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RESEARCH ARTICLE

Performance evaluation of operational energy use in refurbishment, reuse, and conservation of heritage buildings for optimum sustainability

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Abstract

The operational phase of a building project has increasingly gained importance with their energy performance becoming valuable and determining their operational excellence. In most heritage building projects (HBPs), the operational energy use aspects are less considered, and a systematic way of analyzing their energy performance following project delivery is often lacking. The aim of this study is to evaluate the operational performance of refurbishment and reuse of UK listed church projects. The objective is to assess the operational energy use with a view to optimizing their sustainable performance. The methodology includes eight selected case study buildings refurbished and converted for multipurpose use. The case study approach provided qualitative insights into how the study contributes to a more structured requirements for energy management in HBPs with specific attention to energy-efficient building operations. The findings show the need to focus on fundamental areas of operational management (i.e. by developing and implementing more focused policy on operational energy performance of heritage buildings) to minimize the energy required to operate them. The challenges of implementing changes in operational energy performance improvement of heritage buildings are addressed in the form of recommendations that could lead to real results. The study concludes that leveraging these areas requires commitment from all heritage building stakeholders because they all have substantial roles in harmonizing the requirement for the project's sustainability and not just the building operators. Meanwhile, baseline project planning, periodic updating, monitoring, and managing the energy use pattern are suggested as measures that could greatly facilitate better energy performance to optimizing their

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sustainable reuse compared with the traditional approach of trying to improve their thermal performance.

1. Introduction

Current evidence suggests that by 2050, an 80% reduction in carbon emissions will be required by developed countries to avoid the damaging levels of climate change (AEA Technology Report, 2010). The refurbishment of old buildings could cut in carbon emissions of the UK by up to 60% by 2050 (Power, 2010). According to estimates by Carbon Trust, non-domestic buildings in the UK account for close to 20% of all carbon emissions (Kelly, 2010). Essentially, significant savings could be made through the improvement of energy efficiency in non-domestic heritage stock if long-term emissions are to be reduced. Thus, reduction in CO_2 emissions and the national dependency on finite fossil fuel resources can be achieved via major conversion/refurbishment of HBPs. This objective underscores a need to investigate energy use in buildings at both local and global levels to identify practical solutions at each level.

Using energy inefficient buildings locally will lead to greater energy consumption and wasteful utilization of resources with global effects. Meanwhile, if local problems are not sufficiently addressed, then they become global most especially when they are allowed to happen on an everyday basis all over the world. Therefore, seeking other possible approaches and sustainable solutions to curtail energy use in heritage buildings is important. According to Cassar (2009, p. 7), historic buildings must also fully engage in the process of "adaptation to climate change," lest they become redundant and succumb to "environmental obsolescence." Recommending a "long life, loose fit" strategy to managing historic buildings, the author implies that sustainable design practices must adapt to the particular circumstances of each building rather than be applied broadly to the entire built environment.

1.1. Research purpose and objectives

The purpose of this study is to evaluate energy performance of reuse listed church projects. To evaluate the energy performance of these projects, this study investigated the operational energy performance in reuse projects that involve listed churches converted for multipurpose use. The objectives include the following: (i) to investigate the causes of energy consumption in refurbishment and reuse listed heritage building projects and how it affects their performance; (ii) to determine the practical strategies required to deal with the cause based on a field survey conducted on selected buildings and; (iii) to make recommendations on how the gap in current knowledge of performance of heritage buildings in the operational phase could be bridged.

2. Literature review

Older buildings across Europe are key constituents of the existing building stock. In the UK, traditional buildings are categorized as pre-1919 (DCLG, 2010), and according to Coles et al. (2015) these were years when building regulations were completely updated. The traditional buildings are thus historically valuable buildings that align with the definitions presented by Urquhart (2007) and Drewe (2007) as having mass masonry (solid) walls with little or no insulation built into their fabric and have a single glazed window and high air infiltration levels. As part of the UK planning apparatus, in 1947, because of the value of these historical buildings, they became "listed" to protect their historic fabric and to ensure their appropriate conservation and preservation (English Heritage, 2004).

The listing of historic buildings thus relates to their inner and outer configurations (i.e., windows, door, roof, walls) requiring planning permission before they can be modified and/or their essential nature or character can be changed. By 2014, 374,081 listed buildings are already in existence in England alone. The greater parts of listed buildings are of advanced age with essential and growing requirement for their constant repair and maintenance as their age increases. Given the era in which traditional buildings were constructed, different assumptions exist in relation to their properties, such as their energy demand, energy use intensity, and total emissions related to their age. The assumptions are based on the premise that the age of these buildings influences their capacity to adapt the latest and the most efficient technologies (Coles et al., 2015).

According to Levine et al. (2007), when the properties and the technologies they employed are older, their performance is less beneficial. However, this assumption has not been verified in the case of refurbishment and reuse of listed churches. In major cities and urban areas across the UK, most listed buildings are considered "hard-to-treat" buildings, such as churches, and warehouses. Coles et al. (2015) indicated that initial preliminary studies show that the "Listed Building Status" may represent a barrier to improving the energy performance of buildings most especially when they are introduced not only to newer technologies (e.g., solar panels, solar water heating, and wind turbines) but also to more modest measures, such as double and triple glazing (Coles et al., 2015).

Improving the energy performance of these buildings could be argued to be relevant not only to the users and occupants of the buildings and their business operations but also to the existing stock of heritage buildings. However, the BSI 7913 (1998) encourages minimum intervention, a cautious approach to conservation, and energy efficiency improvement by not only putting the historic buildings into consideration but also into the larger environment. This idea is evident in BSI 7913 (1998, p. 7) which states that “in global environmental terms, the balance of advantage strongly favors the retention of existing building stock, particularly when performance in terms of energy consumption in use can be improved.”

Accordingly, English Heritage (2004, pp. 3-4) gave consent to the improvement of energy performance by stating that “retaining existing elements of construction in old buildings and seeking to enhance their thermal performance in benign ways rather than replacing them is a heritage conservation principle in line with the concept of sustainability.” Thus, conservation principles support changes that could be made to historic buildings that would fulfill both energy and building conservation principle.

2.1. Listed building refurbishment and sustainability issues

Currently, the strong drive for sustainability of the built environment and the desire to reuse or recycle existing buildings is constantly increasing with corresponding pressure for existing building stock that are listed because of their heritage value (Akande, 2015). According to Harrison and Oades (1997), a listed building is a structure that has special architectural or historic interest recorded in a statutory list. In England, listed buildings are classified in grades to show their relative importance. Grade I refers to buildings of exceptional interest and considered internationally important; these constitute 2.5% of all listed buildings. Grade II* refers to buildings of particular importance and more than special interest; these constitute 5.5% of all listed buildings. Grade II refers to buildings of national importance and of special interest; these constitute 92% of all listed buildings (English Heritage, 2011). Figure 1 shows the age range of listed buildings in the UK.

In the meantime, if listed buildings are to be acceptable for other use, then refurbishing them will be necessary. Other terms associated with refurbishment include conversion, renovation, retrofitting, and reuse of a whole building following a process of modifications and alternations. These terms imply that existing buildings are unusable in their current state. Riley and Cotgrave (2011) defined refurbishment as extending the useful lifespan of existing buildings through the modification of their basic configurations to provide a new or updated version of the original structure. Ashworth (1996) defined refurbishment as a term that originated from a combination of obsolescence and deterioration.

According to Riley and Cotgrave (2011), refurbishment of buildings is undertaken extensively in the UK for a variety of reasons, such as buildings being of such merit that replacement is less desirable. Most importantly, refurbishing existing buildings presents opportunities to add more value to the building through the possibilities of reducing the carbon cost of buildings through improved energy efficient design. In addition to improved energy efficient design, Sodagar (2013) argued that refurbishment of the existing buildings contributes to safeguarding community heritage and preserves the sense of attachment to a place, thereby justifying the conservation of a building rather constructing a new one. To achieve sustainable refurbishment, all principles of sustainable energy efficient building design should be exhausted where appropriate (Sodagar, 2013).

The concept of sustainability is discussed by Forster (2010, p. 186), who indicated that sustainability has two meanings within the context of building conservation philosophy, namely, a “green” agenda and perpetuation of a building's utility. The author asserted that “the ability of a building to be in continuous use is essential for its survival” in which case “change must be sensitively managed.” Similarly, this aspect is discussed in the ICOMOS Venice Charter (1964, Article 5), which states that *“the conservation of monuments is always facilitated by making use of them for some socially useful purpose.”*

Langston et al. (2007) opined that reuse of buildings has become an integral strategy to ameliorate their financial, environmental, and social performance. Thus, integrating historic building conservation with environmental concerns has become an innate feature of an agenda to support sustainability (Stubbs, 2004; Bullen and Love, 2010). This environmental concern in the reuse of buildings is also acknowledged by other researchers (Diamonstein, 1978; Robert, 1991; Murtagh, 1997; and Fitch, 2001) in historic preservation.

The above literature indicates that conservation principles provide an essential framework for the implementation of conservation projects, whether they are small-scale interventions linked to historic building maintenance or large-scale projects that involve adaptive reuse of a historic

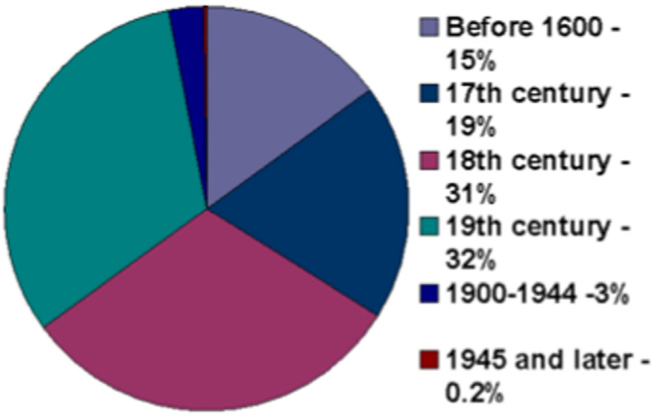

Figure 1 Age range of listed buildings in the UK. Source: English Heritage (2011)

building. While the conservation of listed buildings aligns with the core principles of sustainable development, their energy-led refurbishment is similarly important to their sustainability. May and Rye (2012) noted the dearth of research on energy use reduction within these specific asset types and expressed the importance of addressing this deficiency in relation to how they differ from other asset types.

2.2. Overview of energy assessment of existing buildings

A number of studies (Bell and Lowe, 2000; English Heritage, 2007; Building Research Establishment, 2009) indicate that retaining and upgrading existing buildings is more efficient and operational performance can be improved at less cost than new construction. Itard and Klunder (2007), Braganca and Mateus (2008), and Meijer et al. (2009) expressed the view that the environmental impact of life cycle extension through refurbishment is less than that of new construction. A shift in research has occurred toward understanding the composition and the dynamic behavior of existing buildings in relation to their operation, maintenance, and refurbishment.

Mithraratne and Vale (2004) developed a holistic approach to analyze the life cycle of existing buildings. The survey concentrated on the requirements and life cycle cost of embodied and operational energy over the useful life of an individual house. Their findings revealed the significance of operational energy as an important component within the life cycle and energy use by the building. More importantly, improvements to their insulation level are an essential step to reducing their impact on the environment.

Boardman (2007) reported his findings on the 40% house project and found that 60% of emissions of existing building stock could be reduced. He then described the strategies that could significantly lead to this reduction in the current UK housing stock by 2050. According to the author's findings, a 67% reduction in energy demand was achieved, thereby leading to significant emission reduction. An additional 33% reduction was achieved through the application of low and zero carbon technologies located in and around the buildings to provide energy for heating. The strategy used by the author could be argued to focus mainly on increasing the demolition rate of existing buildings and has resulted in much debate.

In contrast to the recommendation of Boardman (2007), Kohler and Yang (2007) suggested constant repair and renovation as opposed to increased demolition and rebuilding to achieve reduction in the overall emissions from the existing building stock in the UK. Lowe (2007) proposed a 20% cut in total delivered energy to reduce emissions by 60%. The above studies indicate that several approaches exist in determining the energy use capacity of an existing building. However, few studies have concentrated on investigating the operational energy use of existing buildings particularly with specific reference to the reuse of listed churches.

Literature findings indicate that operational energy constitutes the principal part (approximately 85%–95%) of

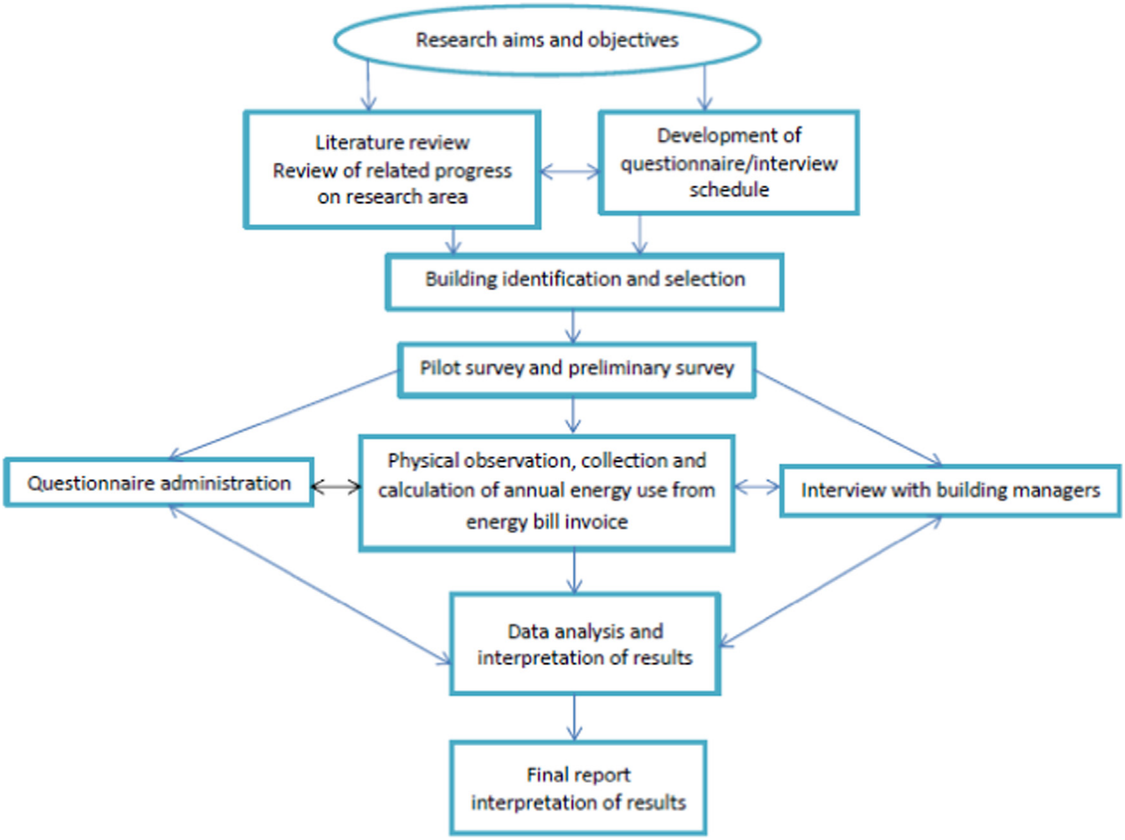

Figure 2 Methodological chart.

energy consumption within the life cycle of a building (Sodagar, 2013). Technically, while the existing building performance can be significantly improved, Judson et al. (2010) expressed concerns about increasing stringent requirements for energy efficiency and focus on ratings founded on operational energy performance, thereby resulting in conflict with cultural heritage significance and values associated with heritage buildings.

To date, minimal research has been conducted to determine the energy performance in the reuse heritage building projects in the UK. Thus, the focus of this study is to identify the current gap in knowledge specifically in relation to the performance of reuse and refurbishment of listed church buildings in the operational phase and how the gap could be bridged.

3. Research design and methods

3.1. Study area

Audet and d'Amboise (2001) and Yin (2009) argued that researchers select a site because of its convenience, access, and geographical proximity, and others select a site that they think can provide similar results or ones that are completely different to answer the research questions raised. East of England was selected for this study because the region constitutes one of the highest number of church conversions in the UK and has a good representative mix of Grade I, Grade II*, and Grade II buildings. In general, the selection of this site not only provides a representative mix of grade of the buildings, but could also provide both similar and divergent results, which could also provide a deeper understanding of the problem under investigation (Audet and d'Amboise, 2001).

In addition, the selection of the East of England was inspired by the research problem under investigation. The region has the third highest number of listed buildings in the UK after South West and South East. East of England has more than 2300 places of worship (Norfolk alone has more than 700) and the largest number of Grade I and Grade A churches. Limiting the scope of this study to this site ensures that the selected buildings share the same regional identity and similar environmental characteristics and challenges.

3.2. Research strategy

Figure 2 shows the methodological chart of the research strategy and design. A qualitative approach and interpretation of data using case study method is adopted for the study. According to Yin (2014), as cited in Coles et al. (2015), the case study approach presents two main opportunities, namely, a greater intensity of engagement between the researcher and the subject, and the triangulation of quantitative metrics with rich qualitative data to make sense of complex phenomena. As recommended by Yin (2014), a purposive sample was applied to select buildings that were refurbished and converted for multipurpose use.

Building operators or managers and owners were approached to obtain their consent to use their buildings. Those who showed interest in taking part in the survey and gave consent to reviewing their energy consumption and operational management styles were contacted. The case study approach has been adopted by other researchers, such as Sodagar (2013), who stated that the approach enabled a detailed analysis of potential improvement to the sustainability of building refurbishment and reuse through quantifying carbon emissions of different uses of the buildings.

3.3. Building selection strategy

The performance evaluation was investigated by Akande (2015) within a broad range of four years of doctoral research on energy management and the refurbishment of UK listed church buildings. Specifically for this study, a purposive sampling of potential building cases was used to select eight UK listed church buildings that were converted for other uses to conduct the survey. This selected number was determined by the building location, accessibility, travel costs, and time factors. According to Saunder et al. (1997), no rules for sample size in non-probability sampling exist. Rather, the actual size depends on available resources and the logic behind the sample selection. Thus, the adopted sampling method and the sample size were deemed sufficient for this study.

3.4. Instrument and procedure

The research adopted a triangulated methodological approach that consists of desk study and a self-developed questionnaire. The developed questionnaire consisted of items in different formats that asked either for one option or all-that-apply questions and dichotomous answers like "yes" and "no." The questionnaire was designed by the researcher and incorporated factors obtained from the review of relevant literature related to energy use in heritage buildings. A pilot study was carried out before fielding the full-scale survey to determine if the questionnaire worked as intended and to test the new procedures for interviewing the respondents.

The questionnaire was administered by the researcher through face-to-face techniques. It was given to the building managers to obtain records of energy bills and other information on the characteristics of the building, such as the type of energy use, construction material, and building age. The copy of the questionnaire is included in the Supplementary Appendix of this paper. The interviews were conducted between late November 2012 and the end of January 2013. The procedure began by visiting the sampled building to locate the building to ensure that the building met the eligibility criteria.

During the first visit to the building, a knowledgeable person was identified for the interview and was given an advance copy of the questionnaire and a note to book an appointment to return for an interview after allowing enough time for the respondent to look over and complete the survey instrument (Table 1). Following this step, another visit was made to the building at the set appointment to conduct the interview. To minimize nonresponse, encourage participation, and achieve the highest possible response rate, the researcher made efforts every week to contact the building managers through e-mails and phone

Table 1 Timeline of administered questionnaire, procedure, date, and duration.

Period	Procedure	Date and duration
Week 1	Questionnaire piloted	November 26-30, 2012 (5 days)
Week 2	Questionnaire modified	December 3-8, 2012 (6 days)
Week 3	First visit and pre-notice letter to building managers	December 10-14, 2012 (5 days)
Week 4	Buildings 1 and 2 visited	December 17-21, 2012 (5 days)
Week 5	Buildings 3 and 4 visited	January 2-4, 2013 (3 days)
Week 6	Buildings 5 and 6 visited	January 7-11, 2013 (5 days)
Week 7	Buildings 7 and 8 visited	January 14-18, 2013 (5 days)

Table 2 Building operational performance evaluation criteria.

	Area of investigation	Data required
1	Building characteristics	Type, size, use, grade listing, construction details e.g. age, when rehabilitated, occupancy maintenance etc.
2	Energy using equipment/systems	Type and key equipment - lighting refrigeration, heating, age efficiency, maintenance /replacement practices, etc.
3	How equipment is used	Hours of operations, controls
4	Energy used	Energy consumption data - type, monthly annually, in total, energy management practices.
5	Energy management options	Actions taken to improve energy performance, policies, etc.
6	Behavior	Actions taken to control user's behavior.

calls prior to the visit. The survey instrument addressed the apparent association between the new use and energy performance, the operational patterns of the new use, and the building performance.

3.5. Data collection strategy

According to Rohdin (2011), two methods may be used in the post-occupancy evaluation of a building's performance, namely, energy auditing and user perception surveys. Energy auditing includes monitoring the energy consumption, temperatures, and humidity levels. The user perception surveys are useful for describing the occupants' perceptions and experiences of the indoor environment. As the focus and the main objective of this study are the post-occupancy operational energy performance, energy auditing was adopted to evaluate the performance of the refurbishment projects. Only energy use of the buildings was monitored by evaluating and examining the energy bill invoice of the last twelve months. No instrument was used to measure the indoor temperature and humidity because of limited resources and more especially because it was not reflected in the objective of the study. To collect relevant and data, access to the selected building premises was requested.

Initially, the intention was to make the data collection a day-long exercise; however, in practice, more time is needed. The basic building information required (i.e., floor space, occupancy, age of the building, listed building status) was obtained in concert with the energy use invoice and metered data (Table 2). The main environmental and operational procedures were noted with notes taken from short unstructured interviews with building operators/managers. Operational energy consumption data necessary to heat, cool, light, and provide electrical services for 12 months were collected. The figures were converted to kg of CO_2 and ranked in order of absolute energy consumption. This step was necessary because the operational lifespan of a building is a substantial factor that affects a building during its useful lifetime.

4. Data analysis method

4.1. Energy benchmarking

To analyze the collected data, energy benchmarking was performed to provide a reference and measurement standard for comparison (Table 3). Wireman (2004) defined benchmarking as the continuous activity of identifying, understanding, and adapting best practice and processes that will lead to superior performance. This approach involves the development of quantitative and qualitative indicators through the collection and analysis of energy-related data and energy management practices (CDM, 2002). The collected data were entered in a database that contained several matrices of quantitative and qualitative data to conduct a preliminary analysis. The procedure involved calculating a series of standard indices for energy use and efficiency considering a range of energy-related practices and behavior.

To convert energy use (kWh) to carbon emissions (CO2e), Defra's conversion factors (Defra, 2010) for gas and electricity was applied. The energy consumption data of the surveyed buildings assumes CO_2 emission factors of 0.184 kg of CO_2/kWh for gas and 0.542 kg of CO_2/kWh for electricity.

4.2. Energy usage and carbon footprint

To obtain the approximate energy of the surveyed buildings, two main methodologies are identified and distinguished from the literature: top-down and the bottom-up. The top-down methodologies rely on the availability of measured energy demand values (Pérez-Lombard et al., 2008). The bottom-up methodologies calculate the energy use intensities (EUI) for representations of buildings (Kavgic et al., 2010). A common reference value to determine the EUI is usually the gross floor area, and it is extensively used in architecture and expresses the size of a building. However, the bottom-up methodologies were adopted for this study. Carbon emissions can be reported in both absolute and relative terms. Absolute emissions refer to the total footprint, whereas relative emissions refer to the absolute figure indexed to a unit of this per m^2 per performance, which can also be referred to as intensity indicators. For the purpose of this research, the carbon emissions of all the surveyed buildings were partly reported in absolute and relative emissions.

4.3. Performance ranking

To facilitate comparison of energy use among the building use typology or pattern of use, total energy use in each category was determined and given an overall rank according to their performance ranges (1=high performance, 8=low performance). The ranking will enable the building owners and the facilities managers to compare their building performance to a building with a similar size and pattern of use to be adequately informed on the actions to be taken to boost the performance of their buildings.

Table 3 Annual utility benchmarking.Source: CIBSE TM46:2008 Energy Benchmarks

Fuel Type	Benchmarks	Units	Benchmarked annual utility consumption
Gas	105 kWh/m^2	390 m^2	40,950 kWh
Electricity	20 kWh/m^2	390 m^2	7800 kWh

4.4. Data coding and ethical issues

During the data analysis, the interpretation, and the presentation of results, ethical issues were taken into consideration by intentionally coding the surveyed buildings with the use of an alphabet B1–B8 (Figure 3) to conceal the building's identities and location. This step is in line with the suggestion of Creswell (2009, p. 89) that the data collection process should not put participants at risk and that the vulnerable population should be respected by the researcher. Similarly, for ethical reasons, the building owners and the operator (i.e., the building managers) were assured prior to the survey that the name and location of their building will remain anonymous.

5. Results and discussion

5.1. Benchmark and energy consumption

Energy consumption records for 12 months in 2014 for each surveyed building and their analyses are presented. The results are compared with the CIBSE public community building benchmark and adjusted for building type and conditioned floor area per square meter. The majority (87.5%) of the building's energy use per square meter is significantly higher than the benchmark (Figure 1), thereby indicating that the energy performance of the buildings is generally poor compared with the benchmark. According to Figure 3, apart from building B7, which uses less energy than the rest of the buildings in similar climate conditions, only the annual energy use of B3 was slightly higher than the benchmark. The annual energy use of other buildings, namely, B2 (seven times higher), B5 (five times higher), B6 (three times higher), B4 (two and a half times higher), B8, and B1 (both two times higher) were significantly higher than the benchmark.

The benchmark figures (Table 3) show that the range of energy performance and differentiation in published energy benchmarks by CIBSE is 105 for gas and 20 kWh/m^2 (electricity), respectively. The major proportion of the energy used by the surveyed buildings originate from the buildings (B1, B3, B5, B7, B8) that use electricity and gas (Figure 3),

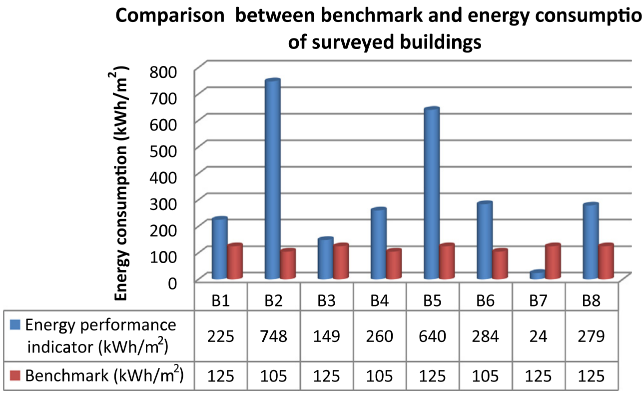

Figure 3 Comparison between benchmark and energy consumption of surveyed building.

Table 4 Building uses and characteristics.

Building code	Building primary and secondary uses	Building listed grade	Year of construction/age of building	Year of conversion
B1	Medieval art museum	Grade I	1313 (700 years)	2009
B2	Visitor attraction	Grade II*	1413 (600 years)	1994
B3	Religious group meetings and other community uses	Grade I	1412 (600 years)	1991
B4	Museum	Grade II*	1150 (900 years)	1958
B5	Food services and conferences	Grade II*	1312 (700 years)	2005
B6	Music concert and community uses	Grade II*	1100 (900 years)	2008
B7	Religious use	Grade I	1300 (700 years)	1990
B8	Community center	Grade II	1841 (200 years)	1996

Table 5 Operational energy performance ranking of surveyed buildings.

Building code	Floor area (m^2)	Building size category	Fuel type (electricity/gas)	Energy performance indicator (kWh/m^2)	Energy performance level	Energy performance ranking
B1	181	Small	Electricity and gas	225	LPB	3
B2	200	Small	Gas only	748	LPB	8
B3	327	Medium	Electricity and gas	149	LPB	2
B4	350	Medium	Gas only	260	LPB	4
B5	383	Medium	Electricity and gas	640	LPB	7
B6	392	Medium	Gas only	284	LPB	6
B7	830	Large	Electricity and gas	24	HPB	1
B8	866	Large	Electricity and gas	279	LPB	5

LPB - low-performing building.
HPB - high-performing building.

leaving only the remaining energy use for buildings (B2, B4, B6) that used gas. However, in the category of the buildings that use the same fuel type, B1 and B8 use double the required energy compared with the benchmark, while B5 uses far more (i.e., five times) the energy required compared with the benchmark. Surprisingly, B7 in this category uses far less required energy compared with the benchmark.

Figure 3 shows that reasonably high energy consumption is noticeable with the buildings (B2, B4, and B6) that used gas when compared with the number of buildings that used electricity and gas (B1, B3, B5, B7, B8) as only a marginal difference (25 kWh/m^2) exists in the total energy consumption between the two groups of buildings. These results indicate that the difference in energy use of the surveyed building is not a factor of the fuel type used by the buildings. The energy consumption of B2 is significant, i.e., up to seven times higher than the benchmark, and thee energy consumption of B4 and B6 is more than double (i.e., two and a half and three times, respectively) the benchmark.

The various uses of the surveyed buildings, their operational performance, and ranking are presented in Tables 4 and 5. The building (B9) used for other religious purposes use the lowest amount of energy (24 kWh/m^2) ranked first and is considered the best performing according to building use pattern. This building was closely followed by buildings used for a combination of religious group meetings and other community purposes, with energy use of 149 kWh/m^2. Buildings used as a medieval art museum ranked third (225 kWh/m^2), followed by buildings used for museum purposes (260 kWh/m^2).

The building used as a community center used 279 kWh/m^2, while the building used for music concerts and other community purposes used 284 kWh/m^2. The buildings used for a combination of food services and conferences and visitor attraction are the lowest-performing buildings with an energy use of 640 and 748 kWh/m^2, respectively (Table 5).

According to Table 5, high-performing buildings were found in only one building typology and categories except for buildings that are used for multiple purposes and as museums. Although B4 (educational art/music) has a smaller floor area (173 m^2), it is ranked third with a higher energy use of 195 kWh/m^2 (8.3%), which is much higher than that of B3 (327 m^2), which has the same building activity and/or function. This result may be due to the use of common office equipment, individual use of computers, and printers, which also present a significant load in buildings used for office/administrative purposes and in which most times sustainable design concepts implemented do not specifically target this type of equipment, thereby leading to no change in the plug load.

5.2. Building use and carbon footprint

Table 6 presents the energy performance indicator (EPI) and carbon emission of surveyed buildings. The largest carbon emission emitters among the surveyed buildings are B2, B5, and B8.

Surprisingly, the major proportion of carbon emissions came from B2, which was used for visitor attraction (ranked 1), followed by B5, which was use for food services and conferences (ranked 2), and B8, which was used for community purposes. Figure 4 shows that the majority (31%) of carbon emissions from the surveyed buildings came from the building used for visitor attraction, such as exhibitions and fairs. Meanwhile, 27% of the carbon emissions from the surveyed buildings came from the building used for food services and conferences and other related activities (e.g., events such as parties and receptions, weddings, dinners, and concerts).

The average carbon emissions from the buildings surveyed was more than 68 and 96 $kgCO_2/m^2$ from electricity and gas and gas only, respectively. This result may be due to the fluctuation in energy consumption of the buildings caused by the amount and different types of activities (and audio-visual facilities) and different outdoor temperatures over the years. However, an interesting finding was that B7 and B3 have a much lower energy use compared with other buildings, although B9 has a much higher performance than the rest of the buildings. The energy consumption of these buildings is influenced by different factors, such as the following: (a) a large volume of air that needs to be heated; (b) high thermal comfort requirements, and (c) low thermal resistance of windows and entrances. Also, because of the buoyancy effect and greater volume of the building that was heated, the temperature directly below the roof would be much higher than the temperature at the ground floor level.

The analysis reveals that for most refurbishment and reuse projects, energy use falls in the range of 181–866 kWh/m^2/year. Variation in energy use levels between the surveyed buildings within the general study sample is greater than the differences between the averages for different study samples. Likewise, no statistically significant differences were observed in levels of energy use intensity (kWh/m^2/year) between the buildings. The difference in energy use of the surveyed buildings could partly be explained as a result of the influence of several factors. For instance, high energy use in the building could result from the need to heat the large volume of space because of the high ceilings, physical parameters of the buildings (i.e., size, construction materials, geographical and climatic location, building age, and fuel type), and the way the systems and the buildings are operated and maintained.

Table 6 EPI and carbon emission of surveyed buildings.

Building code	EPIELEC	EPIGAS	Absolute emission ($kgCO_2$)	Emission per floor area ($kgCO_2/m^2$)	Ranking according to emission per floor area
B1	27	198	9225	51	5
B2	139	609	37,433	187	1
B3	10	139	10,147	31	7
B4	0	260	16,773	50	6
B5	131	510	63,015	165	2
B6	0	284	20,457	52	4
B7	16	8	8912	10	8
B8	41	238	57,339	66	3

EPIELEC – energy performance indicator by electricity use.
EPIGAS – energy performance indicator by electricity use.

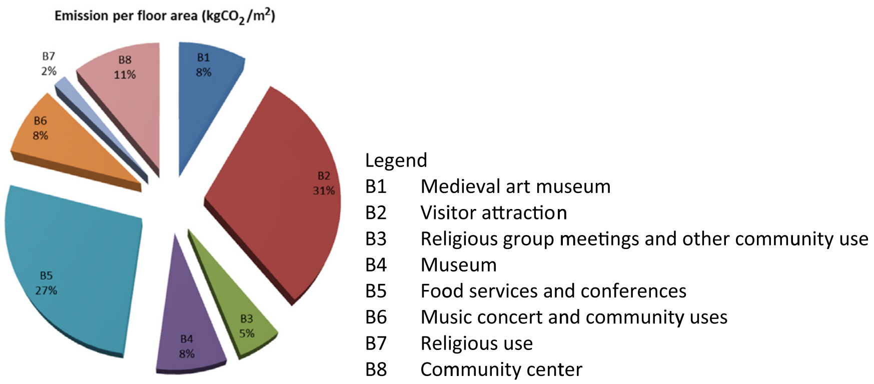

Figure 4 Percentage of emission per floor area according to building use.

Operational parameters observed in the surveyed buildings that contributed to the influencing energy consumption include operating schedules for the different functional use, appliances and equipment within in the building, the number and the nature of the facilities (i.e., eating places, kitchens, in-house laundries, business centers), services offered, fluctuation in occupancy levels, variations in customer preference relevant to indoor comfort, on-site energy conservation practices, and culture and awareness of resource consumption among personnel and guests.

In addition, occupant behaviors (comfort temperature set point, the presence or absence in the building), the efficiency of the heating system, and heat losses of the distribution and the radiant heating systems have to be further examined to explain this divergence between reality and figure information. Meanwhile, building occupant that are rigorous in their efforts to create credible energy baseline plans, disciplined in keeping their plans current and informative to their users, and committed to synchronizing focused work around those plans will experience a significant reduction in energy use and improved energy performance of their building.

6. Recommendations and suggestions

Heritage building professionals and operators need to address the biases that surround the energy performance of heritage buildings to focus on strategies to overcome them. Addressing the deep-rooted perceptions in the heritage building sector working against energy efficiency investments requires an adequate understanding of the performance of the buildings in the post-refurbishment and reuse project phase. Similarly, an understanding of how undertaking a few minor actions, such as changing to energy-efficient light bulbs, efficiency of services, and improvement of the operation of the building (i.e., facility management and the building use pattern of the staff and other users), could contribute to tackling these issues is important.

The benefit of several energy efficiency interventions includes their ability to be integrated with the least interruption to the building's operation; one such intervention includes introducing systematic maintenance by incorporating them into strategic refurbishment plans. Thus, a reduction in operational energy becomes achievable without losing essential services. Meanwhile, baseline project planning, periodic updating, monitoring, and managing the energy use pattern are measures that could greatly facilitate better energy performance to optimize their sustainable reuse compared with the traditional approach of improving their thermal performance. Further areas of suggestions and recommendation include the following:

- **Sympathetic alterations to the building and its subsystems**
  Energy refurbishment of the surveyed building would require amending the layout of the building by altering existing partitions or the erection of new divisions. This approach would require sympathetic horizontal and vertical partition of the interior layout to reduce the volume of spaces to be heated. Meanwhile, the work would need to be carefully appraised and aligned to the following adaptation principles: (i) reversibility of the adaptation and reinstatement of the building; (ii) avoidance of unnecessary damage to the historic interior; and (iii) sympathetic with the history, structure, and character of the building.
- **Exploring potential low-energy interventions**
  Potential low-energy intervention measures could be explored in refurbishment and reuse of listed churches, such as (a) user behavior control and energy management; (b) upgrading and renewing the heating system; (c) replacement of obsolete energy-consuming appliances and equipment used in the operation of the building; (d) using renewable energy; (e) adding an underfloor heating system; (f) insulating the masonry walls; and (g) insulating the stained glass windows. However, because of the highly valued heritage building qualities and characters, limitations and risks are associated with insulating the masonry walls either within or without and complete underfloor heating system. Hence, these approaches would not be advisable in certain circumstances because of the risk of damaging the historic fabric and the possibility of damaging tombstones that may be present underneath the base. However, an increased insulation of a listed building could be achieved by introducing the concept of "building within a building." This method could be accomplished by creating a new insulated wall and roof assemblies inside the existing historic shell to avoid damaging the heritage qualities of the edifice. Refurbishment and conservation of the old buildings should also result in the building's ability to promote the health and well-being of its occupants as this is regarded to be one of the four aspects of the eco-footprint of a building.
- **Energy management awareness building operation and maintenance practices**
  The outcome of the survey suggests that sound operation, maintenance, and management structures are important factors in post-refurbishment and reuse of listed churches with the prospect of achieving savings through low-cost investments, such as ensuring the systematic maintenance of service equipment and upgrading to high-efficiency equipment. In addition, building operator/managers need to have and keep an up-to-date energy metering record and building energy log books essential to monitor energy consumption against a benchmark figure.

7. Research limitations and strengths

The collected data have some shortcomings. Other factors can influence energy use in the surveyed buildings. The factors include but are not limited to the building structural features, (e.g., wall insulation) and space heating equipment, hot water production, and lighting, which were ignored because the available data were grossly inadequate. In addition, the case study approach used in this study depends only on eight projects. On one hand, this number could be perceived to limit the potential to generalize the study's findings. On the other hand, the case study approach could also be contended to offer generalizing theory. This idea implies that application of theoretical explanations of the observed data could be made to other similar buildings within the same contexts. Hence, the possibility that the findings from this study can be applied to other UK listed church refurbishment and reuse projects because of the related environments in which the buildings operate.

8. Implication of the study

The findings of the study would have potentially important implications for listed church owners who face the challenge of managing the considerable decline in congregation size. Likewise, the findings would also benefit developers who are involved in initiating adaptive reuse of listed church project and public agencies interested in the occupancy of this building type. Thus, when the sustainable reuse project is desirable, the outcome of this study can offer valuable information on energy management for sustainability of the project. This finding underscores the need for operational energy efficiency assessment in refurbishment and reuse projects in UK listed church buildings. Therefore, an energy management policy needs to be established on the reuse of HBP projects because of the challenge of integrating the building's new use. This study thus reveals the necessity for a more informed approach by the professionals, and an honest evaluation of the project's energy performance after refurbishment could bring to the fore any gap(s) where the building consumes excessive energy. Although crafting an effective energy management plan may appear challenging, substantial improvement could be achieved if the operators and/or building managers concentrate on some of the available opportunities.

9. Conclusions

The main aim of this study is to evaluate the operational performance of refurbishment and reuse of UK listed church projects especially those that are used for multiple purposes. To achieve the goal of the study, this study considered energy assessment of adaptive reuse and refurbishment literature. The significance of this study is the need for direction in current practice for developing and implementing a more focused policy on the operational energy management of “hard-to-treat” buildings to minimize the energy required to operate them. This study thus posits that leveraging the areas required for operational energy performance improvement of heritage buildings demands commitment from all heritage building stakeholders. Such commitment is necessary because the requirements need to be harmonized to optimize the sustainability of the project and not just the building operators. While heritage buildings may not always conform to stereotypes of energy efficiency measures, they can be effectively adapted to realize additional decreases in energy use within the confines of a sensitive, sympathetic, and appropriate approach. In conclusion, reconsidering how carbon emission reductions of heritage buildings are conceptualized is important. In addition, energy use behavior change among the building operators and users is crucial to future emission reductions.

Appendix A. Supplementary material

The supplementary data associated with the article can be found in the online version at http://dx.doi.org/10.1016/j.foar.2016.06.002.

References

AEA (Atomic Energy Authority) Technology Report, 2010. An examination of factors affecting the decision making process on whether to redevelop or refurbish UK residential property (Authors: Sheirs, D., Rapson, D., Cooke, K. and Le Comu, E.) 〈http://www.sustainableaggregates.com/library/docs/asrp/l0152_ma_1_s_4_05.pdf〉.

Akande, O.K., 2015. Factors Influencing Operational Energy Performance and Refurbishment of UK Listed Church Buildings: Towards A Strategic Management Framework. Anglia Ruskin University,, Chelmsford, United Kingdom.

Ashworth, A., Asessing the life expectancies of buildings and their components in life cycle costing. 1996 COBRA 96 (available Retrieved from www.rics-foundation.org/index.htm.

Audet, J., d’Amboise, G., 2001. The multi-site study: an innovative research methodology. Qual. Rep. 6 (2) 〈http://www.nova.edu/ssss/QR/QR6-2/audet.html〉.

Bell, M., Lowe, R., 2000. Energy efficient modernization of housing: a UK case study. Energy Build. 32, 267-280.

Boardman, B., 2007. Examining the carbon agenda via the 40% House scenario. Build. Res. Inf. 35 (4), 363-378.

Braganca, L., Mateus, R., 2008. Building refurbishment: one step towards sustainable built environment. In: Proceedings of the World Conference on Sustainable Development SB08. Melbourne, Australia.

BSI (BRITISH STANDARDS INSTITUTION), 1998. BS7913:1998 Guide to the Principles of the Conservation of Historic Buildings. London, BSI. Building Research Establishment, 2009. Rethinking Housing Refurbishment. BRE. 〈http://www.rethinkinghousingrefurbishment.co.uk/page.jsp?id=1109〉 (last accessed 19.01.10).

Bullen, P.A., Love, P.E.D., 2010. The rhetoric of adaptive reuse or reality of demolition: views from the field. Cities 27 (4), 215-224.

Cassar, M., 2009. Sustainable heritage: challenges and strategies for the twenty-first century. Apt Bull.: J. Preserv. Technol. 40 (1), 3-11 〈http://discovery.ucl.ac.uk/18790/1/18790.pdf?〉.

CDM, 2002. Consultancy Study on the Development of Energy Consumption Indicators and Benchmarks for Selected Energy-consuming Groups in Hong Kong: Executive Summary for Principal Groups A & B (Final). Camp Dresser & Mckee International Inc. (CDM), Electrical And Mechanical Services Dept.,, Hong Kong.

CIBSE, (Chartered Institution of Building Services Engineers), 2008. Energy Benchmarks: CIBSE TM46. CIBSE, London.

Coles, T., Dinan, C., Warren, N., 2015. Climate change mitigation and the age of tourism accommodation buildings: a UK perspective. J. Sustain. Tour. 23 (6), 900-921.

Creswell, J.W., 2009. Research Design: Qualitative, Quantitative, and Mixed Method Approaches, 3rd ed. Sage,, Thousand Oaks, CA.

DCLG (Department for Communities & Local Government). 2010. Building regulations approved document part L1B & L2B conservation of fuel and power [online document]. Retrieved November 2014 from 〈http:www.planningportal.gov.uk/buildingregulations/approveddocuments/partl/approved〉.

Defra (Department for Environment, Food and Rural Affairs), 2010. Guidelines to Defra/DECC's GHG Conversion Factors for Company Reporting; Version 1.2.1, Final; 2010; Defra: London, UK.

Available online:⟨http://www.rensmart.com/Information/Library/101006-guidelines-ghgconversion-factors.pdf⟩ (accessed 14.09.12).

Diamonstein, B., 1978. Buildings Reborn: New Uses, Old Places. Harper & Row,, New York.

Drewe, D., 2007. Embodied Energy: New Build vs Refurbishment. Context No. 99 May. Institute of Historic Building Conservation, UK. Available online at: ⟨http://ww.ihbc.org.uk/context_archive/99/drewe/pg_0015.htm⟩.

English Heritage (n.d). Listed Buildings. Retrieved from ⟨http://www.english=heritage.org.uk/caring/listing/listed-buildings/⟩ (24.02.14).

English Heritage., 2004. Building Regulations and Historic Buildings - Balancing the Needs for Energy Conservation with Those of Building Conservation: An Interim Guidance Note on the Application of Part L, 2004. Available online: ⟨http://www.englishheritage.org.uk/upload/pdf/ign_partl_buildingregs.pdf⟩.

Heritage, English, 2007. Cutting down on carbon: Improving the energy efficiency of historic buildings. Government Historic Estates Unit Annual Seminar. Building Research Establishment. English Heritage,, Garston.

Heritage, English, 2011. Energy Efficiency and Historic Buildings: Application of Part L of the Building Regulations to Historic and Traditionally Constructed Buildings. English Heritage, London.

Fitch, J.M., 2001. Historic Preservation: Curatorial Management of the Built World.

Forster, A.M., 2010b. Building conservation philosophy for masonry repair: Part 2 "Principles". Struct. Surv.: J. Build. Pathol. Refurb. 28 (3), 165–188.

Harrison, R., Oades, R., 1997. Heritage and technology: New ways of working in historic buildings. DEGW ETL. England.

ICOMOS, 1964. The Venice Charter. International Charter for the Conservation and Restoration of Monuments and Sites (Venice).

Itard, L., Klunder, G., 2007. Comparing environmental impacts of renovated housing stock with new construction. Build. Res. Inf. 35, 252–267.

Judson, P., Iyer-raniga, U., Wong, P. C. James, R., Horne, 2010. Integrating Built Heritage and Sustainable Development: Can Assessment Tools be used to understand the Environmental Performance of Existing Buildings with Heritage Significance? FIG Congress 2010. Facing the Challenges – Building the Capacity. Sydney, Australia. Available at: ⟨www.fig.net/pub/.../ts04m%5Cts04m_judson_iyerraniga_et_al_3977.pdf⟩.

Kavgic, M., Mavrogianni, A., Mumovic, D., Summerfield, A., Stevanovic, Z., Djurovic-Petrovic, M., 2010. A review of bottom-up building stock models for energy consumption in the residential sector. Build. Environ. 45 (7), 1683–1697.

Kelly, M.J., 2010. Energy efficiency, resilience to future climates and long-term sustainability: the role of the built environment. J. Philos. Trans.. R. Soc. A 368, 1083–1089.

Kohler, N., Yang, W., 2007. Long-term management of building stocks. Build. Res. Inf. 35 (4), 351–362.

Langston, C., Wong, F.K.W., Hui, E.C.M., Shen, L.Y., 2007. Operational assessment of building adaptive reuse opportunities in Hong Kong. Build. Environ. 43 (10), 1709–1718.

Levine, M., Urge-Vorsatz, D., Blok, K., Harvey, L.G., Lang, D., Levermore, S., Mehlwana, G., Mirasgedis, A.M., Novikova, S., Rilling, J, A., Yoshin, H., 2007. . 'Residential and commercial buildings'. In: Metz, B., Davidson, O.R., Bosch, P.R., Dave, R., Meyer, L.A. (Eds.), Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel On Climate Change. Cambridge, UK: Cambridge University Press, USA, pp. 387–446.

Lowe, R., 2007. Technical options and strategies for decarbonising UK housing. Build. Res. Inf. 35 (4), 412–425.

May, N., Rye, C., 2012. Responsible retrofit of traditional buildings. [Accessed online 10 February 2013]. Available at: ⟨http://www.spab.org.uk/downloads/STBA%20RESPONSIBLE-RETROFIT.pdf⟩.

Meijer, F., Itard, L., Sunikka-Blank, M., 2009. Comparing European residential building stocks: performance, renovation and policy opportunities. Build. Res. Inf. 37, 533–551.

Mithraratne, N., Vale, B., 2004. Life Cycle Analysis Model for New Zealand Houses. Build. Environ. 39, 483–492.

Murtagh, W.J., 1997. Keeping Time: The History and Theory of Preservation in America. Mcgraw-Hill Companies, Inc., New York.

Pérez-Lombard, L., Ortiz, J., Pout, C., 2008. A review on buildings energy consumption information. Energy Build. 40 (2008), 394–398.

Power, A., 2010. Housing and sustainability: demolition or refurbishment? In: Proceedings of the Institution of Civil Engineers Urban Design and Planning 163. Issue DP4 Pages 205–216 doi:0.1680/udap.2010.163.4.205 Paper 800020. Available at: ⟨http://www.ice.org.uk/ice_web_portal/media/events/housing-and-sustainability.pdf⟩.

Riley, M., Cotgrave, A., 2011. The Technology of Refurbishment and Maintenance. Macmillan Publishers Limited, England.

Robert, P., 1991. Adaptations: New Uses for Old Buildings. Princeton Acrhitectural Press, New York.

Rohdin, P., 2011. Using an epidemiological approach as a supporting tool for energy auditing of culturally and historically valuable buildings. Energy Efficiency in Historic Buildings, Visby, Sweden, February 9-11.

Saunder, M., Thornhill, A., Lewis, P., 1997. Research Methods for Business Student 1st ed. Pitman,, London.

Sodagar, B., 2013. Sustainability Potentials of Housing Refurbishment. Buildings 3, 278–299.

Stubbs, M., 2004. Heritage-sustainability: developing a methodology for the sustainable appraisal of the historic environment. Plan. Pract. Res. 19 (3), 285–305.

Urquhart, D., 2007. Guide for practitioners 6: Conversion of Traditional Buildings. Application of the Scottish Building STANDARDS. Edinburgh, Historic Scotland.

Wireman, T., 2004. Benchmarking Best Practices in Maintenance Management. Industrial Press, New York.

Yin, R.K., 2009. Case Study Research: Design and Methods, 4th ed. Sage, Thousand Oaks, CA.

Yin, R.K., 2014. Case Study Research. Design and Methods, 5th ed. Sage, Thousand Oaks.