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Empirical evaluation of the energy and environmental performance of a sustainably-designed but under-utilised institutional building in the UK

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ABSTRACT

This paper presents a systematic, socio-technical and empirical evaluation of the actual energy and environmental performance of a sustainably-designed institutional building (Southeast England), intended to be a teaching tool and 'living laboratory' of sustainability. Despite the building being designed to high sustainability standards (Energy Performance Certificate rating of A, low reliance on fossil fuels, natural ventilation and rainwater harvesting) and also being under-utilised during the in-use stage (lower hours of occupation and number of occupants), its actual energy-related carbon dioxide-equivalent emissions are four times more than predicted. This is due to poor energy management of the building, underperformance of the biomass boiler and wasteful energy practices in terms of excessive winter overheating in the atrium, inappropriate lighting controls, and electrical equipment being left on standby. Due to lack of training and understanding of the energy manager, the building management system was not used adequately and issues with installation, commissioning and maintenance of the biomass boiler led to its disuse; however the photovoltaic system generated electricity as expected. Findings from the study show how a mixed-methods approach of building performance evaluation (BPE) should be embedded as part of the build process, to ensure that performance outcomes are met in reality.

1. Introduction

The UK Government is legally bound to reduce UK greenhouse gas emissions by 80% by 2050 in relation to 1990 levels [1]. Forty five per cent of UK CO_2e emissions are attributed to the building sector. Though only 3% of these CO_2e emissions are from the public sector (institutional buildings) [2], the public sector has a responsibility in demonstrating leadership and leading the way in reduction [3]. Institutional buildings in particular can act as teaching tools wherein actual performance matters publically. Furthermore, the health and performance of institutional buildings can be a key indicator of socio-economic development of a nation, creating long lasting influence on users [4]. In part, to these ends green building rating and certification systems have been created in many countries with varying approaches and methodologies but with the common objective to reduce the overall impact of the built environment on human health and the natural environment [5]. A few multi-attribute systems (meaning they regulate more than just one environmental concern like energy or water) are: Leadership in Energy and Environmental Design (LEED) based in the USA but worldwide, Green Globes (USA and Canada), Hong Kong Building Environmental Assessment Method (HK-BEAM), Building Research Establishment's Environmental Assessment Method (BREEAM) based in the UK but worldwide, Green Star in South Africa, Green Mark Scheme in Singapore and Institute for Innovation and Transparency in Government Procurement and Environmental Compatibility procedure (ITACA) in Italy. As an example of impact, more than 200 higher education institutions in the USA now have at least one LEED certified building [6].

Institutional buildings present a unique situation where a number of resident and transient users come together in often large public buildings with high sustainability goals. These users can

Abbreviations: BER, Building Emission Rate; BREEAM, Building Research Establishment's Environmental Assessment Method (UK); BRUKL, Building Regulation UK Part L; BMS, Building Management System; BUS, Building Use Study (UK); CIBSE, Chartered Institution of Building Services Engineers (UK); EPC, Energy Performance Certificate; FM, facility manager; HK-BEAM, Hong Kong Building Environmental Assessment Method; ITACA, Transparency in Government Procurement and Environmental Compatibility procedure (Italy); LEED, Leadership in Energy and Environmental Design (USA); O&M, operations and maintenance; PROBE, Post-Occupancy Review of Buildings and their Engineering.

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have differing comfort expectations which can be at odds with the energy management staff or system in place to control energy consumption. To further complicate this energy or facility managers (FM) for institutional buildings are often responsible for a large collection of buildings on campuses or even dispersed collections. Expectation from users and building management can be further complicated by poor installation and commissioning practices, poor material or control choices and poor communication of use [7]. For these and the reasons and the delivery expectations from rating systems mentioned in the introduction, it is important to demonstrate the real results and perception of the buildings built to embody exceptional performance.

A number of articles have been published demonstrating the approach to evaluate institutional buildings certified by green building rating systems. As examples, a university building in Melbourne, Australia rated by Green Star involved analysis of performance data, interviews with design stakeholders, and a building user satisfaction survey [8]; in the USA, a university building was subjected to quantitative and qualitative data collection via investigative and diagnostic techniques including temperature and relative humidity (RH) measurements, water and energy consumption, feedback from FM, departments and almost 600 occupants. Findings revealed degradation in sustainable attributes over time, poor indoor environmental quality (IEQ) and an indication that LEED has poor consideration of occupant behaviour [6].

It is all too common to find a significant gap between predicted and actual energy consumption [9]. Continually, literature demonstrates that green building rating and certification systems do not ensure greater energy performance [10], occupant satisfaction [6] or better IEQ over conventional buildings [11]. Building rating and certification systems are in a constant state of refinement to reflect new standards and goals for achieving progressively higher levels of sustainability [5]. Most important to the issue of the performance gap, systems such as BREEAM and LEED have begun to include measurement and verification of certification indicators. Measurement and verification is important for these systems since previous version of the systems like LEED demonstrated little correlation between measured energy consumption, certification level and most problematically, the number of energy credits achieved at the design stage [12].

Before these standards and systems were widely used, quantification of progress in building performance was considered to be important. Early on, initiatives such as *Post-occupancy Review Of Buildings and their Engineering* (PROBE) [13] revealed that actual energy consumption in buildings is usually twice as much as predicted and that common issues found in building performance evaluations (BPE) today (including this study) were being discovered in institutional buildings in the 1990s (Table 1). Examples include unexpected occupant influence on energy consumption in schools [14] and the strikingly common theme of lack of handover, guidance and training, inadequate commissioning of systems and poor calibration of sub-meters in two different buildings [15]. More recently, this gap was found to be two – nine times higher than predicted in a select 29 non-domestic buildings (16 institutional buildings) from the BPE programme funded by the UK Government's innovation agency, Technology Strategy Board (now Innovate UK) from 2010 to 2014 [16]. In addition, Burman et al. [17] reviewed 600 non-domestic buildings on the CarbonBuzz database of design and actual energy consumption figures in the UK and found that for education buildings the mean performance gap factor was 1.5 (that is, actual consumption is 50% higher than designed consumption) and for offices this factor was 1.6. In other European countries this factor is reportedly 1.3 for non-domestic buildings [17]. In the USA, one study comparing the energy model predictions with actual energy performance of a LEED certified university building, found the building consuming twice the predicted energy usage while causing a high level of occupant dissatisfaction [18].

Studies show that the reasons behind the performance gap vary from issues with building energy modelling at the design stage, changes prior to or during construction, detailing and construction omissions, commissioning and installation omissions, to unanticipated user behaviour after handover [16,24]. Specifically, within the non-domestic BPE programme, buildings experienced problems with integration and operation of new technology, less than optimal performance of technology and metering problems [16]. Also, there was no obvious correlation between airtightness and emissions performance, common findings of overly-complicated controls actually standing in the way of efficient operation, and poorly considered and integrated building management systems [16]. Understanding why the gap occurs and how it can be minimised is a precursor to making real improvements in building performance. This is why BPE adopts a systematic approach for collection and evaluation of data in a rigorous and consistent way on the performance of fabric and systems, energy consumption, environmental performance and occupant opinion. BPE helps to inform the design, modelling, construction, commissioning processes, and operation of buildings, consequentially reducing the potential performance gap in future buildings.

The present paper provides a case study approach to addressing the issue of *energy management in institutional buildings*. This is done through BPE of a new non-domestic building located in Southeast England, an institutional building (higher education) designed as an exemplar to demonstrate sustainable building materials, technologies and techniques. This paper addresses two themes on energy management in institutional buildings:

- The paper presents an empirical evaluation of an exemplary designed building and outlines the necessary transformations, both specifically for the building and for industry, owners and building management, to support the roadmap towards zero energy.
- The study covers building management and the empirical evaluation of energy consumption and IEQ in an institutional building to identify the reasons for the mismatch that occurs between design intent and actual outcomes, and proposes methods for improvement.

2. Methods and case study building

The Technology Strategy Board's BPE programme mandated a prescribed protocol for evaluation and reporting to maintain consistency and comparability in benchmarking and analysis. BPE study elements included: review of design intent through relevant documentation; review of handover, aftercare, operation, maintenance and management procedures; review of installation and commissioning of building services and technology; qualitative review of operation and usability of systems and controls; physical assessment of the building fabric using diagnostic field tests (air-permeability tests and thermographic surveys); occupant satisfaction; and finally, energy and environmental performance (including temperature, RH, and CO_2 concentrations) metered and collected for 19 months from March 2013 to September 2014. Energy data was collected by remotely accessing the building management system (BMS). Environmental data was collected every five minutes from wireless sensors and was transmitted wirelessly from a RT:Wi5 data-hub. These physical data were cross related with qualitative data gathered through Building Use Study (BUS) questionnaires evaluating occupant satisfaction and perception. The BUS analysis method is a quick and thorough way of obtaining feedback data on building performance through a self-completion