9.0 A NOTE ON SUSTAINABLE REFURBISHMENT OF HISTORIC BUILDINGS

Bath and North East Somerset has 663 Grade I listed buildings, one of the highest concentrations in the country.

Sustainability standards and heritage settings are not incompatible. Max Fordham have delivered many projects in Cambridge and Oxford, cities that have 261 Grade I listed buildings between them.

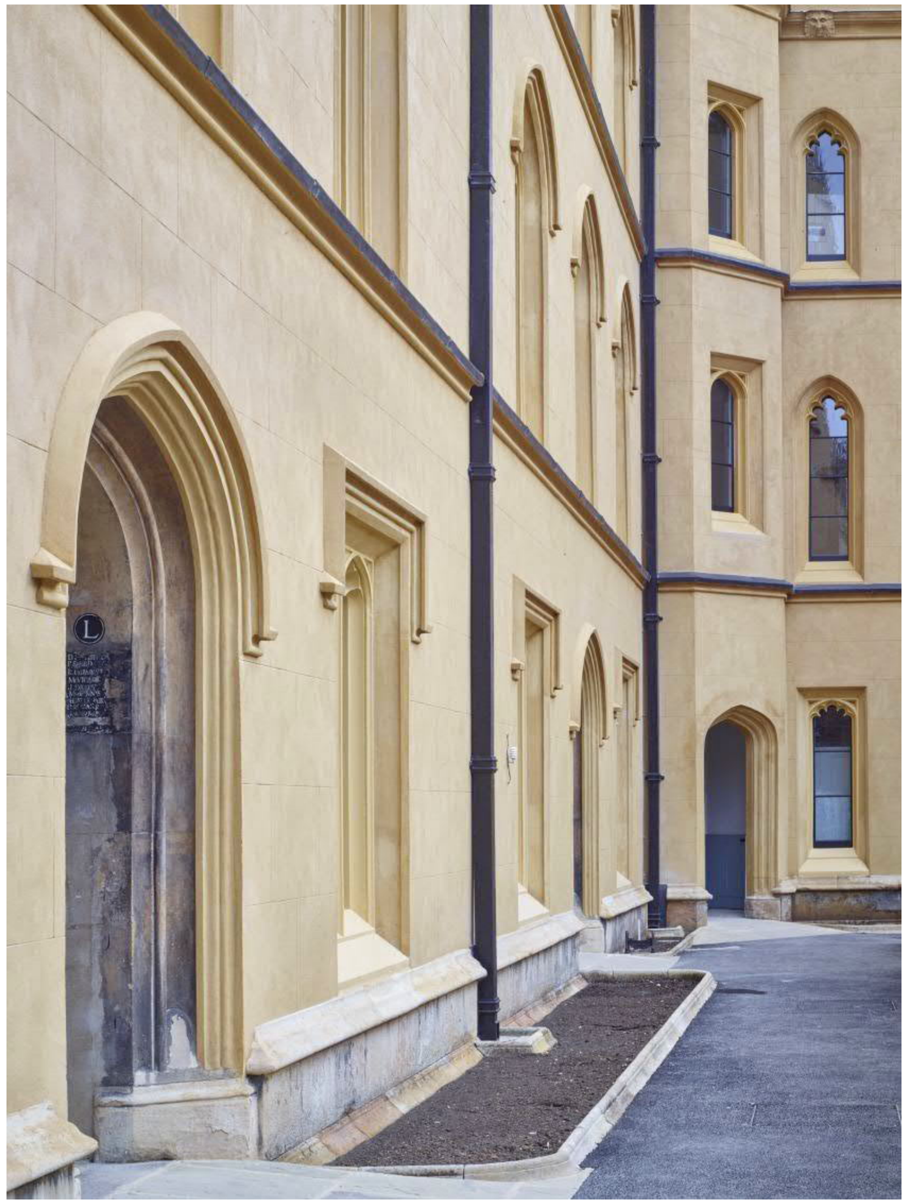
One of Max Fordham's recent projects was the refurbishment of Trinity College New Court in Cambridge. New Court consists of 13 traditional staircases arranged to form three sides of a grade 1 listed quadrangle, located adjacent to the world famous Wren Library on the bank of the river Cam. The aim of the project was to approach Passivhaus energy performance standards and thus set an industry benchmark for sympathetic low energy refurbishment of ancient college building stock. A full description of the project is given in the case study section of this report at 9.1. The project was awarded CFCI Cambridge Design & Construction Award 2016.

Other notable Max Fordham projects that in heritage situations include:

Theatre Royal Newcastle, a Grade I listed
Celebrating its 175th anniversary in 2012, the Theatre Royal Newcastle undertook a project to refurbish and restore the Frank Matcham-designed, Grade 1 listed building. Max Fordham worked on the mechanical and electrical services in the auditorium, resulting in a historically accurate replication but with environmental conditions and equipment levels suitable for the 21st Century. The project was the winner of the RIBA Regional Award 2012 and RICS Conservation Award 2012.

Tate Britain, Grade II*
Tate Britain is one of the UK's most significant and much-loved cultural institutions. The Grade II* listed building attracts more than five million visitors a year. In 2013 a major project to develop the south east quadrant saw eight galleries refurbished. Previously, these galleries were always electrically lit due to the stringent conservation restrictions. Max Fordham devised a solution that allows these galleries to be filled with natural light that does not adversely impact the artwork. External ventilation shades respond to changes in the external conditions via lux-level sensor-controls. The roof has a fixed shading system integrated into the glazing that allows daylight into the galleries, but not directly on the art.

The Church House, Grade II
The Church House, in Westminster, is the Grade II listed administrative headquarters and conference space of the Church of England. The scope of the project involved the conversion of over 3,000m2 of cellular offices into open plan space and upgrading hospitality facilities. Max Fordham carefully coordinated the services installations within the complex spaces, both respecting the architecture and providing the flexibility that open plan offices require. The existing cooling systems were rationalised across throughout the building, artificial lighting levels adjust in response to daylight levels within the space, mechanical ventilation systems are occupancy controlled and the Building Management System has been extended and upgraded, all of which will help to minimise energy use and running costs in operation.



Westcott House, Passivhaus refurbishment project (Gale & Snowden)
Victorian country house renovated and extended to meet the Passivhaus retrofit standard (EnerPHit). Westcott House is a large, private residence located within Dartmoor National Park. A holistic passive design strategy allows the existing property to be upgraded to a level of energy efficiency such that a conventional heating system will only be required in times of extreme winter conditions. At the same time, it will avoid overheating in summer and aims to have minimal environmental impact.

Southwark Bridge Road (Architype)
The old and derelict Victorian library in Southwark was transformed through a major sustainable renovation, including significant fabric upgrades, creation of a new vertical atrium which brings light into the heart of the building and acts as the driver of a new passive stack ventilation strategy. Acoustic ventilation intakes are cleverly integrated into existing window openings and connect from rooms to the atrium through transfer grilles. Heating is by means of wood pellet boilers, and PVs are installed on the new roof top extension.

9.1 Trinity College New Court Cambridge

Trinity College New Court consists of 13 traditional staircases arranged to form three sides of a grade 1 listed quadrangle, located adjacent to the world famous Wren Library on the bank of the river Cam. Its thermal and environmental performance is little improved since its completion in 1825 and the internal accommodation whilst functioning, does not fully serve the College's need for high quality en-suite accommodation and meeting spaces.

Max Fordham was commissioned in 2010 to deliver an appropriate strategy of improvement and upgrade works in relation to the environmental performance, energy consumption and operation of the building services installations. The aim of the project is to approach Passivhaus energy performance standards and thus set an industry benchmark for sympathetic low energy refurbishment of ancient college building stock.

The design team undertook a full review of energy use in the existing New Court buildings to inform the design for the refurbishment and to quantify the effectiveness of the improvements. Proposals include dramatic improvement in thermal performance and air-tightness of the external building fabric by the addition of an internal insulated lining. Max Fordham carried out extensive computational moisture modelling to validate the method and materials of construction of the lining. This also provides an accessible cavity within which new mechanical and electrical services will be hidden.

A crucial aspect of the project brief was to work collaboratively with the College's in-house maintenance department to specify new services which meet their demanding standards and are easily accessible for routine maintenance and allow for adaptation in the future. Renewable and sustainable energy will be provided to the refurbished building via roof mounted photovoltaic panels and a ground source heat pump.

The new services infrastructure had been designed such that the staircases can be split into three distinct construction phases which will be delivered consecutively and with minimum disruption between late 2012 and 2015.

Max Fordham was commissioned to deliver an appropriate strategy to improve and upgrade works in relation to the environmental performance and acoustics.

A crucial aspect of the project was the control of noise from new fans serving bedrooms. We presented acoustic simulations to the college to establish an acceptable target noise level in the bedroom at night. To meet this target, we used low-noise fans, carefully arranged and isolated from the room.

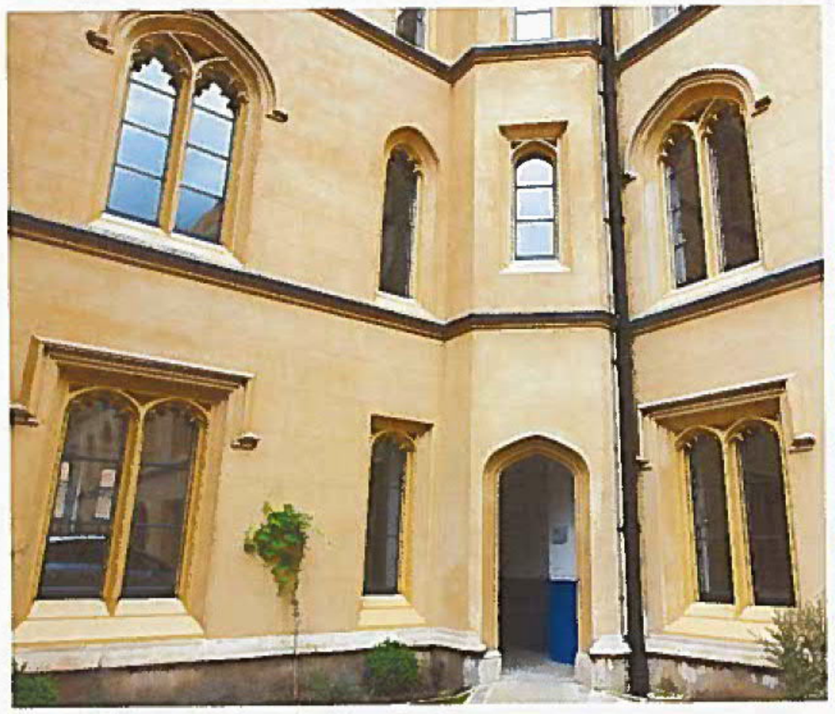
We also advised on the acoustic performance of bespoke partition build-ups in relation to meeting sound insulation regulations.

Awards: CFCI Cambridge Design & Construction Awards 2016

Project data:
£19 million
Client: Trinity College; Architect: 5th Studio Ltd; Engineer: Cambridge Architectural Research Ltd; M&E and Sustainability Consultants: Max Fordham LLP; Project Manager: 5th Studio Ltd

9.2 Cambridge First (CIBSE Article) Trinity College New Court Cambridge

MAX FORDHAM



CAMBRIDGE FIRST

A Grade I listed hall of residence at Trinity College, Cambridge has undergone a highly sensitive upgrade that sets the standard for the green retrofitting of UK's historic buildings. **Andy Pearson** reports

For almost 200 years, New Court in Trinity College, Cambridge, has been a place of study and contemplation. Its neo-Gothic walls have been home to the likes of the poets Tennyson and Hallam and even the current Prince of Wales. However, after two centuries as a student residence, the accommodation in the four-storey courtyard fell far short of current regulatory standards and present-day expectations of comfort and amenity.

The college wanted to refurbish the notoriously draughty Grade I listed block so that it could continue using it for another 200 years, but the block's listing meant that any changes to the structure would require listed building consent.

'The conservation-as-normal approach would have been to do very little in terms of improving performance and sustainability because the integrity of the historic fabric was more important than tackling the building's shortcomings,' says Oliver Smith, a director of architects 5th Studio. To its credit, Smith says, the college decided that 'it had a responsibility to work out if it was possible to do something exceptional in reconciling heritage and sustainability through the refurbishment of New Court'. It appointed 5th Studio and engineer Max Fordham and together the team got to grips with one of the most radical refurbishments of a Grade I listed building ever attempted.

'Fundamentally, the building had a heat loss problem,' says Joel Gustafsson, senior engineer at Max Fordham. Adding insulation to the listed exterior was not an option, so the team set about exploring options for insulating the inside face of the exterior walls. Aside from the issue of obtaining listed building consent for the intervention, there were serious concerns that improvement of the wall's thermal performance would also create moisture and condensation problems.

'When you insulate internally, you change the metabolism of the building; the risk can be anything from cold bridges leading to condensation and mould growth through to timber joists rotting,' Gustafsson explains.

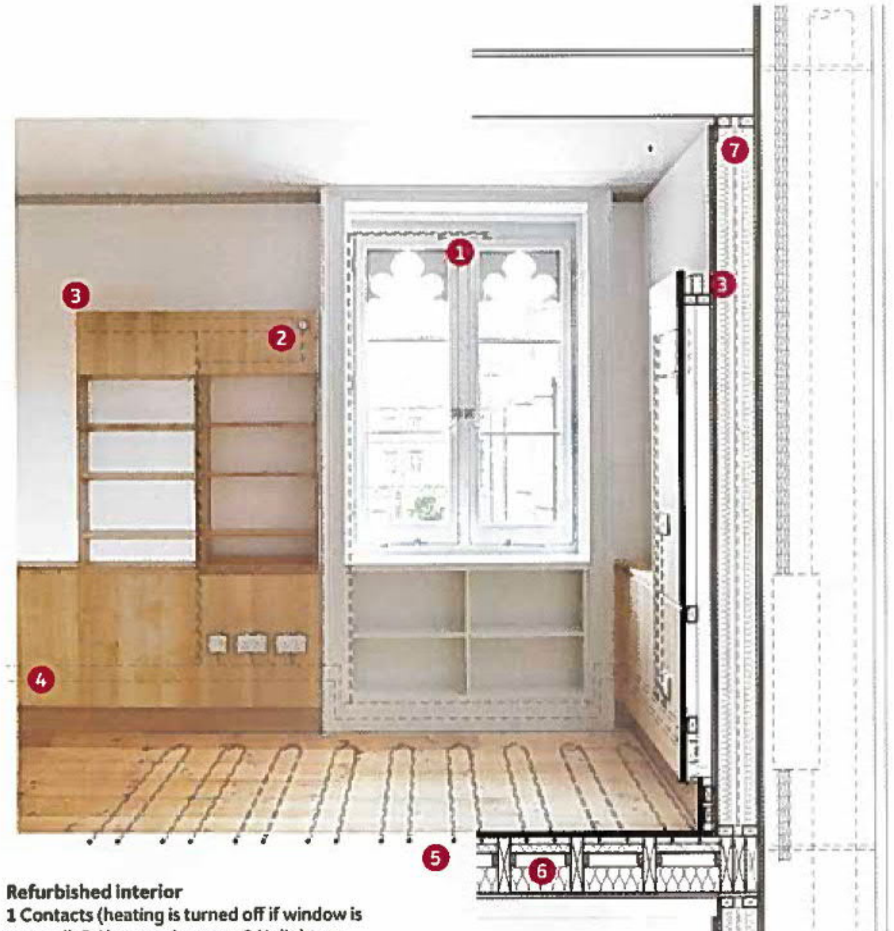
As luck would have it, Max Fordham had just completed a Knowledge Transfer Partnership (KTP) on moisture movement in the fabric of buildings. The New Court project offered the perfect opportunity to employ the theoretical expertise gained on a real project, using the industry standard hygrothermal modelling tool WUFI to characterise how heat and moisture moved through New Court's historic walls.

Using this modelling tool, Max Fordham was able to undertake numerous WUFI appraisals with varying thicknesses of insulation and vapour barrier locations. On new build schemes, the vapour barrier is installed on the inner face of the wall to stop moisture inside the building from entering the wall, while using rainscreen cladding to stop moisture entering from outside. 'The problem we had with New Court's wall of brick, stone and render is that you get solar-driven inward vapour diffusion, which drives moisture into the building. This can lead to a build up of moisture on the cold side of the insulation,' Gustafsson says.

The extensive modelling showed the most promising solution was to do away with the vapour barrier entirely to create what Gustafsson terms a 'vapour open strategy'. This solution would reduce the heat losses,

PROJECT TEAM

- MEP and building physics modelling: Max Fordham
- Architect: 5th Studio
- Contractor: SDC
- Structures: CAR
- Cost consultancy: RUA
- CDM coordinator: Gleeds
- Building performance research: ArchiMetrics
- Specialist sub-contractor: Munro – M+E Service
- Building products: NBT
- Windows: Mat Bateman
- Lime render: AVV
- Joinery: Cousins



Refurbished interior
1 Contacts (heating is turned off if window is opened) 2 Absence detector 3 Uplighters 4 Three-component trunking 5 Underfloor heating pipes 6 Acoustic insulation 7 Insulation to outside wall

Services are concealed in wooden panels that also incorporate uplighters

Fulfilling a seven-year 'watching brief'

Monitoring installations were repeated during the main contract to provide a minimum seven-year 'watching brief', with E4 and E9 locations shown below as examples with slightly different time spans.

E4 (first floor) faces north into the courtyard and is well shaded by building geometry; with a rendered external finish this is perhaps a worst-case scenario.

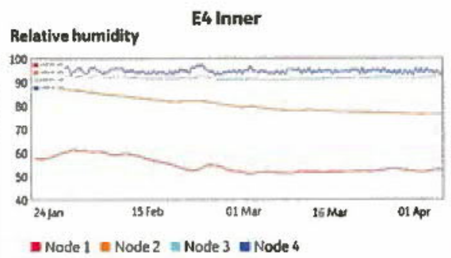
E9 (second floor) faces north onto Garret Hostel Lane and, although in close proximity to other buildings, receives significant direct solar exposure; with the external finish as exposed brick this is perhaps a best-case scenario.

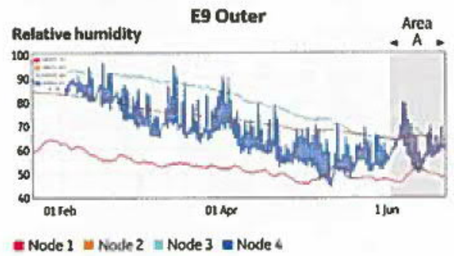
In both cases, the overall trend over time of relative humidity (RH) at all through-wall nodes is downward, although for the two outer nodes (3 and 4) in E4 this is much slower.

RH at the wall/insulation interface node 2 falls below the important 80% value at the end of February in both cases, indicating that drying of construction moisture is taking place.

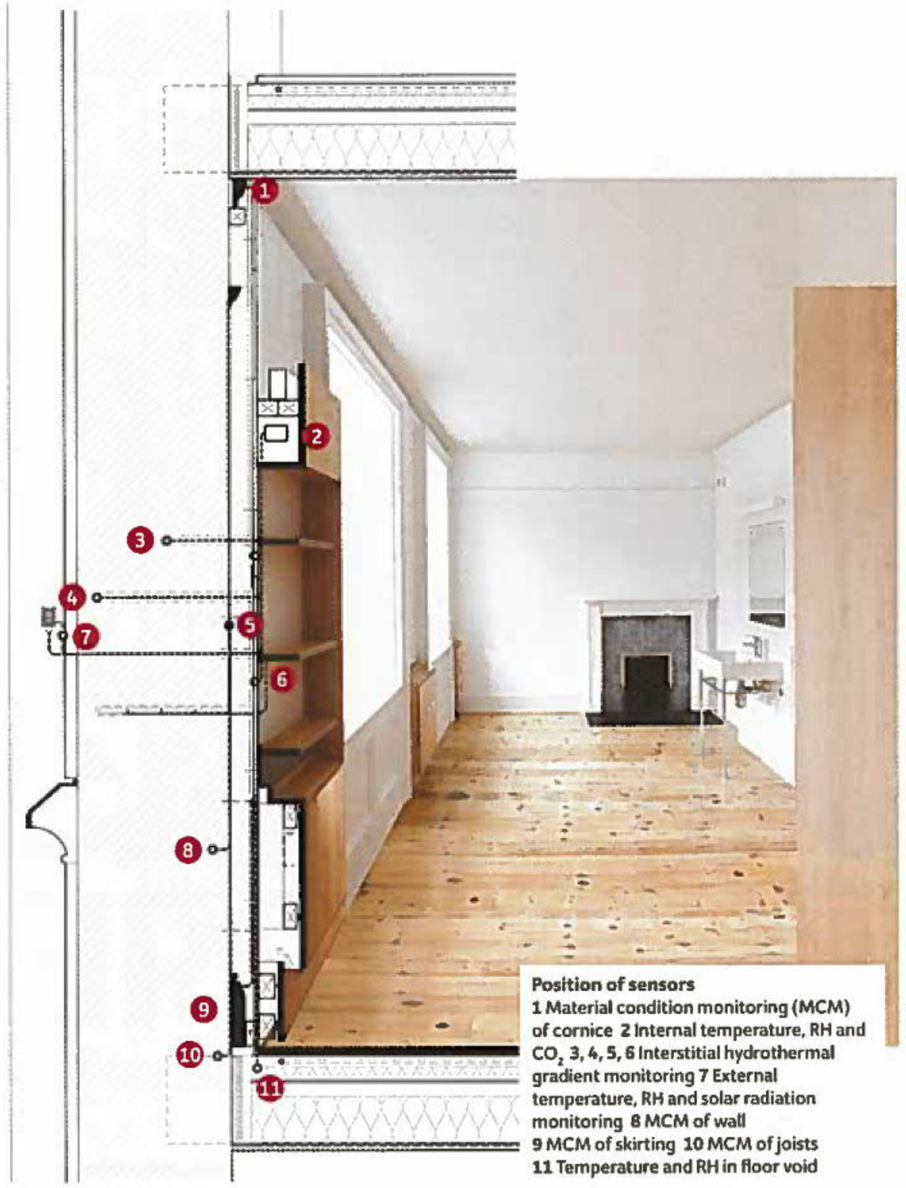
The difference in solar exposure between E4 and E9 is clearly visible. The volatility of RH in E9 node 4 is a signature of 'vapour openness' – the rendered face of E4 clearly being more closed than the exposed brick face of E9, although solar exposure will also be playing a part. The effect of solar exposure on the drying of the outer brick wall in E9 is clear. At the end of May, there were a few grey days that were accompanied by significant rain on 31 May, causing increased RH at node 4 and, in turn, a little later at node 3 – Area A.

Solar activity thereafter affects rapid drying seen at both nodes 3 and 4 – a small residual effect may still be observed at node 2, the masonry/insulation interface sensor.



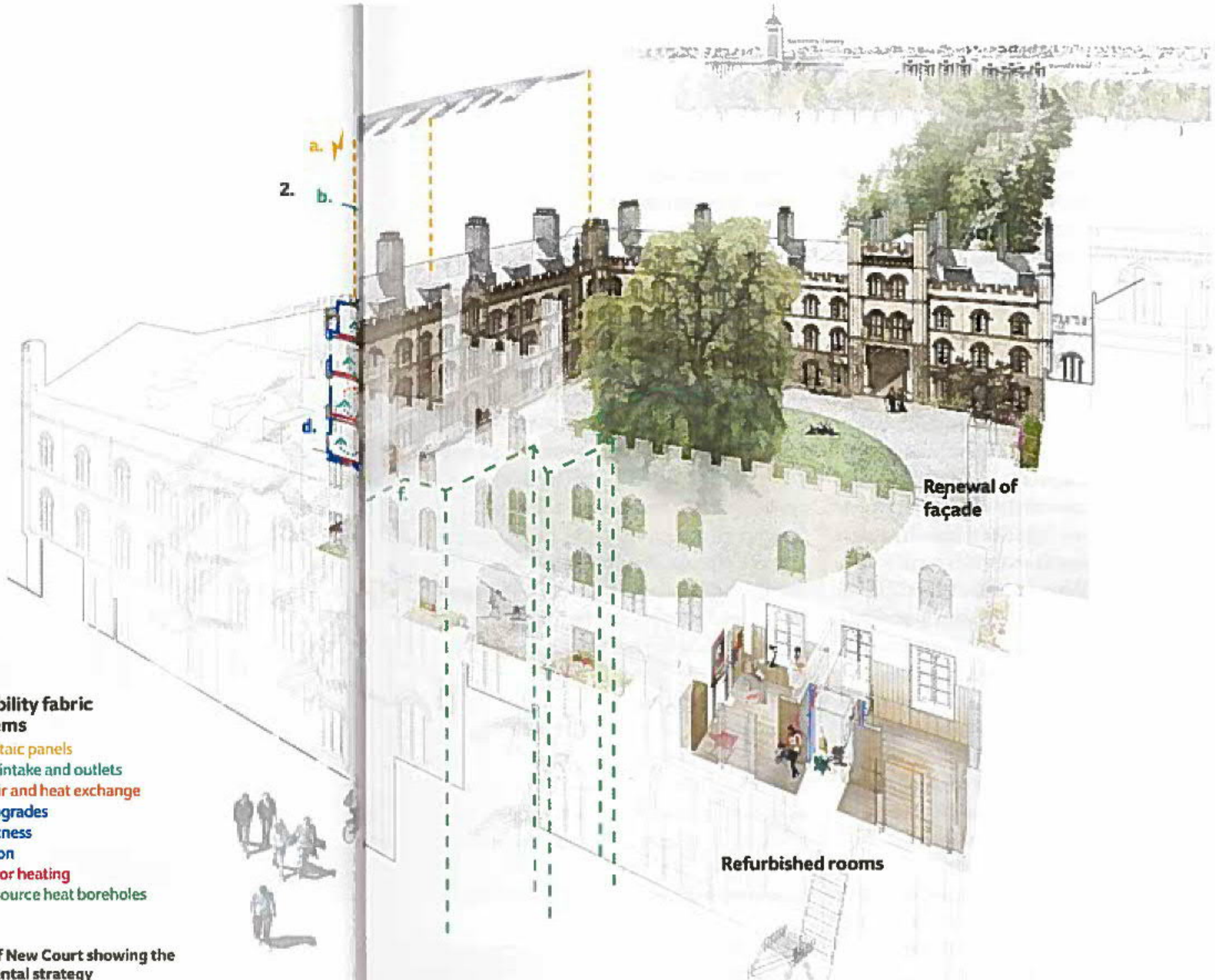


Comparing relative humidty at four nodes within external walls – two locations



Position of sensors
1 Material condition monitoring (MCM) of cornice 2 Internal temperature, RH and CO_2 3, 4, 5, 6 Interstitial hydrothermal gradient monitoring 7 External temperature, RH and solar radiation monitoring 8 MCM of wall 9 MCM of skirting 10 MCM of joists 11 Temperature and RH in floor void

Sensors measure moisture, RH, temperature and CO_2



Drawing of New Court showing the environmental strategy

while still allowing vapour movement through the insulation.

This approach was not without its challenges, because it relies on keeping the moisture as a vapour by limiting the quantity of insulation added to the wall. 'You are slightly limited on what your U value can be because, if you restrict the heat too much, but not the moisture, you will have a condensation issue in the wall,' says Gustafsson.

Precisely how much insulation could be added was dependent on various parameters including the properties of the brick, stone and render used to construct the wall. 'These are all natural materials, so their properties tend to vary considerably,' Gustafsson explains. Nevertheless, because the properties of the materials from which the wall was formed were fundamental to the success of the scheme, samples of each material were sent to testing laboratories at Glasgow Caledonian University.

At the same time as the materials were being tested, the college employed the building performance research practice ArchiMetrics to measure the conditions internally and externally to the block and the moisture and temperature at various points within the wall, using hygrothermal probes. A weather station was also installed. 'This was a key piece of work because it allowed us to calibrate our model,' says Gustafsson.

When, however, the team did compare measured data for the wall with the results from the model, calculated using the measured material properties and the actual weather data for the sample period, there was, according to Gustafsson, 'a small but repeatable difference between the model and the measured data'.

The surface convection coefficient was considered the most likely cause of the variation because it was affected by wind turbulence. The initial modelling had used the CIBSE semi-urban value for the coefficient. However, Gustafsson says the site is actually quite exposed and close to open landscape so that once the convection coefficient had been adjusted to between semi-urban and rural, the model aligned with what had been observed during the monitoring period. 'This gave us confidence in our prediction,' he says.

Using the calibrated model, 5th Studio worked with the consultant to put together a proposal to insulate the walls internally. 'We worked with Max Fordham to work out what type of insulation was best and at what thickness,' says Smith. 'For parts of its life, this was as much a research project as it was a building project.'

The solution eventually decided upon was based on levelling the wall's inner face with a 4mm-thick lime plaster skim, then attaching a 72mm-thick sheet of wood fibre insulation board. The inner surface of the wall is finished with a 15mm-thick layer of gypsum board attached directly to the insulation board.

Because the insulation is attached to the inner surface of the wall, Smith says, there was 'a lot of angst about what to do when it gets to the cornice'. It was decided to leave the cornice exposed in its original position. 'It makes it very explicit, what we have done,' he says.

To help limit moisture build-up in the student rooms, the proposed solution also includes an mechanical ventilation with heat recovery (MVHR) system. 'The MHVR is jointly for energy saving and to help improve air quality and occupant comfort, but is also a key component of the vapour control strategy,' explains Gustafsson.

> To help limit moisture build-up in the student rooms, the proposed solution also includes an MVHR system

The plantroom in the Grade I listed building

Slim vacuum double glazing is fitted to the windows

CASE STUDY TRINITY COLLEGE

Glass panelling allows the cornice to be seen where kitchenettes and ensuite WCs have been added

UPGRADING WINDOWS

In addition to insulating the walls, the team also had to come up with a way to minimise heat losses through the building's combination of sash and wooden casement windows.

Max Fordham appraised the effectiveness of 15 different options, which included fitting new triple-, double- and single-glazed units as secondary glazing or into the existing frames, only refurbishing the existing – and even doing nothing.

English Heritage would not permit replacement with new triple-glazed windows, even though the existing timber frames are already replacements for the original metal windows. Instead the solution decided upon was to take out the old frames, refurbish them, fit draught-proofing and new slim vacuum double glazed units. The team even found rippled heritage glass to add an aged look to the glass.

Along with cutting heat losses, the new windows also help reduce air leakage. 'We aimed for an air permeability of $3\ m^3\ m^{-2}\ h^{-1}$ @ 50 Pa and achieved 3.7,' says Gustafsson.

The MHVR units are hidden in the tiny roof void of each apartment block. At the college's request they are designed to be ultra quiet; in fact they meet Noise Rating 20, the same criteria used for many recording studios. From the roof space, supply air is ducted down the old chimney flues and discharged from the fireplace in each room. The air is either extracted via the ensuite WCs and communal kitchenettes or it passes under the doors before being extracted from the head of the staircase.

The college and 5th Studio applied for listed building consent. The BRE appraised the team's work on behalf of the local council and concluded that the exercise was about as robust as it could have been, but that there was still a residual risk of moisture problems.

When listed building consent was granted, Trinity College decided to commit to the scheme. To manage the residual moisture risk, a condition of being granted listed building consent was that Trinity College has to undertake to monitor and report on moisture levels within the fabric for the next seven years. This obligation will be fulfilled by ArchiMetrics.

As part of the refurbishment, the student rooms were given all new services, including new heating and lighting. The existing radiator-based heating system was installed in the early 1960s when Max Fordham was a student at Trinity and living in New Court. Now, 50-odd years on, the eponymous consultancy he founded has devised a heating scheme for the insulated rooms, replacing the radiators with a low temperature underfloor heating system hidden beneath the original, refurbished wooden floor.

The maximum flow temperature of the underfloor system is designed to be 45°C. Currently the heat is provided from an existing plantroom, but in the not-too-distant future, heat will come from a ground source heat pump. 'We've run two pipes ready to pick up the ground array when it is installed,' says Gustafsson.

To keep energy consumption to a minimum, particularly during college holiday periods, room heating is controlled by an occupancy sensor. Under normal use the rooms are to be maintained at 21°C. However, if the room is unoccupied for more than four hours, the heating temperature will set back. And if the room remains unoccupied after 24 hours the temperature will set back further still. Additionally, sensors in the window frames register when windows are opened for any length of time during the heating season, turning down the heating until these are closed.

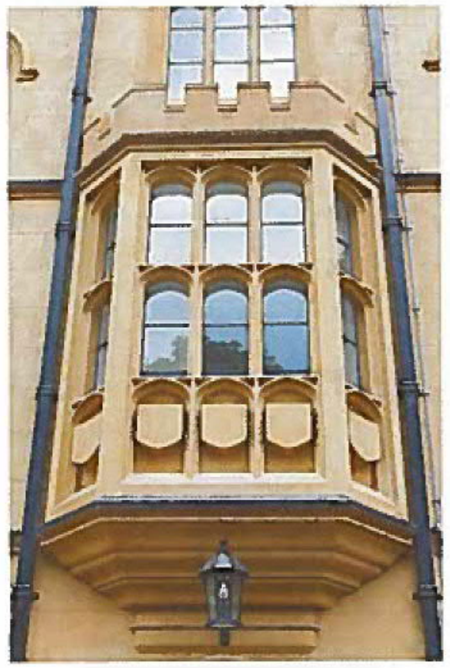
The college required that the rooms also incorporate an electric heated towel rail, which Gustafsson has set to be off by default. 'If you want it hot you push a button and it will come on for an hour,' he says.

Aside from the towel rail, the remainder of the services are incorporated into a clever series of lining panels and attached to the inner surface of the wall. The lining panels hide new LED uplighting – they are a neat solution that eliminates the need to chase cabling into the walls. The panels do, of course, incorporate vents to ensure air circulates behind them to prevent any moisture build-up.

Electrical supply to the panels is from a new courtyard distribution system. This is routed up the building via risers tucked into the central stair well and then out through conduit concealed beneath the floorboards.

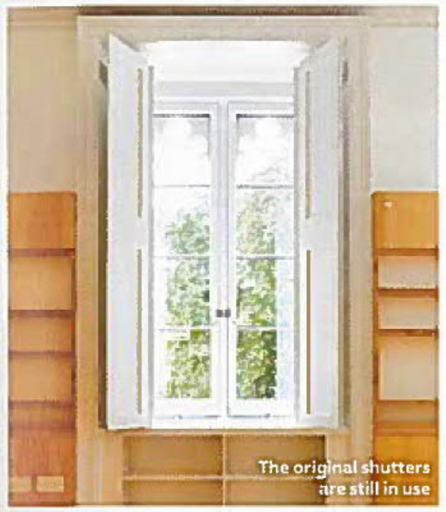
The mechanical services, heating flow and return, and domestic hot water flow and return follow a similar route. All the services are routed from the courtyard, under the main entrance doorway to a service pit hidden beneath removable stone flags in the entrance lobby. The space in the risers was so tight that the mechanical and electrical systems are distributed differently. The electrical systems rise up through the building from the pit, whereas the mechanical services go up to the roof void in larger risers from where they divide, and return back down the building through smaller risers. Each and every riser is different. 'Design coordination meetings were many and long,' recalls Gustafsson. However it was a worthwhile exercise because he says 'everything pretty much went in as designed'.

Oliver Smith is happy too because the building is performing as expected. 'At the beginning of this week we got the first monitoring report, and it backs up what we said we'd deliver,' he says. CJ



> The existing radiator-based heating system was installed in the early 1960s when Max Fordham was a student at Trinity and living in New Court

Supply air from the roof space is discharged via existing fireplaces



The original shutters are still in use

Stone façade on the western side of the Grade I listed New Court

10.0 AUTHORS

Architype
Architype is a vibrant and dynamic architectural practice.

Our purpose is to design life enhancing, genuinely sustainable architecture. As the UK's leading architects for sustainable buildings, we design with an energy and commitment that changes lives for the better, by creating places and spaces that have a positive impact on the people who use them, and on the immediate and wider environment.

Our remit is broad and always exciting. Whether we are working on a private residence or a factory, a hospice or a school or university, we know we are influencing people's lives and that the buildings we design will be used for many years to come. It's our conviction that we should push at boundaries, that there is a better way. It's our intention that clients are liberated and empowered by the process of working with us and by the buildings we deliver for them.

Wherever possible, we carry out a period of thorough consultation, an immersion into the issues and needs of everyone who will occupy the building. We involve them in the process of describing their ambition and developing a plan that is informed by everyone's contributions. This ensures we deliver the building they have a right to, a place they will be proud of.

We love what we do - the profound sense of engagement that comes with each new project, the union of great design and credible sustainability, the pleasure we can bring, and the ripple effect each completed building has on society.

We believe in sharing knowledge and experience, and enjoy the positive impact we can achieve by providing specialist consultancy advice to other architects, engineers, clients and contractors.

Gale and Snowden Architects
Gale & Snowden Architects Ltd, established in 1992, is an award-winning RIBA Chartered Practice that focuses on regenerative design based on permaculture principles. Our projects unify ecology, building biology, physics and landscape design with elegant and efficient architecture to create beautiful, healthy and uplifting buildings and landscapes.

We believe that healthy design is at the core of good design for both building and landscapes. It is important to carefully consider both how buildings are designed and the choice of materials used. By incorporating Building Biology healthy design principles in a design from the outset, a building or landscape can provide an uplifting and life-enhancing environment. Building Biology is the holistic study of the man-made environment, human health and ecology. It is a living subject that brings together fields of study that are otherwise taught in isolation - an interconnecting science that brings together many facets relating to health and construction including: biology, medicine, building physics, chemistry and ecology.

Our designs focus on a fabric first and optimal orientation approach based on Passivhaus principles to first minimise the energy demand of a building, reducing its carbon emissions, before adding renewables where appropriate. The result is low-carbon solutions that respond to a changing climate and tackle fuel poverty at the same time.

We are an integrated team of architects, landscape architects, mechanical engineers, building physicists and biologists, certified Passivhaus designers and permaculture designers. As biologists who are also architects, our focus extends beyond the building. Our designs regenerate the environment, working with, rather than against natural systems; integrating people into designed, productive ecosystems.

Max Fordham
Since 1966 Max Fordham has been driven by sustainability in building design. It was our founding principle and it still guides us today. Our aim is the delivery of beautifully engineered buildings: low-energy buildings that work for the people who use them. We believe buildings should respond to the environment in which they exist. That's our starting point and it drives the engineering approach, making sure that we embed principles of sustainability in everything we do.

Our approach looks at the whole building rather than seeing building services as separate, specialist installations. This also minimises risk. It's vital for us to understand the overall vision for a building – to sympathise with it, to interpret it through engineering. It's equally vital to pay detailed attention to air quality, light, noise, orientation, materials and systems. In that way we engineer comfort for people into buildings.

Our portfolio includes a host of sustainable exemplars including the multi-award winning Keynsham Civic Centre. This project is the first building in the UK to employ the full Soft Landings methodology, where the energy performance aims (of achieving a DEC 'A' after two years) were not just forecast in the design but written into the contract. The building is on track to meet the DEC target at judging time in 2017, once the building has been in operational for 24 months.