AN INVESTIGATION INTO THE ENERGY PERFORMANCE OF SCHOOL BUILDINGS REFURBISHED THROUGH SALIX FUNDING

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Abstract

Schools in the UK are part of the existing stock of buildings whose operational carbon must be reduced for the government to meet its objective of reducing carbon emissions by up to 80% of their 1990 levels by 2050. State funding for refurbishment is the most feasible option for public schools using two routes: Condition Improvement Fund (CIF) which is restricted to improving the physical aspects (e.g. expansion) of school facilities; and the Salix Energy Efficiency Fund (SEEF) aimed at energy/equipment retrofit measures. Although the use of BIM technology (underpinned by the government softlanding (GSL) framework) as well as the use of energy modelling and simulation tools have become integral to making buildings more energy efficient, they are constrained by lack of adoption. This study used a mixed-method approach to investigate the effectiveness of contemporary BIM and energy simulation technologies in refurbishment of existing school buildings. Secondary quantitative data collected from 10 case studies of schools that benefitted from SEEF was supported by interviews of seven heads of schools that had undergone SEEF refurbishment. Results showed that: CIF and SEEF which administratively are mutually exclusive funding streams ought to operate in synergy due to the interaction of a building's physical envelope with heat transfer and energy used by equipment and systems; some schools are not getting technical advice on how to optimise the funds they receive from SEEF leading to non-optimal investment. Recommendations provided include: extensive training on BIM and GSL to heads of schools and advise to government agencies to reconcile the purpose of CIF and SEEF for a holistic solution to carbon reduction in schools.

INTRODUCTION

Globally, buildings are acknowledged in most countries as contributing up to 40% of carbon emitted (IEA, 2010). As part of its wider sustainability targets and legally binding framework, the UK Government has committed to getting existing to reduce their carbon emission by up to 80% of their 1990 levels by the year 2050 (DECC, 2008) and non-domestic buildings in the UK account for 18% of emissions (HM Government, 2010). It has been acknowledged that retrofitting of buildings will be central to the success of this ambition and for non-residential buildings, e.g. commercial buildings, the energy retrofit market is worth up to £9.7 billion which can be spent on matters like optimised lighting, improved building energy management and control systems (BMCS) and more efficient building services (Dixon, et al. 2014). However, the advent of BIM has meant that consideration must be given for accessing building designs via BIM's object-oriented models. Therefore, this means that the efforts to close the so called "performance gap" need to be compatible with BIM – including the provisions of the BIMdriven government soft landings (GSL) and there have been studies which have considered these possibilities such as Tuohy and Murphy (2014) and Kelly et al. (2013). Whereas many existing school buildings would not have been procured using BIM processes or technologies, it is likely that refurbishment and expansion projects on such schools can and should benefit from the use of BIM particularly because BIM was mandated for public sector projects. Since the government's BIM mandate was aimed at public sector projects (for which state schools belong) and because schools are responsible for up to 2% of total carbon emitted in the UK, there is a lot at stake in their performance. Investigating the use of BIM as an effective process for assessing energy performance of school (or other types of) buildings requires an understanding of the BIM process and the underpinning technologies. In this regard, the aim of this research is to investigate the effectiveness of contemporary BIM technologies for assessing the energy performance of existing school buildings. The objective of this paper are: (a) to explore the contemporary issues that shape energy performance of existing schools, including the technologies and funding schemes that support their low carbon performance; (b) to examine the energy performance indicators that are used in post-occupancy evaluation of school buildings and to map these with technologies used in BIM process and their suitability for assessing such school buildings; (c) to evaluate the suitability of BIM processes to meet the post-occupancy energy assessment needs of existing school buildings, particularly in view of Government Soft Landings for Level 2 BIM.

LITERATURE REVIEW

Sustainable buildings, BIM and the government soft landings (GSL)

According to Peace, et al (2012), the construction industry is a major employer and accounts for around 7% of the gross domestic product (GDP) of most countries. However, this sector's importance is often tainted by the extensive use of natural resources, particularly the raw materials used in constructing buildings and the energy required to keep such buildings liveable, based on acceptable indoor environmental quality. Hence, the major cost associated with buildings is the operational cost incurred at the post-occupancy stage. It was in view of this realisation that the UK government has led the world in instituting a Government Soft Landings (GSL) policy (Tuohy and Murphy, 2014). This policy requires a follow up and aftercare services led by the designers and contractors and occurs within a mandatory three-year post occupancy evaluation (POE) phase as part of the mandated BIM strategy. In other words, the GSL strategy is a unique framework that binds BIM to the principles of social, economic and environmental aspects of sustainability. The GSL strategy is expected to provide feedback that is actionable for the benefit of owners, users and managers, as well as those who provide heating and energy services to buildings so that during refurbishments or future designs, improvements can be made. It can therefore be deduced that the GSL can help designers and builders close the so-called energy performance gap by validating, fine tuning and debugging the energy systems. This gap represents the mismatch between predicted energy consumption and actual energy consumption of most buildings (Tuohy and Murphy, 2014; De Wilde, 2014; and Johnston, et al. 2015). The use of sensors and smart devices are currently helping in this regard, by making possible a cyber-physical system (Anumba et al. 2010 and Akanmu, et al.

2013) that enables physical data collected from real-time building use to be mapped into digital models for the purpose of analysis.

As mentioned earlier existing buildings contribute significantly to the emitted carbon that is attributed to global warming. The design, construction and operation of these buildings have therefore not been carried out using low-carbon or sustainable processes and principles. Therefore, the best way to reduce their operational carbon is through refurbishment, repair or maintenance of existing fabric or installed systems. These intervention processes provide opportunities to revisit the use of unsustainable construction materials, e.g. those with high embodied energy/carbon or poor insulation as well as equipment which consume too much energy or those that emit greenhouse gases. Additionally, the spatial design of those buildings can also be reviewed and improved during refurbishment so that defects and inefficient performances can be detected and remediated. In this regard, Dong, et al. (2014) conducted a study where they developed a methodology for diagnostics and detecting faults in existing building can be done by integrating real-time data collected by energy management systems with as-built 3D BIM models. The data incudes heat loss and heat gain across the building fabric. Other studies that have looked at energy diagnosis in buildings have investigated the impact of their age and environmental conditions (Golparvar-Fard and Ham 2013) including fault detection through the use of thermal imaging data that is integrated into gbXML models that are compatible with BIM (Ham and Golparvar-Fard, 2014).

However, other kinds of data that can be used in such a cyber-physical system include occupant movement data (obtained from sensors) which can reveal actual behavioural issues with building use, which could provide more accurate picture of energy use than predicted from simulations (Palmer and Cooper, 2012). This is an important point because even though most energy efficient retrofit measures are related to building envelope and insulation (Shorrock, et al. 2005) the behaviour of people in buildings affects heat loss/gain (Kane, et al. 2011) e.g. opening of doors, leaving electric appliances on (Palmer and Cooper, 2012). Therefore, behavioural aspects of occupants can be said to be an important key and clue about why there is performance gap in constructed buildings. In short, refurbishment is an ideal opportunity to look forensically at a building's energy performance for the purpose of closing any gaps and providing economically, socially and environmentally sustainable buildings. It is noteworthy that the data fed into (and exchanged between) BIM software are mostly about geometry, as evidenced by the gbXML and IFC file formats. However, the review of diagnostic investigations into energy use in buildings (Bahar, et al, 2013) suggests that other formats of data, e.g. thermographic images of heat losses; motion of occupants as captured by sensors; etc, are not supported by such BIM tools. These data are crucial to actual energy utilisation and capturing them can only help close the performance gap. With respect to schools, studies such as Burman, et al. (2014) have shown that actual consumption is much higher than theoretical calculations and simulations. They proposed a plan that requires "measurement and verification" for comparing the theoretical with actual performance so that a reliable process for closing the performance gap can be achieved.

Building Energy and Carbon Management in UK Schools

Kilpatrick, et al. (2011) who reviewed the consumption of energy in school buildings with Scotland, argued that it is only by energy data collection and analysis that an understanding of energy use can be achieved. According to them, the UK is among a minority of countries that have set a benchmark for energy consumption in schools and the target of 110kWh/m²/year is regarded as a reasonable target (Hernandez, et al. 2008). The "Good Practice Guide 343 (or GPG343) has set out good practice benchmarks which include: 191kWh/m²/year for primary schools and 196kWh/m²/year for a secondary school without a swimming pool (Carbon Trust 2003). A recent breakdown of a typical UK School's energy use by the Carbon Trust (2012) shows that space heating accounts for 58% and is allocated around 45% of costs. In view of the importance of schools to the carbon reduction strategy, a consultation paper was developed by the Department for Children, Schools and Families in 2009 (DCSF, 2009). Although schools only accounted for 2% of the total greenhouse gases emitted in the UK, by context this is equivalent to the amount produced from energy and transport by the cities of Manchester and Birmingham combined (DCSF, 2009). The consultation report produced some interesting information about how schools in England contributed to the CO2 emissions by summarising their carbon footprints (Fig. 1). One of the key findings from the study was that modelling results suggested that without active intervention to mitigate the carbon footprints from such schools, the carbon emitted from such schools will remain at their levels up to the year 2050.

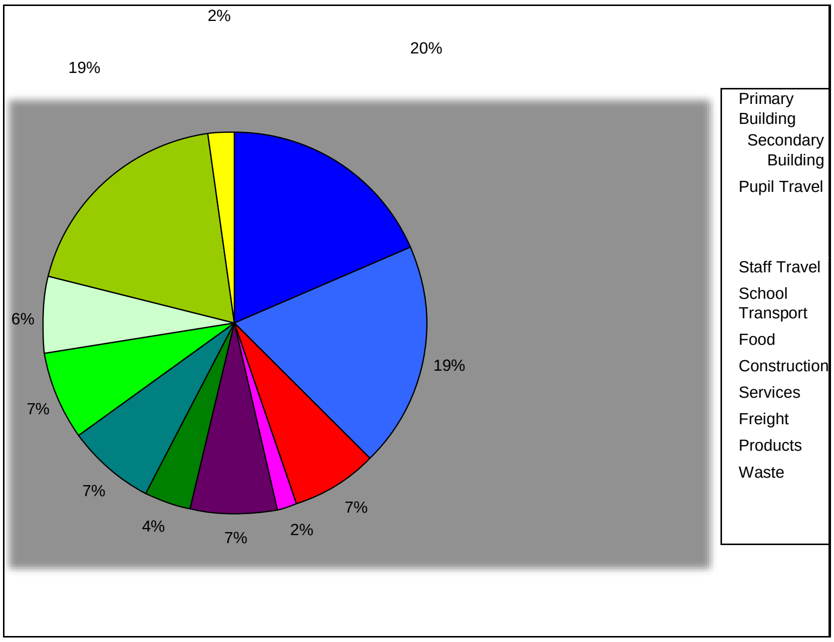


Figure 1: A sector breakdown of schools' carbon footprint in England (DCSF, 2009).

Although this finding from the DCSF consultation paper has contributed to active measures being taken to assist schools[1], it should be borne in mind that there is a performance gap linked to modelling and simulation. This suggests that the data concerning primary and secondary school buildings (Fig. 2) might be under or overestimated. Nevertheless, the data suggests that if business as usual (BAU) is allowed to persist, the UK will not meet its 80% reduction of carbon emissions to the 1990 levels by the year 2050.

[1] Such interventions include Condition Improvement Fund (CIF) and Salix Energy Efficiency Fund (SEEF). See next section.

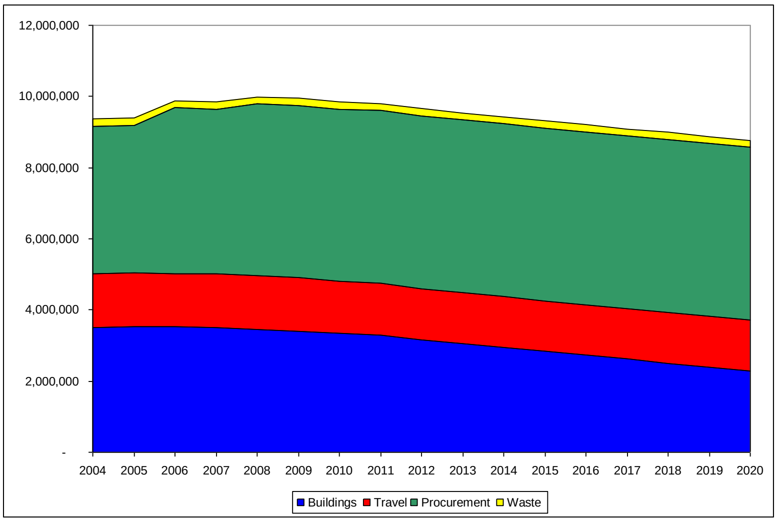
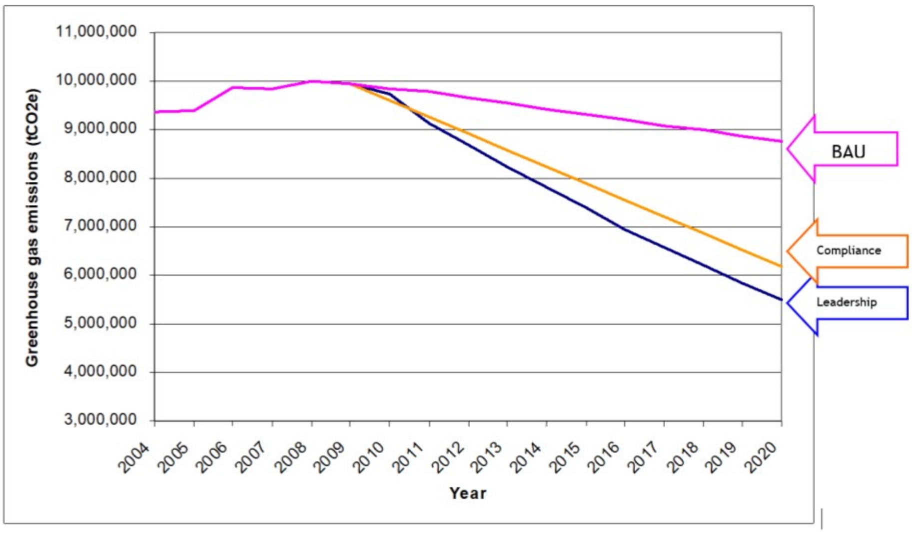


Figure 2: Projected carbon emission trends in English Schools (DCSF, 2009)

Leading up to the year 2020, three possible pathways were recommended for schools, including: Leadership, Compliance or Business-As-Usual (BAU). Using 2004 as the datum or baseline the three pathways differ as follows: the first pathway (Leadership) would lead to a 42% reduction in total carbon emissions by 2020; the second pathway (Compliance) would lead to 34% reduction in carbon emissions; while the last pathway (Business-As-Usual or BAU) will see only a 6% reduction of carbon emissions using 2004 reference levels. The best-case scenario is therefore leadership and the worst-case scenario is to do nothing or continue with BAU (Fig. 3). Obviously merely complying with set guidelines and regulations would lead to significant improvements, but this (34%) reduction is 8% less than the reduction possible by leadership. Nevertheless, the consultation study did not collect or present data about leadership in school's energy and carbon management. Therefore, the thoughts and opinions of school leaders[1] will be critical in the success of a school's carbon management program and this research will exploit the gap by seeking data that could explain the standpoint and readiness of school leaderships.



[1] Leadership of schools here refers to upper management personnel including head teachers, administrators, principals, etc.

Figure 3: Three carbon scenarios for schools in England: Leadership, Compliance or Business-As-Usual (DCSF, 2009)

Interventions for energy efficient school buildings

There are two major intervention programmes that are applicable to schools in England who wish to refurbish their facilities towards improved energy and lower carbon footprints. These programmes are the
Condition Improvement Fund (CIF) and the Salix Energy Efficiency Fund (SEEF). The CIF is a scheme that provides capital funding for academies and sixth form colleges and is sponsored by the Education Funding Agency (EFA). The focus of the funding is to support 'condition projects' i.e. those interventions that will help maintain the eligible schools in a safe, good working or fit-for-purpose state. The issues that would typically be addressed by CIF include: health and safety; energy efficiency; building compliance and poor building condition; continuous heating and water supply as well as weather tight buildings (EFA, 2016). Specifically, the eligible priority work packages that can directly impact energy efficiency include: Block replacement or refurbishment; Boiler and heating systems; Expansion of the gross internal floor area (GIFA); building fabric (weather tightness); mechanical and electrical systems (heating and water supply). The eligibility requirements for CIF restricts it to establishments that are not part of a chain of academy trusts (which have up to 5 academies or a population of pupils exceeding 3000). Schools that are part of an opt-in chain or those that receive 'formulaic funding' are also ineligible to apply for CIF. Projects can be approved under one of three categories as explained below (EFA, 2016): (1) Condition projects: Projects under this CIF category are aimed at improving the general condition of a school building without any expansion to the buildings GIFA; (2) Condition with expansion projects: These projects are also aimed at improving of the general condition of a school building where up to 10% GIFA expansion of the old building is to be done; (3) Expansion projects: Projects funded under this category are aimed at solving overcrowding problems or creating additional places in sixth-form colleges or academies that demonstrate high performance (EFA, 2016). The assessment of all applications made by establishments for CIF financing is based on three main criteria, i.e. Project need (70%); Project planning (15%); and Value for money (15%).

However, some categories of work that are aimed solely at energy efficiency, including lighting, and which do not seek to improve the overall condition of a school are not favoured under the CIF eligibility. Rather, such projects are now supported by an energy efficiency loan scheme through a partnership between EFA and Salix Finance. This scheme known as the Salix Energy Efficiency Fund (SEEF) and provides 100% interest-free loans for Schools to obtain and use for improving the energy performances of their buildings. This funding is available for all schools whether they are traditional academies or large MultiAcademy Trusts (MATs). Therefore, this scheme is more accessible to schools of various kinds and sizes than the CIF scheme. By providing full funding, it is expected that the annual energy savings from such projects will enable them pay back the loans with a period of 8 years. This is an ambitious target that reveals the confidence which the partners (EFA and Salix Finance) have in the cost savings achievable from energy efficiency measures in schools. The experiences of these schools are documented in several case studies, and it would be helpful to appraise these schools based on the core aim of this research. A case study based archival analysis of selected schools will be carried out as part of the data collection and research process.

The main gaps identified in the review of literature can be summarised as follows. First, the tools used for simulating buildings within BIM processes were not originally designed for BIM, but they are able to integrate with BIM software using geometry-based data exchange formats. This is not an issue for new buildings. However, for the purpose of this research and its objectives which centre on existing buildings, other formats of data required for simulating existing buildings, e.g. data collected from sensors, thermal imagery or data loggers are not directly supported by these BIM software, Second, Energy efficiency in schools is governed by the use of gas and electric equipment as well as the building fabric which governs heat loss/gain. However, the CIF funding which supports the condition improvement of buildings (including fabric or construction work) does not support energy efficient measures like lighting and equipment, which is funded by a different scheme (SEEF). This arguably makes it a challenge for schools because you cannot divorce building fabric from energy consumption by lighting and equipment. Finally, from the three possible pathways for energy and carbon reduction in school's leadership is the most effective, followed by compliance to energy regulations and lastly operating the school under a businessas-usual (BAU) regime. However, there is no evidence or data to suggest that school leadership have been investigated or engaged in order to see if they are providing the kind of leadership that will support energy efficiency measures in their schools either through CIF or SEEF schemes. These gaps will be exploited by collecting primary data in accordance with the logical methodology that is deemed suitable for meeting the objectives of the research.

RESEARCH METHODOLOGY

Research methodology is the strategy that shapes the choice and use of research method or methods (Sobh and Perry, 2006). It entails having a plan of action for a researcher to implement as they carry out their investigation and tends to be influenced by the ontological and epistemological positions held by the researcher (Guba and Lincoln, 1994). In other words, the beliefs or world views held by the researcher will influence their preference for (or perceived suitability of) one method over another. It has been argued that some researchers tend to use the presence or absence of quantification as a basis of establishing the differences between quantitative and qualitative methods as while categorising research methods, but this according to Bryman (2012) is not ideal. Rather, these methods should be viewed on the basis of their epistemological positions, where qualitative method is often aligned with positivism while quantitative methods are associated with interpretivism. When mixed method research (which combined qualitative and quantitative methods) is used, this should be on the basis of taking a pragmatist perspective to finding knowledge (Creswell, 2009; Bryman, 2012).

After careful consideration of the nature and aim of the research, it has been decided that this research will be approached from a pragmatic world view. This position allows the research problem to be in focus always and all the potential methods and techniques that can help address the research objectives/questions should be considered and used as necessary. This standpoint gives the research greater freedom (Feilzer, 2010; Johnson and Onwuegbuzie, 2004) so that the research (and researcher) is not unnecessarily tied to a particular method as would entail if either positivist and interpretivist worldviews were used. Going forward, therefore, this research has equally considered the validity of qualitative and quantitative methods in addressing the question of whether BIM technology is effective for assessing the energy performance of existing school buildings. The qualitative data can be obtained from interviews while quantitative data can be acquired from archives (documented case studies) of refurbished schools.

RESEARCH METHODS

Given the initial decision to approach the research from a pragmatic worldview and considering the advantages and disadvantages of both quantitative and qualitative research method, it is viewed that mixed method research will be used. Secondary (quantitative) data will be obtained from documented case studies about schools in existence that can shed light about actual energy assessment of such facilities. In addition, the schools that have been involved in energy performance interventions have had various types of measures put in place ranging from space heating to building management systems (BMS) and this will offer a wider perspective on the impact of BIM-based assessments; The case studies are all drawn from the Salix database of schools (https://www.salixfinance.co.uk/loans/SEEF). Primary data from interviews were designed for heads of schools that have benefitted from CIF and SEEF financing. These heads are in leadership position and so the interview can shed light on their level of energy efficiency awareness, as well as their understanding and leadership in the day to day energy performance of their schools.

RESEARCH RESULTS

Case studies of Salix-financed schools

A case study of 10 schools that had benefited from SEEF was carried out. The selected schools (Table 1) were chosen based on four kinds of interventions including: (1) installation of Building management system (Penair School and Scottish Agricultural College); (2) installation of Efficient gas condensing boilers (Whitstone Academy, Harrogate Grammar School, Bedford Hall Methodist School and Meon Junior School); (3) installation of LED lighting systems (St Brides Major Church Primary School and
Foundry Lane Primary School); and finally (4) general lighting upgrades project (Woodridge Primary School and Our Lady and St George's school). From the case study data, it is apparent that the loan value is not a direct indicator (or directly proportional) to the annual or lifetime savings. For instance, the loans taken by Foundary Lane primary school (£27,019) and Meon Junior school (£18,000) are significantly different. However, the lower amount spent by Meon Junior school led to 211% lifetime savings because it was spent on gas boiler refurbishment whereas the higher loan taken by Foundary Lane primary school that was spent on LED lighting delivered a 182% lifetime saving. Nevertheless, even though the annual savings of CO_2 from

the costlier loan (15 tonnes) was only slightly more than the annual savings of the cheaper loan (12 tonnes), the lifetime savings of CO_2 is more favourable to the costlier LED lighting project.

Table 1: The case study data for 10 schools which took Salix-finance loans[1]

Case ID	Project	Description	Documented year	Loan value	Annual Savings	Lifetime savings	Lifetime savings as % of loan	Annual savings of CO2	Lifetime savings of CO2	Calculated years of CO2 savings	Project payback
1	**St Brides Major Church Primary School**	LED lighting project.	Dec-13	10,125	2,218	28,840	**285%**	11	150	**13.6**	4.5
2	**Foundry Lane Primary School**	LED lighting project.	Dec-13	27,019	3,784	49,191	**182%**	15	196	**13.1**	7.1
3	**Scottish Agricultural College**	Building management system.	Nov-12	120,341	49,229	172,301	**143%**	322	1126	**3.5**	2.4
4	**Penair School**	Building management system.	Nov-12	5,358	2,524	21,256	**397%**	12	98	**8.2**	2.1
5	**Whitstone Academy**	Efficient gas condensing boilers.	Sep-16	220,000	27,500	275,000	**125%**	NA	NA	**NA**	7
6	**Harrogate Grammar School**	Efficient boilers and new zone controls.	Oct-16	223,323	34,343	343,430	**154%**	NA	NA	**NA**	6.5
7	**Bedford Hall Methodist School**	Efficient boilers and heating system.	Nov-16	49,278	11,266	124,280	**252%**	NA	NA	**NA**	4.4
8	**Meon Junior School**	Oil to Gas boiler fuel switching project.	Dec-13	18,000	4,802	38,032	**211%**	12	92	**7.7**	3.8
9	**Woodridge Primary School**	Lighting upgrades project.	Dec-13	4,438	1,379	13,790	**311%**	5	5.8	**1.2**	3.2
10	**Our Lady and St George's**	Lighting upgrade and installation of PIR controls	Nov-16	47,401	6,304	152,497	**322%**	NA	NA	**NA**	8

Similarly, it could be deduced that whereas Penair School took a loan of £5,358 to spend on Building

Management System, leading to lifetime savings of £21,256 and lifetime CO_2 savings of 98 tonnes, the £4,438 loaned to Woodbridge primary school that was spent on lighting upgrades produced a lifetime saving of £13,790 and lifetime CO_2 savings of just 5.8 tonnes.

In summary, the case study data suggests that schools have probably not been strategic in the amount they take as loan or in the types of projects they spent it on (for instance, spending similar amounts of money on lighting upgrades rather than on BMS which would save more carbon). Although it is expected that a school embarking on a costlier type of refurbishment is responding to a need, it is pertinent for the school administrators and designers to study the long-term impacts and make informed decisions accordingly. This is clear from the Penair vs. Woodbridge school projects where the loan amounts are not too dissimilar (£5,358 and £4,438 respectively), but the lifetime savings are drastically different (£21,256 and £13,790 respectively) or 98 tonnes of CO_2 against a meagre 5.8 tonnes of CO_2 respectively.

4.2 Interviews of heads of schools

Interviews were required to engage with several heads of schools across the UK to collect qualitative data about their experiences with SEEF projects implemented in their facilities. A total of seven interviews were carried out from the 13 respondents who indicated interest in participating (Table 2).

[1] In this case study table, the data found in Column 8 (Lifetime savings as % of loan) and Column 11 (Calculated years of CO2 savings) were computed and not part of original data.

Table 2: Summary of interviewees

Interviewee ID	Location in UK	Official Title	Years in role	Type of SEEF project	Age of building
Interviewee 1	East Midlands	Head teacher	4 years	New Boilers	Victorian
Interviewee 2	East Midlands	Head of School	5 years	BMS and sensors	2000s
Interviewee 3	London	School Administrator	3 years	Lighting upgrades	Late 1940s
Interviewee 4	West Midlands	Head Tutor	2 years	LED Lighting	Unknown
Interviewee 5	London	Head Teacher	3 years	New BMS	1990s
Interviewee 6	East of England	School Director	5 years	LED Lighting	Unknown
Interviewee 7	West Midlands	Head of School	3 years	Efficient Boilers	Victorian

From the transcribed interview data, five themes and eleven sub-themes emerged (Table 3) and the relevant verbatim comments extracted from the transcribed data is presented in Appendix 1. The major themes that emerged have been classified as follows: Handing over of buildings; Capability to manage modern energy systems; Integration with existing systems; Support for Measuring and monitoring CO2 savings; as well as the CIF and SEEF funding process. The themes categorised above (Table 3) were generated from the verbatim transcription of qualitative data collected from seven interviewees as summarised in Appendix 1. The transcription of the interview data and generating the themes that emerged, has provided some interesting insights about the processes used in procurement of energy efficient systems. In all cases, the respondents were either heads of school, head teachers or some form of top ranking school administrator whose approval, input and authority must have mattered (in addition to elected boards of governors) towards the decision to apply for SEEF funding and the eventual expenditure. Therefore, these respondents and the data they generated must be regarded as a valid representation of the views of leadership of schools, i.e. the individuals whose guidance is thought (in literature) to be essential for meeting the 2050 carbon reduction targets. In some cases, the leaders have been proactive in adhering to the advice/guidance of the Carbon Trust but in many cases, they are not enlightened enough about BIM, GSL and post-occupancy management issues that determine the effectiveness of energy efficient measures.

Table 3: Interview data summarised into 5 themes and 11 sub-themes

Major themes	Sub themes	Interviewee 1	Interviewee 2	Interviewee 3	Interviewee 4	Interviewee 5	Interviewee 6	Interviewee 7
Handing over of buildings	***Type and location of maintenance information***	Not sure	We have hard copy O&E manuals	This is available in PDF	No response	Kept by maintenance contract firm	Hard copy kept in mechanical room	We have soft copies and hard copes
	Technical language of manuals	Somebody else reads manuals	Too complex to understand BMS manuals	Have not read it so do not know how easy	System came with printed manuals, easy to read	Operating manuals are not easy to understand	No response	Relying on external company for major issues
Capability to manage modern energy systems	***Availability of expertise in schools***	Not an issue, we have expert	We manage systems ourselves easily	Easy to understand and manage sensors and lighting controls	Form tutors in charge of LED control systems	Too complex for staff to learn/use	Automated lighting is sometimes faulty	Janitor is trained by school to manage system

	Sophisticated controls and user-friendliness	Boilers have simple control systems	BMS controls not easy to understand	Lighting controls are use friendly	Not sure	BMS managed and by external staff	Easy to use lighting controls	Boiler controls are very complicated
	Use of external companies	Not responding on time to requests in winter	No comments	Cost implications	Do not need outside help to manage	Additional cost of paying for expertise	Not sure	Running cost not easy to cover in budget
Integration with existing systems	***User control of new vs. old systems***	No comment	Motion sensors are helping to save energy	Infra-red sensors are helpful	Quality of lighting varies across facility	Issues with old controls and new BMS systems	Sometimes difficult to fix LED bulbs	Control systems are easier (touch screen)
	Analogue vs. Digital systems	Not sure	Operating digital and analogue systems concurrently is challenging	No response	Control systems do not work with non-LED lights	Not every part of facility uses BMS, some are old systems	LED lit rooms are preferred to rooms with older systems	New boilers are less noisy
Support for Measuring and monitoring CO_2 savings	***Know-how for carbon monitoring***	Do not know how CO2 is measured or monitored	Need training on carbon and energy efficiency	No response	No response	Not sure who might know this	Lack of expertise in carbon monitoring	Do not know how carbon is monitored of measured
	Real-time smart meters	Need smart CO_2 meters	Smart meters don't measure carbon, only energy used	No response	Smart meters were not installed	Do not think carbon is measured in our smart meters	Smart meters are helpful but not installed in every building	No response
CIF and SEEF funding	***Obtaining funding and payback period***	We had to submit application twice due to complex process	We wanted both CIF and SEED funding but had to settle for SEEF	Did not get enough money to cover entire school	Payback period is too short	Funding not enough to solve condensation problems	Process seemed too tedious for a lighting project	Not sure we will meet the payback period
	Financial vs. Technical advice	Boilers more expensive than budgeted	Needed more advice about the payback period	No response	No response	BMS saving money through automation	No response	Decision to invest needed maintenance team's input

DISCUSSION

The data collected from case studies suggests that there are a few instances were value for money was not realised or maximised. Some schools do not seem to be making informed and strategic decisions on the loan amount and what they spend it on for refurbishment. Interviewee 2 and 5 for example, stated that they needed help in making such investment decisions and the case study data suggests that although a school embarking on a costlier type of refurbishment may be responding to a need, yet where the loan amounts are similar (£5,358 and £4,438 taken as loan by Penair and Woodbridge schools respectively), the lifetime savings can be considerably different (with savings £21,256 and £13,790 respectively for these schools). There was also a significant carbon saving difference between them, i.e. 98 tonnes of CO_2 (Penair) against the relatively smaller 5.8 tonnes of CO_2 saved by Woodbridge. The significance of these results is that Penair spent their £5,358 on building management systems, while Woodbridge school spent their £4,438 on lighting upgrades. The difference that the additional £920 has made to the lifetime savings and carbon emissions savings makes it a better investment and value for money. Although, the uncertainty here is that Woodbridge may already have a BMS in place, this is unlikely since many BMS systems are typically linked with sensor based lighting systems. Therefore, their decision to invest in lighting upgrades as opposed to BMS could have been better informed. The case of Penair vs. Woodbridge school is an example of where professionals can provide guidance because although it is the administrators who apply for loans, the professionals who ought to be aware of energy assessment software and energy assessment standards were probably not involved in the application process. Or perhaps they were involved but did not give the schools the best possible guidance they need to make such investments, but this could be due to the limited expertise of the professionals.

The energy efficiency and carbon reduction decisions taken by school heads are important to the process. This point is buttressed by literature where it was reported that leading up to 2050, leadership was central to meeting low carbon targets, as opposed to mere compliance or carrying on with business-as-usual (DCSF, 2009). It was nevertheless found that some interview respondents [Interviewee 1, 6 and 7] were using the Carbon Trust's guidance on energy efficiency in schools. These respondents were referring to the "Good Practice Guide - 343 (GPG343), Saving Energy – A whole school approach" (Carbon Trust, 2003). It was a welcome development that they would implement guidance if it was provided to them. However further carbon education might be required because some respondents stated that: they "*Need smart CO_2 meters*" [Interviewee 1]; and their "*Smart meters don't measure carbon, only the energy used*" [Interviewee 2] or that "*we do not think carbon is measured in our smart meters*" [Interviewee 5]. These statements demonstrate the naivety among school heads who do not realise that carbon is not measured / metered as easily as electricity or gas. Such naivety may also be prevalent in other facets of the AEC industry.

Nevertheless, whereas Interviewee 1 thought "*We lack technical know-how to advise colleagues and students about boilers and energy efficient practices, but we have Carbon Trust guidelines*", Interviewee 5 argued that "We depend on automation of systems to help us manage the use of buildings. This seems better than depending on people". This point resonates with the findings of Palmer and Cooper (2012) who found that using sensors to reveal actual human behaviour would provide more accurate energy utilisation information than using simulations. However, this should not detract from the usefulness of simulations in predicting the patterns of energy usage. As argued by Shorrock, et al. (2005) most refurbishment work tends to be on envelope and insulation, yet the automation of lighting controls using infra-red or motion sensors [Interviewee 2 and 3] and the use of BMS demonstrates the paradox of funding available to schools, i.e. they either apply for CIF to fund the envelope or apply for SEEF to fund the energy systems, whose efficiency depends on heat loss/gain across envelopes. Perhaps these schools could apply for both funding schemes (obviously at different times) but the fact that the schools investigated in this study (SEEF beneficiaries) were constrained from partaking in CIF applications is a major constraint given the scope and focus of this research.

Interviewers 2 and 5 respectively said "*We had to rely on expert advice about our capability of meeting payback period*", "*Our school is rather old, so I am not sure we got the correct advice about payback period. The BMS helps to cut our bills*". Interviewer 1 said "*we needed some*

advice during the application process", but in one instance [Interviewee 6] the investment decision was deferred to the maintenance team. Interviewer 5 said "*We work with a tight budget and we had to outsource our maintenance needs on contract basis*". The heads of schools (and perhaps board of governors) who are in a best position to provide leadership in carbon and energy reduction targets seem to be not properly educated about important strategies like government soft landings, as suggested by interview data. The school heads interviewed were generally not aware of any post-occupancy or lifecycle use of BIM to manage their facilities although a few [Interviewees 1, 2, 3, 5 & 6] seemed to be vaguely familiar with 3D BIM (Table 4).
Overall, there was a consensus among the interviewees that the energy efficiency of their schools improved after SEEF intervention projects (Table 4) the data points to the inherent link between energy systems and building fabric; e.g. "*We do have condensation problems, but our heating bills have gone down*" [Interviewee 5] and "*we are benefiting from the new energy efficient boilers, but the fabric of the building is quite old*" [Interviewee 7, whose building was of Victorian age]. There are established methods of building pathology which could have helped designers with insights into the age environmental conditions (Golparvar-Fard and Ham 2014) e.g. the use of thermal imaging integrated into gbXML models that are compatible with BIM (Ham and Golparvar-Fard, 2015). Although the data from this study suggests thermography is not used during SEEF refurbishment, it is possible (but doubtful) that it is used even in CIF refurbishment of the physical envelope of schools. This again points to the problematic separation of funding purposes in SEEF and CIF projects. The insights from interview data and established literature raise questions about the wisdom of the policy that constraints schools to applying for either CIF or SEEF but not both, since building age influences heat transfer across building fabric regardless of how modern or efficient the lighting or energy systems might be.

Integrating real-time data collected by energy management systems with as-built 3D BIM models has been shown to be helpful for diagnostics and fault-detection in existing building (Dong, et al., 2014). However, without using such modern building pathology techniques (including energy simulation and thermography), the process of refurbishment may lack the accuracy required, even if when energy-saving systems like BMS are installed, as evident with Interviewee 5 who highlighted the condensation problems that remained after refurbishment. Arguably, the separation of SEEF from CIF funding is not helping. For example, a school wanted both SEEF and CIF funding but had to settle for only SEEF [Interviewee 2]. Such separation means schools are setting for less than optimal ways of reducing their energy and carbon consumptions as further discussed in the next section.

CONCLUSIONS

The funding model for refurbishment of state schools is primarily based on Condition Improvement Funding (CIF) loans or Salix-financed SEEF loans. At the point of application, these funding routes are mutually exclusive whereas from the technical and engineering perspective, the envelope and general condition of a school building (with or without expansion to the GIFA) covered by CIF influences the energy effectiveness of lighting and equipment covered by SEEF.

Therefore, the financial model needs to be revisited from a holistic and engineering point of view. Without active intervention to mitigate the carbon footprints from such schools, the carbon emitted from such schools will remain at their levels up to the year 2050. Therefore, leadership and initiative is thought to be a key determinant for meeting carbon reduction targets but the apparent lack of exposure to BIM concepts like GSL and COBie by heads of schools is problematic. Although some of these leaders are exposed to best practices published by Carbon Trust UK, these practices (Good Practice Guide 343 (or GPG343)) are essentially recommended benchmarks basic operational issues and everyday practices that school residents could adopt to save energy. The use of the stated toolsets for facility management is crucial to achieving the objectives of GSL. The schools that have benefitted from SEEF initiatives have largely benefitted from systems that enable them measure and control direct energy. For instance, the use of sensors for motion detection during lighting upgrades and smart meters that work with BMS has been widespread. These are not necessarily useful for monitoring carbon emissions and other forms of energy performance indicators or metrics like CO_2 monitors which are helpful for indoor air quality as well as airflow and water pressure and consumption monitors (helpful for sustainable use of buildings) do not appear to be used in schools. Given the three carbon reduction scenarios established in literature, i.e. Leadership, Compliance or Business-As-Usual, schools are not showing 'leadership' in reducing carbon. The steps they are taking to refurbish their facilities, is analogous to 'compliance' at best since they are and in many respects following the processes required to get energy efficient systems. However, in many respects, it could be said that they are carrying on with BAU since for example they are not able to receive CIF funding necessary to upgrade the fabric of buildings. Other important aspects of diagnostics and faultdetecting in existing building rely on integrating real-time data collected by energy management systems with as-built 3D BIM models; and the age and environmental conditions of buildings is critical for successful modelling and simulation. However, case study and primary data collected and analysed through interviews suggest that these modern techniques of diagnosis and building pathology are not used in the refurbishment of school buildings.

The recommendations that can be made from the findings of this study include: (i) heads of schools should be given intensive training on how the GSL is integral to the energy efficient and sustainable operation of their facilities; (ii) since the use of BIM has mandatory since April 2016 on all government funded projects, and the loans given via CIF and SEEF are underwritten by government, it should be made clear to professionals that school refurbishment projects should not be an exception, especially since no financial limit (or threshold) has been placed on projects for using BIM; (iii) training would be required for professionals and their organisation who do refurbishment so that they adopt modern processes (e.g. using NBS BIM Toolkit) or technologies (e.g. thermal imaging for fault diagnostics). This is because refurbishment of schools is likely to be done by SMEs who are known to be financially and technically challenged in adopting BIM, and as such, incentives and technical support should be given to them to bring them up to speed with modern developments; (iv) government agencies in charge of approving loans to schools should revisit the policy of granting only one kind of financial instrument (i.e. CIF or SEEF) and make it possible for schools to receive support for improving both the physical condition (CIF) and energy efficiency equipment and systems (SEEF).

Limitations of study and suggestions for future work:

This research is not without limitations. This paper has focused on SEEF funded schools with metrics that only cover cost, energy and carbon emissions. Therefore, schools that have opted for CIF and other education-related matters have already been excluded from the data collection and analysis. Given the scope of subject matter (e.g. refurbishment of SEEF funded schools), interview questions were focused on energy and cost issues. Interview questions could have included other metrics such as "the quality of life of building uses" and "the rate between graduated pupils number and carbon emission emitted by the building". This would have provided a richer set of data for comparative assessment and analysis. These limitations were imposed by time and accessibility constraints but can be addressed in future work through careful design of data collecting instruments and, of course, cooperation of heads of schools.

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