Innovative retrofitting activities for the enhancement of Energy Efficiency in Public Buildings

Ahmed, A; Mateo-Garcia, M. and McGough, D.

Original citation:
Ahmed, A; Mateo-Garcia, M. and McGough, D. (2016) Innovative retrofitting activities for the enhancement of Energy Efficiency in Public Buildings. HERITAGE 2016 - Proceedings of the 5th International Conference on Heritage and Sustainable Conference. ISBN: 978-989-8734-15-0

Green Lines Institute for Sustainable Development

http://heritage.greenlines-institute.org/en/topics/heritage-2016-book-of-abstracts

Innovative retrofitting activities for the enhancement of Energy Efficiency in Public Buildings

Abdullahi Ahmed, Monica Mateo-Garcia, Danny McGough
Coventry University

Abstract

The building sector is responsible for nearly 40% of the total energy consumption in Europe. In order to achieve substantial impact in terms of energy savings and greenhouse gas (GHG) emission reductions, renovation and retrofitting of existing buildings becomes a very important challenge in both domestic and non-domestic building sectors. Retrofitting Solutions and Services for the enhancement of Energy Efficiency in Public Buildings (RESSEEPE) is an EU funded project which aims to bring together design and decision making tools, innovative building fabric manufacturers and a program to demonstrate the improved building performance achievable through the retrofit of existing buildings at a district level. The RESSEEPE framework is being validated by a strong demonstration programme, envisaging the renovation of 102,000 square metres of public buildings. The core idea of the project is to technically advance, adapt, demonstrate and assess a number of innovative retrofit technologies implemented on several pilot cases with different climate conditions across Europe (Coventry-UK, Barcelona-Spain and Skellefteå-Sweden) to ensure a high potential replication of the retrofit solutions. The three demonstrations sites are involved as the main promoters of a very ambitious district level renovation action to demonstrate a systemic approach to technology installation and evaluation, taking into account the benefits of a set of technologies, which properly combined in terms of cost effectiveness and energy performance could achieve energy consumption reductions of around 50%. This paper is an overview of the process and of the challenges that Coventry University faced in this low carbon refurbishment. The main focus is the prioritization of the buildings to be refurbished and analysis of the processes involved in making refurbishment decisions. The building selection such as the building typology and energy benchmarking is explained. The process of making decisions about procurement, technology and alignment with local strategy is described and evaluated. A systemic process is also being implemented that will allow the selection of the best possible retrofitting mix, customized to the needs of the particular building.

Introduction

The urgency for Europe to transform into a low-carbon economy to meet climate and energy security targets is a fact. One of the most cost-effective measures to meet energy reduction targets, as clearly specified in the “European Economic Recovery Plan”, is to address the existing building stock. Buildings account for 40% of the European energy consumption and one third of GHG emissions [1]. By 2050, the energy consumption in buildings could be cut with an amount corresponding to today’s transportation and industrial sectors combined. In particular, the state of European building stock contains a tremendous improvement potential. Retrofitting Solutions and Services for the enhancement of Energy Efficiency in Public Buildings (RESSEEPE) is an EU funded project that focuses on the refurbishment of existing public buildings in three European cities: Coventry (UK), Barcelona (SP) and Skelleftea (SW).

RESSEEPE aims to develop and demonstrate an easily replicable methodology for designing, constructing, and managing public buildings and district renovation projects to achieve a target of 50% energy reduction in public buildings within specified districts. For this purpose, a demonstration and dissemination framework is developed with innovative strategies and solutions for public buildings, energy renovation at building and district level, based on the following pillars: three demonstration district retrofitting projects in three different countries representative of the breadth of EU climate conditions; cost-effective solutions for holistic energy performance improvement at building and district levels; systemic selection process to achieve optimal mix of intervention measures from a wide range of innovative technologies; mass customisation of the proposed business models and development of a strategy for large scale market deployment throughout Europe; market and replication deployment plan, in order to ensure the project impact at business level, and exploitation strategy suitable for achieving a wide impact.

Usually, the diagnosis stages for carrying out a district renovation focus on structural and energy considerations, rather than issues such as user acceptance, financial requirements for the overall retrofitting and final user investment. The RESSEEPE project aims to develop new methodologies for the diagnosis of the potential public district refurbishment taking into account not only the structural and energy analysis, but also the potential problems with the end users in terms of social acceptance and financial constraints. For doing so the decision making procedure followed by Coventry University to select advanced building technologies for high energy performance retrofitting is shown.

Identification of factors conditioning the integration of green energy technologies in public buildings

There are some factors in green energy retrofitting of buildings that influence the choice of technology to be implemented and the way it performs, such as environmental, technical, functional and design aspects. These aspects determine the integration of active technologies or passive elements in the existing building. Before deciding to install a technology or passive measure the existing building design is analysed at urban and building scale.

1. Urban scale

Coventry is a city and metropolitan borough in the county of West Midlands in England (Figure 1). Coventry is the 13th largest city in the UK. It is also the second largest city in the Midlands, after Birmingham, with a population of 316,900. Despite substantial damage during WWII, Coventry retains many of its major medieval buildings and heritage assets. The University and the City Council own 90% of the land within Coventry City Centre. Over the last five years the University has invested over £150m in their estate, with the addition of two award-winning buildings and the refurbishment of different buildings, whereas Coventry City Council is investing £160m in the campus over the next ten years [2]. These developments have contributed to introducing attractive link points between existing heritage assets within the city centre. Also, as part of the City Lab Coventry Initiative, there is the opportunity for a real-life experimentation of innovations.

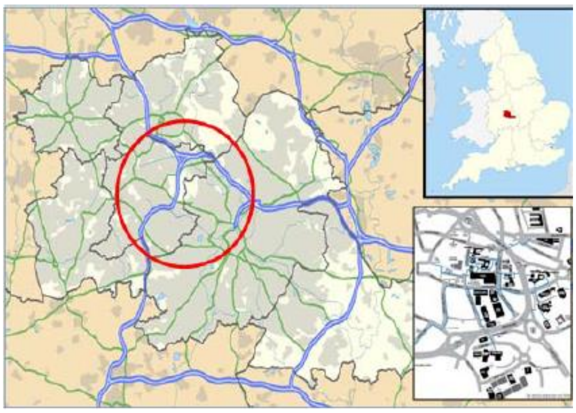

Figure 1: location of Coventry and Coventry University within the United Kingdom

2. Building selection

Most of the Coventry University buildings date from 1930’s to 1970’s, long before the first Energy Efficiency component of the UK building regulation was developed in 1985 [3]. Because of the age of the buildings, the energy performance of most of the building stock is very poor. The six buildings selected from the university to participate in this project were Alan Berry, Ellen Terry, George Elliot, John Laing Building (JL), Richard Crossman (RC) and Student Centre Building. The buildings are university buildings with a mixture of offices, lecture theatres, laboratory spaces and meeting rooms. Table 1 summarises the features of the selected buildings and Figure 2 shows images of the selected buildings.

Building Name	Storey Height	Year of Construction	Description
Alan Berry	2	1963	This building has a Curtain system with panels and 40% glazed proportion. Window frame in this building is metal with 6mm single glazed. The structure is a concrete frame system
Ellen Terry	4	1931	This building has a brick façade and 30% glazed proportion. Window frame in this building is metal Georgian style frame with 6mm single glazed. The structure is a steel frame system
George Elliot	6	1963 Refurbished 1993	This building has a Curtain system which was refurbished in 1993 and 30% glazed proportion. Window frame in majority of façade is UPVC with 12 mm double glazed. Windows of stairway and toilet is metal with 6mm single glazed. The structure is a concrete frame system
John Laing	2	1970	This building has a brick façade and 30% glazed proportion. Window frame in this building is metal frame with 6mm single glazed. The structure is a concrete frame system
Richard Crossman	5	1971	This building has a brick façade and 30% glazed proportion. Window frame in this building is metal frame with 6mm single glazed. The structure is a concrete frame system
Student Centre	2	2005	This is a two storey building constructed in accordance with building control requirements. This building has a brick façade and 30% glazed proportion. Windows are Aluminium frame with Polyester powder coated with 12 mm double glazed.

Table 1: building description

Image 1 : Alan Berry Building

Image 2: Ellen Terry Building

Image 3: George Elliot Building

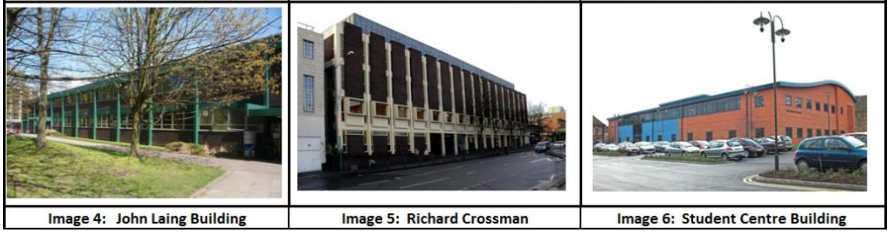

Image 4: John Laing Building

Image 5: Richard Crossman

Image 6: Student Centre Building

Figure 2: Case Study Buildings

3. Benchmarking

Benchmarking is an important process in driving building performance management and prioritizing various retrofit intervention measures. CIBSE set out a procedure for benchmarking building performance with similar buildings in the sector [4]. There are always budgetary limitations in terms of the ability of the organisation to invest in a significant way in a large property portfolio over short, medium and long term perspective. Therefore the refurbishment process has to take into consideration a process of prioritizing the intervention, using a number of indicators such as cost, energy, environmental factors and feasibility of such interventions. In organisations with a large portfolio of old buildings it is essential to plan and prioritise the building stock relative to the urgency of refurbishment action. The selected case study buildings in this project have been benchmarked against each other using overall electrical and gas energy consumption (kWh/m^2/year).

Building	Alan Berry	Ellen Terry	George Elliot	John Laing	Richard Crossman	Student Centre
Year of completion	1963	1931	1960	1970	1971	2005
Net area (m^2)	2799	8564	2799	3660	9306	2837
Electricity (kWh/m^2)	63	96	89	94	116	85
Gas (kWh/m^2) (heating)	178	430	185	129	129	60
Water (m³)	732	1651	1394	957	2462	1085
Carbon Footprint (tonnes)	198.3	448	452	282	841	

Table 2: Comparative data between the selected buildings

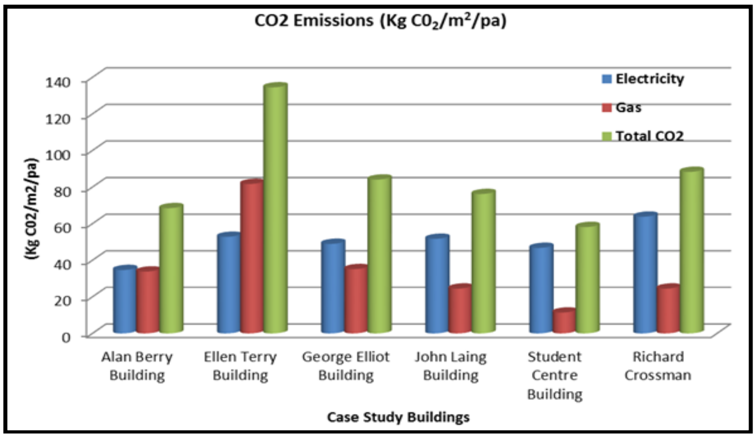

Figure 3: Carbon Emissions associated with case study buildings

Table 2 and Figure 3 show the energy consumption and the carbon emissions associated with the six case study buildings based on both electricity and gas consumption using CO2 conversion factors of 0.55 and 0.19 for electricity and gas respectively. The total CO2 emissions from these buildings reveal, as expected, Ellen Terry Building to have the highest emissions (it is the oldest among the selected buildings, having very poor levels of fabric insulation) followed by Richard Crossman and George Elliot Buildings. The energy consumption and emissions have been used in conjunction with other factors such as available technologies, site access, internal access to space, internal flexibility, opportunity for interventions, planned investments by the Estate Department in Coventry University and risk of interventions in order to inform the selection of the best option for the current intervention. In regards to these factors George Eliot and Ellen Terry both had considerable access issues. Both buildings are structurally connected to secondary building structures making any exterior intervention difficult. Alan Berry's expected life span negatively impacts the financial investment consideration. Likewise due to the recent modern construction methods used in the student centre this option was also discarded as opportunity for further investment on a relatively young building was unlikely. Richard Crossman Building and John Laing Building have been selected as the best option for the current intervention, according to the parameters above-mentioned. John Laing has good surrounding access. The internal spaces have a mix of open and closed volumes providing a platform to test technologies in closed controlled spaces. The façade and envelope has potential for alteration due to a current non-structural façade and accessible load bearing capable frame. Due to the good accessibility and selective isolated nature of spaces within John Laing the risk factor is also reduced. Richard Crossman provided a good opportunity due to good site access, flexibility and variation of internal spaces between closed and open. The existing window construction provided a positive opportunity to replace the current system with zero structural amendments. Additionally the RC building marries up with current investment plans from the University.

Methodology

Detailed performance modelling and simulation will be carried out to predict potential energy and carbon savings from the retrofit process and intervention strategies for each demo site building, with the following steps:

1. Estimate the energy needs/consumptions before retrofitting
2. Evaluate the impact of the solutions on the energy demand/consumption
3. Justify the expected performance of the system on various criteria (energy, economy, environment, comfort).
4. Retrofit some areas of a building, and extrapolate the results to the whole building to evaluate the overall potential savings in the building after its refurbishment.

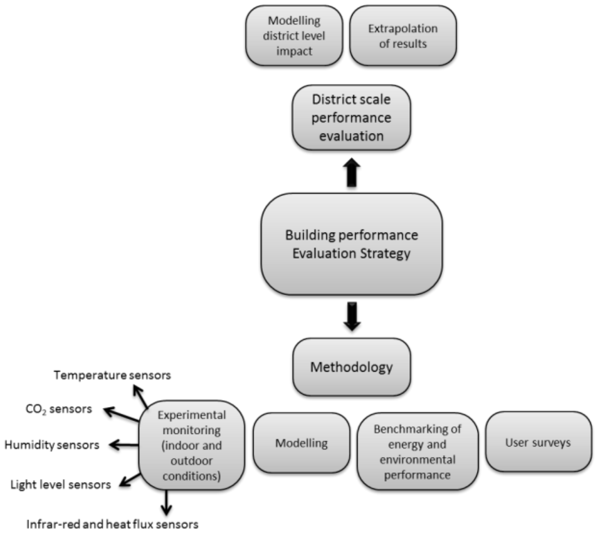

Figure 4. Methodology followed

A range of building performance evaluation protocols will be used to evaluate the performance of the building before and after retrofitting with a view to assessing three key factors, namely building and system characteristics, environmental factors and occupant perception as described in [5]. The purpose of the building performance evaluation strategy is:

1. To monitor the objective measures of comfort within buildings (temperature, humidity, CO2)
2. To investigate building fabric performance, U-value and thermographic surveys;
3. To evaluate user satisfaction of key stakeholders;
4. To model the current performance of the building;

For that purpose, as shown in Figure 4, the methodology followed includes: experimental monitoring, modelling, benchmarking of energy and environmental performance and user surveys. For the evaluation of the performance of the building fabric the key performance criteria should include the analysis of the existing constructive documents of the building in order to get the maximum information about the composition of the external walls, and the measurements of the actual building performance by using non-destructive testing. In order to obtain this performance the following strategies will be followed: definition of the existing building fabric composition, Thermal imaging camera, Infra-red and Heat flux sensors, light level sensors and Indoor Environmental Quality measurements (CO2, Temperature and Humidity).

Further monitoring will be continued after installation to evaluate the benefit of the intervention. It’s significant to note that part of the objectives of the RESSEEPE project will be to explore and test these products further, attaining clear results on performance, reliability and future possibilities. The building performance Evaluation Strategy will include, finally, a district scale performance evaluation, modelling the district level impact and extrapolating the results obtained for the replicability of the model.

1. Technology selection

The technology selection for application in demo-site buildings is dependent on the specific need of the demo-site, both in terms of its climate, building performance challenges, cost, response to user comfort and potential replicability. All the technologies being considered are innovative or have new innovative features. As a result of some of the technologies being in developmental stage, it is essential for the building owners to understand the risks associated with both installation and on-going maintenance challenges, which therefore highlights the need for effective stakeholder engagement at an early stage of the project to explore the benefits as well as the potential risks associated with each technology and intervention strategy. An initial stakeholder engagement provided a vital platform to highlight critical factors such as user comfort, consideration on local planning constraints and disruption to the useable areas. Particularly the engagement and communication of on-going interventions and disruptions to the users of the buildings was vital.

A significant element when evaluating the state of the art technologies named within the project focused on the certification, quality and life span of the technologies proposed. The next evaluation focused on the life span of the technologies, which had to be assessed to attain what level of risk was associated with each installation [6]. Due to the nature of the technologies and the fact that they are on the cusp of future research it was difficult to attain total clarity on the quality and whole life performance of the technologies. The opportunity of the City Lab Coventry Initiative provides a platform to explore this area of research with a clearer understanding of the known and accepted risks of developing untested technologies.

2. State of art of the technology selected

In order to select the best possible material at this stage of the project, Coventry University made analytical evaluations of the feasibility of materials to assess initial potential. The various technologies which are proposed in this project relate to the envelop insulation, photovoltaic panel, storage system and distribution system. The technologies have varying properties ranging from absolute state of the art to more tried intervention methods, each technology has however been selected with a target of reducing the energy demand of buildings. These state of art technologies are categorised into four groups: envelope technologies, services technologies, lighting and renewable technologies (Figure 5).

Coventry University demo-site developed a twin strategy for implementation and testing of these technologies. The first strategy is based on a whole building level intervention, in this strategy advanced established technologies were implemented at a large scale as shown in Figure 5, this is a significant cost outlay for the university and this strategy therefore minimises risks on this investment. The second strategy is to design and implement a selection of innovative technologies in selected areas of an existing building. This gives the project an opportunity to test these technologies in real buildings and climatic conditions while at the same time limiting the risk exposure for the university. Figure 6 shows the technologies selected and in the process of being implemented in JL and RC Buildings.

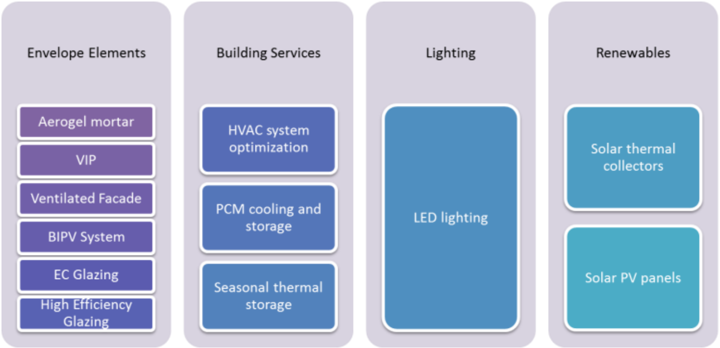

Figure 5: Technologies selected for RESSEEPE project

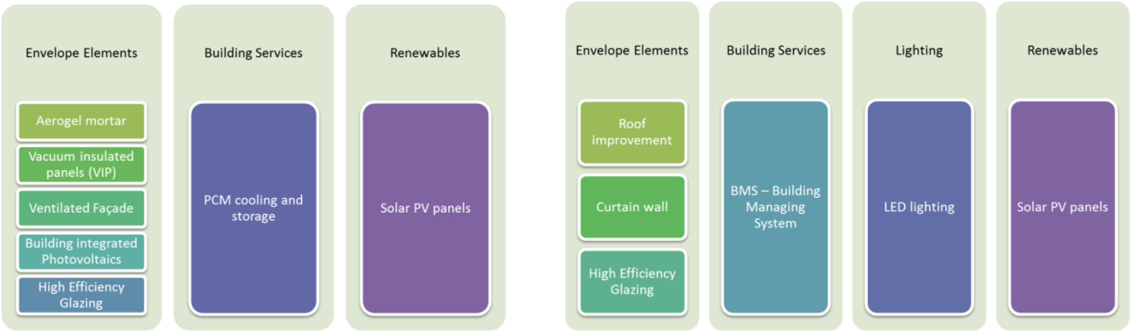

Figure 6: Technologies finally selected for John Laing Building and Richard Crossman Building

The list of technologies finally selected for buildings retrofitting are as follows:

Aerogel mortar: It consists of a very porous ultra-light material that combines aerogel with cement to provide super-insulating properties. Due to its low density and small pores this material shows a remarkably low thermal conductivity (λ), typically on the order of 0.015 W m-1K-1. This property makes this product highly interesting for insulating applications in construction (Figure 7). This is an innovative application of aerogel as rendering because although there are examples of insulating renderings using aerogel aggregates, they are not based in cement materials and their application is for inside building walls [7].

Figure 7. Image of aerogel and aerogel mortar insulation

Vacuum insulation panels: Vacuum insulation panels (VIPs) can be described as 'evacuated open porous materials inside a multi-layered envelope'. They are considered to be one of the most effective insulation materials available. VIPs consist of three components: the core, the envelope and getters (a reactive material to help maintain the vacuum, e.g. desiccants and opacifiers). The core of the plate is evacuated and determines the thickness of the plate. A foil envelope keeps the vacuum inside and avoids gas and moisture permeation into the core as long as possible [8]. (Figure 8)

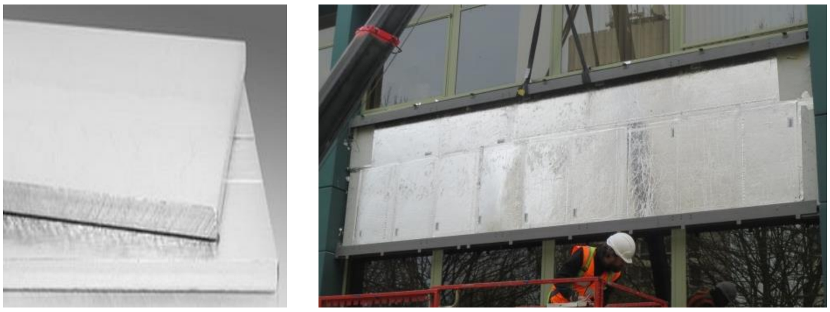

Figure 8. Image of a VIP and Final installation on-site

Ventilated façade with photovoltaic panels: Among the emergent advanced façades, double-skin façades (DSFs) are an efficient solution to control the interactions of indoor and outdoor environments. As a basic definition, "Double-skin façade is a special type of envelope, where a second “skin”, usually a transparent glazing, is placed in front of a regular building façade" [9]. Double skin façades can efficiently reduce the overall HVAC consumption in buildings by absorbing part of the solar radiation during winter and preventing overheating during warm periods [10]

The ventilated façade proposed for the project has a photovoltaic system (PV) as an outer layer. The different parts that compose the ventilated facade are: insulation layer of Vacuum Insulated Panels (VIP), steel substructure and photovoltaic modules fixed with aluminium clamps (Figure 9).

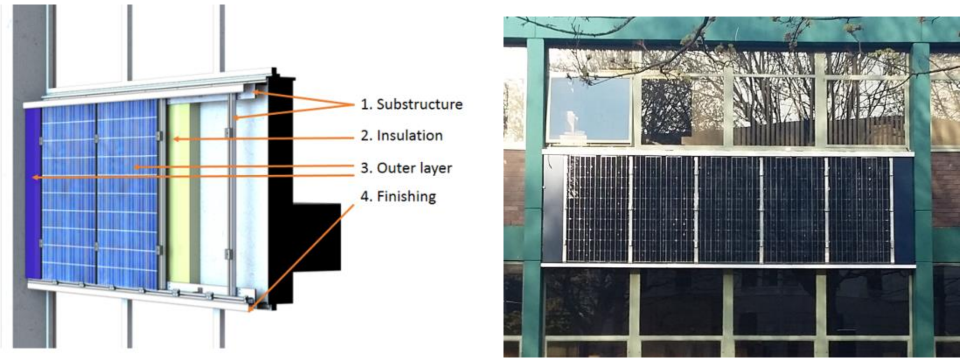

Figure 9. Ventilated façade (Model and Final Installation on-site)

Phase Change Materials Tubes: The thermal storage capacity of a material is a measure of a material ability to absorb and store thermal energy and subsequently release it back to the environment after a period of time. There are two broad types of thermal storage materials, namely sensible and latent heat storage materials. Sensible heat storage materials include brick, concrete, rocks etc. The sensible thermal storage of these materials is as a result of the change in temperature of the materials. Phase Change Materials (PCMs) are material compounds that melt or solidify at certain temperatures to store or release large amounts of energy [11]. PCM products therefore store and release thermal energy during the process of melting & freezing (changing from one phase to another). When such a material freezes, it releases large amounts of thermal energy in the form of latent heat of fusion, or energy of crystallisation. Conversely, when the material is melted, an equal amount of energy is absorbed from the immediate environment as it changes from solid to liquid. (Figure 10). The sizing of PCM is carried out based on the performance specification of 1m long TubeICE provides 0.145 kWh (0.041 TRh) thermal energy storage [12]

Figure 10. Phase change materials tubes (Final Installation on-site)

Results and replicability

After the installation of the different technologies, a year´s monitoring campaign will allow us to measure the performance of the retrofitted buildings. The data acquired will be compared with that monitored before the installation activities and, subsequently, the benefit of the intervention will be evaluated. These results will include, finally, a district scale performance evaluation, modelling the district level impact and extrapolating the results obtained for the replicability of the model.

Replicability is a key target of the project. The results obtained after the monitoring process will help determine the suitability of the technologies applied in order to extrapolate the results in the first place to the rest of the building and in the last place to other buildings of a similar typology (Figure 11).

Figure 11. Example of extrapolation of the results

The project aims to consider a large diversity of the European existing building stock, which should take advantage of localised results at the end of the project. Based on a general replicability model for public buildings, a retrofit decision support process will be created and validated to support the evaluation of the technical and economic parameters to evaluate replication opportunities of the intervention strategies. Using the tools and databases developed or integrated within this project, an overview of the targeted building stock will be made and technical variations will be critically evaluated providing a supporting framework to enhance an informed decision making process.

Discussion and conclusions

The decision making procedure followed by Coventry University to select advanced building technologies for high energy performance retrofitting has identified a number of interesting dynamics of prioritizing buildings for refurbishment and the suitability of the relevant technologies to be applied in the intervention. The systemic process followed has allowed the selection of the best possible retrofitting mix, customized to the needs of each particular building.

The different process of selection of technologies in both buildings has provided us with valuable information for the subsequent replication of solutions. In Richard Crossman the focus has been on certification, quality and life span of the different technologies proposed in the project. For John Laing, due to its status as Living Lab, the opportunity was to consciously prioritise other factors such as real world testing of performance in-situ, integration of multiple state of the art technologies and innovation in refurbishment technique. As discussed previously, due to the nature of the technologies it is difficult to attain total clarity on the quality and whole life of the state of the art technologies, proving the rationale for the real-life experimentation to test these innovations.

As the research project was funded to trial a number of technologies, the monitoring of the performance after the retrofitting works is essential to demonstrate the improved building performance achievable through the retrofit of existing buildings at a district level to ensure a high potential replication of the retrofit solutions. The target of reductions around 50% in terms of energy consumption will be tested using predicted and actual performance data post the intervention processes.

It's significant to note that part of the objectives of the RESSEEPE project will be to explore and test these products further, attaining clear results on performance, reliability and future possibilities. The building performance Evaluation Strategy will include, finally, a district scale performance evaluation, modelling the district level impact and extrapolating the results obtained for the replicability of the model.

Acknowledgements

This project is funded by the European Union Framework 7 research funding scheme, we would like to acknowledge the contribution of all project partners for their participation and ideas during the development of the project.

References

[1] Directive 2010/31/EU on the Energy Performance of buildings. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:153:0013:0035:EN:PDF

[2] Lynch, Lucy (31 July 2008). "Coventry University in £160m expansion". *Coventry Telegraph*. Retrieved 7 August 2013

[3] The Building Regulations 1985 (SI 1985/1066), UK
http://www.legislation.gov.uk/uksi/1985/1065/pdfs/uksi_19851065_en.pdf

[4] CIBSE (2008), TM46 Energy Benchmarks, CIBSE, UK

[5] ASHRAE (2010) Performance Measurement protocol for Commercial Buildings. ASHRAE, Atlanta, GA.

[6] Montazami, A., McGough, D., Ahmed, A.**,** Gaterell, M**.,** and Beck, M. (2014)'Understanding the challenges for low impact retrofitting – case study**'**. in Kibert, C.J., Srinivasan, R., Holzhower, L., Hakim, H., and Pasunuru, R. (eds.)*Proceeding of iiSBE Net Zero Built Environment 2014, '*17th Rinker International Conference'. held 6-7 March 2014 in Gainesville, Florida, 476-487.

[7] Stahl, T., Brunner, S., Zimmermann, M. and Ghazi Wakili, K. (2012). 'Thermo-hygric properties of a newly developed aerogel based insulation rendering for both exterior and interior applications'. *Energy and Buildings*, 44, pp.114-117.

[8] Livesey, K., Suttie, E., Scovell, K. and Thielmans, W. (n.d.). *Advanced thermal insulation technologies in the built environment*.

[9] Ghaffarianhoseini, A., Berardi, U., Tookey, J., Li, D.H.W. and Kariminia, S. (2016) 'Exploring the advantages and challenges of double-skin façades (DSFs)', *Renewable and Sustainable Energy Reviews*, 60, pp. 1052–1065.

[10] Barbosa, S. and Ip, K. (2014) 'Perspectives of double skin façades for naturally ventilated buildings: A review', *Renewable and Sustainable Energy Reviews*, 40, pp. 1019–1029.

[11] Iten, M and Liu, S (2014) 'A work procedure of utilising PCMs as thermal storage systems based on air-TES systems', *Energy Conversion and Management*, 77, pp. 608–627.

[12] PCM Phase Change Material Limited (n.d.) PlusICETM Phase Change Materials Passive Cooling. Available online: http://www.pcmproducts.net/files/passive_cooling_catalogue.pdf. Accessed 04/05/2015.