Approaching Near Zero Energy in Historic Buildings

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Introduction

Northern Periphery and Arctic Programme 2014–2020

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Energy Pathfinder is a project funded by the European Regional Development Fund (ERDF) through the Interreg Northern Periphery and Arctic Programme 2014-2020. The project recognises that historic buildings represent one of the biggest challenges for improving energy efficiency in the region and has worked with owners, residents, and other stakeholders to identify and address the specific challenges involved.

This report is a review and summary of energy assessment results across the demonstrator sites of the Energy Pathfinder project, including surveys, monitoring, and simulation work. It also reports the results of retrofit works which have been undertaken at the demonstrator buildings during the run of the project. The most important and significant retrofit activity has been the extensive renovation projects undertaken at the Viðareiði Vicarage in the Faroe Islands and Bayview in Scotland, in addition to some more limited retrofit work to individual building elements undertaken at the Cathedral of St Mary and St Anne in the Republic of Ireland.

This report is the third in a series as below:

- *T3.1.1 Demonstrator Buildings and Energy Assessment Strategies*
- *T3.2.1 Initial Energy Performance Assessments*
- ***T3.3.1/T4.2.1 Energy Assessment Results and Retrofit Outcomes***
- *T3.4.1 Embodied Carbon and Sustainable Retrofit Approaches*

These reports may be read together for a comprehensive overview of all energy and carbon assessment activities undertaken at Energy Pathfinder demonstrator buildings. In the case of this report in particular it may be helpful to read T3.2.1 first to provide context on the baseline energy performance of the buildings in question.

Historic Environment Scotland (HES) has commissioned this report in its capacity as the work package coordinator for energy management and monitoring within the Energy Pathfinder project. HES is Scotland's lead heritage body and is responsible for the cares for over 350 historic properties and curating an archive of 0.4m records. It also records site of historic interest as well as carrying out a number of statutory functions in the management of Scotland's historic environment.

This report was prepared by Power Circle Projects Ltd, a social enterprise based in Scotland which supports the development of low carbon projects. It is the trading subsidiary of Power Circle Ltd, a company limited by guarantee in the process of registering as a charity. The company's mission is to enable local energy users to access low carbon energy at scale in a way that is affordable, fair, and breaks down social barriers.

Power Circle

The information contained within this report is provided for information purposes only and it should be noted that neither Historic Environment Scotland nor Power Circle can necessarily endorse or recommend the energy assessment strategies or specific retrofit measures which are reported on herein. The reader therefore uses the information at her own risk and neither the European Commission nor any member of the Energy Pathfinder consortium is liable for any such use as may be made of it.

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Bayview (formerly the Old Harbourmaster's House)

Pierowall Harbour, Gill Pier, Pierowall, Westray, Orkney Islands, KW17 2DL, Scotland

Figure 1: Bayview, pre-conversion in late 2019, street-facing main elevation seen from the southwest – Image © Historic Environment Scotland – Photographer: Carsten Hermann

Overlooking the harbour of Pierowall, the largest settlement on the island of Westray, Bayview is a two-and-a-half storey dwelling house of traditional construction built in the late 19th century. Originally the residence of Pierowall's harbourmaster the building later served as a guest house and family residence. Unoccupied since 2018, the building is now in the hands of the Westray Development Trust who are in the process of retrofitting and subdividing the building, with a view to providing affordable long-term rental accommodation for island residents which is in short supply.

At time of writing, as the Energy Pathfinder project draws to a close, the building works are nearing completion and Bayview is in the final stages of conversion into a multi-occupancy structure consisting of four flats and a common stairwell. These works have dramatically altered the shape and size of the building and can be expected to markedly improve energy efficiency and reduce operational carbon emissions. In addition to these improvements to the overall building, the new units will also benefit from sharing a thermal envelope.

Energy Pathfinder's engagement with this demonstrator has focused on assessing the impact of the retrofit and conversion works. This report describes the retrofit work in detail and relates the results of energy assessments which estimate the impact on the energy performance of the building. An extensive modelling exercise has also been undertaken which explores the embodied carbon impact of the works, the results of this exercise form the content of the subsequent report (*T3.4.1 Embodied Carbon and Sustainable Retrofit Approaches*).

Conversion and Retrofit:

Figure 2: Bayview, pre-conversion, viewed from the southeast – Image © Historic Environment Scotland – Photographer: Yasser Battikha

Figure 3: Bayview, mid-conversion, viewed from the south – Image © Historic Environment Scotland – Photographer: Yasser Battikha

Retrofit works undertaken during the conversion project at Bayview have been extensive and a full overview is provided in Table 3 below however the images above and below also illustrate the scale and depth of the retrofit undertaken. Note the removal of the main entrance porch and attached garage visible in Figure 2, the main entrance now replaced by a communal entry door to the new common stair visible in Figure 4. Also noteworthy above are the like-for-like replacement of the existing cement render and double glazed uPVC windows.

Figure 4: Bayview, mid-conversion, viewed from the northeast – Image © Historic Environment Scotland – Photographer: Yasser Battikha

Figure 5: Bayview, mid-conversion, viewed from the northwest – Image © Historic Environment Scotland – Photographer: Yasser Battikha

Figure 4 shows the new common stair at the rear of the building which replaces a demolished two-storey rear section which was also smaller in footprint, this actually represent a reduction of the overall heated volume however as the new stair is unheated, and also introduces a sheltered wall. In Figure 5 a new extension is visible at the north-west corner forming a shower and WC for flat 2, this replaces a small lean-to shed which has been removed. Also visible in the above images above are new skylights in flat 4 which sit within an entirely new roof structure which has been slightly raised.

Table 1: Bayview dimensions, pre-conversion.

Dimensions (whole building, pre-conversion)	
Gross internal floor area*	222.0m^2
Heat loss perimeter (internal)	111.5m

**Not including attached unheated garage and shed*

Table 1 above and Table 2 below show the dimensions of the structure before and after the conversion project to contextualise the change in the volume contained by the building envelope. The overall change is not dramatic however the four individual properties now occupying the converted structure individually now represent only a fraction of the total volume. It

Table 2: Bayview dimensions, post-conversion.

Dimensions (post-conversion)	
Gross internal floor area (whole building*)	257.0m^2
Heat loss perimeter (internal, whole building*)	132.8m
Gross internal floor area (Flat 1)	35.5m^2
Heat loss perimeter (internal, Flat 1)	20.7m

**Includes new unheated common stair formed at the rear of the building*

Table 3 below provides a full overview of the relevant alterations which are included in the retrofit project. Note that no microgeneration or energy storage systems (with the exception of the monofunctional hot water cylinders) have been incorporated at this stage.

Table 3: Bayview, overview of retrofit specification by building element.

Building Element	**Planned Alterations**
Walls	● Existing cement harling to be stripped and replaced with new cement harling ● Foil-backed PIR internal wall insulation to be installed ● All existing internal walls to be removed and rebuilt
Floor	● Foil-backed PIR insulation to be installed in all suspended floors
Roof	● Foil backed PIR insulation to be installed in common wall, coomb ceilings, and apex loft
Openings	● All windows and doors to be replaced with modern uPVC double-glazed units
Space Heating	● Panasonic Etherea air-to-air heat pumps to be installed as the main heating system in each of the four flats

Hot Water	● New hot water cylinders to be installed in each flat, to be heated from the space heating system with electric immersion backup
Ventilation	● All new windows to be supplied with trickle vents ● Intermittent extractors to be fitted in all kitchens and bathrooms

Overall, the conversion project has achieved a considerable improvement to fabric thermal performance across all elements of the building envelope. In addition, changes to building services can be expected to dramatically reduce operational carbon. This effect will be compounded by Scotland's relatively low carbon electricity network, especially in Orkney which regularly boasts a surfeit of renewable generation. At present, running costs for the new air-to-air heat pumps may be expected not to differ dramatically from those of the pre-existing oil boiler in terms of price per kWh of heat delivered. However, all other factors being equal[1], a dramatic reduction in cost and energy consumption might be anticipated compared to the pre-conversion condition. It should be noted however that the building is now a multiple occupancy structure and a simple before and after comparison is of limited utility.

Energy Assessment:

Table 4: Bayview, energy assessment method.

Method:	Aim:	Notes:
Pre and post retrofit assessment using RdSAP	Produce a reliable estimate of building energy performance before and after the Westray Development Trust retrofit project.	RdSAP is the UK's national assessment methodology for existing buildings under the EPBD

The limited set of investigations ultimately deployed at Bayview by the Energy Pathfinder project reflects the difficulties both of undertaking retrofit work and building energy assessment in a remote islands context. These pre-existing difficulties were also further exacerbated by travel restrictions due to the coronavirus pandemic, which in effect made the islands inaccessible to HES staff throughout 2020 and much of 2021.

Historic Environment Scotland had intended to undertake thermal imaging, IAQ monitoring, and air tightness testing in addition to the RdSAP assessment and embodied carbon/hygrothermal risk study actually carried out. Principally, these aborted plans were derailed by delays to completion of the retrofit works which resulted in the building being without a power supply (and therefore without both heating and an internet connection) until mid-2022. This was in large part due to delays in delivery of a necessary reconfiguration of the local electrical grid by the privatised network operator for northern Scotland. This parallels the experience at North Ronaldsay where the energy upgrade study identified a constrained power supply and local electricity network, and a lack of flexibility from the network operator in terms of allowing the reconfiguration of existing generating assets, as amongst the key barriers to progress at the site. This commonality would suggest that electricity grid constraints are a common issue for the retrofit of traditional buildings in remote communities and further exploration of this issue may be a fruitful avenue of exploration for a future project.

[1] Unfortunately, as a result of multiple factors impacting global energy costs, not least the Russian invasion of Ukraine, it's likely that overall energy costs will increase considerably even if savings were realised. These are now shared between multiple properties however.

Nonetheless, in spite of the aforementioned difficulties, pre-and-post retrofit energy assessments using the RdSAP methodology do illustrate the magnitude of the upgrade achieved by the WDT in terms of operational energy and carbon emissions compared to the baseline condition of the building. Results of the embodied carbon/hygrothermal risk study mentioned above, and in earlier reports in this series, are related in the subsequent and final report (T3.4.1).

Assessment Results:

Introduction to RdSAP Methodology:

RdSAP[2] is the UK's national calculation methodology under the Energy Performance of Buildings Directive[3] (EPBD). Unlike the national methodologies of some EU member states[4] it should be noted that the score produced by the methodology (the "SAP rating") is essentially a reflection of running cost per area. In Scotland, an EPC is mandatory when a property is sold on the open market or at the outset of a new tenancy, currently they are valid for 10 years with proposals to reduce this to 5 or 3 years in order to reduce the time lag in tracking energy and carbon improvements towards Scotland's national net zero target in 2045.

SAP ratings are placed in bands from A to G which are used to group properties for research, compliance, and policymaking purposes. In practice then, the worst possible score is expressed as G1. It should be noted that scores above 100 are possible and reflect a building which the methodology has determined will produce more revenue from exported energy than it will cost to run, assuming a SAP rating of 105 for the sake of argument this would be expressed as A105. In practice however, the only properties with SAP ratings in excess of A100 are a very small population of eco-homes.

SAP ratings and bands are already used in Scotland to access both government and private funding for energy efficiency improvements, and the methodology is intended to be the assessment tool regulating compliance with minimum energy efficiency standards (MEES) which are expected to be rolled out across Scotland's building stock over the coming years[5].

It should be noted also that the methodology does have some significant long term issues. For example, it tends to lag behind developments in domestic energy technology and there are known errors in some formulae and assumptions used. Historic Environment Scotland continues to be extensively engaged in efforts to continually improve the SAP and RdSAP methodologies in order to ensure that it more accurately represents Scotland's traditional housing stock.

Nonetheless, the methodology represents an effective and impartial energy assessment and benchmarking tool which has tracked the results of energy retrofit work across Scotland's building stock since 2010 and shown considerable improvement during the last decade. During this period the share of Scotland's properties falling into the most efficient SAP bands (A,B, or C) increased from 24% in 2010, to 51% in 2019; similarly, the share of properties falling into the least efficient SAP bands (E,F, or G) decreased from 27% to 12% in the same period (Scottish Government, 2020).

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[2] https://bregroup.com/sap/standard-assessment-procedure-sap-2012/

[3] https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en

[4] The Republic of Ireland's BER methodology (https://www.seai.ie/home-energy/building-energy-rating-ber/), by contrast, uses primary energy factor as the main metric by which buildings are scored.

[5] https://www.gov.scot/policies/energy-efficiency/energy-efficiency-in-homes/

RdSAP Assessment:

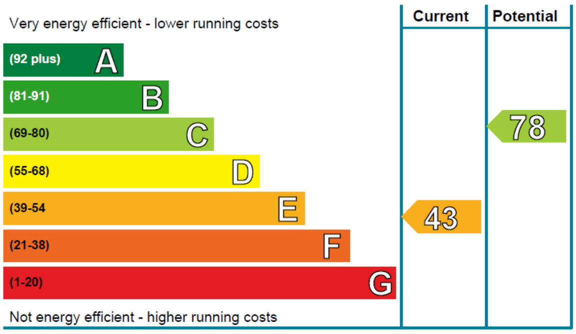

Figure 6: Bayview, pre-retrofit SAP rating for the whole building, assessment by a local domestic energy assessor 07/08/2017.

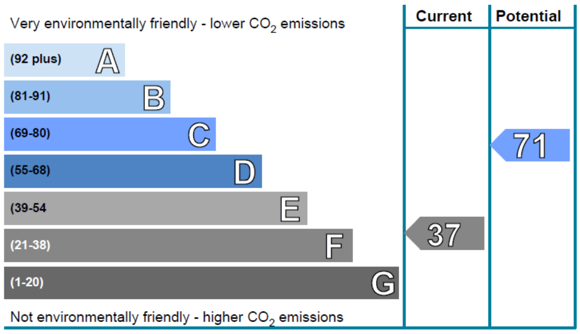

Figure 7: Bayview, pre-retrofit carbon rating for the whole building, assessment by a local domestic energy assessor 07/08/2017.

The above images, Figure 6 and Figure 7, show the SAP and carbon rating for Bayview as a whole building prior to the conversion project undertaken by the WDT. For context, the average Scottish dwelling in 2019 had a SAP rating of C65 and a carbon rating of D61 (Scottish Government, 2020). It should also be noted that the average SAP rating for a Scottish property not on the mains gas network was D58, the average rating for a rural property was D56, and the average rating for a pre-1919 property was also D56 (Scottish Government, 2020). At a glance, in its baseline condition Bayview was underperforming the Scottish average across its various categories by a considerable margin.

This assessment is likely to be a relatively true reflection of the building's pre-retrofit performance and may even overestimate the true energy performance by omitting the volume of the habitable attic rooms. RdSAP surveys are governed by a set of conventions and omission of the attic may have been a correct application of these, it is impossible to determine this as HES staff were unable to inspect the interior of the building in its pre-retrofit condition. Alternatively the omission may have been in error which would be reflective of an additional issue known to impact EPC assessments in Scotland, and which has been documented in a study by Heriot-Watt University; specifically, inconsistent quality of surveys and application of the RdSAP conventions (Jenkins, Simpson and Peacock, 2017).

Table 5: Bayview, RdSAP projections for post-retrofit energy performance.

	Flat 1	Flat 2	Flat 3	Flat 4
RdSAP indicator	C72	D68	C75	D68
Carbon indicator	C74	C71	C78	C71
Energy	9,988kWh/year	15,328kWh/year	8,748kWh/year	16,559kWh/year
Energy (Building)	50,623kWh/year			

Source: RdSAP assessment by Historic Environment Scotland member of staff, building surveyed 15/03/2022.

The results of these before (Figure 6 and Figure 7) and after (Table 5) assessments indicate that a considerable gain in overall energy performance has been achieved as a result of improvements to the building fabric. In addition to this, considerable gains appear to have resulted from sharing a single thermal envelope between multiple properties, with flat 3 benefitting most (Figure 8) and flat 4 least (Figure 9), in spite of higher energy consumption overall (50,623kWh/year) compared to the baseline condition (30,922kWh/year). A substantial carbon benefit has also been realised, chiefly as the result of eliminating heating oil as an energy source.

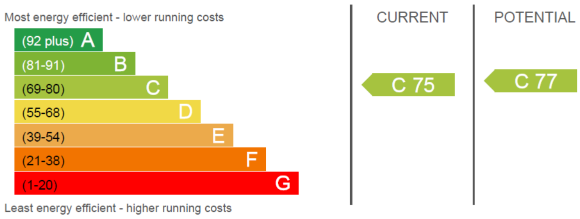

Figure 8: Bayview, projected post-retrofit SAP score for flat 3, mid-floor semi-detached. Assessment by HES member of staff 15/03/2022.

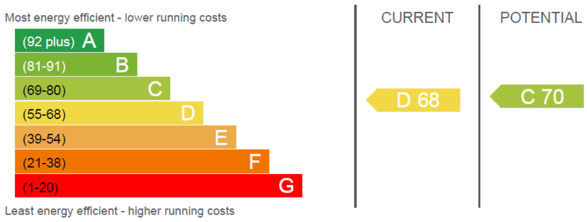

Figure 9: Bayview, projected post-retrofit SAP score for flat 4, top-floor detached. Assessment by HES member of staff 15/03/2022.

Overall, from an operational energy perspective, the retrofit has been tremendously successful, both as a result of fabric improvements and of a heating system upgrade from oil to an air-to-air heat pump though it should be noted this does not have a large impact on the SAP rating as running costs for the two systems are currently very similar in Scotland. From an operational carbon perspective also the retrofit represents a major improvement

Summary and Evaluation:

From the point of view of immediate social good, Bayview represents a model project; a community development trust acquiring a derelict property and converting it into a community owned asset which addresses a pressing need for long term housing among the resident population.

The challenge of providing affordable long-term housing for the resident population is replicated across Scotland, is particularly acute in remote areas and island communities, and may be attributed to multiple factors. These factors are general changes in Scotland's demographics combined with increasing numbers of properties exiting the long-term rental market to become holiday homes and short term lets. These factors conspire to increase prices and reduce availability for the resident population. This affects young people in particular as they generally lack the financial resources to compete in a market increasingly occupied by distant property investors, a situation which is particularly damaging to island communities for whom the ability to retain young people of working and child-rearing age is a matter of survival. From this point of view therefore, the creation of these needed housing units and their being retained in community ownership to prevent them potentially being lost to the short term rental market represents a prudent investment by the local development trust which may be regarded as a model to be followed by island and remote communities across Scotland and potentially the wider NPA region.

From a technical standpoint the outlook is more mixed, as detailed above the retrofit may be considered a major upgrade in terms of operational energy, running costs, and operational carbon emissions. The project has also achieved zero direct emission heating, a major element of the Scottish Government's strategy to achieve net zero across Scotland's housing stock.

However, in terms of the long-term health of the building fabric there is much to be desired; with the retrofit approach having introduced a considerable risk of long term degradation. This is due to decreased permeability resulting from the introduction of impermeable materials in every element of the building envelope. This will significantly impair the ability of the building to shed moisture whilst internal vapour loading will increase dramatically as a result of higher occupation, creating a significant risk.

Traditional buildings are resilient, and local conditions can often lead to unexpected outcomes so it is impossible to say at present whether this risk will materialise into a real problem of fabric deterioration in years ahead. Indeed, the surprising finding during the conversion project that the masonry was very dry and in excellent condition following two years unoccupied and unheated suggests that conditions in the immediate local environment may be protecting the building, but only time will tell if this is the case.

Keepers' Cottages, North Ronaldsay Lighthouse

Dennis Ness / Versa Breck, North Ronaldsay, Orkney Islands, Scotland

Figure 10: The lighthouse complex, seen from the northeast in October 2021, the southeast block is partially obscured behind the lighthouse, while the northwest block is the rightmost of the buildings visible in the photo – Image © Historic Environment Scotland – Photographer: Kenneth Easson

The Keeper's Cottages at the Dennis Ness lighthouse complex are situated at the north-eastern tip of the Orkney Islands, on the remote island of North Ronaldsay. Originally, the entire complex was constructed during the 19th century by the Northern Lighthouse Board, who retain ownership and continue to operate the lighthouse and two small ancillary buildings on site. The Energy Pathfinder demonstrator buildings are the two accommodation blocks constructed alongside the lighthouse to provide workshop space and dwellings for the lighthouse keepers. The south-eastern block is the earlier of the two (1850s) and is of solid brick construction, while the north-western block was constructed later (probably late 19th to early 20th century) and is of poured concrete construction. Details of the building fabric and configuration of pre-existing HVAC systems are related by the preceding report.

Today, the Keepers' Cottages are owned and occupied by the North Ronaldsay Trust (NRT) and are an important community asset for the island, hosting a pair of holiday lets, a café/visitor centre, and a woollen mill processing fleece from the island's flock of unique, seaweed eating, sheep. Energy Pathfinder engagement with the site has focused on assisting the NRT by understanding the buildings as they stand today with a view to exploring viable retrofit pathways to upgrade and restore the buildings going forward. An extensive modelling exercise has also been undertaken which principally explores the embodied carbon impact of an extensive hypothetical fabric retrofit, the results of this exercise form the content of the subsequent report (*T3.4.1 Embodied Carbon and Sustainable Retrofit Approaches*).

Figure 11: The southeast building, ancillary buildings remaining in ownership of the NLB are on either side of the image with yellow parapets – Image © Historic Environment Scotland – Photographer: Carsten Hermann

The southeast building, pictured above, originally housed a pair of cottages which remain known as the 1st and 2nd Assistant Keepers' Cottages. These are now holiday lets which provide a much needed revenue stream for the upkeep of the complex and the NRT as a whole, supporting other community projects and the island economy. Below these units are referred to as cottage 1 and cottage 2 (left and right respectively in Figure 11 above). The northwest building below, originally housed the Head Keeper's Cottage (below referred to as Cottage 3, foreground-right in Figure 12) and a machine shop (below referred to as the Workshop, centre in Figure 11) supporting the operation of the beacon. These now serve as a café/visitor centre, and as a workshop which currently hosts the aforementioned woollen mill. The NRT currently intends to convert the Head Keeper's Cottage back into a residential unit, ideally tied to a permanent caretaker post at the complex, with the café/visitor centre moving into the workshop unit, and the woollen mill moving offsite elsewhere on the island.

Figure 12: The northwest building and the lighthouse, the latter of which remains in the ownership of the NLB, a squat building housing the defunct foghorn can also be seen in the distance to the left – Image © Historic Environment Scotland – Photographer: Carsten Hermann

Assessment Methods:

Table 6: Keepers' Cottages, energy assessment methods.

Method:	Aim:	Notes:
Energy upgrade study*	Identify and evaluate options for improving HVAC, energy storage, control, and microgeneration systems, including both changes to hardware and energy management approaches.	This study will incorporate a detailed energy model of the north-western block and a slightly simpler model of the south-eastern block.
Indoor air quality monitoring	Monitor and evaluate indoor air quality.	
Air tightness testing	Determine overall air tightness and estimate passive ventilation rate.	
RdSAP assessment	Estimate current energy performance and SAP rating.	
DE HRA assessment	Estimate energy performance and model both technical and fabric improvement options.	DE HRA (Dynamic Engine Home Renewables Advice) is bespoke software used by Scotland's national energy efficiency advice service, Home Energy Scotland.
Thermal imaging	Assess the in-situ performance of existing building fabric.	

*(Shimmin and Kelly, 2022)

The assessment strategy at the North Ronaldsay demonstrator focused on understanding both the current energy performance of the building and exploring potential retrofit pathways for improvements at the site going forward. The key element of this strategy is the energy upgrade study, which Historic Environment Scotland funded from the Energy Pathfinder project budget. This funded energy consultants Power Circle to undertake the study which included extensive energy modelling and a writeup by subcontractors Atamate. This study has uncovered a complex set of constraints impeding progress at the site which forms an ideal case study illustrating the difficulties faced by isolated and remote communities in maintaining and deriving benefit from community assets such as the Keepers' Cottages, even where these are in community ownership and where funding is available to support work.

This is also a good case study of a further issue of increasing relevance in Scotland, specifically the challenge of supporting communities to maintain and derive benefit from community owned buildings. This been made more pressing as a result of expansion in community ownership in Scotland, a legacy of community right-to-buy legislation dating to the 2000s. This has allowed communities across Scotland, most notably remote rural and island communities, to acquire assets ranging from community ownership of single buildings to entire estates spanning thousands of hectares. The impact of this legislation overall has been very positive but a notable challenge which has emerged is the issue of communities left to care for assets without the resources or technical expertise to manage them effectively or take forward projects.

Other Assessment Results:

Indoor Air Quality (IAQ) Monitoring

IAQ monitoring at the Keepers' Cottages was undertaken using a pair of commercially available Airthings[6] sensors measuring levels of radon, PM1, PM2.5, volatile organic compounds (VOCs), carbon dioxide (CO_2), relative humidity (RH), temperature, and air pressure[7]. The sensors have a sampling interval of 5 minutes and upload data continuously to the internet which allowed continuous monitoring by HES members of staff. Unfortunately, the network connection to the sensor in Cottage 2 dropped out after several weeks of monitoring. HES staff were unable to travel to site and NRT staff found they were unable to reconnect the sensor, again underlining the challenge of working in a remote island context. The other sensor remained connected however and was able to accumulate six months of IAQ data while emplaced in the indoor seating area of the café in the unit described above as either Cottage 3 or Café/Workshop.

The conclusions that may be drawn from this period of monitoring are limited by the sporadic occupancy of the building and by the fact that it was undertaken over six months during summer. Nonetheless, some findings do present themselves. Firstly, levels of radon, an inert radioactive gas which is geological in origin, are well below safety limits and therefore do not present an issue. VOCs, PM1 and PM2.5 in the indoor environment appear to result overwhelmingly from occupant activities, most likely cooking and cleaning based on the use of the building. This conclusion is based on a close correlation between levels of PM, VOCs, and CO_2 across the monitoring period. Current background ventilation plus extract provision appears to be sufficient as levels decline rapidly to atmospheric baseline at the end of periods in occupation. This concurs with the results of airtightness testing which show a reasonably healthy background ventilation rate of 5.3578 $m^3/(h.m^2)$ (see airtightness testing below) in addition to powered extractors. There is also no recent or current building work taking place, and no meaningful degree of nearby traffic owing to the remote location

[6] https://www.airthings.com/en-gb/

[7] PM1 and PM2.5 stand for "particulate matter" where the particle size is 1 and 2.5 microns respectively, in the indoor environment PM typically arises from building works, DIY, cooking, or external sources such as traffic or industrial pollution.

and it is therefore exceedingly unlikely that pollution is the result of infiltration from exogenous sources.

Sustained high levels of relative humidity and low internal temperatures do appear to represent a problem. This is most likely the result of multiple factors including vapour due to internal activity, the local maritime climate, and most importantly an inadequate heating system. At present these issues for indoor air quality are unlikely to present an issue as the café/visitor centre is a place of business and both staff and visitors arrive attired for the local climate. However, if plans proceed to turn this unit back into a residence then expectations of thermal comfort are likely to be higher and sustained high humidity may present a risk to respiratory health due to the attendant risk of mould.

Airtightness Testing

Airtightness testing was principally undertaken to provide context for indoor air quality monitoring and to validate assumptions made in building the energy model for the energy upgrade study. Testing was undertaken by Orkney Air Testing[8], under fair conditions with ambient temperatures approximately 15 to 16°C, and ambient pressure approximately 1015 millibars. The test was undertaken by increasing the internal air pressure to 50Pa overpressure with all external doors and windows closed, all internal doors open, all combustion appliances turned off, and fireplaces and extractors temporarily sealed. Findings for air permeability for the three units tested were as below:

- Café = 5.3578 $m^3/(h.m^2)$
- Workshop = 7.4131 $m^3/(h.m^2)$
- Cottage 2 = 11.6412 $m^3/(h.m^2)$

Overall, the key finding from this testing was that the buildings are more airtight than expected, in particular the northwest block containing the workshop and café, which is somewhat surprising considering their age and visible signs of fabric decay in places. This may be taken as testament to good workmanship in the execution of the most recent renovation of the buildings in the 2000s.

Considering the sustained high levels of relative humidity revealed by IAQ monitoring it is not advisable for the airtightness of the buildings to be increased without also addressing ongoing issues of inadequate heating and giving appropriate consideration to a holistic ventilation strategy going forward.

RdSAP[9] Assessment

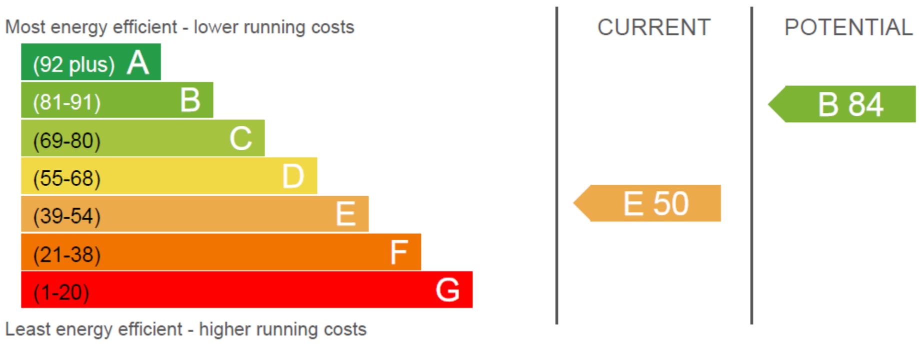

Figure 13: Cottage 1, estimated SAP rating at time of survey assuming a functional main heating system. Assessment by HES member of staff 15/03/2022.

RdSAP assessment of the cottages was undertaken by HES staff based on the building in its present condition with a single variation; specifically, for the purposes of comparison this assessment was

[8] http://www.orkneyairtesting.com/

[9] For an introduction to the RdSAP methodology and discussion concerning its relative strengths and weaknesses as a means of energy assessment, please see the preceding chapter covering assessment activity at the Bayview demonstrator site.

based on a scenario which assumed the prior configuration of the main heating system was restored to working order. The results for the two cottages of the southeast block are shown above and below (Figure 13 and Figure 14). Note the small but significant variation in the SAP rating which results from the slightly smaller footprint of Cottage 2, and the presence of a party wall separating it from the public toilet to which it is attached and which is not present in the case of Cottage 1. This may be considered essentially a quirk of the methodology as the likelihood that much real benefit is derived from this party wall Is very limited.

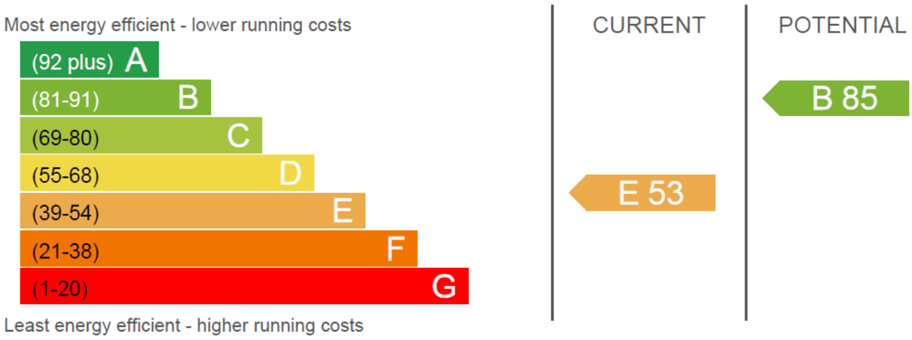

Figure 14: Cottage 2, estimated SAP rating at time of survey assuming a functional main heating system. Assessment by HES member of staff 15/03/2022.

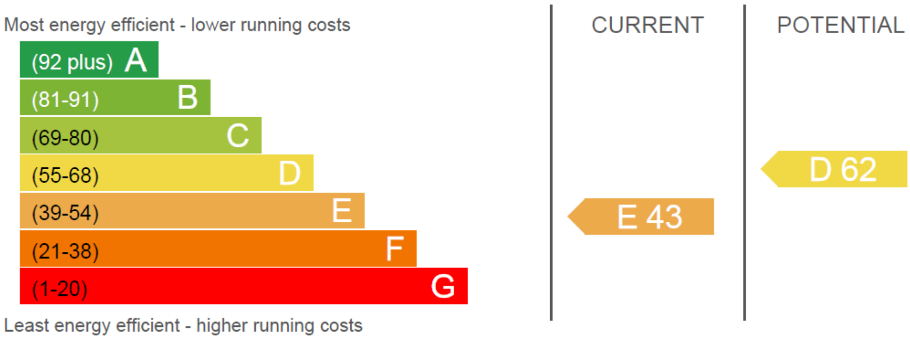

Figure 15: Cottage 3, estimated SAP rating at time of survey assuming a functional main heating system. Assessment by HES member of staff 15/03/2022.

A further quirk of the RdSAP methodology is identified by considering the lower "potential" rating for Cottage 3 (Figure 15 above). This lower potential is calculated based on the incorrect assumption that the walls of that property are unsuitable for insulation. This is reflective of the ongoing issues faced by the methodology and which are discussed in greater detail in the preceding chapter covering the Bayview demonstrator on Westray.

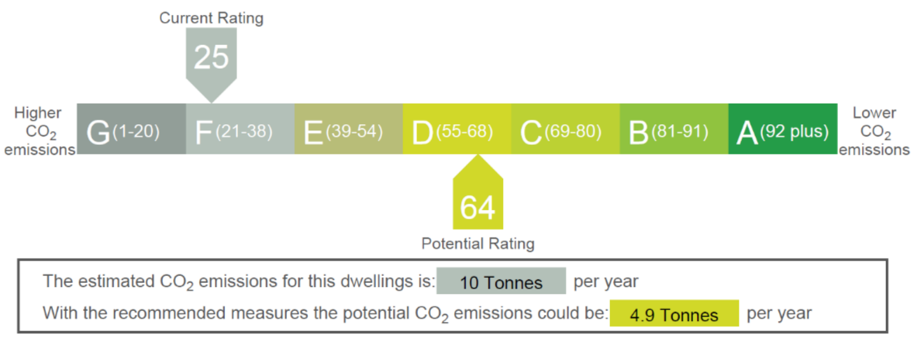

Figure 16: Cottage 1, estimated environmental rating at time of survey assuming a functional main heating system. Assessment by HES member of staff 16/03/2022.

Low environmental scores for the Keepers' Cottages accurately reflect the fact that the modelled energy use is dominated by space heating which in the modelled scenario is provided by a functioning communal oil boiler. Again, the suggested potential rating falls well short of reality because the software is not equipped to consider a change of fuel type as a possible option.

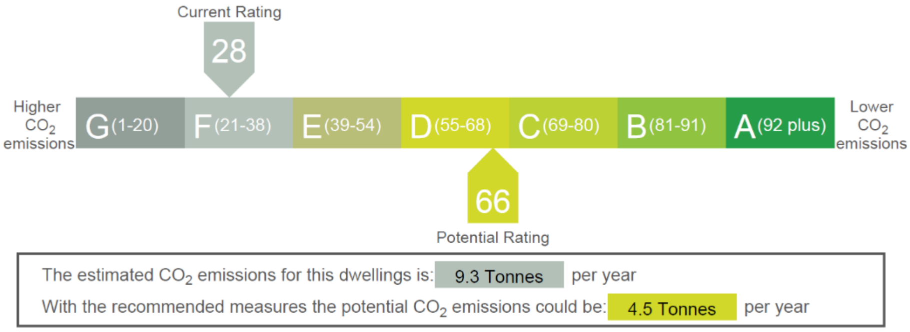

Figure 17: Cottage 2, estimated environmental rating at time of survey assuming a functional main heating system. Assessment by HES member of staff 16/03/2022.

Cottage 2 is nearly identical to Cottage 1 with the slightly higher actual and potential environmental ratings attributable to the same factors identified as responsible for variation in the SAP ratings.

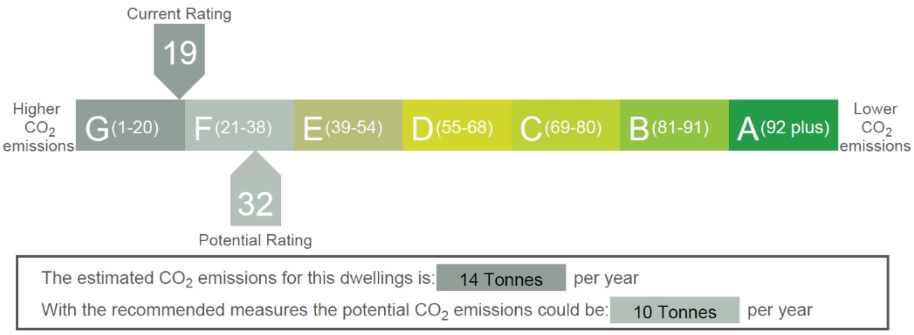

Figure 18: Cottage 3, estimated environmental rating at time of survey assuming a functional main heating system. Assessment by HES member of staff 16/03/2022.

Overall, Cottage 3 is the worst performer in environmental terms due to a larger footprint, lesser degree of attachment (meaning a shorter party wall) and because the wall type is considered to be of lower thermal performance which in this case is likely to be correct. Again, as with the other units on site, the potential rating is not a true reflection because a change of fuel type is not considered as an option, and additionally in this case because wall insulation has not been considered as an option.

The RdSAP assessment at the North Ronaldsay demonstrator was undertaken by HES staff using software provided by the Elmhurst[10] energy assessor accreditation body and operated by a certified domestic energy assessor.

Dynamic Engine – Home Renewables Assessment (DE HRA) Reports

Unless otherwise noted all graphics and photographs in this subsection are sourced from a Home Energy Improvements Report completed by a Home Energy Scotland specialist advisor following a site survey at the Keepers' Cottages on 15th June 2022.

The two cottages of the southeast block were also assessed using DE HRA software which is built on the RdSAP methodology but which is equipped with additional capabilities over and above those of basic RdSAP. DE HRA software is capable of modelling the energy performance of a building in two different modes referred to as SAP mode (attempting to estimate pre and post-retrofit SAP rating as

[10] https://www.elmhurstenergy.co.uk/

closely as possible) and best-estimate mode (attempting to model real world energy performance as closely as possible).

Historic Environment Scotland has supported the development of this software which was originally commissioned and is owned by the Energy Saving Trust[11]. The primary purpose of the software as to support the delivery of the Home Energy Scotland[12] specialist advice service. Home Energy Scotland is Scotland's national domestic energy advice service and is funded entirely by the Scottish Government, managed by the Energy Saving Trust, and delivered by four different organisations across Scotland.

An immediate advantage that DE HRA has over RdSAP is that it is designed to be operated by specialist advisors who can tailor specific recommendations within a package of retrofit measures based on their expertise and the ambitions and objectives of the building owners, rather than relying excessively on software. DE HRA reports for Cottages 1 and 2 were created by a specialist Home Energy Scotland advisor following a site survey on 15th June 2022.

Figure 19: North Ronaldsay, Cottage 2, photograph taken on 15/06/2022 during survey by Home Energy Scotland's specialist advisor for Orkney.

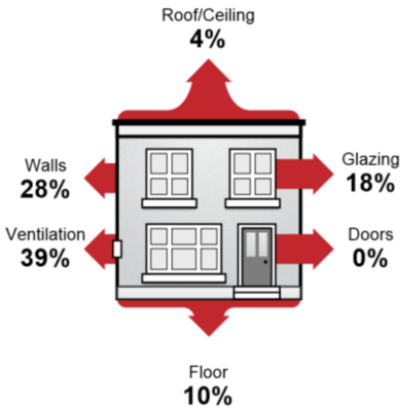

Figure 20: Simple graphic produced by DE HRA as an output of its "best estimate" model, in this case providing an overview of heat loss from Cottage 2.

The below narrative focuses specifically on the DE HRA modelling of Cottage 2 for ease of comparison with the above RdSAP assessments.

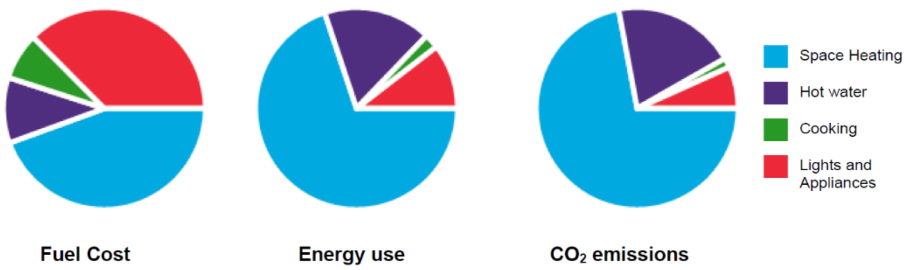

Figure 21: Simple graphic output by DE HRA providing an estimated breakdown of operational costs, energy use, and emissions at Cottage 2.

The most notable difference between the output of RdSAP and DE HRA is that the breakdown of energy use in the building is far more granular, as illustrated by Figure 20 and Figure 21 above. This is designed to support the ambitions of a building owners which may be oriented towards financial, energy efficiency, or environmental goals. This reflects DE HRA's primary function, which is to

[11] https://energysavingtrust.org.uk/
[12] https://www.homeenergyscotland.org/

support a specialist advice service, as opposed to RdSAP which is principally a compliance and benchmarking tool.

The fact that DE HRA is designed to be operated by a specialist advisor also allows more detailed inputs, including occupancy criteria and specific fuel costs and tariff details which RdSAP consciously avoids. This allows DE HRA to model building performance far closer to reality when running in best estimate mode and is particularly important in a remote island setting such as North Ronaldsay where lifestyles and energy costs will both be more variable compared to the national norms and averages used by RdSAP assessment. This is neatly illustrated by the outputs of each for Cottage 2:

RdSAP Output (Cottage 2)
Energy consumption = 32,455 kWh/year
Carbon emissions = 9,307 kgCO_2e/year
Cost = £1,191/year

DE HRA Output (Cottage 2, Best Estimate Mode)
Energy consumption = 20,179 kWh/year
Carbon emissions = 7,604 kgCO_2e/year
Cost = £1,357/year

Table 7: Projected benefits from a package of energy efficiency and renewable heating measures in Cottage 2

Recommended Improvement	**Indicative Cost**	**Annual Savings**		
	£	**kWh**	**kgCO2e**	**£**
Replacement of remaining incandescent lightbulbs with low energy lightbulbs	£20	52	6	-£2
Main walls - Internal wall insulation	£3,800	1,761	654	£67
Extension wall - Internal wall insulation	£1,100	441	164	£22
Main floor - Standard insulation between floor joists (150mm)	£2,500	1,399	520	£60
Extension floor – Solid floor insulation (150mm)	£1,100	163	60	£7
Air source heat pump, Secondary heating log stove, Oversize radiators, New hot water cylinder, Programmer, room thermostat & thermostatic radiator valves for oversized radiators	£23,700	11,392	5,212	£7
Draught proofing for external doors	£20	37	7	£7

Source: Assessment by Home Energy Scotland advisor, building surveyed 15/06/2022.

Finally, DE HRA is capable of outputting up to four customised scenarios, showing the projected measure-by-measure impact in cost, carbon, and energy terms for a package of retrofit measures customised by the advisor in question.

Table 7 above shows the output of a scenario modelled for Cottage 2, for which the total projected impacts are listed below:

- Total financial saving = £341/year
- Total energy saving = 16,122kWh/year

- Total carbon saving = 6,788kgCO_2e/year

Thermal Imaging

Due to challenging circumstances at the time of the survey it is not possible to draw extensive conclusions from the infrared thermography carried out by Historic Environment Scotland at the Keepers' Cottages. Specifically, a defunct heating system prevented a temperature differential between the internal and external environment (which is crucial for thermal variation across the building fabric to become visible in infrared) from being created in three of the four units on site. A temperature differential was created in the Café/Visitor Centre by an improvised reconfiguration of a hot water cylinder to provide heat to radiators however, which facilitated survey of that unit. The findings of that survey are related below:

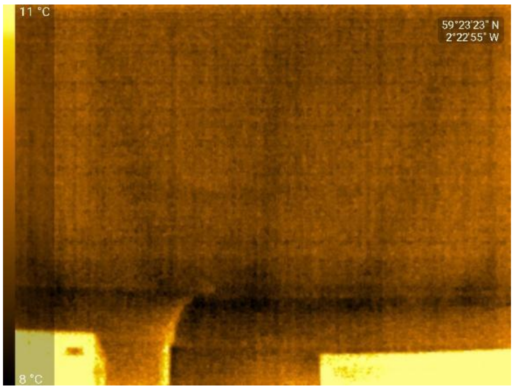

Figure 22: Infrared image showing the thermal trace of concealed joists supporting a false ceiling – Image © Historic Environment Scotland – Thermographer: Kenneth Easson

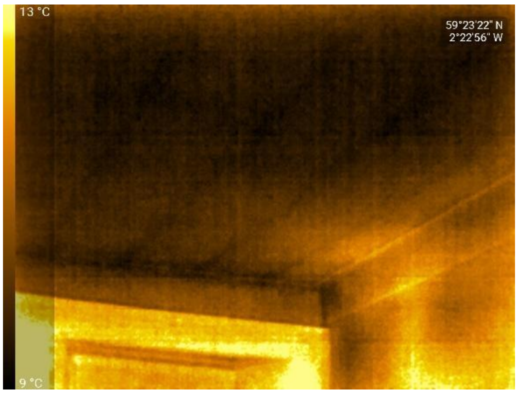

Figure 23: Infrared image showing the thermal trace of concealed joists supporting a false ceiling – Image © Historic Environment Scotland – Thermographer: Kenneth Easson

Figure 22 and Figure 23 illustrate the key finding HES staff were able to derive from the thermal imaging survey, which was confirmation of the presence of an insulated false ceiling identified by the infrared trace of its supporting joists on the ceiling below. Figure 23 also shows a warm area extending up the wall and onto the ceiling and cornice (bottom right of the image), this is the result of warm air convection above a radiator.

Figure 24: Cottage 3 (aka the Café/Visitor Centre) viewed from the northwest – Image © Historic Environment Scotland – Thermographer: Kenneth Easson

Figure 25: Cottage 3 (aka the Café/Visitor Centre) viewed from the southwest – Image © Historic Environment Scotland – Thermographer: Kenneth Easson

External images of the café/visitor centre showed no visible infrared anomalies in the building fabric which concurred with the results of the visual survey and tests using a pinless moisture meter. It was also in line with anecdotal evidence suggesting that the overall condition of the building fabric is good and that the building remains dry and weathertight in spite of less than ideal conditions created by the defunct heating system and ongoing fabric maintenance challenges.

Figure 26: Local residents observe the thermal imaging survey – Image © Historic Environment Scotland – Thermographer: Kenneth Easson

Energy Upgrade Study:

The energy upgrade study at the Keepers' Cottages was undertaken by Power Circle, and included report writing and energy modelling undertaken by subcontractors Atamate. This company takes an innovative "services first" approach to retrofit (Atamate, 2021), inverting the far more widespread "fabric first" approach that is established practice.

The upgrade study sought principally to build a detailed energy model of the building in order to explore and analyse potential strategies for upgrade of building services. The model was constructed in two parts, incorporating both steady state and annual dynamic modelling of the northwest building. A simpler model of the southeast building was also constructed and conclusions inferred from the results of the more detailed northwest building model.

In spite of the conscious adoption of a services first approach the result of the study suggest that it will be necessary to undertake a considerable thermal upgrade of the building fabric before any low-carbon upgrade for space and/or water heating systems becomes viable. The study therefore recommends that a comprehensive plan for improvement of the building be drawn up, utilising both architectural and engineering skillsets. With this long term roadmap in place the authors suggest that intermediate interventions may be planned in and executed to ultimately achieve the level of fabric performance needed for a sustainable and effective heating solution to be implemented.

For example, one finding of the energy model was that by upgrading the insulation in floors and ceilings, and upgrading the windows to higher-performing equivalents, the heat demand of the buildings can be cut by half.

North Ronaldsay – Key Barriers to Progress:

Going forward, the key contribution of the study undertaken by Power Circle and Atamate, is that the key barriers to a sustainable long term solution at the Keepers' Cottages have been positively identified. These paint a very clear picture of the complex challenge facing owners and managers of traditional buildings across the NPA region more widely, but especially in remote and isolated locations, which in many cases is compounded by the difficulties that come with community ownership of built assets. Five key barriers are identified which individually might be relatively easy to overcome but which together form a mutually-reinforcing complex which is much more difficult to develop a solution to. These should be understood in the context of the three overarching objectives common to almost all retrofit projects:

- ***Reduce Operational Carbon***
- ***Reduce Operational Costs***
- ***Achieve Thermal Comfort***

The five key barriers identified are as below:

- ***Heat Demand of the Buildings***
  The relatively poor thermal performance of the building fabric at the Keepers' Cottages imposes a high overall heat demand, limiting the available technology options especially those that benefit from low circulation temperatures.
- ***Size of Existing Radiators***
  Related to the above, the size of the existing radiators in both buildings was found to be inadequate to the heat demand of the rooms they serve. In some cases, existing radiators were found to be inadequate even at high circulation temperatures.
- ***Capacity of Incoming Power Supply***
  The available power supply to the site is limited by a single transformer which supplies the entire complex via a main meter in the Workshop (minus the Lighthouse and NLB ancillary buildings which have their own separate supply). This limits the input energy available making electrically powered systems such as heat pumps or storage heaters impractical at present.
- ***Restrictions on Local Electricity Grid***
  The local electrical network on North Ronaldsay is highly constrained, preventing an upgrade of the buildings' incoming power supply for the foreseeable future. This also has implications for potential solutions involving storage technologies, new microgeneration systems, or reconfiguration of existing microgeneration assets, which will require the consent of the network operator. Engagement with the network operator was undertaken as part of the study and they indicated that changes at the site would be difficult to achieve consent for due to the highly constrained nature of the local network, both in terms of infrastructure on North Ronaldsay itself and the capacity of the interconnector serving the island.
- ***Remoteness and specific vehicle access issues at the site***
  Vehicular access to the site is very challenging, with only a single ferry sailing per week to and from the island. The ferry doesn't run in stormy weather conditions, which are a frequent occurrence in the local maritime climate. This makes access for professionals, trades, and suppliers extremely challenging, and makes any heating system requiring delivery of fuel (such as woodfuel, bioethanol or biokerosene) undesirable.

In combination, the five key barriers above are creating an apparently insurmountable roadblock to the implementation of an effective retrofit solution at North Ronaldsay that does not involve extremely high capital costs which would be unaffordable to the North Ronaldsay Trust. Positively identifying the barriers to progress is a positive first step however, and both Power Circle and Atamate hope to take forward further work at the site on behalf of the NRT, with potential for financial support by Historic Environment Scotland and Scotland's community energy advice service, Local Energy Scotland[13]. The full writeup of the study on North Ronaldsay is available via the link below, and Historic Environment Scotland currently intends to republish this as a technical paper in the coming years. The results of Energy Pathfinder's energy assessment activity on North Ronaldsay were also the subject of a presentation at the projects final conference in Cork.

Further Reading:

- ***Mechanical Services Feasibility Study for North Ronaldsay Lighthouse Keepers' Cottages***
  (Shimmin and Kelly, 2022)
  Full text: https://www.energypathfinder.eu/wp-content/uploads/2022/09/Energy-Upgrade-Study-Atamate-2022.pdf

[13] https://localenergy.scot/

Cathedral of Saint Mary and Saint Anne

Roman Street, Blackpool, Cork City, Ireland

Figure 27: Cathedral of Saint Mary and Saint Anne in the city of Cork, Ireland, viewed from the south.
Image © Sebastian "sebrem" B… via Wikimedia Commons [CC BY-SA 3.0]

The Cathedral of St Mary and St Anne, otherwise known as the North Cathedral, was constructed in multiple phases across the 19th and early 20th century. Indeed, at time of writing, there remains some uncertainty as to the exact chronology of certain elements (JCA Architects, 2020). Like many large ecclesiastical buildings, especially those of traditional construction, the cathedral presents a challenge from an energy management and retrofit perspective, with a large internal volume, high form factor, poor thermal performance of building fabric and low airtightness. An instructive parallel may be drawn with the Tegs Kyrka demonstrator which despite being entirely different in age, construction, and thermal performance presents remarkably similar behaviour and more or less the same overall challenge.

This key challenge in large ecclesiastical buildings is that of achieving an acceptable level of user comfort, especially in the large main volume (nave), whilst avoiding excessive energy consumption. This has been the focus of the efforts undertaken at the North Cathedral during the Energy Pathfinder project, with the principal investigation a study by energy consultants DCSix Technologies (2022) exploring space heating management strategies for the building.

In addition to this, some fabric retrofit was undertaken during the project period which insulated the main pitched roof above the nave (immediately to the right of the belltower in Figure 27 above). This element of the structure was previously uninsulated.

Retrofit Work:

Figure 28: Insulation installation in the cathedral pitched roof during 2021 – Image © NCE Insulation

Attic spaces within the main pitched roof structure were insulated during summer of 2021 using a combination of blown cellulose fibre installed over horizontal ceilings and mineral wool batts installed against vertical stud walls. This was supported by grant funding issued by the Sustainable Energy Authority of Ireland (SEAI). Draught-sealing of windows in the cathedral was noted by JCA Architects (2020) as a sensible option for further work but (at this time) NCE Insulation has elected, noting the significance of the building, not to proceed with this until an appropriately qualified conservation professional can be appointed to support the work.

Figure 29: Maintenance work in progress, refelting on one of the principal flat roof sections over the altar – Image © NCE Insulation

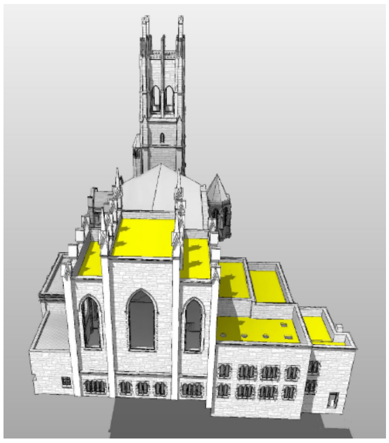

Figure 30: 3D visualisation of the cathedral showing flat roofs identified as in need of maintenance – Source: (JCA Architects, 2020)

JCA's (2020) feasibility study also identified an urgent need for maintenance work on a number of flat roofs at the eastern end of the cathedral, this was completed during summer of 2020. Whilst this does not represent retrofit work per se it is relevant to note as poor maintenance of building fabric is an ongoing problem for traditional buildings in many contexts. This can directly impact energy efficiency as the thermal performance of traditional fabric materials declines dramatically with increasing moisture content (Banfill, 2021). A legacy of inadequate maintenance can also be an indirect drag on improving energy efficiency as it often results in a backlog of issues which must be addressed before retrofit work can take place.

At this time it has not yet been possible to quantify or to estimate the outcome of the above described interventions at the cathedral. This is principally due to a limited time having elapsed at time of writing following the completion of retrofit work at the building in late summer of 2021. It should also be noted that sustained changes to the occupancy pattern of the cathedral resulting from the covid-19 pandemic are still a confounding factor preventing side-by-side comparison with recent energy consumption data (see below).

Assessment Methods and Results:

Table 8: Cathedral of St Mary and St Anne, energy assessment method.

Method:	Aim:	Notes:
Energy management study*	Optimise operation of existing heating systems to minimise overall energy spend whilst maintaining a comfortable indoor environment for users.	Undertaken during early 2022 by local energy consultants DCSix Technologies

* (DCSix Technologies, 2022)

The table above appears in the preceding Energy Pathfinder report, *T3.1.1 Demonstrator Buildings and Energy Assessment Strategies,* and sets out the approach adopted by NCE Insulation to energy assessment of the North Cathedral. An energy management approach was adopted as a response to the key energy challenge in a building such as this one, that of achieving an acceptable level of thermal comfort whilst avoiding excessive energy consumption. Historic Environment Scotland has some direct experience in this area and their *Refurbishment Case Study 19 (HES, 2015)* sets out their experience of installing an air source heat pump and infrared radiant heating at a rural church in Kilmelford, Scotland.

Review of Operational Energy for 2018 and 2019 by NCE Insulation

Table 9: Cathedral of St Mary and St Anne, operational energy 2018 and 2019.

	2018	2019
Electricity Consumption (kWh)	6,725	9,326
Electricity Cost*	€2,282	€2,799
Gas Consumption (kWh)	305,554	231,057
Gas Cost*	€15,815.77	€11,809.88

Source: NCE Insulation

**Costs are EUR for the period in which the energy bills were issued and have not been adjusted for inflation.*

The above table shows the energy consumption and cost data for the cathedral during 2018 and 2019. This provides context for the energy management study summarised below and, combined with the narrative of recent upgrades at the building, some limited conclusions may be drawn.

An air-to-air heat pump (A2AHP) was installed in 2018, and electric vehicle chargers were installed in 2019, which probably account together for the increase in electricity consumption and some of the decrease in gas consumption. It would be unwise to attribute this entirely to the installation of the A2AHP however as the effect on gas consumption seems outsized compared to the increase in electricity, especially when it is factored in that some of that is likely to be the electric vehicle chargers. It's therefore highly likely that variations in weather conditions and occupancy patterns from year to year are also at work.

It should also be noted that in 2016 lighting throughout the cathedral was upgraded to LED and a roof mounted ~4kWp solar PV array was installed. Whilst it's not possible to directly quantify the impact of these past interventions this may explain why the electrical consumption of the cathedral is comparatively limited for a building of its size hosting a variety of community functions in addition to its primary function as a place of worship.

DCSix Energy Management Study – North Cathedral Heating Analysis

This study began with the goal of optimising the use of existing heating systems at the cathedral which consisted of a gas-fired boiler, gas-fired warm air system, and the A2AHP installed in 2018. The principal focus was the warm air system and A2AHP which heat the main internal volume of the cathedral. Gas consumption was measured indirectly via monthly bills, with electricity consumption monitored directly using a Wattrics monitoring system. This system provided direct measurement of electrical consumption by the A2AHP and was able to directly measure electrical consumption by the circulation fans and electrical components of the warm air system as a proxy for overall energy consumption. Two hygrothermal (air temperature and relative humidity) sensors also monitored the indoor environment.

Following the study period, the measured output and running costs of the two main heating systems were found to be as below:

Table 10: Cathedral of St Mary and St Anne, main volume space heating system characteristics.

	Peak Output (kW)	Running Cost (€/kWh)
Gas-fired Warm Air System	246	0.21
Air-to-Air Heat Pump	26.25	0.07

Source: (DCSix Technologies, 2022)

Based on the above, and on the existing usage pattern observed during the study period, DCSix were able to recommend the following pattern of operation(Table 11) which optimises for minimum cost by using the A2AHP as a weather-dependent pre-heater to minimise the need for the more powerful warm air system which activates only for long enough to bring the main volume to an acceptable temperature at the required time. They have estimated that annual savings from this alternative operating style will amount to €3,562/year at current energy prices.

Table 11: Cathedral of St Mary and St Anne, new operating pattern proposed by DCSix technologies.

Cathedral Start Temperature	[A2AHP] Schedule	[Warm Air] Schedule	Typical Cost/Day
<12°C	05:00 –11:00	09:45 –10:30	€10.75 + €40 = €50.75
12 –13°C	05:00 –11:00	10:00 –10:30	€10.75 + €26.25 = €37
13 –14°C	05:00 –11:00	-	€10.75
14 -15°C	06:00 –11:00	-	€8.95
15 -17°C	07:00 –11:00	-	€7.16
>17°C	-	-	-

Source: (DCSix Technologies, 2022)

Summary and Evaluation:

From a technical standpoint, the upgrades and maintenance work undertaken during the period of the Energy Pathfinder project represent a significant positive step for the building. In buildings of traditional construction in particular, timely maintenance of the building fabric is of paramount importance to energy efficiency. This is because traditional buildings are often constructed of permeable materials which evidence a disproportionate increase in thermal conductivity when allowed to become damp due to defects in weather proofing or rainwater management. It should be noted that loose, blown insulation materials installed in draughty spaces such as attics sometimes have a tendency to drift over time which can result in gaps appearing and result in cold spots. It would therefore be advisable to check the newly insulated attic spaces on a regular basis to ensure this is not occurring.

Going forward, optimising the operation of existing heating infrastructure as proposed by DCSix Technologies (2022) represents a promising avenue for exploration, with significant potential for carbon and financial savings. Although a major component of this existing heating infrastructure is fuelled by fossil fuel (mains gas), there is no immediately obvious technical solution which can replace this, although the option of infrared heating as explored in a similar context by Historic Environment Scotland in 2015 may merit consideration.

It's also worth noting that the cathedral annex has not been addressed during the Energy Pathfinder project. This part of the structure is also heated using mains gas but presents a very different challenge from the Cathedral's large nave and would be better explored as part of a future project.

Further Reading:

- ***North Cathedral Heating Analysis***
  (DCSix Technologies, 2022)
  Full text: https://www.energypathfinder.eu/wp-content/uploads/2022/09/20220531-DCSix-Report.pdf
- ***Outline Feasibility [Study] for the Cathedral of St Mary and St Anne […]***(JCA Architects, 2020)
  Full text: https://www.energypathfinder.eu/wp-content/uploads/2022/09/Study-Outline-Feasibility-JCA-Architects-1.pdf

Myross Wood House

[Parish Ardagh, County Cork, Ireland](#)

Figure 31: Myross Wood House, principal elevation of original Georgian house with early side extensions – Image © Historic Environment Scotland – Photographer: Carsten Hermann

Myross Wood House, in Ireland's County Cork approximately 60km south-west of Cork City, was originally the country seat of a landowner and dates to 1817. Various additions to the building were made during the 19th and 20th centuries, the most recent being the south wing added in 1959. During this period the building also ceased to be a residence and became a seminary and venue for religious gatherings, most recently under the care of the Missionaries of the Sacred Heart. The building has now been leased by environmental group Green Skibbereen who are in the process of converting it into the West Cork Centre of Excellence for Climate Action and Sustainability (CECAS). The structure is included on the Republic of Ireland's National Inventory of Architectural Heritage but is not subject to statutory protection.

Engagement at Myross Wood House by the Energy Pathfinder project has principally supported the ambitions of Green Skibbereen through studies exploring the potential for retrofit of the building fabric and upgrade of technical services, including renewable heating and microgeneration potential. Co-design activity has also taken place concurrently and the results of these exercises are covered in the relevant Energy Pathfinder reports.

Figure 32: Courtyard with 20th century extension left of centre; the original building with older extensions right of centre – Image © Historic Environment Scotland – Photographer: Carsten Hermann

Assessment Methods:

Table 12: Myross Wood House, energy assessment activities.

Method:	Aim:	Notes:
Energy upgrade study*	Explore potential for upgrade of the building fabric and potential renewable sources of heat and electricity	
Retrofit strategy study**	Develop a detailed strategy for fabric retrofit which is compatible with the health of the building fabric and preservation of built heritage	
Energy audit***	Estimate the current energy performance and environmental footprint of the building, and suggest potential efficiency improvements	This is an audit carried out using a standard methodology designed by Ireland's SEAI to assist SMEs in reducing their energy consumption and carbon footprint

* (Akiboye Conolly Architects, 2021)
** (Carrig Conservation International, 2020)
*** (SEAI, 2022)

Energy assessment activity at Myross Wood House has been carried out in support of proposals exploring potential retrofit pathways for the building, with fabric upgrades the principal focus, but also incorporating technical services and microrenewable options. It remains early days for Myross Wood House in its new role as the West Cork CECAS and activity has consequently been focused on exploring the potential of the building going forward.

This report section is a synthesis and summary of the key conclusions reached by the three principal energy studies carried out at the building as listed in Table 12 above. Each of these represents a complete investigation in its own right however, in particular the Akiboye-Conolly and Carrig studies, and reading of these reports is strongly encouraged for anybody looking to understand the building itself or the widespread retrofit and maintenance challenges for traditional buildings generally that Myross Wood House neatly embodies.

Some ongoing monitoring work continues to take place, supported by University College Cork and Green Skibbereen, however insufficient time has elapsed to draw meaningful conclusions from this data at present.

A more comprehensive summary of the fabric makeup and technical services configuration at Myross Wood House is available in the preceding report. In addition, some contextual information on historic energy consumption, sourced from the Carrig (2020) study has been included below to aid understanding of the overall energy picture at the site.

Recent Energy Consumption:

Table 13: Annual heating oil consumption and carbon emissions for Myross Wood House.

Year	Annual cost for heating oil (€)	Average annual cost of heating oil in Ireland (€/1,000 litres)	Estimated oil consumption (litres)	Estimated carbon emissions (kgCO2e)
2012		€1,104.20		
2013		€1,069.20		
2014		€974.30		
2015		€677.40		
2016	€15,421.82	€582.70	26,466.14	67,118.13
2017	€18,251.32	€632.20	28,869.53	73,213.14
2018	€17,523.85	€692.60	25,301.54	64,164.72
2019	€17,180.00	€714.30	24,051.52	60,994.65

Source: (Carrig Conservation International, 2020)

Table 13 above shows the energy consumption of Myross Wood House through the years 2016 to 2019, and the average cost of heating oil in Ireland for the years 2012 through 2019. This information was sourced from the previous occupiers and (continuing) owners of the building, the Missionaries of the Sacred Heart. Although high energy consumption and high resulting costs are not unusual for a country house of this size it is worth noting that the building was very underoccupied at the time, and that in the years since 2019 energy prices have increased significantly. This is due to multiple global factors, most sharply in 2022 following Russia's invasion of Ukraine and the resulting disruption to European energy supplies. Considering that use and occupancy of the building is expected to increase dramatically as it transitions into its new role, it is clear there is an urgent need for an effective retrofit and operational strategy going forward.

In isolation, it is difficult to draw meaningful conclusions from the data above due to the aforementioned underoccupancy. However, Akiboye Conolly (2021) note that a crude analysis returns a figure for overall building energy consumption of ~180kWh/m^{2}year. Their simulation of the building under full occupancy returns a figure of 436kWh/m^{2}year, approximately three times higher. Considering the underoccupancy of the building as the context for the real-world figure above this appears to be reasonably accurate. They note that this would score the second-lowest rating of F if assessed for a Building Energy Rating (BER[14]) certificate.

Carbon figures, presented in kilograms or tonnes of CO_2 equivalent as in Table 13 above are often opaque to non-expert readers. To assist, Carrig (2020) also provided the information in Table 14 (below) to contextualise the large carbon footprint of Myross Wood House in its present condition. This is mainly the result of the building continuing to use heating oil as the primary source of energy for space and water heating.

Table 14: Carbon emissions equivalent in square metres of oak woodland and kilometres driven by car.

Year	Estimated carbon emissions (kgCO2e)	Equivalent area of oak woodland required each year to consume all CO2e emitted (m^2)	Equivalent distance driven in an average car (km)
2016	67,118.13	2,483.10	431,281.16
2017	73,213.14	2,708.59	470,445.88
2018	64,164.72	2,373.83	412,303.42
2019	60,994.65	2,256.55	391,933.49

Source: (Carrig Conservation International, 2020)

[14] https://www.seai.ie/home-energy/building-energy-rating-ber/

Assessment Results:

Energy Audit – Sustainable Energy Authority of Ireland - (SEAI, 2022)

This report, carried out by an energy auditor from Ireland's SEAI in early 2022, is designed to assist the new occupiers of the building in reducing the running costs and operational emissions of Myross Wood House. This service is available to businesses across the Republic of Ireland and designed to both support the businesses themselves and to contribute towards national net-zero and energy efficiency targets.

Broadly, modelled estimates of energy expenditure and emissions are very similar to those undertaken by Carrig and Akiboye-Conolly. Estimated energy costs in this report are €56,704/year (of which heating oil represents the major component at €54,028/year and 377,820kWh/year) and corresponding emissions total 103.8tCO2e/year; with potential to reduce this operational footprint to a cost of €10,427/year, representing an 82% saving, and emissions of 6.2tCO2e/yr. Electricity consumption figures are sourced directly from recent bills and are probably therefore accurate, totalling €2,405/year and 12,505kWh/year. The savings potential is based on an optimal combination of the suggested energy saving actions listed in Table 15 below:

Table 15: SEAI energy audit recommended energy action at Myross Wood House.

Action	Annual Saving (€)	Emissions Reduction (tCO_2e/yr)	Cost of Action (€)	Payback Period (Yr)
Consolidate activity to a smaller area of the building	12,870	23.75	10,000	0.78
Install TRVs* and improved boiler controls	5,148	9.50	8,500	1.65
Draughtproofing of doors and windows	2,717	5.01	4,600	1.69
Replace older single-glazed windows	2,860	5.28	50,000	17.48
Improve attic insulation**	2,000	3.69	10,000	5.00
Isolate disused heating boiler	1,251	2.31	250	0.20
Install heat pumps to provide hot water	3,191	7.05	35,000	10.97
Install heat pumps to provide space heating	28,716	63.48	150,000	5.22
Install solar photovoltaics	12,000	16.23	77,000	6.42
Total	**70,753**	**136.30**	**345,350**	**4.88**

Source: (SEAI, 2022)
**Thermostatic radiator valves*
***As per Energy Upgrade Study*

It is worth noting that not all of the above actions are necessarily compatible and, as noted by the SEAI report, that some actions will impact the savings resulting from others. This is why the total saving in Table 15 does not equal the maximum possible saving quoted above. Equally, certain technologies may prove to be dependent on further upgrades which are not mentioned in the report, such as insulation of the external walls. Maintenance work to improve the condition of the building fabric, which is discussed extensively by the other studies (Carrig, 2020; Akiboye Conolly, 2021), and which would improve thermal performance considerably is also not mentioned. This reflects that SEAI's audit service is designed to assist businesses generally rather than specifically those occupying traditional and/or historic buildings. That being said, it does serve to highlight the difficulties faced by owners and occupiers of such buildings, as suitable expert advice can represent an additional expense to maintenance and suitable contractors with traditional skills can be difficult to secure, particularly for regular maintenance and smaller repair jobs.

Energy Upgrade Study – (Akiboye Conolly Architects, 2021)

Figure 33: Three levels of intervention – Source: (Akiboye Conolly Architects, 2021)

This study is structured around a set of upgrade options proposed across the various elements of the building, focusing on fabric upgrades but also covering technical operations. The proposed intervention strategy divides the building into three parts based principally on the degree of heritage constraint present in each of these areas (Figure 33 above). Most constrained is the original East wing, followed by the less constrained North and West wings, and finally the South wing which the authors consider to be unconstrained from a heritage standpoint. There is also an outline exploration of renewable technology options and of the environmental footprint of the building.

It's worth noting that both this study and the Carrig (2020) study are good examples of the “fabric-first” approach to retrofit which is at present widely accepted as best practice. Akiboye-Conolly’s report going so far as to include a process diagram which illustrates the three-stage logic of the approach; firstly understanding user needs, then determining the optimum fabric improvements, followed by upgrades or changes to the building’s sources of energy.

This contrasts the “services-first” approach which is gaining in popularity among a minority of professionals. In this approach the latter two stages are reversed, with fabric upgrades undertaken if expedient or necessary to facilitate the desired services upgrades (e.g. installing additional insulation to make a low temperature heat pump viable). This alternative approach was adopted partially out of necessity at the North Ronaldsay demonstrator, but also partly because this approach is favoured by consultants Atamate (2021, p. 9) who were subcontracted to deliver the building simulation element of that study.

Table 16: Myross Wood House, proposed retrofit of fabric elements by building element.

Building Element	Proposed Upgrades
Walls	● Constrained: 38-50mm cork-lime external render or equivalent ● Less constrained: 100mm cork-lime external render or equivalent ● Unconstrained: 250-300mm woodfibre external wall insulation plus 50mm cavity wall insulation
Floor	● Suspended floors: ~200mm cellulose fibre insulation, ensuring that ventilation of the solum void is not obstructed ● Solid floors option 1: Vacuum insulation over existing floor slab with new floor finish ● Solid floors option 2: Excavate existing floors and install new insulated lime concrete slab, potentially suitable for use with underfloor heating
Roof	● Top-up of existing 100mm loft insulation to a total thickness of 400mm, noting that if existing loft insulation is contaminated or in poor condition it should be removed and new insulation installed to a depth of 400mm
Openings	● Constrained and less constrained: Ideally upgrade from existing heritage-sensitive uPVC double-glazing to triple-glazing ● Unconstrained: Modern high-performance triple glazing, potentially with supply air windows (Figure 34 below)

With reference to glazing upgrades, the study notes that triple glazing may not be technically feasible if timber sashes are preferred. In this case, slim-profile vacuum double-glazing could potentially work well in addition to restoration and retro-insulation of the existing timber shutters present in the historic areas of the building.

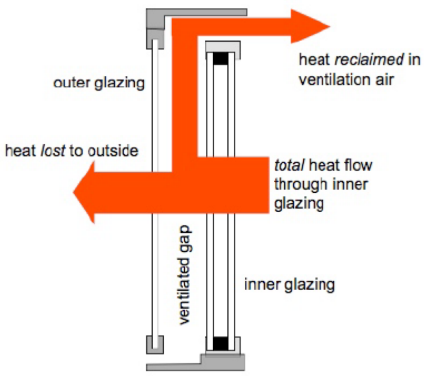

Figure 34: Heat flow via a supply air window – Source: (Akiboye Conolly Architects, 2021).

In addition to the above fabric upgrades, upgrade of the existing ventilation arrangements is recommended. At present, the building relies upon passive ventilation as it would have done originally. As seen in many other traditional buildings, a number of passive ventilation routes have since been closed off or impaired. This is not unusual and can be as a result of poor maintenance such as encroaching ground levels occluding underfloor vents, inappropriate retrofit such as the replacement of sash-and-case windows without introducing alternative ventilation routes, or lack of knowledge on the part of occupants such as a chimney baffle which lies unused because occupants do not know it is there.

In this study, the optimal recommendation suggested is a mechanical ventilation heat recovery (MVHR) system for the building, though this is acknowledged to be expensive and disruptive to install. Intermediate solutions proposed include partial heat recovery extract ventilation focused on moisture producing areas, humidity controlled extract ventilation, or passive stack ventilation. It is noted by Akiboye-Conolly that the existing infiltration rate is fairly high and that this has assisted in keeping the majority of the fabric relatively free of moisture. However, it is also noted that in higher occupancy areas condensation has been a chronic issue and that any intervention implying a reduction in the overall ventilation rate should not be countenanced unless a strategy is in place to control internal humidity.

Table 17: Myross Wood House, overall fabric performance before and after all recommended upgrades.

Building Part	Existing	Upgraded
East Wing *923m^2 equivalent to:*	368 MWh/year 399.7 kWh/m^{2}year	99 MWh/year 107 kWh/m^{2}year
North and West Wings *1,269m^2 equivalent to:*	567 MWh/year 447 kWh/m^{2}year	165 MWh/year 130 kWh/m^{2}year
South Wing *702m^2 equivalent to:*	327 MWh/year 466 kWh/m^{2}year	62 MWh/year 88 kWh/m^{2}year
Whole Building ***2,899m^2 equivalent to:***	**1263 MWh/year** **436 kWh/m^{2}year**	**327 MWh/year** **113 kWh/m^{2}year**

Source: (Akiboye Conolly Architects, 2021)

Retrofit Strategy Study – (Carrig Conservation International, 2020)

The following paragraphs principally summarise the retrofit strategy section of the Carrig study (section 8, pp36 – 41) which describes their proposed approach to fabric upgrades at Myross Wood House. The specific fabric upgrades proposed are not included in this report as these are almost identical to the upgrades proposed by the Akiboye-Conolly study summarised above, and indeed the Carrig report has had considerable influence on these recommendations. The proposed retrofit strategy is based on an assessment of the building's condition, current thermal performance, and an impact assessment considering heritage significance.

In its own right, this study represents an extensive document which draws upon a wide body of literature and is a useful reference for best practice in traditional building retrofit, in addition to being a linking point to further material on the subject.

The condition assessment highlights a number of key issues which are mutually reinforcing and negatively impacting both the health of the building fabric and its thermal performance. The primary issue identified is damp across various areas of the building, most significantly rising and laterally-penetrating damp affecting masonry walls at ground floor level and in some cases resulting in rotting of floor timbers. This has resulted from encroaching ground levels around the building compounded by impermeable cement-based render installed on the exterior face of external walls, and in parts of the east wing impermeable polystyrene insulation on the interior face.

The key conclusion evidenced by these issues is that the health of the fabric and thermal performance of the building is being adversely affected by inappropriate maintenance and inappropriate retrofit works, however well intentioned, that were carried out previously.

As a consequence of the issues described by the condition assessment, Carrig estimate that the thermal transmittance (U-value) of the external walls is currently 30% higher than it would otherwise be due to the elevated moisture content of the wall fabric. The external walls in question are solid masonry of approximately 600-700mm thickness and Carrig have estimated that the current U-value is 2.1W/m^{2}K and that if dried out following remedial works this could be reduced to 1.3W/m^{2}K. In practice, this represents a 20% reduction in heat loss via these external walls compared to the building in its present condition. This highlights both the importance of returning traditional buildings to a good standard of repair as part of any effective retrofit strategy, and also of ensuring that the design quality of retrofit work is high in order to ensure that further issues are not created (for example, by introduction of impermeable materials which impede the ability of the building fabric to shed moisture).

Further Reading:

- ***Energy Upgrade Study***
  (Akiboye Conolly Architects, 2021)
  Full text: https://www.energypathfinder.eu/wp-content/uploads/2022/09/Study-Energy-Upgrade-by-Akiboye-Connolly-Arch.pdf
- ***Retrofit Strategy Study***
  (Carrig Conservation International, 2020) Full text:
  https://www.energypathfinder.eu/wp-content/uploads/2022/09/Study-Retrofit-Strategy-by-Carrig.pdf
- ***Energy Audit***
  (SEAI, 2022)
  Full text: https://www.energypathfinder.eu/wp-content/uploads/2022/09/Energy-Audit-by-SEAI-Liam-McLaughlin.pdf

Rector’s House

[Rantakatu 7, 92100 Raahe, Northern Ostrobothnia, Finland]

Figure 35: The Rector’s House – Image © Historic Environment Scotland – photographer: Kenneth Easson

The Rector’s House is a two-storey timber house originally constructed in 1900 as a residence for the headmistress of the local teacher’s college by the State of Finland’s National Board for Public Housing. The building has seen multiple uses and some modification over the course of the 20th century, most recently and significantly its complete renovation in 1991. Although currently vacant, the most recent use of the building was as part of the school of engineering and as an office for the Oulu University of Applied Sciences from 1999 to 2014. The exterior of the building is in the protected S2 category under the Finnish system of heritage management.

The baseline condition and energy performance of the building is related by the preceding report in this series (3.2.1). In the case of this demonstrator there has been no retrofit work and comparatively limited energy assessment activity during the project period. However a detailed thermal imaging survey and energy modelling work by engineering students at the Oulu University of Applied Sciences (OAMK, acronym from Finnish). This work has supported and informed an in-depth co-design process seeking to establish a pathway by which the building can be returned to good condition and brought back into active use. This report principally looks at energy-related material in isolation but more details on the co-design process may be found in other Energy Pathfinder materials on the subject produced by lead partner for co-design, University College Cork.

Assessment Methods:

Table 18: Rector's House, energy assessment methods.

Method:	Aim:	Notes:
Energy upgrade study*	Explore promising energy upgrade options in support of a co-design process	This has been undertaken by engineering students at OAMK and forms part of a masters level thesis in architecture
Thermal imaging**	Assess the in-situ performance of existing building fabric	

** Part of* (Heinonen, 2022)
**** (Hukka and Korpi, 2022)

This assessment strategy represents an exploration of the building's energy performance designed to inform and support the co-design process and planning for reoccupation and change of use which are the focus of Heinonen (2022).

Energy Upgrade Study – forming part of Heinonen (2022)

This study explored potential option for improvement of the Rectors' House, principally by constructing a detailed energy model for the building. Based on the output of this model a plan for renovation and retrofit of the building was proposed which focused on improving airtightness and upgrading the existing mechanical ventilation system to incorporate a heat recovery system. The projected results of this renovation are related by table

Table 19: Energy consumption calculation before and after proposed renovation.

	Before Renovation (kWh/year)	After Renovation (kWh/year)
Floor	3,465	3,465
Walls	16,057	16,057
Roof	4,560	4,560
Windows	17,684	14,147
Balcony Doors	0	0
Outer Doors	6,594	3,979
Envelope (Total)	**48,360**	**42,208**
Air Leakage	25,210	8,403
Ventilation	52,522	9,086
Domestic Hot Water	0	0
Internal Energy Sources	3,957	10,379

TOTAL HEAT DEMAND (Whole Building) (per m²)	***122,135*** ***243***	***49,319*** ***98***
Carbon Emissions (Whole Building) (per m²)	***29.3 tonnes/year*** ***58 kg/year***	***11.7 tonnes/year*** ***23 kg/year***

Source: (Heinonen, 2022)

The proposed renovation was also costed by the students using Haahtela TAKU[15] quantity surveying software providing roughly equivalent information to the UK's building cost information service (BCIS[16]) and other similar products elsewhere. This yielded a projected total cost for the proposed renovation of €1,205,360 including VAT versus a project total cost of €3,179,960 including VAT for construction of an equivalent new building (Kamula *et al.*, 2022). Considering that an equivalent new building would incur a cost nearly triple that of the proposed renovation, and also that adopting a "demolish and rebuild" approach would inevitably incur additional carbon emissions both as a result of demolition itself and embodied in the new building, this study outlines an extremely strong financial and environmental case for retention and renovation of this historic structure.

The reasonable counterargument in this case might be based on the probably higher operational emissions in a retained historic building compared to a new build. The proposed renovation performs relatively well by this metric as well, reducing operational emissions from 29.3 tonnes/year to 11.7 tonnes/year. Though it must be acknowledged that this remains a considerable footprint this is based on a carbon intensity of incoming energy of 240gCO_2/kWh which may later be reduced further by action on site such as introduction of local microgeneration. Remote factors may also act to reduce this carbon factor, such as decarbonisation of industrial processes at the Raahe Steelworks (which powers the district heating system with waste heat) and decarbonisation of the Finnish electrical grid via the ongoing phase-out of peat-fired generation, expansion of the country's nuclear fleet, and increased share of renewable energy.

Thermal Imaging - Hukka & Korpi (2022)

This survey was carried out by OAMK construction architecture students Enni Hukka and Ella Korpi during Spring of 2022 using a FLIR[17] infrared camera. For the most part, conditions on the day of the survey were normal for a Finnish spring, with the exception of wind which was unusually strong:

- Outdoor: -0.7°C, 87% relative humidity
- Indoor: 14.1°C, 30.6% relative humidity
- Windspeed = 14.2m/s (Beaufort force 7, moderate gale)

As noted by Hukka and Korpi in their report, the high wind speed on the day of the survey has the potential to exaggerate the impact of any defects which affect the airtightness of the structure and this should be borne in mind when reviewing the below results.

When interpreting the images below, it is advisable to note the scale at the right side of the image, which shows the thermal range present within the camera's field of view, this varies from image to image meaning that the same colour in two different images will not necessarily correspond to the same measured temperature. Spot temperature, on the top left of each image, indicates the

[15] https://www.haahtela.fi/fi/kiinteisto-ja-rakennustalouden-palvelut/ohjelmistotuotteet/
[16] https://bcis.co.uk/
[17] https://www.flir.co.uk/

temperature of the object to which the central reticule is pointing in the image, assuming that the camera has been properly calibrated to the emissivity of the surface.

It should also be noted that objects which reflect visible light (i.e. objects which are shiny as opposed to matt) usually also reflect infrared radiation. Care must therefore be taken where reflective surfaces are present, as in Figure 36 below where the infrared reflection of the wall mounted radiator can be seen in the slightly shiny parquet flooring.

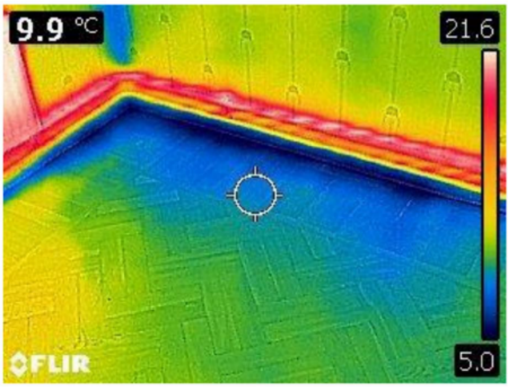

Figure 36: Heat loss at the wall-floor junction on the ground floor – Image © OAMK

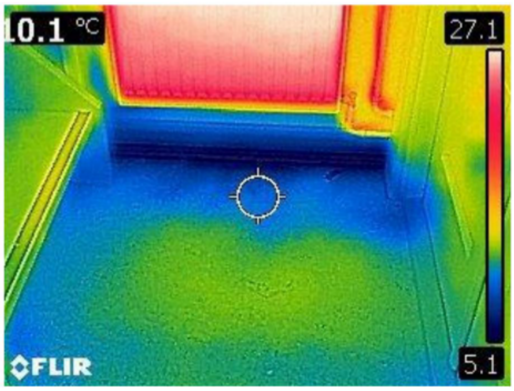

Figure 37: Heat loss below a radiator at the wall-floor junction on the ground floor – Image © OAMK

The above images show heat loss at wall-floor junctions on the ground floor. This is typically a site of significant heat loss due to geometric thermal bridging and conductive losses to the ground via the building foundations. Good construction detailing is important to avoid this in new-build structures and it is difficult, often uneconomical, to correct through retrofit.

The somewhat streaky character of the cold areas in these images is suggestive of air movement, conceivably this could be indicative of issues with airtightness but it is difficult to conclude how significant these are under normal conditions due to abnormally strong winds on the day of the survey. Especially as these rooms were on the windward side of the structure.

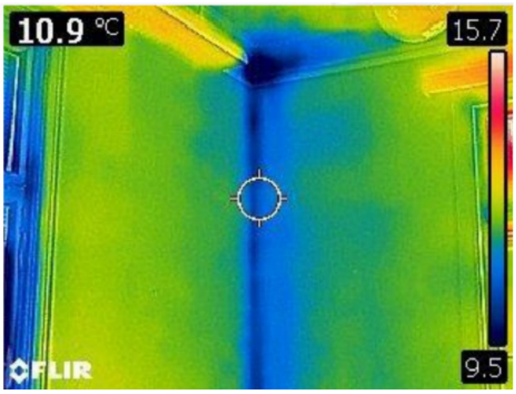

Figure 38: Heat loss at and above the wall junction at a corner of the ground floor – Image © OAMK

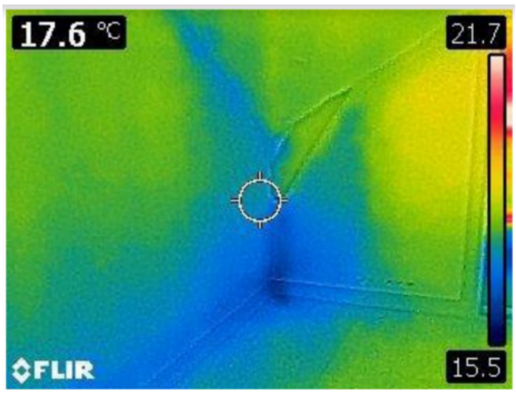

Figure 39: Heat loss at the junction of stud walls and floor in the 1st floor room-in roof – Image © OAMK

Heat loss at the corner of a building is almost always higher due to geometric thermal bridging however this usually presents as a narrow line in the very corner of the room. By contrast, Figure 38 on the left in particular is more pronounced than would normally be expected as a result of geometric thermal bridging alone, with the cold area at the top corner probably indicating cold air infiltration above the ground floor ceiling. This is supported by Figure 39 on the right which appears indicative of cold air infiltration between floors.

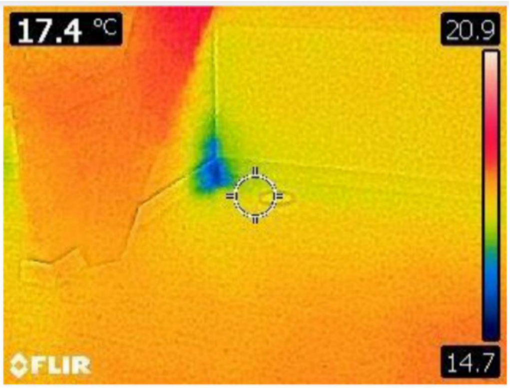

Figure 40: Heat loss at the junction of stud walls and floor in the 1st floor room-in-roof – Image © OAMK

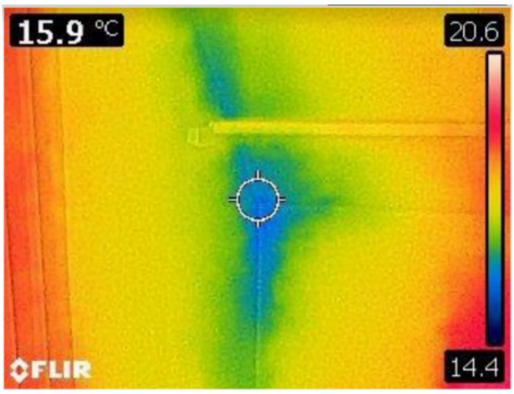

Figure 41: Heat loss via a stud wall junction in a 1st floor cupboard – Image © OAMK

Figure 39 and Figure 40 above show isolated areas of heat loss in corners of the 1st floor room-in-roof areas and are indicative of imperfect detailing of insulation installed in these areas.

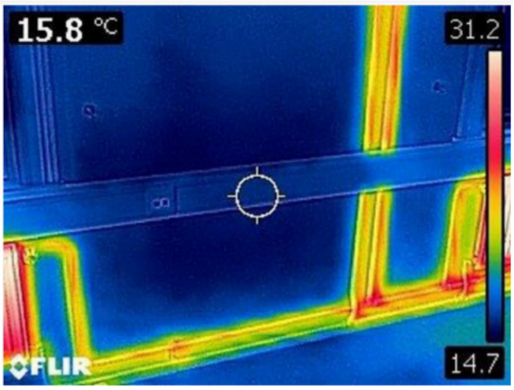

Figure 42: Heat loss in the middle of an external wall on the ground floor – Image © OAMK

In Figure 42 above, a dark area in the centre of the wall is suggestive of heat loss resulting from insulation which is either missing or is beginning to slump down within the wall cavity under the force of gravity. This is often observed in loose materials such as cellulose fibre and vermiculite, and in wool materials such as batts of mineral wool, hemp wool, or sheep's wool.

Summary:

From an environmental standpoint, the Raahe Rector's House as it stands today already performs well, the building is connected to a district heating system which is powered by waste-heat, and fossil fuels are already absent as a local energy source. As the carbon figures quoted by Heinonen (2022) illustrate, however, this is highly dependent on the carbon factor ascribed to this waste heat. Nonetheless, her thesis and the supporting work by Kamula et al., (2022) conveys a strong financial and environmental case for retention and reuse of the building, to say nothing of the considerable built heritage that the structure represents.

Therefore, the key challenge at this stage has been identified as that of returning the building to active use and a good standard of repair which has prompted exploration of potential routes to achieving this via an ongoing co-design process. From a technical standpoint, the most promising avenue for future retrofit work appears to be improvement of airtightness and the addition of heat recovery to the existing mechanical ventilation system, together representing a projected 40% reduction in the total heating energy demand from 122,135kWh/year to 49,319kWh/year.

Further Reading:

- ***Raahen Seminaarin Rehtorien Talon Kunnostus Ja Käyttötar-Koituksen Muutos***
  Refurbishment and Change of Use at the Rector's House, Raahe: Art Residence Plans and Co-Design Process (29 Sep 2022) (Heinonen, 2022)
  Full text: https://www.energypathfinder.eu/wp-content/uploads/2022/09/Final-Version-of-Heinonen-Thesis.pdf
- ***Lämpökuvausraportti: Raahen Seminaarin Rehtorien Talo***
  Thermal Imaging Report: Raahe Seminary Rectors' House
  (Hukka and Korpi, 2022)
  Full text: https://www.energypathfinder.eu/wp-content/uploads/2022/09/Thermal-Imaging-Report-20220929-1.pdf

Tegs Kyrka (Tegs Church)

Jägarvägen 16, 904 20 Umeå, Västerbotten County, Sweden

Figure 43: Tegs Kyrka front elevation, seen from the northwest in June 2022 – Image © Historic Environment Scotland – Photographer: Kenneth Easson

Construction of Tegs Kyrka began in 1964 and the church was inaugurated following completion in 1969. The building's expressive design was conceived in 1963 by the Stockholm architect Carl Hampus Bergma who won an architectural competition in that year. Hampus worked for Le Corbusier and Alvar Aalto, two of the most internationally-important architects of the 20th century. The influence of Le Corbusier and Aalto is clear to see in the use of exposed shuttered concrete (as at Le Corbusier's convent, La Tourette) and the freestanding campanile (bell tower) favoured by Aalto at his churches and civic buildings. It was designated a listed building in 2011 on account of its architectural interest and is on the building register of the Swedish National Heritage Board, Riksantikvarieambetet.

The building is substantially unaltered since its original construction, although an acoustic coating has been added to ceilings in the main internal volume, some minor changes have been made to windows, and the internal and external faces of the principal walls have been painted a yellow-pink colour. The building remains in its original use, under the ownership of the Church of Sweden, and serves the primarily residential neighbourhood of Tegs, south of Umeå's city centre and the Ume river. The baseline condition and thermal performance of Tegs Kyrka are outlined in the preceding report. No retrofit activity occurred at this demonstrator during the period of the Energy Pathfinder project but the building was the venue for extensive research exploring the optimisation of thermal comfort and energy expenditure, principally utilising energy simulation of the building including computational fluid dynamic (CFD) modelling of internal air movement.

Research Method:

Table 20: Tegs Kyrka, energy assessment methods.

Method:	Aim:	Notes:
Energy simulation including computational fluid dynamics (CFD)*	Analyse thermal zoning and patterns of air movement within the internal volume	This will also form the research component of a PhD project at Umea University and utilise IDA-ICE commercial energy simulation software (www.equa.se/en/ida-ice).
Thermal imaging**	Assess the in-situ performance of existing building fabric and services	

** (Zhang* et al.*, 2020, 2022)*
*** (Zhang* et al.*, 2022)*

The results of this research have been written up for publication as a conference paper (Zhang *et al.*, 2020) and as an article in a scientific journal (Zhang *et al.*, 2022) and links to the full text of these are provided at the bottom of this section. Of these, the 2020 paper is based mainly on CFD modelling of the main internal volume at Tegs Kyrka designed to explore the impact of envelope design, principally window size, position, and window-to-wall ratio on the internal environment and consequently on thermal comfort. The 2022 paper builds upon this work and relates the results of further research at the building exploring the optimisation of existing HVAC infrastructure to deliver thermal comfort whilst minimising operational costs.

Poor thermal comfort is a well-known issue for ecclesiastical buildings across the NPA region. Previous research partially attributes this problem to unwanted airflows resulting from cold surfaces, especially windows. Zhang et al (2020) and (2022) posit that improved knowledge of internal airflow in the large internal volumes typical in these structures can inform improved façade design in new buildings in addition to improved retrofit strategies and HVAC operating patterns in existing buildings. On this basis, energy simulation incorporating CFD was selected as a principal research method.

Overall, the research conducted by Umeå University at the demonstrator building principally explores the issues of poor thermal comfort and high energy consumption in large single-zone buildings with large internal volumes. As noted, ecclesiastical buildings (of traditional construction or otherwise), often embody these issues and the challenge for the building owners at Tegs Kyrka bears a marked similarity to the Cathedral of St Mary and St Anne in spite of significant differences in age, construction, and thermal performance. With that in mind however, Zhang et al (2022) are careful to note that within the typology of ecclesiastical buildings, the needs and priorities of the building, occupants, and objects stored within are highly varied. Therefore, in spite of the similarity of the overall challenge that might be faced, owners are well advised to approach their building as an individual case when optimising the operation of HVAC systems or considering retrofit options, rather than reaching for a one-size-fits-all approach that is unlikely to achieve the desired outcomes.

Summary of Key Findings:

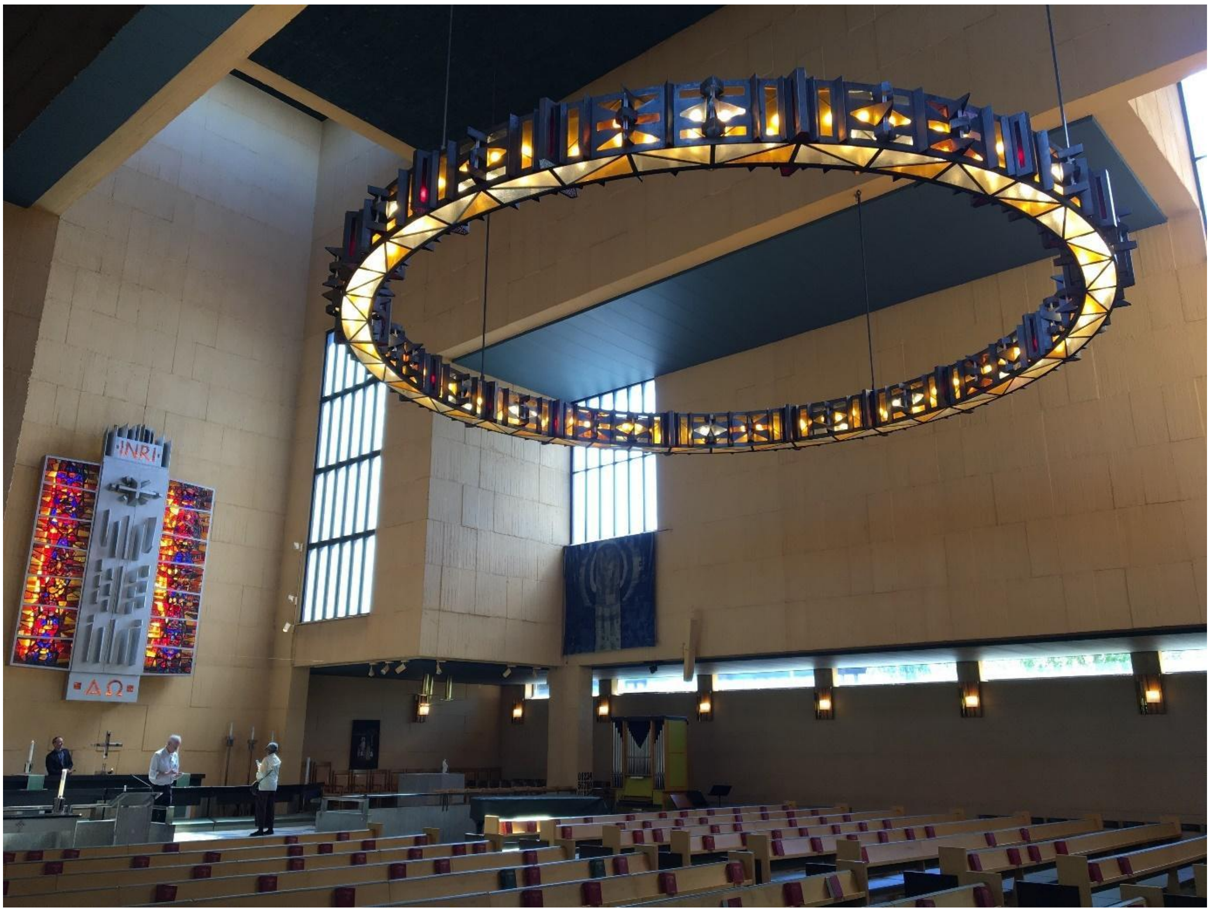

Figure 44: Tegs Kyrka, main internal volume modelled in detail by Zhang et al. (2020) *and* (2022) *viewed from the north corner – Image © Historic Environment Scotland – Photographer: Kenneth Easson*

Zhang et al. (2020)

This paper relates the results of an investigation, principally via a validated CFD model of air movement in the main internal volume (Figure 44) using the large eddy simulation (LES) method of CFD modelling. This explores the impact of window size, position, and window-to-wall ratio on thermal comfort. The model confirmed the intuitive assumption that the heat deficit rate (HRD), a proxy for thermal comfort were a higher HDR equates to lower thermal comfort, increases linearly with window area. The rate of increase of the HDR was highly dependent on the simulated occupants level of clothing, with heavy winter clothing resulting in a rate of increase of 14.33W/m^2 while light clothing resulted in a rate of increase of 32.70W/m^2.

Higher air velocity was also found to increase the HDR and this was impacted by window position (due to convection resulting from the cold surfaces of the windows) however the effect only impacted air velocity locally (in the volume immediately adjacent to the windows) and had a minimal impact on mean air velocity in the main occupied areas.

One potential response to this finding would be to reduce the area of glazing however there is an obvious tension here as large windows and glazed facades are typically considered desirable in cold and dark northerly climates such as those found across the NPA region. This is because they improve daylighting during the relatively short winter days, an important consideration for the physical and mental health of building occupants.

The findings of this research will principally be applicable to envelope design in new structures, especially large single-zone buildings.

Figure 45: Warm air system plant room, also mixes pre-heated fresh air with recirculated air to provide ventilation – Image © Historic Environment Scotland – Photographer: Kenneth Easson

Figure 46: Warm air input vent, corresponding extract vents appear adjacent to the opposite wall in the main space – Image © Historic Environment Scotland – Photographer: Kenneth Easson

Zhang et al. (2022)

This paper relates the results of an investigation using field measurements and numerical analysis[18] to explore thermal comfort proxies and energy use within the main volume of Tegs Kyrka. This main volume is heated by electric underfloor heating (referred to as radiant floor heating (RFH)), an electric warm-air system, and wall-mounted electric convector heaters. The key objective of the research was to investigate different operating patterns for this existing HVAC infrastructure and optimise for thermal comfort and energy efficiency.

The reference case for this investigation was the pre-existing operating pattern already in use. This saw the RFH used in isolation, running 24 hours a day at a constant setpoint. The building owners were dissatisfied with this, citing concerns in particular about running costs and poor thermal comfort.

The energy model was validated using sensors which monitored hygrothermal conditions at two points inside the main volume (air velocity, temperature, and relative humidity) and by comparing previous energy bills with the simulation output for the reference case.

The study investigated 13 operating patterns in total, including constant setpoint, cyclical setpoint, and intermittent operation, using various combinations of the existing heating infrastructure in isolation and in combination. These modes of operation were evaluated on overall use of energy, management of the indoor environment, and thermal comfort (using a predicted mean vote (PMV)/predicted percentage dissatisfied(PPD) method, a proxy which accounts for natural variation in thermal comfort preferences between individuals.

A thermal imaging survey was also incorporated in support of the principal energy modelling exercise (see Figure 47 and Figure 48 below).

[18] Using IDA-ICE, commercial energy simulation software (https://www.equa.se/en/ida-ice).

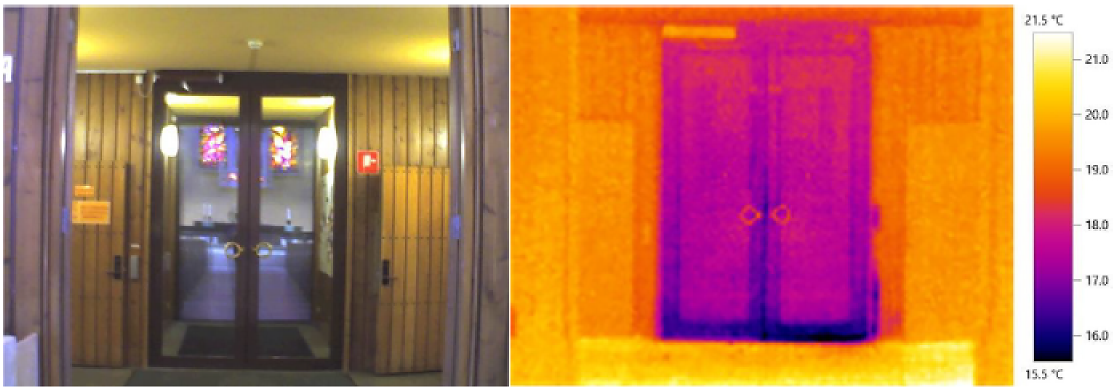

Figure 47: Thermal image showing vestibule and internal doors – Source: (Zhang et al.*, 2022)*

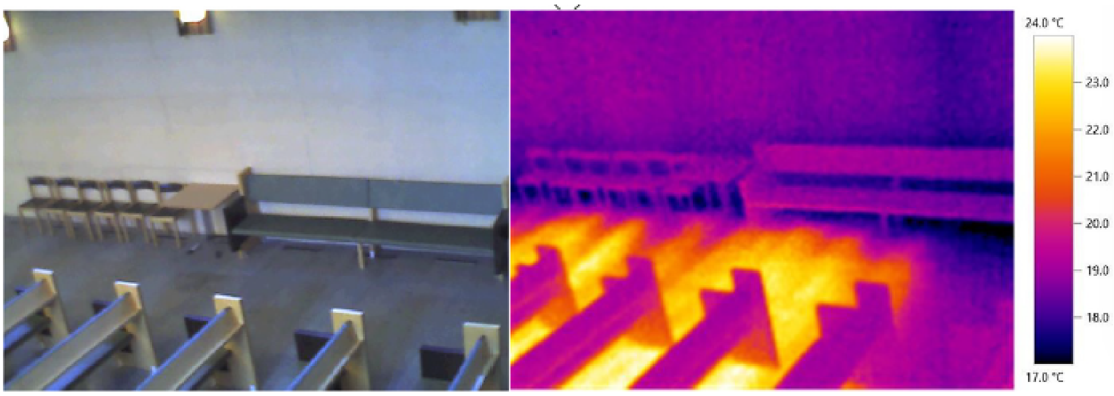

Figure 48: Thermal image showing underfloor heating in operation – Source: (Zhang et al.*, 2022)*

The first key finding of the research was that the main potential for energy saving lies in upgrade of the building envelope, with the model predicting a 27% overall saving resulting from upgrade of the existing windows to energy efficient equivalents.

The second key finding was that, of the operating patterns studied, energy use can be reduced by between 2.1% and 3.7% for the constant setpoint strategies by varying the mode of operation in terms of intermittency and use of different heating systems.

Intermittent heating using the warm air system in isolation was found to be least reliable due to susceptibility to changes in the external environment. A further noted issue with this strategy which has been observed in similar building is the tendency for this type of heating to result in turbulent airflow and thermal stratification which causes heat to accumulate near the ceiling and leave occupied areas with poor thermal comfort. For tall spaces in a cold climate, this suggests that intermittent heating by a warm-air system may therefore not be appropriate due to poor outcomes in terms of both energy consumption and thermal comfort.

For Tegs Kyrka, the authors propose that the most effective heating strategy is likely to be one of the cyclic setpoint strategies, cases 11, 12, and 13, as shown in Figure 49 below.

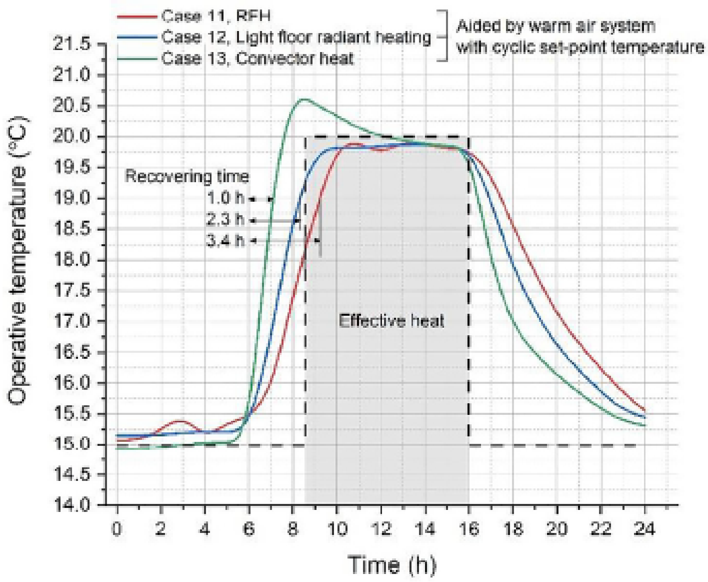

Figure 49: Recovering time and operative temperature (simulated) on the coldest day of the year – Source: (Zhang et al.*, 2022)*

The final key finding of the research was that the main difference between these three operating modes which used a cyclic setpoint was recovery time to the higher setpoint, determined by the thermal inertia of the heating system being used. The authors therefore propose that heating systems with lower thermal inertia should be preferred for this function in order to minimise recovery time to setpoint. They further suggest that the appropriate temperature for the lower setpoint should be selected on the basis of avoiding condensation based on prevailing local conditions, in the case of Tegs Kyrka this meant a lower setpoint of 15°C.

The key results and findings of this research at Tegs Kyrka parallel the experience at the Cathedral of St Mary and St Anne in Cork. In that demonstrator, DCSix technologies (2022) have proposed in their report, commissioned by NCE Insulation, a mode of operation for the Cathedral which is broadly similar to the cyclic setpoint strategies proposed by Umeå University for Tegs Kyrka. Monitoring the success of these proposed strategies at both demonstrators could therefore be a fruitful avenue of exploration for a future project.

The conclusions of this work also parallel the prior experience of Historic Environment Scotland in their Kilmelford Church refurbishment case study which uses an air source heat pump to provide background heating equivalent to the lower setpoint, with infrared radiant heating (a system with close to zero thermal inertia for all intents and purposes) used to directly heat the occupied areas when the building is in use (HES, 2015).

Journal Articles:

- ***Cold windows induced airflow effects on the thermal environment for a large single-zone building*** (Zhang *et al.*, 2020)
  Full text: https://www.energypathfinder.eu/wp-content/uploads/2022/09/Zhang-et-al-2020.pdf
- ***Field measurements and numerical analysis on operating modes of a radiant floor heating aided by a warm air system in a large single-zone church*** (Zhang *et al.*, 2022)
  Full text: https://www.energypathfinder.eu/wp-content/uploads/2022/09/Zhang-et-al-2022.pdf

Viðareiði Vicarage

Viðareiði, Viðoy island, Faroe Islands

Figure 50: The Vicarage seen from the northwest in October 2019, the partially heated "cowhouse" is at the eastern end of the building on the left of this image – Image © Historic Environment Scotland – Photographer: Carsten Hermann

Previous Energy Pathfinder reports in this series have provided an introduction to the demonstrator site at Viðareiði, where the northernmost vicarage in the Faroe Islands has stood for around 500 years. The building that stands today was constructed in 1854 and is an excellent example of vernacular Faroese construction techniques which developed in a context where all building materials, besides turf and stone, were scarce and expensive.

The retrofit project, started in 2018 by the Diocesan Authorities of the Faroe Islands with the assistance of Landsverk, has sought to balance the need for maintenance and upgrade of the building with protection of the built heritage it embodies, and with sensitivity to its appearance and local significance. Co-design has been a vehicle for this alongside a focus on high quality design and craftsmanship. Energy assessment and monitoring activity has been designed to evaluate the success of the retrofit alongside regular contact and feedback from the occupants.

Future plans for the building involve the addition of microgeneration, with the expectation that this will most likely be in the form of micro-hydro by reinstatement of a long vanished watermill immediately adjacent to the vicarage which once milled grain from local farms. Solar photovoltaics also represents a possible option for the future however visual impact is a concern and the economics of this technology in the Faroe Islands are currently poor due to high cost of equipment and a limited solar resource due to the islands' climate and latitude.

Retrofit Work:

Table 21: Viðareiði, overview of retrofit specification by building element.

Building Element	Specified Alterations
Floor	● Suspended floor insulation introduced throughout ground floor
Openings	● Optoglas secondary glazing system installed as an improvement to existing double-glazed windows ● New double-glazed window installed to reinstate a previously boarded over window in the eastern gable ● Three new double-glazed windows installed to reinstate previously boarded windows in the smokeroom ● Six new double-glazed dormer windows added to the main building room-in-roof
Space Heating	● New Nibe F1155 GSHP installed to replace existing oil-fired boiler ● Existing system of radiators replaced by a new wet distribution system combining underfloor heating and radiators, design flow temperature 40°C
Hot Water	● New hot water cylinder installed to supply domestic hot water at 65°C, heated by GSHP
Ventilation	● Existing passive ventilation routes retained

Viðareiði and Bayview (the Scottish demonstrator on Westray) represent the most in-depth retrofit projects observed by Energy Pathfinder. Indeed, both projects fit the definition of "whole-building retrofit" which is advocated by governments and industry as necessary throughout the building stock of the NPA region in order to meet national and international net-zero targets.

In the case of Viðareiði, the project began in 2018, and was initiated by the Diocesan Authorities of the Faroe Islands as owners of the building. The objective of the project was to achieve a quality-of-life improvement for occupants and users, to restore the building, and to make the future operation of the building environmentally sustainable. The Diocesan Authorities are also responsible for many similar buildings across the Faroe Islands and Viðareiði is considered to be a testbed for potential retrofit work at other churches and vicarages. Energy Pathfinder partner organisation Landsverk has acted in a supporting and advisory role throughout the project. Work on the building was completed by the end of 2019 with the occupants returning in December of that year.

Although it is not the focus of this report, it is relevant to note that a key objective for this project was preservation and enhancement of built heritage and historic character. At the outset, the project found a building much altered from its original configuration, but still with many original features and much of its historic character intact. Ultimately, in addition to preservation, considerable heritage gain was achieved in the retrofit project and it serves as a good example of how the aims of heritage conservation and energy retrofit can align to support each other where projects are well executed and design quality is high.

Fabric:

Figure 51: Pre-retrofit, deterioration of existing window frames – Image © Landsverk

Figure 52: Pre-retrofit, internal spaces were noted as being cold and poorly lit – Image © Landsverk

At the outset in 2018, the building fabric was already relatively well insulated thanks to the last refurbishment which had occurred in 1992. As a result, significant upgrade to most of the building envelope was not deemed necessary. The main exception to this was the introduction of an Optoglas[19] secondary glazing system and upgrading existing double glazed windows to which significant maintenance work was also carried. These had fallen into disrepair as shown in Figure 51 above. Six new dormers with double-glazed windows replaced skylights in the first floor room-in-roof areas to improve daylighting which had been highlighted as an issue by the occupants. Four more new double-glazed windows were also added, reinstating windows which had been present in the original structure and had later been boarded over.

This approach was based both on the desire to avoid overtly disruptive fabric interventions in the interest of heritage preservation and also on the local climate, which does not typically experience extreme temperatures (either hot or cold) but is windy, rainy, dark in the winter, and highly changeable. Viðareiði in particular is open to the west and sometimes experiences storms up to hurricane strength. Consequently, thermal performance of the fabric was viewed as having a lesser importance to weather and air-tightness.

Services:

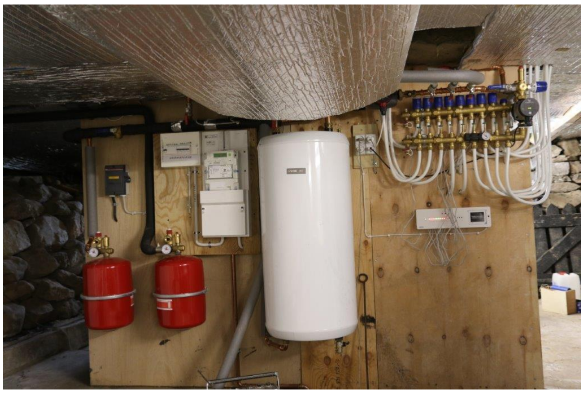

Figure 53: New GSHP plant equipment during installation, note the distribution system manifold on the right of the image – Image © Landsverk

Figure 54: The GSHP is supplemented by a wood burning stove – Image © Landsverk

The key intervention was changing the main heating system from an oil-fired boiler to a ground source heat pump (GSHP). The unit is a Nibe F1155, housed in the unheated basement of the

[19] https://www.optoglas.dk/en/home/

vicarage. This circulates brine[20] at an average temperature of 8 to 9°C through a vertical collector loop sunk into a 240 metre borehole from which the system draws thermal energy. The pump then transfers this heat at higher temperature into a wet distribution system consisting mainly of underfloor heating loops, with wall-mounted radiators in rooms on the first floor and in certain rooms on the ground floor where there was a desire not to disturb floor coverings due to heritage concerns. Radiators were also later added at the western end of the ground floor in response to occupant feedback and the results of a thermal imaging survey (see “Infrared Thermography” below). The flow temperature for the central heating system is 40°C and the system also provides domestic hot water at 65°C via an indirect cylinder.

The building continues to rely on passive ventilation which appears to be wholly adequate at this time (see “Indoor Air Quality” below) and space cooling is not an issue thanks to the Faroese climate.

Assessment Methods and Results:

Table 22: Viðareiði Vicarage, energy assessment methods.

Method:	Aim:	Notes:
Meter readings	Determine energy consumption pre-refurbishment	5 years of energy consumption data available in the form of oil purchases and electricity bills
Review of energy consumption data from Energy Key system	Determine energy consumption post-refurbishment	Energy Key is a monitoring system developed in Denmark
Infrared thermography	Assess and analyse overall patterns of heat loss	Equipment used: Elma Instruments FLIR
Monitoring of CO2, relative humidity, and temperature	Monitor and evaluate post-retrofit indoor air quality	

The energy assessment strategy at Viðareiði consisted of the methods listed in the table above and was designed by Landsverk to support and evaluate the retrofit project in combination with regular feedback from occupants and users of the building.

[20] “Brine” is a term used to describe the heat exchange fluid circulated in the ground loop of a heat pump and in various other heat exchange applications. Typically, this consists of a water-antifreeze solution.

Post-Retrofit Energy Consumption

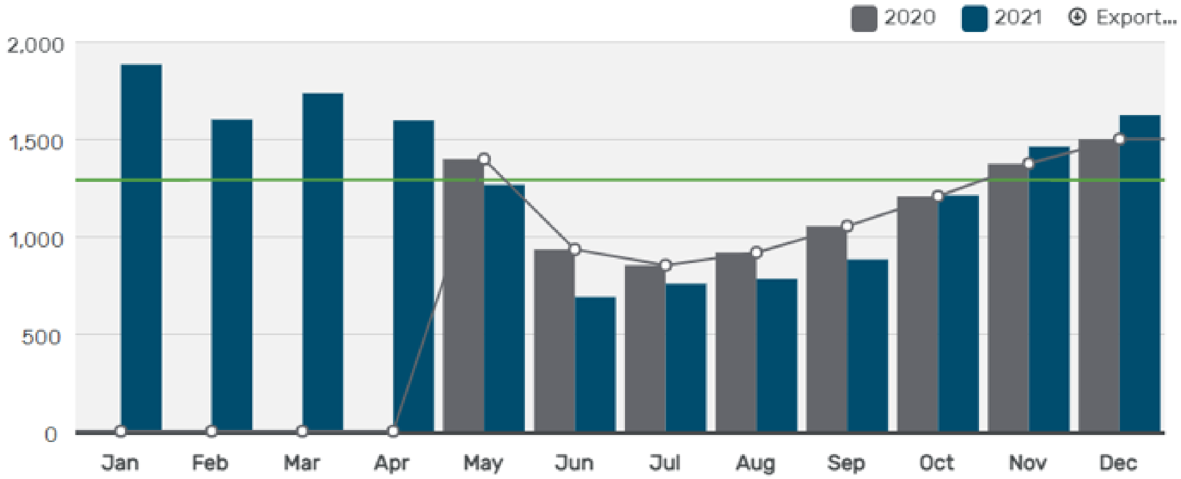

Figure 55: Electrical consumption of the building, kWh/month for 2020 and 2021 – Source: Landsverk

Shortly after the completion of the retrofit, a Danish monitoring system called Energy Key[21] was installed to provide accurate monitoring of electrical consumption by the building (Figure 55) and the newly installed heat pump (Figure 56). Headline results from this monitoring are also summarised below in Table 23.

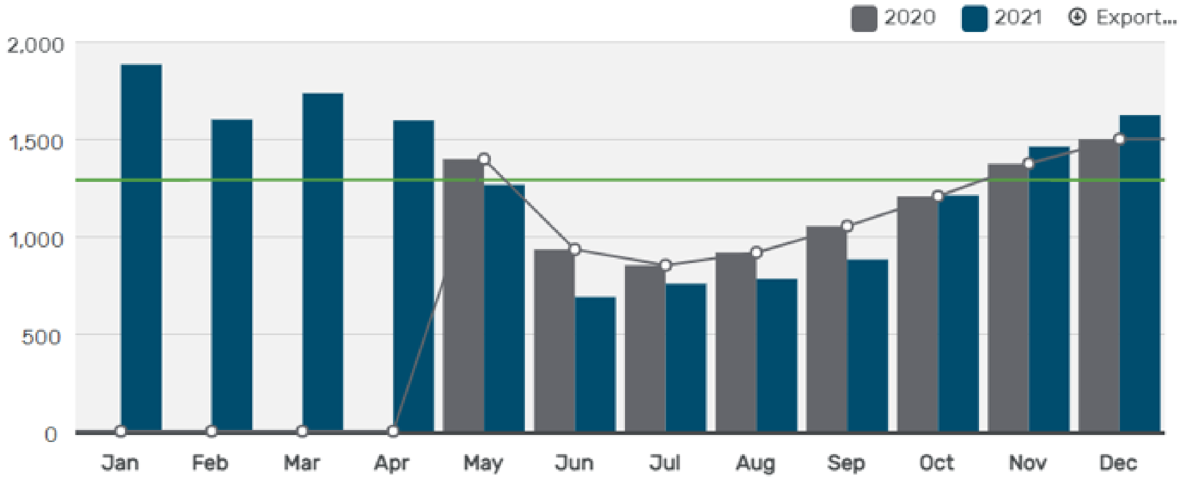

Figure 56: Electrical consumption of the GSHP, kWh/month for 2020 and 2021 – Source: Landsverk

The results of this monitoring indicate that electrical demand for both the heat pump and other use follows a seasonal pattern. Both peak in January and nadir in June, which is the expected norm for a northern European climate. Total electrical consumption of the building amounts to ~48kWh/m^2/yr, with space heating demand amounting to ~200kWh/m^2/yr, reflecting a relatively good seasonal coefficient of performance (SCoP) for the heat pump of around 4. For a detached traditional building in a high exposure location this is a relatively good value, especially considering the limited scope for fabric interventions due to heritage and practical constraints.

Table 23: Viðareiði Vicarage, electrical consumption breakdown in 2021.

	Non-GSHP Electrical Consumption (kWh)	GSHP Electrical Consumption (kWh)	Total (kWh)
2021 Total	3,708	11,768	**15,476**

[21] https://www.kmd.dk/loesninger-og-services/loesninger/energi/kmd-energykey

Monthly Average	309	981	**1,290**
Highest Month	409 (Jan)	1,473 (Jan)	**1,882 (Jan)**
Lowest Month	208 (Jun)	481 (Jun)	**689 (Jun)**

Source: Landsverk

Infrared Thermography

Figure 57: Heat loss at eaves below fascia boards and via timber joints – Image © Landsverk

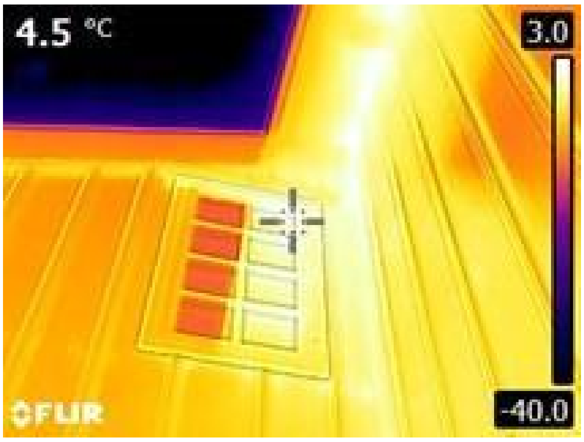

Figure 58: A replacement window, note the infrared reflection of the soffit above – Image © Landsverk

Results from a thermal imaging survey conducted following the retrofit project broadly align with the conclusions of energy modelling, showing no particular points of weakness in the building fabric. Figure 57 and Figure 58 above show higher heat loss at timber joints and at wallheads, both of which are expected due to linear and geometric thermal bridging. Also notable is the infrared reflection of the warmer soffit in the glass of the window. Glass is typically highly reflective in infrared and inexperienced persons will often interpret thermal images of windows and other shiny surfaces incorrectly as a result of warmer or colder objects reflected by them. This illustrates the need for an experienced professional, or at least an informed amateur, when deploying certain assessment methods to minimise the risk of false conclusions being drawn.

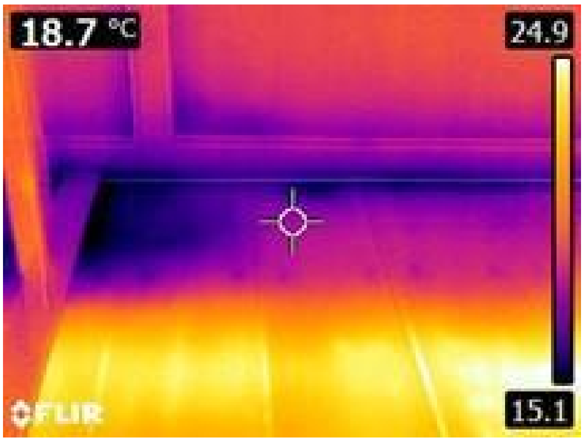

Figure 59: Heat loss via thermal bridging through the wide stone foundation – Image © Landsverk

Figure 60: Heat radiating through floorboards from distribution pipework below – Image © Landsverk

The most notable outcome resulting from ongoing evaluation of the retrofit thus far has been the installation of additional radiators to rooms at the western end of the building to supplement the underfloor heating already present. It was first noted by occupants in their feedback that these rooms became chilled when the external temperature was low, especially during strong winds. On that basis it was initially theorised that the western end of the building was not sufficiently airtight.

However, the thermal imaging survey indicated that this was unlikely to be the case. It was later concluded that the real issue was wide stone foundations which partially underly the ground floor in this part of the building. These both reduce the area of floor available as an emitter for the underfloor heating system and also appear to cool the spaces directly through thermal bridging, an effect seemingly exaggerated when the thermal gradient across the envelope is greater.

This somewhat counterintuitive finding is notable because most retrofit projects (especially at the domestic scale where resources are typically quite constrained) are carried out based on standard assumptions and the rational deduction of retrofit professionals based on their experience and knowledge. Findings such as this are a reminder of the value of empirical evidence in checking these assumptions and professional judgements against physical reality.

Indoor Air Quality Monitoring

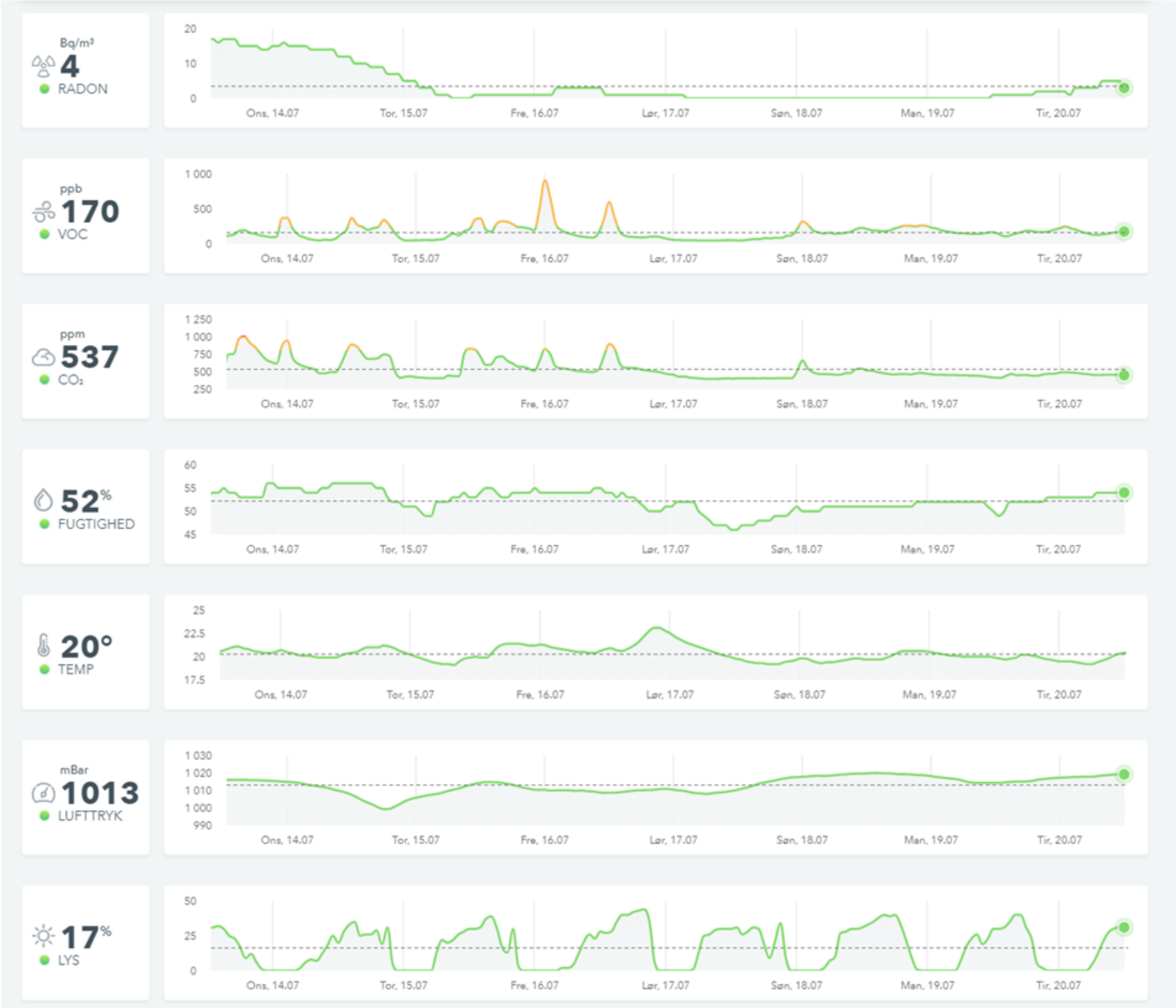

Figure 61: IAQ monitoring data, 13/07/2021 to 21/07/2021 – Source: Landsverk

Monitoring of the indoor environment was the final element of post-retrofit assessment at the vicarage. To accomplish this, commercially available Airthings[22] sensors were used to monitor multiple metrics defining indoor air quality (IAQ) to monitor the quality of the indoor environment

[22] https://www.airthings.com/

over time and to verify that the quality of the indoor environment had not been compromised by the retrofit works. Two periods of IAQ data are provided, Figure 61 above and Figure 62 below, as representative examples of the data gathered by Landsverk during 2021 and 2022. The former shows slightly higher resolution data covering a one week period in July, and the former shows approximately two months' worth of monitoring data during June and July of that year.

The devices monitor radon concentration, volatile organic compound (VOC) concentration, CO_2 concentration, relative humidity, temperature, pressure, and light level with sensors sampling every 5 minutes. Data is continuously uploaded online and can be remotely viewed which has allowed for continuous remote engagement by Landsverk staff.

A very positive sign in the higher resolution data (Figure 61) above is the stable humidity level indicating that the building is shedding moisture effectively as a result of fabric permeability and ventilation. It should be noted though that this is not difficult to achieve in summer. Data covering the winter months will offer a more robust indication and Landsverk are continuing to monitor on an ongoing basis.

It's also worth noting that VOC and CO_2 concentrations tend to rise together, indicating that VOCs within the building are principally resulting from the day-to-day activities of the occupants such as cooking, cleaning, burning candles, and the use of aerosol products, rather than persistent off-gassing by any synthetic products introduced during the retrofit and redecoration works. Occupants themselves also off-gas VOCs though generally not at a rate sufficient to meaningfully raise concentrations in the indoor environment.

Figure 62: IAQ monitoring data, 01/06/2021 to 31/07/2021 – Source: Landsverk

In the lower resolution data above, values broadly remain almost entirely within the "good" range, reflecting a good balance between energy efficiency and ventilation. It is worth noting once again, however, that this is not difficult to achieve during the summer months and that data during the winter months will offer a better indication when available.

For approximately a two week period in June, internal temperature drops into the "cold" range. This was when the occupants were on holiday and the building was left empty, note that this corresponds to flat, low values for humidity and CO_2. That this also corresponds to a period of flat, low values for VOCs is a further positive indication that periods of short-term VOC concentration are the result of day-to-day activities rather than synthetic material off-gassing.

Summary and Evaluation:

Overall, Landsverk and the Diocesan Authorities consider the retrofit project at Viðareiði to be a success. Considerable quality-of-life improvements have been achieved for its occupants through improved thermal comfort and improved daylighting of the interior. This was achieved as the outcome of a project which has implemented co-design throughout and within which an emphasis on high design quality was present throughout. The use of occupant feedback in conjunction with building monitoring during post-occupancy evaluation to validate the expected effects of the retrofit work and optimise the final configuration of the building may also be taken as an example of best practice.

The result has been positive from a heritage point of view, with the existing fabric disturbed to a minimal degree considering the scale of the project and heritage gains achieved by reinstatement of some original layouts and features. The project has also achieved good outcomes from a social standpoint, the building represents an important community asset for this remote population and has considerable sentiment attached to it. Successfully safeguarding this asset by addressing maintenance issues and making it fit for the future whilst being sensitive to the building's heritage has made this project a considerable boon for the local community.

From a technical and environmental standpoint, considerable reductions in operational energy use and the complete elimination of fossil fuel as a heat source also represent a major positive achievement.

One potential criticism could be that the building still consumes a considerable amount of energy in operation, with a post-retrofit electrical demand of approximately 48kWh/m^2/year which could have been reduced still further by targeting an ambitious retrofit standard such as EnerPHit[23]. Inevitably however this would have meant a dramatic increase in cost and disruption, potentially conflicting with the needs of the client and certainly in conflict with conservation of built heritage. This would also inevitably entail the use of synthetic insulants and related products which would add embodied carbon. Considering finally that, following this retrofit, the building will begin to approach zero carbon operation as the Faroese grid decarbonises and local microgeneration is added in the future, the case for adoption of such a standard, in terms of environmental sustainability, seems weak.

[23] https://passipedia.org/certification/enerphit

Concluding Remarks

Although the Energy Pathfinder demonstrators buildings are a small and highly varied sample of historic and traditional buildings across the NPA region, each found within its own idiosyncratic circumstances, some common elements and challenges emerging from the energy assessment activity undertaken across the group of demonstrators by the project partners.

Large single-zone buildings are explicitly identified as a challenging population to deal with from a retrofit perspective by Umea University. Indeed, two of the project's demonstrator buildings, Tegs Kyrka and the Cathedral of St Mary and St Anne, are large ecclesiastical buildings and present a remarkably similar challenge from an energy retrofit perspective despite their very different ages, construction, and fabric thermal performance. Large numbers of historic and traditional buildings across the NPA region are large single-zone buildings, typically either ecclesiastical structures or large community halls, which present a similar challenge. The results of work carried out during the Energy Pathfinder project suggest that optimising the operation strategy of existing heating infrastructure and understanding air movement and thermal comfort within their large internal volumes presents a promising route forward. Both of the project's large single-zone demonstrators leave questions unanswered to some degree and a future project might look to monitor the proposed solutions and further explore best practice retrofit and operational strategies for this typology.

Both of the Scottish demonstrator buildings have illustrated the profound challenges posed by remoteness, in addition to the challenge (possibly more acute in the Scottish context) of community ownership of built assets where communities often lack the resources and knowledge to manage them effectively. These demonstrators also highlight the challenges posed by constrained electricity networks, with inflexible grid connection arrangements identified as a key barrier to progress at both the Westray and North Ronaldsay sites. Developing solutions and/or workarounds for such problems may be a fruitful avenue of exploration for a future project and may include innovative energy storage, smart energy, and local energy systems options. Energy Pathfinder has only had very limited engagement in this area and a future project would certainly benefit from a more in-depth exploration of this rapidly growing field.

The threat of inappropriate, but commonplace, conventional approaches to retrofit in traditional buildings has also been effectively illustrated by a number of the Pathfinder project's demonstrator sites. Typically, these problematic approaches are characterised by the introduction of impermeable materials or by alterations to ventilation pathways that impede the ability of the building to shed moisture, generally resulting in fabric degradation over time. The recent retrofit work at Bayview, and 20th century interventions at Myross Wood House, are good examples of this. National competent bodies for built heritage, such as partner organisations HES and Landsverk, are extensively engaged in efforts to promote heritage-appropriate retrofit but these efforts are often hampered by economics, established practice in the industry, and limited resources. However, examples such as the retrofit project undertaken at the Viðareiði Vicarage are an effective showcase of best practice.

The widespread and related issue of poor (or sometimes inappropriate) maintenance was also noted. In traditional buildings this often directly impacts the thermal performance of the fabric (e.g. through higher moisture levels in masonry walls) and can have an indirect impact by creating an overhead of maintenance issues which need to be addressed before meaningful retrofit can take place. The example of the Cathedral of St Mary and St Anne is illustrative here, where flat roof coverings were found to have exceeded their design life by a considerable margin and had begun to deteriorate, showing that the deteriorating condition of specific elements can creep up even on a building which is generally well cared for.

The value of empirical data and the use of real world case studies, as opposed to an over-reliance on modelling and standard assumptions, was also validated by the Energy Pathfinder experience at some demonstrators. This is an important consideration as retrofit decisions are often made on the basis of modelling, assumptions, and rational judgement rather than empirical information. The demonstrator at Viðareiði can provide a good example, a snagging issue following the main retrofit project was initially theorised to be caused by poor airtightness, but this was overturned by a thermal imaging survey which strongly indicated that the problem was the result of thermal bridging.

Finally, the ever present, but perhaps long dormant, risk of major disruptive events taking place at a global scale has highlighted itself in both the execution of the project itself and of the retrofit projects at demonstrator buildings. Firstly, and most significantly the coronavirus pandemic, but then also supply chain disruptions and economic issues, and now a dramatic upsurge in energy prices and the war in Ukraine. These have all impacted on Energy Pathfinder and the demonstrator projects in one way or another. Perhaps this is a timely reminder of our dependence on the stability of a highly interconnected world in which unpredictable events on one side of the planet can have unpredictable consequences on the other.

Bibliography

Akiboye Conolly Architects (2021) *Myross Wood House Energy Upgrade Study*. Cork.

Atamate (2021) *Going Net-Zero: Atamate Approach for Non-Domestic Retrofit*. Oxford.

Banfill, P.F.G. (2021) ‘Hygrothermal simulation of building performance: data for Scottish masonry materials’, *Materials and Structures/Materiaux et Constructions*, 54(4). Available at: https://doi.org/10.1617/s11527-021-01759-x.

Carrig Conservation International (2020) *Myross Wood House, Leap, County Cork - Retrofit Strategy*. Dublin. Available at: www.carrig.ie.

DCSix Technologies (2022) *North Cathedral Heating Analysis*. Cork.

Heinonen, J. (2022) *Raahen Seminaarin Rehtorien Talon Kunnostus Ja Käyttötar-Koituksen Muutos*. Oulu University of Applied Sciences.

Historic Environment Scotland (2015) *Refurbishment Case Study 19 - Trial Church Heating: Radiant Panels and Air Source Heat Pump at Kilmelford Church*. Edinburgh. Available at: https://www.historicenvironment.scot/archives-and-research/publications/publication/?publicationId=97fe7075-3d8c-4b73-8ad5-a59300fa03e6 (Accessed: 16 August 2022).

Hukka, E. and Korpi, E. (2022) *Lämpökuvausraportti: Raahen Seminaarin Rehtorien Talo*. Oulu.

JCA Architects (2020) *Outline Feasibility for the Cathedral of St Mary & St Anne, Roman St., Cork City.* Cork.

Jenkins, D., Simpson, S. and Peacock, A. (2017) ‘Investigating the consistency and quality of EPC ratings and assessments’, *Energy*, 138, pp. 480–489. Available at: https://doi.org/10.1016/j.energy.2017.07.105.

Kamula, J. *et al.* (2022) *Renovation Plan - Rector’s House*. Oulu.

Scottish Government (2020) *Scottish house condition survey: 2019 key findings*. Edinburgh. Available at: Scottish house condition survey: 2019 key findings.

SEAI (2022) *Energy Action Plan: Green Skibbereen - Myross Wood House*. Dublin.

Shimmin, J. and Kelly, K. (2022) *Mechanical Services Feasibility Study for North Ronaldsay Lighthouse Keepers Cottages*. Oxford.

Zhang, Y. *et al.* (2020) ‘Cold windows induced airflow effects on the thermal environment for a large single-zone building’. Available at: https://doi.org/10.1051/e3sconf/20201720.

Zhang, Y. *et al.* (2022) ‘Field measurements and numerical analysis on operating modes of a radiant floor heating aided by a warm air system in a large single-zone church’, *Energy and Buildings*, 255. Available at: https://doi.org/10.1016/j.enbuild.2021.111646.