staged retrofit approach



We compared the sensitivity of operational carbon emissions and energy costs that are changed by different heating and cooling temperature set points



Increasing a temperature set point from **18°C to 20°C** results in a **48% increase** in energy demand

Our modelling study shows that an average of 85% of the total energy cost savings can be achieved across all archetypes by adding a whole-house retrofit while ventilation and cooling needs are provided. A system-first retrofit can significantly reduce operational carbon emissions across all archetypes by approximately 72% compared to the existing condition, encompassing both cooling and ventilation requirements, while the relative balance of gas and electricity carbon emissions (i.e. the carbon emission factor for gas is 3.4% higher than that for electricity in 2025) is also taken into account. A whole-house retrofit, which reduces residual heating demands and provides cooling and ventilation, has more profound operational carbon savings than energy cost savings, resulting in a typical semi-detached house with 2.28 tonnes of annual operational carbon savings.

Carbon Paybacks

The upfront embodied carbon investment for system and fabric retrofit in larger buildings is higher than in smaller ones. The material and system choices for retrofit influence the carbon payback year. A typical existing semi-detached house emits about 2.5 tonnes/year of operational carbon for heating, whereas about 5.7 tonnes of embodied carbon investment is required to achieve a whole-house retrofit. In general, the carbon payback year between embodied and operational carbon is found from 2-4 years if glass wool insulation for the roof and floor and EPS (Expanded Polystyrene) insulation for the wall, is considered in a fabric-first and whole-house retrofit across different building archetypes. Decarbonising the grid can facilitate a lower embodied carbon investment, as material decarbonisation can be achieved by electrification of industrial processes and transport. This will further reduce the carbon trade-off payback time between embodied carbon investment and operational carbon savings for a whole-house retrofit. Integrating passive (e.g., the whole life embodied carbon of external sliding shutters is 4.5 times higher than internal venetian blinds[2]) retrofitting approaches could further alter building performance, carbon payback and long-term energy and carbon savings.

Retrofit prebound and rebound sensitivities

Environmental payback times are quicker than economic payback times, and different requirements for comfort and socio-economic conditions could also influence both paybacks. In practice, when the building occupiers purposely set heating and cooling set point temperatures to reduce energy costs, the prebound effect occurs. Likewise, setting a higher heating set point or a lower cooling set point temperature causes the rebound effect. Considering this, we compared the sensitivity of operational carbon emissions and energy costs that are changed by different heating and cooling temperature set points. The results show that the average annual heating demands of the existing archetypes could increase from 14,500 kWh/a to 21,500 kWh/a, a 48% increase, by switching a 2°C difference of the heating set point from 18 °C to 20 °C. However, about a 19% change could be expected by switching a 1°C difference of the heating set point from 20 °C to 21 °C. As real-world energy use and carbon savings from post-retrofit homes could significantly diverge from theoretical models due to occupant behaviour and comfort needs for individual differences, we recommend a retrofit policy that integrates behaviour change design for energy consumption (e.g., education and reward programs), user engagement strategies, and provides necessary information about retrofit sensitivities in different archetypes.

Recommendations for South Yorkshire and the UK

This case study demonstrates that there are inequalities in energy demands and carbon emissions across different building archetypes. For instance, the oldest archetypes, such as the Victorian and Georgian ages, have higher energy demands due to poor fabric performance and typically larger floor areas to heat. Comparisons of fabric, systems and a combination of both retrofits inform the need to develop a future retrofit policy to:

- ensure residual energy demands are minimised by adding retrofit intervention,
- integrate grid and material decarbonisation for shorter carbon payback time from retrofit intervention,
- provide sufficient information about different types of retrofit intervention and address future retrofit rebound sensitivities across different archetypes.

This context-dependent dialogue example for the South Yorkshire housing stocks can be applied to similar housing stocks and the whole UK.

2 Edwards PT, Fordham M, Arnold M. (2023),Shading for housing: Embodied carbon of shading products. Good Homes Alliance.