RIDGE

MULTIDISCIPLINE PROPERTY AND CONSTRUCTION CONSULTANTS

Garth House: Design research and evaluation report

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GARTH HOUSE:

DESIGN RESEARCH AND EVALUATION REPORT

Garth House as an example to retrofitttting and thermally upgrading the UK existing Non-Domestic building stock to meet 2050 net zero carbon targets

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1. INTRODUCTION

Historic buildings typically come with an unwelcome combination of high fuel demand and low comfort levels for building users. This toxic condition is due predominantly to poor insulation and inadequate airtightness.

Despite common knowledge of how to improve the thermal performance, any refurbishment of a historic building poses a multitude of complex challenges, including the need to preserve the historic character and building features as well as minimising occupant disruption. To tackle these obstacles, it is important that reliable quantifiable data is sourced to the building's physical characteristics (construction, energy, environmental performance) and actual experience of occupants, to ground the appropriate and considered refurbishment measures selected.

This research project deployed and evaluated an innovative low energy refurbishment of a historic town council building (Garth House) in Bicester (Oxfordshire), underpinned by a systematic building performance evaluation approach pre- and post-refurbishment. Pre-refurbishment monitoring established the baseline performance and revealed issues of discomfort and 'chilliness' from low surface temperature walls and low response times to heating the spaces, despite heating being on continuously.

The innovative refurbishment strategy addressed the challenges of maintaining the historic character, minimising disruption for building users while improving comfort, by deploying a pioneering slimline internal insulation technology on to the internal face of external walls, integrated with subtle secondary glazing and mechanical ventilation systems. The central strategy was to create a new airtight and continuous thermal envelope that integrated with the existing structure to maintain its integral heritage value.

The key innovation employed was WHISCERS™ (Whole House In-Situ Carbon and Energy Reduction System), a technique to rapidly apply internal wall insulation whilst the building remains occupied and applied to a non-domestic historic building in the UK for the first time. Post-refurbishment monitoring showed a 58% reduction in energy consumption, in line with the design target, while indoor temperatures ranged between 15-23°C during winter and 20-26°C during summer, along with airtightness being doubled. As a result, most users found the spaces comfortable all year round, a marked improvement on pre-refurbishment conditions. The project demonstrated that it is possible to make significant energy-savings in a historic building in continuous and undisturbed occupation.

How this is further developed into a broader, widespread uptake will be defined by the usability and accessibility of the approach. It can be illustrated that the measures and outcomes of the thermal renovations of Garth House has a wider encompassing potential.

The pressing impact of climate change is being brought to our direct attention and for the construction industry to fulfil their part of the bargain they must look at the appropriate renovation of our existing building stock. The IPCC report outlining the severity and urgent challenges of climate change has dropped a gauntlet on industries to react. UKGBC, RIBA have all weighed in on preparing stepped benchmarks for the construction industry to target. Much of the focus is on reducing the impact whole life carbon footprint of new buildings, with less energy stressed on the existing building stock. Operational energy accounts to 40-60% of a building's whole life energy demands. Therefore, for the 2050 targets to be met, reduction on operational energy in our existing building will be paramount in successful delivery.

2. CONTEXT

Today, climate change is undoubtably one of the most important and pressing challenges facing humanity and our planet. The world is 0.8 °C warmer than it was only a mere 100 years ago, in 2018 the United Nations Intergovernmental Panel on Climate Change (IPCC) published a landmark report warning that global warming must be kept at a maximum of 1.5 °C. At the current rates of warming global average temperatures are predicted to rise by 4-5 °C above pre-industrial levels by 2100 and reach the 1.5 °C threshold between 2030 and 2052 (Committee on Climate Change).

In May 2019 the UK Government declared a climate emergency and went on to make a legally binding commitment to becoming Carbon Neutral by 2050, the first of the G7 nations to do so. (BEIS 2019). In June 2019, Parliament passed legislation requiring the Government to reduce the UK's net emissions of greenhouse gases by 100% relative to 1990 levels by 2050. (The Climate Change Act 2008 (2050 Target Amendment) Order 2019) This legislation surpasses the previous targets to make the UK a 'net zero' emitter. Prior to this, the UK was committed to reducing net greenhouse gas emissions by at least 80% of their 1990 levels, also by 2050.

Buildings are reportedly the third largest carbon emitting sector in the UK and buildings are not on track to meet this legislated net zero target. Achieving a net zero carbon-built environment requires substantial reductions in energy demand from buildings, combined with decarbonisation of the electricity grid through an increase in the renewable energy contribution, as well as ensuring heat sources are fossil fuel free.

According to LETI, of the annual carbon emissions associated with buildings about 80% is associated with ongoing operational carbon emissions relating to the existing building stock. (LETI 2020)

The building industry including designers, constructors, owners, managers and occupiers are poorly prepared and informed of the changes required to meet these necessary targets.

The 1.8 million non- domestic buildings in the UK accounts for 17% of UK carbon emissions (UKGSBC, 2011). Of the building stock in the UK 50% of the commercial and industrial buildings were built before 1940 and only 9% were built after 1990 (Pout and MacKenzie, 2005). There is a high probability that most of the building stock in 2050 are already in existence today. If these buildings are to adhere to Government aspirations, then appropriate action is required. The good news is that there is huge potential for cost-effective carbon mitigation in the built environment. Almost twice as much, in fact, compared to any other sector.

The Carbon Trust has shown that a carbon reduction of 70-75 % can be achieved in non-domestic buildings at no net cost. A reduction of this magnitude can be made in a way that not only is cost-effective, but brings with it other additional benefits in terms of improving productivity and quality of life for those who occupy buildings, which in time will translate into value for building owners, occupiers and investors.

In 2018 21% of all homes in England were over 100 years old (VOA, 2019). These properties are generally uninsulated, either solid masonry or timber frame construction and have poor levels of airtightness.

In 2019, Historic England commissioned on behalf of the Historic Environment Forum, as part of its Heritage Counts series, research into the important contribution that the historic environment can and must make to the reduction of carbon emissions. Making the case for retrofit and refurbishment of existing buildings by demonstrating that one third of the carbon emitted from a new home is released during the construction and demolition process. This embodied carbon has until recently been overlooked but when properly considered and understood means that our focus should shift from demolish and rebuild to refurbish and retrofit.

The UK Government's independent advisory body the Committee on Climate Change conclude there is an urgent need to reduce carbon emissions from existing buildings.

"We cannot meet our climate objectives without a major improvement in the existing building stock". (CCC,2019)

As Historic England is concerned with the preservation of our historic assets it is promoting sympathetic retrofit and is encouraging the appropriate reuse of historic buildings, the importance of good maintenance regimes, the importance of occupant's use and management of buildings and the importance of disseminating research and findings to influence the day to day activities and decisions of the custodians of our historic buildings whether they be domestic or non-domestic. This approach of whole life carbon of the building is a compelling narrative which needs further research to increase the predictive capacity of life cycle assessment models of historic buildings

Buildings are responsible for 32% of global energy consumption (IEA, 2016c) and have a large energy saving potential with available and demonstrated technologies such as energy efficiency improvements in technical installations and in thermal insulation.

Reports indicate large saving potential in heating and cooling through improved building design, efficient equipment, lighting and appliances (IPCC 2018). In existing buildings, the focus identified in the IPCC report was for appropriate refurbishment to enable both energy and cost saving.

It is shown (IPCC 2018) that 1.5°C-consistent pathways require building emissions to be reduced by 80–90% by 2050, new construction to be fossil-free and near-zero energy by 2020, and an increased rate of energy refurbishment of existing buildings to 5% per annum in OECD (Organisation for Economic Co-operation and Development) countries.

It is within this context that this research project has important methodologies and findings which have real world applications that are both timely and imperative.

Figure 1

RIBA 2030 Climate Challenge target metrics for non-domestic buildings

RIBA Sustainability Outcome Metrics	Current Benchmark	2020 Targets	2025 Targets	2030 Targets	Notes
Operational Energy kWh/m2/y	225 kWh/m^2/y DEC D rated (CIBSE TM46 benchmark)	<170 kWh/m^2/y DEC C rating	<110 kWh/m^2/y DEC B rating	0 to 55 kWh/m^2/y DEC A rating	UKGBC Net Zero Framework 1. Fabric First 2. Efficient services, and lowcarbon heat 3. Maximise onsite renewables 4. Minimum offsetting using UK schemes (CCC)

Extracted from RIBA 2030 Climate Challenge Report
Comparison of annual operational energy consumption benchmarks

3. GARTH HOUSE PROJECT

3.1 Introduction

Garth House is a Victorian hunting lodge constructed in the 1830's in Bicester, Oxfordshire. Following the death of the original owner and with help from local benefactors, the building was purchased by Bicester Town Council in 1846. The building is situated in nine acres of formal gardens and parkland, now named as Garth Park, which exists as a remnant of its intended historical use. However, the lands are but a small token amount from the original expansive hunting grounds, with adjoining land sold for housing development over several periods.

Garth House is of significant local importance and a recognisable building in Bicester but is not subject to any formal protection as a listed building. However, the architectural value and merit of its heritage mean the preservation of such attributes are key to the sustainable future of the building.

Typical of its era, Garth House was uninsulated when constructed of solid brick and stone on ground floor, timber frame with vertical hung tiles at first and with a cut plain tile roof. In recent remedial work, the building underwent a re-roofing exercise and incorporated insulation to bring it towards modern and liveable standards.

Despite or perhaps due to the building's grandeur, time slowly but inevitably moved Garth House towards thermal inefficiency and below modern living standards. Over many years Garth House had suffered slow but accelerating decline and had fallen into a state of some disrepair, with the roof causing particular problems to the extent that the top floor had suffered significant water damage and was unusable.

3.2 Refurbishment Project

In 2014 Bicester Town Council was the subject of a low energy, in situ refurbishment and building performance evaluation research project. The project was undertaken by a collaborative team involving Oxford Brookes University, Bioregional and Ridge and Partners with Bicester Town Council.

This paper presented the findings of a two year research project funded by Innovate UK and the Department of Energy and Climate Change as part of the Invest in Innovative Refurbishment Programme and places it within the context of the UK's current climate challenge with a view to disseminating these findings to those who can apply this methodology and approach to other specific projects. The project was shortlisted for the RIBA Presidents Awards for Research 2016.

3.3 Overall Project Aim

This research project evaluated, deployed and succeeded in improving comfort levels for occupants, achieving a 58% reduction in overall energy use, completion of the works whilst the building was in occupation and the preservation of historic fabric and features of the original building.

The aspects that this research project focussed on are as follows:

- Appropriate physical interventions within an historic building setting; ensuring the preservation of character and retention of historic features
- Relative effectiveness of retrofit measures in reduction of carbon emissions and energy need
- Improvement of comfort levels of the building occupiers
- Avoiding relocation costs and disruption by undertaking the works in occupation

The methodology employed was tested and evaluated during the project implementation and has resulted in various findings which are being actively applied and will be further developed and disseminated.

The methodology involved a building performance evaluation approach where data on the performance of the building fabric, systems and occupants use of the building are collected and analysed over a period of time so that a thorough and holistic understanding and appreciation of the building both pre and post refurbishment informs the choice of the most appropriate and effective interventions.

3.4 Relevance of the Garth House Project

Garth House has remained relatively unchanged during its lifetime, although it has undergone a number of internal changes and superficial refurbishments to adapt to its changing functions. These have included updating sanitation facilities and heating and lighting systems to meet ever changing modern standards. This piecemeal approach to maintaining an existing building is unfortunately common, where focus was mainly aligned to keeping things ticking over, rather than fundamental fabric improvement. It is sadly typical of many of our UK building stock which is dominated by pre-war era buildings which are dogged by poor levels of thermal performance and user comfort.

Such buildings require innovative approaches to improve comfort and reduce carbon emissions whilst preserving their inherent historic character, an often-cited barrier to retrofit or refurbishment along with cost. The costs can include both the expenditure of the interventions as well as relocation costs due to the need to vacate premise whilst disruptive work is being carried out.

In response to the two major challenges, it was essential that any refurbishment of historic buildings is underpinned and supported by useful and reliable information. A thorough understanding of the physical properties (construction and current conditions) and use of the building (user needs) are understood to select appropriate improvement measures. An appropriate balance between building conservation and energy efficiency improvement measures must be achieved, considering factors such as ease of installation of the improvement measures and cost and time constraints. As a result, innovative solutions in all aspects of the refurbishment (e.g. technology selected, method of installation and interaction with technology and the building performance post refurbishment) will be essential.

The Garth House project addressed these issues and provided useful insight into both domestic and non-domestic buildings as well as solid wall and poorly insulated buildings where the protection of the historic fabric was important.

Key challenges that historic buildings face include the following:

- Retention of historic character and features, often meaning that the most cost effective and simple method of upgrading insulation by the application of external insulation and new windows is not an available option.

- The alternative method of internal insulation is disruptive to users as it is often complex and as a result labour intensive and slow.

- The combination of new heating and ventilation systems with insulation can result in unintended consequences which can damage historic fabric.

- The cost of and contribution to the reduction of carbon emissions and improved comfort of each intervention is not easily assessed so it is difficult for designers and owners to decide what to prioritise.

4. THE "BUILDING PERFORMANCE APPROACH"

The project sought to directly address the issues that this typical building faced. The approach was to rigorously examine and evaluate the performance of the building in terms of its building insulation and fabric, its heating and ventilating systems, energy consumption, controls and operation of the building and the occupant's comfort levels.

To evaluate the individual interventions an assessment of the performance of each improvement measure (pre and post refurbishment study) was undertaken. This would include both technical and sociological assessments.

To summarise the pre-refurbishment evaluation included the following studies and activities with the objective of providing a base line reference to the performance of the building. A thorough review and analysis of the methods and outcomes are illustrated later:

- Technical analysis of the building fabric to understand how the building performs physically.

a. Energy assessment, through IES calibrated modelling.
b. Review of heating, ventilation, and lighting systems
c. Review of controls
d. Measure and review the internal environmental conditions, temperature, humidity etc

- Social assessment through BUS questionnaires and close interviews with occupants to gain subjective feedback.

- Identify the refurbishment needs and hypothesise interventions, assessing potential savings of each one.

The post-refurbishment evaluation objective aim was to determine the impact of the refurbishment works and to understand the relative contribution of the interventions to provide tested learnings for future projects. The study and activities focussed on the following:

- Measure the savings against the refurbishment work and assess any performance gap between as designed and actual real world.

- Assess through post occupancy feedback the performance against baseline and record potential improvements or enhancements to the methodology.

5. ANALYSIS AND FINDINGS

5.1 Pre-Refurbishment Performance

The section of the building to be refurbished was monitored in the pre-refurbishment evaluation. There an assessment of energy consumption was conducted to establish annual energy consumption baseline for the building before the refurbishment. The assessment covered a one-year period, providing the closest estimation of annual energy usage before the intervention. The actual energy consumption and the resulting carbon emissions of the existing building were compared with the CIBSE TM46 benchmarks for a general office. The resulting carbon emissions were calculated using conversion factors based on DEFRA values.

An examination of the relationship between weekly gas consumption and heating degree days (HDDs) showed that a one HDD increase resulted in 6.8kWh increase in gas consumption. The line of best fit also shows a poor level of control of the heating system as gas consumption only explains 4.6% of the variation in heating degree days. This is confirmed by the finding that the heating system was on for 24 hours a day during the heating season. The high gas consumption was therefore due to the heating being on all the time and poor level of control of the heating system.

The fabric performance of Garth House before the refurbishment was assessed through an air tightness test with the results as follows:

- Measured air permeability on the ground floor and first floor – 20.52 m3/h.m2 @50Pa
- Measured air permeability on the second floor (unused attic space – 44.80 m3/h.m2 @50Pa

Air permeability in the occupied spaces was double the Building Regulation benchmark of 10m3/h.m2 @50Pa and in the unused attic space, it was more than four times the benchmark. These high air permeability levels are mainly due to the lack of insulation and the air leakage paths in the building fabric.

A detailed evaluation of occupants' feedback on the building and their comfort levels whilst in the building was recorded. This was assessed through the BUS questionnaire metric and semi-structured occupant interviews.

The main perceived concern raised by the occupants was the expected disruption caused by a long refurbishment, whilst the occupants were expected to work in tandem as normal. Another concern reported was 'cold feeling' despite the heating being constantly on and high air temperatures had been recorded. This indicates that there are low surface temperatures on the walls and windows, causing localised thermal discomfort.

As well as the need to maintain the historic character of the building and minimise disruption to occupants during the construction stage, the other issues identified to be addressed by the refurbishment were as follows:

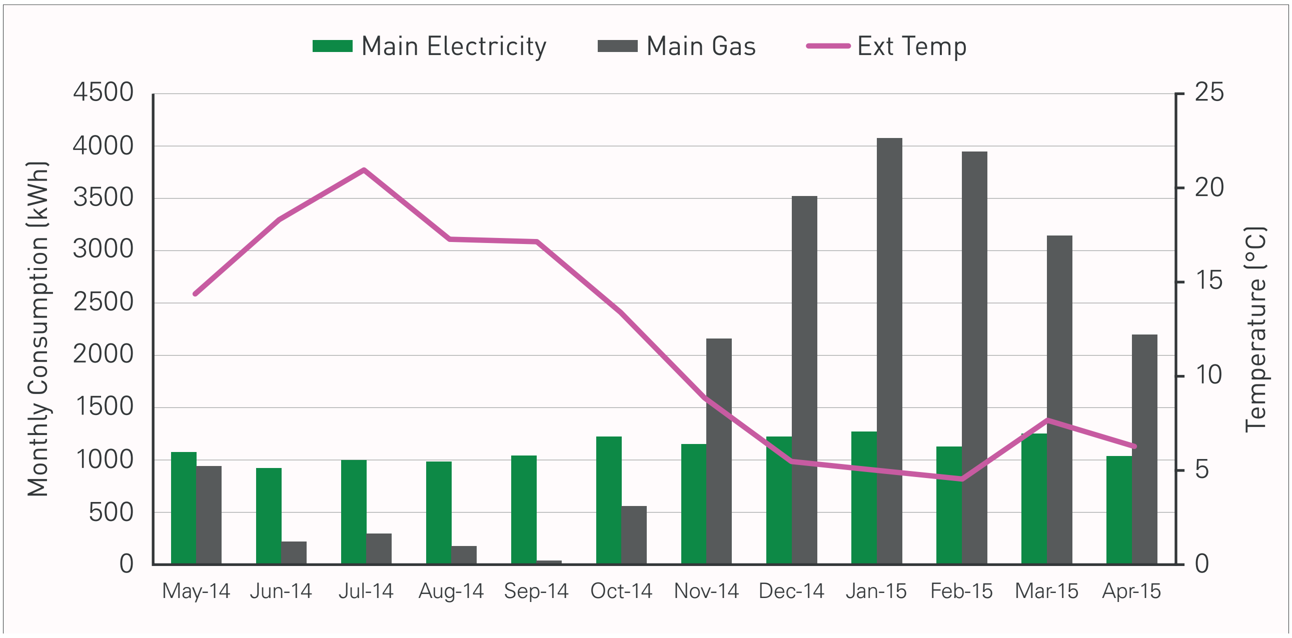
- Heat loss through the building fabric due to lack of insulation and uncontrolled air paths and the energy required to provide a comfortable internal environment
- Lack of user interaction with the building and ability to alter their environment–opening windows, adjusting radiator valves and heating controls
- Overheating in the ground floor rooms. The conservatory was found to heat up in the morning and then the sun moves around the building and warms the adjacent spaces through the bay windows. However, there was no user control of the window and so they were not opened to reduce the heating. This resulted in high overheating potential.

Based on the findings of the pre-refurbishment evaluation study, the main improvement needs identified were insulation of the walls and windows. The central strategy was to create a new airtight and continuous thermal envelope that is carefully integrated with the existing structure. Due to the historic character of the building, the project's intention was to combine a number of existing products and processes to provide a replicable internal wall insulation and secondary glazing solution that will retain the historic features while ensuring a comfortable well-ventilated environment for occupants. Therefore, key to the integration was the sensitive placement of the proposed elements that actively avoided the concealment or worse, damage of historical features.

Figure 2
Summary of main findings from pre-refurbishment evaluation study

PRE-REFURBISHMENT BPE STUDY ELEMENT	OUTCOME
Energy consumption and CO2 emissions assessment	Annual gas consumption was 194kWh/m^2, exceeding the energy benchmark typical of a general office
Fabric performance assessment	Air permeability of 20.52 m^3/h.m^2 @50Pa
Occupant feedback	Concerns over the length of the refurbishment period and the associated disruption and uncomfortable thermal conditions in the building
Environmental assessment	Heating on all the time to maintain comfortable indoor temperatures. Occupants found the indoor thermal conditions too hot in the summer and too cold in the winter.

Figure 3
Monthly electricity and gas consumption in Garth House and external temperature at the location



5.2 The Refurbishment Solution

The refurbishment design and selection process were guided by the outcomes and findings of the pre-refurbishment evaluation study. A comprehensive assessment involved the comparison of different types of low energy improvement measures and installation solutions for different areas in the building. The criteria for the investigation process sought to identify the most sensitive yet innovative solution. The following factors were considered as the criteria for selection:

- Performance (thermal and energy)
- Preservation of historic character
- Reduced disruption to occupants
- Innovation
- Cost

The primary measures selected were internal insulation and double-glazed secondary glazing.

An innovative installation strategy called WHISCERS™ (Whole House In-Situ Carbon and Energy Reduction System) was used to supply and install the internal insulation and its integration with the internal secondary glazing in order to retain much of the detail and character of the building. This technology has been used in hard-to-treat buildings, using a laser to survey the rooms in the building, allowing off-site cutting of the insulated plasterboards which can then be installed rapidly like a jigsaw to each internal wall. Eliminating the reliance on dirtier on-site cutting of insulation material, which in turn reduces waste, mess and offers a faster, less disruptive installation process. Ultimately allowing building occupants to continue to work or live in their buildings throughout the refurbishment period.

Figure 4
Summary of refurbishment measures

REFURBISHMENT MEASURE	PERFORMANCE	PRESERVING HISTORIC CHARACTER	REDUCED DISRUPTION	REDUCED COST	INNOVATIVE
Internal wall insulation using an innovative installation strategy	✓	✓	✓		✓
Floor insulation using Aerogel bonded plaster chipboard	✓	✓			
Roof void using blown insulation	✓			✓	
Secondary glazing	✓	✓			
Natural ventilation	✓	✓	✓	✓	
Automated openings for natural ventilation		✓	✓	✓	
Whole building MVHR	✓			✓	
Mechanical extract ventilation				✓	

This technology has previously been successfully applied in residential properties, ranging from single terraced properties to tower blocks. However, the application of this technology in this project was, pioneering in its application to a historic, non-domestic building and a in the United Kingdom. Its use in this project therefore offered a litmus test in the heritage building environment whilst the building was continuously occupied.

To complete the encapsulation of the thermal envelope the solid ground floor and internal ground floor walls were insulated. The eaves were also insulated to avoid gaps with roof insulation and heat loss at eaves level. The design intent of the insulation and the secondary glazing was to reduce the air permeability from 20.52 m3/h.m2 @50Pa to the building regulations benchmark of 10m3/h.m2 @50Pa.

To tackle the challenge of ensuring adequate ventilation, a user controlled natural ventilation strategy was developed for the first floor. This included manually operated natural ventilation use of the existing sash windows and some through-wall vents to allow cross ventilation into single sided rooms.

A centralised, whole building mechanical ventilation with heat recovery (MVHR) system was installed to replace the existing through-wall individual vents, thus reducing the number of openings in the façade. To reduce the risk of overheating, roof lights and louvers automatically controlled by actuators linked to room thermostats were installed above the ground and first floor windows. The design intent of the combination of ventilation systems was to improve the ventilation and indoor air quality in the building.

Other low-cost thermal improvement measures utilised included the sealing of penetrations, redundant pipework and gaps located around the existing windows and in the external fabric. This was done in order to improve the airtightness of the building envelope and provide zoning between floors and installing of wireless thermostatic radiator valves (TRV) with the design intent to improve the user control of space heating.

To estimate the energy saving potential from the refurbishment measures, a model was simulated in IES and each improvement measure was assessed. Overall, the refurbishment measures were predicted to achieve a 58% savings in energy consumption and a 37% reduction in carbon emissions.

5.3 Post Refurbishment Performance

Some study elements of the post-refurbishment BPE were conducted during early occupation of the building just after the refurbishment works (such as review of commissioning and handover processes, building fabric performance assessment), while other study elements (such as energy metering and sub-metering, remote monitoring of environmental conditions) were carried out over a period of one year, to assess the in-use performance of the refurbishment and evaluate the energy and CO_2 savings achieved. [Figure 5]

5.4 Commissioning, Handover and User Training

On completion of the refurbishment works, all mechanical services installed were commissioned and a comprehensive user guide was put together and training took place during early occupation. Observations made in the BPE study showed that there was generally good communication between the designer and the building user and occupants understood the ventilation strategy well. However, a review of the handover documentation revealed that written information on the commissioning of the MVHR system was missing. Furthermore, the building manual was incomplete and there was no building logbook.

Figure 5
Monitoring strategy in post refurbishment BPE study

PARAMETER MONITORED	TOOLS
Mains gas and electricity consumption	Web-based remote system, recording at 5 minute intervals
Sub-metered electricity usage (ventilation and water heating systems)	Web-based remote system, recording at 5 minute intervals
Moisture content in building fabric	12 sensors installed recording at 5 minute intervals and data obtained from web-based remote system
Indoor environmental conditions (air temperature, relative humidity)	11 sensors installed in selected locations and data obtained from web-based remote system, recording at 5 minute intervals
Indoor CO_2 concentration	Standalone data loggers installed in selected rooms recording at 5 minute intervals
Heating behaviour (heating on/off)	Standalone data loggers installed in selected rooms recording at 15 minute intervals

5.5 Building Fabric Performance

After the completion of the refurbishment, a second air permeability test was conducted on Garth House to determine compliance with Part L2 of the Building Regulations. The results showed that there was a significant improvement in the fabric performance as air permeability reduced by 52% after the refurbishment, more than half of the levels before the refurbishment. This showed that the installed insulation, secondary glazing, and localised infilling improved the overall performance of the building fabric.

Following the air-tightness test, a smoke pencil survey was carried out to identify the specific areas of leakage. Paths into the floor voids were identified around door frames, and skirting board perimeters. The test revealed also that the secondary glazing was not always successfully sealed.

A second thermal imaging survey was also conducted after the refurbishment and assessed against previous conditions. An assessment of pre-post refurbishment conditions conducted at similar external conditions found that heat loss through the window openings had reduced due to the installation of the secondary glazing.

5.6 Performance of Systems and Controls

The installation process and the commissioning procedure of the mechanical ventilation system was reviewed as part of the post-refurbishment evaluation study. A walkthrough observation was conducted by an evaluation team and this revealed some issues with the installation and commissioning of the ventilation system. The following issues were recorded:

- Supply and extract valves found in the 'unlocked' position.
- Ducts were too short hence the valves were not fully engaged with the duct resulting in significant airflow bypassing the valves and flowing directly into the ceiling void.
- Oversized cuts in the plaster board where the distribution valves were mounted were products of miscommunication with the contractor during installation
- Most of the supply and extract terminals were not installed as specified in the drawings, with the supply terminals installed in position of the extract terminals and vice versa.
- Some ceiling terminals were found to have been fitted too close to the wall, failing to follow design guidelines, which resulted in ineffective air distribution

Figure 6
Pre and post-refurbishment air permeability test results

	TARGET AIR TIGHTNESS ($M^3/H.M^2$ @50PA)	MEASURED AIR TIGHTNESS ($M^3/H.M^2$ @50PA)
Pre-refurbishment test (November 2013)	-	20.52
Post-refurbishment (July 2014)	10.0	**9.31**

5.7 Review of the Performance and Usability of Controls

According to the Building User Guide, the building's response to heating and cooling was expected to change and an informed occupant with a good grasp of the control measures would be crucial in order to achieve comfortable conditions throughout the year. The review of the usability of controls in the case study building revealed several unintended consequences with the control of the heating system. The discrepancies were focused on the lack of correct zoning, unintuitive controls with complex user guides and control central structuring issues.

The secondary glazing units that were installed were easy to use and opened fully, allowing good access to the original sash windows. However, with new windows which opened internally, it was found that accessibility could occasionally be hindered by furniture arrangements in the room.

Figure 7
Workflow for pre and post refurbishment evaluation studies of Garth House

PRE-REFURBISHMENT EVALUATION STUDY		
1	Existing building performance and existing occupancy and management evaluation	■ Review of as-built drawings and specifications ■ Energy analysis (energy bills and TM22 assessment) ■ Fabric performance assessment – air permeability test, thermal imaging survey ■ Occupant surveys using the building user survey (BUS) questionnaires and semi-structured interviews to record habits, concerns and needs ■ Walkthroughs with building management team
2	Pre-refurbishment briefing	■ Identify ideal refurbishment strategies based on the (1) and clarify design priorities
3	Prediction of savings from proposed refurbishment measures	■ Estimate energy and carbon savings from the proposed refurbishment measures using dynamic thermal simulation ■ Determine a focus point for building performance analysis
POST-REFURBISHMENT BPE		
1	Post construction and early occupation evaluation	■ Review of drawings, interviews and feedback from design and construction teams to compare design intentions to built reality and later performance ■ Fabric performance assessment – air permeability test, smoke pencil test, thermal imaging survey ■ Review of installation, commissioning and operational use of installed systems and handover processes
2	In-use evaluation	■ Assessment of building energy consumption (monitored energy use) ■ Assessment of indoor environmental conditions – air temperature, relative humidity and carbon dioxide ■ Assessment of insulation performance – moisture content of external wall and timber studs ■ Review of usability of control interfaces ■ Occupant survey using questionnaire to record satisfaction, concerns and feedback

5.8 Energy Assessment

The post-refurbishment energy assessment of Garth House covered a one-year period. Post-refurbishment, Garth House achieved a 22% reduction in electricity use and a 67% reduction in gas use compared to pre-refurbishment.

There was a 58% reduction in overall annual energy consumption, perfectly matching the design prediction from the dynamic model. The overall emissions reduction achieved post-refurbishment was 48% of the pre-refurbishment figure. This is greater than the design prediction (37%) and the discrepancy was due to the model not fully accounting for the continued use of electric heaters and fans post-refurbishment.

After the refurbishment, a strict heating schedule was applied, and the heating was turned on only during occupied hours. This resulted in a significant reduction in gas consumption, in line with the pre-refurbishment prediction.

Figure 8
Comparison between actual energy and resulting emissions and CIBSE TM46 benchmarks for a general office

	GARTH HOUSE	CIBSE TM46 (GENERAL OFFICE)
Annual electricity consumption (kWh/m^2)	51	95
Annual electricity CO^2 emissions ($kgCO2/m^2$)	23	50
Annual gas consumption (kWh/m^2)	194	120
Annual gas CO^2 emissions ($kgCO2/m^2$)	36	23

5.9 Moisture Content of the Building Fabric

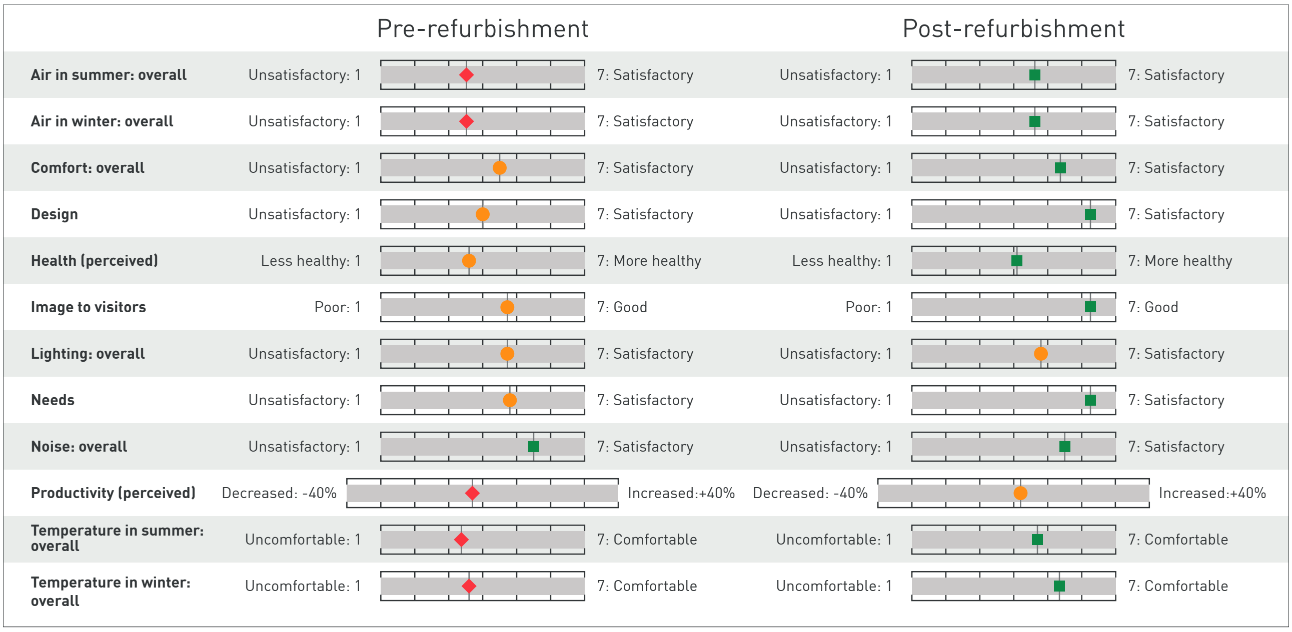
In addition to the standard environmental building monitoring system, sensors were installed to measure moisture content (Wood Moisture Equivalent (WME)) in the cavity construction formed behind the internal wall insulation and the timber studs at various locations. Moisture build-up within the building fabric can result in mould growth and health risk to occupants as well as structural damage through rot. Moisture content of the timber studs reduced gradually from a maximum of 23% to below 16% over the first three months after the refurbishment and subsequently remained relatively stable, well below 20% for the remainder of the monitoring period.

5.10 Occupant Feedback

The overall picture of the BUS survey conducted after the refurbishment revealed a very positive opinion of the staff members towards the building. Following the refurbishment, occupants found that their thermal comfort had greatly improved and they commented that the refurbishment had succeeded in making the building warmer and less draughty even though the heating system was not on as much as before. Air quality was also considered as improved and satisfactory after the refurbishment.

The BUS questionnaire evaluated 6 occupants' responses in 7 aspects including comfort, air quality, lighting, noise, control, design/needs and facilities management. In general, occupants noted they were happy with the noise, lighting, and design. They were less satisfied with comfort and air quality. The results indicated that occupants feel cold in winter and hot in summer with strong variation in temperature during the day in summer. Air quality was noted as draughty, smelly, and stuffy in winter; and low levels of overall satisfaction in both winter and summer were recorded generally.

Figure 9
Occupant feedback on environmental parameters and overall comfort in the building before and after the refurbishment



5.11 Impact, Significance, and Outputs

The refurbishment of Garth House successfully tackled the challenges presented by refurbishing historic buildings to achieve a step-change reduction in primary energy use and CO2 emissions primarily through the improvement of the building fabric. Additionally, there was a significant upgrade to the environment and occupant comfort making it an attractive option for organisations operating in historic buildings. The refurbishment project was delivered on time and within budget and the building's occupants responded positively to both the improvement of the internal environment and to the retention of historic features.

While no electricity-saving measures were installed, electricity use was reduced by 22% which can be partly attributed to users becoming more energy-conscious due to the works. The Garth House retrofit marks the pioneering first implementation of WHISCERS™ (Whole House In-Situ Carbon and Energy Reduction System) on a non-domestic and historic building in the UK. This technology can now be considered for typical projects. Furthermore, with 12 months of detailed monitoring on the actual energy and environmental performance of the retrofit, the project offers significant information and the opportunity for shared learning to help other organisations implement their own projects.

This refurbishment project has a strong significance and impact as it tackled the main challenges facing refurbishments of historic commercial buildings to achieve the following:

- Minimising disruption to occupants and work routines was successfully preserved which avoided costs associated with renting alternative offices during renovation.
- Garth House is now far more attractive to potential tenants due to its reduced energy bills and improved internal environment
- Staff wellbeing has been boosted with improved environment (e.g. better air quality and warmer in winter months)
- Bicester Town Council is involved in the delivery of NW Bicester (the UK's first eco town led by developer A2Dominion). This refurbishment has furthered its experience and reputation of pioneering sustainable development.

Communicating the success of this project could make similar installations more attractive to other project teams. The combined incentives of energy bill savings and reduction in carbon emissions as well as the improvements for occupants are compelling given the challenges of refurbishing historic buildings. While policy changes would be required to facilitate large-scale uptake, this project demonstrates how the barriers to energy-efficient retrofits can be overcome and could be used to inspire action.

Contextualising these outcomes, they can be applied to other historic buildings even though it is important to acknowledge the impact of differences between each historic building and its needs. The innovative retrofit of Garth House demonstrates the wide-ranging benefits of energy efficiency for project teams planning refurbishment projects. The project also successfully demonstrated that refurbishments do not have to negatively impact upon building use or damage the appearance of heritage buildings – which are two recognised barriers to the uptake of energy-efficiency measures. Wider lessons and recommendations relating to the effectiveness of the BPE approach can be drawn for clients, designers, contractors and builders, the supply chain, building operators and users.

6. FUTURE STEPS

PART 2

Since the finalisation of the project at Garth House, great strides have been made in the industry in bringing wholesale solutions to thermal upgrades. The technology and methodology are more mainstream and the cost to implement now is greatly reduced. We are on a trajectory for the costs to continue to be reduced and the solution of thermally upgrading existing buildings becoming more common place. How this is implemented is dependent on a myriad of push and pull factors, ranging from interests of strategic Governmental bodies, invested in both climate change and heritage protection, to the financial incentives and viability.

6.1 Conservation Conundrum

The construction industry in the UK can be viewed as essentially split into two parts. The 'mainstream' industry essentially deals with the conception, design, construction, and performance of modern buildings. Generally, the intent is to deliver a hermetically sealed environment with reliance on moisture and air extraction from mechanical or passive stack ventilation systems to keep the interiors comfortable. By contrast, the conservation repair and maintenance sector (CRM) rely upon an understanding of the history, various pre-existing constructional techniques, and intrinsic breathability, where moisture transfer is dissipated through the structure by inherent natural ventilation routes. This fundamental difference creates the 'conservation conundrum' as far as BIM is concerned. The protection of the existing fabric can often come at the cost preservation of its future.

With over 6 million of the UK's pre-1919 structures of traditional construction commanding approximately £6billion of industry related activity per year, the correlated developments in BIM are urgently required to create a more realistic balance of need in the approach.

Historic England has published technical advice documents on surveying and recording heritage. In BIM for Heritage: Developing a Historic Building Information Model there are numerous case study examples of heritage assets being documented in this way. This outlines the range of benefits in visualization, monitoring, education, and research, with the paradigm shift for conservation practice well under way.

However, the application of BIM as an information management process (IMP) in both the operational phase of a building's lifecycle and in the delivery of conservation repair and maintenance (CRM) and restoration projects has yet to become fully established in the heritage sector.

6.2 Industry Wide Targets and Measures

The UK Green Building Council (UKGBC) has undertaken 'top-down' calculations to determine energy performance targets for offices based on the available supply of zero carbon energy in 2050. Through consultation and direct engagement with stakeholders, UKGBC identified a need for 60% reduction in energy use from the office sector which translates to the 'Paris Proof' targets.

UKGBC has indicated that wholesale Energy Use Intensity (EUI) values for a series of typical building archetypes will help target the existing building stock. As an immediate priority, (EUI) targets for existing buildings must be developed. This can follow the methodology set out by the Dutch Green Building Council for 'Paris Proof' targets.

For existing buildings, UKGBC intends to explore the use of the 'Paris Proof' targets approach pioneered by the Dutch Green Building Council. This approach has set targets in the Netherlands for energy use intensity for different building types based on estimates of national renewable energy capacity in 2050. There is the opportunity to build on existing good practice such as the Design for Performance initiative and Real Estate environmental Benchmark (REEB) to develop similar targets for the UK.

The LETI design guide (2020) benchmarks 2020-2025 as the period for design and build pathfinders; working out what to do with existing stock and states from 2025 we should be targeting the upgrading of existing non-domestic building stock. The tactics and metrics to address the improvement of the existing building stock has not matured and much of the research into how the construction industry can fulfil their obligations are focused on new buildings.

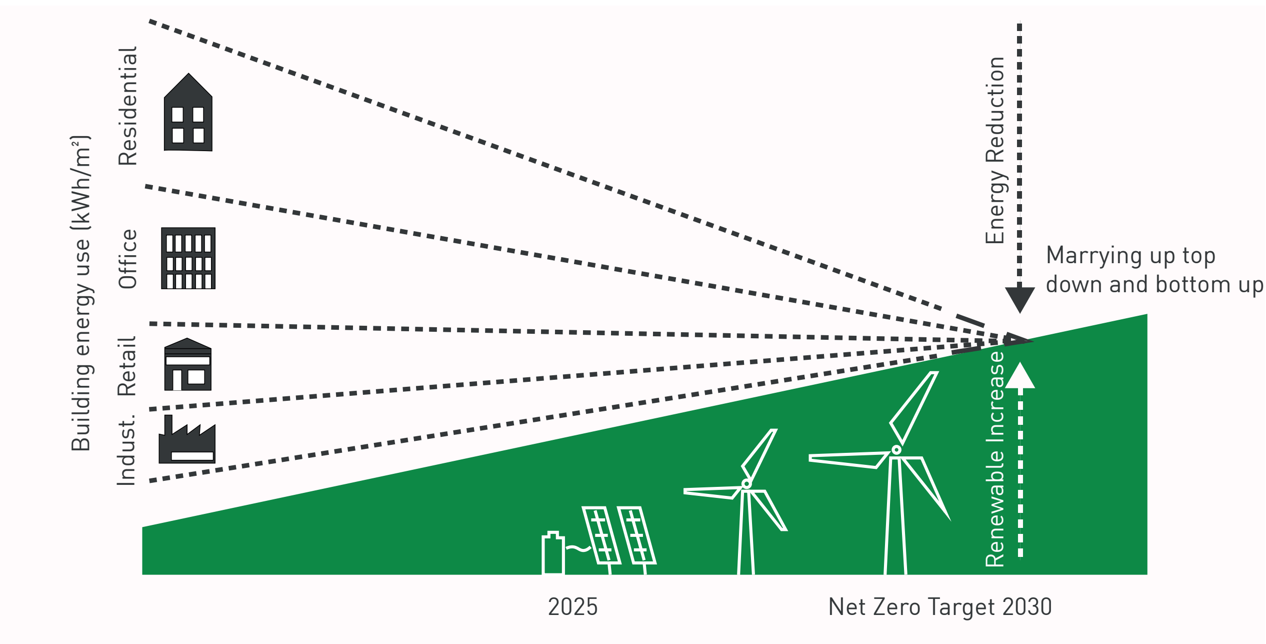
The Garth House project illustrates a good pioneering project in how to achieve these in an existing building condition. It showed the importance of existing and post-performance evaluation to give a measured assessment of the improvements. The study also identified some pitfalls with the development of the thermal upgrading of existing buildings, namely coordination and construction management. But mainly the project showed an exciting and achievable pathway for the improvement of the existing building stock.

Assessing the improvements to the internal environment and displaying them is seen as a critical tool in standardizing approaches and identifying best practices. Display Energy Certificates (DEC) are the recommended approach for collating energy data for non-domestic buildings. The DEC methodology and reporting should be reviewed and changes to the reporting scale considered to allow future continuous improvement. The Garth House project research was built upon assessing pre and post refurbishment conditions. The actions taken showed a great benefit to the energy demand and DEC would be a great way to showcase and illustrate these benefits publicly.

Although a detailed review of the cost implications on the Garth House project were not undertaken there is compelling evidence to suggest that the improvements in the thermal envelope produce passive yet pronounced financial gains. The industry as a whole is responding to this and a JLL research paper (2020) investigated the value impact on sustainability and found there is a correlation between incorporating sustainable measures in a development and increased profit. There is a recent growing sense in the industry of the importance of sustainability. In a JLL survey of stakeholders in 2019 measuring of trends on the UK market, only 7% put sustainability as a major factor. Only a year later in 2020, the importance of sustainability shot up to 67%, placing it firmly as the most important factor for future trends.

The market is also moving towards more importance on operational rating for buildings, the link to value will become much clearer. Users of space will be more able to make a distinction of how their asset is performing operationally, and more importantly how it compares to other spaces. The stimulus for a developer to invest in a higher rated building is to increase value and to promote their brand. It is only a matter of time before building regulations become tougher, to drive a reduction in energy consumption

Figure 10
Extracted from LETI Climate Emergency Design Guide
Top-down meets bottom-up approach to energy to meet Net Zero Targets 2030



and carbon emissions. As sustainability performance becomes clearer and more defined, it is likely that premiums will disappear and that those buildings that don't comply will underperform. Buildings that are not designed to be net zero carbon will require costly retrofits in the future, which are likely to result in the displacement of tenants and lost rent.

A UKGBC Task Group has been convened to develop guidance further detailing best practice in developing a carbon tax, including the potential inclusion of an explicit carbon price for use in conjunction with the hierarchy in UKGBC's net zero framework. Whilst this has not yet been published, the guidance has a targeted publication date of spring 2021.

Net zero whole life carbon is not proposed as an approach at present due to current limitations in the reporting of carbon from the maintenance, repair, refurbishment, and end-of-life stages of a building's lifecycle. Instead, buildings are encouraged to aim for net zero carbon in construction (new buildings and major refurbishments) and for operational energy (existing buildings), until greater familiarity with whole life carbon impacts has been achieved.

RIBA 2030 has issued an overall target of 55kWh/m2 per year for non-domestic buildings. The target < 55 kWh/m2 /y operational energy use for non-domestic buildings by 2030 (minimum DEC A or 75% reduction in operational energy as compared to CIBSE TM46 benchmarks), including maximising the use of on-site renewables. [figure 1]

6.3 Application to Future Projects and Suitability of UK Buildings

The Garth House project showed that an improvement of thermal performance in a building through internal insulation could be viable to any building under the right management conditions. It has been typically used in residential works with regular modularised rooms. The laser survey technology could be most efficiently utilised in complex spaces or those that are difficult to read using conventional techniques. Laser surveys generally are becoming more common place in general building surveying. The growing use in the industry therefore makes the prospect of making cutting schedules more uniform and streamlined more likely.

During the implantation of the proposal a number of challenges emerged which in the case of this project present limits the market potential identified in the project proposal.

It is preferable for breathable insultation to be adopted in the renovation of older buildings. Furthermore, for listed buildings breathable insulation materials are often required to obtain listed building consent. Unless breathable materials are developed with matching thermal properties as phenolic board then the system may not achieve its full market potential. Currently the deeper profiles needed to accommodate breathable materials to reach the required thermal performance may prove to be disadvantages to maintaining the existing internal proportion and features.

Experience in installers and understanding the importance of ensuring airtightness is still developing. A growing understanding and education in the industry of the importance of correct installation will minimise the risk of poor airtightness due to poorly fitted junctions and openings. This precision can only be enforced by the professional team ensure the key requirements are properly relayed and agreed.

Clearly the laser survey has great potential to be a useful tool for the project design team, if detailed enough to record existing building features, as well as being used to produce a cutting schedule for a CNC machine. As many surveying companies begin to offer similar laser surveys this could be added by a third party.

The CNC machine and cutting service for insulation boards was not offered in house by for the Garth House project and instead outsourced to third party. However for market potential, on a large project it may be more preferable to have the CNC machine centrally located on the same site the insulation is being installed on to allow survey, cutting and install in the same location.

It was advised In the Garth House project that the insulation boards being installed could be a maximum size 1150 x 1150mm due to the largest dimensions the CNC machine flatbed can work with. This is a reduction from a full-size standard 2400x1200mm sheet resulting in many more pieces to the jigsaw, resulting in many more joints to be filled potentially weakening the insulation line with open paths for heat loss.

As labour is more costly than the material, the smaller panels sizes led to an increase in costs as labour was increased in both cutting and installation time. However to reach full market potential, it would be advantageous to use full size boards wherever possible with boards only cut where needed to allow the jigsaw puzzle rather than being controlled by the limitations of the flat bed size of the CNC machine.

Due to licensing issues the Garth House project was required to use K18 Kingspan insulated plasterboard. This is a solid phenolic insulation board bonded to 12.5mm plasterboard which delivers a good thermal performance and is a vapour barrier (the joints between the boards may not be). However, the board is not breathable or Hydroscopic as many other natural and artificial insulation types are. These properties may be of primary importance in certain building / heritage environments making such product less appropriate. Furthermore, it would be of greater benefit for the technology to utilise more environmentally friendly materials with lower embodied carbon to enhance project credentials of reducing carbon.

Notwithstanding the issues surrounding the Contractor, the project was heralded as a great success. The individual elements of the design were integrated to improve the entire thermal envelop of the building. The improved air tightness along with improved air quality, showed clear enhancement of the internal comfort levels beyond purely insulating the external walls.

6.4 Conclusion

The construction industry has predominantly focused on the improvements in new building stock to contribute to the reduction of carbon reliance through innovative methods of construction and embodied energy – cradle to cradle assessments. Whilst these steps are important to propelling the industry, the framework and guidance to retro fit existing building stock is lagging.

Immerging evidence cites thermal improvement through insulation retrofit as a good passive measure to meet net zero targets. Operational carbon represents between 40% and 65% of a building's whole life carbon. It influences the ability to achieve a net zero built environment through a number of different interdependent factors. Operational carbon is arguably the most direct consistent environmental impact that a building has throughout its life cycle and is directly related to the ways in which we occupy and interact with buildings. It is a building's carbon legacy. In the context of the climate emergency, there is an urgent need to limit these ongoing impacts.

Garth House renovation showed the keyways that the amalgamation of technology – 3D Surveying, environmental modelling and modern methods of manufacturing can help preserve the past for the future by reducing this operational energy demand. This approach offers protection of historical assets both through retaining the detail aesthetics and maintaining good environmental conditions.

The combination of technologies implemented in Garth House proved that a coordinated approach could ensure that renovation could occur during occupation. Such attributes are crucial in winning the argument to adapt and renovate. Without having to vacate the premises or disrupting occupiers during construction activities can continuing without harming productivity.

The reversibility of the internal insulation also protects the building should insulation technology improve. The insulation applied at Garth House is a a solid phenolic insulation board that is not breathable or hydroscopic. For large scale implementation of retrofitting insulation, the development of efficient breathable and natural insulating materials would be key for widespread adoption.

As the industry develops strategies to overcome the climate change response, the importance of adapting existing building stock is coming to the fore. The lessons learned in the Garth House project showed that the adoption of, now well-grounded technologies can yield improvements to match both the moral aspiration and financial viability. The Garth House project was undertaken when the methodologies employed were not as widespread as today. The future intake and adoption of the methods will be dependent of the accessibility of the techniques for Layman users, improvement in natural breathable thermal materials and a growing acceptance of the need to act. As the general population become more aware of their individual, community, and societal responsibility to reduce carbon and with the emerging methods to doing so are becoming more mainstream the findings of Garth House are all the more pertinent.

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