Impact Assessment of a shell Element Retrofit: Measuring U Value Change with a Non-Intrusive Metering System

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Abstract:- Retrofit of an entire building is often a multitask procedure that requires significant resources in order to minimize its' energy consumption. Therefore in several cases, shell retrofit is more appealing and approachable. This article presents a technique that was developed and validated in the field, during the RESSEEPE project (FP7). The technique allows the estimation of the U value change of a retrofitted shell element and directly link's this change to the factual retrofit impact. The method is based on remote, real time, infrared scanning of just one surface temperature of the element before and after the retrofit. Apart from the element's surface temperatures, both the indoor as well as the outdoor temperature are also required. The method is very easily and remotely set up, is completely non-intrusive, while its' cost efficient leasing model makes it quite promising. Thereupon the purpose of this study is to present a reliable, objective and cost effective assessment of a shell element retrofit impact by measuring the U value changes. As this estimation could affect the decision making process, regarding the verifiability and accuracy of the earnings claims, one can only realize this work's contribution, as it provides facts where opinions are formed.

Keywords:- *Shell retrofit; U value change; monitoring modul.*

I. INTRODUCTION

According to the European Commission buildings are responsible for 40% of energy consumption and 36% of CO2 emissions in the EU [1, 2]. While new buildings generally need fewer than three to five liters of heating oil per square meter per year, older buildings consume about 25 liters on average. Hence existing buildings consume a large proportion of total energy end-use worldwide [3]. As the replacement rate of the building stock is less than 5% per annum [4, 5] improving their energy efficiency and thus their energy consumption (energy retrofit) becomes essential and a major task for every country in order to reduce overall the global energy use.

Last decade European Union acknowledged the fact that in order for energy efficiency targets to be met, a widespread improvement in policy level was needed across European Regions [6]. Energy efficiency has to be increased at all stages of the energy chain, from generation to final consumption [1, 2]. At the same time, the benefits of energy efficiency must outweigh the costs like those that result from carrying out renovations. EU measures therefore focus on sectors where the potential for savings is greatest, such as buildings. Thereupon several projects aiming to energy efficiency improvement in existing buildings were financed by EU. At the same time, several researchers who have been investigating different energy efficiency opportunities in order to improve energy use within the existing building stock [3], have concluded that building retrofitting or refurbishment could reduce significantly energy consumption [7].

As building retrofitting is considered the work needed to upgrade an aged building, it hides a lot of challenges due to buildings' subsystems which are highly interactive. Dealing with these uncertainties makes the selection of the retrofit technologies a complex task. Apart from the practical challenges there are also several financial limitations and barriers that a potential investor have to overcome. The overall cost, the long payback periods, the long lasting and stressful procedures when the financial support comes from the government are few of the bottlenecks that could outshine retrofitting significant benefits (reduced maintenance costs, improved internal conditions etc.). All the above along with the fact that now day several retrofit measures could be adopted transforming thus a decision to a multi optional proposal add further value to this article. One of the building retrofit problems is to apply the right technology for enhanced energy performance while maintaining acceptable indoor thermal comfort, under a given set of operating constraints [3].

Thereupon this paper aims at providing not only insight on the difficulties that are encountered and solved by the proposed technique on measuring or communicating energy retrofit impacts but also facts to a potential investor concerning his retrofit technology choice, by introducing an easily deployed and cost effective methodology, which will allow a fast and accurate assessment of energy retrofits in buildings and thus decision making. By doing so this paper allows not only the building owner or the investor to comprehend the impact of his investment, but also the retrofit provider to fully understand his/hers solution limitations and launch continuous improvement strategies [8] adding therefore more value to this study.

II. LITERATURE REVIEW

One of the major building retrofit problems is to determine which method will be used for a pre-valuation of the adopted technology for achieving enhanced energy performance under a given set of operating constraints. A variety of energy simulation models have been developed and used to estimate energy performance of different retrofit measures [3].

2012 [9]	A multi-objective mathematical model that allows the simultaneous consideration of all available combinations of alternative retrofit actions.
2012 [10]	A transient building physics and energy supply systems modeling process that simulates the effect of large set of building retrofit options.
2012 [11]	A static simulation modeling technique that is sufficient as an underlying technique for retrofit analysis.
2011 [12]	An evidence – based methodology that calibrates whole building energy models.
2009 [13]	A Building Information Modeling (BIM) that predicts the energy performance of retrofit measures by creating models of existing buildings and modeling improvements.
2008 [14]	An artificial neural network (ANN) that predicts the energy savings for building equipment retrofits.

Table 1:- Simulation models for estimating energy performance of different retrofit measures [3, 9, 10, 11, 12, 13, 14]

The above studies point out the significant role that a simulation model plays in analyzing the performance of retrofit measures. Since different models offer different prediction reliabilities with different uncertainties, the model selection and its parameter identification are essential to ensure reliable estimates [3]. According to International Performance Measurement and Verification Protocol – IPMVP [15] measuring energy savings should be based on the following general equation:

Energy Savings = Baseline (pre retrofit) Energy Use – Post Retroft Energy Use ± Adjustments

This equation's main challenge is the identification and measurement of energy changes in non-energy retrofit factors. Thereupon IPMVP proposes four Measurement and Verification (M&V) options that can be used for energy saving estimation and verification. These options have been widely used from various researchers [16, 17, 3] providing evidence that M&V is an effective approach of measuring energy savings achieved by retrofit technologies.

However the last part of the equation accounts to changes of external conditions such as weather and occupancy information [15, 18], key external parameters that will also be used in our approach, and which are only one of the many difficulties that need to be overcome towards our aim i.e. an accurate, reliable and cost efficient assessment of the retrofit impact. Hence defining the baseline energy consumption in a cost effective and practical way may present in some cases significant difficulties [8].

Another critical issue is the duration of the measurement period before and after the retrofit as time is of great importance when it comes to making decisions. The more we can shorten the monitoring protocol duration while reaching valid impact results, the more promising the methodology would become for the business world.

Taking under consideration the previously mentioned key issues this research uses a methodological framework that addresses two types of possible parameter variation for managing and carrying out adjustments when trying to assess the impact of a retrofit: weather and indoor conditions.

Thereupon the baseline of this research's conceptual framework which was presented in 2014 by Sakkas and Kaltsis and further on evolved the following year [19], is summarized within the following basic equation:

$U = h_{in} [T_{in} – T_{wall}]/[T_{in}-T_{out}]$

where

h_{in} , is the inner surface resistance [W/m^{2}K]
T_{in} is the inner space temperature [K]
T_{out} is the outer space temperature [K]
T_{wall} is the wall's temperature [K].

Hence this study's calculation method is based on constant metering of the three temperatures in the equation. As the calculation of h_{in} may depend a lot on the emissivity of the surface [20], Table 2 suggests an applicable approach which transforms this method if not to an accurate measurement of the U value, to a reasonable approximation.

Type of Retrofit	h_{in}	Equation
External retrofit / External wall	Is considered the same before and after the retrofit	$U = h_{in} [T_{in} – T_{wall}]/[T_{in}-T_{out}]$ (1)
Internal retrofit / Internal wall	It is not safe to assume it remains the same	$U = 1 / R_{swall} [T_{wall,i} – T_{wall,o}]/[T_{in} – T_{out}]$ (2) where R_{swall}, is the element resistance [m^{2}K/W] $T_{wall,i}$, is the inner wall temperature [K] $T_{wall,o}$, is the outer wall temperature [K]

Table 2:- Suggested values of hin [19]

Equation (2) does not include h_{in} but introduces R_{swall} which depends on the materials composing the investigated wall element [21] and its estimation could once again introduce to our equation some error in its calculation.

Consequently using equation (2) could present some advantage over equation (1) only in the case where the estimation of R_{swall} parameter would have some accuracy advantages over that of the surface resistance h_{in}. In the case of a retrofit impact where h_{in} is essentially factored out, equation (2) does not present any advantage over equation (1).

This article therefore presents not only the required field validation of equation (1), while monitoring how the calculated impact evolves as the monitoring duration proceeds by calculating the theoretical U value of a shell element, but also a monitoring method easily placed, remotely set up and completely non-intrusive.

III. METHOD

The importance of U values in the energy efficiency of buildings is well known in the academic community, as well as in the construction sector. In addition, performing a validation of energy performance of a building often requires knowledge of real U-value figures, since their theoretical values could deviate considerably from the real ones. Thus the theoretical U value of a shell element may be calculated using complex material and surface related information, while its practical validation is conducted usually by equipment that requires tedious installation and constant contact with the examined element [19]. Typically U-value requires the installation of a flux meter using a full-contact method which can be tedious and intrusive.

This article suggests a non-contact method for the real time measurement of U value based on the three temperatures presented in equation (1). As the accurate measurement of “in” and “out” ambient temperatures present no difficulty the challenge of this approach to measure the inner wall temperature with a non-contact technology was resolved by applying UVA measurement procedures and specifically via contact-free thermophile technology (infrared sensors).

UVA allows a factual, fast, non-intrusive and cost efficient assessment of the U value change of a shell element during a retrofit. UVA is based on a few simple wireless sensor readings like indoor and outdoor temperature, air speed as well as remote, IR based, wall temperature. “Wall” refers here to the non-retrofitted wall. Thus, if the retrofit was external the internal wall would be required to be monitored; and vice versa. For this UVA approach to provide the necessary data the following wireless modules were required and hence used:

- A module that could scan the temperature of the non-retrofitted wall (called IRSENSE). Thus, if the external wall was retrofitted then the IRSENSE should scan the internal wall, and vice versa.
- A module that could report the indoor temperature (called ENVSENSE).
- An external source (like a weather service) for an hourly, outdoor temperature data collection, or a module installed outside (called ENVSENSE-W).

Based on these three module choices, Figure 1 illustrates the general principle of the applied methodology.

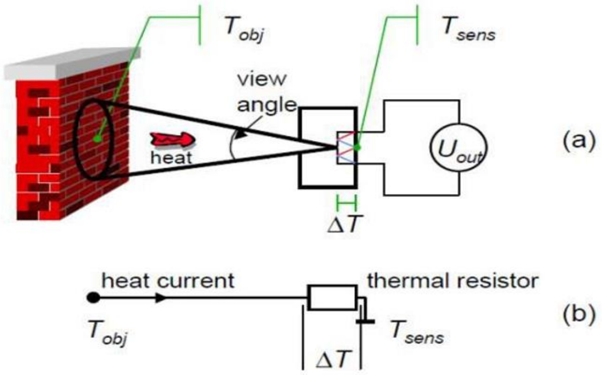


Fig 1:- Non-contact distant measurement methodology

The IR sensors used for wall temperature measurement in the case of a wall is side mounted and in the case of a window ceiling mounted. This method is very easily and remotely set up and is completely non-intrusive. However as the inner surface resistance and therefore the U value could be affected due to air drafts (ventilation use), it was decided to turn off the sensing system during ventilation operation. Hence the value of the surface resistance coefficient would not be affected by air movement [19], and h_{in} values would be effectively eliminated. Also in the case of a glazing retrofit it would be more suitable to restrict the measurements to the night hours alone, in order to avoid complex sunlight interaction phenomena and isolate the U value change from g value considerations. Adopting hence a night metering protocol would eliminate the sun impact on the surface resistance values, which could result to negative U values which would make no sense. However this is not the case within this research.

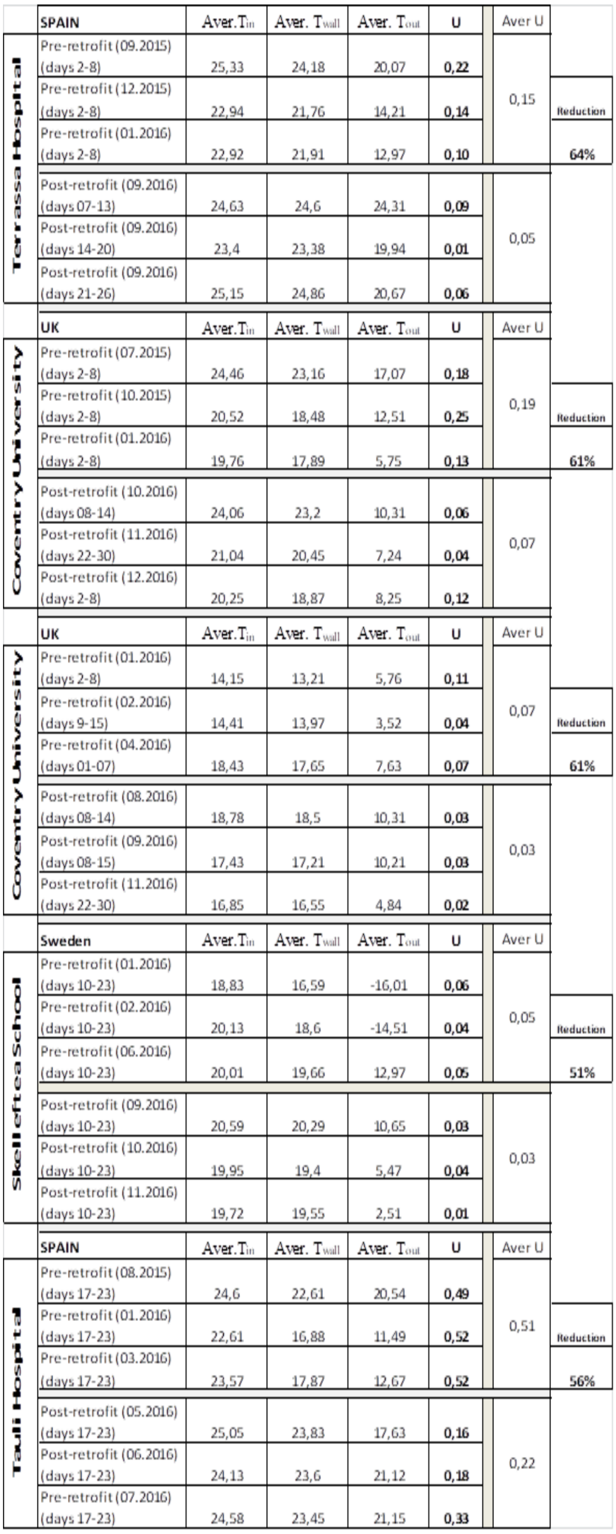
A. Fieldwork results

The field validation of the previously mentioned technique was acquired in several places across the EU. More specifically five buildings open to the public were selected, within four different land fields located in three different countries.

- Terrassa Hospital (Spain)
- Tauli Hospital (Spain)
- Coventry University, Building 1 (UK)
- Coventry University, Building 2 (UK)
- Skelleftea School (Sweden)

Thus five set ups have been put in operation within each building at areas that were planned for retrofit activity and more specifically for installation of insulating panels (of the same thickness). As the main purpose of these case studies was not the actual metering of U value but the validation of the previously mentioned method and hence a safe assessment of its change due to the planned retrofit, the suggested campaign duration of a week [8] was adopted.

By using the IR sensors for measuring wall temperature (see Figure 1) and a module that reports the indoor and outdoor temperatures, a significant amount of data were recorded. A parametric analysis on these acquired data from all five cases was then carried out and thus Table 3 presents the results. Based on Table's 2 equation (1), the change of U values were calculated and hence the impact of the retrofit becomes evident to the reader.



	SPAIN	Aver.T_{in}	Aver. T_{wall}	Aver. T_{out}	U	Aver U	
Terrassa Hospital	Pre-retrofit (09.2015) (days 2-8)	25,33	24,18	20,07	**0,22**	0,15	
	Pre-retrofit (12.2015) (days 2-8)	22,94	21,76	14,21	**0,14**		**Reduction**
	Pre-retrofit (01.2016) (days 2-8)	22,92	21,91	12,97	**0,10**		**64%**
	Post-retrofit (09.2016) (days 07-13)	24,63	24,6	24,31	**0,09**	0,05	
	Post-retrofit (09.2016) (days 14-20)	23,4	23,38	19,94	**0,01**		
	Post-retrofit (09.2016) (days 21-26)	25,15	24,86	20,67	**0,06**		
	UK	Aver.T_{in}	Aver. T_{wall}	Aver. T_{out}	U	Aver U	
Coventry University	Pre-retrofit (07.2015) (days 2-8)	24,46	23,16	17,07	**0,18**	0,19	
	Pre-retrofit (10.2015) (days 2-8)	20,52	18,48	12,51	**0,25**		**Reduction**
	Pre-retrofit (01.2016) (days 2-8)	19,76	17,89	5,75	**0,13**		**61%**
	Post-retrofit (10.2016) (days 08-14)	24,06	23,2	10,31	**0,06**	0,07	
	Post-retrofit (11.2016) (days 22-30)	21,04	20,45	7,24	**0,04**		
	Post-retrofit (12.2016) (days 2-8)	20,25	18,87	8,25	**0,12**		
	UK	Aver.T_{in}	Aver. T_{wall}	Aver. T_{out}	U	Aver U	
Coventry University	Pre-retrofit (01.2016) (days 2-8)	14,15	13,21	5,76	**0,11**	0,07	
	Pre-retrofit (02.2016) (days 9-15)	14,41	13,97	3,52	**0,04**		**Reduction**
	Pre-retrofit (04.2016) (days 01-07)	18,43	17,65	7,63	**0,07**		**61%**
	Post-retrofit (08.2016) (days 08-14)	18,78	18,5	10,31	**0,03**	0,03	
	Post-retrofit (09.2016) (days 08-15)	17,43	17,21	10,21	**0,03**		
	Post-retrofit (11.2016) (days 22-30)	16,85	16,55	4,84	**0,02**		
	Sweden	Aver.T_{in}	Aver. T_{wall}	Aver. T_{out}	U	Aver U	
Skellefteа School	Pre-retrofit (01.2016) (days 10-23)	18,83	16,59	-16,01	**0,06**	0,05	
	Pre-retrofit (02.2016) (days 10-23)	20,13	18,6	-14,51	**0,04**		**Reduction**
	Pre-retrofit (06.2016) (days 10-23)	20,01	19,66	12,97	**0,05**		**51%**
	Post-retrofit (09.2016) (days 10-23)	20,59	20,29	10,65	**0,03**	0,03	
	Post-retrofit (10.2016) (days 10-23)	19,95	19,4	5,47	**0,04**		
	Post-retrofit (11.2016) (days 10-23)	19,72	19,55	2,51	**0,01**		
	SPAIN	Aver.T_{in}	Aver. T_{wall}	Aver. T_{out}	U	Aver U	
Tauli Hospital	Pre-retrofit (08.2015) (days 17-23)	24,6	22,61	20,54	**0,49**	0,51	
	Pre-retrofit (01.2016) (days 17-23)	22,61	16,88	11,49	**0,52**		**Reduction**
	Pre-retrofit (03.2016) (days 17-23)	23,57	17,87	12,67	**0,52**		**56%**
	Post-retrofit (05.2016) (days 17-23)	25,05	23,83	17,63	**0,16**	0,22	
	Post-retrofit (06.2016) (days 17-23)	24,13	23,6	21,12	**0,18**		
	Pre-retrofit (07.2016) (days 17-23)	24,58	23,45	21,15	**0,33**		

Table 3:- Table Styles

It is evident from the above, and in agreement with Aste N. et al. [22], that controlling the thermo physical characteristics of the building elements such as thermal transmittance (U-value) can improve the thermal performance of the building envelope. Therefore by using this non-intrusive monitoring technique, presented in Figure 1, a potential investor can easily comprehend the impact of his/hers investment, as the percentage of the U-value reduction is a distinct understandable parameter for every reader.

Closing this section it should be mentioned that the value of Table 3 derives from the fact that one look is enough for any reader, potential investor or not, to decide if a retrofit technique is worthy.

IV. CONCLUSIONS

We have presented above a compact and non-intrusive technology for U value change assessment, based on the real time monitoring of the indoor, outdoor and wall temperatures. As the metered wall was not the one that was retrofitted, the same value of surface resistance was assumed, before and after the retrofit, minimizing thus any loss of accuracy while estimating the U value change.

The fieldwork provided proof that this technique is an easily comprehensive methodology for retrofit evaluation, which is not only practical and short in time but also without the requirement to resort to costly and expensive measurements and without the need to carry on the monitoring period for more than a week.

Also as the method is not affected by the time season where the data were collected, this technique is thus transformed to a promising methodological approach for decision making via a cost efficient leasing model. As already mentioned in all fieldwork cases, campaign duration of at least a week before and after the retrofit appeared to be adequate to collect accurate measurements and reach an efficient and acceptable result. After the measurement and monitoring completion the installed modules were decommissioned and returned to the service provider.

All the above along with the fact that several retrofit measures [23] could be adopted transforming thus a decision to a multi optional proposal add further value to this article's proposed technique as it:

- Is easily deployed and cost effective methodology,
- Allows the building owner or the investor to comprehend the impact of his/hers investment,
- Allows the retrofit provider to fully understand his/hers solution limitations and launch continuous improvement strategies.

Apart from the previously mentioned benefits of this methodological approach, another significant factor that transforms this technique to a promising one is the fact that the more we can shorten the monitoring protocol duration, while reaching valid impact results, the more promising this methodology would become for the business world.

V. DISCUSSION – FURTHER RESEARCH

The technique presented within this study is the fieldwork validation of a conceptual methodological approach aiming at practical retrofit evaluation. As 35% of the EU's buildings are over 50 years old, improving their energy efficiency could reduce total EU energy consumption by 5-6% and lower CO2 emissions about 5% [1, 2]. Therefore the next step of this research would be to monitor glazing retrofit approaches, as glazing retrofit should be combined with shell retrofit in order for a building owner to reach the maximum energy efficiency goal.

In the case of a glazing retrofit nonetheless and based on fieldwork data collection, it is important to restrict the measurements to the night hours alone, in order to avoid complex sunlight interaction phenomena and isolate the U value change from g value considerations. Night hours present less thermo dynamical challenges and thereupon constitute a better monitoring scheme. Adopting hence a night metering protocol would eliminate the sun impact on the surface resistance values, which could result to negative U values.

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