Pool Innovation Centre

NOTE: This report combines two BPE studies: Pool Innovation Centre and Tremough Innovation Centre.

This document contains a Building Performance Evaluation report from the £8 million Building Performance Evaluation research programme funded by the Department of Business Innovation and Skills between 2010 and 2015. The report was originally published by InnovateUK and made available for public use via the building data exchange website hosted by InnovateUK until 2019. This website is now hosting the BPE reports as a research archive. As such, no support or further information on the reports are available from the host. However, further information may be available from the original project evaluator using the link below.

Innovate UK project number	450043 A
Project lead and author	AHR (formerly Aedas Architects)
Report date	2013
InnovateUK Evaluator	Roderic Bunn (Contact via www.bpe-specialists.org.uk)

Building sector	**Location**	**Form of contract**	**Opened**
Offices	Pool, Cornwall	Design and build	2010
Floor area (GIA)	**Storeys**	**EPC / DEC**	**BREEAM rating**
3747 m^2 (3785 m^2 on DEC)	3	A (23) / N/A	Excellent

Purpose of evaluation

Pool Innovation Centre is a three-storey building in Cornwall, configured as two wings around a central atrium. The rentable floor space provides flexible workspace and business support for start-up and innovation businesses. The performance evaluation covered the building's fabric performance, energy consumption, and occupant satisfaction.

Design energy assessment	**In-use energy assessment**	**Electrical sub-meter breakdown**
No	Yes	Yes

The heating system consists of a biomass lead boiler and three gas-fired high efficiency condensing boilers . Mains electricity is supported by solar PV. The mains electricity meter significantly underestimated electricity use and was not reliable enough for energy use analysis. An Elcomponents SPC Pro clamp meter was installed to record the building's electrical demand and electricity use every five minutes. Records of wood pellets delivery and gas meter readings were also used to establish the building's thermal energy performance. The Electricity consumption was estimated at 76.3 kWh/m^2 per annum, and thermal energy (biomass and gas) at 69.4 kWh/m^2 per annum.

Occupant survey	**Survey sample**	**Response rate**
BUS, paper-based	130	97 (75%)

Occupants scored the building above the benchmark and scale midpoint on all summary variables except perceived health, which is ranked typical. Recurring issues were people feeling too warm, window controls, lighting controls, outside noise, floor box layouts, not having enough space to park, the toilets not being clean enough and some parts of the building appearing to age too fast (such as the cedar cladding). The majority of positive comments relate to good design, the airiness of the building, the daylighting, productive layouts, quality of indoor environment and occupier needs generally being met.

Tremough Innovation Centre

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Report date	2013
InnovateUK Evaluator	Roderic Bunn (Contact via www.bpe-specialists.org.uk)

Building sector	**Location**	**Form of contract**	**Opened**
Offices	Tremough	Design and build	2011
Floor area (GIA)	**Storeys**	**EPC / DEC**	**BREEAM rating**
3909 m^2	3	A (23) / N/A	Excellent

Purpose of evaluation

Tremough Innovation Centre is a three-storey building in Cornwall, configured as two wings around a central atrium. The rentable floor space provides flexible workspace and business support for start-up and innovation businesses. The performance evaluation covered the building's fabric performance, energy consumption, and occupant satisfaction. At the time of the performance evaluation the building was only 70% occupied. 42% had worked in the building for over a year.

Design energy assessment	**In-use energy assessment**	**Electrical sub-meter breakdown**
No	Yes	Yes

The building was a pilot project aiming to achieve a zero carbon target by following a 'fabric first' approach. The heating system consists of a biomass lead boiler and three gas-fired high efficiency condensing boilers . Mains electricity is supported by solar PV. Records of wood pellets delivery and gas meter readings were used to establish the building's thermal energy performance. The estimated electricity consumption was estimated at 72.9 kWh/m^2 per annum, and thermal energy (biomass and gas) at 108.2 kWh/m^2 per annum.

Occupant survey	**Survey sample**	**Response rate**
BUS, paper-based	70	49 (70%)

Occupants scored the building above the benchmark and scale midpoint on all summary variables. Recurring issues were people feeling occasionally too warm in both summer and winter and delay on the window controls. The majority of positive comments related to design and internal environment, professional settings, the communal areas, lighting and daylighting, productive layouts, quality of indoor environment and occupier needs generally being well met.

Innovate UK is the new name for the Technology Strategy Board - the UK's innovation agency. Its role is to fund, support and connect innovative British businesses through a unique mix of people and programmes to accelerate sustainable economic growth.

For more information visit www.innovateuk.gov.uk

About this document:

This report, together with any associated files and appendices, has been submitted by the lead organisation named on the cover page under contract from the Technology Strategy Board as part of the Building Performance Evaluation (BPE) competition. Any views or opinions expressed by the organisation or any individual within this report are the views and opinions of that organisation or individual and do not necessarily reflect the views or opinions of the Technology Strategy Board.

This report template has been used by BPE teams to draw together the findings of the entire BPE process and to record findings and conclusions, as specified in the Building Performance Evaluation - Guidance for Project Execution (for domestic buildings) and the Building Performance Evaluation - Technical Guidance (for non-domestic buildings). It was designed to assist in prompting the project team to cover certain minimum specific aspects of the reporting process. Where further details were recorded in other reports it was expected these would be referred to in this document and included as appendices.

The reader should note that to in order to avoid issues relating to privacy and commercial sensitivity, some appendix documents are excluded from this public report.

Contents

1 Introduction and overview

Technology Strategy Board guidance on section requirements:	This section of the report should be an introduction to the scope of the BPE and will include a summary of the key facts, figures and findings. Only the basic facts etc should be included here – most detailed information will be contained in the body of this report and stored in other documents/data storage areas.

The two Innovation Centres form part of a larger group of seven buildings monitored by AHR (formerly Aedas) as part of Innovate UK's (formerly Technology Strategy Board) Building Performance Evaluation (BPE) Programme. Unlike the other projects studied, which were all education buildings, Pool and Tremough Innovation Centres are office buildings located in Cornwall. The evaluation was led by UCL Building performance researcher Jamie Bull and coordinated by Dr Judit Kimpian with specialist engineering input from Esfandiar Burman.

Similar in configuration and specification, these two buildings were pilot projects, undertaken by the same design team, aiming to achieve a zero carbon target by following a 'fabric first' approach. The targets were eventually revised to an EPC B for Pool and an EPC A for Tremough during Stage D. The as-built EPC ratings following the completion of buildings were B/28 and A/23 respectively. Both buildings achieved a BREEAM Excellent rating.

The BPE study was undertaken by the R&D group of AHR, who did not participate in the design of the buildings and acted as a semi-independent entity. Supported by UCL researchers, the BPE project was set up entirely independently from the building contract and gained the buy-in of the client, the building operators, the contractor and the design team.

At the time of the application Pool Innovation Centre (PIC) had been completed for 18 months and Tremough Innovation Centre (TIC) was still under construction, due for completion in November 2011. It was the aspiration of the monitoring team to carry out an informal Soft Landings process as part of the BPE study and ensure that the lessons learned from PIC inform the commissioning, handover and the first year of operation at TIC.

Although no **formal Soft Landings** steps took place, the BPE process did result in aspects of the Soft Landings process being implemented. Meetings were held with the contractor, FM and the client highlighting the importance of commissioning and actions agreed to improve commissioning outcomes at TIC. The monitoring team found that the primary benefit of the BPE was that **going after energy data three months after occupation highlighted issues with metering and other building elements**, such as BMS, window controls and the biomass boiler. Some of these were **remedied during the Defects Liability Period**.

As in the case of all the other BPE projects undertaken, establishing detailed actual energy consumption proved to be the most challenging aspect of the project. Reconciliation of submeters and main meters took far longer than expected and some discrepancies were not possible to explain even during the two-year monitoring period. A key recommendation of the team is to **incorporate the collection of energy data and occupant feedback in the contractor's prelims** to keep the cost of data-collection low and ensure that the metering equipment is correctly installed and commissioned.

Major metering problems were revealed at both sites and the BPE process highlighted significant barriers that need to be overcome in this area if clients were to get a better value for their investment in metering. Meters have been shown to be poorly specified, installed or missing, not calibrated and not linked to a building management system (BMS) or not possible to set up logs for over the BMS. The meters were not observed to play any role in the facilities management of the buildings. If **extracting data from meter readings** were **straightforward** then energy performance contracts for maintenance could be set up much more easily.

Due to the metering errors encountered, the reconciliation of the meters and diagnostics of the building services were delayed and eventually had to be carried out at both buildings by a UCL researcher with a background in engineering, specialising in building performance. This BPE project was led by architects with the premise that BPEs should be possible to carry out by architects familiar with the BPE process. However, where issues with metering and building services are encountered, (so far in 100% of the 15 buildings surveyed by AHR), the detailed building diagnostics required the leadership of such a specialist.

A **full reconciliation of the meters** was achieved towards the end of the project due to challenges of metering. At PIC a faulty mains meter meant a clip-on meter had to be installed to be able to reconcile electricity consumption and at TIC the submeters took over 18 months to fix. Had the meters been functioning as specified the full diagnostic exercise could have taken place earlier and TIC may have been able to address the higher than expected heating energy encountered within the time frame of this project.

The **natural ventilation approach has allowed less room for error** than that witnessed in similar size mechanically ventilated buildings, in terms of problems arising from installation, commissioning and BMS control. On the other hand, **much of the plant equipment controlled by the BMS encountered problems**.

The heating system, supplied by a combination of biomass boilers and backup gas boilers in both buildings, used three times the predicted energy at TIC and only about a fifth more than predicted at PIC, where both the BMS and the biomass boiler systems were much simpler. Unexpected and expensive maintenance issues with the biomass boilers have led the facilities manager to advise the local authority, **not to use biomass boilers in the future**.

Pump energy use was also higher than expected at TIC, but in actual fact close to that of PIC, suggesting that the prediction at PIC may have been more realistic.

The **window controls** were raised as problematic at both buildings and the team recommends that this area is **further studied** by the architecture team **to improve the specification** of the products in a way that limits the potential effects of any value engineering on usability. At PIC, where the specified system was retained, only the noise of the windows opening and closing and the manual window levers were raised as problematic. At TIC, where the chosen supplier was not the one preferred by the design team, there were more severe control issues in addition to these, affecting both the comfort of occupants and heat consumption.

In the summertime, the data loggers showed that the stack-ventilation was able to keep **temperatures at comfortable levels** during the hotter summer days, and adequate air change rates (resulting in low CO_2 concentrations) in the wintertime. The architecture team will be able to use these examples to argue for this solution at future projects.

In the lecture theatre of TIC, where significant cooling loads were expected, these were met by earth tubes. These worked to the satisfaction of occupiers as well as facilities managers and will be considered on other projects.

Both buildings achieved a Display Energy Certificate (DEC) Rating equivalent of C. The engineers, CH2M stated that the initial ambition for a zero carbon target helped these buildings perform better than the raw TM46 benchmark for this building type. However the EPC target did not overcome the commissioning issues witnessed on other BPE projects and the monitoring team concluded **that incentives other than notional performance targets are needed to address this problem**.

Even if the higher than expected heating energy (at both buildings) and auxiliary consumption (at TIC) is brought back in line with that of the EPC there is still room for further reductions in lighting, small power and server room loads. An interesting observation was that in both buildings server room cooling was installed after building completion and final Building Regulations compliance calculations although air conditioning for server rooms was specified by designers during design stages. While there might have been perfectly legitimate reasons to install split air conditioning units outside the main contract, this has led to unrealistic as-built calculations which do not represent the design intent and what was eventually going to be installed in these buildings. One could argue that, at least to some extent, this is an unintended consequence of the existing regulatory framework that does not take into account the changes made in the immediate aftermath of building completion and early stages of operation.

Another problem observed in both buildings was that the contribution of **biomass boilers to heating was much lower than design intent**. There was also a significant mismatch between the heat meters installed for the primary and secondary low temperature hot water loops at TIC that points to waste of energy in plant room. The problem of lower than expected contribution of Low or Zero Carbon technologies where conventional back-up technologies have been installed is endemic in the industry and the research team have come across it in other buildings as well. The new CIBSE publication AM15, Biomass Heating, points to the shortcomings of the existing control strategies used in the industry that can lead to significant underperformance of biomass boilers. This publication also provides a set of ‘preferred’ hydronic arrangements in contrast to the ‘typical’ arrangements used in the industry that could be deployed to achieve the expected performance from biomass boilers and more widely other LZC technologies that interact with back-up systems.[1] This shows that the underlying **root causes of performance gap can go well beyond the remit of individual projects and project teams**, and a review of the existing industry guidelines that have not been updated to accommodate the modern complex building services arrangements is required.

These findings have important implications for the UK and EU regulatory debate on ‘nearly zero carbon’ buildings. If these two buildings, targeting such performance from the start, can only achieve one DEC rating above the average UK office building, and even that with the help of biomass boilers, **a new approach is needed to achieve significant reductions of energy use in operation.**

A recurring problem for establishing the Performance Gap in BPE projects was the lack of an energy consumption baseline, against which operational energy use can be compared. The UCL research team proposed the **use of ‘adjusted’ EPCs to create a potential end use energy consumption baseline for a building**, if the EPC assumptions reflect reality. This is significant progress, as currently there is no agreed mechanism to establish a baseline energy consumption profile for buildings, which is a major barrier to carrying out BPEs and diagnostics within the defects liability period. EPC XML files offer an insight into likely equipment loads used to calculate building heat loads. If the buildings are operated in line with standardised conditions these equipment loads can be added to the other specified end use consumption figures to arrive at a ‘baseline energy end use budget’.[2]

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[1] For further information please refer to CIBSE AM15 Biomass heating, 2014 (Chapter 7).

[2] For further information please refer to the following source:
Burman, E., Hong, S., Paterson, G., Kimpian, J. and Mumovic, D., 2014. *A Comparative Study of Benchmarking Approaches for Non-domestic Buildings: Part 2 – Bottom-up approach*, International Journal of Sustainable Built Environment, DOI: 10.1016/j.ijsbe.2014.12.001.

Displaying these energy end use budgets as a simple energy bar in CarbonBuzz style helps communicate building performance to decision makers. Collated against data on internal environmental conditions and occupant feedback, fast conclusions can be drawn on where a building is not performing optimally. Is it delivering the expected indoor environmental conditions? Is it using as little energy as possible to do that?

The Building Use Survey (BUS) highlighted aspects of building performance that are not necessarily visible from an energy audit but have major implications for overall usability as well as energy use and comfort. Overwhelmingly, comments from users referred to controls to the building interface: temperature, window openings (manual and automated), lighting and glare, zoning and BMS controls and noise. The monitoring team believes that building controls are one of the most overlooked areas of building design and a barrier to good building performance. There is clearly a **major opportunity for architects, engineers and product designers to collaborate to transform the technical capability and interface design of controls in buildings.** However as long as legislation does not target operational building performance, innovation in this area is unlikely to occur on a large scale and will require other financial incentives or expert clients**.**

The Building Performance Evaluations of PIC and TIC demonstrated a trend observed in the previous BPE projects. Where occupiers were satisfied with the building design they were more tolerant to issues experienced with controlling their immediate environment in terms of temperature, fresh air and light. The comments from the Building Use survey highlighted many control and comfort issues, the energy use is also higher than expected, yet occupiers seemed overwhelmingly satisfied with the buildings.

The availability of daylight, having operable windows, the usability of the space and responsiveness of the facilities management were coming across as important factors in achieving the positive feedback that was received via interviews with occupiers and the BUS.

2 Details of the building, its design, and its delivery

Technology Strategy Board guidance on section requirements:	This section of the report should provide comments on the design intent (conclusions of the design review), information provided and the product delivered (including references to drawings, specifications, commissioning records, log book and building user guide). This section should summarise the building type, form, daylighting strategy, main structure/ materials, surrounding environment and orientation, how the building is accessed i.e. transport links, cycling facilities, etc – where possible these descriptions should be copied over (screen grabs - with captions) from other BPE documents such as the PVQ. This section should also outline the construction and construction management processes adopted, construction phase influences i.e. builder went out of business, form of contract issues i.e. novation of design team, programme issues etc. If a Soft Landings process was adopted this could be referenced here but the phases during which it was adopted would be recorded in detail elsewhere. If a Soft Landings process was adopted this can be referenced here but the phases during which it was adopted would be recorded in detail elsewhere in this report and in the template *TSB BPE Non Dom Soft Landings report.doc*.

2.1 Introduction

Pool Innovation Centre (PIC) and Tremough Innovation Centre (TIC) are three storey buildings with rentable floor space, providing flexible managed workspace and business support for start-up and innovation businesses. These centres are part of the wider development of business incubation in Cornwall and have been procured by the same client, with a near identical brief but located on distinct sites.

Both buildings comprise of largely cellular offices. Flexibility was a major driver resulting in raised access floors and moveable partitions. The main wall construction is a lightweight steel frame system with 150mm deep mineral wool fill, sheathing board, rigid insulation, ventilation gap and timber cladding. Tremough also includes insulated render. Heat and CO2 sensors were planned into all rooms. Lighting has intelligent controls, occupancy sensors, manual override, and daylight sensors.

PIC and TIC are part of the wider development of business incubation in Cornwall. They were procured by the same client with a near identical brief and will be delivered by the same design team, AHR (then Aedas) and CH2M (then Halcrow) but built by different contractors, Pool by McAlphine and Tremough by Leadbitter. Pool was completed in May 2010 while Tremough started on site in Nov 2010. The buildings offered a great opportunity for a 'compare and contrast' study - in the case of Tremough, many of the lessons learned from Pool fed into its execution.

As part of the BPE study the team was looking to verify if the passive natural ventilation strategy worked: is there a difference in comfort levels and overheating between Pool north and south facades, and how these compared to Tremough. The team was also looking to establish whether low-carbon features such as ventilation stacks and night purge brought real benefits.

In the case of Pool, the design team reported some lack of user awareness of how to operate windows. These were on restrictors which could be released manually – the monitoring team was keen to find out whether these issues could be addressed. We were also looking to verify if the BMS controlled heating, fixed lighting, localised air conditioning and night purge were correctly operated.

The impact of extended operating hours was studied in detail, with occupancy survey results compared with daily consumption profiles.

Summertime overheating was studied to find out if the buildings were able to shed enough heat through the openings provided despite the high level of insulation in the solid façade elements.

Lighting design incorporated PIR, daylight sensors, manual overrides with lighting zoned according to proximity to windows. The team studied whether this was exploited and if it supported the user expectation.

With regard to renewable energy sources – any issues relating to the operation of biomass boilers and pvs were explored.

2.2 Pool Innovation Centre (PIC)

Figure 1 Pool and Tremough Innovation Centres

PIC was completed in May 2010 and since has won INSIDER South West Property Awards 2010, Sustainable Development of the Year, CIBSE and GreenBuild performance awards.

The building has solid facades with punched windows, using a local cedar cladding. Curtain wall is used around atrium breakout space (enclosed by two wings) and in one of its corners. Wings have a central corridor which has ‘borrowed light’ through glazed office doors and large windows at each end. Ventilation strategy varies between North and South sides with the latter being cross-ventilated through local wind chimneys. The North side offices have single-sided ventilation. Windows have low level operated manually whilst high are linked to the BMS with manual override. Only corner meeting rooms have fan coil systems, vented to the roof.

The building structure is steel frame & precast concrete floors. Two and a three storey wing encloses atrium. Corner site. 16m floor deep with central corridor. 7.8m deep offices. Floor to soffit 3.075m.

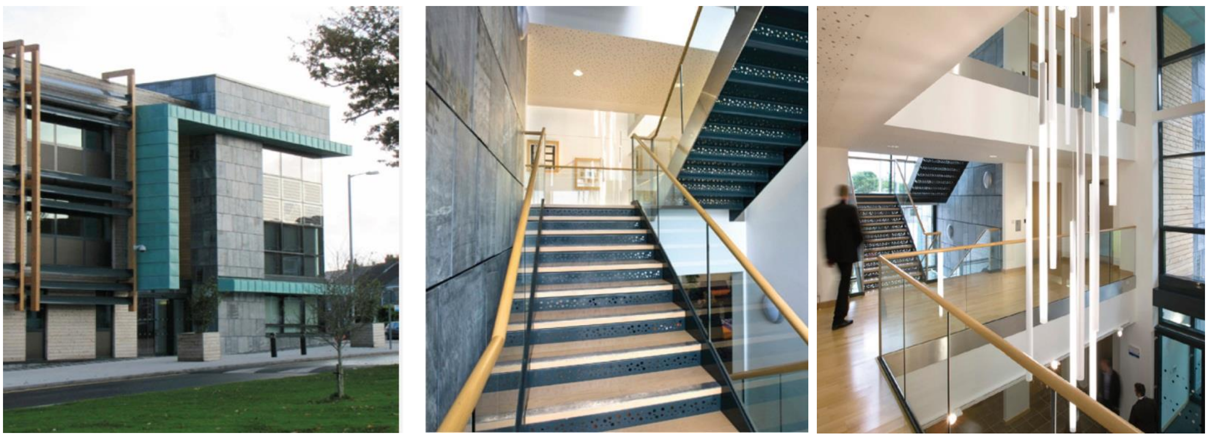


Figure 2 Pool Innovation Centre

PIC comprises 51 offices varying in size from 24 m2 to 67 m2 in 3 or 2 storey blocks either side of a central atrium. The atrium contains the reception area, and access to meeting rooms and the main conference room. A ground floor kitchen and coffee spaces on ground and upper floors are provided, together with WCs & showers, disabled WCs and shower, cyclists' drying spaces and lockers.

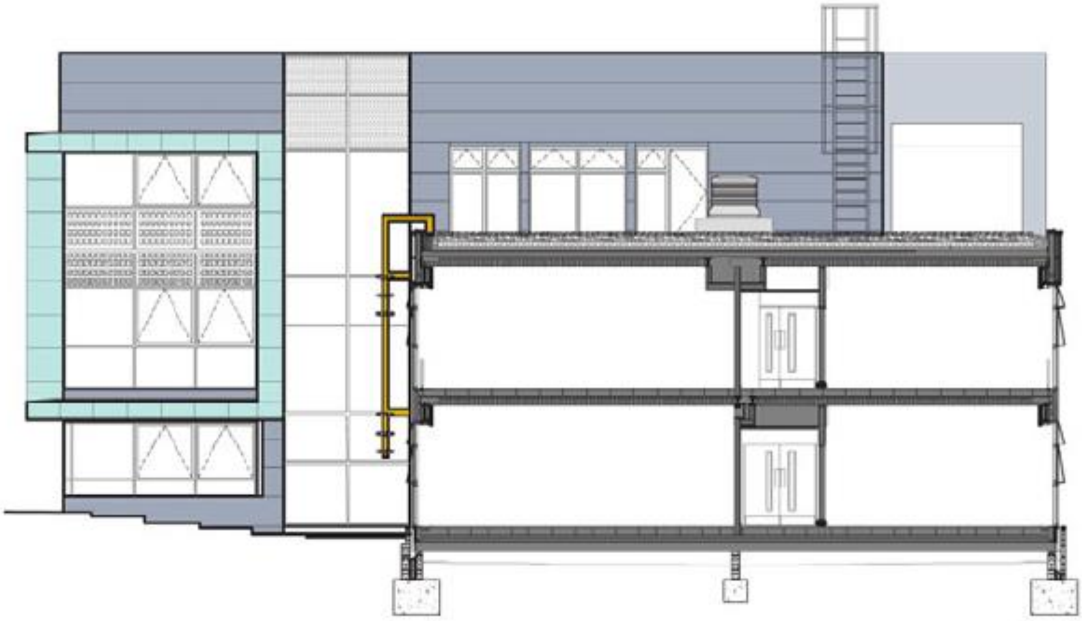


Figure 3 PIC East Wing Section

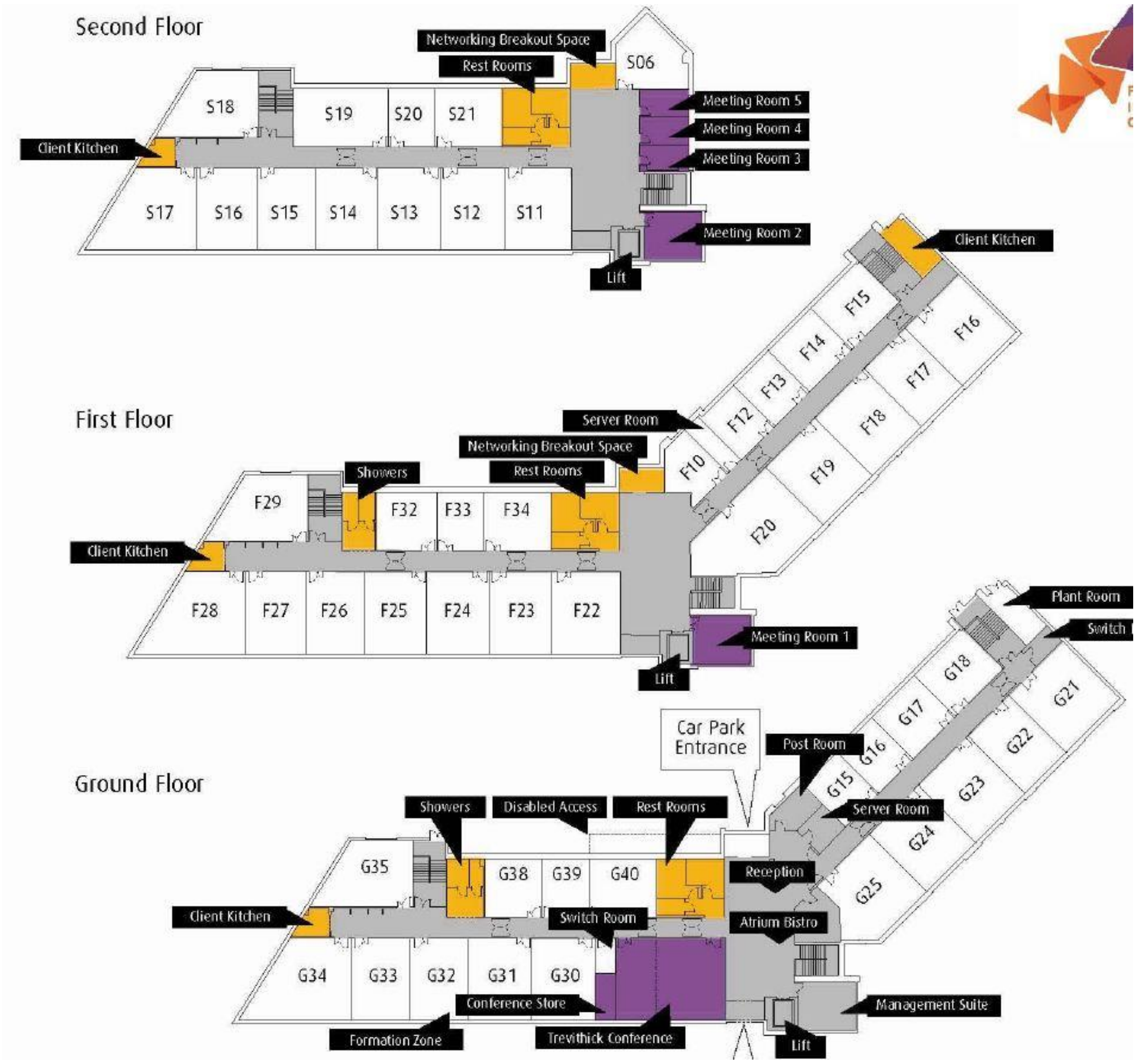


Figure 4 PIC spatial organisation

The south side of the east wing on the ground floor is sparsely-occupied with offices there used variously as a show office, a storage room, and as occasional overspill meeting rooms when other meeting rooms are occupied. No specific zoning strategy is employed in terms of controlling heating or lighting.

Surface	Area m^2	U value W/m^2K	%age of surface area
Red cedar-clad steel frame	957	0.20	17%
Slate-clad steel frame	311	0.20	6%
Copper-clad steel frame	31	0.20	1%
Curtain wall glazing	365	1.70	7%
Aluminium/timber composite windows	943	1.70	17%
Flat roof	1,444	0.15	26%
Precast concrete suspended floor	1,500	0.15	27%
Total surface area/average U value	**5,551**	**0.53**	

Table 1 PIC u values

2.2.1. Walls

There are a number of different wall finishes at PIC, although all have the same steel framed structure and similar calculated U values of 0.20 W/m²K.

Figure 5 PIC Surface finishes

2.2.2. Floors

The floors are concrete with a raised floor allowing services to pass below.

Figure 6 Under-floor services visible in a riser access cupboard

2.2.3. Windows
Windows are by Velfac and are fitted with actuators on the upper light which are controlled by the WindowMaster system. The lower lights are manually operated.


Figure 7 Windows, interior and exterior view

2.2.4. Roof
PIC has an extensive sedum roof which is doing very well as can be seen by the two pictures taken approximately six months apart. A large number of species seem to have colonised the roof in that time.


Figure 8 Extensive sedum roof and wind-catcher vents, six months apart

2.2.5. Brise soleil
The horizontal brise soleil at PIC are effective at reducing excessive solar gain in the non-air conditioned offices on the SE and SW facades.

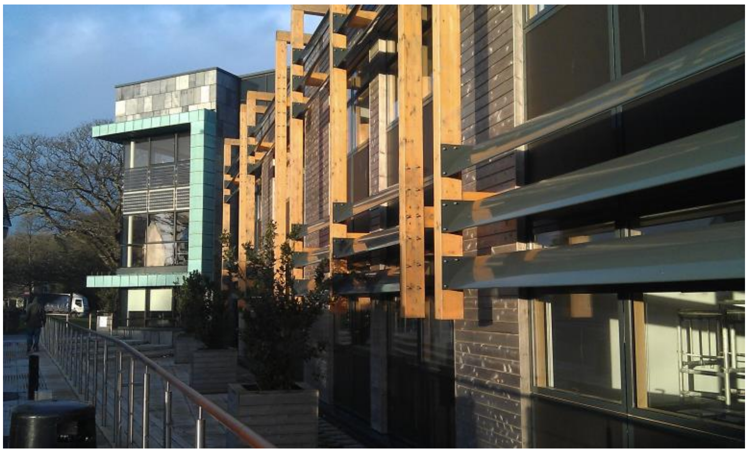



Figure 9 Brises soleil on the south-east façade

2.2.6. Air curtain

The atrium has two horizontal air curtains, one alongside the internal sliding door of each air lobby. However these are not in use, since they are very noisy in operation and are immediately adjacent to the reception desk.

Figure 10 Unused air curtain

2.2.7. Air tightness

Building fabric airtightness target was 10 m3/hr/m2 and the achieved performance returned by the airtightness test was 8 m3/hr/m2.

2.2.8. Thermal imaging

The results of the thermal imaging tests showed that there were no major discontinuities in the building fabric. The openings were where most of the heat loss occurred in wintertime.

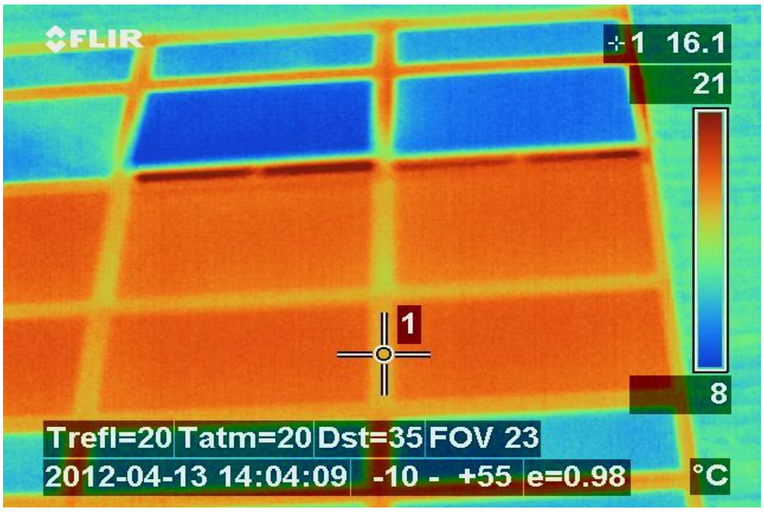


Figure 11 Thermal image from PIC showing heat loss via open windows

2.3 Tremough Innovation Centre

The new Innovation Centre is a three storey building configured as two wings around a central atrium. It was constructed as an in-situ concrete frame & roof with the external walls formed with curtain walling. The roof finish is a metal standing seam type & the internal walls are plasterboard on jumbo stud. Materials were specifically sourced to include locally grown oak cladding, copper cladding, laminated timber curtain wall, composite windows. The offices have exposed concrete ceilings.

Offices open from a double sided corridor on each floor – their average depth is 6m, the floor to soffit height is 2.95m, with3.5m. Floors are approximately 1500m2 each. The contract was Design and Build and the contractor was Leadbitter. Soft Landings was not part of the original contract but Leadbitter was keen to find out more about it at the time of the application. The building achieved a BREEAM Excellent target.

Figure 12 TIC office atrium, front entrance, entrance atrium

TIC comprises 51 offices in 3 storey blocks either side of a central atrium. The atrium contains the reception area, and access to meeting rooms and the main conference room. A ground floor kitchen and coffee spaces on ground and upper floors are provided, together with WCs & showers, disabled WCs and shower, cyclists' drying spaces and lockers. To facilitate tenant circulation, collaboration and networking, all central services including reception, meeting rooms, conference facilities, breakout areas, toilets and kitchens are shared.

2.3.1. Walls

As can be seen from the construction photograph, the walls at TIC are concrete framed. There are a range of finishes, all with a U value of 0.25 W/m2K

Figure 13 Construction photo showing the concrete frame under construction

Target wall U values and related areas are detailed below:

Surface	Area m^2	U value W/m^2K	%age of surface area
Timber-clad steel frame	700	0.25	13%
Rendered panel-clad steel frame	958	0.25	18%
Copper-clad steel frame	105	0.25	2%
Curtain wall	247	0.25	5%
Aluminium/timber composite windows	525	1.70	10%
Standing seam pitched roof	1,291	0.15	24%
Concrete suspended slab	1,464	0.20	28%
Total surface area / Average U value	**5,290**	**0.36**	

Table 2 Schedule of surface areas and U values

2.3.2.Ground floor

The ground floor at TIC is predominantly slab on grade, with a small area to the north east which is suspended and supported by concrete columns.

Figure 14 Suspended concrete slab at the north-east corner of the building

2.3.3.Windows

The windows at TIC are also Velfac aluminium-clad timber frames. As at Tremough the upper panes are automated although in this case they are linked to the BMS – the Windowmaster system was value-engineered. The triggers include temperature and CO2 levels.

Figure 15 Window looking north

2.3.4. Roof

The roof is an aluminium standing seam pitched roof. It was not possible to access the roof during the survey due to health and safety issues (the building manager had not undertaken training on the mansafe system). The only access possible was to the walkway area of gravelled flat roof accessible from the second floor.

Figure 16 Roof

2.3.5.Air tightness:

The building fabric performed better than the design target value of 5m3/hr/m2. The air tightness test returned a result of 4.66 m3/hr/m2. This was an improvement on the PIC air tightness result.

2.3.6.Thermal imaging

The results of the thermal imaging tests showed that there were no major discontinuities in the building fabric. The openings were where most of the heat loss occurred – in particular at Pool the windows were perceived open during the winter period.

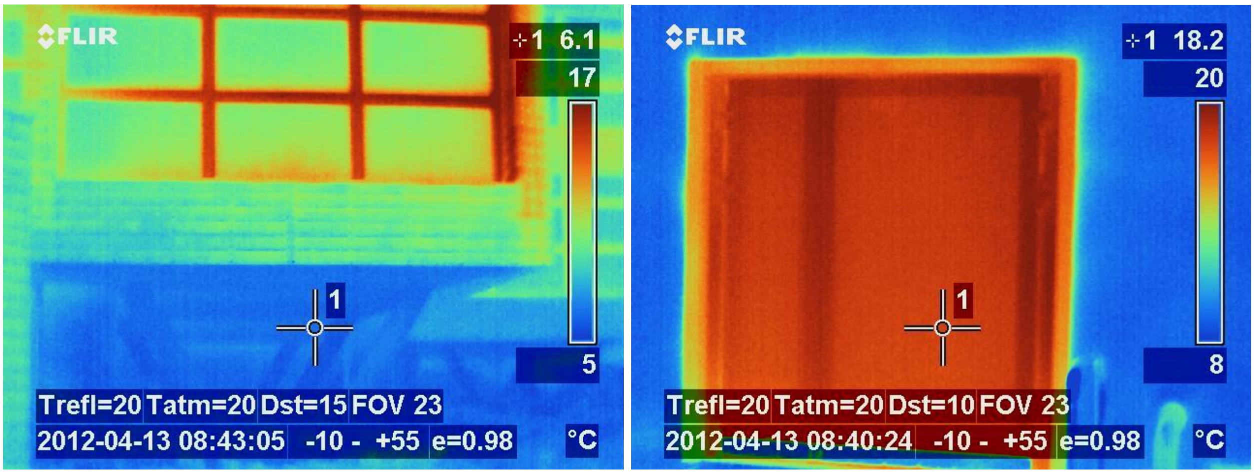


Figure 17 Thermal images of TIC

3 Review of building services and energy systems.

Technology Strategy Board guidance on section requirements:	This section should provide a basic review of the building services and energy related systems. This should include any non-services loads – which would therefore provide a comprehensive review of all energy consuming equipment serving the building or its processes. The key here is to enable the reader to understand the basic approach to conditioning spaces, ventilation strategies, basic explanation of control systems, lighting, metering, special systems etc. Avoid detailed explanations of systems and their precise routines etc., which will be captured elsewhere. The review of these systems is central to understanding why the building consumes energy, how often and when.

3.1 Pool Innovation Centre

Building systems at PIC are detailed below.

3.1.1. Heating

Heating and hot water are provided by a biomass wood pellet boiler with backup gas boilers for peak loads, typically when the outdoor temperature falls below 5 degrees C.

The biomass boiler is a Binder RRK149 145 kW model. It is housed in an external container which has pipes for blowing in fuel deliveries. Three 85kW gas boilers are located in the plant room. The accumulator tank at PIC is significantly smaller than that at TIC, due both to the smaller size of the building and the lower wall U values.

Figure 18 Tools required for manual de-ashing and the containerised woodchip store and boiler house

The Biomass Control Box receives signals from two buffer vessel temperature sensors and the external temperature sensor. It modulates the pellet boiler to maintain the buffer vessel temperature at the set point of 80ºC 24 hours a day.

The Master Control Panel also receives signals from the buffer vessel temperature sensors. If the buffer vessel temperature drops below a lower limit set point of 70ºC, this is the cue for the gas boilers to provide “top-up” heating to supplement the biomass boiler. Once the buffer vessel has reached its set point temperature, the gas boilers will be automatically switched off to allow the pellet boiler to take the heat load.

The boiler is monitored by a Schneider Electric building management system (BMS) located at the ground floor control room behind reception. Thermostats are located on the back wall in each room with a rotary dial for occupant control of temperature in each room. TRVs on radiators allow a degree of tenant control although these have been supplied with stoppers to limit occupier settings.

The Master Control panel provides “weather compensation” which reduces the temperature of the variable temperature (VT) heating circuits to the radiators when the external temperature is warm and the need for heating is low, so unnecessary energy consumption is reduced. The Master Control panel achieves this by signalling to the 3-port valves on the VT circuits to mix return heating water into the flow.

When the temperature in each room reaches the set point temperature of the thermostatic radiator valves (TRVs), the TRVs independently shut-off the heating water from their radiators. The heating pumps in the plant room then sense the higher pressure and automatically slow down. So that the heating pipes throughout the building don’t cool down when the radiators are shut off, differential pressure by-pass valves (DPVs) open to allow a trickle of heating water to flow through the pipes.

Figure 19 The plant room contains three wall-hung gas boilers as back-up.

3.1.2.Ventilation

The building is naturally ventilated apart from the glazed meeting rooms in the Southernmost corner of the building, which have localised fan coil units and the Conference room, which is mechanically ventilated by an air handling unit. Manual controls are wall-mounted in both spaces.

Figure 20 Air-conditioned meeting room and conference room fan controls

All the rooms located on the Southern and South-Western elevation have ventilation stacks with Monodraft Windcatchers that are linked to the Windowmaster system along with the high-level automated windows to facilitate cross-ventilation. The Windowmaster system was specified to provide night-purge ventilation – each office has an exposed ceiling for thermal mass. Tenants are able to override the Windowmaster settings via local switches. The Windowmaster system has its own BMS, installed on a different computer from the rest of the building's BMS. Windowmaster have remote access to this.

Figure 21 window controls at IC and brise soleil

The low level windows are manually operated and the latch can be un-hooked on each one to provide greater open area in summertime. The windows are equipped with a manually operated brise soleil.

The Windowmaster sytem also controls nigh-cooling, by opening the motorised windows and ventilation stacks at night during periods of very warm weather, to cool the heavy-weight fabric of the building. The WindowMaster system is fully addressable meaning that different parameters can be set for different rooms, such as temperature set-points and maximum window openings.

3.1.3.Small Power

Socket outlets are generally provided via floor boxes and in some areas supplemented with flush wall sockets. These boxes will contain 2No. twin switched socket outlets and 4No RJ45 data sockets. The rest of the building has socket outlets mounted on the wall apart from the Meeting rooms and Youth room which will have a combination of both floor boxes and wall mounted outlets.

3.1.4.Lighting:

Lighting in the offices is by suspended luminaires with acoustic damping built into the fittings. The lights are grouped into rows and switched with retractable wall switches. When these are pressed the lights turn on and those in the row closest to the windows automatically dim in response to the daylight from the window. The occupant can then dim the rest of the lights manually via a wall-mounted dimmer-switch. The rooms are equipped with absence detectors programmed to 20 minutes.

Lighting in the meeting rooms and Conference Room is by downlighter fittings recessed into the suspended ceiling grid. These lights are switched on/off and dimmed by occupants at the dimmer switch on the wall. Similar to the offices, the rows of lights by the windows are automatically dimmed according to the levels of daylighting and the infra-red detector senses when the rooms have been vacated for 20 minutes and switches off all the lights.

The external lighting is switched by a timeclock in reception and a daylight sensor on the north face of the east end of the building, above the plantroom. The external lights are automatically switched on during the hours of darkness, except in the cycle shelter where these are triggered by infra-red presence detector with daylight sensors.

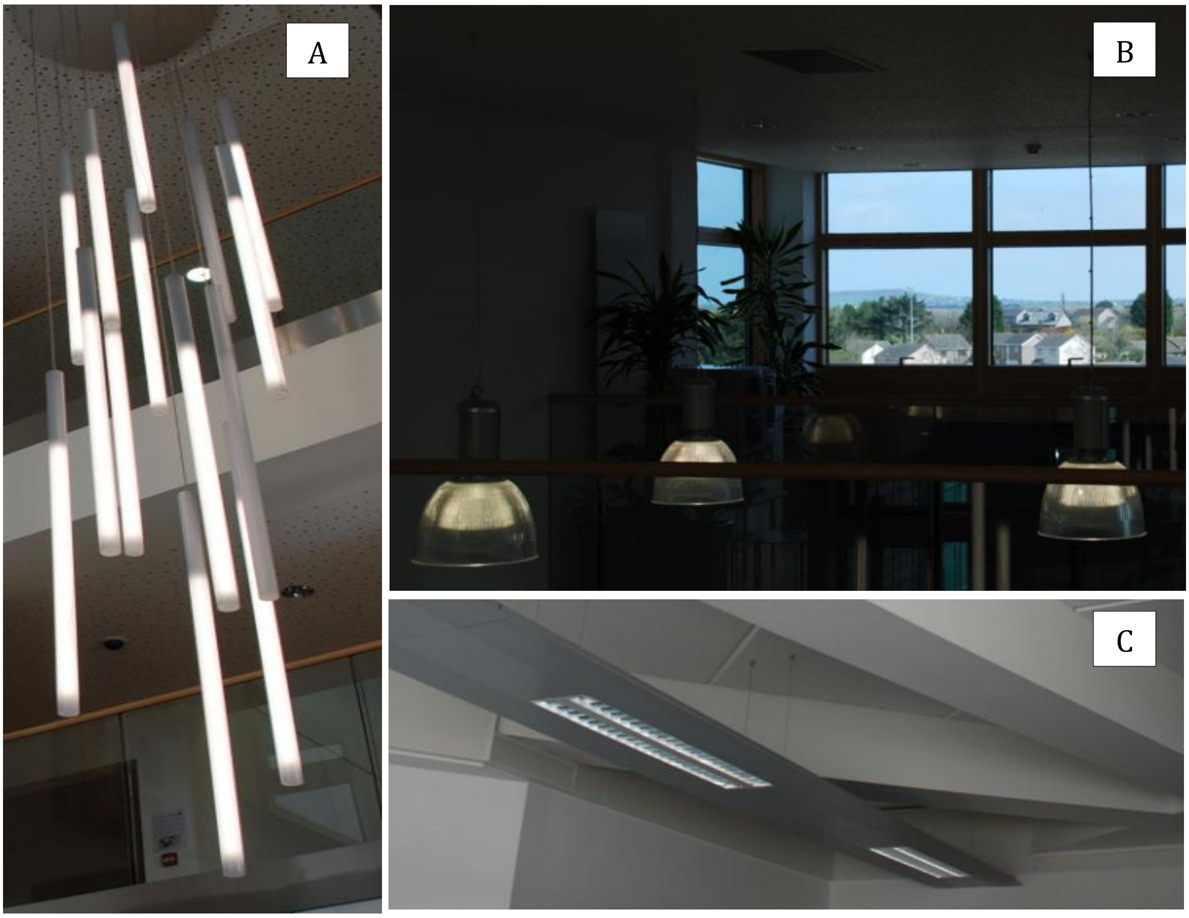


Figure 22 A Feature lighting in atrium, B Suspended lighting in atrium, C Fluorescent strips

3.1.5.Data, Access Control and Alarm

The offices are supplied with data outlets in the floor boxes connected with Category 6a data wiring to patch panels located in a data cabinet in each office. Internet and telephone connections are provided by multi-bundle copper links from the office data cabinets to the central server rooms. In parallel to the multi-bundle copper cabling, fibre cables have been laid but not connected, for use if higher data rates are required in the future.

An extensive access control system is installed throughout and comprises of electronically controlled doors. Door entry is only granted on presentation of a valid key fob. There are six external and three internal CCTV cameras installed. Each office space is installed with its own, independent intruder alarm. The offices each have 2No presence detectors and an alarm set/reset point in the office, which is activated by a key fob. One key lesson from PIC was to turn these sensors away from the windows so that the alarm is not triggered by insects during night-purge.

The fire alarm is linked to the access control system, and on sending the evacuation signal, all the access controlled doors will be unlocked to allow unhindered escape.
The operator can administer and control the access control system from a PC monitoring point in a lockable cupboard in reception.

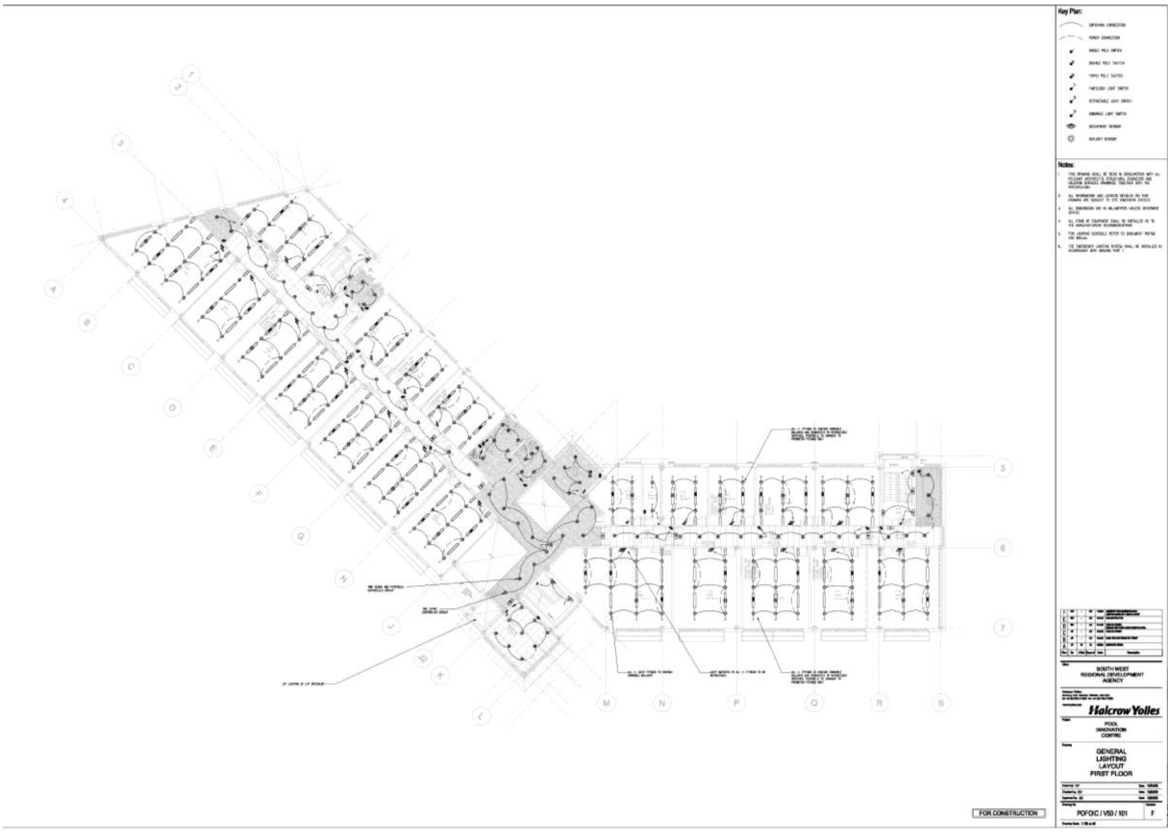


Figure 23 PIC lighting schedule for L1

3.1.6.Vertical transportation:
There is a 13 person Kone lift in the building near the central core.

3.1.7.Solar Photovoltaic:
The southern corner of the building housing the meeting rooms is curtain glazed with solar pvs incorporated into the low level panels on Level 2.

Figure 24 Solar PVs incorporated into curtain wall

3.1.8.Water management, rainwater harvesting:

A rainwater harvesting system has been installed to collect and store rainwater from the roof drainage and use this water to flush WCs and urinals. Washroom basins (standard and accessible) are provided with a single percussive tap. It is blended to provide warm water, and is fitted with an aerating (low flow) head. General purpose toilets are included with proprietary panel system to conceal dual flush (6/4 litre) water saving push button cisterns. Leak Protection on the incoming water main is provided with an audible alarm. The alarm is activated when a pre-set flow rate and duration are exceeded. The system is able to identify different leakage rates over a set time period and is linked to the BMS. Metering is provided by pulsed meters, linked to the BMS system to enable automatic meter reading.

3.1.9.Metering:

The main electricity, gas, water as well as PV and rainwater harvesting meters are located in the ground level metering room. Meters are provided on incoming supplies, LV Panels and sub-branch supplies as dictated by the regulations. Heat meters are provided to enable the separate metering of the heating demands for each floor of the building.

Each meter is equipped with a pulsed output which was intended to be monitored by the BMS – this did not prove to be reliable.

Each office is submetered however lighting and small power are not separated. Kitchenettes, the lift and other key end uses are submetered largely following CIBSE TM39.

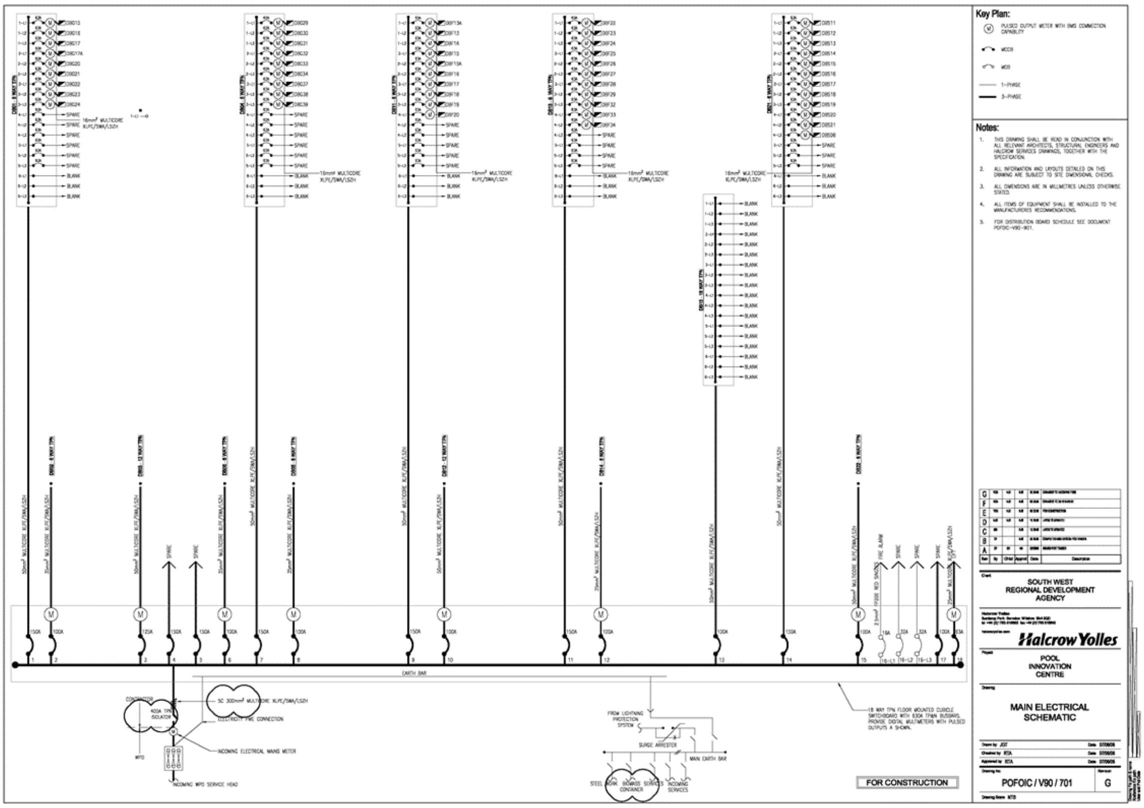


Figure 25 Meter schedule

Room by room electrical meter readings were mapped onto the floorplate schematics to visualise the rooms where electrical consumption was higher. This information was used to choose typical rooms for sampling high, medium and low level electrical consumption around the building.

Figure 26 Visualisation of room by room electrical consumption

3.1.10. Building Management System:

The Schneider Electrics BMS is operated from the same control room as the Windowmaster system. Its visual output is projected via a TV screen in the building lobby. It is intended to show the consumption of water, electricity and heat, and shows the contributions to these from the renewables installations, i.e. the rainwater harvesting, biomass heating and photovoltaic glazing in the meeting rooms, and related carbon emissions.

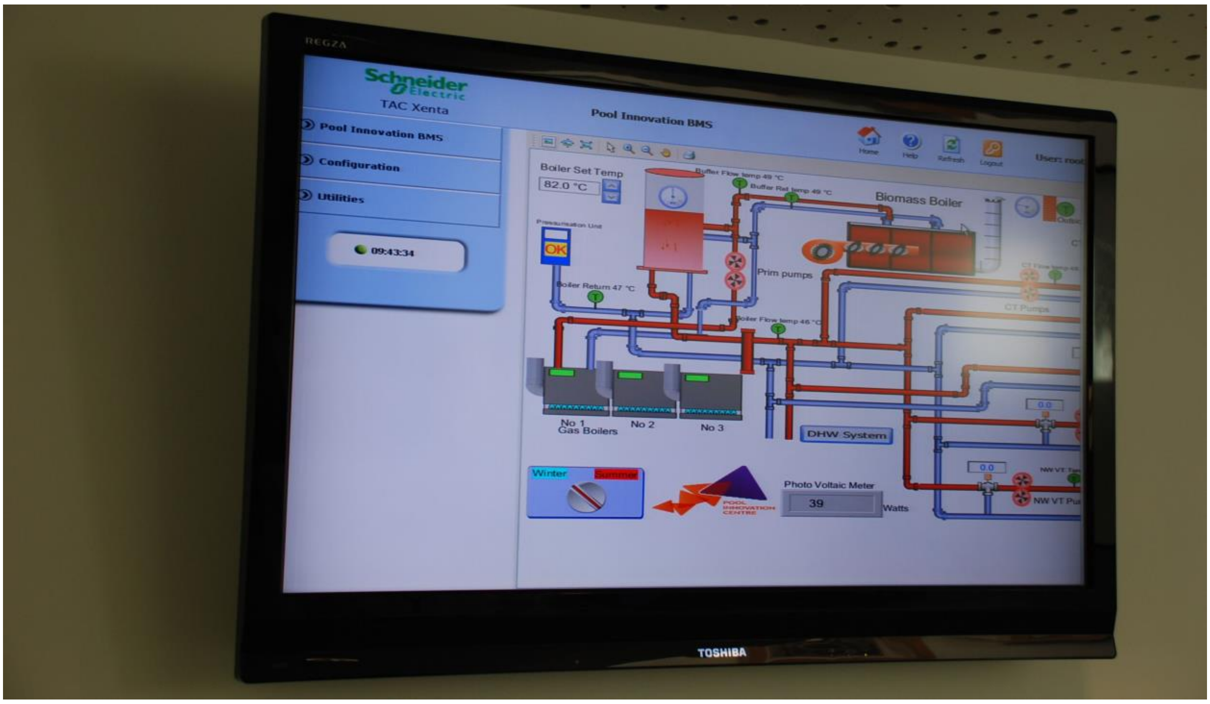


Figure 27 BMS screen output in building lobby

“Low fuel” and “heating failure” indicator lamps are also found in the reception, to provide warning that a wood pellet order needs to be placed or that the system requires attention.

The fire alarm is linked to the control panel. On fire alarm activation, the boilers and air handling systems will automatically disable.

3.2 Tremough Innovation Centre

TIC was completed in Nov 2011. The energy strategy was led by a fabric first approach as at PIC. Numerous sustainability features were incorporated in the design including natural ventilation, a biomass boiler, earth tubes, rainwater harvesting, brise soleil, mineral wool insulation, and AAA rated appliances.

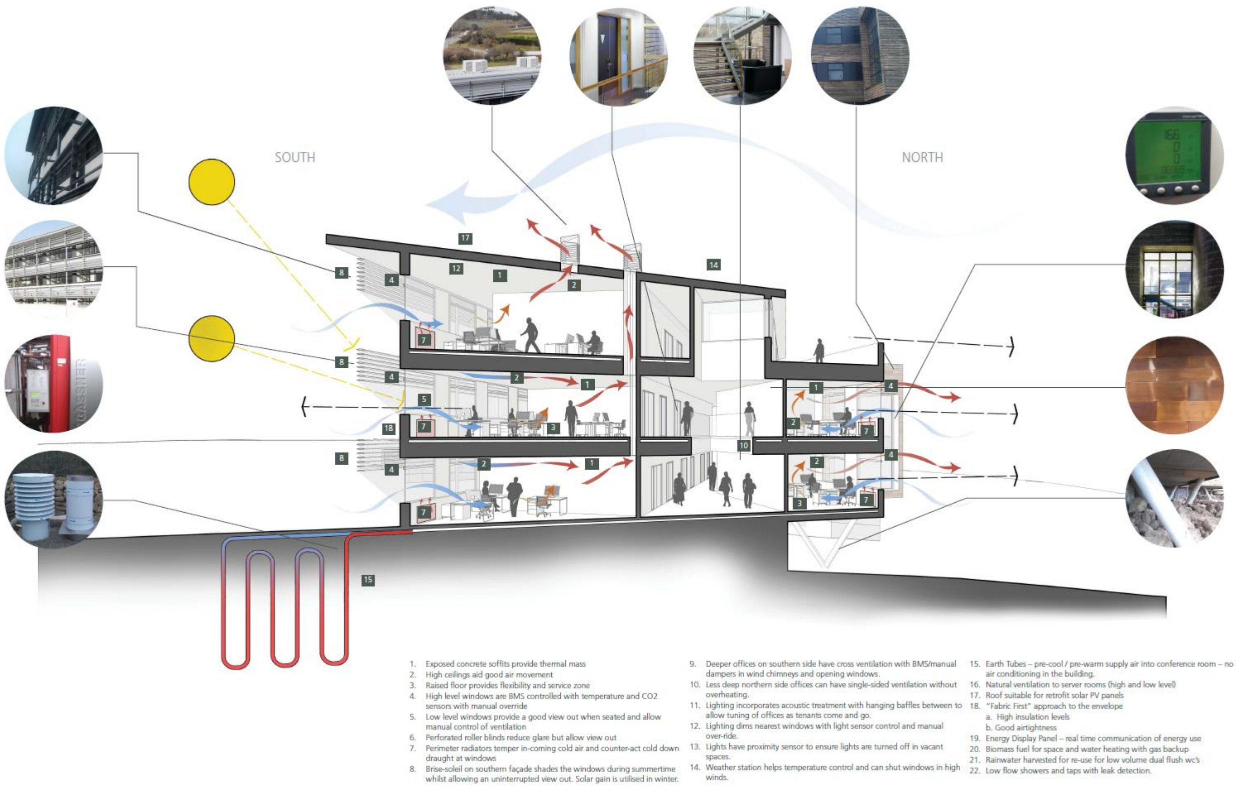


Figure 28 Image of TIC environmental strategy

3.2.1.LTHW Heating

The Heating system consists of a biomass lead boiler assembly & 3 number gas fired high efficiency condensing boilers to top-up during peak loads & provide back up to the biomass. LTHW heating is generated, stored (within the biomass buffer) & circulated around the primary circuit at 80°C. From here Variable & Constant Temperature secondary circuits have been installed to supply heating water to the domestic hot water, radiators & air handling plant within the building.

Twin head, intelligent inverter driven pumps have been fitted to optimise energy usage – pressure transducers monitor the system pressure & self-regulate to maintain a constant head, determined during commissioning. This ensures that the flow through the secondary circuits is reduced as control valves (radiator TRV's) shut down around the building.

Heat emitters within the building are predominantly perimeter radiators – steel panel type in Office spaces, vertical column in the Central Lobby & low level floor standing type in front of full height glazing. Each radiator has a Thermostatic Regulating Valve (TRV) fitted on the flow & a matching lockshield valve on the return fitted for control & balancing purposes. Trench heating has been installed to some offices. The boilers, pumps & ancillary plant are controlled / monitored from the BMS control panel mounted on the wall in the Plantroom.

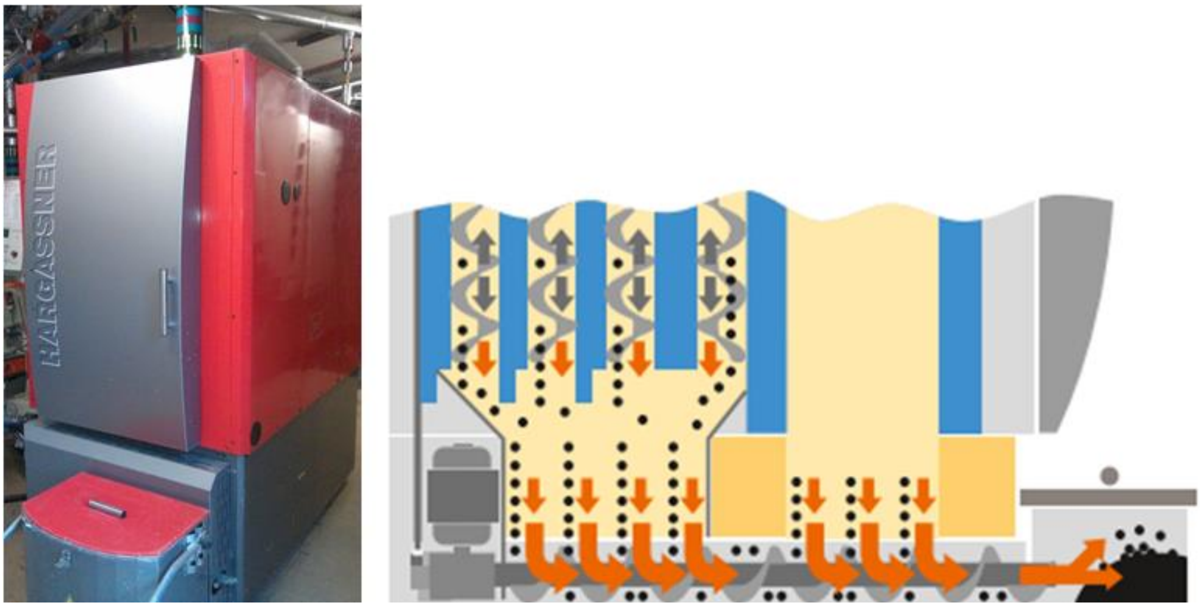


Figure 29, Pellet boiler and diagram of automatic de-ashing system

A Hargassner WTH110 (100 kW) pellet boiler has been installed at TIC. It has a very large fuel store due to originally being specified as a woodchip boiler. Woodchips have a lower energy density than pellets, meaning they require more storage to give the same amount of running time between fuel deliveries. In contrast to the biomass boiler at PIC, this boiler is self-cleaning and so does not require administrative staff to de-ash it on a regular basis.

3.2.2.Heating loops

The hot water system consists of an un-vented, indirect central storage cylinder; with heat supplied via a pumped constant temperature LTHW circuit. Hot water circulation temperatures are maintained by the installation of a pumped return circuit, with hot water being stored & circulated at 60°C flow, to offset mains losses & ensure a minimum return water temperature of 55°C to control the risk of Legionella.

Figure 30 Picture of heating pipes in plant room

3.2.3.Radiators

Generally, perimeter radiators are installed with TRVs. Primary heat source is part load biomass with full gas top up.

3.2.4.Trench heaters

Although most offices at TIC are heated with radiators, several offices have trench heaters instead. These offices have floor-to-ceiling glazing and so cannot have below-window radiators. These heaters do not appear to provide enough heat to offset the losses from the large area of glazing and negative feedback has been received.

Figure 31 Trench heaters in meeting rooms

3.2.5.Rainwater harvesting

A separate rainwater harvesting system has been installed to provide rain water for the wc's, urinals & external irrigation & wash-down outlets. Surface water from the roof is filtered & collected within an underground holding tank. From the underground tank, water is pumped to a day tank within the building & from here; grey water is distributed as above to the required final devices.

A mains water top-up has also been connected to the day tank to ensure the service is maintained during periods of low rainfall. Pulsed water meters have been installed on the rainwater & mains water supplies to the day tank, which will provide details of the amount of mains water saved through rainwater harvesting via a digital display panel. The meters are also linked to the BMS to permit historical data logging if desired.

3.2.6.Ventilation

The majority of the building is naturally ventilated. Each room generally has both low level manually openable windows and high level, intelligently controlled, motorised windows. The windows also include trickle vents. The south elevation rooms, which are deeper plan, also have a wind chimney at the back of each room. A single wind chimney shaft serves one room only, i.e. separate rooms do not share a chimney. A motorised damper is provided at the top of each wind chimney.

All motorised windows and dampers are individually addressable and are linked to the fire alarm. As they are all individually addressable, certain windows and dampers can be programmed to remain open whilst others can be programmed to close when the fire alarm is activated.
The Conference Room is served by a dedicated air handling unit (AHU) and is linked to the fire alarm and will shut down in the event of fire alarm activation.

The three meeting rooms are served by in room balanced heat recovery units. The air intake and exhaust is via a wall penetration adjacent to the atrium stairwell. A local wall mounted controller operates each individual unit with adjustment of ventilation rate & time schedules. Gravity back draught dampers have been fitted to isolate the fresh air intake & exhaust ducts when the units are not running. All units have been linked to the fire alarm system to shut down during fire alarm condition. Fire dampers are installed where ductwork passes through fire compartments.

A domestic style extractor hood has been specified for the kitchen which extracts at roof level and rises through the building in a fire rated enclosure.

In order to satisfy the BREEAM requirements, mechanical ventilation has been designed to provide fresh air at a minimum rate of 12ltrs/sec/person (Building Regulations specifies a minimum rate of 10ltrs/sec/person) and natural ventilation calculations have been undertaken to demonstrate sufficient ventilation rates in both the single sided rooms and cross ventilation in rooms with wind chimneys. Each room has a window openable area of at least that equivalent to 5% of the floor area.

3.2.7. Earth tubes

Earth tubes are used to pre-condition air which is brought into the conference room at TIC. The system draws air in through a labyrinth of heat exchange pipes.

The earth tube heating system at Tremough added a certain level of complexity to the design, but meant that active air conditioning could be avoided.
Energy saving is a function of annual heating and cooling gain and annual energy consumption by fans. Heating and cooling gain depend on the respective demands, and the rate of heat transfer which is a function of time air spends in contact with the surface of the pipes (itself a function of air flow rate and turbulence of the flow), temperature differential between the incoming air and the pipe surface, and the conductivity and thermal capacity of the soil.

Figure 32 Earth tubes in conference room

An optimal system would balance an increase in specific fan power with a reduction in cooling and heating energy (and pump energy to supply the heat/coolth to coils). It would also balance heat and coolth extracted across the heating and cooling seasons.

3.2.8.Cooling

Post contract air conditioning has been instructed. As a result these units are not shown on the as installed drawings.

The Server Rooms on each floor have split DX cooling only systems installed to maintain internal space conditions at the requirements of the data equipment contained within. The systems comprise an internal wall mounted cassette situated at high level in each Server room linked to an external condensing unit via brazed copper pipework, thermally insulated with armaflex. The condensing units are situated externally on the second floor north balcony. All pipework & wiring is contained on galvanised containment installed within the Server room riser and floor voids. Local wall mounted controllers have been fitted to control & monitor each individual system.

An IP rated isolator has been mounted externally to enable isolation and maintenance of the equipment. The internal unit is powered by the external condenser unit.

3.2.9.Lighting

The lighting at TIC followed in the footsteps of PIC. Suspended luminaires with acoustic damping built into the fittings were installed at the offices and compact fluorescent recessed downlights in meeting rooms and common areas. The lights were surveyed using a combination of lighting schematics and on-site checks of luminaires installed.

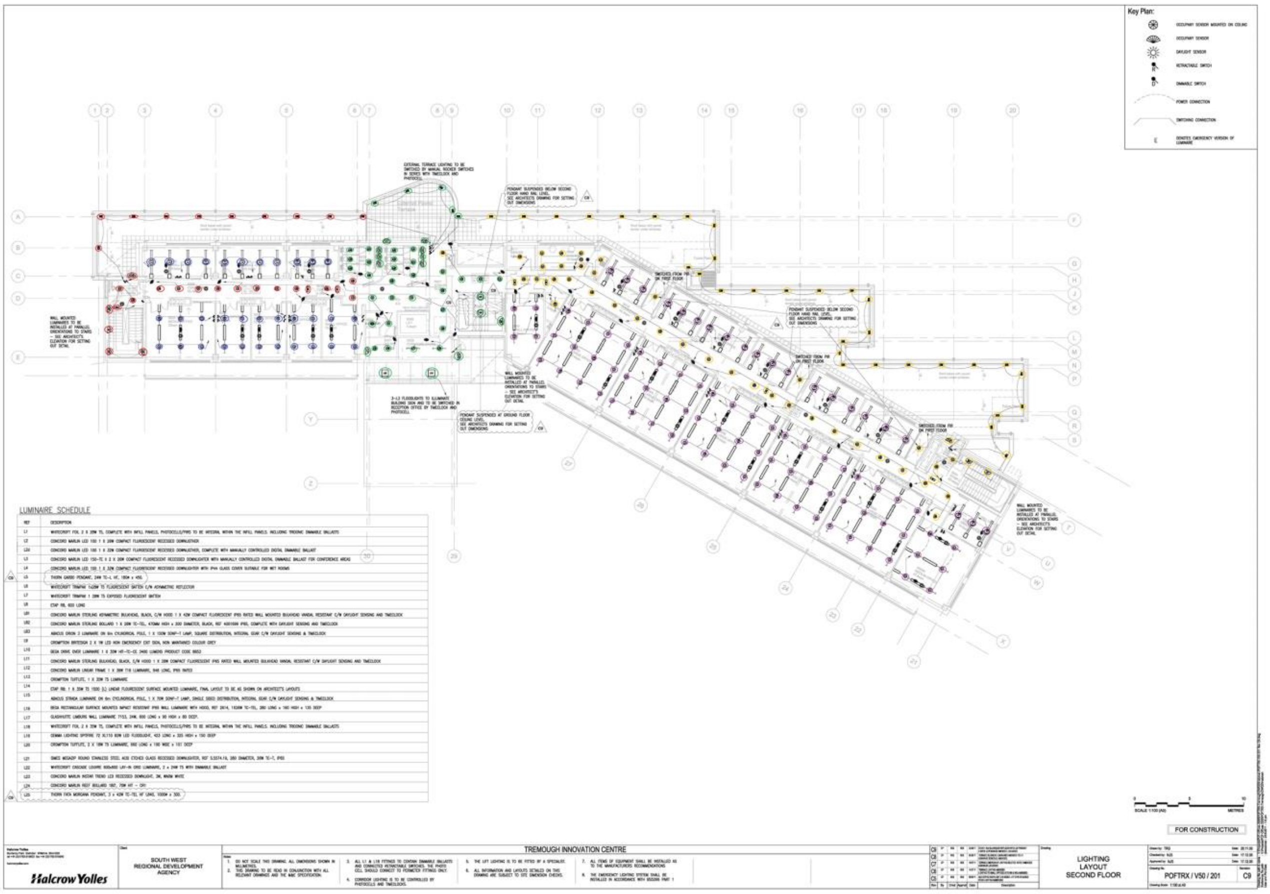


Figure 33 TIC 2nd floor lighting schedule

3.2.10. Metering

Electricity sub-metering has been specified throughout to sub-meter substantive energy uses such as ventilation plant and also separately tenanted areas such as the cellular office spaces. As at PIC, the appliance loads in offices were not metered separately from lighting. Heat meters are also specified for the biomass plant. The principles of the metering strategy detailed at PIC were largely followed at TIC.

3.2.11. Access Control
Maglocks have been specified on the main corridor doors and entrance doors to the building. These are linked to the FA and will unlock in the event of FA activation. In addition, emergency break glass units have been provided to provide direct de-activation of the Maglock.

3.2.12. Fire Alarm
Magnetic door hold opening devices have been specified on the secondary corridor doors. These are linked to the fire alarm and will release on fire alarm activation.

Disabled pull cords have been specified in all disabled toilets.

The main escape doors from the building are currently specified to be linked to the fire alarm but shall be re-specified to be linked to the intruder alarm (in order to deter misuse).

An L2 fire alarm system has been specified which generally comprises of a combined smoke detector with sounder and flashing beacon in each space. Break glasses have been included on all internal doors and at the top of stairwells.

A disabled refuge intercom linking all refuge points with the main entrance had been specified.

3.2.13. Vertical transportation
A Part M compliant 13 person lift has been specified. The lift is also connected to the fire alarm and will return to ground floor with doors open in the event of fire alarm activation.

3.2.14. Building management System
A new intelligent BMS control panel has been installed within the Plantroom to supply, control & monitor the Mechanical Services to the Innovation Centre. The panel is interlocked with the fire alarm system to shut down plant during alarm mode & to provide status indication of the fire alarm back at the head-end terminal.

4 Key findings from occupant survey

Technology Strategy Board guidance on section requirements:	This section should reveal the main findings learnt from the BPE process and in particular with cross-reference to the BUS surveys, semi-structured interviews and walkthrough surveys. This section should draw on the BPE team's forensic investigations to reveal the root causes and effects which are leading to certain results in the BUS survey; why are occupants uncomfortable; why isn't there adequate daylighting etc. Graphs, images and data could be included in this section where it supports the background to developing a view of causes and effects.

4.1 Pool Innovation Centre BUS Analysis

4.1.1.Introduction

The Innovation Centre is a business incubator where individual organisations lease classroom-size offices that are arranged in an open plan. Occupants are predominantly desk-based and vary in density and in their hours of use. They are almost uniquely start-ups with a maximum period of three years' stay in the building. 43% of employees have been there for a short time.

The Building Use Survey was conducted in July 2013 in accordance with the BUS guidelines. 130 survey sheets were handed out and 97 of these got returned, indicating a 75% response rate.

Further characteristics that need to be borne in mind are as follows:

- 66% of those surveyed are over 30
- Gender distribution is approximately 50/50%
- 41% sit next to a window
- 57% worked in the building for over a year
- 97 out of 130 forms returned – 75% response rate

4.1.2.Overall results

The overall BUS results are shown in Figure 2, below. Green squares represent mean values that are better or higher than both the benchmark and the scale midpoint. Amber circles are mean values worse or lower than the benchmark scale midpoint. The benchmarks, calculated based on a rolling database of 50 UK buildings of all types, are shown as illustrated in Figure 1.

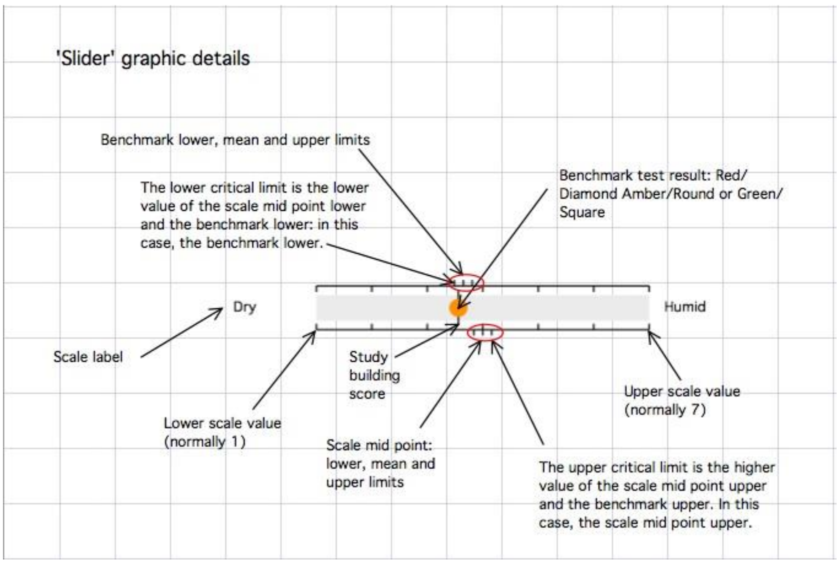


Figure 34 BUS Slider

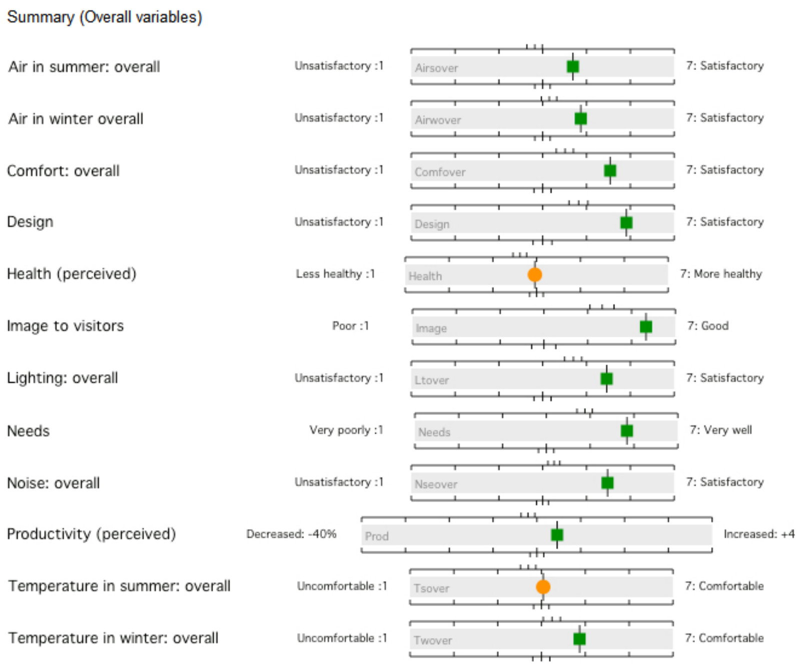


Figure 35 Summary Comfort Scores

Occupants scored the building above the benchmark on all summary variables. Occupant feedback on all variables will be explored in further details in the remaining sections of the report. Recurring issues were people feeling too warm, window controls, lighting controls, outside noise, floor box layouts, not having enough space to park, the toilets not being clean enough and some parts of the building appearing to age too fast (such as cedar cladding). The majority of positive comments relate to good design, the airiness of the building, the daylighting, productive layouts, quality of indoor environment and occupier needs generally being well met.

4.1.3.Temperature

The graphs in Figure 3 show that the survey respondents scored within the confidence limits of the benchmark. Variability is well within the benchmark. Occupants report that winter temperatures appear to exceed the optimum range while variability is within this.

Occupant comments support the BUS results, many have commented on feeling too warm, others cold:

"Being too hot. Back and forth with the windows cold when open, too hot when closed. Windows are broken, blinds bang when windows open."

"Noise & heat are biggest set backs"

"Gets hot in summer"

"Glare on screen. Uncomfortably warm & humid except when windows decide to freeze the room"

"Office can sometimes be too warm"

"The heat. It is really warm without heating. A little too much"

"Better temperature control"

"too warm ,windows seems to be mad sometimes"

"Good design -winter -warm summer-cold"

"I dress warmly for the office in winter"

"I sometimes wear more clothes as its cold"

"Temperature really lets it down. Gets too hot quickly and only way to cool down is to open the windows so you get a freezing draught! Needs better aircon"

The results are in line with our observations during walkabouts that areas of the building can be warm in the summer as well as in winter. Several companies with high equipment loads occupy south facing rooms as shown on the electrical appliance use 'heat map' provided in previous reports. Thermal comfort over the summer could be further improved by adjusting the night purge settings in the building. Due to the poor positioning of security sensors, which face the windows and were often triggered by insects and as a result this function has been switched off in the BMS.

We also received comments from occupants about the meeting rooms being too hot in the summer. These rooms are mechanically ventilated and cooled but there is a time lag between the systems kicking in and optimum comfort levels being reached.

Perception of excessive heat in wintertime could be addressed by lowering set points and heat flow temperatures of the heating system. During onesemi-structured interview the FM commented that it is difficult to cater for different comfort perceptions. Some tenants require higher temperatures and that drives the heating setpoints because it is easier for everyone to open the windows when they are warm rather than allowing some tenants to be too cold. The radiators have been equipped with stop-caps that prevent occupants that feel cold increase temperatures in their space too much.

Our advice to the building managers was to lower wintertime set points, monitor occupant satisfaction and consider removing the radiator valve stops in the rooms where occupants are cold.

With regard to the BUS benchmark the building is around the 90th percentile for control of both heating and cooling. Temperature in winter, is outside the benchmark optimum range as illustrated in Figure 36.

Figure 36 Temperature variables

Insightful occupant comments were as follows:

"The sensor for the windows are located a long way from them and the windows have often caused problems with being too cold in winter

"There is no control of temp. Windows don't work all the time

"Too hot & stuffy. Cannot control temperature. Auto windows broken."

"Automatic windows opening on windy days"

"Windows do not always stay open"

"Heating control via reception"

4.1.4. Air quality

The results here fall within or below the benchmark for all variables except winter air movements. Perception of odours in both summer and winter are better than the benchmark. Winter air is perceived more still than the benchmark range in the BUS database. Freshness in the summer is marginally lower than the BUS benchmark.

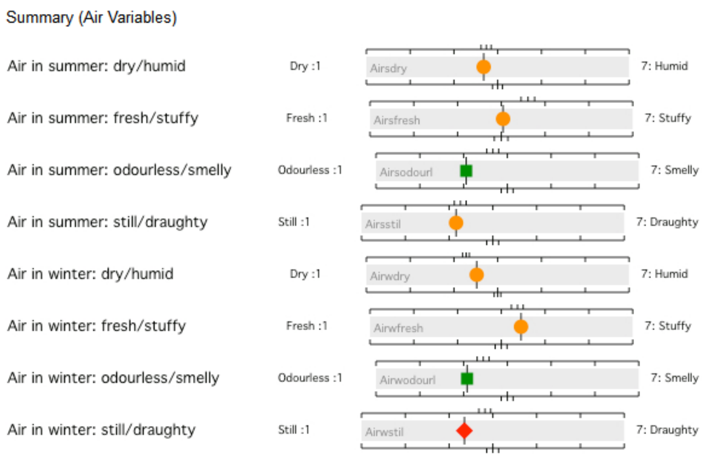


Figure 37 Air variables

Occupier comments were as follows:

"Good ventilation"
"the light airy atmosphere is conducive to hard work"
"Sec. temperature"
"Being too hot,stuffy,cold makes it difficult to be productive"
"We do seem to pass cold/flu around quite quickly"
"Stuffy when windows are shut"
"Usually very ….. & comfortable"
"Very comfortable"
"Improved conditions from previous premises better condition, overall feel happier & more productive"

Survey results for control over ventilation were as follows:

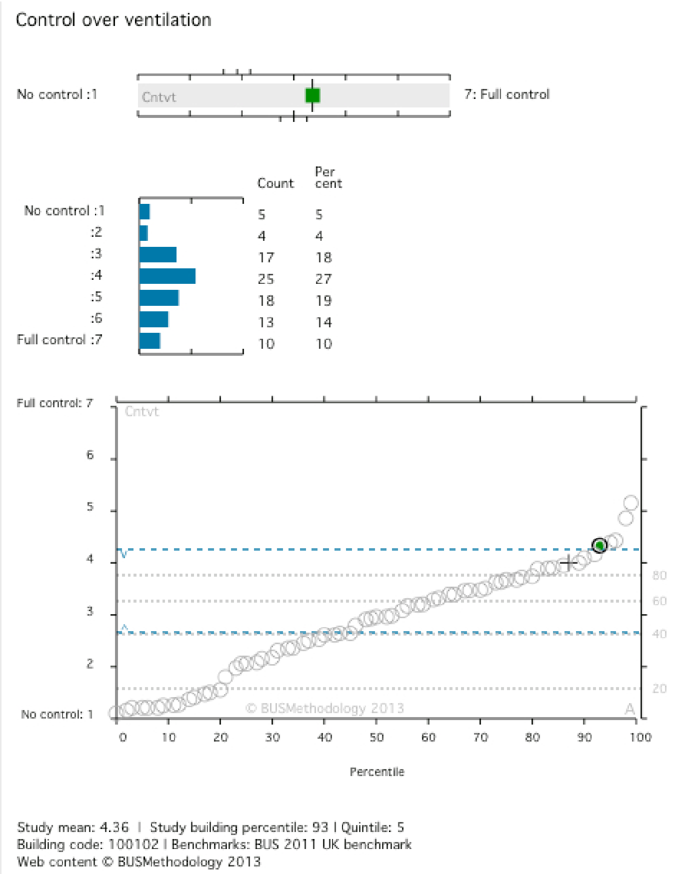


Figure 38 Ventilation results

Occupier comments included the following:

“Asked for automatic windows to open more frequently, no change noticed.”

“have occasionally asked for windows to be opened”

The overall ratings for air quality in both summer and winter are above the benchmark and occupants report that they don't lack control opportunities.

4.1.5.Lighting

67% of occupants considered artificial lighting to be at the scale mid-point. A further 15% thought it was a bit too much (score 5) with the remaining 9% and 7% rating it as too much and too little respectively. Glare from lights was slightly below the scale midpoint but typical against the benchmark. In terms of the availability of natural light 65% of those surveyed thought it was just right and 20% thought it was too much. Interestingly feedback on glare was well within the confidence range, again scoring close to the scale mid-point.

Figure 39 Lighting variables

Few occupants commented on artificial lighting:

“Office lighting gives migraine to colleague, very intense”

"Sometimes I get headaches from the lighting, but also the computer screen is also a factor"

With regard to natural light the following comments may provide some explanation on 'too much light' being marked on the survey sheet:

"Blinds too thin, don't stop the sun blinding you & creating glare on screen"
"on front of building the sun coming into offices does create glare"
"The blinds aren't very good, the sun still beats through it can be blinding when facing the window."
"The window blinds are inadequate if the sun is shining directly into the office.

Yet others stated that "Blinds helpful" and many rated the daylighting a positive feature of the building:

"Car park side great. Too bright on road side"
"good"
"Perfect"
"All fine"

There were several comments relating to lighting controls:

"Lights automatically turn off after 30 mins have to manually turn on again. Faulty??"
"Lights turn off in meetings and when sitting working"
"Lights turning themselves off in the evening is annoying"
"Sensor are ineffective. Turns off when people are in the office!"
"Auto switch off lights is annoying as they switch off when I don't want them to! Sometimes at night time!"

The survey results show that electric lighting was within the benchmark:

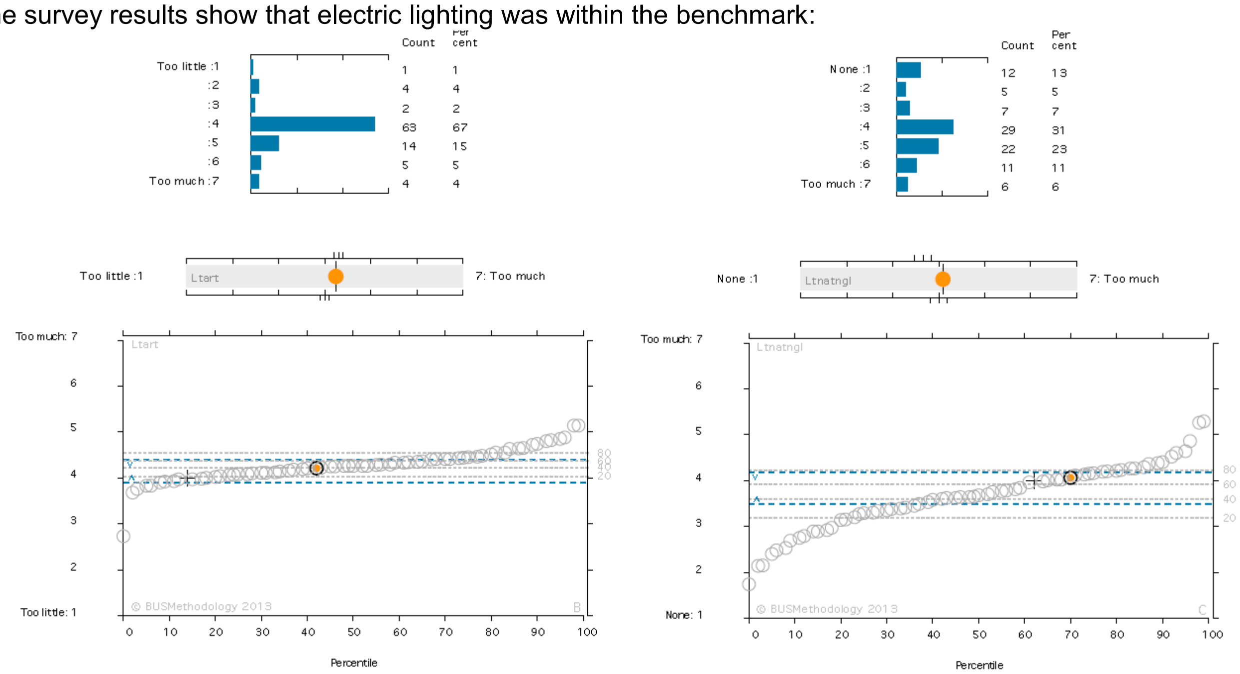


Figure 40 Electric lighting and glare results

The team recommends agreeing with the tenants on the time lag for absence control on a room by room basis. The blinds should be examined and a change in system considered at the system's end of life. It is not clear whether glare is a problem during the summer or the winter and we suggest further discussions with the tenants around this.

4.1.6.Noise

Occupiers scored noise overall in the 96 percentile of the study buildingswith 72% rating the conditions abovescale mid-point and the reference benchmark dataset. Negative feedback arose from the extensive construction works undertaken on one side of the building, with occupiers finding the construction noise disruptive. The survey results show that control over noise was generally satisfactory.

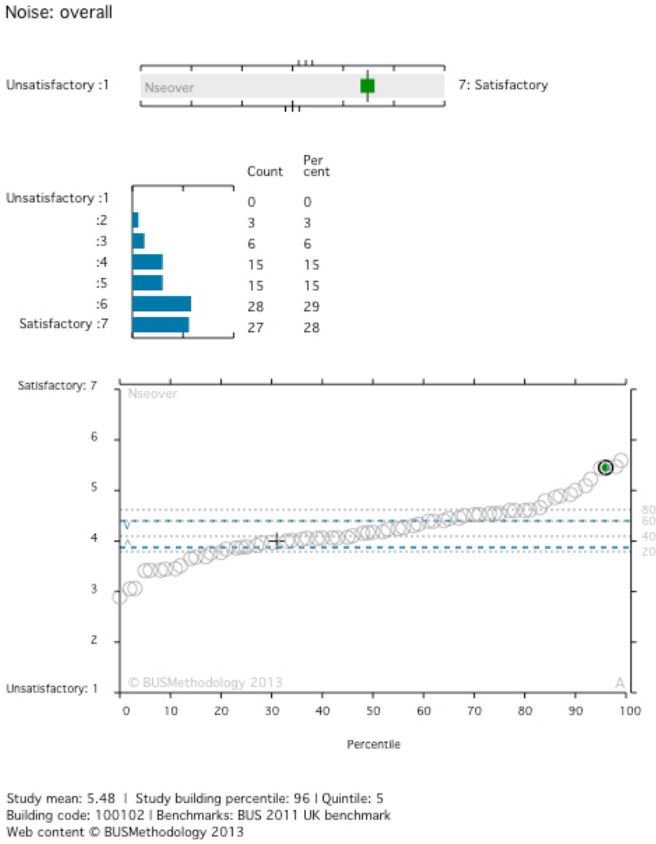


Figure 41 Noise control results

The detailed scores however highlight noise from the outside being somewhat too much while noise from other people and noise from colleagues being close to the scale mid-point and within benchmark. These do not seem to cause unwanted interruptions.

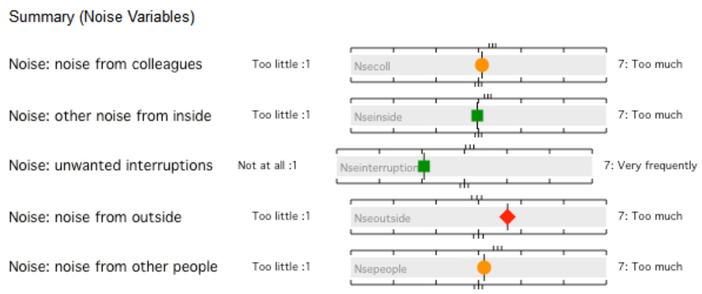


Figure 42 Noise Variables

Occupiers commented on the following:

“All fine”
“Building noise could be distracting but is obviously unavoidable”
“Building site noise was awful but over now. Sometimes if windows open get screaming students outside”
“Building site (not recent) small amount from road, not too bad”

"Building work"
"Building work next door very loud. Wind whistles through windows very loud."
"Depends, if we have an event going on in the atrium it can be noisier than usual"
"Road side is too noisy & hot. Car park side great"
"Road side office very noisy when windows are open"
"Traffic noise is the only issue, particularly when windows are open , so more of an issue in the summer"
"The road noise when the windows are open is awful, it's so bad, hearing the phone is difficult"
"Some people make phone calls in the corridor and this can be heard from within the office."
"When there are gatherings in the atrium noise does travel upwards and can be very loud and disruptive if you are in the breakout area"

Preceding the survey the site adjacent to the building had ongoing demolishing and building works for an extended period of time. Comments around road noise were raised on the roadside elevation and this is not uncommon for a naturally ventilated building overlooking a busy road. However this did not seem to interrupt people's work nor was occupants' sense of their control over noise affected: overall noise control scores were in the 92nd percentile of the benchmark building set.

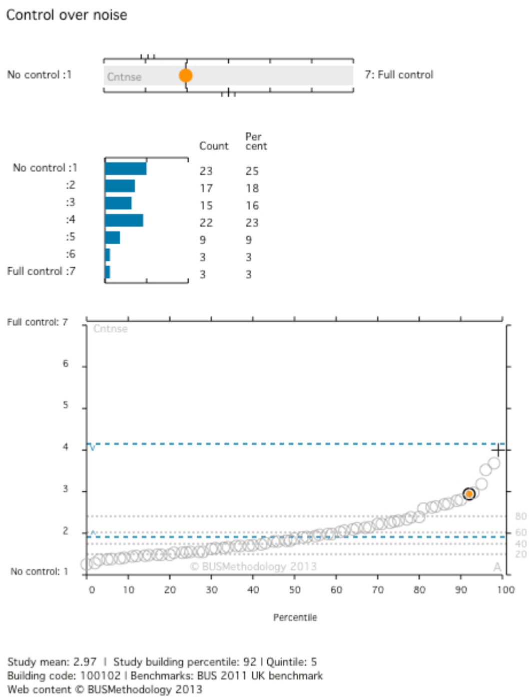


Figure 43 Noise control results

4.1.7.Controls overall

Controls are discussed in this report in further detail against each of the BUS variables... Survey responses place the building around the typical benchmark, except for control over ventilation, which was scored significantly higher than the benchmark dataset. Despite the positive score, window controls were mentioned often in the occupiers' comments, which will feed into the specification of automated window systems in the future.

Figure 44 Overall control results

4.1.8.Design/Needs

The building scores above benchmark.

In line with the high level of satisfaction we see from the variables the majority of comments are positive, with negative ones relating to parking, IT and the lack of communal/café space. Window control, outside noise and heat are highlighted both by comments and the survey variables.

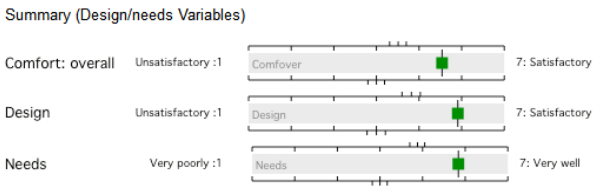


Figure 45 Design variables

“Aesthetically well designed. Good layout”
“Modern & bright”
“Good design -winter -warm summer-cold”
“Impressive design & very modern”
“Interesting without being overtly different. Nice use of materials reflecting Cornwall”
“Very smart, clean and crisp looking”
“Well designed building, good features”
“Local, secure, available 24hrs, well placed”
“Facilities are great, all needs met.”
“Sufficient office space”
“Love the way it looks but some of the functions let it down, kitchens, heating & lighting”
“Nice exterior. Interior has aged a lot”
“The kitchen space is not sufficient. Meeting rooms are good”
“No small offices, poor reception layout, inadequate parking”
“Window, noise, blinds, toilets”
“Love the way it looks but some of the functions let it down, kitchens, heating & lighting”
“Canteen/café would be good. More parking”

The meeting clearly meets occupier needs and users appear to be extremely happy in the building and there is a low turnover of tenants.. Some tenants mentioned to the monitoring team during walkabouts that they would find it difficult to leave once their tenancy period expires – there is a maximum term of three years for each organisation. Such comments were reflected in structured interviews with the FM.

4.1.9. Facilities management

Apart from having too much space at desks all variables scored above the benchmark. Occupiers perceived the building to significantly contribute to their productivity – the building is in the 97th percentile of the database on this variable and 95th with regard to facilities. The competence of facilities management may have contributed to the high positive score of the building. During site visits facilities staff were always friendly and responsive, displaying a high awareness of occupier needs.

Similarly to TIC only one variable is marked red, relating to 'space at desk' despite the vast majority of comments received indicating high satisfaction relating to desk space..

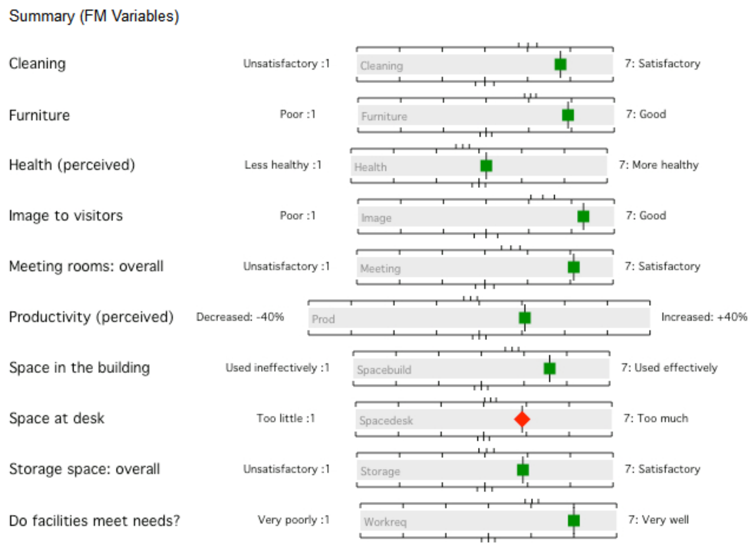


Figure 46 FM variables

"High speed broadband,comfortable desk,comfortable climate"
"Good space for set up of desk arrangements"
"Good amount of space"
"Could do with more space"
"Plenty of space comfortable desk area"

4.1.10. Conclusions

PIC is a naturally ventilated building with a C rated DEC achieving good comfort ratings. It is clear that the occupiers are happy with the design too with the main architectural criticisms being raised relating the degradation of finishes and allocation of kitchen space. The building seems marginally warm to some users in winter. Some issues were also highlighted around controls for temperature and lighting. Excessive noise from building works outside had an impact on occupants' perception of noise and results relating to winter air quality were tending towards hot and still.

The occupants' scores on perceived health were typical against benchmark and just below scale midpoint. and further examination of the comments indicated that aside from two comments the building was not perceived to have had a strong influence on occupiers' health.

Some aspects of the BUS scoring were found to be inconclusive. The Building scored 'red' on natural light(too much) and space at desk (too much), yet the occupier comments appear to be overwhelmingly positive around these aspects of the building. the reason for occupants reporting too much space at desk is unknown.
An explanation of how the BUS benchmarks were defined would be helpful. It is understood from Arup that all the non-domestic buildings in the TSB BPE study were benchmarked against the same set.

4.2 Tremough Innovation Centre BUS Analysis

4.2.1.Introduction

The Innovation Centre is a business incubator where individual organisations lease classroom-size offices that are arranged in an open plan. Occupants are predominantly desk-based and vary in density and in their hours of use. Almost all are start-ups with a maximum period of three years' stay in the building. 57% of employees have been there for less than a year. At the time of the survey the building was only 70% occupied.
Further characteristics that need to be borne in mind are as follows:

- 64% of those surveyed are over 30
- Gender distribution: 60% male
- 63% sit next to a window
- 42% worked in the building for over a year
- 70 BUS forms were distributed, 49 were returned giving a 70% response rate

The Building Use Survey was conducted in July 2013 in accordance with the BUS guidelines. 70 survey sheets were handed out and 49 of these got returned, indicating a 70% response rate.

4.2.2.Overall results

The overall BUS results are shown in Figure 2, below. Green squares represent mean values that are better or higher than both the benchmark and the scale midpoint. Amber circles are mean values worse or lower than the benchmark scale midpoint. The benchmarks, calculated based on a rolling database of 50 UK buildings of all types, are shown as illustrated in Figure 47.

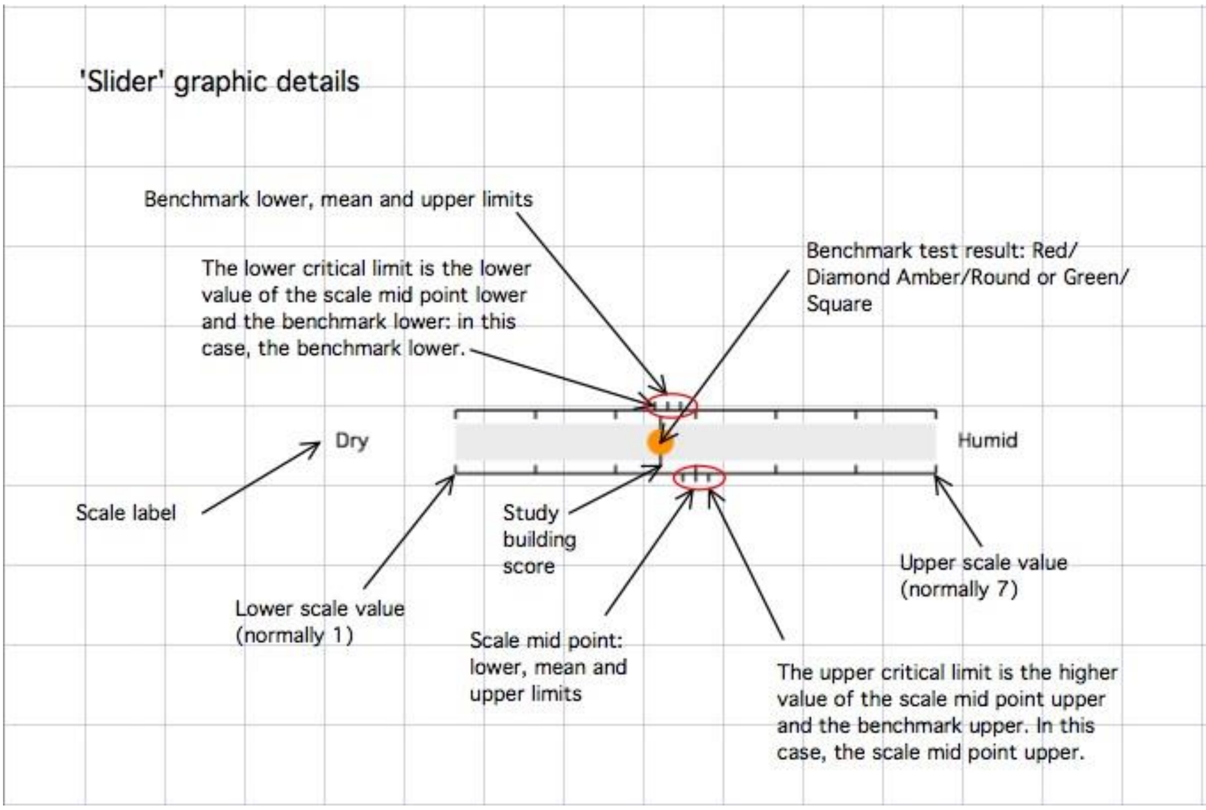


Figure 47 BUS Slider

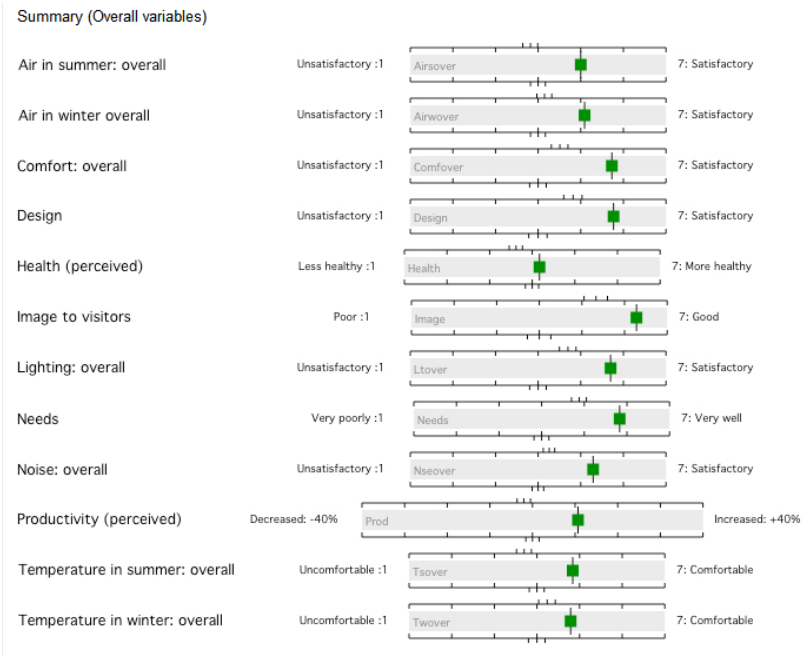


Figure 48 Summary Comfort Scores

Occupants scored the building above the benchmark and scale midpoint on all summary variables. Detailed results and comments will be explored in the sections below.

Recurring issues were people feeling occasionally too warm in both summer and winter and delay on the window controls. The majority of positive comments relate to good design, great environment, professional settings, the communal areas, lighting and daylighting, productive layouts, quality of indoor environment and occupier needs generally being well met.

Occupants highlighted areas that could be improved, which included more breakout booths for skype and other telephony, fewer locked doors to kitchen and other spaces, a request for a café, increasing the size and capacity of kitchen and storage and the quality of the wifi connection. These comments reflect an increasingly common requirements for office environments in the internet age.

4.2.3.Temperature

The graphs in the figure below show that the survey respondents scored summer temperatures within the benchmark. Summer variability is well within the benchmark. Winter temperatures are better than the benchmark, while variability is better than the benchmark.

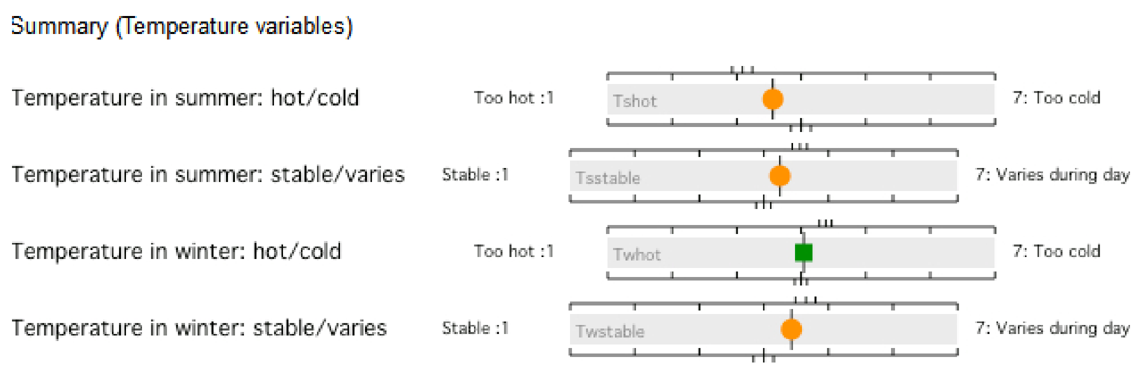


Figure 49 Temperature variables

Occupant comments support the BUS results, many have commented on feeling warm, others cold:

"Asked about changing heating"

"Heating noisy"

"Obviously if the temperature in the office is too hot/cold affects your working environment. The thermostat seems to take a while to kick in hot and cold"

Some comments indicate that there is room for improvement in particular when it comes to the automatic window controls:

"The automatic windows are unusual they often open at inconvenient times, make the rooms too cold and are slow and loud"

"Windows open unpredictably"

"Last year the window opened at 5pm every day causing the office to be too cold.We work until 6pm so it was very problematic"

"Window control either not working or has delayed response to button (several minutes) or opens and close Autonomously"

4.2.4. Air quality

The overall ratings for air quality in both summer and winter are above the 90th percentile and control over ventilation is similarly over the 87th percentile of the benchmark project set.

The data histograms behind the variables below indicate that the air is perceived to be towards the drier end of the scale for more than a third of occupants during summer and winter. There were no comments on this point from the occupants. Air was also perceived to be too still and too dry in summer and winter and some tenants requested better flow of air.

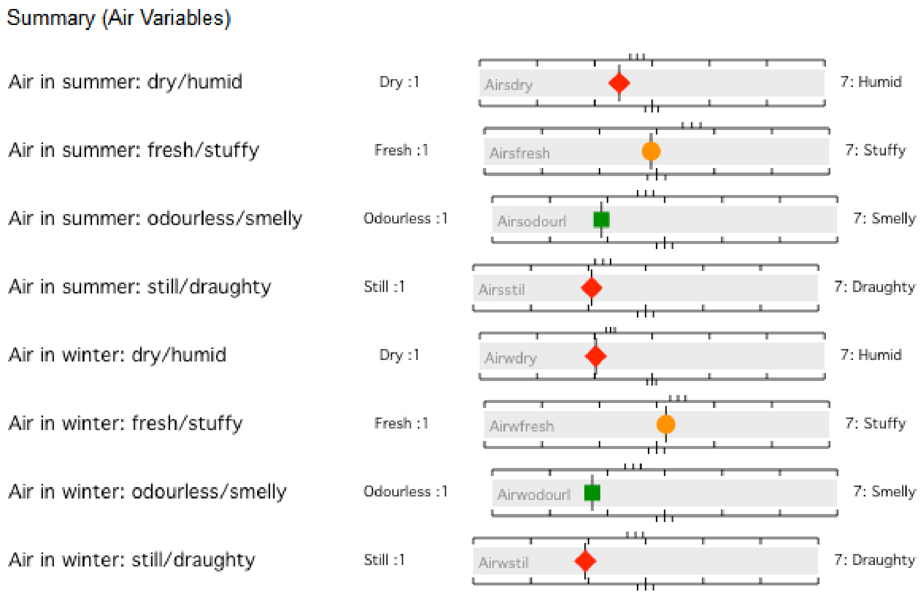


Figure 50 Air quality variables

Occupier comments were as follows:

"Sort out the heating and windows to enable better flow of air"

"I don't feel more or less healthy although can be stuffy sometimes"

"Windows: unpredictable opening and noise"

Issues with window controls may be the key cause of the perception of dry and still air. Yet the distribution of responses regarding control over ventilation show that the distribution is normal around the mean:

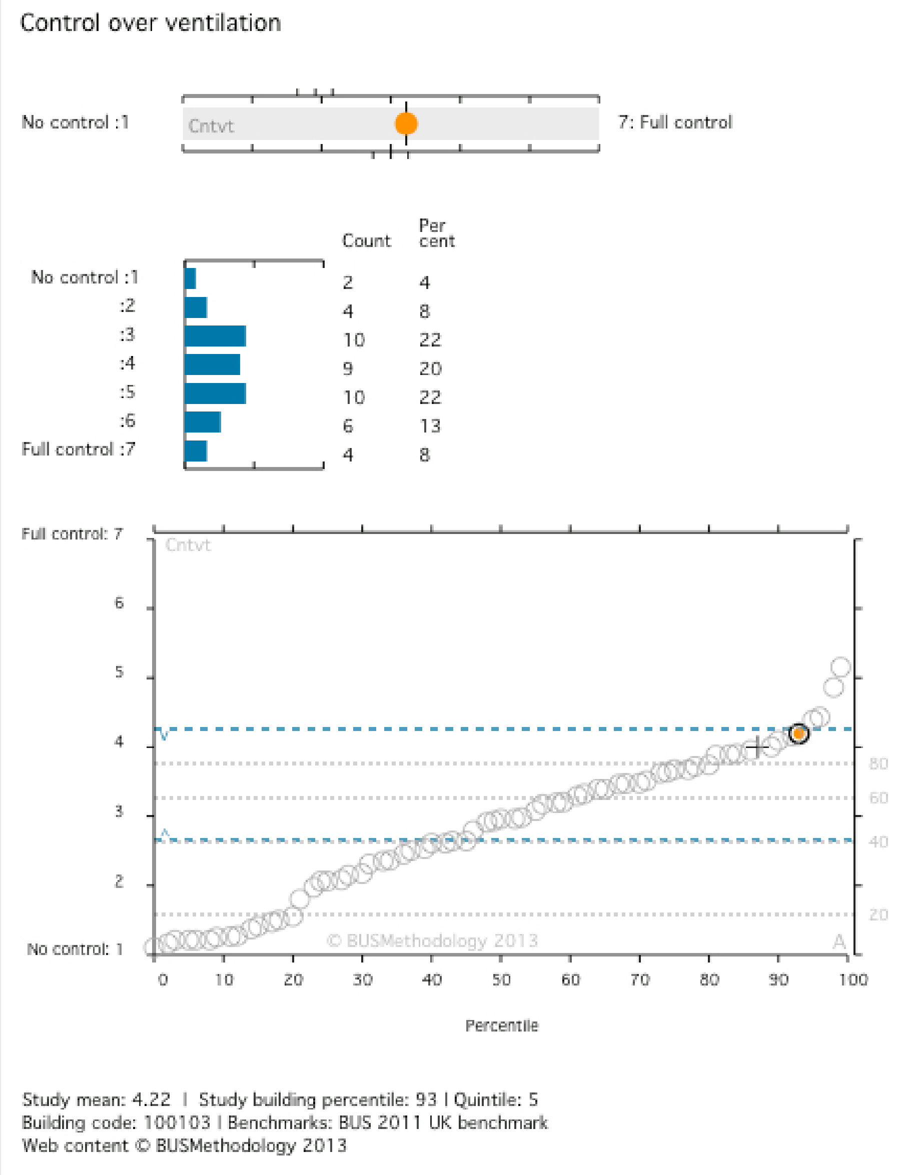


Figure 51 Ventilation control results

However, occupier comments included the following:

"Personally very happy, only thing is when windows decide to open & close when they want!!!" "The automatic windows are unusual they often open at inconvenient times, make the rooms too cold and are slow and loud"

"Random Auto window opening"

"Windows open unpredictably"

"Windows: unpredictable opening and noisy"

"The incorrect functioning of windows &the troop of people to check it out has been exasperating and still not fully resolved"

"Window distraction seems to be the only environmental effect"

"Asked for issue with irregular opening and closing of electric windows to be resolve"

"Last year the window opened at 5pm every day causing the office to be too cold"

"Window control either not working or has delayed response to button (several minutes) or opens and close Autonomously"

"Hard not to change your behaviour when everyone else notices and responds to the windows"

"Personally very happy, only thing is when windows decide to open & close when they want!!!"

"Sort out the heating and windows to enable better flow of air"

"The automatic windows are unusual they often open at inconvenient times, make the rooms too cold and are slow and loud"

"Serious issues with ventilation-automatic window opening/closing"

"windows poor"

"Too airless at time in office, sorted by window opening!"

During winter walkabouts the monitoring team noticed that occupants don't always open the windows enough when the rooms feel stuffy.

We advised the facilities managers to review the CO2 and temperature set points for the automatic windows for both summer and winter and agree with tenants on optimised settings.

4.2.5.Lighting

67% of occupants considered artificial lighting to be OK. 30% thought it was a bit too much. Glare from lights was slightly below the scale midpoint but within benchmark. Occupants felt there was too much natural light, and responses were significantly below benchmark and above scale midpoint. Feedback on glare was well within the critical region, again scoring close to the scale mid-point and well within the benchmark range.

Figure 52 Lighting variables

Few occupants commented on lighting:

"Lighting should dim automatically" "Lights themselves are fine but would be great to have some adjustability." "Often need artificial lighting even when sunny. Blinds can block out sun glare though" "When sunny (rare) the blinds are pretty inefficient" "Switches off regularly out of hours, very inconvenient."

With regard to lighting control the building scores above the 96th percentile far above the benchmark and the scale midpoint.

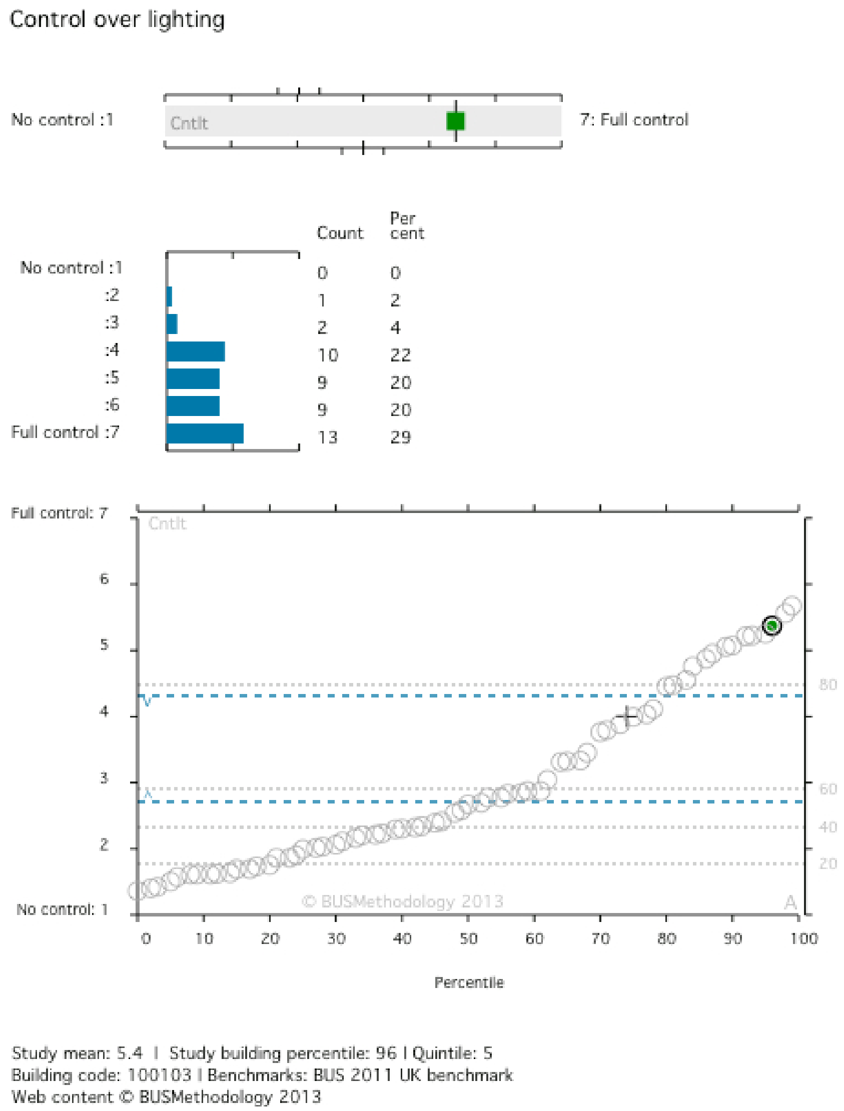


Figure 53 Lighting control results

4.2.6.Noise

Occupiers scored noise overall in the 95th percentile of the study buildings.

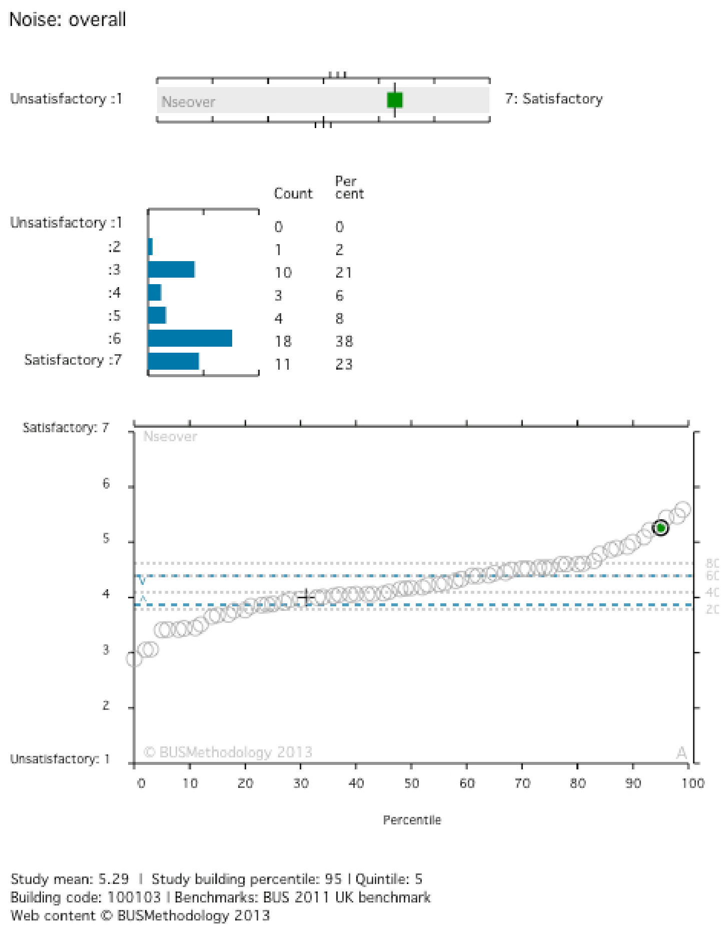


Figure 54 Noise control results

Noise levels from colleagues is perceived to be a little low, and significantly lower than the benchmark reference.

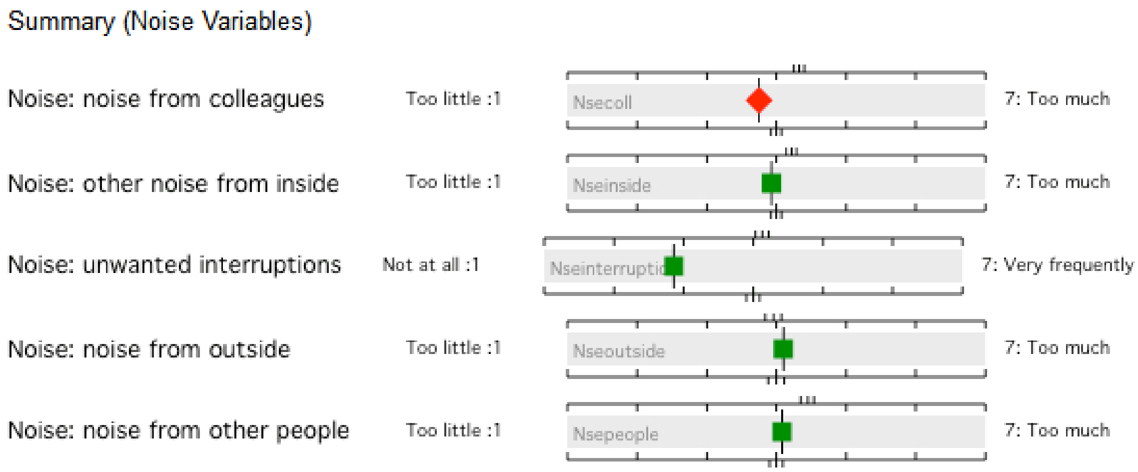


Figure 55 Noise variables

Occupiers commented on the following:
"Can hear people in offices next door on phone- seems quite loud sometimes"
"Environment is very quiet such that corridor noise of "slamming" doors become the main distraction"
"Formation zone is a bit too quiet. Would be good to have more background noise. Occasionally interrupted by visitor but not too disruptive"

“Noise from neighbouring offices having phone conversation in corridor”

At the time of the survey the building was not yet fully occupied and many occupants commented on the lack of background noise, which can affect the perception of noise from colleagues. Overall ‘Control over noise’ was marked lower than the scale midpoint.

4.2.7.Controls overall

Control variables were within the benchmark and above for ventilation.

Figure 56 Control variables

4.2.8.Design/Needs

The building scores around the 90th percentile of the benchmark set with regard to design.

In line with the high level of satisfaction we see from the variables the majority of comments are positive, with negative ones relating to space allocation, heating, the quality of the wifi connection and the window controls. Interestingly, four of the window control comments are raised under design, even though the compromised installation and commissioning were outside the control of the design team.

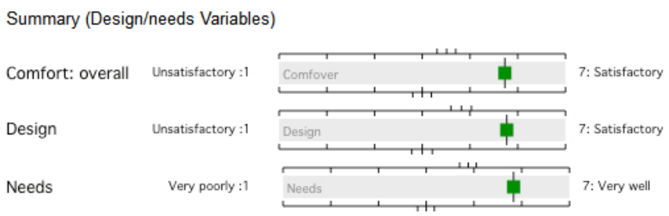


Figure 57 Design variables

“Good work environment”
“We work "smarter here than we did in our old office. Hard to translate into % on productivity”
“Good facilities generally “
“Communal area would be nice-a relaxed café environment where we could all mingle”
“Hideous green/purple décor, will date within 2 years”
“Styling, bold & attractive, fits with our surroundings”
“Building looks impressive .Nice offices & communal space. Shower rooms & locker nice touch”
“Modern & stylish”
“Nice & clean- looked after”
“Serious issues with ventilation-automatic window opening/closing”

"Spacious, light, warm"

The survey reveals that the respondents believe the building meets their needs on a range of comfort variables,

4.2.9. Facilities management

The occupants scored all variables scored above the benchmark except for 'space at desk'. Note that all the comments relating to desk space were positive, commenting on 'ampleness' rather than 'too much', so the scores for too much space at desk are puzzling. Occupiers perceived the building to significantly contribute to their productivity – the building is in the 97th percentile of the database on this variable and 95th with regard to facilities.

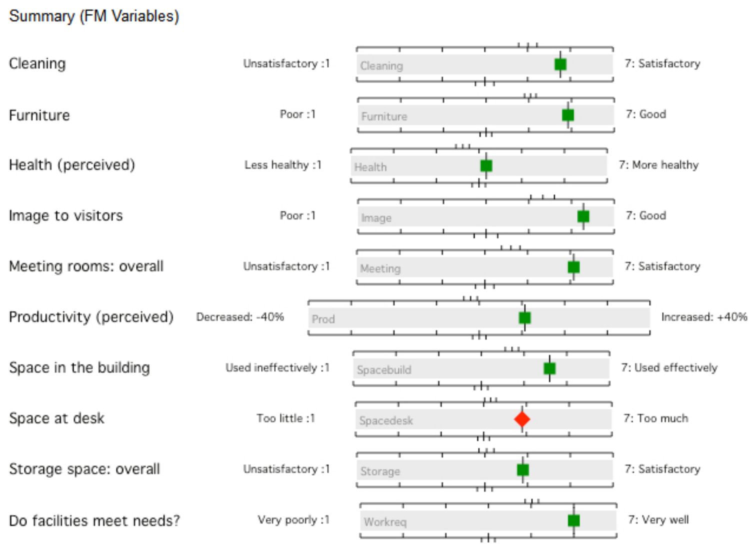


Figure 58 FM variables

Some occupant comments shed light on this:
"Deskwise great"
"Good size desk & draw facilities"
"Shelving /drawers on desk would be convenient"

"Nice & clean- looked after"
"Reception very efficient."
"Clean, quiet work space with effective communications"
"Front of house services, presenting very professional image.Use of meeting rooms to break out from office"
"I have been less healthy since working here, most people in the office have been ill too."
"TIC is bright, spacious,& clean. I find this lends itself to feeling healthy at work."
"Good facilities generally"
"Formation zone is a bit too quiet. Would be good to have more background noise. Occasionally interrupted by visitor but not too disruptive"

4.3 Discussion and Conclusions

Compared with Pool Innovation Centre control over cooling is marginally worse, heating is marginally better, lighting significantly better, noise is similar and ventilation somewhat worse.

Window controls, in particular the time lag for switches, has been raised sixteen times in comments. The technical review has highlighted an issue around the value engineering of the Windowmaster system for a cheaper control solution, which has resulted in serious problems with both the automatic and manual controls of the windows.

It is clear that the occupiers are happy with the building. The response to the BUS survey is in-line with the feedback from the structured interviews. A low turnover of tenants supports this perception, the tenants often stated that they will find it difficult to leave once their tenancy period expires – there is a maximum term of three years for each organisation.

Some criticism was raised relating to air quality, excessive natural light, the lack of a cafe and the allocation of kitchen space. The building seems marginally warm to some users in winter and cold to others and the window controls were raised as problematic. Some issues were also highlighted around lack of noise from other occupants and dry airg. .

The monitoring team recommended that absence control timer settings are agreed with tenants on a room by room basis where needed. The blinds were discussed with the building manager in the context of the comments with the conclusion that only a very small minority of tenants find the glare an issue, who can have some training on how to use the system better but that this does not warrant a change.

Positive feedback on facilities management is in line with the impression we got from our visits. AHR believes that the competence of facilities management contributes to the positive score: facilities staff were always friendly and responsive, displaying a high awareness of occupier needs. It is difficult to understand why too much space at desk would be a negative mark.

5 Details of aftercare, operation, maintenance & management

Technology Strategy Board guidance on section requirements:	This section should provide a summary of building operation, maintenance and management – particularly in relation to energy efficiency, metering strategy, reliability, building operations, the approach to maintenance i.e. proactive or reactive, and building management issues. This section should also include some discussion of the aftercare plans and issues arising from operation and management processes. Avoid long schedules of maintenance processes and try to keep to areas relevant to energy and comfort i.e. avoid minor issues of cleaning routines unless they are affecting energy/comfort.

5.1 Summary of aftercare, operation, maintenance & management

Halcrow were the Building Services Engineers, BREEAM Assessor and Structural Engineer for the whole of the design and construction program on this project. The Design Team were appointed by the ultimate Client, South West Regional Development Agency (SWRDA)/Cornwall Country Council (CCC) to produce the Tender design package and were then novated to the Design & Build Contractor on award of the Contract. This building was preceded by Pool Innovation Centre and involved the same Design Team, Client and Building Operator. This provided an opportunity to use lessons learned from Pool Innovation Centre to further evolve the design for Tremough Innovation Centre.

There were a number of improvements in Tremough Innovation Centre, but the completion, commissioning and handover process still did not run as intended by the designers and there were a number of new learning points to be drawn from this building. The BPE study overlapped with the construction and commissioning period and the monitoring team was able to have minimal involvement during the commissioning process.

Several structured interviews were held with the facilities managers, employed by Tamar Science Park, who subsequently handed the day-to-day facilities management over to Plymouth University. They participated in the commissioning of the building services and received training with regard to the building controls. The FM are only present during working hours – even though both buildings operate on a 24hour access basis.

Leadbitter, the contractor who built TIC looked after maintenance at PIC during the defects period were on site in an adjacent building, which meant that they were able to deal with emergencies such as leaks very quickly. In the first six months still in the defects liability period and so the management have not yet set up a planned maintenance schedule – other than for regulatory requirements such as Legionella and fire extinguisher checks. The M&E subcontractors were Lorne Stewart.

Compared to PIC, the tenants at TIC are using the building outside core hours to a much greater extent. This includes tenants in the mining sector with a large proportion of their client base in South and Central America. Outside core hours the lights are PIR controlled so only come on when there is movement detected. There was a problem with access card readers so it was not possible to conduct the same exercise as was done at PIC to estimate levels of occupancy at different times of day and night.

A suggestion was made that it might be possible to locate businesses with similar hours in similar areas of the building, and some extent that has happened with the mining consultants located close together.,
Both buildings were provided with a user-friendly building manual as part of the BREEAM Excellent compliance. The TIC manual was incorporated into the O&M manual and was incomplete in several places, in some cases referring to installation drawings or product brochures only or missing information altogether, such as lighting.

The BMS at both buildings can be managed remotely. Both buildings were well sub-metered, however no energy targets were set as part of the facilities management scope. Extracts from interviews with the facilities managers and engineer illustrate some of the issues encountered under Technical Issues.

5.2 Soft Landings

Although the M&E consultant has not been involved in any Soft Landings builds, when the process was described to him he was of the opinion that it sounds like a description of things that should be happening anyway. In particular he mentioned that having the building user involved during design at TIC has led to improvements which would be something that occurred during a formal Soft Landings process.

The FM had also not been involved in any Soft Landings builds, although he had read up on the process. His description of their involvement as future operators of the building during the construction process sounded a lot like the Soft Landings process, although not formalised.

> *"The client invited us to the table at construction stage. These things are all design and build so that's probably the best time to be invited, and then we can interact with the contractors. The contractors are quite forthcoming in welcoming our comments as they know that that bit really needs to be appeased." FM, PIC & TIC*

It is the view of the monitoring team that the requirement for energy data helped focus the monitoring effort and provided important clues to diagnose issues with installation, commissioning and operation. The Soft Landings terminology provided a useful framework to share and resolve the issues identified. Both data collection and Soft Landings are only effective if the client is engaged with building performance outcomes.

5.3 Clerk of Works

The M&E consultant spoke about the presence of a clerk of works from the client's side present during defects inspections, although since they are not involved with the design his perception was that they are not fully aware of the design intent. Given this, the M&E consultant's statement that the clerk of works "served as a helpful second pair of eyes, since they had the time to look at the large number of small details which couldn't be covered in our brief periodic visits" may be seen as a reasonable endorsement. On interviewing the FM, it was revealed that there is a difference in the way the clerk of works role was handled between TIC and PIC. At PIC the role was kept in-house by the client, Cornwall Council, whereas at TIC it was contracted out to a team. One of the team is a former Lorne Stewart employee and the FM says that he had a tendency to get distracted by areas of the building that were outside of his remit. This was suggested as a reason for the M&E consultant's perception. The FM was quick to point out several areas where the mechanical and electrical clerks of works had been invaluable in bringing elements of the building to his attention. He also suggested that bringing in external contractors was preferable to having the job done in house.

5.4 Training

The fact that the installation of meters and connection to the BMS was still incomplete a year after completion meant that training had also not been provided beyond the basics of how to change temperatures in individual offices. This was very frustrating for the management team at TIC. Training at PIC was easier as the systems were less complicated.

6 Energy use by Source

Technology Strategy Board guidance on section requirements:	This section provides a summary breakdown of where the energy is being consumed, based around the outputs of the TM22 analysis process. This breakdown will include all renewables and the resulting CO_2 emissions. The section should provide a review of any differences between intended performance (e.g. log book and EPC), initial performance in-use, and longer-term performance (e.g. after fine-tuning and DEC – provide rating here). A commentary should be included on the approach to air leakage tests (details recorded elsewhere) and how the findings may be affecting overall results. If interventions or adjustments were made during the BPE process itself (part of TM22 (process), these should be explained here and any savings (or increases) highlighted. The results should be compared with other buildings from within the BPE programme and from the wider benchmark database of CarbonBuzz.

6.1 Summary of TM22 analysis

6.1.1. Tremough Innovation Centre

Simple Assessment: Total annual energy performance for Tremough Innovation Centre (TIC) was established by using half-hourly data provided by the electricity supplier, records of wood pellets delivery for biomass, and gas bills.
The following Figures provide the outcomes of the TM22 simple analysis.

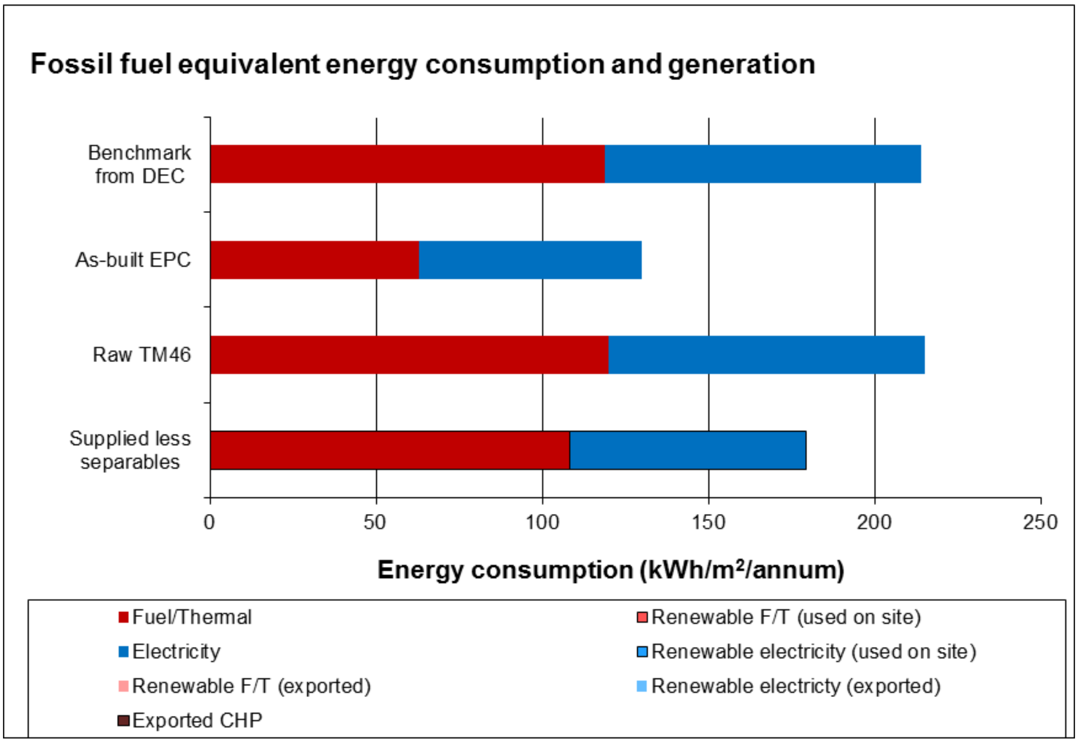


Figure 6.1: TM22 simple assessment for TIC: energy consumption

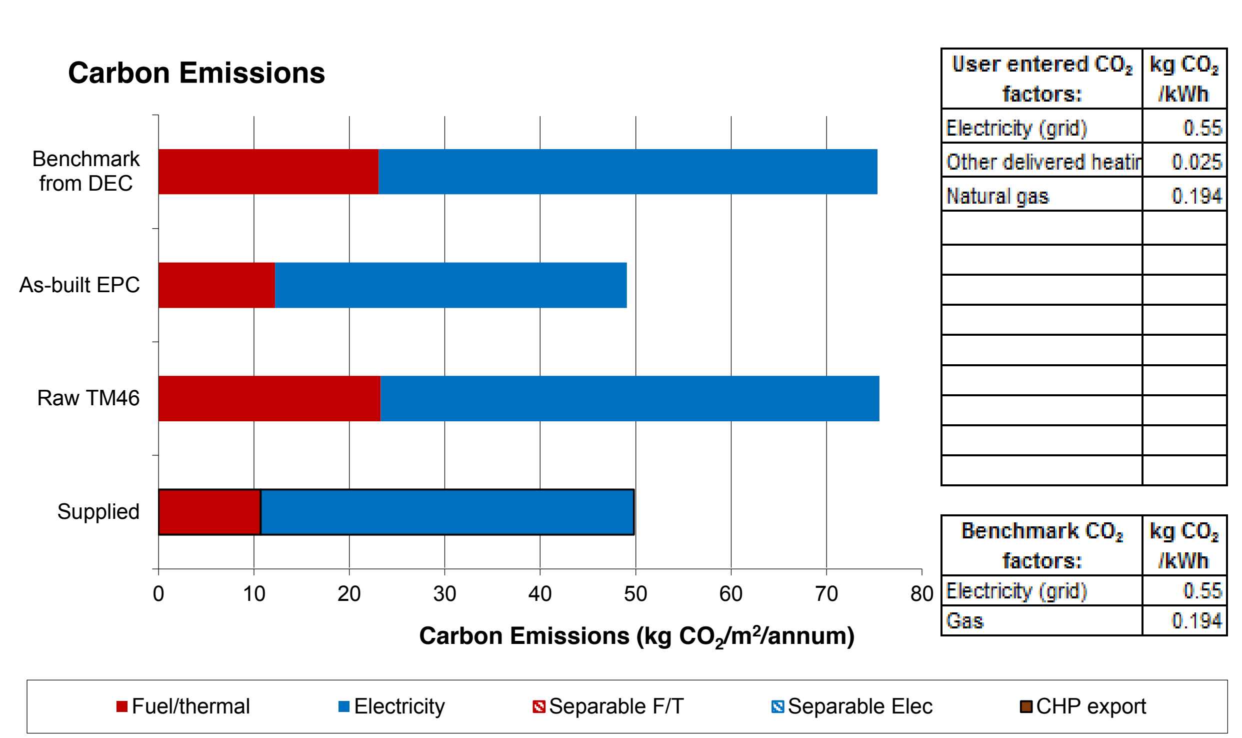


Figure 6.2: TM22 simple assessment for TIC: CO_2 emissions

The DEC benchmark used for the simple assessment is based on weather-corrected TM46 benchmarks for gas and electricity use in offices. The user specified benchmark is based on the outcomes of the EPC calculations carried out on completion of the building. It should be noted that the default equipment load used in EPC calculations has been extracted from the xml file lodged with the Landmark and included in the graph to ensure the User Specified benchmark includes all energy end-uses. The default equipment load used for EPC calculation is based on power densities and operation profiles defined for various activity types in the National Calculation Methodology (NCM). The CO_2 conversion factors used to convert energy figures to CO_2 emissions are reported in Figure 6.2.

These graphs show that TIC's thermal energy use is lower than DEC/TM46 benchmarks, but around 70% higher than what was derived from EPC calculations. As a large proportion of thermal energy is provided by biomass boiler, building performance scores better when the CO_2 emissions metric is used; the CO_2 emissions associated with thermal energy use at TIC are lower than all benchmarks reported in Figure 6.2.
The electricity use is lower than DEC/TM46 benchmarks, but around 6% higher than the User Specified benchmark. It should also be noted that the building has not reached its full design occupancy yet, and the average occupancy of the tenant areas during the measurement period was 70%.

Overall, the main conclusion derived from the simple assessment is that, while thermal performance of TIC is better than the median of existing building stock, it is significantly higher than the design estimation. It should be noted that the EPC calculations were carried out under standardised NCM operating conditions that are not necessarily consistent with the actual operation. However, TIC's operation follows typical operational pattern of office buildings with core occupancy hours of 8:30-17:30, Monday to Friday, and occasional out-of-hours use. Therefore, the EPC result for thermal performance, which reflects the as-designed U values and tested air permeability, is a good yardstick to assess the thermal performance of this building.

Bottom-up Analysis: To have a better picture of electrical energy performance of the building, a bottom-up analysis was carried out using TM22 tool. The installed metering at TIC made it possible to split total electricity use into busbars, server rooms, plantroom and lift. The bottom-up analysis was then used to reconcile the energy end-uses related to these sub-meters with the metered data.

In addition to the abovementioned core occupancy hours, an extended occupancy profile was used to allow for building management (Landlord areas) and cleaning time (7:00-20:00). A separate profile was also defined for the first floor Café that runs between 8:30 am and 3 pm during weekdays. A usage factor of 0.7 was used for the lighting energy use in tenant spaces, to reflect the unoccupied spaces based on site visits and information provided by the building management.

The half-hourly data provided by the electricity supplier shows that the baseline electrical power demand of the building is around 20 kW and the peak loads are consistent with office core occupancy hours (Figure 6.3). It was therefore decided to reconcile the baseline power demand with the metered data first, and then carry out the daytime calculations based on core office hours plus an allowance for building management and cleaning time. The breakdown of the electrical baseline load allowed for in TM22 analysis is included in Table 6.1 and adds up to approx. 19 kW which is close to the average annual baseline electrical load reported by the electricity supplier.

Electrical load	Electrical power (kW)
Server Room & data hub room loads including server room cooling	8.7
External lights	4.4
Small power (computers, laptops and other miscellaneous office equipment)	2.5
Internal lights (stairs core and occasional out-of-hours)	1.2
Access control & security	1.1
Plantroom operation and control	0.8
Fridges and water coolers	0.2
Extract fans' trickle mode operation	0.02
Total baseline electrical load	**18.92 kW**

Table 6.1: Breakdown of the baseline electrical power demand allowed for in TM22 analysis for TIC

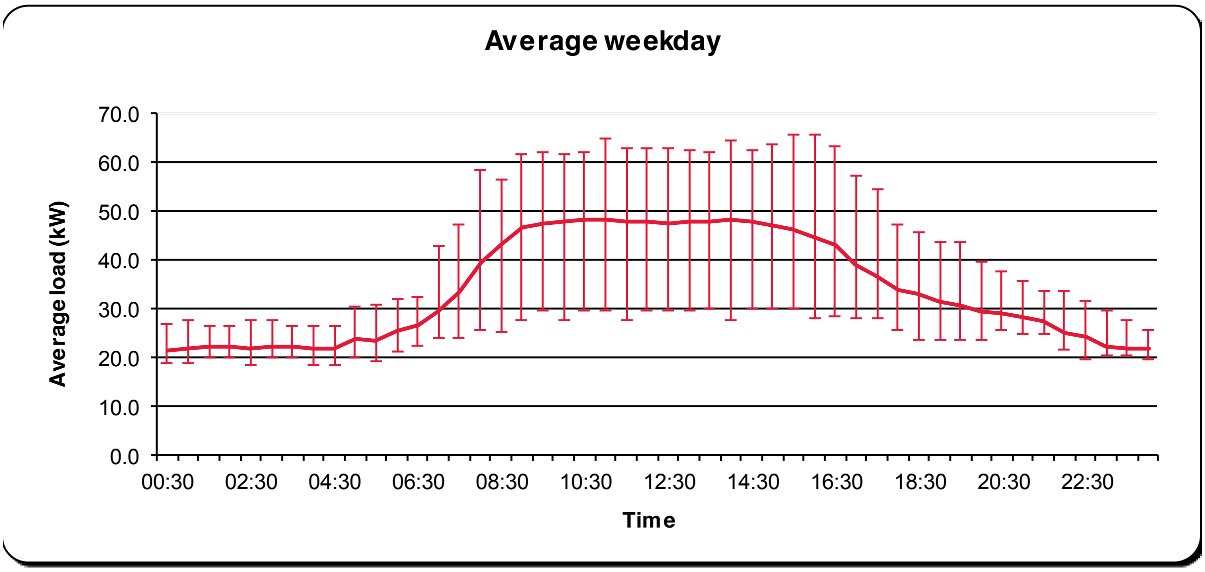


Figure 6.3: Annual electrical power demand for TIC during weekdays (2013)

The daytime average electrical power demand of TIC during weekends is around 3-4 kW higher than the baseline load (Figure 6.4). The peaks in average electrical power observed around 6:30 am and 8:30 pm are consistent with the beginning and end of the operation of heating system. This suggests that the weekend average electrical load during daytime follows the operation of the HVAC system set up for occasional out-of-hours use of tenants. Wider variations in daytime electrical power demand than night-time in Figure 6.4 also confirm occasional out-of-hours use of tenanted spaces. However, the average power during daytime is almost on a par with peaks associated with the HVAC system suggesting that out-of-hours use during weekends is not significant. Our interviews with the building management and tenants also confirm that the pattern of out-of-hours building use is highly irregular and cannot be fully captured in a normative calculation. An allowance was made for weekend operation of a typical tenant space as a proxy for occasional weekend operation.

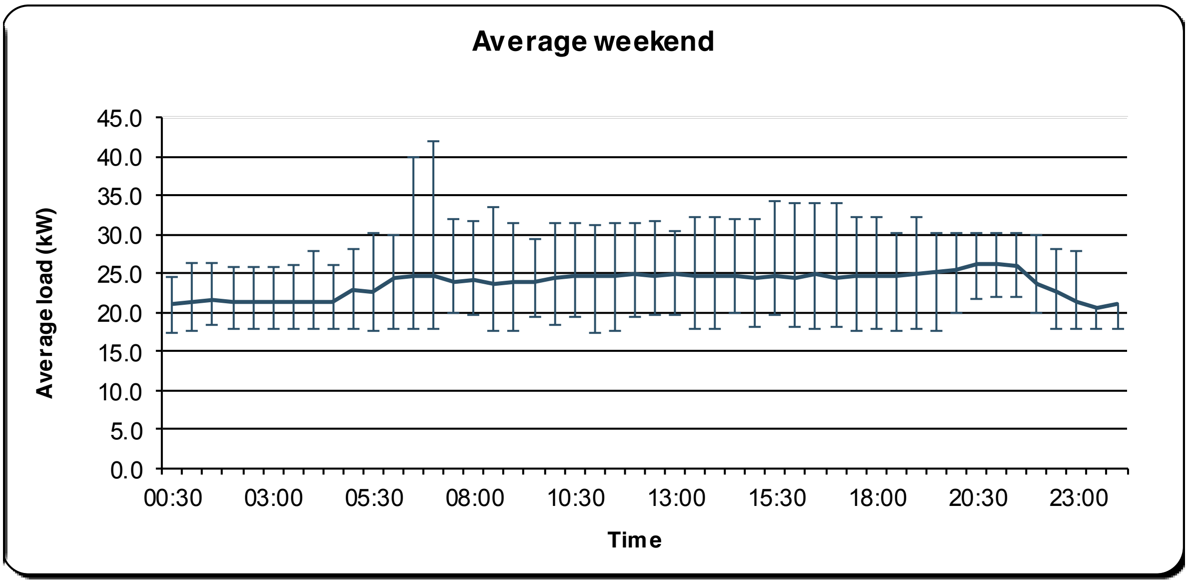


Figure 6.4: Annual electrical power demand for TIC during weekends (2013)
(The peaks around 6:30 am and 8:30 pm are consistent with the beginning and end of the operation of heating system.)

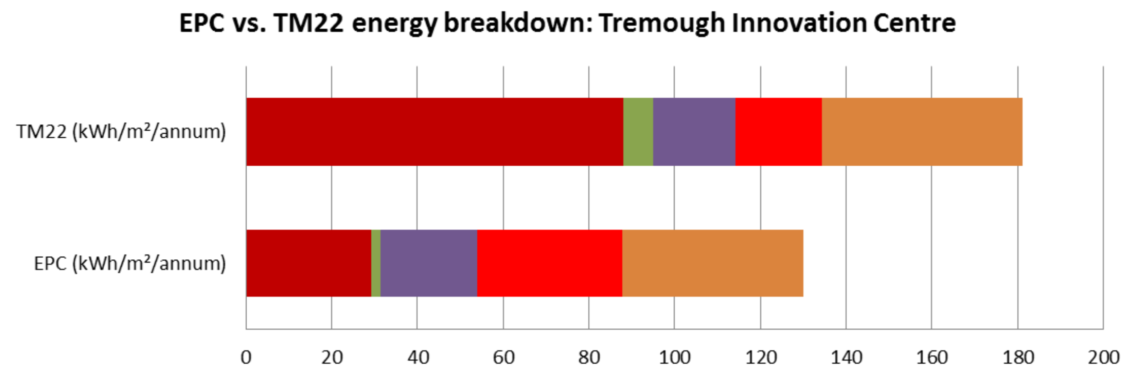
Following the TM22 detail assessment, the end-uses reported in Table 6.2 were reconciled with the mains electricity within 3%.

System	Fuel/Thermal demand ($kWh/m^2/year$)	Electricity ($kWh/m^2/year$)
Space Heating	88.1	0.0
Hot water	20.1	0.0
Fans	0.0	1.2
Pumps	0.0	4.9
Controls	0.0	0.7
Lighting (Internal)	0.0	19.4
Lighting (External)	0.0	4.9
Small Power	0.0	17.5
ICT Equipment	0.0	19.4
Catering - Central	0.0	2.3
Catering - Distributed	0.0	2.2
Lift	0.0	0.4
Total	**108.2**	**72.9**

Table 6.2: TM22 energy assessment for TIC: detailed analysis

The Energy Performance Certificate (EPC) produced for TIC following the completion of the building is A rated (A/23). Although EPC calculations are based on default schedules of operations, default occupancy density, and default set points and do not include the effect of actual equipment load, it is useful to compare the end-use estimations of EPC with actual figures. The EPC profiles and assumption for offices are based on the so-called ‘standardised’ conditions and, as such, the EPC estimations for fixed building services could arguably be used for benchmarking purposes as long as the building’s operation is not too dissimilar to the typical building stock. The half-hourly data confirm that this is the case for TIC; overall, it follows a normal occupancy pattern expected from office buildings. Figure 6.5 compares the results of TM22 energy assessment in-use and the

EPC estimations for end uses.3 It should be noted that the EPC estimations provided in this graph (and other similar graph in this report) include the ‘Equipment’ load used in the calculation engine to estimate the heating and cooling demand under ‘Non-regulated end-use’ category. This load is not directly included in the EPC rating. Nonetheless, it is useful to compare it with the actual equipment load to have a better understanding of the assumptions behind EPC assessment and its relevance to actual loads.



	EPC (kWh/m²/annum)	TM22 (kWh/m²/annum)
Heating	29.3	88.1
Cooling	0	0
Auxiliary	2.1	6.8
Lighting	22.5	19.4
DHW	33.9	20.1
Non-regulated end-use	42.3	46.7

Figure 6.5: EPC vs. In-use TM22 energy analysis for TIC

The following findings are based on the comparison between the outcomes of EPC and TM22 assessments and on-site observations:

Heating: actual heating energy is significantly higher than the EPC estimation. This is, to some extent, the result of extended operation of the heating system over the weekends to allow for occasional out-of-hours use that is not reflected in the EPC calculations. Furthermore, the natural ventilation strategy causes heat loss in winter that, again, is not necessarily reflected in the EPC calculations. However, the difference between the actual and estimated heating energy suggests there might be other root causes for this significant gap.

One of the findings of the building performance evaluation was that, according to the installed heat meters, there is 67% discrepancy between the heat output from the biomass buffer vessel and heat input to it. There is also 52% discrepancy between the total heating energy provided to the building in the secondary heating loops and the energy supplied by biomass and gas-fired boilers (see Figure 6.6 and Table 6.3). If we are to accept these figures at face value, this means almost half of the heating energy is wasted in the plant room.

The research team was not able to find a severe and unusual problem with the buffer vessel and pipework insulation in the plantroom. It is possible that heating meters are not accurate, although, having checked the wirings and the location of temperature and flow probes, we have not found any evidence to justify such an assumption. Even if the heating meters are not accurate, it is notable that such discrepancy between primary and secondary heat meters has gone unnoticed by building users and contractors. This raises questions about the effectiveness of installing ever-increasing number of sub-meters without ensuring they are accurate and using them to benchmark energy performance. It should also be noted that two large building energy display panels report heat meters’ data every few seconds in the reception area, and apparently no one has noticed the significant imbalance between heating energy supplied in the primary loop and heating energy metered in the secondary loop.

[3] The EPC energy end-uses have been extracted from the xml file lodged with the Landmark. Auxiliary energy use includes fans, pumps and control.

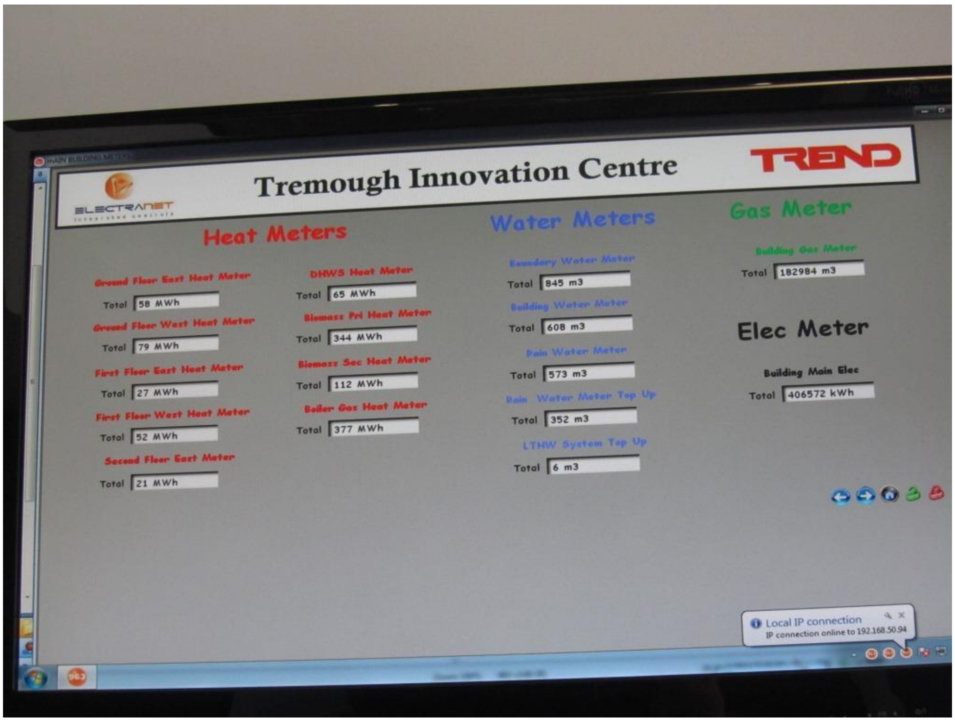


Figure 6.6: Snapshot of primary and secondary heat meter readings from the BMS

Heat Meter	Energy (MWh)
Biomass Boiler	
Biomass primary heat meter (before buffer vessel)	344
Biomass secondary heat meter (biomass **output heat** after buffer vessel)	**112**
Gas-fired Boilers	
Boilers' heat meter (boilers' **output heat**)	**377**
Secondary Loop Heat Meters	
Ground floor east heat meter	58
Ground floor west heat meter	79
First floor east heat meter	27
First floor west heat meter	52
Second floor heat meter	21
Total **heat input** to the secondary low temperature hot water loop measured by secondary loop heat meters	**237**

Table 6.3: Heat meters' energy balance (recorded on 17/04/2014)

- **Auxiliary (Fans, Pumps and control):** auxiliary energy use of the building is significantly higher than the EPC estimation. Apart from the differences in operational profiles that stem from building's out-of-hours use, it should be noted that EPC calculations do not take into account actual pump ratings in the low temperature heating loop. EPC calculations use default pump power densities defined based on a broad definition of HVAC system type and control strategy[4]. These calculations do not take into account building geometry, the length of the heating loop index run and actual pressure drops. Maximum pump power density used in EPC calculations for low temperature heating loop is 0.6 W/m². Actual installed pump power density for the low temperature heating loop at TIC is 1.5 W/m².

[4] Communities and Local Government, A Technical Manual for SBEM, 31 March 2011, p.83, available at www.ncm.bre.co.uk [accessed on 22.07.2014]

- **Lighting:** TM22 estimation for actual lighting energy use is slightly lower than the EPC estimation. It should, however, be noted that not all tenant spaces were occupied throughout the measurement period.

- **Domestic Hot Water:** The EPC estimation for domestic hot water use is significantly higher than actual hot water use. This often happens where the NCM 'changing' activity type is used in a thermal model. According to the EPC xml file, this is the case at TIC. The NCM assumes 30 L/day/m² DHW use for changing area; if the 'changing' activity type is used to define the drying and storage areas in addition to the shower area, this assumption may lead to higher than expected DHW estimations.

- **Non-regulated end-use (Equipment):** The EPC estimation for non-regulated loads, which is based on equipment loads assumed for various activity types in the National Calculation Methodology, is actually very close to the TM22 estimation. This is an indication that the NCM default equipment loads for offices may lead to reasonable estimation of energy use associated with office equipment. These default loads are used to estimate heating and cooling loads in the calculation engine. Therefore, it is reasonable to include them in total performance when comparing operational and calculated energy performance, to have a more realistic understanding of performance gap.

The main issue at Tremough Innovation Centre seems to be the higher than expected heating energy use. While heating energy use at TIC is lower than the benchmarks derived from existing building stock, it does not quite live up to what is expected from a new-build building with high performance fabric and low air permeability demanded by new Building Regulations. However, the building has not reached its full design occupancy yet; if the building had reached its full design occupancy, the casual gains could have reduced building's heating demand to some extent.

It is also notable that, according to the EPC xml file, it was assumed the heating and DHW demand will be entirely satisfied by biomass boiler. The estimation for natural gas use recorded in this file is zero. However, in practice, gas-fired boilers provided around 44% of total heating and DHW energy during the measurement period. This huge discrepancy calls for more realistic assumptions at design stage to account for the contribution of supplementary systems installed to back up low or zero carbon technologies. It would also be beneficial to review the operational control strategy of the building to ensure the biomass boiler always acts as the lead heating system and does not lag behind gas-fired boilers. According to the design control strategy, the supplementary gas-fired boilers should only be enabled if the temperature sensor mounted in the flow from the buffer vessel records a temperature less than 70 °C for 15 continuous minutes and should deactivate if it records a temperature of more than 75 °C for 15 continuous minutes. These settings could be re-adjusted. Shortcomings in buffer vessel insulation or inaccuracies associated with the temperature probes may lead to unnecessary use of gas-fired boilers.

Another example of discrepancies between EPC calculations and reality is server room cooling. Initially the server room and data hub room did not have air conditioning equipment installed, and only mechanical ventilation was provided to these areas. However, few months after occupancy started, three split air conditioning units were installed to provide cooling to the server rooms. It appears that provision had been made at the initial stages of design to install air conditioning systems in addition to mechanical ventilation; mechanical ventilation was designed to minimise the run time of the air conditioning system and not to substitute it. However, according to the construction issue specification, the installation of wall mounted split units were not carried out in the main contract and was postponed "to be installed post contract by others". The exact reason for this is unknown to the research team. However, a perhaps unintended consequence of this change in specification was an optimistic view of energy performance of the as-built building as no allowance was made for server room cooling in the Building Regulations compliance and EPC calculations.

6.1.2. Pool Innovation Centre

Simple Assessment: The mains electricity meter installed for Pool Innovation Centre (PIC) significantly underestimates electricity use and is not reliable for building performance evaluation (Figure 6.7).

An Elcomponents SPCPro clamp meter unit was installed as part of the BPE project to record the building's electrical demand and electricity use every five minutes (Figure 6.8). Records of wood pellets delivery and gas meter readings were also used to establish the building's thermal energy performance.

PIC's design philosophy and operational profiles are very similar to TIC. One of the major differences between these two buildings is the installation of Photovoltaic arrays with maximum power output of 28.2 kWp on the PIC's roof which took place in December 2011, less than 2 years after building completion (Figure 6.9). The estimation of the potential energy yield of the PV panels provided by the system installer, using SAP 2005 calculation methodology, was 21,048.5 kWh per year (5.6 kWh/m² per year). The actual annual contribution of these panels according to the installed sub-meter has been very close to this estimation at 19,041.0 kWh per year (5.1 kWh/m² per year). The generated electricity is significantly lower than the building's baseline demand and the exported electricity is negligible, 0.07 kWh/m2/yr. This does not affect the TM22 graphs generated via the simple assessment (Figure 6.10).

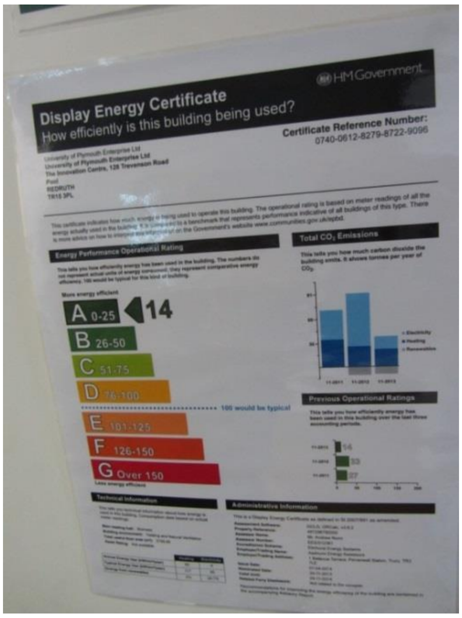


Figure 6.7: The DEC lodged for PIC is A rated; this is based on 8 kWh/m² per year electricity use billed by the electricity supplier using their meter. Actual electricity supplied, measured by the BPE team, using a clip-on meter and its readings reconciled with bottom-up TM22 analysis was 67.5 kWh/m² per year,.

Figure 6.8: Clamp meter installed to record electrical power demand and electricity use at PIC

Figure 6.9: PV arrays installed on the roof (maximum design power output: 28.2 kWp)

Figures 6.10 and 6.11 show the outcomes of the TM22 simple analysis.

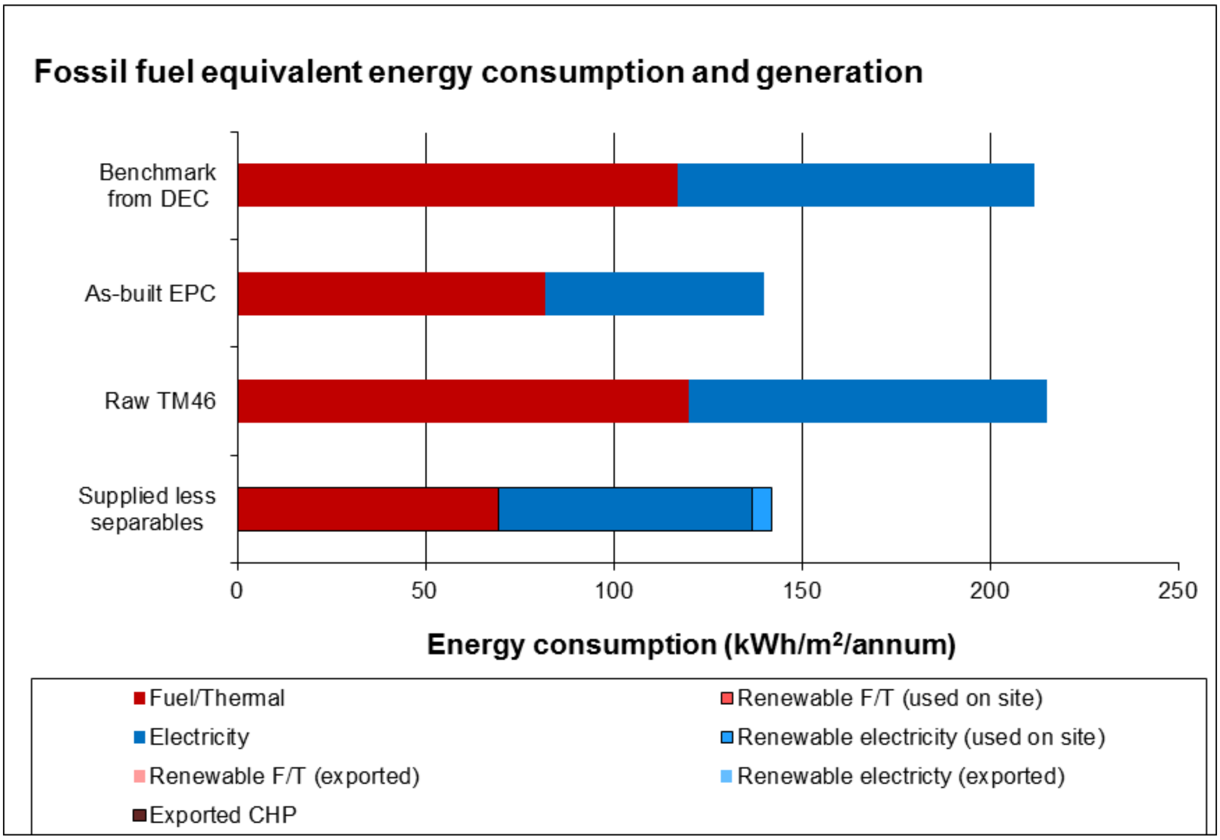


Figure 6.10: TM22 simple assessment for PIC: energy consumption

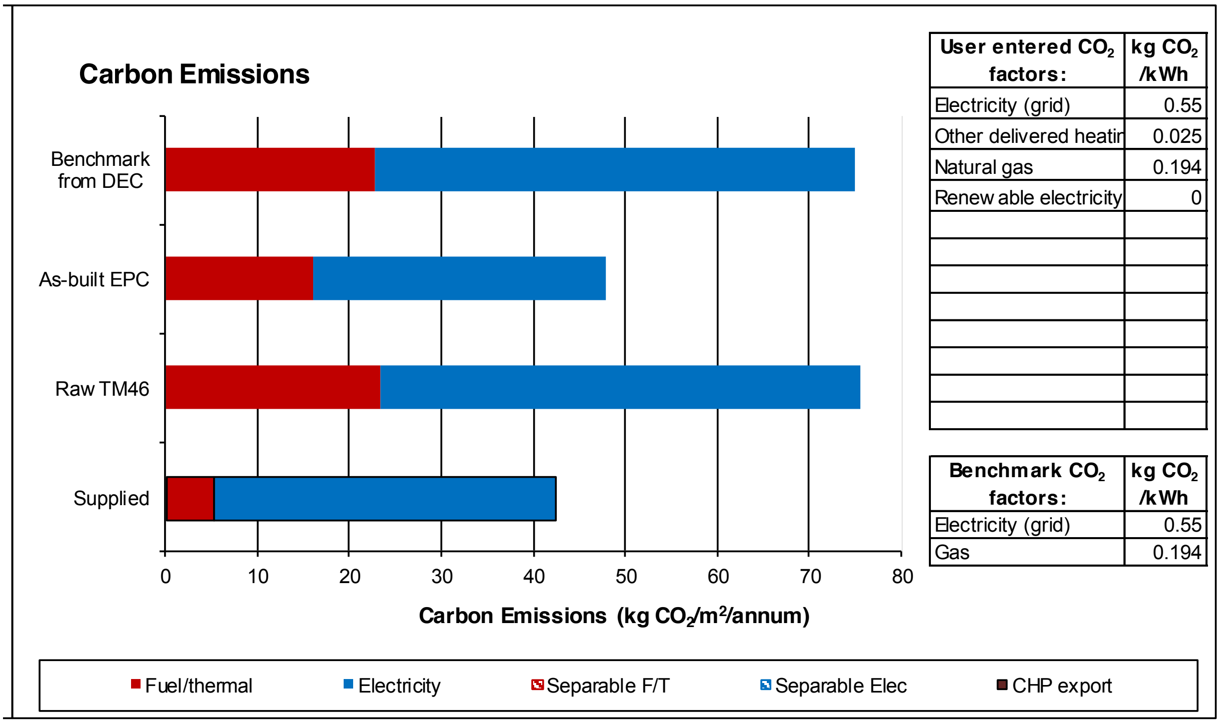


Figure 6.11: TM22 simple assessment for PIC: CO_2 emissions

The DEC benchmark used for the simple assessment is based on weather-corrected TM46 benchmarks for gas and electricity use in offices. The user specified benchmark is based on the outcomes of the EPC calculations carried out on completion of the building, including the default equipment load.

Figure 6.10 shows that thermal energy performance of the building over the TM22 measurement period (3-4 years after building completion) has better than all benchmarks. Furthermore, 70.9% of total fuel thermal use has been provided by biomass and, therefore, CO_2 emissions associated with thermal energy performance are significantly lower than benchmarks. Electricity use is also better than DEC and raw TM46 benchmarks, but 16.4% higher than the EPC estimation. However, it should be noted that the building has not reached its full design occupancy level yet. On average, 85% of the tenant areas were occupied during the measurement period.

While the displayed DEC certificate in PIC is obviously flawed thanks to extremely low values reported for electricity use, the building's total energy performance is reasonably good with an estimated C operational rating.

Bottom-up Analysis: To have a better picture of the electrical energy performance of the building, a bottom-up analysis was carried out using TM22 tool. Apart from the sub-meter installed for the PV arrays post-occupancy, other sub-meters report extremely low values and are not reliable. The bottom-up analysis is, therefore, based on the metered data available from the clamp meter and the operational profiles observed in the building which are broadly similar to TIC.

Figures 6.12 and 6.13 show typical weekly electrical loads of PIC in summer and winter respectively measured by the clamp meter.

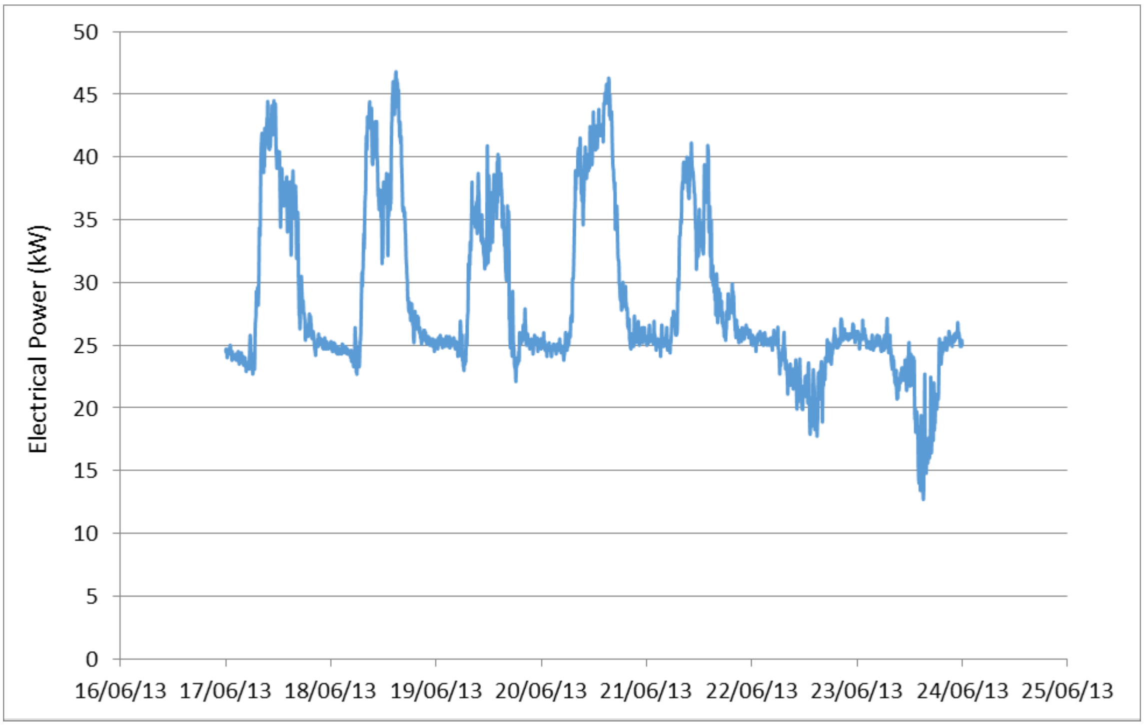


Figure 6.12: Profile of PIC electrical load in summer (typical week: 17/06/2013-24/06/2013)

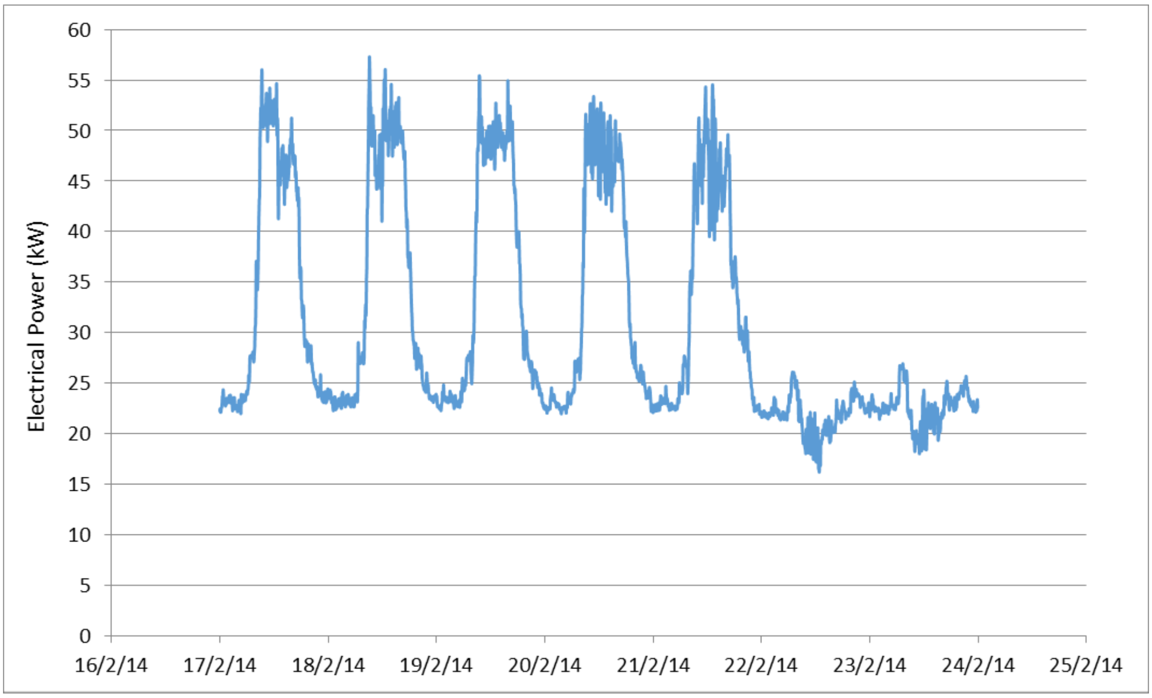


Figure 6.13: Profile of PIC electrical load in winter (typical week: 17/02/2014-24/02/2014)

The decline in daytime electrical load over the weekends indicates the contribution of PV arrays that is more effective in summer as expected. This can also help estimate the peak demand during weekdays. PIC's baseline electrical load is slightly higher than TIC. This is partly because the net lettable area in PIC is higher than TIC (2,245 m² vs. 2,200 m²) with more equipment in tenant spaces, and there is also a tenant with regular out-of-hours activity on the first floor.

PIC's electrical load during weekdays confirms that its operation follows the operation of typical office type buildings with core office hours between 8:30 am and 5:30 pm and some activities related to building management and cleaning time (Figure 6.14).
The same approach taken for TIC was used to establish the baseline and daytime power demands. A usage factor of 0.85 was used for lighting energy use in tenant spaces, to reflect the unoccupied spaces based on site visits and information provided by the building management.

In addition to server room cooling load that is included in ICT Equipment end-use category (and similar to TIC, was not allowed for in Building Regulations compliance and EPC calculations), three Mitsubishi Heavy Industries air conditioning split units provide comfort cooling to the meeting rooms.

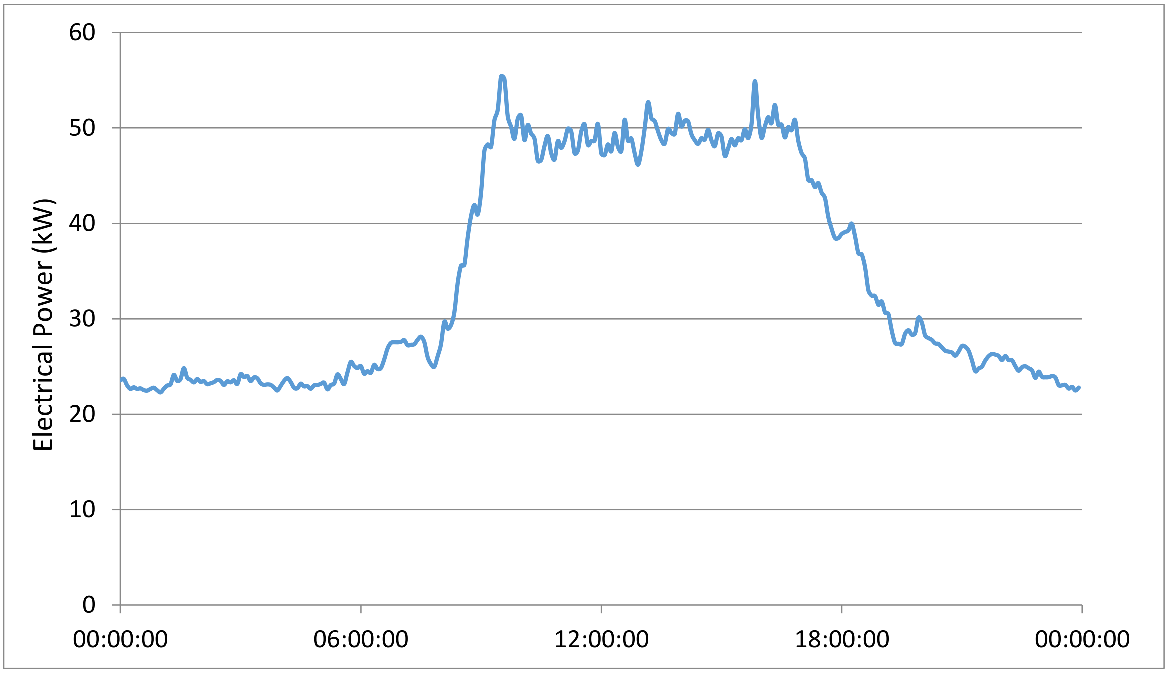


Figure 6.14: 24-hour electrical load in PIC (typical weekday: 19/02/2014)

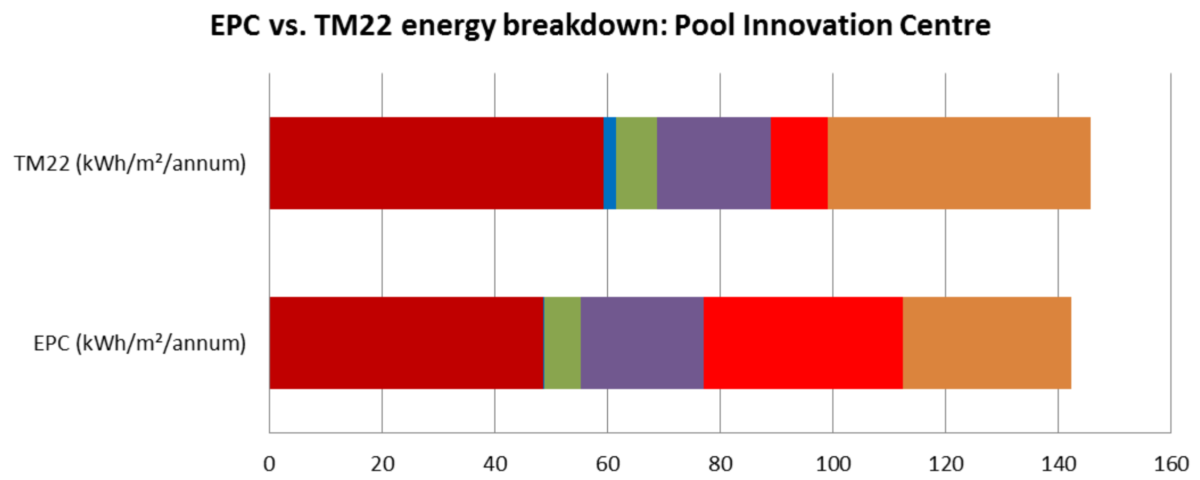
Following the TM22 detail assessment, the end-uses reported in Table 6.4 were reconciled with the mains electricity within 5%.

System	Fuel/Thermal demand (kWh/m²/year)	Electricity (kWh/m²/year)
Space Heating	59.4	0.0
Hot water	10	0.0
Refrigeration	0.0	2.2
Fans	0.0	2.4
Pumps	0.0	4.2
Controls	0.0	0.7
Lighting (Internal)	0.0	20.1
Lighting (External)	0.0	4.4
Small Power	0.0	22.0
ICT Equipment	0.0	16.6
Catering - Distributed	0.0	3.2
Lift	0.0	0.4
Total	**69.4**	**76.3**

Table 6.4: TM22 energy assessment for PIC: detailed analysis

The Energy Performance Certificate (EPC) produced for PIC following the completion of the building is B rated (B/28). Figure 6.15 compares the results of TM22 energy assessment in-use and the EPC estimations for end uses.5

[5] The EPC energy end-uses have been extracted from the xml file lodged with the Landmark. Auxiliary energy use includes fans, pumps and control.



	EPC (kWh/m²/annum)	TM22 (kWh/m²/annum)
Heating	48.6	59.4
Cooling	0.2	2.2
Auxiliary	6.4	7.3
Lighting	21.9	20.1
DHW	35.3	10
Non-regulated end-use	29.8	46.6

Figure 6.15: EPC vs. In-use TM22 energy analysis for PIC

The following findings are based on the comparison between the outcomes of EPC and TM22 assessments and on-site observations:

- **Heating:** Actual heating energy use is around 22% higher than the EPC estimation. While this discrepancy is much lower than what was observed at TIC, and differences in actual operating conditions and operational profiles assumed in EPC can also explain part of this discrepancy, there is still room for improvement. Figure 6.16 shows a photograph of the biomass boiler buffer vessel installed for PIC. The sensory equipment installed for the buffer vessel pass through metal bars installed on the surface of the vessel which are not insulated and, therefore, feel quite hot. These can lead to high standing heat loss for the buffer vessel.

Figure 6.16: Shortcomings in biomass buffer vessel insulation can lead to high standing loss

- **Lighting:** TM22 estimation for actual lighting energy use is slightly lower than the EPC estimation. It should, however, be noted that not all tenant spaces were occupied throughout the measurement period.
- **Domestic Hot Water:** The EPC estimation for domestic hot water use is significantly higher than actual hot water use. As explained in the previous section for TIC, this often happens where the NCM 'changing' activity type is used in a thermal model.
- **Non-regulated energy use:** energy use associated with the equipment in PIC is 56% higher than what was allowed for in the EPC calculations. It is notable that the default equipment energy allowed for in EPC calculations for TIC is also much higher than PIC's EPC. Given that the net lettable area of PIC is actually a bit higher than TIC, there seems to be an unexpected inconsistency between the EPC default equipment loads in these buildings that might be related to the way the zones were defined in the respective models. Without access to the source models, it would be difficult to establish the root cause for such discrepancy.

Overall, apart from potential inaccuracies involved in the EPC calculations in defining DHW demand and default equipment loads, energy performance of Pool Innovation Centre is reasonably close to the modelling results. Improving plant room insulation and energy efficient operation of the natural ventilation system in winter could narrow the gap between actual and estimated heating energy use.

6.1.3. Conclusions

The following conclusions could be drawn from the detailed energy analysis carried out for Tremough and Pool Innovation Centres:

- TIC has an EPC (asset rating) of A and a DEC (operational rating) of C.
- PIC has an EPC (asset rating) of B and an estimated DEC (operational rating) of C.
- Both buildings utilise biomass boilers that use wood pellets. The biomass boilers have been very effective in achieving good asset ratings and relatively good operational ratings. Overall, compared to other examples witnessed by the research team, these buildings are examples of successful use of

biomass boiler. However, building managers are not entirely satisfied with biomass boilers due to various operational problems they experienced with these systems especially during the early stages of post-occupancy.

- The EPC results for both buildings show no natural gas use; it appears that thermal demands of the buildings were entirely met by biomass boilers in the modelling process. In practice, the 'back-up' gas-fired boilers satisfied 44% and 29% of TIC's and PIC's thermal demand respectively. More reasonable assumptions about operation of biomass boilers and supplementary gas-fired boilers would be necessary at design stages to reflect the sizing of the systems, the learning curves associated with biomass boilers, and their operational & maintenance issues.

- The server rooms in both buildings were completed with mechanical ventilation only and no air conditioning system. However, air conditioning split units were installed shortly after building completion with knock-on effect on electricity use. Similar to other BPE projects investigated by this research team, this example, along with the issue raised above with regards to biomass boilers, point to a degree of optimism about energy performance potential of buildings that is not always justified and should be addressed to enable project teams to have a more realistic view about how buildings will actually perform in practice.

- The installed metering at PIC is not reliable. The electricity use billed by the supplier is significantly lower than actual electricity use. The electrical sub-meters are not calibrated and commissioned properly. Furthermore, contrary to TIC, there is no heat meter in the plant room. The installed metering at PIC represents the extreme case in the malfunctioning metering strategies investigated by this research team in the BPE projects and a poor example of building procurement for a building completed in 2010. It is important to include metering in the commissioning plan and ensure there is a robust, reliable and functional metering strategy on completion of a building and at initial stages of post-occupancy.

- The main operational issue related to energy is the heating energy use of TIC that is significantly higher than the EPC estimation. It is also significantly higher than PIC despite similar design philosophy, operational profiles and geographic locations. The evidence collated from the plant room heat meters point to excessive heat loss in the plant room. Although it is likely that heat meters are not accurate, the difference in thermal performance of these buildings points to potential operational problems associated with the TIC heating system. It is notable that the size of the biomass buffer vessel in TIC is much larger than PIC. Discontinuities in buffer vessel insulation, similar to what was observed in PIC, could lead to much higher heat loss in TIC's plantroom. It is also notable that, although the size of the biomass buffer vessel in TIC is much larger than PIC, the contribution of biomass boiler to building's thermal demand in TIC is actually lower than PIC (56% in TIC vs. 71% in PIC). It is recommended that further investigation is carried out by contractors to identify and address the root causes of heating system underperformance at Tremough Innovation Centre.

7 Technical Issues

Technology Strategy Board guidance on section requirements:	This section should review the underlying issues relating to the performance of the building and its systems. What are the technical issues that are leading to efficiency results achieved to date? Are the automated or manual controls effective, and do the users get the best from them? Are there design related technical issues which either need correcting/modifying or have been improved during the BPE process? Did the commissioning process actually setup the systems correctly and, if not, what is this leading to?

7.1 Consequences of squeezed commissioning phase

The commissioning period was squeezed hard at both buildings. There was pressure from the occupier, who wanted to start using the building and the contractor was pushing for completion to address their cash-flow. In the end the client refused to take over TIC at the contractor's preferred date as the commissioning was not undertaken. At the second attempt at handover the building manager at TIC was satisfied with the majority of the work undertaken but still understood that the commissioning was left un-finished. The M&E consultant explained that it would have been possible to hand over buildings in which performance-related elements have not been fully commissioned (though it is not advisable), on the understanding that they are completed while the client starts to move in.

It is common for the commissioning of the BMS not to take place before the client has moved in. To connect the BMS head end, the data connections and routing need to be in place in the building. This means that the BMS sub-contractor can't complete their job until after the client has installed their IT systems. However this isn't normally a problem and wasn't in this case either.

7.2 Consequences of Value Engineering in D&B Procurement

The FM had a couple of points to make about the design and build model of construction.

> *"A lot of blame has to be levied at the design and build process… It's been said many times before that design and build comes with its advantages but don't underestimate the disadvantages from an operator's and client's perspective. I think that has potentially been at the root of all of this."*

He reiterated this later:
"[D&B] divorces the people that had the original intention from the process of resolution."

In the FM's opinion the success of a design and build project rests with on the quality of the project manager and he gave the example of another Innovation Centre which is currently under construction by BAM and is likely to come in ahead of schedule and having been fully commissioned and tested.

D&B was also mentioned as the source of the problems experienced with the windows of TIC and other defects raised. It is not in the interest of the contractor to act on issues flagged up by the design team and issues raised with the contractors do not get added to the defects log. Interestingly, the BPE exercise gave an opportunity for issues to be aired with the client and end users, which resulted in some of these being added to the defects list. This does potentially create a conflict of interest situation for the consultants that are novated to the contractor which needs to be addressed in the long-term.

As the following section illustrates D&B contracts often result in the erosion of the original design intent through 'value engineering' carried out under the radar of the client and novated consultants. Without clear and validated building performance targets the pressure to cut cost means that decisions about product replacement or omission is made by individuals who are not aware of the potential impact of their decisions on the overall performance strategy.

7.3 Detailed findings

Window control issues at TIC
In what was an unpopular move with the M&E contractor, the BMS specialist was contracted to do the natural ventilation controls. After a meeting with a representative from the BMS Specialist, the main Contractor and the M&E Sub-Contractor the M&E consultant was a little happier, but in retrospect this seems to have been misplaced optimism.

> *"The guy who attended seemed to understand natural ventilation and I left reasonably happy that he could do the job. But then he wasn't seen again, and based on the software in place, the site operative wasn't given the appropriate support or natural ventilation control software." M&E Consultant, Halcrow*

Manual override systems are present on the windows at both PIC and TIC, with the system at PIC being vastly preferable. PIC has a press-and-hold control with no delay, while the controls at TIC have a 6-7 second delay making the controls extremely confusing.

Window actuator time-lag
The windows should respond to control inputs with an imperceptibly short time lag, to provide confirmation to the User that their control input has been recognised. However, it has been found that there is a time lag of 6-7 seconds from a manual override input and first movement of the windows. The cause of the time lag is not entirely known at present, but the Controls Specialist has suggested that it may be introduced within the integral control of the actuators themselves. We are advised that the clock cycle of the local control panels is 1 second, so theoretically, the longest possible delay between a user input and an output signal from the local control panel is 1 second. The engineers requested that the cause and solution to the time lag was investigated and reported back but this was never done.

In addition, the specification required the window actuators to operate at three different speeds, with a very slow speed used for automatic operation in order to minimise noise disturbance to occupants. A faster speed would then be used in manual mode and a high speed on a fire signal. Whilst the installed window actuators have the capability to be controlled at three different speeds, this also requires a communication cable to be installed between each window actuator and the local control panel, to relay the speed control signal and window position. Unfortunately, the communication cable was not installed, and the Controls Specialist has since advised that they are not able to provide the speed control signals, so the windows do not operate at a very slow speed in automatic mode.

The specification called for the windows to be controlled as an electric window in a car, whereby the user would push and hold the switch until the windows are in the desired position, then release the switch. This would operate at a faster speed, so the sight of the windows moving and the noise generated by the motors would provide visual and aural feedback to the User. However, due to the time lag and slow speed of movement under manual control, it was not practical to implement this strategy. The Controls Specialist therefore implemented a work around solution, whereby the windows open or close by a 10% increment for every discrete push up or down. Once this was explained to the Users and the Building Operator, they were generally satisfied that it provides the control they need. Unfortunately, it did not carry through the design intent of providing instant visual feedback to the users and is not sufficiently intuitive to be self-evident without explanation. A potential solution to the lack of feedback, would be to provide manual override switch faceplates complete with indication of the opening position that the windows are being driven to, via neon bar indicator lights or similar.

Night cooling at TIC
An elaborate set of instructions for night cooling and morning fresh air provision were specified in CH2M's Design vs As-built Report in the appendices. The original design intent was to use "degree hours" to determine the extent of night cooling for each space, as per BSRIA TN11/95 section 2.2, but this has not been implemented. We believe that the actual night cooling strategy aims to maintain a calculated room temperature set point from 2am-6am, by modulating the window openings. We understand that the calculated target set point is reduced if the daytime temperature is higher, and visa-versa, however, we doubt that lower internal room temperature set points can be achieved during warm weather. Interrogation of the BMS temperature logs on a warm week indicated that the building was not being significantly cooled overnight, with Users complaining of their offices feeling too warm and "stuffy" in the morning, so the evidence suggests that there is room for improvement on the currently implemented strategy. The engineers have suggested that the restriction of

cooling to 2am-6am be lifted, so night cooling can occur for the whole of the unoccupied period, in order to maximise the potential for night cooling.

Window-master commissioning at PIC
At PIC, WindowMaster were unable to complete the seasonal commissioning and were wary of sharing their commissioning documents. The engineer noted that the seasonal commissioning should have been carried out but due to the D&B contract, he was unable to assert this. The building received its BREEAM certificate despite the absence of the seasonal commissioning, which was part of the criteria. Other issues with the BMS were highlighted, such as the heating system being set to 24 hours.

Eventually, due the feed-back from users led WindowMaster to change the auto-vent settings to address at least the auto-venting timings in the winter.

> *"[P]erhaps [it] auto-vented a little bit too much… [in winter it was] set to auto-vent on the hour for five minutes it probably doesn't need that so we've changed the setting on that now."*

The interviewee suggested that more training could have been given in operation of the systems, which is a comment that was made frequently by other interviewees.

Biomass commissioning and maintenance
The most common issue that the engineers experienced with renewables was in biomass fuel feed systems at both sites.

"The thing to be aware of is the need for more user involvement – biomass boiler combustion chambers need periodic clearing of ash, and someone needs to remember to check the fuel level and re-order when it gets low. Automatic alerts can be set up via the BMS, to prompt re-ordering."

The biomass boiler is a woodchip boiler and needs cleaning out around once a week.
The team discovered that this was no longer the responsibility of the administrative staff and an outside contractor was engaged to come in to de-ash on a regular basis.

At PIC administration staff were originally expected to handle clearing of ash from the combustion chamber (though an external contractor has now been engaged), and TIC ran out of fuel, for which the M&E consultant has suggested an automatic fuel level alert to be set up via the BMS.

To make a comparison to the wood pellet boiler at Pool Innovation Centre, the biomass boiler at Tremough Innovation Centre is a larger, more sophisticated unit, designed to cope with the more onerous demands of burning wood chip. One of the points of difference that has been especially appreciated by the Operator is the automatic ash clearing function, which aimed to reduce the manual labour burden associated with running the biomass boiler. At several site visits the FM was witnessed emptying the ash directly onto the rear lawn by hand to 'fertilise the lawn'. Unfortunately at TIC the more sophisticated biomass boiler incurred other severe maintenance costs.

As a BREEAM assessor and former architect the FM is well placed to flag up issues with integrating sustainability features. Endorsing BRE's work with BREEAM, he states:

> *"When they [biomass boilers] were the new shiny thing we tripped over ourselves and over-complicated things and they were more trouble than they were worth. I think now, and through the support the BREEAM system gives, the right measure has been arrived at." FM, PIC & TIC*

At the final meeting with facilities managers both the FM for PIC and TIC agreed that they would not recommend the use of biomass boilers in the future due to the complications and costs associated with maintenance.

Follow-up of other defects and commissioning shortcomings
At TIC, the commissioning was not complete, more than six months after handover. There was some disagreement between two interviewees regarding how many items were on the defects list (850 vs. 130 defects) – although some weeks passed between the two interviews in which the list could have reduced. It may also be that the M&E contractor is including resolved defects in his count.

The engineer was concerned that the issues on the defects list did not cover the issues the engineer raised with controls. The monitoring team also added items to the client's defects list although it was noted that this had to be done 'discreetly' so that it does not jeopardise the success of the monitoring with the contractor. Clearly, the client benefited more from the BPE than the contractor. Whilst some of the items raised were subsequently rectified, including errors with meters, the ventilation controls were still not addressed at the time of completing the BPE study.

The presence of biomass boilers, wind-catchers, rainwater harvesting and other sustainability features required special attention during commissioning and seasonal commissioning. However many of the actual issues encountered were not caused by the renewables themselves but they certainly add complication. For example the rainwater harvesting at Pool had a problem where someone broke a water main across the road and so the filters had become clogged with dirt and gravel.

Wind Catchers

Wind catchers are simple devices and the only control element is a damper, the control of which is taken care of in the natural ventilation control commissioning. One of them had a leak which suggested it wasn't installed in accordance with Monodraught's weather detailing. This would normally be addressed as a defect but was raised during commissioning.

Conference Room Controls

At TIC, the louvres in the conference room should have had an interlock with the fan and this was not programmed, which meant that the room was being pressurised, so the targeted flow rates were most likely not being achieved.

Automatic lighting controls

In terms of addressing issues during the defects liability period, the following is a good example of how difficult it can be to resolve a problem once the control systems are set up:

An issue was raised with the automatic lighting controls. These were not set up as the occupants would have liked in some rooms and (four or five according to the interviewee), but since the sensors were on a closed protocol it is thought to be very expensive to source a controller to change the settings.

In addition the daylight dimming sensors for lights do not appear to be working in some areas, which was eventually raised as a defect.

LTHW Circuits

The as installed low temperature hot water pumping circuits differed significantly from the design and have experienced a number of issues. The actual installation comprises a modular heating pipework system incorporating square tee joints (instead of swept tee branches) with smaller pipe sizes than required by the original design. This has resulted in significantly higher hydraulic pressure drops in the variable temperature secondary heating circuits to radiators and trench heaters, to the extent that it has been reported that some secondary heating circuits provide approximately 60% of their design flow rate. The pumps had to be replaced with larger units, which would account for the larger than expected pump loads at TIC.

Metering:

Several electrical sub-meters on the main panel board were not operating or connected to the BMS for several months after handover. These were later re-set to work by the M&E Sub-Contractor and then connected to the BMS by the Controls Specialist. Many of the readings displayed on the BMS were incorrect, due to initial errors in calibration and/or communication between the meters and the BMS. Some of these have been calibrated (between the meters and BMS) and reconciled (between the meters themselves) but the uncertainty meant that meters had to be manually read for the TM22 exercise.

Energy Monitoring and logging:

The Building Management System should have been set up to make it possible to monitor and log energy and building performance data in a remote web-based database (e.g. SQL), to allow access to historical records for assessing energy efficiency and building performance. This would have been an invaluable resource for the purposes of seasonal commissioning, optimisation and ongoing management and maintenance.

Energy Display Screen
The energy display panel in the atrium currently displays cumulative meter readings, but does not include an information point to help interpret them, as required by the M&E Specification.

Other
A list of other issues have been detailed in the engineers' Design vs As Built report, including:

- Value engineering of LTHW Heat emitters being of lower quality than those specified
- LTHW Heating control and flow temperatures not correctly programmed in BMS
- Heating vs Cooling setpoint deadbands set up so that TRV settings fight window opening settings
- Optimised start/stop controls using corridor temperatures for heating benchmark
- Weather compensation for LTHW temperature control missing internal temperature sensors causing disproportionately large reduction in heating capacity in winter, particularly affecting rooms with highest heat losses

The report raised further issues caused by the value engineering of the following systems at TIC:

- Low Voltage distribution – hindering effective metering of tenant areas
- Lighting and emergency escape lighting – cheaper luminaires in some offices
- Security systems – faulty keypads making intruder alarm settings contentious resulted in a client recommendation to return to keys in subsequent developments
- Automatic number plate recognition – failing in 4% of cases

BMS feedback from TIC
The mismatch between expectations and reality with the BMS is summed up by the following quote:

> *"The BMS is probably the most baffling [system]. It reminds me of a footballer who's the best footballer in the world but never gets the ball so can't score. I just think it's under-utilised."*

The FM felt at both buildings that the BMS should be connected to a lot more systems and provide much more feedback. The ability to read the electricity meters for each room is one feature which it was suggested would be a great help. This was in fact part of the design specification and turned out to be another shortcoming of the BMS commissioning.

Rainwater harvesting
The FM appeared very pleased with the rainwater harvesting system. This was despite the fact that he once had to return to deal with a problem with the system locking out after a power cut just before New Year's Eve 2011. This problem had since been rectified and the system provides around 80% of water for flushing toilets at PIC.

At TIC the meter to the rainwater supply was inadvertently installed on the mains top up incoming supply, so the measurements of rainwater consumption were incorrect for the first 9 months. As can be seen on the metering specification from the O&M manual (in the following section) there should have been two cold water meters connected to the rainwater harvesting system and these should have been connected via a pulsed output to the BMS and the Trend logging system. The meter was eventually re-fitted onto the correct pipe.

7.4 Conclusions and key findings for this section

The Innovation Centres provide a high quality work environment and a focal point for small businesses in the area, and are considered by the client as successful buildings on the whole. However, this study has highlighted a number of areas for improvement in the procurement and construction, particularly in relation to the mechanical, electrical and control systems, commissioning, handover and seasonal commissioning.

Most, but not all of the original design intent was followed through into the finished building. Unfortunately, some of the derogations from the design have resulted in sub-optimal control of the internal environment and higher energy consumption and carbon dioxide emissions.

There were a number of deficiencies in the commissioning and handover process and latent defects which were not resolved in a timely manner. It would be a fair assertion that the buildings were not ready on the day they were handed over. In the case of TIC it was hoped that renewed pressure by the Client on the Contractor would help to bring the highlighted outstanding items to a satisfactory conclusion.

The Design & Build procurement process is inherently exposed to such issues, since control of the construction cost and the building quality is nearly all held by a single organisation, the main Contractor. This gives rise to an adverse incentive mechanism, whereby it is in the Contractor's interest to finish the job, achieve handover and get paid as quickly as possible at the lowest Construction cost, which can be at the expense of quality of the finished product and the performance of the building.

The CH2M engineer working on the project said:

"In a Traditional Contract, the Design Team remain working directly for the ultimate Client and are therefore impartial to the Contractor's financial interests. In a Design & Build Contract where the Design Team are novated to the Contractor, they rescind ultimate control over the final design and installation. In many cases, derogations from the design are only likely to be noticed by the designers, but can cause the long term performance of the building to suffer. While the Design Team can offer their guidance and advice during construction, it is an unfortunate reality that the Contractor and Sub-Contractors are only likely to act upon it if failure to do so is likely to be noticed by the Client and lead to commercial penalties."

7.5 Conclusions - Summary

Following the architecture team's review of the report the following were highlighted for action on future AHR projects:

- TIC - used more heat than expected due to excessive heat loss in the plantroom
- PIC - used more electricity than expected
- The faulty electricity meter resulted in a better than expected DEC rating (A instead of C)
- Gas boilers were used more than expected
- Post completion installation of server cooling managed to bypass compliance issues
- FM blamed VE in D&B for a lot of the issues encountered
- Manual override systems are present on the windows at both PIC and TIC, with the system at PIC being vastly preferable. PIC has a press-and-hold control with no delay, while the controls at TIC have a 6-7 second delay making the controls highly confusing.
- Overly restrictive night time cooling time band resulted in occupant discomfort
- Better training in the use of systems would help
- TIC's biomass boiler has automatic ash clearance. PIC's does not
- At the final meeting with facilities managers both the FM for PIC and TIC agreed that they would not recommend the use of biomass boilers in the future due to complications and maintenance costs.
- During the contract modular heating circuits were sold to the client as being 'quicker' or 'better' - but this change has led to lower flow rates and the need to install larger pumps
- Metering was problematic
- Interpretation of the energy display screens in the lobby is difficult
- Online energy monitoring capabilities coupled with BMS logging capability would simplify data collection
- FM felt that the BMS should be connected to a lot more systems to provide much more feedback, and was happy with the rainwater harvesting systems
- Recommend a reporting role for the architect AND the M&E consultant to assist in overcoming VE leading to poor performance in use.

8 Key messages for the client, owner and occupier

Technology Strategy Board guidance on section requirements:	This section should investigate the main findings and draw out the key messages for communication to the client/developer, the building owner, the operator and the occupier. There may also be messages for designers and supply chain members to improve their future approaches to this kind of building. Drawing from the findings of the rest of the report, specifically required are: a summary of points raised in discussion with team members; recommendations for improving performance, with expected results or actual results where these have already been implemented; a summary of lessons learned: things to do, things to avoid, and things requiring further attention; a summary of comments made in discussions and what these could be indicating. Try to use layman's terms where possible so that the messages are understood correctly and so more likely to be acted upon.

8.1 Recommendations

These two projects appeared to have the same teething problems as many others monitored by the team. The improved outcomes were partly thanks to the resilience of the design, the perseverance and professionalism of the project team and the engagement of the client and the facilities managers. The building performance evaluation appeared to have had an important role in identifying and rectifying some issues, particularly at TIC.

A key observation of the BPE team was that correct installation and commissioning of the specified equipment and products is often compromised if value engineering is allowed to occur without overall building performance checks, if commissioning time is reduced and building performance is not adequately validated in use. There is one other key factor – the lack of well-designed controls available on the market for managing indoor environmental comfort, security and equipment performance.

The majority of the issues identified could be traced back to these causes and the following steps are recommended to prevent these in the future:

1. Performance targets in terms of energy end use, fuel consumption, water consumption, temperature, CO2 levels, relative humidity and lighting levels are specified up-front and tracked from design to operation.
2. That building characteristics and elements/products contributing to these are entered into a risk register, which is tracked from design to operation and incorporated into the contractor's prelims. Should the contractor wish to make changes to the items in the register, the project energy model would need to be re-calculated.
3. The Building Management System and other controls are identified as a major risk area up-front and the contractor is penalised by any performance shortfall arising from the commissioning of the building
4. Building Performance Evaluations are carried out routinely by an independent team, in collaboration with the project team. This needs to be incorporated into every consultant and contractor scope, including the requirement to supply specifications and performance data to the BPE team during the first two years of the building's operation. The results are benchmarked against predictions and reviewed on behalf of the client.
5. A budget is identified up-front to prototype the control mechanism of the more complex interfaces of the design, such as the window controls, BMS interface, etc.
6. Seasonal commissioning is enforced
7. Incorporate building performance markers such as the above in the scope of the facilities management team

A key finding of this study was the resilience of the fabric first strategy to procurement and operational risks. The results of targeted data logging at both PIC and TIC are reassuring in that none of the rooms studied show a problem with over-heating even at times of high outdoor temperatures. This was despite the problems identified with night purge, which implies that the buildings have further resilience to draw on as extreme temperature events become more frequent.

Both buildings have an untapped potential in their BMS – with a small investment in improving its interface some basic changes could be made in both buildings that would further improve the feedback from occupiers.

9 Wider lessons

TSB Guidance on Section Requirements:	This section should summarise the wider lessons for the industry, clients/developers, building operators/managers and the supply chain. These lessons need to be disseminated through trade bodies, professional Institutions, representation on standards bodies, best practice clubs etc. As well as recommendations on what should be done, this section should also reveal what not to do on similar projects. As far as possible these lessons should be put in layman's terms to ensure effective communication with a broad industry audience.

9.1 Final conclusions

The introduction to this report is intended both as an executive summary and a synthesis of wider lessons and recommendations. One area that was not discussed in great detail was the amount of time it required to trace and compile the information in this report. BPEs are not currently cost effective because the information developed for the employer's requirements, construction and compliance do not include a detailed and usable description of the building performance and aspects of the design and specification that is critical to achieve it.

The making of this report required information to be forensically extracted from sources, which were incomplete, faulty, prepared for a different purpose or simply unavailable: Drawings, building user guide, O&M manual, log books, surveys, data loggers, thermal cameras, design reports, EPC XML files, DEC Advisory Report, specifications, to mention a few. One of the most useful inputs were the documented structured interviews conducted with the engineers and the facilities managers. The BPE team was delighted where the study led to further discussions with the client and facilities managers on preventing and addressing performance issues on other projects. Key to the industry-wide adoption of improved building performance practice is CIBSE and RIBA joint action on providing standards and guidance on standard scopes for BPEs/POEs. In addition it is essential that the professional bodies campaign on their members' behalf that insurers view the adoption of BPEs as a means to lower project risk rather than increase, which is the status quo. Currently, practices or contractors offering these services are uncompetitive in the bidding process as they have to price in their risks.

A level playing field is needed to address this needed to address this, which could come from a regulatory source or it is possible to address such criteria in the bidding process for a specific client. The latter is likely to be available to a small minority of client bodies where the expertise to oversee such a process is readily available. Yet the arguments for this are overwhelming. There is an enticing potential to improve the productivity of all stakeholders engaged in construction. The costs of the unrealised performance benefits of poorly installed and commissioned equipment, the unproductive time spent on reckless value-engineering and mitigating the resulting problems, the excessive time spent on recovering performance data that should be automatically supplied to project and maintenance teams, not to mention the loss of productivity of uncomfortable occupiers, would amount to a significant percentage of a building's construction budget that would be much better spent by investing in the robust delivery of outstanding building performance.

These two buildings have demonstrated ways of getting it right and where further improvements can be made. Certainly, the project team's dedication and commitment has paid off as occupiers have been largely delighted with the building – it was the first time that the monitoring team encountered feedback that said: "This building makes me feel human!"