iCon Building

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Innovate UK project number	450033
Project lead and author	East Midlands Sustainable Construction iNet
Report date	2014
InnovateUK Evaluator	Unknown (Contact via www.bpe-specialists.org.uk)

Building sector	**Location**	**Form of contract**	**Opened**
Office	Daventry	Design and build	2011
Floor area (GIA)	**Storeys**	**EPC / DEC 2013**	**BREEAM rating**
4024 m^2	Single	B (26) / C (60)	Excellent

Purpose of evaluation

Intended as a practical demonstration of how to achieve high levels of energy and environmental performance in a cost-effective construction technique and procurement route.

Design energy assessment	**In-use energy assessment**	**Electrical sub-meter breakdown**
Yes	Yes	Partial

Estimated electricity use: 79.2 kWh/m² per annum; thermal (gas): 47.2 kWh/m² per annum .

Occupant survey	**Survey sample**	**Response rate**
BUS, paper-based	56	N/A (not recorded)

Overall, the building was rated well by its occupants, meeting the needs of its users and delivering generally satisfactory thermal comfort.

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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.

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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.

1.1 Project Scope

This report describes the TSB funded Building Performance Evaluation (BPE) project carried out between August 2011 an October 2013 at the iCon Building in Daventry. The building was chosen as the subject of the evaluation project because it presented a good case study opportunity, having been recently completed and intended to be a practical demonstration of how to achieve high levels of energy and environmental performance while maintaining a cost effective construction technique and procurement route. The project set out to establish via a detailed evaluation in-use whether these objectives were met and to identify any shortcomings and potential pitfalls to be avoided in future projects. It is also intending to identify whether these factors arose from decision made during the design, construction or operation of the building. The project is also intended to provide feedback to project partners who committed at the project's outset to integrate skills developed through the BPE process and use the project's findings to inform their future projects, aiming to close-the-loop between building design and performance.

1.2 Project Outline

The evaluation process was organised into four themes, each considering the building from a different perspective. The first of these themes, tenant engagement used a combination of semi-structured interviews and a standard occupancy survey questionnaire to develop an understanding of the building's performance from the point of view of its occupants and users. This theme is described in more detail in chapter 4. The second theme considered the building from the point of view of the design and construction team. This included a design team workshop to capture and share lessons from the design and delivery process. The workshop was followed by individual interviews to provide further details on issues identified during the workshop and to discuss/identify performance risk factors that could be used as part of a design-stage 'due-diligence' process. The outcome of these activities is described in chapter 2. The third theme reviewed the as-built performance of the building from a technical perspective and included a technical walk-through, indicative thermographic survey and a review of as-built information. The fourth theme reviewed the operational performance of the building through on-going energy monitoring and regular operational performance review meetings with the building management and maintenance team. The energy monitoring and analysis is described in chapter 6 while the findings of the technical review are described in chapter 7.

1.3 Key Facts & Figures

Building Information

Sector	Commercial
Type	General office
Floor Area	4024m^2
Completion	2011
EPC Rating	B (asset rating 26) (16 March 2011)
DEC Rating	C (operational rating 60) (11 May 2013)

Table 1: Building information

1.4 Key Findings

The building was completed on-budget after a three month delay, the result mainly of an unanticipated need to divert gas and water utilities crossing the site. The building achieved a BREEAM Excellent rating and met a design CO_2 emissions target of 15 $kgCO_2/m^2$.yr with a modelled building emission rate of 12.2 $kgCO_2/m^2$.yr. Overall the building is rated well by its occupants. It meets the needs of its users and delivers generally satisfactory thermal comfort. During the first two years of operation however there have been occasions where thermal comfort did not meet expectations as a result of problems with both the heating and natural ventilation systems. A number of factors contributed to these problems: design issues, component failures, incomplete commissioning and a lack of understanding about how best to operate and maintain the building. Some of these could have been avoided by ensuring sufficient time before and after handover to complete the commissioning process, deliver adequate operation and maintenance documents and training to the building management and maintenance team. Although direct comparisons between the building’s design energy target and its operational energy consumption are not possible due to the differences in metrics, it is clear that the building's current in-use energy performance does not meet its potential. The evaluation project has resulted in a number of improvements that have recently been implemented. In order to verify the effectiveness of the improvements beyond the duration of the BPE project, the building performance monitoring will be continued by researchers at Loughborough University in conjunction with building management staff.

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 Brief and design intent

The building project came about from the shared motivation of the University of Northampton (UoN), West Northamptonshire Development Corporation (WNDC) and Daventry District Council (DDC) to create a centre for sustainable construction. An opportunity to access matched funding provided by the European Regional Development Fund (ERDF) arose and a bid was prepared by WNDC and UoN. The University then led the development of a brief in conjunction with Building Research Establishment (BRE) and the funding bodies WNDC, DDC and the East Midlands Development Agency. A design competition, run by BRE and RIBA (Royal Institute of British Architects) was announced in March 2008. WNDC took the lead in managing the project following the competition stage.

The competition brief was for a sustainable centre of excellence supporting education, training, conferences and business incubation in Daventry. The building would be an iconic architectural example showcasing and complementing innovative thinking and technology in a sustainable manner. The accommodation to be provided would include flexible start-up offices, conference facilities for 200 people, exhibition spaces, meeting rooms, break-out space, canteen and supporting facilities. The preliminary competition brief set the budget at £5,200,000.

The competition to select the winning design was a two-stage process. The first stage was judged anonymously on the basis of two presentation boards and a short design and environmental statement submitted by each design team. A number of teams were short-listed and issued with a more detailed second stage brief. The winner was selected on the basis of the design's innovativeness and visual impression, contextual response to the site, adherence to the requirements of the brief and demonstration of sustainability and energy efficiency. Entries were also considered on their awareness of issues of practicality and financial feasibility involved in constructing an exemplar zero carbon building.

The competition was administered by RIBA, with the involvement of the partners responsible for developing the brief. There were 75 entries at the first competition stage. This was reduced to 5 short-listed entries, which were developed in more detail during the second competition stage. The completion was judged by a panel however this did not include a clearly defined client, which may have reduced the focus of the judging process.

Targets / Aspiration

The design teams were required to demonstrate the practical aspects of energy efficiency and sustainability. One of the project's main criteria was the achievement of an innovative energy performance status, to be explored fundamentally by minimising the actual energy demand and therefore operational costs. The emphasis was placed firstly on incorporating appropriate design measures to minimise energy use and secondly on the use of suitable renewable energy technologies. The proposed design strategies were expected to reduce the energy demand whilst maintaining occupants' comfort throughout the year.

The second stage of the competition required the designer to submit a carbon statement outlining targets, strategies and assumptions made to achieve best performance in several areas including CO_2 emissions, heating and electrical loads, thermal performance and air tightness. The building was developed with the clear aspiration of achieving a BREEAM 'Excellent' rating (the highest attainable at that time) and meeting a CO_2 emissions target of 15 $kgCO_2/m^2$.yr.

It was not possible to obtain details of the individual competition entries however the winning design's energy and environmental stage D scheme design report was obtained. This was prepared by the architect's environmental services consultant prior to tender in early 2009. It outlines the proposed low-energy measures including improved airtightness, heat recovery, enhanced U-values, phase change material (PCM), daylight-linked dimming and low resistance pipe and duct design. This combination of measures was estimated to achieve an annual CO_2 emission density of 13.7kg/m^2, which compared favourably with best practice operational figures from the ECON 19 benchmarks and measured data from the Elizabeth Fry Building. The estimated figure included electrical power consumption, an unregulated end-use, in addition to regulated end-uses such as heating, hot water and lighting. Together with the fact that the benchmarks used are in-use figures this suggests that the emissions target was interpreted as an in-use figure at this stage in the project.

	Heating (kWh/m²)	Hot Water (kWh/m²)	Fans & Pumps (kWh/m²)	Lighting (kWh/m²)	Power (kWh/m²)	Other Electricity (kWh/m²)	CO_2 Emissions ($kgCO_2/m^2$)
ECON 19 Best Practice	79		2	14	12	3	28.1
Elizabeth Fry Building	37		18	26	8		29.0
Improved airtightness	55	7	6	14	12	3	26.6
Heat recovery	45	7	6	14	12	3	24.7
Better U-values	11	7	6	14	12	3	18.2
PCMs	5	7	6	14	12	3	17.1
Daylight-linked dimming	5	7	6	10	12	3	15.4
Low-velocity design	5	7	2	10	12	3	13.7

Table 2: Stage D Building Performance Targets

Discussion at the design team workshop revealed a lack of clarity regarding the nature and origin of the building's design CO_2 emission target. Although a target was clearly stated, it was not explicit whether it represented the building's actual energy consumption in-use, or merely the regulated energy consumption at design stage. This lack of clarity had a significant impact on the building's energy performance as an in-use target would have been more onerous than a design target. During the project, the target shifted from an in-use target to a design target, for comparison with results of the building regulations compliance calculations. As a result it is not possible to use the target to verify the performance of the actual building in operation. The project team, including the client, should have been fully aware of these issues from the outset. When the target was being established a carbon neutral solution was proposed but was perceived to be infeasible given the budget constraints. There was some debate over definitions of “carbon neutrality” and the integration of renewable energy sources but the questions were apparently never fully resolved. Because of this, there was some disruption later on in the project when a proposal was made not to have a mains gas connection, in the belief that with such a connection the building could never be “carbon neutral”. This led to the design and installation of an all-electric kitchen, even though the aspiration to carbon neutrality was never met.

Other than the ambiguity regarding the CO_2 emissions target the brief was generally clear and expressed a comprehensive set of client requirements. At the design team workshop it was however questioned whether these requirements were actually developed in conjunction with the end-user. Similarly, although the brief represented an aspirational design, in the sense that the client had aspirations for a high performance building, it was questioned whether the budget was sufficient to meet the aspiration.

Architectural Design Issues

From the architect's point of view, some aspects of the fit-out design were not considered to be well integrated with the base build design, for example the kitchen. The attention to detail in the design is considered sufficient, however the design and build procurement route could have had an effect on the level of detail developed in the early design stages. There are general precedents for the design concept, however this may be a first for the specific combination of design elements although they have been demonstrated successfully in individual application. Late design changes in building projects may be inevitable, particularly in the case of one-off public sector projects. A clearer understanding by the client of their requirements could have prevented some of the late changes that occurred on this project. One example of this is the decision to enclose the café and break-out areas after realising they would effectively be unheated spaces. It was originally intended for these areas to be open to the internal street. However it became apparent that the spaces would be cold in winter and could not be provided with a fixed heating system. The option of adding seasonal heating (such as infra-red heaters) was rejected as not fitting the building's low-energy image and not providing acceptable occupant comfort. Despite the difficulty and structural implications of enclosing the café and breakout spaces during the construction phase it was decided that the added cost was necessary. Fortunately there was sufficient leeway in terms of the building's design stage CO_2 performance to allow underfloor heating in the café without compromising the design CO_2 target. In hindsight the implication of occupied areas being open to an unheated space should have been made clearer and understood by all members of the team prior to the design freeze.

A value engineering exercise undertaken towards the end of the construction stage moved a number of items specified in the strategic brief to the client's fit-out. These items included security, comms and IT systems. The process was complicated by the lack of a defined client to take decisions and specify functionality. The unanticipated change to ownership by the University resulted in network connectivity problems due to differing IT system requirements. This might have been avoided had the University been involved in earlier decisions relating to fit-out.

Technical Design Issues

There were fewer problems from the building services design point of view, however raised floors were eliminated by value engineering and the kitchen is more heavily serviced than originally expected. The original proposal included a ground-source heat pump with ground loop pipework embedded in the building's foundations. Cost and the contractor's concern about buildability forced the designers to use an air-source heat pump as an alternative. The technologies used in the iCon building do have a successful track record but not necessarily in similar buildings. For example, exhaust air heat pumps have been successfully used to supplement domestic hot water systems in flats and hotels, but are not widely used to provide space heating in offices. The technologies are relatively simple, however the procurement route may have resulted in the loss of knowledge of design intent as operational problems suggest a lack of understanding of system control strategy. From the designers' point of view problems with the building services systems are generally less a result of poor robustness and more a result of incorrect usage (although it was acknowledged that natural ventilation actuators are notorious for in-service failure). It is likely however, that the overall performance is sensitive to the performance variation of individual components. Manufacturers' data sheets are often the only source of technical information on which to base performance estimates. The information they contain is however typically based on bench testing individual components under standard conditions. Data from field trials and whole-system tests need to be used in conjunction with manufacturers' data to ensure appropriate assumptions are used to develop performance estimates.

The building performance modelling work was considered to be of a good standard, and the assumptions made were based on best available knowledge (given the limitations of manufacturers' data described above). The environmental consultant suggested that this work should be carried out by people with a mechanical engineering background, which provides them with a common-sense understanding of the building plant items. It is believed that this was the case on this project. The software used was an industry standard approved package, however it was unable to take account of the PCM wall board used on the project. It was also pointed out that the output of the software does not allow for any deviation from input assumptions in actual operation. For example the size of ventilation openings was shown to be sufficient under design conditions but does not include any safety margin to allow for variation in occupancy or equipment density. It should be considered whether similar technical combinations have been modelled before, and whether there are any lessons to be drawn from previous experience.

Some specialist support was provided, mostly limited to a review by BRE of the thermal modelling. This review questioned some of the assumptions built into the model, such as the efficiency of the exhaust air heat pump and the free area provided by ventilation openings. It was not evident that the points identified in the review were ever addressed.

2.2 Construction Process

The winning design team was selected three months after the announcement of the competition. The team was led by architects Consarc, along with services consultants Synergy, structural consultants SKM Anthony Hunt and cost consultants Potter Raper Partnership. Design to RIBA stage C was completed in December

2008, and went out to tender in February, approximately between RIBA stage D and E. The design and build contract was won by Winvic. Preliminary work on site started in August 2009 and foundations were completed during the autumn.

Procurement Route

The use of a design-and-build procurement route, specified in the brief, added some constraints to the project. There was a loss of consistency when the project went to tender and stakeholders changed. The environmental design consultant was not novated to the design-and-build contractor. Their role was reduced to a watching brief, with no design input. This was felt by the design team to have adversely affected the focus on the building's energy performance and reduced the integration of architectural and environmental design. In hindsight the chosen procurement route may not have been the best from the point of view of supporting innovative design despite helping to meet the project budget. From the consultants' point of view a traditional procurement route allowing greater involvement would have been helpful to retain design intent. From the contractor's point of view, design and build is capable of delivering the client's requirements and satisfying design intent, provided the brief is robust. Although design and build procurement may have been necessary to achieve the budget price a traditional contract with increased consultant involvement could have delivered a better result although at greater expense.

It was suggested that the client culture in public sector projects is very risk averse. Design and build projects are favoured as a way of reducing client liability. There is a trade-off however between liability and control that makes project success more sensitive to the contractor's ability to make cost and efficiency savings without compromising design intent, particularly in the technical design.

The contract covered all aspects of the base-build in sufficient detail for a design and build project however the contractor felt the fit-out specification was not sufficiently developed. The scope of work should be clearly defined. The issue of including 'quality' requirements in the contract was raised but it was questioned whether they could be defined without ambiguity or unduly restricting design flexibility.

Project Management

After the competition stage the decision was made for WNDC rather than UoN to act as project manager. The project funding was provided through WNDC but although WNDC were the financial client they were not going to run the building. During the project several different project managers were involved the project at different times. The identity of the project client was also an issue. It was felt that the project lacked a clearly identified client able to make timely decisions throughout the whole project. The lack of clarity over the building operator/end-user was also seen as a significant obstacle to defining appropriate client requirements. In some ways the client seemed to be more like a committee with only one or two effective decision makers. There was a lack of continuity in terms of client involvement as well as in project management which may have resulted in a lack of understanding of design requirements and may also have affected the leadership of the project. The client didn't appear to have as much authority as on other projects as a result of differences of opinion among client consultees and a high level of risk aversion that hindered decision making. The division between client team and project management was not clear. On the other hand, the definition of roles and responsibilities within the design team was much clearer.

There was a good level of cooperation and openness that also extended to the client team, however this did depend on who was involved at the time. There is a risk of personality clashes in all team activities, however in this case working relationships were generally good. The designers considered the contractors to be more friendly and less confrontational than might have been the case with larger companies. Frequent design team meetings and a higher than usual involvement of the architect provided feedback on progress and helped develop a shared project vision among the design team. Central data management and clear lines of communication allowed technical information to be shared effectively. There was good continuity among the design team, although the architects team was fairly large and included staff who were not continuously involved in the project.

Early involvement of the construction team is often difficult to arrange. Much of the required input would be from sub-contractors, who would be working at risk if the main contractor's tender bid is unsuccessful. Manufacturers however can also be a useful source of advice and tend to be more willing to help at early stages. On this project the main contractor did carry out some pre-appointment work on the potential for value engineering. The particular combination of envelope and servicing on this project was new for the design and construction team. The main contractor and M&E sub-contractor have worked successfully together in the past. The architect and building services consultant are based in the same building and have also worked successfully together in the past. It was generally assumed that project team members are always committed to the success of the project. This project was particularly interesting for the design and construction team and provided useful learning despite some frustrating issues with the client team.

The design and construction team considered the build quality to be good. It was observed that attention should be focussed on areas with the potential for significant impact on the building's performance. Inspection of the build quality was driven by the architect and focussed more on things like finishes and less on the M&E installation.

Value Engineering

By the time of the design freeze the budget had been committed, so further changes could have compromised the ability to complete the project. A value engineering exercise at the planning stage (post RIBA stage D) was undertaken to get the tendered budget back in line with the cost plan (£5.7m at that stage). The outcomes included a decision to omit raised flooring and movable wall partitions, and to reduce the cost of the cladding. The changes to the flooring and walls were considered to have reduced the flexibility of the accommodation. Although the building designers were keen to avoid “eco-bling” they did want to include some indication that a “normal” building could be a sustainable building. The public façade of the building was designed to give information to passers-by and building users on the building's energy usage. The value engineering reduced the impact of this display (however the facility to program the display to change colour according to electricity use still exists – there are simply no resources to implement it). The value engineering process was considered not to have significantly affected the environmental services and passive design strategy.

External Constraints

In theory a well managed project programme will allow sufficient time for completion. Problems will occur if the project is poorly managed and executed. In this particular project, the diversion of utilities crossing the site should have been completed earlier. Handover and commissioning are important tasks and sufficient time should be assigned to them. As they occur at the end of the project however they can often become squeezed into the remaining time available.

It appears to be a fact of life that project funding is never sufficient for the proposed design. There was some suggestion that the target budget wasn't realistic given the aspirations contained in the brief. The use of ERDF money, which contributed about one third of the construction costs, imposed significant constraints on the design programme. Strict time-scales for draw-down of funds led to long periods of inactivity followed by intense bursts of work. This reduced the time available for submitting competition entries as well as the production of tender documentation. As a result of rushed procurement the design was underdeveloped at these key project stages with little time for checking or refinement. It was felt that this may have caused problems in developing an innovative design. The building's hand-over date was also determined by funding constraints regardless of the building's readiness.

There were no problems with suppliers; smaller companies are likely to be more risky but nothing unusual was encountered. Alternatives could have been found for most of the suppliers, apart from the exhaust air heat pump system, which was designed around a specific manufacturer's product.

Site issues are always a source of risk; It was necessary to carry out diversion work on utilities (gas, water, and electricity) crossing the site. This was supposed to have been organised by the local highway authority when the site was originally made available. Shortly before construction began however it was discovered that the work had not taken place. This resulted in an unanticipated £0.5m being taken out of the budget. As the water diversion took place after the piling had begun, the contractor had to rework their schedule to delay piling in affected areas until the diversion has been completed. It is not clear why the presence of utilities crossing the site and the need to divert them wasn't identified earlier in the project. Inclement weather resulted in a small delay however this is a risk to every construction project and is managed by the main contractor.

Compatibility with existing systems is a greater source of uncertainty in refurbishment projects than in new constriction. Had it been known that the University of Northampton would be the eventual operator, it may have been possible to design the BMS to be connected to the main campus system. Although this wouldn't have eliminated the problems experienced it might have made diagnosis easier.

There were no significant difficulties in obtaining planning permission however it was necessary to change some minor visual aspects late in the design process. Closer involvement with the local planning authority would have reduced the need for late changes. Regulatory approval wasn't considered a problem but it was not clear whether building control actually had the ability to review the technical submission. In addition to building regulations approval, other certification such as BREEAM could result in delays if design changes were necessary to achieve specific credits. In this project it was only necessary to make small design changes as a result of planning conditions. These changes were not considered to have significant implications for the building's energy performance. It's a challenge for engineers to satisfy legislation and changes in the regulations are always a possibility, however these are not usually retrospective, so are unlikely to affect buildings already under construction.

Commissioning and handover

The building was scheduled to be operational by the end of 2010 however due to project delays it was completed approximately three months late in March 2011. The project programme was not particularly tight however delays during the fit-out stage resulted in a rush to meet the completion deadline. As a result only the minimum necessary commissioning work was carried out. It was felt that the building would have benefited from a more extensive commissioning exercise. It only became apparent late in the project that the building would actually become part of University of Northampton estate. Although an informal arrangement to involve the university estates department in M&E snagging was made ahead of the transfer there were no meetings with the design and construction team. The architect felt it would have been beneficial to have had a meeting with representatives from the university. If it had been known from the outset that the university would ultimately take the building on, much uncertainty about the end-user requirements would have been avoided. Even dialogue at a relatively late stage would have been helpful in explaining the building's design and operation concept to the university estates department.

One of the consequences of rushed handover was incomplete and inaccurate O&M documentation. The building log book, contained in the O&M manual, includes design estimates and good practice figures for overall annual energy performance. The design estimates were given as 16 $kgCO_2/m^2$ and 48 $kgCO_2/m^2$ respectively for gas and electricity. The combined figure of 64.5 $kgCO_2/m^2$ is more than four times larger than the design target of 15 $kgCO_2/m^2$. Furthermore, the good practice figures of 18.6 $kgCO_2/m^2$ and 66.6 $kgCO_2/m^2$ respectively for gas and electricity appear to be the ECON 19 benchmarks for standard air-conditioned offices using VAV air-conditioning and air-cooled water chillers. Clearly neither the design estimates nor the benchmarks relate to the actual building. In addition, the treated floor area is given as 6913m^2, which is much larger than the actual building. Also included in the building log book is an energy end-use comparison however no benchmarks are included and the design estimates relate to a different building and are therefore meaningless.

2.3 Design Team Evaluation

At the design team workshop held as part of the BPE project in March 2012, participants were asked for their opinion on whether the building had met key design aspirations. Table 3 shows that the majority of participants considered the aspiration to include natural ventilation and passive cooling strategies was well met. The other aspirations were only considered to be partially met.

Design Aspiration	**“Well met”**	**“Partially met”**	**“Not met”**
Natural ventilation and passive cooling strategies	75%	25%	
A high quality building	13%	88%	
Energy efficiency	29%	71%	
Use of renewable energy technologies	13%	75%	13%
A major focus for Daventry	25%	75%	

Table 3: Design and construction teams' view of design aspirations

2.4 Building Features

The architect's design was based on a decision to do something unusual and innovative that might have been harder to achieve in a more traditional commercial setting. The finished building is very similar to the initial competition entry, consisting of two blocks separated by an internal street. The three storey north western block houses 55 self-contained business incubator units and support facilities. The south eastern 'showcase' block houses a conference facility incorporating a 300 seat hall, 60 cover café, 3 meeting rooms and ancillary functions. The internal street provides a full height exhibition, breakout and circulation space between the incubator and showcase blocks.

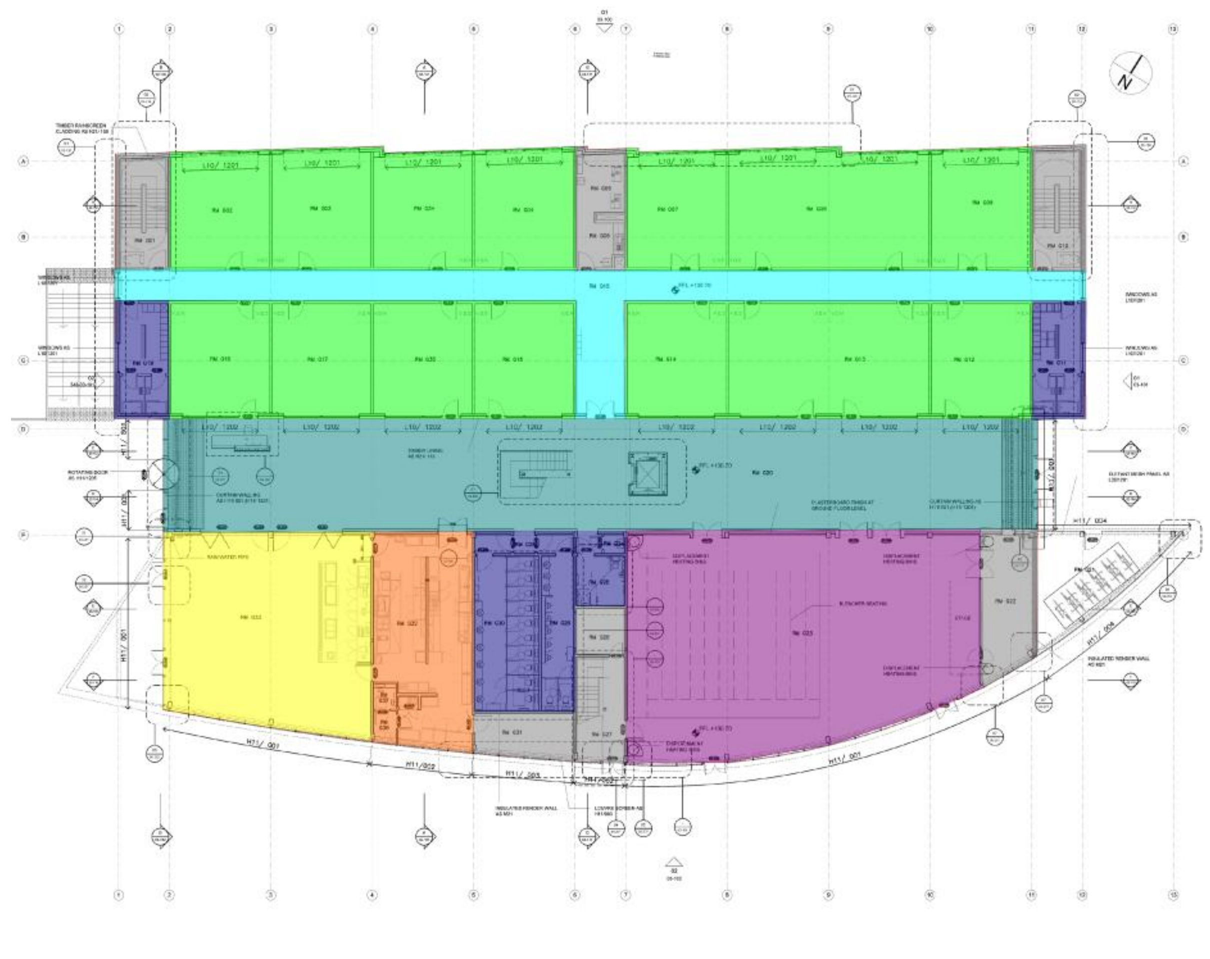
The project was originally envisaged as part of a wider master-plan for Daventry. However the changes in economic climate during the early stages of the project meant features such as a canal basin and integrated transport system never materialised.

Main entrance

Internal view towards main entrance

Café

Auditorium



	Incubator units (offices)		**Internal street**
	Corridor		**Café**
	Toilets & showers		**Kitchen**
	Other spaces		**Auditorium**

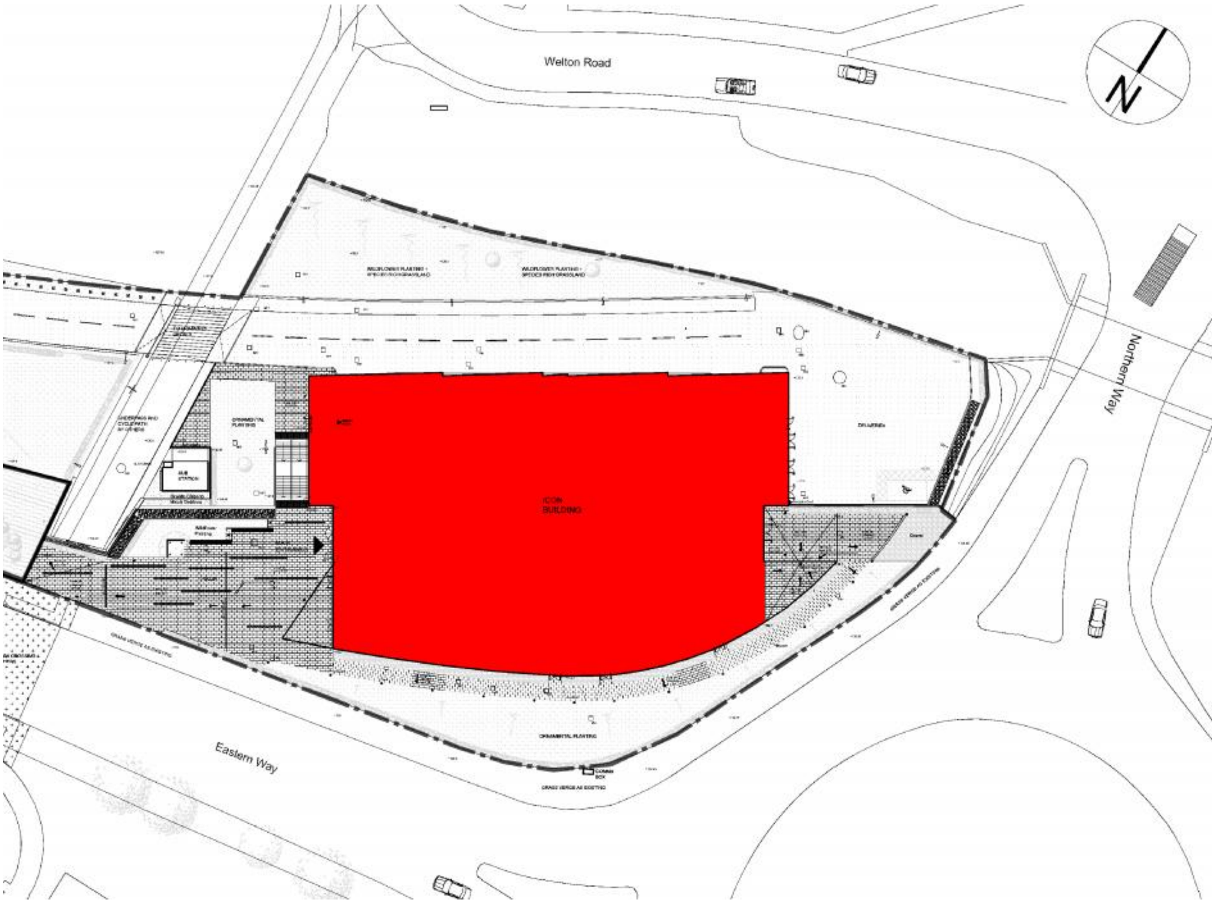
iCon internal layout (ground floor level)

Building Fabric

The building fabric was developed with consideration for low embodied energy and passive design intended to minimise the use of active environmental control. The use of a panelised system-build approach was intended to increase the speed of construction. Lightweight timber frame construction is used throughout the building. A degree of thermal mass is provided to a selection of incubator units by the incorporation of phase change material (PCM) panels into the ceiling. This was originally included in all the units but thermal modelling (which did not include the effect of the PCM panels) suggested it was unnecessary. PCM panels were retained in some of the units with the intention of comparing units with and without to evaluate their effectiveness. In practice however the varying occupancy and load densities in the units makes comparison extremely difficult. The incubator units are timber-clad. Thermal insulation is typically twice that required by building regulations Part L2A 2006. Although a low air permeability of 3 m^3/m^2.hr @ 50Pa was proposed the contractor was only able to commit to a figure of 7 m^3/m^2.hr @ 50Pa. On completion the building achieved a better figure of about 5 m^3/m^2.hr @ 50Pa. The showcase block features a sedum 'biodiversity' roof. The internal street, roofed with translucent ETFE pillows, is intended to act as a climatic buffer, reducing heat loss from adjacent spaces while maintaining a connection with the external environment. Daylight is provided to the outward-facing incubator units by windows in approximately 40% of the external façade area. Inward-facing units receive daylight from the street through windows of a similar size. Glare and solar gain control is provided by internal roller blinds.

Surrounding environment and orientation

The building is located on the northern edge of Daventry town centre between a large roundabout to the east and an open grassed area to the west. To the north there is a residential area, allotments and Daventry Country Park beyond.



iCon Site Plan

Cycling and Public Transport

Daventry has no access to the rail network; the nearest station is about three miles away at Long Buckby. There are up to 10 buses daily from Long Buckby to Daventry bus station, which is about a ten-minute walk from the iCon building. Local buses stop a short distance from the building. A cycleway passes close to the main entrance at the west of the building. There is a covered cycle rack at the eastern end of the building.

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 Overview

The building's services systems were designed to deliver cost-effective low energy performance. The design intent was to provide simple and robust systems rather than complex high-tech solutions. The building is predominantly naturally ventilated, with mechanical cooling restricted to areas of high equipment gain, such as IT server rooms, and areas of high occupancy such as the auditorium and meeting rooms. During the summer the incubator units are intended to be ventilated via opening windows and roof-level ventilation doors. During the winter the ventilation doors are closed and air is mechanically extracted from the incubator units. This extract air is ducted to an exhaust air heat pump (EAHP), which is intended to satisfy the majority of the heating demand. The heat pump is supplemented by a gas boiler to meet peak demand. Heat is delivered to most of the building via a weather compensated variable temperature circuit feeding low temperature radiators. This circuit also feeds an underfloor heating system in the café. Heating and cooling in the auditorium is provided by a packaged air handling unit incorporating a reverse-cycle heat pump.

Details of the system configuration and operating strategies would ideally be obtained from the building log book and other O&M documentation, however the information provided is incomplete and inaccurate in key areas. As a result it has taken considerable effort to identify the building services systems and operating strategies present in the building. Much of the following description of systems had to be pieced together from existing information from a variety of sources combined with the evaluator's understanding of the building services developed during the evaluation process from site inspections and operational issues meetings.

Low/Zero Carbon (LZC) Technology

The local planning requirement was for 10% of the development's CO_2 emissions to be offset through the use of LZC technology. The building design documentation does not specifically address this requirement and the building does not make use of any technology traditionally considered to be LZC (e.g. solar PV and wind generation, solar hot water, biomass heating, CHP and ground source heating/cooling). However as air source heat pumps are now included within the LZC definition it is likely that the exhaust air source heat pump system would meet the planning requirement.

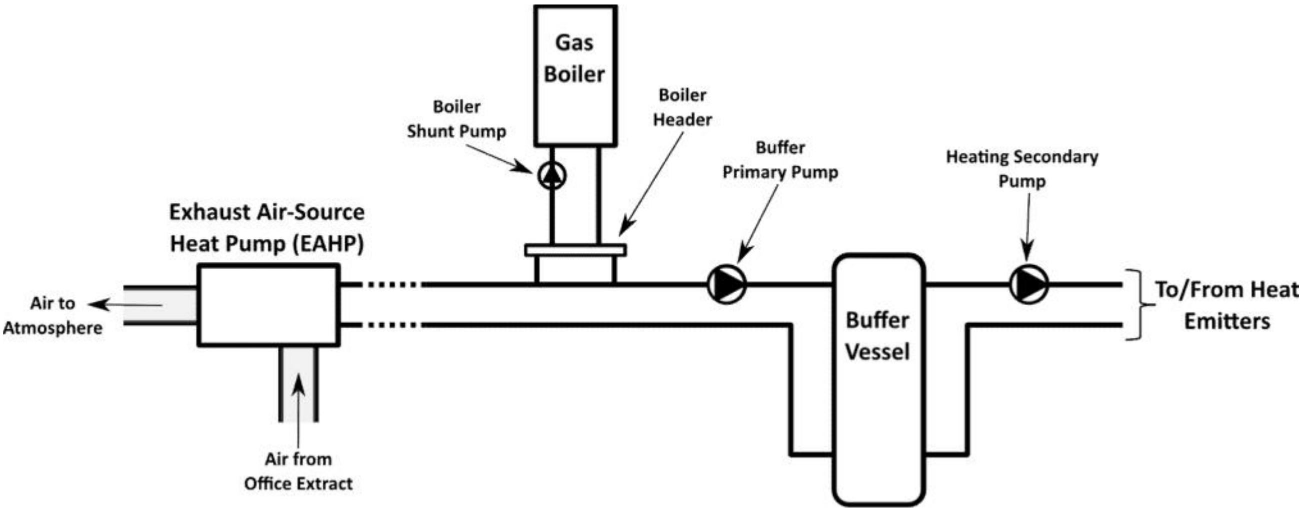
3.2 Heating

The primary heat source is an EcoCiat 90V exhaust air heat pump, with a maximum heat output of 30kW. This unit is located on the roof of the office block and recovers heat from the exhaust air extracted from the offices. The heat pump is intended to provide the building's base heating load. A Remeah Quinta 65kW gas boiler is intended to provide supplemental heating during periods of peak demand.

Roof-mounted exhaust-air heat pump (EAHP)

Identical boilers serving separate space heating and DHW circuits

The boiler is connected via a small header to the primary heating circuit running from the heat pump to a 1000l buffer vessel. The boiler header is bypassed by a three-port valve when only the heat pump is running. Fig. 1 shows a schematic diagram of the primary heating system. The heating secondary circuit draws hot water at a design temperature of between 40°C and 55°C (depending on ambient temperature) from the buffer vessel to serve radiators throughout the building. A branch from the secondary circuit serves underfloor heating in the café. The radiators have been sized for operation at a mean water temperature of 50°C at a room temperature of 21°C. They are all fitted with thermostatic radiator valves (TRVs) to allow local temperature control.



Heating primary schematic

Control Strategy

The operation of the heating (and ventilation) system changes between summer and winter modes automatically at a pre-set ambient temperature threshold. In summer mode both the heat pump and boiler are deactivated by the BMS. In winter mode operation of the heat pump and boiler are sequenced by the BMS in response to the output of a control loop that attempts to maintain the secondary heating flow at the required temperature. The secondary heating flow is temperature compensated; the flow temperature is reduced as the ambient temperature rises. The flow temperature can vary between set-points at 20°C and 0°C ambient. In order to take advantage of the output from the exhaust air heat pump and gain maximum efficiency from the gas condensing boiler these set-points were originally configured for heating flow temperatures of 50°C at 0°C ambient and 40°C at 20°C ambient. The building log book implies that the flow temperature is adjusted by the action of a three-port control valve however control is actually achieved by on/off control of the boiler and heat pump. The strategy also includes a buffer charge mode, designed to derive additional benefit from the heat pump by allowing it to continue running when heat recovered from the office extract ventilation can be usefully transferred to the buffer vessel.

Optimum Start

The heating start signal is controlled by an optimum start strategy. This applies to the operation of both boiler and heat pump (contrary to the log book, which states that only the boiler is controlled by the optimum start strategy while the heat pump operates on a fixed time schedule). The strategy attempts to start the heating before occupancy starts in order to raise the minimum measured internal space temperature to the heating set point by the beginning of the scheduled occupancy time, without heating the building unnecessarily during the unoccupied period. The start time is automatically determined by the BMS based on the measured space temperature, ambient temperature, heating circuit flow temperature and the building's building heat loss rate and heat up time, which are automatically learned by the BMS over time.

Pumps

The heating system includes three pump sets: a single head boiler shunt pump, a dual head primary circuit pump and a dual head secondary circuit pump. The pumps operate according to on/off control signals from the BMS. The operation of dual head pumps is alternated weekly by the BMS to even the run-time of duty and standby pumps. The pumps incorporate variable speed drives however as the boiler shunt pump and primary circuit pumps are designed for constant volume flow the variable speed adjustment is only used for commissioning. The secondary circuit pump circulates temperature compensated heating water around the building, in order to accommodate the closing of thermostatic radiator valves this pump operates in variable speed mode.


Heating boiler shunt pump


Secondary circuit pump, serving building heat emitters

3.3 Domestic Hot Water

Domestic hot water (DHW) is provided by two indirectly heated calorifiers of approximately 300l each served by a dedicated gas-fired boiler of the same type as the heating system. The secondary circuit is pumped to circulate the hot water around the system to ensure the hot water reaches reach 50°C within one minute of turning on the tap. The boiler is controlled by the BMS to maintain a pre-set primary flow temperature (regardless of the calorifier temperatures). Bypass valves on the calorifier primary coils are used to maintain a pre-set calorifier temperature of 60°C. The primary circulation pump is a dual-head unit operated in a similar manner to the dual-head heating pumps. The secondary circulation pump is a smaller single-head unit with a constant speed setting.

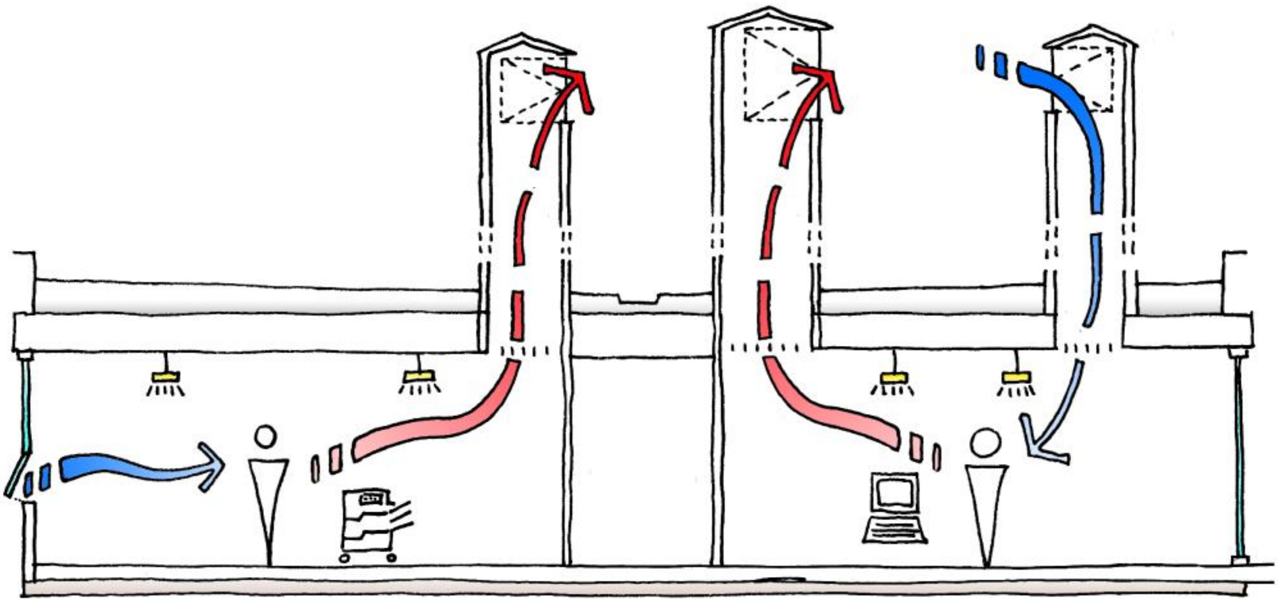
3.4 Ventilation

The building is designed to combine the benefits of natural ventilation in summertime with mechanical ventilation and heat recovery during the heating season. The natural ventilation system is enabled according to a pre-set ambient temperature threshold between summer and winter modes. This threshold is separate from the threshold controlling the heating system. In winter mode the natural ventilation system was intended to be deactivated with the vents remaining closed. However the system currently has separate and overlapping set-points for heating and ventilation systems, in response to tenant demands for additional ventilation in some units during the heating season. As a result, simultaneous heating and natural vent opening is possible. When the ventilation system is enabled it operates according to a pre-set time schedule. The operation of the natural ventilation system is interlocked with both wind and rain sensors. Should high winds or rain be detected the ventilation doors will be automatically closed. Similarly, the ventilation doors will be automatically closed in the event of a fire being detected.

Incubator Block Ventilation

Natural ventilation in the incubator units is provided by a combination of opening windows and ventilation shafts leading to roof level vent doors fitted with motorised actuators. Offices with external opening windows have a single ventilation shaft leading to an opening facing in the opposite direction to the window.

Offices facing the internal street do not have opening windows, instead they have two ventilations shafts with openings facing in opposite directions. The direction of the openings is intended to promote wind-driven cross ventilation.



Natural ventilation principle

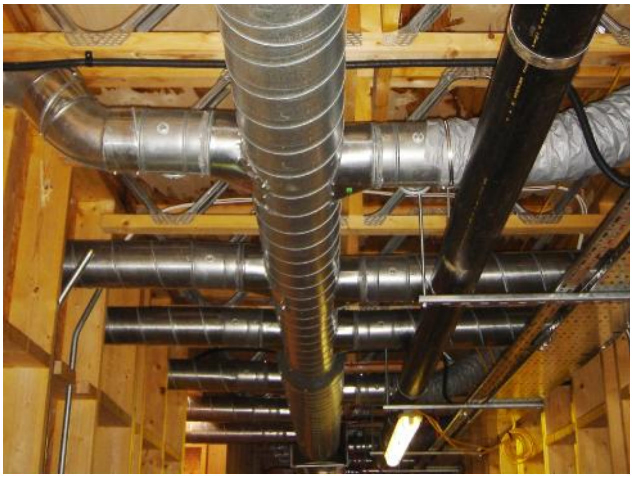
Roof level ventilation terminals during construction

Under automatic operation the BMS compares the temperature measured by wall mounted sensors in each office with each office's set-point temperature and opens the vents if the set-point is exceeded. Each office has a 3-way momentary action switch that allows a manual override to open or close the vents when the system is active. The override remains active for a pre-set time period, after which control returns to automatic operation. Outside of the pre-set schedule the vents will automatically close. A night purge setting has been added to the BMS that allows the vents to operate under automatic control if external temperature is above a pre-set value, regardless of the natural ventilation time schedule.

Ventilation controls (momentary open/close switch) and temperature sensor

The incubator office mechanical ventilation system consists of a central extract fan installed on the roof that draws air from the ventilation shaft in each office via a main duct within the second floor ceiling void. The system is sized to provide an extract ventilation rate of 10l/s.person. The extract fan delivers air to the exhaust air heat pump described above.

View into natural ventilation shaft showing mechanical extract terminal



Main extract duct and connections to extract terminals

Street Ventilation

The street is fully naturally ventilated by a row of opening windows at high level. These are opened by motorised actuators controlled by the BMS when the average space temperature within the street exceeds a threshold set-point. There are three space temperature sensors in the street; two at ground floor level and a third retrofitted at the second floor landing level.

Street level vents at high level

Incubator Block Toilet Extract Fans

Air from the incubator block toilets and shower rooms is extracted by fans in the second floor ceiling void at either end of incubator block. The building log book states that these fans are powered from local lighting circuits however the distribution board schedules do not indicate any supplies to the extract fans. The fans are locally controlled by PIR presence detectors with a 20 minute run-on.

Showcase Block Toilet Heat Recovery Unit

Air from the ground floor toilets is extracted by a heat recovery unit located in the plant room. This unit is powered from the mechanical services panel. It is operated according to a time schedule set on the BMS. Supply and extract run/fault information is returned to the BMS panel.

Meeting Room Ventilation

The first floor meeting rooms and breakout area are provided with fresh air via a heat recovery ventilation unit that extracts air from the void above the meeting rooms. Like the incubator block toilet extract fans, the power supply for the extract fan is apparently derived from a local distribution board however its connection does not appear on any distribution board schedule. The extract fan is either controlled from local PIR sensors or is interlinked with the room units.

Kitchen Ventilation

The kitchen is provided with a 4-speed variable extract fan mounted in the kitchen ceiling void and exhausts air directly outside the kitchen. The fan is powered from the local small power circuit.

3.5 Air-Conditioning

Auditorium

The auditorium is provided with heating, cooling and ventilation by a packaged air handling unit (AHU) situated in the second floor plantroom. When operating, this unit delivers tempered air at a constant volume flow rate to displacement terminals in each corner of the auditorium. The AHU includes a local control panel, interfaced to the BMS to allow adjustment of system parameters. The system can be operated on a pre-set weekly schedule.

IT/Comms and Meeting Rooms

In addition to the auditorium, the three IT/comms rooms serving the incubator units and the three first floor meeting rooms are provided with wall mounted fan coil cooling units. The power supplies for the outdoor units are taken from local distribution boards however it has not been possible to identify the supplies to the indoor units. Both meeting room and comms room air conditioning were originally controlled from a BMS time schedule although because the servers run constantly the comms room air conditioning is also operated continuously.

3.6 Rainwater Harvesting

The building includes a boosted rainwater harvesting system to provide water for toilet flushing in the incubator unit block. Rainwater is collected in a tank in the lower-ground floor plantroom and supplied by a booster pump. The tank water level is maintained above a lower limit by an automatic top-up from the mains cold supply. High and low level conditions are monitored by the BMS, as is the operation of the booster pump.

3.7 Control System

The building includes a Trend BMS that controls most aspects of the building services. The supervisor software runs on a dedicated PC in the centre manager's office. This provides a schematic representation of the systems under BMS control.

3.8 Lighting

Internal Lighting

Internal lighting is provided mainly by linear and compact fluorescent lamps. Induction lamps are used at high level in the internal street on account of their long service life. Metal halide lamps are used for uplighting effects in the street. The incubator offices are lit using tri-phosphor T5 fluorescent lamps. These are controlled by momentary switches that turn the lights off and on with a single click and dim if held down. The office lighting is controlled by PIR detectors and dimmable daylight compensation , which may be overridden by the switch. Corridor and toilet lighting is also controlled by PIR detectors. Elsewhere lights are controlled by manually operated local switches.

Incubator office luminaire

Lighting control PIR and illuminance sensor

External Lighting

The building's external lighting serves the entrance roadway, cycle path, plaza, perimeter walkways and goods in area. The entrance roadway and cycle path are lit using column mounted high-pressure sodium (SON) road lanterns. The plaza and perimeter walkway are lit using compact fluorescent lamps mounted within bollards. Additional plaza lighting is provided by a road lantern and buried uplights. The goods in area is lit using column mounted SON lanterns and a PIR controlled tungsten halogen floodlight. The external lighting is operated by a timer.

The building features a dynamic lighting system on the façade visible from the main road. This is based on vertical strips of coloured LEDs and is linked to the BMS to provide a visual indication of the building's hourly electrical demand at four different levels.

3.9 Metering and Monitoring

The main electrical distribution boards are sub-metered and connected to a monitoring system that records cumulative pulse counts. Additional metering was installed to monitor the gas consumption of the heating and DHW boilers and the electricity consumption of the heat pump, auditorium AHU and comms room air conditioning. The BMS is capable of monitoring temperature measurements, which are supplemented by additional monitoring of humidity, CO_2 and light levels in each incubator unit.

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 Evaluation Method

The evaluation of the building from the point of view of its users was conducted using semi-structured interviews and a standard questionnaire. A selection of tenants who had been in the building for about a year took part in settling-in interviews. The Building Usage Studies (BUS) questionnaire was issued to all tenants, and a small sample of the tenants who had completed the BUS questionnaire took part in follow-up interviews.

The settling-in interviews were carried out in September and October 2012. By this time the building had been open for over a year and was about 65% occupied with 27 different businesses. Most of the tenants interviewed had moved into the building between May and September 2011. The tenant interviews were intended to investigate tenants' experiences moving into the building, the level of support they received during the settling-in period and their general experience and usage of the building.

The BUS questionnaire is aimed at identifying the strengths and weakness of how well the building meets the needs of its users. The three page questionnaire includes tick box questions for rating specific aspects of the building and text boxes for more detailed comments. The questionnaires were distributed in the morning of the 27th February 2013 and most were collected later in the afternoon. A total of 56 questionnaires were returned, which represents an excellent response rate (the exact number of questionnaires issued was not recorded but is thought to be about 60). The completed questionnaires were transcribed into a spreadsheet that was sent to Arup to be entered into a database for analysis. Key findings from the BUS survey are described below. A more detailed report is included as an appendix to this document.

The follow-up interviews were carried out on 12th August 2013, roughly 6 months after the BUS survey. These were intended to investigate whether there had been any changes in problem areas identified in the BUS survey. Staff from eight offices were interviewed, four from the two-person offices on the top floor and four from the larger four or eight-person offices on the ground and first floors. These were all staff who had participated in the original survey. In addition to the survey follow-up questions, occupants were asked about their occupancy patterns, use of electrical equipment and hot water consumption. These questions were intended to provide addition context for understanding the variation in energy consumption between units.

4.2 Key Findings

Settling-in interviews

Most of the tenants interviewed reported a fairly satisfactory settling-in process having found it easy to move in and start work. There were some initial problems with the phones and IT configuration however these had largely been resolved at the time of the interview. Subsequent problems were experienced however, including a period of downtime shortly before the BUS survey. Tenants were generally satisfied with most aspects of the building induction however information about the building's environmental strategy and control systems could have been much clearer.

Momentary on/off light switches, push and hold to dim

Interestingly, the tenants interviewed felt that the environmental ethos was not as strong as it should be. Attitudes towards environmental impact vary, some tenants reported that they did try to ensure heating, lighting, etc. are not used unnecessarily while others placed greater emphasis on getting the building to provide comfort. This could be partly attributed to the limited communication of the building's environmental concept. Earlier on, tenants felt that the building's management team were somewhat overwhelmed by the operational challenges of the building but by the time of the interviews building management was responding more quickly. Tenants appreciated being kept informed of progress in dealing with problems. Responsibility for technical issues (e.g. with maintenance and IT) should have been more clearly identified. Some of the tenants had generated business from other tenants but there was a feeling that opportunities for business generation are limited. On the whole however, the majority of tenants interviewed reported that business had grown since moving to the building.

There were several reports of summertime overheating, particularly in the street-facing units. The outward-facing units were perceived to be more comfortable because the windows can be opened. The automatic operation of the vents was mentioned frequently, with tenants preferring a greater degree of manual control. The delay on manual opening and closing of vents is considered to be too long. The responsiveness of the vents to rain was mentioned; it sometimes takes too long to close when it rains. Heating in winter was generally satisfactory although there were some reports of offices being chilly at the beginning of the day. A number of tenants commented on the extremes of temperature experienced in the street. There were no reported problems with office light levels, although the automatic control is not well understood and apparently can't be overridden if lights aren't required; few tenants realised that the lights could be dimmed. There were some comments about poor soundproofing between units and noise from the rooftop ventilation fan, which can be heard in the second floor offices. There was also a comment about the length of time taken for hot water to reach the showers.

Some tenants mentioned usability issues relating to the security system and concern about limited CCTV coverage. The main problem is the need to manually activate and deactivate the alarm based on the in/out board. As there is no way to guarantee the in/out board will be used the alarm could either be mistakenly activated when the building is still occupied or left deactivated when the building is unoccupied. A desire to improve CCTV coverage, particularly in the temporary car park, was also mentioned.

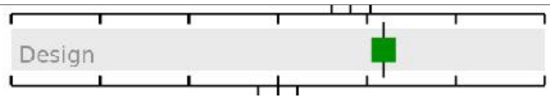
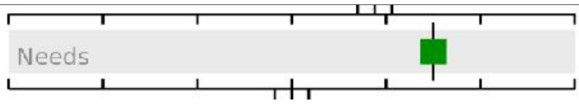
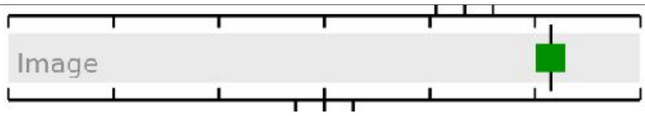
The tenants were asked to rate the building's performance against its design aspirations in the same way the design and construction team members were asked in the workshop session. They were also asked to rate the importance of each of the design aspirations expressed in the brief. The top five parameters are shown in the table below.

Design Aspiration	**"Well met"**	**"Partially met"**	**"Not met"**	**"Don't know"**	**Ave. Importance Rank**
Natural ventilation and passive cooling strategies	11%	44%	33%	11%	1
A high quality building	67%	33%			=2
Energy efficiency		22%	11%	67%	=2
Use of renewable energy technologies	22%	44%		33%	=2
A major focus for Daventry	11%	67%	22%		3

Table 4: Tenants' view of design aspirations

Problems with overheating are likely to have increased the average importance rank of 'natural ventilation and passive cooling strategies'. It is interesting to note the high percentage of responses that 'don't know' about the building's energy efficiency. The message that could be communicated more strongly is that although the building's efficiency is considerably better than an average building it is currently not as good as it should be, and the building management and maintenance team are still solving initial problems and finding out how best to operate the building.

BUS Questionnaire

Building Design	Unsatisfactory :1		7: Satisfactory
Needs	Very poorly :1		7: Very well
Image to visitors	Poor :1		7: Good

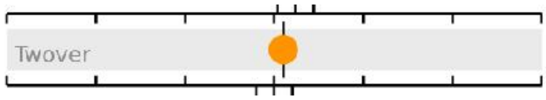
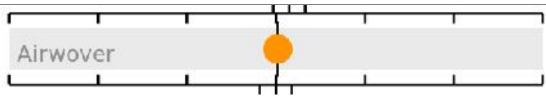
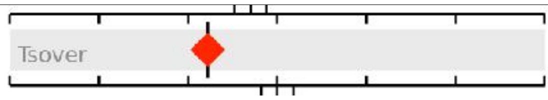
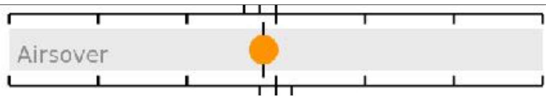
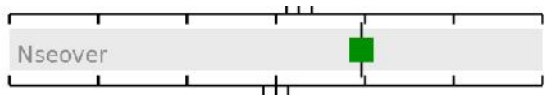
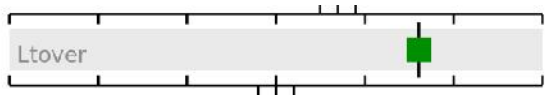
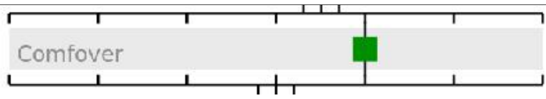
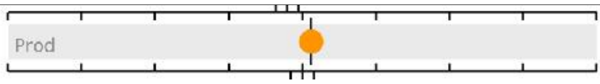
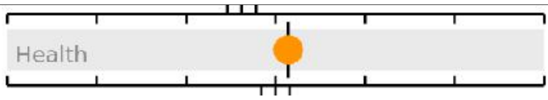
Temperature in winter	Uncomfortable :1		7: Comfortable
Air quality in winter	Unsatisfactory :1		7: Satisfactory
Temperature in summer	Uncomfortable :1		7: Comfortable
Air quality in summer	Unsatisfactory :1		7: Satisfactory
Noise Overall	Unsatisfactory :1		7: Satisfactory
Lighting Overall	Unsatisfactory :1		7: Satisfactory
Comfort Overall	Unsatisfactory :1		7: Satisfactory
Productivity	Decreased: -40%		Increased: +40%
Health	Less healthy :1		7: More healthy

Table 5: BUS questionnaire results - key indicators

The results of the BUS questionnaire survey were broadly consistent with earlier feedback from the tenants and building management, although there were one or two surprising findings. Overall, the building was rated well as a workspace that meets its users' needs. No significant positive or negative effects on the occupants' perceived health and productivity were reported. The problems with the building's natural ventilation and heating systems were reflected by the less satisfactory ratings for thermal comfort and air quality, particularly during summer. Despite this, occupant comfort overall is rated higher than the benchmark average. The levels of control over heating, cooling and ventilation were not significantly different from the survey benchmark, however these variables were rated as important by about a quarter of respondents. Lighting overall and lighting control also scored well however individual scores for artificial light and glare from lights were not significantly different from the benchmarks. Noise is not a significant problem; the questionnaire results suggest if anything there is too little rather than too much noise, however this is contradicted by several occupant comments mentioning noise and vibration from the floors above.

Improving the reliability of the heating system and the effectiveness of the natural ventilation system would increase the scores for comfort in winter and summer. These problems have been noted previously and work has been carried out to improve the situation. Addressing reliability problems with the building's comms/IT system might improve the score for perceived productivity. The wider environmental impact of the building could be reduced if the percentage of single-occupancy car journeys to and from work was reduced. The availability of public transport in the vicinity of the building is limited, however car sharing and cycling should be encouraged. There were a few comments directly relating to health and safety, such as the provision of car park lighting and icy conditions in winter, which were raised with building management.

Follow-Up Interviews

The earlier technical problems with the opening vents appeared to have been fixed a few weeks before the follow-up interviews took place. Despite this, some of the occupants questioned their usefulness, given that the windows alone appear to provide sufficient ventilation in warm weather and in hotter weather the vents make little difference (or in one instance reportedly made matters worse).

From the tenants' point of view the problems experienced with the heating system at the beginning of December 2012 appear to have been resolved. In one of the second floor offices the radiator is not used; due to the high levels of insulation and the level of internal gains no additional heating is required. In a different office the occupants mentioned that the unit tends to be cold in the morning, even with the heating running constantly. On occasions they have used a fan heater to get their office up to temperature. This office is adjacent to a unheated stairwell, which may explain why it is slightly colder than offices with heated spaces on either side.

Tenants are generally happy with the controllability of building services however some suggestions were made to improve the usability of the ventilation controls and again the ability to adjust the pre-set light level was mentioned. A quote has now been obtained for a remote control to allow light levels to be pre-set as required. The ventilation control provides a manual open/close override however this returns to automatic control after a pre-set delay, currently 5 minutes on the ground and first floors and 20 minutes on the second floor. Increasing the delay times would reduce the need for occupants to make frequent use of the override switch however they would then have to wait longer before the system reverted to automatic control. The control strategy could be modified by adding an additional automatic/manual switch to allow fully manual control however this would need to be reset at the end of the working day to prevent vents being unintentionally left open overnight.

The wide range of tenants in the building is responsible for the large variation in energy consumption between units. Seven out of the eight offices interviewed operate typical office hours however the smaller organisations may operate more variable hours. Electrical loads vary, mainly due to different levels of IT equipment use. Hot water use is also variable, some of the occupants interviewed use the showers from time to time, while others use very little hot water.

A number of general issues were mentioned, including problems with erratic water temperatures in the showers and the lack of hair-driers was also mentioned. The provision of recycling bins in tenant areas was suggested. Whilst there has been no recurrence of serious problems with the IT/Comms system some occupants have commented on the speed of the internet connection.

4.3 Root Causes

Natural ventilation and overheating

The building's natural ventilation system relies on providing sufficient outdoor air to offset internal heat gains. Unlike systems incorporating passive cooling such as earth tubes or evaporative cooling, the air entering the offices is not tempered and can be no lower than ambient temperature. During particularly hot weather the system will cease to provide any cooling effect and providing outdoor air may become counterproductive. As the air movement is driven by a combination of wind and stack effect, warm and still conditions could also reduce the effectiveness of the system. Some of the incubator units do incorporate PCM boards but it has not been possible to establish their effectiveness. Although occupants are generally aware the building is naturally ventilated they may have expectations that the building should remain at a steady temperature. A better explanation of the building's ventilation strategy may be one way to manage occupants' expectations.

The design stage overheating modelling carried out to achieve Part L compliance showed a minimal risk of overheating in the offices. Interestingly it did show a significant risk of overheating in the street but this result was apparently disregarded as the street is not an office space. The design stage assumptions regarding internal heat gains may have been over optimistic. While the assumed lighting gains are appropriate for each office, the assumed occupancy and equipment gains are lower than those published in CIBSE Guide A.[1] The actual equipment gains vary widely between offices, with some occupants running their own servers. Similarly, occupancy varies between offices, with some of the smaller 2-person offices occupied by up to four people. The overheating modelling does not provide any indication of the risk of overheating in situations like these where design assumptions are exceeded. If there is little or no safety margin in the design of the natural ventilation system some overheating will be inevitable.

Overheating has been exacerbated by the failure of several vent actuators which took some time to replace. During this time it was not possible to provide ventilation to the affected units. As a result some tenants were allowed to move into different office units. All of the faulty actuators were eventually replaced, however their long-term reliability is questionable.

To alleviate some complaints of stuffiness and overheating during the winter the ventilation strategy set-points were adjusted to permit vent opening when the heating system is running. While this may have helped individual offices at times it may have had unintended consequences such as reducing the mechanical ventilation rate in other offices. The design intent was for the ventilation system to deactivate when the heating system is running. Allowing simultaneous operation could result in heating being provided to offices while the radiators are on, particularly if the immediate response to reduce office temperature is to open vents rather than reduce the TRV setting. Furthermore allowing vents to open when the mechanical extract system is running could unbalance the system, reducing the extract rate from offices with closed vents and instead drawing cold air in via the open vents thus reducing the temperature of the air provided to the exhaust air heat pump.

Heating

Although there have been complaints that the street is too cold it was always intended to be an unheated buffer space. A better explanation of the role the street plays in the building's low energy design to reduce heat losses may be helpful. The perception that the street is too cold may be partly due to the fact that the street separates two heated areas. Occupants visiting the breakout area for meetings or to make hot drinks must pass across the unheated street and are more likely to notice the variation in temperature. This is a design issue that may need to be addressed in future buildings incorporating buffer spaces.

[1] 65 W sensible occupant gain and 10 W/m^2 equipment gain as opposed to the Guide A figures of 75 W sensible occupant gain for moderate office work and 15 W/m^2 for equipment gain in a $12m^2$/person office.

Reports of cold offices may have been linked to problems with vent actuators that had failed to close tightly or had jammed in an open position. In addition, the offices adjacent to the unheated stairwells tend to be colder on average than the other offices. Problems with the heating system have occurred, particularly in December 2012 when the heating system failed to start automatically on several occasions. The reasons for this are unclear, however the optimum start control was found to be incorrectly configured and in one instance branch valves on the heating pipework had not been reopened after maintenance. Problems with a faulty pressurisation unit and pipework air-locks also interfered with the heating system. Some of these problems may have been due to incomplete commissioning and a lack of understanding of the heating control strategy by maintenance and building management staff.

Lighting

The level of daylight and artificial light is good. The use of white soffits, light walls and neutral floor finishes was part of the design intent to contribute to a pleasant visual environment. The usability of the lighting control however is hindered by the lack of instructions about the dimming function, which would give occupants the ability to set the desired light level. There is a further problem, apparently inherent in the lighting control, that the dimmed level is not retained, i.e. the lights return to their full brightness when they have been turned off and on again. This can happen during the day when tenants have left the office for lunch or meetings. Some tenants have requested the ability to change the default light level, however this adjustment is typically carried out once during commissioning and requires a lighting remote programmer. If a programmer were available, light levels could be recommissioned in individual units if necessary.

Noise

As the building's occupancy increased, problems with noise breakout from individual incubator units became apparent. While the level of sound insulation between offices on the same floor is good there is a problem with noise from offices above. Tenants have reported being able to discern conversations, which may be confidential, from other offices. This is a potentially a serious issue that could affect the ability to let office space in the buildings. This is partly inherent in the timber frame construction, which does not provide the level of acoustic isolation that might be provided by a concrete floor structure, however the ventilation stacks are also suspected as a path for noise leakage. Although the shafts are faced with fire rated plasterboard and form a fire compartment together with the office unit they serve they may not provide sufficient acoustic isolation between adjacent vent shafts. Lining the shafts with sound-absorbing material or installing ducting within the shafts could reduce noise break-out however this would not be a feasible retrofit due to the cost and disruption caused.

Telecoms / IT

The most significant usability issue identified by the occupant survey and interviews was the reliability of the telephone and IT system. The root cause of the problems remains unclear however the compatibility of systems installed by different providers may have been an issue. Changing requirements and a lack of clear responsibility for service provision may also have contributed to problems. The usability of the alarm system was mentioned. The current system may have been the best option given the cost and feasibility of alternatives, however the problems experienced suggests that its usability was not considered earlier in the design. Again a more clearly defined client and set of requirements could have identified this earlier.

Continuity of Design Knowledge

A contributing factor to all of the issues identified above is the process of transferring design knowledge though the design process. Although the original environmental concept for the building is largely present in the delivered building a detailed understanding of the interaction of components and system controls is lacking. For example the BMS configuration and the operating strategy of ventilation system and heating system have been established largely by trial and error. The novelty of certain aspects of the system, such as the interaction of heat pump, boiler and ventilation system has made the process difficult for maintenance staff used to more traditional installations. Adjustments made without understanding sub-system interactions risk causing further problems (e.g. simultaneous heating and ventilation, boiler and heat pump cycling and excessive flow temperatures in the heat pump circuit). These issues are discussed in more detail in section 7.

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 Aftercare

There was no formal requirement for post-handover support specified in the building contract. As a result no aftercare plan was implemented. Members of the project team were involved with rectifying defects identified during the first 12 months of operation however their involvement was limited to specific defects. Further support would have had to have been paid for separately. After handover, responsibility for the building's maintenance passed to the University of Northampton's facilities management team, however it was not clear who was responsible for day-to-day management of the building services systems.

Training

A short training session was provided after handover but it might not have been delivered to the right staff, i.e. those with responsibility for the day-to-day operation of the building. No additional training was provided when new staff took over from the original building manager. There can be two aspects to training building users; the first involves the project team training the building owner/operator, while the second involves the building owner/operator (possibly supported by the project team) training the building occupants. Although training raises awareness of appropriate building management and operation it does not guarantee the cultural change necessary for its implementation. The efficient operation of the building depends to a large extent on the motivation of the users. For example, although each incubator unit has its own electricity meter tenants are not billed for their electricity usage so there is no incentive for tenants to minimise their electricity consumption. New tenants are provided with a handbook that contains information on the facilities available in the building. This includes a section describing the building's heating and ventilation strategy and provides guidance on operating heating, ventilation and lighting controls. From discussion with tenants it was evident that few were aware that this information was provided.

5.2 Operation and Maintenance

Operational Issues

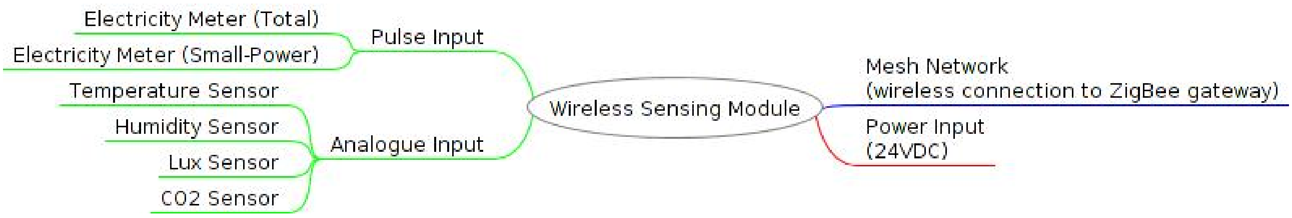
During the course of the BPE project, quarterly meetings were held to identify operational issues and potential solutions. Without the BPE project it is unlikely that a formal system of review would have been put in place. The reports arising from these meetings were used to form the basis for discussions with the design and construction team during the defects liability period to prioritise possible solutions for investigation into their cost and feasibility. Following this period the operational issues reviews have involved the building's management and maintenance team in identifying problems and potential improvements.

Energy and Environmental Monitoring

The BMS strategy includes logging of plant and space temperatures, with measurements recorded at 15 minute intervals. Output pulses from the incoming utility meters (gas and electricity) are also recorded by the BMS and used to calculate an average hourly rate. By default the supervisor keeps a log of the last 1000 readings of monitored parameters. At a monitoring interval of 15 minutes this represents just over 10 days of recorded data. As it was necessary to record data over a longer period the supervisor was later configured to save its logs to disk on a daily basis. The BMS supervisor is not accessible remotely so data must be transferred periodically to a USB stick.

In addition to the BMS, a bespoke self-contained wireless monitoring system was installed during the building's fit-out. This system comprises a desktop PC with a ZigBee wireless dongle, which acts as a central data collection point, a network of ZigBee wireless sensing modules and associated sensors and a small number of EnOcean solar powered temperature sensors operating in conjunction with an EnOcean to ZigBee gateway. A custom logging application runs under Windows XP on the desktop PC. The application polls the modules in sequence as a user configurable interval (typically 10 minutes). The application logs the data collected at each polling interval to a series of daily text files containing comma separated values. The PC is accessible via the Internet through the use of a remote desktop client.

The majority of the wireless sensing modules have six data inputs for local connection to analogue sensors and pulse meters. The exact configurations of the modules will depend on the requirements for monitoring individual zones and end- uses. In the incubator units for example, analogue signals are received from temperature, relative humidity, CO_2 and Lux sensors. Pulse signals are received from two electricity meters, one measuring total consumption, the other measuring small-power consumption.



Wireless sensing module schematic

The BMS supervisor is used on a day to day basis by the building manager typically to adjust ventilation set-points, enable and disable the auditorium AHU and check the operation of heating and ventilation plant. The BMS logs have been used by the building evaluator to develop a detailed understanding of the operation of services systems, which has contributed to the operational issues reviews. The wireless monitoring system logs have also been used by the building evaluator and other researchers at Loughborough University.

5.3 Manageability

The design team are not involved with the operation of the building and their involvement with the evaluation project has been limited so although feedback has been provided to them from the project there has been little opportunity to receive knowledge that would be useful for the day-to-day operation of the building. As a result there is generally perceived to be a lack of understanding how to best operate the building.

The building has presented challenges to its operators. The day-to-day management staff are on site, and are able to respond quickly to reported problems. Progressing from the initial response to a resolution of technical problems takes longer as there are no on-site maintenance staff. The building is part of the University of Northampton estate but the estates department are not responsible for its maintenance. Instead, a large property maintenance service provider is directly contracted to provide planned and reactive maintenance. Although they cover the maintenance of the building's M&E plant, a further sub-contractor provides the maintenance of the BMS and controls. Between them they do take prompt action to fix reported problems however the recurrence of related problems (such as with the heating system) suggest that these fixes are not addressing root causes. In fact, it is possible that the cumulative effect of adjustments made in response to individual symptoms is an unreliable system that no longer matches the design intent. A lack of thorough understanding of the system's operation and design intent is a serious obstacle to achieving satisfactory performance. This has contributed to a perception within the University that the iCon building is not only on the periphery of their estate but is also something of a problem. This is a result not only of its location remote from the other campuses but also the nature of the building, which is quite different from the rest of the University estate. It was felt that the estates team needs to be more involved with the building. Partly in recognition of this problem, the University estates department has commissioned an independent consultant to evaluate and make recommendations on the building's systems and their operational strategy. This evaluation activity has taken place alongside the BPE project's operational performance reviews.

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 Design Energy Performance

Concept

The building was designed to achieve a high level of energy efficiency. The energy statement issued by the environmental services consultant demonstrated that a combination of energy saving measures could reduce the annual CO_2 emissions intensity from a good practice benchmark figure of about $30kgCO_2/m^2$ .yr to less than the design target of $15kgCO_2/m^2$.yr. These figures included unregulated power loads such as office equipment and 'other electrical' loads such as lifts and external lighting. Auxiliary energy consumption includes fans, pumps and controls. Catering loads were not considered. Table 6 lists the energy saving measures included in the proposed design.

Option	Description
0	Base case
1	As option 0, but with improved airtightness (to reduce heating energy consumption)
2	As option 1, but with heat recovery (to reduce heating energy consumption)
3	As option 2, but with better u-values (to reduce heating energy consumption)
4	As option 3, but with PCMs (to reduce heating energy consumption)
5	As option 4, but with daylight-linked dimming (to reduce lighting energy consumption)
6	As option 5, but with low velocity design (to reduce auxiliary energy consumption)
7	As option 6, but with heating and hot water provided by GSHP (to reduce heating and hot water energy consumption)

Table 6: Proposed energy saving measures

Fig. 6 illustrates the predicted effect of combining successive options to reduce total energy consumption. The most striking effect of the proposed energy saving measures is an over thirtyfold reduction of heating energy from the good practice benchmark.

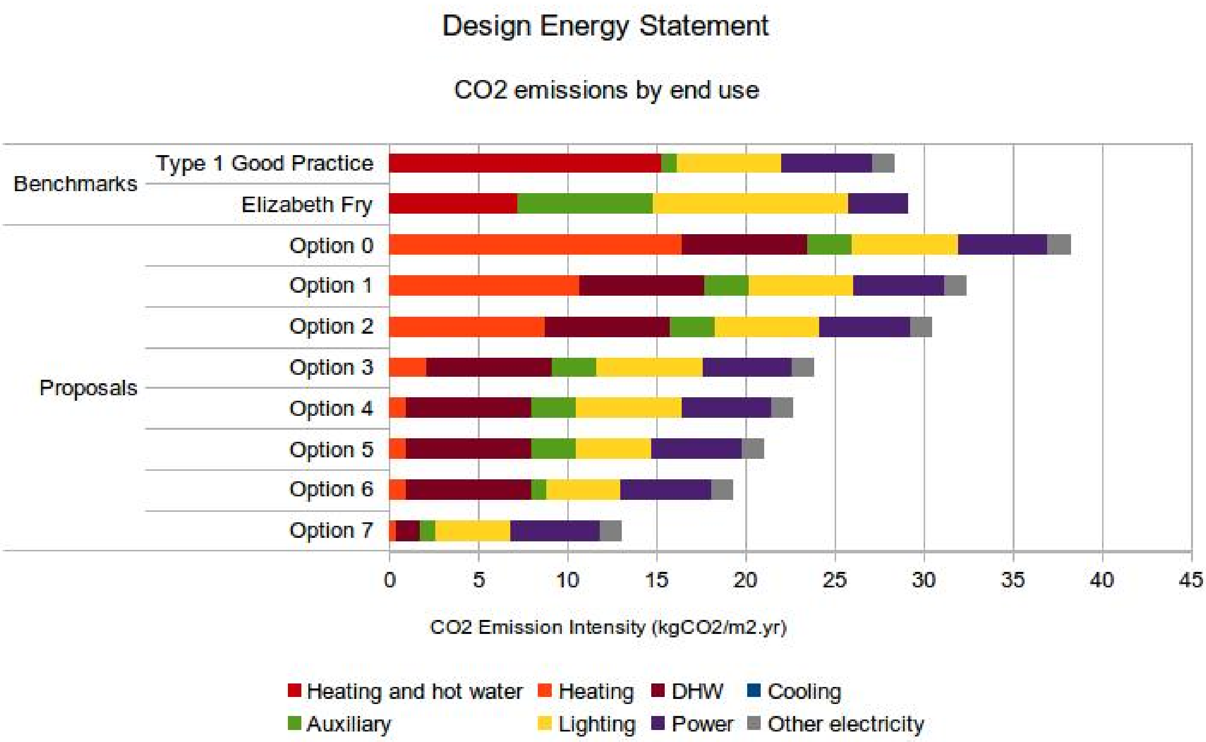
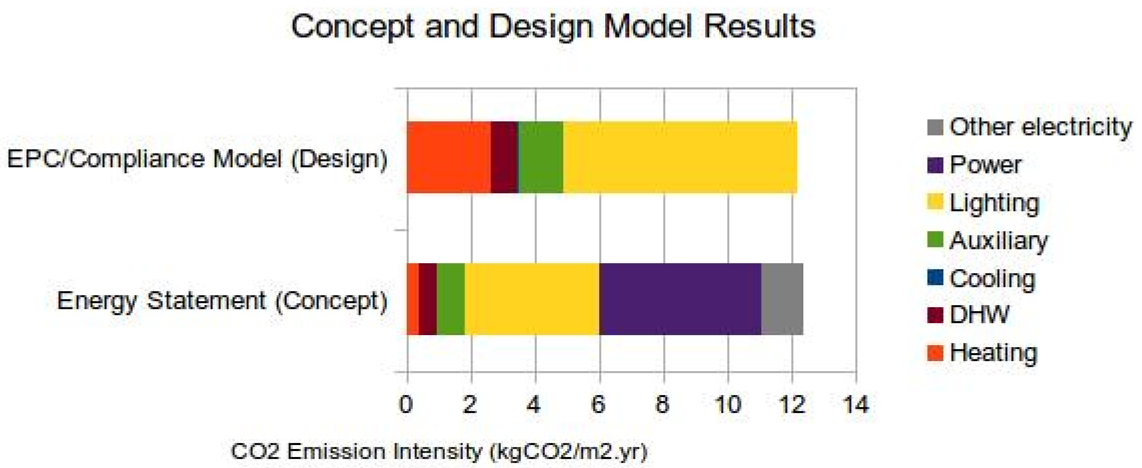


Fig. 6: Design energy statement - CO_2 emissions by end use

Compliance Model

The building achieved an EPC Asset Rating of 26 (a 'B' grade) with a Building Emission Rate of 12.18 kg CO_2 /m^2. This figure only includes regulated loads as the power and other electrical loads allowed for in the energy statement are not included in compliance and EPC calculations. Interpreted in this way, the design target is easier to meet than if it were an 'in-use' target that included unregulated loads. A copy of the building's EPC is included in this report's appendix.



Concept and design model results

The graph above illustrates the difference between the performance estimates at concept and design stage. The total figures are similar, however the design stage estimates of regulated loads are double those at concept stage. The concept estimates did however attempt to account for some unregulated loads unregulated (power and other electricity).

The energy statement figures are clearly over optimistic however this is likely to be a general characteristic of early estimates. At the concept state of a project, the design team is at risk of abortive work should they not win the tender therefore it does not make commercial sense to invest significant resources in developing robust energy estimates.

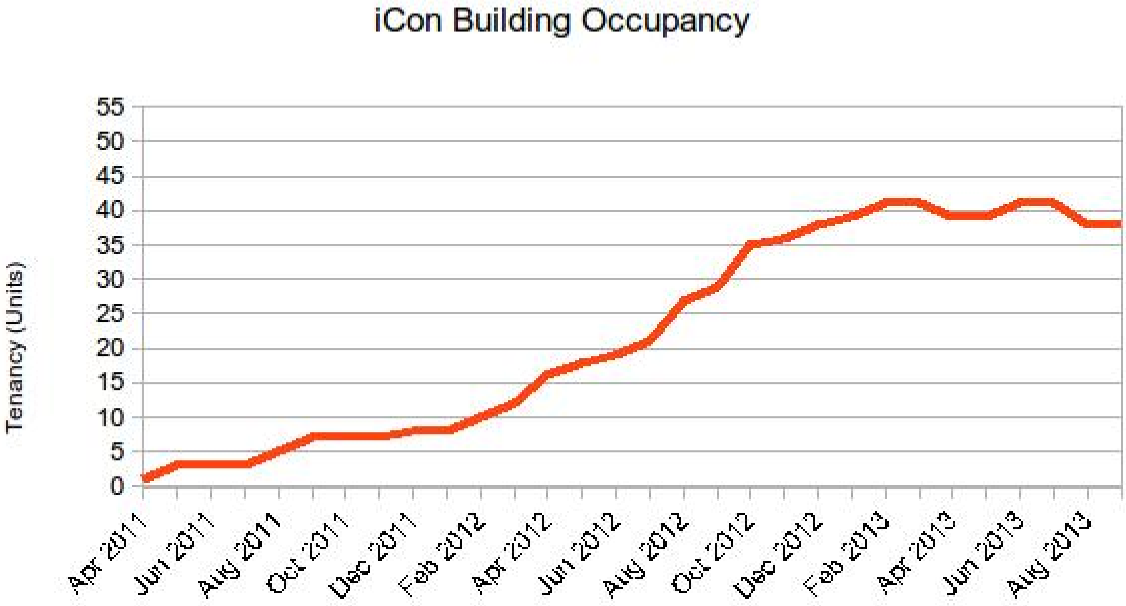
Concept and design calculations were based on CO_2 emissions factors of 0.422 kgCO_2/kWh and 0.194 kgCO_2/kWh respectively for electricity and gas.

6.2 Operational Performance

Operational performance data is available in the form of manual sub-meter readings taken at approximately monthly intervals since July 2011. Automatic sub-meter readings taken at approximately ten minute intervals by the wireless monitoring system became available from late 2011 when most of the meters had been connected to the system. Whole-building half-hourly electricity consumption for the period April 2011 to August 2013 was obtained from the electricity supplier. Operational CO_2 emissions figures are based on emissions factors of 0.55 kgCO_2/kWh and 0.194 kgCO_2/kWh respectively for electricity and gas.

Display Energy Certificates

Two DECs have been generated for the building; the first, dated June 2012 showed an operational rating of 48 (a 'B' grade), a year later the operational rating has risen to 60 (a 'C' grade). Copies of the building's DEC certificates are included in this report's appendix. The change in operational rating is due partly to the increasing level of occupancy in the building. This is illustrated in Fig. 8, below. For the building's first year of operation, occupancy slowly rose to about 35%. By the middle of the following year occupancy had risen to 75% and remained above 70% for the rest of the year.



Building occupancy

While it may be tempting to attempt a comparison of the EPC and DEC scores, there is a fundamental difference between them. The EPC rating is an estimate of the theoretical performance of the building as a result of its fabric and fixed services (regulated loads such as heating and lighting). The DEC expresses the actual performance of the building, including, in addition to regulated loads, unregulated loads such as office equipment, catering and external lighting.

Consumption by End-Use

The building sub-metering has enabled the building's overall energy consumption to be partially disaggregated by end-use. Because some of the sub-meters serve a mixture of end-uses it has been necessary to make certain assumptions. For example, the main sub-meter serving the incubator units also serves the Comms Room UPS. This was not separately metered until June 2013 however since then its load has been fairly stable at 1.5 kW. It was assumed that this was running constantly throughout the period under consideration. Each incubator unit has a pair of sub-meters recording total and small power consumption, lighting consumption is obtained from the difference of the two. In five units, one or other of these meters is faulty so the combined consumption measured by the individual meters is less than that obtained from the main sub-meter after subtracting the consumption due to the Comms Room UPS. The small difference, less than 4% of the sub-metered total, cannot be assigned to a specific end-use and has therefore been added to an 'other electricity' end-use category. Further assumptions were necessary for other plant items such as the auditorium AHU, EAHP and Comms Room AC. Although these have their own electricity meters their electricity consumption falls into a number of end-use categories. This made it necessary to estimate the proportion of each item's consumption by end-use. This was done according to the equipment's operating current ratings and estimated utilisation factors and is illustrated in Table 7, below.

End use item	Heating	Cooling	Fans

Auditorium AHU	33%	33%	33%
EAHP	90%	0%	10%
Comms Room AC	0%	67%	33%

Table 7: Assumed electricity consumption breakdown for individual plant items

Fig. 9, below illustrates the energy consumption by end-use, measured over the year from August 2012 to August 2013. Fig. 10, below expresses the consumption by end-use over the same period in terms of carbon emission intensity and compares the measured data with design and benchmark figures.

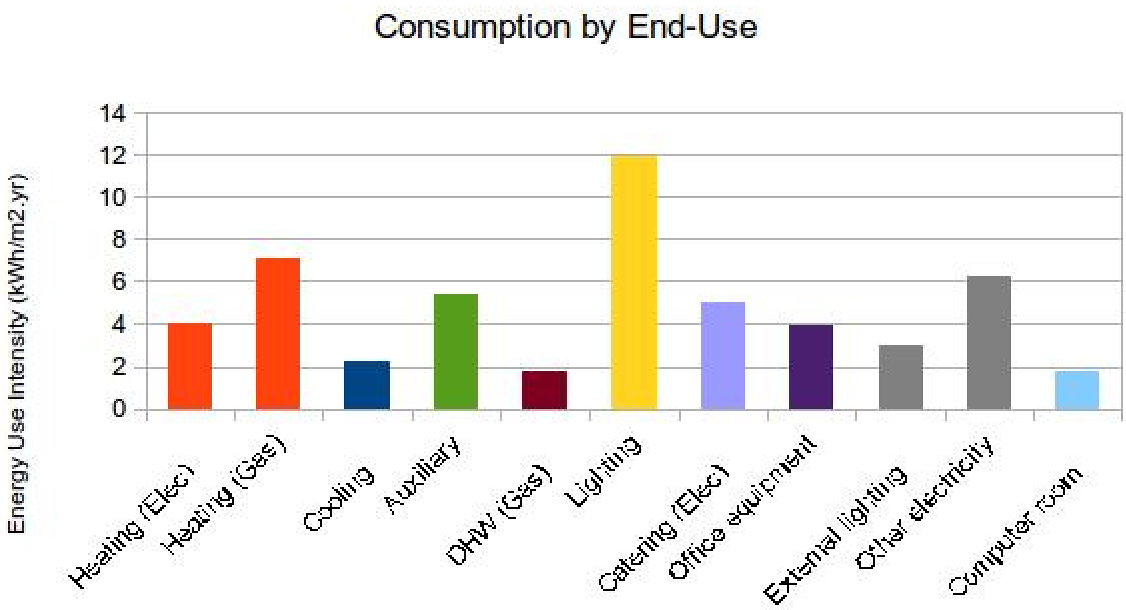


Fig 9: Measured energy consumption by end use

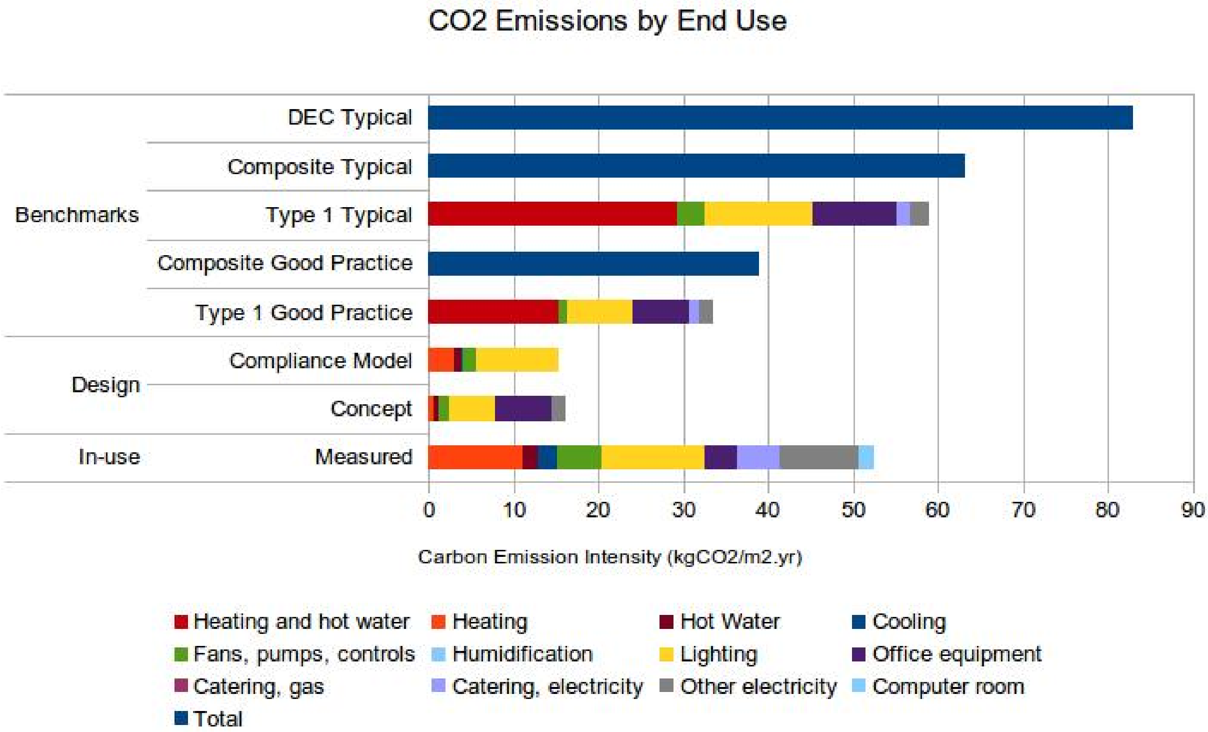


Fig. 10: Measured, design and benchmark CO_2 emissions by end use

Although the in-use carbon emission intensity is much higher than the design estimates it is lower than the DEC typical figure and the Type 1 typical benchmark. The DEC figure is representative of offices in general, which would include a range of building ages and heating, ventilation and air conditioning systems. A more relevant comparison is against the Type 1 office benchmarks, which are applicable to naturally ventilated cellular offices. The building however includes a kitchen and café as well as an air conditioned auditorium. To account for these space types composite benchmarks were derived from an area weighted average of appropriate benchmarks.[2] The building's in-use carbon emission intensity exceeds the composite good practice benchmark by 35%. Table 8 shows the components of the composite benchmark.

Category	**Floor Area** (m^2)	**Good practice** Fossil fuels ($kWh/m^2.yr$)	**Good practice** Electricity ($kWh/m^2.yr$)	**Good practice** Total ($kgCO_2/m^2.yr$)	**Typical practice** Fossil fuels ($kWh/m^2.yr$)	**Typical practice** Electricity ($kWh/m^2.yr$)	**Typical practice** Total ($kgCO_2/m^2.yr$)
Education (further and higher)							
Catering, bar/restaurant	207.4	182.0	137.0	110.7	257.0	149.0	131.8
Lecture room, arts	271.3	100.0	67.0	56.3	120.0	76.0	65.1
Offices							
Naturally ventilated, cellular	3545.0	79.0	33.0	33.5	151.0	54.0	59.0
Area Weighted		85.7	40.7	39.0	154.4	60.4	63.2

Table 8: Composite benchmarks

2 Source: CIBSE Guide F 2012 *Energy efficiency in buildings*

Although the composite benchmark, which more closely reflects the usage of the study building, is a more appropriate basis for comparison it still does not account for the mixed-mode operation of the offices, which uses an extract fan that runs when the building is in heating mode. Furthermore the composite benchmark cannot be disaggregated by end-use like the office benchmarks, which have therefore been used for the end-use comparison. In terms of CO_2 emissions (which allow a direct comparison of electricity and gas consumption), the measured energy consumption for heating and hot water is slightly lower than the good practice benchmark. This is encouraging since improvements to the control of the heating system are expected to reduce its consumption. Cooling and computer room energy consumption does not feature in the naturally ventilated building benchmarks so a direct comparison is not possible. Similarly, benchmark energy consumption due to fans in the 'fans, pumps and controls' category will be much smaller in fully natural ventilated buildings. The auditorium air handling unit and office extract ventilation contribute to the measured figure for this building. Lighting energy consumption is comparable with the typical benchmark. Better control of lighting in communal areas could reduce this. Office equipment energy consumption is less than the good practice benchmark, however this may be a result of the occupancy level and intermittent usage of some of the office units. Catering energy consumption is significantly higher than the benchmark figures, which only assume the provision of tea-points rather than full kitchens. Furthermore, the kitchen in the study building is all-electric which could increase its relative CO_2 emissions. The 'other electricity' includes external lighting and electricity consumption that could not be assigned to any other category due to limitations of the sub-metering and sparse documentation of circuit schedules. About one third of this 'other electricity' is due to external lighting.

6.3 Energy Trends

Fig. 11, below shows daily total electricity consumption calculated from the half-hourly data obtained from the electricity supplier. The daily consumption shows frequent variations due to the reduction in consumption during weekends. Applying a seven-day filter to the data makes the weekly variation clearer although there is still a wide variation in consumption during the monitoring period. The overall trend, calculated from the data, shows a steady increase during the first year of operation, followed by a levelling out during the second year. Although this is broadly consistent with the overall trend in occupancy shown in Fig. 8, not all the building's electrical loads are occupancy related.

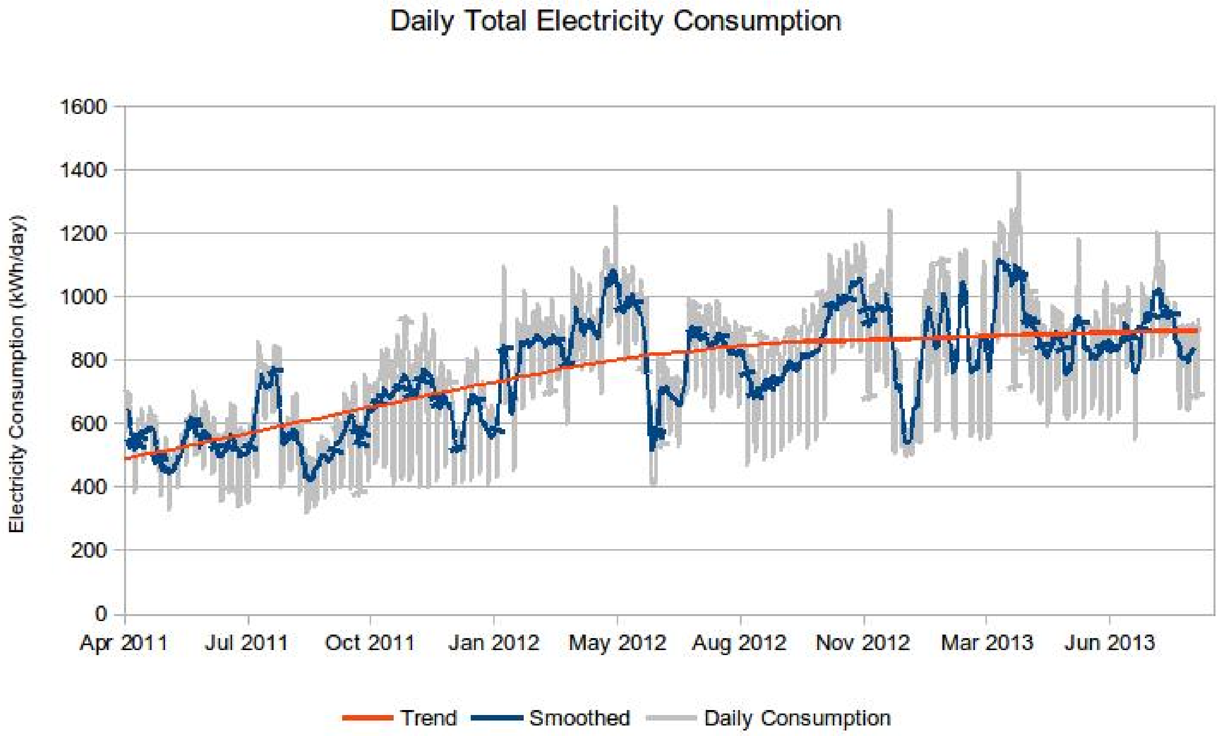


Fig. 11: Daily total energy consumption

Fig. 12, below shows monthly average electricity consumption from the building's sub-meters. The greatest variation from month to month is in plant power, shown in more detail in Fig. 13.

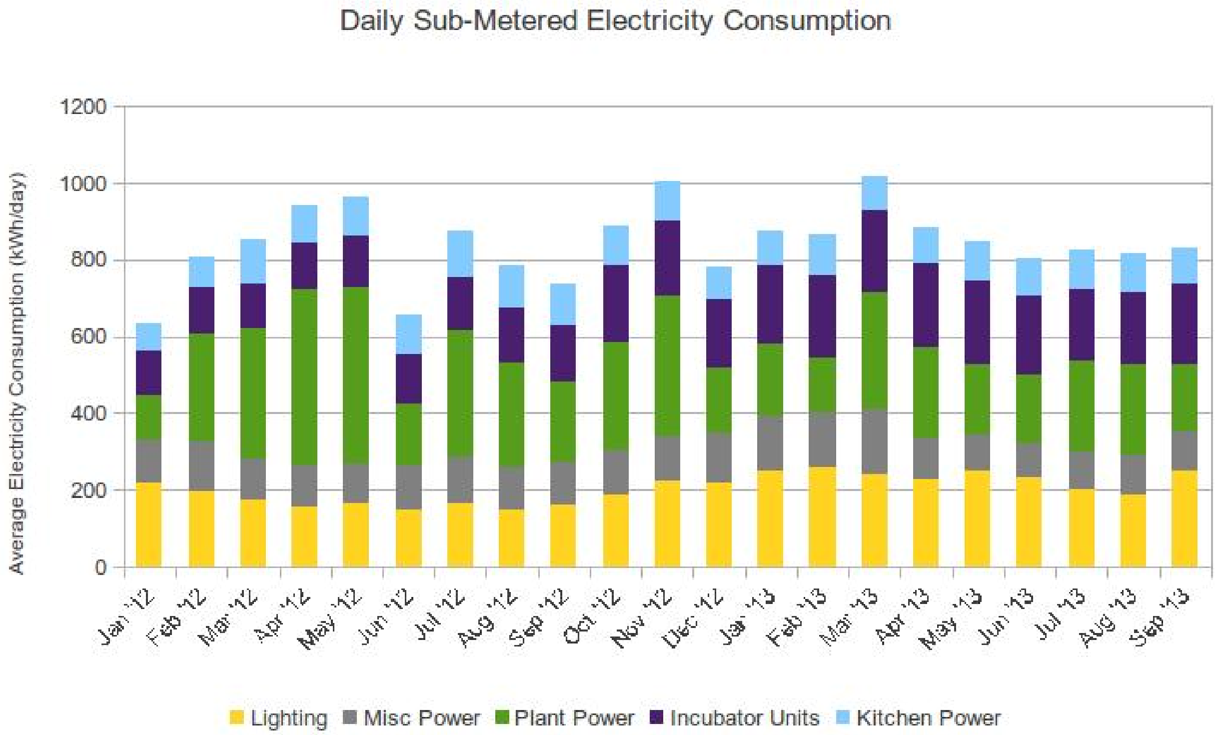


Fig. 12: Monthly average sub-metered electricity consumption

Plant Power

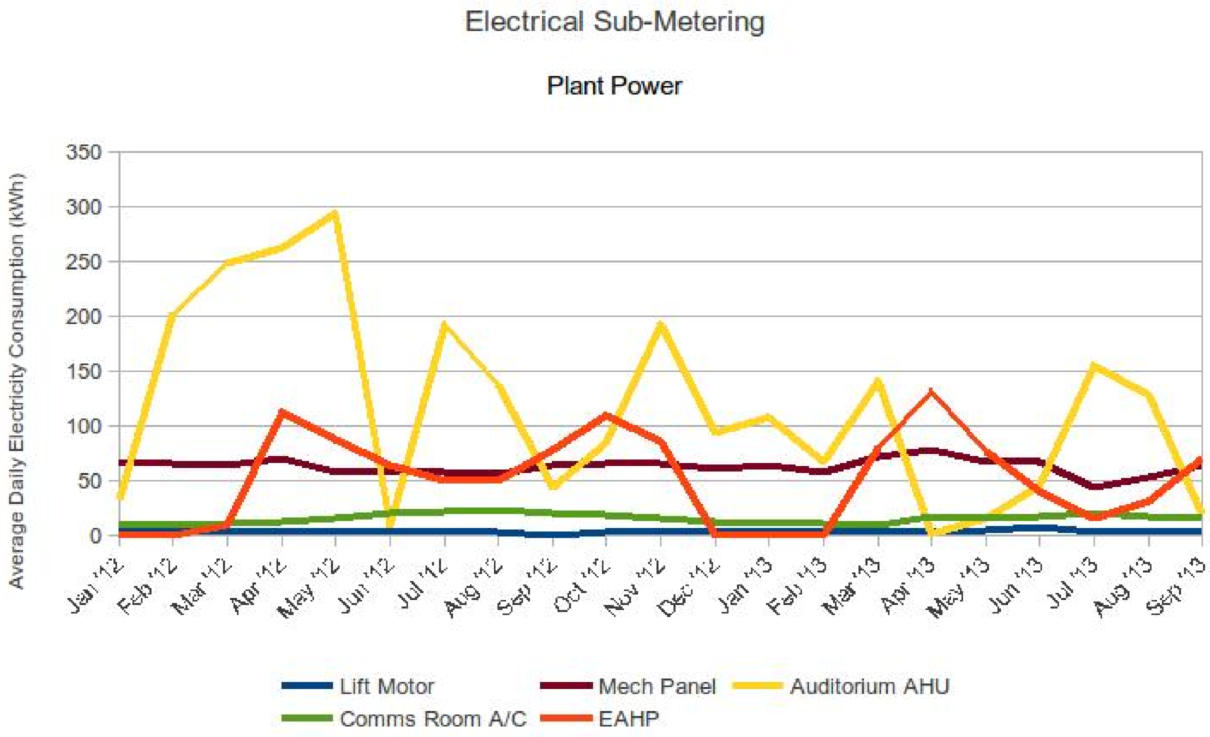


Fig. 13: Electrical sub-metering - Plant power

The variation in plant power consumption is due to the intermittent operation of the auditorium AHU and the exhaust air heat pump, the building's two largest single consumers of electricity. At the beginning of 2012, the auditorium AHU was left running permanently as it was otherwise unable to maintain the auditorium at a satisfactory temperature in cold weather. This was due to a compressor fault that has since been rectified. Even in warm weather the unit was frequently left running either accidentally or intentionally because the building operators were concerned that the unit, which had proved unreliable, will fail to restart if turned off. The extract air source heat pump was not fully operational during either of the two winters during the evaluation period. It was however in operation during spring and autumn seasons and surprisingly during the summer as well.

Lighting

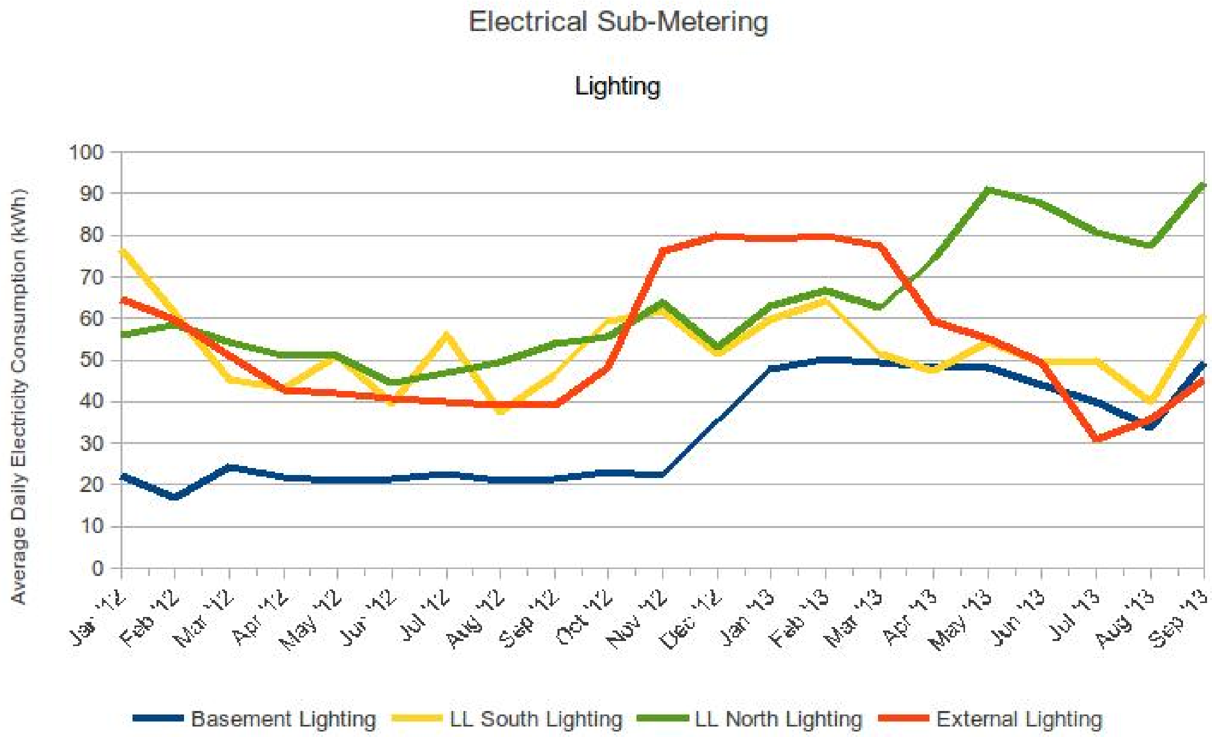


Fig. 14: Electrical sub-metering - Lighting

There is a seasonal variation in lighting electricity consumption, much of this is due to the external lighting, which operates on a time switch that is periodically adjusted to account for daylight availability. Landlord north lighting electricity consumption increased dramatically between March and May 2013. This may be due to the fire exit stairs being increasingly being used for general movement between office floors. The lighting in these stairwells is not controlled by PIR and is often left on overnight. The basement lighting electricity consumption has almost doubled since November 2012. This may be the result of manual adjustment or a failure of the PIR control and is due to be investigated.

Incubator Units

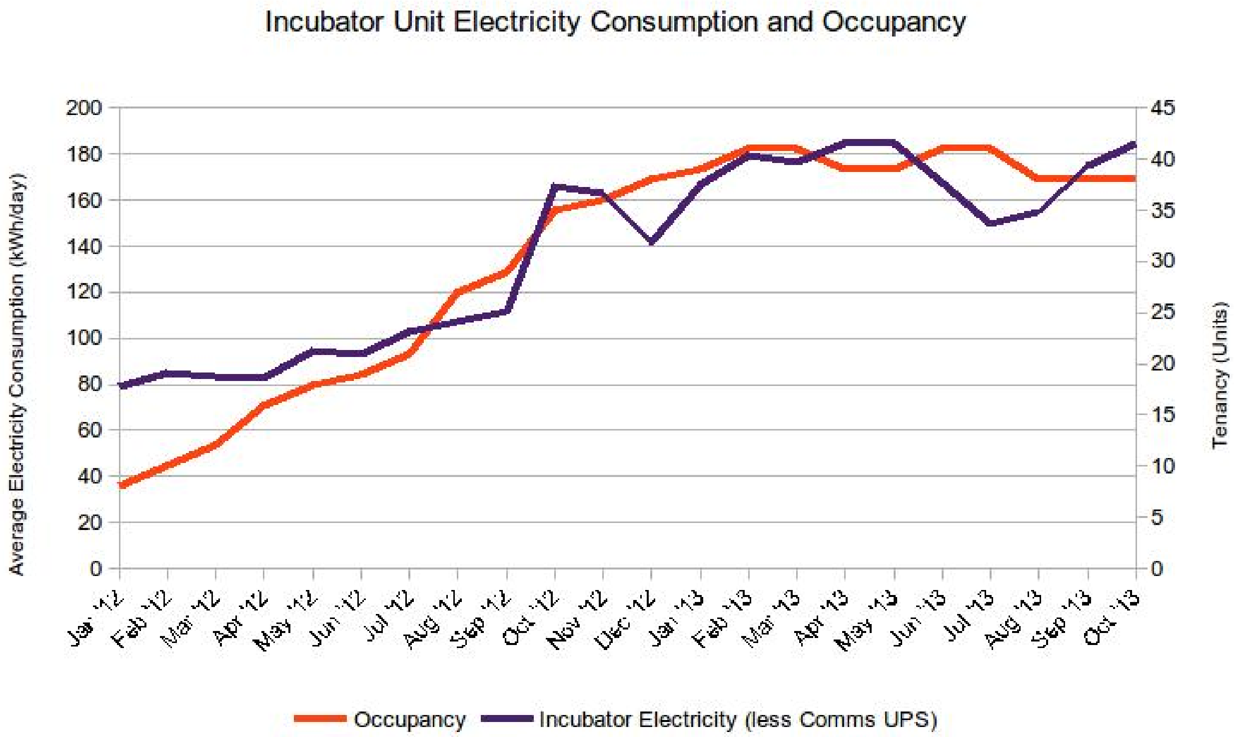


Fig. 15: Incubator unit electricity consumption and occupancy

Fig. 15 shows the incubator unit electricity consumption (less the Comms Room UPS) and the building's occupancy. The incubator unit consumption has increased, broadly in line with the increasing number of tenants in the building. Tenants generally work core hours of 9-5 but part time occupancy is common, particularly in the smaller incubator units. Out-of-hours occupancy is infrequent. The amount of electrical equipment in the units is fairly light, typically including small office equipment such as laptops and personal printers, however one or two tenants run servers in their offices. Desktop equipment is generally turned off when tenants leave their office, however some things like printers are left on standby.

Kitchen Power

Kitchen power has remained fairly constant (around 100 kWh/day) throughout the monitoring period. The kitchen was found to have a base load of about 2.5 kW due to fridges, freezers and possibly other equipment being left on. The café is open to the public, so the number of meals served is less closely related to building tenancy. On an average weekday, the café serves about 50 hot drinks, 25 cold meals and 10 hot meals. Assuming this is equivalent to about 40 meals the energy consumption per meal served is approximately 2.5 kWh/meal. This falls in the range of good practice benchmarks for coffee shops (approx 1.4 kWh/meal) and staff restaurants (approx 3.9 kWh/meal)[3].

[3] Source: CIBSE TM50 2009 *Energy efficiency in commercial kitchens*

Miscellaneous Power

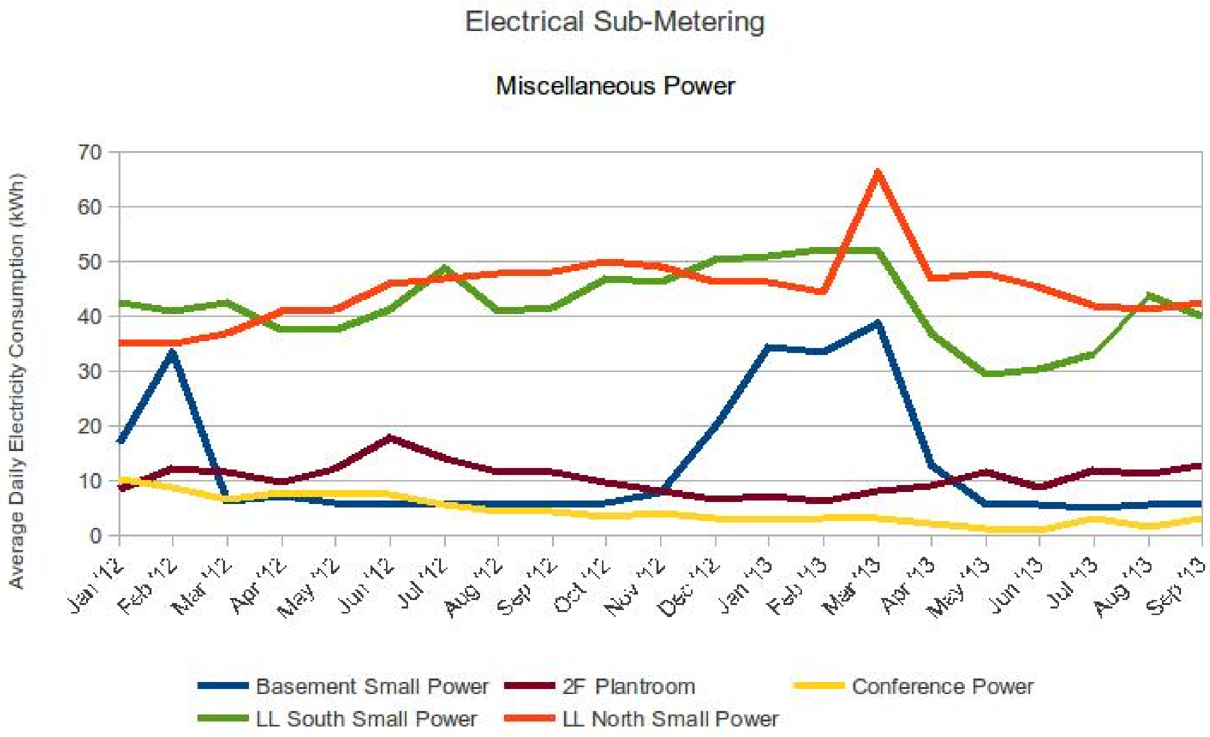


Fig. 16: Electrical sub-metering - Miscellaneous power

Fig. 16 shows the miscellaneous power consumption. Much of the variation in consumption is due to the operation of trace heating for pipework in the undercroft car park during cold weather. This is served from the basement small power distribution board. The consumption figure for the landlord north small power distribution board in March 2013 is artificially elevated due to the EAHP meter being offline (therefore it was not possible to subtract the EAHP consumption from the other loads on the distribution board). There was a significant reduction in the landlord south small-power consumption during spring 2013 however it was not possible to identify the reason.

Heating & Hot Water (Electricity and Gas)

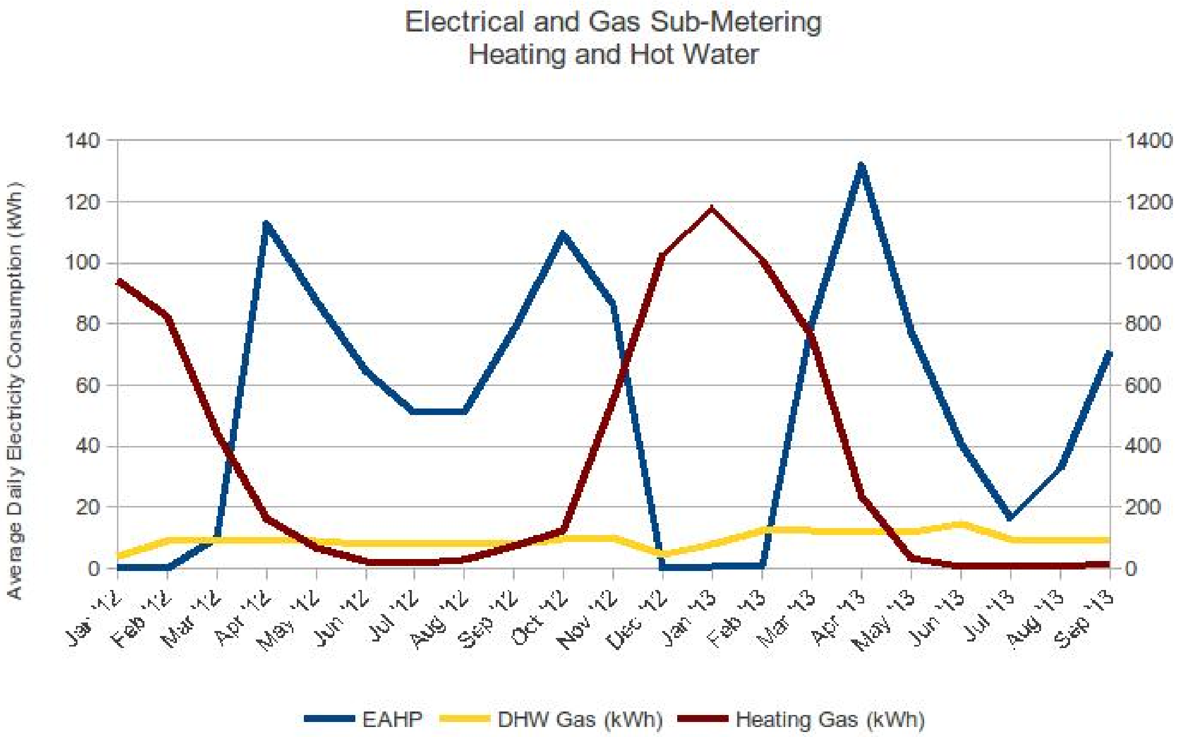


Fig. 17: Electrical and gas sub-metering - Heating and hot water

Fig. 17 shows the electricity and gas consumption used for heat generation. Gas consumption for domestic hot water is relatively stable. As the system appears to be oversized for the level of demand, most of the energy is used to maintain storage and circulation temperatures. Gas consumption for heating shows clear wintertime peaks, which are likely to have been exacerbated by the EAHP not contributing to the building's heating during both winters as well as the switch in December 2012 to 24/7 operation of heating (due partly to concern that it would fail to restart if left to BMS control). The EAHP continues to operate during the summer. This is probably unnecessary and is due to the high ambient temperature at which the heating plant is deactivated (currently 20°C). It must be noted that this comparison between kWh of gas and kWh of electricity does not take into account the greater efficiency of the heat pump, nor does it take into account the differences in primary energy or carbon intensity between gas and electricity. Fig. 18, below expresses the space heating system's gas and electricity consumption in terms of CO_2. Although the EAHP was intended to satisfy the majority of the building's heating demand the gas usage when the EAHP was operating is significant. This has been recently identified as a consequence of the boiler's flow temperature being set to 80°C, causing unnecessary cycling of both the boiler and EAHP. The flow temperature has been reduced to 60°C which should reduce cycling and allow the EAHP to operate more effectively. When designing and commissioning systems such as this that use a combination of heat sources, their compatibility (for example flow temperatures) must be considered.

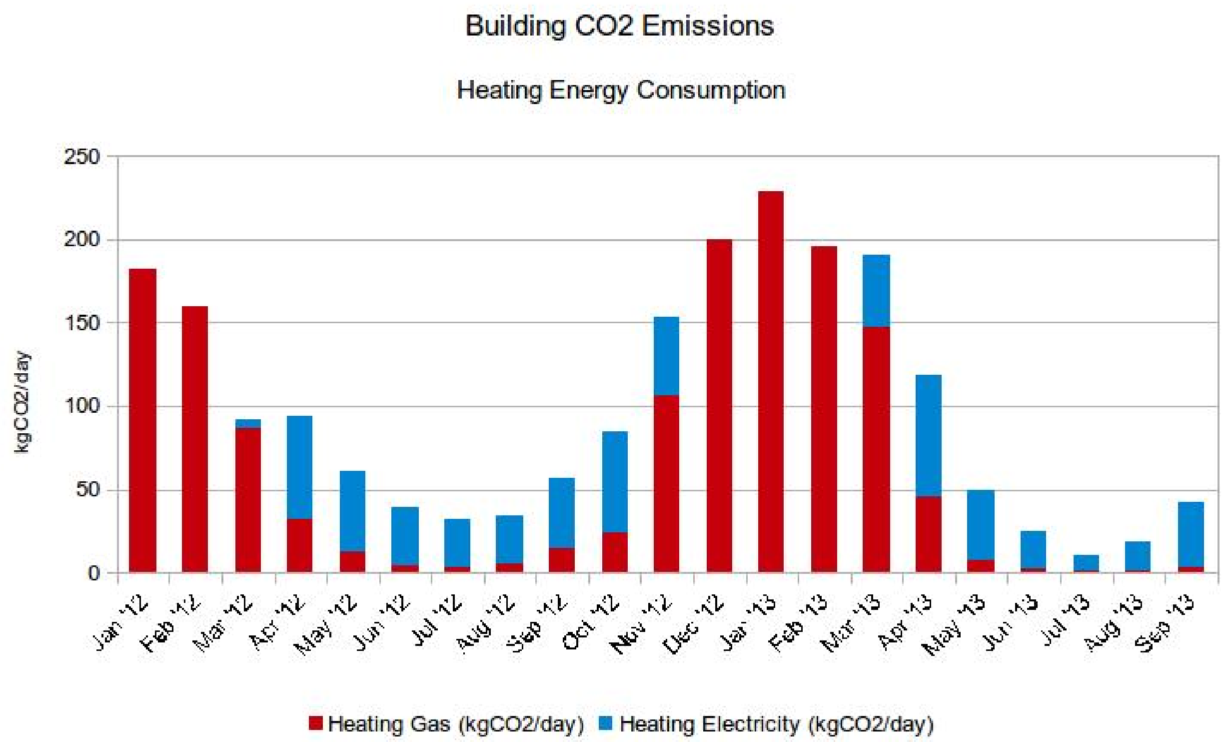


Fig. 18: Building CO_2 emissions - Heating energy consumption

6.4 TM22 Analysis

This section summarises the results of the TM22 analysis. Further information on the assumptions and data sources used, notes on individual worksheets and a general discussion of the TM22 approach is attached as an appendix to this report. Tables 9 and 10 show the annual delivered energy and CO_2 emissions for electricity and gas.

Energy, carbon and cost summary	Units	Electricity	Fuels	Thermal
Non renewable fuel or electricity supplied to site	kWh/annum	318,499	189,833	0
Separable energy uses	kWh/annum	0	0	0
Renewable energy used on site	kWh/annum	0	0	0
Renewable energy exported	kWh/annum	0	0	0
Output from CHP used in building	kWh/annum	0		0
Exported CHP	kWh/annum	0		0

Table 9: TM22 Simple assessment - Annual delivered energy by type

Unit values	Energy supplied (kWh/m^2 GIA)		Carbon dioxide emissions (kg CO_2/m^2 GIA)		
	Fuel/thermal	Electricity	Fuel/thermal	Electricity	TOTAL
Supplied	47.2	79.2	9.2	43.5	52.7

Table 10: TM22 Simple assessment - Annual delivered energy and CO_2 emissions by type (normalised)

Fig. 19 provides a comparison of the supplied (in-use) energy consumption with the benchmark figure used to generate the building's current DEC. This is a composite benchmark that takes into account the different space categories within the building (general offices, auditorium and café). The benchmark also includes an adjustment to allow for the influence of ambient temperatures on heating energy consumption. The user specified benchmark is based on the design energy consumption obtained from the compliance model.

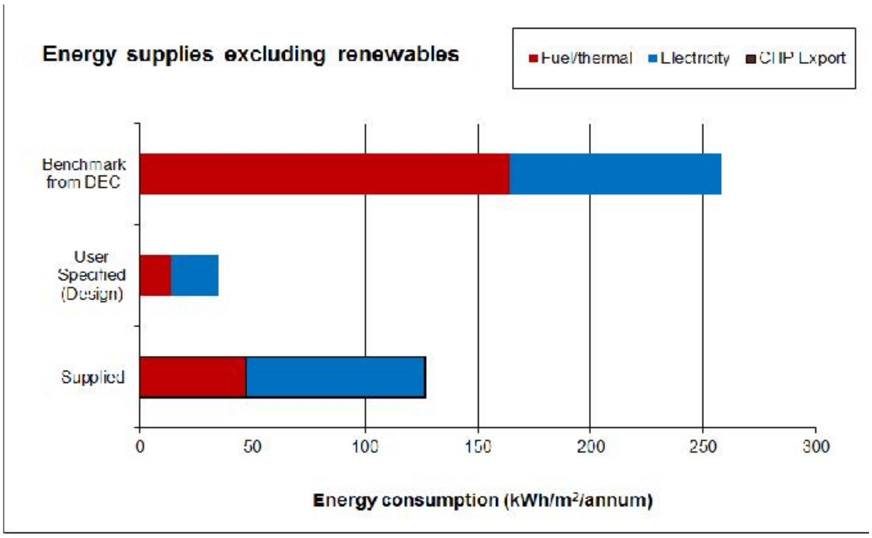


Fig 19: TM22 Simple assessment - Benchmark, design and in-use energy consumption

In terms of energy consumption, the building's electricity use is similar to the benchmark figure while the heating energy is significantly lower. The DEC benchmarks are intended to be representative of the whole building stock so a recently constructed building complying with recent building regulations would be expected to use significantly less energy heating provided it is operated reasonably well. Fig. 20 shows the same energy consumption in terms of CO_2 emissions, with a reduction in the percentage due to gas consumption on account of the lower CO_2 emissions conversion factor.

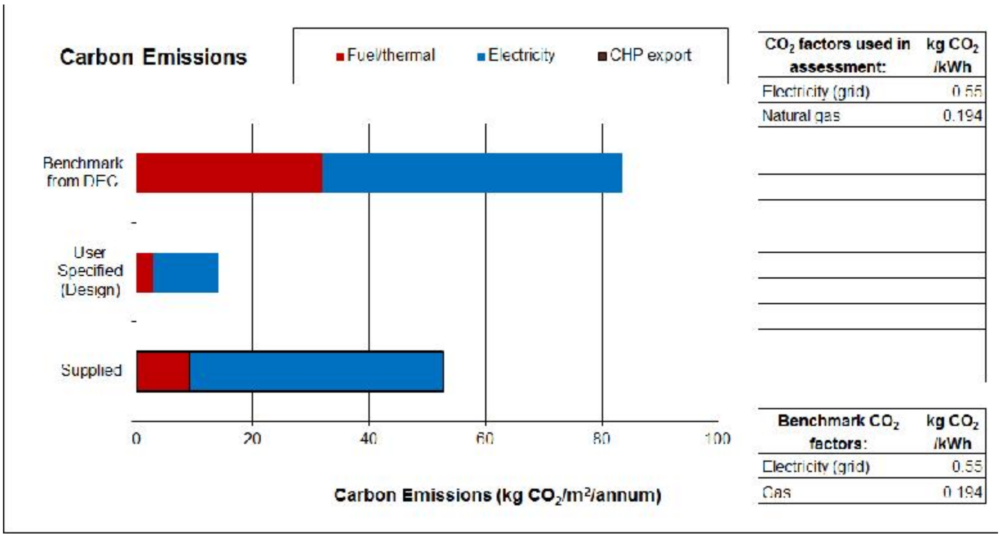


Fig 20: TM22 Simple assessment - Benchmark, design and in-use CO_2 emissions

In addition to the simple assessment shown above, the TM22 spreadsheet attempts to disaggregate energy consumption by end-use. This is based on a reconciliation of sub-meter readings against estimated consumption figures obtained from installed loads and adjustment factors for load duty, operating hours and seasonal variation. This is a different approach to the disaggregation described above so, although the resulting end-use figures are broadly similar, they will not correspond exactly. Fig. 21 shows a comparison of benchmark heat demand with design and in-use figures. As well as the DEC benchmark, the detailed assessment includes a comparison with office benchmarks from Energy Efficiency Consumption Guide 19 (ECON19). The benchmarks given are for naturally ventilated cellular offices. Because the graph expresses heat demand rather than energy consumption an average thermal efficiency of 75% is applied to the benchmark figures. A similar figure has been applied to the design and in-use space heating and hot water energy consumption. In terms of heat demand the domestic water is similar to the typical figure however the space heating demand would appear to be less than both typical and good practice benchmarks. In this building however, space heating demand is intended to be met primarily by the air source heat pump, which is an electrical load rather than a thermal fuel load.

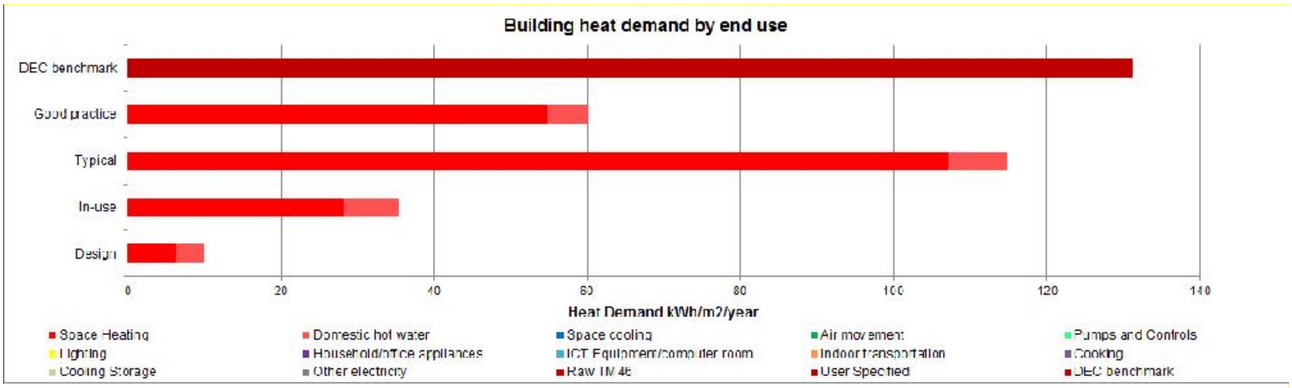


Fig. 21: TM22 Detailed assessment - Heat demand by end-use

Fig. 22 shows a comparison of benchmark electricity demand with design and in-use figures. The design figures clearly don't include any unregulated loads such as offices appliances and catering. The in-use figures are larger than both the good practice and typical benchmarks. This is due partly to the inclusion of heating energy consumption, which is absent from the benchmarks because it is assumed to be provided by thermal fuel, and cooling and air movement energy consumption, due to the presence of a mixed-mode ventilation system and air conditioning in the auditorium, meeting and comms rooms.

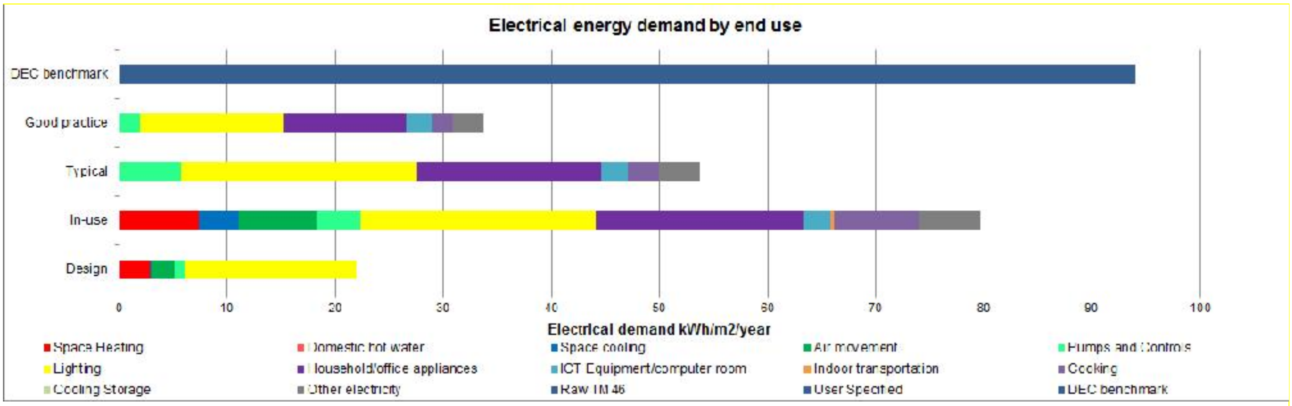


Fig. 22: TM22 Detailed assessment - Electricity demand by end-use

The following graphs, Figs. 23 and 24, show average daily electrical load profiles obtained by processing the supplier's half-hourly consumption data with the TM22 half-hour data analysis module. Both profiles show a large variation in half-hourly loads from about 8am to 10pm. Outside of these hours there is less variation about what appears to be a baseline load of 25 kW, which doesn't change at weekends. This average baseline load will be made up of a variety of end-uses including external lighting, internal lighting left on overnight, mechanical plant such as the heat pump that may have been running continuously, kitchen fridges and freezers, as well as IT equipment that run continuously. Average weekday consumption increases between about 7am and 9am, corresponding to the beginning of the working day. Consumption beings to tail off in the afternoon. The rate at which consumption increases is greater than the rate at which it tails off. This is probably due to there being greater variation in occupant leaving times than arrival times. There is a slight increase in average consumption from 8am to 10pm on weekends, which is due to occasional weekend use of the building.

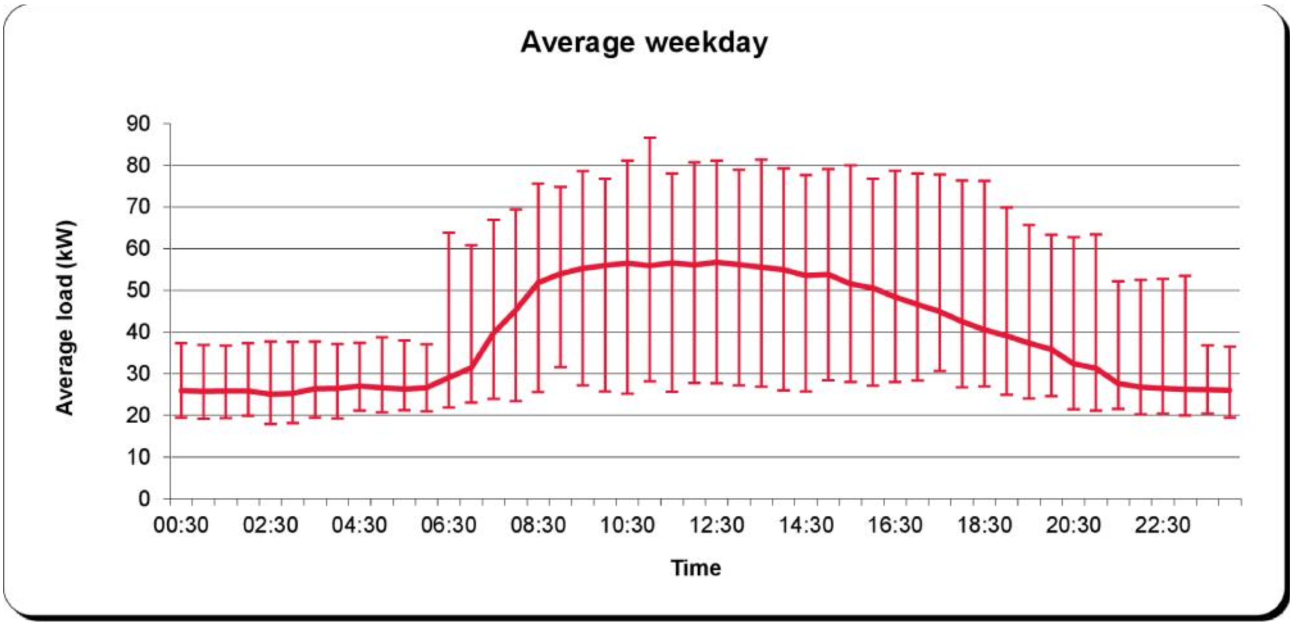


Fig. 23: TM22 Half-hourly electrical load profile - Average weekday

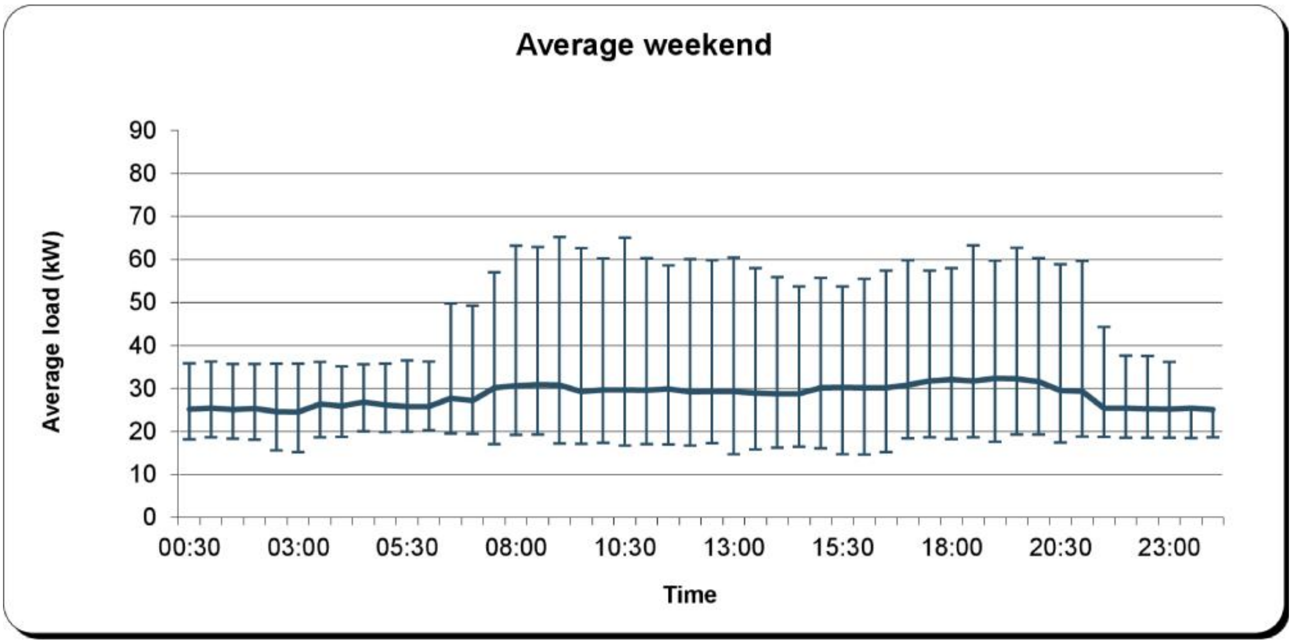


Fig. 24: TM22 Half-hourly electrical load profile - Average weekend

6.5 Conclusions

There is a clear discrepancy between the building's design and operational energy consumption. There are many factors that contribute to this discrepancy however they can be considered in terms of two principal issues. The first issue relates to the nature of the design estimate of energy consumption which, in common with many buildings, is derived from the building's compliance modelling. As this modelling makes no attempt to account for unregulated energy use it is not surprising that the design figures underestimate operational energy consumption in the presence of significant external lighting loads and an all-electric kitchen. Even if unregulated energy uses are excluded, the operational figures still exceed the design model figures by a factor of 2. This is partly due to modelling assumptions about the performance of building services plant such as the exhaust air heat pump. It is also due to the use of standardised occupancy and load densities in the compliance methodology. The second issue is due to unanticipated factors such as continuous operating of the heating system, use of the auditorium AHU and poor control of lighting in communal areas. To address these principal issues both greater realism in design energy estimates and diligence in building energy management are necessary.

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 Heating

The heating system has been problematic since the first winter of the building's operation. During November and early December 2011 there were complaints from tenants that the system was not operating correctly and the offices were unacceptably cold, particularly at the beginning of the week. The mechanical contractor and facilities management staff attended site to investigate and made a number of adjustments including increasing the hot water system pressure and adjusting the temperature compensation settings to provide a higher flow temperature. After two months of apparently reliable operating the temperature compensation settings were returned to their original values.

The following autumn problems were again experienced. The system was apparently unable to maintain temperatures in the building when running or simply failed to start up in the morning. During December, as a result of these ongoing problems, the BMS schedule was changed to run the heating system constantly. This has solved the problem of providing heat to the building but is a wasteful way of operating the heating system. The source of the reliability problems was not clear; they may well have been the result of a combination of factors rather than a single fault. The optimum start controller was discovered initially to have been set to respond to the minimum space temperature of zones including the unheated street. The street was removed from the controlling set of zones but low temperatures in unoccupied offices where the heating had been switched off would have also reduced the effectiveness of the controller. Shortly before the end of the project the controller was set to respond to the average space temperature rather than the minimum space temperature. As a result the optimum start controller has begun to reduce its pre-heat time but further adjustment may be necessary. At one point it was suspected that the boiler shunt pump wasn't running as intended, or that the BMS was incorrectly sensing that it wasn't running. A current sensing switch, used to monitor the shunt pump's operation, was adjusted and then replaced but it was not clear whether it was actually defective. On subsequent occasions when the boiler shunt pump failed to start it was started by switching the pump to manual operation. On another occasion the heating system pressure was unusually low, which could have affected the system's operation or even prevented the boiler from running. As no leaks were found it was suspected that the pressurisation system wasn't working properly. The system was re-pressurised and appeared to run however it still failed a number of times to start in the morning. It was discovered that the BMS was not being isolated from the fire alarm system when weekly alarm tests are carried out. The controls maintenance contractor suggested that the resulting emergency shutdowns were a potential cause of ongoing problems with the BMS.

During spring 2013 however the heating system was generally reliable although continuous operation was clearly inefficient. The BMS alarm logs suggested that BMS was still not being isolated from the fire alarm when carrying out the weekly alarm test however there was no evidence that this was causing any problem. A temporary loss of heat to some of the radiators in one part of the ground floor was attributed to an air lock. The heating circuit pump was returned to automatic speed setting after being found set at maximum speed, possibly in an attempt to restore heat to the radiators. It was also possible that branch valves were adjusted in response to the problem. By the beginning of summer 2013 the heating gas consumption was negligible and the EAHP electricity consumption is less in magnitude and variability that the same quarter the previous year. However, the cumulative effect of individual adjustments and modifications made in immediate response to symptoms, possibly without understanding the effect these changes may have on the operation of the whole system, could be a system that no longer operates according to design specifications. For example, the heating continues to run constantly at ambient temperatures up to the heating system's ambient threshold of 20°C. Reducing this threshold would reduce the unnecessary operation of the EAHP during summer months and may also reduce the risk of overheating.

External Review

In recognition of the need to realign the building services system to design specifications, an independent consultant was commissioned by the University of Northampton to conduct a review of the plant and BMS operation, identify issues that could affect its reliability and efficiency and suggest actions for improvement. The consultant carried out their own review of information provided by the building's O&M manual and noted that there are some inaccuracies and omissions in the document. The consultant also reviewed pump settings and worked closely with the BPE operational issues review process to identify a number of other improvements. These included adding a facility to isolate the BMS from the fire alarm system when alarm tests are carried out, modifying an overspill air damper on the exhaust air heat pump in an attempt to improve control reliability, fitting additional space temperature sensors to allow better control of the auditorium AHU and reviewing the control strategy, which will hopefully enable the system to be operated more efficiently during the next heating season. Since most of this work was carried out towards the end of the evaluation project its long-term impact has yet to be established. It would have been useful to involve the environmental consultant responsible for the original operating strategy as well as the controls contractor who implemented it however this was not possible. Further areas for investigation include assessing whether additional measures (such as night purging or additional ventilation) are necessary to prevent overheating, particularly in the second floor street-facing units, assessing whether the mechanical extract system provides adequate ventilation to each office, particularly when vents are open in some of them, and assessing whether the auditorium air handling unit is now operating satisfactorily.

EAHP

The exhaust air heat pump, which is central to the building's low carbon heating strategy, was not operating for much of the winter in both 2011-2012 and 2012-2013. It was however operating throughout the summer. It is important that this unit is brought under better control so it can contribute usefully to the building's heating requirement. The control strategy, the interaction of the heat pump with the gas boiler and buffer tank, and the temperature and volume of air extracted from the offices are all factors that contribute to the heat pump's performance.

The increase to heating system flow temperature in December 2011 was believed to render the EAHP unable to contribute to the building's heating. Under the increased temperature settings the target heating flow temperature would exceed 55°C when ambient temperatures were below about 16°C. This compromised the ability of the EAHP to contribute to the building's heating system, which was designed to operate at lower temperatures than a traditional gas boiler system; the heat pump is unable to operate at heating water temperatures above 55°C. At the beginning of February 2012 the flow temperature was reduced back to its design value however the exhaust air heat pump remained offline due to a fault condition. This was eventually cleared and the heat pump was operational by the end of March. The EAHP operated until the end of November 2012. There was no indication of why the unit then ceased operating. At the time maintenance work was being carried out in relation to a heating system failure. In spring 2013 the problem with the exhaust air heat pump was traced to a control wiring modification. The control wiring was altered allowing the heat pump to operate however the adjustment affected the operation of a motorised pressure relief damper, resulting in air flow though the heat pump apparently exceeding its maximum duty. A simple solution was recommended by the heat pump manufacturer. This involved replacing the motorised damper with a spring loaded damper to allow excess air exhaust without needing additional controls. This work was carried out shortly before the end of the evaluation project.

Motorised damper prior to replacement

Pumps

Three of the building's water heating circuits are driven by twin-head pumps. These are configured to alternate operation on a weekly basis to even the wear on each pump. It was noticed that the system flow rate was changing on a weekly basis as a result of the pumps in each set operating in different modes. As it was not possible to confirm any of the design pump settings a representative from the pump manufacturer was asked to provide advice on the appropriate settings. On 17th April 2013, circulation pump settings were checked with a remote controller. The 'as found' settings were recorded and, where necessary, adjusted to be more consistent with the 'as commissioned' values. The pumps in the twin head units were set to the same speed and pressure to prevent weekly changes from duty to standby causing different volume flow rates. The control buttons on the pumps were then disabled to prevent further changes to the settings. The effect of these adjustments was monitored and the heating system appears to be operating satisfactorily.

7.2 Domestic Hot Water

The boiler serving the DHW calorifiers is controlled to maintain a 70°C flow temperature. Because the calorifers are oversized for the quantity of hot water used the boiler cycles frequently. While it may be more efficient to maintain a pre-set minimum calorifier temperature rather than a primary flow temperature, concerns about Legionella meant the building maintenance team were reluctant to make changes. There have been problems with the water supply to the showers however they appear to have been resolved by the end of the evaluation project. The problems were believed to be caused by the failure of a PIR solenoid valve (intended to isolate water to showers to prevent them being left on).

7.3 Ventilation

Incubator Units

Overheating was reported in some of the incubator units and the street during the first summer of the building's operation in 2011. Some of this was due to a lack of ventilation caused by actuator failures. The faulty actuators were identified and replaced. Further problems occurred during warm but rainy weather. These were traced to the rain sensor, which is intended to close the vents to prevent rain ingress. The sensor was remaining damp after a rain shower had passed, preventing the vents from reopening. The problem was addressed by replacing the rain sensor with one that incorporated a heating element. The heated rain sensor is less likely to be triggered by dew or condensation and will dry more quickly when rain stops. The location of the sensor, at the side of the ventilation stacks, actually means that in certain wind directions it is sheltered from rain, reducing its sensitivity. Raising the sensor above the roof-line of the stacks would improve its sensitivity.

BMS rain sensor

During the first winter of the building's operation there were complaints of stuffiness and overheating in some of the units. Although the stuffiness could be a symptom of overheating, it could also be due to an inadequate fresh air supply. When the heat pump is enabled an axial fan in front of the exhaust air heat pump operates to extract air from the incubator units. Fresh air is assumed to make up to difference, entering each incubator unit by infiltration from outside or around the internal doors from the corridors. The fan was sized to provide a ventilation rate of 10 l/s.person in the incubator units however there are no commissioning records available so it's not known whether the system works as intended. In response to the complaints the natural ventilation ambient temperature set-point was modified to allow the vents to open even during cold weather. The original set-point had effectively disabled the natural ventilation system during the heating season. Following the adjustment, overlapping set-points meant it became possible to open a unit's vent while the extract fan is running. This could cause the extract system to become unbalanced by introducing a path of least resistance that could result in less air being drawn from the offices whose vents remain closed. It could also result in cold ambient air being drawn into the extract system, reducing the temperature of the air entering the EAHP, which will reduce its efficiency and ultimately prevent it operating if the inlet air temperature drops below 18°C. It will also have the effect of allowing the vents to open even though the heating is on. The possibility of using RF controlled TRVs was discussed with the operational issues team, these could allow central control that might offer some alleviation of local overheating during the winter. If necessary, they could also be linked by the BMS to the ventilation opening to turn the radiators off when the vents are opened.

During May 2012 a spell of hot weather resulted in complaints of overheating, particularly in the internal (street-facing) offices. On 23rd May, one unit had reached nearly 30°C by early afternoon and remained over 28°C until the small hours of the morning. During this week there were six successive days the ambient temperature reached 25°C, however the night-time temperature usually dropped to about 12°C. To mitigate overheating the natural ventilation opening setpoints were reduced and the BMS schedule was changed to allow vents to open overnight. However these changes were not reversed after the weather turned cool again. During the long bank holiday weekend the temperature in the units that had earlier overheated dropped to below 15°C. When staff returned later in the week the complaints were of offices that were too cold. The BMS control strategy includes a night purge function regulated by the minimum space temperature however it does not appear to be fully implemented. This may explain why it was necessary to change the natural ventilation occupancy schedule to 24/7 to allow night purging. If the system is configured to allow night ventilation it may be necessary to adjust the operating of the heating to prevent it running when the vents are open. Ideally this should be handled by the BMS but it may need manual intervention.

Summer 2012 was relatively cool, so it was difficult to ascertain whether the lack of overheating in the incubator units was due to weather conditions or the use of longer scheduled operating periods to permit night-time ventilation. The vent actuators have continued to cause problems; incubator unit vents have been found to be open despite the internal temperature being below the vent opening set-point and the BMS reporting the vents to be closed. The manual override switch was unable to close the vents, which suggested that the actuators themselves were faulty, unless the BMS was failing to register that the vents are open. An inspection of the roof in spring 2013 revealed several incubator unit vent doors were taped or tied closed and a number of other vent doors failed to open. During the summer the faulty actuators on the rooftop ventilation doors were replaced. The work was signed-off after each actuator has been demonstrated to work correctly.

Incubator unit vent taped-up

Incubator unit vent tied closed

There is some uncertainty about the level of internal heat gains in different office units. The overheating calculation made assumptions about the amount of equipment in each unit. Tenants with higher equipment densities or equipment running permanently such as servers will be at greater risk of overheating. Overheating could be due to equipment density or incorrect setting of the TRVs (possibly due to tenants misunderstanding their operation).

A minor build defect in the ventilation stacks has been identified, which allows air to move between adjacent stacks and could cause drafts in incubator units despite their own vents being closed. It should be possible to rectify this by extending the lining of each stack up to close a small gap at the top of the stack terminal. It has not been possible to carry out remedial work however, due to difficulties setting up access platforms for safe working within the stacks.

Street

The street experiences high temperatures during hot weather, and has been the source of some complaints. The street is not considered to be a permanently occupied space and therefore was not required to satisfy any overheating criteria at design stage. The design stage compliance report actually indicates that the street would experience significant overheating however no action was taken. Even with a working ventilation system the street is likely to become very warm on the upper levels in sunny weather. This has been exacerbated by failed vent actuators. The building contractor has been asked to provide a report from the actuator manufacturer concerning the street vents, which rely on two actuators operating in tandem to open and close. It has been suggested that the actuators on the street vents are installed incorrectly and should be controlled with contactors rather than relays. The reason for this is not clear as the relays have a current rating more than adequate for the load. At time of writing a number of street vents are remaining open despite the rain signal, however they open outward so rain ingress is unlikely, others appear to remain closed. Failed actuators are scheduled to be replaced in 2014. The installation of louvres in the curtain walls at either end of the street remains a possibility. This was proposed to provide a path for air movement vertically through the street as there are currently no openings at low level to allow air circulation.

Only four of six vents on one side of the street were opening properly

7.4 Air Conditioning

Auditorium AHU

The auditorium air handling unit has suffered from a number of potentially related problems. The unit has been unable to provide sufficient heating during periods of cold weather when trying to heat the auditorium after it had not been used for some time. The auditorium was designed to achieve a wintertime internal condition of 21°C at -4°C ambient however at an ambient temperature of around 0°C the AHU was unable to raise the auditorium temperature from temperature of 12°C to any more than about 16°C. A heavy duty electric fan heater was used temporarily to pre-heat the auditorium to a temperature at which the heat pump's output was sufficient to offset the space heating load and maintain design temperatures. At the time it was suggested that background heating is necessary to supplement the AHU and that perimeter radiators were originally part of the design but were omitted as part of value engineering. The alternatives to supplementary heating were either running the AHU continuously to try to maintain the background temperature or starting the AHU sufficiently in advance of the auditorium being used in order to reach an acceptable temperature. Further work by the BMS installer and maintenance contractor revealed the problem was partly the result of a misconfiguration in the manufacturer's supplied control strategy and partly due to component failure and refrigerant leaks within the heat pump unit. After several maintenance visits its performance appeared to improve and by January 2013 it was able to bring the auditorium up to temperature after being turned off over the Christmas period. Further testing is necessary to determine how long the AHU takes to raise the auditorium space temperature when it has been off for some time. Although the system was intended to be operated on a pre-set weekly schedule the auditorium is generally used intermittently, so the system is enabled as required. On occasions, either due to a lack of confidence that the unit would work when required or just accidentally, it has been left running continuously, significantly increasing the building's electricity consumption. Continuous operation in warm weather will cause a build-up of condensate. Normally this should flow freely into drain pipework. On at least one occasion however it appears to have collected within the unit and eventually leaked causing substantial water damage to the room below. This was investigated by the maintenance contractor who suspected inadequate traps and pipework fall. In addition to the technical problems experienced, it is still unclear how best to operate the unit. Currently the unit is only capable of operating on full fresh air supply. Combined with the limited output of the unit's heat pump the AHU is unlikely to be able to provide sufficient heating in cold weather if the internal temperature drops below about 13°C. This is unlikely if the auditorium is in regular use, but can happen if the auditorium is unheated for longer periods during cold weather. At higher internal temperatures enough heat is recovered by the recuperator unit to sufficiently temper the incoming fresh air. The AHU includes two small side dampers on the recuperator unit. If the control strategy was able to open both dampers while closing the fresh air dampers the AHU may be able to provide a full recirculation mode to pre-heat the space. Understanding of the unit's operation is hindered by the lack of information available on the BMS head end, which effectively only indicates on or off.

Server/Comms Rooms

The server rooms are unventilated and run cooling permanently to maintain a set temperature. During cold weather temperatures server rooms have dropped below 18°C but the air conditioning units continued to run. The use of free cooling during cold weather could have been investigated at design stage. There was an incident when the server room air conditioning did not automatically restart after a power failure. This led to overheating and damage occurring after the servers and comms equipment restarted. The system was modified to automatically restart following power supply interruptions. The cooling set-points were found to be set to 22°C which is actually unnecessarily low. The cooling set-points have since been increased to 25°C. Although IT equipment can operate reliably at ambient temperatures up to about 27°C, the equipment's internal fans typically begin to increase their speed above 25°C, which will increase electricity consumption and heat generation.

Both the comms room cooling and the meeting room cooling appear to be run on a time schedule according to the BMS supervisor however electricity meter readings show the comms room cooling operating 24/7. It is possible that there was BMS control of the cooling but this has since been disabled. It makes sense to allow the comms room cooling to run 24/7 but not necessarily the meeting room cooling.

Meeting Rooms

The building log book describes the condensers as being situated within an external plant space on the roof however the condenser unit serving the meeting rooms is actually located within the second floor plant room. The plant room may have originally been intended to be an external plant space however with no ventilation in warm weather the temperature within the plant room could adversely affect the efficiency of the unit. As the meeting rooms are infrequency used the potential savings due to increased efficiency may not justify the cost of relocating the unit.

Condenser unit located in unventilated plant room

7.5 Water Metering

There are three water meters in the lower ground floor plant room. These measure the water supplied to the kitchen, the rainwater supplied to the incubator unit toilets and the mains water used to top-up the rainwater tank. Neither the kitchen nor rainwater meters appear to be working; the readings on the dials do not seem to reflect likely water consumption. Two of the meters have pulse output cable connected however no consumption is being recorded by the BMS. The kitchen water supply meter's pulse output cable has not been wired up.

7.6 Control System

In the first few months after the building was handed over the BMS supervisor was displaying a large number of alarms. It was not clear to building management staff whether they were important or could be safely dismissed. There was very little guidance given on how to deal with them. The BMS was configured to log space and plant temperatures however these logs were not stored permanently and only contained the last 1000 measurements (just over 10 days of readings at 15 minute intervals). In February 2012 the BMS supervisor was reconfigured to save the logs to disk at regular intervals.

7.7 Lighting

Internal Lighting

Electricity monitoring revealed that lighting energy consumption was unusually high for two unoccupied units. The lights in these units were found to be remaining on despite the automatic light switching. Switching off manually appears to have solved the problem in these rooms. A query from a tenant about lights remaining on in their unit was investigated by reviewing energy consumption and lux levels, which revealed that the lights had been operating erratically, i.e. switching on and off at intervals when room is unoccupied. A defective PIR control is the most likely cause of this random switching. These issues have been raised with building maintenance.

External Lighting

The external lighting appears to be operated on a time schedule. In spring the lights have been noticed to be on longer than necessary. If it is not possible to control the lights using a photocell the time schedule should reviewed periodically, particularly during spring when the days lengthen, to ensure the external lighting does not operate unnecessarily. The dynamic façade lighting does not function as intended. Although the strips light up, the colour has not been seen to change, which may mean the system is not operating correctly or the electrical demand threshold levels need to be changed.

7.8 Wireless Monitoring System

Progress on getting the wireless monitoring system completed and fully operational was very slow. The system's supplier had ceased trading at the end of 2011 but to their credit continued to provide support commissioning the system. Unfortunately it has not been possible to obtain further support beyond system commissioning.

Lux Sensors

During the commissioning of the monitoring system the ceiling mounted Lux sensors were found to be defective in a number of incubator units. Two of the defective units were removed and returned to the manufacturer for testing. After a manufacturing fault was confirmed the remaining defective units were replaced. On closer inspection it appeared that polarity labels had been affixed incorrectly, so the installer, by following the labels, had inadvertently connected the supply voltage to the sensor's output, which caused the sensor to fail. The replacement sensors were fitted and their operation verified by the end of May. During this process, one incubator unit was found not to have a sensor installed despite sensors being specified for every unit. This omission should have been picked up in the snagging process.

Temperature Sensors

The temperature measurements from the wireless monitoring in each room have been compared with corresponding measurements from the BMS. Several significant discrepancies were discovered, which have mainly been due to differences in mounting and location. The BMS sensor's sensing element is a bead situated at the front of a surface mounted box, while the wireless monitoring sensor is contained in a unit that clips to a surface mounted connection plate. This makes the sensor more sensitive to the temperature of the wall on which it is mounted. Lower temperatures are recorded where the wireless monitoring sensors have been installed on colder walls (such as those separating incubator units from the unheated fire exit stairwells), or have cables emerging from colder void spaces (such as in the street). Additional solar powered temperature sensors were intended for installation in the café, street and auditorium. As the blinds are left shut in the auditorium and it is often unoccupied for several days the solar powered sensors were unable to provide continuous output. The communication gateway to these solar powered sensors was offline since early August 2013 due to a power supply failure.

Server Reliability

The reliability of the server logging data from the monitoring system has not been as good as it should be. There have been several occasions when the server has been rebooted resulting in data loss as the logging application was not able to start logging automatically on start-up. The software was eventually modified to correct this issue. There have also been hardware problems such as the failure of the hard disk in the original monitoring PC, which resulted in the loss of five days of monitoring data. The whole PC was replaced with a more up-to-date machine and a new remote access script was written to simplify monitoring the PC's operation. Early in summer 2013 the system went offline and a site visit was necessary to diagnose the problem; a failed power supply in the monitoring PC. This was replaced with only a few days of lost data. Since then the monitoring PC has been operating reliably however there are occasions when communications via the wireless ZigBee network has failed. It is not clear whether this was caused by external interference or whether the intermittent failure of a single wireless module caused a knock-on effect to the whole network. In general, the monitoring system is currently working reasonably well however it is not reliable enough to operate without supervision for long periods.

EAHP Heat Meter

Monitoring of the EAHP's electricity consumption and heat output has been ongoing since April 2012. Between April and September the average daily electricity consumption appeared to exceed daily heat output, resulting in an average COP of less than one. Although the unit was unlikely to achieve the optimistic seasonal efficiency of 5.4 used in the Part L compliance calculation (the manufacturer's quoted COP was 3.8) such a large discrepancy required further investigation. Checks were carried out to establish whether the calculations and measurements were correct. A similar calculation based on metered heat output and gas consumption was carried out on the boiler serving the DHW calorifiers. This gave an average daily efficiency of 71% and a fairly linear relationship between heat output and gas consumption, which suggested that at least the calculation method was reasonable. It was suspected that the heat meter was not giving accurate measurements of heat output however the flow and return temperatures measured by the heat meter matched fairly closely those reported by the BMS. This suggested that the problem was the measurement of water flow in the primary circuit. The flow readings logged were found to be erratic, showing little relationship with the design flow rate. A supplementary monitoring exercise was carried out in March/April 2013 to verify the water flow rate through the unit. Flow rates in the buffer vessel primary circuit, which passes through the heat pump, were monitored with a non-invasive ultrasonic flow meter hired from a supplier of monitoring and test equipment. The flow rate for the measured period was found to be steady, as expected for a constant volume circuit, but less than the design value (average 0.6l/s instead of 1.1l/s). The output from the heat meter installed in the pipework adjacent to the heat pump showed an average of about 0.2l/s for the same period. An inspection of the heat meter revealed that the flow measurement head had not been installed in accordance with the manufacturer's recommendation. The head has been installed at the top of the pipe, which renders it sensitive to air bubbles in the fluid flow. It was recommended that the head be reoriented 90° from the vertical, as it should have been installed originally, to see whether this improved the reliability for the flow readings however the work has not yet been carried out. Until reliable heat metering is provided it is not possible to take advantage of the EAHP's output as a 'renewable' heat source on the building's DEC.

Electricity Metering

Data from the electricity meters has been reviewed and was used to generate the analysis included in chapter 6. The main distribution board electricity meters have a pulse resolution of one pulse per kWh. Although this is acceptable for the more heavily loaded boards it not sufficiently fine to determine half-hourly load profiles for most of the lightly loaded boards. A resolution of 10 pulses per kWh would be better as when the consumption is less than 48 kWh/day a pulse resolution of 1 pulse per kWh generates less than one pulse per half hour, which makes it impossible to differentiate a half-hourly average load. The incubator unit electricity meters have a pulse resolution of 2000 pulses per kWh, which make it possible to differentiate much lower average loads. It has not been possible to calculate consumption in three of the incubator units as there are five meters that are not registering pulses. This means the aggregate reading for the incubator units is not completely accurate. The fault has proved impossible to diagnose despite testing the wiring, swapping the wireless modules and swapping the meters themselves. When the meter readings from the main distribution board serving the incubator units was compared with the aggregate readings of the individual units the resulting discrepancy was larger than could be explained by the faulty meters. On investigation it was discovered that the comms room UPS is connected to the same distribution board. This is not reflected in the circuit schedules in the O&M documentation. A dedicated electricity meter for the comms room UPS was installed in June 2013 however it has not been connected to the wireless monitoring system. Manual readings were taken monthly to establish the average consumption of the comms room UPS and connected equipment.

7.9 Conclusions

The technical evaluation revealed a range of problems. Some of these were the direct result of insufficient attention to commissioning, such as the variation in pump speeds and incorrect heat pump and AHU controls configuration. Other problems appear to be design flaws, such as issues with the interaction of the gas boiler and heat pump and the need to adjust the office ventilation system that permitted simultaneous operation of natural ventilation and heating. Equipment failures were also responsible for problems; in particular the summertime overheating that occurred due to broken vent actuators.

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.

The building is generally well constructed and aesthetically pleasing and, for the most part, provides a good working environment. There are however some problems that do compromise occupant comfort, the most serious of these being poor ventilation and overheating. There are also problems that affect the building's energy performance, such as issues with the heating system and the exhaust air heat pump. While some of these problems are potentially the result of latent defects (such as failure of the natural vent actuators), others have occurred as a result of weaknesses in the procurement process. Client requirements were unclear early on in the project. A better requirements capture process and a better understanding by all members of the project team of the consequences of design decisions would have improved the outcome. The handover process was also problematic, with incomplete commissioning and poor O&M documentation and transfer of knowledge. There have been many parties involved in dealing with ongoing problems since handover. These problems are due to a combination of factors including incorrect configuration, a lack of information on how the system should best be operated and component failures. It is also likely that system adjustments and modifications have been made without the full awareness of the consequences involved, to the extent that the building is no longer operating in line with design intent. A process of re-commissioning may be necessary first to return the building to its intended operation and then to improve its efficiency. Although the maintenance team were not involved in the pre-handover and handover process their involvement in the BPE operational issues meetings has been helpful.

Value engineering is often blamed for buildings not achieving desired levels of environmental performance. A number of value engineering savings were made during the design process but in this case none of them were expected to adversely affect building environmental performance. The alternative solutions that were proposed were intended to provide an equivalent level of performance while delivering better value for money (for example the choice of an exhaust air source heat pump as opposed to a ground source heat pump with condenser loops embedded in concrete piles).

The recommendations made below have been split into three categories. The first contains short term actions that can be implemented relatively easily by building management and maintenance staff. The medium term actions are either likely to require a greater investment of time and money or are ongoing activities. Finally, the project team feedback is intended to draw attention to areas for improvement in future projects, in terms of design, construction and project management.

8.1 Recommendations for Improvement

Short Term Recommendations

Communication to users

Some issues such as comfort and office energy use can be addressed by managing users' expectations. For example an explanation of the role of the street as a buffer space intended to reduce the building's heat loss in winter as opposed to a fully heated space would be helpful. This could be in the form of a single slide displayed on the TV monitor in the street, perhaps showing a comparison of indoor and external temperature. Incoming tenants do receive a verbal introduction to the building's environmental strategy and controls, this information is also included as part of their general information pack. The technical information in the information pack is not presented well, lacks important information but contains irrelevant details that obscure the key points. An additional concise illustrated explanation of the building's heating, ventilation and lighting controls would be helpful. Each office could be issued with a laminated 'cheat-sheet' not to be removed from the office. In particular the cheat-sheet should explain that the building's heating system is designed to the keep the building comfortable with radiators that are warm, not hot, to the touch and that TRVs should be set to just over three bars (and then left alone) to maintain a temperature of about 21°C. It should also include instructions on dimming the lights and what to expect from the natural ventilation system.

Building services systems

The risk of overheating in the incubator units increases in summer. Ensuring the reliability of the vent actuators is important, particularly in the street-facing offices that lack external opening windows. The cause of the actuator failures needs to be identified if the building management is to have confidence that the problem has been resolved. It could be due to a design or reliability problem with the actuators themselves (it is worth noting that this particular type of actuator is no longer manufactured), but it may also be due to problems with the way the actuators are installed and wired, or the way the control system drives the actuators. If occasional failures are inevitable it may be useful to maintain a stock of spare parts to ensure a quick response. The need to frequently adjust vent opening set-points suggests a problem with the vent control strategy or that tenants have an unrealistic expectation of the speed of response of the natural ventilation system to internal temperatures. It is worth checking that the BMS is not opening vents unnecessarily because of excessively low opening set-point temperatures.

The review of building services performance and control strategy should be completed. If necessary the systems should be re-commissioned to return the building to its intended operation before re-evaluating energy performance and assessing improvements such as reverting to optimum start/stop control instead of continuous heating. The reasons for excessive wintertime temperatures in some of the incubator units should be investigated. The cause could be overheating due to internal gains, or incorrectly set or defective TRVs.

A few other issues were identified: The induction loops in the auditorium and reception desk should be checked to ensure they are working correctly. It is worth checking the drainage on the roof in the vicinity of the heat pump as it may need unblocking. The electrical sub-meters should be set to normal operation rather than unnecessarily showing two decimal places (this is a simple adjustment that requires DIP switch 6 behind the meter to be moved to the off position). The water meters in the lower-ground floor plant room all have pulse outputs but none are connected to the BMS. It is believed that the problems with the auditorium AHU have been solved however its performance should be monitored closely during summer operation to verify this. Some tenants have requested the default light level in their offices be changed, the building manager should have access to a remote controller in order to do this.

Energy saving measures

A number of specific energy saving measures should be considered. These include:

- Ensuring the cooling temperature in comms rooms is set no lower than 23°C.
- Reducing the heating ambient temperature threshold from 20°C.
- Ensuring lights in the street are not left on unnecessarily. For example by checking every morning whether they should be switched off (the manual light switches could be changed to include a visual indication that they're on).
- Improving control of lights in other communal areas, such as stairwells, by retrofitting light level or PIR sensors as appropriate.
- Regularly reviewing external lighting time switch settings, alternatively consider changing the external lighting control to use an external light level sensor rather than a time switch.
- Investigating reasons for increased basement lighting consumption.
- Using timers to switch equipment such as the street TV display off out of hours.
- Checking kitchen equipment operation out-of-hours; are there any unused fridges/freezers or other equipment being left on?
- Ensuring ventilation systems such as the auditorium AHU and kitchen extract fan are not left running when not required.
- Investigating whether it is possible to switch the BMS supervisor and access control PCs off out of hours.
- Adjusting the Zip water heaters to operate on energy saving mode out of hours.

Medium Term Improvements

The robustness of the building's comms/IT infrastructure should be improved as downtime can affect business performance and have a serious impact on occupant satisfaction and perceived productivity. If better reliability can not be achieved, some form of back-up service should be available. The security system is not entirely satisfactory, consideration should be given to better management of the alarm setting/unsetting outside of office hours, such as a system that requires building users to touch-in and touch-out with their access cards. The coverage of the CCTV system should also be reviewed for possible improvement.

Further work is necessary to verify the correct operation of the office extract system and the impact of opening vents while the extract is running. This should include monitoring of occupancy and CO_2 levels to investigate the effectiveness of the ventilation system. As no commissioning records are available for the extract ventilation system the extract air flow rates in each office should be checked and the system recommissioned if necessary. Opening vents while the heating system is running could result in inefficient operating, particularly if the TRV and vent opening set-points overlap. Similarly, if the system is configured to allow night ventilation it may be necessary to adjust the operating of the heating to prevent it running when the vents are open. Ideally this should be handled by the BMS but it may need manual intervention.

The domestic hot water system appears to be oversized, based on the metered hot water demand. It may be possible to reduce storage losses by decommissioning one of the two calorifiers.

The building's energy consumption was monitored in detail as part of the BPE and related research however it is important that provision is made to continue the monitoring activity beyond the end of the BPE project. Establishing energy targets would help in this respect. Design estimates of operational energy consumption would have been helpful to provide a baseline energy target. Regular meter readings should continue. The readings could be taken as part of the regular maintenance visits and entered in a simple tracking spreadsheet. These could be reconciled with utility bills obtained from University of Northampton.

8.2 Project Team Feedback

Design Targets

The lack of operational energy consumption targets means there is no clear baseline other than published benchmarks for evaluating the building's energy performance.

Architectural Issues

The layout of the building is generally good. The location of the bike racks at the opposite end of the building from the café and main entrance is inconvenient however, as is access to the smoking area via a fire-door. The building's usability would benefit from better integration of the security and access control. The allocation of plant space is uneven, with a tightly packed ground-floor plant room accessible through the kitchen and a spacious but underused lower ground-floor plant room. The location of condenser units in the enclosed second floor plant-room is not ideal.

The street functions effectively as a buffer space in winter, although it is perceived as being cold by building users. In summer however, the provision of high level ventilation is insufficient to prevent overheating. The thermal modelling carried out to demonstrate Part L compliance indicated a high risk of overheating however no remedial action was taken, due to the space being considered unoccupied. The street is intended to be used as an informal meeting area and exhibition space, as well as a circulation area, so summertime overheating is an issue that should have been considered in more detail.

The problem with noise breakout is probably due to the design of the ventilation stacks. Future designs using ventilation stacks within timber frame construction should ensure greater acoustic isolation between individual stacks, perhaps by lining them with sound-absorbing material or installing low resistance ducting within the stacks.

Commissioning and handover

The commissioning and documentation of the building services including the BMS was found to be inadequate. This may be due in part to the limited time allowed for commissioning. Future projects should be managed in such a way that sufficient time is allocated. The building was scheduled to be operational by the end of 2010 however due to project delays it was completed approximately three months late in March 2011. The snagging process concentrated on architectural issues such as surface finishes, with less attention to the services systems.

One of the consequences of rushed handover was incomplete and inaccurate O&M documentation. The building log book, contained in the O&M manual, includes design estimates and good practice figures for overall annual energy performance. The design estimates were given as 16 $kgCO_2/m^2$ and 48 $kgCO_2/m^2$ respectively for gas and electricity. The total figure of 64.5 $kgCO_2/m^2$ is more than four times larger than the design target of 15 $kgCO_2/m^2$. Furthermore, the good practice figures of 18.6 $kgCO_2/m^2$ and 66.6 $kgCO_2/m^2$ respectively for gas and electricity appear to be the ECON 19 benchmarks for standard air-conditioned offices using VAV air-conditioning and air-cooled water chillers. Clearly neither these sets of figures relate to the actual building. In addition, the treated floor area is given as 6913m^2, which is much larger than the actual building. Also included in the building log book is an energy end-use comparison however no benchmarks are included and the design estimates, which evidently relate to a different building, are meaningless.

Sub-Metering

The basic provision of energy sub-metering is limited and doesn't appear to fully satisfy the requirements of Part L. In particular, assigning annual energy consumption to the various end-use categories is not straightforward due to the presence of multiple end-use categories on each sub-meter. The base-build did not provide monitoring of the EAHP's performance and automatic meter reading is limited to the main electricity and gas meter readings for the current and previous period. The additional wireless monitoring system does include logging of sub-meter readings however the output is not readily available to the building management. The EAHP performance is still not monitored due to the faulty heat meter installation. The inadequate sub-metering may be the result of limited understanding or enforcement of Part L compliance however appropriate sub-metering is essential for evaluating building performance according to energy end-use. Until the requirement for a level of sub-metering capable of supporting detailed performance evaluation is taken seriously it will be necessary for building clients and designers to ensure requirements for metering are clearly specified.

8.3 Improvements that have been made

The project has increased the understanding of the building among its users, operators and maintenance staff. Occupant behaviour is changing slowly as expectations become more in line with the building's environmental strategies. The forensic investigation carried out would not have happened without the evaluation project. This has identified numerous issues with the building services and controls. The operation of the boiler and heat pump has been improved, reducing boiler cycling and increasing the contribution the EAHP can make to the building's heat demand. The EAHP control strategy has been simplified, by replacing the automatic overspill damper with a spring loaded relief damper as recommended by the EAHP manufacturer. This should improve reliability by removing the damper actuator interlock that was responsible for previous problems with the unit's operation. Problems with the auditorium AHU's control strategy have been rectified and its mechanical reliability has been improved. The operation of the natural ventilation rain interlock has been improved, preventing dew and light showers from unnecessarily disabling the ventilation openings. The documentation of maintenance work and adjustments has also been improved. Copies of the contractor's logs are now being kept in the building manager's office to provide an audit trail of changes and adjustments to the building's systems. It is now also possible to access the electronic logs completed by controls maintenance staff. Energy monitoring has identified opportunities for reducing wasteful operation of plant, equipment and lighting. The project has also increased the understanding of how best to operate the building, and user expectations are becoming more aligned to the building's environmental strategy. Monitoring of the building's performance will be continued beyond the BPE programme by researchers at Loughborough University in conjunction with building management staff to verify the effectiveness of the improvements and ensure they are maintained.

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 Lessons Learnt

Client Identity

The absence of a clearly identified client at the very early stages of the project had a far-reaching impact that led to the development of a building without the involvement of an end-user. The close involvement of a clearly identified client in the development of the competition brief and judging process could have resulted in a better specification of user requirements. Further into the project, when decisions needed to be made about building fit-out, a client with a clear understanding of end-user requirements would have been a more effective decision maker. Had it been known that the University of Northampton would be the end-user and facilities manager, their earlier involvement would have pre-empted compatibility issues with the BMS and IT/comms systems. It would have also improved the building's integration into the University's estate management portfolio.

Performance Targets

A performance target was embedded in the competition brief however the ambiguity of the target reduced its effectiveness. It appears to have been interpreted as an operational energy target, which included unregulated electricity consumption such as office equipment. The environmental consultant's energy statement showed that the proposed design met the target with an estimated energy consumption of half the ECON 19 good practice benchmark for naturally ventilated offices. During the design stage, compliance energy modelling showed that the design also met the target, however this was now interpreted as a design target rather than an operational energy target. As such, unregulated electricity consumption was excluded from the calculation. Evidently the earlier estimates were highly optimistic as even after excluding unregulated loads the building's actual energy consumption was over twice the performance target.

Clear performance targets and an understanding of the reasons for the differences between design and in-use performance are therefore essential. There should be no ambiguity whether targets refer to design estimates, operational estimates or measured operational performance. The energy end-uses included in the target should be clearly specified. There is also a need for greater realism in consultants' energy estimates, particularly when highly ambitious figures are presented. Increasing the use of benchmarking, guidance such as CIBSE TM54[4], and feedback from projects such as this will be helpful in developing energy estimates that

[4] CIBSE TM54 2013 *Evaluating operational energy performance of buildings at the design stage*

also account for operational energy consumption. Ultimately, project teams need to consider more than just Part L compliance and BREEAM credits to achieve satisfactory operational energy performance.

Team Effort

The level of cooperation and communication between project team members has a great influence on project success. A feature of this project was the size of the project team and the number of different project managers involved over the course of the project. A smaller core team and better continuity of project management with a clear vision for the building would have made the design process smoother. Establishing earlier communication and more frequent discussion with a wider range of project stakeholders such as building control, the local highways authority and utilities companies could have reduced unexpected delays during the project. Similarly, an earlier understanding of the implications of the chosen funding route on project timescale could also have reduced delays.

The use of a design and build procurement route introduced specific challenges to maintaining design consistency and knowledge transfer. Developing the design, particularly the technical design, in more detail before the tender stage would have reduced the uncertainty about technical performance. The implications of design decisions (such as the enclosure of the café) should be clarified earlier and understood by all members of the design and client teams. Novation of the environmental design consultant would provide one way to retain design input, if this is not possible it would be useful to find some other way to provide support and advice to the design and build contractor and their subcontractors throughout the project. The Soft Landings Framework[5], which is intended to run alongside the design and construction process, addresses this and a number of other issues identified during the evaluation project.

Design Robustness

The robustness of the design performance modelling approach is as important as the robustness of the delivered building and its services. The validity of the modelling approach is an important consideration due to the impact of the modelled results on overall performance ratings. Valid results, based on sound engineering principles, empirical data and appropriate assumptions, are critical if they are used to inform design decisions. Low energy and passive design requires just as much if not more work to get right than active mechanical systems. A system that appears to work under design conditions may fail if design assumptions are not matched by reality. Ensuring system robustness may require additional evaluation that considers the impact of deviation from design assumptions on, for example, overheating. This should form part of a necessary 'due diligence process' when innovative designs are proposed, particularly when consultants' designs are to be handed on to design and build contractors and M&E sub-contractors. Robustness can be eroded by unnecessary complexity, for example BMS control strategies should not present options that are not fully understood by building management.

Handover & Training

Despite the natural tendency for delays to reduce the time available at the end of the projects, tasks such as commissioning, handover, snagging and training are crucial in achieving satisfactory operational performance. Failing to reserve sufficient time for these tasks can contribute to poor performance and a lack

5 BSRIA BG4/2009 *Soft Landings Framework*

of understanding of how best to operate the building. Commissioning should be completed and correctly documented, along with the O&M documentation, which should be checked for completeness and accuracy. The design team should be involved in post handover training as they are likely to be in the best position to explain the concept design and operation to the end-user, building management and maintenance team. Tenants should be provided with a clear guidance about the building's environmental strategy and how to work with the building's control systems. In naturally ventilated buildings, expectations of rapid response and stable conditions need to be tempered by an understanding of the limitations of most natural ventilation systems. A building designed to achieve high environmental credentials may only deliver them if occupants have a clear understanding of the concepts involved and the potential benefits attained and are given the opportunity and support to adapt their usage habits and expectations.

Performance Monitoring

Without monitoring it is not possible to understand whether a building's performance is meeting expectations. Clients should emphasise the importance of energy metering, at least to the level required by Part L. Tighter regulatory control may ultimately be necessary, with more scrutiny given to provision of acceptable sub metering and documentation of installed loads in building log books, described in CIBSE TM39[6] and TM31[7]. Consideration should be given to the collection, analysis and presentation of the metered data; merely installing a set of sub-meters in a basement plantroom is not sufficient. Performance monitoring is also important for the longer-term process of seasonal commissioning and fine tuning of building performance.

9.2 Key Risk Factors

This section lists the key risk factors considered to affect the performance of the study building.

A) Design and Engineering

- Clarity of energy performance targets
- End-user involvement in developing brief
- Accuracy and robustness of modelling
- Use of realistic design assumptions

B) Management and Process

- Clarity and consistency of core team (including client and project management)
- Retention of consultant to have a greater involvement during later project stages
- Adoption of the Soft Landings Framework

6 CIBSE TM39 2009 *Building energy metering*

7 CIBSE TM31 2006 *Building log books*

C) External Constraints

- Managing constraints on accessing sources of funding
- Early identification of site issues

D) Operation and Maintenance

- Avoiding rushed handover and commissioning
- Involvement of design team in sagging and checking of O&M documents
- Provision of training to relevant building management and maintenance staff
- Establishment of energy monitoring and targeting

10 Appendices

Technology Strategy Board guidance on section requirements:	The appendices are likely to include the following documents as a minimum: • Energy consumption data and analysis (including demand profiles) • Monitoring data e.g. temperatures, CO2 levels, humidity etc. (probably in graph form) • TM22 Design Assessment output summaries • A DEC – where available • Air conditioning inspection report – where available • TM22 In-Use Assessment output summaries • BUS Occupant survey – topline summary results • Additional photographs, drawings, and relevant schematics • Background relevant papers

10.1 TM22 output summaries

The following table shows the figures presented in Fig 22 (electricity demand by end use)

	Electricity demand (kWh/m²/year)			
System	**Design electricity (kWh/m²/year)**	**In-use electricity (kWh/m²/year)**	**Typical benchmark (kWh/m²/year)**	**Good practice benchmark (kWh/m²/year)**
Space Heating	2.9	7.4		
Domestic hot water	0.0	0.0		
Space cooling	0.2	3.6	0.0	0.0
Air movement	2.1	7.2	0.0	0.0
Pumps and Controls	0.9	4.1	5.7	1.9
Lighting	15.9	21.7	21.9	13.3
Household/office appliances	0.0	19.3	17.1	11.4
ICT Equipment/computer room	0.0	2.4	2.4	2.4
Indoor transportation	0.0	0.3		
Cooking	0.0	7.9	2.9	1.9
Cooling Storage	0.0	0.0		
Other electricity	0.0	5.6	3.8	2.9
Total	**21.9**	**79.6**	**53.7**	**33.7**
Metered building energy use	79.2	79.2		
Variance TM22 versus metered total	-57.2	0.5		
Variance TM22 versus metered total	-72%	1%		

TM22 Detailed assessment - Electricity demand by end-use

The following table provides further information on the loads and operating hours of each end-use. The two most significant electrical uses are internal lighting and small power, which are comparable to the type 1 typical office benchmark figures (23kWh/m2.yr and 18 kWh/m2.yr respectively).

System	In-use electricity (kWh/m²/year)	In-Use Full load W/m²	System hours/year	Utilisation
Space Heating	7.4	2.8	2,598	29.7%
Hot water	0.0	0.0	0	0.0%
Refrigeration	3.6	2.5	1,480	16.9%
Fans	7.2	1.7	4,374	49.9%
Pumps	3.4	0.6	5,869	67.0%
Controls	0.7	0.1	8,760	100.0%
Lighting (Internal)	21.7	9.5	2,293	26.2%
Lighting (External)	5.6	1.2	4,615	52.7%
Small Power	19.3	2.5	7,701	87.9%
ICT Equipment	2.4	0.3	8,760	100.0%
Vertical Transport	0.3	1.0	313	3.6%
Catering - Central	7.9	19.1	415	4.7%
Total	**79.6**	**41.1**		

TM22 Sub-system analysis - loads and utilisation