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Author: Julie Bon

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American Institute for Conservation
727 15th Street NW, Suite 500
Washington, DC 20005
info@culturalheritage.org www.culturalheritage.org

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Collaboration and Innovation: Developing the Potential of Environmental Monitoring Data at the National Library of Scotland Through Industrial and Academic Partnerships

INTRODUCTION

The National Library of Scotland (the Library) is the successor to the Library of the Faculty of Advocates, which opened in 1689. In 1925, the Faculty presented its collections, with the exception of the works on law, to the nation, and an Act of Parliament formally constituted the National Library. This National Library Act was further expanded to amend the governance of the Library. It is funded through the government and is governed by a Board of Trustees.

The Library's collections consist of manuscripts and archives, rare books and general and modern collections. The Library is one of only six legal deposit libraries in the UK and the collection grows by more than 2 million items a year: the majority of this, in the region of 89%, is now born-digital material, but the Library still acquires a significant number of physical collection items on an annual basis. Currently, the Library holds more than 31 million items which are stored on more than 120 miles of shelving made up of a mixture of fixed and mobile stacking. The Library takes a mixed approach to boxing, with a number of collections open on shelving and some boxed in either phase boxes or newly designed cabinet boxes.

The Library's flagship building on George IV Bridge, in the heart of Edinburgh, was started in 1938. Construction work was halted during the Second World War and finally completed in 1956. By the 1970s, the growth of the collections was occurring at such a rate that it became clear that further space was required. Work started to build the Causewayside building, on the south side of the city, in 1983, and it was opened in two phases between 1989 and 1995. The Library also encompasses a moving image archive housed in Kelvin Hall in Glasgow and a storage unit for this collection based

just outside the city. The book and paper collections housed in the George IV Bridge and Causewayside buildings form the focus of this article.

In George IV Bridge, the majority of the stacks are on subterranean floors. As a solid stone building from the 1950s, the stack areas are consistently environmentally stable and existing air handling systems work well to maintain this stability. The main areas of concern, in terms of the environment, centre around office spaces and areas not originally designed for collection storage, and use, which have been repurposed over the years to accommodate an expanding organisation.

The design of the Causewayside building placed all of the services and access routes to the different floors on the exterior planes, allowing as much space as possible within the centre of the building for collection storage. There are two subterranean storage floors which are environmentally controlled black-boxes. However, some of the detailing of the exterior of the building meant that certain areas were susceptible to water ingress, and this had caused a number of issues for the collections. The Library undertook remedial work to this building from 2015 which involved replacing the roof and making improvements to the external cladding of the building. Defects in the design were rectified, and other improvements were undertaken to ensure that the building is now water-tight, more energy-efficient and easier to maintain.

ENVIRONMENTAL MONITORING AT THE LIBRARY

There have been a number of methods of environmental monitoring employed at the Library over the years, but by 2013, there were several catalysts prompting a change to the Library's approach. At this time, the Library's Building Management System (BMS) was a Trend 963 system. This was a closed-protocol system, and the controllers were no longer supported. Trend 963 systems had been on the market from 2003, and the older, no longer supported,

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versions were vulnerable to cyber-attack (Trend Control Systems Ltd. 2020). At this time, the Library identified that it needed to upgrade and replace up to 100 sensors across the estate; with sensors costing around £7000 each, this meant that the Library required to find £686,000 of capital funding.

The existing system also had a number of deficiencies, including the nonalignment of three stand-alone monitoring systems and the BMS. All of the systems worked on closed protocols, making access, and the sharing of data, awkward and cumbersome. The existing system required manual monitoring and downloading of data, with further software interventions required to enable data analysis and reporting. This resulted in time-lagged multiple data sets which were difficult to interrogate and led to reactive action and inefficient processing. The existing BMS also offered only very limited submetering for energy usage analysis.

Research and development into system upgrade options continued at the Library, but by 2016 the BMS controllers were completely saturated. There was no availability for further development or expansion, and the system was working to absolute capacity. Over the years, the Library estate BMS controls had been altered, upgraded and enhanced, and it was clear that the existing Trend 963 legacy system and controllers had reached the end of their useful life expectancy. This presented a major risk of failure and needed to be urgently addressed.

In 2017, the new British Standard 4971:2017 was released which demanded higher levels of environmental storage controls than the previous standard (British Standards Institute 2017). Concurrently, all of the energy-saving quick wins across the estate had been exhausted, but the organisational, and political, pressure to achieve lower energy targets was still high. By 2017, Trend 963 systems were being withdrawn and replaced with Trend IQ Vision systems: the Library needed to be able to respond to this change.

Replacing and upgrading the Library's environmental monitoring system across the whole estate became a strategic priority, which came with a number of challenges. There was a need to implement a system upgrade without causing any detrimental effects to the collections. To this end, the temperature (T) in the storage stacks needed to stay between 16 and 20 °C and the relative humidity (RH) between 40% and 60%. It was agreed that there should be no detrimental effect to the organisation's environmental parameters, so fluctuations were not to exceed 10% for RH and 5°C T in any 24-hour period (National Library of Scotland 2016).

The Library also faced a number of common constraints when planning and delivering this system upgrade: there was limited financial funding and resource availability; the Library estate comprised Grade A & B listed buildings, resulting in restrictions concerning structural interventions; there were limited providers in the market with the knowledge

and experience required to deliver this sort of project; and no suitable single integrator of services had been identified (Historic Environment Scotland 2019).

DEVELOPMENT OF AN INDUSTRIAL PARTNERSHIP

These challenges and constraints led the Library to develop an industrial partnership with a company that could help develop and deliver the required system upgrade. The Library wanted to be ambitious and develop an entirely new user interface to address a number of deficiencies with the current system. After carrying out a market survey and option appraisal, it was apparent that there was no single provider available but that the Library needed to work with an "integrator" of sorts that could enable and pull together the outcomes required. This led to the development of an industrial partnership with Craigalan Controls Limited (CCL). The Library had worked with CCL before, and the company had emergent experience of working in the heritage sector in Scotland. They had wide experience of developing BMS with an energy-saving focus across other professional areas, including the university, financial and prison sectors (Craigalan Controls Limited 2020).

Through this industrial partnership, the Library became one of the first institutions in the UK, and the first in Scotland, to install this new software using Trend IQ Vision as the front end. The Library was able to work with CCL as an industrial partner to create a bespoke open protocol platform allowing intuitive access, available to those who needed it. The approach taken, in terms of this system upgrade, presented a real opportunity for the Library, as a public-funded body, to support local innovation and business and build a bespoke model which suited very particular needs.

Benefits of the Industrial Partnership for the Library

The integration of a number of systems within this new BMS setup has delivered several benefits for the Library: there is greater environmental control in real time allowing a proactive, rather than simply a reactive, approach to the data; the new system has led to increased energy savings; and the Library now has integrated security systems enabling a faster response to issues. All of this has been achieved while reducing capital expenditure.

The new LEEP (Library Environmental and Energy Platform) system offers a one-stop shop for a number of controls systems. What is particularly exciting is that all of the data is displayed in real time, which is opening up several avenues for further research. Examples of the sort of information being gathered, and options available to the user, include monthly carbon footprint per zoned section of each building; T, RH and rate of change data for floors and zones; external weather (with five-day forecast); energy usage per floor level and percentage of total daily cost for

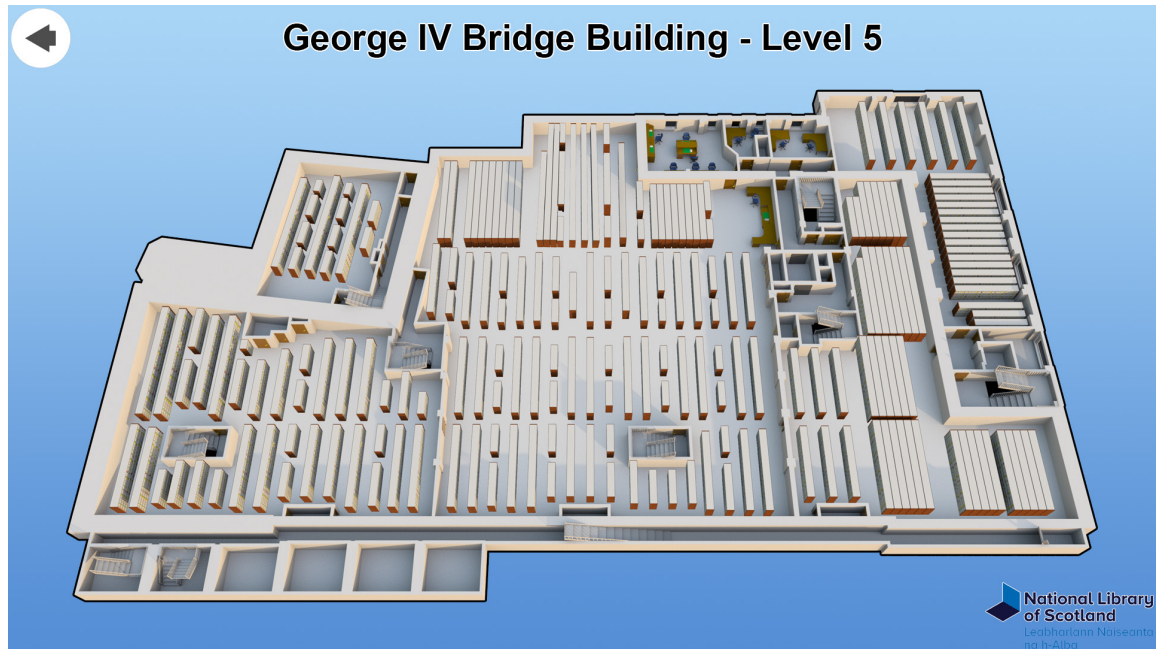


Fig. 1. Screen shot of the Library's new LEEP system.

that building; and sensor alarms across buildings, by floor and by zone, set to cover RH and T compliance against set-points, boiler performance and AHU performance. Other advantages of the system are that it allows access to online data and software storage, remote technical support and energy performance solutions.

The design of the new system also brings a number of benefits to the user, as it is intuitive and easy to navigate. It provides a single interface but enables multiple users to gain access at any one time. The system allows real-time data analysis leading to more efficient management of collection environments. The setup has allowed the development of new analytical tools, including rate of change graphics as standard across all monitored spaces; the potential of these will be explored in future research. A key advantage of the new system is that it enables secure and automatic archiving of historical data. The Library can now demonstrate full compliance with UKRG and GIS standards and share this data easily and quickly with depositors, lenders and borrowers. The system also offers the potential for national networking and sharing of data across institutions in the heritage sector.

Another clear benefit for the Library of this new system has been the cost savings. From an initial investment of £35,000, an immediate saving of £351,000 was made on the cost of replacing all of the sensors across the estate. Utilising the benefits of the new system has also enabled the Library to become more energy efficient. During financial years 2017–2019, the Library achieved a 32% reduction in greenhouse gas emissions and a 9.24% reduction in energy consumption

(against 2016–2017 baseline figures). Unfortunately, data analysis for 2019–2020 is not yet available, but other calculations show that total energy costs have fallen over the past year and that the Library is set to continue with its lower energy consumption trajectory. However, reductions are now harder to achieve, as the organisation has cut out waste and employed a number of energy-saving techniques. The Library needs to make significant investment, including replacing several boilers, to make further savings. This is one of the main reasons academic partnerships are now being explored to undertake research to help the Library become even more energy efficient as an institution and a business.

BEGINNING AN ACADEMIC PARTNERSHIP

The Library has embarked on a collaborative academic and industry doctorate entitled “Applying ANN (or Artificial Neural Network) technology to determine acceptable microclimate parameters for the National Library of Scotland’s Collections to enable significant energy efficiency improvements”.

The research is being generously funded by the Library, Heriot Watt University and the Energy Technology Partnership (ETP). It is being hosted by the Library and the Institute for Sustainable Building Design at Heriot Watt University in Edinburgh. This is a first for the Library, as it has regularly hosted arts and humanities doctoral students but has never hosted a student from the STEM sector. The value of this successful funding bid through the ETP, in terms

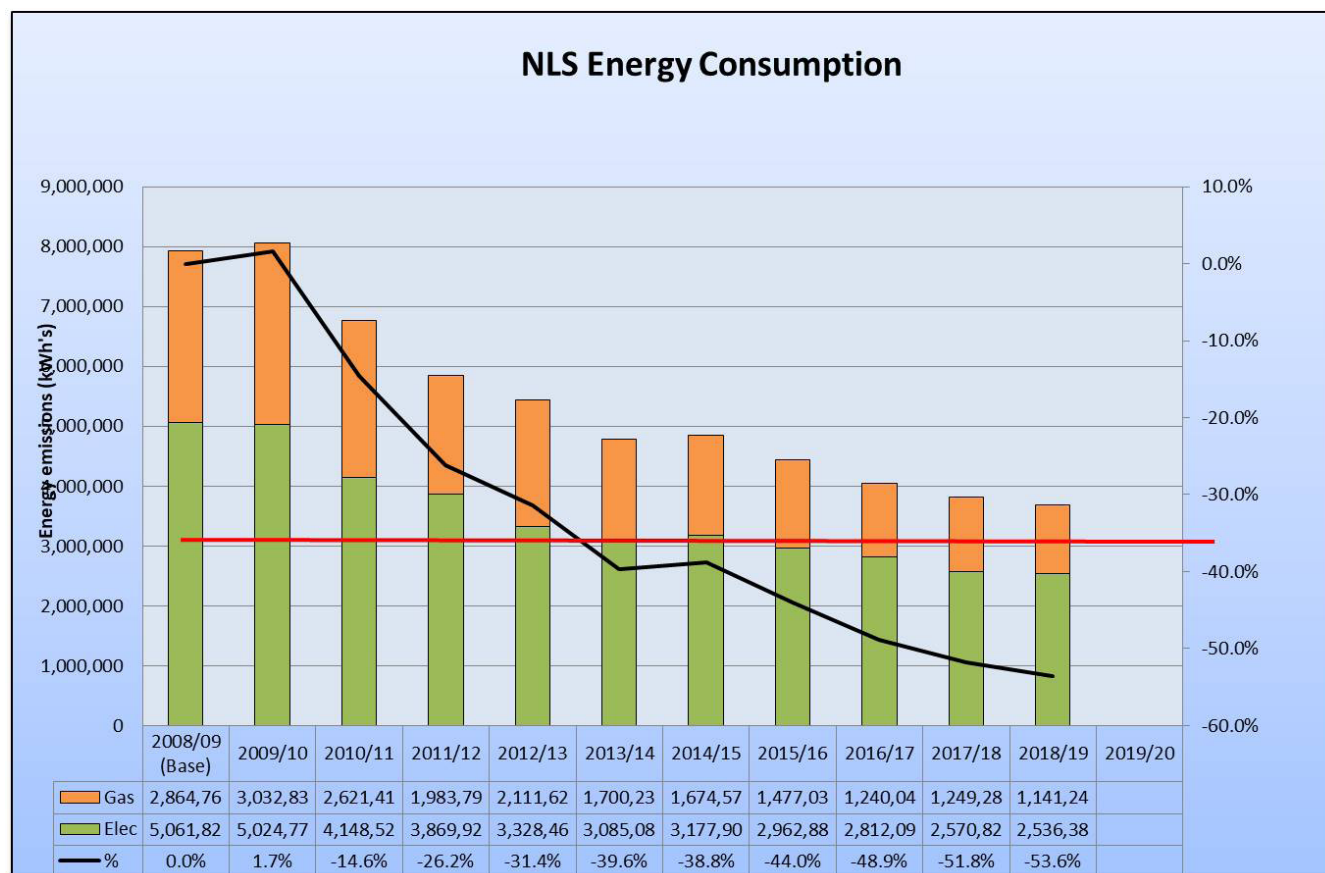


Fig. 2. Library energy consumption showing energy and cost savings. National Library of Scotland Estates department.

of internal advocacy for conservation and heritage science at the Library, has been immeasurable.

The ETP’s established Energy Industry Doctorate Programme addresses

[T]he strategic demands of industry and government for ‘industry-ready’, post-doctoral researchers to enhance energy industry innovation and knowledge exchange effectiveness. A defining characteristic of the programme is strong industry engagement where companies and co-investors support project specification and engage with the research directly. (*Energy Technology Partnership 2020*)

The ETP is a research pool drawing together energy knowledge, expertise and innovation from 13 Scottish higher-education institutions and is supported and co-funded by the Scottish Funding Council. The vision of this partnership is “to build on the existing areas of excellence and collaborative working to ensure that Scotland remains a globally competitive driving force in energy research and innovation” (*Energy Technology Partnership 2020*). The joint doctorate between the Library and Heriot Watt University fits the ETP

research theme of *Energy Utilisation in Buildings* and aligns closely with the Scottish Government’s *Scottish Energy Strategy* (The Scottish Government 2017). The two key drivers for this project are to further assist the Library in achieving legislative compliance with the Scottish Government’s energy-efficiency targets for public-sector organisations, and to increase public access to the Library collections by running exhibitions in local properties that do not have sophisticated environmental control systems (The Scottish Government 2015).

The appointed doctoral student will use the real-time environmental and energy consumption data, that the Library’s open protocol BMS can provide, to research the impact of microclimates on the preservation of Library collections. This will be done through the strategic placement of environmental monitoring sensors throughout the building and stack floors. Sensors will also be positioned within display cases and storage enclosures (a variety of boxes and enclosures used by the Library) to monitor the buffering effect of such enclosures. This data will be combined with data concerning the condition of collection items selected to form part of the study to develop optimum storage protocols

for Library collections. The research student will then use ANN modelling, which simulates the way the human brain analyses and processes information, and mock-up tests to predict and examine the effect of environmental fluctuations in a room on the microclimate inside a number of typical storage and display cases to establish an acceptable level of fluctuation that would allow the Library to loosen current tight environmental controls and therefore reduce energy consumption.

Benefits of an Academic Partnership for the Library

The likely results of this research will help the Library manage energy consumption through the development of new environmental guidelines for stored and displayed collections (likely advocating a more pragmatic and less rigid approach to environmental control parameters). This would enable the Library to become more cost efficient through achieving further energy savings and would demonstrate its commitment to achieving Scottish Government energy use targets. The Scottish Government's *Climate Change Plan* sets out a trajectory to 2032 which requires 70% of nondomestic buildings' heat to be supplied by low carbon technologies and a reduction in nondomestic buildings' heat demand by 20% through improvements to the building fabric by 2032 (The Scottish Government 2018).

The research is also likely to inform decisions around enclosure design, and how best to prioritise the boxing of the Library's collections in storage. At the Library's in-house box-making facility, the Preservation Services Unit based in the west of Edinburgh, Library staff have been developing a new box, called a *cabinet box*, which is a cost-effective design because it uses limited card and provides protection for a number of collection items at once. It is hoped that the microclimate research will help refine the design and verify that this boxing methodology provides suitable protection for collections so that their production can be accelerated to get as many collections in storage boxed and protected as possible.

The research project will also provide benefits for the display of Library collections, as the results should lead to the development of a new strategy that will enable the relaxation of the tight environmental controls for both display and storage. In essence, this will allow the Library (and possibly other national organisations) to display collections in smaller libraries, museums and galleries that are currently unable to meet such parameters. Public access and engagement is a key driver for the entire heritage sector, so the academic rigour of this research and its findings, once disseminated, will help other institutions achieve this aim. The Library is already working with local museums, archives and schools on a variety of display and engagement projects, and the results of this research will allow an extension of this program. For instance, the Library is involved with the Art UK Masterpieces in Schools program, but until now, there has been a limit to what

collections can be accessed in this way (Art UK 2020). The findings from this research will help the Library develop this partnership, and others, further.

An important aspect of this research project is dissemination and advocacy, and there is a strong schedule being put together to ensure that the findings of this research are shared widely across the heritage, building management and engineering sectors in the UK and further afield. This will allow other organisations to benefit from our research and spread the confidence to make changes to display parameters, growing the possibilities for lending collection items from national to non-national institutions. This is an area of increasing interest for the heritage sector and has been investigated, on the international scene, since the late 2000s (Atkinson 2014). It is hoped that the Library's research project, by combining the use of real-time environmental monitoring and energy usage data, as well as the developments in ANN modelling at Heriot Watt University, should help move the argument further towards an agreed relaxation of environmental parameters.

A final benefit of the proposed research is the internal and external advocacy that it will garner for the Library. It is hoped that the successful completion of this heritage science doctorate will be a stepping stone for the organisation to undertake further STEM-related studies. An important aspect of this has been the sector-wide recognition that our partnership work with industry and academia has gained, not least through recent success at the UK National Premises and Facilities Management Awards 2019 (Premises and Facilities Management 2019). The Library won the Partnership in Smart Facilities Management award (with CCL) and also won the overall winners award. This is a reminder that collections care success can spread across into other sectors and that awards can help bring this to the attention of those that make financial decisions in heritage organisations.

It is hoped that this research will also raise the profile of conservation within the organisation and demonstrate the value, through cost savings and innovation, it can bring. This advocacy has already started. Energy efficiency and sustainability is more prominent in the new Library strategy (2020–2025) which will be launched later this year (National Library of Scotland 2020). The possibility of extending the display opportunities for Library collections is also a key objective. This five-year strategy will take us through to the Library's centenary year in 2025. Internal advocacy on the value of taking a preventive approach to caring for our collections, of which this research project and the attractive funding it has brought with it has been an important part, has helped make the case for resourcing the newly appointed, first-ever Preventive Conservator post at the Library. Development of this project has also allowed the Collections Care team and the Estates team at the Library to work more closely together.



Fig. 3. Stack storage at the Library's George IV Bridge building. Courtesy of Joe Jackson.

CONCLUSION

The industrial partnership to develop and upgrade the Library's environmental monitoring system grew from a user-led demand for a bespoke product. This has led to a number of anticipated, and some unanticipated, benefits for the organisation as a whole. Immediate cost and energy savings were realised. Data analysis is now more straightforward, efficient, reactive and secure. The value of this data for the day-to-day management of buildings and collections has been demonstrated, but its potential for future research and development has only recently been identified. The Library is at the start of a journey to explore the potential of academic partnerships available within the STEM sector to utilise data, and develop modelling, to make predictions about future outcomes. The potential for this research is wide ranging, and the predicted benefits include future energy efficiency to comply with Scottish Government targets; data to support the refinement of box and enclosure design; opportunities to expand and develop the Library's exhibition lending activities; and internal and external advocacy for collections care and the value of preventive conservation. Through these different partnerships, the Library has demonstrated its commitment to energy efficiency and good collections care and management. It has also demonstrated an ambition and a will to push the envelope, in terms of industrial and academic opportunities, and has shown a forward-looking and responsible attitude towards the work involved in caring for important national collections.

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JULIE BON, ACR
 Head of Collections Care
 National Library of Scotland
 Edinburgh, UK
 j.bon@nls.uk