OPW
Oifig na nOibreacha Poiblí
Office of Public Works

Energy Upgrade Case Study 2

Block M Offices, Dublin Castle

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Introduction

The Dublin Castle Block M Offices renovation is an exemplar of the highest quality heritage craft skills and innovative energy upgrade works to a traditional building construction. The energy renovation demonstrates best practice energy performance design and measures to reduce risks in the energy efficiency upgrade of traditional and historic buildings and also implements post-works hygrothermal monitoring to gain valuable insights into the actual performance of the retrofit measures. The project applied in practice the principles of the recently published OPW technical guidance 'Approaches to Improving the Energy Performance of Heritage Properties in State Care' (henceforth referred to as the OPW Guidance), which is based on the recommended framework set out in I.S. EN 16883:2017 *Conservation of cultural heritage - Guidelines for improving the energy performance of historic buildings*. It aimed to improve the energy efficiency of the building as far as practicable without jeopardising the heritage value of the building. In addition to operational emissions, embodied emissions were considered from the start of the project through a review of Environmental Product Declarations (EPDs) for renovation materials. With the installation of performance monitoring equipment at project completion, Block M was established as an innovative 'living laboratory', the first of its kind in Ireland, which will provide the OPW with long-term quantitative moisture and temperature data on two types of relatively new-to-market vapour-open internal wall insulations installed within the same physical context.

Block M is an end-of terrace, five-bay office building, built in the early 19th century and as a typical Georgian building of a common traditional construction type. Block M is a valuable case study for its replicability. Though not a protected structure the building is identified as being of regional importance on the Dublin City National Inventory of Architectural Heritage (NIAH) survey. The structure backs onto Great Ship Street and faces into Dublin Castle. The building was originally built as the Quarter Master General's Office, forming part of the larger Great Ship Street Barracks at Dublin Castle, and has provided office accommodation since its renovation by OPW in the early 1990s.

The Block M energy renovation is the second case study report developed to support the OPW Guidance. In contrast to the first case study (No 7 Merrion Square, Dublin 2), Block M was a live project, rather than theoretical, and afforded the opportunity to implement the approaches recommended in the OPW Guidance in a real-world scenario. The property was due to undergo roof, fire safety and general upgrade works as part of its overall refurbishment, thus, with a significant scope of works planned and with most internal wall finishes removed decades prior, there was an opportunity to implement a range of energy efficiency upgrades in a timely and cost-effective manner. The BER rating of the building prior to works was an E1, which was improved to a B1 rating post-renovation. The refurbishment of the building was completed in late 2023 and now provides office accommodation for the state.

This case study report focuses specifically on the energy efficiency design aspects of the project and is laid out according to the recommended template from the OPW Guidance, starting with the basic project details under *Stage 1. Project Initiation*. *Stage 2. Building Assessments* covers the heritage values, uses, construction type and condition, environment and context, and existing energy performance of the building. *Stage 3. Setting Objectives* builds on the information gathered in Stage 2 and is used to set realistic objectives for the energy upgrades. *Stage 4. Design and Specification* provides the fabric and services upgrade strategies for the buildings with detailed drawings, hygrothermal modelling and NEAP modelling of the final design. Finally, *Stage 5. Implementation, Post-Occupancy Evaluation and Monitoring* provides details on the installation process and guidance on post-completion monitoring and evaluation.

The Block M energy renovation demonstrates that while energy upgrade works to historic buildings must be approached with utmost care, the energy efficiency and carbon emissions of these buildings be can significantly improved without sacrificing valuable heritage aspects. As Carl Elefante pointed out so many years ago, 'the greenest building is the one already built' and with a sensitive, site-specific approach to their energy renovation, Block M shows that our historic buildings can play a vital role in meeting our national climate action targets.

1

Initial Stage

Stage 1. Project Initiation

1.1 Project Brief

The aim of this renovation project was to conserve and upgrade the energy efficiency of the Block M Offices, the former Quarter Master General's Office (b. 1811) within Dublin Castle, whilst respecting the building's heritage significance. A key aspect of this was improving the energy performance from an E2 Building Energy Rating (BER) to a post-works B1, which aligns with the National Development Plan goals for public sector buildings.



Figure 1.Front façade of Block M facing onto Dublin Castle prior to any works being carried out on building. Source: National Inventory of Architectural Heritage (NIAH)



Figure 2. Rear façade of Block M facing onto Great Ship Street prior to any works being carried out on building. Source: National Inventory of Architectural Heritage (NIAH)

1.2 Project Description

The project was carried out in two phases:

Phase 1: External restoration works, including;

- Roof repairs and new natural slate and copper valleys
- Installation of wood fibre insulation between the rafters
- Removal of cementitious pointing and repointing in lime based mortar to upper levels.
- Drainage repairs

Phase 2: Internal renovation works relevant to energy upgrade, including;

- Energy renovation analyses (e.g. in-situ U-value testing, hygrothermal and thermal bridge modelling, NEAP modelling)
- Internal insulation to external solid walls
- Airtightness measures
- Window repairs including installation of slim-line double glazing
- LED lighting upgrades
- M&E services upgrades

Following the completion of works, post-works performance monitoring has been commissioned, which measures interstitial, surface and ambient moisture, temperature and relative humidity for a minimum of one year.

Additional project information:

- Works commenced: May 2021
- Project completed: December 2023
- Cost: €2.2 million
- Post-works monitoring: Ongoing (2024 – 2025)

1.3 Project Team

The project was led by OPW Conservation Services with OPW Structural Engineering Services, OPW Mechanical and Electrical Engineering Services and JV Tierney & Co. M&E Services (Phase 2). Support from external energy consultants was provided by Shaffrey Architects, Passivate Building Energy Consulting and Arup Engineering.

The contactor team consisted of the following:

- Main Contractor Phase 1: PJ Hegarty and Sons
- Main Contractor Phase 2: Sensori Facilities Management
- Mechanical & Electrical Contractors: Tritech Group
- Roof works: Skyline Roofing and Building
- Brickwork and pointing: Classic Conservation & Restoration
- Plastering (including insulating plastering): Hillfort Plastering
- Window Restoration: MacLyn Conservation Joinery

2

Building Assessment

Stage 2. Building Assessment

2.1 General Information

Block M is a five-bay, four-storey, end-of-terrace building, built as the Quarter Master General's Office at Dublin Castle, part of the larger Great Ship Street Barracks complex.

While the exterior of the building retains its historic form, articulation and openings, the interior finishes have been more comprehensively altered, although the historic plan form substantially survives along with the fine staircase. The building had fallen into a state of dereliction by the 1980s and as part of the 1990s renovation, the interior wall finishes were mostly stripped back to the existing brickwork walls with cement plaster reveals added to window and door openings.

Block M, Great Ship Street Overview:

- Statutory Status: Non-protected structure
- National Inventory of Architectural Heritage (NIAH) No.: 50910021 (Regional rating), date recorded 2015
- Construction date: circa 1805-1815
- Current and past uses: Office
- Proposed use: Office
- Architectural style: Late Georgian
- Construction description: Four bay, four storey, brick building with part calp limestone wall at base of west façade onto Great Ship Street. Solid brick masonry walls, natural slate finish on timber pitched roof, timber joists sitting on a solid concrete floor slab to ground floor, timber floor joists with floorboards above to intermediate floors, timber doors & sash windows.
- General condition: Prior to Phase 1, water ingress was discovered at roof level and was one of the primary reasons for the Phase 1 external repair works, which included the renewal and improvement of the roof coverings and rainwater disposal system. External façade repairs comprised repointing of brickwork using lime mortars. The timber framed single-glazed windows were installed in the 1990s and were repaired as required and upgrades with slimline double-glazing. After these works, the general condition of the building was considered fair.



Figure 3. Front (left) and rear (right) façade of Block M. Note: photo taken after brick re-pointing carried out, stripping and reinstating roof, and removal / replacement of some windows.

2.2 Heritage Value

(a) Architectural Heritage Value Assessment

The 1756 John Rocque Map shows the east side of Great Ship Street as a terraced street with individual plots. These appear to be typical of the type of terrace buildings in the area, many with rear returns, and identified on the John Rocque map as residential structures, with the north end-of-terrace building a public structure.



Figure 4. 1756 John Rocque Map. Block M is located on the footprint of four terrace buildings – identified as three residential and one public unit at the north end-of-terrace

The current configuration of buildings along the east side of Great Ship Street date from the early to mid-19th century when existing buildings were complemented by new additions to form the Great Ship Street Barracks The buildings were used over the years for a variety of purposes, including accommodation, training and offices and were altered and added to as necessity required. However, by the 1980's the buildings were abandoned and derelict. In the 1990's, the OPW worked to renovate the buildings and restore the facades along Great Ship Street.

The building, now referred to as Block M, was originally constructed as part of the Quarter Master General's Office, as indicated on the 1847 first edition OS Map. This map includes the ground floor plan, showing the central stairwell flanked on either side with sub-divided two bay rooms. The current stair arrangement differs from that drawn on the 1847 map, which suggests the stairs may have been altered or replaced. The Quarter Master General's Office was connected to barrack yard (the old Parade Ground) in the twentieth century.

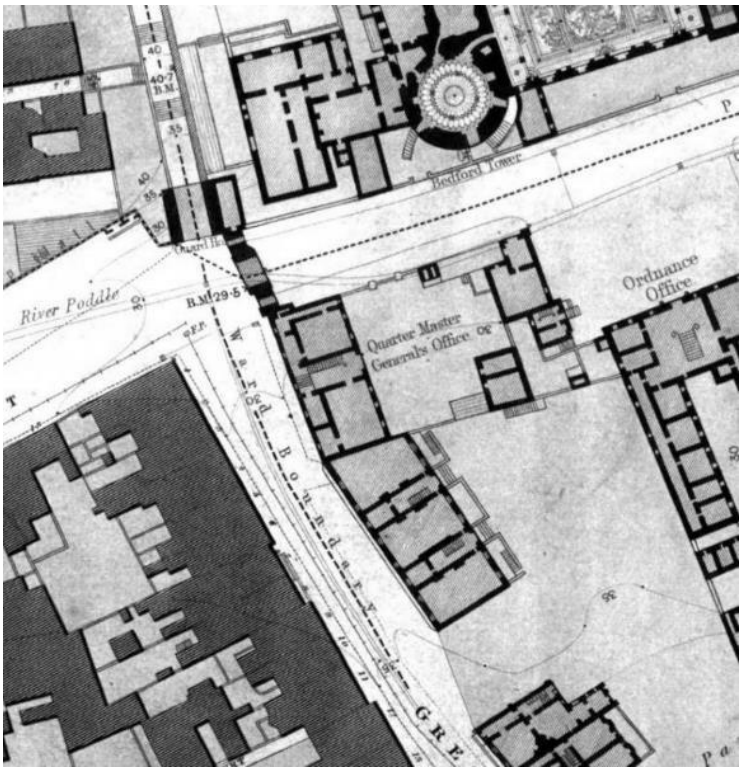

Figure 5. 1847 25inch OS Map. Showing the internal layout to Block M

The former Quarter Master General's Office (Block M) and the main entrance gate to the Barracks, to the north of Block M, were designed by Francis Johnston, architect to the Board of Works at the time.

Block M is not a protected structure however it is within the curtilage of protected structures, and is identified as being of regional importance by the National Inventory of Architectural Heritage (NIAH) which describes Block M as follows:

"End-of-row five-bay four-storey office building, built 1808-11, front elevation facing into Dublin Castle complex and backing onto Ship Street Great. Hipped slate roof concealed behind parapet, with blue/black clay angle ridge and hip tiles, brick chimneystacks to north and south ends. Brown brick Flemish bond walling on granite plinth to east elevation, limestone tooled ashlar plinth rising to sill level on west elevation, and moulded granite parapet coping surmounted by granite blocking course. Camber-arch window openings to both elevations, with granite sills to eastern and sills to western, with rubbed brick voussoirs. Painted timber sliding sash windows, six over-six pane to ground, first and second floors, and three-over-six pane to third floor, with metal grilles to ground floor windows of rear elevation. Segmental-headed entrance to east elevation, having rubbed brick voussoirs, and glazed door screen of c. 2000. Square-headed secondary door to north end of east elevation, with rubbed brick voussoirs, painted timber panelled door, moulded transom and three-pane fanlight. Ship Street Gate to north, and contiguous similarly scaled building to south. Interior remodelled c. 1997."



Figure 6. View of entrance to Dublin Castle from Great Ship Street. Drawing from 1949 by Brian Coghlan. Source: National Library of Ireland

The assessment criteria for determining significance refers to the Architectural Heritage Protection Guidelines for Planning Authorities; Guidance on Part IV of the Planning and Development Act 2000 (DoAHG 2011). The areas of special interest in Block M are Architectural, Historical and Archaeological.

a) Architectural: Block M forms part of Dublin Castle infrastructure and is an intrinsic element of Great Ship Street. It is part of the continuous street façade along Great Ship Street and facing into Dublin Castle.
b) Historical: As part of the Great Ship Street Barracks and Dublin Castle complex, the area has been at the heart of significant episodes in Irish history, in particular the journey from British occupation to independence.
c) Archaeological: Within a significant archaeological part of Dublin, including the site of Dubh Linn, the 'black pool' which gives its name to Dublin, and part of the Viking city and its subsequent centuries of urban development.

(b) Phases of Development

The Quarter Master General's Office and adjoining army barracks buildings replaced a residential street laid out in the 17th/18th century. The footprint of Block M approximately aligns with the footprint of four buildings between Proud Street and Buckridges Court (since infilled). These four buildings are indicated on Rocque's 1756 map as three dwelling houses with a non-residential building at the northern end, to which another dwelling is attached to the east, addressing Proud Street.

The houses on the Rocque Map were cleared in the early 19th century to allow construction of the Great Ship Street Barracks complex, including the Quarter Master General's Office (Block M). While the houses faced onto, and were entered off Great Ship Street, the entrances to the new military buildings were from within the Castle grounds, which itself was entered through controlled gateways.

Internally, Block M today largely retains the configuration of the 1847 OS map plan, with a central stair flanked on both sides with front (east) and rear (west) rooms. Original fireplaces and chimney stacks are located on the central dividing walls between front and east rooms, with later partitions subdividing these rooms.

Block M has most recently been in office use. Internally, little historic decorative finishes survive. The internal walls (including the external wall inner face) were stripped of their plaster finish and left with brickwork exposed. Cement plaster surrounds had been applied as architraves and reveals to window and door openings. However, the central staircase remains, as well as some fireplace surrounds. The timber floorboards and joists to the upper floors appear to be historic, however, ceilings had been removed and replaced with modern suspended plasterboard ceilings.

(c) Photographic Evidence

External Walls: The walls are predominately solid brick with calp limestone to the ground floor plinth on the west façade facing Great Ship Street.



Figure 7. View of rear façade facing onto Great Ship Street prior to works being carried out. Walls are solid brickwork above calp limestone base

Windows / Doors: The windows are single glazed timber sash windows with a brick cambered arch head. The main entrance door is a modern replacement timber panel door with glazed fanlight and sidelights. There is a solid timber door with glazed fanlight over the northeast corner of the building. As part of the Phase 1 works, the glazing was upgraded from single to slimline double glazing.



Figure 8. View of front façade facing onto Dublin Castle prior to works being carried out. Windows are single glazed timber sashes. Note: missing sections of lime pointing around window cill

Roof: The roof is a recent replacement roof with wood fibre board installed between the joists, retaining the plasterboard ceiling below and reinstating the natural slate roof finish.



Figure 9. View of roof after works were carried out to strip and reinstate roof. New copper gutters and lead flashings installed throughout

Wall Finishes: Internally most of the walls had been previously stripped of historic plaster finishes with brickwork left exposed. There is no historic plasterwork, such as cornices or decorative mouldings remaining

on the walls. The window surrounds have been finished with a modern cement plaster. Similarly, there are areas where cement plaster has been installed to provide a flush surface for fitting joinery, such as behind skirting boards. The cement plaster is finished with a paint coating. Modern internal partitions are stud partitions of plasterboard and painted finish.



Figure 10. Internal images prior to works commencing internally. Images showing exposed brickworks walls with some areas of cement render, such as around openings and behind skirting boards

Floor Finishes: At first through third floor, historic floorboards (though possibly not original) remain on historic floor joints. The ground floor is a modern tiled finish on a modern replacement floor build up. To the central stair area the floor is a solid concrete slab with a tiled finish. To the rooms either side of the stairs these are timber joists sitting on solid concrete slabs with plywood and a tiled finish over the joists.





Figure 11. Images of floor finishes prior to works commencing internally. The ground floor has a tiled finish with the upper floors of timber floorboards

Central Staircase: The central staircase is possibly original, or at least of considerable age. It is a timber staircase with a plaster soffit. It has a simple yet elegant carved profile along the cut string. The spindles are a simple profile, with a sweeping curved timber handrail from third floor terminating at a simple newel post at ground floor.

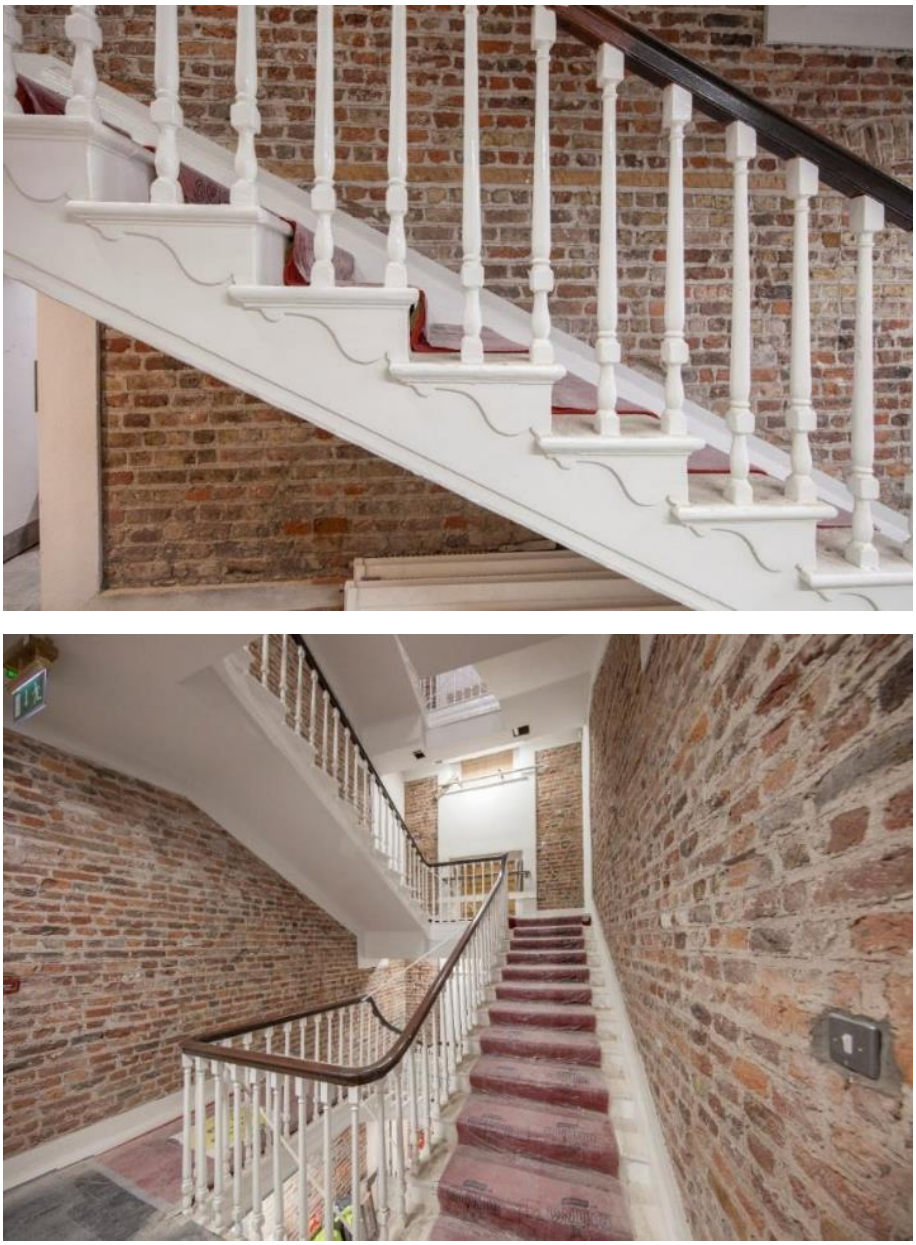

Figure 12. The central staircase is one of the important retained elements within the building

Joinery: There is little historic joinery remaining in Block M. Any window joinery which may have existed, such as shutterboxes or timber linings, have been removed with no physical evidence surviving. All internal doors are modern flat panel doors, with cement plaster architraves. Skirting boards are modern square profile replacements.



Figure 13. Images of interior prior to works commencing internally. No surviving historic joinery, such as window surrounds or panelling

Fireplaces: There are a variety of different fireplace surrounds that survive. The flues are mostly open, with the chimney pots capped as part of the recent works carried out.



Figure 14. Images of the different types of fireplaces throughout

Services: The services throughout Block M are modern replacement, with nothing of heritage interest remaining. The space heating and hot water heating is supplied by a gas-fired boiler which serves a number of other buildings along Great Ship Street. The lighting is incandescent throughout, and the building is naturally ventilated.

2.3 Use

(a) Past, Present and Proposed Use(s)

Block M was originally in use as the Quarter Master General's office, and later used for training and office accommodation as part of the Great Ship Street Barracks. The building was vacant by the 1980's.

The building has most recently been used as offices until circa. 2021-2022 when the Mahon Tribunal completed its role. The OPW then undertook a programme of works to address maintenance issues and to provide a new office use for a new government tenant.

The current layout of Block M retains much of its historic plan form, with the central stair flanked on both sides by a front and rear room separated on all levels by a solid masonry wall containing fireplaces for each room and supporting rising flues and chimney stack, with the larger of the rooms facing towards Dublin Castle. Modern stud partitions had been installed to subdivide these rooms, however, these required removal to provide a more suitable office layout and to address Building Regulations Part B issues.

The proposed use will see the building solely occupied for office use, with associated ancillary spaces, such as toilets, meeting rooms, etc. It is expected that the new use will accommodate up to 30-40 staff desks.



Figure 15. Existing plans of Block M

2.4 Construction and Condition

(a) Description of Architectural Style

Block M was built in the late Georgian period. Its simple unadorned elevations, mainly of brickwork, present an imposing façade as a continuation of the Great Ship Street Barracks complex and forms an impressive boundary to both Dublin Castle and along Great Ship Street. While the exterior of the building retains much of its original fabric and the internal layout is substantially intact, the interior decorative finishes have been altered and in some cases lost altogether.

It is a traditionally constructed building, with solid masonry walls, predominately solid brickwork, bedded and pointed with lime mortars. At ground floor level facing onto Great Ship Street, the base of the wall is faced externally in dressed calp limestone with brick internally. The roof is a hipped roof with natural slate finish and two brick chimney stacks, parallel to, but set back slightly from the central ridge. There is a continuous copper-lined parapet gutter set behind the brick parapet walls. Roof and rainwater goods were repaired as part of the advance maintenance works programme.

There is no basement, and the ground floor is a timber floor joist sitting on a modern concrete slab to the rooms either side of the central staircase. The floor in the central staircase area, however, is a modern solid concrete slab. The windows throughout are single glazed timber sash windows, while the doors are solid timber with glazed fanlight and sidelights.

Typical of this type of traditionally constructed building, Block M relies on the vapour permeability of the building fabric and natural ventilation to regulate excess moisture and vapour. Chimney flues naturally extracted warm moist air with sash windows providing incoming fresh air. Maintaining this vapour permeability of the structure is important to avoid promoting damp and mould growth.

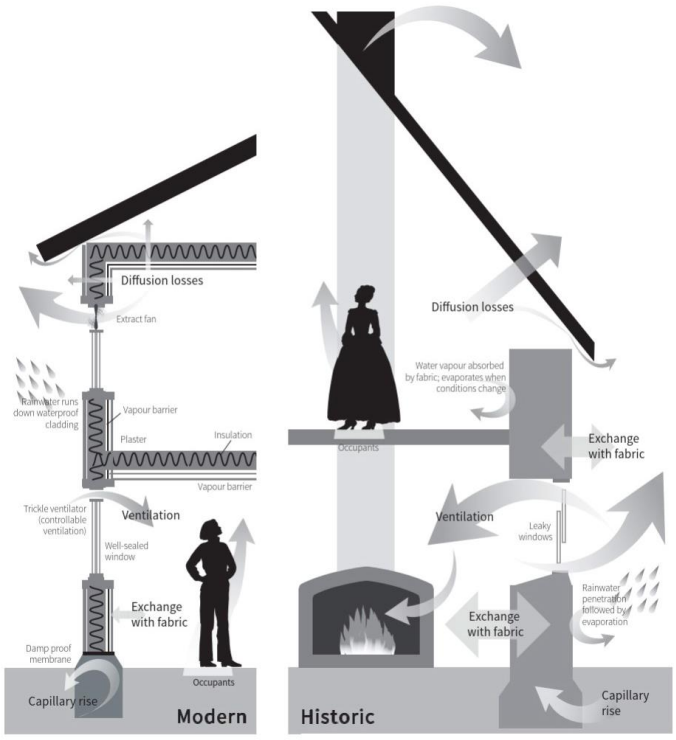

Figure 16. Image showing comparison of modern and historic construction typologies. Source - Historic England, Energy Efficiency and Historic Buildings

(b) Building Fabric and Construction

The following is a description of the individual thermal envelope elements, including their known or assumed construction build-ups, as well as any recent alterations or material changes.

Front and side/gable façades (front façade facing east onto Dublin Castle): The front and side façades consist of a brownish brickwork in a Flemish bond, with lime mortar bedding and pointing. Internally the plaster finish has been stripped back and brickwork walls exposed. It appears that the walls are solid brick throughout, approximately two bricks (approx. 450mm or 18 inches) thick to both façades on all levels. The brick facades required localised repointing.

Rear façade (facing west onto Great Ship Street): From ground floor up, the walls are a brownish brickwork in a Flemish bond as the front and side facades, with lime mortar bedding and pointing. As with the front and side facades, these walls appear to be solid brickwork throughout, though thicker at approximately 2-and-a-half bricks wide (570mm or 22 ½ inches) on all levels. At low level the wall is faced externally with a dressed calp limestone plinth. Localised repointing was also required to this façade.



Figure 17. Image of rear façade facing onto Great Ship Street showing brickwork and calp limestone plinth. Note: image shown was taken after re-pointing was carried out to window cambered arch and calp limestone plinth

Windows: Windows are located on the front and rear façade only, with the north-facing gable façade blank. The windows are single glazed hardwood timber sash windows throughout, installed as part of the 1990s works. To both the front and the rear, the windows are six-over-six sashes at ground, first and second floor with the third-floor windows three-over-six. No historic window frames or glazing survive.



Figure 18. Internal image of window prior to works commencing. Existing windows are a timber sash with modern single glazing

Roof: Hipped roof with clay ridge tiles and natural slate finish on King Post truss roof structure with timber purlins, rafters and battens. Plasterboard fixed to the underside of the rafters with the main timber King Post truss elements exposed within the third-floor rooms. The roof had recently been stripped to address water ingress issues, with the opportunity taken to improve the energy performance of the roof build up. Wood fibre board insulation was installed between the rafters, with a vapour control layer below and a breathable membrane above, and reinstatement of the natural slates on battens and counter battens. The plasterboard ceilings were retained, thus restricting the depth of space for insulation to 90mm.

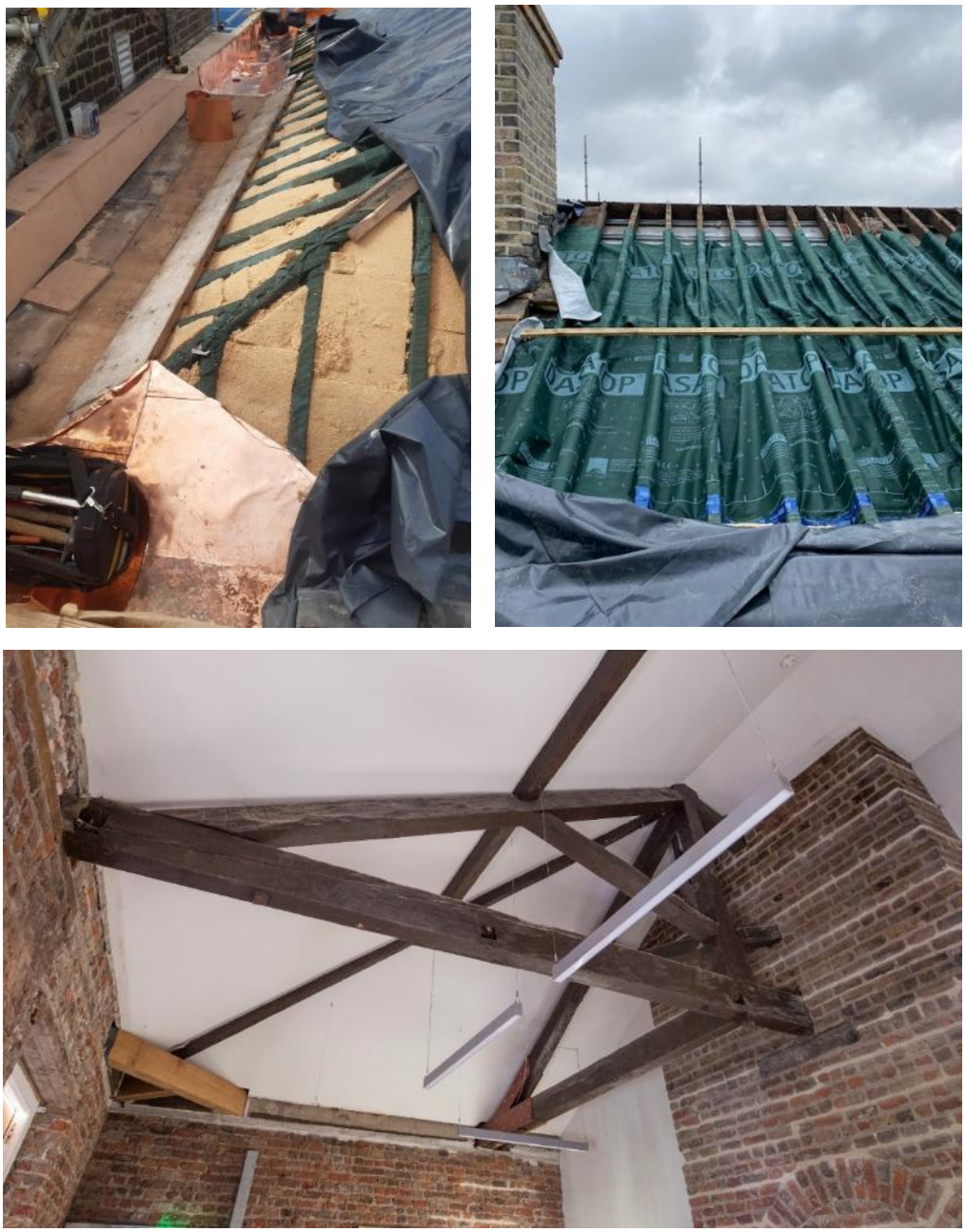

Figure 19. (top) External images of the roof being upgraded with wood fibre insulation c. 2021/2022. (bottom) Internal image of the plasterboard ceiling retained with exposed King Post truss

Ground Floor: To the rooms either side of the central staircase, the ground floor build up is a solid concrete slab sitting on hardcore / earth, with timber joists and counter joists sitting on the concrete slab. Above the joists is a layer of plywood with a modern tile floor finish above. Within the central stair hall, the floor is a solid concrete slab on hardcore / earth. Both floor types are uninsulated and there is no evidence of a DPC or similar damp proof layer. The floor build-ups are likely a late 20th century intervention.




Figure 20. Image of opening up works to ground floor. Floor build up for rooms either side of central staircase with timber joists on concrete screed with plywood and tile finish above

Intermediate Floors: Historic timber floor joists, running front to back, sitting in pockets on the external brickwork walls. Historic, though possibly not original, timber floorboards above, with the original lath and plaster ceiling below replaced with a suspended plasterboard ceiling. Modern steel beams installed below the floor joists, likely in the late 20th century, when the lath and plaster ceiling was likely also removed.



Figure 21. View looking up at intermediate floor structure after removable of existing plasterboard suspended ceiling

(c) Condition Assessment

The overall condition of Block M was fair at the outset of the project, but as noted in the Introduction and Project Description, the building was due to undergo roof, fire safety and general upgrade works as part of its overall refurbishment. The scope of works were then expanded upon to include energy efficiency measures. Remedial and repair works generally included:

- Comprehensive roof renewal, including new copper gutters, lead flashing, and repointing to the chimney stack;
- Refurbishment of sashes;
- The internal cement plaster had been identified as an issue of concern and was due to be removed as part of the wider scope of refurbishment works;
- Installation of helical stainless steel reinforcing bars within the walls to rectify separation of junction between facades and party walls, as well as cracks within the brick walls.
- Externally the lime pointing had deteriorated in localised places and was due to be renewed with lime pointing.

Some opening up works were carried out to confirm construction build ups for the hygrothermal risk assessment modelling and energy renovation designs. As the walls were exposed and the records of the recent roof works were available, these opening up works were focused mainly on the floor build up. Localised trial pits were excavated to confirm the floor build up, including sizes / thicknesses of individual elements.

2.5 Environment and Context

Block M is a four-storey end-of-terrace building with a long rectangular form. There is also a section of the party wall that is an enclosed, unheated space, used for a fire escape. Due to the long form of the building and the fact it is an end-of-terrace structure, the building has a larger area of exposed façade, with only one, shorter party wall side next to a heated space. Therefore, the form of the building is not very efficient.

The building, however, is running north to south and receives direct sunlight on both the front and rear facades. Only the north gable receives little direct sunlight. To the south of Block M, the Great Ship Street Barracks is of a similar height, with the buildings on the Dublin Castle side of a lower height. The buildings on the opposite side of Great Ship Street are, however, taller and therefore cause some shading to the rear façade, though they also provide a degree of protection from the prevailing wind.

As the building is an end-of-terrace structure there is sufficient space on three sides to provide access for carrying out works.

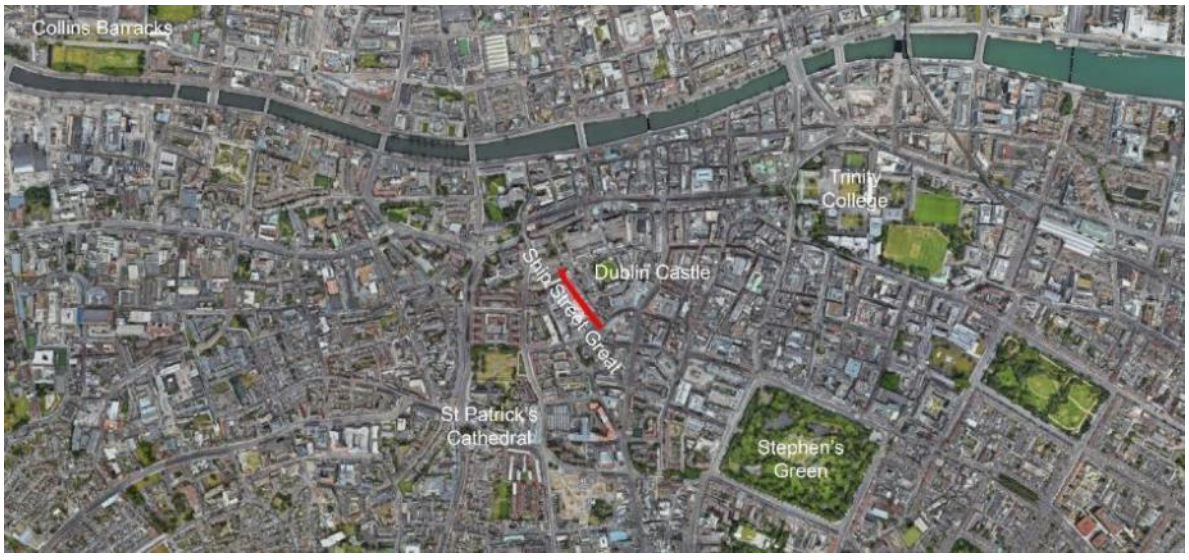

Figure 22. View of Great Ship Street in relation to Dublin City



Figure 23. Great Ship Street in relation to Dublin Castle

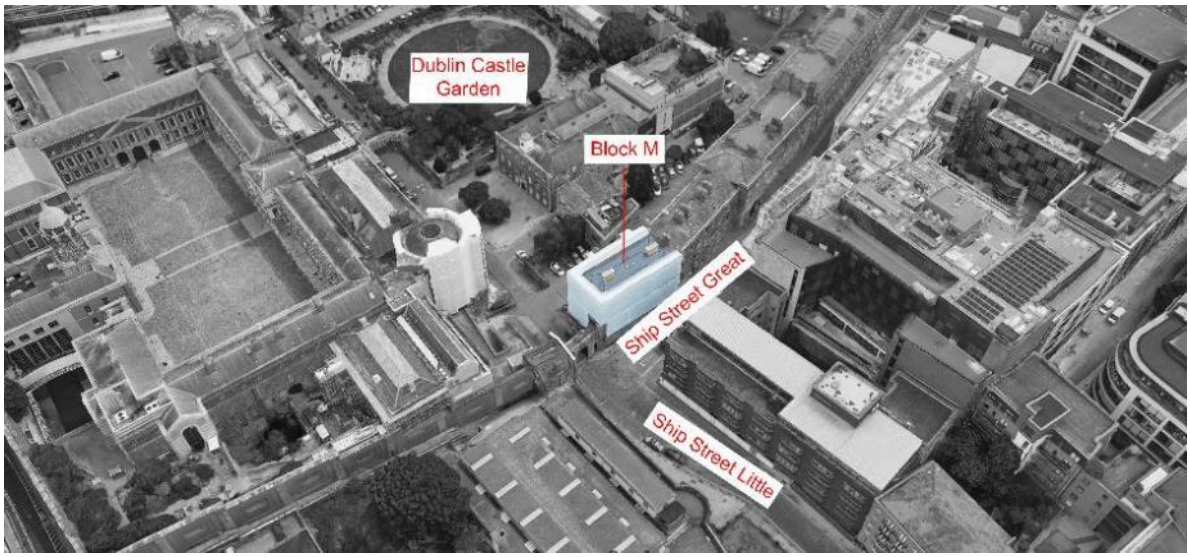

Figure 24. Bird's eye view of Block M. Note: view shows Block M with scaffolding surrounding building



Figure 25. View of end gable of Block M showing building in context. Building is exposed on three sides

2.6 Existing Energy Performance

(a) In-situ Testing

Further investigation of the existing fabric was carried out to determine the existing performance of the building fabric. This was required to provide a more accurate U-value calculation for the external walls, as well as the required information for the WUFI analysis.

(i) Karsten tube

The Karsten Tube test was undertaken on the rear façade of Block M to test the absorption rate of the existing brickwork. The absorption rate is required when testing the proposed details in WUFI. The assessment was carried out on a centre of brick, centre of perpend brick, side of brick, and centre of mortar joints. The results were area-weighted over the percentage brick to mortar ratio to provide a single value for use in the one-dimensional WUFI model.

During the test the water begins to spread laterally across the surface while also being absorbed into the brick. The mortar showed a far lower rate of water absorption as would be expected where the brick is of normal-to-high porosity. The extent to which water travels laterally at the surface vs. straight into the brick is unknown. For this reason, a second test was carried out with three tubes on a single brick in order to force water absorption directly into the brick and reduce the extent of lateral water transport. The results were not significantly affected, and therefore the initial results were deemed reliable and representative to be used.

Based on the measured results of the Karsten tube test, a liquid transport coefficient for redistribution of 0.0271kg/m^{2}s$^{0.5}$ was applied to the outer 10mm of brick.

(ii) In-situ U-value tests

Two in-situ U-value tests were carried out on the rear facade brickwork walls at first floor level and provided ISO 9869-1:2014 compliant results. The in-situ U-value tests were carried out at the beginning of February 2023, when the weather was colder, however, as the building was unoccupied there was a requirement to install temporary heating to ensure the temperature difference (delta T) of 5°C between inside and outside was maintained. The sensors were left in-situ over a two-week period to achieve compliant results.

The test results show the U-value of the existing wall is 1.135W/m^{2}K. A desktop thermal model of the wall was also carried out and showed a very strong correlation between the calculated U-value as well as surface temperature between the thermal model and the monitored results, therefore providing a degree of certainty that the in-situ U-value tests were accurate.



Figure 26. Images of in-situ U-value monitoring tests

3

Setting Objectives

Stage 3. Setting Objectives

3.1 Primary Goals

After carrying out the assessments outlined in Stage 2 and in response to the project brief, the energy consultants reviewed the following objectives and targets to identify any major concerns relative to Block M. Table 1 below is an initial assessment of Block M against potential TGD Part L values. This is not to suggest that Part L values must be the target values, instead they are used as an initial gauge to compare the performance of the existing building against and to provide commentary on the likelihood of achieving these targets.

Table 1. Fabric Upgrade Targets

Elements	Existing value	Commentary	Part L value[1]
BER Rating	*E1*	*Achieving B rating may be difficult as the existing building rating is low.*	*B (Project Brief BER Target)*
Primary Energy (kWh/m^2)	*393.49*	*Achieving Cost Optimal rating may be difficult as may not be possible to improve performance of certain elements or significantly upgrade existing heating system.*	*124 or 180* (Cost Optimal Target)*
Roofs	*4.37 W/m^{2}K*	*The upgrades to the roof have already been determined therefore the proposed performance will be fixed.*	*0.16 W/m^{2}K*
Walls	*1.135 W/m^{2}K*	*Likely to achieve Part L value as the walls could receive IWI.*	*0.6 W/m^{2}K*
Floors	*0.46 W/m^{2}K*	*Possible to achieve Part L value as floor is a modern replacement, however, replacing the floor may not be achievable from a programme or budget perspective*	*0.15 W/m^{2}K*
Windows & Doors	*5.6 W/m^{2}K*	*Part L value should be achievable as windows are to be upgraded*	*1.60 W/m^{2}K*
Airtightness	*25m^3/(h.m^2)*	*Achieving Part L value may be possible as airtightness measures can be carried out*	*5m^3/(h.m^2)*

[1] Part L values are not the target values, instead are used as a gauge to assess existing building against
** 124 kWh/m^2 for naturally ventilated office use. 180 kWh/m^2 for air-conditioned office use.*

3.2 Assessment Criteria

Following the I.S. EN 16883:2017 guidelines, the project Primary Goals were reviewed at a high level to identify any major areas of concern.

Table 2. Principle Goals Assessment Criteria

Assessment Category	Comments
Technical Compatibility	The existing fabric relies on vapour permeability. Any interventions must be compatible with existing fabric and not cause a greater risk to the structure. Hygrothermal risk assessment to be carried out on interventions to determine suitability.
Heritage Significance	Internally most of the historical decorative elements have been removed or lost with many of the walls stripped back to exposed brickwork. While the loss of historic fabric is unfortunate, the current situation allows for more

	flexibility in applying interventions to the existing fabric.
Economic Viability	The brief was to provide an office that met current standards for user comfort and wellbeing. As more than 25% of the building envelope was being renovated, a cost optimal energy upgrade was pursued in line with the EU Energy Performance of Buildings Directive and Government Climate Action Plan. The project was seen as economically viable.
Energy Performance	Although the baseline model was set out as if no interventions have been carried out, in reality Phase 1 was in progress (roof upgrades and external repairs). The overall energy performance of the roof was therefore set and had likely been improved as much as practical due to building constraints, e.g. parapet height. However, other elements of the thermal envelope presented opportunities for further energy efficiency improvements.
Indoor Environmental Quality	The indoor environment should be improved, particularly through the upgrading of the windows and level of airtightness, which should reduce the level of uncontrolled natural air infiltration. However, this may require introducing mechanical ventilation. Assessment of the outdoor air ventilation requirements should be carried out based on the occupancy levels in each room. The use of natural products, paints, etc. should be encouraged. Where mechanical heat recovery ventilation (MHRV) cannot be accommodated, consideration should be given to retaining an open flued chimney for ventilation, drawing air through an openable section of the window. However, the chimney breast should be fitted with an operable damper to open or close the flue depending on indoor and ambient conditions.
Impact on Outdoor Environment	The building currently relies on natural gas as the main heating source. The heating systems is interlinked with other properties within the Great Ship Street Barracks. It may be challenging, practically, to disconnect the heating system of Block M from the other properties. There may also be restrictions in locating outdoor plant to provide for a renewable energy source (i.e. heat pumps). Therefore, in the short term, it may be necessary to stick with a version of the current heating system but make improvements through the replacement of the existing boiler with a high efficiency gas-fired condensing boiler and introduce zonal control. This may negatively impact on the carbon dioxide emissions performance while improving on the energy efficiency rating of the building.
Aspects of Use	The current use of the building is office, with the proposed use also office. This should not have a major impact on the building. It is intended to install post occupancy monitors in the wall fabric. This will need to avoid impacting the office use, otherwise it may get moved or damaged.

3.3 Cost Optimal & Major Renovations

(a) Baseline Energy Model

A baseline model was carried out using a building energy model (IES modelling software) to establish the existing condition. Establishing the baseline condition is an important step to assess how the existing structure is performing and can help to identify where improvements may be most effectively targeted.

Although some works to the roof and windows had already been carried out on Block M by the time the baseline model was established, it was agreed to set the baseline model using the existing conditions prior to

any of the most recent works being undertaken. This decision was taken as it would provide a more comparable case study scenario between an existing condition, which would not have any recent interventions carried out, and the proposed condition after all the interventions were undertaken. Therefore, for the Block M baseline model, the roof was taken as an uninsulated build up and the windows were taken as single glazing throughout. The remaining floor and wall elements, as well as the existing services, were taken as per the current condition at the time of establishing the baseline model.

The following is a comparison of the various building fabric elements. For the baseline model a mix of measured values, calculated values and default values were used to establish the baseline condition. This was done to provide a more accurate existing condition using measured or calculated information where available and default information where not.

Table 3. Baseline Energy Model

Building Element	Description	Default Value	Measured / Calculated Value
Walls	*solid brickwork walls with lime pointing*	*1.6 W/m²K*	*1.135 W/m²K*
Floors	*uninsulated concrete slab, with timber joists / counter joists and plywood in rooms either side of central stair*	*1.62 W/m²K*	*0.46 W/m²K*
Roof	*uninsulated rafters with plasterboard below*	*2.44 W/m²K*	*4.37 W/m²K*
Glazing	*single glazing timber sash windows*	*5.60 W/m²K*	*5.60 W/m²K*
Airtightness	*leaky building*	*25 m³/(h.m²)[1]*	*25 m³/(h.m²)*
Thermal Bridge *Surface temperature factor (fRsi) range*	*high thermal bridging*	*N/A*	*0.34 – 0.77*

Black – default values; Red – measured values; Blue – calculated values

Details on the existing services were also included in the baseline model for the heating, domestic hot water, lighting, and ventilation.

Space heating and hot water were provided by a centralised gas-boiler that provided heating and hot water to multiple properties within the Great Ship Street Barracks complex. Space heating to Block M was provided by modern aluminium radiators. Lighting was provided by standard incandescent bulbs throughout. And ventilation was provided by uncontrolled natural ventilation through draughty windows and existing chimney flues, with additional ventilation provided by openable windows.

The results of the baseline model identified the existing building as a BER rating of E1 and a Primary Energy rating of 393.49 kWh/m2. The breakdown of Primary Energy was Heating 70.49%, Lighting 27.05%, Auxiliary 01.02% & DHW 1.44%. Cost Optimal Primary Energy

The cost optimal Primary Energy level for office use as defined in TGD Part L is 124 kWh/m²/yr. There is an allowance in TGD Part L for additional 15% over the cost optimal level for flexibility in application if required. This would mean a cost optimal Primary Energy level of 142.6 kWh/m²/yr. Therefore, to achieve the Primary Goals above the proposed energy performance improvements would need to achieve a Primary Energy rating of less than 124 kWh/m²/yr (or 142.6 kWh/m²/yr if the additional 15% is included), or a BER rating of B or greater.

(b) Major Renovation Threshold

As stated in TGD Part L, providing that where more than 25% of the surface area of the building envelope undergoes renovation the energy performance of the whole building should be improved to Cost Optimal level in so far as this is technically, functionally and economically feasible.

This is important in the context of Block M since the project initially involved only renovation to the roof area, which was below the 25% threshold. However, when the additional works (i.e. windows and walls) are included in the Major Renovation calculation this bring the total area over the 25% threshold. Therefore, as the building is not a protected structure there is a requirement to comply with Building Regulations Part L and Part F.

As noted previously the case study design team provided advice on the energy performance strategies only. Building Regulation compliance was under the remit of the wider Project Team and is therefore not expanded on as part of the case study report.

4

Designing Improvements

Stage 4. Design and Specification

4.1 Existing Defect Repair Strategy

As noted above, works had already commenced on Block M and any defects were either already addressed or were due to be addressed as part of the overall scope of works. Therefore, the existing condition of the building fabric was fair, or would be made fair, allowing interventions to be carried out which would not mask or conceal defects.

A summary of some defects is identified below to highlight the repair strategy carried out.

Table 4. Defect Repair Strategy

Defect	**Repair Strategy**	**Urgency** (low / medium / high)	**Timeline** (month)
Water ingress at roof level	Roof was completely stripped from above including gutters, and replaced with new copper gutters, breathable membrane, battens and natural slates.	High	N/A
External brick pointing had failed in various places	Façade to be repointed with NHL lime mortar	Medium	N/A
Internal cement plaster applied to walls	Remove cement plaster and replace, where required, with suitable NHL lime plaster	Low	N/A
Structural cracks between external walls and party walls	Rake out joints either side of crack at set vertical intervals and install structural ties between adjacent walls. Repair joint with NHL lime mortar	High	N/A

4.2 Overall Fabric Improvement Plan

(a) Overall Fabric Upgrade Strategy

The following is a full list of the energy improvement interventions. It is worth noting that the list includes interventions that were part of the existing scope of works (i.e. roof and windows), however, in assessing the overall improvements, these were taken as being part of the proposals for the overall fabric upgrade strategy.

Table 5. Overall Fabric Upgrade Strategy

Existing Condition	Intervention	Heritage Impact	Technical Assessment	Existing U-value	Target U-value[1]
Roof					
Uninsulated rafters with plasterboard below	Wood-fibre board insulation to be installed between rafters.	Installation of insulation between will not disturb any historic fabric and will not visually impact the building.	Installing insulation between rafters takes advantage of work programmed to repair the roof and would be relatively straightforward and low risk.	4.37 W/m2K	0.16 W/m2K
Walls					
Solid brickwork walls with lime pointing	Internal Wall Insulation (IWI) applied to exposed brickwork wall – two options proposed (see below)	As the building has been altered significantly internally, with no decorative plasterwork or window joinery surrounds remaining, IWI would not have a significant impact on the building	It is critical that a vapour permeable insulation solution is proposed. As the walls were already stripped, it would be relatively straightforward to apply IWI to existing surface	1.135 W/m2K	0.6 W/m2K
Ground Floor					
Uninsulated concrete slab with timber joists / counter joists and plywood above to rooms either side of central stairs. Uninsulated concrete slab to central stair	Retain as existing	The existing floor build-up is a modern replacement. However, there were restrictions in the programme and budget which minimised the interventions to the floor.	The existing build-up contains a solid concrete slab. This is a non-permeable layer. However, it does not appear to be causing issues with trapped moisture. The floor to be repaired locally where required	0.46 W/m2K	0.46 W/m2K
Windows					
Single glazing timber sash windows	Replace existing with new windows with narrow double glazing	The existing windows did not appear to contain any historic glazing. While the frames could have possibly been retained, they would have required significant alterations to accommodate upgrades	Internally the reveals to all windows have been altered which allows the existing windows to be removed from inside and replaced in the same position. Exposed reveal allows for improving airtightness level around windows	5.60 W/m2K	1.60 W/m2K
Doors					
Solid timber doors with single glazed fanlight & sidelights	Replace existing with new solid timber doors and narrow cavity double glazing	The existing doors are modern replacement with a configuration not typical of this type of building. Replacing it with a better performing door will afford the opportunity to provide a more suitable design for the door	The existing door can be easily removed internally with the new door replacing the existing in the same position	5.60 W/m2K	3.0 W/m2K

[1]Target U -value are a combination of Building Regulations TGD Part L values and retained existing values



Figure 27. Proposed building fabric overall strategy plan showing location of interventions. Note two different areas of internal wall insulation application

Following the development of the overall fabric upgrade strategy, individual junctions were identified, with proposals assessed for each junction using thermal modelling software to determine the risk of surface condensation and mould growth. The list of key junctions are as follows:

- Ground floor / wall junction,
- Roof parapet junction,
- Window / door cill,
- Window / door head,
- Window / door reveals, and
- Intermediate floor.

Each of the junctions are explored in detail below, identifying the intervention and material assessment carried out to determine the most suitable approaches. Alongside this the full suite of proposals were assessed using WUFI to determine the hygrothermal risk analysis. A summary of the thermal modelling of the junctions and WUFI analysis are provided below following the review of all the junction details.

As part of the overall fabric upgrade strategy, it was proposed to test two different types of Internal Wall Insulation (IWI) methods on the walls. This would allow the different methods to be compared against each other in similar installations. The plan form of the building suitably splits the building in two with the central staircase, thus allows either side of the stairs to have a different treatment, creating similar conditions for both methods to be assessed.

(b) Details – Ground Floor / Wall Junctions

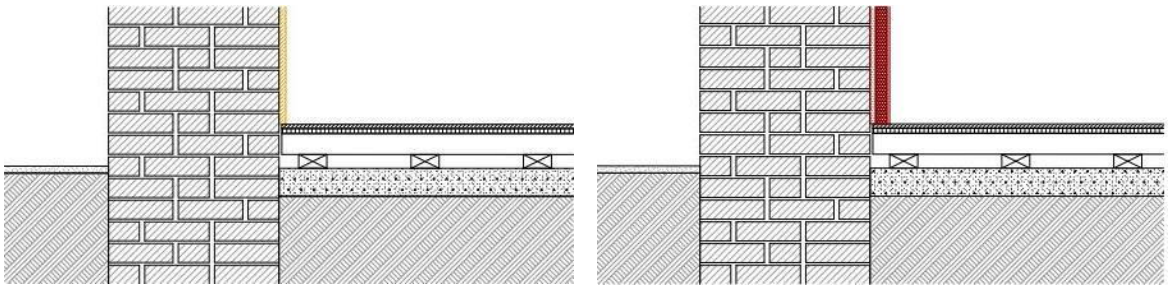

Figure 28. Existing and proposed detail of floor to wall junction with ground floor build up retained and internal wall insulation applied

This junction is located at ground floor level, between the external front wall and the ground floor. The ground level externally is lower than the internal finished floor level. The existing ground floor build up to the rooms either side of the central stair consists of a tiled floor finish, on plywood, on joists and counter joists, on a concrete slab on earth. The floor build up to the central stair is a solid concrete slab on hardcore / earth with a tiled floor finish above. The existing wall build up consists of cement plaster internally, on solid brickwork with lime mortar.

As identified in the overall fabric upgrade strategy, the ground floor build-ups are to be retained. The original programme and budget had not allowed for significant works to the floor, as they were in fair condition, and there was no scope to alter to allow for replacing the floor to improve the energy performance. An initial high-level assessment of the IES model was carried out to determine if retaining the floor build up would have a significantly negative impact on the BER and Primary Energy rating. The initial results showed that it would be possible to achieve a high rating without replacing the floor build-up. Therefore, it was determined to retain the floor build-up as existing and only repair locally as required.

Although the existing build-up includes a non-vapour permeable solid concrete slab, there is no evidence of mould growth or surface condensation issues.

To the walls the cement plaster is removed, and Internal Wall Insulation (IWI) is applied to the inner face. The walls are solid brickwork, therefore a vapour permeable insulation is required to avoid trapping moisture within the build-up. The IWI is to continue into the reveals of the windows and between floor joists to provide a continuous line of insulation.

As part of the development of the overall fabric upgrade strategy, it was identified that Block M could become a test bed for different IWI solutions, which would then be monitored with embedded sensors post-occupancy to examine interstitial moisture within the proposed build-up. Two different approaches were explored to the rooms either side of the stairs (north rooms and south rooms). To the north room an insulated plaster is applied directly to the walls, while to the south rooms a wood-fibre board is adhered to a new lime plaster levelling coat.

Table 6. Fabric Upgrade Summary

Existing Build-up	Insulation	Thickness	Thermal Conductivity	Existing U-value	Part L U-value	Proposed U-value
Ground Floor						
Uninsulated concrete slab with timber joists / counter joists and plywood above to rooms either side of central stairs. Uninsulated concrete slab to central stair	*None*	*N/A*	*N/A*	*0.46 W/m²K*	*N/A*	*0.46 W/m²K*
Wall – Rooms to north of stair						
Solid *brickwork walls (circa. 500mm) with lime pointing – cement plaster internally removed*	*Insulated cork and lime plaster directly applied to exposed brickwork*	*50mm*	*0.037 W/mK*	*1.135 W/m²K*	*0.6 W/m²K*	*0.43 W/m²K*
Wall – Rooms to south of stair						
Solid *brickwork walls (circa. 500mm) with lime pointing – cement plaster internally removed*	*Lime plaster levelling coat, wood fibre insulation board, lime plaster finishing coat*	*40mm*	*0.039 W/mK*	*1.135 W/m²K*	*0.6 W/m²K*	*0.55 W/m²K*

An intervention assessment was completed for the junction detail, highlighting any areas of concern that may need to be reviewed or addressed. Where information was not available this has been omitted.

Table 7. Risk / Benefit Assessment Scale

Assessment Scale				
High Risk		Neutral		High Benefit

Table 8. Intervention Assessment Criteria

Intervention Assessment Criteria – Ground Floor / Wall Junction			
Assessment Category	Assessment Criteria	Comments	**Scale**
Technical Compatibility	Hygrothermal risks	IWI is high risk – hygrothermal risk assessment required. Material to be vapour permeable	
	Structural risks	Low risk. Floor slab is to remain	
	Corrosion risks	Low risk. Non-corrosive fittings to be used where insulated plaster is installed	
	Salt reaction risks	Low-medium risk of salt penetrating through wall and becoming visible on internal surface	
	Biological risks	Low risk	
	Buildability / Reversibility	IWI is reversible. Floor is retained	
Heritage Significance	Material / constructional impact	Medium risk. Caution when removing cement plaster internally to avoid damage to brickwork	
	Risk of visual impact	Low risk. Minimal visual change externally. Internally building has been altered significantly already	
	Risk of spatial impact	Minimal impact	
Economic Viability	Capital cost		**N/A**
	Economic savings		**N/A**
Energy	Impact on energy demand	Improved energy performance of wall will have a positive impact on the energy demand	
	Life cycle energy demand		**N/A**
Indoor Environmental Quality	Conditions suitable for building	Risk of trapped moisture in fabric if unsuitable material chosen	
	Conditions suitable for occupants	A more comfortable environment will be provided to occupants	
	Emission of harmful substances	Natural materials to be chosen as much as possible	
Impact on Outdoor Environment	Greenhouse Gas Emissions	Preference for natural thermal insulation	
	Emission of harmful substances	Preference for biologically safe materials	
	Natural resources	Preference for natural materials	
Aspects of use	Influence on the use of building	Minimal impact as spaces remain the same	
	Consequence of change of use	N/A	**N/A**
	Ability of users to operate system	Minimal change in how space is operated	

Following the high-level assessment of the intervention, a material selection assessment was carried out. As the wall build-up was retained it was not necessary to carry out a material selection assessment for this area.

Therefore, this was only carried out for the walls. This table compares a variety of different products against the proposed intervention to determine the most suitable material.

Table 9. Material Selection Assessment Criteria

Material Selection Assessment Criteria – Wall					
Assessment Category	Assessment Criteria	Polyisocyanurate Insulation (PIR)	Calcium Silicate Board	Cork Insulated Plaster	Wood Fibre Board
Technical Compatibility	Hygrothermal risks				
	Structural risks				
	Corrosion risks				
	Salt reaction risks				
	Biological risks				
	Buildability				
Heritage Significance	Material / constructional impact				
	Risk of visual impact				
	Risk of spatial impact				
Economic Viability	Capital cost				
	Economic savings				
Energy	Impact on energy demand				
	Life cycle energy demand	N/A	N/A	N/A	N/A
Indoor Environmental Quality	Conditions suitable for building				
	Conditions suitable for occupants				
	Emission of harmful substances				
Impact on Outdoor Environment	Greenhouse Gas Emissions				
	Emission of harmful substances				
	Natural resources				
Aspects of use	Influence on the use of building				
	Consequence of change of use				
	Ability of users to operate system				

Based on the material selection assessment process, the preferred solutions can be identified.

For the walls, it is very clear that PIR insulation is not suitable for IWI due to its vapour closed characteristics, which would increase the hygrothermal risk. As two different methods were to be proposed the two most suitable solutions were identified from the assessment table. The insulated cork plaster has the added benefit of being applied directly to a rough surface (such as exposed brickwork), while the wood fibre board has the lowest Greenhouse Gas Emissions impact.

Table 10. Material Selection Information

Insulation Material Selection Summary			
Location	Ground Floor	Wall – North Rooms	Wall – South Rooms
Type	None	Insulated cork plaster	Wood fibre board
Thickness	N/A	50mm	40mm
Vapour Open	N/A	✓	✓
Thermal Conductivity	N/A	0.037 W/mK	0.039 W/mK

(c) Details – Roof / Wall Junctions

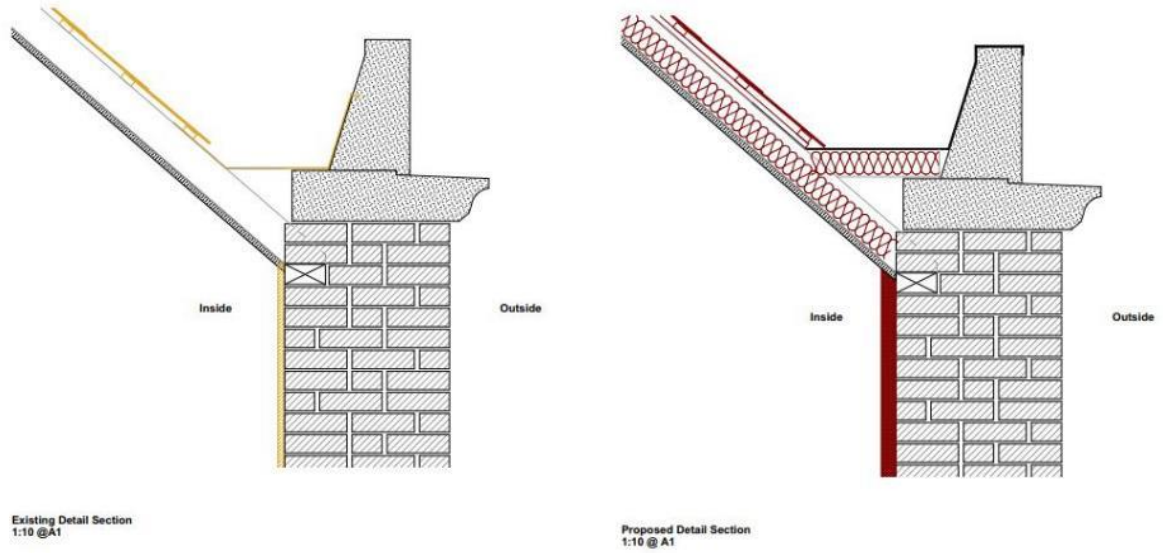

Figure 29. Existing and proposed detail of roof to wall junction. Note: although the roof had already been upgraded, for the purposes of running the energy improvement assessment the existing condition of the roof was taken as uninsulated and the proposed included the recently installed insulation.

This junction is located at roof level, between the external front wall and roof parapet. The existing stone parapet conceals the gutter behind. The existing wall build up consists of solid brickwork with lime mortar, with moulded granite parapet coping surmounted by granite blocking course. The roof is a hipped natural slate roof with plasterboard to the underside of the rafters.

The previous junction analysis in Section 4.2 (b) identified the proposed solution to the walls, a summary of which has been included in the table below.

To insulate at rafter level involved stripping the roof completely while retaining the plasterboard to the underside of the rafters. This was done to maintain the ceiling internally as it had been replaced relatively recently. A vapour control layer was installed wrapping up and across the rafters and over the top of the plasterboard. Wood fibre board was installed between the rafters with a breathable membrane over the top of the rafters. Battens and counter battens were installed over the membrane with natural slates reinstated. All the gutters were replaced with new copper gutters throughout, as well as lead flashing around the chimney stacks.

On the walls, the IWI continued up to abut the insulation within the roof to ensure a continuous line of insulation between the wall and roof.

While it was not possible to alter the roof proposal details, they were however tested as part of both the thermal modelling and WUFI analysis.

Table 11. Fabric Upgrade Summary

Existing Build-up	Insulation	Thickness	Thermal Conductivity	Existing U-value	Part L U-value	Proposed U-value
Roof						
Uninsulated rafters with plasterboard below	*Wood fibre insulation board*	*100mm*	*0.036 W/mK*	4.37 W/m^2K	*0.16 W/m^2K*	*0.33 W/m^2K*
Wall – Rooms to north of stair						
Solid *brickwork walls (circa. 500mm) with lime pointing – cement plaster internally removed*	*Insulated cork and lime plaster directly applied to exposed brickwork*	*50mm*	*0.037 W/mK*	*1.135 W/m^2K*	*0.6 W/m^2K*	*0.43 W/m^2K*
Wall – Rooms to south of stair						
Solid *brickwork walls (circa. 500mm) with lime pointing – cement plaster internally removed*	*Lime plaster levelling coat, wood fibre insulation board, lime plaster finishing coat*	*40mm*	*0.039 W/mK*	*1.135 W/m^2K*	*0.6 W/m^2K*	*0.55 W/m^2K*

An intervention assessment was completed for the junction detail, highlighting any areas of concern that may need to be reviewed or addressed. Where information was not available this has been omitted.

Table 12. Intervention Assessment Criteria

Intervention Assessment Criteria – Roof / Wall Junction			
Assessment Category	Assessment Criteria	Comments	**Scale**
Technical Compatibility	Hygrothermal risks	IWI is high risk – hygrothermal risk assessment required. Material to be vapour permeable	
	Structural risks	Low risk	
	Corrosion risks	Low risk. Non-corrosive fittings to be used where insulated plaster is installed	
	Salt reaction risks	Low-medium risk of salt penetrating through wall and becoming visible on internal surface	
	Biological risks	Low risk	
	Buildability / Reversibility	IWI and roof intervention are reversible	
Heritage Significance	Material / constructional impact	Medium risk. Critical to ensure ventilation to roof rafters	

	Risk of visual impact	Low risk	
	Risk of spatial impact	Minimal impact	
Economic Viability	Capital cost		**N/A**
	Economic savings		**N/A**
Energy	Impact on energy demand	The roof insulation thickness is limited by the depth of the rafters and there is no further scope to increase thickness. Nonetheless the energy performance of the wall and roof area greatly improved	
	Life cycle energy demand		**N/A**
Indoor Environmental Quality	Conditions suitable for building	Risk of trapped moisture in fabric if unsuitable material chosen. Risk of condensation if roof is not ventilated properly	
	Conditions suitable for occupants	A more comfortable environment will be provided to occupants	
	Emission of harmful substances	Natural materials to be chosen as much as possible	
Impact on Outdoor Environment	Greenhouse Gas Emissions	Preference for natural thermal insulation. Wood fibre chosen for the roof insulation	
	Emission of harmful substances	Preference for biologically safe materials	
	Natural resources	Preference for natural materials	
Aspects of use	Influence on the use of building	Minimal impact as spaces remains the same	
	Consequence of change of use		**N/A**
	Ability of users to operate system	Minimal change in how space is operated	

As the wall material has already been assessed and the roof insulation was already installed, it is not necessary to carry out a further Material Selection Assessment Criteria analysis. However, the Intervention Assessment Criteria highlighted the importance of choosing suitable vapour permeable materials.

Table 13. Material Selection Information

Insulation Material Selection Summary			
Location	Roof	Wall – North Rooms	Wall – South Rooms
Type	Wood fibre board	Insulated cork plaster	Wood fibre board
Thickness	100mm	50mm	40mm
Vapour Open	✓	✓	✓
Thermal Conductivity	0.036 W/mK	0.037 W/mK	0.039 W/mK

(d) Details – Window / Door Cill, Head & Reveals

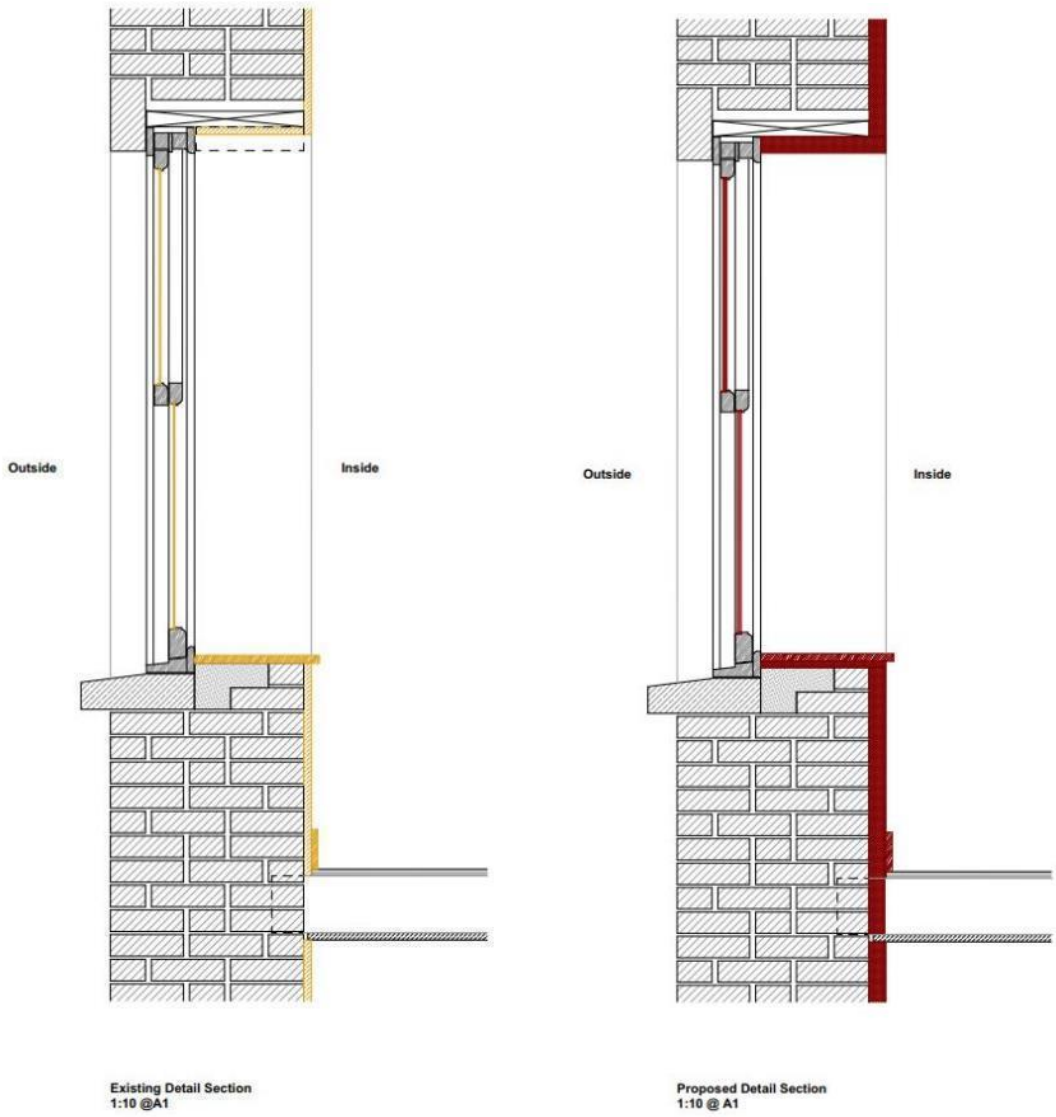

Figure 30. Existing and proposed detail of window cill and head junction

This junction is the typical detail around windows and doors. There is a good degree of consistency throughout the building in how the windows and doors were installed, which were typically installed sitting flush against the back of the outer brick leaf, with the inner reveals splayed brickwork. The window and door heads contain timber lintels with brickwork above. The window cills externally are granite and internally are timber window boards sitting on a combination of brickwork and mortar infill.

As before, the analysis in Section 4.2 (b) identified the proposed solution to the walls. This detail assessed the junction between the wall and the window / door frames to identify any thermal bridging or risk of mould and surface condensation.

New hardwood timber frame windows had been installed with the 1990s works so these only needed to be upgraded with slim double glazing to improve their thermal performance. The front door was not historic and was replaced with a more sympathetic door.

As the internal window and door reveals no longer contained any surrounding joinery, only a cement plaster reveal, the plaster was stripped back to the exposed brickwork. It was therefore possible to continue the thickness of Internal Wall Insulation (IWI) into the reveals and head to abut the window / door frames. A thinner layer of IWI was installed below the reinstated window board. This ensured there were no gaps between the insulation and frame that would promote mould growth or surface condensation. In addition, airtightness tape was applied around the frames and embedded in the IWI build up.

Table 14. Fabric Upgrade Summary

Existing Build-up	Insulation	Thickness	Thermal Conductivity	Existing U-value	Part L U-value	Proposed U-value
Windows						
Single glazing timber sash windows	*New timber sash windows with narrow double glazing*	*12mm (glazing)*	*N/A*	*5.6 W/m^2K*	*1.6 W/m^2K*	*2.7 W/m^2K*
Wall – Rooms to north of stair						
Solid *brickwork walls (circa. 500mm) with lime pointing – cement plaster internally removed*	*Insulated cork and lime plaster directly applied to exposed brickwork*	*50mm*	*0.037 W/mK*	*1.135 W/m^2K*	*0.6 W/m^2K*	*0.43 W/m^2K*
Wall – Rooms to south of stair						
Solid *brickwork walls (circa. 500mm) with lime pointing – cement plaster internally removed*	*Lime plaster levelling coat, wood fibre insulation board, lime plaster finishing coat*	*40mm*	*0.039 W/mK*	*1.135 W/m^2K*	*0.6 W/m^2K*	*0.55 W/m^2K*

An intervention assessment was completed for the junction detail, highlighting any areas of concern that may need to be reviewed or addressed. Where information was not available this has been omitted. It is worth noting that this Intervention Assessment Criteria table is similar to the previous tables due to the repeating IWI application, however, it is important to tailor the assessment to the specific intervention (i.e. the junction between the wall and the frames).

Table 15. Intervention Assessment Criteria

Intervention Assessment Criteria – Window / Wall Junction			
Assessment Category	Assessment Criteria	Comments	**Scale**
Technical Compatibility	Hygrothermal risks	IWI is high risk – hygrothermal risk assessment required. Material to be vapour permeable	
	Structural risks	Low risk	
	Corrosion risks	Low risk. Non-corrosive fittings for fixing windows where insulated plaster is installed	
	Salt reaction risks	Low-medium risk of salt penetrating through wall and becoming visible on internal surface	

	Biological risks	Low risk	
	Buildability / Reversibility	IWI intervention is reversible	
Heritage Significance	Material / constructional impact	Window replacement is a significant intervention	
	Risk of visual impact	Replacement double glazing will have a visual impact externally	
	Risk of spatial impact	Minimal impact	
Economic Viability	Capital cost		**N/A**
	Economic savings		**N/A**
Energy	Impact on energy demand	The replacement windows and wall insulation will have a positive impact on the thermal performance	
	Life cycle energy demand		**N/A**
Indoor Environmental Quality	Conditions suitable for building	Risk of trapped moisture in fabric if unsuitable material chosen.	
	Conditions suitable for occupants	A more comfortable environment will be provided to occupants	
	Emission of harmful substances	Natural materials to be chosen as much as possible	
Impact on Outdoor Environment	Greenhouse Gas Emissions	Preference for natural thermal insulation	
	Emission of harmful substances	Preference for biologically safe materials	
	Natural resources	Preference for natural materials	
Aspects of use	Influence on the use of building	Minimal impact as spaces remains the same	
	Consequence of change of use		**N/A**
	Ability of users to operate system	Minimal change in how space is operated	

As the wall material has already been assessed and the replacement windows was already specified, it is not necessary to carry out a further Material Selection Assessment Criteria analysis. It is worth noting that while the U-value of the new windows is lower than the target value proposed, they are a significant improvement on single glazing. When the overall energy performance of the building was assessed it was achieving a high energy rating, therefore it was not necessary to propose higher performing windows.

Table 16. Material Selection Information

Insulation Material Selection Summary			
Location	Window	Wall – North Rooms	Wall – South Rooms
Type	Narrow cavity double glazing	Insulated cork plaster	Wood fibre board
Thickness	12mm	50mm	40mm
Vapour Open	X	✓	✓
Thermal Conductivity	1.9 W/mK (glazing only)	0.037 W/mK	0.039 W/mK

(e) Details – Intermediate Floor

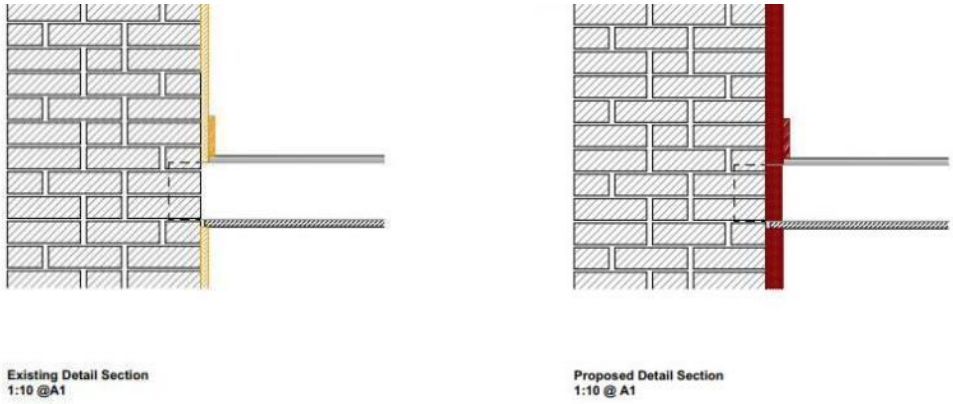

Figure 31. Existing and proposed detail of intermediate floor to wall junction

This detail assesses the penetration of the upper floor joists in the external brickwork wall, with the Internal Wall Insulation (IWI) finished around these joists. The existing timber joists sit within pockets in the external wall. The joists are in good condition with the bearing ends in fair condition. The existing suspended plasterboard ceiling below the joists is removed as part of the wider scope of works. Above the joists are existing timber floorboards.

The junction is assessed to determine the risk of mould growth and surface condensation within the floor joist zone and to assess the risk of installing insulation around the floor joists.

For this detail, the floorboards are lifted along the external wall to access the zone between the floor joists. The floorboards are set aside to be reinstated. A flexible vapour permeable airtightness membrane is painted onto the junction between the wall and the joists. The IWI is then installed around and between the floor joists, with the airtightness membrane embedded within the IWI.

(f) Details – Thermal Modelling & Hygrothermal Risk Analysis

(i) Thermal Modelling

The key junctions identified above were tested using thermal modelling software, Psi-Therm 2D. This assesses the existing and proposed details to determine the risk of mould growth and surface condensation by calculating the surface temperature factor (fRsi-value). This is used to assess whether there is a greater or lesser risk with the proposed detail. It also calculates the linear thermal bridge (Psi-value) for each junction, which provides a more accurate input into the NEAP model.

The surface temperature factor (fRsi-value) range for the existing building is between 0.34 – 0.77. For reference the critical fRsi-value in TGD Part L for offices is 0.5. The higher the fRsi-value the better the thermal insulation in this area and the lower the risk of mould growth and surface condensation. The fRsi-value range for the proposed interventions is between 0.66 – 0.9. The lowest value in the proposed interventions is the junction between the roof and wall, where the roof intervention had already been determined. Excluding this junction, all other junctions achieved between 0.8 – 0.9 fRsi-value.

The linear thermal bridge (Psi-value) is also calculated using the thermal modelling software. The Psi-value calculates how much heat loss occurs at a particular junction (e.g. between the wall and window frame). The Psi-value is an important value for inputting into the NEAP model as it provides a more accurate result, however, comparing the existing and proposed Psi-values can be misleading.

The proposed Psi-values for Block M appear worse than the existing Psi-values. This may seem like the proposed interventions are not preforming as well as the existing, however, this is due to the improved thermal performance of the adjacent surface (e.g. wall, roof, floor). Since the adjacent surface is much better insulated in the proposals, the ratio of heat loss through the junctions is therefore greater than in the existing condition, where a greater proportion of the heat loss escapes through the adjacent surface.

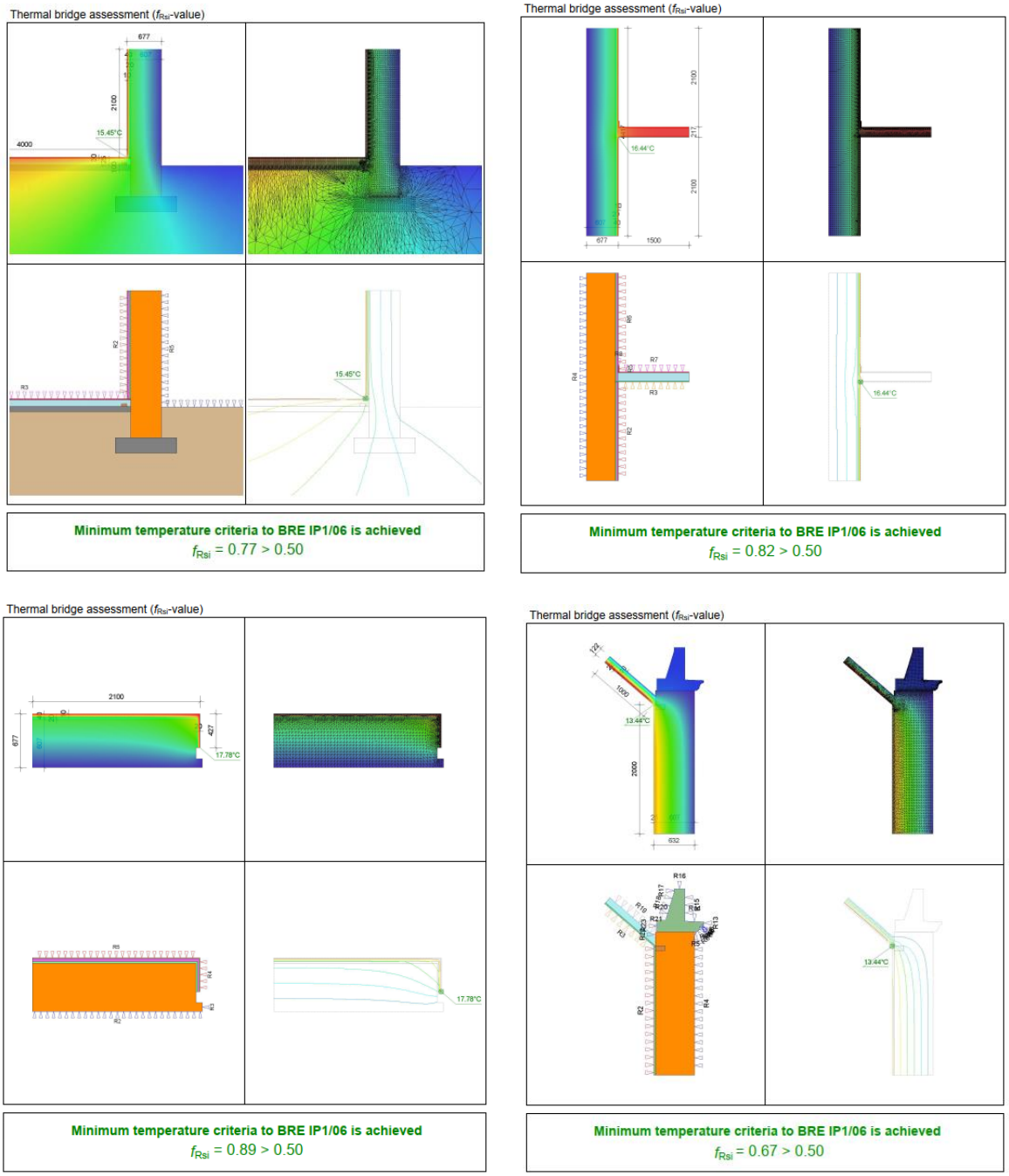

Figure 32. Images of thermal modelling carried out on various junction details as described above. Note: the images show the results of the proposals and calculates the fRsi value. A separate thermal modelling was carried out to calculate the proposed psi-value

(ii) Hygrothermal Risk Analysis

A hygrothermal analysis was also carried out to determine the risk associated with the Internal Wall Insulation. The analyses were carried out in accordance with ISO 15026 using validated software WUFI as developed by the Fraunhofer Institut, Germany. The results from the Karsten tube testing are required to feed into the WUFI analysis to provide an accurate absorption rate for the existing brick wall.

Hygrothermal Risk Assessment was carried out on the walls to investigate the potential to install insulated plaster as well as the wood fibre insulation using WUFI in accordance with ISO 15026 and Fraunhofer guidance on handling of typical constructions of solid wall with internal insulation systems. Hygrothermal risk assessments are simulations and are not in any way a guarantee of actual in-situ performance. They offer the user an assessment of which designs pose a higher or lower risk than others and can be used to stress test a design with variations in a number of parameters such as orientation, insulation thickness, exposure, building height and location, uses of membranes and their specifications, among a wide number of other input factors.

Solid walls with absorptive outer surfaces, e.g. uncoated brick, present a number of key points of interest when considering whether to apply internal insulation. Firstly, it is important to check the relative humidity at the interface of the new internal wall insulation and original substrate. This should remain below 95% in order to prevent risk of freezing occurring in winter at this interface. Although more likely in colder climates, this is possible in the Irish climate also and must be considered. Secondly, overall water content in the wall must be shown to reduce following initial commencements of the analysis and reach equilibrium, repeating a cycle over the following years. Thirdly, the relative humidity close to the brick outer surface (e.g. 10mm from the outer face) should be considered also, to ensure that application of internal insulation doesn't increase the risk of freeze/thaw cycling effects in winter near the outer brick facing. Separately, no annual increase in moisture content of any material should be observed.

Figure 33 below shows the relative humidity and temperature at the interface of the internal wall insulation and original brick substrate. As shown and expected, temperatures at the interface are coldest in winter, which results in an increase in relative humidity at this point. However, relative humidity remains below 76% in the worst case, and therefore no risk of freezing or condensation is predicted in this case. In addition, temperatures at the interface do not drop below 11°C, and therefore freezing would not be possible.

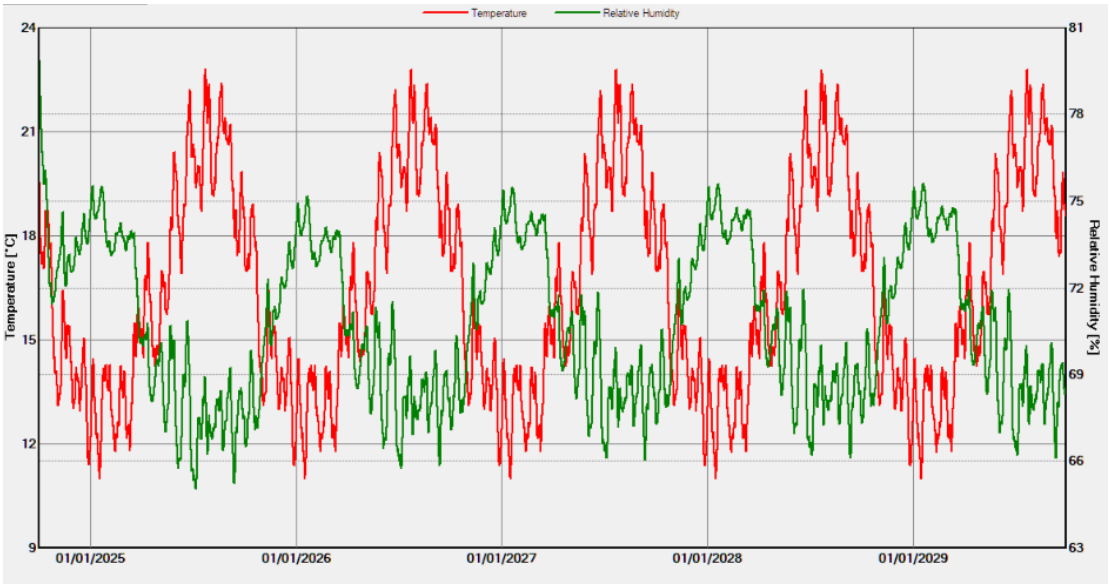

Figure 33: Relative humidity at the wood fibre / brick wall interface

The moisture content of the wood fibre insulation is shown in Figure 34 below. As shown, it is stable between 9-10.5% moisture by mass.

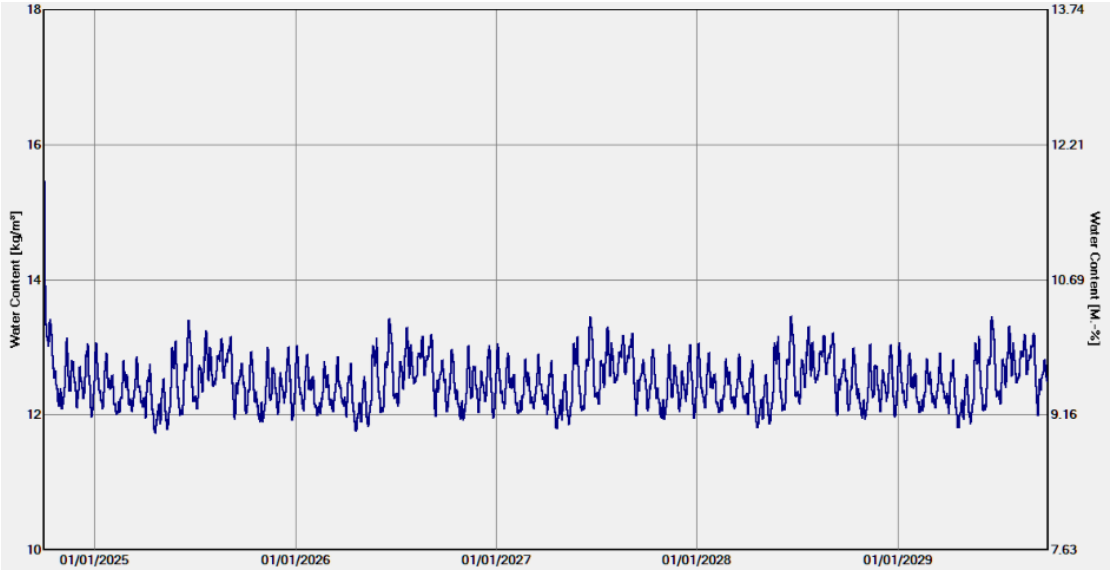

Figure 34: Moisture content of wood fibre board

Figure 35 below shows the total water content of the wall with insulating cork-lime plaster. In this case, the initial relative humidity of all material layers is set to 80%. The total water content increases slightly after the initial year of assessment before reaching equilibrium. This indicates that the equilibrium moisture content of the total wall structure is slightly higher than that assumed with an 80% relative humidity across all materials at their outset. However, there are no critical moisture levels noted at any crucial interface or within any material layer, and therefore the slight initial increase in total water content in the first year of assessment prior to equilibrium being reached is not of concern in this case.

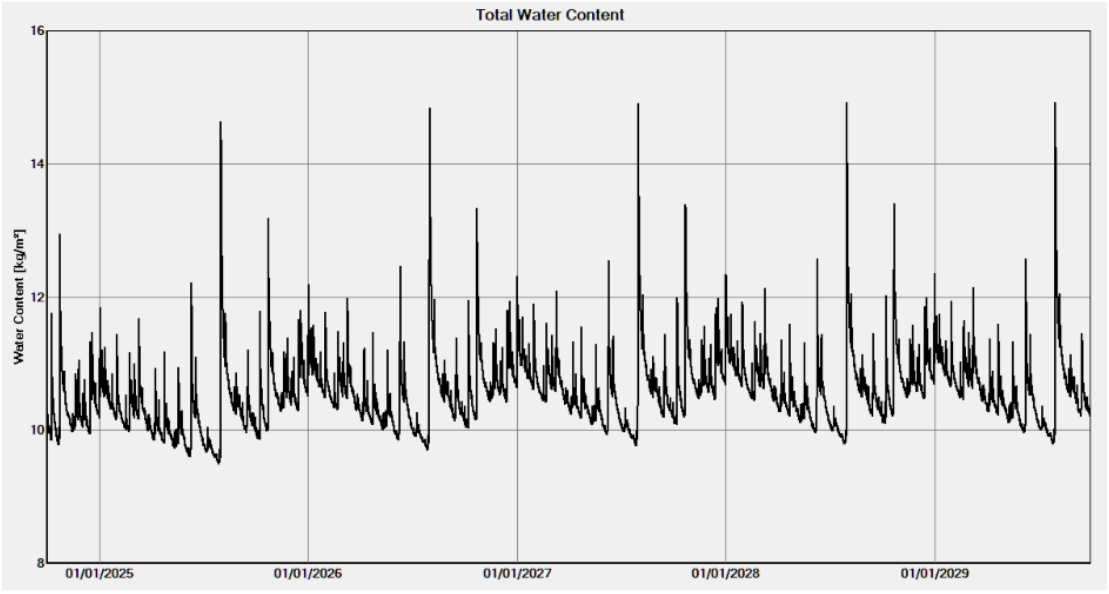

Figure 35: Total water content - insulating cork-lime plaster on brick wall

The total water content graph of the wood fibre insulated wall mimics the behaviour of the cork-lime insulated wall very closely, albeit with slighter lower total water content being observed in the wood fibre-insulated wall.

(g) Details – Airtightness Strategy

The existing building was not tested for airtightness levels prior to work commencing on the structure. Therefore, for the existing airtightness level the default level, as per NEAP, of an air permeability of 25m^3/(h.m^2) was assumed.

The overarching airtightness strategy involves creating a continuous airtightness barrier of the building envelope while maintaining the building vapour permeability. The airtightness barrier is designed into the building envelope, with the detailing around key junctions vital. The target level of airtightness for Block M is an air permeability of 5m^3/(h.m^2)

The key interventions to achieve the required airtightness level include:

- Applying wet plaster/insulated plaster to existing solid masonry walls, including hidden areas such as between floor joists bearing on external walls;
- Airtightness membranes to floors are taped to external walls;
- Applying vapour permeable airtightness membrane to ends of floor joists;
- Applying airtightness tape between windows, doors and adjoining walls and integrating in IWI system;
- New windows and doors to include draught-proofing seals; and
- Sealing around services passing through the external building fabric, i.e. walls, floors and ceilings.

An air pressurisation test is due to be carried out as part of the post-occupancy monitoring works. While this would typically be carried out prior to the completion of the works, this was not possible due to programme constraints. Results will be published as an addendum to this case study once the testing is complete.

(h) Building Fabric Summary

Below is a summary of the overall building fabric upgrade strategy with existing, Part L and proposed U-values.

Table 17. Summary of finalised fabric upgrade details

Existing Build-up	Insulation	Thickness	Thermal Conductivity	Existing U-value	Part L U-value	Proposed U-value
Roof						
Uninsulated rafters with plasterboard below	*Wood fibre insulation board*	*100mm*	*0.036 W/mK*	4.37 W/m^{2}K	*0.16 W/m^{2}K*	*0.33 W/m^{2}K*
Wall						
Solid *brickwork walls (circa. 500mm) with lime pointing – cement plaster internally removed*	*Insulated cork and lime plaster directly applied to exposed brickwork*	*50mm*	*0.037 W/mK*	*1.135 W/m^{2}K*	*0.6 W/m^{2}K*	*0.43 W/m^{2}K*
Solid *brickwork walls (circa. 500mm) with lime pointing – cement plaster internally removed*	*Lime plaster levelling coat, wood fibre insulation board, lime*	*40mm*	*0.039 W/mK*	*1.135 W/m^{2}K*	*0.6 W/m^{2}K*	*0.55 W/m^{2}K*

	plaster finishing coat					
Ground Floor						
Uninsulated concrete slab with timber joists / counter joists and plywood above to rooms either side of central stairs. Uninsulated concrete slab to central stair	*None*	*N/A*	*N/A*	*0.46 W/m²K*	*N/A*	*0.46 W/m²K*
Windows						
Single glazing timber sash windows	*New timber sash windows with narrow double glazing*	*12mm (glazing)*	*N/A*	*5.6 W/m²K*	*1.6 W/m²K*	*2.7 W/m²K*
Doors						
Solid timber doors	*N/A*	*N/A*	*N/A*	*3.0 W/m²K*	*3.0 W/m²K*	*3.0 W/m²K*

4.3 Overall Services Improvement Plan

(a) Individual Service Upgrade Details

The services strategy was developed in conjunction with the OPW M&E Engineers. The OPW M&E Engineers were the main design lead on the strategies, with the energy consultants providing advice in relation to the energy performance as necessary. The constrained location of the building and the lack of external lands made it particularly difficult for positioning plant externally. In addition, the existing heating system was interconnected with other properties along Great Ship Street. While this makes it difficult to separate out Block M from the other properties, in the future it could be beneficial if a district heating system were employed for the wider Dublin Castle site. A light touch ventilation system approach was adopted to minimise the impact on the existing building.

A summary of the services strategies is identified below. These are developed in more detail further on. While all the strategies are explored in more detail, the lighting and domestic hot water are more straightforward, therefore a brief overview only is provided for these.

Table 18. Overall Services Strategy

Existing System	Intervention	Location	Heritage Impact	Technical Assessment
Space Heating				
Gas-fired boiler interconnected with adjacent properties along Great Ship Street	*There is no external space suitable for locating a heat pump and district heating is currently not available. Existing gas-fired boiler*	*Throughout*	*Fossil fuel heating is no longer an acceptable solution based on Government policy so less carbon intensive alternatives need to be sought. District heating may be an option in the future where wider area-based works are undertaken. Hydrogenated Vegetable Oil*	*Where existing gas-fired boilers are the only option, consideration should be given to use of bio-methane mix in the gas supply. The existing heating output (i.e. radiators) can be reused with the new boiler.*

	system to be retained		*(HVO) or Biomethane should be considered where heat-pumps are not possible.*	
Ventilation				
No dedicated ventilation system. Ventilation provided through excessive draughty fabric, chimney flues and windows	*Natural ventilation via openable windows and chimney flues*	*Throughout*	*Minimal heritage impact on building. Natural ventilation avoids requirement for numerous holes in external walls or ductwork routes internally*	*Indoor air quality to be monitored to ensure adequate ventilation is being provided. IEQ / IAQ CO_2 levels need to be maintained below limits (1000ppm) defined by the HSA in their recently published Code of Practice for IAQ*
Water Heating				
Gas-fired boiler interconnected with adjacent properties along Great Ship Street	*Existing gas-fired boiler system to be retained*	*Throughout*	*Retaining the existing hot water heating system will have minimal heritage impact on the building*	*This is relatively straightforward to provide for*
Lighting				
Incandescent	*LED*	*Throughout*	*Internally little historic fabric remains, including no historic light fittings. High-quality contemporary lighting could be provided that compliments the existing fabric*	

(b) Details – Space Heating

The existing space heating system in Block M uses an off-site gas-fired boiler with modern aluminium radiators. This boiler is interconnected and serves other adjacent properties along Great Ship Street. The existing site is constrained. There is no external space associated with Block M where it would be suitable to house external plant. The roof is also a simple hipped roof visible from various points around Dublin Castle, which would also not be suitable to house plant. Therefore, locating an external plant, such as a heat-pump, would not be achievable as it would have a major impact on the building setting.

In the future there may be a wider Dublin Castle heating system where Block M could be incorporated into a district heating system, however, as something like this is not available yet, the only viable solution is to retain the existing boiler system. This has the added benefit of retaining the existing system and reuse any existing infrastructure that is not redundant.

In terms of the heating output system, the options of underfloor heating or radiators were explored, however, as underfloor heating is more suitable to lower output temperatures and would involve more significant intervention in the floors, radiators were deemed more suitable. Anodised steel radiators in keeping with the style of the building were installed.

Table 19. Services Upgrade Summary

Intervention	**Existing Delivered Energy Use*** (kWh/m²)	**Existing Primary Energy Use*** (kWh/m²) *[1](used for BER)*	**Existing CO_{2eq} Emissions**** (kgs/m2)	**Target Delivered Energy Use*** (kWh/m²)	**Target Primary Energy Use*** (kWh/m²) *[1](used for BER)*	**Target CO_{2eq} Emissions**** (kgs/m2)
Existing gas-fired boiler system to be retained	*252.15*	*277.37*	*56.86*	*72.1*	*79.31*	*16.26*

** Primary energy usage of the building = Delivered electrical energy x Primary Energy Factor (PEF)*
Natural Gas PEF = 1.1 and for grid electricity PEF = 1.9.
*** CO_2 emissions from delivered energy = Delivered energy x CO_2 factor*
[1]Used in NEAP for BER.

An intervention selection assessment was carried out to assess the heating output source. While the assessment table used is the same as the building fabric interventions, and is based on the IS EN 16883 standard and the OWP general guidance document, some of the criteria are not relevant to the services systems and were therefore marked as N/A.

Table 20. Intervention Selection Assessment Criteria – Space Heating

Intervention Assessment Criteria – Heating Output				
Assessment Category	Assessment Criteria	Cast Iron Radiators	Aluminium Radiators	Underfloor Heating
Technical Compatibility	Hygrothermal risks	N/A	N/A	N/A
	Structural risks			
	Corrosion risks	N/A	N/A	N/A
	Salt reaction risks	N/A	N/A	N/A
	Biological risks	N/A	N/A	N/A
	Buildability			
Heritage Significance	Material / constructional impact			
	Risk of visual impact			
	Risk of spatial impact			
Economic Viability	Capital cost	N/A	N/A	N/A
	Economic savings	N/A	N/A	N/A
Energy	Impact on energy demand			
	Life cycle energy demand	N/A	N/A	N/A
Indoor Environmental Quality	Conditions suitable for building			
	Conditions suitable for occupants			
	Emission of harmful substances	N/A	N/A	N/A
Impact on Outdoor Environment	Greenhouse Gas Emissions	N/A	N/A	N/A
	Emission of harmful substances	N/A	N/A	N/A
	Natural resources	N/A	N/A	N/A
Aspects of use	Influence on the use of building			
	Consequence of change of use	N/A	N/A	N/A

	Ability of users to operate system			

(c) Details – Water Heating

The existing domestic hot water system in Block M is fed by the off-site gas-fired boiler. As with the space heating, the existing hot water heating system is to be retained. Further improvements are to be sought with improved boiler efficiency. Consideration should be given to adopting direct electric under-sink heating of hot water for washing to switch away from fossil fuel fired heating systems. At the very least, this would enable shut-down of the gas fired boiler during the warmer months of the year.

Table 21. Services Upgrade Summary

Intervention	**Existing Delivered Energy Use*** (kWh/m^2)	**Existing Primary Energy Use*** (kWh/m^2) *[1](used for BER)*	**Existing CO_{2eq} Emissions**** (kgs/m2)	**Target Delivered Energy Use*** (kWh/m^2)	**Target Primary Energy Use*** (kWh/m^2) *[1](used for BER)*	**Target CO_{2eq} Emissions**** (kgs/m2)
Existing gas-fired boiler system to be retained	*2.98*	*3.27*	*0.67*	*2.19*	*2.41*	*0.49*

** Primary energy usage of the building = Delivered electrical energy x Primary Energy Factor (PEF)*
Natural Gas PEF = 1.1 and for grid electricity PEF = 1.9.
*** CO_2 emissions from delivered energy = Delivered energy x CO_2 factor*
[1]Used in NEAP for BER.

(d) Details – Ventilation

Prior to retrofit, ventilation to the existing structure was provided through the naturally occurring permeability of the building fabric, as well as the open chimney flues, and manually openable up and down sash windows.

The airtightness of the building was improved as follows:

1. New replacement windows and doors include draught-proofing, with a greater level of airtightness detailing employed throughout the building to make the building fabric more airtight;
2. Internal lining and plaster of wall; and
3. Roof upgrade (membranes).

Improving airtightness reduces air infiltration which can reduce the indoor air quality of the building below acceptable levels.

A hybrid managed ventilation system has been adopted by the OPW M&E Engineers to meet ventilation requirements.

The existing chimney flues are used as a natural ventilation stack, with indoor air quality monitors provided to identify when additional ventilation is required. If required, the occupants of the room are alerted to open the windows. The improvements noted below are from an improved baseline, where the 'existing' Primary Energy Use pertains to an already improved building's thermal performance.

Table 22. Services Upgrade Summary

Intervention	**Existing Delivered Energy Use*** (kWh/m^2)	**Existing Primary Energy Use*** (kWh/m^2) *[1](used for BER)*	**Existing CO_{2eq} Emissions**** (kgs/m2)	**Target Delivered Energy Use*** (kWh/m^2)	**Target Primary Energy Use*** (kWh/m^2) *[1](used for BER)*	**Target CO_{2eq} Emissions**** (kgs/m2)
Hybrid managed ventilation solution via chimney flues and openable windows	*2.12*	*4.02*	*0.51*	*2.12*	*4.02*	*0.51*

** Primary energy usage of the building = Delivered electrical energy x Primary Energy Factor (PEF)*
Natural Gas PEF = 1.1 and for grid electricity PEF = 1.9.
*** CO_2 emissions from delivered energy = Delivered energy x CO_2 factor*
[1]Used in NEAP for BER.

An intervention selection assessment was carried out on the ventilation strategies. As before, the assessment table used is the same as the building fabric interventions and is based on the IS EN 16883 standard and the OWP general guidance document, some of the criteria are not relevant to the services systems and were therefore marked as N/A.

Table 23. Intervention Selection Assessment Criteria – Space Heating

Intervention Assessment Criteria – Ventilation				
Assessment Category	Assessment Criteria	Natural ventilation	Mechanical ventilation	Hybrid managed ventilation
Technical Compatibility	Hygrothermal risks	N/A	N/A	N/A
	Structural risks			
	Corrosion risks	N/A	N/A	N/A
	Salt reaction risks	N/A	N/A	N/A
	Biological risks	N/A	N/A	N/A
	Buildability			
Heritage Significance	Material / constructional impact			
	Risk of visual impact			
	Risk of spatial impact			
Economic Viability	Capital cost	N/A	N/A	N/A
	Economic savings	N/A	N/A	N/A
Energy	Impact on energy demand			
	Life cycle energy demand	N/A	N/A	N/A
Indoor Environmental Quality	Conditions suitable for building			
	Conditions suitable for occupants			
	Emission of harmful substances	N/A	N/A	N/A
Impact on	Greenhouse Gas Emissions	N/A	N/A	N/A

Outdoor Environment	Emission of harmful substances	N/A	N/A	N/A
	Natural resources	N/A	N/A	N/A
Aspects of use	Influence on the use of building			
	Consequence of change of use	N/A	N/A	N/A
	Ability of users to operate system			

(e) Details – Lighting

The existing lighting in Block M was incandescent bulbs throughout. All the existing fittings, wiring, etc. were modern installations, with nothing of historic significance. All lighting is changed to LED throughout. As the internal finishes are new throughout, it is possible to install contemporary light fittings that complement the spaces. This would have minimal impact on the building.

Table 24. Services Upgrade Summary

Intervention	**Existing Delivered Energy Use*** (kWh/m^2)	**Existing Primary Energy Use*** (kWh/m^2) *[1](used for BER)*	**Existing CO_{2eq} Emissions**** (kgs/m2)	**Target Delivered Energy Use*** (kWh/m^2)	**Target Primary Energy Use*** (kWh/m^2) *[1](used for BER)*	**Target CO_{2eq} Emissions**** (kgs/m2)
Lighting changed to LED throughout	*56.02*	*106.44*	*13.45*	*12.31*	*23.39*	*2.95*

** Primary energy usage of the building = Delivered electrical energy x Primary Energy Factor (PEF)*
Natural Gas PEF = 1.1 and for grid electricity PEF = 1.9.
*** CO_2 emissions from delivered energy = Delivered energy x CO_2 factor*
[1]Used in NEAP for BER.

(f) Services Summary

Below is a summary of the overall services upgrade strategy with existing and target energy and CO_2 performance.

Table 25. Services Upgrade Summary

Intervention	**Existing Delivered Energy Use** (kWh/m^2)	**Existing Primary Energy Use*** (kWh/m^2)	**Existing CO_{2eq} Emissions**** (kgs/m2)	**Target Delivered Energy Use** (kWh/m^2)	**Target Primary Energy Use*** (kWh/m^2)	**Target CO_{2eq} Emissions**** (kgs/m2)
Heating	*252.15*	*277.37*	*56.86*	*72.1*	*79.31*	*16.26*
DHW	*2.98*	*3.27*	*0.67*	*2.19*	*2.41*	*0.49*
Ventilation	*2.12*	*4.02*	*0.51*	*2.12*	*4.02*	*0.51*
Lighting	*56.02*	*106.44*	*13.45*	*12.31*	*23.39*	*2.95*
Total	***313.27***	***391.1***	***71.49***	***88.72***	***109.13***	***20.21***

Delivered energy is the energy used in a building. Primary energy is the energy at source
** Primary energy usage of the building = Delivered electrical energy x Primary Energy Factor (PEF)*
Natural Gas PEF = 1.1 and for grid electricity PEF = 1.9.
*** CO_2 emissions from delivered energy = Delivered energy x CO_2 factor*
[1]Used in NEAP for BER

4.4 NEAP Analysis of Proposed Upgrades

Throughout the development of the building fabric and services strategies the proposals were assessed in an IES model to determine the BER and Primary Energy rating, to inform the various approaches. This was an ongoing process with the results part of the strategy development stage.

Alongside this ongoing process of assessment, a sequence of improvements was developed to identify how each intervention impacts on the BER and Primary Energy rating. It is worth noting that this is, in some ways, an academic exercise since such interventions would not practically be carried out on their own and are often interlinked with other interventions. However, it is a useful exercise as it can identify which interventions have the greater / lesser impact. In this way if changes are required to certain strategies (e.g. to improve the BER rating or to review challenging interventions) they could be more focused. The sequence of improvements identified for Block M are as follows in Table 26 and Table 27.

The first table (Table 26) below is based on default values while the second table (Table 27) is based on the measured / calculated values where available.

This is partially informed by the works already carried out at the commencement of the case study.

Table 26. Sequenced Energy Renovation NEAP Model based on default values

Seq No.	NEAP Model - Key input criteria	BER (indicator)	Primary Energy (kWh/m2)
1	Existing Baseline Model - Using Default Values	E2 (2.50)	460.71
2	Roof upgraded (incl. Psi-value) and air permeability improved to 20 $m^3/(h.m^2)$	E2 (2.27)	419.84
3	Windows / doors upgraded (incl. Psi-value) and air permeability improved to 15 $m^3/(h.m^2)$	E1 (2.00)	368.82
4	Walls upgraded (incl. Psi-value) and air permeability improved to 5 $m^3/(h.m^2)$	D1 (1.60)	295
5	Lighting upgraded from existing incandescent bulbs to LED	B3 (0.90)	167.32
6	Heating system upgraded to high-efficiency boiler and DHW supplied by Instantaneous Water Heaters	B2 (0.69)	127.82

Table 27. Sequenced Energy Renovation NEAP Model based on measured / calculated values

Seq No.	NEAP Model - Key input criteria	BER (indicator)	Primary Energy (kWh/m2)
1	Existing Baseline Model - Using Measured Values	E1 (2.18)	401.57
2	Roof upgraded (incl. Psi-value) and air permeability improved to 20 $m^3/(h.m^2)$	D2 (1.78)	329.34
3	Windows / doors upgraded (incl. Psi-value) and air permeability improved to 15 $m^3/(h.m^2)$	C3 (1.42)	262.39
4	Walls upgraded (incl. Psi-value) and air permeability improved to 5 $m^3/(h.m^2)$	C1 (1.03)	190.36
5	Lighting upgraded from existing incandescent bulbs to LED	B2 (0.76)	141.18

6	Heating system upgraded to high-efficiency boiler and DHW supplied by Instantaneous Water Heaters	B1 (0.61)	111.73

In terms of cost optimal as per TGD Part L, a BER of B2 aligns with cost optimal level upper limit when the 15% allowed as a buffer is included.

The following is a summary of the final proposed intervention values. As with the baseline energy model, two proposed energy models are calculated, one using default values and one using measured / calculated values. Since SEAI currently do not accept measured in-situ values, the default value calculation would be the official published BER.

Table 28. Proposed Energy Model

Building Element	**Description**	**Proposed Model Default Value**	**Proposed Model Measured / Calculated Value**
Walls	*IWI applied to solid brickwork walls with lime pointing*	*0.5 W/m²K*	*0.43 W/m²K & 0.55 W/m²K[2]*
Floors	*Insulation and concrete screed over retained concrete slab with floor finish above*	*1.62 W/m²K*	*0.46 W/m²K*
Roof	*Insulation between rafters with plasterboard ceiling retained below*	*0.33 W/m²K*	*0.33 W/m²K*
Glazing	*double glazing timber sash windows*	*2.70 W/m²K*	*2.70 W/m²K*
Airtightness	*Airtightness measures implemented*	*5 m³/(h.m²)[1]*	*5 m³/(h.m²)*
Thermal Bridge: *Surface temperature factor (fRsi) range*	*low thermal bridging*	*N/A*	*0.66 – 0.9*
BER ***Primary Energy***		***B2*** ***124.05 kWh/m²***	***B1*** ***111.73 kWh/m²***
Primary Energy Ratios	*Heating*	*75.71 %*	*70.98 %*
	Lighting	*17.36 %*	*22.92%*
	Auxiliary	*2.84%*	*3.94 %*
	DHW	*4.09 %*	*2.16 %*

Black – default values; Red – measured values; Blue – calculated values

The final model identified the proposal resulting in a BER rating of B1 and a Primary Energy rating of 111.73 kWh/m2. The breakdown of Primary Energy was Heating 70.98%, Lighting 22.92%, Auxiliary 3.94% & DHW 2.16%.

As noted in the OPW Guidance, the use of measured in-situ values are not acceptable in published BERs. Therefore, a separate published BER may be required to be produced which may have a different rating to the actual BER and Primary Energy rating above.

[2] The two U-values here correspond with the two types of internal wall insulation as specified in Table 6 in section 4.2(b).

5

Implementation & Post Occupancy

Stage 5. Implementation, Post-Occupancy Evaluation and Monitoring

5.1 Implementation

The proposed energy improvement works were carried out as part of the wider scope of works. This was inspected throughout the process by both the OPW architects and the energy consultant team. The works were completed by December 2023.

General access for works – As there was only one central access stairs, works typically were carried out from the top down.

Removal of sand cement – The remains of sand cement plaster on the internal face of external perimeter walls had to be removed prior to the installation of vapour open internal wall insulation. This was done in sections and a methodology agreed in advance.

Application of the insulating lime plaster – Metal depth gauges were fitted to the walls to ensure the minimum thickness was achieved in all areas. Depth gauges were then removed and backfilled with insulating plaster. A spray on application with an electric machine was used, which had to be dismantled and reassembled to get it up through the building.



Figure 36. Images of insulated plaster being applied to wall. Note: light gauge steel posts inserted into wall plaster as a guide are removed prior to applying final coat.

Application of wood fibre insulation – As the wall was uneven, it was first finished with a levelling coat of lime plaster. The wood fibre insulation was installed over this with a lime plaster finish.



Figure 37. Images of wood fibre board being applied to wall. Note: levelling coat of lime plaster applied to exposed brickwork walls prior to application of wood fibre boards.

Works at sash windows - As space was limited at sash boxes and to reduce thermal bridging a thin application of spray-on insulating lime plaster was used (e.g. +/- 10mm). This thin application didn't impact the operation of the sash weights / cords. A detail was established to close off any gaps between the window frame and brick wall using an expansion tape and was then covered over with a compatible airtightness tape. This approach allowed the insulation be applied up to the window frame around the reveals. All windows were modern sash replacements of teak / iroko from the 1990s refurbishment works and there was no existing shutter boxes or liners which made this approach easier.





Figure 38. External and internal images after works completed to Block M

Services – To take the building up to a modern office standard multiple services had to be installed. The ceiling void was used for horizontal routes and services rose up through the building using dedicated riser rooms which were constructed at each landing level on the stairs.

5.2 Airtightness

An air pressurisation test creates a pressure differential that allows the amount of air leakage through the building envelope to be quantified. This test should be carried out in conjunction with a smoke test to identify if, and where, significant air leakage is occurring.

An air pressurisation test is to be carried out to confirm the airtightness level of the building following the energy upgrades. While it would be preferable to carry out this test prior to the completion of the works on site to allow for any areas of excessive air leakage identified to be address, a post-completion test would nonetheless provide guidance for future projects and will be a useful comparison against the assumed airtightness level included as part of the design assessment. Due to programme constraints it was not possible to complete this prior to handover.

5.3 Indoor Air Quality

The rate of air exchange within a building is an important factor in the accumulation of many indoor pollutants. Most traditional buildings were passively ventilated. The upgrade work will improve the airtightness of the building and will therefore reduce the natural ventilation of the building. It is important to distinguish between ventilation (controlled) and infiltration (uncontrolled). Reducing the amount of ventilation or infiltration in traditional buildings through modification or renovation can potentially have an impact on the ability of the building to deal with indoor pollutants and moisture, needing careful consideration. Maintaining adequate ventilation in traditional buildings is important to disperse and remove internal pollutants and moisture. Ventilation should be specifically designed to remove moisture and pollutants from the internal environment. There is no standard approach to ventilation, each space in a building needs to be considered individually dependent on influencing factors such occupancy patterns and use.

The use of Indoor Air Quality (IAQ) sensor technology empowers occupants to take an active control in the opening of windows for natural ventilation. The use of chimneys for natural ventilation should not be overlooked and controllable flaps in the throat of the chimney can improve air quality substantially through retention of heat in winter and availing of increased natural ventilation (and cooling) in summer.

Using IAQ sensor technology with data shown on a liquid crystal display (LCD), will inform occupants as to when it is necessary to open windows and chimney flaps to increase natural ventilation (albeit for short periods of time in cold or inclement weather).

Monitoring of indoor temperature, relative humidity and CO_2 levels provides the occupants with information needed to respond to changes in the indoor environment.

5.4 Energy Use Intensity

Energy Use Intensity (EUI) is the delivered energy consumption per m2 that is required by the building over the course of a year. When assessing energy used by a building one needs to be careful in comparing this to that predicted by the Building Energy Rating certificate. There will always be key differences between the two. The BER certificate does not include for 'plug' loads, i.e. all equipment connected to the general-purpose plug outlets, server rooms and power for data management systems, and catering functions. Also, the BER assessment is based on a standard set of operational hours, typically 10 hours a day, 5 days a week. Any deviations from the assumed hours of operation in the BER assessment will lead to differences in the energy used versus the predicted energy use.

The energy use for Block M on Great Ship Street can be monitored be compiling the energy bills for the building in use and comparing this against the designed values. This would be most useful after a full year of occupancy to calculate a full season cycle.

5.5 Interstitial Moisture Monitoring

A process of post-occupancy monitoring is ongoing in Block M. From the early stages of the project, real-time interstitial moisture monitoring of the IWI was a key aspect of the energy renovation works and provides the greatest potential for learnings from Block M. This in-situ monitoring provides long-term data on how the wall interventions are performing and can be compared against the designed and manufacturer's data. The sensors were installed in December 2023 with monitoring ongoing.

Interstitial moisture monitoring is used to determine the rate at which the fabric dries out post-construction, as well as to monitor moisture levels at points of interest in the façade over time post-occupancy. At the time of writing this study is ongoing and therefore results are not presented in full here. In Block M the moisture monitoring was installed in December 2023. The analysis is carried out by inserting relative humidity probes into the wall at specific depths to arrive at a point of interest. In this case, the probes were installed to monitor relative humidity at the interface of the newly installed internal insulation system (i.e. wood fibre board insulation and insulated cork plaster) and the original substrate (i.e. brickwork wall). While the results from the monitoring are required to be validated against the designed values, the initial data suggests the interventions to the walls are performing broadly in line with the design assumptions.

Site-installations of monitoring equipment is always a challenging task in reality due to a number of constraints which can be common to most buildings or unique to any given situation. In this case, the exact thickness of levelling lime plaster varied across the façade, as did therefore the thickness of the insulated cork plaster applied. It is therefore difficult to gauge whether the probe is located exactly at the point of interest or very nearby. This must be considered where assessing any results. Similarly, although for the wood fibre the thickness was known, the thickness of the levelling lime plaster was not, and therefore comparison of the in-situ monitored values with values presented in a hygrothermal risk assessment should be treated with caution.

Other factors will also influence differences between hygrothermal risk assessment results and measured in-situ values, such as limited knowledge of material properties during hygrothermal assessment, actual weather on-site vs. a generated climate data file, user behaviour, heating and moisture production within the building, ventilation, orientation and solar gains on the façade, amongst others.

As a validation exercise to determine whether hygrothermal risk assessment provides a reliable assessment of moisture risk in a real-world scenario, it is hoped that while the comparable values of relative humidity may not match each other, that the general observed trends in moisture balance across the wall are in alignment.

Due to the equipment costs and challenges in installing such equipment, as well as the knowledge required to carry out accurate data validation and comparison of the measured versus calculated values, this is not a monitoring procedure that would be recommended on all building projects, but rather in situations where perhaps new methods are being employed, or a new material is being used for which not a lot of information is currently available.

Ideally, this monitoring would take place over a period of at least one year, with two-to-three years providing a more robust data set against which comparisons can be drawn, and under which the drying-out period should be complete. The continuous monitoring can then be used to ensure critical moisture levels are not reached, and examine the effects of severe weather events, be that excessive rain or indeed heat, may have on the performance and behaviour of the wall.



Figure 39. Interstitial moisture monitor installed on walls.

5.6 Occupant Satisfaction Survey

Following occupation of the building an occupant satisfaction survey should be carried out to evaluate the building's performance to check if the objectives have been met in practice and whether the strategies are performing as designed. This provides important information on the project and may highlight any shortfalls in the strategies.

An initial evaluation should be carried out soon after occupation of the building and focus on functionality and the need for any adjustments. A second evaluation should be carried out within 1-3 years.

Summary

The Block M office renovation is an exemplary best practice project that prioritised low carbon, sustainable insulation materials and employed state-of-the-art risk analysis measures and tools. A team of highly skilled architects, engineers and energy consultants worked together to arrive at the most appropriate energy upgrade solutions that were safe, effective and respective of the heritage significance of the building.

The energy renovation of traditional buildings is more complex than modern construction and Block M renovation provided a number of valuable learnings and key takeaways.

First, it is worth noting that often projects will start out with only a minor scope of works to a particular element of the building and will then expand as the project develops in a piecemeal approach. In Block M the Phase 1 works began with repairs to a roof leak and expanded to include the insulation of the roof, repointing of the walls and upgrades and repairs to the existing timber frame windows. With respect to the forthcoming requirements of the revised Energy Performance of Buildings Directive and the obligation to upgrade the worst performing buildings, this highlights the importance of creating a long-term whole building strategy for energy upgrades, even if only minor or initial works are proposed. Doing so will avoid a 'lock-in effect' where it may make it harder or more expensive to implement other upgrade measures in the future.

Another key takeaway during the renovation of Block M related to adapting the energy efficiency strategies to the existing services for the complex of buildings in that area of Dublin Castle. The heating system for Block M was fed by an existing gas-fired boiler, which was interconnected with a number of other properties along Great Ship Street. Therefore, it would be very complex and challenging to decouple the heating supply for Block M from the other properties. Although there was no scope to introduce external plant to Block M for a separate heating system within this project, such as an air-source-heat-pump, from a practical point of view maintaining the existing heating system was the more sensible option. In any case the existing boiler had a high efficiency ratio, which assisted in achieving a higher BER rating. In the future Dublin Castle could introduce a district heating system which would feed Block M, therefore it would be beneficial for the heating system to remain part of the wider complex.

The live laboratory at Block M where two types of vapour permeable insulations readily available on the Irish market were applied in mirror situations has begun to return promising results and valuable data. The in-situ monitoring of interstitial, surface and ambient temperature, moisture and relative humidity will continue for at least one year beyond installation to provide data on any changing conditions. At that point, a report will be supplied to the OPW from the energy consultants with an analysis of the results. Internal wall insulation for solid masonry walls is a higher risk measure so the findings from this monitoring will provide valuable insights to inform the approaches to upgrading and managing the energy performance of other traditionally constructed buildings within the OPW's care.

Finally, a relatively minor, but nonetheless useful point is the benefit of using the IES / NEAP model as a tool to assist the decision-making process through the development of the fabric and services strategies. The instinct may be to only test the model at the beginning to create a baseline model and then again after developing all the strategies and details to confirm the BER and Primary Energy rating, however, using the model throughout can assist in choosing the type of material, thickness, or proposal for an intervention. For example, in Block M the initial overall fabric upgrade strategy included for the ground floors to be upgraded throughout. However, a concern was raised over the impact on the budget, programme and structural stability of the building. The model was tested again at this stage to determine if the ground floor could be retained as-is and still achieve the target BER and Primary Energy ratings. This showed it was possible and, after testing the revised detail in the thermal model analysis, it was agreed to omit the proposed upgrades to the ground floor. The retention of the existing concrete floor slab also saved on the expenditure of additional embodied carbon through its replacement with new materials.

The Dublin Castle Block M Offices renovation is an exemplar of high quality heritage conservation skills and innovative energy upgrade works to a traditionally constructed building. It demonstrates measures to reduce hygrothermal risks associated with the insulation upgrades whilst respecting the historic character of the building. It also implements post-works hygrothermal monitoring to gain valuable insights into the actual performance of the retrofit measures.



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