Comparative building performance evaluation of a ‘sustainable’ community centre and a public library building

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Abstract

This paper uses a forensic building performance evaluation approach to undertake a comparative evaluation of the in-use energy and environmental performance data (collected over two years) of two civic buildings located in Southeast England – a small community centre (<1000m^2) and a medium-sized public library building (~4500m^2), which are designed to high sustainability standards (EPC A rating) and low heating demand met by on-site low/zero carbon technologies. Although both buildings achieved measured air-permeability rates of ~5m3/hr.m2, they encountered similar issues related to poor documentation of ‘as-built’ drawings, poor handover and guidance, problems with integrating and maintaining new technologies (heat pumps, biomass boilers and solar thermal), lack of calibration of sub-meters, and issues with automatic window controls. However the actual carbon emissions of the community centre are double the predicted, while they are almost five times in the case of library building. This is because the community centre management team overcame some of the issues through their continuous engagement and interest in the building’s performance, whereas the management team of the Library building failed to engage with energy management, resulting in disuse of the biomass boiler and solar thermal system.

Practical application

Comparative building performance evaluation (BPE) systematically reveals the similarities and differences in the actual energy and environmental performance of two ‘sustainable’ civic buildings.

Careful management of heating and electricity loads, good occupant control over the indoor environment and high performance of low-carbon technologies in the Community Centre result in the building performing better than good practice benchmark.

Regular changes in FM staff result in inadequate energy management and control over heating, ventilation and lighting, that undermines occupant comfort and leads to excessive energy use in the library building.

For civic buildings to perform as designed, it is vital that metering, sub-metering and controls are set up, commissioned and used properly by the FM team. Design teams should ensure that easy-to-understand user guides are made available before handover for FM and occupants.

Keywords

Building performance evaluation, Energy efficiency, Performance Gap, Public/civic buildings

Introduction

The UK Government has set a legally binding commitment to reduce UK greenhouse gas emissions by 80% by 2050 in relation to the 1990 levels [1]. Given that around 45% of emissions come from buildings, out of which 18% are from public and commercial sector [2], there is no way to meet the targets without reducing energy use in buildings. This is why Building Regulations in the UK have become increasingly stringent, demanding higher standards of energy performance. Despite the improvements in building fabric and the deployment of innovative services and systems, a significant gap between predicted and actual energy consumption in non-domestic buildings is observed [3], leading to higher than expected energy use [4-6].

Studies show that the reasons behind this gap are related to issues with building energy modelling at the design stage, changes to the specification prior to construction, detailing and construction omissions, commissioning and installation as well as unanticipated user behaviour after handover [7-10]. An understanding of why the gap occurs and how it can be minimised is a precursor to making real improvements in building performance [11]. A recent study has shown that the performance gap in buildings increases as a result of the complexity of the systems installed and the lack of effective management [12]. Bordass and Leaman argue that buildings and regulatory requirements seem to become ever more complicated as a result of a poorly closed feedback loop from operational insights into the practices of briefing, design and construction, and regulation [13]. Furthermore, independent evaluation of how much energy is actually used when buildings are in operation is very rare and there is a perceived lack of information and data on the actual energy performance of the UK building stock, which is likely to lead to a widening of the gap between theory and practice and a failure to achieve strategic goals [14].

Initiatives such as PROBE (Post-occupancy Review of Buildings and their Engineering) [5] investigated the performance of 23 buildings (1995-2002) previously featured as 'exemplar designs' in the Building Services Journal (BSJ) [5, 6] and revealed that actual energy consumption in buildings is usually twice as much as predicted. Since then, feedback on the performance of buildings in-use has also been provided by the Usable Buildings Trust and Carbon Trust case studies through their Low Carbon Buildings Accelerator [15, 16]. The 'Closing the Gap' report highlights the underlying reasons behind the performance gap, underlining that as-designed predictions that achieve regulatory compliance do not account for all energy uses, with actual regulated consumption being up to five times higher than the prediction across the five case study building illustrated [16]. In an attempt to promote clarity and understanding on building energy use, the CarbonBuzz platform, launched in 2008 by the Royal Institute of British Architects (RIBA) and the Chartered Institution of Building Services Engineers (CIBSE), allows practices to share and publish data on building energy use online [17]. The platform enables users to compare actual building energy use with design predictions, benchmarks and other building of similar typology, illustrating the extent of the performance gap. More recently (from 2010 to 2014) the UK Government's Technology Strategy Board (now Innovate UK) ran an £8 million national research programme on Building Performance Evaluation (BPE), to address the performance gap challenge in new domestic and non-domestic buildings. In total, the programme has completed 101 studies, 48 of which cover non-domestic buildings, providing insights on the performance of design strategies, building fabric, actual energy use, construction methods, occupancy patterns, handover and operational practices [7].

Methodology

The study adopts a BPE approach to comparatively evaluate the performance of two sustainable civic buildings located in Southeast England. BPE is conducted through a systematic collection and analysis of qualitative and quantitative information related to energy performance, environmental conditions and occupant feedback. Evolving from Post Occupancy Evaluation, a diagnostic evaluation of actual building performance typically taking place after construction and occupation, the term BPE was first used by Preiser and Schramm [18] to recognise the importance of feedback at every lifecycle stage of the building. BPE involves feedback and evaluation reviews at every phase of the building delivery from strategic planning to occupancy, adaptive reuse and recycling [19]. Post-occupancy evaluation of buildings provides useful feedback regarding a building’s performance in use [20].

The study has been sponsored by the UK Government’s Technology Strategy Board BPE programme [21], under the category of non-domestic buildings that are in operation for more than three years post completion. The programme mandates a prescribed protocol for evaluation and reporting to maintain consistency and comparability in benchmarking and analysis. Besides an assessment of the building fabric and monitoring of energy use and environmental conditions (indoor and outdoor) in the two case study buildings, BPE study elements also include the review of design intentions and documentation, critical review of installation and commissioning of building services and technologies, understanding of the aftercare, maintenance and management arrangements, review of the operation and usability of systems and controls, evaluation of the handover procedures and an occupant satisfaction survey.

Data were collected from January to December 2013 every five minutes from wireless sensors that monitor temperature, relative humidity and CO_2 and is transmitted wirelessly from a RT:Wi5 data-hub and streamed remotely over Global System for Mobile communications mobile phone networks.

Overview of case study buildings

Design and layout

The Community Centre is a one-storey cavity wall masonry building with exposed interior timber structural elements. The internal floor area of the community centre is 563 m^2 which includes a multi-purpose hall that can seat 200 people, two meeting/activity rooms, an entrance hall and a kitchen (Figure 1). Its construction was completed in September 2009 and it was fully occupied in May 2010.

Figure 1 (Left) External view of the community centre. (Right) Main Hall of the community centre.

The Library building is bigger with more complex functionality, designed to provide a range of county council services including a central library and offices and accommodation for administrative and social services. The building is four-storeyed (stepping down to two storeys at the rear) and arranged around a central atrium with cantilevered floors that provide some shading to lower floors. The gross internal floor area is 4,468m^2 (2,678m^2 library , 502m^2

register services, and 378m^2 public social services and 910m^2 administration). While the library covers the first three floors of the four-storey volume, the upper floor accommodates council social services arranged in an open plan office space (Figure 2). The two-level volume includes the social service cellular offices and register services offices and ceremony rooms. The building opened its doors in December 2008.

Figure 2 (Left) External view of the Library. (Right) Main atrium of the Library.

Occupancy schedules

The Community Centre is occupied from Monday to Sunday from 9am to 10pm. There is one member of staff managing the building during occupancy hours while approximately 50-80 people visit the building on a daily basis. Occupancy varies depending on the activities taking place in the Main Hall and meeting rooms. The Centre is available for children’s activity classes, indoor sport activities, choir, painting, cooking and computer classes, and church activities.

The Library building is occupied from Monday to Friday 8am – 5pm. The library areas are also open on Saturdays from 9am until 7pm. Occupancy varies significantly during the day. It is estimated that about 1,000 people per day visit the Library during weekdays while approximately 75 – 100 people work in the offices.

Sustainability features

Both buildings have achieved an Energy Performance Certificate rating of ‘A’ and were designed to have a low heat demand. Table 1 summarises the physical characteristics of the buildings, while Table 2 lists the energy systems and services installed.

Table 1 Physical characteristics of the case study buildings

Building type	**Community Centre**	**Public Library and Offices**
Area (m^2)	563	4,468
Main construction elements U-values (W/m^2K)	Walls: Cavity wall, Masonry, Design U-value 0.23 Roof: Timber framed Pitched Roof, Design U-value 0.2 Windows: Double glazing filled with Argon, Design U-value 1.2 Floor: Tarmac top floor with sand/ cement screed, Design U-value 0.2	Walls: Insulated render, Design U-value 0.23 Stone cladding, Design U-value 0.25 Engineering brick, Design U-value 0.25W Glazing: Curtain wall, Design U-value 1.6 Roof: Inverted roof, Design U-value 0.16
Air tightness ($m^3/(h.m^2)$ @ 50 Pascal)	5.77 (Test 22.09.2009)	4.88 (Test 24.10.2008)
Sustainability rating	EPC rating A (2010)	Display Energy Certificate (DEC) Grade D (2010)
Date of completion	September 2009	December 2008

Table 2 Energy systems and services

	Community Centre	**Public Library and Offices**
Space heating system	Ground Source Heat Pumps (x2) feeding underfloor heating	149 kW Biomass boiler with 175kW gas back up boiler, underfloor heating (four storey section) and radiators (two storey section)
Space cooling	No cooling system	Peak looping system only. A chilled water cooling system serves a series of air handling units and fan coil units located throughout the building, together with providing primary cooling for the underfloor heating/cooling system.
Hot water system	Ground Source Heat Pump with electric element as back-up	Solar thermal panels and central gas fired calorifiers.
Renewables	60 Photovoltaic panels providing 10.2 kWp with an estimated annual yield of 8200 kWh	Solar thermal panels
Ventilation strategy	Natural ventilation; manually openable windows with trickle vents; and roof lights with electrically operated controls. Mechanical extract fans in toilets and kitchen	Combination of Natural and Mechanical Ventilation with heat recovery in some spaces. Air supplied through Air Handling Units and underfloor voids, extracted at high level.
Lighting systems	Fluorescent tube and compact fluorescent lamps, manual control and PIR (in toilets)	Photometric sensors, dimmable fluorescent lights, PIR and manual control.

The Community Centre is double glazed and has high levels of insulation throughout. The design incorporates a significant degree of natural light into all rooms except the entrance hall. Ground Source Heat Pumps (GSHPs) provide all the space and hot water heating needed for the Centre. Also, an array of 60 Photovoltaic panels (PVs) is installed on the roof of the Centre. The PVs are capable of providing 10.2kWp, with an estimated annual yield of 8200 kWh. Any excess power generated is fed back to the grid. The building is naturally ventilated with mechanical extract for the toilets and kitchen. The lighting consists of a combination of fluorescent tube and compact fluorescent lamps with a mix of manual switches and PIR controls (only in toilets).The external finish takes its cues from the surrounding properties which are a mix of brick and flint walls. The building fabric has been designed to U-values of < 0.2 W/m^{2}K for the roof and floor, 0.23 W/m^{2}K for the walls and 1.96 W/m^{2}K for the windows.

The Library building was designed to have high thermal mass, controlled daylighting, a flexible mixed mode ventilation system and cross ventilation. Heating in the building was designed to be provided by a primary biomass boiler with a condensing gas boiler as backup. Heat distribution through the four storey section takes place via underfloor pipework, with a radiator system in the two-storey section. A chilled water cooling system consisting of an air cooled chiller located on the roof, serves a series of air handling units and fan coil units located throughout the building and also provides primary cooling through the underfloor pipework that runs through the four storey section. The rest of the building is naturally ventilated by automatic window controls. The majority of lighting was designed to operate on photometric control, along with occupancy sensors in the library. Despite the high sustainability standards, the building received a Grade D in the DEC.

Despite their different sizes and energy systems, the two buildings have common characteristics. Both are civic buildings that play an important role in their communities and accommodate a high number of transient users on a daily basis. Both buildings also feature a range of low/zero carbon technologies in order to reduce their carbon footprint. A comparison between them can provide useful insights into the actual performance of civic buildings in the UK.

Technical Performance

Fabric performance

The fabric performance of both buildings was evaluated through air-permeability tests and thermographic surveys. Although measured air-permeability rates are close to best-practice ($5m^3/hr.m^2$) in both buildings, thermal imaging showed a number of thermal anomalies resulting from design detailing and installation during construction (Figures 3 and 4). In the Community Centre building, air leakage through the roof pitch and cold spots were identified on the ceilings due to poor installation of the structurally insulated ceiling panels. Similarly, in the Library, air leakage was revealed around windows and cold bridges at the wall/ceiling junction were found in a number of rooms. These findings suggest that the building industry still needs to cover some ground in order to achieve in practice the high standards specified at the design stage.

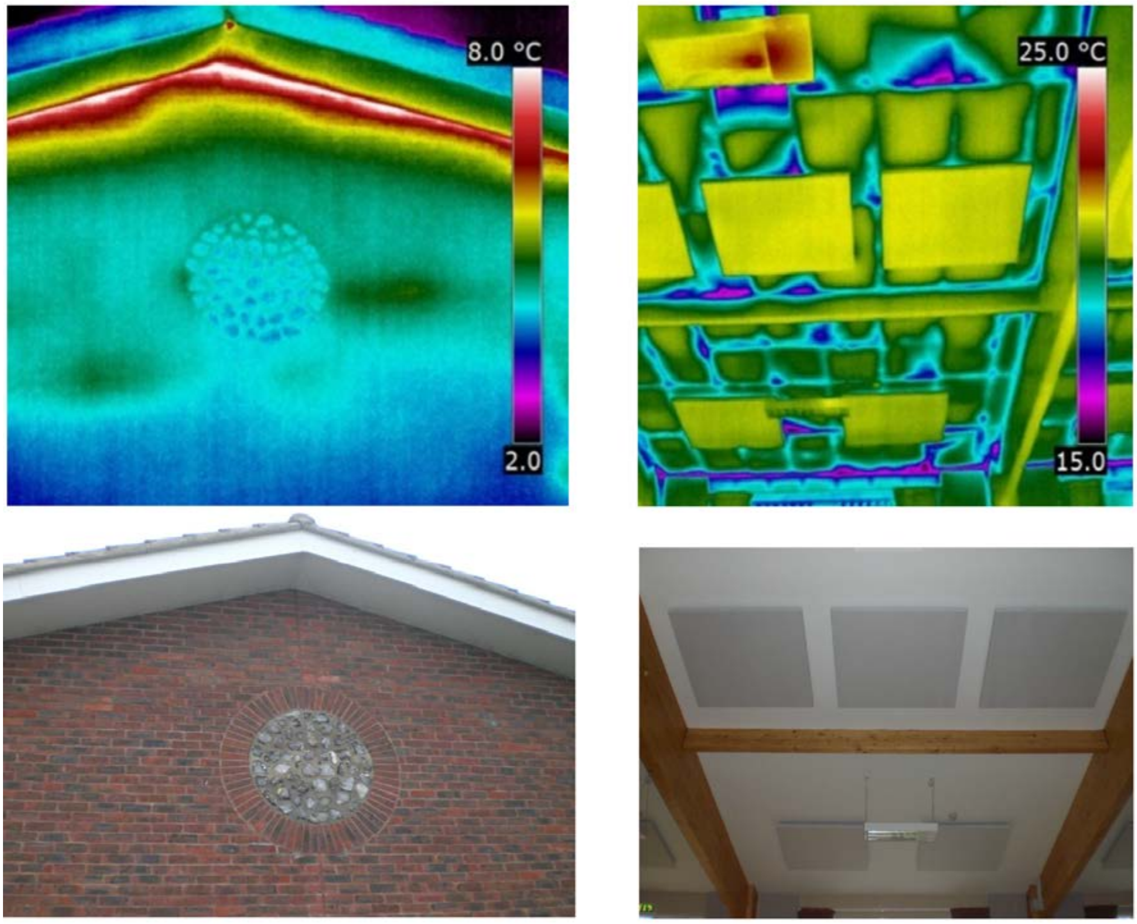

Figure 3 Heat loss through the roof and ceiling in the Community Centre.

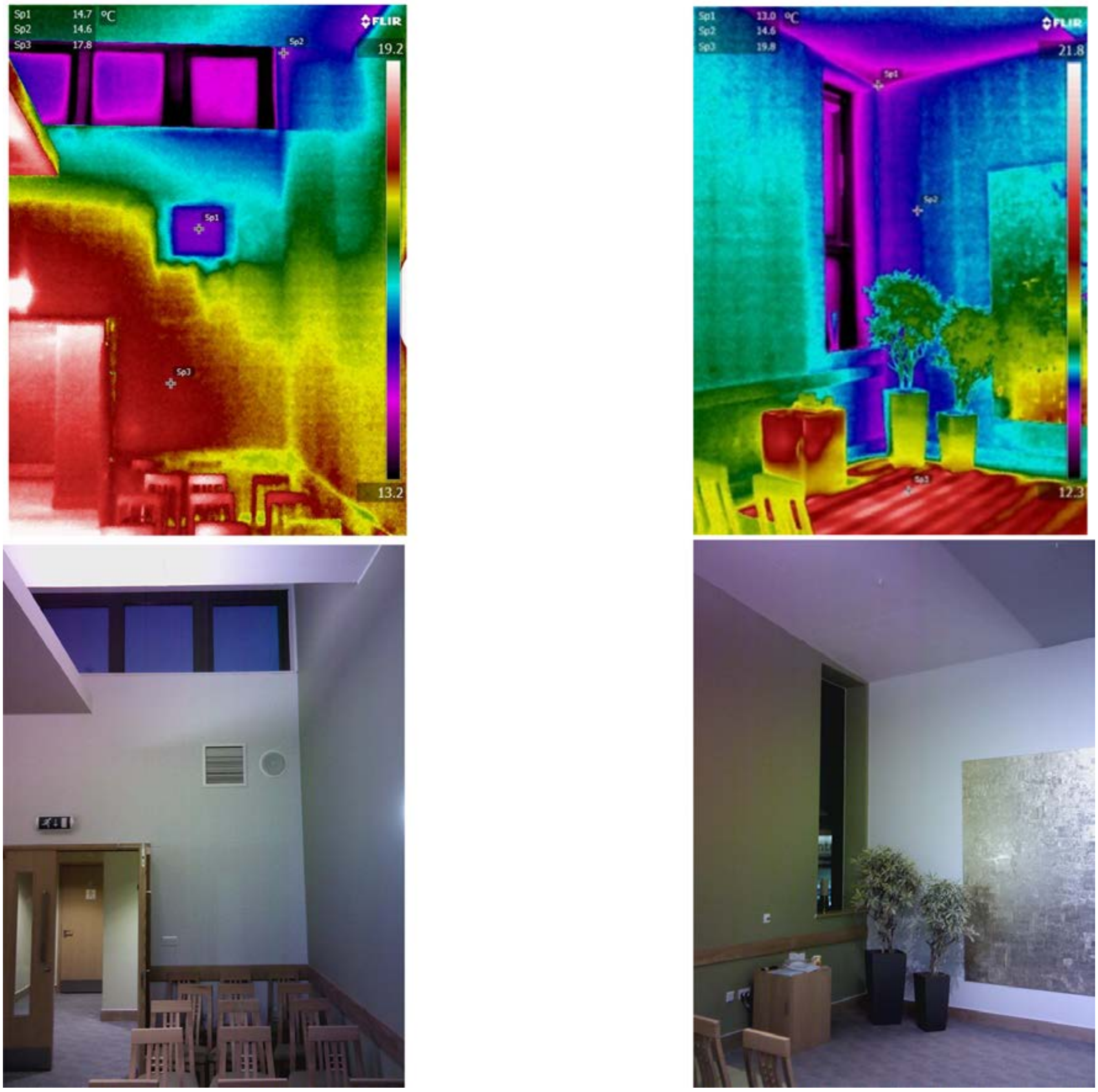

Figure 4 Air leakage around windows and thermal bridges in the Library

Actual energy performance

The energy use and generation of the buildings was monitored for a period of one year and benchmarked using the latest version of the CIBSE TM22 methodology. The TM22 assessment

[22] produces a rapid initial estimate of the breakdown of energy use and associated CO_2 emissions, based on metered energy use and sub-metering data.

Comparison of the actual energy use of the buildings with a design estimate[1] is shown in Figure 5. In the case of the Community Centre, there is no discrepancy between the design prediction and the total actual metered energy use. It can be observed that the actual energy use for heating is slightly higher than the design estimate, but this is counterbalanced by the fact that actual energy use for small power is lower than the predicted. In the case of the Library however, actual energy use appears to be higher than the design estimate by a factor of 1.8. Figure 5 shows that the energy use for lighting, cooling, catering and servers is much higher than the design prediction.

The annual energy use per m^2 area differs greatly between the two buildings despite the fact that both had received an EPC A rating. Figure 6 shows the energy use of the buildings compared to current energy benchmarks. Annual energy use in the Community Centre is 50 % lower than the CIBSE Guide F Good practice benchmark and 70% lower than the TM46 benchmark [23]. In the Library, annual energy use is similar to the Good practice benchmark; however, electricity use exceeds the TM46 benchmark by 23% and the Good practice benchmark by 70%. The electricity used in the Library for cooling, and mechanical equipment

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[1] The design prediction was estimated using BRUKL calculations (that follow Part L Regulations) and CIBSE TM54. BRUKL calculations do not account for all end-uses and include only heating, hot water, cooling, fans and pumps and fixed internal lighting. Other end-uses such as small power, server looms, lifts, catering and external lighting were added following the guidance provided in TM54, in order to compare actual energy use with a more accurate design estimate.

(fans and pumps) along with the electricity use for lighting and appliances is high compared to that used in the Community Centre. The ‘unregulated’ loads for small power, catering and computer equipment rooms and associated air conditioning (not included in the Part L calculations) make up 16% of the total electricity use of the Community Centre and 36% of the total electricity use of the Library. The Library Hub room that includes a large server and its AC system consumes 9% of the total electricity use, lighting consumes 31% of the total and appliances consume 18%.

In the case of the Community Centre, the heat pump is highly efficient and the PV panels are performing well, with PV generated electricity making up 20% of the electricity used in the building. On the other hand, the thermal solar panels and biomass boiler in the Library are not working properly due to maintenance issues, thus negatively affecting the energy use of the building that has to rely on gas and grid electricity.

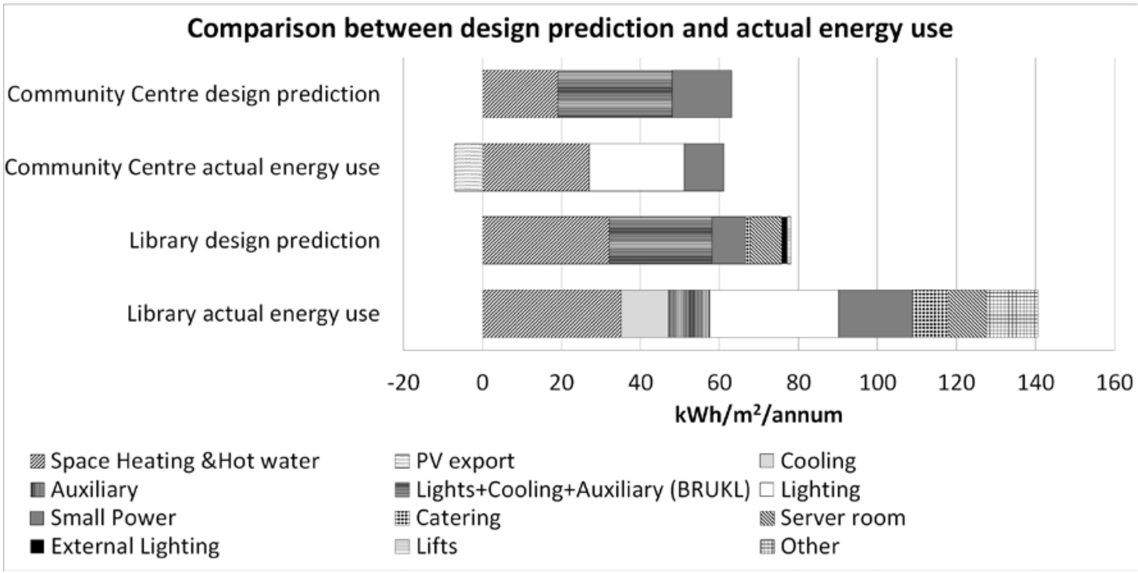

Figure 5 Comparison between design prediction and actual energy use. The design prediction was calculated using BRUKL estimate and extending it using TM54.

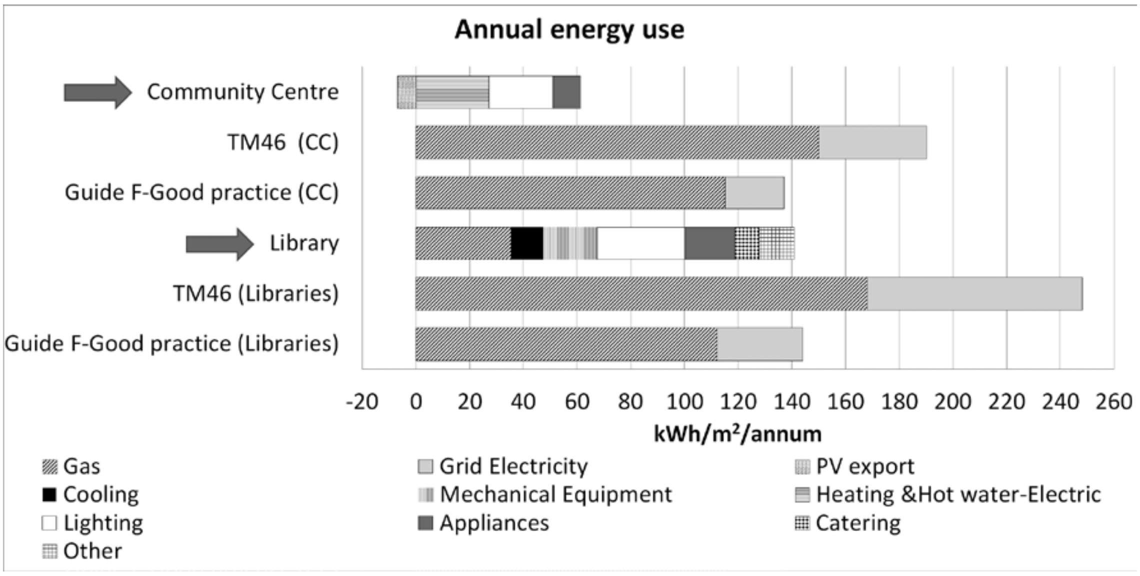

Figure 6 Actual annual energy use and comparison with CIBSE TM46 and CIBSE Guide F Good practice benchmarks.

Comparison with other buildings of similar use is shown in Figure 7. The Community Centre uses far less energy than most other Centres, which were studied between 2006-2007 (all except Mayville/Mildmay Community Centre) and were found to have poor fabric performance in terms of insulation and air leakage. The Library building is compared to two other library buildings [24] and uses more energy than Visby library (Sweden) but nonetheless performs better than the Gloucester Building that suffers from low air-tightness and poor management.

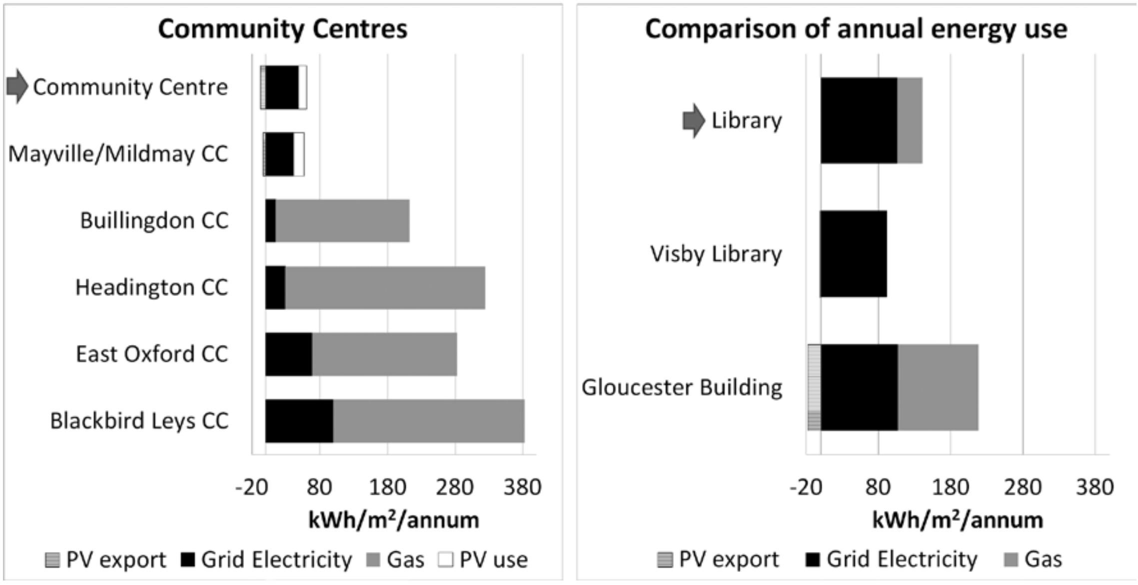

Figure 7 Comparison with other buildings

In order to understand the parameters affecting the performance of the buildings, the environmental conditions were monitored, the commissioning and maintenance arrangements were reviewed and interviews with the occupants and management were carried out.

Occupant feedback and environmental performance

The Building Use Study (BUS)[2] methodology [25] was used to evaluate user satisfaction in each of the study buildings to indicate whether a building is providing a comfortable and productive

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[2] The BUS analysis method is a quick and thorough way of obtaining feedback data on building performance through a self-completion occupant questionnaire; the results of which can be compared against a national non-domestic benchmark database. The questionnaire prompts the respondents to comment on the building's design and image, occupant control, comfort and daily use of the building features. The questionnaire variables are compared with their respective scales midpoint and BUS benchmarks to provide a slider showing the mean score across the responses using green/amber/red lights depending on where it sits within the upper and lower limits of the scale midpoint and benchmark

internal environment and to also flag up critical design issues. In the community centre all respondents are visitors; however, in the library all respondents are staff, i.e. no visitors were assessed using the BUS questionnaire in the library.

Figure 8 summarizes the key findings of the BUS surveys across the two buildings. Overall users feel that the buildings meet their respective needs. They are satisfied with the design, appearance and image of the buildings. Interestingly, the users of the Community Centre are more satisfied with the environmental conditions of their building and control over their surroundings, than the users of the Library. It is however noted that the community centre respondents are visitors, albeit frequent visitors and library respondents are staff, experiencing the space with higher frequency. With that said, as previous research has shown [26], users are generally more tolerant of ‘green buildings’ for all-embracing summary variables such as ‘comfort overall’ or ‘lighting overall’, which should be taken into account when reading the occupant satisfaction survey results.

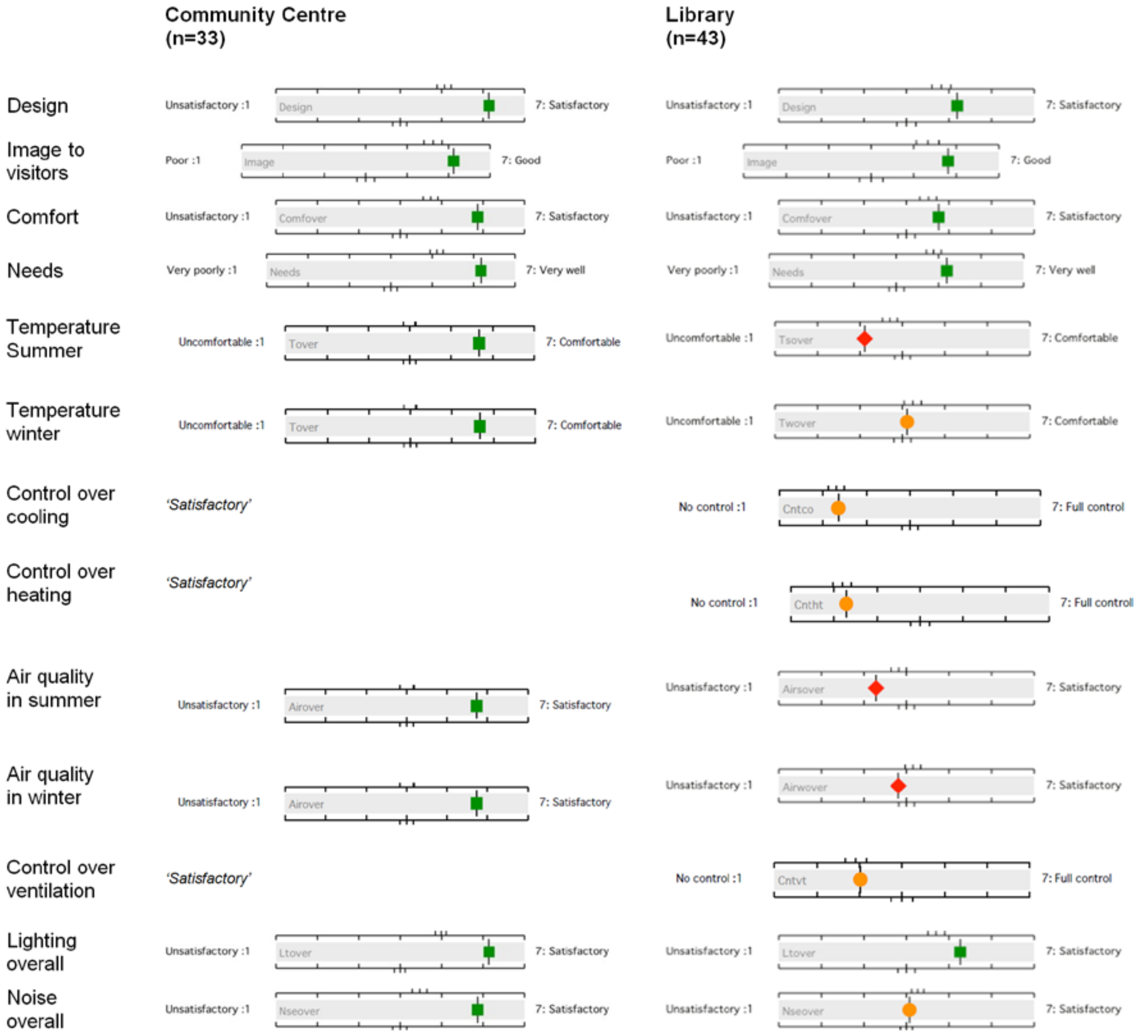

Figure 8 Issues highlighted by occupant survey (green square = better than benchmark, amber circle = similar to benchmark, red diamond = worse than benchmark)

Overall, the survey and interviews with occupants reveal a positive opinion towards the Community Centre, with design, image and quality of light being the most appreciated elements. Temperatures are generally regarded as quite comfortable and air quality is regarded as satisfactory, along with control over ventilation and temperatures. Monthly mean internal temperatures during the monitoring period remain mostly within the band of 21-24°C, while maximum temperatures during winter reach 26°C (Figure 9), indicating there is potential for energy reductions. Summer temperatures in the Community Centre rarely exceed the comfort band (Figures 9, 11), and no instances of overheating were reported. Interviews revealed that occupants involved in light and sedentary activities are satisfied with the temperatures in the building, whereas occupants involved in more intensive activities (dancing, sports etc.) find the spaces warm and open the windows and use portable fans to cool themselves down. The Centre would benefit from the installation of ceiling fans in some of the spaces as well as zoning for tighter control of indoor temperatures. It is recommended that some spaces are kept at lower temperatures depending on occupancy and use. Tighter control over temperatures would help in increasing comfort levels and reducing energy consumption. External shading in the south facades and night-time ventilation would also help prevent high temperatures during summer.

Building users pointed out that the air can get dry during the winter. Relative humidity levels during winter fall below the recommended limit of 40% indicating that the air in the building can get dry when internal temperatures are high and windows are mostly kept closed (Figure 11). Mean CO_2 levels range between 700-900 ppm during winter months (Figures 10, 12). During times of large congregation, CO_2 levels may go above 1000ppm but that only occurs for 12% of occupancy hours and does not point to any significant air quality problems.

In the Library building, the BUS survey revealed the staff members have a positive opinion towards the modern design of the building and the quality of light. However, a significant amount of comments were made regarding the high temperatures during summer months (“Hot and stuffy”) and the lack of proper ventilation throughout the whole year (“Poor air circulation”). The latter had a negative effect on the comfort rating and seems to also have potential implications on the health and productivity of some of the staff. Monthly mean internal temperatures during the monitoring period range between 21-24^{o}C, mostly remaining around 21^{o}C during the winter months (Figure 9). Average hourly winter temperatures are lower than those recorded in the Community Centre, ranging between 19-23^{o}C (Figure 11). Minimum temperatures recorded during the winter months range from 17-19^{o}C. These temperatures in addition to the cold draughts reported to be coming from the ventilation ducts and the sedentary activities (low metabolic rate) of the Library users could explain why almost half of the respondents of the BUS survey reported feeling cold during winter. CO_2 levels remain below the limit of 1000ppm throughout the year indicating good air quality (Figure 10). The sense of stuffiness expressed by some occupants seems to be more related with the low relative humidity levels (Figure 11) and could also be partially attributed to the lack of perceived control over the windows and ventilation.

During summer, most people find the spaces uncomfortably hot, and comments received imply problems with the cooling system and control over the opening and closing of windows. Indoor temperature measurements show that even though mean summer temperatures do not exceed 24^{o}C, maximum values can reach 28^{o}C. This could account for a significant amount of staff experiencing air as hot and stuffy. Overheating is a major issue during summer in the second floor offices, where occupants often use portable fans as a means to increase airflow and get relief from excessive heat levels. Poor control over temperature and ventilation leads to occupant dissatisfaction and increased use of electric heaters and portable fans during winter and summer respectively.

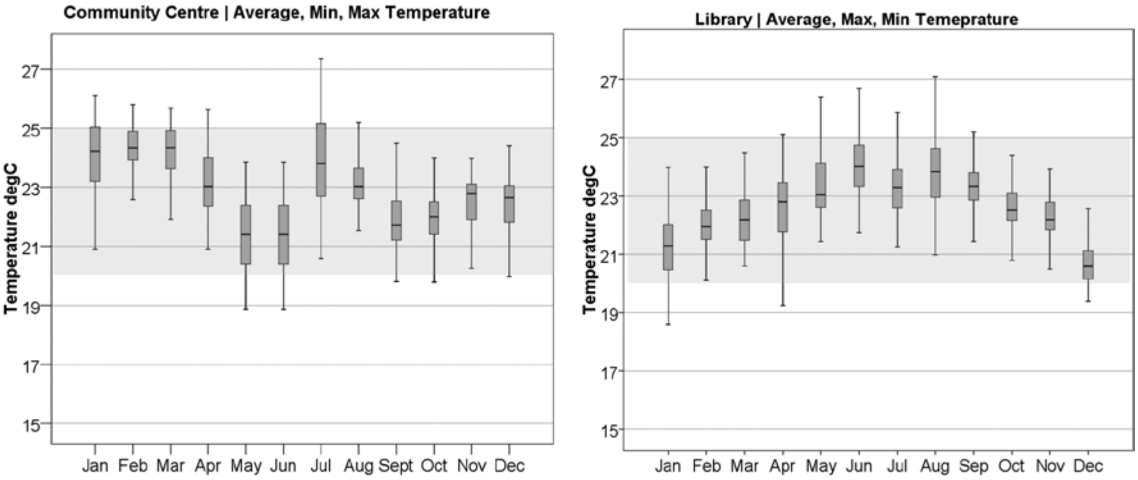

Figure 9 Monthly average, maximum and minimum temperatures in the buildings (January 2013-December 2013)

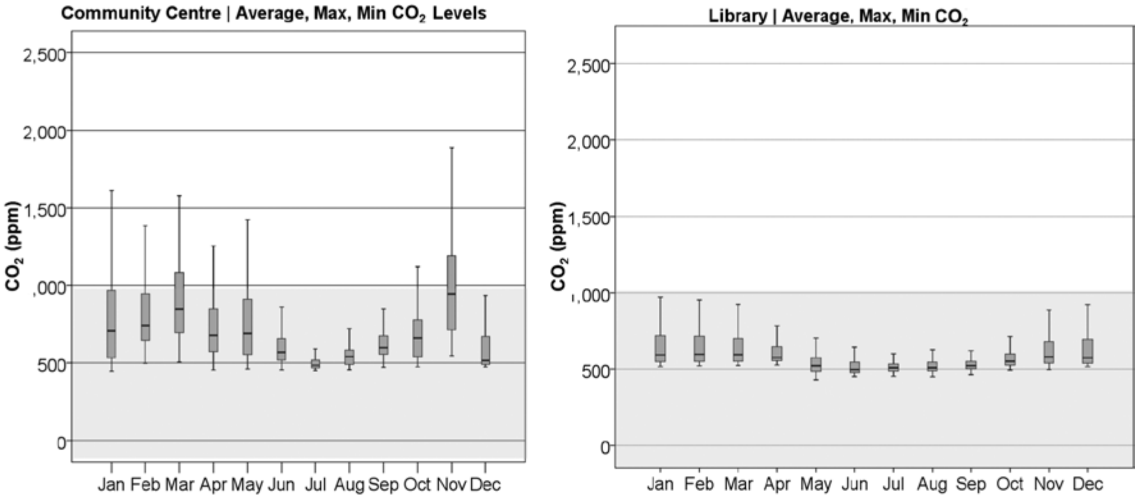

Figure 10 Monthly average, maximum and minimum CO_2 levels in the buildings (January 2013-December 2013)

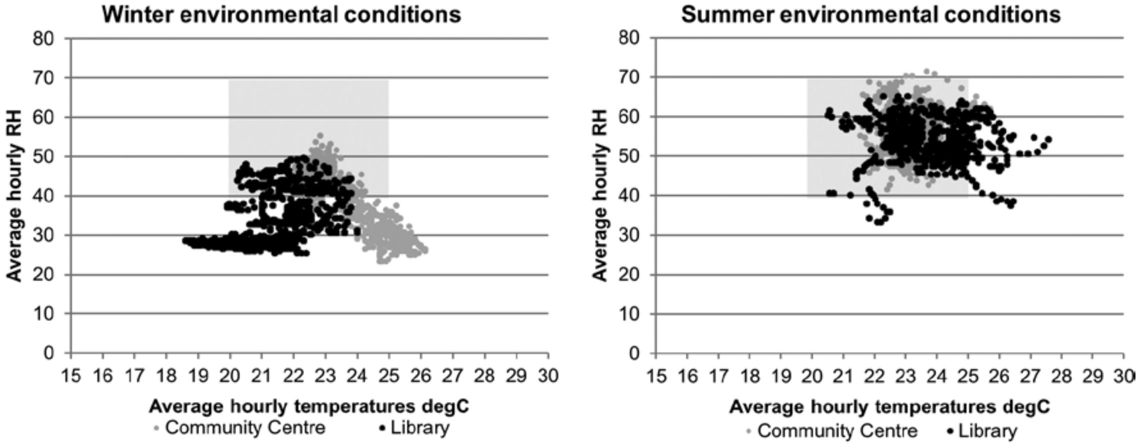

Figure 11 Average hourly temperatures and RH levels during winter (January 2013) and summer (August 2013).

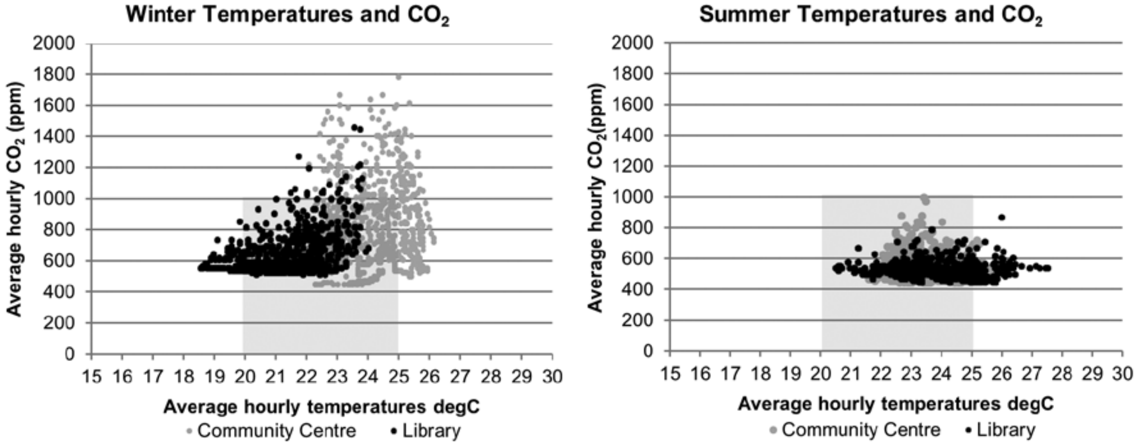

Figure 12 Average hourly temperatures and CO_2 levels during winter (January 2013) and summer (August 2013)

Common issues identified

Technical issues

Metering and sub-metering systems

Energy monitoring in both buildings proved to be a challenging and complicated task due to the lack of documentation on sub-metering arrangements (parts of the Operation and Maintenance (O&M) manuals were missing and the building log book was not available) and poor commissioning of the sub-metering systems. Sub-meters in both buildings were either installed incorrectly or had been poorly calibrated.

Close inspection of the sub-metering arrangements of the Community Centre building revealed that the three sub-meters had not been installed properly and were displaying false values. The sub-meters were re-commissioned and additional sub-metering arrangements were installed as part of the study, in order to monitor the performance of the heat pumps, electricity by end-use and PV generation and export.

In the case of the Library building, 27 electricity sub-meters were originally installed, offering a good level of detail and control through the BMS. These were expected to monitor the energy use of chillers, fans and pumps, lighting and small power by zone. However, inspection revealed that eight of the sub-meters had never been connected to the Building Management System (BMS). Also, detailed information on the sub-metering arrangements was missing and there was no clear documentation showing what each of the sub-meters was monitoring. As part of the BPE study the BMS system was re-commissioned (twice) and connected to all the electricity sub-meters to record data.

Commissioning and aftercare arrangements

A review of commissioning and interviews with management were carried out to identify arrangements for seasonal commissioning, aftercare and maintenance of the systems and services. Findings are consistent with research outcomes that highlight the importance of usability, manageability and less complication [27]. Several problems emerged in both buildings during the defects period and other commissioning errors and omissions were revealed. Maintenance contracts were not set up for all systems in the buildings and logbooks were not kept up to date.

In the case of the Community Centre, during the defects period of one year, the Community centre management team regularly contacted the builders, sub-contractors and system installers for help with technical issues that emerged. Maintenance contracts were setup for the GSHPs, security and fire alarm whereas warranties were relied upon for electrically controlled windows. The Building Logbook and User Guide were never provided, contrary to the requirements of 2006 Part L Building Regulations. Other necessary documents were also missing, including: electrical and mechanical specification and commissioning documents, metering and sub-metering schematics, water and electrical circuit diagrams and as-built drawings, thus seriously affecting maintenance and repairs.

In the case of the Library, several commissioning and installation issues were revealed during the defects period. Following this period, the biomass boiler encountered mechanical failures due to inadequately sized woodchips and foreign objects found in the fuel. Maintenance provided did not address the problems effectively as the system kept failing, remaining out of operation for nearly two years. As a result, the system was perceived by the facilities management (FM) team as unreliable and difficult to maintain. Similarly the chilled water cooling system and the solar thermal panels were also not functioning properly but little was done to resolve these issues. In addition to this, there was no feedback mechanism set up in the building to report all the aforementioned building issues to the management. Poor maintenance and management issues are particularly evident in the case of the BMS. The system had not been optimized and some BMS sensors had not been well calibrated. These problems resulted in the poor performance of the heating and cooling systems. After continuous efforts of the BPE team, actions were taken to address these issues, but without a maintenance contract in place many of them are likely to re-appear.

Non-technical issues

Handover procedures and user guidance

The purpose of a building handover and the initial aftercare period is to enable building users and the FM team to understand, manage and operate their building effectively [28, 29]. Table 3 summarises the common issues across the two buildings that emerged from the review of handover and documentation provided. Surprisingly, no training took place during handover in either of the buildings and no *user guide* was provided to occupants to assist them in understanding their new environment, and how they should control it.

The handover of the Centre took place between the building owners and contractors, but the building users and facilities manager were not present and did not receive any training on how to operate the building and its systems during the move-in. The building manager had to contact the contractors at a later stage in order to request help and to arrange individual training on the operation of the systems. The handover documentation provided to the users included an Operation and Maintenance Manual, PV and Heat Pumps system manuals and equipment specification documents. These documents were very technical and did not facilitate the efficient use of systems.

The review of the Library's handover documentation revealed that no User Guide was provided and that information was missing from the O&M manual. The Building Logbook was not kept up to date and there was no log of breakdowns, repairs and maintenance procedures. After the initial handover, several changes in the FM team occurred, but no subsequent training was provided to familiarise the new FM members with the installed systems. No BMS training was provided to the new FM team members.

Table 3 Emerging issues highlighted by review of handover

Issues	**Community Centre**	**Library**
Several issues were revealed during the 1-year defects period	x	x
BMS/Sub-metering systems not included in maintenance contract	x	x
Commissioning documentation is incomplete	x	x
Logbook is not being kept up to date.	x	x
User Guide was not provided	x	x
Training provided to FM team was not sufficient	x	x
Management is effective in addressing maintenance issues	x	
Management has good control over the building's energy use	x	

Building specific issues

Despite there being common building performance issues across the two buildings, they perform considerably differently in terms of operation of services and systems, and usability of controls. There are also building specific issues related to the operation of the BMS system in the library building.

Operation and usability of systems and controls

Control interfaces are the meeting point between the users and the building technology. To understand the effectiveness of management and control, the six-point criteria developed by the Buildings Controls Industry Association (BCIA) were used to visually rate (on a 5-point scale from poor to excellent) the performance and usability of control interfaces [30] of heating, ventilation and lighting systems as well as touch-points of the building fabric (window controls). These criteria include *clarity of purpose, intuitive switching, usefulness of labelling and annotation, ease of use, indication of system response, degree of fine control* as well as *accessibility*. Emerging issues from this assessment are summarized in Table 4 below. In the Community Centre, control over temperatures, windows, ventilation and lighting was found to be good, while in the Library poor control was one of the major problems the FM team and the users were facing.

Table 4 Emerging issues highlighted by usability survey of controls

Issues	**Community Centre**	**Library**
Poor control over heating	x	x
Poor control over temperatures		x
Poor control over windows and ventilation		x

Poor control over lighting		x
Poor control over BMS		x

It is evident that there is a marked difference in the usability of controls across the two case study buildings. Most of the building controls in the Community Centre building were found to be easy and intuitive to use and conveniently located. Some of the controls originally installed in the building, including the control for the electrically operated roof-lights were complicated to use, but the building management had them changed for more user-friendly ones. Control over indoor temperature was also rated positively, despite the lack of zoning, as the GSHP interface offers a good level of fine control to the FM team and the windows are easy to operate.

In the Library building, however, control appears to be one of the most problematic issues. Occupants don't have sufficient control over their environment; they can't make any significant changes and rely on automatic BMS sensors. Occupants report that they cannot control ventilation effectively as windows are primarily controlled by the BMS system to which they do not have access. Poor understanding of the BMS results in the FM team being unable to monitor or adjust the BMS settings (made before occupants moved in), and not being able to address the numerous complaints made by the occupants. In addition to this, fine control is very limited as each control operates large rows of windows, thus undermining individual occupant control over their immediate environment. Windows that only open in groups were identified as a source of dispute in the open plan office area creating comfort issues for individual occupants. Control over lighting use is also compromised. PIR lighting controls appear to be set to excessively long periods and occupants appear to have overridden daylight sensor controls resulting in energy wastage. These findings clearly indicate that poor control over systems undermines occupant comfort and environmental conditions leading to excessive energy use.

Building management

Despite the several aftercare and commissioning issues already discussed, the management team of the Community Centre has been successful in addressing all the teething and breakdown problems. The building manager became the energy champion of the building, closely monitoring performance and addressing maintenance and control issues. Strict and careful day-to-day management and control over the heating (achieved by setting the thermostat at 19^{o}C throughout the year) and lighting use, allowed the building to perform well resulting in high occupant satisfaction and low energy use. Both management and visitors are conscious of reducing electricity consumption by switching off lights and appliances when not needed. As a result, the management team is presently satisfied with the energy use of the building and the electricity bills.

Contrary to the Community Centre, the FM team of the Library has no involvement in the energy management of the building, be it through energy monitoring or paying of the energy bills. Instead, the fiscal meters of the building are remotely monitored half-hourly by the County Council and no energy feedback is provided to the FM team. This lack of engagement of the on-site FM team affects the actual performance of the building that has been left to run on its own. Lack of proper management further complicates issues in the Library as there is often poor or delayed communication between services teams. There is often conflict as to who is responsible for the maintenance and repair of specific systems, such as the solar thermal panels and the biomass boiler. Furthermore, the lack of FM training already discussed reflects in the daily operation and management of the building. The FM team is not fully aware of the location and operation of several controls and systems installed throughout the building (solar thermal panels, biomass boiler, BMS) and lacks information and knowledge on how to provide cooling in the offices during summer and more heating during winter. All these issues have a big effect on actual energy use as well as comfort.

Conclusion and recommendations

Despite having similar design aspirations, BPE studies of the two civic buildings (with different use and sizes) revealed similar problems in terms of building performance: lack of handover, guidance and training, inadequate commissioning of systems and poor calibration of sub-meters. Notwithstanding these issues, the Community Centre performs well and is much more appreciated by its users who are satisfied with its environmental conditions, comfort and energy use. The Library users, on the other hand, have several complaints regarding the indoor temperatures and air quality, and control over their environment. The Library does not perform well in terms of energy either, with actual energy use being nearly double the design predictions.

The BPE study has also helped to reveal the reasons for the large difference between the energy and environmental performance of the two buildings. Strict management of heating and electricity loads, good occupant control over the environment and high performance of the low-carbon technologies installed in the Community Centre resulted in the building performing much better that the CIBSE Guide F Good practice benchmark. The Community Centre management team, led by an energy champion, managed to overcome building performance issues through their continuous engagement and interest in the building's performance. In the future, zoning of the heating system would provide better control over indoor temperatures and reduce the heating load, while the addition of ceiling fans and external shading combined with night-time ventilation would improve comfort conditions and make the building more resilient to high summer temperatures.

The Library, on the other hand, still suffers from handover, commissioning and maintenance issues, confounded by a lack of training of the FM team. Regular changes in FM staff since handover mean that the environmental control strategy, BMS and sub metering is not well understood by the FM team, which is not able to monitor the energy performance to enable energy savings to be targeted. Lack of user guidance and understanding of the processes that take place in the building, together with minimal individual control over heating, ventilation and lighting, further undermines occupant comfort and leads to excessive energy use in the library and office spaces. As a result, there is little engagement in managing the building and its performance. Going forward, in-depth training of the FM team to use the BMS system, as well as proper maintenance of the biomass and solar thermal technologies would improve control over the building systems and environmental conditions.

Using the findings from the two BPE studies, wider lessons and recommendations are drawn for designers, constructors, clients, building operators and the supply chain, as explained below:

- Although renewable energy systems are selected at the design stage, so as to get credits with BREEAM or EPC, it is vital that only tried and tested systems and low/zero carbon technologies are installed with a clear understanding of their maintenance regimes, operation and control.
- Unmanageable complexity in operation and maintenance should be avoided as building management functionality in such buildings is becoming limited and shared across multiple buildings.
- Issues with thermal performance of building fabric can be picked up using a combination of thermal imaging and air-tightness testing especially for early detection of problems. In the long term changes in design practices and construction skills are required to prevent these issues.

- Documentation of design intent, ‘as built’ information and commissioning records should be enforced to ensure effective management of the building. Accurate ‘as-built’ energy models (already required under Building Regulations) should become be enforced rigorously for all projects of all scales. This could ensure that SBEM worksheets and drawings are updated to record changes made on-site that could affect the energy use.
- Maintenance contracts should be set up from the outset for unfamiliar low carbon systems such as biomass boilers, solar thermal and even BMS.
- Metering and sub-metering arrangements should be carefully designed and installed according to end uses and zones. It is important to ensure that sub-meters are calibrated and commissioned properly, and reconciled after handover in order to correct problems quickly and allow effective energy management.
- Design teams should ensure that easy-to-understand user guides are made available just before handover operation for management teams and occupants.
- Commissioning records of services and systems should be used to check the performance of systems. Lack of proper documentation creates problems in maintenance and repairs, while lack of understanding of systems results in frustration and high energy use.
- The need for a good balance between automation and occupant control is also highlighted. Control interfaces need to be intuitive, labelled and properly designed, and installed in an accessible location that encourages occupants to interact with their environment in an adaptive and positive manner.

Ultimately it is vital that all stakeholders (clients, designers, constructors, supply chain) use BPE studies to develop foresight for improving future building design, specifications and performance.

Acknowledgements

The authors are grateful to Innovate UK's (formerly Technology Strategy Board's) BPE programme for sponsoring these research projects (BPE reference numbers: 450003 and 450048). Our sincere thanks to the users, clients and project design teams for their help and support during the studies. Thank you also to Matt Gregg for providing editorial support.

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