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TESTING INNOVATIVE TECHNOLOGIES FOR ENERGY-EFFICIENCY: COVENTRY UNIVERSITY AS A LIVING LAB[1]

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Abstract. 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 programme 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 technologically 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 demonstration sites are involved as the main promoters of a very ambitious district level renovation, demonstrating 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 reductions around 50% in terms of energy consumption.

Coventry University is acting as a Living Lab in order to test some advanced technologies already in the market and others developed specifically within the RESSEEPE project. Those innovative technologies implemented in the pilot case are: Vacuum Insulated Panels, PCM tubes, Ventilated façade with Photovoltaic Panels, Electrochromic windows and Aerogel Mortar. The main feature of this installation is that it acts as a testing bed for where to install different advanced technologies covering specific areas of the building, rather than refurbishing it as a whole.

This paper documents the testing of prototype technologies in a pilot case in Coventry University, analysing the process of selection of the different technologies and showing all the challenges faced during installation and coordination of installation activities. The installation

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process is shown and discussed, highlighting the difficulties, setbacks and challenges faced during the low carbon refurbishment. The key issues are related to technical and health and safety risks. Also, to financial, coordination, planning and legislation barriers etc. It will also show ways forward and solutions adopted. The study also analyses the process of monitoring the energy performance of the spaces retrofitted and the data obtained through the monitoring of the building before and after the installation of the different technologies. The idea behind the Living Lab pilot case is to monitor the performance of those installations in isolation in order to obtain results which allow us to make conclusions about the replicability of the technologies selected in other locations. Ultimately, what is discussed is the overall process followed. This discussion seeks to show the lessons learnt throughout the process and to obtain conclusions from the barriers and engagement issues faced during the installation when retrofitting a public building.

Keywords: Low-Energy Retrofit, Living Lab, Public Buildings, Stakeholder Engagement, Performance Modelling and Monitoring;

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JEL Classifications: I23, O32, Q55
Additional disciplines: Ecology and Environment, Construction Engineering

1. 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 European energy consumption and one third of GHG emissions (Directive 2010/31/EU). 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.

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. This paper shows a Higher Education building case study used as a Testing Bed for innovative technologies developed specifically within the project framework, for the improvement of energy efficiency in buildings. All the technologies selected for the project are innovative or have new innovative features. They have varying properties ranging from absolute state of the art to more thoroughly tested intervention methods. These advanced technologies are not aimed at refurbishing the building as a whole, being applied just in some areas in order to evaluate the performance of the retrofitted elements in isolation. The idea behind the Living Lab pilot case is to monitor the performance of those installations in order to obtain results, which allow us to make conclusions about the replicability of the technologies selected.

2. Literature review

Buildings account for about 40% of total energy consumption in the European Union, there are indications that this will increase as the number of buildings increase over time to meet population growth etc. (Zero Carbon Hub, 2011). If the European Union is to reduce its energy dependency and greenhouse gas emissions, it is essential that the energy consumption in the built environment is reduced. The existing building stock across Europe offers one of the most significant challenges for meeting the energy and environmental targets. Annually new non-domestic buildings represent less than 1.5 percent of the total building stock, therefore the improvement and management of existing non domestic buildings offers significant potential for achieving energy and environmental savings compared to the construction of new buildings (Baker, 2009).

The European Union responded to this challenge by increasing building energy efficiency standards through the Energy Performance of Building Directives, which came into force in 2002. The aim of the EPBD is to reduce energy consumption in both the residential and non-domestic sectors by raising awareness of energy use through mandating Energy Performance Certification and Display Energy Certificates in Public building, mandating minimum standards, and requiring inspections of key plant. The EPBD also states 'Major renovations of existing buildings, regardless of their size, provide an opportunity to take cost-effective measures to enhance energy performance'(EPBD, 2010). The United Kingdom also set a legally binding target of an 80% reduction in greenhouse gas emissions by 2050 compared to 1990 levels (Climate Change Act, 2008) which sets out the government ambitions for greenhouse gas emission reduction. The UK construction strategy was developed to improve efficiency in the construction lifecycle of buildings (Government Construction Strategy 2011), which aims to reduce costs, improve and optimise the buildings processes and performance of the construction industry.

The retrofit in Coventry University is focussed on the University Buildings. The Association of University Directors of Estate (AUDE) commissioned and published a paper entitled "The Legacy of 1960s University Buildings" (AUDE 2008) The paper focuses on the refurbishment of post 1960 higher education buildings and highlighted a common issue that many universities are facing, which is the problem of building stock that is progressively becoming out of date and unfit for purpose. The choice that owners are facing is whether to condemn the buildings or refurbish them or carry out a full demolition and rebuild. As stated within the AUDE report, the "report considers one of the big issues in Higher Education today – how to renew a very large proportion of the property portfolio that was built in the 1960's.

Four key points that were identified as a significant part of the study;

- Academic buildings can often be refurbished more successfully than residential;
- While the financial case for refurbishment might look poor, with costs in some cases as high as 80% of a new build option, there are often significant environmental benefits from refurbishment; High standards of environmental performance can be achieved on refurbishment projects, provided that the objective is at the core of the design from the outset;
- Architectural excellence can still be achieved in refurbishment projects.

AUDE (2008) stated the need to re-evaluate how pre-assessments of higher education building refurbishments are carried out. An example of the demand for the project was expressed through the indication that the University of Bath alone had earmarked "£40M of investment decisions that will need to be taken which directly impact 1960's buildings." (AUDE 2008).

Technologies Review

There are a number of technologies that can be used to improve the energy and environmental performance of buildings. Figure 1 shows a number of technologies that are considered within the RESEEPEE project.

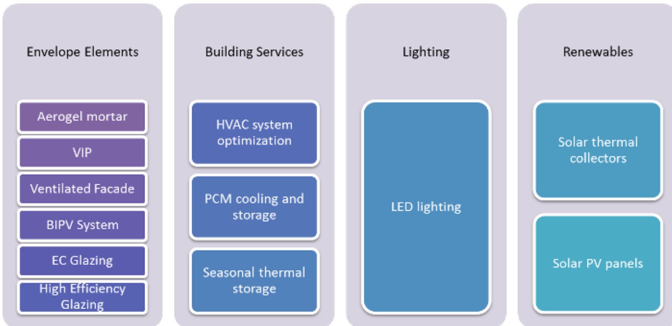

Figure 1. Technologies selected for RESSEEPE project

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. 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 (Stahl, T. *et al* 2012). Figure 2 shows the process of installation of the mortar on abrick wall.

Figure 2. 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 shown in Figure 3 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 (Livesey, K. *et al* 2013).

Figure 3. 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" (Ghaffarianhoseini, A. *et al.* 2016). 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 (Barbosa, S. *et al.* 2014). The ventilated façade proposed for the project shown in Figure 4 has a photovoltaic system (PV) as an outer layer. The different parts that compose the ventilated façade are: insulation layer of Vacuum Insulated Panels (VIP), steel substructure and photovoltaic modules fixed with aluminium clamps.

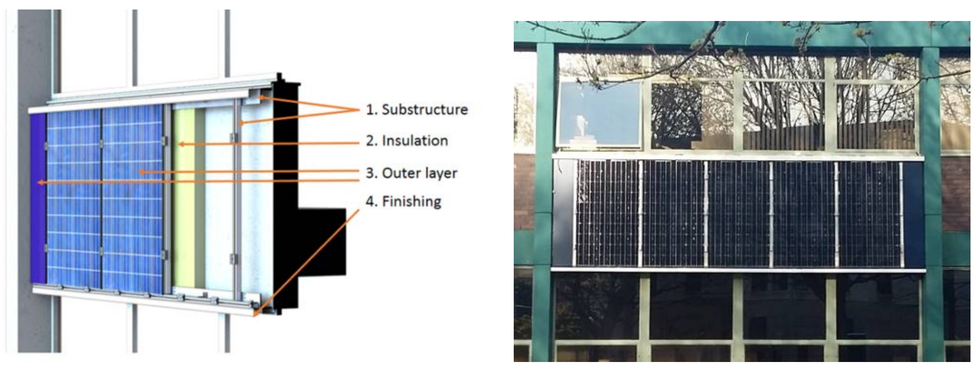

Figure 3. Ventilated façade (Model and Final Installation on-site)

Phase Change Materials Tubes: The thermal storage capacity of a material is a measure of its ability to absorb and store thermal energy and subsequently release it back into 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 (Iten, M. and Liu, S.. 2014), (Iten, M. et al, 2016). They behave similarly to ice, in that the material 'freezes' and melts at a fixed temperature. 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. 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 (PCM Phase Change Material Limited).

The PCM installed in Coventry is a S27 phase change material, which is a salt hydrate that peaks at 27 Cº. In reality, the PCM may start the melting process at 25 Cº and be completely liquid at 29 Cº. In reverse, the PCM may show signs of solidification at 29 Cº and be completely solid at 25 Cº. The PCM Tubes are installed and respond to the surrounding temperature of the room (Figure 5). At the beginning of the day, the TubeICE are frozen. As the room heats up due to body heat, and heat from the sun, the PCM Tubes passively cool the room by absorbing the heat until completely melted. The duration of the cooling effect is dependent on the intensity of the heat being absorbed. I.e. the PCM will melt quicker if the ambient temperature in the room is 40 Cº compared to if the temperature is 35 Cº, much like a block of ice would. As the temperature cools over night, so does the PCM. The PCM effectively loses energy to the immediate surroundings, charging for the next day.

Figure 4. Phase change materials tubes (Final Installation on-site)

3. Research methodology

The Case Study at Coventry provides enough data and perspective to enable extrapolation to wider urban retrofit and living lab strategies. The case study building was selected due to the replicability of the building typology, which brought strong possibilities for the extrapolation of results and findings. The case study approach utilises descriptive data collection techniques. These techniques cover a number of practical interventions within the adoption of innovative technologies. As stated by Stake (2012), qualitative method is an iterative and reflexive process that begins as data is being collected rather than after the data collection has ceased. This strategy will be effective, as the aim is to provide a qualitative view of the case study at Coventry University. The process of adopting interventions within the case study into living lab buildings will lead the research into areas unknown from the outset. Descriptive analysis will be adopted to enable the research team to reflect on the challenges within the living laband adoption of state of the art technologies. Patterns, which describe the use of descriptive analysis, can be found as "descriptions of objects or phenomena, explanations of processes, and predictions on the future behaviour of the object of study." (Routio 2007)

A range of building performance evaluation protocols has been 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 (ASHRAE, 2010). 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 evaluate the installation process;
5. To model the current performance of the building;

Therefore the methodology followed will include: experimental monitoring, modelling, benchmarking of energy and environmental performance and surveys to key stakeholders and people involved in the installation process. Figure 6 summarises the strategy for stakeholder evaluation and engagement throughout the research project:

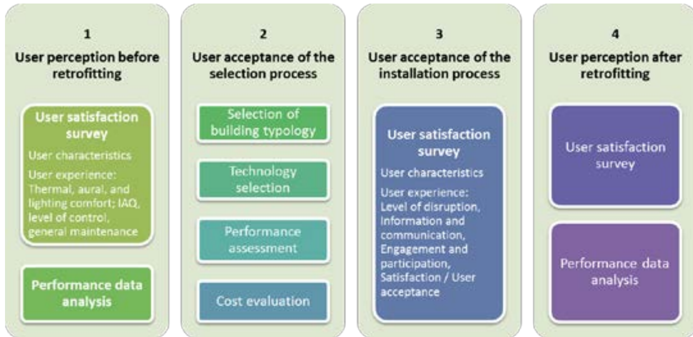

Figure 5. Evaluation of social acceptance

For the evaluation of user perception, user satisfaction surveys have been carried out before and after the retrofitting activities among the users of the building: students and academics. This provided a range of data set to compare the user satisfaction before and after the interventions. Stakeholder engagement events will be organized to get their feedback regarding the selection and installation process. Some interviews will also be done with the stakeholders involved in the installation process: technology providers, contractors, etc. Their views in conjuction with our personal assessment of the installation process will provide us with a solid material from which evaluations and lessons learnt from the process can be extracted. 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 systems based on 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.

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.

4. Case Study Description

Coventry University is a large contributor to the city's economy, the university and the council own 90% of the land within the city centre. The current estate is part of an ongoing investment to rejuvenate a number of areas around campus with investment surpassing £150m in the last 5 years (Lynch 2008). The case study at Coventry University is focused on two selected buildings, Sir John Laing (JL) and Richard Crossman (RC) Buildings. The buildings were selected as part of a robust benchmarking of the current university estate, which was carried out early within the project (Montazami *et al*. 2014). Part of the planning for the city moving forward is the recognition of a living lab status, "Establishing Coventry as a test-bed, incubation hub and international showcase for low carbon innovations" (City Lab Coventry, 2016). The living lab status holds high relevance to this project, as the JL building will encompass a living lab ethos, acting as a live experimental environment for a number of innovative technologies.

Coventry University demo-site developed a dual 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 in RC Building. The second strategy is to design and implement a selection of innovative technologies in selected areas of an existing building (JL). 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. These state of the art technologies are categorised into four groups: envelope technologies, services technologies, lighting and renewable technologies. Figure 7 shows the technologies selected to be implemented in John Laing Building.

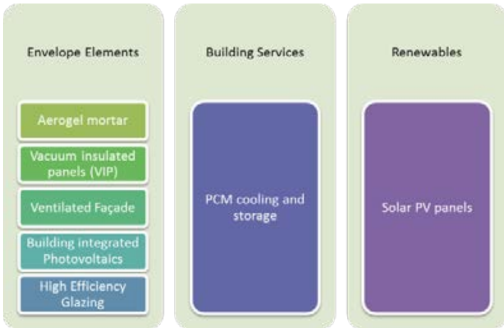

Figure 6. Technologies finally selected for John Laing Building

Technologies were selected for specific spaces within the case study building using a process of energy modelling simulation, user comfort responses and field lab testing opportunities. A viability analysis was also carried out to assess the final selection of the best mix of technologies. Table 1 shows the impact assessment of the individual retrofitting solutions. The assessment has been made considering the effect of only one solution implemented on the building. Yet to reach the objectives in terms of energy efficiency, the retrofitting project integrates combinations of several individual solutions, aiming at a maximum level of complementarity of the measures

	Solution	Ventilated façade system	Innovative Mineral Mortar ETIC	PCM	PV
Energy/CO2	Fuel gain (kWh/year)	160 000	40 000	80 000	0
	Electricity gain (kWh/year)	38 000	11 000	1 000	17 000
	Environmental gains (tonne of CO2/year)	61	17	20	10
Financial aspects	Instant financial gain (€/year)	14 000	4 000	4 000	3 000
	Investment (€)	110 000	130 000	80 000	30 000
	Maintenance cost (€/year)	3 150	0	0	1 500
Life cycle impact	Lifetime (Year)	25	30	25	25
	Fuel gain (kWh)	4 800 000	1 300 000	2 400 000	0
	Electricity gain (kWh)	1 150 000	320 000	40 000	510 000
	Environmental gains (tonne of CO2)	1 800	500	600	300
	Financial gain total (€)	450 000	160 000	150 000	0
	Global cost (Inv + Maintenance cost)	180 000	130 000	80 000	70 000
Return on investment	Payback (year)	10	24	14	19

Table 1. Impact assessment of the individual retrofitting solutions

3. Results and Discussions

The first major works at Coventry consisted of the installation of Phase Change Materials (PCM), ventilated façade with vacuum insulated and solar panels, and exterior insulation with aerogel mortar, Figure 8 shows the location of the various technologies on the building façade and internal spaces. The installation process was managed by the technical coordinators and the technology providers with support from Coventry University.

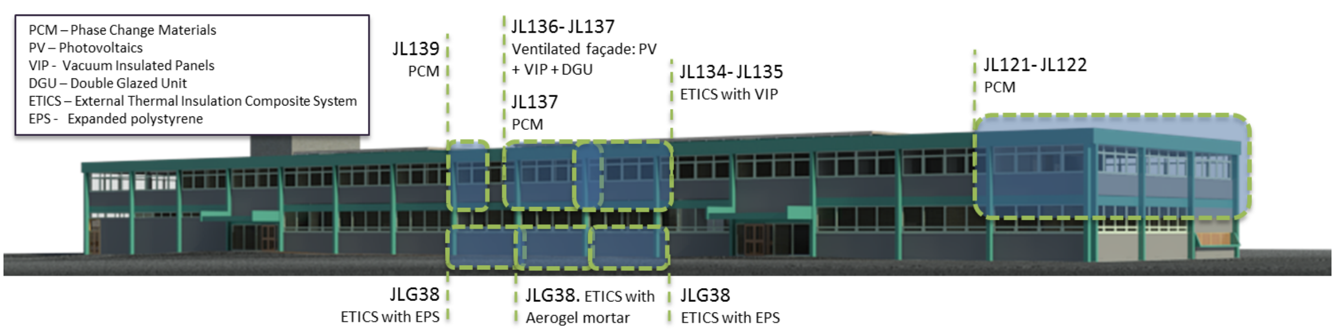

Figure 7: Location of the interventions

PCM was selected for use in the architectural studio space which is located in southern and south eastern orientation of the building to counteract specific overheating issues identified through user responses and simulations. The spaces are occupied by high student numbers over long hours during day and night. The architecture studio also has high internal gains due to density of computers and other heat emitting equipment. The space is naturally ventilated providing the ideal environment for testing a passive solution. To investigate different space use and and control mechanisms, PCM was installed in small office spaces (less than 20m^2).The selected offices are located on the west façade of the building with high risk of overheating.

VIP insulation has been selected on a west office to counteract the current poorly insulated cavity brick system. During the winter months users often report cold temperatures especially in the mornings. The VIP is intended to improve the overall insulation of the space without being invasive of the existing cavity. To further test insulation improvements ETICS with EPS and Aerogel mortar have also been implemented in neighbouring spaces providing a spread to the data experiments. A significant aspect of the interventions is the interaction combination space of JL137, which has been impacted by PCM and Ventilated façade (VIP and BIPV). This provides a critical zone where the interconnection of technologies can be analysed.

One of the challenges with installation was due to lack of experience and knowledge of PCM. A number of local contractors were approached to install but were put off by the increased risk of dealing with a new technology. Contractors have to consider the increased level of risk and liability that they will take on when dealing with technologies and installation procedures that they have little prior experience of installing. Prior to installation there were concerns over the integrity of the tubes and the risk of leakage of the PCM. The tubes were enclosed within a very robust structure, which reduces this concern. Once the contractor had been identified the installation was fairly straightforward. Certain protocols had to be adhered to such as a structural assessment of the space and an asbestos survey, both to ensure that firstly the structure could hold the increased loading of the PCM tubes and secondly to ensure that there is no risk of exposure to asbestos by both installers and users of the building. Figure 9 shows the PCM tubes were fixed using a standard tube fixing bracket system, which was fixed to the underside of the ceiling. The spaces and tubes will be monitored over the next year to evaluate performance of the system, both objective and subjective data will be used to compare rooms with PCM to selected controls rooms.

Figure 8: Installation of the PCM tubes

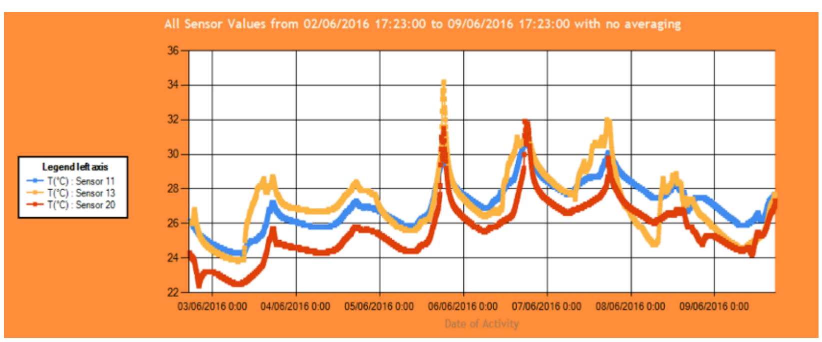

Figure 9. Indoor temperature of PCM rooms (11 & 20) and a control room (13)

Initial results from the indoor environmental monitoring suggest more comfortable internal environment compared with the control rooms. Figure 10 shows that the control room has a consistently higher peak indoor temperature over the 5 days monitoring period. This trend will be assessed over a long period and also evaluate the influence of user behavior in terms of opening and closing of windows. The result shows that there is a peak temperature difference of about 4K between rooms with PCM and the control room. The dirnal temperature variation is higher in the control rooms, 10.4K compared to two rooms with PCM with 6.4K and 9.50K diurnal temperature range.

The ventilated facade was conceived andmanufactured within the RESSEEPE project. The partners involved in the manufacturing of the structure and the assemblies of the system were from a different country, which implied a carefully designed installation process and the validation of the system beforehand. However, even with a very detailed assembly plan there were some logistic issues regarding the delivery of materials, lack of specific tools and lack of a Risk Assessment plan and disposal of the waste materials. The installation process was successful at taking into account all the challenges that were faced as mentioned above. Surface sensors were integrated into the different layers in order to get a real time performance of each material. Figure 11 shows the installation of VIP and Ventilated Façade and the completed system.

Figure 11. Installation of the ventilated façade

The aerogel mortar was tested and manufactured specifically for its application in Coventry University. Due to its innovative nature a theoretical and practical training was done by the manufacturer in order to ensure a good product application. The application of the aerogel mortar was done by hand instead of the spray system, this implied having to test different percentages of water-mortar ratio in order to get a good performance. During the construction a number of thermocouples were integrated into the layers of the façade systems, which will provide information on the thermal gradient through different layers of the façade. Figure 12 shows the installation process of the aerogel mortar.

Figure 12: Installation of the aerogel mortar

An international prototype installation requires an effort of understanding and cooperation. Having to coordinate the construction works from another country is very complicated and with a lot of logistic challenges such as bringing heavy tools & equipment as well as a language barrier. Some risk was assumed by the demo-site derived from difference in Health and Safety culture, waste disposal measures and damage to existing landscape. Additionally it could be argued that many of the problems were due to the impact of having no robust method statement and risk assessment. Many delays were experienced due to the lack of robust planning which resulted in extended disruption to CU day to day activities. As a result of some of the technologies being in developmental stage, it is essential for all the stakeholders involved to understand the risks associated with both installation and on-going maintenance challenges, which 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. Some of the setbacks could have been avoided if all the coordination had been done by just one company with experience of the construction culture and procedures in the pilot country. 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. The engagement and communication of on-going interventions and disruptions to the users of the buildings was particularly vital for achieving the socio-ecomomic and environmental benefit of low energy retrofit.

At this stage it is too early to evaluate energy data in great depth as the in-situ monitoring study is still in its infancy. Additionally, user experiences will be evaluated over the next year before disseminating results. This approach will ensure that performance data is evaluated over summer and winter seasons. A period of 12 months of user experiences and monitoring will provide a robust level of data to establish greater generalisation and ensure higher quality analysis and extrapolation.

Conclusions

The RESEEPEE project aims to achieve energy reduction in the region of 50% through the use of innovative building fabric and systems to retrofit public buildings. The project developed a building selection process for retrofitting and a clear methodology for selecting technologies for implementation within selected case study buildings. The aim of this paper is to critically review the process of stakeholder engagement and evaluation and the process of technology installation. The paper reviews the relevant technologies and describes the process of stakeholder engagement. The challenges faced during installation of the various technologies shows that effective stakeholder engagement at different stages of the project life cycle is essential for maximising the socio-economic and environmental benefits of a low energy retrofit project. It is also essential that the installation process of the various technologies is centralised and coordinated by a single entity with experience of local culture and procedures to ensure efficient installation process. So far some results of the PCM performance have been presented which reveals very interesting trends showing that the PCM will be useful for alleviating discomfort, especially in the summer months. The installations will be monitored over the coming 12 months and detailed performance evaluation of the various systems will be evaluated. Additionally the stakeholder engagement process will continue post installation and in conjunction with objective measurement come up with clear performance metrics for each technology. Results from the demo-sites will be extrapolated to other public buildings in order to achieve potential urban scale retrofit analysis.

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