NDM HEATH LTD
Sustainable Energy Services

# REPORT

## Cheynes Farm, Cottered – Retrofit Assessment

Report prepared for [redacted]

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| Author: | Nicholas Heath, Director |

NDM Heath Ltd. Registered office: 21 Kirkgate, Knaresborough, North Yorkshire HG5 8AD
T: 07763 110264 | E: enquiries@ndmheath.co.uk | W: www.ndmheath.co.uk
Registered Company Number: 8587277

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## 1.0 INTRODUCTION

This proposal relates to the proposed retrofit of Cheynes Farm, Warren Lane, Cottered, Hertfordshire. The property comprises a main timber-framed house with adjoining kitchen extension and converted barn, together with a self-contained cottage and a number of outbuildings sitting in grounds of c.5.5 acres. The earliest parts of the main house date from the 16th century, while the conversion of the kitchen and barn buildings is thought to date from the early 20th century. The property is Grade II listed and is situated just outside the boundary of the Cottered Conservation Area[1].

The property has been recently purchased by the clients, and a full retrofit of the main house, kitchen and barn is planned, with a view to further renovation/extension work on other buildings in future. The clients are keen to improve the comfort levels, running costs, environmental impact and long-term sustainability of the buildings, but in a sensitive and appropriate manner that looks after the building fabric and futureproofs the buildings for low-carbon heating technologies.

Significant improvements are possible in buildings such as those at Cheynes Farm, but this requires a carefully considered approach based on a sound understanding of the principles and details of upgrading traditional and historic buildings.

This report sets out the main options available to maximise the efficiency, running costs and sustainability of the main house, kitchen and barn. The main focus of the report is on the building fabric, as the client has a detailed understanding of services requirements and a clear view on their preferences. Options are considered within the context of discussions held before and during the site visit to determine client aspirations and likely levels of intervention.

## 1.1 Caveats & Disclaimer

Building observations are based on a non-invasive site visit and remote assessment including photographs, drawings, sales particulars, online review and architect discussions. No previous energy modelling, airtightness testing or moisture assessment have been carried out, although a detailed third-party heritage assessment was recently undertaken (not available at the time of writing this report). Any figures and/or brand names used in this report are indicative / examples only.

This report is advisory and does not act as a specification. As such, it should not be relied upon exclusively by the client for decision-making purposes, and should be read in conjunction with good-practice retrofit guidance for traditional and historic buildings. Any relevant findings from future investigations (e.g. surveys, energy modelling, airtightness testing, hygrothermal moisture risk analysis etc.) should be taken into consideration alongside this report.

While we have undertaken our assessment and prepared this report to the best of our ability and following relevant technical guidance, this does not guarantee the performance of any measure taken forward and NDM Heath Ltd. cannot accept any responsibility for any issues that may arise as a result of any works carried out.

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[1] Cottered Conservation Area appraisal & management plan (East Herts Council, 2018)

## 2.0 SITE REVIEW & CONTEXT

### 2.1 Location & setting

Cheynes Farm is situated in the small village of Cottered in East Hertfordshire, in largely rural countryside. It comprises a number of buildings including the original house, a later single-storey extension, a converted barn, a cottage and other outbuildings, all of which sit in mostly green grounds of c.5.5. acres. There is little shelter from the prevailing weather, although the site is not in a high exposure zone (see Section 2.3).

### 2.2 Conservation & planning

The main farmhouse dates from the 16th century; the converted barn dates from the 17th century and the single-storey kitchen extension is believed to have been converted around 1900; the age of the other buildings is not known. The buildings in question are Grade II listed; the listings for these buildings provide a summary of noteworthy details and highlight the prominence of the barn in views from the churchyard[2].

The village of Cottered is also designated as a Conservation Area. The Cottered Conservation Area Appraisal & Management Plan (East Herts Council, 2018) notes that Cottered is 'of considerable historic and visual importance', citing the many listed buildings 'of the highest quality' as well as the relationship between buildings and green spaces. Cheynes Farm is not specifically mentioned, but the unconverted 18th-19th-century timber outbuildings are noted as 'important buildings within the curtilage of listed buildings'; these outbuildings are also highlighted as being on the Council's Heritage At Risk Register[3]. (N.B. The Conservation Area Appraisal also notes that grant assistance may be available for the repair of these buildings).

East Herts Council has a range of broader planning policy and guidance documents, but the main focus is on new development and there is very little focus on energy performance or sustainability in existing buildings. Nonetheless, there is some useful guidance on sustainable buildings and wider environmental issues, and support for efficient, sustainable buildings is apparent. The following extracts provide an overview of the various policy documents, and may be cited in any formal applications to support proposed works.

The East Herts District Plan (2018) contains relatively little content in relation to existing buildings, although there are some useful broader references:

- 'The Council will expect all proposals for extensions and alterations to dwellings and residential outbuildings to be of a high standard of design that is appropriate to the character and appearance of the dwelling and the surrounding area'

- Policy HA1 Designated Heritage Assets
  'Development proposals should preserve and where appropriate enhance the historic environment of East Herts ... Where there is evidence of neglect of, or damage to, a heritage

[2] See https://historicengland.org.uk/listing/the-list/list-entry/1295347 & https://historicengland.org.uk/listing/the-list/list-entry/1348020
[3] East Herts Council Heritage At Risk Register (July 2021)

asset, the deteriorated state of the heritage asset will not be taken into account in any decision'

- Policy HA4 Conservation Areas
  'New development, extensions and alterations to existing buildings in Conservation Areas will be permitted provided that they preserve or enhance the special interest, character and appearance of the area'

- 'Listed buildings of special architectural or historic interest must be sensitively repaired and improved, using traditional materials and techniques. Appropriate and sustainable new uses should be found for them in order to secure their future survival'

- Policy HA7 Listed Buildings
  'The Council will actively seek opportunities to sustain and enhance the significance of Listed Buildings and ensure that they are in viable uses consistent with their conservation'

The District Plan section on climate change in particular is short and lacks detail, and there is no reference to existing buildings. It does however cite a Hertfordshire-wide sustainable development guide, Building Futures, which includes a Sustainable Design Toolkit to support planning applications. This toolkit has some useful content on areas including energy and climate change, materials and climate change adaptation, although much of the current content again focuses on new development sections on design and retrofit sections are not yet available.

The Sustainability SPD (2021) focuses on new development, but also contains references to existing and in particular historic buildings.

- 'Climate change is a key challenge facing society and the Council is committed to tackling its causes and impacts. In July 2019 the Council declared a climate change motion, with the goal that both the Council and East Herts as a district will be carbon neutral by 2030'

- 'It is…recommended that this guidance is referred to from the very start of the design process, including in early discussions with the client. Early and meaningful collaboration of sustainable design specialists in the design team… is also strongly encouraged'

- 'Climate Change can have a range of direct impacts on the historic environment, for example, accelerated weathering to building fabric, erosion of archaeological sites through severe weather and flooding, and harm to historic landscapes or changes in vegetation patterns. Equally, climate change mitigation and adaptation responses can also have unwelcome impacts on the historic environment, such as damage to historic fabric through poorly designed energy-saving measures, or erosion of historic character through inappropriately located micro-generation equipment … Actions required to limit further damaging emissions and adapt to a changing climate are vital and can be successfully achieved, but need to be balanced with measures to protect the historic environment'

- ‘It is recommended that buildings should achieve the highest possible standards of thermal insulation, air tightness and energy efficient lighting. The Council recommends the use of good practice standards in residential…development’

- ‘The Government intend to exclude gas boilers from new homes by 2025. Alternative heating systems are therefore encouraged, which could include (but are not limited to) electric boilers, solar thermal panels, heat pumps or other energy efficient systems’

- ‘The use of onsite renewable technologies is strongly encouraged to decrease CO2 emissions’

- ‘Retrofitting is important to ensuring all buildings contribute to carbon neutrality. Submitting evidence of carbon reduction in household applications, to improve the sustainability of existing buildings/ extensions is encouraged’

- ‘When applicants address the guidance in…this SPD to maximise solar gain and improve the fabric performance of buildings, it is essential this is considered alongside measures to reduce overheating’

- ‘It is important that good design principles are incorporated from the outset in order to avoid costly and problematic alterations further down the line’

- ‘Building design should prioritise energy efficiency in order to reduce the need and size of heating plants’

The Council’s 2019 Declaration on climate change notes that ‘East Herts District Council has a pivotal role to play in tackling climate change and enabling sustainable living. We recognise the importance of tackling climate change both in the terms of reducing greenhouse gas emissions to minimise future global climate change and planning for the unavoidable local impacts of climate change.’ The Council also commits to ‘do everything we can in supporting the whole of East Herts District to become carbon neutral by 2030; … ensure that where at all possible we support climate friendly planning and building control regulations … [and] take account of climate impacts within existing decision-making processes’.

East Herts climate change strategy 2022-2026 (2022) is primarily a route map for the Council to achieve carbon neutrality by 2030, but it also includes (mostly aspirational) narrative on supporting district-wide achievement of this target. Domestic $CO_2$ emissions are confirmed as accounting for a third of the district’s total emissions, and the most important cited issues for residents include domestic energy efficiency and using planning policies to tackle climate change. Other extracts of relevance include the following:

- ‘The council must support everyone living in, working in or visiting East Herts to play their role in the collective effort to achieve carbon neutrality across the whole. We will use our regulatory powers to promote action by others. This includes our planning powers and duties regarding the development of new homes and commercial buildings as well as conversion or extension of existing buildings’

- 'We aim to make a real difference by…using our regulatory powers to promote action by others [and] influencing and encouraging others to do things'

- 'A key strand of our efforts to reduce carbon emissions across East Herts is based on influencing, encouraging and making it as easy as possible for our residents…to take action that will enhance sustainability'

The Council's Environmental sustainability action plan (2022) contains little of relevance to this project, but it does note the Council's close working relationship with the Hertfordshire climate change & sustainability partnership to deliver action on climate change across Hertfordshire. Their Sustainability action plan for carbon reduction (2022) contains a number of as-yet-uncompleted actions which would boost policy support for efficient buildings, and notes the following general points: 'As of 2018, annual emissions across Hertfordshire were estimated to be 5.61 MtCO2e … This level of energy consumption is primarily focused in three key sectors: business and industry usage, residential energy usage and transportation emissions. This indicates the extent at which carbon-based energy consumption is embedded within Hertfordshire society, with essential needs such a heating and transportation powered by unstainable means of energy production … Local authorities have powers or influence over roughly a third of emissions in their local areas. More than half the emission cuts needed rely on people and businesses taking up low carbon solutions'

The only Council-published document to contain any focus on retrofit is the Home insulation guide: Green our Herts. Unfortunately this is a relatively basic guide with little specialist guidance on older buildings, and some of the content around measures such as solid wall insulation demonstrates a limited understanding of the technical complexities of these measures.

It is clear that retrofitting the buildings at Cheynes Farm requires a sensitive approach. However, the extent of the current renovation plans, the likely budget and the client's technical knowledge and desire to treat the buildings both thoroughly and appropriately all present a considerable opportunity to maximise their efficiency and environmental impact and contribute to local, regional and national targets. This objective is backed up by the wealth of national guidance and case studies for traditional & historic buildings which demonstrate that, with due care and attention, nearly all such buildings can be made considerably more sustainable.

### 2.3 Climate & exposure

Historic weather data shows that the local area (and Eastern England in general) has higher-than-average temperatures compared with England as a whole[4], with summer temperatures being comparable with the London area which tends to be the warmest part of the UK. Indeed, 'a noteworthy feature [of the area] is that many of the UK maximum temperature records are held by stations in Eastern England'[5]. While low winter temperatures present obvious comfort issues, high summer temperatures can also cause considerable discomfort and potential health issues during extremely hot weather periods (particularly at night in buildings where it is hard to purge the hot air), and this is likely to become more of an issue as the global climate changes. Recent predictions suggest

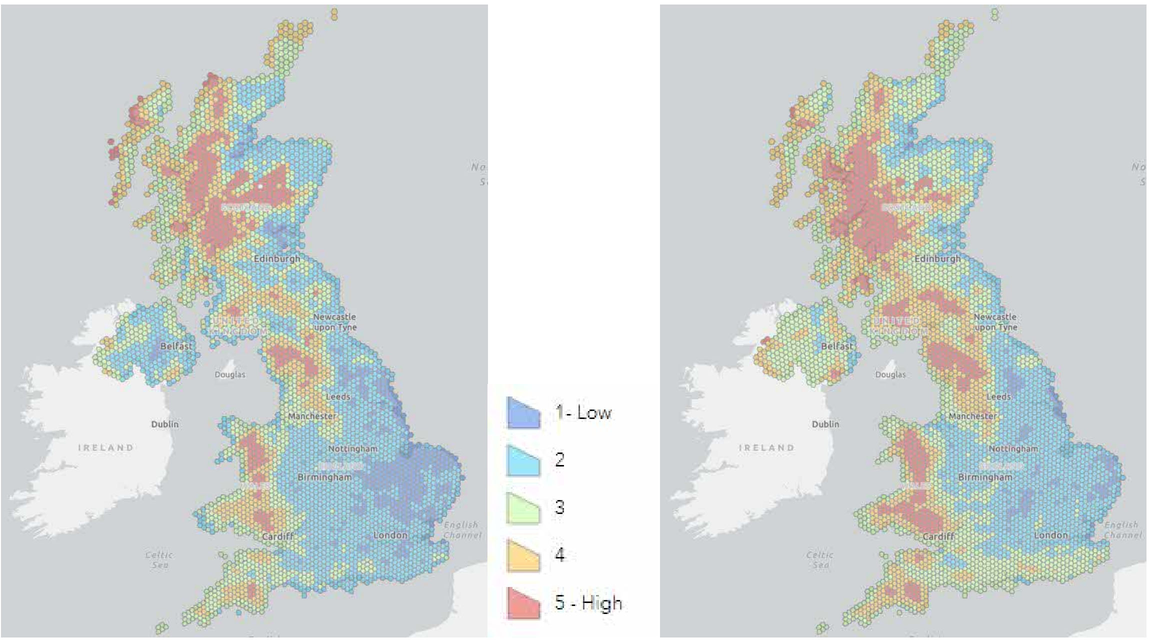
[4] Met Office data for the closest climate station at Rothamsted.
[5] Met Office.

a 50% likelihood of UK summers like that of 2018 by 2050[6], and the recent (July 2022) heatwave saw temperatures in S-E England exceed 100ºF (37.8ºC) for only the second time since records began; nearby Cambridge recorded the highest-ever UK temperature by some margin, followed by further record temperatures of over 40ºC being recorded across multiple weather stations in England, *'far outside the range of summer temperatures normally observed'*[7]. While these figures relate to daytime peaks, it is also noteworthy that highest minimum temperature records were also broken, with some areas not dropping below 26.8 ºC over a 24-hour period – the threshold for domestic overheating is commonly set at 25 ºC). As such, consideration of overheating is a fundamental part of any retrofit project. For Cheynes Farm, the main farmhouse and kitchen extension have long façades facing East and West but windows are not unduly large, and the surrounding greenery may help mitigate overheating risk to a degree; the converted barn includes a large area of South-facing glazing which would be likely to contribute to significant solar gain, although this space is not a core part of the daily living space which will limit comfort impacts. Summer comfort is not currently noted as being an issue in the property, but following retrofit the buildings are likely to be considerably better insulated and more airtight, while ventilation is likely to be managed by a combination of intermittent extract fans and manual control via windows.

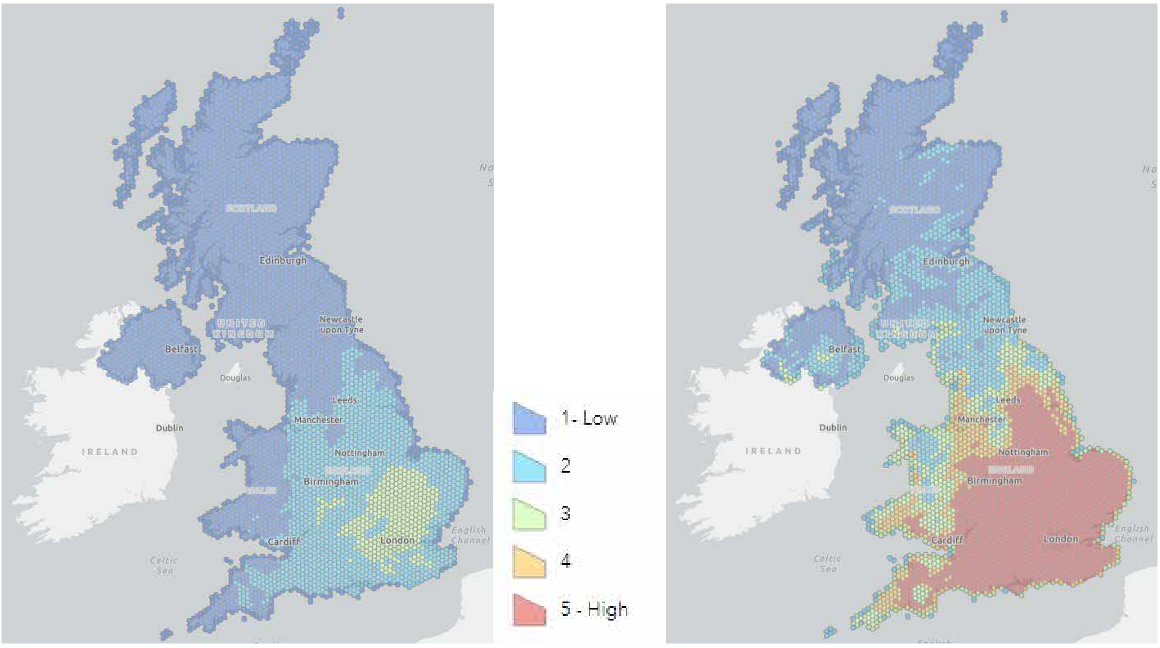
While the local area has slightly higher average rainfall than East Anglia in general, the region is one of the driest parts of the country with average rainfall levels nearly half of the UK average[8]., although there appears to be more summer rainfall than average. The general area is relatively sheltered and is designated as Zone 1 ('Sheltered') on the map of UK zones for exposure to driving rain[9] (see Fig. 5). However, such broad outlines are inevitably somewhat generalised and cannot account for local topography, and microclimates can vary considerably even between adjacent sites. Cottered is on relatively high ground (Cheynes Farm sits at c.140m above sea level), and the higher ground of the Chilterns to the South-West is unlikely to provide significant sheltering from the prevailing weather. There are few buildings to the South or West of Cheynes Farm, and relatively little tree cover (see Figs. 6-9). The buildings will therefore be subject to periodic bad weather and experience suggests that, for retrofit purposes, it would be prudent to assume reasonable levels of exposure to driving rain, as well as wind and solar irradiation, all of which place stresses on building fabric and internal conditions.

Regional and micro-climates are an important consideration when designing a low-energy building and particularly an existing building retrofit. Building integrity and occupant wellbeing can both be affected by external and internal conditions, exposure to sun and rain, temperature levels and so on, and design details have to respond to these local contexts accordingly. Any robust retrofit strategy must be mindful not only of insulation but also overheating, indoor air quality and building fabric, all of which will be affected by future climate trends. Most evidence suggests that, in the long term, the UK is likely to be subject to increasing average temperatures (see Section 4.9) but also to more erratic and extreme weather incidents (e.g. heavy, driving rainfall) all of which will place more stress on the built environment (see Figs. 1-4). A good retrofit must therefore be built for both current and future conditions.

[6] UKCP18 Science Overview Report (Met Office, March 2019)
[7] Met Office review of summer 2022.
[8] Met Office data for the closest climate station at Rothamsted.
[9] Building Regulations 2010: Approved Document C (HM Government, 2013)



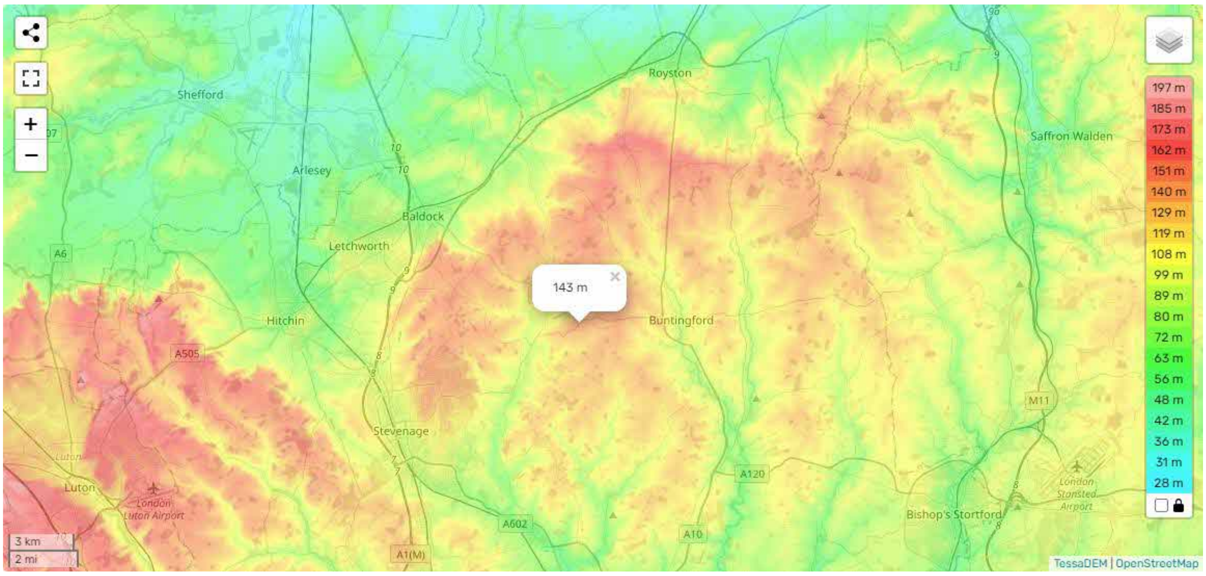

Figs. 1-2    Storm damage exposure, current (left) & future (2060, right) (© [National Trust Climate Hazards])

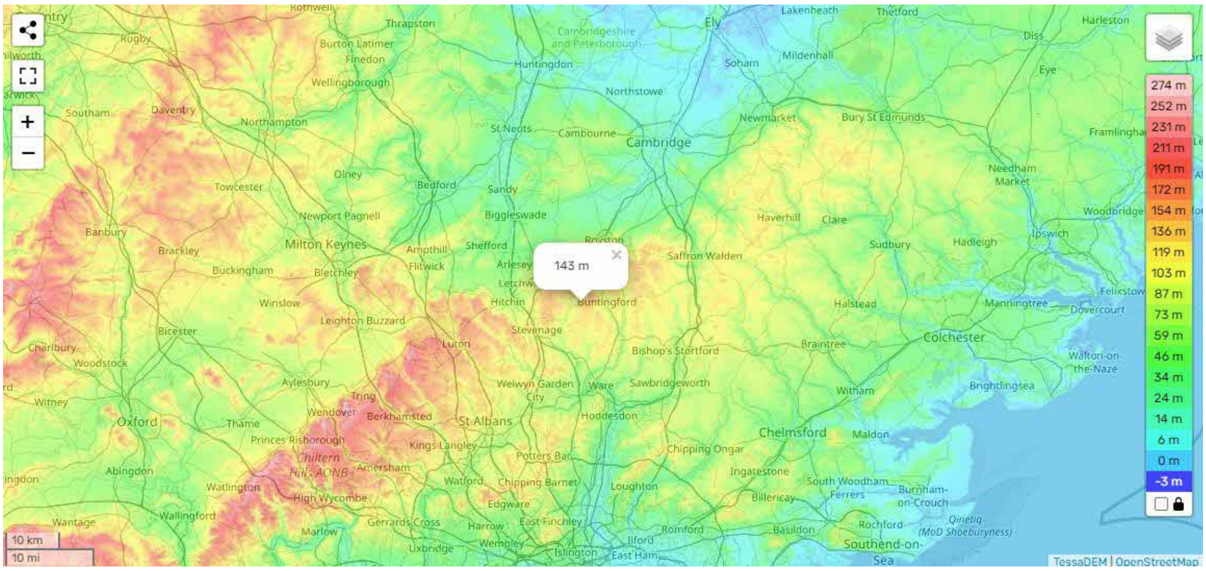



Figs. 3-4    Overheating & humidity exposure, current (left) & future (2060, right) (© [National Trust Climate Hazards])


Fig. 5 UK zones for exposure to driving rain (Source: Building Regulations Approved Document C)

Figs. 6-7    Location & context (© Google Maps)



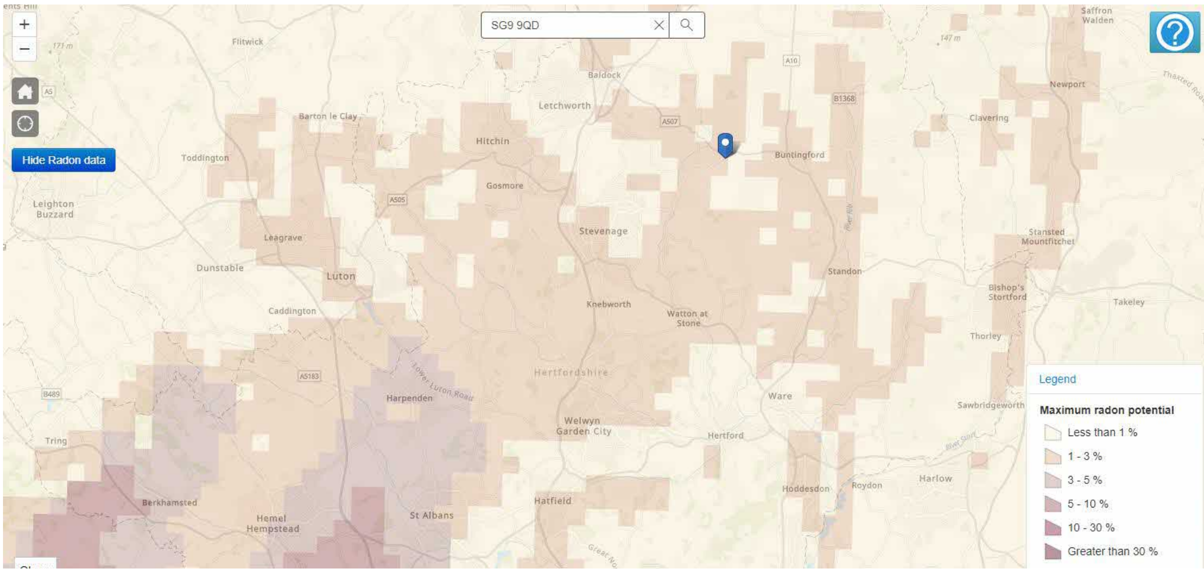



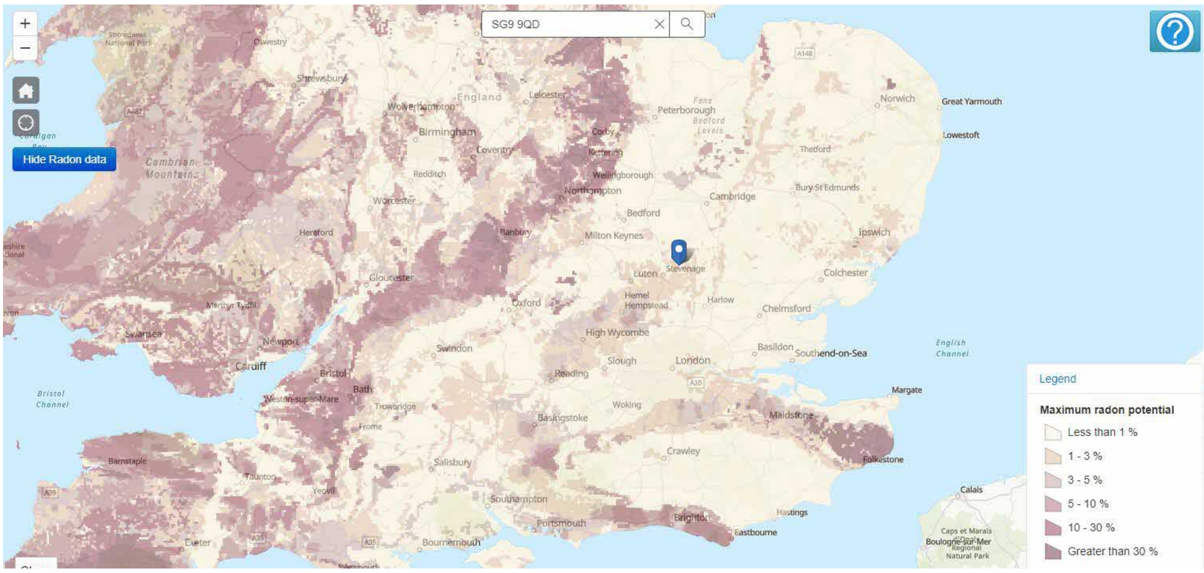

Figs. 8-9    Topographic context (© topographic-map.com)

## 2.4 Radon

While regional maps do not give conclusive evidence on a site's exposure to radon, Cheynes Farm appears to have a relatively low risk of significant radon potential (see Figs. 10-12). However, given the fact it is not a zero-risk area and significant improvements in insulation and airtightness are planned, it may be beneficial to confirm site-specific radon levels via site testing (a straightforward and inexpensive process[10] which provides an exact measurement of radon levels in a given property). Where levels are high enough to warrant action, it is essential that this is adequately considered to maintain a healthy indoor environment; UK Radon can provide advice on mitigation measures – e.g. radon membranes, ventilation provision etc. – which may be built into the specification of works.

[10] UK Radon can provide two monitors, which are left in situ for 3 months before being sent back for analysis and results. The cost is just over £50. Further details are available at UK Radon.




Figs. 10-11 Maximum radon potential for the area (© UK Radon)

## 3.0 BUILDING REVIEW

A non-invasive site visit was carried out in December 2022. The following summary observations are based on this visit and remote assessment including drawings, photographs, dialogue with the architect and online review.

### 3.1 Building overview

The main farmhouse dates from the 16$^{th}$ century, possibly with earlier elements in some areas. The barn originally dates from the 17$^{th}$ century; both it and the single-storey kitchen extension are thought to have been converted in the early 20$^{th}$ century, but more recent works have also been carried out on the barn.

The farmhouse and barn are timber-framed buildings, while the single-storey kitchen extension is of solid brick construction. Walls are finished eternally in a range of materials including painted render (likely to be a mix of lime- and cement-based materials) which covers the timber-frame elements, timber weatherboarding and exposed timber frame with brick infill (incorporating apparently cement-based mortar). The client reports that the rendered walls were first rendered at least 200 years ago. Roofs are timber with tiles. Floors in the main house and kitchen extension are thought to be concrete throughout with either carpet or tile finishes, and there are some level changes across the ground floor; the floor of the barn is suspended timber. Windows are relatively modern and mostly have timber frames and single glazing, with diamond-pattern leadwork.

Internally, walls are finished in a combination of painted brick, exposed timber frame with plaster infill (type unknown, but not original), simple timber wainscoting (in the barn) and either plasterboard or lath & plaster. Ceilings in the main house are flat, while those in the kitchen extension and barn follow the roofline. The barn is largely open plan, with small storage & W/C rooms to one end and a partial mezzanine level.

The client has confirmed that there is apparently nothing of historic significance in the kitchen extension or barn.

Rainwater goods are inadequate and appear to be undersized. Drainage provision is unknown, but is thought to be inadequate. External ground levels appear to be raised in some areas, but it is not clear whether these breach the masonry wall bases. The land around the buildings is largely flat, comprising a mixture of gravel, hardstanding, paving slabs and grass.

As is common in properties of this age, it is clear that the buildings have evolved over time to suit differing occupant needs, over several hundred years in some areas.

### 3.2 Building condition

The buildings in question appear to be in generally good condition, although as expected in properties of this age there are some maintenance issues requiring attention either before or during the retrofit works.

Issues observed during the site visit and/or reported by the client and architect include the following:

- Moisture problems & associated fabric damage around some wall bases to the SW corner of the main house; some staining also observed at low level to West elevation of main house
- Moisture problems & associated fabric damage to the East elevation of the end room at high level around the bay window, likely to be due to a combination of roof detailing, inadequate rainwater goods and cracked render
- Insect infestation to the timbers of the end room in the main house
- Possible raised external ground levels to part of the West elevation of the main house
- A historic roof leak above the North-facing window of the converted barn
- Inadequate, undersized rainwater goods
- Likely inadequate drainage
- Cracks in render
- Slipped / damaged roof tiles
- Apparently impermeable roof membrane, with poorly-sealed duct openings in places

As noted above, it is essential that these and any other defects are addressed as part of the planned retrofit works, to ensure the building fabric is sound, dry and able to manage rainwater and internal moisture loads away from the property. Getting a building 'retrofit ready' is a key first step in any robust retrofit project (this is covered in more detail in Section 4.1); and can also present opportunities to open up currently uninspected areas and check for other issues.

### 3.3 Fabric & services efficiency

All buildings were constructed and/or converted well before any thermal efficiency targets, and the layout of the farmhouse, kitchen extension and barn present very large external envelope areas with high associated heat loss.

The roof in the main house is insulated at ceiling level with mineral wool quilt, although the depth and coverage is ad-hoc and variable, with some areas having little or no insulation (likely to have been pulled away to access cables, spotlights or other services) and the loft hatch being uninsulated. It is unclear whether there is any insulation in the roof of the kitchen extension as it is not accessible without opening up works, but if it has not been altered since its conversion it is unlikely to be insulated. It is understood that the barn was re-roofed relatively recently and there may therefore be some insulation present, but the type, depth and coverage are unknown.

Ground floors in the main house and kitchen are understood to be solid concrete and are almost certainly uninsulated. The ground floor of the barn is suspended timber, also uninsulated. Uninsulated suspended timber and concrete floors create discomfort, and both types have a poor thermal performance (sometimes significantly worse than assumed by most energy modelling tools[11]). Uninsulated concrete floors can also potentially exacerbate any moisture issues around perimeter wall bases, while suspended timber floors can contribute to poor airtightness.

Walls are a combination of timber frame and solid brick. While the client reports a nominal amount of mineral wool or similar insulation behind the plaster in the end room, this has been removed and it is

[11] Small-scale testing in various locations has identified significantly worse U-values for both suspended timber and sold concrete floors than those calculated by approved software. Examples include Suspended timber ground floors: measured heat loss compared with models (Sofie Pelsmakers, 2017), Energy Heritage: A guide to improving energy efficiency in traditional and historic homes (Changeworks, 2008) and in-situ testing carried out by Historic Environment Scotland.

assumed that the timber-framed walls are entirely uninsulated. Timber-frame construction often results in very thin walls, as at Cheynes Farm, with effectively hollow cavities between the timbers offering little insulation value; depending on their condition they can also contribute to poor airtightness, although the render finish will benefit both airtightness and thermal performance. The solid brick walls are also very thin (c.100mm masonry, with only a paint finish internally and either nothing or ventilated rainscreen cladding externally). When in good condition, solid masonry walls can often perform better than assumed by energy models and/or U-value calculations[12], but they still lose far more heat than modern constructions[13] and the thin construction of the brick walls at Cheynes Farm will further affect their thermal performance.

Windows appear to be in reasonable condition but are entirely (or almost entirely) single glazed. Windows are often the weakest fabric element of a building in terms of thermal performance (even after retrofit): single glazing, for example, has an extremely poor centre-of-pane U-value of c.5.5 $W/m^2K$, and contributes not only to heat loss but also to uncomfortably cold areas around the windows themselves where temperature differentials create convection currents. These issues are exacerbated where draught proofing is absent, and the leadwork is also likely to increase heat loss. While it does not affect thermal performance, the windows are mostly relatively small and many include a large proportion of frame, significantly reducing daylighting potential and increasing reliance on artificial lighting.

Airtightness levels cannot be confirmed without testing, but the range of construction types, services penetrations and unknown draughtproofing provision mean that the buildings are unlikely to be particularly airtight. Poor airtightness can lose significant amounts of heat, undermining even good fabric U-values.

Table 1 provides an estimate of the main building components' likely thermal performance in their current state. Note that this is approximate only and is based on a combination of informal U-value[14] calculations, energy modelling experience and monitored performance data. Note also that U-values only provide one metric for thermal performance (i.e. heat transfer through a particular element) – heat loss from the building as a whole as a result of thermal bridging and infiltration can considerably undermine even good U-values.

[12] As demonstrated at length by widespread monitoring of stone, brick and other traditional wall build-ups by numerous organisations including SPAB, Historic England, Historic Environment Scotland and the BRE.

[13] By way of comparison, a typical solid brick wall may have a U-value of c.1.5 $W/m^2K$, while a new-build wall built to current Building Regulations will have a U-value of c.0.18 $W/m^2K$ or better.

[14] A U-value is a measurement of the rate of heat transfer across a material. The higher the number, the worse the thermal performance. For context, in a newly-built house typical U-values might be as follows: walls 0.18 $W/m^2K$, roof 0.11 $W/m^2K$, floor 0.13 $W/m^2K$ and windows 1.2 $W/m^2K$ – with an air permeability of c.5 $m^3/hr/m^2$ @ 50 Pa.

| Element | Indicative U-value (W/m²K) | Notes |
|---|---|---|
| Walls | | |
| Solid brick, c.100mm | 2.5-3.35 | ▪ Assumed based on in-situ monitoring elsewhere[15] & informal calculations<br>▪ Poorer where wet |
| Timber frame | 1.3-2.5 | ▪ Assumed based on in-situ monitoring elsewhere[16], informal calculations & default performance assumptions[17] |
| Roofs | | |
| Insulated/uninsulated | 0.18-2.3 | ▪ Default performance value range[18] |
| Windows & doors | | |
| Single glazing | 5.5 | ▪ Assumed based on in-situ monitoring elsewhere[19] |
| Doors | 3.0 | ▪ Default performance value[20] |
| Floors | | |
| Solid | 3.6 | ▪ Assumed, based on in-situ monitoring elsewhere[21] |
| Suspended timber | 0.54-2.04 | ▪ Assumed, based on in-situ monitoring elsewhere[22] |
| Air permeability | | |
| | c.7-12 $m^3/hr/m^2$ @ 50 Pa | ▪ Assumed; high uncertainty |

Table 1  Indicative assumed thermal performance

Space and water heating are provided by a combination of oil-fired central heating with radiator distribution and electric underfloor heating (UFH), supplemented by an open fireplace and closed stove. Hot water comes from the main heating system, with two insulated HWCs. Radiators are old and/or undersized in some rooms, although the client states that the buildings can be heated to a comfortable temperature. Controls are unknown but are assumed to include programmers, room thermostats and at least some TRVs. While the boiler is relatively new and therefore likely to be reasonably efficient, the client reports that the overall heating configuration and pipe runs are currently very inefficient. Electric UFH is not generally regarded as being cost-effective where it forms a significant part of the space heating system. Open fires are notoriously inefficient, with up to c.85% of heat being lost up the chimney; stoves are more efficient than open fires, but older models perform significantly less well than new high-efficiency models.

In terms of financial and environmental costs, oil is an expensive and carbon-intensive fossil fuel, as is the electricity used for the UFH and power requirements[23]. Electricity prices in particular have increased dramatically in the past 12 months (see Fig. 12), and this trend appears likely to continue.

[15] The SPAB Research Report 1: U-value report (SPAB, 2012)
[16] Ibid.
[17] SAP 2012, Appendix S, Table S7 (BRE, 2014)
[18] SAP 2012, Appendix S, Table S10 (BRE, 2014)
[19] Historic Environment Scotland / SPAB / Historic England / UCL / BRE / Changeworks.
[20] SAP 2012, Appendix S (BRE, 2014)
[21] Changeworks / Historic Environment Scotland (N.B. Small-scale testing).
[22] Sofie Pelsmakers (http://www.sofiepelsmakers.com/suspended-timber-ground-floors.html) / Historic Environment Scotland (N.B. Small-scale testing).

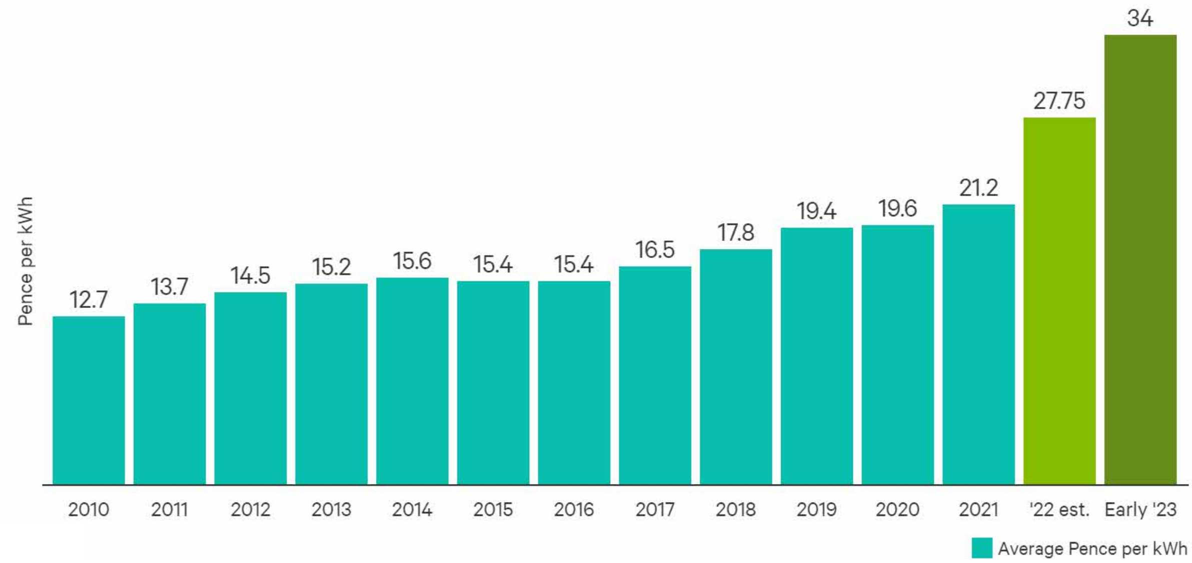



Fig. 12 Historic per-kWh electricity prices in the UK (@ Nimblefins)

Ventilation is largely natural (i.e. via manually-controlled windows & doors, incidental infiltration & intermittent extract fans in wet rooms) and uncontrolled, leading to excess heat loss as a side-effect of maintaining a healthy indoor environment. There is also a large fan in the East gable wall of the barn, although it is not clear whether this is used.

## 3.4 Use

The main house and kitchen extension will be permanently occupied by 2-4 adults, with the barn likely to have less intensive usage patterns. There will inevitably be periods of higher occupation and services will need to cater for these conditions. Home working is expected, entailing long sedentary periods when comfort will be particularly important.

[23] Although carbon factors for electricity have significantly reduced in recent years.

## 4.0 FABRIC UPGRADE OPTIONS

The clients are planning a full & methodical renovation and retrofit of the buildings in question, to include full stripping back and resolution of all defects as part of the process; re-wiring and re-plumbing; a small extension is also planned to the NE corner of the kitchen extension, to create a plant room. The clients also have the capacity to move out of these buildings during the works.

The aim of the planned works is to update the buildings for current and future needs, continuing the evolution of Cheynes Farm and creating a high-efficiency, low-impact home futureproofed for low-carbon heat & power technologies and for the changing climate. Comfort, efficiency and appropriate treatment of these traditional, historic buildings to bring them up to modern standards are all important drivers behind the desired efficiency measures.

The current maintenance requirements, extent of the planned works and the client's ability to move out temporarily all present an ideal opportunity to address energy efficiency, sustainable energy and wider sustainability issues. It is widely acknowledged that the general refurbishment of a building represents the ideal window of opportunity to address not only energy performance and environmental impact but also issues of comfort, health and wellbeing: it maximises the cost-efficiency of energy improvement measures while minimising the added labour and disruption, as much of the work can be incorporated into related building works. Such opportunities are infrequent for most buildings (for example, Cheynes Farm was last subject to any significant refurbishment works at least 30 years ago), which makes it all the more important to take advantage of such windows when they present themselves.

However, in the context of buildings of traditional and complex construction, care is required to understand and avoid any potential adverse effects relating to individual and combined retrofit measures, to achieve a) a programme of refurbishment works that is both building- and site-sensitive and b) a sustainable home in the long term.

This section outlines the main options deemed viable for incorporation into the refurbishment of Cheynes Farm. The context for these proposals must also be highlighted: the clients have a clear focus on both fabric efficiency and low-carbon heating technologies, and appear to have the knowledge, means and motivation to implement works thoroughly and to a very high standard. As such, this may be considered a 'deep retrofit', although specific performance standards have not been discussed and it is assumed that no particular retrofit standards are sought.

Further information on all the options covered in this section, including example design/installation details and drawings, is provided at Section 7. The information in this report is indicative and does not form a specification: system providers should also be contacted in all cases to confirm viability & installation and use procedures, and all measures should be appropriately designed and installed.

Consents will be required from the local authority for many of the planned measures, and early discussions with the planning department are therefore advisable.

### 4.1 'Retrofit ready'

This principle is referenced obliquely elsewhere this report, but merits highlighting as an explicit principle to be borne in mind throughout all the preparatory stages of the project.

One of the most important success factors in any retrofit is the robustness of the building prior to insulating. Retrofit should make a building better, but if done imperfectly it can make it worse – and often, problems are not 'created' solely as a result of the retrofit measures but rather they exacerbate underlying issues that were not resolved prior to retrofit. In keeping with all conservation guidance, maintenance is the first port of call and must be regarded as the essential first measure in any energy efficiency project. If a building is sound, in good condition, dry throughout and has properly functioning drainage, rainwater goods and drainage, it should be 'retrofit ready' and works can proceed from this robust base.

#### 4.1.1 Managing risk

Changes to traditional buildings must be carefully considered and appropriate in order to avoid unintended consequences (often moisture related). The best way to address risk is to gain a proper understanding of the building, all retrofit measures and any operational requirements – and to keep it simple. Following the best-practice principles outlined in most good retrofit guidance (see Section 7), and being aware of potential problems and past failures, will in most cases lead to appropriate design details. The use of experienced contractors with a meticulous attention to detail should allow these details to be implemented in practice.

Some of the key principles to adhere to include:

- Building preparation & defects resolution – understand what you're dealing with; make the building 'retrofit ready'
- Materials & systems – select according to the building fabric & its moisture characteristics
- Coverage & coherence – aim for unbroken insulation and airtightness layers; avoid thermal bridging and pay attention to the details; adopt a 'whole-building' approach
- Complexity – adopt a simple, robust, low-maintenance approach throughout; identify & design out risks; consider worst-case scenario and avoid any approach that can't mitigate this
- Ventilation – adequate ventilation to both heated and unheated spaces; essential for moisture management and indoor air quality
- A balanced approach – don't push the fabric too far in thermal terms; strike a balance between energy demand, building & occupant health, environment & conservation
- Timing – plan works carefully to take place at appropriate times of year, allow appropriate sequencing and build in additional time for unexpected issues
- A joined-up approach – engage with planners, building control, contractors and system providers at an early stage, and work with them to identify mutually acceptable approaches
- Behaviour & maintenance – understand the importance of building maintenance and any system-specific operational & maintenance requirements

It is also beneficial to learn from similar projects and discuss real-world considerations with the designers/installers/occupants where possible, to gain a balanced understanding that accounts for both theoretical solutions and practical constraints; Section 7 includes a selection of case studies.

Note also that there is a wealth of technical guidance supporting the above approach to risk management, as well as local guidance; these resources can and should be drawn upon in any local authority negotiations to demonstrate the strength of this approach to retrofit.

## 4.2 Building Regulations

Energy performance requirements for existing dwellings are set out in Building Regulations Approved Document L: Conservation of fuel & power: Volume 1: Dwellings. This document takes into account the fact that traditional and historic buildings require different treatment from more modern buildings, and any retrofit strategy will be aided by a sound understanding of the regulations. Key sections are set out below:

> 0.9 Work to a dwelling [that is listed and/or in a conservation area] must comply with the energy efficiency requirements where this would not unacceptably alter the dwelling's character or appearance. The work should comply with standards in this approved document to the extent that it is reasonably practicable
>
> 0.10 The energy efficiency of historic and traditional buildings should be improved only if doing so will not cause long-term deterioration of the building's fabric or fittings. In particular, this applies to historic and traditional buildings with a vapour permeable construction that both absorbs moisture and readily allows moisture to evaporate
>
> 0.12 In determining whether full energy efficiency improvements should be made, the building control body should consider the advice of the local authority's conservation officer
>
> 0.13 Additional guidance is available in Historic England's Energy efficiency & historic buildings: Application of Part L of the Building Regulations to historic & traditionally constructed buildings

While most of the above is self-explanatory, certain aspects merit further consideration and/or clarification, as follows:

- Words and phrases such as 'unacceptable' and 'as far as is reasonably practicable' are imprecise, and their interpretation is therefore subjective. These can be used positively or negatively, and there can be a risk of them justifying a 'do nothing / don't touch' approach for historic buildings. The Regulations clearly state that these buildings should be improved
- The key to avoiding inappropriate measures is understanding. As the wealth of good-practice guidance and successful case studies in this area demonstrate, there are many improvements that can be made to most traditional and conservation-grade buildings. Planning teams often include experts on building conservation, but they may not have a full understanding of energy performance, retrofit measures or building physics – these must be imparted in a clear manner by the applicant both to ensure a good understanding and to provide reassurance that the proposals are appropriate for the building
- There is a clear focus on avoiding moisture-related problems. References to moisture movement, permeability, damp and fabric decay all refer to the way traditional building materials manage moisture, and to the potential risks of reducing their ability to manage moisture by introducing inappropriate materials or measures. Most building defects are moisture related, and the same applies with retrofit defects, hence the need for an appropriate approach based on sound understanding. (N.B. As noted, this is likely to become increasingly important as the climate continues to change)

- As noted previously, there is a wealth of more detailed technical guidance on retrofitting traditional and historic buildings, including the Historic England guide cited in the Building Regulations but also many others. Examples are referenced throughout this report, and can be used to demonstrate alignment with good-practice approaches

Building Regulations Approved Document F: Ventilation: Volume 1: Dwellings also requires some consideration. Part F is sometimes criticised as being inadequate for existing buildings, and particularly older buildings and those undergoing energy-related retrofit, and while improvements have been made in the recent update it is still ambiguous in some respects. While it clearly states that 'building work should not reduce the ventilation provision', for building work that will affect ventilation it merely states that 'the ventilation of the dwelling should…not be less satisfactory than before the work was carried out' – in the context of retrofit this is not robust, as many buildings have inadequate ventilation provision and active improvements are often required (see below). For traditional buildings, listed buildings and those in conservation areas the terminology is similarly vague – 'work to [such buildings] should comply with the ventilation standards…where reasonably practicable' – although it does make clear that work should not affect significance or building fabric. The recently-updated Part F does, however, include a dedicated section on installing energy efficiency measures (Sections 3.6-3.13), which describes a simplified assessment method (based on counting up 'minor' and 'major' energy efficiency measures) to help determine whether expert advice is required and what level of ventilation provision is likely to be needed. Once the retrofit strategy has been confirmed, this assessment process should be followed and acted upon as needed.

In recent years ventilation has become much more widely recognised as an essential component of a successful retrofit, and yet this is still an area often neglected due either to lack of awareness or lack of understanding. Ventilation is not always well understood (either by designers and occupants), and in the context of traditional buildings ventilation may also be overlooked or avoided on aesthetic grounds. The reports of inadequate ventilation are becoming increasingly common, even in new buildings. Good practice guidance for retrofit of traditional buildings now stresses the importance of ventilation in maintaining building fabric, indoor air quality and health and well-being, through managing moisture and pollutants effectively. Some such guidance[24] recommends following new-build requirements when undertaking a retrofit project, and even then treating these requirements as only the starting point; one low-energy services consultant has stated that 'if you just follow Building Regulations, you're probably under-ventilating'[25].

Cheynes Farm is likely to undergo a significant level of retrofit, and the above principles should be applied appropriately according to the level of work undertaken, particularly in relation to post-retrofit levels of insulation and airtightness.

## 4.3 Site & building preparation

As noted in Section 3.2, there are a number of building-wide issues requiring attention before or as part of any retrofit works, to resolve defects and make the building 'retrofit ready'. It is assumed that resolving these issues will form part of the refurbishment, and no particular detail is therefore required here, other than to re-emphasise the importance of enabling the building fabric to continue

[24] Designing out unintended consequences when applying solid wall insulation (BRE, 2016)
[25] Alan Clarke, AECB webinar, 2018

managing moisture effectively to avoid fabric damage and detrimental internal conditions. In the first instance this entails managing rainwater away from the building, followed by appropriate specification, design and installation of retrofit and refurbishment measures (fabric & services). It will also be beneficial to ensure the building fabric is as dry as possible before any insulation materials are applied.

The following issues will require attention before or during the retrofit works:

- Resolution of all moisture-related defects in end room & elsewhere as needed, including identification & resolution of root causes to prevent recurrence
- Removal of all defective timbers and other materials; repairs to retained timbers as needed
- Allowing any damp fabric to dry
- Appropriate insect infestation treatment as needed
- Checks & lowering of any raised external ground levels
- Resolution of any roof or rainwater goods defects
- Repairs to cracked render as needed, pending full replacement
- Ensuring building is fully weatherproof
- Improvement / replacement of rainwater goods, ensuring they have sufficient capacity to cater for future climate conditions (this may lead to the incorporation of rainwater goods that are deemed to be oversized for today's climate)
- Checks & improvement of drainage as needed
- Removal of any redundant services

It is assumed that issues such as the cement-based pointing and apparently impermeable roof membrane will be addressed as part of the main refurbishment works to the walls and roofs.

Additional, measure-specific preparatory works are covered in the sections below.

(N.B. In the event that some of the planned stripping-back works do not take place, localised opening-up and/or thermal imaging (during the winter months) will help identify the nature of any insulation in hidden areas such as vaulted ceilings).

## 4.4 Roofs

The roofs may be separated into two distinct elements, the main house with flat ceilings and the kitchen extension and barn with vaulted ceilings. In both cases, the planned full stripping of the roofs from above should make it relatively straightforward to achieve high levels of insulation and airtightness in these areas, eliminating all existing maintenance issues and other vulnerable areas and providing a robust, weatherproof covering for the buildings. This level of intervention has the added benefit of enabling removal of any inappropriate materials, and of facilitating robust detailing around all wall-roof junctions which is particularly critical where external and/or internal wall insulation are implemented (see Section 4.7).

In all cases, it is important to follow the key considerations relating to traditional buildings set out below.

Regardless of approach, it is imperative that all roof assemblies are dry, weatherproof, free from defects and adequately ventilated where needed to protect the building fabric: incorporation of the maintenance measures highlighted previously is therefore an essential part of the roof retrofit.

It is assumed that existing roof tiles will be retained and re-used, minimising the loss of existing fabric and wasted resources. The same retention & re-use principles are assumed to apply to the roof timbers, with the exception of any timber damaged beyond repair. (N.B. The client reports that most of the roof timbers in the barn have been replaced, with a small number of primary timbers constituting the only remaining historic fabric.)

Use of low-impact (usually natural) materials will reduce the environmental impact of the retrofit, improve the sustainability of the buildings and tie in with good-practice principles for traditional building retrofit. Guidance from Historic England and many others promotes the use of 'moisture-open' insulation assemblies in traditional constructions in nearly all cases, as these tend to work better with traditional building fabric by allowing moisture to move through a construction build-up and minimising the risk of trapped moisture. Impermeable insulation systems – in roof areas, these are generally petrochemical foam-based rigid boards or sometimes multi-foil layers – can be more prone to problems and should generally be avoided (unless an entirely new roof construction is being created, in which case they may be viable); some foam-based board systems can also shrink over time, leading to thermal bridging and reduced thermal performance, and allowing spaces for warm, moist internal air to pass through into vulnerable areas where there is no airtightness layer. An additional benefit of some (but not all) moisture-open materials is their higher density, which improves their ability to mitigate overheating risks (particularly at rafter level), in contrast to lightweight foam-based boards that can exacerbate these risks. Natural materials have added benefits in terms of environmental impact, embodied energy and air quality management (hygroscopic materials can help regulate humidity levels).

Common moisture-open materials for roof build-ups include woodfibre, jute fibre, hemp fibre, mineral wool, sheep wool and cellulose, which come in a range of forms including loose-fill blown fibre, flexible 'batts' and rigid boards. Flexible insulation batts are generally most appropriate between timbers as it is easier to achieve a tight fit and avoid gaps, particularly in older buildings with irregular timbers – but it is also important to insulate above or below the timber elements to prevent thermal bridging. For joist-level insulation (i.e. flat ceilings), additional layers of flexible insulation batts may be added over the joists to a total depth of c.300mm or more, with special joist raisers[26] being used to accommodate storage and access platforms without compressing soft insulation. For rafter-level insulation, rigid boards (e.g. woodfibre) may be installed either above or below the rafters to address thermal bridging: installation from above can be particularly effective if it is acceptable to raise the roofline – which would require early discussion with the local authority – otherwise the rigid boards would be applied below the rafters. In the case of the barn and kitchen extension the underlinings are assumed to be of no historic significance (and may even incorporate inappropriate impermeable materials) so it should therefore be possible to replace these, and any reduction in ceiling height is unlikely to be an issue in either building. In either case, tongue-and-groove boards can be beneficial in improving airtightness, and appropriate taping will be required at all board junctions and perimeters to ensure good airtightness. Example woodfibre-based rafter-level insulation build-

[26] E.g. Loftzone, Smart Six.

ups are available here (external) and here (internal); please note these are indicative only. (Architect discussions suggest that the preferred approach for the barn and kitchen extension is likely to incorporate woodfibre or sheep's wool batts between the rafters with rigid woodfibre boards over the top and a ventilated batten space below the tiles.)

For rafter-level insulation, internal finishing options include wet-applied lime plaster and dry vapour-permeable boarding; the latter option would allow a service void to be incorporated into the assembly, which can increase lighting options (potentially useful in the kitchen extension) and provide some protection to any airtightness membrane that may be included in the assembly.

Airtightness may be partly addressed by a wet lime plaster finish internally, where appropriate, as this is relatively easy to design and install, but additional layers may be needed on occasion: common options include 'intelligent' vapour-permeable membranes[27] or appropriate rigid boards (which are more robust than membranes). These are commonly vapour permeable, in order to allow the moisture-open roof assembly to function. Depending on the insulation system selected, the system provider should be contacted to establish an appropriate specification and location for any vapour-permeable airtightness layer. In all cases, particular attention to detail is required around all perimeters and awkward junctions (e.g. around rafter ends) both at design and installation stages, to ensure no gaps are left. In our experience, particular care is also requires around any openings (e.g. rooflights) and services penetrations (e.g. flues) to avoid compromising the airtightness of the whole building at roof level.

For insulation at rafter level, if the roof is being stripped and re-done it should be straightforward to achieve good ventilation below the tiles via battens and counter-battens. Stripping the roofs from above also presents an opportunity to replace any impermeable roof membranes with appropriate vapour-permeable alternatives where needed, again to help moisture management.

The main house is already largely insulated at joist level, so interventions here are likely to be a case of refinement and improvement where needed rather than total replacement. Again, stripping the roof from above will allow all defects to be resolved, enable replacement of the roof membrane with an appropriate vapour-permeable alternative, and facilitate removal of all redundant services and installation of any new ducts (likely to be required for the bathrooms). Insulation can then be checked and rearranged & topped-up as needed to ensure coherent, unbroken coverage across the ceilings; current guidance typically suggests c.300mm insulation. Cables and services should remain above the insulation and should be insulated as needed (e.g. pipework), and any downlighters should be insulated over, using protective cages to prevent insulation coming into contact with the lights. Any storage platforms may be installed as noted previously. As the roof void is ventilated at the eaves, blown insulation materials (e.g. cellulose) should be avoided as it may be blown around, resulting in uneven coverage and blocking of ventilation paths. It is essential to ensure that ventilation provision is adequate to allow any moisture entering the very cold roof space to escape, or it will condense and could lead to timber damage. This risk is exacerbated where poor ventilation is accompanied by the presence of an impermeable roof membrane (as appears to be the case at Cheynes Farm), and where ceiling airtightness is poor (e.g. where there are poorly-sealed loft hatches, spotlights and/or gaps in

[27] E.g. Intello Plus is one of the more well-known 'intelligent' airtightness membranes.

airtightness layers). Proprietary systems are available to keep eaves ventilation routes open, and these may be beneficial in the main house. Loft hatches need to be fully insulated and draught proofed and to close securely, again to avoid warm moist air from the main dwelling entering the cold roof space; pre-insulated hatches are readily available[28], and it would be beneficial to replace the existing hatch as part of the works. These details will help achieve a coherent, unbroken layer of insulation that avoids thermal bridges and their associated heat loss and moisture risks.

Appropriate sequencing will also be beneficial, to tie in with the planned wall insulation to allow an unbroken insulation layer from walls to roofs. On a related note, roofline extensions can be highly beneficial in protecting external walls from rainwater penetration; if this is deemed unacceptable at Cheynes Farm, particular care should be taken with detailing and construction around roof perimeters to maximise the protection they can provide to the walls. (N.B. There may be more scope for overhanging eaves on the new extension, if it can be designed to blend in with the existing roofs.)

### 4.5 Floors

The ground floors are a mix of suspended timber and solid concrete, all uninsulated. As noted previously both floor types create discomfort and often have a poor thermal performance (significantly worse than assumed by most energy modelling tools). Uninsulated concrete floors can also potentially exacerbate any moisture issues around perimeter wall bases, while suspended timber floors can also contribute to poor airtightness. A robust insulation strategy is therefore required for all ground floor areas.

N.B. From technical and design perspectives it can be easiest to adopt a single floor construction throughout. While the barn is largely detached from the kitchen extension which therefore minimises the extent of any complex junctions between different floor types, it may be worth considering a solid floor assembly throughout all buildings: a solid floor assembly avoids the need for embedded timbers in the walls and sub-floor ventilation, both of which can be vulnerable in the face of sub-optimal conditions; it can also be easier to achieve lower U-values and good airtightness with a solid floor construction rather than a suspended floor; and a solid floor facilitates under-floor heating which is of considerable benefit where heat pumps are planned (see Section 5), as at Cheynes Farm. However, it is acknowledged that the technical complexity and listing may make this approach unworkable, and both floor types are therefore covered below.

Regardless of the preferred floor types, a number of external checks and maintenance works will be required at an early stage as outlined in Section 4.2, to ensure wall bases are dry and able to manage moisture effectively. If the suspended timber floor in the barn is retained, it will be important to ensure adequate sub-floor ventilation is maintained (see below) which may require various preparatory works.

#### Suspended timber floors

If the suspended timber floor in the barn are being retained, the condition of all timbers (including those embedded in the wall bases) should be checked and any repairs carried out at an early stage. The depth and general condition of the sub-floor void should also be assessed, removing any debris, ventilation blockages and redundant services. Sub-floor ventilation provision should also be checked

[28] E.g. Wellhofer airtight attic hatch.

and improved as needed (assuming this is possible), to ensure effective cross-ventilation of this space across the entire floor post-insulation: this should include not only external wall vents but also any hit-and-miss brickwork in dwarf walls. If adequate ventilation appears unworkable, this may strengthen the case for replacement with a solid floor.

Insulating suspended timber floors is less disruptive from below, but this is not an option for the barn. Insulating from above is more disruptive, but the extent of planned works should make this approach relatively straightforward. If the existing floorboards are to be retained, it may be advisable to draw a labelled plan and number the boards to allow them to be re-laid in the same position; some damage may be expected when removing older floorboards particularly if they have tongue-and-groove edges, so it may be advisable to look for matching boards from e.g. salvage yards. (Some guidance[29] recommends only removing sections of floorboard at any one time, to reduce disruption and avoid the risk of destabilising any dwarf walls, although this would make it impossible to add insulation and/or under-floor heating on top of the joists.) Insulation is commonly applied in a similar manner to joist-level roof insulation, with flexible, moisture-open insulation material (e.g. woodfibre / hemp / jute / sheep's wool / mineral wool batts) fully filling the spaces between the joists and ideally an additional, rigid layer of insulation (e.g. rigid woodfibre) applied above to eliminate thermal bridging through the joists; the slight change in floor level should be accounted for during design. A vapour-permeable airtightness layer is generally included[30] (e.g. a vapour-permeable membrane) to prevent infiltration and the passage of moisture into the cold sub-floor void: in this case the membrane is often installed first, draped over the joists and pulled taut between them to hold the insulation. Any boards or membranes should be carefully taped at all junctions and securely sealed around the perimeters before wall bases are plastered over. Considerable care is needed to achieve a good seal to old masonry and timber, so perimeters will need proper preparation to ensure they are clean and free of dust and other debris; some system providers also provide primers which can be beneficial in such areas. Further guidance on suspended timber floor insulation is provided in Section 7, and some insulation providers have their own guidance (e.g. here and here).

Solid floors

The main options to improve thermal performance in this area are a full floor replacement or, where a solid floor is being retained, the addition of a floating floor of insulation material. Full floor replacement is likely to be the most effective approach to improve thermal performance; this would also make it easier to incorporate underfloor heating to link up with a heat pump (see Section 5), resolve existing level changes and enable good moisture management around wall bases. As noted previously, solid floor constructions can also be beneficial in improving airtightness.

For full replacement, the first consideration is which approach to adopt. In buildings of traditional, solid masonry construction, insulated limecrete floors are becoming increasingly popular instead of conventional insulated concrete slab systems, as the latter are impermeable and concerns have been raised about the potential for moisture to migrate from the earth under the floor into wall footings[31]. Insulating limecrete floors also have a lower environmental impact than a conventional concrete slab, and avoid the use of petrochemical-based insulation materials. Subject to more detailed discussions

[29] Short Guide 1: Fabric improvements for energy efficiency in traditional buildings (Historic Environment Scotland, 2013)
[30] The floor insulation provider should confirm the specification as part of their system.
[31] See as an example pp.5-10 of Energy efficiency & historic buildings: insulating solid ground floors (Historic England, 2016)

with system providers and a water table check, an insulating limecrete floor may be a good fit for the main house and kitchen extension.

There are numerous specialist firms in the UK that offer insulating lime floor systems, and most offer good online specifications. The most conventional approach for an insulating limecrete floor involves removing the existing floor and digging out to a suitable depth (dependent on systems, materials and finishes, target U-value, condition and depth of foundations and so on), then installing the new floor build-up. An example assembly is illustrated in Fig. 13 below. (N.B. It is also possible to add insulation (e.g. hemp fibre or LECA pellets; see below) to the lime concrete itself and lay it as a homogenous whole[32], but this is not common.)

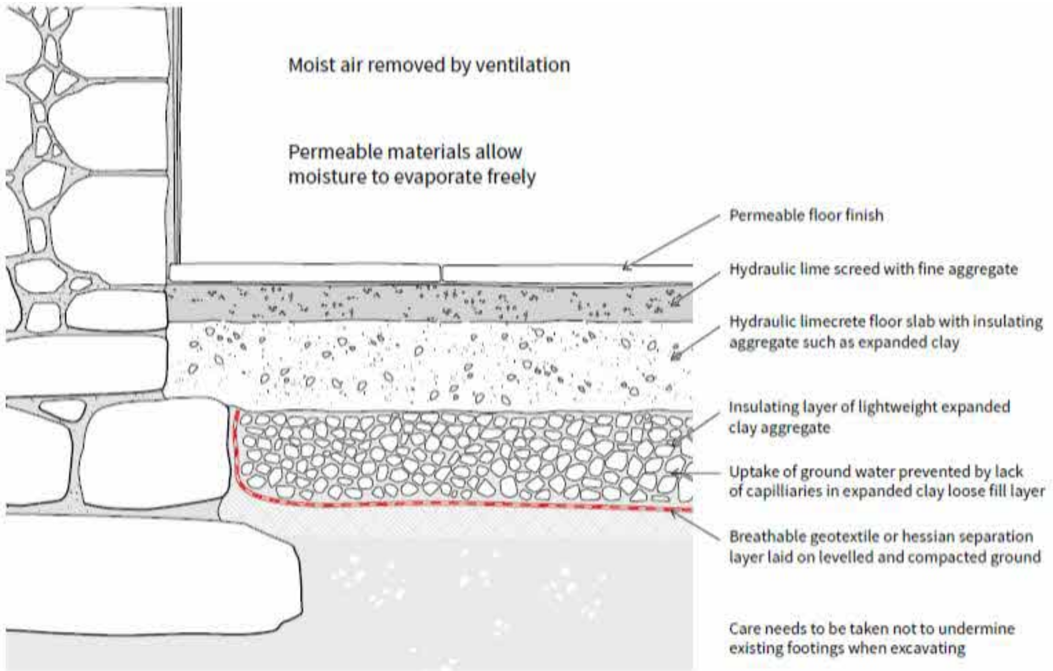



Fig. 13 Example build-up of an insulating lime concrete slab (© Historic England)

When digging out, care is required to avoid undermining foundations, and it is not uncommon for some underpinning to be required on older buildings. Once the existing floor is removed this provides an additional opportunity to inspect the wall bases and address any defects found.

The predominant aggregate/insulating material is Recycled Foamed Glass (RFG), although Lightweight Expanded Clay Aggregate (LECA) pellets can also be used in some cases. LECA pellets are slightly less thermally efficient and require a greater depth to achieve the same U-value; they require more layering and can therefore lengthen the installation process; and they are more difficult to walk on as they are roughly spherical – this is not any barrier to use, but worth being aware of during the installation stages. RFG systems seem to be increasing in popularity, as they tend to have fewer layers (e.g. a loose fill layer and a slab) and can therefore be simpler to install; they can be cheaper; and they provide good stability, although they require compacting. It is generally advisable to install a strip of perimeter insulation (e.g. 30-40mm cork) between the walls and the floor slab to minimise thermal

[32] Short guide 1: fabric improvements for energy efficiency (Historic Environment Scotland, 2013)

bridging, particularly if considering wall insulation. If installing underfloor heating coils, these will be affixed in clip rails prior to the floor slab/screed.

An indicative installation option is provided in Fig. 14 below. Thermal performance is dependent upon individual floor configurations and depth of aggregate, but good performance values can be achieved. Note that drainage works are often a component of insulating limecrete floor systems: as this work is likely to be required at Cheynes Farm in any case, this provides an opportunity to maximise the efficiency of work sequencing.


Fig. 14 Ty-Mawr sublime insulated limecrete floor[33] (© Ty-Mawr)

Once fully installed, the floor needs to be cured, and will need to be protected and adequately ventilated during this time. Note that any suggested curing times are only guidelines, and can vary considerably depending on slab depth, materials and external/internal climatic conditions. Curing periods should be shorter in warmer, drier weather, and consequently winter should ideally be avoided for installation. The amount of moisture that comes out of such a floor assembly should not be underestimated, and every effort should therefore be made to carry out the installation in good conditions for drying. (N.B. The same applies for any wet-applied wall insulation systems (see Section 4.7), further strengthening the case for installation of all such measures at an appropriate time of year; this often requires good levels of advance planning.) A range of finishes may be applied depending on the system installed; examples of one system are available here.

As mentioned above, solid floor replacement facilitates the incorporation of under-floor heating throughout the property. This is often considered beneficial over conventional radiator heat distribution, in several respects: it is the distribution system best suited to heat pumps (see Section 5) as it allows effective space heating with a relatively low water temperature (which maximises the

[33] Ty-Mawr

efficiency of heat pumps); it frees up wall space that would otherwise be taken up by radiators; it provides a uniform heat distribution; it allows the feet to be warmed, which is important to human bodies in achieving overall comfort; and it helps provide warmth around wall bases, which can be vulnerable to cold and moisture-related problems.

As noted earlier there appear to be a relatively low risk of radon issues in the area (subject to site testing), which should remove the need for any mitigation measures that could affect the vapour permeability of this floor type[34]. Should an insulating limecrete floor not be appropriate for any other reason (e.g. high water table) then a conventional insulated slab would have to be implemented.

If solid floor replacement is not an option, a 'floating floor' of insulation can be applied on top of the existing floors. While this is unlikely to be as robust or effective as full floor replacement, it may be cheaper and less disruptive. In the case of floating floor insulation, space and level impacts should be borne in mind: as well as potentially creating steps between rooms if not carried out everywhere, doorway and ceiling heights will be reduced and additional knock-on works are generally required (e.g. removing and reinstating skirting boards, sockets and kitchen / bathroom units, threshold alterations, trimming doors). These issues can generally be minimised by treating the whole ground floor and using a slim-profile, high-performance insulation material such as aerogel: this material is available for use as floor insulation, pre-bonded to a rigid board[35] and using whatever depth of aerogel insulation is required (typically 10-30mm). Previous discussions with system manufacturers suggest that this may be compatible with under-floor heating, but further checks would be required to ensure that the (minimal) compressibility of the aerogel would not affect the integrity of any pipe junctions within the rigid UFH carrying board[36]. Common finishes such as floorboards can then be applied on top of the insulation layer. Aerogel comes at a cost premium, but this should be considered against the labour savings associated with fewer knock-on works.

### 4.6 Windows & doors

Addressing thermal performance in these areas is a fundamental requirement, as windows are often the weakest point in the thermal envelope of a building. (For example, single glazing has an extremely poor centre-of-pane U-value of c.5.5 W/m$^2$K, and contributes not only to heat loss but also to uncomfortably cold areas around the windows themselves where temperature differentials create convection currents; these issues are exacerbated where draught proofing is absent.) This often applies even after retrofit: assuming typical post-retrofit U-values of c.0.2 W/m$^2$K for roof and floor and c.0.5 W/m$^2$K for walls, depending on their specification window U-values may range from c.1.7-0.65 W/m$^2$K, i.e. they remain the poorest of all building elements.

The windows at Cheynes Farm are single glazed and are believed to date from the 1980s, and therefore have no historic significance. Full replacement of all windows is currently proposed, and upgrade options associated with retained windows (e.g. secondary glazing) are not therefore covered in this report.

[34] It is possible to incorporate a radon membrane in an insulating lime concrete floor build-up, although some compromise on moisture management is inevitable.
[35] See example here (Spacetherm Multi for floors).
[36] The amount of compression movement is dependent on the depth of aerogel.

The historic significance of Cheynes Farm means that sensitive approach to replacement is needed. However, most of the windows are of a relatively simple and non-original design, so replacement should be relatively straightforward and many options are available. (N.B. We understand that the Bronze Casements window systems are currently under consideration. It should be noted that the thermal performance of these systems is in most cases relatively poor compared with that offered by some other systems, although they do offer a thermally-broken frame option which is more in line with improved performance standards; the bronze frames will also have a greater environmental impact than timber frames. Should these systems be pursued, it would be beneficial to discuss options with them of incorporating improved glazing systems (see below) into their frames, to maximise their thermal performance.)

Triple glazing

On grounds of thermal performance, triple glazing is often considered in the first instance – good triple-glazed units can achieve a whole-window U-value of c.0.65 $W/m^2K$. The depth of triple glazing units often requires relatively thick frame sections, which can have a slightly less refined appearance than their original (single-glazed) predecessors, although this is most noticeable in older multi-pane windows (e.g. Georgian 6-over-6 sash windows). At Cheynes Farm many of the windows already have relatively thick sections, and it is understood that there is scope to simplify the design in the replacement units – this should also make it easier to achieve the best possible thermal performance[37], increase daylighting provision and potentially reduce costs.

In case multi-paned units are acceptable and of interest, good-quality triple-glazed units are available; examples are shown in Figs. 15-18.

[37] A wide range of passive-rated units is available on the Passive House Institute's Component Database.




Figs. 15-18 Examples of triple-glazed multi-pane window units in traditional buildings (© Green Building Store[38])

Double glazing & vacuum glazing

Alternative options include double glazing and vacuum glazing, the latter of which is becoming increasingly common where budget permits. Conventional double glazing is ubiquitous and needs little explanation, although it should be highlighted that, while a good double-glazed unit may now commonly achieve a whole-window U-value of c.1.2 $W/m^2K$, this remains considerably worse than most insulated wall assemblies. Similar issues around glazing bar thickness may also remain with conventional double glazing, which leads to consideration of more specialist systems appropriate for historic buildings.

There are now many specialist slim double-glazing systems available in the UK that are designed specifically for traditional and historic buildings[39], with many successful examples on listed buildings across the UK: these may be built into new frames or, in some cases, retrofitted into existing frames. The slim-profile nature of these units allows fine glazing bars to be used, retaining the aesthetic of traditional single-glazed windows while improving performance. However, most of these units are

[38] https://www.greenbuildingstore.co.uk/product-category/triple-glazed-timber-windows/
[39] A detailed assessment of these units is available in a demonstration project report (see Double glazing in listed buildings: Project report, Changeworks, 2010) and associated technical reports published by Historic Environment Scotland.

filled with inert gases[40] and are therefore reliant on the perimeter seal to maintain performance, as with standard double-glazed units. Warranty periods tend to be relatively short with most of these systems, and the whole-window U-value is likely to remain considerably higher than that of a conventional double-glazed unit. The alternative is vacuum glazing, another type of slim-profile system which relies upon a vacuum rather than inert gas for insulation performance. Of all the slim-profile double glazing systems, vacuum units have the best performance and generally the longest warranty periods, and as such are at the top end of this market.

A vacuum is highly thermally efficient, and allows a very narrow cavity (down to 0.1mm) and an overall unit depth of down to c.6mm (i.e. more like a single pane of glass). This makes it much easier to incorporate fine glazing bars and dimensions if required, and contractors report that such glazing is much easier to work with than more conventional slim double-glazed units[41]. Some systems[42] have a visible sealing cap in one corner of each unit, but newer systems manage to avoid this (see below). All systems use 'microbeads' to hold the two panes of glass apart: these are visible on close inspection, but are hardly noticeable from the outside or on a day-to-day basis from the inside. Centre-of-pane U-values can be extremely low (ranging from 1.0-0.42 W/m$^2$K), and warranty periods are up to 15 years. One system[43] is able to offer these units with toughened glass, where this is required. All vacuum units are considerably lighter than conventional double or triple glazing, and their slim dimensions also allow for improved light transmission over most other options including triple glazing.

There are currently three main vacuum systems available; for this project, the most appropriate may be the FINEO[44] system, for various reasons. It has no corner sealing cap, which considerably improves the aesthetics of the whole window. Its thermal performance is extremely good, with a centre-of-pane U-value of 0.7 W/m$^2$K. The warranty period is 15 years. Light transmission, solar gain capacity (g value) and sound insulation are all better than those of standard triple glazing: it is reported to let in 15% more light than triple glazing, and reduce traffic noise by 10dB[45]. In addition, unlike the other vacuum systems it is manufactured relatively locally[46]. It is understood that a toughened glass option will soon be made available, should this be required. While there is a limit on unit size, this is unlikely to be an issue at Cheynes Farm. The overall unit depth (c.6-8mm) is many times thinner than that of triple glazing, which allows cost and thermal performance to be balanced with aesthetics. They also offer a choice of six types of 'restoration glass' to mimic glazing from the 1880s through to the 1960s[47]. While 'stick-on' glazing bars are often criticised (with good reason in some cases) they can be very discreet when combined with vacuum glazing in good-quality units, and the use of single, larger panes would reduce capital costs and achieve a better thermal performance than if multiple, smaller panes were used.

[40] Generally krypton. Xenon is sometimes used as this has a superior thermal performance, but the embodied energy is much greater and calculations have shown these units use more energy in their manufacture than they save over their operating life.
[41] Double glazing in listed buildings: Project report (Changeworks, 2010)
[42] Pilkington Spacia / LandVac.
[43] LandVac.
[44] FINEO.
[45] Ibid.
[46] In Belgium; the other units are made in Japan and China.
[47] FINEO.

Figs. 19-22 Examples of FINEO vacuum units in traditional buildings (© FINEO)

Other options & considerations

Regardless of the glazing system selected, timber frames generally have the best environmental credentials and, if maintained, can have a very long lifespan; selection of good-quality hardwood units is of considerable benefit in this respect. Composite frames – e.g. timber frames with an aluminium covering – are also available, which can reduce maintenance needs (i.e. no external painting is required), but if environmental impact is of interest it is important to check the source of the aluminium as virgin aluminium has a very high environmental impact, and these windows may not be deemed appropriate at Cheynes Farm. Regardless of frame type, selecting thermal bridge-free units with insulated frames provides further performance benefits and reduces the chance of localised cold surfaces vulnerable to moisture accumulation.

Other considerations for windows include solar gain and shading. The former can be managed through selecting glass with an appropriate g-value, to achieve a balance between daylighting, heat gains and heat losses. The latter can be addressed by either external or internal shading options; this is covered in more detail in Section 4.9, and requires due consideration early in the design process as it can be very hard retrofitting shading and other cooling measures effectively.

As with windows, the introduction of new doors makes it easy to achieve good levels of thermal performance in these areas. Passive-rated doors are available[48] which combine very low U-values with excellent airtightness properties and thermal bridge-free frames, but these may not be appropriate at Cheynes Farm in which case appropriate alternatives would be required. In respect to any new doors, it is important to note that multi-door units – e.g. sliding / bi-fold units – can present airtightness issues, particularly over time as these units move, wear and/or swell/shrink in varying climatic conditions: this can undermine the airtightness strategy of the whole building, and on this basis it is generally advisable to keep door designs as simple as possible. If space permits, the introduction of a draught lobby (secondary front door) inside the building can provide further thermal benefits. If any existing doors are retained, glazed areas may be upgraded as per the windows; draughtproofing (e.g. integrated brush strips / compression seals) may easilty be incorporated; and thin aerogel insulation materials (described previously) can be applied internally, either to the thinner central panels or the whole door – this approach has been successfully trialled on a number of traditional building retrofit projects[49], and can result in a considerably improved performance although the work is somewhat fiddly. Upgrading the door between the barn and kitchen extension may also be beneficial, on the assumption that the barn is only used and heated occasionally.

Regardless of the approach and systems chosen for windows & doors, as noted in other sections it is important to ensure that all elements of the insulation envelope are properly joined up and avoid gaps and thermal bridges wherever possible. This is particularly important where walls are also insulated, as thermal bridges around window and door reveals can be some of the most vulnerable areas for moisture accumulation and associated issues (e.g. mould growth).

Airtightness, ventilation and overheating also require consideration for windows & doors; these are covered in Sections 4.8 and 4.9.

## 4.7 Walls

(N.B. This section deals with the walls of the existing buildings. For the planned extension, there are many options available for new-build wall assemblies: common assemblies may include conventional cavity construction, or timber-frame construction with a low-impact materials such as blown cellulose or woodfibre used as insulating materials and timber rainscreen cladding, which would blend in with the existing finishes. Support can be provided on this element if required once the design has been developed further.)

Detached buildings lose a considerable amount of heat through their walls, particularly those of traditional, solid masonry construction and uninsulated timber frame, the latter of which is a relatively lightweight construction form that can be subject to large fluctuations in internal temperature over a 24-hour period. From a technical perspective, therefore, the walls can often form

[48] E.g. Passive House Institute's Component Database.

[49] This approach has been adopted by Historic Environment Scotland in numerous traditional building retrofit projects, and a similar approach was adopted on external doors by Arboreal Architects in their Clapham Retrofit project of a listed London townhouse.

an important part of a whole-building retrofit plan, where budget permits. Discussions with the client suggest that whole-building wall insulation is an important element of the project for Cheynes Farm.

The two different wall types require a different approach to insulation, and these are addressed separately in this section. Note that wall insulation is one of the most technically complex retrofit measures, and this section is therefore relatively long. Note also that any wall insulation proposals can benefit from a robust moisture risk assessment to determine the robustness of proposed assemblies and further inform the detailed design process (see Section 4.7.2).

General preparation principles

(N.B. This section provides general principles only; regardless of the system used, manufacturer's guidelines for preparation and application should be followed precisely in order to avoid problems and ensure the system functions as intended.)

For any wall insulation, walls and surrounding elements need to be carefully prepared prior to insulating, in line with principles outlined previously. This includes resolving any moisture issues and eliminating their root cause wherever possible; stripping away any fixtures and other objects (e.g. services, plants) that could interfere with the continuity of insulation; carrying out any wall and roof repairs as needed, particularly those relating to water management (e.g. gutters, leadwork, overhangs, leaks); ensuring rainwater goods and drainage are adequate; and lowering any raised external ground levels. Any incompatible material (e.g. cement-based render) should be removed, and any repairs carried out as needed. Appropriate internal finishes should be used, to maintain the moisture-open nature of the wall. While lime-based materials can act as something of a poultice and allow drying through them, any damp fabric should ideally be allowed to dry before insulating; this dictates installation at an appropriate time of year, which would in any case be recommended to facilitate installation under good conditions even for internal insulation. Careful sequencing of other related works (e.g. window upgrading, roof replacement) and identification of services penetrations are also required to ensure works are carried out in a logical order and insulation / render / airtightness layers are not compromised. Windows and doors are often installed before wall insulation and prepared with appropriate weatherproofing/airtightness tapes, allowing the insulation and/or finish to overlap the frames; in this case it is important to protect the windows and doors from any spray-applied materials such as insulating lime render.

Wall insulation should be designed and installed to join up coherently with roof and floor insulation, windows & doors (which can benefit from being in the plane of the insulation layer), and other key building junctions wherever possible to prevent thermal bridging. Any external or internal fixings may require particular materials, and this should form part of the detailed design process to avoid additional retrospective works.

For any wall insulation works on traditional buildings, particularly those involving the proposed insulating lime render system, the use of experienced contractors[50] is recommended. Discussions with such contractors will also be beneficial for the client to gain a full understanding of the practicalities of installation.

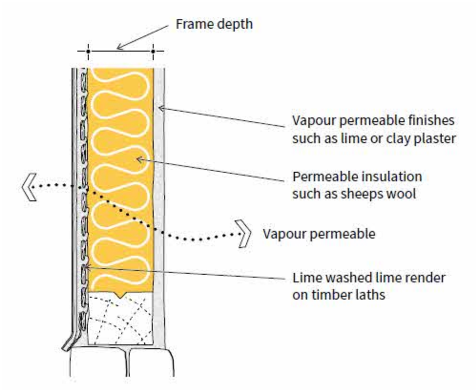
[50] For the Diathonite insulation system, the UK distributor (Ecological Building Systems) has a list of suggested contractors on its website, which includes installers relatively local to the site. Clearly this is suggestive only, and the client and design team would have to satisfy themselves with the chosen installer's credentials.

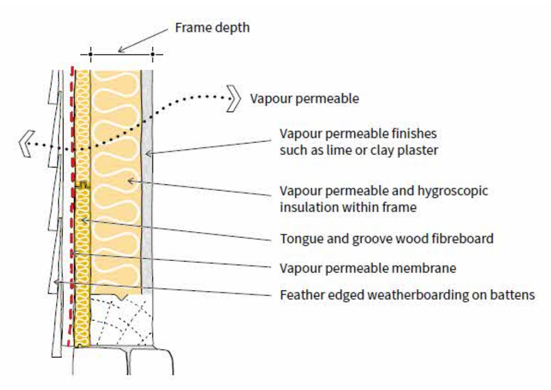
There is a wealth of guidance available on insulating timber-framed and solid masonry walls, which should be read at an early stage to inform the detailed design and installation works; examples are provided in Section 7.

#### 4.7.1 Timber-framed walls

Insulating older timber-framed walls is notoriously complex, and requires care and attention to detail throughout design, preparation, installation and maintenance. Risks can be particularly uncertain where the timber frame remains exposed externally, but at Cheynes Farm the external render and weatherboarding across the whole timber frame should considerably improve the robustness of any insulation strategy. (There is one small section of exposed timber frame with brick infill to the rear of the kitchen extension, but this is thought to be more modern and it is assumed this will also be covered with timber weatherboarding as part of the works.)

For the main, older timber-frame walls, current proposals are to strip back the walls both internally and externally; fill the spaces between the timbers with moisture-open insulation batts (woodfibre or sheep's wool); plaster internally between the timbers; and externally apply a) wood wool boards + lime render to the currently-rendered walls and b) rigid woodfibre boards + ventilated timber weatherboarding to the currently-weatherboarded walls. Figs. 23-24 show approximate cross-sections of these approaches; Figs. 25-26 show examples of sheep's wool between the frame with wood wool boards over the top.




Figs. 23-24 Insulated timber frame with render finish (left) & weatherboard finish (right) (© Historic England[51])

Figs. 25-26 Sheep's wool between timber studs (left); wood wool boards over the top (right) (© Anglia Lime Company)

While both these approaches are broadly in line with good-practice guidance, the proposed assembly for the rendered walls could be vulnerable to thermal bridging from the timbers (depending on the thermal performance of the wood wool boards), and associated performance drop-off and possible technical risks. It would be beneficial to a) assess the potential impact of this via 2D thermal bridge calculations, and/or b) consider an insulating layer on the outside of the timber frame to address these potential thermal bridges (as per Fig. 24). In terms of thermal performance, it is hard to determine the actual U-value of an older timber-framed wall due to the inconsistencies in the wall structure, but informal calculations suggest that, with a 1/3 timber bridging fraction[52], a 100mm timber-framed wall may achieve a U-value of c.0.7 W/m$^2$K with a high-performance woodfibre material (λ 0.036 W/mK) installed between the timbers; with a 20mm layer of similar woodfibre material installed over the top this would improve to c.0.5 W/m$^2$K, while to achieve a U-value approaching 0.3 W/m$^2$K would require a 60mm woodfibre layer externally.

[51] Energy efficiency & historic buildings: Insulating timber-framed walls (Historic England, 2016)
[52] Based on site observations; subject to variation depending on individual wall construction.

Alternatively, it may also be possible to use an insulating lime render rather than a conventional lime render. In recent years a number of different insulating lime render systems have become available in the UK market, some of which are manufactured in the UK and some of which have a longer track record in mainland Europe. Most systems are essentially similar (and most can be used both internally and externally), but use a range of different materials to improve thermal performance; the most common materials used in these mixes are cork, hemp, perlite (expanded volcanic glass), recycled blown glass beads or other recycled mineral aggregates. Thermal performance varies accordingly and the difference can be considerable: the stated thermal conductivity (lambda or λ value) of the main systems currently available in the UK ranges from 0.19 to 0.037 W/mK[53]. There appears to be a considerable increase in the use of these systems on traditional buildings across the UK in recent years, and consequently there is a wide range of case studies available (these and further technical details can be provided on request); Figs. 27-28 show examples on traditional buildings of different ages and designs. However, the use of any such system in conjunction with the proposed insulated timber frame assembly would require further assessment (e.g. discussions with system providers) to confirm viability[54].

Figs. 27-28 Diathonite systems in Allonby, Cumbria (left) & Clane, Ireland (right) (© Ecological Building Systems)

Anything that makes the wall thicker on the outside than it was before would require careful assessment to ensure that a) it is permitted and b) associated details such as roof overhangs, rainwater goods, drainage and window & door reveals will remain robust and keep the buildings weatherproof – although the extent of planned works should make it relatively straightforward to address these areas.

For the insulation between the timbers, materials such as hemp fibre batts, flax fibre batts, cellulose fibre and even wet-applied hemp-lime composites may also be considered alongside woodfibre and sheep's wool[55]. Poor airtightness can present significant heat loss through timber-framed walls, so it is important that insulation fully fills the spaces and junctions are appropriately sealed; it would be

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53 For context, the λ value of a typical brick is c.0.62 W/mK, a good woodfibre insulation material c.0.035 W/mK and a high-performance phenolic foam insulation c.0.018 W/mK

54 For example, in their guide on insulating timber-framed walls Historic England suggests that 'high-strength hydraulic lime-based mortars and renders (NHL 3.5 and above) should not be used on historic timber-framed buildings', but it is not certain whether this blanket approach is always required. One of the more popular insulating lime renders, Diathonite Evolution, includes NHL 3.5, but there are a number of other systems available in the UK.

55 Energy efficiency & historic buildings: Insulating timber-framed walls (Historic England, 2016)

advisable to discuss with insulation providers the need or otherwise for any form of airtightness membrane or similar as part of the insulated wall assemblies.

(N.B. It is assumed that the timber frame will remain exposed internally in the main house, which excludes any coherent internal insulation approach. The existing plaster is, however, believed to be of no significance and it is assumed this will be replaced with an appropriate lime-based plaster. In the barn, the timber framed walls are already covered internally, which may provide scope to consider an appropriate internal insulation layer if required.)

4.7.2 Solid masonry walls

As noted previously (see Section 3.3), solid masonry walls often perform better than assumed by energy models and/or U-value calculations but they still lose far more heat than modern constructions. The thinness of the brick walls at Cheynes Farm will further exacerbate heat loss: the indicative calculated U-value for a 100mm-thick brick wall is 3.35 $W/m^2K$, and while this may not be wholly accurate (see above) it is significantly poorer than a thicker or insulated wall; the timber bridging elements in the exposed brick wall area may further impact on thermal performance.

Solid walls may be insulated either on the outside or on the inside – and if done well, the presence of insulation should not be apparent. External insulation (EWI) is generally the preferred option from a technical perspective, for several reasons: it is easier to achieve full coverage and avoid many common thermal bridges; it allows the thermal mass of the walls to be retained internally; it reduces any overheating risk; and if done properly it protects the wall fabric from external water ingress (e.g. wind-driven rain), which is a key risk factor for internal wall insulation and which is becoming increasingly important as the climate continues to change. In the context of traditional and historic buildings it is generally viewed as being most viable where the existing building is already rendered or has been in the past, but the changing climate means that new external coatings are increasingly being considered to protect buildings from the weather. The robustness of external insulation is also improved by some traditional building details, good maintenance and the presence of roof overhangs. Internal insulation (IWI) can also be very effective with proper preparation and detailing, but meticulous care and attention are required at all stages to achieve a coherent, unbroken layer of insulation; weatherproofing of the outer wall surface remains an ongoing challenge; it can carry increased moisture risks compared with external insulation, particularly around embedded timbers; and the increased level of disruption makes it best-suited to major refurbishment. Appropriate systems and materials must be used in all cases. Many of the potential risks associated with internal insulation can be considerably reduced where the external façade is in good condition and protected (e.g. by lime render), and in some cases, both external and internal insulation may be combined. With the right materials a combined external-internal approach can be highly successful, providing protection from the weather in an increasingly unstable climate and reducing internal space impacts.

At Cheynes Farm, current proposals are to insulate the brick walls externally and possibly internally as well. External proposals are similar to those for the weatherboarded timber-framed walls, i.e. rigid woodfibre behind ventilated weatherboarding; internal options are not yet defined and appear likely to be considered only if thermal performance targets cannot be met with external insulation alone. The fact most of the brick walls are already finished in weatherboarding means that consent should not be an issue for this approach; for the relatively small area of exposed brickwork, the need to blend in with the adjacent walls and protect the masonry from wind-driven rain should provide sufficient justification for continuing the same approach (evidence and guidance references can be provided if needed). On this basis, it is assumed that all walls will be covered externally, i.e. that internal insulation alone will not be pursued; should this change, further consideration will be needed to address the potential technical risks associated with this approach.

Regardless of approach, it would be beneficial to discuss with insulation system providers the merits of replacing the cement-based pointing with an appropriate lime-based mortar, in order to help manage moisture through the masonry particularly given the presence of timber elements.

External insulation

Assuming appropriate preparation, design, installation and aftercare, the proposed EWI approach is in line with good-practice guidance. As noted previously, EWI is generally preferred over IWI where possible as it provides a more robust solution for solid masonry walls. Use of moisture-open woodfibre insulation should allow any moisture within the masonry to dissipate to the vented cavity, while the timber weatherboarding should protect the insulation and masonry from wind-driven rain. It is important that any internal finishes are also moisture-open, to allow moisture dissipation to the inside as well as the outside, particularly as there are timber elements in the exposed masonry walls.

In our experience, many of the defects associated with imperfect EWI relate to weather ingress (often in conjunction with pre-existing defects and/or impermeable insulation systems); this makes weather protection and system selection critical, as well as effective design and installation detailing. The proposed maintenance checks & defects resolution, full roof refurbishment, new rainwater goods and improved drainage should all offer increased protection to the masonry walls; if it were deemed acceptable to extend the roof overhangs, this would provide an added layer of protection. Detailing around all openings will require careful attention during design and installation to ensure they remain robust and keep the buildings weatherproof. Further details on EWI are assumed to be unnecessary here, as the architects have prior experience of such installations and appear to have a clear idea of their preferred approach for Cheynes Farm.

If EWI alone is used, a relatively thick layer of woodfibre may be needed to achieve a low U-value (depending on target performance); this increased wall depth would require assessment and possibly consent. By way of example, 60mm woodfibre ($\lambda$ value 0.036 W/mK) on a 100mm brick wall would achieve an indicative calculated U-value of c.0.50 W/m$^2$K, while to achieve a U-value of 0.3 W/m$^2$K would require 110mm of the same insulation. (N.B. Such low U-values generally increase potential moisture risks in IWI-only assemblies, but for well-executed EWI it is generally easier to achieve low U-values without undue risk.) Should the added wall depth make this amount of EWI unacceptable, it would be possible to split the insulation between the outside and inside of the walls. The rest of this section therefore focuses on internal wall insulation (IWI), for which no suggestions have currently been made by the client or architect.

Internal insulation

Many of the risks around IWI are significantly increased where the external masonry face is exposed, particularly for such thin brick walls as those at Cheynes Farm; as noted previously, it is assumed there will be no exposed masonry once the buildings are retrofitted.

There are many considerations in selecting the most appropriate approach to internal wall insulation (IWI) in traditional buildings: these include wall condition; characteristics of external and internal faces; moisture characteristics of wall fabric and insulation; exposure and orientation; presence of timber elements; desired finish; ease/complexity of application; maintenance requirements; fixings; and so on. It must be emphasised that there is no one-size-fits-all 'best' approach – the solution for a given building depends almost entirely on a holistic understanding of its context and condition. However, for solid masonry walls a moisture-open system is nearly always recommended to minimise technical risk.

Preparation

Many of the preparation and installation guidelines are similar to those for EWI. Regardless of the system used, stripping back of wall linings and any impermeable materials lends itself to good practice for insulating traditional masonry walls internally, as most moisture-open internal systems need to be bonded directly to the masonry[56]. This also allows any damp masonry to dry out prior to insulating, although this is not thought to be an issue in the kitchen extension. Once stripped back, further inspection of the underlying wall structure and, in particular, any embedded timbers may also be carried out. Stripping back existing finishes also creates more space, allowing more insulation to be incorporated without any significant effect on floor area.

All moveable fittings and fixtures need to be removed (e.g. radiators, services, plumbing, meter boxes, fitted furniture etc.), and preparation of the external walls is also essential (to include roof, guttering and rainwater goods, adequate perimeter drainage, repointing in lime as needed, lowering of any raised external ground levels and so on): again, at Cheynes Farm it is assumed that all these measures will be carried out in any case. The siting of all new services, service routes and penetrations through the masonry walls (heating & ventilation systems, radiators, meter boxes, ductwork, pipework & cables), fitted furniture such as kitchen & bathroom units, and any other internal fittings will require careful planning in advance to ensure appropriate sequencing, and any such fixtures that could interfere with the continuity of insulation will need to be removed in advance.

Materials

Once the walls are prepared, several different insulation options may be used; the choice of system is generally determined by a combination of aesthetics, space and moisture management needs. Many moisture-open materials are natural materials with lower embodied energy and less toxicity potential than petrochemical foam insulation boards, and they can also be relatively dense which can help mitigate overheating risk. Commonly-used moisture-open systems include woodfibre boards[57], aerogel 'blanket'[58] and insulating lime plaster[59] (see below), although there are of course other materials available. An overview of these three materials is provided below.

Woodfibre is made from natural materials and has a relatively low embodied energy. There are many woodfibre insulation systems available, including soft 'batts' installed between timbers (e.g. floor/ceiling joists), rigid boards and even loose-fill woodfibre material; woodfibre is probably the

[56] If lime plaster is present and in good condition it may be possible to leave this in place, although the condition of internal finishes and extent of refurbishment work is likely to make a full internal wall strip the most robust option.
[57] E.g. Steico.
[58] E.g. Spacetherm.
[59] E.g. Diathonite Evolution / Diathonite Thermactive.

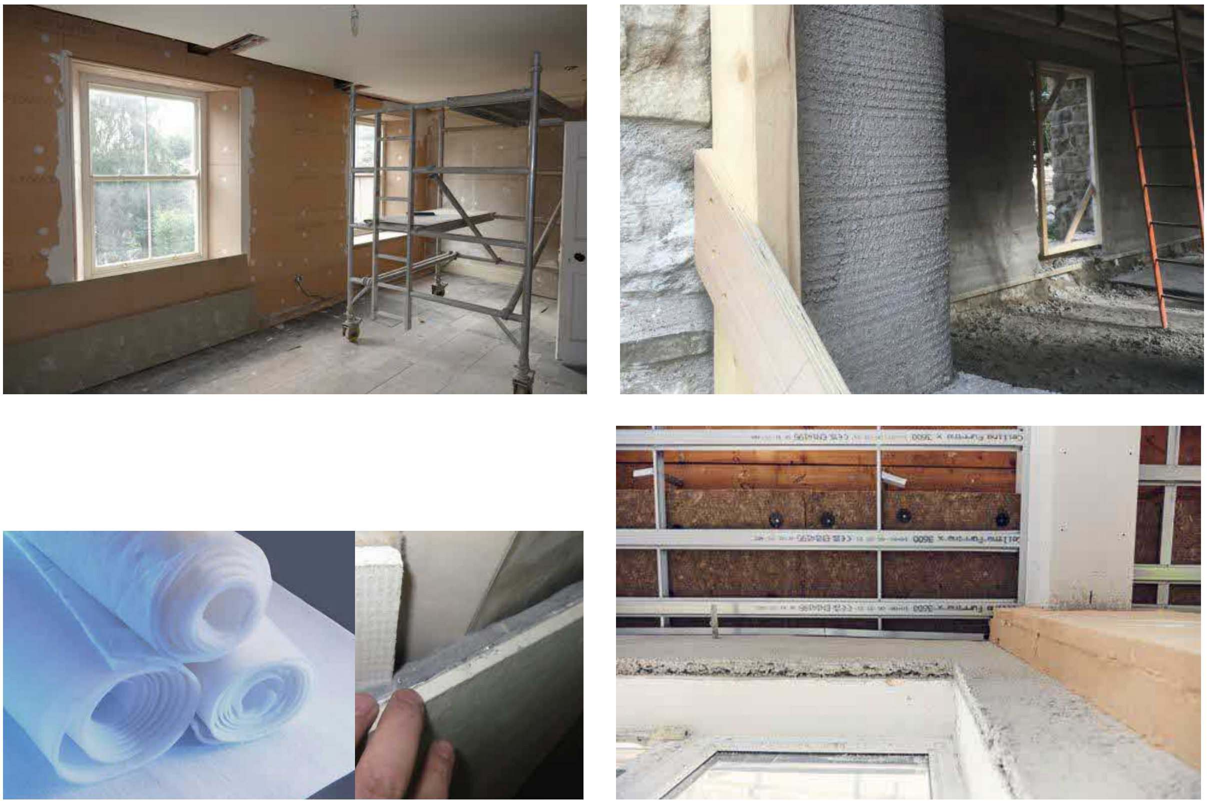
most commonly-used of the natural moisture-open insulation systems in the UK. For IWI, rigid boards are generally used, affixed to walls using adhesive and/or mechanical fixings. As with any rigid board-based insulation system, the walls often need to be levelled first using a parge coat of lime plaster (unless it can be applied directly onto pre-existing lime plaster), and the insulation boards should be taped at all junctions with an appropriate airtightness tape prior to finishing. Boards which incorporate tongue-and-groove edges lend themselves to good-quality, gap-free installation. Woodfibre assemblies are generally finished in lime plaster or with a plasterboard or equivalent, and they can also incorporate a service void on the warm side of the insulation if needed; this can provide a more robust finish that gives added protection to the insulation and any airtightness membranes. An appropriate airtightness layer (e.g. a vapour-permeable 'intelligent' airtightness membrane) may also form part of the build-up, although in some cases good airtightness can be achieved by the lime plaster layers and any external treatments. The depth of insulation is dependent on the U-value targeted but it is typically applied at depths of 40-80mm; at Cheynes Farm, this would be dependent on the amount of EWI applied. Thinner boards are available for areas where space is restricted (e.g. window reveals), but in some cases it is necessary to use aerogel in these areas (see below). Woodfibre is vapour permeable and is capillary active to a degree, allowing the passage of both water vapour and liquid water and thereby facilitating the dissipation of moisture that may enter the wall assembly; it is also hygroscopic, enabling it to help regulate internal humidity levels by absorbing excess moisture during periods of high relative humidity.

Aerogel is a man-made, vapour-permeable material and has an extremely good thermal performance, which means that a good level of insulation can be achieved with a significantly thinner layer than would be needed with most other insulating materials. It is also one of the most expensive insulating systems. For these reasons, aerogel tends to be used where space is at a premium – e.g. around window reveals, on walls with cornices, at the back of cupboards – although it can also be used on curved walls as it is flexible in some forms; it can also be used behind window shutters and wood panelling, all of which may be removed and replaced over the insulation. Aerogel is available as a 'blanket' (affixed to the wall with mesh and finished in lime plaster) or pre-bonded to plasterboard or magnesium board. The depth of insulation is dependent on the U-value targeted, but it is typically applied at depths of 10-30mm. As noted above, aerogel is vapour permeable, but it is not capillary active or hygroscopic.

Insulating lime plaster is becoming significantly more popular in recent years; there are now many different systems available in the UK, some of which are manufactured in the UK and some of which have a longer track record in mainland Europe. Most systems are essentially similar, but use a range of different materials (e.g. cork, hemp, perlite, recycled blown glass beads or other recycled mineral aggregates) to improve thermal performance. Thermal performance varies accordingly and the difference can be considerable, but the best-performing system currently available[60] has an equivalent thermal performance to woodfibre. Insulating lime plaster is broadly similar to conventional lime plaster, but is generally sprayed on in layers: while messy, this installation process makes it relatively easy to achieve good coverage, access awkward areas and minimise thermal bridges. These systems are also relatively simple, providing multiple functions (levelling, insulation, airtightness and finish) in a single product. Being a wet system some drying time is required, which can be facilitated by carrying out the installation at an appropriate time of year (i.e. summer) and

[60] Diathonite Thermactive.

ensuring adequate heat and ventilation during the drying period. Insulating lime plasters are becoming increasingly popular for traditional building retrofits, partly due to their moisture-managing abilities and partly for the 'all-in-one' approach, and are in keeping with the traditional lime plaster finish often used in older buildings. The depth of insulation is dependent on the U-value targeted and the thermal performance of the system selected, but the best-performing system is typically applied at depths of 40-60mm (again depending on the amount of EWI applied at Cheynes Farm). Like woodfibre, insulating lime plasters are vapour permeable, hygroscopic and capillary active, although they are more capillary active than woodfibre and this means they can be particularly effective in managing moisture; they also tend to have particularly good fire ratings, and are alkali meaning they are naturally mould-resistant. Anecdotal reports suggest that some systems can be somewhat fragile; this would require further exploration with system providers. It should also be noted that insulating lime plaster can on occasion be used in conjunction with woodfibre, providing a thick, insulating parge coat below the woodfibre; this approach has been successfully used on several recent UK retrofit projects[61].



Figs. 29-32 (Clockwise from top left) Woodfibre; insulating lime plaster; combined woodfibre + insulating lime plaster; aerogel (© Nicholas Heath / Bob Prewett / CISL)

At Cheynes Farm, the planned use of woodfibre externally may make this a sensible choice for any internal insulation, minimising the number of different materials contractors are asked to install. However, it is possible that slim systems such as aerogel may be needed around reveals and other areas of restricted space.

[61] E.g. The Entopia Building in Cambridge, which achieved the EnerPHit performance standard.

Depth of insulation

In many cases, moisture-related risks with IWI increase as the insulation gets thicker. The thicker the IWI layer, the less heat from inside will reach the masonry, and cold walls can increase the likelihood of problematic moisture build-up. The effects of thermal bridging and/or gaps in the airtightness layer (see below) can also be increased where very thick layers of insulation are used.

While most of these issues should be largely addressed by the proposed EWI installation, increased insulation depth brings with it a further consideration where insulating lime plasters are concerned, namely drying time and internal conditions during this period. It is important that these systems should be installed at an appropriate time of year as cold, damp conditions will considerably prolong the drying time – but if a thicker-than-average layer of insulating lime plaster is installed this will also affect drying times. Where new solid floors are installed this will also contribute to internal humidity as it dries, and this combined with a wet IWI system would create a considerable drying load. Clearly, the use of a dry, board-based insulation system would avoid these drying issues.

In addition, for any insulation the greatest impact comes from the initial layers, i.e. the law of diminishing returns is observed, with a relatively modest amount of insulation providing significant benefits but ever-thicker layers providing ever-decreasing returns. Various guidance also suggests that coherence and good detailing of insulation and airtightness layers can be more important and beneficial than a thicker layer of insulation alone. At Cheynes Farm, it is not anticipated that a thick layer of IWI would be required in any case given the planned EWI.

Detailing, coherence & coverage

Regardless of the insulation system chosen, it is important to achieve thorough insulation coverage to avoid leaving thermal bridges which lead not only to heat loss (undermining the performance of the insulation) but also moisture build-up and associated problems; this should not be such an issue at Cheynes Farm as there will be a coherent layer of EWI on the other side of the masonry. While this should not be such an issue at Cheynes Farm as there will be a coherent layer of EWI and general stripping back works are planned, particular care is required to achieve continuity at junctions between different building elements (e.g. window-wall junctions, roof & floor junctions) and around any service penetrations. Much of this can be achieved by appropriate sequencing of works and good communication between contractors; technical fixes are likely to involve the use of airtightness tapes and services penetration grommets at key interfaces, opening-up of floor and ceiling perimeters to allow insulation to continue through these areas, early completion of any wall stripping and preparation works, and possible use of thin insulation systems in areas such as window reveals where space is often restricted. These may seems like small details, but leaving small gaps can have disproportionately large effects, all of which should be avoided wherever possible.

If any of the above areas cannot be addressed for any reason, 2D thermal bridge analysis can be beneficial to assess risk levels for individual junctions.

With any internal wall insulation system, specialist materials and fixings may be required where e.g. kitchen units or other wall hangings are required. This can require careful consideration at an early stage, and early discussions with system providers can be beneficial in this respect.

Whichever insulation system is chosen, manufacturers and suppliers should be contacted for more detailed design and specification discussions (contact details can be provided on request), and the use of experienced contractors is recommended. Manufacturer's guidelines for preparation, application, curing and maintenance should be followed precisely, together with good-practice retrofit guidance for traditional buildings (referenced throughout this report; also see Section 7), in order to avoid problems and ensure the system functions as intended.

Embedded timbers

These are often among the most vulnerable elements in masonry walls. Timbers can be affected by moisture build-up from both inside and outside, as well as from maintenance issue, e.g. defective rainwater goods and drains, raised external ground levels. Risks are elevated under certain conditions: these include weather exposure, use of an impermeable insulation system internally, application of a thick layer of insulation, failure to address airtightness and insulation around embedded timbers and inadequate internal ventilation. While some risk factors (e.g. location) are hard to resolve, many can be minimised through good design and attention to detail during installation.

At Cheynes Farm, it is anticipated that most risks can and will be addressed through the general thorough approach to works and the planned EWI and weatherboarding; in addition, the kitchen extension is a single-storey building with a solid floor and it is assumed there are no embedded roof timbers. Nonetheless, the exposed brick walls to the rear contain timber frame elements which it is assumed will remain in situ; while the risks outlined above are deemed to be relatively low overall in this case, these timber elements make it all the more important that any IWI is designed and installed in accordance with good-practice guidelines for traditional buildings.

Further guidance & assessment

Further guidance on the principles and detailing of internal wall insulation in traditional buildings should be read at an early stage to inform the detailed design and installation works further. A list of relevant resources is provided at Section 7, but particularly recommended guidance includes the Sustainable Traditional Building Alliance's A Bristolian's guide to solid wall insulation (STBA / Bristol City Council, 2015), the Scottish Ecological Design Association's Sustainable Renovation: Improving homes for energy, health & environment (SEDA, 2018), Historic England's Energy efficiency & historic buildings: Insulating solid walls (Historic England, 2016) and BEIS' Retrofit internal wall insulation: Guide to best practice (BEIS, 2021) – all of which are freely available online. As a summary, however, a review of the two drawings overleaf (taken from the above SEDA guide) will help reinforce the importance of an informed approach. Case studies are also available across the UK; details of projects involving any particular system or approach can be provided on request.

Any solid masonry wall insulation, particularly if applied internally, can benefit from a robust moisture risk assessment, and this is specifically recommended in increasing good-practice guidance for internal wall insulation. While it is anticipated that the proposed assemblies at Cheynes Farm should be relatively low risk if designed and installed effectively, a detailed hygrothermal analysis[62] can help assess how moisture in the proposed wall assembly is likely to behave over time in reality. We would be happy to provide this service if required, and can provide more details on request.

[62] Using software such as WUFI, in line with BS 15026 and as recommended in BS 5250 Management of moisture in buildings (BSI, 2021) and in guidance from BEIS, the BRE, the STBA and Historic Environment Scotland, among others.

## Common Issues with Conventional Internal Wall Insulation

### Energy Problems

1. heat loss via gaps in the insulation
2. heat loss: no insulation across floor joist junction with wall
3. heat loss around window: insulation is not taken into reveals
4. air leakage around window
5. increased heat loss due to saturation of wall in places
6. thermal bypass: cold air behind plasterboard cools internal surfaces increasing radiant heat loss
7. thermal bypass: cold air flowing behind plasterboard draws away heat within fabric to outside
8. high performance insulation with high embodied energy

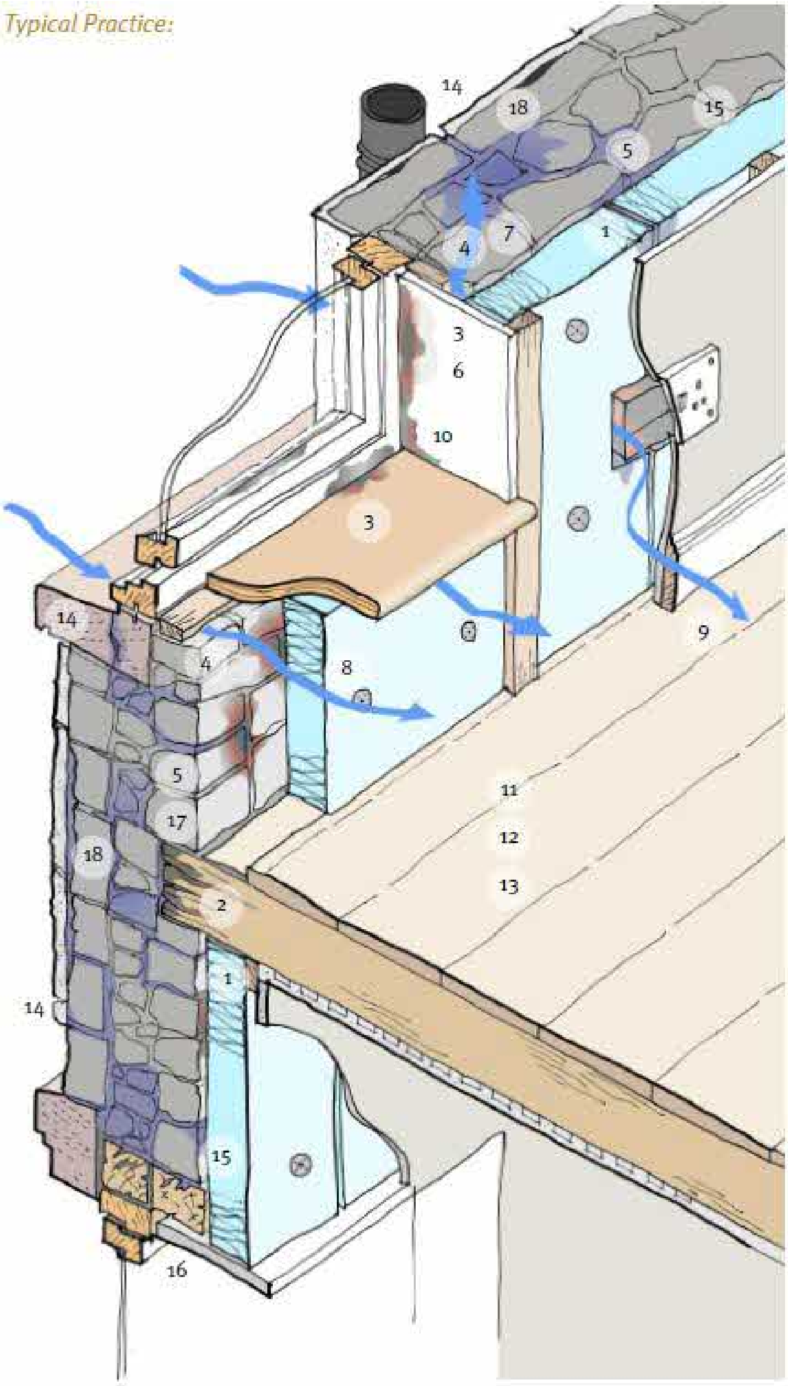
### Comfort & Health Problems

9. discomfort due to draughts
10. condensation and mould forming on cold surfaces
11. internal insulation reduces access to thermally massive / hygroscopic surfaces, increasing fluctuation in temperature and humidity, with accompanying increased health risks
12. reduced IAQ: increased presence of mould spores, increased humidity, VOCs etc. from synthetic materials

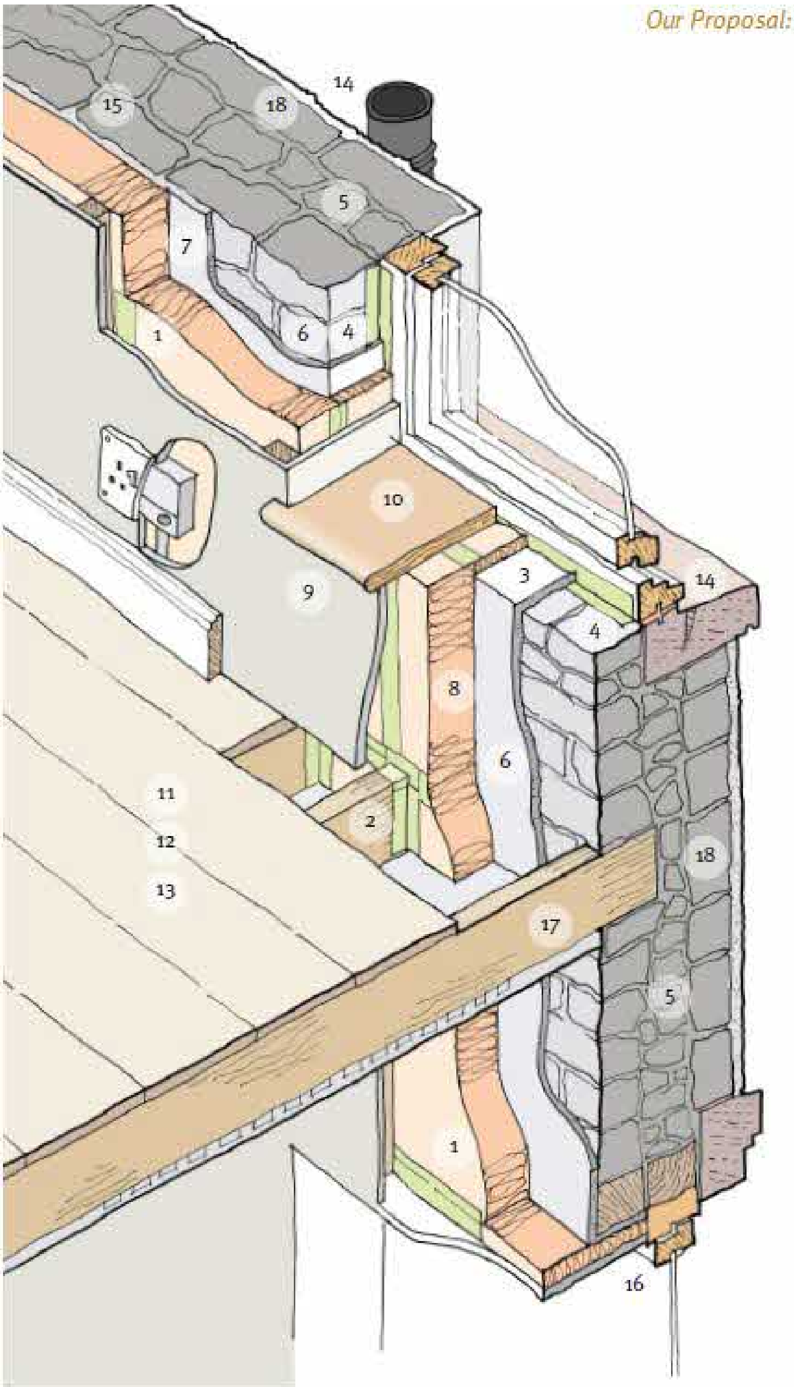
### Building Fabric & Conservation Problems

13. loss of original cornicing / plaster / linings, both a conservation loss and a resource / waste issue, more to landfill
14. opportunities for maintenance and repair not taken, with conservation and practical implications. (downpipe fixing loose, downpipes blocked / water flowing into hole created, crack in cill, cracks in render and missing / boss render.) this also creates H&S issues if masonry falls
15. combination of interstitial condensation, gaps in insulation, rainwater penetration, lack of breathability and capillary action create moisture spread between insulation and wall - ideal conditions for rot
16. increased risk of rot / insect attack of timber safe lintols
17. increased risk of rot / insect attack of floor joist ends
18. saturation of wall leading to increased risk of leaching of salts, failure of mortar, spalling of masonry to outer faces

*Typical Practice:*




*The drawing on the left shows a range of problems which can result from poorly conceived and installed internal wall insulation. The drawing on the right shows our recommendations for avoiding almost all of these problems and achieving in reality an energy efficient, healthy, and durable installation.*



*Our Proposal:*

**Recommended Internal Wall Insulation Solution**

**Energy Solutions**

1. no gaps in insulation, all joints / corners taped
2. insulation taken across floor depth and taped against all joists
3. insulation taken into all reveals.
4. window fully taped / sealed to surrounding wall (no air leakage)
5. wall remains dry: better insulation
6. no thermal bypass: no cold air entering, insulation tight to wall: internal surfaces remain warm
7. no thermal bypass: no cold air behind plasterboard so no heat loss
8. natural, hygroscopic insulation with lower embodied energy

**Comfort & Health Solutions**

9. no draughts, greater comfort regardless of air temperature
10. all surfaces are relatively warm: less risk of condensation and mould
11. relatively dense and hygroscopic insulation offers both thermal and moisture balancing mass, so temperature and RH fluctuations from loss of access to masonry not as problematic
12. minimal reduction to IAQ through use of natural materials, non-toxic finishes, more balanced RH, less risk of mould

**Building Fabric & Conservation Solutions**

13. loss of original fabric still an issue, but refer to alternatives for an approach which avoids all removal of original finishes
14. external maintenance carried out first. downpipe cleared, fixing repaired, render repaired, all pointing and render in lime to allow wall to dry out, crack in cill repaired. no h&s issues with insecure masonry
15. vapour permeable insulation + equalising coat reduces risks of interstitial condensation; condensation that does occur is diffused within construction and can dissipate
16. reduced risk of rot / insect attack of timber safe lintols (dry wall, warm surfaces, moisture can dissipate internally)
17. reduced risk of rot / insect attack of floor joist ends, same reasons as above
18. wall remains relatively dry, thus reduced risk of leaching of salts, leaching of mortar, spalling of masonry to outer faces via freeze / thaw action etc.

## 4.8 Airtightness & ventilation

It is increasingly clear that, in terms of ventilation and indoor air quality, projects involving a significant level of retrofit should be viewed as new constructions. Indeed, BRE guidance specifies exactly this approach: 'In those cases without restrictions relating to historic buildings, it may be more prudent to follow the new build requirements of the regulations … This should only be considered the starting point when assessing ventilation provision, since the introduction of thermal upgrades may influence moisture movement within a building'[63]. This is echoed by another well-regarded low-energy building services consultant: 'If you just follow Building Regulations you're probably under-ventilating'[64].

Airtightness measures have been partly covered in previous sections, but further detail[65] is needed to highlight the importance of this issue. Uncontrolled air leakage should be avoided as this undermines the intended performance of the insulation layer, but sufficient controlled ventilation is essential. Whether intentionally or unintentionally, insulating the building fabric will generally help address infiltration by blocking off uncontrolled gaps in the building envelope, but this alone should not be relied upon: good airtightness does not happen by accident … it requires forethought and a delivery plan'[66]. Maintenance works, fully-insulated roofs, floors and walls, high-performance new windows and doors, a small new-build extension and wet plaster finishes will all improve airtightness (assuming good design and installation), although these will be offset to some extent by any open chimneys.

No airtightness tests have taken place at this stage. In many retrofit projects, three tests would ideally be conducted: one before any works have taken place, to establish the baseline airtightness and set a target; one after the main works are complete but before finishes are applied, to confirm whether the target has been met and identify any outstanding areas requiring attention; and one post-completion to confirm the final performance. If only one test can be conducted the middle one would be the most valuable, in order to remedy any outstanding areas of weakness. Without testing, post-retrofit airtightness levels can only be estimated: assuming all of the above measures are implemented to a good standard, it is estimated that – depending on the chimney strategy – an air permeability of somewhere around 4-8 $m^3/hr/m^2$ @ 50 Pa might be achieved.

The more airtight the building becomes (and certainly below 5 $m^3/hr/m^2$ @ 50 Pa), the more important it becomes to consider mechanical ventilation. The importance of ventilation is increasingly highlighted in technical retrofit guidance but nonetheless is frequently misunderstood or dismissed, and this partly explains the low general awareness of its benefits and of the options available. Ventilation controls not only moisture (particularly important in older buildings) but also pollutants, helping maintain a healthy living environment and good indoor air quality. It can also help manage overheating, but this should not be misinterpreted: 'you can't ventilate away overheating'[67] and no design strategy should rely on ventilation to manage internal heat levels, but it can be part of a wider strategy to help cross-ventilation, night-time purging and so on, which will be particularly important across the UK given the changing climate.

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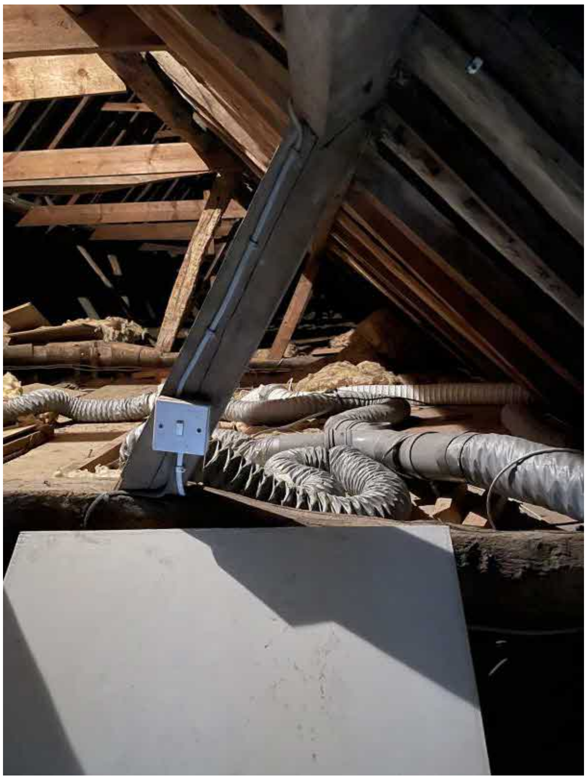
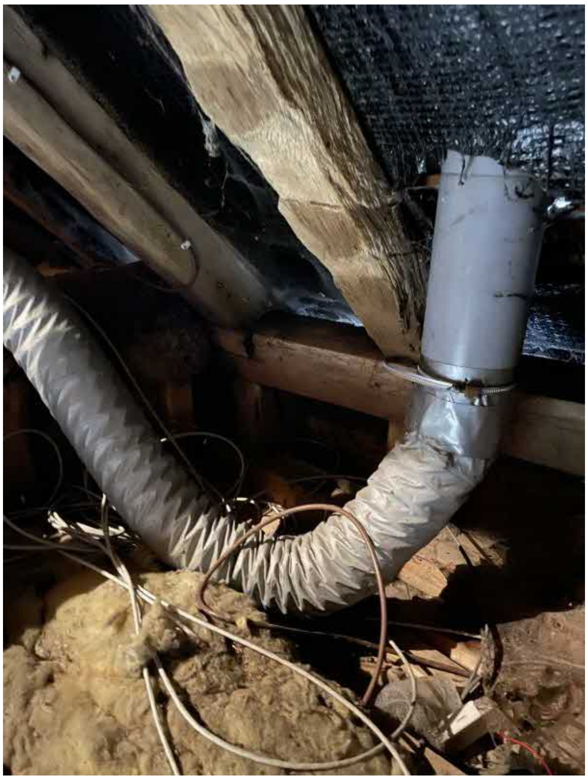
[63] Designing out unintended consequences when applying solid wall insulation (BRE, 2016)
[64] Alan Clarke, during a ventilation training course.
[65] Demystifying airtightness: Good practice guide (Passivhaus Trust, 2020) provides detailed advice on achieving desired airtightness rates.
[66] Paul Jennings, The airtightness process (AECB online training session, May 2020)
[67] Alan Clarke, during a ventilation training course.

At its simplest level domestic ventilation tends to rely on natural ventilation (via window opening, chimneys and other infiltration including trickle vents where present) supported by intermittent extract fans in wet rooms. Unfortunately this is largely uncontrolled and is often not sufficient particularly following insulation and airtightness works, and homes that in many cases were built to rely on natural leakage are less able to do so as they become better insulated and more airtight. The other key variable is building user, who is often unaware of the importance of ventilation and overrides ventilation routes (for example, by turning off extract fans, closing trickle vents, blocking other vents, or not opening windows to avoid heat loss, running costs and/or traffic noise). In the case of Cheynes Farm the current occupants appear to have a good understanding of ventilation and occupant levels are modest for the size of the property, but any ventilation system should be futureproofed to cater for different occupancy patterns and levels of understanding.

It is not possible to provide detailed ventilation guidance in this report as the target airtightness levels are not yet known. At the very least, robust ventilation systems should be installed in wet rooms; the age and construction of the buildings at Cheynes Farm mean that a single centralised, whole-building system is unlikely to be viable, but one or more smaller centralised systems may be appropriate in some areas (e.g. the cluster of first-floor wet rooms in the farmhouse, and/or the kitchen extension). Figs. 33-34 show the current set-up above the first-floor wet rooms, which would benefit from improvement: the ducting is unnecessarily long, which will increase resistance and noise and could increase the likelihood of debris and condensation; flexible ducting will also increase resistance and noise and is more prone to crushing than rigid ductwork; and the roof penetration appears ad-hoc and is not sealed. The controllability and efficiency of this ventilation is not clear, although there are no reports of moisture issues in these wet rooms and occupancy levels are modest.





Figs. 33-34    Extract ventilation provision above first-floor wet rooms

There are two main options for continuous mechanical ventilation, either a centralised system – with ductwork leading from wet rooms to a central fan unit – or a decentralised system – where each wet room has its own fan unit. Centralised systems are generally preferable on performance grounds, but it is not always possible to accommodate such systems if space cannot be found for duct runs. If decentralised (i.e. individual room) systems are preferred, care should be taken to install high-quality units with a good reputation, as it can be hard to achieve the stated performance levels with decentralised systems.

Regardless of the ventilation approach adopted, early incorporation of the ventilation strategy into the design and installation works will help facilitate siting of any fan units and ductwork and optimise performance. Good guidance is available and system providers should provide detailed, project-specific recommendations, but for centralised systems fundamental considerations such as using the right ductwork, minimising duct runs and bends, and appropriate siting of the fan unit (to avoid any noise implications but ensure it is accessible for maintenance) are generally easy wins. Any inlets or outlets should be discreet to blend in with the building fabric[68].

Should a centralised system be desired there are two main options, either MVHR (Mechanical Ventilation with Heat Recovery) or MEV (Mechanical Extract Ventilation). For a project such as this, selection would be largely dependent on client preference and retrofit targets, but it is assumed that a high-performance, demand-controlled MEV system(s) may be more appropriate than MVHR. Given the client's background and technical understanding of such services, no further detail on these options is provided here (further information can be provided on request).

In terms of aesthetics, a range of vent options are available to help blend in with the surrounding building fabric, but function must come first: a ventilation system is fundamentally impaired if it does not function as required, and this in turn affects the performance of the building and the wellbeing of its occupants.

For any centralised ventilation system it is advisable to use the services of a specialist third party to help with the design and specification of the system and avoid common pitfalls – some system providers may be able to provide this design support as part of their service, but independent support can be beneficial. Regardless of the final choice, the system should be as simple, clear and robust as possible, with minimal need for user interaction and easy controls. Any maintenance needs must be carried out regularly to avoid system under-performance.

### 4.9 Overheating

For Cheynes Farm, the main farmhouse and kitchen extension have long façades facing East and West but windows are not unduly large, and the surrounding greenery should help mitigate overheating risk to a degree; the converted barn includes a large area of South-facing glazing which could contribute to significant solar gain, although this space is not a core part of the daily living space which will limit comfort impacts. Summer comfort is not currently noted as being an issue in the property, but there are no external shading mechanisms; following retrofit the buildings are likely to be considerably better insulated and more airtight; ventilation appears likely to be managed by a combination of localised extract fans and manual control via windows; and the climate continues to

[68] The architect has suggested Tudor roof vents.

change (see below). While the overheating risk for Cheynes Farm is deemed to be relatively low overall, some consideration of this issue is nonetheless advisable to help safeguard the performance of the buildings in the long term.

High summer temperatures – likely to become more of an issue in the future (see Section 2.3) – can cause considerable discomfort and potential health issues during extremely hot weather periods, particularly at night in buildings where it is hard to purge the hot air. The design of any new or retrofitted building should consider the need for it to be passed on to future generations as a year-round sustainable building. Fig. 35 shows the range of possible future temperatures (summer and winter) for Luton, based on best- and worst-case scenarios. Note that in the worst-case scenario (emissions continue unchecked through the 21st century), average temperatures by 2100 could be nearly 5ºC higher in the winter and almost 6ºC higher in the summer.

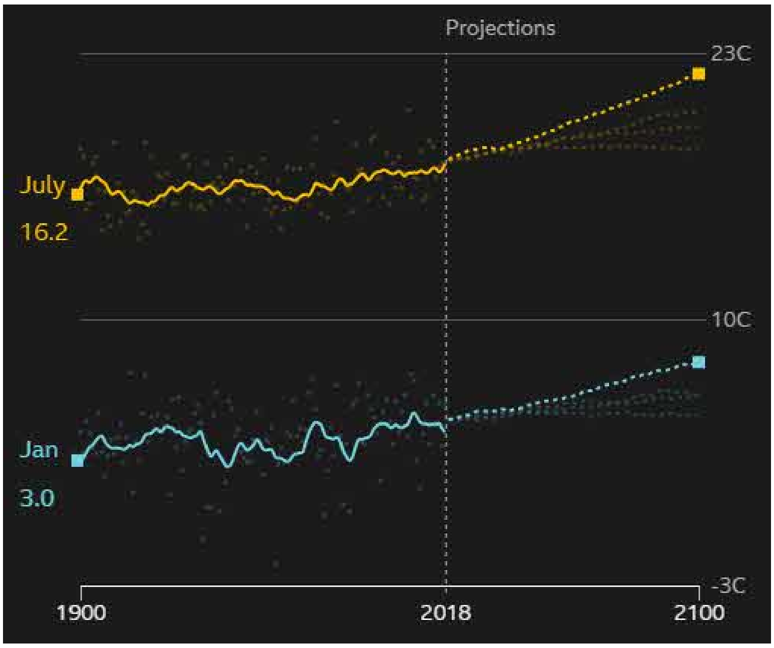



Fig. 36 How much warmer will Luton be? (© BBC[69])

Detailed overheating assessment is beyond the remit of this report, and some mitigation measures can be harder to implement in existing buildings and in an aesthetic context like that of Cheynes Farm, but some of the following measures may be beneficial for this project:

- Minimise internal gains via high-efficiency lighting & appliances, & efficient, well-insulated hot water pipe runs and storage vessels, all sited in appropriate locations
- Effective ventilation (see above)
- Surrounding greenery for shading & absorption of solar irradiation
- Careful assessment of size, type and transmittance factor (g value) of new glazing to achieve a balance between daylighting, heat loss and solar gain; avoidance of excessive East-, South- or West-facing glazed areas in any new extensions

[69] https://www.bbc.co.uk/news/resources/idt-985b9374-596e-4ae6-aa04-7fbcae4cb7ee (accessed December 2022).

- Use of dense rather than lightweight insulation materials, and external rather than internal insulation where possible
- Shading to glazed areas:
  - External shading is considerably more effective than internal shading as it prevents heat getting into the building in the first place. Common options include fixed horizontal and/or vertical shades, external shutters (hinged or sliding), external blinds (manual or automated), and trellises (which can also benefit from deciduous plant growth, providing shade during the summer but not during the winter). External sliding louvres or similar can also be integrated over external doors and windows, allowing them to remain open for ventilation while keeping the sunlight out. Options at Cheynes Farm are likely to be limited for aesthetic reasons, but should be carefully assessed nonetheless (even if only to rule them out)
  - Internal shading is not nearly as effective as external shading, but may be beneficial for any windows where summer comfort may be an issue (e.g. bedrooms). Timber shutters can be more effective than blinds, and are in keeping with the traditional character of older buildings, but these would require early integration into the design and would likely be bespoke for the property; they can also help reduce heat loss during the winter months
- Appropriate behaviour and a good understanding by occupants

## 5.0 HEAT & POWER

(N.B. This report focuses on building fabric upgrade options, as the client's background and experience gives them a sound understanding of the services options for the buildings and a relatively clear idea of the preferred options has already been set out. This section is therefore relatively brief, highlighting particularly relevant considerations. Further detail on these and other micro-renewable technologies in traditional buildings is available in Section 7.)

Space and water heating are provided by a combination of oil-fired central heating with radiator distribution and electric underfloor heating (UFH), supplemented by an inefficient open fireplace and closed stove likely to be of some age. Radiators are old and/or undersized in some rooms, and controls are not known in detail. While the boiler is relatively new and therefore likely to be reasonably efficient, the client reports that the overall heating configuration and pipe runs are currently very inefficient. The client reports that there is no micro-bore pipework in the property. Electric UFH is not generally regarded as being cost-effective where it forms a significant part of the space heating system.

The client is aiming to make the property sufficiently well-insulated and airtight for heat pump technology to be viable in terms of efficiency and running costs. At present there is an aspiration to explore the potential to use a combination of water-source (drawing from the existing pond) and air-source heat pumps, although the viability of the water source is by no means clear and requires considerably more investigation.

For all technologies, the use of local installers is generally preferable as this makes resolving any issues and accessing regular maintenance simpler; they should also have experience of local conditions and similar types of installation, which should improve the likelihood of a successful installation.

### 5.1 Heat pumps

The efficiency of a heat pump is determined by several different factors, but the thermal performance of the host building is key and good levels of insulation and airtightness will considerably increase a heat pump's efficiency. Manufacturers' performance claims should be treated with caution, but by way of example a well-installed air source heat pump (ASHP) retrofitted into a reasonably well-insulated and airtight property might achieve a COP of c.3 (i.e. a 3:1 ratio of energy generated vs energy used). Assuming all the works set out in this report are implemented to a good standard, heat pumps may therefore provide a good fit for Cheynes Farm, and the possible new ground floor would facilitate the introduction of under-floor heating which provides a good fit with heat pump technology. The more the works are scaled back, however, the less viable a heat pup system would become, not only in terms of environmental benefits but also running costs, particularly given the recent and likely future electricity cost trends.

While water-source heat pumps (WSHP) are the most efficient option (all things being equal), it is not clear whether the existing water body at Cheynes Farm has sufficient capacity to make such an installation viable, particularly as it is known to dry out annually. While the planned diversion of rainwater into this water body may help in this respect, the prediction for longer, drier periods of weather does not bode well in this respect, and any installation should be planned to function over the long term. ASHPs are planned to take over when the proposed water-source systems stop functioning, but it would be advisable also to consider ground-source (GSHP) as an option, given the long-term predictability of this heat source, the longevity of ground-source systems and the extensive space available for either a trench or borehole system; this would also remove the need for 'back-up' ASHPs. Any GSHP installation would be subject to installer and ground condition surveys, and the installation costs are significantly higher than those for ASHPs (although where space permits, a trench system can be considerably cheaper to install than a borehole system), but the longevity, performance, noise and aesthetic benefits may make this additional cost worthwhile.

ASHPs require little explanation or narrative for this project, for reasons already explained. While the proposed siting means that noise and draught should not be an issue, higher-end fan units tend to be quieter and lasting longer than cheaper models[70].

The lack of micro-bore pipework and the numerous undersized and/or ageing radiators may lend weight to the case for under-floor heating throughout the buildings, maximising the efficiency of any heat pumps at the same time as creating insulated floors and removing the costly electric UFH.

Controls should be simple and their operation must be well understood by occupants, as they do not deliver heat in the same way as conventional boiler systems that can provide rapid heat increases as needed; the client is assumed to have a thorough understanding of this and all technical aspects of the technology.

In terms of finance, GSHPs are considerably more expensive to install than ASHPs but should last far longer. As noted previously, the current climate of ever-increasing electricity costs mean that building efficiency and consequent heat pump efficiency will be critical in controlling running costs. Heat pumps historically attracted a considerable income stream through the Government's domestic Renewable Heat Incentive (RHI) subsidy, but this has been replaced with a cashback scheme which currently provides a grant towards the capital costs of some renewable energy measures[71].

Increases in both environmental and financial savings can be achieved by combining a heat pump with other renewable energy technologies (e.g. photovoltaics and/or solar water heating).

## 5.2 Biomass

Biomass boilers can be relatively sustainable where there is a truly sustainable local fuel supply. However, they are not common in domestic buildings and require more occupant interaction than other heating systems; the long-term price and security of fuel supplies is also uncertain. At this stage it is assumed that a biomass boiler is not of interest for this property (should this not be the case, further information can be provided on request), but a high-efficiency log stove may be beneficial.

[70] There are many different makes and models of fan unit, and installers are likely to have their own preferences – care should be taken to understand why any particular make or model is being promoted. Cost tends to dictate quality so it is generally worth paying more for a better unit, which should last longer and perform better. If noise is an important consideration, Stiebel Eltron models are reported to be relatively quiet. There are also higher-end units such as the Austrian Ochsner systems available, but these inevitably come at a cost.
[71] https://www.gov.uk/apply-boiler-upgrade-scheme

Wood stoves lend themselves to traditional buildings, and can often accommodate fireplaces and chimneys within which stoves and flues can be sited. At Cheynes Farm there is currently an open fire and a closed stove (age & model unknown): while open fires and some older stoves are highly inefficient, modern stoves can be over 90% efficient, providing far more heat for far less fuel; higher-end stoves also include technology to minimise particulate emissions[72] and are not particularly more expensive to buy than lower-efficiency models. Depending on siting and weather conditions, they can either be used a main heat source if the whole house does not need to be heated, or as back-up heating during extremely cold weather or, when paired with an electric heat pump, in case of power cuts. The fact they provide mainly radiant heat is also beneficial in terms of comfort, as radiant heat is more important than air temperature in determining human comfort[73].

Where there is a truly sustainable, local source of fuel the $CO_2$ load of high-efficiency stoves is negligible. The manual and visual elements of running a wood stove are also helpful in keeping users in touch with fuel consumption and efficiency as, unlike most other heating systems, users inevitably become aware of how much fuel they are using, how long it takes to burn, how much heat it generates and how much fuel is left.

Fuel quality is essential in managing efficiency and air quality, and care should be taken in this respect: properly-seasoned hardwood that is kept dry and well ventilated will produce significantly more energy and less waste and pollution than poorly-seasoned softwood that is kept in poor conditions.

## 5.3 Solar energy

The client has no interest in considering solar technologies at this stage, although this may change if/when the outbuildings are converted and possibly when the small new extension is being designed. Some narrative on both solar thermal and photovoltaics (PV) is therefore provided, for future reference.

As well as the existing outbuildings, it may be possible to incorporate a solar array onto the roof of the new extension particularly if a mono-pitched design is used, as this would face West and appears unlikely to receive any significant shading (although this would require further assessment, mainly for the trees along the North boundary). The relatively small size of the new roof makes solar thermal more likely than PV to be viable, as the latter requires a relatively large area to install a meaningful array. If there is any possibility of retrofitting solar technologies onto this roof at a later date, this should be factored into the design to avoid conflicting siting of rooflights or flues.

In relation to aesthetics and visibility, it is worth noting that there is commonly a presumption that solar technologies are best hidden away out of sight. This creates an implicitly negative view of solar power in the context of traditional and historic buildings. In some instances, there can be a case for deliberately making such systems visible in order to emphasise and raise awareness of the sustainability credentials of the site. Clearly care is required in this respect, but in the right circumstances and with early local authority engagement this can be a positive approach.

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[72] For example, British-made Burley stoves claim the highest efficiency in the world, and their stated efficiency and particulate emission rates are well beyond the minimum requirements of the Eco Design 2022 and clearSkies standards.
[73] Source: AECB CarbonLite course

### 5.3.1 Solar water heating

Solar thermal systems (either flat-plate panels or evacuated tubes) can provide a useful contribution of free, renewable hot water in the right circumstances (a generic rule of thumb is c.50% of annual hot water needs), and can be linked in with a heat pump. However, capital costs remain relatively high which affects the cost-benefit ratio (although these initial costs can be offset to some degree by the cashback scheme mentioned previously).

While there are many design variants, there are two basic types of solar thermal array: flat-plate panels and evacuated tubes. The former are more common and robust; the latter cost slightly more but are also slightly more efficient, can provide a pleasing aesthetic in the right setting and can be laid flat which increases discretion on flat roofs. There are also combined systems that incorporate both solar thermal and photovoltaics (PV) with a uniform appearance.

In terms of siting, orientation and lack of shading are important, although the latter is not so critical as it is for PV (see below). While South is the optimal orientation for any solar array, anywhere from East to West is viable; in all cases, care would be needed to minimise shading from future tree growth.

### 5.3.2 Photovoltaics

Photovoltaic (PV) electricity is a relatively simple renewable energy technology, tried and tested and generally reliable as long as it is suitably sited and not shaded. A good system should still be generating 80% of its original output after 20 years, and replacement is generally straightforward; a typical array should have an anticipated lifespan of c.25 years, although some electrical components (e.g. inverters) are likely to need replacing around every 10 years. Predicted output is also relatively accurate (unlike many other renewable energy technologies), and in some instances actual output can exceed predictions. However, it is important to note that the savings associated with PV can vary widely, mainly dependent on lifestyle and energy use habits.

Of the electricity generated by a PV array, an indeterminate proportion will be used directly at source (i.e. in the home, as it is generated) while the rest will be diverted into the national grid. Exported energy receives a modest payment, but this is significantly lower than the per-unit cost of electricity bought by domestic customers, i.e. a householder sells daytime-generated electricity to the grid for a low price, then has to buy it back at a higher price when they need it in the evenings. Clearly, therefore, the more PV-generated energy that can be used at source and the greater the fuel bill savings will be: most generic estimation tools assume 25% may be used at source, but this figure can be much improved where occupants will be at home for a lot of the day and can plan daytime use of appliances. There are several ways to maximise the financial benefits, and straightforward guidance is available online.

One of the most effective methods of maximising the benefits of PV is to store the power that is generated for future use as needed. While batteries are available, performance and capital costs are not always sufficiently beneficial to make this worthwhile, although this is likely to change in future. An alternative way of maximising benefits is to install it in conjunction with other renewable energy technologies: the suggested heat pump provides a mechanism for this, as it runs on electricity and so can use PV-generated electricity at source, thus avoiding diversion into the grid and consequent financial impacts. PV arrays can also be connected to an immersion heater in the thermal store, allowing them to 'dump' the electricity they produce into the thermal store and store the energy in the form of hot water. Further benefits can be realised by charging electric vehicles, for which the infrastructure is already in place at Cheynes Farm.

PV output predictions are usually reasonably reliable, but it is harder to account for issues like shading which can have a considerable impact on output depending on design: with a single inverter, all panels are linked (unless the array is split) and shade falling on a single panel affects the whole array, but this can be mitigated by using micro-inverters which effectively allow affected panels to be isolated. Assuming good siting conditions with no shading, a typical 4kWp domestic array at Cheynes mounted on a South -facing roof pitch (e.g. the timber outbuilding) should generate towards 4,300 kWh/yr, or if sited on the West-facing extension roof the same array should generate c.3,500 kWh/yr[74].

Performance can also be affected by site conditions and system selection. Recessed panels can be cost-efficient as they form part of the roof covering, and they are generally more discreet than surface-mounted panels which can make them preferable for planning. However, they can require removal of existing tiles, and could present a greater risk of overheating[75] as it is harder to gain good airflow behind the panels. PV can also be integrated into glazing, which can create pleasing dappled light internally, but these systems are less efficient than high-quality panel systems; the same applies to PV roof tiles which can mimic the aesthetic of slate or clay tiles. On grounds of performance alone, a standard surface-mounted array (if anything) may therefore be preferable for this project.

### 5.4 Lighting & appliances

Regardless of the use or otherwise of renewable energy technologies to provide heating & power, a simple first step in minimising electricity demand (and internal heat gains) is incorporation of low-energy lighting, appliances, IT kit and water appliances & fittings throughout (replacement of all showers is already planned). These should be coupled with efficient controls for both heating and power (e.g. zoned heating, programmers and thermostats, PIR lighting), and efficient pipe runs with full pipework insulation.

[74] PVGIS
[75] Performance can drop off considerably once the temperature around the panels rises above c.26°C

## 6.0 CONCLUSIONS

'Conservation, at its most basic, involves handing on to future generations what we value. Conservation advisors are not there to stand in the way of change, but to negotiate the transition from the past to the present in ways that minimise the damage that change can cause, and maximise the benefits. Conservation is this a process which seeks both to question change and to reconcile modern needs with the significance of what we have inherited in order to safeguard the interests of future generations' (English Heritage)[76]

'Climate change can have a range of direct impacts on the historic environment … Actions required to limit further damaging emissions and adapt to a changing climate are vital and can be successfully achieved … A key strand of our efforts to reduce carbon emissions across East Herts is based on influencing, encouraging and making it as easy as possible for our residents…to take action that will enhance sustainability … Retrofitting is important to ensuring all buildings contribute to carbon neutrality. Submitting evidence of carbon reduction in household applications, to improve the sustainability of existing buildings/ extensions is encouraged' (East Herts Council)

This retrofit assessment has considered the condition and planned renovation of Cheynes Farm. Options have been set out to improve energy efficiency, comfort, running costs and environmental sustainability while maintaining the character and building fabric of these historic buildings; the range of measures is judged to be in line with local policy and guidance documents, as well as national standards and best-practice guidance. The site has considerable potential to be made far more sustainable in the long term, following best-practice principles for the low-energy retrofit of traditional buildings and demonstrating what is achievable with an informed, sympathetic approach.

While the exact mix of improvement options is subject to client preference, as well as approval from the local authority, based on the assessment in this report a wide range of measures are considered viable for this property, including upgrade of all fabric elements and the incorporation of renewable energy technologies and other efficient services (as well as a high-efficiency extension). Potential measures for the existing buildings include the following, subject to installer/system provider confirmation and adhering to best-practice guidance for traditional buildings in all cases:

- Thorough maintenance & repairs throughout, to ensure the existing buildings are dry, sound, weatherproof & 'retrofit ready'. To include repairs to roof & walls as needed; removal of any inappropriate or damaged materials; consideration of repointing in lime mortar; insect treatment; roofline repairs; new, appropriately-sized rainwater goods; adequate perimeter drainage; lowering of any raised external ground levels; checks & repairs to timbers as needed; removal of redundant services; new electrics & plumbing, ensuring compatibility with planned services
- Roofs – refinement & improvement of ceiling-level insulation in farmhouse to ensure coherent, unbroken insulation, good ceiling airtightness & adequate void ventilation; replacement of any impermeable roof membranes with appropriate vapour-permeable

[76] Informed conservation: understanding historic buildings and their landscapes for conservation (English Heritage, 2001)

membranes as needed; full strip & insulation of roofs to extension & barn, avoiding thermal bridging & using appropriate moisture-open insulation systems throughout
- Ground floors – Consideration of new, insulated limecrete floors incorporating under-floor heating in farmhouse & extension; consideration of same in barn, or stripping & insulation of existing suspended timber floor, avoiding thermal bridging, using appropriate moisture-open insulation systems throughout & ensuring adequate sub-floor ventilation
- Windows & doors – New, high-performance units throughout (performance TBC), preferably incorporating thermally-broken frames; appropriate sizing, g-values, ventilation ability and shading mechanisms where needed/viable to achieve optimal balance between daylighting, ventilation, solar gain and control of overheating; simplicity of design for any sliding / bi-fold doors (e.g. barn) to minimise airtightness issues
- Walls – Strip & insulate timber-framed walls using appropriate moisture-open insulation systems throughout (between & over timber frame), avoiding thermal bridging, finishing externally with lime render / insulating lime render / timber weatherboarding; strip & externally insulate masonry walls using appropriate moisture-open insulation systems throughout, avoiding thermal bridging, finishing externally with timber weatherboarding, & possibly incorporating internal insulation if required (subject to thermal performance targets & possible moisture risk assessment)
- Airtightness – Improved airtightness throughout, with planned airtightness strategy at an early stage
- Ventilation – TBC; likely to comprise targets ventilation strategies around kitchen extension & first-floor wet rooms; preferably high-efficiency, centralised, demand-controlled systems, supported by manual ventilation via windows & doors
- Space & water heating – Heat pumps (possibly water+air source or ground source), with fully-insulated pipework & thermal store sited in new plant room; careful design of pipework runs to maximise efficiency & minimise unintentional internal gains
- Secondary heating – Possible high-efficiency, low-emissions log stove(s) with local, sustainable, high-quality seasoned fuel supply & appropriate storage conditions
- Overheating – Consideration of overheating risk throughout design; maximisation of passive mitigation measures where possible
- Solar energy – None planned at present; possible solar thermal array in new plant room roof; possible large PV array on outbuilding if/when converted
- Maximum-efficiency lighting & appliances
- All insulation and services designed and installed in accordance with best-practice guidance
- (Small extension to form new plant room; high-efficiency design possibly based around timber-frame construction with low-impact insulation materials)

Adopting a fabric-first approach is always recommended, and is particularly important where heat pump technology is proposed. All fabric upgrades should follow good-practice guidance for traditional & historic buildings, and consider year-round comfort. Any retrofit measures should be preceded by all necessary works to address maintenance issues and ensure the buildings are dry, sound, free from inappropriate materials as far as possible and 'Retrofit Ready'.

By adopting the broad approach set out in this report, it is possible to achieve significant improvements in thermal performance & efficiency, comfort, running costs & environmental impacts.

Performance values of upgraded building elements are dependent on final specification, although some indicative values are provided in the main report. Table 2 below gives an indication of possible post-retrofit performance parameters although this is highly dependent on final specification and, as mentioned previously, heat loss from the building as a whole as a result of thermal bridging and infiltration can considerably undermine even good U-values. Guidance on meeting any desired performance standards can be provided as required. In this context it is important to stress the need to balance thermal performance with moisture management to safeguard building fabric. While measures may be adopted according to client preferences to a degree, for the fabric elements this should not be a simple 'pick-and-choose' process with some areas treated and others omitted – it is important to adopt a coherent, whole-building approach regardless of the depth of retrofit targeted in order to create a robust, healthy property in the long term and minimise the chance of unintended consequences. The overriding principle is to treat the buildings as a whole even if scaling back on fabric targets.

| Element | Indicative U-value ($W/m^2K$) | Notes |
|---|---|---|
| Walls (timber frame / solid brick) | 0.3-0.7 | ▪ Dependent on final specification & desired thermal performance targets<br>▪ Brick wall assembly potentially informed by moisture risk assessment |
| Roofs (insulated throughout) | 0.15-0.25 | ▪ Likely to vary across different constructions |
| Windows (new) | 0.65-2.4 | ▪ Triple / vacuum / double glazing<br>▪ Also dependent on frame specification |
| Floors (new limecrete / suspended timber) | 0.2-0.3 | ▪ Dependent on specification |
| Air permeability | c.4-8 $m^3/hr/m^2$ @ 50 Pa | ▪ Assumed; high uncertainty<br>▪ Dependent on airtightness strategy incl. chimneys |

Table 2 Potential post-retrofit thermal performance

Early discussions with the local authority, system providers and installers are recommended to confirm viability of all potential insulation and renewable energy measures; there are numerous providers of materials & systems appropriate for this project and we would be pleased to provide further details as needed.

Early investigations likely to be beneficial include assessment of drainage assessment; condition assessment of any unseen embedded timbers; 2D assessment of any unavoidable thermal bridges; and possibly a detailed moisture risk assessment of solid wall insulation proposals.

While beyond the scope of this report, there is considerable potential to maximise the wider sustainability of the site. This may include the incorporation of low-impact materials; enhancement of existing water body with appropriate planting in & around the pond; additional ponds; green roofs on any new outbuildings (e.g. tennis court changing room); bird & bat boxes; appropriate native planting & hedgerow management; rainwater harvesting; composting; & fruit & vegetable growing.

## 7.0 FURTHER INFORMATION

'Regardless of your reasons for retrofitting, the key to success is understanding' (Sustainable Traditional Buildings Alliance)[77].

The list below, while not exhaustive, provides considerable relevant information for this project, and is followed by a selection of best-practice case studies. Publications are listed alphabetically by author, then in date order. In all cases publication date should be noted, along with an understanding that some details or guidance in older publications may since have been superseded. More detailed guidance, research and case studies can be provided on request.

- BEIS:
  - Retrofit internal wall insulation: Guide to best practice (2021)
  - Thin internal wall insulation (2021)
  - Guide to best practice: Retrofit floor insulation – suspended timber floors (2020)
- British Standards Institute (BSI):
  - Moisture in buildings: an integrated approach to risk assessment & guidance (2017)
- Changeworks:
  - Renewable Heritage: A guide to microgeneration in traditional & historic homes (2009)
  - Energy Heritage: A guide to improving energy efficiency in traditional & historic homes (2008)
- Historic England:
  - Energy efficiency & historic buildings (series of insulation guides, 2016)
  - Energy efficiency & historic buildings: solar electric (photovoltaics) (2018)
  - Energy efficiency & historic buildings: heat pumps (2017)
- Historic Environment Scotland:
  - Technical Papers (2008-present)
  - Guide to energy retrofit of traditional buildings (2021)
  - Managing change in the historic environment: micro renewables (2020)
  - Short Guide 11: Climate change adaptation for traditional buildings (2017)
  - Short Guide 5: Maintaining your home (2014)
- Morgan, C. – Sustainable renovation: improving homes for energy, health & comfort (2018)
- Passivhaus Trust
  - Avoiding summer overheating (2021)
  - Demystifying airtightness: Good practice guide (2020)
  - Good practice guide: MVHR for single dwellings (2018)
  - Passivhaus insulation: Good practice guide to achieving insulation continuity (2017)
  - Designing for summer comfort in the UK (2016)
- Sustainable Traditional Buildings Alliance (STBA):
  - Planning responsible retrofit of traditional buildings (2016)
  - A Bristolian's guide to solid wall insulation: improving the energy efficiency of traditional homes in Bristol (2015)

[77] A Bristolian's guide to solid wall insulation (STBA / Bristol City Council, 2015)

- UK Centre for Moisture in Buildings (2017): Health & moisture in buildings (2017)
- Wellesley-Smith, M. – Avoidance & diagnosis of problems associated with internal wall insulation (2017)

Lastly, further perspective may be gained from reviewing other traditional and historic building retrofit case studies, to demonstrate not only what can be achieved but also the consistency of approach regardless of individual solutions. In addition to the case studies referenced in the main report, the following provide a range of relevant details; further case studies are available on request. Note that one resource provides mostly European case studies: this is included as the projects include timber-frames structures.

- Residential retrofit: 20 case studies (Marion Baeli, 2013)
- Refurbishment Case Studies, Historic Environment Scotland:
    - https://www.historicenvironment.scot/about-us/what-we-do/conservation/refurbishment-case-studies/
- Various UK historic building retrofit project case studies:
    - http://www.sparaochbevara.se/goda-exempel/engelsk-energieffektivisering/
- Low Energy Buildings Database:
    - https://www.lowenergybuildings.org.uk/
- Passivhaus Trust project database (retrofit & new build):
    - https://www.passivhaustrust.org.uk/projects/
- Historic Building Energy Retrofit Atlas:
    - https://www.hiberatlas.com/en/welcome-1.html

NDM HEATH LTD
Sustainable Energy Services


21 Kirkgate
Knaresborough
North Yorkshire
HG5 8AD

T: 07763 110264
W: www.ndmheath.co.uk


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