Understanding Our Heritage: Monitoring of energy and environmental performance of traditional terraced houses of Northern England.

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Abstract *– Existing buildings play a key role in the achievement of the ambitious energy saving and greenhouse gas reduction targets that Europe has fixed for 2020 and 2050. Research has demonstrated that the impact in terms of decrease of energy use and CO2 will be strong, considering that, in Europe, 80% of the 2030 building stock already exists and 30% are historical buildings. To achieve these goals, reliable data about energy consumption, building components and systems performance of the existing building stock is needed to implement adequate strategies.*

United Kingdom (UK) is one of the most advanced European countries in regards to the implementation of regulations and programs to measure and assess the real performance of its old buildings. One of these programs is the Green Deal Go Early Project (GDGE) that the University of Salford has conducted for the UK Government during 2015 and which first discussions are presented in this paper. The values obtained from the monitoring of 16 solid-wall pre-1919 Victorian terraced houses in Greater Manchester are in accordance to those extracted from the BRE report on "In-situ measurements of Wall U-values in English Housing", what validates the methodology followed to approach the monitoring of these case study houses as well as the preliminary results. This alignment provides a closer definition of the real U-value of solid wall housing typology confronted with those currently provided by the Standard Assessment Procedure (SAP) and Reduced Data Standard Assessment Procedure (RdSAP), leading the way to a better understanding of the performance of historic buildings and hence an improvement in the retrofitting strategies.

Keywords – Traditional Housing; Monitoring; Energy Performance; Northern England; Terraced Houses

1. INTRODUCTION

The urban fabric of European cities is largely shaped by old and inefficient residential buildings whose energy demand can exceed 200kWh/m² per year [1]. More than 40% of our European residential buildings have been constructed before the 1960s when energy building regulations were very limited [2]. As a matter of fact, the energy used in domestic buildings contribute a large percentage of the world's carbon emissions [3]: while modern building techniques are able to produce dwellings with a low in-use energy requirement, a greater impact can be made by improving the existing, poorly performing housing stock [4].

Additionally, architectural heritage deserves very particular attention within a sustainable architectural approach, with regard to sustainable energy development and historic buildings protection [5]. Preservation of the architectural heritage is considered a fundamental issue in the life of modern societies [6] contributing significantly to the value of the city by branding the city´s character. The need of preserving historical constructions is thus not only a cultural requirement, but also an economical and developmental demand [7].

In United Kingdom (UK), the number of new buildings contributes at the most 1% per year to building stock [8] whilst the other 99% are already built buildings. In fact, UK is one of the countries in Europe with the largest components of older buildings [9]: 21% of UK housing were built before 1919 and the advent of cavity walls [10]. Terraced houses account for 6.788.000 [11] what supposes a 29.9% of the total building stock [12]. Moreover, from the 3.076.000 dwellings in North West England (where Greater Manchester is sited), 35.5% are terraced houses [12]. The retrofitting of this residential stock could so provide considerable potential in energy conservation and sustainability benefits [13]. However, the achievement of the benefits reaped from the retrofitting could be jeopardised by the scarcity of knowledge about the behaviour of historic buildings and its consumption patterns, what supposes a major obstacle to take right decisions over a specific building stock.

This research seeks to address the following two questions: first, the need to establish an efficient monitoring system assuring good data availability and data quality; and second, the need to develop a systematic understanding, methodology and analysis when approaching these buildings which incorporates the many interactions both within specific elements and at a whole house level including technical factors and user behaviour [14]. It reviews the research conducted on 16 Victorian terraced houses sited in the area of Great Manchester and it is the result of a two-year monitoring of pre and post-retrofitted housing developed under the Green Deal Go Early (GDGE) project run by the University of Salford for the UK Government. Whether some air test results and Energy Performance Certificates (EPC) energy use calculations are provided, this paper does not present results but preliminary descriptions and discussions. Therefore, no results chapter has been provided.

2. STUDIED SAMPLE: TERRACED HOUSES OF NORTHERN ENGLAND

Our targeted building stock is described by English Heritage as “a property built prior to 1919 with solid walls constructed of moisture-permeable materials” [14]. This stock is defined by a solid two layers of brick non-insulated envelope. The insulation of solid wall housing is indeed one of the greatest challenges for energy efficiency policy, but it also potentially offers some of the most significant savings [15].

The Building Research Establishment (BRE) [16] defines two types of housing among this stock: Standard and Non-Standard. Standard buildings are those with less than 330mm wall thickness while Non-Standard are those beyond. Only two of our examples are Non-Standard houses with a triple brick solid wall dated before 1800. They have been considered as part of the sample because the time period, wall structure and material use.

Table 1. Housing samples definition and identification

ID	Archetype	Standard/Non-Standard
C1 - C18	Semi-detached Pre1800 brick.	Non-Standard
C8 - C9 - C10 - C12 - C14 - C15, S2	Semi-detached pre 1919 solid wall.	Standard
C6-C17	Mid terraced pre 1919 solid wall.	Standard
S3 - V1 - V3 - V4	End terraced pre 1919 solid wall.	Standard
V2	Terraced pre 1919 solid wall.	Standard

As aforementioned, all buildings improved in this study had solid walls with no cavity. Insulation was placed on the inside or outside face of the buildings during the retrofitting respecting the original fabric and the authenticity of the historic values of the buildings. In most cases, the insulation was placed on the outside of the buildings around the rear and sides, and the façade was preserved by installing insulation on the inside across the front elevation although internal insulation caused much more disruption to the occupants, removing some of the living space. The insulation layers also needed to 'overlap' somewhat to prevent the brickwork becoming a cold bridge. On a couple of the buildings, thin tiles that resemble the original brickwork where placed over the insulation to mimic the original appearance.

3. METHODOLOGY

The methodology followed in the project focuses on gathering and storing data from buildings that could be analysed in the future. The relevant steps for this paper are building selection and data collection, which correspond respectively to the processes to *identify and select buildings to monitor* and the *collection of quantitative and qualitative data* from the selected buildings.

3.1 BUILDING SELECTION

The eligible dwellings are a sub-set of those that forms the GDGE monitoring project. Started in 2012, this project included in-use performance monitoring and fabric testing of domestic properties across greater Manchester with the aim of investigating the effectiveness of the UK government's Green Deal (GD) program. This report concerns itself with the terraced archetype. Sixteen properties have been classified by experimental group: either 'Control' (unaltered, no retrofit measures) or 'Retrofit' (significant energy efficiency measures applied), and by ownership status: 'Owner Occupied' (owned by the occupant) or Housing Association (owned by a third body, responsible for the retrofit measures, and rented to the occupant). Figure 1 shows how the sample properties are distributed regarding to these indicators:

Carbon Coop: Properties recruited through a cooperative community benefit society formed by householders from Greater Manchester. The houses included are mid- and end-terraced houses.

Control Group: Unimproved end terraced houses.

Housing association: recruited from a housing association in Greater Manchester, the retrofit houses are all end terraces.

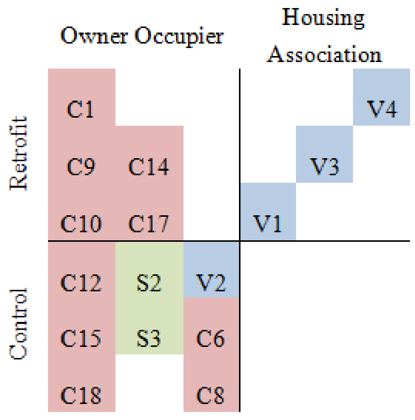

Figure 1: Classification of sample properties

3.2 DATA COLLECTION

The goal of this task is to collect dwelling quantitative and qualitative data as follows: quantitative data about the house as a whole is collected by direct *monitoring* with sensors and by the *availability of EPCs*; quantitative data of the building fabric is collected using both testing methods (*U-value* and *air tightness*) and *thermography;* and finally, qualitative data about user satisfaction with the retrofitting is gathered with a survey.

3.2.1 Whole House Methods

Monitoring: The monitoring period, between 2013 and 2015, comprised the adoption of retrofit strategies in some of the housing examples what provides pre and post retrofitting measures to the study. The monitoring equipment included small, battery powered sensors that communicated wirelessly with a central ‘hub’ that periodically stored/updated data into a central server. Data includes information of primary energy consumption (gas and electricity), internal conditions (temperature, relative humidity and CO2 emissions) and external temperature.

Energy Performance Certificates (EPC) In many cases, EPCs where available for retrofit houses in their pre-retrofit state, allowing a before and after comparison. In the UK, EPCs are generated using a reduced version of the Standard Assessment Procedure and presented as a band A to G (A is higher efficiency) and a score 1 to 100(100 is higher efficiency) [12].

3.2.2 Building Fabric Methods

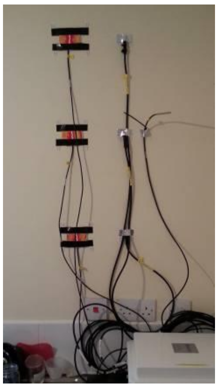

Figure 3: U value measurement

Figure 4: Air tightness test

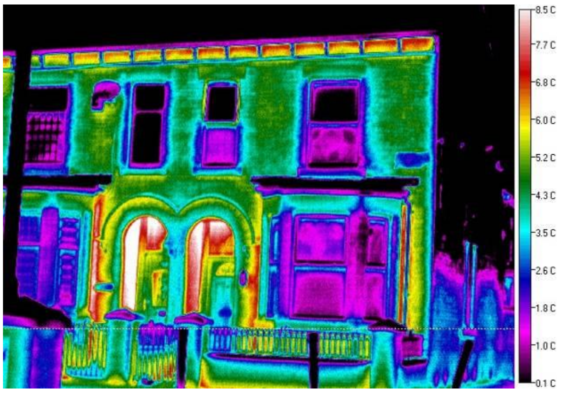

Figure 5: Thermographic image

U- value testing: The U values of several of the houses where measured according to ISO 9869-1:2014 [17] (Figure 3, above). U values were also calculated using BS EN ISO 6946:2007 methodology [18].

Air tightness testing: Air tightness tests using the ‘blower door’ method (figure 4, above) were carried out to determine the rate of air infiltration. The test gives a result as a q50 value, being the volume of air (m3) infiltrating the building envelope (m2) per hour (hr) at a pressure difference of 50 pascals (50pa). The tests conformed to BS EN 13829:2001 methodology [17].

Thermography: For maximum accuracy, and in conformity with the BS EN 13187:1999 methodology [18] (Figure 5), the surveys where carried out in the evening at least 2 hours after sunset when the internal temperatures of the building where a minimum of 10°C higher than external air temperature.

3.2.3 User Methods

User Survey: The households filled in a personal survey conducted by the expert before and after the retrofitting. This survey gives a qualitative approach to the measures. The preliminary findings of the project indicate that it is very difficult to disaggregate the effects of fabric improvement from the occupant's behaviour.

4. FIRST OUTCOMES AND DISCUSSION

This paper presents the preliminary outcomes of the monitoring of 16 terraced dwellings as well as the methodology followed. The obtained data is being processed using a bottom-up and top-down approach:

Bottom-Up: Energy consumption is a key indicator to evaluate the improvement of a retrofit strategy. Gas and electricity consumption has been measured in all the selected houses. A first problem encountered was that primary energy use data cannot be compared between houses directly as the monitoring interval was not identical. As an assumption, degree day regression was used to normalize the energy use against external temperature. Graphics comparing the consumption and the degree day regression assumption has been developed for all the houses what allows direct comparison of energy data from multiple houses over different time periods (see Figure 6 and 7). The distribution of the values in figure 7 display a strong positive correlation, with an r^2 value of 0.77. This is at the high end of the range of r^2 values indicating that the energy use in this house is particularly responsive to changes in temperature, suggesting an effective use of heating controls.

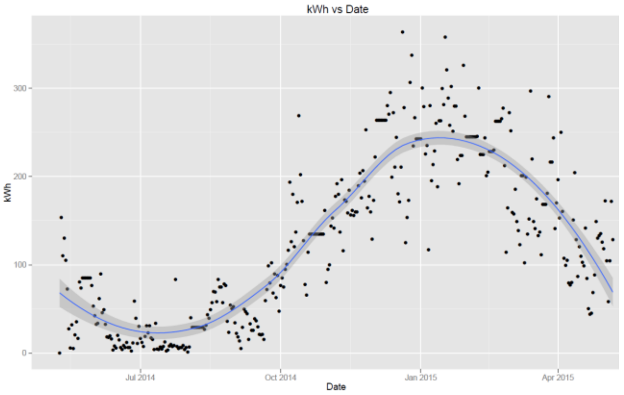

Figure 6: kWh gas use by date (example)

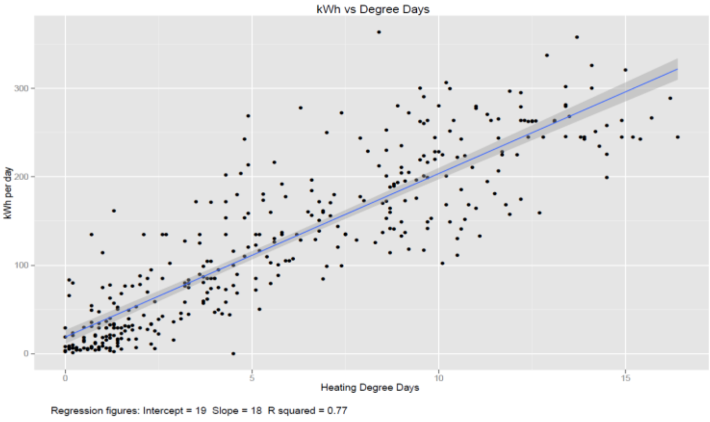

Figure 7: Degree day regression on same data

Table 2. Summary of results compared with those of the BRE report [13]

Retrofit improvements	Archetype	U-Value Measured_Mean (W/m²K)	Measured U-Values BRE_Mean (W/m²K)	Percentage difference
As built	Semi-detached Pre1800 brick.	1.6	1.28	25%
	Semi-detached pre 1919 solid wall.	1.3	1.57	-17%
	End terraced pre 1919 solid wall.	2.38*	1.57	-50%
External wall insulation	Semi-detached Pre1800 brick.	0.4	1.28	69%
	Semi-detached pre 1919 solid wall.	0.29	1.57	82%
	Mid terraced pre 1919 solid wall.	0.32	1.57	80%

In 2014, BRE published their report about in-situ measurements of wall U-values in English Housing [16]. This report concludes that the averages of the measures values for solid un-insulated walls are below the standard values used in the RdSAP methodology and below the mean of the theoretical calculated U-value regarding to the wall typology. Table 2 shows the comparison of those results with the ones measured in the monitored housing. The U-values of the ‘as built’ pre retrofit properties fall within an acceptable margin of the BRE report. Differences could be due to the number of examples used for the different studies - 300 in the case of BRE - that provides them with more accurate averages. The improved properties with ‘external wall insulation’ show a sizable improvement when compared to the same archetypes in the BRE report. The U-value measured from the End terraced pre 1919 solid wall (* above) is particularly high, possibly due to the deterioration of the building fabric due to damp. However, the figure is within the 99% confidence interval of the BRE report sample (assuming normal distribution, within three standard deviations from the mean), suggesting that although unusually high, the value is not necessarily in error.

Top-Down: the GDGE project has provided data of pre and post retrofit measures. Among the 16 sample cases, half of them were retrofitted. Figures 8 and 9 show the impact of retrofitting strategies on air infiltration (q50) and primary energy consumption calculated from the EPC [16]. Regarding to EPC rating, important improvements could be appreciated in the semi-detached solid wall typology. During the measurements, it was noted that unimproved properties can be more airtight than expected due to regular maintenance; the attitude of the occupants towards draught proofing has a large effect on the q50 value. Conversely, the disruption to the building fabric caused by the retrofit measures, particularly the installation of internal or external insulation, can potentially cause disturbances to the fabric that lead to an increase in the infiltration rate.

The results presented in this paper are just a preliminary overlook of the datasets collected during the last two years. A methodology has been established to approach a unified understanding of the outcomes that could be compared through all the housing examples. Some assumptions have been made in the adoption of this methodology that need refining in the ongoing analysis.

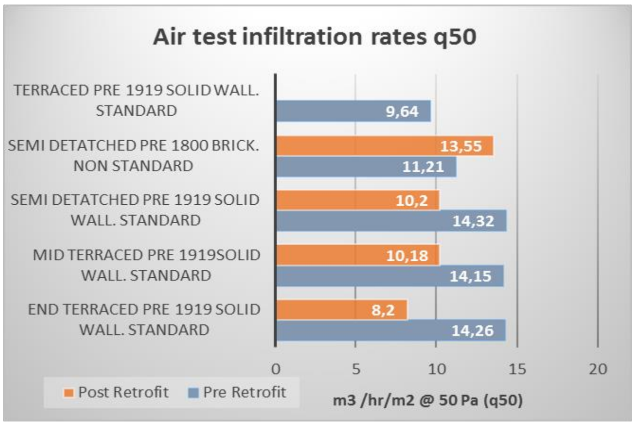

Figure 8: Air infiltration rates pre and post retrofit

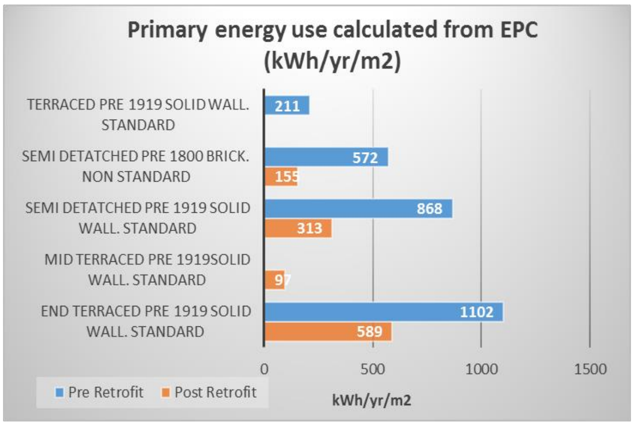

Figure 9: Primary energy use pre and post retrofit (Figures from EPC)

Currently, the data has been processed in the micro-scale by looking to individual measures separately by individual housing. Some clues of a wider look have already been introduced in the discussion but more work has to be done in proposing global reliable values that define the whole building stock.

5. CONCLUSION

The approach to traditional buildings needs a systematic understanding, methodology and analysis. This paper presents the results of a two years monitoring of pre and post retrofitted examples of solid wall terraced buildings in the area of Greater Manchester. The outcomes of this study serve as base to a better understanding of the performance of these buildings. The results included in this paper suggest consistent improvement in air infiltration rates, U-Values and EPC calculated energy use estimates. As the analysis progresses more detail into the effectiveness of the retrofit measures will emerge, which will contribute to further programs of retrofit measures promising reductions in energy consumption and CO^2 emissions in the whole building stock.

The green deal, now defunct, relied on a "golden rule": that the occupants will always be paying less for their heating even with the additional surcharge added to their bills to pay for the improvements. The preliminary findings of the project indicate that it is very difficult to disaggregate the effects of fabric improvement from the occupant's behaviour, for example, comfort taking, ventilation practices, secondary heating. Therefore, a simple calculation based on estimated energy saving will be insufficient. For future government initiatives for retrofit, a different finance mechanism should be considered.

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