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A wireless sensor network prototype for post-occupancy troubleshooting of building systems

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ABSTRACT

The correct commissioning of mechanical and electrical services is critical to new buildings' performance, but there is seldom sufficient time available to complete this skilled-labour intensive task. Accumulated delays from the rest of the project eat into the available time and there can be little left to complete commissioning before the handover. No provision for post-occupancy commissioning would be made either. It is argued that the process would be improved if commissioning engineers had access to good monitoring data, but that the main building energy management system is seldom suitable for this purpose. The practicality and limitations of using a network of wireless sensors as a portable enhanced intensive monitoring regime are explored by constructing and testing a prototype system. On the basis of a deployment in a field trial, a number of design constraints are identified. However, results show the major potential of this approach in post-occupancy commissioning.

1. Introduction

'Commissioning' of mechanical, electrical and plumbing (MEP) services is a well-defined component of the construction process (e.g. in Stage 6 of RIBA Plan of Work [1]). Given that it is a critical step for the realisation of the design, it is surprising that it has not attracted more attention in the literature [2]. In practice, there are two important professional guidance documents suites addressing commissioning, by CIBSE [3] and ASHRAE [4] respectively. The former has been referenced in British Building Regulations under a requirement that services be commissioned, though there is some doubt that this requirement is ever enforced [5]. In addition, the guidance documents presuppose the following:

i. There is enough time left before the handover to properly commission the building.
ii. The installed MEP is as designed.
iii. There are no errors in the design.
iv. The patterns of use are as assumed in the original client brief and associated design guidance.

There is no reason to suppose that any of these conditions hold for a real construction project [6]. Indeed construction projects are infamous for failing to meet their as-designed energy efficiency targets [7,8]. However, the cost of post-occupancy troubleshooting falls on the revenue budget for facilities management (FM), and not on the capital budget for the final cost of the building. From FM perspective, ensuring comfortable conditions for the occupants takes precedence and the fixes to achieve this may well further deteriorate energy performance, resulting in certain services defaulting to 'on' or energy saving measures being disabled.

The original motive of this research was to investigate technologies that would accelerate pre-occupancy commissioning to address problem (i). While the work described below could contribute to more effective commissioning, since it does not remove the pressures for the handover to happen as early as possible, it could equally result in even less time being left to commission the building and so hardly addresses problems (ii) to (iv). After handover, it becomes difficult to perform the extra tasks that would have been left out because the systems are live and can no longer be isolated.

Improving energy performance under normal building operation regime, when under control of the FM team, is discussed in terms of on-going commissioning [9] or monitoring based commissioning [10]. However, this paradigm is based on detecting buildings drifting out of specification rather than bringing them on their initial specification [11]. In addition, those measures are often implemented several years after the construction of the building, once poor performance has been recorded. At this stage, detailed knowledge of the design and construction will have been lost as the different contactors would have disengaged from the project.

The industry has envisaged that post-handover, once the MEP have been 'set to work', there needs to be a soft landing [12], much akin to a

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sea trial of a cruise liner. This process aims to tuning the building to optimal performance given its realised pattern of use, to providing a smoother transition between construction and operation, and to providing feedback for the building industry [13]. For some low energy designs, where the building operates in different modes in different seasons, additional commissioning is in any case essential. However, the current scope of commissioning limits seasonal commissioning to testing only extreme loads resulting in potential poor system performance when operating on intermediate loads and having taken limited account of occupants influence. The problem for soft landings and commissioning is gaining sufficient data from the occupied building to make intelligent decisions when there are problems to troubleshoot.

This paper focuses on using new wireless communication technology opportunity to solve the aforementioned problem. The idea of using wireless sensors in the built environment is not new, but, in practice, applications are limited despite the recognised potential of this technology [21] and more research in the domain is needed to lift the barriers. In this perspective, the data needed to perform a post-occupancy commissioning (PO-Cx) service were reviewed and specific requirements were laid down based on a previous study of commissioning's relation to wireless sensing [2]. To evaluate the practical feasibility of the method, a prototype was implemented and current technical limitations are highlighted. A test case was used to demonstrate the type of data service additional wireless data monitoring can provide and how it can improve commissioning for energy performance and occupant's comfort.

The following section addresses the problem of data availability to troubleshoot new buildings. Section 3 lays the requirements for a monitoring system for post-occupancy commissioning. Section 4 describes the realisation of such a monitoring system and the case study used to assess the method. Section 5 presents results from the study and the findings of this paper are discussed in Section 6, before concluding in Section 7.

2. Data availability

In this section, the possible sources of data available to perform post-occupancy commissioning are examined. Traditional commissioning measurement tools are mostly hand-held and thus require intensive labour to collect data, which can be justified only if other forms of intervention from the same person are needed on site. A modern commercial building will have a building management system (BMS). A BMS is a scaled-down version of an industrial control system. It will normally have the capability to control remotely all the system plants using more or less complex algorithms [14]. BMS data have also been shown to be useful for maintenance tasks [15], fault detection [16], modelling [17], or combined with BIM [18].

However, the BMS is usually booted up late in the commissioning process after the MEP plant has been set to work and part of the system might not be operational at the handover. It would also be unusual (since the design is likely to have suffered the inevitable value engineering exercise) for the tendered BMS to have dedicated monitoring capability for post-completion troubleshooting of troubles that have yet to manifest themselves. For example, the BMS is unlikely to have detailed comfort and energy related data. In addition, the BMS architecture is not designed to enable thorough data analysis as data is stored for a limited amount of time and can mostly be used towards visualisation of pre-defined time series plots.

When a particular problem area is identified after occupation, the cost of hard-wiring sensors for forensics in an occupied building looks prohibitive, whereas wireless sensing can provide temporary data with limited labour time. This is the motivation in this paper in exploring the use of wireless sensor networks (WSN) in commissioning and soft landings.

A WSN utilises self-powered sensors that are able to communicate wirelessly. WSN main commercial applications in the building industry include home automation, HVAC controls and to a lesser extent energy metering [19]. Benefit of WSN over wired technics includes portability, flexibility, fast set up, the possibility of time synchronisation, limited disruption for occupants and cost saving on installation [20]. At the moment, most WSN applications focus on replacing existing wired applications when they have the potential to create a new niche. Further development of commercial applications is limited by the lack of confidence of decision makers in the following aspects: cost, reliability, power management, interoperability, ease of use and maintenance, and security [21]. Theoretical research on all those aspects is on-going [22] and should wave the limitations once put in practice.

The flexibility of WSN systems enables Pop-Up Monitoring™ [23] where the sensors can arrive on site in a 'suitcase', be deployed, provide the necessary forensics, and then put back in the 'suitcase' to go to another site or another problem.

Information technology is infamous for being simple to conceptualise but very hard to realise. The research presented here reports the lessons learned from implementing a prototype of a portable wireless sensor network (PWSN) in a diagnostic context. The PWSN was deployed on a teaching space conditioned by a set of fan coil units (FCU). A FCU is a useful test bed because it embodies many of the typical troubleshooting issues [24]. For example, this includes FCU cooling and heating in the same space or a single FCU oscillating between heating and cooling without stabilising at the right temperature. However, given the number of FCUs deployed in a building it is very unlikely that the BMS would have comprehensive instrumentation suitable for troubleshooting performance.

3. WSN system requirements

3.1. Requirements for post-occupancy commissioning

In this section, the requirements that must be met by a PWSN for commissioning, particularly during the post-occupancy phase, are presented. The prototype was used to identify the most feasible way of meeting these requirements. Following the argument above, commissioning pre- and post-occupancy need to be seen as an integrated process. At the end of the process the reasons for the resultant energy consumption should be verified, and the occupancy satisfaction requirements met. The building is then ready to enter the exception monitoring stage of the on-going commissioning cycle. The data requirements for the commissioning process must then enable:

i. Performing seasonal commissioning over a complete spectrum of operating conditions
ii. Systematic performance checking
iii. Responding to occupant feedback
iv. Evaluation of services and their controls in use

PO-Cx requires data at different spatial scales. The BMS exists to exercise central control and provide exception monitoring. It can locate problems at a high level but would be unable to analyse issues further. A PWSN system should therefore be able to interface with the BMS data though not necessarily be part of the BMS command structure. This can be done using a data aggregator to pull data from the BMS and store it in the PWSN database for combined analysis.

The skilled staff deploying the PWSN should not be expected to be IT experts, nor qualified electricians. The network should essentially be plug-and-play, as should the process of bringing a new node into the network. Therefore an intuitive network commissioning piece of software needs to be developed alongside the WSN. Even then, given the time limitations on site, the system should have been pre-tested if possible before arrival on site. The sensor nodes should be as small as possible to have greater flexibility in their location. They need to be easy to attach and remove. All the sensing techniques need to be unobtrusive to avoid disruption of normal operations. This means that it