Glasgow Caledonian University

University for the Common Good

Could refurbishment of “traditional” buildings reduce carbon emissions?

Atkins, Richard Nigel; Emmanuel, Rohinton

Published in:
Built Environment Project and Asset Management

DOI:
10.1108/BEPAM-08-2013-0030

Publication date:
2014

Document Version
Peer reviewed version

Could refurbishment of "Traditional" buildings reduce carbon emissions?

R. Atkins[1], R. Emmanuel[1]

[1]School of Engineering and Built Environment, Glasgow Caledonian University, Glasgow, UK

Citation:

Atkins R, Emmanuel R. 2014. Could refurbishment of "Traditional" buildings reduce carbon emissions? Built Environment Project and Asset Management, Vol. 4 No. 3, pp. 221-237. DOI: http://dx.doi.org/10.1108/BEPAM-08-2013-0030

Could refurbishment of "Traditional" buildings reduce carbon emissions?

Structured Abstract

Purpose - Evaluate the post occupancy performance of a typical ‘traditional’ building using multiple Post Occupation Evaluation (PoE) protocols against design intents to learn lessons about their suitability in meeting UK’s climate change reduction targets.
Design / Methodology / Approach - PoE studies of a single case study, Norton Park, using three PoE methodologies. Gaps and overlaps between the PoE protocols are assessed and their role in improving energy and carbon emission performance of traditional buildings is explored.
Research Limitations / Implications – Traditional buildings could positively contribute to achieving climate change reduction targets; Regular feedback loops improve performance over time.
Findings – Refurbishment of the type undertaken in this case study could halve the energy use in traditional buildings with comparable savings in CO_2 emission.
Practical Implications - Quantification of the likely national benefit of focusing retrofit actions on traditional buildings is explored.
Originality / Value - The research study demonstrates that very high levels of energy saving can be achieved when traditional buildings are refurbished. In addition on-going monitoring and PoE studies highlight opportunities to optimise the performance of traditional buildings.

Keywords: Energy Efficiency, Comfort, Refurbishment, Post Occupancy Evaluation (PoE), Traditional Buildings

1 Introduction

The need for steep reductions in carbon emission is widely recognised (IPCC, 2013) and the UK has enacted legislation for an 80% reduction in CO_2 emission by 2050 over the 1990 levels (Climate Change Act, 2009). Scotland has a similar overall target but its path to this final destination is much steeper.

44% of the UKs annual CO_2 emissions come from the built environment. 26% are associated with domestic and 18% with non-domestic buildings (Carbon Trust, 2009; UKLCTP, 2009). And, nearly 87% of the buildings that will stand in 2050 (the target year for the Climate Change Act) are already built (Emmanuel and Baker, 2012). Hence the focus of this study is on existing, rather than new buildings (cf. Sullivan, 2007).

‘Traditional’ buildings are a key sub-group of the existing stock. The Scottish Government defines traditional buildings as ‘*those built using hygroscopic materials and techniques allowing water vapour to move through the building fabric*’ (Technical Handbooks, 2010). They were the predominant form of building construction prior to 1919 and 19% of Scotland's housing stock falls in this category, with an average annual CO_2 emission of 9.2 tonnes per dwelling per year (Walker et al., 2010) compared to 1.5 tonnes for a typical new building as assessed by SAP 2009 (Technical Handbook, 2013). Although the age and size of the non-domestic building stock in Scotland is unknown, the magnitude of the carbon challenge is likely to be similar to domestic buildings since their construction methodologies are similar – thick stone walls lined with lath-n-plaster and timber roof structures with either slate or tiled coverings (Urquhart, 2007). The combination of the historical and cultural importance of traditional buildings (Scottish Government, 2013b), the financial value of the existing stock and the slow rate of new construction means that the pre-1919 building stock will continue to accommodate many of Scotland's businesses and families long into the future.

In this study we investigate the performance of Norton Park (NP), a typical pre-1919 building refurbished in 1999, using three post occupancy evaluation (PoE) methods to explore its suitability in meeting the climate change reduction targets as well as to compare and contrast the ability of the PoE methods to capture the actual performance. NP is already well known (BRESCU, 2001) to have had a much improved energy performance and one of the present authors (Richard Atkins) was the Project Architect during its refurbishment.

2. Background

The United Nations Conference on Environment and Development (UCED) in June 1992 led to the United Nations Framework Convention on Climate Change (UNFCCC) in 1997, to which the UK is a signatory and from which key legislation has been passed by European, UK and Scottish Parliaments, reinforced by strategic plans and targets. Prominent amongst these are the Energy Performance of Buildings (Scotland) Regulations 2008, which brings into Scottish law the requirements laid down by the European Directive 2002/91/EC(2003) – Energy Performance of Buildings Directive (EPBD, 2008). These included the provision of Energy Performance Certificates (EPCs). Nationally, the Climate Change (Scotland) Act 2009 set a target of a 42% reduction in CO_2 emissions by 2020 and an 80% reduction by 2050, both relative to 1990. In compliance with Section 35 of the above Act the Scottish Government's published policies includes a commitment that "*by 2050, direct emissions from the (*non-domestic*) sector will be almost zero through reducing the sector's energy demand, the use of low carbon electricity sources, and our ambition for a largely decarbonised heat sector by 2050, with significant progress by 2030*" (Scottish Govt., 2013a).

2.1 Retrofit options in cool/temperate climates

Traditional construction was a robust response to a challenging climate, using locally sourced materials and ensured that as water vapour moved through the building fabric it was dried by the internal impact of open solid fuel fires and externally by wind movement. The acceptance of lower internal temperatures during the winter, greater ventilation losses, restricted access to bathing and the practice of cooking over a range within the chimney piece minimised moisture generation within buildings. However, user expectations and lifestyles have changed and in the present context the main approach to low or zero carbon (LZC) existing buildings is to reduce heat loss. This can be achieved by adding thermal barriers (insulation) to roof, walls and/or floors and increase the air tightness of buildings (mainly through windows and openings).. Furthermore, efficient mechanical heating systems reduce energy and CO_2 emissions commensurate with achieving acceptable indoor comfort levels (Emmanuel and Baker, 2012).

While the basic approach to CO_2 emission reduction in non-domestic buildings is similar to domestic buildings (insulation, windows and glazing, heating and controls) a key difference is the internal thermal loads in large non-domestic buildings, which make them behave as cooling dominated buildings even in temperate climates. Thus, the efficiency of appliances and lighting installations should be improved before any other measures are undertaken (Jenkins et al., 2009). Without this, fabric improvement such as increased insulation and air tightness alone could potentially be counter-productive (Gul, et al, 2012) and could lead to overheating problem, especially under predicted climate change scenarios (Phillipson et al., 2007).

Jenkins et al., (2009) highlighted the following key issues facing non-domestic buildings in temperate climates:

1. On-site energy generation can only achieve significant savings if very large systems are installed and these are difficult to justify economically. The goal should be an overall reduction in the CO_2 intensity of delivered energy.
2. Capital and whole life cycle costs of technologies needed for large emissions reductions (especially beyond 50%) are high.
3. The goal of "net-zero" carbon non-domestic buildings will not be achieved, by any definition, without dramatically reducing the energy consumption of appliances and lighting, since few existing buildings will be able to satisfy their electrical energy demand through on site generation of energy using renewable sources (Jenkins et al., 2009).

2.2 Role of Post Occupancy Evaluation (PoE) in retrofit decision making

PoE has emerged in recent times as an effective monitoring tool, largely for new buildings shortly after completion (Bordass, Leaman, 2005). PoE is designed to provide feedback to owners, managers and designers (Loftness, et al, 2009) and three methodologies have come to the fore in the UK. Table 1 shows a comparison of these methodologies using the BREEAM "in-use" checklist

A. BREEAM “in-use”
Building Research Establishment Environmental Assessment Method (BREEAM) “in use” (BES5058, 2011) is an extension of the BREEAM Tool that assesses the design intentions of a building. BREEAM “in-use” consists of an on-line tool which delivers ratings for Asset, Building Management and Organisation from a single set of assessment criteria. BREEAM “in-use” reconciles the inherent conflict between qualitative and quantitative data by quantifying the existence of policies, targets and the reporting of qualitative issues. It can be used as a self-assessment tool by building owners / managers or as a "certified" performance tool by independent auditors. The author's undertook a self assessment andthe result have not been independently audited.

B. Soft Landings
The Soft Landings (BSRIA BG, 2009) approach aims to avoid the post completion blame culture and has recently been integrated into the Royal Institute of British Architects (RIBA) Plan of Work 2013: www.ribaplanofwork.com/ which includes aftercare stages 4 and 5 where the building fabric and systems are evaluated. Its recommended method is a Building User Satisfaction (BUS) survey developed by the Usable Buildings Trust (UBT), now available through http://www.busmethodology.org.uk/process/ together with an energy audit in line with TM22 developed by the Chartered Institute of Building Services Engineers (CIBSE, 2006). UBT provided the authors with access to their software, but have not audited the results.

C. Design Quality Method
The Design Quality Method (DQM) (Cook, 2007) is a visual non-intrusive survey by expert assessors who take energy meter readings, internal comfort parameters such as temperature, sound and light levels and interview key building users and managers. The observations and conclusions are recorded as narrative and in a series of tables benchmarked against a peer group of similar buildings. The process itself is proprietary, protected and available on a commercial basis from DQM Solutions Limited, www.dqm.org.uk The authors undertook the analysis based on the published guidance and benchmarked NP against their own experience.

Table 1: Comparative Criteria of the PoE Methodologies

Parameter	BREEAM “in-use” Asset Rating	Soft Landings	DQM	Remarks
Energy	CO_2 emissions Sub-metering energy uses Sub-metering areas Renewables Low emissions	CIBSE TM22	Meter readings provided by building user	BREEAM prescribes 5 measurables, whereas Soft Landings makes use of an existing methodology and DQM relies on utility bills.
Water	Consumption Metering Leak detection Recycling	No specific criteria are included. But performance KPIs can be set at the outset of a project	No specific criteria are included	Only BREEAM “in-use” addresses these issues explicitly
Materials	Robustness Maintenance Security Fire Protection	Aftercare steps include review and walkabout steps to identify failure before it occurs	Consideration of fitness for purpose of materials is spread across a number of the DQM matrices	
Waste	Storage availability			Only BREEAM “in-use” addresses this issue explicitly
Health & Wellbeing	Daylighting	Soft landings makes use of UBT’s Building User Satisfaction (BUS) survey process	Consideration of design quality is spread across a number of the DQM matrices, based on professional judgement informed by on-site measurements	
Pollution	Ground Water Flood Risk Flood Management Refrigerants Emissions NO_X etc Land Contamination	No specific criteria are included. But performance KPIs can be set at the outset of a project	No specific criteria are included	Only BREEAM “in-use” addresses these issues explicitly
Transport	Amenities Cyclist Facilities Accessibility Pedestrian / cyclist safety	No specific criteria are included but performance KPIs can be set at the outset of a project	No specific criteria are included but spatial planning is included as a criteria	Only BREEAM “in-use” addresses these issues explicitly
Land Use & Ecology	Ecological Value			Only BREEAM “in-use” addresses this issue explicitly
Finance			DQM includes a matrix on whole life costs	Only DQM addresses this issue explicitly
Information	The provision of information is covered in the building management and organisational rating sections	Soft Landings includes the requirement to make information available through both after care steps		

2.3 The case study building: Norton Park School, 57 Albion Road, Edinburgh

Formerly a school built in 1902, NP is Category B listed (Historic Scotland, 1995) and was refurbished by Burnett Pollock Associates in 1999 to form co-location offices for the voluntary sector. The client's brief included a commitment to reduce energy consumption to well below the requirements of the local building codes for new buildings at the time (Scottish Executive, 1999)

Figure 1: Main Elevation

Figure 2: Mezzanines in Former Class Rooms

On completion the project was recognised by "The Sir Robert Grieve Award for Sustainability," a "Scottish Regeneration Award" and a mention in the "Civic Trust Awards" all in1999. Norton Park has been the subject of a number of academic papers (Atkins, 1999, Atkins and Emmanuel, 2012) and has been cited as a case study in two publications (CIBSE, 2002; The Prince's Trust, 2010).

2.3.1 The Design Approach

The design approach consisted of internally insulating walls, adding secondary glazing and loft insulation to improve fabric performance together with modern services and controls including background ventilation. The refurbishment increased both the floor area and the net to gross from 61.7% to 72.8% by adding mezzanines within the former class rooms (Figure 2).

A noteworthy achievement of fabric improvement was the reduction in the average U-value from 1.94 to 0.45 W/m^2K (much below even the present standards) (Table 2). The building regulations in place at the time required no fabric improvements, as the change of use from school to offices was not considered to be more onerous. Even today the current building regulations only require improvements to listed buildings where these can be made without compromising those characteristics which led to the listing. A background ventilation system provides fresh air, has heat recovery and incorporates a passive solar slate system on the top floor (Figures 3 and 4), where the solar gain from the south west roof is used to pre-heat the ventilation intake air. This system provides fresh air during the heating season but was not intended for summertime cooling in this otherwise naturally ventilated building.

Table 2: Comparison of Fabric and Services improvements

Element	Prior to refurbishment	Post Refurbishment	Regulatory target in 2013 regulations for new buildings
Thermal Transmission (U-Values) (W/m^2K)			
Ground Floor	0.28	0.28	0.25
Pitched Roof	4.32	0.14	0.16
Flat Concrete Roof	3.49	0.20	0.25
Flat Timber Roof	1.71	0.35	0.25
Roof Lights	N/A	1.10	2.2*
Stone Walls	1.55	0.20	0.3
Windows in Stone Walls	5.70	0.90	2.2*
Brick Walls	1.40	0.22	0.3
Windows in Brick Walls	5.70	1.10	2.2*
Average fabric U-value	1.94	0.45	0.75
Air Infiltration rate	15 m^3/m^2 @50Pa	10m^3/m^2 @50Pascals	10m^3/m^2 @50Pascals
Boiler	Oil 65% efficiency	Gas 89% efficiency	73% efficiency
Controls	Timed	Zoned for time, temperature, weather compensation, optimized start, etc	Included in overall efficiency
Lighting	Fluorescent, locally switched	T5's light / movement /timed	Power density = (illuminance / 100) x 3.75

* Total area of all openings equals 40% of the gross overall area of the external walls in setting the target for regulatory purposes

Figure 3 Passive Solar Slate System

Figure 4 Solar Gains to SW Roof Surface

At the time of refurbishment the client brief included the ambition to achieve the ENCON 19 – Best Practice performance levels noted in Table 4. Overheating was identified as a potential risk and the proposed solution was to include de-stratification fans given the natural ventilation approach of the building. However these fans were omitted as a cost saving measure post tender.

As part of this study the National Calculation Methodology (NCM) for non-domestic buildings for the UK (Simplified Building Energy Model [SBEM], available at http://www.ncm.bre.co.uk/) was used to predict the performance of NP as altered but not improved compared with altered and improved which are the numbers reported in the Energy Performance Certificate (EPC). The results in Table 4 show a predicted reduction in energy use of 61.7% and CO_2 emissions of 60% using this method.

3. Research Method

Results from the three PoE protocols described in the previous section were compared and contrasted against actual energy use and indoor temperatures. Data collection involved the following:

- Weekly meter readings available from the building owner (Albion Trust: http://www.nortonpark.org/) for a five year period (01.05.2006 – 30.04.2011);
- Structured interviews with the client and key facilities management staff, past and present (during these interviews summer overheating was identified as a continuing issue);
- BUS survey (14.08.2012);
- Thermal imaging;
- Indoor temperature using TinyTag data loggers at seven locations for a three month period (07.08.2012 – 08.11.2012).

Guidance to each of the three PoE Methodologies was obtained from their authors and the results were analysed to identify gaps, overlaps and, with particular relevance to this paper, identify practical options for further optimisation of the performance of NP. The energy usage and CO_2 emissions in use were compared with those expectations set during the design stage and with those benchmark values that were relevant at the time.

The analysis of predicted energy use and metered data was undertaken over the summer months of 2012. The BUS Survey was undertaken on 14th August 2012 which happened to be the second hottest day of the monitoring period (see Figure 7 for temperatures). 122 building users (approximately half the number of total users) responded to the survey, which was issued by the reception staff who asked that complete surveys be "posted" anonymously in a ballot box provided. UBT recommend that the researchers remain on hand to encourage completion of the survey however this was not possible in a multi-tenanted building.

4. Results

4.1 PoE Survey Results

The BREEAM "in-use" results are presented as a number of “Stars” (1 = acceptable, 2 = pass, 3 = good, 4 = very good, 5 = excellent and 6 = outstanding). The scores for NP were:

- Asset: Three stars – Good (53.7%)
- Building Management: Four stars – Very Good (59.81%)
- Organisation: One star – Acceptable (53.94%)

The user has no access to the mechanism by which answers to the questions are scored thus it is hard to explain why the Organisational Rating is only “acceptable” but has a percentage score greater than the Asset Rating. A possible explanation is that the building owner felt that they directly employed too few staff (4-6 full time-equivalent) to justify a transport policy and therefore do not record, report or target travel nor calculate the CO_2 emissions associated therewith. Consequently a section of the questionnaire was by necessity left blank which may have reflected badly in the ‘Organisation’ category.

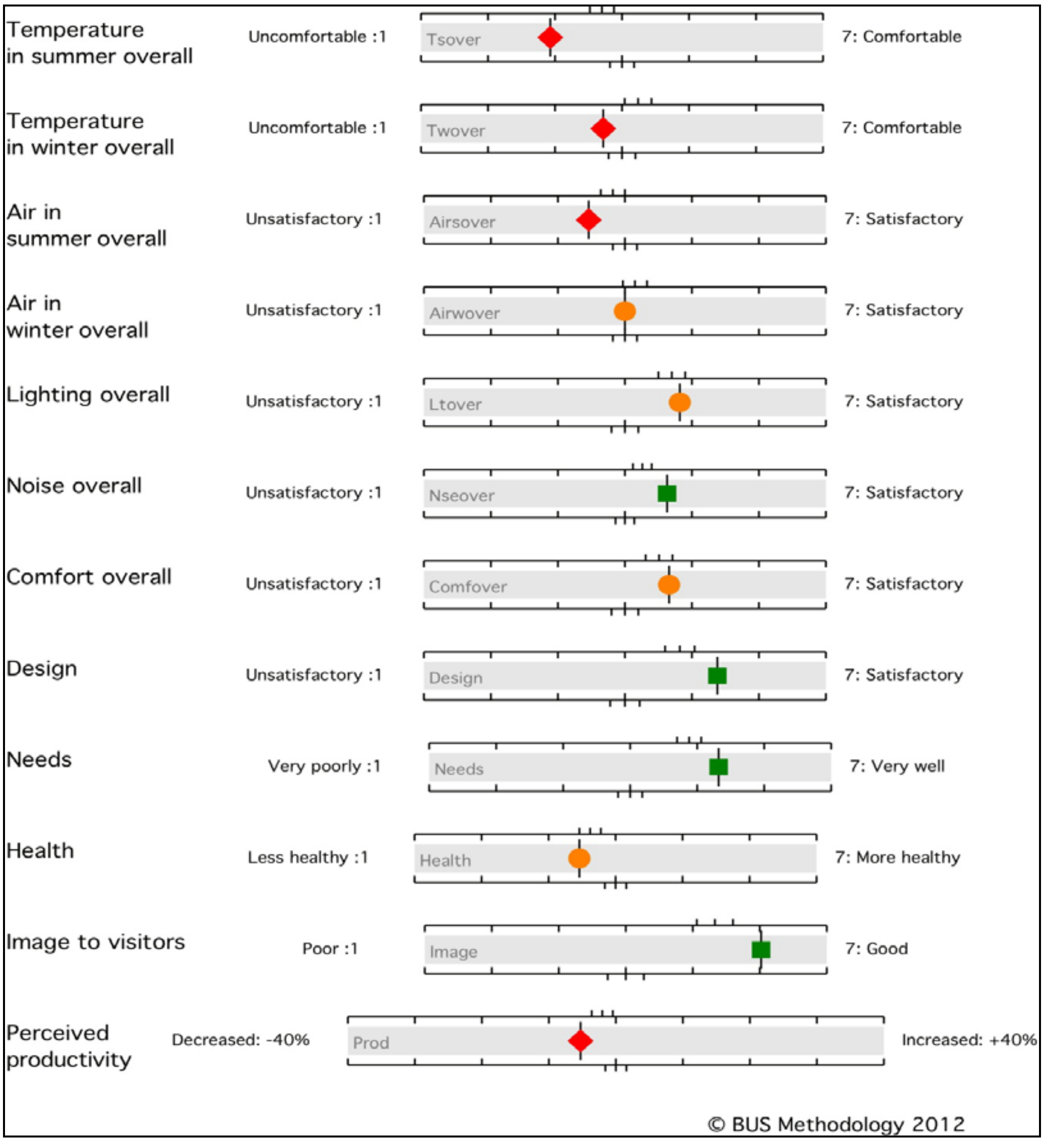

Figure 5: Overall Results of the Building User Satisfaction Survey.

The summarised results of the BUS survey are shown in Figure 5. The green squares in Figure 5 show which criteria in NP outperform the benchmarks established over time by UBT, orange circles mark criteria in line with benchmarks and red diamonds are those that fell below the benchmarks. NP falls short in temperature control and air quality in summer as was confirmed by monitoring of internal temperatures.

Figure 6 shows the DQM results, derived from the authors' assessment, across five matrices covering architectural quality, environmental engineering, user comfort, whole life costs and detailed design. Each of these matrices has sub-criteria and they are drawn together in an overall matrix. These mirror the BUS survey results with a lower than 'Best Practice' performance in user comfort. Looking beyond the ratings and graphical outputs from each methodology DQM's reliance on a narrative explanation is the most pro-active of the three.

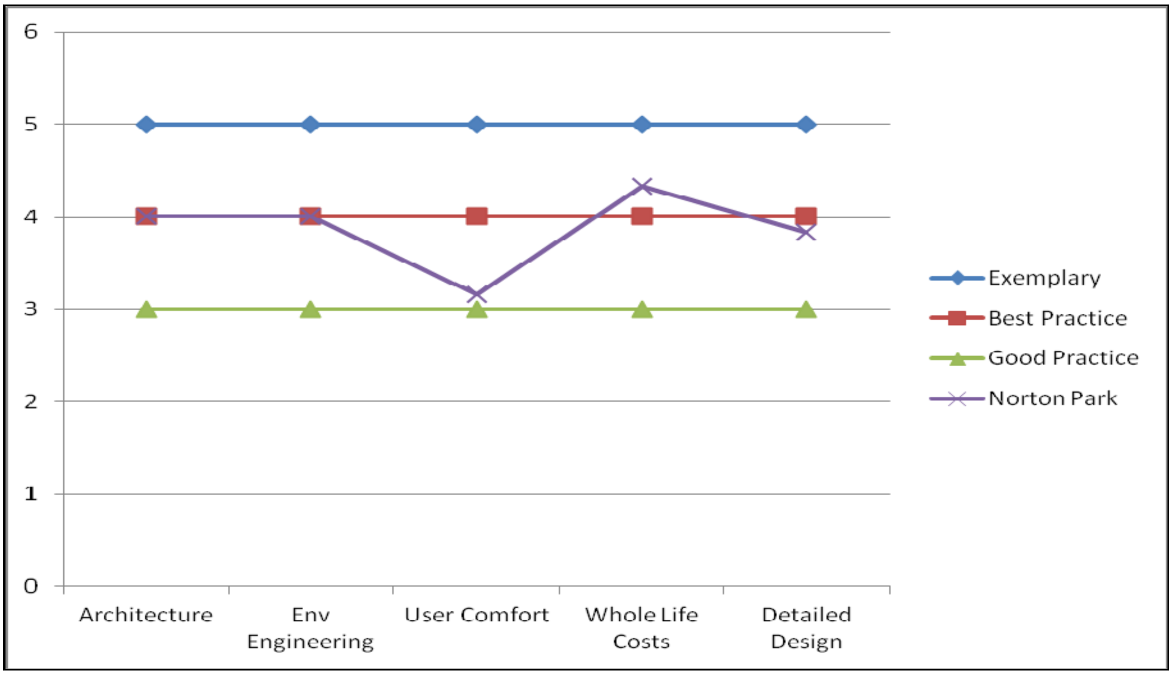

Figure 6: Overall DQM Results

4.2 Internal Temperature and Weather Data

Given the indication of summer overheating problem provided by survey participants we report only the hottest day during the measurement period (Figure 7) clearly showing those areas suffering most from overheating.

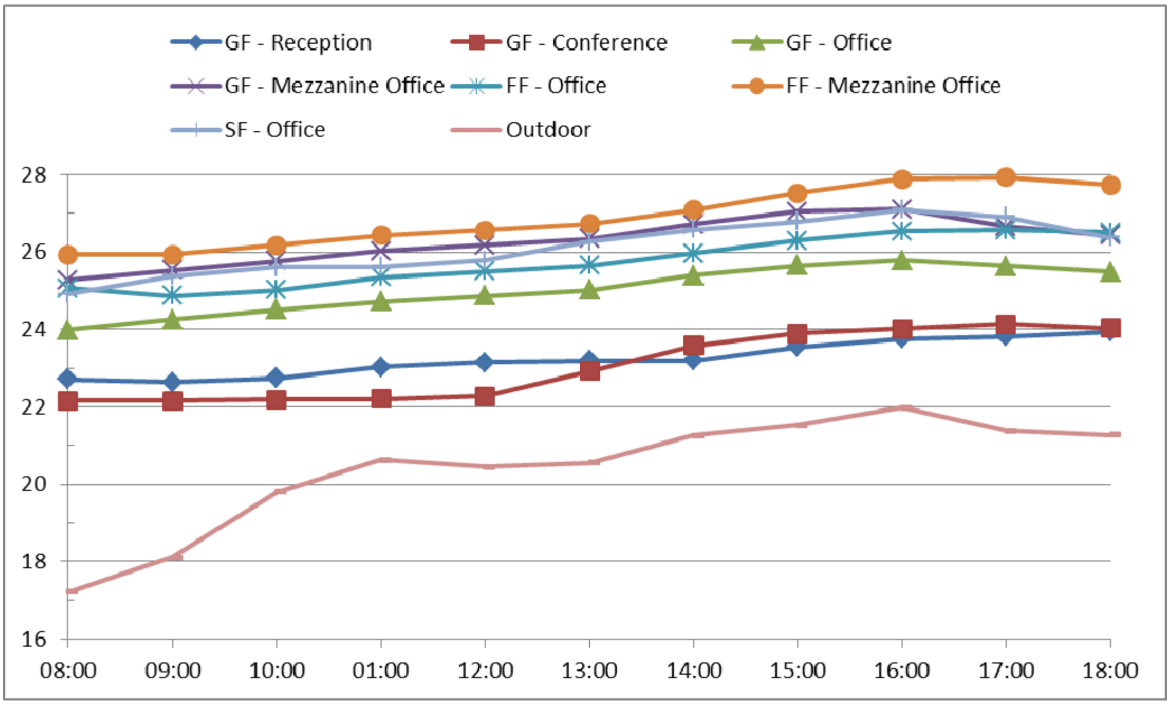

Figure 7: Internal Temperatures on the day of the Building User Satisfaction Survey

Note: GF = Ground Floor; FF = First Floor; SF = Second Floor

Table 3: Weather Data

Data Type	Monitoring Period (07.08.2012-08.11.2012)	BUS Survey (14.08.2012)
Maximum Temperature (°C)	23.0°C	22.0°C
Minimum Temperature (°C)	-3.0°C	15.4°C
Average Temperature (°C)	10.25°C	18.5°C
Ave. Temp drop over 24 hours	7.9°C	-
Temp. drop Over 24 hours	-	6.6°C
Maximum Relative Humidity	100%	97%
Minimum Relative Humidity	45%	61%
Average Relative Humidity	83.2%	81%

Table 3 summarises the weather data which was downloaded from www.wunderground.com (Station ID: ICITYOFE6) for the monitoring period (07.08.2012-08.11.2012) as well as the BUS survey date (14.08.2012). Although the monitoring period coincided with unusually warm temperatures, there was still a diurnal temperature change of 7.9°C, presenting an opportunity for overnight cooling.

4.3 Performance in Use

Table 4 presents energy consumption and CO_2 emission performance in use as calculated by the present study and compares these with various benchmarks over the life of the post-refurbishment period. Energy Consumption Guide 19 – ENCON 19 (EEBPP, 2000) was a commonly used benchmark for new buildings at the time of the refurbishment. The client set a design requirement to meet or better the "Best Practice" energy targets of ENCON 19. Energy Performance Certificates (EPCs) became mandatory following the introduction of the Energy Performance of Buildings (Scotland) Regulations 2008 and an EPC was completed in March 2009. The BRESCU study (2001) was a post occupancy evaluation carried out immediately following the handover of the refurbished building in 1999. TM22 re-measurements were carried out by the present study based on meter readings over a 5 year period (01.05.2006-30.04.2011). These are then translated into CO_2 emissions equivalent for each set of data based on the UK current emissions factors available from: http://www.bre.co.uk/sap2009/page.jsp?id=1642 (0.198 $kgCO_2/kWh$ for gas and 0.517 $kgCO_2/kWh$ for electricity).

It is important to note that the SBEM prediction and the Energy Performance Certificate (EPC) CO_2 emissions ratings, unlike the ENCON 19 benchmarks and the actual consumption data (TM22) do not include the energy and CO_2 emissions associated with the use of appliances such as computers, printers etc. On completion of the project there was a hiatus prior to the appointment of a knowledgeable Facilities Manager (FM), which coincided with the start of the BRESCU survey in 1999. On appointment the FM identified common commissioning issues such as high set point temperatures, timers left to run 24 hours a day, etc. Correcting these reduced energy use by 40% (from 249 to 150 $kWh/yr/m^2$) and CO_2 emissions by 36% (from 77.4 to 49.5 $CO_2kg/yr/rm^2$) bringing them more in line with the design intentions.

The results show that the total energy consumption (as measured by the TM22 re-measurement averaged over 5 years) is 5% greater than the design target (159 $kWh/yr/m^2$ against 167 $kWh/yr/m^2$), but the total CO_2 emissions are 5% lower (54.1 against 57.0 $CO_2kg/yr/m^2$) due to the different balance in emission factors between electricity and gas.

Table 4: Energy Consumption and CO_2 Emissions

	Gas kWh/yr/m^2	Electricity kWh/yr/rm^2	Total kWh/yr/m^2
SBEM – Altered but Unimproved	241(Oil)	114*	355
SBEM – Altered and Improved (EPC)	58	78*	136
ENCON 19 – Typical	151	137	288
ENCON 19 – Best Practice (Client KPI)	79	80	159
Before Appointment of Facilities Manager in 1999	161	88	249
After Appointment of Facilities Manager in 1999	88	62	150
TM22 Re-measurement 2013	101	66	167

	Gas CO_2kg/yr/m^2	Electricity CO_2kg/yr/rm^2	Total CO_2kg/yr/m^2
SBEM – Altered but Unimproved	72 (Oil)	26.9*	98.8
SBEM – Altered and Improved (EPC)	14.0	25.5*	39.5
ENCON 19 – Typical	29.9	70.8	100.7
ENCON 19 – Best Practice (Client KPI)	15.6	41.4	57.0
Before Appointment of Facilities Manager in 1999	31.9	45.5	77.4
After Appointment of Facilities Manager in 1999	17.4	32.1	49.5
TM22 Re-measurement 2013	20.0	34.1	54.1

* excludes unregulated electrical consumption

5. Discussion

The above results indicate that the refurbishment of NP has continued to deliver the design intentions, even fifteen years after the refurbishment. This was possible due to a client-driven requirement to reduce energy use by setting challenging KPI's. It took some time to optimise the mechanical and electrical systems and the previous BRESCU (2001) monitoring project greatly helped in this regard, underpinning the need and benefits of setting KPI's and then monitoring the results.

The FM staff were aware of localised problems with summertime overheating. The BUS survey quantified the impact on user comfort and bore out the view that in a group office, not everyone liked having windows open. The DQM narrative lead to a solution, now being trialled, which is to open the inner secondary windows overnight during the summer in the problem areas.

A nascent PoE industry is emerging driven by a relatively small number of clients keen to optimise their building stock, report to funders or meet their corporate social reporting commitments (Per, et al, 2012). The fact that no single methodology has yet triumphed from the three divergent approaches used in this study suggests that the industry is still at the stage of VHS v Betamax (Gibbs, 2004) and therefore malleable towards a more user-friendly and less data-intensive process. Despite their differences BREEAM "in-use", BUS/TM22 and DQM all aim for the same goals (Meir et al, 2009) - enable optimisation of a particular building, to inform future brief building and to develop benchmarks. A future direction for the PoE process is to use it to identify trigger points for specific interventions in the existing built environment, such as a major refurbishment, rather than on a limited basis to optimise existing assets.

Atkins and Emmanuel (2012) had previously estimated the payback period for the additional improvements at the time of alteration and refurbishment to be of the order of 12 years on a purely commercial basis. Given these facts, it is clear that traditional buildings such as NP are capable of contributing to the stiff emission reduction targets imposed by the Climate Change (Scotland) Act (2009). Given that the fabric improvements carried out in NP are compatible with traditional domestic properties, there is no reason to demolish traditional buildings to make room for more modern low carbon buildings simply to achieve the emission reduction targets.

5.1 Implications

This research study demonstrates that PoE offers a mechanism by which building managers can come to know and operate their building better, improving both energy performance and user comfort. PoE has a part to play in the development of improved standard assessment methodologies and both of these attributes could help deliver reduced energy use and CO_2 emissions.

All of the PoE protocols require a degree of knowledge and expertise on the part of the user to assess subjective observations and compare objective data. In the case of the BREEAM "in-use" and BUS the analysis of this data has been to some extent automated. This requires the user to have faith in those who have developed the tools. By contrast DQM relies more on the user having extensive experience in using the methodology. Each methodology has strengths. BREEAM "in-use" provides an extensive checklist and looks beyond just the built asset to management functions and organisational values. BUS/TM22 relies on statistically significant database from many studies. DQM is particularly well suited to the assessment of an estate of similar buildings, such as schools, where the aim is to share best practice across building managers and ensure that these lessons are ingrained in future projects.

6. Conclusions

The pre-1919 building stock can play its part in meeting the Scottish Government's emission reduction targets for 2020 and 2050. If the stock is refurbished to achieve a high performance at approximately 2.5% of the floor space per annum the energy usage of the stock can be more than halved. With greater CO_2 emissions achieved by a combination of decarbonising the electricity grid and the installation of some renewable technologies then the targets are achievable.

The PoE studies of NP show that NP is being operated very efficiently and is much liked by its users. It also provided confirmation that there are instances where the building overheats in specific locations in summer and that there is a simple management solution to this which is consistent with the original design intention. The growing evidence of the benefits of PoE (Bordass et al, 1997), (Audit Scotland, 2008) are supported by this study which has directly contributed to further optimising NP. When applied to those existing assets which are not necessarily as well managed, the energy cost savings can be extensive and justify the cost of a PoE study.

Ensuring that buildings are comfortable for their occupants has direct benefits for workplace productivity (Bluyssen et al. 2011) and by extension health or learning outcomes in the relevant buildings. These comfort levels need not be bought at the financial and environmental cost of extensive mechanical and electrical services (Atkins and Emmanuel, 2012).

If Scotland is to achieve the high CO_2 emissions targets that it has set for itself then there is a requirement for government, building owners, designers and other stakeholders to be more proactive in understanding traditional buildings and their performance. In embracing a "design approach" (Siva and London, 2012) the value of the existing building is assessed and understood through greater use of Conservation Statements (Forsyth, 2007) through to the use and alteration of traditional buildings. Where the design team have a thorough understanding of the differences in traditional versus modern construction (Oxley, 2003), the impact of previous adaptations and the current occupiers needs can be reconciled. Such an approach requires challenging but attainable performance targets to be set for any future intervention.

The simple act of retaining existing buildings, including where necessary finding new uses for them, and making alterations to cope with those uses to meet current regulations is increasingly important where individual buildings carry a high social importance or where the alternative might otherwise be area regeneration (Jacobs, 1961).

6.1 Further Research

This research study reinforces the belief that the vast majority of buildings in Scotland are underperforming in terms of energy consumption and comfort levels. The wide scale deployment of PoE studies would reveal both immediate "housekeeping" measures and potential fabric and services improvements that could be planned for. Specific areas of the further research needed are:

1. The development of a systematic approach to the collection of building data (Sunnika-Blank, Galvin, 2012)
2. More studies of traditional building before and after refurbishment (the few but excellent case studies that exists at present, such as the PROBE series of studies, are predominately of new buildings)
3. Calibration of current tools for energy performance and emissions measurement with actual in use data
4. More detailed testing of traditional buildings before and after alteration for airtightness and thermal imaging
5. The mechanisms by which PoE can be used on a regular, longitudinal and cost effective basis require developing and deploying.

References

Atkins, R. 1999. The Repair and Conversion of Norton Park, Edinburgh: A Sustainable Future for a Historic Building. *Journal of Architectural Conservation*, 5, 1, pp. 7-24

Atkins, R. Emmanuel, R. 2012. Carbon and energy reduction: a lifecycle case study of Norton Park, Edinburgh: *Sustainability Assessment Tools 2012 Conference Papers*: PP727 - 736.

Audit Scotland, 2008, "Improving the school estate": ISBN 978 1 905634 90 3, Audit Scotland, Edinburgh

Bluyssen, P, M. Janssen, S. van den Brink, de Kluizenaar, L.H.Y 2011, Building and Environment: *Assessment of wellbeing in an indoor office environment* : Vol46, Issue12 pp 2632-2640

Bordass, B. & Leaman, A. 2005, "Making feedback and post-occupancy evaluation routine 1: A portfolio of feedback techniques", *Building Research and Information*, vol. 33, no. 4, pp. 347-352.

Bordass, B. Cohen, R. Standeven, M. 1997, "PROBE 9": Building Services Journal April 1997 ppE21-E25

BRE-Global. 2011. *BES5058: Issue 1.2. BRE Environmental & Sustainability Standard*: http://www.breeam.org/filelibrary/BREEAM%20In%20Use/BES_5058_Issue_1_2_BREEAM_In_Use.pdf (accessed 26.06.2014)

BRESCU, *Norton Park Building, Edinburgh – feedback for designers and clients:* New Practice Study Case Study 127, Building Research Establishment, Garston, Watford. Available at: http://www.retrofitscotland.org/media/22647/npcs-127_brecsu.pdf, last accessed 26.06.2014

BSRIA BG. 2009. *The Soft Landings Framework for better briefing, design, handover and building performance in-use*. ISBN 978 086 022 6857, BSRIA BG, Bracknell, Berkshire

Building Standards Division of the Scottish Government (2010) *The Scottish Building Standards Technical Handbooks:* Appendix A - Defined Terms PP556, Building Standards Dvision of the Scottish Government, Edinburgh

Carbon Trust (2009), The Carbon Trust, Building the Future Today, Carbon Trust, London

235 Chartered Institute of Building Services Encinere (CIBSE). 2002. *Guide to building services for historic buildings: Sustainable services for traditional buildings*. ISBN: 1-903287-30-8

CIBSE. 2006. *Technical Memorandum 22: Energy Assessment and Reporting Methodology (EARM) Office Assessment Method*, CIBSE, London

Climate Change Act 2008. London: The Stationery Office. Avaliable at: http://www.legislation.gov.uk/ukpga/2008/27/pdfs/ukpga_20080027_en.pdf (last accessed 26.06.2014)

Cook, M,G. 2007. *The Design Quality Manual: improving building performance*. Blackwell. ISBN 1-4051-3088-1

Emmanuel, R. & Baker, K. 2012. *Carbon Management in the Built Environment*. Routledge. ISBN 978-0-415-68406-4, Routledge, Abingdon

Energy Efficiency Best Practice Programme (EEBPP). 2000. *Energy Consumption Guide 19: Energy use in offices* (Crown Reprint), Energy Efficiency Best Practice Programme, Brussels

EPBD, 2008. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:001:0065:0071:EN:PDF (accessed 26.06.2014)

Forsyth, M (2007) *Understanding Historic Building Conservation.* Chapter 14. ISBN9781405111720, Wiley and Sons, Oxford

Gibbs, Mark. "Betamax is Dead, Long Live the Case." *Network World Canada* 14, no. 19 (Oct 15, 2004): 23

Gul, M., D. P. Jenkins, S. Patidar, PFG Banfill, G. Menzies, and G. Gibson. "Tailoring a Future Overheating Risk Tool for Existing Building Design Practice in Domestic and Non-Domestic Sectors." *Building Services Engineering Research & Technology* 33, no. 1 (02, 2012) pp105-117

Historic Scotland, 1995. HB Number 30323 listed 9th August 1995: http://hsewsf.sedsh.gov.uk/hslive/hsstart?P_HBNUM=30323

Intergovernmental Panel on Climate Change (IPCC), 2013. The Fifth Assessment Report. www.ipcc.ch/ (accessed 26.06.2014)

Jacobs, J. (1961): *The death and life of great American cities: The failure of town planning*: Vintage reprint 1992 ISBN: 0-679-74195-X

Jenkins D, Banfill P, Pellegrini-Massini G. 2009. Non-domestic conclusions of the Tarbase project – Reducing CO2 emissions of existing buildings, TARBASE Project report. Available at: http://www.sbe.hw.ac.uk/documents/TARBASE_ND_REPORT.pdf, accessed 26.06.2014

Loftness, V., Aziz, A., Choi, J., Kampschroer, K., Powell, K., Atkinson, M. & Heerwagen, J. 2009, "The value of post-occupancy evaluation for building occupants and facility managers", *Intelligent Buildings International*, vol. 1, no. 4, pp. 249-268.

Meir, I.A., Garb, Y., Jiao, D. & Cicelsky, A. 2009, "Post-Occupancy Evaluation: An Inevitable Step Toward Sustainability", *Advances in Building Energy Research (ABER)*, vol. 3, no. 1, pp. 189-219.

Oxley, R. “Survey and Repair of Traditional Buildings – A Sustainable Approach”: Donhead, Dorset. ISBN 1 873394 50 0

Per, A.J., Theo van, d.V., Coenen, C., Daniel, v.F., Lindholm, A., Susanne, B.N., Riratanaphong, C. & Pfenninger, M. 2012, "In search for the added value of FM: what we know and what we need to learn", *Facilities*, vol. 30, no. 5, pp. 199-217

Phillipson, M. C., P. H. Baker, M. Davies, Z. Ye, A. McNaughtan, G. H. Galbraith, and R. C. McLean. "Moisture Measurement in Building Materials: An Overview of Current Methods and New Approaches." *Building Services Engineering Research & Technology* 28, no. 4 (11, 2007), pp303-316

Royal Ins of British Architects (RIBA), 2013. Plan of Work. Available at: http://www.ribaplanofwork.com/, last accessed 26.06.2014

S. Walker et al, "Scottish House Condition Survey: Key Findings for 2009" Published by the Scottish Government, 25th November 2010

Scottish Executive, 1999. *Technical Standards for Compliance with the Building Standards (Scotland) Regulations 1990*. Available at: : http://www.scotland.gov.uk/Topics/Built-Environment/Building/Building-standards/publications/pubtech/tech5thamd (accessed 26.06.2014)

Scottish Government, 2013a. "Low Carbon Scotland: Meeting our Emissions Reduction Targets 2013-2027: The Second Report on Proposals and Policies (RPP2)" http://www.scotland.gov.uk/Topics/Environment/climatechange/scotlands-action/lowcarbon/meetingthetargets (accessed 26.06.2014)

Scottish Government, 2013b. Creating Places: http://www.scotland.gov.uk/Publications/2013/06/9811/downloads (accessed 26.06.2014)

Siva, Jessica and London, Kerry. "Client Learning for Successful Architect-Client Relationships." *Engineering, Construction and Architectural Management* 19, no. 3 (2012) pp253-268

Sullivan L, 2007. "A Low Carbon Buildings Strategy for Scotland", Scottish Buildings Standards Agency, Livingston, ISBN 978-1-904320-06-7, Available at: http://www.scotland.gov.uk/Resource/Doc/217736/0092637.pdf, last accessed 26.06.2014

Sunnika-Blank, M., Galvin, R., 2012, 'Introducing the Prebound Effect: The Gap between Performance and Actual Energy Consumption', *Building Research & Information*, 40:3, 260-273

The Carbon Trust, Building the Future Today, 2009

The Prince's Trust. 2010. *The Green Guide for Historic Buildings: How to improve the environmental performance of listed and historic buildings*, ISBN 9780117068445, TSO, London

UKLCTP: "The UK Low Carbon Transition Plan - National Strategy for climate and energy", (2009), ISBN 978-0-10-850839-4, TSO, Norwich

Urquhart D. 2007. *Conversion of Traditional Buildings Application of the Scottish Building Standards Part 1*: Historic Scotland, Edinburgh

Usable Buildings Truct, 2008. Building User Survey (BUS) Methodology. http://www.busmethodology.org.uk/process/, last accessed 26.06.2014

Walker S, Cairns P, and Cormack D. (2010), Scottish House Condition Survey: Key Findings for 2009, Scottish Government, Edinburgh.