University of Nottingham
Energy Institute

# Energy Costs and the Zero Carbon Agenda

**Prof Lucelia Rodrigues**

Chair in Sustainable and Resilient Cities

University of Nottingham
UK | CHINA | MALAYSIA

THURSDAY 16 JUNE

ARCHITECTURE AND BUILT ENVIRONMENT
**End-of-Year Show 2022**

EXHIBIT!22 OPENING

Lisa Finlay
Partner & Group Leader
Heatherwick Studio

Architecture Quad
University of Nottingham
University Park
NG7 2RX

6PM

ONLINE

# exhibit!22

Building Futures
Alexander Adams, Year 3

University of Nottingham
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# University of Nottingham Energy Institute

www.nottingham.ac.uk/research/research-areas/energy-institute/


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# Background


Free image by Callum Shaw – www.callumshaw.com


www.nottinghamcity.gov.uk/your-council/about-the-council/carbon-neutral-nottingham-2028/why-do-we-need-to-act/

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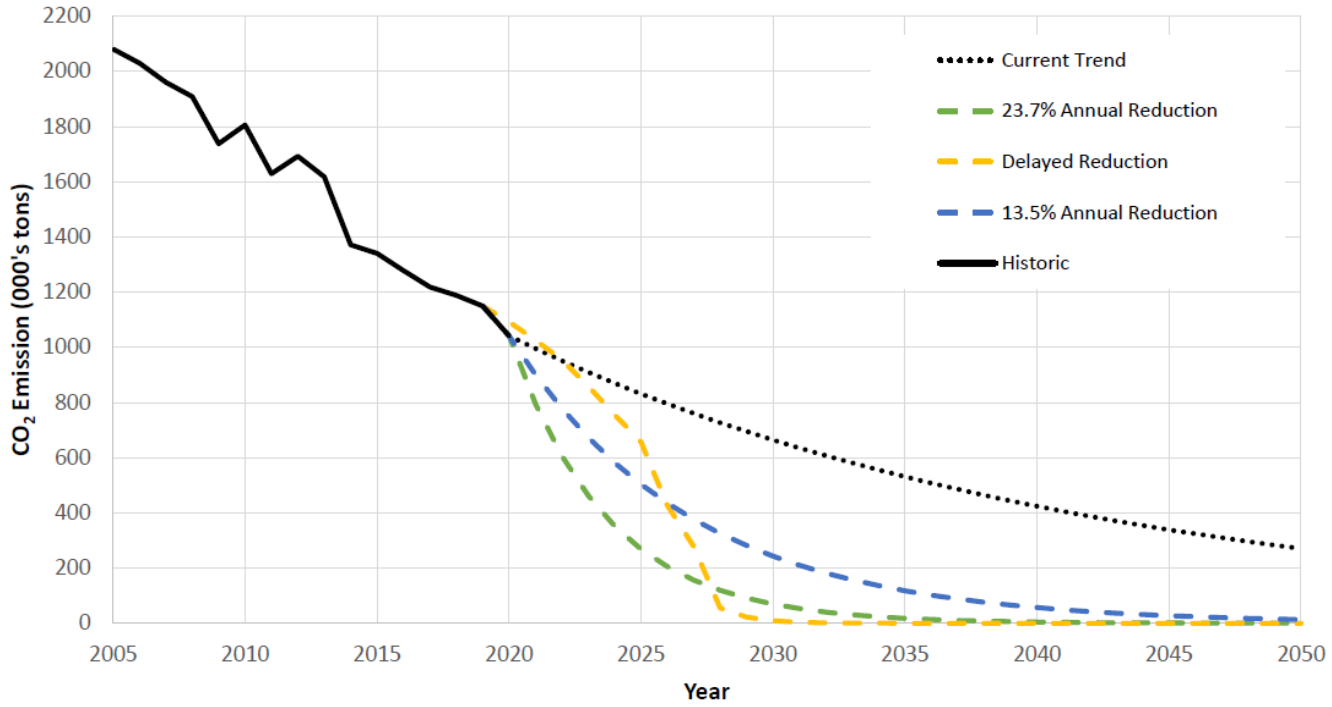
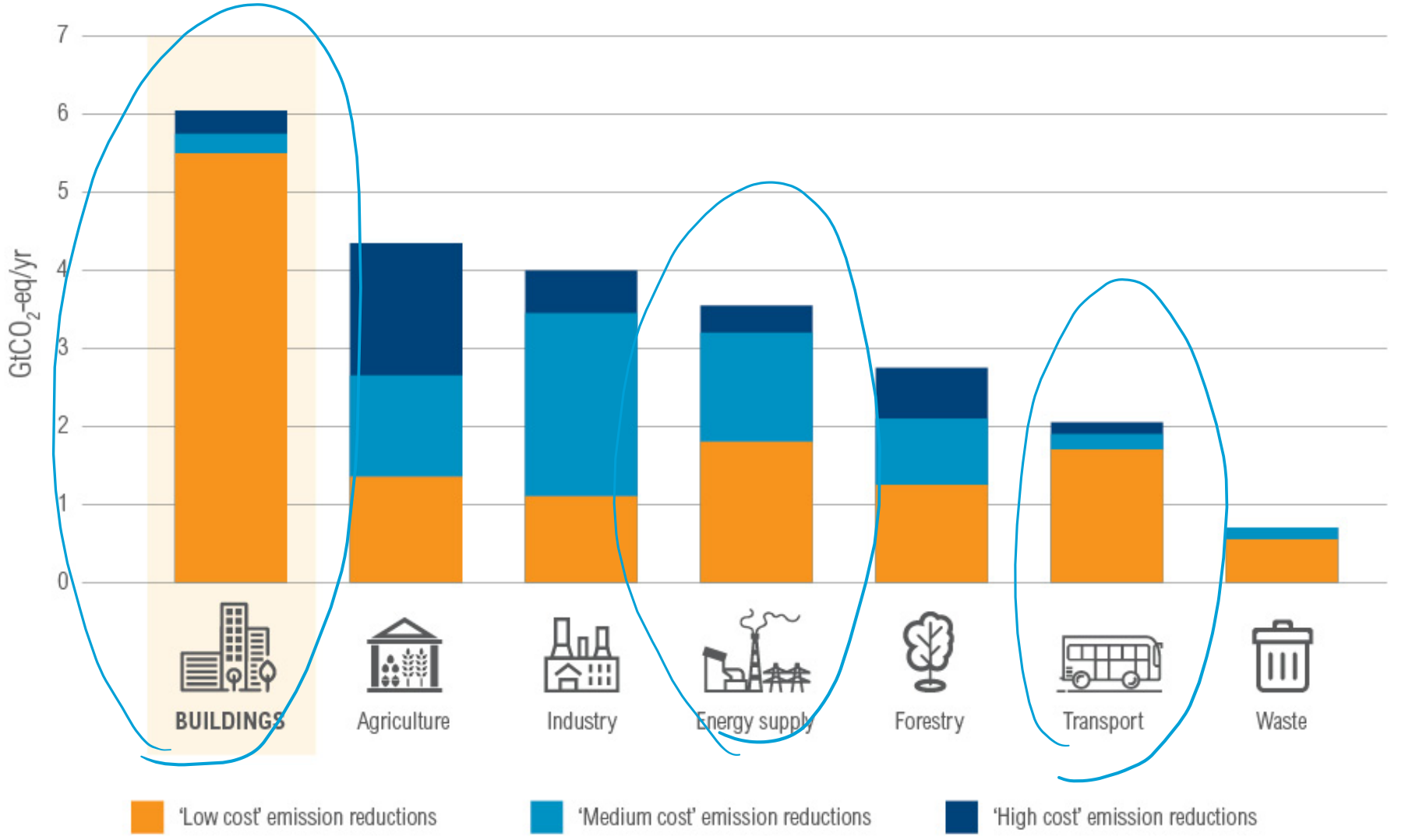
# Nottingham's $CO_2$ emissions pathway




Graph by Nottingham City Council, October 2022
Data published by BEIS in June 2022, for 2020

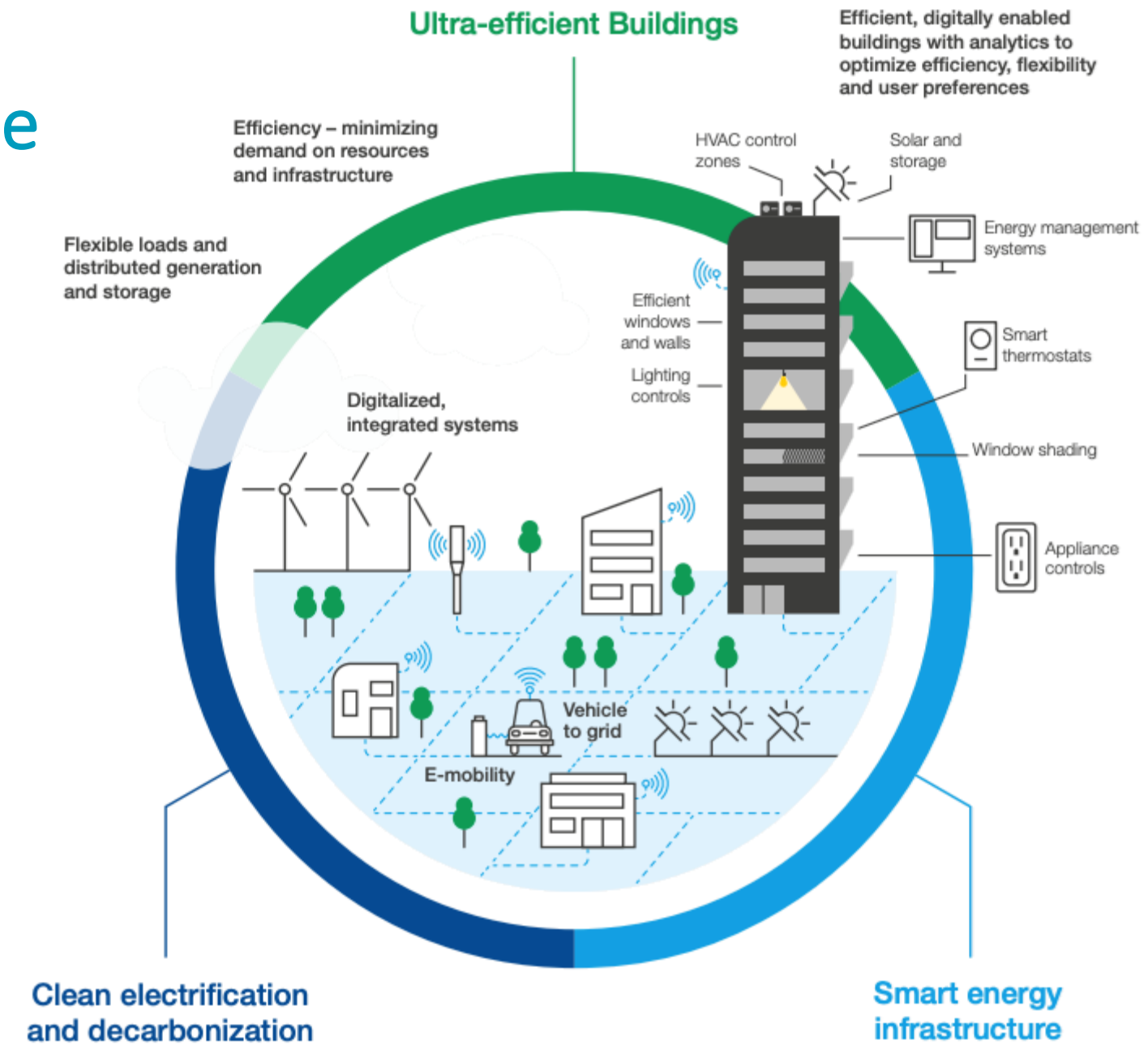
- Nottingham has reduced city wide $CO_2$ emissions by 49.96% since 2005
- **57.7% per capita reduction in the last 15 years**
- City one of the top 100 world cities for climate action




Economic Mitigation Potential by Sector, 2030

World Resources Institute, Accelerating building efficiency: Eight Actions for Urban Leaders. Available at https://publications.wri.org/buildingefficiency/

Rationalise




Smartify

Electrify

World Economic Forum

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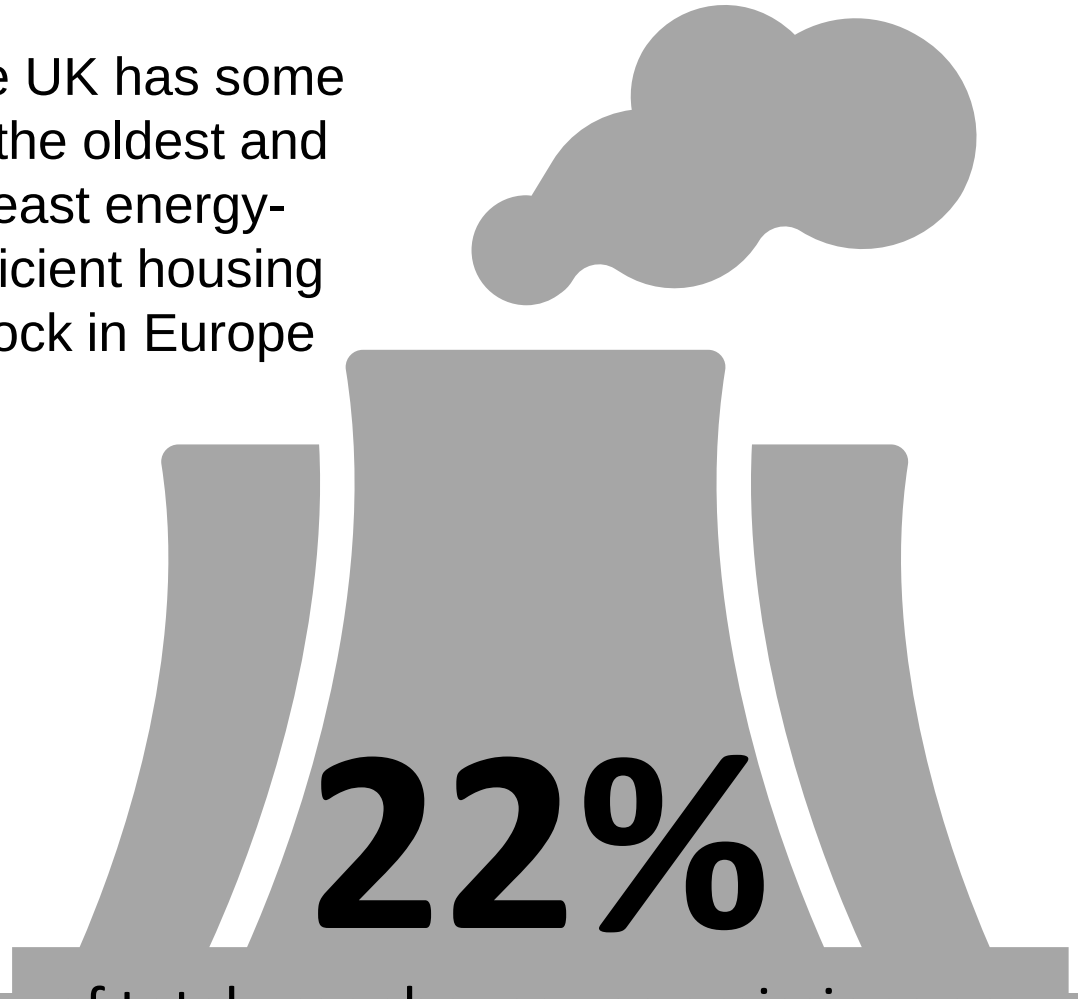
# Rationalise

# Why Retrofit?

The UK has some of the oldest and least energy-efficient housing stock in Europe

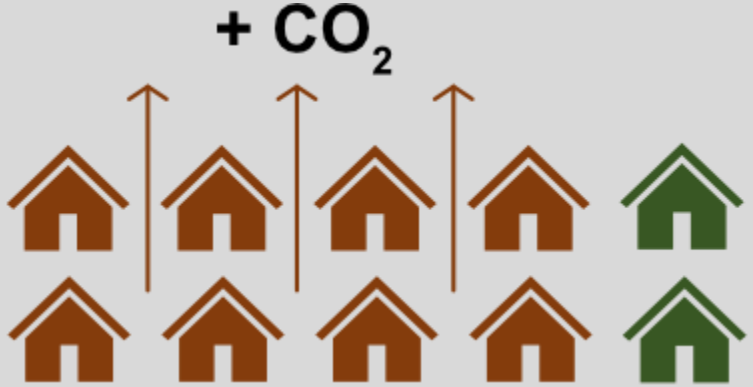


**22%**

of total greenhouse gas emissions are produced by residential buildings in the UK (LETI, 2020, p. 14, 58)

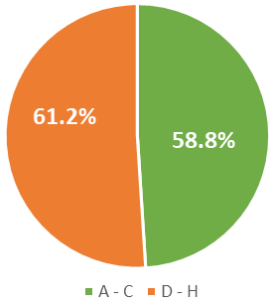
**80%**

of the buildings that will form the UK 2050 housing stock were built before the introduction of energy performance standards and are far from meeting future energy needs (Passivhaus Trust, 2022, p. 6)

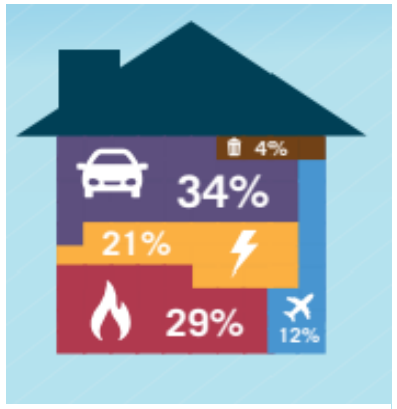


# Why Retrofit?

164k





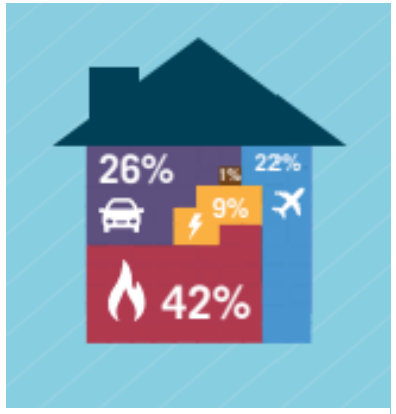



6 tonnes of $CO_2$

2030

164k





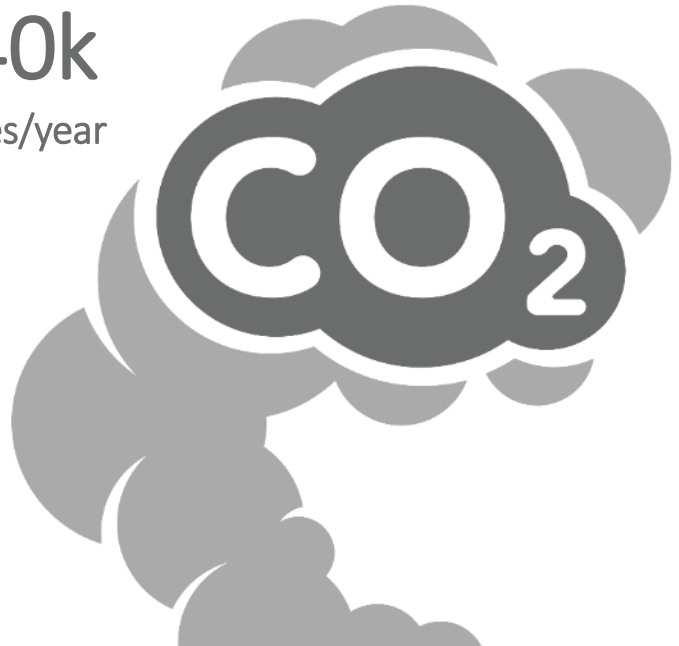

4.5 tonnes of $CO_2$

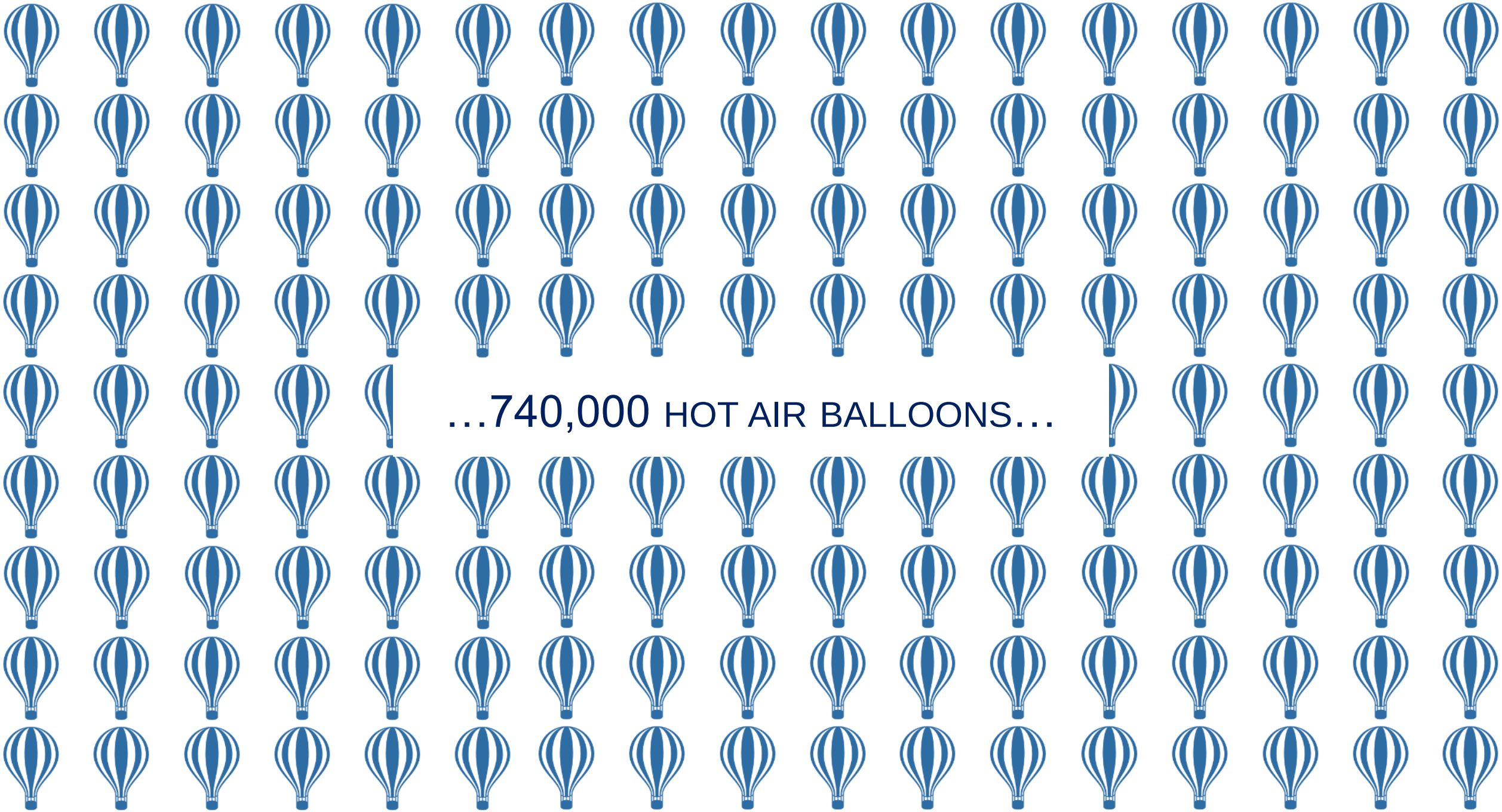
247k

tonnes/year

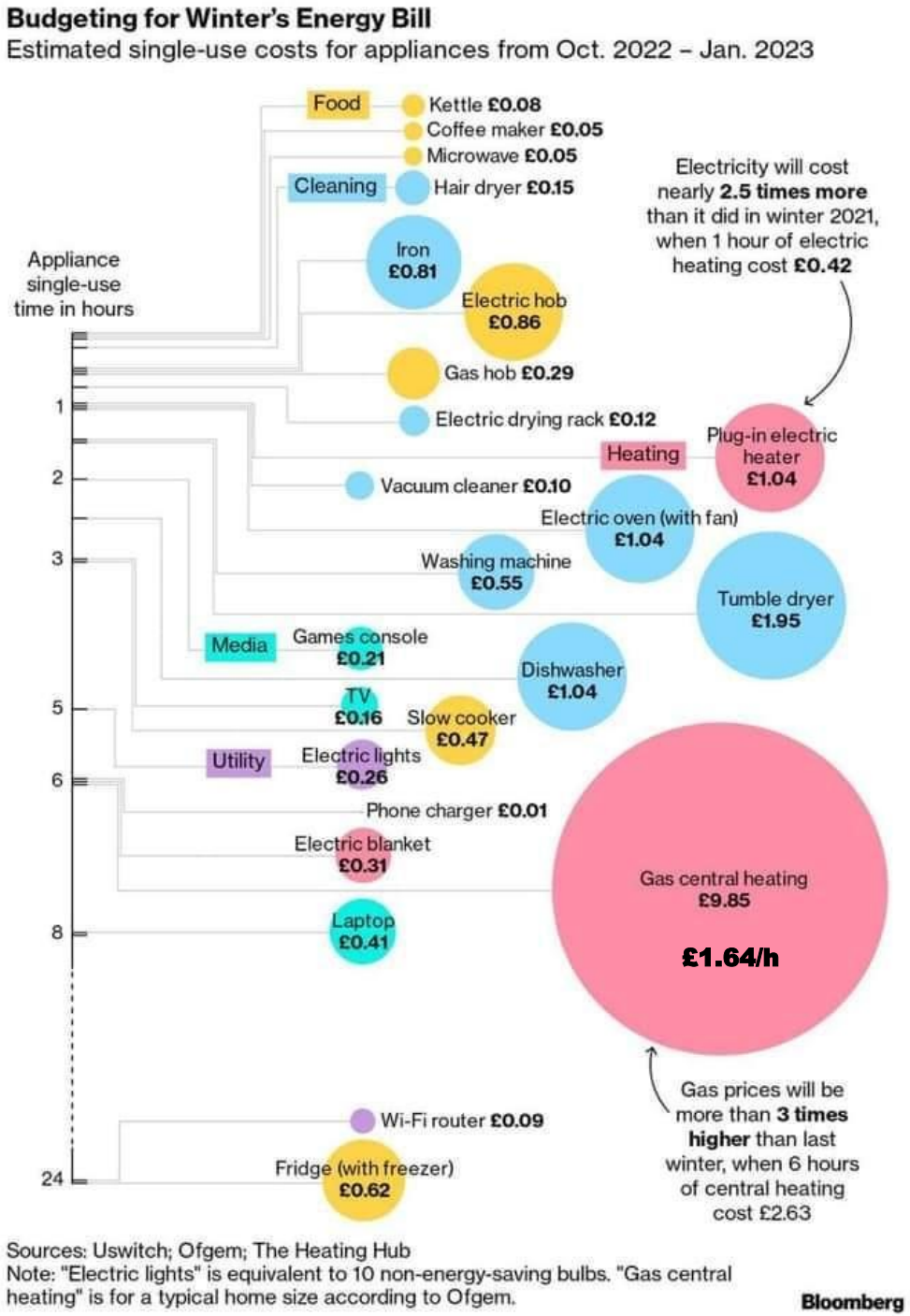

740k

tonnes/year




…740,000 HOT AIR BALLOONS…


…74,000 HECTARES OF TREES…




Electricity prices are circa
2.5 x higher than last winter

Gas prices are circa
3 x higher than last winter

Funded by:

UK Government

@UoN_Cities
@NottinghamCEDI
#NottinghamRetrofit

# NOTTINGHAM RETROFIT ROADMAP

Partners:

Nottingham City Council

UK Government

CN28 Carbon Neutral Nottingham 2028

European Union
European Regional Development Fund

University of Nottingham
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nep nottingham energy partnership

ACTIVE BUILDING CENTRE RESEARCH PROGRAMME

FOCUS
Create. Deliver. Assess.

# PROJECT PARTNERS

- Energy and carbon assessment
- Cost and feasibility analysis
- In situ compliance
- Cost-effectiveness appraisal
- Engaging the community and the workforce

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FOCUS
Create. Deliver. Assess.

ACTIVE BUILDING CENTRE RESEARCH PROGRAMME

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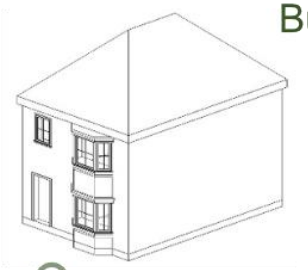
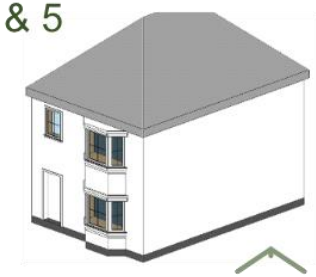
# DEEP AND TYPICAL RETROFIT MEASURES

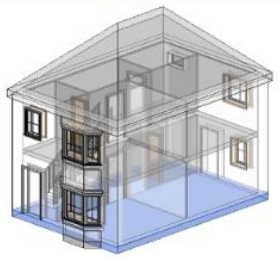


Building fabric optimisation key: Deep retrofit measures: 1, 2, 3, 4 & 5 Typical retrofit measures 1, 3, & 5

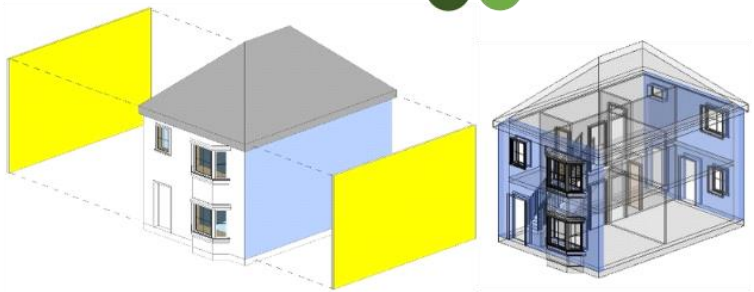
Whereas deep retrofit involves taking a wide range of measures to reduce a building's energy needs considerably, typical retrofit measures exclude more costly and disruptive measures. Measure can be broken into 3 stages including: **Retrofit Stage 1** - **building fabric optimiisation**; **Retrofit Stage 2** - low-carbon heating systems and **Retrofit Stage 3** - renewable energy generation and storage.



**1. Add loft insulation**

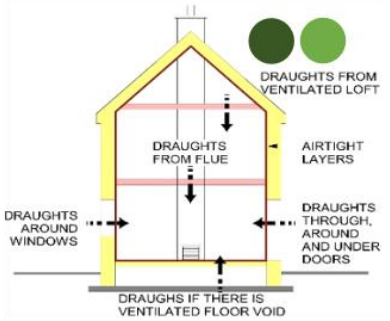


**2. Add floor insulation**



**3. Add wall insulation**

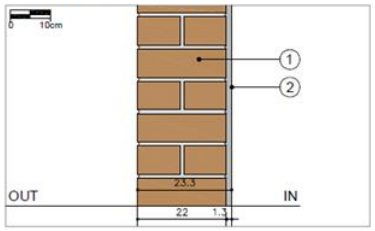
**4. Add energy efficient glazing/doors**

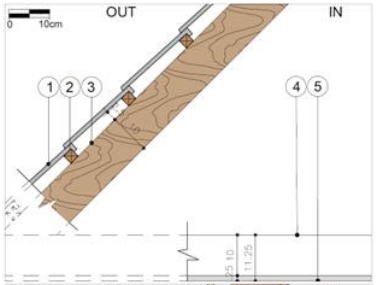


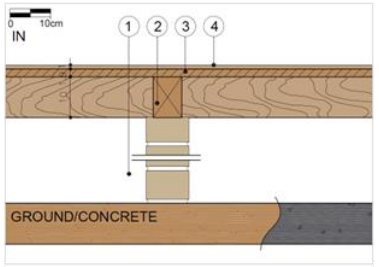

**5. Draught proofing and airtight envelope**

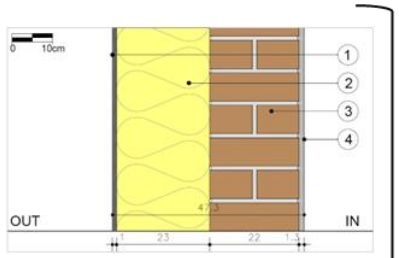
# BUILDING FABRIC OPTIMISATION

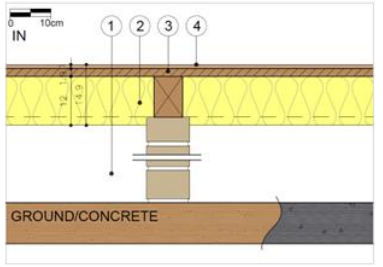
## Prior to 1930



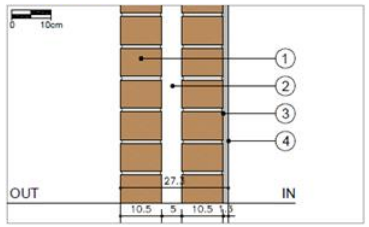



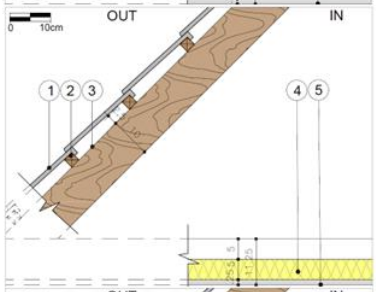



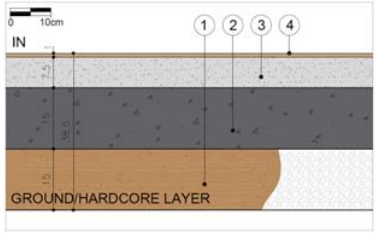



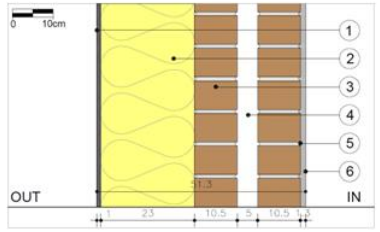




## 1930 - 1970

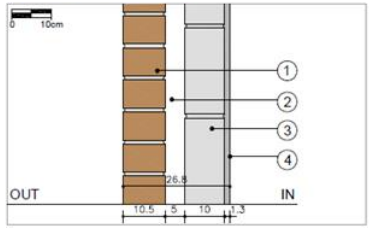


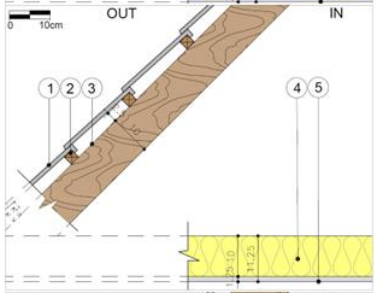



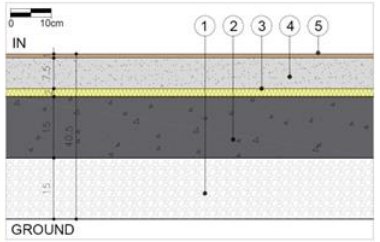



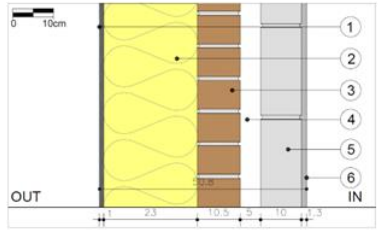




## 1970 - 1980

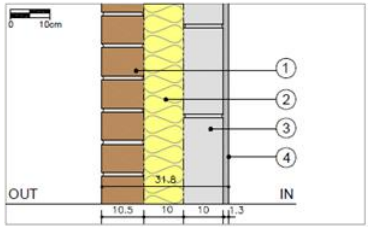


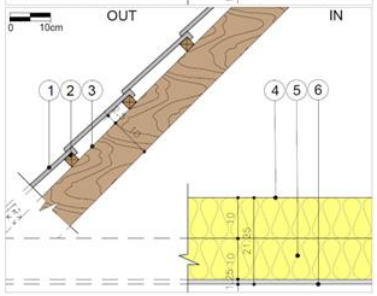



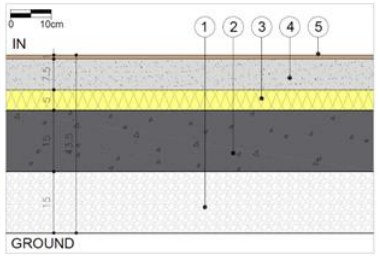



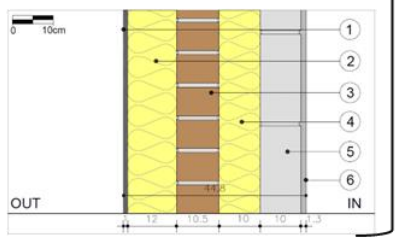



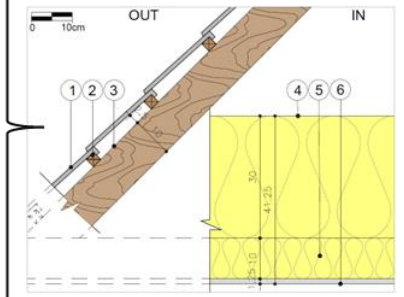

## Post 1985

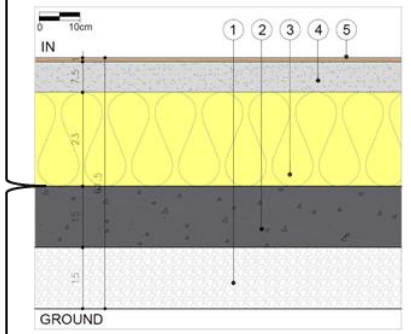


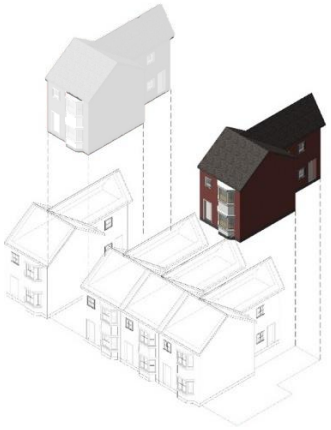
# Generic Representative Models

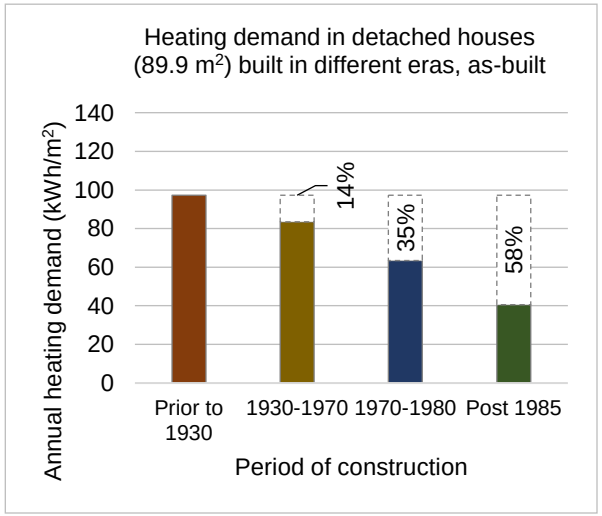
## Detached

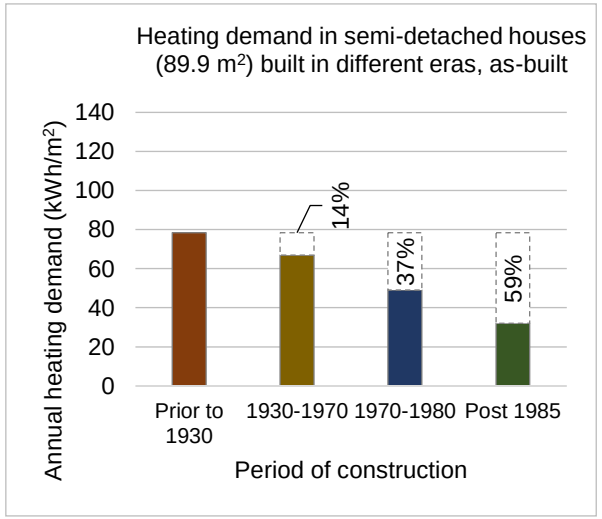
## Semi-detached

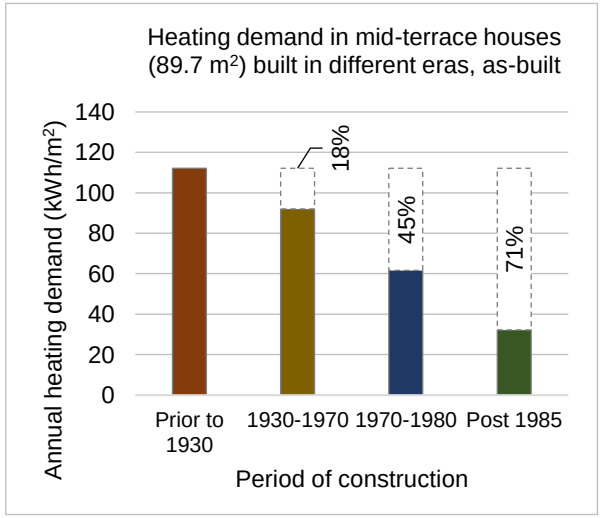
## Mid-terrace

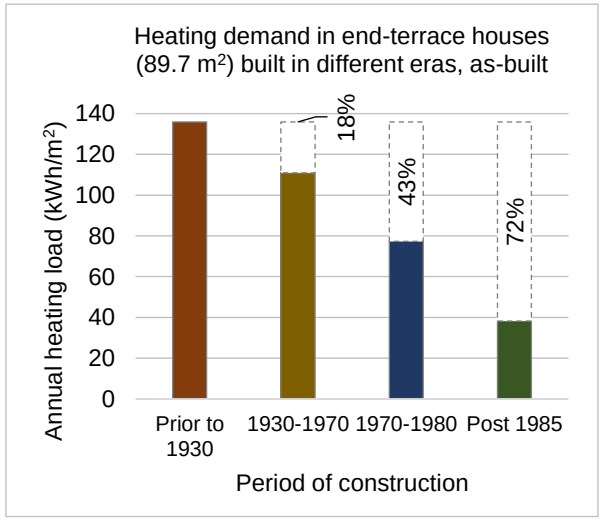
## End-terrace





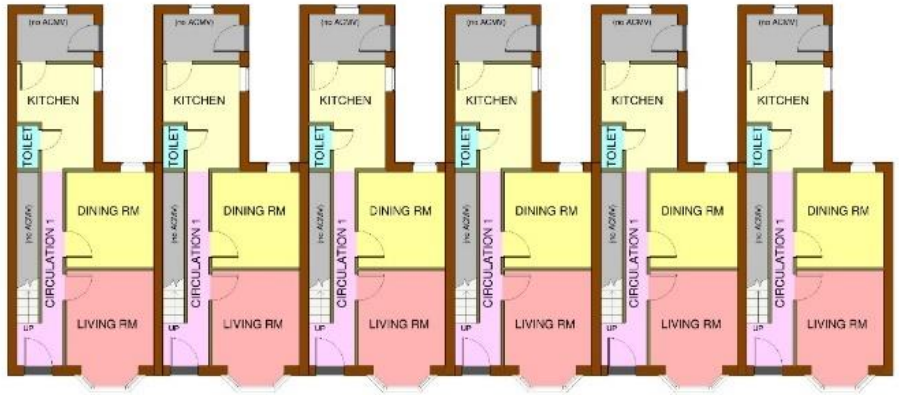



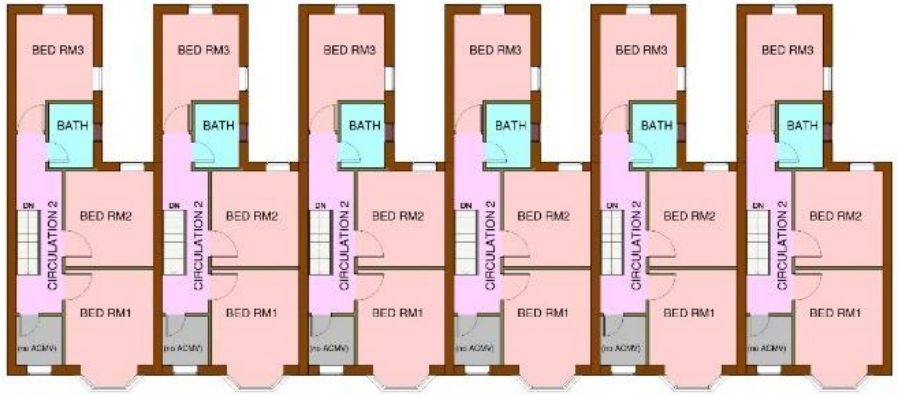
# GENERIC MID-TERRACE ARCHETYPE

This housing typology represents 34.5% of Nottingham's total housing stock.

The typical EPC rating of this housing typology ranges from D-G (67.7%).



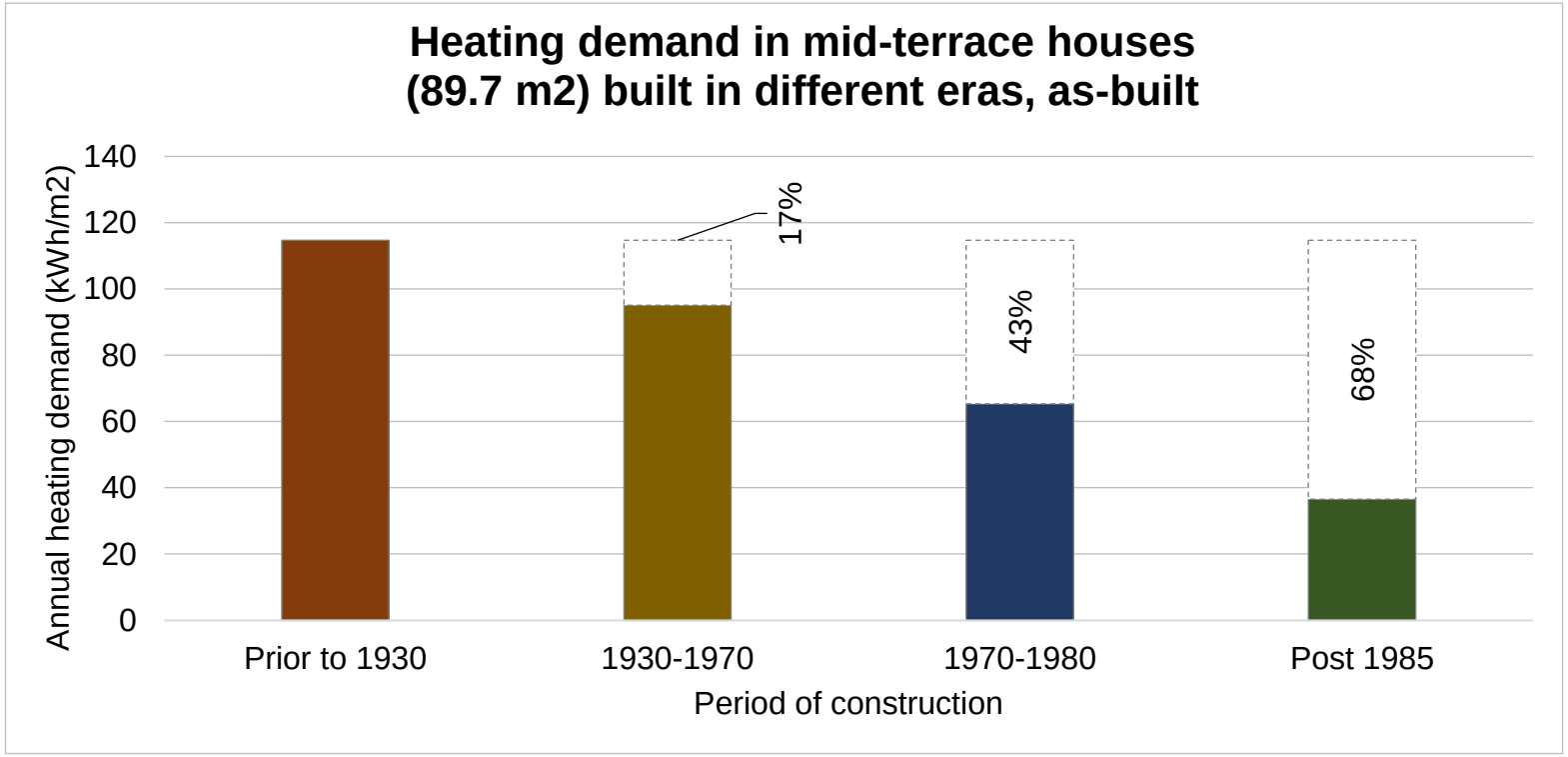

Ground Floor




First Floor

# MID TERRACE ARCHETYPE – HEATING DEMAND

The performance of a typical mid-terrace Nottingham housing archetype was considered as was built over four time periods (**prior to 1930**, **1930-1970**, **1970-1980**, **and post-1985**), to determine incremental retrofit performance improvements.

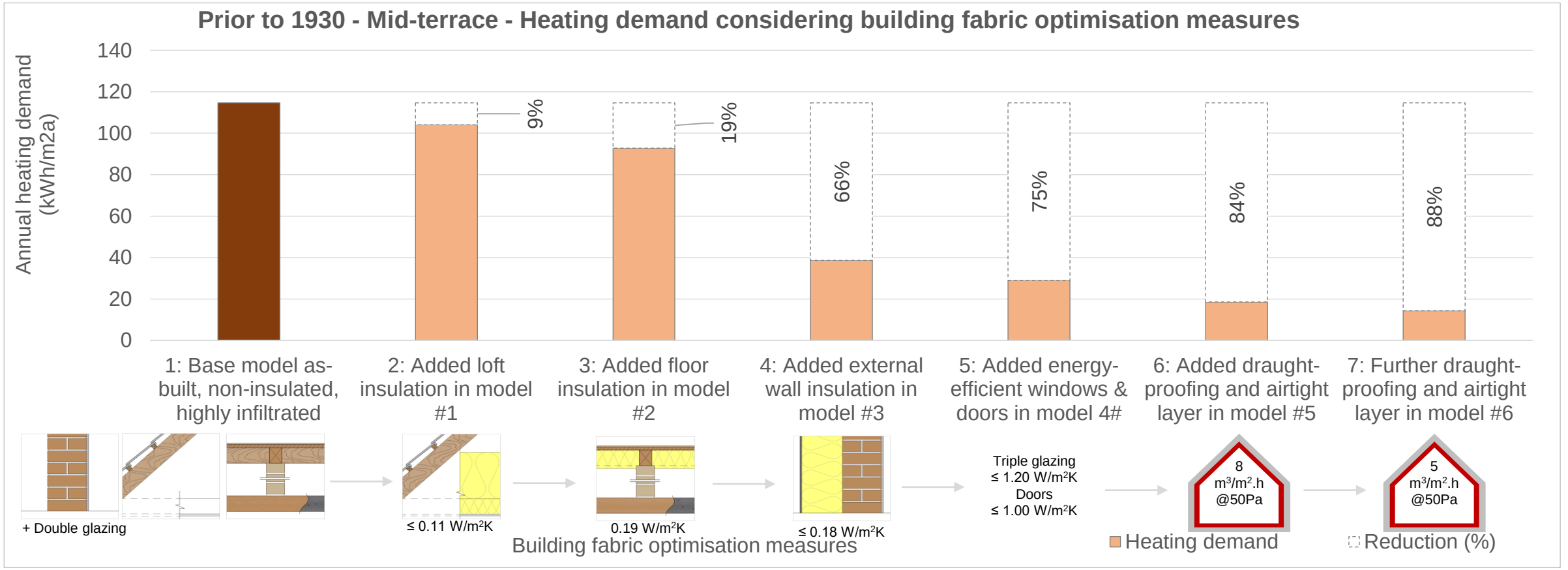



- Heating on from Oct-Mar using occupant profiles
- No cooling systems
- No active design improvements

# MID-TERRACE ARCHETYPE – DEEP RETROFIT

## Retrofit Stage 1 – building fabric optimisation

### Prior to 1930




Target: Part L 2021 notional levels

Heating on from Oct-Mar using occupant profiles

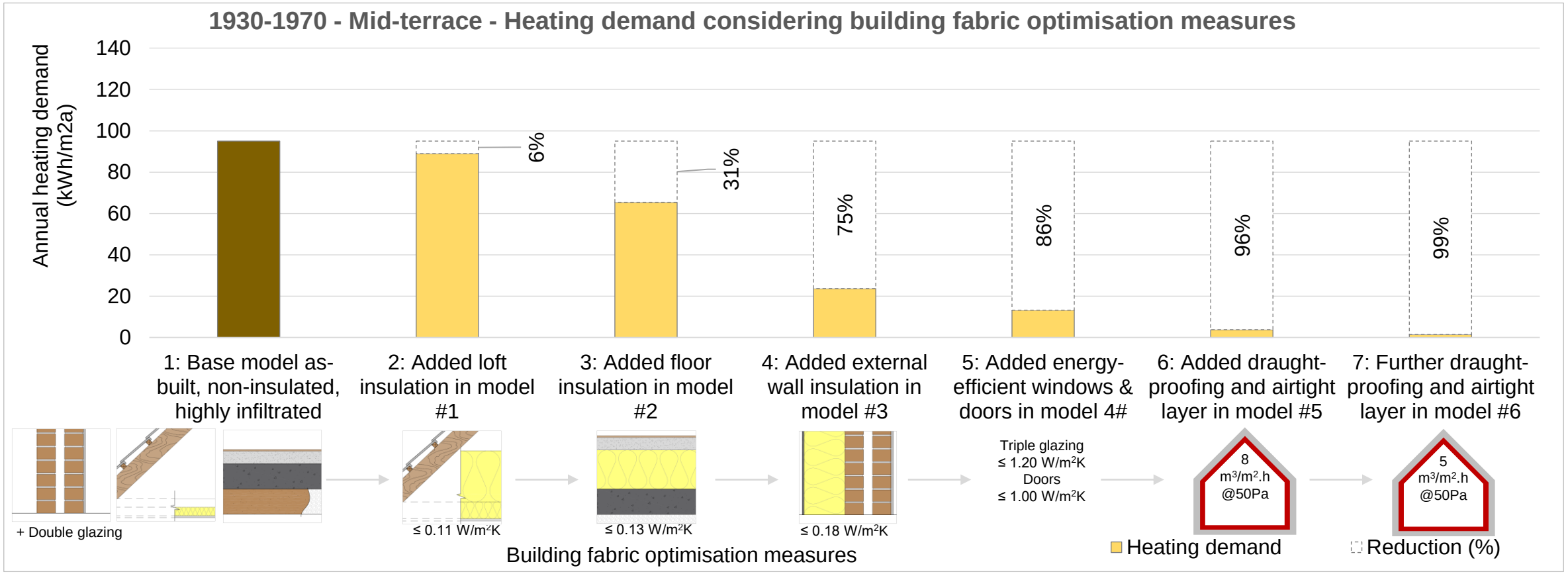
No cooling systems

No active design improvements

# MID-TERRACE ARCHETYPE – DEEP RETROFIT

## Retrofit Stage 1 – building fabric optimisation

### 1930-1970

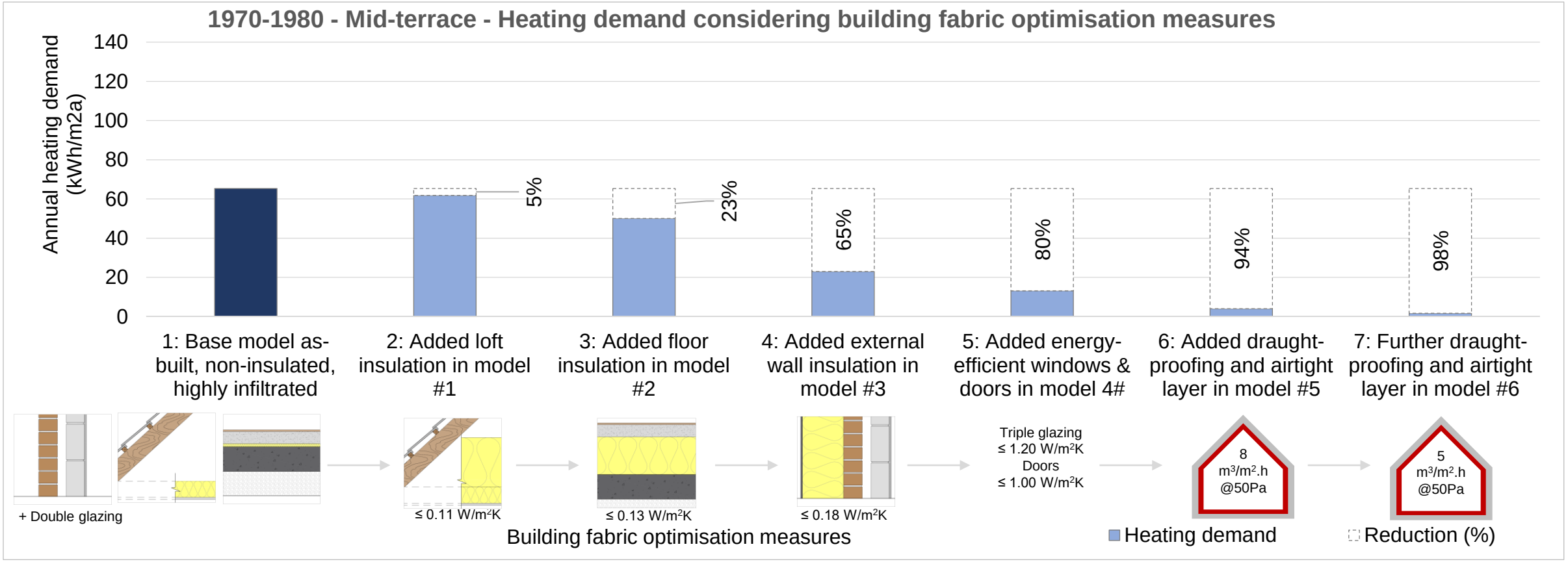



Target: Part L 2021 notional levels
Heating on from Oct-Mar using occupant profiles
No cooling systems
No active design improvements

# MID-TERRACE ARCHETYPE – DEEP RETROFIT

## Retrofit Stage 1 – building fabric optimisation

### 1970-1980




Target: Part L 2021 notional levels

Heating on from Oct-Mar using occupant profiles

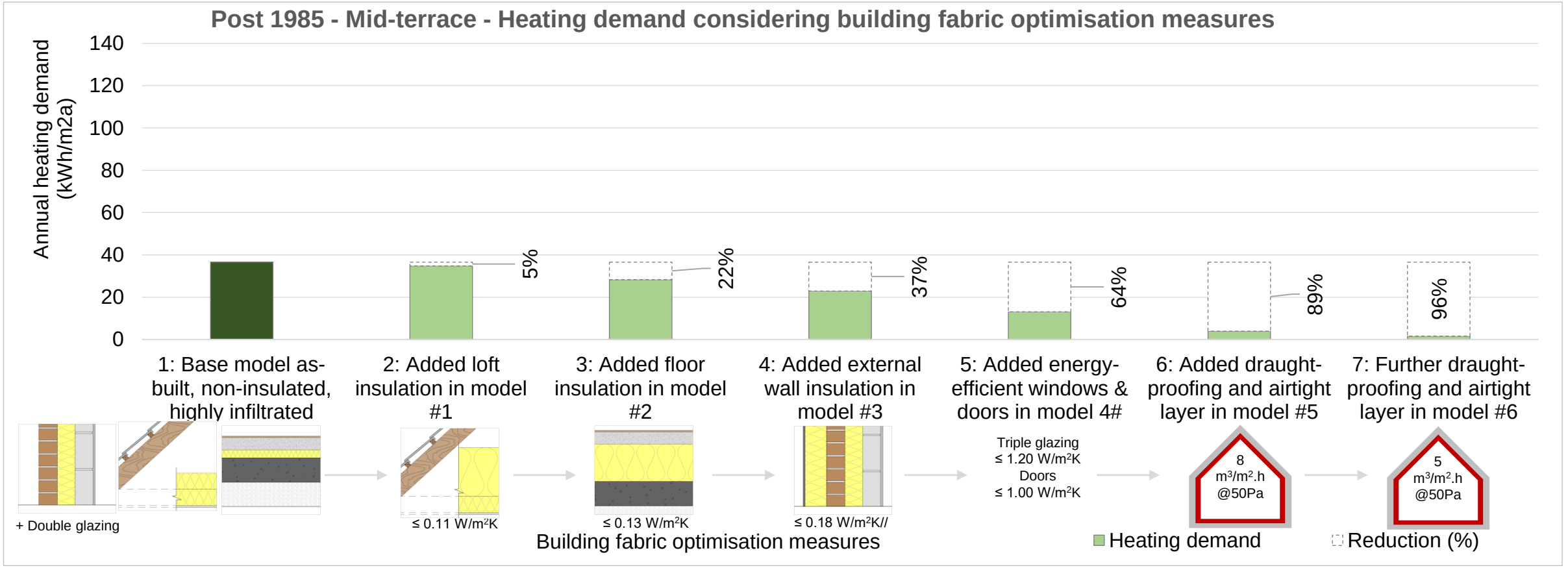
No cooling systems

No active design improvements

# MID-TERRACE ARCHETYPE – DEEP RETROFIT

## Retrofit Stage 1 – building fabric optimisation

### Post 1985




Target: Part L 2021 notional levels

Heating on from Oct-Mar using occupant profiles

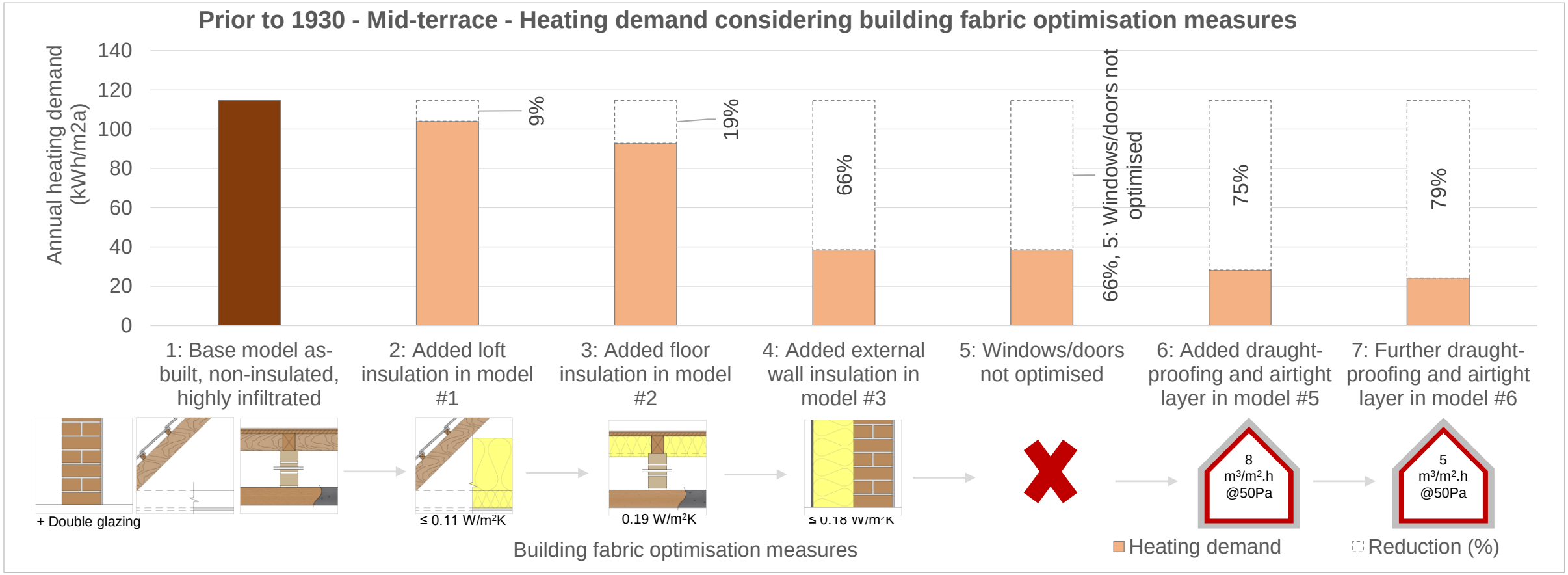
No cooling systems

No active design improvements

# MID-TERRACE ARCHETYPE – TYPICAL RETROFIT ONLY

## Retrofit Stage 1 – building fabric optimisation

### Prior to 1930




Target: Part L 2021 notional levels

Heating on from Oct-Mar using occupant profiles

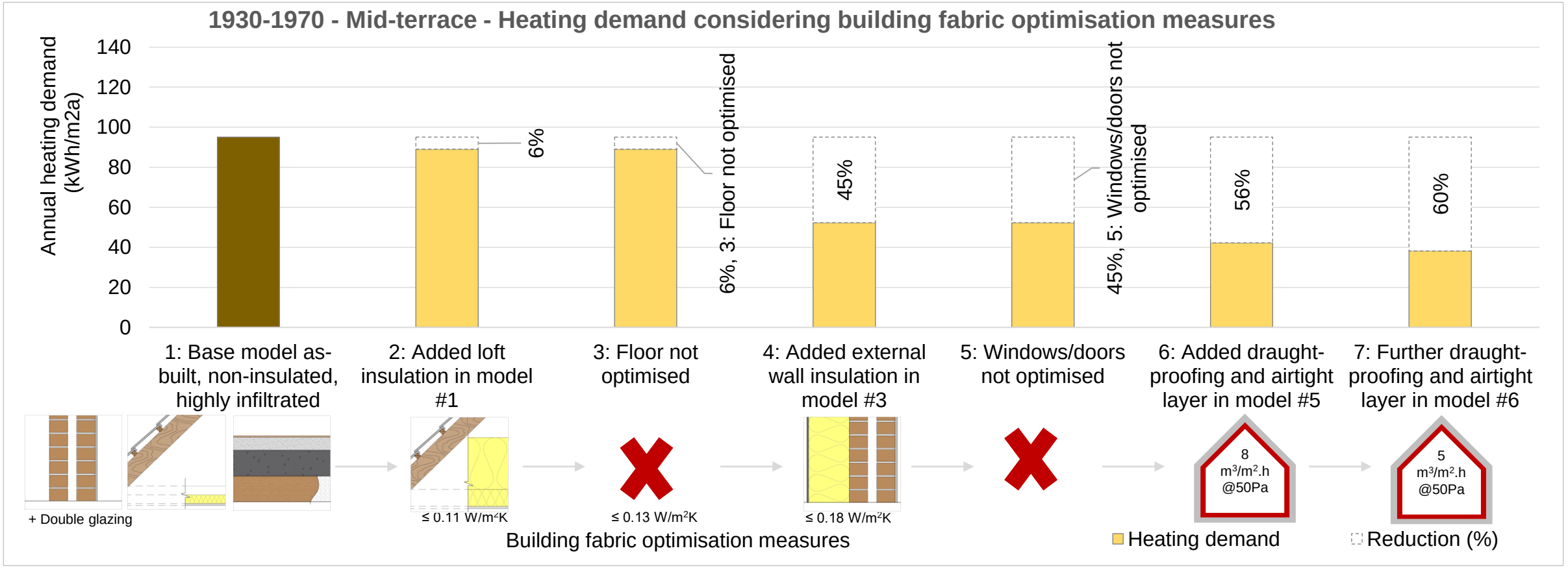
No cooling systems

No active design improvements

# MID-TERRACE ARCHETYPE – TYPICAL RETROFIT ONLY

## Retrofit Stage 1 – building fabric optimisation

### 1930-1970




Target: Part L 2021 notional levels

Heating on from Oct-Mar using occupant profiles

No cooling systems

No active design improvements

# MID-TERRACE ARCHETYPE – TYPICAL RETROFIT

**Retrofit Stage 1 – building fabric optimisation**

**1970-1980**

# MID-TERRACE ARCHETYPE – TYPICAL RETROFIT

**Retrofit Stage 1 – building fabric optimisation**

**Post 1985**

# Case Study Mid-terrace Archetype in Sneinton

- The case studies are part of the DZ2 Project and include different archetypes: end-terrace, mid-terrace, and flats
- End and mid-terrace houses are oriented both east-west and west-east while flats are oriented north-south only
- The end-terrace, mid-terrace archetypes are 3-storey, 3-bedroom houses
- The flats (first floor; mid-terrace flat & Ground floor; end terrace flat) are 1- bedroom properties

Mid-terraced House & End-terraced House

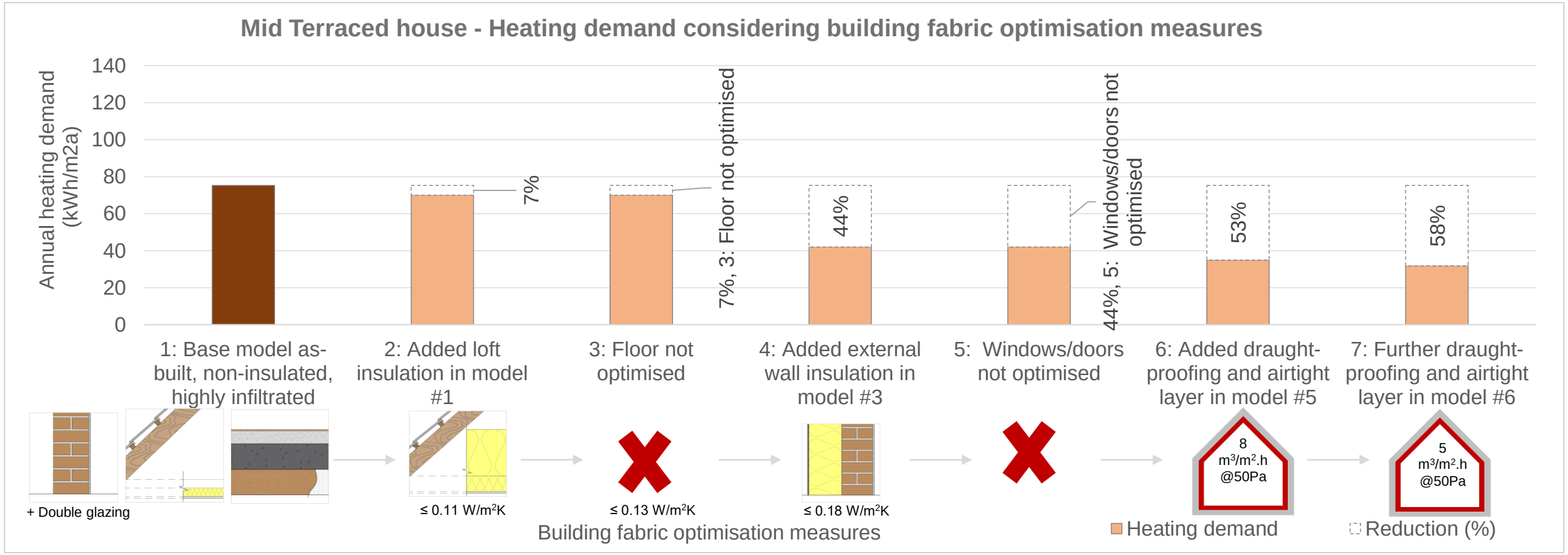
Mid-terraced Flat (First Floor) & End-terraced Flat (Ground Floor)


Site Plan. Based on Nottingham City Council (2022)

# MID-TERRACE ARCHETYPE – TYPICAL RETROFIT

## Retrofit Stage 1 – building fabric optimisation

### Prior to 1930




Target: Part L 2021 notional levels

Heating on from Oct-Mar using occupant profiles

No cooling systems

No active design improvements

# Typical Air-Source Heat Pump vs Typical Boiler

**Electricity**

5kW

An Air-Source Heat Pump is around 250-300% efficient, so for every 1 kWh of electricity, an air source heat pump can produce 3kWh of heat

Ideal 35°C, maximum 50-55°C

Heat Pump

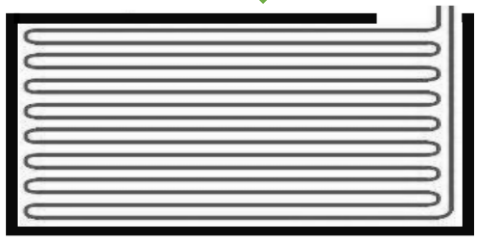
**Gas**

24-42kW

Boiler

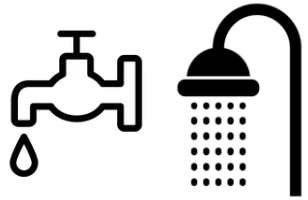
The most efficient gas boilers are only around 80-90% efficient, so for every 1kWh of gas you put in, you might get 0.9kWh of heat

Typical 70-82°C



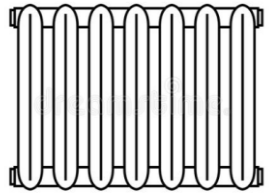
Typical 30-35°C

Underfloor Heating



Typical 50-60°C

Hot Water



Typical 60-70°C

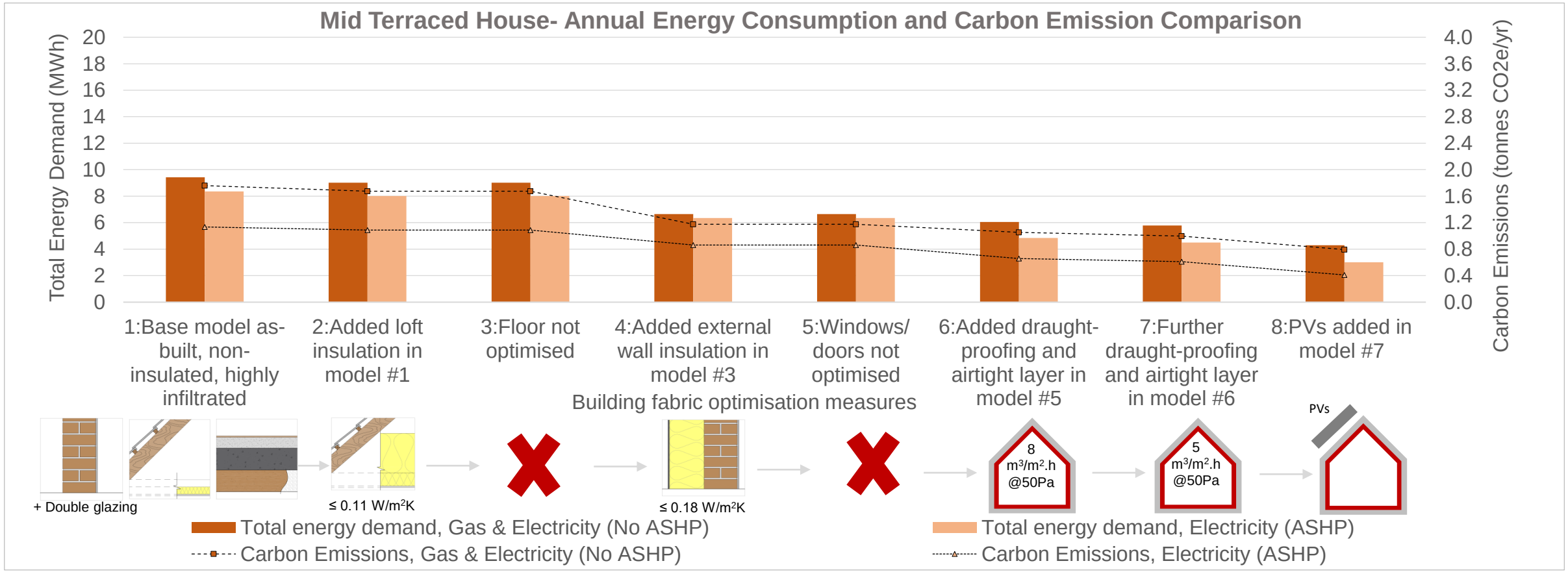
Radiator Heating

High temperature heat pumps can achieve operating temperatures of between 60-80°C but cannot produce the heat at the same rate as a boiler and require more electricity because the unit has to work harder

# MID-TERRACE ARCHETYPE – TYPICAL RETROFIT

## Retrofit Stage 2 – integration of low-carbon heating systems*

### Prior to 1930



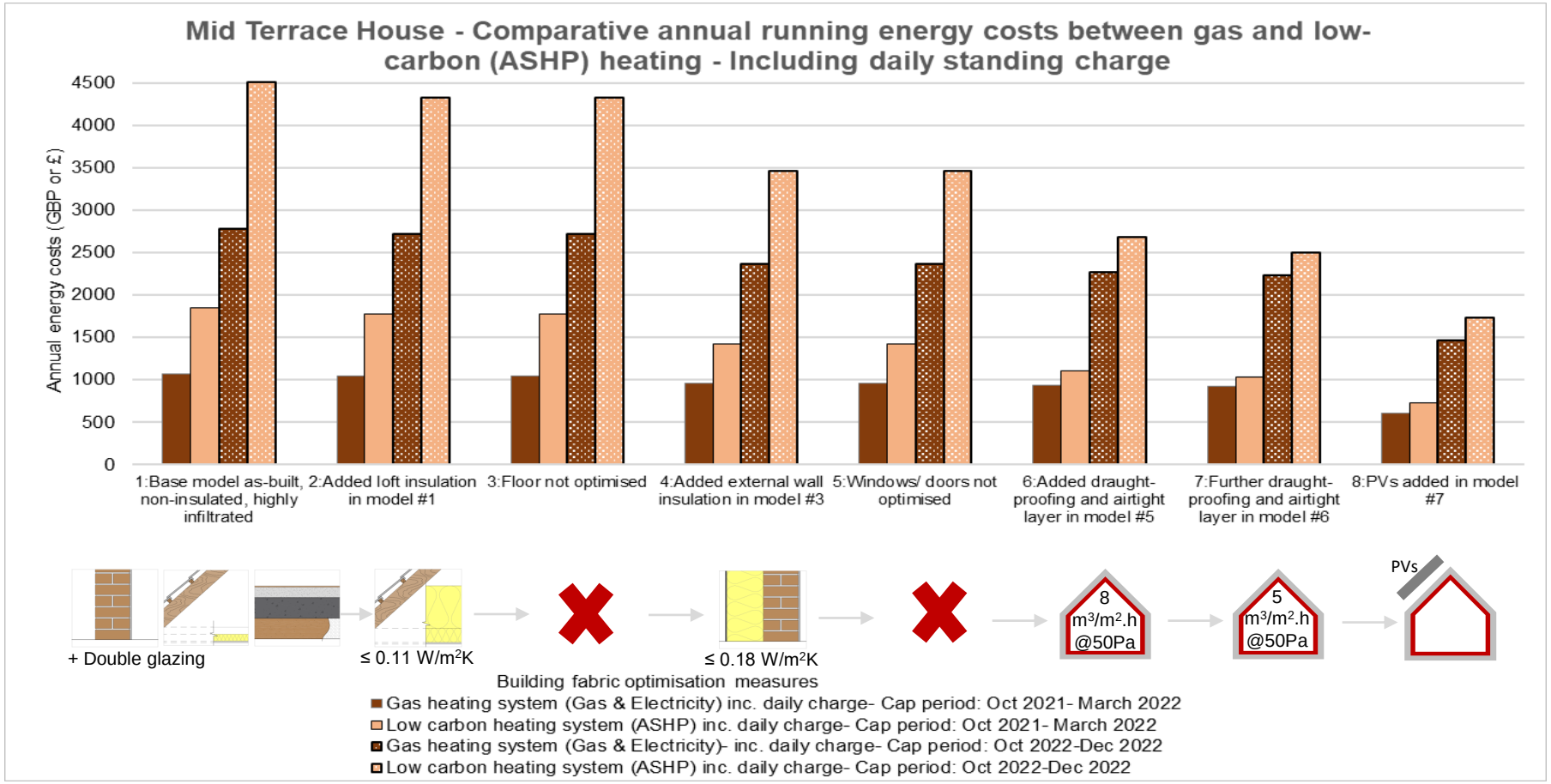

*A comparison of annual energy consumption and carbon emissions values after integration of low-carbon heating systems (with and without air source heat pumps [ASHP]).

Gas boiler seasonal efficiency: 0.89; seasonal coefficient of performance (SCoP): 0.8
ASHP SCoP for Space heating – 1.8 for non-retrofit and increased to 2.8 at later stages
ASHP SCoP for Domestic hot water - 1.5 for non-retrofit and increased to 2 at later stages

# MID-TERRACE ARCHETYPE – HEATING SYSTEMS

## Retrofit Stage 2 – annual running cost comparison- winter 2021 & winter 2022*

### prior to 1930




| | |
|---|---|
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*Data considered is as per price cap details released in September 2022. For more information, please refer to the Nottingham Carbon Neutral Housing Report.

Gas boiler seasonal efficiency: 0.89; seasonal coefficient of performance (SCoP): 0.8
ASHP SCoP for Space heating – 1.8 for non-retrofit and increased to 2.8 at later stages
ASHP SCoP for Domestic hot water - 1.5 for non-retrofit and increased to 2 at later stages

# Cost examples of Nottingham retrofit programmes – social housing development – per archetype

| Archetype | Description | M2 (gross internal floor area) | Cost |
|---|---|---|---|
| 0 | Semi/End/Mid Terraced house, 2/3 bed Trad House Pre 1945 | 94 | £74,069 |

| Element | Cost per M2 | Overall cost for element |
|---|---|---|
| **EWI Works - Mauer External Wall Insulation System**<br>- Including enabling works, lintels and wall ties<br>-0.2 U-Value | £188 | £17,633 |
| **Window Replacement**<br>-UPVC, White A rated 1.2 U-Value | £62 | £5,800 |
| **Renewable Energy Generation System & Storage** | £37 | £3,473 |
| **Roof Works- Removal and reinstatement of roof coverings, including insulation of the roof**<br><br>-Removal and renewal of clay tile roof covering; (Northstone Donard Old English Red)<br>-400mm thick (min U Value of 0.8 W/m2K) mineral wool quilt insulation to the whole footprint of the roof void<br>-Tyvec Supro (or equal and approved) breather membrane to the whole of the pitched roof area | £152 | £14,318 |
| **Ground floor insulation- Q Bot insulation to ground floor area**<br>-Utilising Q-Bot technology apply insulation materials to the underside of the existing suspended timber floors; average depth to be 150mm thick and achieving a nominal U-Value of 0.15 W/m2K | £23 | £2,195 |
| **Heating and ventilation**<br>-Boiler & Flue Adaption, and replacement of extract fans with heat recovery<br>-Air Source Heat pump and installation costs | £127 | £11,922 |
| **Materials Storage & Transportation Costs** | £3 | £255 |
| **Site Accommodation/Preliminary Costs** | £12 | £1,083 |
| **General Building/ enabling Works** | £27 | £2,577 |
| **Contingency Allowance - 10%** | n/a | £5,926 |
| **Over head - 10%** | n/a | £5,926 |
| **Profit - 5%** | n/a | £2,963 |
| **Total Per Property:** | | **£74,069** |

| Element | M2 Cost | Cost for Element |
|---|---|---|
| **Fees**<br>-Crane License Fee | £9 | £454 |
| **Substructure works**<br>-Site Preparation<br>-Alterations to gullys - Hand dig Excavation below ground level to expose existing gully / Break into existing drain / Fit new gully / Supply of new gully / Make good existing area after new gully is fitted / Slabbed area<br>-Foundations to the front and rear elevations | £150 | £7,213 |
| **EWI System**<br>-Factory production of insulated timber panels including external weatherboarding, prefitted windows, flashings<br>- Panel Installation<br>-Craneage for offloading and erection of panels<br>-Undercroft ceiling works<br>-includes building fabric sundries | £511 | £24,550 |
| **Scaffolding Cost - per property** | £30 | £1,417 |
| **Renewable Energy Generation System** | £184 | £8,848 |
| **Renewable Energy Generation System - Battery** | £62 | £2,953 |
| **Roof Works**<br>-Factory production of roof cassette<br>-Strip & clear existing roof covering including tiles, felt & batten<br>-Install Roof Cassette<br>-Supply and Install new plastic fascia board<br>-Supply and Install new plastic rwps and gutters | £356 | £17,090 |
| **Heating & Ventilation**<br>- Internal Heating system alterations, including decommission, flushing & removal of gas boiler, pipework & flue, radiator stats, room stats - Including Electrical Disconnection Works and mechanical alteration works to existing services.<br>- Supply & Install of air source heating system- Vaillant/Pochin (including enabling works and commissioning)<br>-Removal of existing ventilation system<br>-Supply and installation of loft hatch<br>-Aereco - supply and installation of demand controlled ventilation system, including fans, grills, trickle vents.<br>- Supply and installation of Ductwork (verplas)<br>-Builders work and making good included | £216 | £10,377 |
| **Electrical Works**<br>- Controls and sensors installation (carnego) (£4,109)<br>-Other associated works, including further sundry electrical works and builders work etc | £168 | £8,043 |
| **Surveys**<br>-Asbestos, Non notifiable asbestos, bat surveys | £20 | £971 |
| **Preliminaries**<br><br>(Figure based on total prelims cost for the programme/14 properties - scaffolding) | £203 | £9,751 |
| **Risk & Contingency -**<br>Provisional allowance for compliance Works over and above that included in the Employers Works Information | n/a | £1,437 |
| **Overhead** - 10% | n/a | £9,310 |
| **Profit** - 5% | n/a | £4,655 |
| **Total Per Property** | | **£107,070** |

| Archetype | Description | M2 (Gross internal floor area) | Cost |
|---|---|---|---|
| **1** | Terraced House | 96 | £114,075 |
| **2** | Bungalow | 48 | £107,070 |

Costs (£ thousand) including all case studies and archetypes

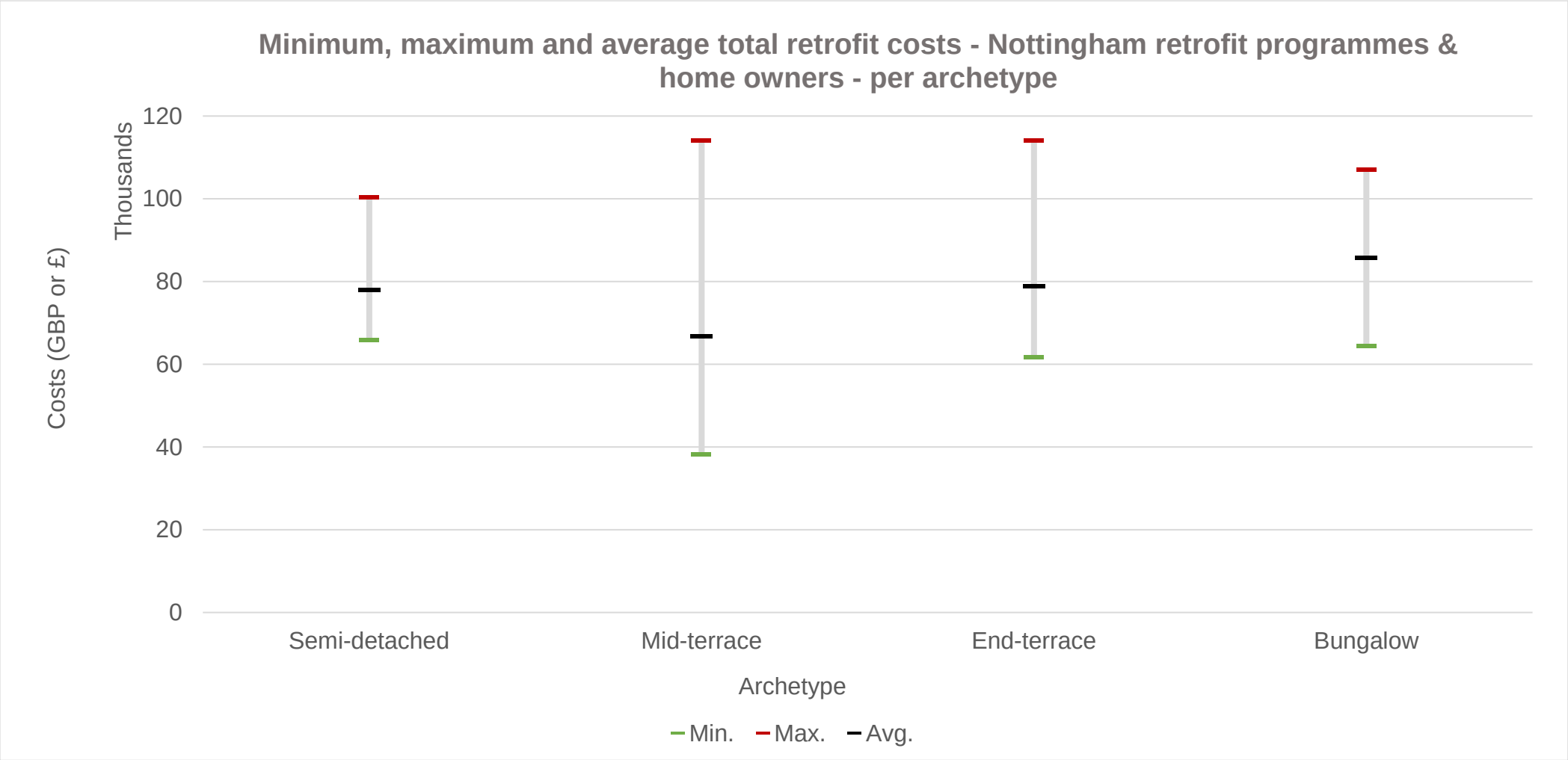
| Min. | Max. | Avg. |
|---|---|---|
| 38k | 114k | 69k |

Costs vary significant depending on the retrofit initiatives

# Per archetype – Estimated Costs

## Cost variation- Retrofit per archetype*

## Case study performance assessment data findings

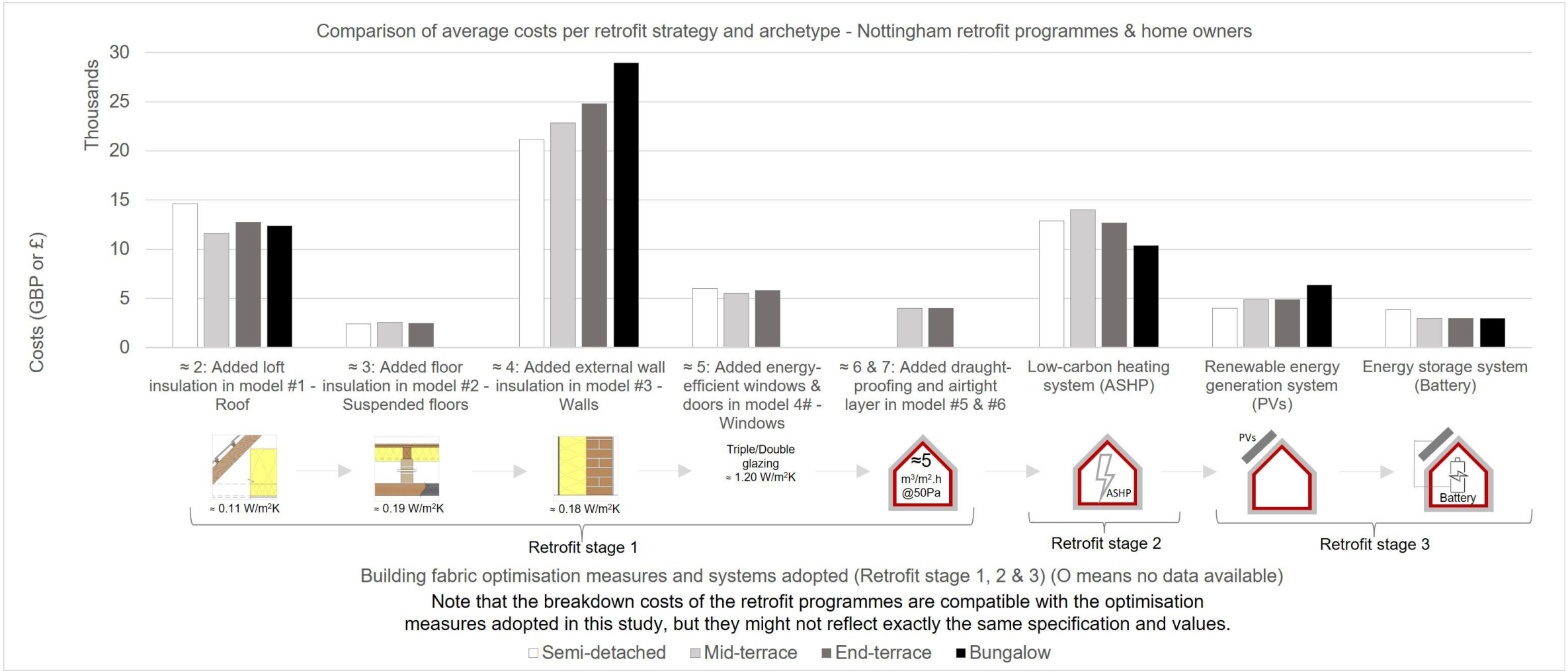



*Data considered is as per price cap details released in September 2022. For more information, please refer to the Nottingham Carbon Neutral Housing Report.

# ALL ARCHETYPES – ESTIMATED COSTS COMPARISON

## Retrofit Stage1, 2 and 3*

## Case study performance assessment data findings

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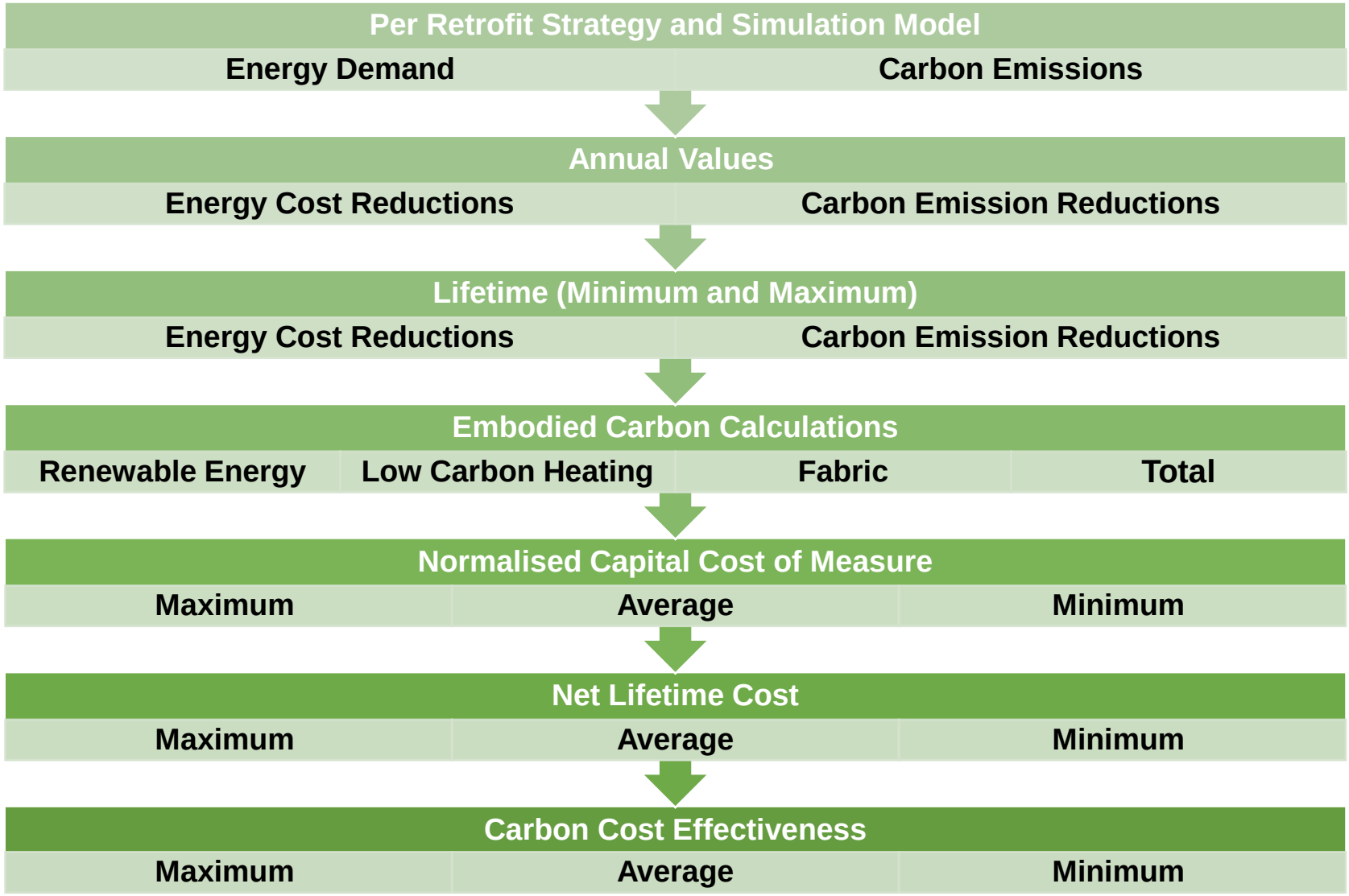
# Carbon Carbon Effectiveness Assessment Method

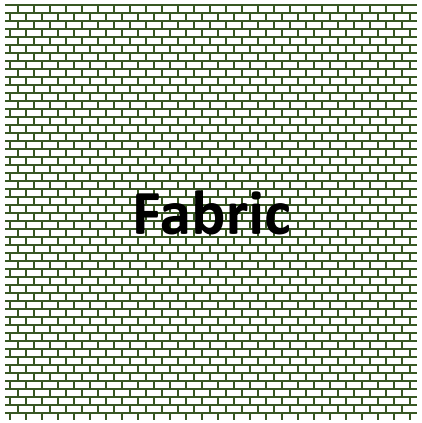



| |
|---|
| Simulation outputs always assume a fabric-first retrofit process |
| Costs are exclusive of VAT |
| Lifespan assumptions made (see following slide) |
| Degradation of PV performance not factored over lifetime of the installation |
| Carbon factors and energy tariffs assumed (see following slide) |
| Capital cost assumptions made in accordance with the full report and detailed calculation spreadsheet (available as an Appendix). |
| Embodied carbon calculation spreadsheet available as an Appendix. Assumptions made according to the main report (generally WLC Stages A1-A3) |
| Net Lifetime Cost is provided as a total value specific to the particular property. Costs and other assumptions are linked to property GIA. |
| Carbon Cost Effectiveness is provided as a total value specific to the particular property. Costs and other assumptions are linked to property GIA. |

# Net Lifetime Cost

**Net Lifetime Cost (£)** = **Total Lifetime Capital Cost (£)** − **Total Lifetime Savings (£)**

## Simulation outputs always assume the following retrofit sequence:




→ **Low Carbon Heating** →

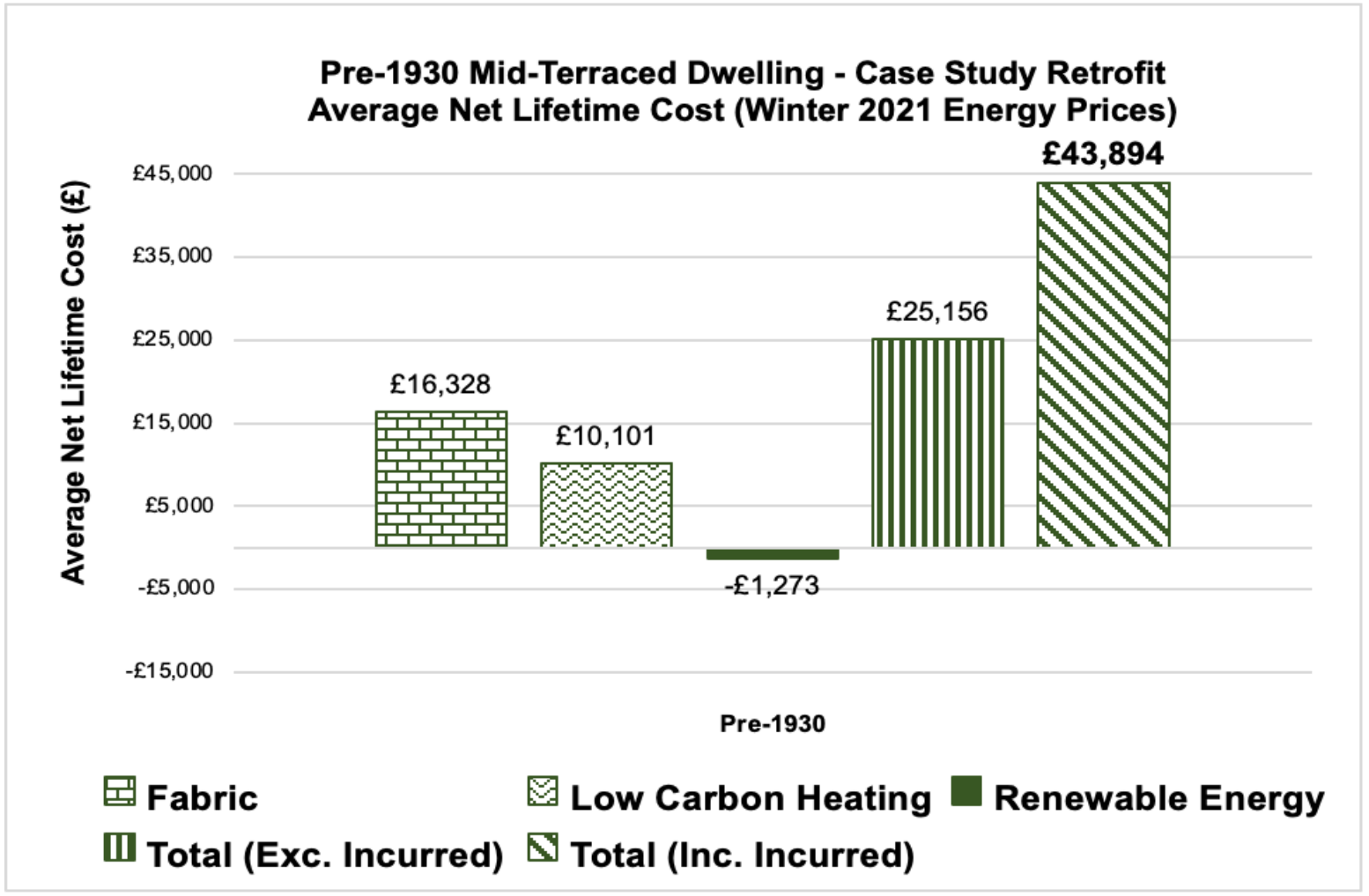
**Renewable Energy**

- Based on 'case study retrofit' simulation model
- All costs are exclusive of VAT
- Areas are updated according to the revised Case Study model (52.87m² GIA)
- Incurred Costs include: preliminary costs, enabling works, contingency allowances, overheads, profits, and retrofit preconstruction costs including assessment, design and coordination
- Lifetime Capital Costs do not make allowances for lifetime repairs, upgrades and maintenance
- **Fabric Measures.** Total Capital Costs include: External Wall Insulation (EWI) and removal and reinstatement of roof covering including insulation
- **Low Carbon Heating Measures.** Total Capital Costs include: 5kW Vaillant aroTHERM Air Source Heat Pump (ASHP), demand controlled ventilation
- **Renewable Energy Measures.** Total Capital Costs include: 5x 400Wp Monocrystaline Jinko solar panels, battery storage installations

# Mid-Terraced Archetype – Case Study Retrofit
# Net Lifetime Cost – (Pre-1930) Winter 2021 Energy Prices

**Capital Cost = £48,714 (Exc. VAT, including Incurred Costs)**

**GIA = 52.87m²**




| Life Expectancy | |
|---|---|
| Fabric | 20-30 years |
| Low Carbon Heating | 20-25 years |
| Renewable Energy | 15-25 years |

| | |
|---|---|
| Gas price cap (Oct 2021- March 2022) (Ofgem, 2022b) | 0.04 GBP per kWh |
| Gas daily standing charge (Oct 2021- March 2022) (Ofgem, 2022b) | 0.26 GBP |
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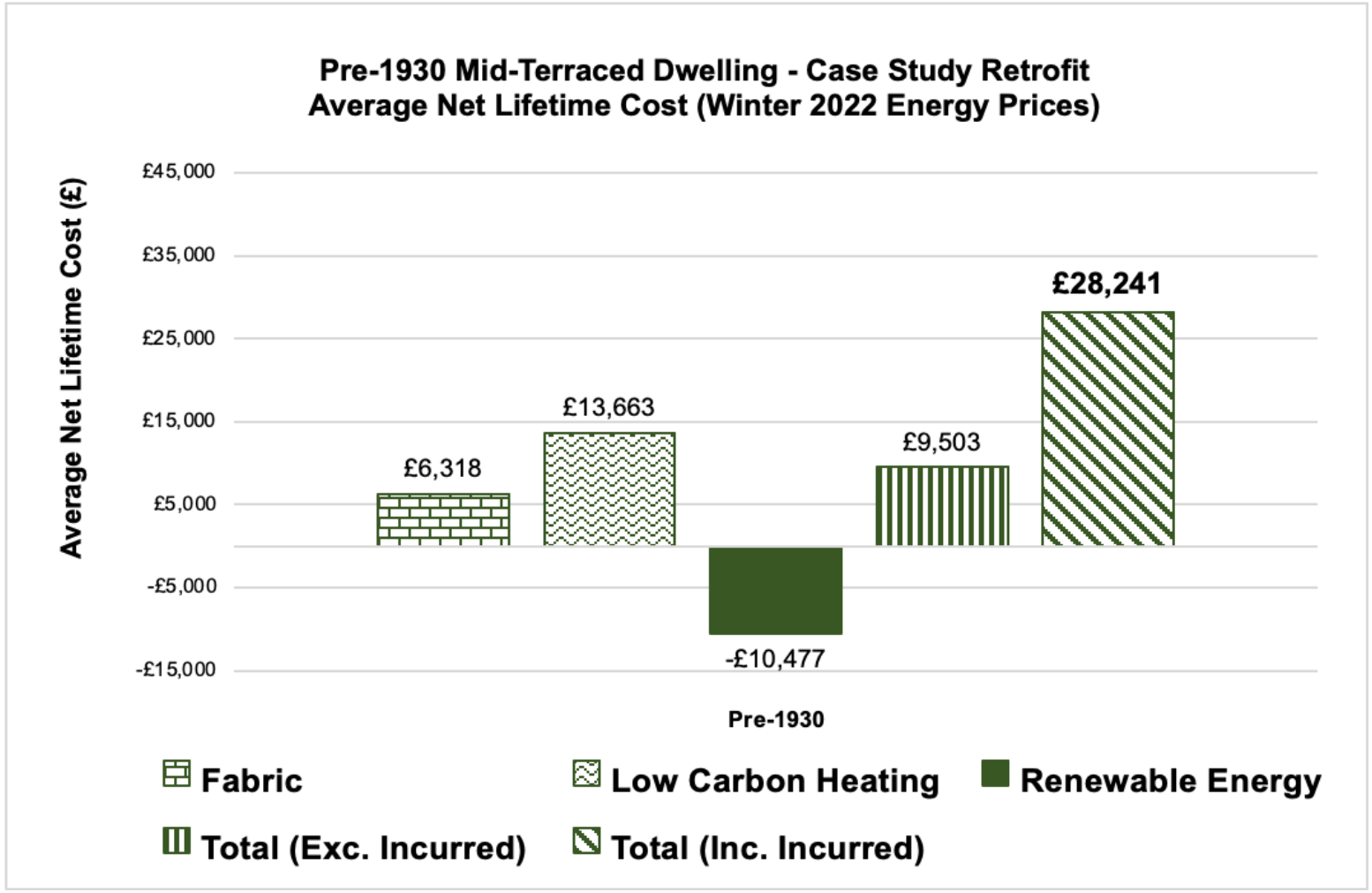
| Electricity daily standing charge(Oct 2022- Dec 2022) (Ofgem, 2022b) | 0.46 GBP |
| Electricity Grid Carbon Emission Factor - SAP 10.2 (BRE, 2022, p. 189) | 0.136 $kgCO_2e$/ kWh |

# Mid-Terraced Archetype – Case Study Retrofit Net Lifetime Cost – (Pre-1930) Winter 2022 Energy Prices

**Capital Cost = £48,714 (Exc. VAT, including Incurred Costs)**

**GIA = 52.87m$^2$**

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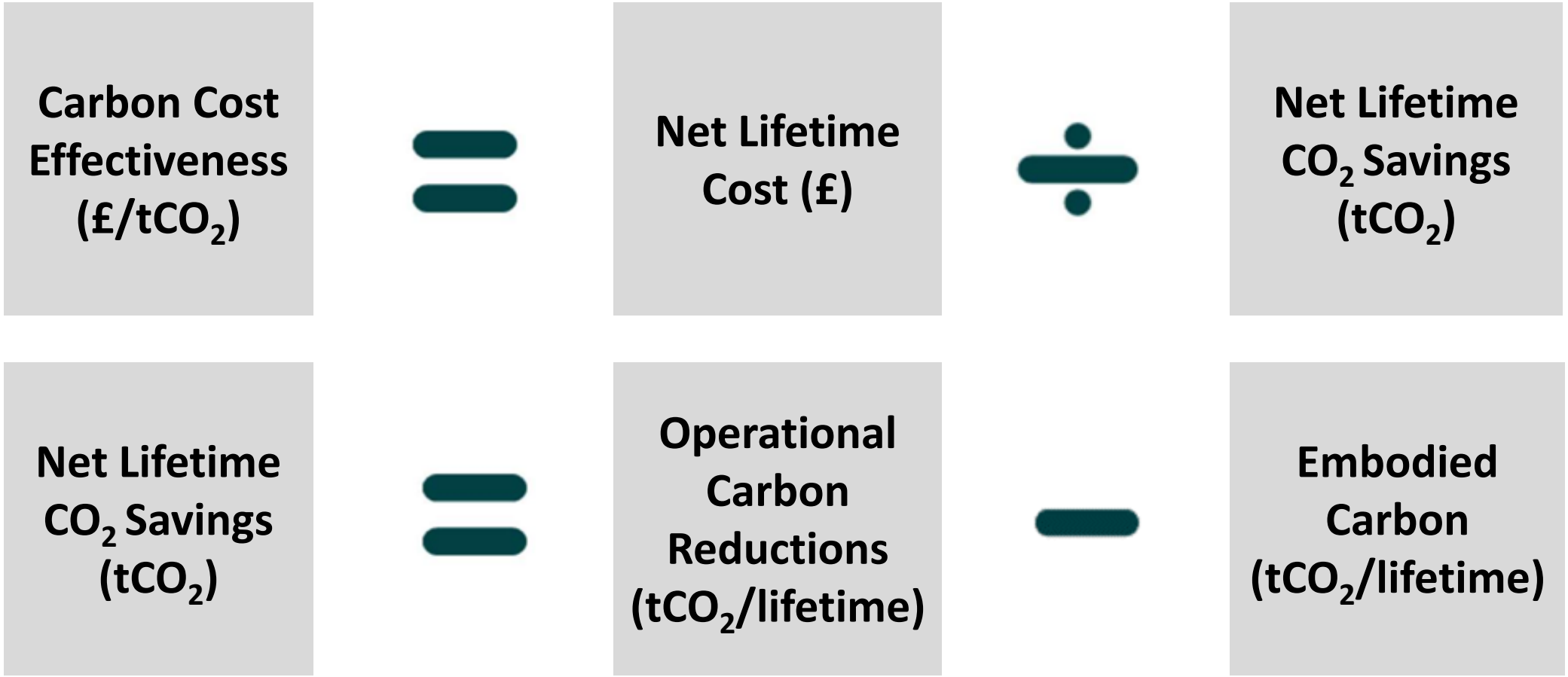
# Carbon Cost Effectiveness

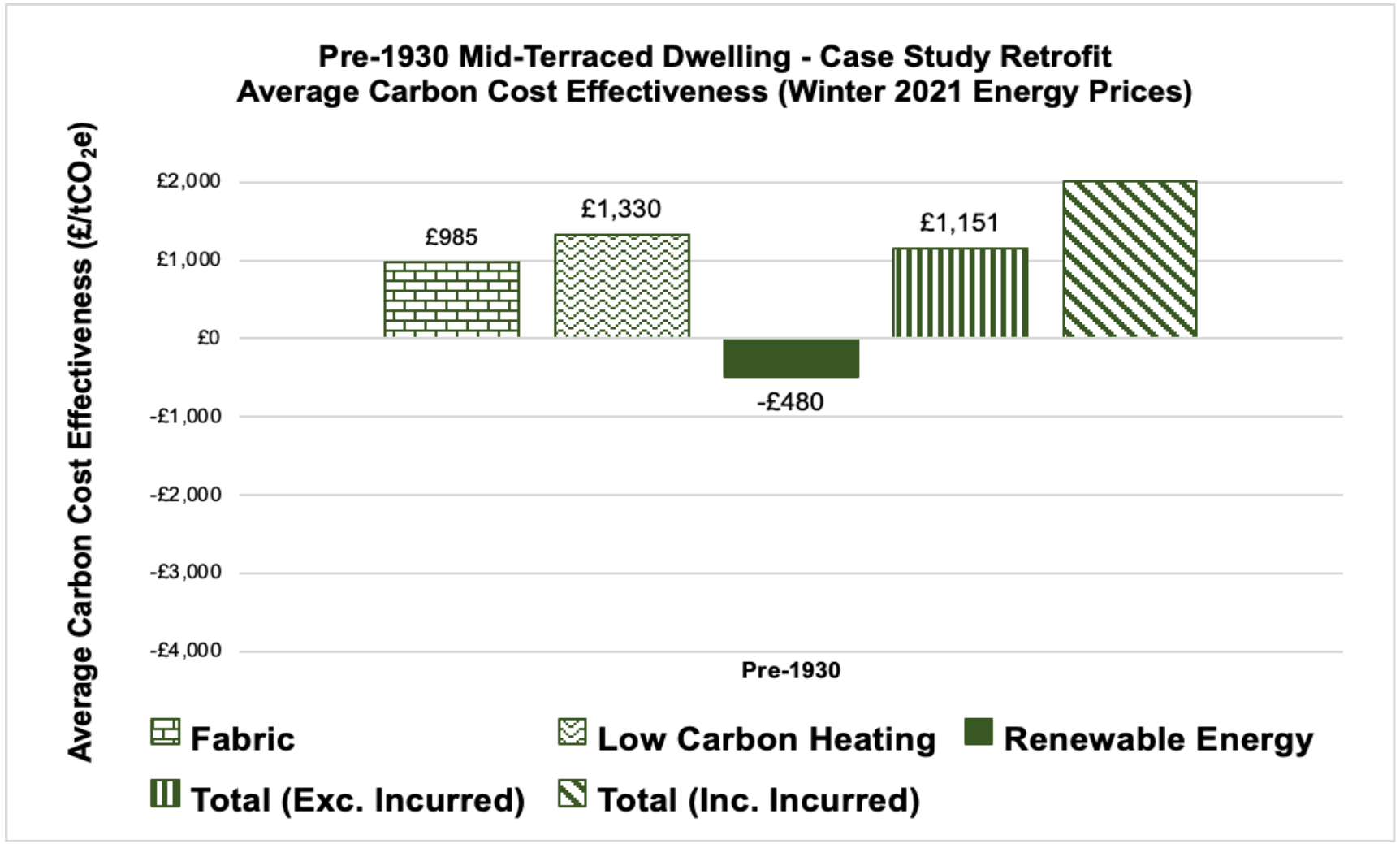



- Lifetime assumptions are made on a minimum and maximum basis: fabric 20-30 years, low carbon heating 20-25 years, renewable energy 15-25 years
- All Net Lifetime Cost assumptions, limitations and exclusions apply
- Based on 'case study' simulation model
- All costs are exclusive of VAT
- Incurred Costs include: preliminary costs, enabling works, contingency allowances, overheads, profits, and retrofit preconstruction costs including assessment, design and coordination
- Embodied Carbon calculations are based on a series of assumptions highlighted within the report
- In general, Whole Life Cycle stages A1-A3 are considered within Embodied Carbon calculations

# Mid-Terraced Archetype Pre 1930– Case Study Retrofit Carbon Cost Effectiveness (Winter 2021 Energy Prices)

**Net Lifetime Cost (Total) = £41,405 (Exc. VAT, including Incurred Costs)**

**Net Lifetime Carbon Reductions (Total) = 23.2 Tonnes of CO2 (equivalent)**




| Life Expectancy | |
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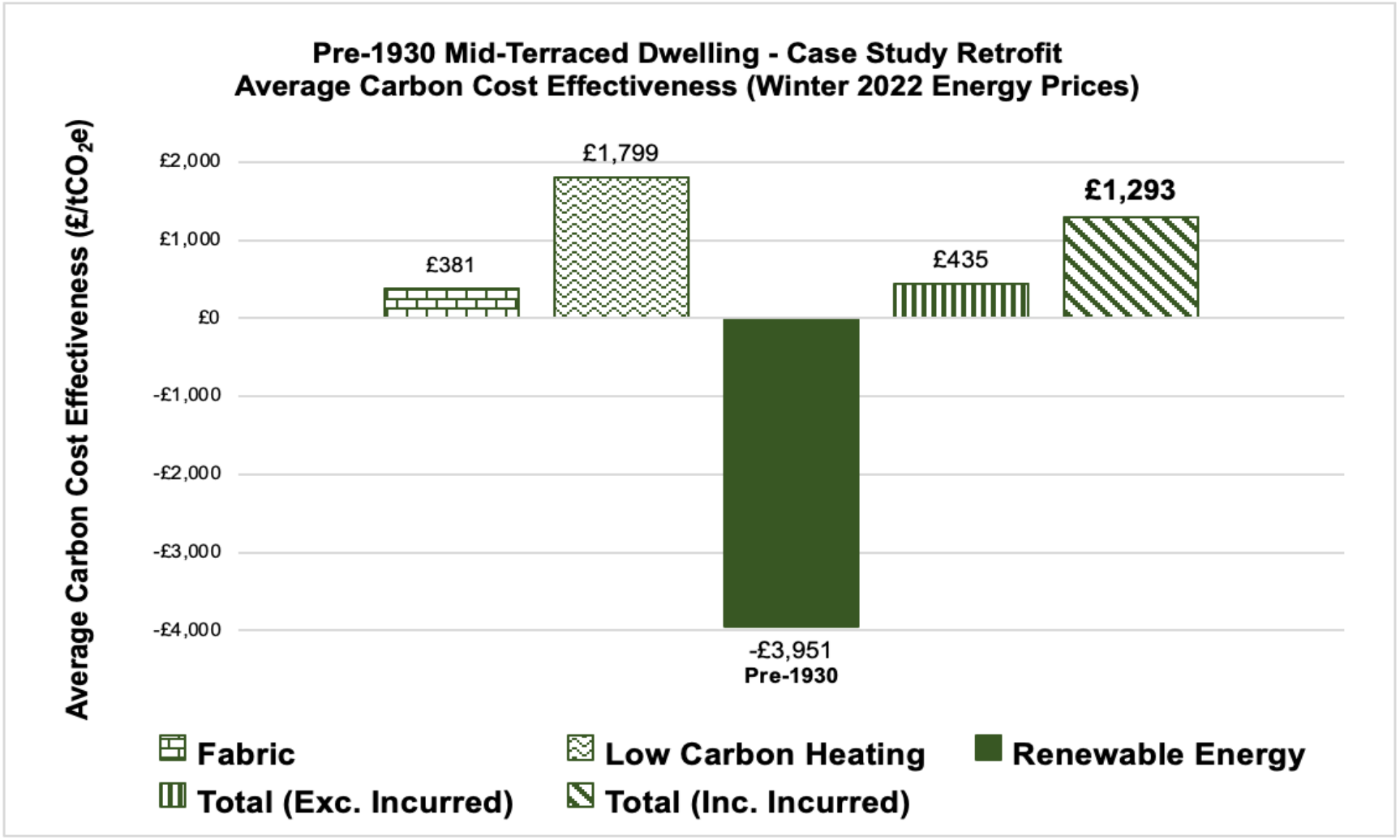
**(GIA = 52.87m²)**

# Mid-Terraced Archetype Pre-1930 – Case Study Retrofit Carbon Cost Effectiveness (Winter 2022 Energy Prices)

**Net Lifetime Cost (Total) = £25,753 (Exc. VAT, including Incurred Costs)**

**Net Lifetime Carbon Reductions (Total) = 23.2 Tonnes of CO2 (equivalent)**




| Life Expectancy | |
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| Fabric | 20-30 years |
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**(GIA = 52.87m²)**

# How do we retrofit?

The solution lies in an integrated whole-house retrofit approach to bring existing houses to near net zero energy demand

| Stage 1<br>Building fabric optimisation | Stage 2<br>Low-carbon heating systems | Stage 3<br>Renewable energy generation & storage integration |
|---|---|---|

Performance Target: Part L 2021 notional levels

# Capital Cost and Carbon Emissions Reduction

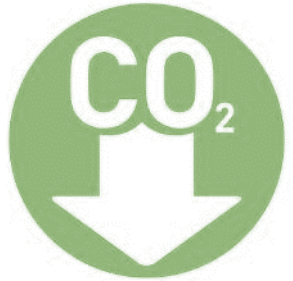
| | Capital Cost (£ billion) | Net Carbon Reduction (Tonnes of CO2e thousand) |
|---|---|---|
| Detached | £0.68bn | 553k |
| Semi-detached | £2.6bn | 301k |
| Mid-Terraced | £2.1bn | 1,073k |
| End-Terraced | £1.4bn | 1,273k |
| Total (Exc. VAT) | £6.7bn | 3,200k |

**6,700,000,000**

**capital investment in retrofit of houses**

**3,200,000**

**tonnes over lifetime of intervention**



# IF YOU WANT TO KNOW MORE…

Check our Climate Emergency Design initiative website, where you can download detailed information per archetype.

Climate Emergency Design Initiative Nottingham

www.nottinghamcedi.org

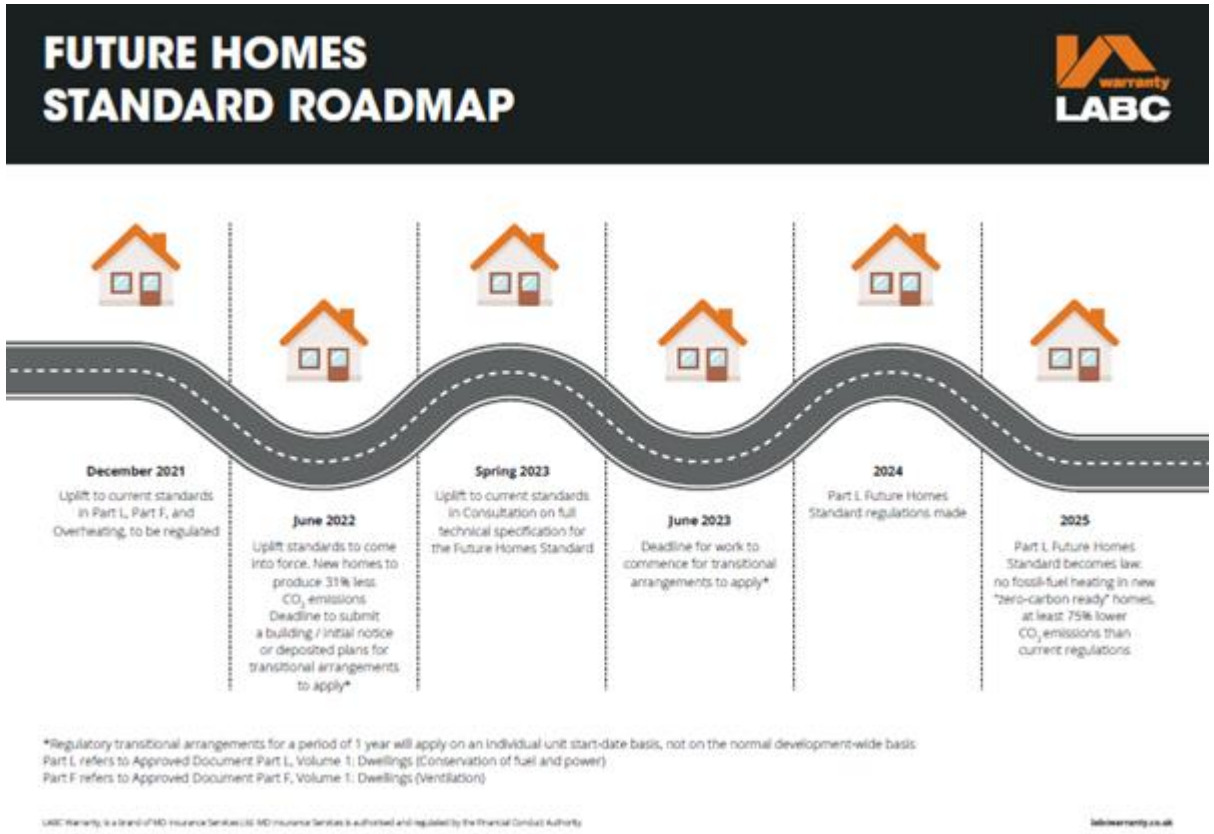
Or get in touch with

Lucelia.Rodrigues@nottingham.ac.uk

# Future Homes Standard

The cost of retrofitting new homes built to current standards today has been estimated at **5 times** the cost of building to the **Future Homes Standard now**

(Holmes et al., 2019)



University of Nottingham
Energy Institute

# Thank you!

Lucelia.Rodrigues@nottingham.ac.uk