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Pilgrims' Barn, Suffolk

A Carbon Negative Class Q Retrofit for Post-Hydrocarbon Living

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PILGRIMS' BARN: A CARBON NEGATIVE, CLASS Q RETROFIT FOR POST-HYDROCARBON LIVING It is of paramount importance that humanity responds to the existential threat of climate change. We are also potentially at a tipping point in our relationship with nature. An integral part of combatting climate change is the need for us to be 'Nature Positive' in how we live our lives. That also must apply to how we build our homes, fit for the Future.

Pilgrims' Barn is an exemplar Class Q adaptive reuse project in rural England. This demonstrates how retrofit can surpass new-build performance standards. Achieving EPC A (134) and outstanding Whole Life Carbon Assessment (WLCA) results; it integrates passive solar design, high thermal mass, and triple-glazed fenestration to provide year-round comfort with negligible heating and cooling demand. Circular, nature-based systems include rainwater harvesting, integrated SuDS, reedbed wastewater, tertiary treatment; biodiverse landscaping, reduces environmental impact, while advanced air quality enhances health and wellbeing; we have to create more healthy homes. Fully electric, it is powered by 75 PV panels with 40.5 KWHs battery storage. WLCA results outperform LETI, RIBA 2030, and NZCBS benchmarks, demonstrating carbon negative performance; giving net carbon positive overall, over its 300-year design life. This paper shows that rural Class Q conversions, as well as new build can deliver post-hydrocarbon living, with carbon negative, low-cost, and healthy outcomes.

Keywords: WHOLE LIFE CARBON ASSESSMENT (WLCA), ADAPTIVE REUSE RETROFIT, PASSIVE SOLAR DESIGN, ENERGY AUTONOMY, NATURE-BASED INFRASTRUCTURE, LOW-CARBON BUILDINGS

1. The Imperative for Building Design Change

The threats and impacts of climate change are paramount in shaping how we need to live our lives, both now and in the future. Indeed, the challenges besetting us seem so daunting that we almost need a superhero to rescue us from so bleak a fate. Mercifully the key answers, if we dare to open our eyes, properly, are available to us. Those answers lie with Mother Nature herself, coupled with excellent and empathetic design, based upon science. This paper takes us on that journey.

An integral part of combatting climate change is the need for all master-planning, construction form and services, to be 'Nature Positive'. We are potentially at a tipping point in our relationship with nature. The loss of biodiversity and the rapid degradation of ecosystems have reached critical levels, close to irreversible changes. The Global Biodiversity Framework (GBF) [1] has set ambitious goals to address this. Nature is the very foundation that underpins our economy, our safety and our wellbeing; it is not just an optional extra for the built environment. All involved in the development industry, have to start working in harmony with the GBF, throughout their operations.

Perhaps the most fundamental area to consider is how we build all our buildings to be fit for the future. Firstly, we must change our construction form and services; otherwise, we shall only increase climate change. Secondly, we must create the buildings in which we live, work, learn and play, to be best suited for our needs; they must protect us in summer and winter from the impacts of climate change; this is in addition to design and dimensions appropriate for their purpose. The author has often in the past, whilst delivering papers for the King's Foundation, regardeds buildings as the ultimate 'clothes' that we wear; they must be suitable for use and provide the environment around us, which puts us at our ease, or inspires us for their particular purpose.

2. Introduction

Pilgrims' Barn is an exemplar Class Q adaptive reuse project in rural England. This demonstrates how a technical retrofit can even surpass new-build performance standards. Achieving EPC A (134) and outstanding Whole Life Carbon Assessment (WLCA) results; it integrates passive solar design, high thermal mass, and triple-glazed fenestration to provide year-round comfort with very little heating and cooling demand. Circular, nature-based systems include rainwater harvesting, integrated SuDS, reedbed wastewater, and tertiary treatment. Biodiverse landscaping reduces environmental impact, while advanced internal air-quality management enhances health and wellbeing. Fully electric, it is powered by 75 PV panels with 40.5 KWHs battery storage. WLCA results outperform LETI, RIBA 2030, and NZCBS benchmarks, demonstrating carbon negative performance over its 300-year design life.

This paper shows that rural Class Q conversions, as well as newbuild, can deliver post-hydrocarbon living, with carbon negative, low-cost, and healthy outcomes. The Pilgrims' Barn construction form and all its services were originally designed by Profs Brenda and Robert Vale from their research in the 1980s, when they were also much involved with the Building Research Establishment [2]. It was then refined by the Hockerton Housing Project. The Vales research was specifically into how best to build and service autonomous two to four bedded homes at scale and built at no greater cost per square metre than standard, non-eco homes. Pilgrims' Barn proves that their research was incredibly well-founded and sufficiently flexible to be applied to any form or size of building, at any scale of development.

3. The Four Columns of Sustainable Construction

To achieve this, it is necessary to follow the Four Columns of Sustainable Construction. These are:

1. **Whole Life Cycle Carbon Integrity** – demonstrated and validated through Whole Life Cycle Assessment (WLCA).

2. **Ultra-Low Energy Demand with Energy Autonomy** – passive fabric dominance combined with solar generation and storage (including mobility).

3. **Fully Integrated Water Management** – rainwater, grey and waste streams, giving quality place-making and BNG value.

4. **Healthy Indoor Environments** – measurable air quality and environmental stability.

This essential framework will be built upon throughout this paper.

4. The Construction Form of Pilgrims' Barn

As stated, this follows the research work of Profs Brenda and Robert Vale, largely as set out in their books, 'The Autonomous House' [3], and 'The New Autonomous House' [4]; these remain one of the most rigorous accounts of integrated sustainable architecture ever produced. Pilgrims' Barn also includes refinements from the directors of The Hockerton Housing Project in Nottingham. They have long studied the Vales' research and work, put it into practice, both for themselves at Hockerton and for their clients at home and abroad.

Pilgrims' Barn site is typical of many other flat open fields in the UK. As at Hockerton [5], its layout and services can easily be replicated on other such sites, for large developments.

There should be minimal shading from the south to maximise solar gain. Orientation is crucial to maximise home energy efficiency. For Pilgrims' Barn, facing just west of south is ideal. Houses facing 20 degrees or even 30 degrees either side of south are possible, though angled west of south is more desirable, because of morning mist or fog. Thus, it is perfectly possible to replicate this on very large sites with attractive and varied layouts to optimise the size and shape of the site.

Surplus subsoil from all excavations to accommodate the foundations and deeply insulated floor area. This had either to be used on site or transported away, probably some distance. It is desirable to protect the house from the very strong winds often experienced on the western and northern sides of the house. Therefore, a bund of 1 metre running the length of the northern boundary and northern part of the western boundary was created. This used the 400 cu metres of excavated subsoil. Not one lorry-load of surplus soil was taken off site. As well as saving on transport cost and carbon, it has proved effective as a windbreak and screen. On large development sites, this technique needs to be considered rather than the automatic norm of transporting all surplus off-site, with a huge carbon footprint as well as financial cost.

Pilgrims' Barn performance is achieved due to an enhanced version of the Vale's construction form. This follows the requirement of para 3.2 above namely - Ultra-Low Energy Demand with Energy Autonomy; this follows 'Three Principles' [6].

The first is orientation, to optimise passive solar heat and light, as well as maximise a large roof area with solar panels.

Second is dense building-mass of all internal walls, set on 300mm of concrete floor [7]. Airtightness is also essential to reduce heat losses through building fabric.

Thirdly, this dense mass is enveloped in 300mm insulation, under a concrete floor, then wrapped up the outside of the internal leaf of the external wall. At the wall-top, it is carefully integrated with 440mm roof insulation. High performing triple-glazing is essential. This construction retains heat in winter and helps to protect it from over-heating in summer. From a median heat through the year of about 22C, the house seldom moves more than 2C above or below this temperature.

Space heating in Pilgrims' Barn relies almost entirely on heat from passive solar gain, incidental gains and heat derived from occupation. The heat is stored in the mass of the buildings (e.g. concrete floor/dense blockwork in all internal walls) and released when the indoor air temperature drops below that of the building fabric. The design of Pilgrims' Barn provides good internal daylighting as well as maximising passive solar gain through the large floor-to-ceiling windows on the south and western sides. The Eastern side is far less important for passive solar gain as morning mist will be a natural impediment.

The newly planted tree and shrub, biodiversity areas to the south are all deciduous. For the most part they consist of species which will not grow to forest-tree size; thus, they allow sunlight penetration, once they lose their leaves in autumn; these will continue to benefit the home. During the summer, shading is created within the home due to the high angle of the sun and the slightly protruding, large roof-guttering; this reduces thermal gain and glare inside, when it is least wanted. Rooms that are not so dependent on natural light, such as utility, spare bedrooms, bathing areas and workshop, are located on the rear of the home, on the northern side. The northern and northwestern sides are increasingly protected from cold winter winds by an array of larger trees planted along those boundaries and on the metre-high bund. They will form an excellent barrier over time. Correct landscape planting, at the master-planning stage, is an essential part of protecting any development from the elements in summer and winter.

Ventilation in any air-tight building is essential. This is provided by a Mechanical Ventilation Heat Recovery (MVHR) system that recovers up to 80% of heat from outgoing air to pre-warm incoming fresh air [8]. It is therefore an essential form of low-cost heating, although its total energy requirement in this large house is less than 0.5 KWh per day throughout the year, as all air heating is via a heat-exchanger.

The hot-water system. Once again, the Pilgrims system was conceived by the Vales but greatly enhanced by Hockerton [9]. The 450 litre hot water tank is typical of all Hockerton buildings and super-energy-saving. All water is heated on demand; the water in the tank stays in it and is solely the means of heating the 30 metre-long, coiled pipe which feeds in at the base of the tank and heats the water to the desired temperature by the time it reaches the tank top, thence to feed the hot-water plumbing. Because water is heated on demand, it can be heated to only 50C as there is no Legionella danger. The first energy saving is therefore from only heating water to this lower heat. It is the last 15 to 20 degrees of heat Celsius, which requires the greatest energy. There are two 3KWh immersion heaters, but only one is ever used; the other is for an emergency such as the first heater failing on a Friday afternoon! The second saving is from the basic tank having its own insulation but then being packed tight in its special cupboard with rockwool, or similar, so that there is barely a cubic centimetre of air, anywhere around it. According to the Hockerton research, this saves a further 43% of the energy required to heat the tank if not super-insulated. The actual energy used in hot water heating in 2025, when there were often up to ten people staying in Pilgrims' Barn, was 2.8 Mwhs in the whole year, or an average of less than 7.7 KWhs per day, as set out on the Pilgrims' Barn Energy Use [16].

Because Pilgrims' Barn is a large home and for much of the time, only three of the family live there permanently, Hockerton advised the installation of an underfloor electric wire heating system, which was agreed. This lies about 200mm below the finished floor level; it was very firmly attached to the steel reinforcement mesh, set in the upper 150 mm layer of concrete; thus, the reinforcement, which runs to the very extremes of the floor acts as an excellent heat-spreader, both in winter and summer. This last is borne out by the fact that when the floor surface is regularly tested for surface temperature, other than on very hot, sunny days in summer, spring and autumn, the south side of the floor is seldom more than 1 degree C more than on the north side of the floor. In a normal-sized home for three or four people, as proven by the Vales original house and all the houses at Hockerton, no heating is required. The energy used in heating Pilgrims' Barn, a large house, to a really comfortable temperature (never below 20 to 21 C in the coldest part of winter), is all provided by the integrated Off-Grid Energy System in section 5 below and details of energy use, for all services on the property [16].

5. The Off-Grid Energy System

The energy source is from 75 solar panels set out on the south-facing side of the roof. These have a total capacity of 27KWHs, but are governed by three 8KWHs Inverters, installed neatly on the garage wall, feeding into the three, close-by, Tesla Powerwall Batteries; together these total 40.5 KWHs of storage. This feeds all internal and external requirements via the fuseboard of 54 fuses. In the calendar year of 2025, as set out [16] total generation was 25.57 MWHs; Total Import from the grid was 20.65 MWHs, largely from winter charging of cars and necessary underfloor heating. Total Export to the grid, of 26.12 MWHs, comprised not only a large proportion of energy generated, but also some imports from the grid, mainly at night when the price was very low; therefore, after fully energising the house and charging two EVs, the net surplus sold to the grid was 5.46 MWHs. This demonstrates the synergistic benefit of having the appropriate capacity of both solar panels and battery storage.

6. The Fully Integrated Water System

Normally in the UK, water in all its different forms – potable, grey and waste (or foul) water - is managed in as many different, separate systems; when on public mains, managed by different organisations. At the present time, the Environment Agency predicts that, extrapolating forward, even taking into account essential water savings, through water-saving fittings, by 2050, there will be a shortfall of 5 billion litres of water per day in England alone. This seemingly impossible situation, going forward is nevertheless entirely manageable if, but only if, the government is prepared to require the necessary changes in water management practice to be made; in other words, only if the government insists on our overall water system being managed in a fully integrated manner with 'joined-up thinking'. We are also increasingly suffering in the UK (as even more so around world) from typical climate change, rainfall 'deluges'. These are often causing damaging and increasingly disastrous flooding events, even in parts of the UK, though far worse elsewhere in the world. We have experienced many UK-level 'deluges' here at Pilgrims' Barn since 2022. However, we are fortunate that our system is fully integrated and in a natural cycle. Although different from the Hockerton integrated system, many of the techniques used there [10] have been further refined and integrated at Pilgrims' Barn [11].

The 6,000 litre Rainwater Harvesting Tank. This cylindrical tank is sited underground close to the house, set into a 100mm concrete base. This takes only the clean rainwater direct from the roof via copper guttering and downpipes into the tank. The copper gutters and downpipes are not there just to look attractive; they provide the primary treatment of the water, as it flows across the copper; this method has been used for centuries. Further, basic filter treatment is carried out as the water is pumped from the tank back into the house to supply water to all toilets and washing machines, as well as all water for garden and external use. This amounts to about 80% of the total water requirements for the property. Firstly, it effectively manages too much water in an otherwise flooding situation; secondly, it saves precious water from being unnecessarily removed from the natural environment; thirdly, it saves the cost of purchasing about 80% of the required supply, if all water had to be purchased from the public water main. Therefore, this same Rainwater Harvesting Tank is also our Sustainable Drainage System Tank (SuDS), a No. 1 tank for 'deluge-water'. When that tank is full, it is automatically diverted to the Wildlife Pond.

The Wildlife Pond (19x16 m) also incorporates a Natural Swimming Area (9 x 6 m). It is lies to the west of the house, immediately beyond the paved, sitting-out and sun-lounging area. This lined pond forms the SuDS No.2 holding area, once the Rainwater Harvesting tank is full. The bund to the west of the pond provides some vital shelter from the often powerful, prevailing winds from the south-west; this was created by using all spoil from the excavation of the pond itself; once again, this negated the need to remove any surplus subsoil by lorry from site. Within months of completion, the pond was in use by the family and in early spring, joined by many families of great crested newts, who have each spring since returned. They seem to love the pond and hide in water covered by boarding, on the swimming pool side of the main pond area; they know they are out of sight and safe! When as happens sometimes in a prolonged period of very heavy rain, even the pond overflows; it then discharges into a wide and deep swale, the SuDS No.3 holding area; this swale, purely in drainage terms, is sufficient for this house without the need for the big pond. However, since its creation, the pond has become a very precious feature of the property; its extensive planting alone has created something of real beauty; this, together with the plethora of visiting birds and other wildlife, is wonderful to watch, both from the paved area and from inside the house.

From the swale, water flows into the treated wastewater, 'finishing', Reed-bed Pond [12], SuDS number 4. This pond primarily removes chemical enrichment (nitrates and potash) from the already fully treated water, from the Sewage Treatment Facility. When this pond becomes full, it overflows into an old drainage pipe. This pipe historically drained all rainwater direct from the whole chicken shed roof, together with other ground water; the remaining section of pipe now only carries any overflow from the Reedbed Pond to discharge into the adjoining farm pond and thence into the local field-drainage system. When Pilgrims' Barn was purchased the easement to discharge was included.

The Sewage Treatment Facility. This is initially formed as a conventional septic tank system with two tanks in tandem, for a more effective system. The resultant fully treated liquid effluent then discharges from the septic tank, via a sump to the centre of the base of the one-metre-deep Reed-bed Pond. Here, the profusion of established reeds, with their roots grown down to the pond bottom, take up the nitrates and phosphate from the treated effluent and so render it safe to discharge in areas where the discharge of enriched water is prohibited. There is absolutely no aroma from any part of this system. Within a few months of the Reedbed pond being full and working, the family was thrilled to discover a pair of rare water voles finding the pond and happily settling there! There is also a pair of ducks which return annually to nest and raise their ducklings. The additional habitat formed by these ponds and the swale is remarkable; the wildlife it supports is excellent and wonderful to watch and enjoy.

7.Healthy Homes and Air Quality

The issue of healthy homes has long been considered in many European countries and the United States. In the UK, indoor air quality (IAQ) has emerged as a critical but under-addressed component of public health and housing quality. With UK residents spending up to 90% of their time indoors, the condition of our homes, particularly in terms of ventilation, damp, and pollutants, has significant implications for respiratory and developmental health [13]. Despite this, indoor air is still subject to minimal regulatory oversight compared to outdoor pollution. Progress in this area has been incredibly slow, though now is being pressed hard by many organisations, not least, by the NHS, The Royal College of Physicians and the Royal College of Paediatrics and Child Health. The costs to the country (and therefore, ultimately to every taxpayer) is huge. The House of Commons Library's February 2023 research briefing confirmed [14]. the NHS spends an estimated £1.4 billion annually on treating illnesses associated with cold or damp housing, with this rising to £15.4 billion when wider societal costs are included. This is building up to become a major health crisis.

There are aspects of pollution found indoors that are notably different to outdoors. Mould and damp can lead to elevated concentrations of biological aerosols when compared to those found typically outdoors. The indoor environment can accumulate much higher concentrations of volatile organic compounds (VOCs) than are found outdoors in the UK, due to their release from construction and furnishing materials and use of cleaning and personal care products [15].

Asthma is among the most direct health consequences of unhealthy housing. The NHS spends approximately £3 billion per year treating asthma in the UK. Two-thirds of the more than 1,000 asthma deaths in the UK each year are considered preventable. Key facts include:

1. More than one in three people (37%) who have previously lived in homes with condensation, damp, or mould — but no longer do — still report that someone in their household has asthma or a weakened immune system, reflecting the lasting legacy of exposure.

2. Children in cold homes are more than twice as likely to develop respiratory problems as children living in warm homes.

3. In new-build homes, that have to achieve high levels of air-tightness, the dangers of damaging pollutants is all the greater if there is no built-in means of mechanical ventilation, probably coupled with a Heat Recovery (MVHR) system. This is the case with Pilgrims' Barn, where the entire air is changed about once every four hours, with all doors and windows closed. In May 2025, a comprehensive air-quality monitoring system was installed, which since then has produced some encouraging results. Figure 1 demonstrates how well the house performs in this respect. It should be noted that the first graph shows the AVERAGE daily temperature over 24 hours. Therefore, it is important to note that in August 2025, the temperature recorded was 37 degrees C and in January 2026, the lowest temperature recorded was -6 degrees C. This, therefore, shows the remarkable ability of the house, internally, to remain tranquil.

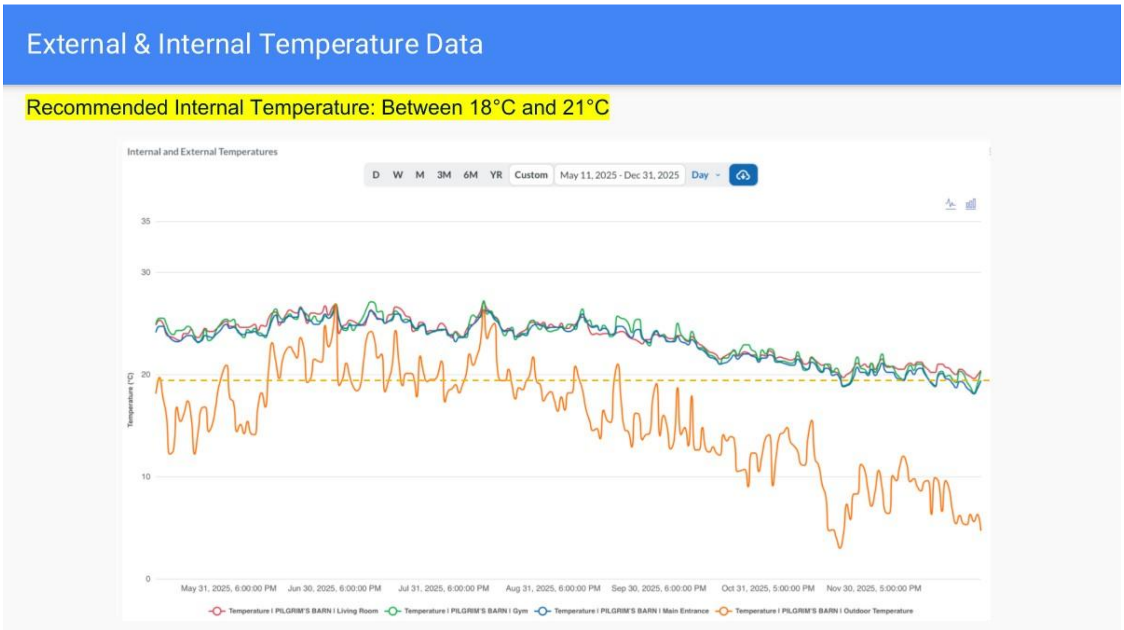

Figure 1. *External and Internal Average daily temperatures over 24 hours for a period of Approx. 6 months.*

Recently, when collating the records for this paper, the author of this paper learnt a very important, but tough lesson. Due to a severe illness, the author, for over four months was prevented from carefully cleaning the two main filters in the MVHR unit. During this period, the ppm of CO_2 rose and stayed up for the rest of the recorded period as set out for this paper, as shown in Figure 2 below. This also appears to apply to the stats relating to both particulate matter and, to a lesser extent, TVOCs; however, both CO_2 and TVOCs are well within limits, as shown in Figure 3 below. Because Pilgrims' Barn is sited in the middle of arable and pasture-land, it is most probable that the particulates (without further analysis) are mainly beneficial/low toxicity natural ones stemming from the land rather than those found in urban situations. Immediately following a very vigorous clean, the CO_2 content in ppm dropped to approximately half the previous reading. A very clear lesson from all this has now been learned; strict regular cleaning has now been instigated. This is now a clear lesson to all for any situations in which air quality monitors are fitted.

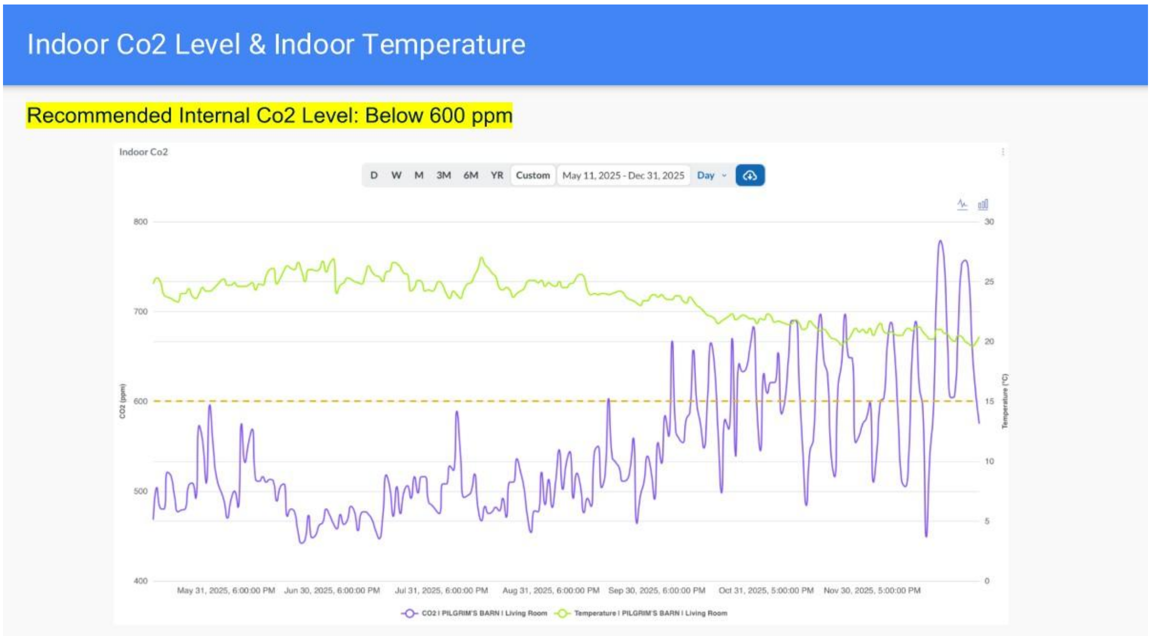

Figure 2. *Indoor Co2 Levels and indoor temperature over a period of Approx 6 months.*

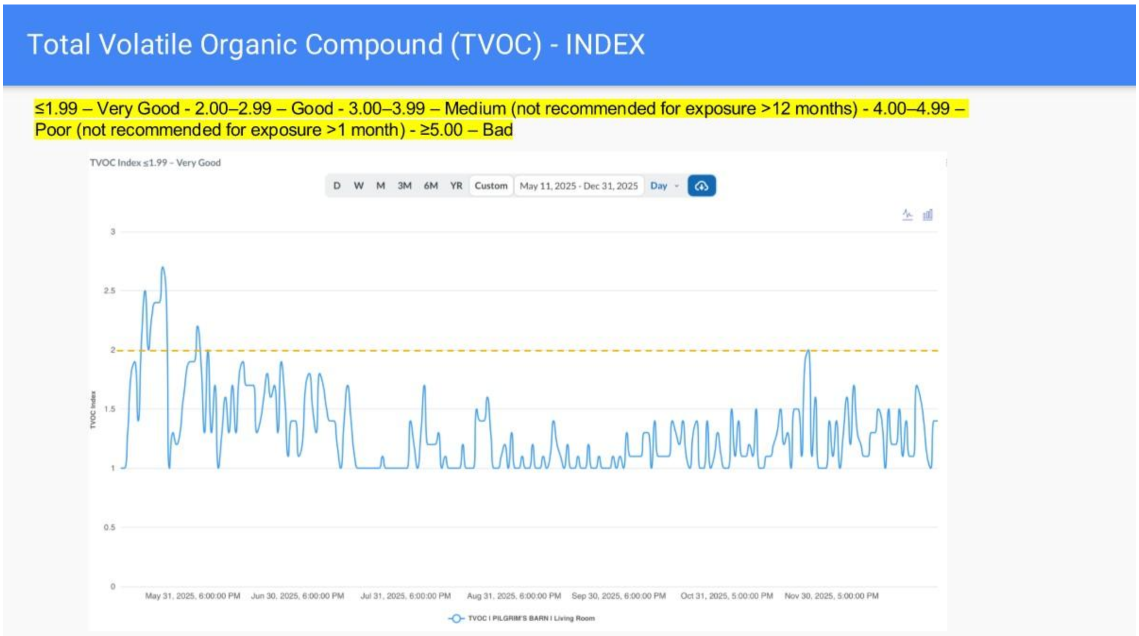

Figure 3. *Total Volatile Organic Compound's (TVOC's) for Pilgrim's Barn over a period of Approx. 6 months.*

8.Whole Life Cycle Carbon Assessment (WLCA)

A Whole Life Carbon Assessment (WLCA) [16] was undertaken for Pilgrims' Barn in accordance with the Royal Institution of Chartered Surveyors Whole Life Carbon Assessment for the Built Environment Global Standard (2nd Edition) [17], applying the life-cycle framework established by EN 15978, ISO 14040 & 14044 [18], [19], [20]. The purpose of the assessment was to quantify both embodied and operational greenhouse gas emissions associated with the adaptive reuse and long-term occupation of the building, and to evaluate performance against emerging UK net-zero carbon benchmarks [21].

The assessment was undertaken using recognised whole-life carbon modelling tools and industry datasets aligned with the methodology established within the RICS global standard, with the analysis undertaken by a practitioner experienced in lifecycle carbon assessment and the development of industry carbon assessment frameworks [17], [22].

The study assessed the principal life-cycle modules associated with the project, including upfront embodied carbon (A1–A5), use-stage embodied impacts including maintenance and replacement (B1–B5), operational energy and water use (B6–B7), and end-of-life impacts (C1–C4). Results were normalised by gross internal area and reported as $kgCO_2e/m^2$, enabling comparison with current industry benchmarks and notional residential baselines.

Pilgrims' Barn performs particularly strongly in relation to upfront embodied carbon. Excluding solar PV, the project records an A1–A5 impact of 367 $kgCO_2e/m^2$, equivalent to approximately 170 tonnes CO_2e. This places the scheme below the commonly referenced good-practice threshold of 400 $kgCO_2e/m^2$ for residential upfront embodied carbon identified by the Low Energy Transformation Initiative [23] and also below the pilot limit proposed by the UK Net Zero Carbon Buildings Standard [21] for new single-family housing. This is a significant result for a large rural dwelling, particularly one delivered through Class Q conversion, where structural adaptation, servicing upgrades and performance enhancement must all be carefully integrated with replacement structure, significant retention, reuse and repurposing of the pre-existing agricultural building.

Across the broader embodied life cycle, excluding operational energy, Pilgrims' Barn records a total embodied carbon impact of 508 $kgCO_2e/m^2$ for modules A1–A5, B1–B5 and C1–C4, equivalent to approximately 234 tonnes CO_2e. This also compares favourably with the 2030 Climate Challenge targets established by the Royal Institute of British Architects (RIBA) for domestic buildings [24]. The result reflects the carbon benefit of adaptive reuse, the retention of substantial existing building fabric, and the avoidance of the far greater material demand normally associated with demolition and new-build replacement. In carbon terms, the project demonstrates the value of upgrading & retention of an existing structure rather than defaulting to replacement construction.

The operational performance of Pilgrims' Barn is equally notable. The building achieves an exceptionally low regulated and unregulated operational Energy Use Intensity (EUI) of 17.5 $kWh/m^2/yr$, before accounting for on-site renewable generation. This figure is substantially lower than current UK housing norms and is also stronger than the energy demand thresholds typically associated with present and future net-zero residential benchmarks [20]. The result is enabled by the integrated design approach described elsewhere in this paper, including passive solar orientation, high thermal mass, deep insulation, airtightness, triple glazing, mechanical ventilation with heat recovery, and ultra-low-energy servicing systems.

When on-site solar PV generation is taken into account, the operational balance improves further, producing an effective net operational EUI of approximately –38.4 $kWh/m^2/yr$. This demonstrates that the building does not merely reduce energy demand; it can contribute renewable electricity beyond its own annual non-transport building demand under favourable conditions. The combination of large-scale roof-mounted PV and substantial battery storage is therefore central to Pilgrims' Barn's post-hydrocarbon performance model.

At whole-life level, the project records a total WLC outcome of 226 $kgCO_2e/m^2$ over a 60-year reference study period, equivalent to approximately 104 tonnes CO_2e, when electric vehicle use is excluded. When EV charging is included within the boundary, the total rises to 491 $kgCO_2e/m^2$, or approximately 226 tonnes CO_2e. This distinction is important because it shows that the building itself is highly efficient and low carbon while also being capable of supporting wider household electrification, including mobility. In this respect, Pilgrims' Barn should not be understood simply as a low-energy house but as a prototype for a wider electrified domestic lifestyle.

A particularly important finding emerges when the lifecycle modelling is extended beyond the conventional 60-year study period. While most lifecycle carbon assessments adopt a conventional 60-year reference study period, buildings of robust construction and adaptable layout can realistically remain in use for significantly longer. For this reason, an extended lifespan scenario was also modelled for Pilgrims' Barn. Because the project combines modest embodied impacts with very low operational demand and substantial on-site renewable generation, the whole-life carbon balance continues to improve over time. Modelled over a 300-year design life, Pilgrims' Barn records an overall whole-life carbon result of –60 $kgCO_2e/m^2$, equivalent to approximately –27 tonnes CO_2e. On this basis, the project can reasonably be described as whole-life carbon negative over its extended design life. This is a rare and important outcome, particularly in the context of UK housing, where operational gains are often offset by high embodied carbon associated with new construction.

The significance of this result is twofold. First, it demonstrates that Class Q adaptive reuse can outperform not only typical existing rural buildings but also many contemporary new-build dwellings when assessed on a whole-life basis. Second, it reinforces the proposition that long-life, fabric-led, energy-autonomous retrofit can form part of a credible pathway toward a post-hydrocarbon built environment. In this case, carbon performance is not the product of a single technology or isolated specification choice; it arises from the careful integration of building form, passive design, retained structure, low-energy services, renewable generation and long-term durability.

Pilgrims' Barn therefore provides evidence that rural retrofit and conversion projects can make a meaningful contribution to climate mitigation when assessed rigorously through WLCA. Rather than treating adaptive reuse as a compromise against new-build standards, this project suggests it can be a route to superior whole-life carbon performance, while also delivering resilience, healthy indoor environments, water autonomy, biodiversity value and low running costs. In that respect, the WLCA does not merely validate the project technically; it substantiates the wider argument of this paper that post-hydrocarbon living is already achievable through intelligent, nature-aligned design.

9.Evaluation

9.1 Whole-life carbon (RICS / EN 15978, benchmarks, lifespan modelling)

The whole-life carbon assessment demonstrates that Pilgrims' Barn achieves exceptionally low lifecycle emissions compared with contemporary residential benchmarks. The project records an upfront embodied carbon value of approximately 367 $kgCO_2e/m^2$ (A1–A5), which sits below commonly referenced good-practice thresholds for residential construction [20], [21], [22]. Over a 60-year reference study period the building records a total whole-life carbon impact of 226 $kgCO_2e/m^2$, reflecting the combined effects of modest embodied carbon, extremely low operational energy demand, and substantial on-site renewable generation.

When lifecycle modelling is extended beyond the conventional reference study period, the cumulative carbon balance continues to improve. Under a 300-year design life scenario, the building becomes net negative in whole-life carbon terms. This result demonstrates the importance of considering building longevity alongside operational efficiency when evaluating the carbon performance of the built environment.

9.2 Operational EUI and Renewable Contribution

The energy performance of Pilgrims is remarkable, but these results come from the essential combination of:

- Adequate solar generation with battery storage
- Ultra-low-energy services, systems and very low heating requirements

With the anticipated coming of more electric cars, it will be increasingly necessary to emulate the Pilgrims' Barn model, whereby not one but two, fully electric cars are kept fully charged at their home base. Adequate Solar Generation becomes even more important to be planned from the outset, at the Master-Planning (including orientation) and throughout the design stages.

Looking ahead, large developments will need ultimately to be connected to the grid, but seldom if ever, reliant upon it. For such projects, it will be necessary to consider creating Community Energy Microgrids. In these, all homes will require sufficient energy creation on their roofs and domestic storage for normal use. However, the domestic batteries, instead of being connected direct to the grid (as is the current system), each house will be connected through its own batteries to a large battery, or battery bank. This battery bank will then provide both balancing power, when necessary to all the houses on the site. It will also be connected direct to the grid, via a Smart, AI computer-driven system; this will incorporate all this with energy trading with the grid 24/7. This will obtain a substantial additional income as well, for the management company running the energy system on the overall development site as well as greatly reducing the energy cost to all home-owners. The author is endeavouring to incorporate such a system on several of the larger development projects, which he is currently taking forward; he has discussed this with the Department of Energy Security and Net Zero; who have welcomed this work as being essential policy to consider, for a more sustainable future and an exemplar example of thinking global and acting local.

9.3 Capital Cost Parity with Conventional Housing

The total cost of the construction cost, together with all services was at the rate of £1,825 per sq metre on the internal footprint. Several architects have asked that for a house of this quality they have expected it to be between £2,500 and £3,000 per sq metre. The cost does not include the large Wildlife Pond and Swimming area, as stated above, the pond is not needed for SuDS purposes, as, after filling the Rainwater Harvesting tank, the Swales and Reedbed Pond are adequate. A leading, national architect reckoned that a small group of conventional (non-eco) dwelling would have cost £2,000 per square metre and that a Passive House would have cost at least £2,200 metre, but such would still not have the performance of Pilgrims' Barn, neither its very long lifecycle.

9.4 The Potential to Upscale Pilgrims' Barn

Pilgrims' Barn has now been inspected and analysed by a very large number of commercial as well as Council Planners from all across the County of Suffolk and many others from further afield. Many visiting architects and engineers have been hugely impressed by what they have seen, including the analysis of costs and performance; a number of them are keen to take forward projects based upon the Pilgrims/Hockerton format. One of the critical issues, is the Fully Integrated Water System, in section 6. It has been heartening to have had many Council Planners and others, following a verbal presentation, to come outside to see how it works and truly integrates on the ground. Many have come up to the author to tell him that what has been designed specifically for Pilgrims, could well be upscaled to cater for a large development site and achieve all the same benefits. Energy provision and storage for a large site has been set out in 9.2 above; it is essentially a huge upscale of the Pilgrims situation.

10.Summary and Conclusion

This paper demonstrates the potential of rural Class Q conversions, as well as new-build homes to deliver negative energy costs, proven health benefits, remarkable whole-life carbon (WLCA) performance aligned with net-zero trajectories. By showing outcomes with robust WLCA data, it demonstrates adaptive retrofit as a viable and replicable pathway for a post-hydrocarbon, built environment.

This paper proves that to achieve such performance in all respects, it is necessary to follow all the principles as set out. An example is in the comprehensive energy management of the whole property; it is essential not only to have adequate generation and storage, but also ultra-low energy demanding services, not normally found in houses. Pilgrims' Barn also, reveals that a complete building format, which in terms of just heat, does most of the work with little additional heating requirement, even in a large building. Also of note is the successful fully integrated water system which should be a property of all building in a water deprived future.

The Vales research was specifically on how best to build and service normal-sized homes at scale and built at no greater cost per square metre than standard, non-eco homes. The Hockerton Housing Project and now Pilgrims' Barn further proves that their research was incredibly well-founded; importantly, it is sufficiently flexible to be applied to any form or size of building, at any scale of development.

What is revealed here is a fascinating interconnection with all aspects of the natural world. Pilgrims' Barn is not just a home; it is a revelation of living with and through nature. Living here is a special experience. All dwellings should follow this example.

Data availability statement

The datasets supporting the findings of this study, including life cycle assessment modelling data and supporting methodological information, are available in the Zenodo repository at https://doi.org/10.5281/zenodo.18930496

Underlying and related material

No additional supplementary material or external repository datasets are associated with this article.

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Competing interests

The authors declare that they have no competing interests.

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