Post Occupancy Evaluation (POE) in Residential Buildings Utilizing BIM and Sensing Devices: Salford Energy House Example

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Abstract:
Residential energy use accounts for 29% of global energy consumption and 21% of global CO2 emissions, making the residential sector an important focal point in relation to the dual issues of climate change and resource depletion. Improving heating in households would also have important socio-economic impacts, especially in relation to the health of the occupants. For example, in 2008/09 there were an estimated 36,700 more deaths during the winter period in England and Wales compared to an average non-winter period. Much of this excess mortality has been attributed to "fuel poverty", which is defined by the UK Government Department for Energy and Climate Change (DECC) as "households needing to spend more than 10% of income on fuel to maintain a satisfactory heating regime."

Traditionally, Post Occupancy Evaluation (POE) is conducted against the prescribed performance specification and mainly relies on two activities; i) The effective collection of real world data and ii) the formulation of this data into models that allow trends and deviations to be observed. However, it is required to gain efficiencies by identifying potentially easier and more economical methods and tools for the collection of data such as wireless sensors.

Thus, the paper sets out a new vision of how future post occupancy evaluation in residential dwellings can be conducted. It explores the use of BIM (Building Information Modelling) that is progressively becoming more popular for developing building information throughout the building lifecycle. The paper employs a comparative study to build up greater understanding of the relationship between the fabric and the building use. Although the paper is grounded on the UK experience, it does also explore the international relevance of the issues.

Keywords: Building Information Modelling, Energy Consumption, Retrofitting, Post Occupancy Evaluation, Wireless Sensors.

1 Introduction

Although varying methods and techniques are available for POE conduit, in the majority of building projects POE is not performed, which is due to the cost of real time data collection for post occupancy evaluation. Conducting POE has the potential to reveal problems, which are not known by stakeholders involved due to liability and credibility issues. However, POE should be integrated with quality inspections and defects management that occur during the buildings lifetime.

In this case, POE is not predicted, observed and explained even though this does describe some part of the process. Current views on post occupancy evaluation suggest that it should cover user satisfaction, technical performance, financial performance and the impact of the built environment on the living or working conditions.

Stated by Wargocki et al (1999), people spend 80–90 per cent of their lives in buildings, living, studying, working, entertaining themselves, consuming and even exercising, which means that the indoor conditions can have a strong imprint on well-being, health and productivity. There are millions of "sick" buildings throughout the world consuming energy unnecessarily and causing increased operational costs for owners. According to surveys conducted in the US, energy usage intensity of the building, which are surveyed, deviated more than 25% from the design projections (Turner et al 2008).

Many buildings that win awards are not popular with their users. All buildings are predictions, all predictions are wrong (Brand, S. 1997). When we consider the predictions we used to create and maintain buildings there are those based on errors of judgement which are unavoidable and those mistakes which are avoidable. If we fail to adequately learn by evaluating our existing building stock effectively then we fail to avoid avoidable mistakes. This has a fundamental impediment in our ability to create a built environment which meets future aspirations. If we truly wish to ensure sustainability objectives are met we need to more regularly and effectively evaluate buildings in use.

Currently the primary motivation for POE tends to be on user satisfaction. The beneficiaries of POE in residential dwellings are residents by enhancing living environment and community by ensuring that a building's impact on the environment and the community is favourable to all. Integrating into the development process informed feedback from existing developments is an essential part of design improvement. To develop and maintain buildings at a lower cost we need to understand how buildings in use deviate from the expectations of their design. The list of topics covered by POE inevitably will expand as the collection of information becomes easier. This POE information in turn may lead to the greater use of evidence based design within the preconstruction phases of the building lifecycle. Also POE can lead to a better understanding of building value and non-traditional investment criteria (NCIC). This in turn may give a better understanding of the building real estate market.

Historically POE has mostly been conducted using questionnaires and face to face interviews. But buildings are becoming more intelligent and adaptive responsive to changing environmental conditions. As technology develops (easy-to-integrate wireless solutions) the methods of intermittent and real-time data feedback increase (Menzel et al 2008). If remote sensors are already being supplied to buildings these have the potential to perform dual roles (thus providing feedback at a lower cost). These roles are i) part of a building management system ii) as a method of validating design intent. Previous investigations in this area have included the coordinated management of Intelligent Pervasive Spaces (Yong, C. et al 2007).

Adopting the concept of the "internet of things" people are becoming and will become more connected to inanimate objects. This will be both through radio frequency identification (RFID) and through sensor networks. Cisco systems in their literature on the convergence of IT and building systems point to the convergence of building systems and user systems. The impact of distributed data and increased processing power offered though cloud computing should not be under estimated. Additional streams of data are also likely to become available through the use of mash-up concepts where data from disparate sources is combined in new and innovative ways. Using this and associated technologies it should be possible to evaluate building performance and the way we use the built environment in ways that were not possible before. The granularity that is potentially offered is very different and POE in future maybe considered at a building, building part or area level.

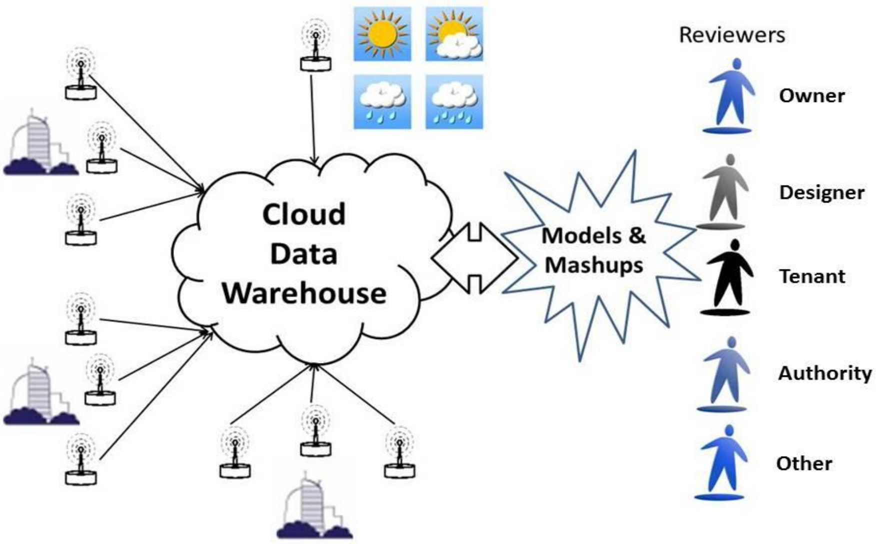

Figure 1 Possible framework for POE evaluation

Building information models generated for sensing devices should not be considered as static models but simulations. Benchmarking of buildings of a similar building type is also likely to reveal variations for analysis. This information then can be used to actively amend or augment the building performance and also feedback into future building projects. Theoretical design models can be compared with real world measurements.

2 Literature Review

The information used for POE has traditionally originated from 3 sources. These are occupant feedback, Bills and Metrics and measurements and readings. Building walkthroughs have also been parts of various methods of POE (the De Montfort method, BUS Building User Studies (BUS) occupant survey and Post-occupancy Review of Buildings and their Engineering (PROBE).

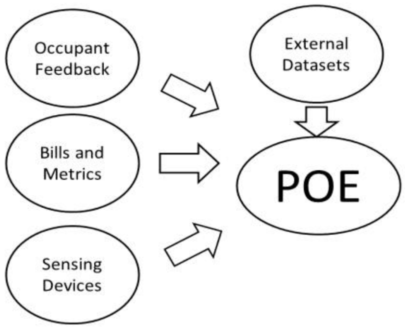

Figure 2 Sources of Data collection

Occupant feedback can be acquired through the use of Human Resource systems. If the questionnaires used to collected the feedback in machine readable form then the data can more easily be integrated with the BIM models. A graded-question technique is one method to approach this problem. Another option is to allow users to make their comments in a virtual environment by attaching their comments to the objects in question. Bills and metrics should also be made available in electronic form. Although it is possible to define the data required for POE it is perhaps better to think of the concept of a data warehouse where the use of the data has not been determined at the time of collection. In reality data collected from building sensor is likely to form a mash-up with other data from other sources. An example of other data available might be police statistics for the neighbourhood. These would give an indication of safety in and around the building.

Information from sensing devices is one method of data collection. Sensing devices have become ubiquitous in certain building types. These devices both can monitor the building environment and track the movement of objects and people within the building. Through the effective collection of data a building informational model maybe maintained but a buildings operational model may also be created.

Many forms of remote sensors can be installed into buildings. Various wireless technologies are emerging as possible candidates for the communications infrastructure of the modern sensor networks.

Most commonly, standards such as IEEE802.15.4 and ZigBee are being implemented to effectively deliver solutions for wide range of applications including consumer electronic device control, energy management and efficiency, building and industrial plant management (Tasshik and Yongsuk, 2009).

Han and Lim (2010) state that ZigBee network model services have been proposed in different domains of our everyday life such as in homes, offices, streets, building and school. The wireless sensor network in the home area can be distributed in different services throughout our daily lives.

Additionally, due to inefficiency of the current electricity grids, smart grid concept is emerging. Smart metering is the way that consumers are engaged to smart grids. Smart meters transfer data along with power, so there is an opportunity for utilities to collect data from consumers (buildings) for real time monitoring of energy consumption and simulation of energy use behaviour. Smart meters make it possible to monitor not only the energy consumed, but also the amount of energy generated on site via building integrated micro-generation technologies, (ENSG, 2009). US Department of Energy explains in 2007 that Broadband over Power Lines (BPL) technology engaged to smart meters is focused on Internet access and Voice Over Internet Protocol (VoIP) for consumers, and BPL is increasingly being deployed to meet utility needs for distributed energy resources (DER), Automatic Meter Reading (AMR), Demand Response (DR), and consumer portal applications, as well as Distribution Automation (DA) and video monitoring (primarily for security) applications and other high-speed data needs on the system side. BPL has a promising potential to become a data transfer medium for two way data flow between sensor networks and cloud data warehouses.

The following Table 1 briefly explains the implementation areas of available sensors:

Table 1

Classification of sensors	*Sensors*
HVAC and Indoor Air quality	- Temperature - Humidity - Carbon oxides
Occupancy sensors	- Motion Sensors attached to Lighting systems
Safety and security sensors	- Motion sensors for alarm systems - Fire Detecting Sensors - Gas Detecting Sensors - Smoke Detectors
Outdoor Sensors	- Outdoor Motion Sensors for Security - Compact Weather Stations

It is important to mention that, the given table shows only the basic applications and there is a very high potential to extend the table according to specific requirements of users (occupants). As an example, it is possible to implement toilet flush counting sensors in elderly people's houses for health monitoring purposes; hence the trend/rate of toilet use can give health professionals an idea about basic health condition of the occupants. Simmers et al (2009) state that digestion related health indicators are important criteria for health assessment of elderly people. Perhaps it is best to think of multifunctional sensors.

Moreover, it should be noticed that outdoor sensors are very important (but generally neglected) hence outdoor conditions have a big influence over indoor conditions of buildings and so the occupants. More accurate, on-site monitoring and sensing of outdoor parameters such as wind, temperature and humidity will enable more efficient implementations of Building Management Systems (BMS). Figure given below illustrates an implementation example of indoor and outdoor sensors with building integrated micro-generation technologies.

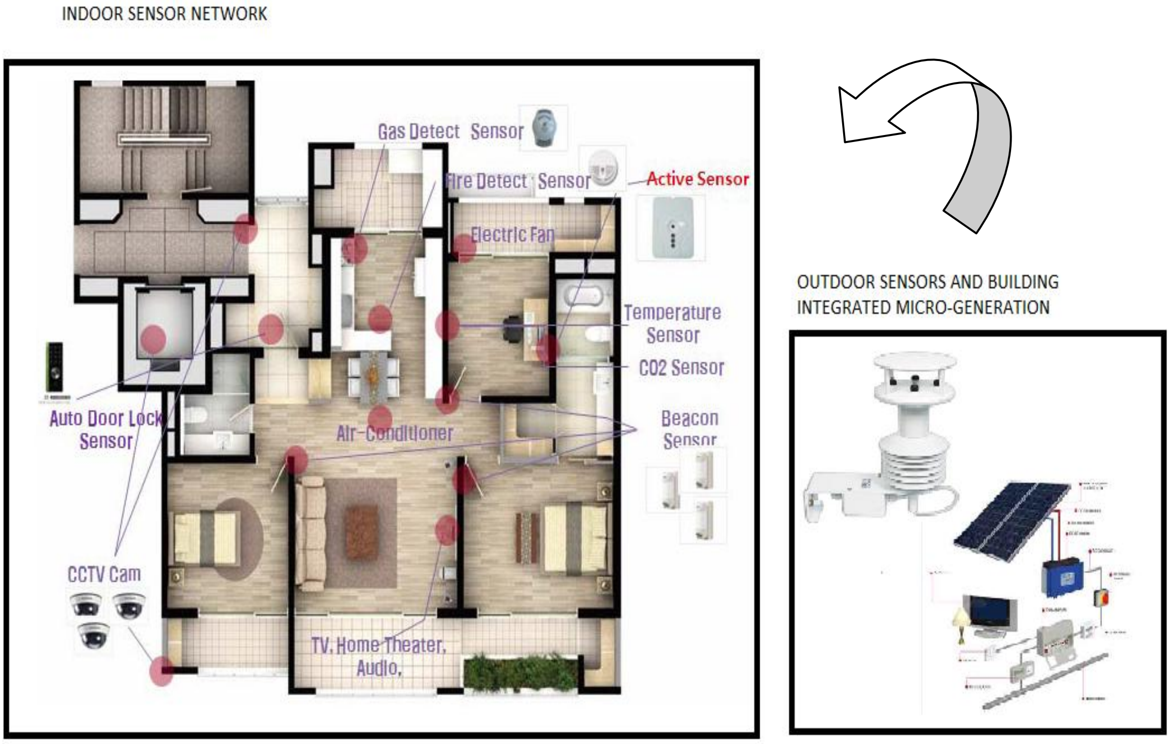

Figure 3 Indoor (adopted from Han and Lin) and outdoor sensor implementations

3 Research Methodology

3.1 Main Data Collection and Analysis Lab for Observatory Experimentation

In this study, Salford Energy House, which is a R&D facility to test building fabrics and systems to develop low carbon options within a controlled environment, is used as a case study test-bed. Salford Energy House is also acting as a platform for both academia and industry to develop and test new technology and solutions to improve the energy efficiency of existing projects and processes.

The house itself is a traditional pre 1920’s Victorian terrace house that has been reconstructed using reclaimed materials from local sources to represent more than one fifth of the UK current housing stock and rebuilt using the traditional methods of the time, including lime mortar, lathe and plaster ceilings. The house is classed as a hard to treat property in terms of energy efficiency due to the lack of cavity walls. These properties of the house make it an invaluable facility for retrofitting studies for the existing building stock (www.energy.salford.ac.uk/energy_house).

3.2 Case Study Experimentation

Given figure-4 is a screenshot from Energy House Monitoring System and it illustrates the layout of energy house, sensors used and their positions, and real time monitored parameters such as temperature, humidity and energy consumption.

Currently available sensors in the Energy House are high quality HVAC sensors that measure temperature and humidity parameters both within the Energy House itself and the sealed chamber. These sensors are positioned at three different levels (upper, middle and lower) in order to enable a more realistic trend output.

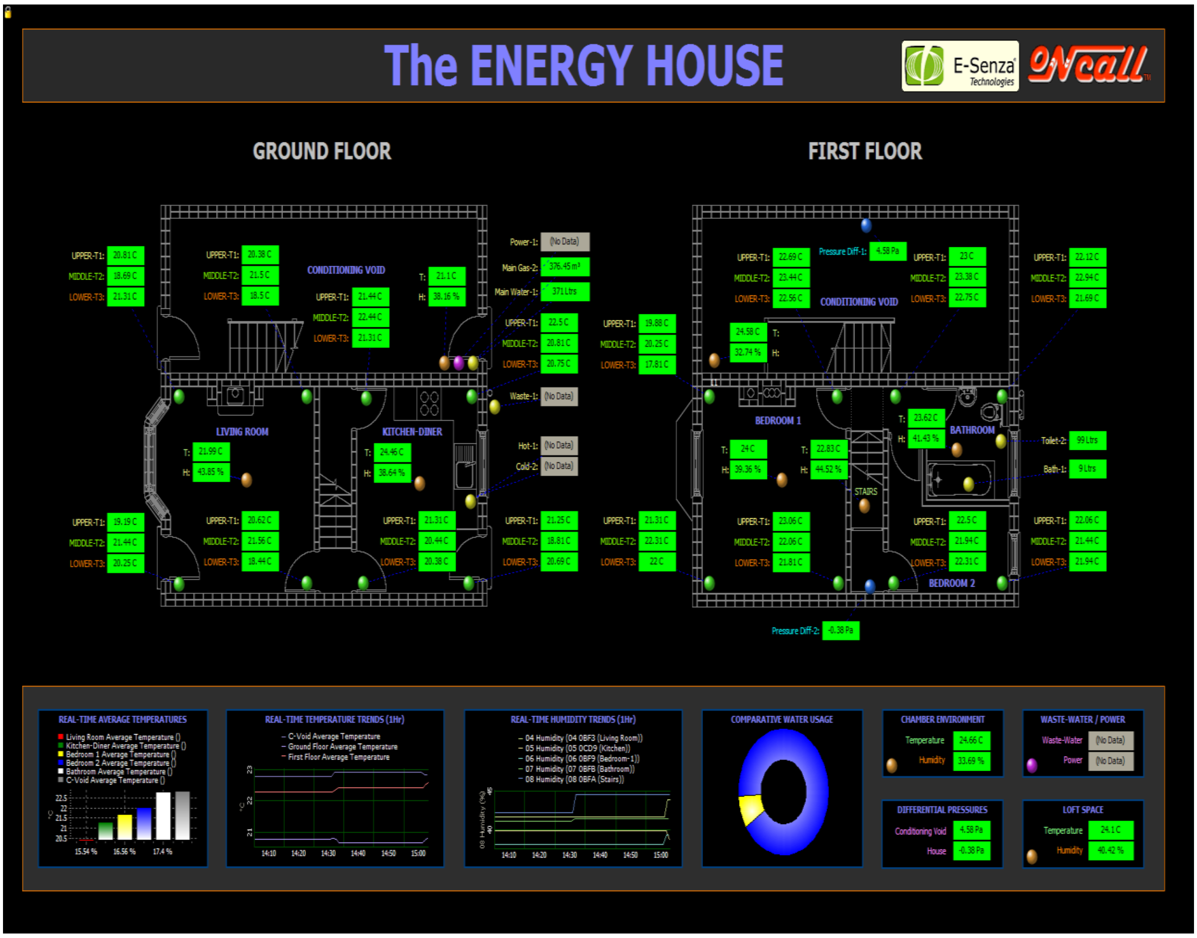

Figure 4 Screenshot from Energy House Monitoring System

Additionally, appliance level energy monitoring devices for identifying energy consumption (gas and electricity) and thermal imaging system to assess thermal performance of the building fabric are present at the Salford Energy House. The given figure 4 is an example of thermal image of a building façade that shows thermal leakage along the surface (CEEC, 2010).

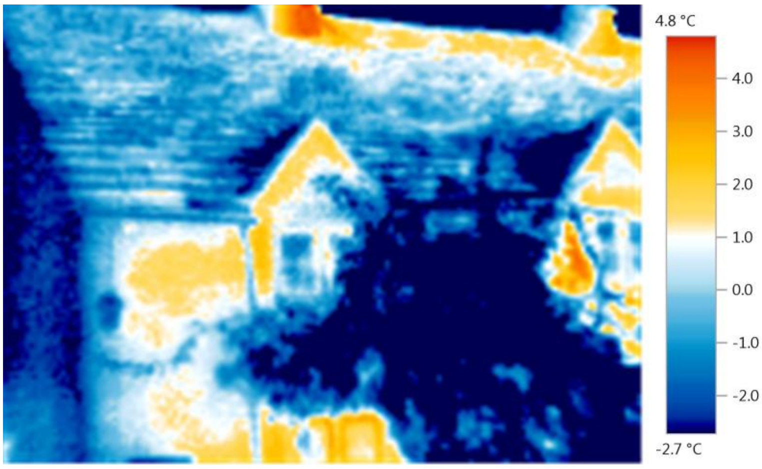

Figure 5 Thermal Image of a Façade of a semi detached residential building

4 How wireless remote sensor information can augment BIM models

Building models come in a whole range of forms. The challenge is developing the appropriate modelling form to expose important issues. What determines an effective model is how it supports the decisions to be made.

One developing techology is immersive 3d which may become the preferred interface for some evaluation tasks (Hailemariam 2010). BIM models of post-construction are usually part of or attached to an FM system. This means the data available is considerably more than just the BIM graphical database.

Examples of remote sensor population BIM models already exist. Data acquisition technology (DAT) has already been integrated with Onuma Planning Systems (a BIM tool). This links with real time energy sensors, lighting and webcam data. Autodesk are currently investigating this area as part of their Project Dasher. PACRAT (Performance and Continuous Re-commissioning Analysis Tool) is a tool for "mining" recorded meter and system operational data to improve facility operations and planning. The Taloinfo system by Granlund has also demonstrated some of the capabilities of this technology (Granlund 2006). Ennovatis and IDMS have also developed energy monitoring systems. These systems need to be realigned to address the issues raised as part of post occupancy evaluation. It is through benchmarking buildings against simillar buildings that a true understanding is gained. Archibus a FM system that links with BIM models already has the ability to show building benchmark comparisons.

Although BIM offers one source of post construction data, numerous source of data are likely to become available. Using data mining and knowledge discovery in databases, patterns, relationships and predictions can be revealed. When considering POE in the future data maybe be acquired from many sources creating a data agregation. The Metadata for Architectural Content in Europe project (MACE) which integrated a vast amount of content from diverse repositories created in several large projects is an example of how data can be acquired from multiple sources. Filtering data is what databases are good at. The issue is developing BIM model representation that effectively aid decision support.

5 Findings And Discussion

Sensors play an important role in data collection process for POE. Sensors should be varied according to the needs of the occupants. Nowadays, with the help of developed technology wireless sensors, which are more flexible in terms of easing implementation are becming very common in POE. There are various types of HVAC and occupancy sensors available in the market.

Even though Salford Energy House currently occupies only HVAC sensors it has the potential to implement and test other type of sensors as well. It is possible to enhance the efficiency of the BIM based BEM and BMS systems via increasing the variety and the number of sensors within the building itself and within the sealed chamber as this method will help to obtain precise feedback from internal and external environment parameters.

6 Conclusion and Further Research

This is a developing field, as with all changes in process when new technology is adopted old terminology and perspectives no longer fit. This is now the case with post occupancy evaluation and BIM models. The terms evaluation and models both seem to suggest static analysis with the help of technology available so that real-time analysis becomes possible. Architects and building owners have used POE in order to understand buildings better. In the future, building related feedback is expected to be more widely available and people will be able to interact with intelligent buildings in new ways. Developing a standard framework has potential benefits but with the current development of software and sensing devices this could quickly become out of date. Yet sensing devices once installed are unlikely to be updated with the systems they integrate with will continue to develop. If government place a greater emphasis on actual measured sustainable building performance this is likely to drive standards in this area.

The major cost of a building is the operating and maintaining the building. POE has a potential to lower this bottom line. It is likely that the knowledge a building owner has of his building will in future be a significant criteria affecting the value of said building. These automated methods should not be seen as replacing questionnaires, interviews and walkthroughs, these remain valuable tools.

In the future a greater understanding of buildings and a more developed ICT structure will in turn provide the building blocks to create smart neighbourhoods and cities.

Ultimately it is suggested that by using this approach decisions concerning the built environment will move from being “guessimates” to being decisions supported by real data.
As a future work, from Salford Energy perspective, a further iteration should be made after the installation of additional occupancy sensors. It is also important to model ‘real-world’ simulations by enabling real occupants reside within the Salford Energy House. This will allow the future research to be more accurate and realistic. Additionally, a BIM based FM (Facility Management) tool should be implemented and integrated with a Building Energy Management (BEM) tool in order to simulate the real time building related energy performance and how it affects POE.

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