Sustainable Design Theory & Practice: Integrated Energy Retrofit design proposal for a Victorian end Terrace house built in 1920s

Master of Science in BIM and Digital Built Environment
Supervised by: Dr Yingchun Ji

By: Solomon Tesfaye
February 2025, Manchester

Integrated Energy Retrofit Design Proposal for a Victorian end Terrace House

In Manchester

University of Salford

Sustainable Design Theory & Practice: Integrated Energy Retrofit design proposal for a Victorian end Terrace house built in 1920s

Assignment 1 (~ 3300 words used)

Master of Science in BIM and Digital Built Environment
Supervised by: Dr Yingchun Ji

By: Solomon Tesfaye
February 2025, Manchester

What to Expect

List of Figures and Tables

- List of Figures

- List of Tables

Abbreviations and Acronyms

Abbreviation or acronym	Term
ASHP	Air-Source Heat Pump
SAP	Standard Assessment Procedure
COP	Coefficient of Performance
ACH	Air Changes per Hour
U-value	Thermal Transmittance
PIR	Polyisocyanurate
PHRV	Passive Heat Recovery Ventilation
LED	Light-Emitting Diode
HVAC	Heating, Ventilation, and Air Conditioning
$kWh/m^2/year$	Kilowatt-hours per Square Meter per Year
EPBD	Energy Performance of Buildings Directive (EU)
Part L	Part L of UK Building Regulations
SDG	Sustainable Development Goal
BRE	Building Research Establishment
DLUHC	Department for Levelling Up, Housing & Communities (UK)
SBEM	Simplified Building Energy Model
OFGEM	Office of Gas and Electricity Markets
IPCC	Intergovernmental Panel on Climate Change
EST	Energy Saving Trust
BEIS	Department for Business, Energy & Industrial Strategy (UK)
MHRV	Mechanical Heat Recovery Ventilation

Table 1. Abbreviations and acronyms

1. Background

About 39% of the world's embodied and operating carbon dioxide emissions come from the built environment (Ürge-Vorsatz et al., 2020). Energy efficiency solutions are a top priority because domestic buildings in the UK have a substantial carbon footprint (Pomponi & Moncaster, 2016).
A large portion of the UK's building stock consists of Victorian homes, which have low energy performance due to old construction, minimal insulation, and inefficient heating systems (Ascione et al., 2015).
Retrofitting existing older buildings is difficult, as there is a balance between energy efficiency improvement and architectural heritage preservation (Baker, 2011). However, successful retrofits can deliver significant energy consumption and carbon saving efficiencies, meeting the UK's net-zero 2050 targets (Department for Business, Energy & Industrial Strategy, 2021). This report presents a whole-house energy retrofit strategy for an end-terrace Victorian house from the 1920s, combining passive and active design measures to enhance efficiency, decrease emissions, and enhance occupant comfort without sacrificing historical integrity.

2. Introduction

2.1. The Need for Building Upgrades in the Context of Sustainable Development

The matter of the priority which is today, the upgrading of the existing structures is very closely as regards the global sustainability strategies that are aimed at the efficiency of the way energy is consumed and the consequent reduction of greenhouse gases into the atmosphere. Buildings are the primary source of greenhouse gas emissions and consuming about 40% of the global energy, renewing the global carbonization process while giving sustainable transformation (Ürge-Vorsatz et al., 2020). The United Nations Sustainable Development Goals (SDGs) are calling for better ways of building properties to deliver them under SDG 11 (Sustainable Cities and Communities) which provides information on the development of sustainable urban environments and SDG 7 (Affordable and Clean Energy) in energy efficiency as the central policy area (United Nations, 2015). Likewise, the 2015 Paris Agreement on climate change is requesting member countries to pass laws that promote the use of very efficient methods and materials in building construction to limit the warming of the climate no more than 1.5°C above pre-industrial levels (IPCC, 2021).

2.2. Global Frameworks and Commitments

For a global level of coordinated climate efforts, international legal institutions, and regulatory bodies adopted strict energy performance policies. According to the European Union's Energy Performance of Buildings Directive, the regulations are based on the Directive that all new buildings should be close to zero-energy (EPBD), and thus give an incentive to not only introduce new buildings earlier but to creatively utilize the existing buildings as well, in order to reduce the use of greenhouse gases and when necessary clean up the environment (European Commission, 2020). The United Kingdom, in the aftermath of the Brexit, enacted legislation that ties the country into the legally binding Climate Change Act (2008) in which it sets a goal to reach the net-zero emissions of the national economy by 2050 (UK Government, 2021). As it stands, the majority of the 85% of the UK's current building stock are still expected to be in use by 2050; for that reason, efficient energy upgrades are the most necessary, even for such Historic buildings so that energy targets could be met and the buildings would be environmentally friendly (Department for Business, Energy and Industrial Strategy, 2021).

2.3. The UK's Commitment and the Role of Building Upgrades

Historic buildings, including Victorian-era homes such as the 1920s end-terrace house analyzed in this report, pose significant challenges due to their lack of insulation, inefficient heating systems, and excessive heat loss (Fouseki & Cassar, 2014). These outdated construction methods result in higher energy costs and increased carbon emissions (Gupta & Gregg, 2016). Implementing high-performance insulation, renewable energy technologies, and smart energy management systems is essential for aligning these buildings with contemporary energy performance standards while preserving their historical and architectural integrity (Baker, 2011).

2.4. Challenges and Opportunities

Even though retrofitting is beneficial for both the environment and the economy, there exist a number of obstacles. The financial problems, technical difficulties, and regulatory issues are often the reasons why the historic building owners choose not to upgrade their facilities on a larger scale. Nonetheless, the possible advantages are worthwhile. Retrofitting causes a dramatic drop in energy costs, improved comfort with thermal, and higher property valuation is achieved (International Energy Agency, 2013). In addition, the environmentally friendly buildings are not only a financial boon but are also socially responsible because they put less pressure on the national electricity grid and they cause less environmental pollution. The combination of building retrofit actions designed in line with international sustainability frameworks and energy policies of the country is the guarantee that they will have a substantial impact on the long-term environmental and economic issues.
This proposal has put together a complete energy retrofit programme for a Victorian end-terrace house built in the 1920s, which is thought to be a historic style of house that has been remodelled to meet the contemporary requirements of energy efficiency thus help the UK to achieve net zero.

3. Energy inefficiency of the selected building

3.1. Building Characteristics Affecting Energy Performance

Before analyzing specific inefficiencies, it is essential to understand the construction and design features of the building that influence its energy performance. Thus, Table 2 summarizes the construction and design features of the Victorain-era end-Terrace House used in this report.

Table 2. Construction and design features of the 1920s Victorian end-terrace house.

Parameter	Details
Orientation	The front of the building faces south, influencing solar gain and passive heating potential.
External Walls	225 mm solid brickwork with internal plastering; cavity with 225 mm brickwork and 45 mm EPS slab.
Partition Walls	115 mm brickwork with 13 mm internal and external plastering; connections to cavity include plastering and 225 mm brickwork.
First Floor	Synthetic carpet and timber flooring with cavity and plaster.
First Ceiling	Timber board with 100 mm glass-fiber quilt insulation, cavity, and plaster.
Roof	Stone chipping with felt/bitumen layers and slate tiles.
Ground Floor	Synthetic carpet and timber flooring with cavity and dense cast concrete.
Glazing	6 mm Pilkington single glazing.
Attributes	Background infiltration rate of 1 ACH (Air Changes per Hour).
Occupancy	Assumed to be a working couple with one children, influencing daily heating, lighting, and appliance usage patterns.
Lighting	Controlled by occupants, primarily used in the evening when home, except during sleeping hours.
Internal Gains	Heat gains from lighting and appliances in the living room (e.g., 8W/m² when occupied).
Ventilation	Natural ventilation via openable windows, providing up to 6 ACH in summer.
Heating System	Ideal heating system assumed by default, with set points at 20°C and operating when occupants are present.

3.2. Energy Performance Issues in the Building

The old Victorian house's energy inefficiency is an obstacle in the way of carbon reduction goals. The priors of these constructions, which were erected before any energy efficiency measures, consist of solid brick walls without cavity insulation, poor heating systems, and single-glazed windows all of which lead to high levels of heat loss (Sunikka-Blank & Galvin, 2012). In the UK, many older homes are responsible of consuming higher amounts of energy than the new ones (Cao et al., 2016). The building presented in this report is a very good representation of an old Victorian house that is far behind in terms of energy efficiency if compared to the existing building standards. Standards such as Part L of the UK Building Regulations (2021) and Passivhaus standards, which presuppose that walls should have U-values of 0.18 W/m²K, roofs 0.13 W/m²K, and glazing 1.6 W/m²K, are lower than the Victorian-era house. On the other hand, the selected building has much higher U-values, with external walls at 2.05 W/m²K, a roof at 6.05 W/m²K, and glazing at 5.56 W/m²K. What these numbers clearly suggest is that the house does not provide a stable enough thermal comfort to maintain a desirable temperature. Therefore, energy retrofit should be the main target to meet the UK standards.

- **Comparison and Implications**

The **walls** of the house are made of solid brick, the U-value of it is about 2.05 W/m²K gives a very less insulation when they are compared to the modern insulated cavity walls, which are 0.18 W/m²K or lower. In a like manner, partition walls have a U-value of 1.97 W/m²K, which points to the selective thermal separation and the resultants of the heat loss the building between rooms.
Roof: The 6.05 W/m²K U-value is way above the modern building regulations, it causes severe heat loss especially when the warm air rises naturally and as a result the heating costs are high.
Ceiling & Flooring: The first floor sealing insulation is rated at 0.34 W/m²K, which is better than the floor at 1.39 W/m²K, seems that the lost heat and consequently the thermal efficiency of the ground floor are significantly affected.
Glazing: The single-glazed 6mm Pilkington windows with a U-value of 5.56 W/m²K allow the heat to be lost significantly when compared to the newest assemble (Part L) that's double or triple glazing, with the U-value of1.0 W/m²K or lower.

3.3. Benefits of Upgrading the Building

Improving the energy efficiency of this building will provide multiple benefits, including economic, environmental, and health improvements.
Below are some of the benefits that can be gained by upgrading the Victorian-era house.

- **Reduction in Carbon Footprint**

The UK aims to reach net-zero status by 2050 and thus, this means a reduction of 40% of the energy efficiency of buildings which are currently getting supply. Retrofitting measures such as insulation, improved glazing, and air-source heat pumps drastically reduce energy demand, decrease carbon emissions, and thus, are in line with the national as well as international climate goals.

- **Economic Savings and Energy Efficiency**

Energy-efficient upgrades can slash heating expenses by half, which is a substantial benefit of numerous financial savings. Only a wall and roof insulation can bring heating down by 30-40%, while replacing single glazing with triple glazing can save £250-£400 yearly. Swapping of a gas boiler to an air-source heat pump inevitably reduces the heating costs and cuts down the carbon emissions thus, advancing long-term affordability (BRE, 2016).

- **Improved Indoor Comfort and Health Benefits**

Dump and wet dwellings may result in respiratory problems and uncomfortable feelings. Retrofitting improves indoor air quality due to the dampness and the increased mold growth which can be removed by the vapor barrier. This ensures steady indoor temperature and, therefore, it can have a great effect on human health. Moreover, Double/triple glazing option will create less problem with noise which is another way to support the feeling of the households having relaxation and good sleep (BRE, 2016).

4. Retrofit Design Package

4.1. Phased Retrofit Strategy

This retrofit design package is to provide a step-by-step process to the enhancement of the energy efficiency of a 1920s Victorian end-terrace house that has high heat loss and energy issues due to its solid brick construction, single glazing and an inefficient heating system. The solution is made up of a fabric-first approach which is designed to be a priority and the actions like insulation and airtightness improvements are carried out before upgrading heating systems and installing smart energy management solutions. The objective, in this case, which is to provide a substantial decrease in energy consumption, reducing carbon emissions and the improvement of the people´s comfort while the practical implementation is respected. Through the Standard Assessment Procedure (SAP), the SAP rating should improve from its current grade, Band G (1–20) , to acheive Band B (81-91). The retrofit process is divided into five phases (see Table 4, p14), and each one of these phases is focused on progressively improving the energy performance and maintaining the balance between the costs and comfort.

4.2. Phase Descriptions and Cost Justifications

- **Phase 0: Calculation Breakdown and baseline**

Before implementing any retrofit measures, an initial energy performance assessment establishes baseline heat demand, energy consumption, and SAP rating. Studies from Historic England (2023) and the BRE Group (2023) indicate that uninsulated Victorian homes typically require 220–250 kWh/m²/year for space heating, with significant variation depending on building orientation, exposure to wind, and occupancy patterns. Based on this assumption, the pre-retrofit heating demand is set at 250 kWh/m²/year. The total floor area (TFA) assumed of 78m² is multiplied by this heat demand figure, resulting in a total annual heating requirement of 19,500 kWh. With gas prices at £0.0634/kWh, (OFGEM, 2025) the space heating cost amounts to £1,237 per year. Additionally, domestic hot water demand is estimated at 3,500 kWh/year for 3 people (Energy Saving Trust, 2023), contributing £222 per year to energy costs. Electricity usage for appliances and lighting is calculated at 2,900 kWh/year (Energy Saving Trust, 2023), amounting to £721 per year. Factoring in standing charges of £339 per year, the total annual energy cost before retrofitting is £2,519 per year (see Table 3 for summary). The SAP rating at baseline is calculated as 3.92 (Band G).Therefore, the Heating demand for both floors (assumed as 78m²) would be:

Space Heating Demand= (Heat Loss Rate*TFA)
=(250 kWh/m²/year* 78m²)
=19,500 kWh/year

Primary Energy Demand Calculation
Total energy consumption for heating, hot water, lighting, and appliances.

Gas: Heating + Hot Water = 19,500kWh + 3,500 kWh = 23,000kWh/year

Electricity: Appliances + Lighting = 2,900 kWh/year
Apply Primary Energy Factors Convert delivered energy to primary energy using SAP 10.2 (2023) factors.
PrimaryEnergy=(Gas*1.1)+(Electricity*2.21)
= (23,000 kWh/year*1.1)+(2,900 kWh/year*2.21)
=25,300+6,409 =31,709 kWh/year

Description	Calculation	Annual Cost (£)	References
Space Heating Cost Calculates heat loss based on building fabric and gas prices.	Floor Area*Heat Loss Rate*Gas Price 78m² *250 kWh/m²/year*£0.0634/kWh	£1,237	BRE Group (2020); OFGEM (2025)
Hot Water Cost Estimates energy for hot water based on occupancy	Occupancy Demand*Gas Price 3,500 kWh/year*£0.0634/kWh	£222	Energy Saving Trust; OFGEM (2025)
Electricity Cost Calculates lighting/appliance costs using OFGEM data.	Annual Usage*Electricity Price 2,900 kWh/year*£0.2486/kWh	£721	OFGEM (2025)
Standing Charges Fixed daily fees for gas/electricity supply.	(Gas Standing Charge+Electricity Standing Charge)*365 (£0.3165+£0.6097)*365	£339	OFGEM (2025)
Total Annual Cost Sum of all energy costs.	Heating+Hot Water+Electricity+Standing Charges £1,237+£222+£721+£339	£2,519	

Table 3. Calculation breakdown for Space Heating cost, Hot Water cost, Eletricity cost, and Standing charges.

Normalize by Floor Area Calculate primary energy intensity per square meter.
Primary Energy/TFA(m²)
=31,709kWh/year/78m²
=406.41kWh/m²/year

EPC Calculation for Phase 0 (Existing):

1. Energy Cost Factor (ECF):

ECF = 0.42*Annual Energy Cost (£)/TFA(m²)+45

Therefore, ECF is:
0.42* £2519/ (78 m² +45)≈8.60

2. SAP Formula:
If ECF ≤ 3.5: SAP=100−(13.95*ECF)
If ECF > 3.5: SAP=117−(121×$\log_{10}$(ECF))

Therefore, Since 8.60>3.5, SAP is:
SAP=117−(121*$\log_{10}$(8.60)) ≈4 (Band G)

Carbon Emissions (using UK emission factors):

= (Total Gas Consumption kWh/year *0.184 kg CO_2/kWh) + (Total Electricity Consumption kWh/year* 0.233 kg CO_2/kWh)
= (23,000*0.184)+(2,900*0.233)
= 4,232kg+676kg=4.9tonnes/year

- **Phase 1: Low-Cost Energy Efficiency Enhancements**

The first phase of the retrofit process focuses on low-cost, high-impact interventions aimed at reducing uncontrolled air infiltration and improving heating efficiency. Draught-proofing is implemented by seal-

Table 4. This summary table reflects the Retrofit propoal at each Phases that will be applied to the Victorian house including the strategies used, the annual total energy cost, the heating demnad need, SAP ratings, carbon emissions, and cost savings.

Phase	Passive Strategies	Active Strategies	Annual Bill (£)	Heating Demand (kWh/m²/year)	Carbon Emissions (tonnes CO_2/year)	SAP Rating	Retrofit Cost (£)	Energy Savings (%)
Phase 0 (Existing)	None	None	2,519	250	4.9	5 (G)	0	0%
Phase 1	Draught-proofing, door,window, ventilation adjustments	smart heating controls	2,272	200	4.4	9 (G)	2,850	10%
Phase 2	Loft, floor, wall insulation, double glazing	None	2025	150	3.5	15 (G)	9,650	20%
Phase 3	Enhanced wall insulation, airtightness improvements	ASHP Hybrid Heating System (COP 3.5)	1,000	80	1.1	52 (D)	22,500	60%
Phase 4	Airtightness enhancement (0.8 ACH), floor insulation	ASHP optimization (COP 3.7)	650	70	0.8	69 (C)	11,500	74%
Phase 5	None	Solar PV integration, MVHR system	400	65	0.5	81 (B)	7,500	84%

ing gaps around windows, doors, and floorboards, as studies from BRE (2016) indicate that air leakage in Victorian homes can account for up to 20% of heat loss. External weatherstripping, underfloor sealing, and skirting board insulation are introduced to minimize cold air ingress, thereby reducing heat demand and stabilizing indoor temperatures. In addition to passive heat retention, smart heating controls are installed, which adapt heating schedules based on occupancy patterns and external temperature fluctuations (Ofgem, 2023). The combination of these measures reduces the heating demand from 250 kWh/m²/year to 200 kWh/m²/year, leading to a total energy cost reduction from £2,519 to £2,272, reflecting a 10% savings. The SAP rating improves to 9.34 (Band G), while carbon emissions are reduced from 4.9 to 4.4 tonnes CO_2/year. The total retrofit cost for this phase is £2,850. The SAP calculation at this Phase is as follows:

ECF = 0.42 * £2,272/ (78 m² +45)≈7.77
ECF > 3.5

Therefore, SAP is:

SAP: $117-(121 * \log_{10}(7.85)) \approx 9$ (Band G)

- **Phase 2: Fabric Improvements**

Phase 2 strengthens the building's thermal envelope by implementing multiple layers of insulation to improve heat retention. The loft is insulated with 400mm mineral wool (Knauf Insulation, 2025), achieving a U-value of 0.13 W/m²K, drastically reducing heat loss through the roof. Single-glazed windows are replaced with double-glazed units having U-value 1.4 W/m²K (Anglian Home Improvements, 2025), improving thermal performance by reducing window-related heat loss by 50% (Energy Saving Trust, 2023). Additionally, internal wall insulation using 150mm (U-value of app. 0.14 W/m²K) PIR boards (Celotex, 2025) and a vapour-permeable membrane (Pro Clima, 2025) further reduce heat loss while allowing moisture to escape, ensuring a healthy indoor environment. The replacement of the existing door with an insulated composite door (Rockdoor, 2025) eliminates a common source of drafts.

These enhancements lower heating demand to 150 kWh/m²/year, reducing annual energy costs to £2,025, a 20% cumulative savings. Carbon emissions decrease further to 3.5 tonnes CO_2/year, and the SAP rating improves to 15.39 (Band G).

The estimated cost for Phase 2 is £9,650, covering loft insulation, wall insulation, window replacements, and door insulation.

ECF = 0.42 * £2,025/ (78 m² +45)≈6.91
ECF > 3.5

Therefore, SAP is:
SAP: $117-(121 * \log_{10}(5.85)) \approx 15$ (Band G)

- **Phase 3: Upgrading Heating with ASHP System**

Phase 3 represents a shift to renewable energy-based heating, eliminating reliance on fossil fuels. The installation of a Vaillant Air Source Heat Pump (ASHP) with a COP of 3.5 (UK Government, 2021) enables the property to draw heat from the air, reducing heating-related emissions. This transition includes the replacement of the old gas boiler, shifting all heating and hot water provision to electricity-based solutions. The implementation of ASHP reduces heating demand to 80 kWh/m²/year, lowering energy costs to £1,000 per year (60% cumulative savings). Carbon emissions drop significantly to 1.1 tonnes CO_2/year, reflecting the impact of the shift away from gas heating. The SAP rating improves to 52 (Band D), a critical milestone in improving the home's energy efficiency.

ECF = 0.42 * £1000/ (78 m² +45)≈3.41
ECF < 3.5

Therefore, SAP is:
SAP: 100 − (13.95 * 3.41)≈ 52 (Band D)

The total retrofit cost for this phase is £22,500, comprising £10,200 for internal wall insulation and airtightness measures, and £12,300 for the ASHP installation. This phase demonstrates the critical role of fabric-first retrofits combined with renewable heating systems in achieving substantial energy and carbon savings.

- **Phase 4: Airtightness and ASHP Efficiency Optimization**

Phase 4 targets airtightness improvements, reducing air leakage to 0.8 air changes per hour (ACH) by sealing service penetrations, window frames, and skirting boards. The ASHP is optimized to a COP of 3.7 (Heat Geek, 2025), improving efficiency and reducing electricity demand to 1,481 kWh/year. To address ground-floor heat loss, 50mm aerogel insulation with U-value of apprximately 0.10 W/m²K (Kingspan, 2025) is installed above the existing concrete slab, enhancing thermal performance.

By implementing these improvements, heating demand decreases to 70 kWh/m²/year, reducing energy costs to £650 per year (74% cumulative savings). Carbon emissions continue to decline, reaching 0.8 tonnes CO_2/year, and the SAP rating improves to 69 (Band C).

The investment required for Phase 4 is £11,500, covering ASHP tuning, enhanced insulation, and airtightness measures.

ECF = 0.42* £650/ (78 m² +45)≈2.22
ECF < 3.5

Therefore, SAP is:
SAP: 100 – (13.95*2.22)≈ 69 (Band C)

- **Phase 5: Renewable Integration and Final Upgrades**

The final phase focuses on integrating renewable energy sources and optimizing heating efficiency. A 3.5 kWp solar PV system (E.ON Solar, 2025) is installed, generating 3,200 kWh/year to offset electricity usage, significantly reducing dependence on grid energy. Additionally, a Mechanical Ventilation with Heat Recovery (MVHR) system (Vent-Axia, 2025) ensures proper ventilation while retaining up to 90% of heat, further improving efficiency.

With these final upgrades, heating demand drops to 65 kWh/m²/year, reducing annual energy costs to £400 (84% cumulative savings). Carbon emissions decline to 0.5 tonnes CO_2/year, and the SAP rating improves to 81 (Band B), achieving the final goal of this retrofit. The total cost for Phase 5 is £7,500, covering solar PV installation and ventilation upgrades.

ECF = 0.42* £400/ (78 m² +45)≈1.37
ECF < 3.5

Therefore, SAP is:
SAP: 100 – (13.95*1.37)≈ 81 (Band B)

5. Other Considerations

- **Building Orientation**

Because the house is south-facing, it benefits from passive solar heating during the winter that lessens heating demand. Recommendations that would limit passive heating in summer like external shade against different angles of incidence, reflective coating in the glazing, or high ventilation rates are therefore mandatory to maintain the level of comfort required.

- **Lighting and Internal Gains**

Thermal load due to heat gains from lighting, appliances and household activities. Internal heat gain is set to be estimated as 8 W/m² in living room and 5 W/m² in bedrooms based on lighting and electronical devices. High-efficiency LED lighting with occupancy sensors can be included to reduce excessive heat gains and to further increase energy efficiency; the system is designed to operate only when necessary, balancing comfort with reduced electricity costs.

- **Ventilation Provision**

Indoor air quality (IAQ) is critical in well-insulated, airtight buildings. In summer, heat drives natural ventilation rates upward to 6 air changes per hour (ACH), enabling passive cooling via openable windows (CIBSE, 2020). However, winter's uncontrolled ventilation increases heating demand significantly, necessitating efficient solutions. The retrofit's Phase 5 integrates airtightness enhancements with mechanical heat recovery ventilation (MHRV) systems, which recover up to 90% of heat from exhaust air (IEA, 2021). These systems optimise airflow while minimising thermal loss, ensuring a balance between energy efficiency and occupant health

- **Climate Considerations for Manchester**

Manchester's temperate maritime climate produces relatively mild summers and cool winters, but a long space heating season from October to April. As average winter temperatures range from 1°C to 7°C, space heating is still the most significant energy demand. Passive heating strategies can be considered feasible, and the dominant southwest winds can also be utilized for improved natural ventilation, decreasing dependency on mechanical cooling plants during hotter months.

6. Changes in Behaviour for Extra Energy Savings

Although, structural improvements create a tremendous potential increase in a building's energy efficiency, but a building's occupants are the key that can unleash real savings. Energy-wasting habits can diminish the benefits of retrofits, so energy-savvy behavior is a must for further reducing energy use, greenhouse gas emissions, and household energy expenses (IPCC, 2022).

- **Control of Heating and Thermostat**

Heating adjustments yield major savings: lowering thermostats by 1 C reduces heating costs by 10% (IEA, 2022). Efficient systems maintain optimal temperatures at 18–20 C when occupied and 16 C when unoccupied (WHO, 2018). Prioritize zonal heating for occupied rooms, bleed radiators for even heat distribution, and use retrofit-integrated smart controls to automate temperature adjustments (Energy Policy, 2020).

- **Energy-Efficient Appliance and Lighting Use**

Appliances account for ~30% of household energy use, but behavioural changes can curb waste (UK GOV, 2023). Switching off appliances (not standby) saves 65/year, while eco-modes, avoiding tumble dryers, and LED lighting with sensors cut lighting energy by 75% versus incandescent bulbs (IEA, 2021).

- **Smart Energy Monitoring and Optimization**

Smart meters and real-time monitoring systems enable residents to track usage, identify waste, and schedule appliances during off-peak periods, lowering costs and grid strain (DECC, 2022). Studies show such systems reduce energy demand by 5–15% through heightened awareness (Darby, 2017).

- **Ventilation and Indoor Air Quality Management**

TRetrofit ventilation systems improve air quality, but strategic usage is essential. Short, targeted window opening, trickle vents, or heat recovery systems minimise heat loss. Keeping furniture clear of radiators and vents optimises airflow efficiency (Energy Saving Trust, 2021).

- **Impact of Behavioural Changes on Savings**

Adopting these measures can reduce annual energy bills by 10–20% (European Commission, 2020). Combined with retrofits, they maximise efficiency, cost savings, and sustainability, demonstrating the symbiotic role of technology and behaviour in energy conservation.

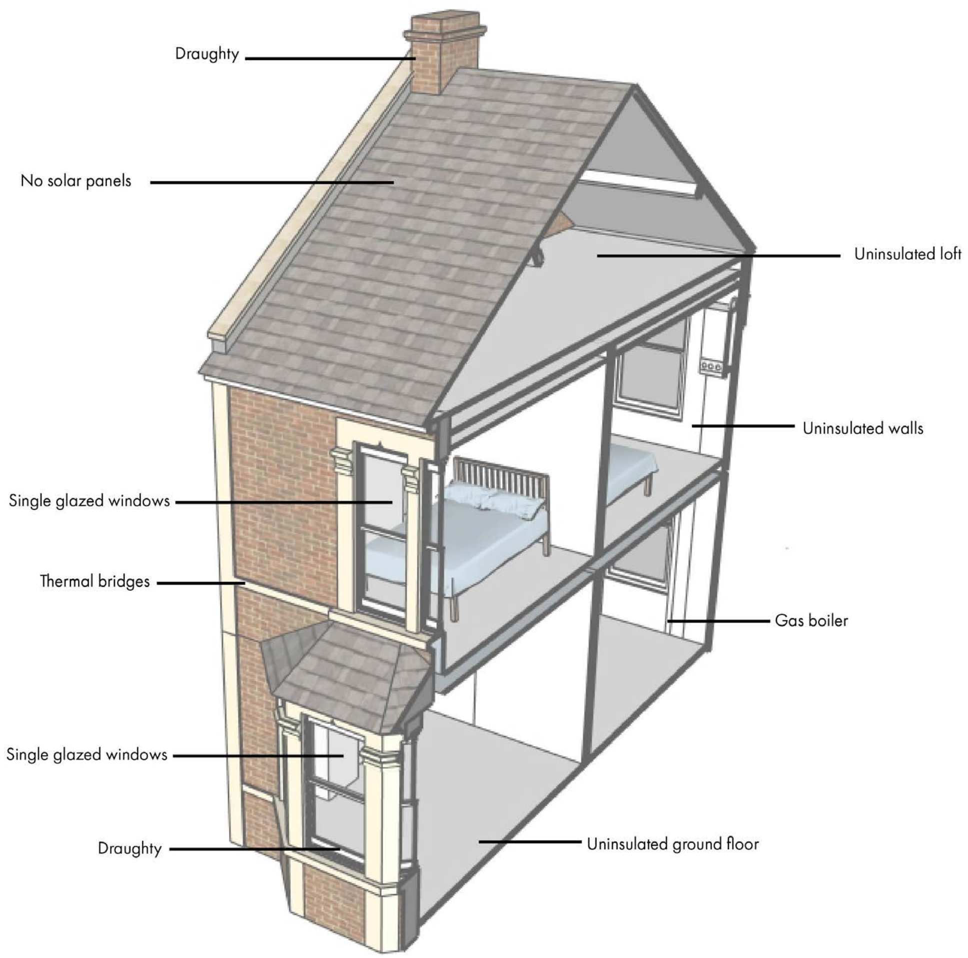

Figure 1. Pre-Retrofit condition of the house.

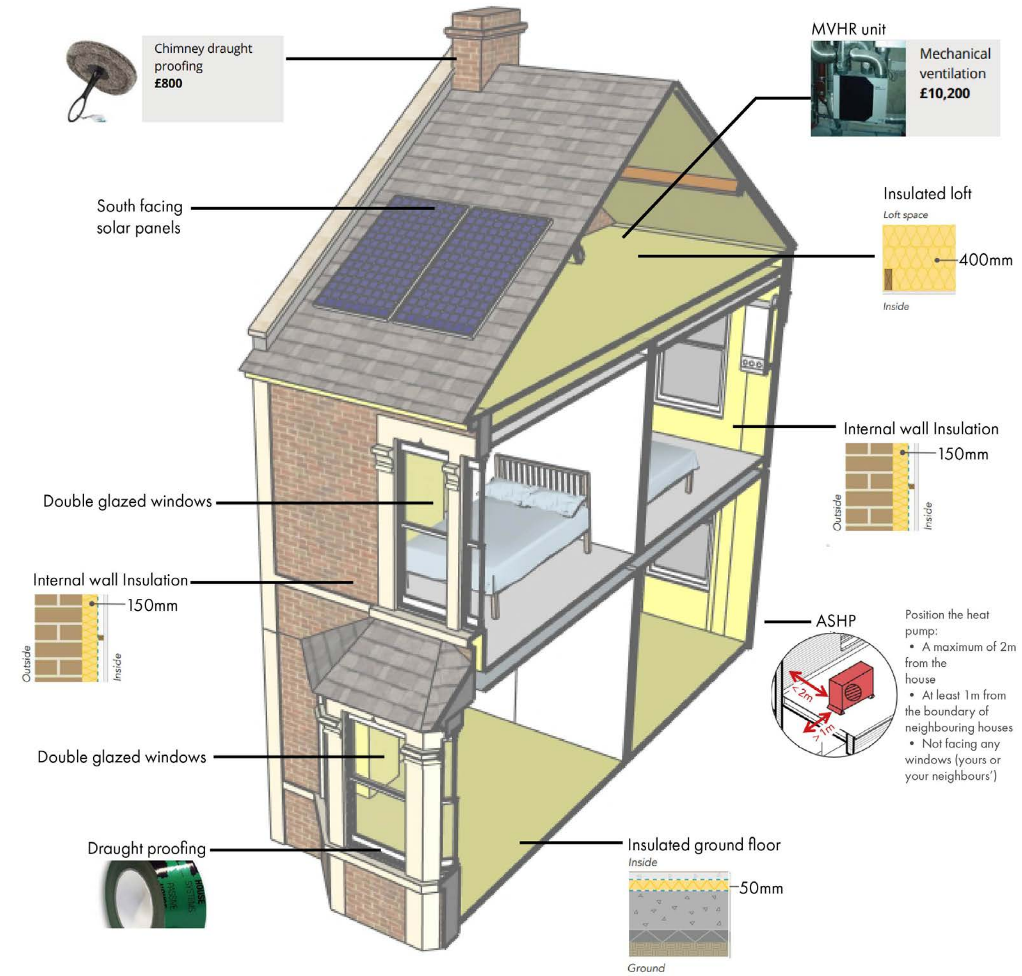

Figure 2. After Retrofit condition of the house.

7. References

Ascione, F., Bianco, N., De Masi, R. F., de' Rossi, F., & Vanoli, G. P. (2015). Energy retrofit of an educational building in the ancient center of Benevento: Feasibility study of energy savings and respect for the historical value. Energy and Buildings, 95, 172-183.

Anglian Home Improvements. (2025). Double glazing solutions. Retrieved February 19, 2025, from https://www.anglianhome.co.uk/

Baker, P. (2011). U-values and traditional buildings: In situ measurements and their comparisons to calculated values. Historic Scotland Technical Paper 10.

Boardman, B. (2007). Home truths: A low-carbon strategy to reduce UK housing emissions. Environmental Change Institute, University of Oxford.

BRE Group. (2023). Energy performance of Victorian homes. Retrieved February 19, 2025, from https://www.bregroup.com/

Building Research Establishment (BRE). (2016). Energy-efficient retrofit of traditional buildings. Building Research Establishment.

Cao, X., Dai, X., & Liu, J. (2016). Building energy-consumption status worldwide and the state-of-the-art technologies for zero-energy buildings during the past decade. Energy and Buildings, 128, 198-213.

Celotex. (2025). PIR insulation boards. Retrieved February 19, 2025, from https://www.celotex.co.uk/

Department for Business, Energy & Industrial Strategy (BEIS). (2021). Heat and Buildings Strategy. Retrieved from https://www.gov.uk/government/publications/heat-and-buildings-strategy

Department for Levelling Up, Housing & Communities (DLUHC). (2021). Approved Document L: Conservation of Fuel and Power. HM Government.

Department of Energy & Climate Change (DECC). (2014). UK National Energy Efficiency Action Plan.

Dowson, M., Poole, A., Harrison, D., & Susman, G. (2012). Domestic UK retrofit challenge: Barriers, incentives, and current performance leading into the Green Deal. Energy Policy, 50, 294-305.

Darby, S. (2017). Smart Metering: What Potential for Household Engagement?

E.ON Solar. (2025). Solar PV systems for UK homes. Retrieved February 19, 2025, from https://www.eonenergy.com/solar

Energy Saving Trust. (2023). Home insulation guide. Retrieved February 19, 2025, from https://energysavingtrust.org.uk/

Heat Geek. (2025). ASHP optimization and efficiency. Retrieved February 19, 2025, from https://www.heatgeek.com/

Hive Active Heating. (2025). Smart Thermostat Solutions. Retrieved February 19, 2025, from https://www.hivehome.com/products/hive-active-heating

Historic England. (2023). Heat loss in historic buildings. Retrieved February 19, 2025, from https://historicengland.org.uk/

Knauf Insulation. (2025). Mineral wool insulation. Retrieved February 19, 2025, from https://www.knaufinsulation.co.uk/

Kingspan. (2025). PIR insulation solutions. Retrieved February 19, 2025, from https://www.kingspan.com/

Marmot Review. (2011). The health impacts of cold homes and fuel poverty. Friends of the Earth & the Marmot Review Team.

Ofgem. (2025). Energy Price Cap: Unit rates for electricity and gas (January 2025). Office of Gas and Electricity Markets. Retrieved from https://www.ofgem.gov.uk/publications/energy-price-cap-update

Pomponi, F., & Moncaster, A. (2016). Embodied carbon mitigation and reduction in the built environment: What does the evidence say? Journal of Environmental Management, 181, 687-700.

Pro Clima. (2025). Vapour-permeable membranes. Retrieved February 19, 2025, from https://www.proclima.com/

Rockdoor. (2025). Insulated composite doors. Retrieved February 19, 2025, from https://www.rockdoor.com/

Screwfix. (2025). Draught-proofing materials. Retrieved February 19, 2025, from https://www.screwfix.com/

Standard Assessment Procedure (SAP). (2023). The Government's Standard Assessment Procedure for Energy Rating of Dwellings (Version 10.2). Department for Energy Security & Net Zero. Retrieved from https://www.gov.uk/government/publications/sap-2023

Sunikka-Blank, M., & Galvin, R. (2012). Introducing the prebound effect: The gap between performance and actual energy consumption. Building Research & Information, 40(3), 260-273.

rge-Vorsatz, D., Khosla, R., Bernhardt, R., Chan, Y. C., & V rez, D. (2020). Advances toward a net-zero global building sector. Annual Review of Environment and Resources, 45, 227-269.

UK Government. (2021). Boiler upgrade scheme. Retrieved February 19, 2025, from https://www.gov.uk/

UK Government. (2021). Future Homes Standard: 2021 Building Regulations Consultation. HM Government. Retrieved from https://www.gov.uk/government/publications/future-homes-standard-2021-building-regulations-consultation