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Building monitoring protocol development for deep energy retrofit

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Abstract. This paper presents the design of a monitoring protocol to support retrofit strategies and drive the evaluation of a low carbon house. Monitoring is used during pre-intervention stage to facilitate the decision-making process, as well as in the post-intervention to evaluate the performance of the building and systems. The first phase refers to monitoring as a diagnostic tool with a view to reduce the uncertainty of suggested low carbon solutions by providing real measurements and evidence on building conditions, comfort, systems and occupants behaviour and interactions. The second phase utilises monitoring as an evaluation tool to quantify benefits and challenges of the retrofitting by providing information and analysis on the supply and demand reduction, the difference in comfort and the effectiveness of each intervention. The study explains the protocol development and discuss different monitoring depths and requirements based on the performance indicators required. A typical pre-1919 Welsh end-terraced dwelling is used as a case study to demonstrate the two phases of the proposed protocol. The protocol was developed as part of the Low Carbon Built Environment (LCBE) project at Cardiff University and it was tested in various building types and research-led retrofit packages.

1. Introduction

It is well understood that buildings are a major contributor to greenhouse gas emissions [1, 2]. This is more significant in countries with old buildings such as the UK where emissions from buildings account for 37% of the total emissions and 2/3 of this coming from residential properties [1, 2] . The Welsh building stock is one the oldest in Europe with 75% of the houses built before 1980 and 36% before 1944 [3]. From 1976 building standards have been established to ensure high standards of energy efficiency in old and new-built properties. Improvements to the existing building stock is of a major importance in order to reduce emissions, energy bills and levels of fuel poverty and increase the standards in comfort and health [2, 4-6]. Governments push the market by providing incentives and schemes that offer a variety of mediums towards low carbon retrofitting. However, the design and implementation of technologies in existing occupied dwellings is a challenging process involving a variety of stakeholders and expertise with a high risk for performance gaps.

The SPECIFIC Low Carbon Built Environment (LCBE) project in Welsh School of Architecture (WSA), Cardiff University is a European funded project in collaboration with the industry, government, academia and the public on ten low carbon built environment demonstration projects. These demonstration projects combine appropriate renewable energy supply, energy storage, and energy demand reduction technologies to create a low carbon built environment that is both replicable and affordable. The project, amongst others, targeted 24 old residential buildings in west Wales and Valleys area and applied a deep retrofitting holistic process. This involves the identification and modelling of the most appropriate low carbon technologies, the implementation and demonstration of these technologies in practice and the monitoring, before and after, to provide evidence of the impact of the retrofitting solutions.

This study will describe how building monitoring fits in all the different stages of a deep retrofit process. From the pre-intervention to the post-intervention, a monitoring protocol will be described with the aim to propose a procedure replicable as a whole or partially depending on the depth of the retrofitting, the maturity of the implemented technology and the performance indicators set by the stakeholders. In this study the term building monitoring summarises all the measuring, monitoring and instrumentation processes and techniques to quantify parameters related to the building, its systems, occupants and environment as well as all the data processing procedures required to respond to the performance indicators established to quantitively describe the impact of the interventions. The protocol has been applied in full for research purposes, to a number of SPECIFIC LCBE case studies; one of the case studies, a semi-detached end-terrace house in the Wales valleys us used in this study to exemplify each monitoring step in a real-life setting.

2. Protocol development

The monitoring protocol was evolved to respond to the different steps of the retrofitting process and evaluation:

- To assist in decision making process of the interventions.
- To quantify the benefits of the interventions.

The first reason refers to the pre-intervention stage where monitoring is a design tool, whereas the second one is an evaluation tool and refers to both the pre and the post-interventions stage. In order to quantify the benefit of an intervention, the difference between the post and pre-intervention needs to be measured, meaning that monitoring actions must be taken before the intervention to make this comparison feasible. A brief overview on how monitoring processes scheduled before and after the retrofitting interventions are shown in figure 1.

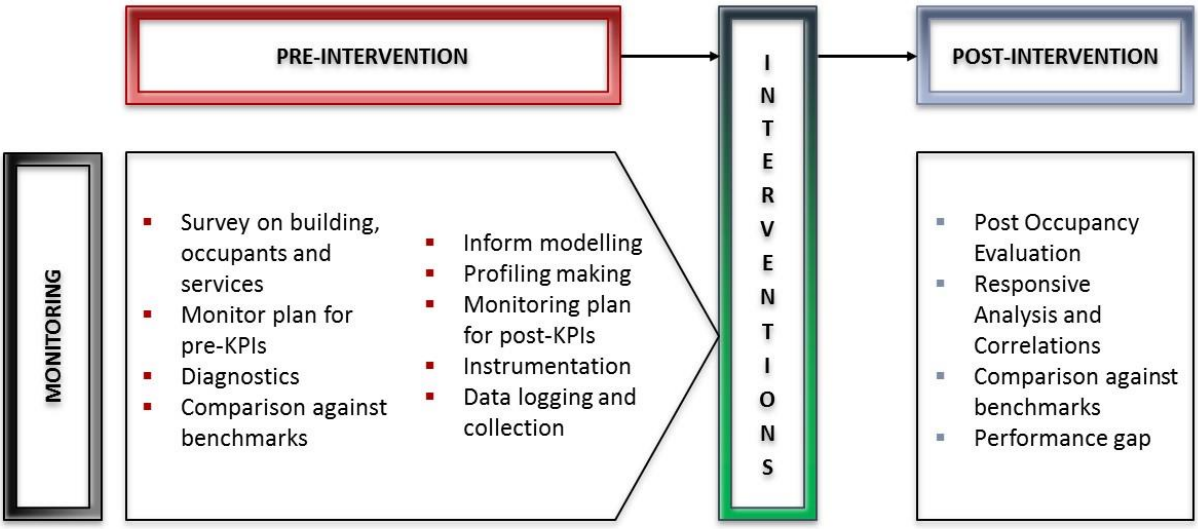

Figure 1. A summary of monitoring processes before and after the interventions

The very first step in a retrofitting process is the identification of the building related issues and concerns; this can be initiated by the occupants, housing associations or councils by gathering complains and by analysing more objective mediums such as Energy Performance Certificates (EPCs). These initiation routes include some risks as the occupants may not report issues or do not have the technical background to detect and recognise technical problems; in addition, EPCs (if exist) include some indicative information on potential retrofitting benefits but they lack information on comfort, dynamic modelling and accurate measurements.

Building monitoring as a powerful diagnostic tool is essential to recognise, quantify and characterise the building as a parametric framework where the environment, systems and occupants interact. Also, monitoring assists the design/sizing of the interventions responding to a specific building and occupants. However, one of the most crucial decisions to be made in the initial stage of the retrofit is if the interventions will respond to the existing occupants/tenants or to a typical occupancy profile for the house type and area. This will drastically affect the monitoring procedure as in order to create a typical demand or comfort profile, benchmark data may be enough; whereas in order to create real profiles, extensive monitoring processes are required. In this study, real life occupancy patterns were monitored; however, it is suggested that every profile should be compered against benchmarks to detect any extreme differences and understand if the interventions could be replicable.

Another vital decision that will drive the monitoring process as a performance evaluation tool is the identification of the key performance indicators (PIs). This is mainly depended on the stakeholders and the multiple perspectives and priorities on what the performance focus and depth is. An example on the different views on the performance indicators is illustrated in figure 2 where each stakeholder asks different possible questions on the implementation of an innovative low carbon technology. The building evaluation methodology used in this study was based in monitoring techniques and protocol developed in the Welsh School of Architecture as well as literature and guidance on building metrics and performance evaluation protocols [2, 6-13]. The focus and PIs are research driven and examine both the building as a whole and the impact of individual systems in response to real life demand profiles.

Figure 2. Example of the different perspectives in the performance evaluation - key performance indicators for a variety of building associated stakeholders

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3. Dynamic and non-dynamic monitoring

By using the term non-dynamic monitoring, we refer to all the measuring processes and data collection that are not depended on the occupancy patterns or dynamic weather conditions. This type of data refers to the site, the building, the systems and the occupants' static (unchanging) information. There are a lot of tools to extract the information needed, described in table 1 below, such as a site survey, building survey, EPCs, occupants survey, historic weather data files, building envelope tests etc. The data analysis of this information collected is the output of the initial building's diagnosis which will inform the first stage of the decisions on passive and active retrofitting interventions.

Table 1. Non dynamic pre-intervention monitoring & data collection

Task Details	Action/Equipment/Technique
Site analysis and surroundings	Collect information of natural context such as nearby natural resources in abundance, topography, landscape, climate and weather trends, rivers, lakes, shading of surrounding and vegetation, mountains coordination etc. Tool: site survey, weather data files
	Collect information of artificial context such as surrounding buildings and neighbourhood context and patterns, artificial shading, noise, drainages, utility grids (gas, electricity, water etc) and future developments. Tool: site survey, DNOs, research
Building type, envelope, dimensions, construction, fabric details	Obtain information on building type, listed facades, age, orientation, access, views, number of storeys, roof inclinations, EPCs or other certificates Tools: building survey, research, occupants survey
	Record information about the building envelope and structure, openings and glazing ratio, type, frames, seals etc., fabric/roof materials and layering, insulation, loft boarding, U values Tools: Building survey, research, EPC U value tests (heat flux meters)
	Take dimensional measurements, internally & externally, fabric thickness, roof slopes, record flashing, ridge, eaves, soffits, downpipes, gutters, sills, floor joists, base course, air bricks, grills, trickle vents, chimneys etc. Tools: Building survey, occupants survey, EPC, dimensional instruments (tape, laser, ultrasonic meter)
	Inspect defects in fabric, air and water tightness, drainages (cracks, mould, dampness, degradation etc), air permeability. Tools: Building survey, thermography, Blower door test
Systems survey, existing capacity and nominal performance	Record energy mains, gas and water piping, consuming unit capacity, existing meters, suppliers and utility companies. Tools: Building survey, occupants survey,
	Collect nominal information on all the systems (electrical, mechanical), setting points, usage, number and capacity of appliances and lighting, specs and efficiency of boiler, electric shower, air conditioning units, electric heaters, mechanical ventilation units, renewables etc.

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	Tools: Building survey, occupants survey, EPCs, research, wattmeter, air velocity meter
Occupancy	Collect subjective/objective information from the occupants on behaviour, set points, comfort, occupancy patterns, activities, bills, cost, ability to change and adjust. Tools: building survey, bills and specs data collection

The second stage of the decision-making process requires more information on the building performance as a response to weather/occupancy variation. This will then inform any modelling/projection in terms of systems feasibility, sizing and running costs. Also, long term performance outputs (for example monthly) can be produced in order to compare the effectiveness of the systems by comparing pre and post intervention indicators. The long-running monitoring usually refers to weather, comfort and energy data with a view to create profiles on different occupancies (weekdays / weekends) or heating patterns (heating / non-heating season) etc. Both, the monitoring indicators and tools and techniques are presented below in table 2.

Before applying a long-term monitoring plan, the duration and the time interval of the data collection needs to be identified. In the case study presented below, a 12-months pre-intervention and a 12-month post intervention monitoring period was decided to include a full heating and non-heating season. The interval was decided to be 5 minutes which provides a higher resolution than the suggested in the existing protocols [9, 11, 14]. This was decided for research purposes as the project investigated real time systems performance and efficiencies in response to transient and intermittent weather conditions. Extra attention was given to synchronise all sensors in order to represent simultaneous measurements despite any inertias. The data collection was grouped in one logger (CR1000 from Campbell scientific) and the information was sent back wirelessly to WSA servers every five minutes to enable live data visualisation and analysis.

Table 2. Dynamic pre-intervention and post intervention monitoring

Task Details	Action/Equipment/Technique
Weather data	Data logging of weather data on site: solar radiation, ambient temperature and relative humidity, barometric pressure, rainfall, wind direction and speed Tools: installation of weather station on site. Monthly average/total analysis and 24 hours profiles for heating and non-heating season
Comfort data	Data logging of temperature, relative humidity and CO^2 (in main or all occupied spaces). Tool: Installation of temperature, humidity & CO^2 sensors and loggers. Monthly average/total analysis and 24 hours profiles for heating and non-heating season
Energy data	Data logging of main electricity import (or export if exists), data logging of main generators (photovoltaics, air condition unit etc). Data logging of main gas meter and gas boiler. Tool: Installation of main meters and sub-meters (clamp-on or inline with pulse output) for electricity. Installation of a main or secondary meter for gas mains and gas boiler (induct with pulse output). Monthly average/total analysis and 24 hours profiles for heating and non-heating season
	Data logging of space heating and hot water

	Tools, heat meters if water based system, mass flow rates + temperature sensors if air heating system. Monthly average/total analysis and 24 hours profiles for heating and non-heating season
	Data logging of electricity sub-meters (most important or all circuits in the consuming unit). Tool: Installation sub-meters in the consuming unit (inline DIN-rail with pulse output) for electricity. Monthly average/total analysis and 24 hours profiles for heating and non-heating season
	Data logging of any other supplementary system or sub-system, For example DC circuits, solar thermal systems, heat exchanger units etc Tool bespoke approach depending on the system. Preferably meters with pulse output per energy unit, alternatively, installation of apparatus that monitors individual components of their energy delivery equation. Monthly average/total analysis and 24 hours profiles for heating and non-heating season

4. Case study: Protocol Application

A monitoring plan based on the pre and post intervention protocol as well as the non-dynamic and the dynamic monitoring suggested above was designed to fit the development priorities set in the LCBE project. The plan aimed to respond to two main principles: to assist the decision making process of the interventions and to facilitate the quantification of their impact. The case study building is a typical 100 years old, two storey 80m2, semi-detached end-terraced house in south Wales. During the monitoring period, the occupants were a family of two adults and two children, spending most of the time at home (social housing). The main heating system a gas fed combi boiler did not change, providing space heating and hot water. There were complaints on the building fabric in terms of air tightness and damp. The improvements on building envelope included external (EWI), internal (IWI), loft, and overlapping (anti-thermal bridging) insulation. Also, LED light bulbs were fitted and mechanical ventilation system with heat recovery (MVHR) was installed with a delivery of fresh air to all living spaces. On the supply side, photovoltaic (PV) panels were mounted on the double pitched roof (5.9kWp), electric batteries (13.5kWh) were fitted in the attic and transpired solar collectors (TSC) were installed on the south facade feeding solar heated warm air to the ventilation system during the heating period (figure 3). The system allows the export of excess renewable electricity generation to the grid.

The monitoring plan indicates the monitoring works in three categories: The first category includes non-dynamic studies on the building fabric such as, multiple U-values tests, air infiltration test and thermal imaging. In addition, it includes all the static data gathering on the building and site. Most of these measurements were taken before the interventions, however, some measurements were repeated after the interventions to identify changes of the building fabric and occupants' perception. The second and third box in the figure below contain long term monitoring processes refer to both pre and post intervention whereas some of them refer to the new systems installed. The plan also includes a brief indication of the position of the sensors in terms of location and in response to the systems of the building. The results of the monitoring informed the retrofitting strategy followed including the type of insulation and the type and size of the technologies. Also, the results included PIs such as total energy and operational cost reduction, changes in comfort, contribution of the individual system and payback times.

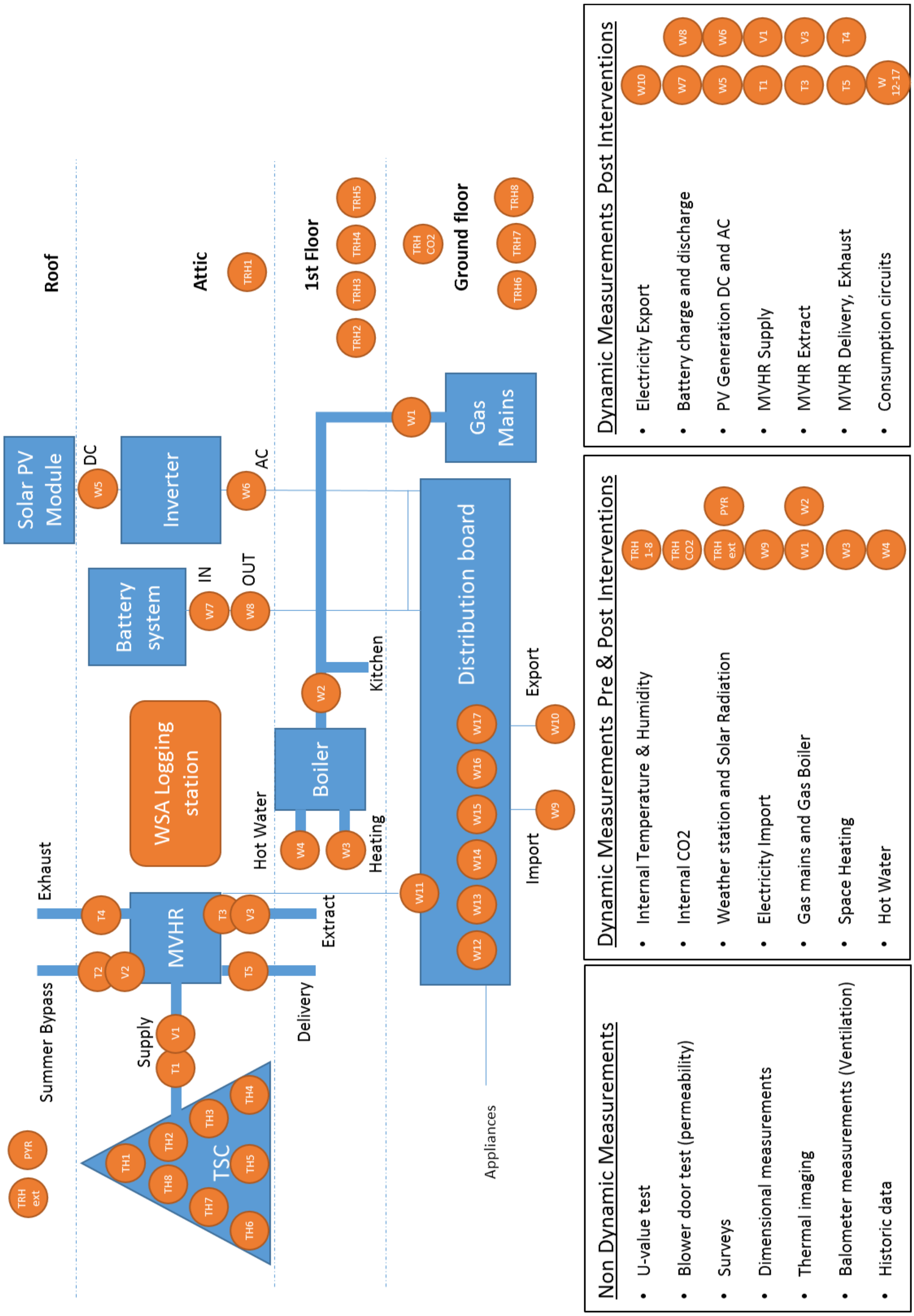

Figure 3. Monitoring Plan and Measuring indicators applied in a Welsh case study

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5. Conclusion

This study introduces the development of a monitoring protocol to be used in a retrofitting of a dwelling. The process enhances the understanding of the building and enriches the interventions proposal with qualitative evidence. Also, the monitoring is used for building and system evaluation and for quantifying the benefit of the intervention in terms of energy, comfort and cost. This work splits the monitoring work into dynamic and non-dynamic monitoring. The non-dynamic is the pre-intervention initial monitoring that works as a diagnostic tool whereas the dynamic monitoring refers to long-term monitoring to explain and group variations in response to energy, comfort and weather. The dynamic monitoring assists the modelling process providing realistic profiles and allows for analytical building and systems performance evaluation. Tools and techniques are also analysed and used in a case study in a dwelling in south Wales.

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