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Built2Spec

Built to Specification : Tools for the 21st Century Construction Site

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D5.1 Automated Quality Assurance and Compliance Methodology

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DISCLAIMER

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Separate D5.1 Documents

The primary outputs from D5.1 are in workbooks and a PDF document which are separate documents to this public report and are listed below:

Workbook 1 : Key Energy Efficiency Measures (.xls workbook)
Workbook 2: Summary of Building Regulations (.xls workbook)
Workbook 3: User Stories, Items of Work for Energy Efficiency Measures (.xls workbook)
Workbook 4: User Stories, Items of Work for B2S Test Technologies (.xls workbook)
Document 5: Workflow Diagrams (PDF's)

1.0 Executive Summary

WP5 is the link between the previous WP's and WP6 where the project's **Virtual Construction Management Platform** **[VCMP]** is being developed. The primary objective of T5.1 is to use the experience of the partners to develop a comprehensive methodology of quality checks, self-inspection techniques and test procedures for construction activities which will help to close the performance gap between the design and the occupied building. The quality checks and test procedures had be analysed and broken down into detailed step by step processes which are then described in a standard format for software development. The software industry uses 'User Stories', 'Items of Work' and 'Workflow Diagrams' to communicate to the software developers the functionality and objectives of the software so that they can create the most efficient software system for the VCMP.

Using the partners' collective experience in the construction industry and our knowledge of energy efficiency in buildings the first step was to identify the most critical areas of building design, construction and occupation which affect the energy performance and indoor environmental qualities of a building. The three stages of design, construction and occupation each have an impact on the actual performance of a building and an integrated approach involving all three stages is essential to create healthier and more energy efficient buildings.

The five innovative testing technologies being developed in the project will be integrated into the VCMP. To achieve this User Stories, Items of Work and Workflow Diagrams have been developed by the technology partners in collaboration with the T5.1 team so that their use as performance and quality tests can be implemented on a building site.

Measurable performance targets need to be set for each quality check and test so that compliance reporting can be automated in the VCMP. As many of the targets will be the minimum standards of the Building Regulations in the country or region where the project is located a summary of the project partners' Building Regulations was collected and collated for the regulations which affect energy efficiency. These summaries will be kept in the VCMP Standards Datastore for extracting targets and standards when a project is set up on the VCMP.

2.0 DoA Description of T5.1

"Using the combined field expertise of the partners, current standards and EU building regulations as the primary sources the processes for each self-inspection technique and relevant construction process step which have the greatest impact on building energy performance and indoor environmental quality will be detailed in a series of step by step methodologies.

A specific set of Key Energy Efficiency quality check measures that are critical to compliance and performance targets relative to the energy performance of a building will be identified and the step by step methodology for these will be developed in detail.

The quality check measures will extend to the design team professionals to involve them in the education of the building users beyond handover so the design knowledge and intentions are transferred to the building users. This will extend to seasonal commissioning of the building services in the first year of occupation to ensure the building services function properly and efficiently, a common problem.

The detailed knowledge of the self-inspection techniques has come as outputs from WP2, WP3 and WP4 and the partners involved. These will include thermal performance assessments air pulse testing, IAQ, acoustic performance, imagery and smart materials, BIM based construction details and the Soft Landings Framework."

3.0 Key Energy Efficiency Measures

A building needs to be considered as a integrated system using a 'systems thinking' approach to understand the dynamics of building physics and building performance. Determining which interconnected aspects of a building are fundamental and critical to improving performance and creating higher standards of indoor environmental quality is challenging. It is relatively easy to develop a long list of details that all have an impact on a building's performance as buildings are complex assemblies of materials, components and systems. The challenge is to consider these from a higher level using a systems thinking approach and to categorise the details which affect performance into a generic set of high level measures. We have concluded that this is possible with 18 Key Energy Efficiency Measures which are listed in the table below.

KEY ENERGY EFFICIENCY MEASURES			
1	Targets	10	Electrical Equipment & Appliances
2	Design	11	Water Services
3	Windows and Doors	12	Energy Recovery
4	Solar Shading	13	Energy Storage
5	Airtightness	14	Renewable Energy Systems
6	Thermal Bridging	15	Controls
7	Insulation	16	Monitoring
8	Ventilation	17	'Soft Landings'
9	Heating Cooling and DHW	18	Overall Performance

We have developed detailed generic step by step methods for self-inspection, quality checks and performance testing for these Key Energy Efficiency Measures so that by using these methodologies during the design, construction and occupation stages the performance gap can be reduced.

The step by step methods have to be generic for the VCMP platform because there are many building methods, materials and designs and it is impossible to catalogue in detail all the quality checks and tests for all the different ways buildings are designed, built and used. The VCMP platform is being developed strategically to allow Users working on specific projects to develop their own detailed quality checks and tests appropriate to their specific design and choice of building methods and materials. Users will be guided by the generic methods and processes we have developed in T5.1 for the Key Energy Efficiency Measures and they will be able to easily develop and add to these to suit the specifics of their building project.

This is achieved by uploading a project specific list of 'Items of Work' into the VCMP to add to the generic quality checks in the 'Evidence of Use' app that is a central part of the VCMP. These Items of Work are concise instructions for tasks which are sent to the mobile devices of assigned Users to complete the task. These tasks usually involve gathering information on site about the actual work being done so that it can be compared to the design details and specification.

The tasks range from scanning bar codes; taking photos of reference numbers, serial numbers and product labels; taking photos of materials and components as they arrive on site; taking photos at specific locations before, during and after certain works are undertaken; and testing or checking for performance indicators using project specific targets for each test or check. These tests may involve airtightness testing, thermal imaging, acoustic testing, indoor air quality testing or checks on the dimensional accuracy of certain components or constructions.

The rationale for selecting these specific 18 Key Energy Efficiency Measures is outlined below for each measure. The principles of reducing demand before selecting efficient and renewable supply systems is considered fundamental to this approach. These measures work together as an effective, integrated strategy for designing, constructing and using buildings to minimize the use of energy and improve the indoor environment.

3.1 Targets

Setting performance targets is the necessary first step for improving energy efficiency and indoor environmental quality so that measured performance can be compared and a "Pass/Fail" in a quality check process can lead to corrective action. Minimum targets are set by Building Regulations and other building standards. Clients and their design teams can agree higher standards which suit their needs and aspirations.

All standards and targets are a necessary part of the design process so that calculations can estimate the performance of a design in an iterative process.

In the construction stage the targets and design calculations can be used to check any changes in the specification that may be considered to ensure the targets are satisfied.

In the occupation stage the original design targets can be used to compare with monitored performance and provide useful feedback to the design team.

3.2 Design

The design for a building is obviously critical to its performance in use but a focus on energy efficiency is not always considered at an early enough stage in the design process. Fundamentals such as the 'surface area to volume ratio'; orientation to the sun or prevailing winds; the microclimate determined by site layout and landscaping and consideration of renewable energy resources all affect the energy performance of the building. Decisions on these fundamentals are often made without considering the impact on energy performance which is often undertaken later in the design process.

Energy models of building designs are an important tool for estimating performance and checking design decisions against the performance targets in the design and construction stages.

In the occupation stage it is these energy models which provide the comparison with the monitored energy use and where the overall success in closing the "performance gap" can be measured.

A dynamic design process with feedback loops built into the process is more effective at achieving low energy buildings than the conventional linear design process.

The *Integrated Design Process* (IDP) pioneered by the IEA in Task 23 (http://task23.iea-shc.org/integrated-design-process3) provides a useful framework and tools for introducing this process to design teams and projects.

The *Integrated Design and Delivery Solutions* (IDDS) approach is a step beyond IDP which includes the construction and occupation of a building. It is this approach which B2S supports by integrating quality assurance (QA) procedures for the three stages (design, construction, occupation) in an information management platform, the VCMP.

3.3 Windows and Doors

The external envelope is the major determinant of a building's energy performance as it mediates between the indoor environment and the outdoor environment. People usually want a stable indoor environment created by the building to mitigate the dynamic weather conditions of the outdoor environment. A 'fabric first' approach to energy efficiency is considered cost optimal.

Windows and doors are the most dynamic components of the external envelope as they generally allow more thermal energy into and out of the building than the opaque parts of the external envelope. The orientation of the windows and doors affects the amount of solar gain and heat loss. When used for natural ventilation the design and positioning of the windows and doors affects the amount of air that enters or is extracted from the building. This is even more critical when a design for natural ventilation is used as a low energy strategy.

The specification of the glazing, frames and thermal performance of windows and doors has a significant impact on overall energy performance and thermal comfort. Usefully most windows and doors are now rated under a number of different certification programmes which test the components for airtightness, thermal performance, overall U-value, glazing U-value and g-value (solar reflectance) and overall thermal performance. These values can be incorporated into the design process and used in quality checks and tests in the VCMP.

3.4 Solar Shading

Solar energy gains through glazing in windows and doors can be useful to heat up a building in the morning and in the heating season and windows should be designed to optimize their solar gains to reduce heating energy use. Conversely at later times in the day and in warmer weather too much solar gain can create thermal discomfort or trigger the use of energy for cooling the building.

Correctly designed solar shading can provide an optimal balance between allowing solar gains at the right times and excluding solar gains when they are generally not needed. Computer models of buildings which simulate solar tracking for specific locations can be used to design accurate solar shading devices. The information from the design model can then be used to check the angle and position on the building during construction.

3.5 Airtightness

The airtightness, or air permeability, of a building's external envelope has a major impact on the overall energy performance of the building. Airtightness can affect overall energy use significantly and yet the cost of achieving a very airtight envelope is not significant when effective construction details and specifications are prepared for a project. Workmanship is the bigger issue in achieving airtightness consistently across a whole building envelope as so many workers are involved.

Quality checks and tests for airtightness are very effective at improving this workmanship with minimal time and effort. It is the author's direct experience on several building projects that a focus on airtightness is welcomed as a challenge by most construction workers who compete to achieve measurably (by blower door testing) better airtightness results. Anecdotally the site managers think a focus on airtightness improves the overall quality of work on their site.
Airtightness is measured by the now conventional blower door tests using 50 Pa pressure difference and in B2S we are trialling and testing the innovative Pulse System which uses 4 Pa pressure in a short pulse of air pressure. The metrics are either ACH (air changes per hour) or air permeability in m3/hr/m2 of external envelope area.

3.6 Thermal Bridging

Thermal bridging across the insulation zone of an external envelope has a significant impact on the thermal performance of a building as one detail with thermal bridging may be repeated over a length of many metres. For example one cill detail with poor thermal bridging may be repeated at every window cill in the building and the total heat loss through this detail can be very significant. Thermal bridging can also cause condensation which can lead to mould growth and deterioration of the materials affected by the thermal bridge.
Thus thermal bridging needs to be considered for all details of the external envelope during the design stage.
Thermal bridging calculations can be done with various software systems such as *Therm* which also output useful images similar to thermal images from IR cameras.
Quality checks for correct construction need to be carried out vigilantly during construction and any problems during occupation need to be investigated to see if thermal bridging may be the cause. Thermal imaging can be used to analyse the performance of a thermal bridge detail.
The metric for thermal bridging is the Psi value.

3.7 Insulation

Optimising the insulation of the external envelope is essential for an energy efficient and thermally comfortable building. The amount and type of insulation needs to be carefully considered separately for the basement, ground floor, the walls and the roof. The design of the external envelope requires a good working knowledge of building physics appropriate for the climate of the site combined with knowledge of the building methods and systems being used for the various elements of the building.
Insulation is used primarily to slow down the movement of thermal energy through a building element and this characteristic is measured by its lambda value. U-value calculations for specific constructions are used to calculate the thickness of insulation required to meet the specified targets.
The insulation material and its position in the construction also affects the movement of moisture through the construction, the location of the dew point and the potential for interstitial condensation within the construction. *WUFI* software (https://wufi.de/en/) analyses the movement of moisture and thermal energy

through a construction over time and should be used to design most wall and roof constructions in low energy buildings.
The quality checks for insulation include lambda value, thickness, U-value, vapour permeability, fire rating, GWP and a *WUFI* hygrothermal calculation for the overall construction of the building element.

3.8 Ventilation

Buildings are for people whose well-being and health are significantly affected by the quality of the indoor environment as people in Europe now spend about 90% of our time indoors. The quality of the air we breathe has the most impact on our comfort and experience after thermal comfort. Exposure to pollutants in the air can affect health (sick building syndrome) and in the short term can be uncomfortable, affect well-being and productivity.

The pollutants which affect indoor air quality are various with many pollutants originating in the multitude of chemicals we use in and outside our buildings. Outdoor air is not necessarily 'fresh' and in dense urban environments the outside air can be more polluted than used indoor air due to vehicle and industrial emissions from nearby roads. Common pollutants found in commercial buildings include CO2, CO, NOx, SO2, moisture, particulates (PM2.5, PM10), VOCs, radon, ozone, aldehydes and man-made fibres.

Well designed ventilation systems delivering high quality air to all spaces in a building are essential for human health and well-being. Designed ventilation strategies and systems are especially important as building envelopes become more airtight for energy efficiency. Openable windows for individual local control can be part of the ventilation strategy and have important psychological benefits.

Ventilation strategies for low energy buildings are either natural ventilation, mechanical ventilation or hybrid ventilation which combines aspects of both natural and mechanical systems. In all strategies the volume and rate of air changes required to maintain high indoor air quality is related to building use and occupancy. Using natural ventilation to cool a building is an energy efficient strategy.

Air quality standards in commercial and industrial buildings are often in Health and Safety Regulations rather than Building Regulations. The metrics are either in "volume/time/ occupancy" such as "8 litres/second/ person" or in "volume/time" as in "0.5 air changes per hour".

Balometers and other airflow measuring devices are used to measure and check the airflow in ventilation ductwork. The airtightness of ductwork affects the energy efficiency of the ventilation system and the efficacy of the ventilation system so this should be tested during installation.

3.9 Heating, Cooling and DHW

The heating, cooling and hot water systems in a building typically use most of the building's energy so it is important to design and specify the most energy efficient systems available. Low temperature systems can take advantage of the principles of exergy and renewable energy systems which often deliver lower temperatures than fossil fuel 'fired' systems.

Integrated systems can achieve synergies that contribute to energy efficiency and there are many proven innovative and very efficient systems on the market that are not yet well known. For example cooling systems generate heat which should be used to heat the DHW or the thermal energy should be stored for when heating is required.

The pipes and ducts which deliver these services around a building should be designed to minimise standard right angle junctions which create large pressure drops and increase pump and fan power requirements. Instead easy radius bends and junctions designed for low resistance fluid flow with larger pipes and ducts and smaller pumps and fans will reduce noise and significantly reduce the energy consumed in distributing the air and water around the building. (RMI publication Feb 2011; "Big Pipes, Small Pumps"; Factor Ten Engineering)

The performance of the selected systems should be included in the energy model for the building so that the sub-metered and monitored performance of these systems in the occupied building can be compared and analysed to check how efficiently they are performing. Using continuous feedback during occupation should result in continuous improvements in building performance.

Controls and renewable energy for heating, cooling and DHW are discussed in items 3.14 and 3.15 below.

3.10 Electric Equipment and Appliances

To reduce demand for electricity the most energy efficient electrical equipment should be specified. The development of ever more energy efficient electrical equipment, components and appliances is an opportunity to significantly reduce the electricity use by careful specification.

The nature of the contracting industry where tenders are won on the lowest price requires vigilance during the construction stage to ensure that the specification is being met by sub-contractors, some of whom may not be in direct contact with the Design Team. Some components can look identical but perform completely differently depending on their model number which can only be checked with a bar code or serial number.
Thus a detailed checking process of bar codes, reference and serial numbers of all electrical components delivered to site is essential to ensure the building is "built to spec". Photographic evidence of the installed equipment allows checking for any substitutions that may have taken place during the construction stage.

3.11 Water Services and Plumbing

It is possible to reduce the demand for water in a commercial or residential building by 40% using plumbing fittings and fixtures designed for low water use. Aerating taps, low flow shower heads, low flush toilets, waterless urinals and automatic shut-off valves all reduce water use without the user noticing a reduction in service.

All pipework for water services should be designed using the Factor Ten Engineering principles outlined in item 9 above to minimize the pumping power necessary to provide the water services.

A rainwater harvesting system can reduce the wasteful use of treated mains water for flushing toilets, cleaning and maintenance. Such a system provides a useful storage buffer for dry periods when the public water infrastructure may be under stress and use restrictions are in force.
Flow sub-meters on water sub-systems can provide useful monitored feedback during occupation to improve the efficient management of the use of water.
Checks on adherence to the specification during construction are essential.

3.12 Energy Recovery

Energy recovery systems can return a significant amount of useful energy to a building. They are not yet included in the design of every system in every building even though they are cost effective and have short payback periods.

The recovery of thermal energy, both hot and cold, from ventilation and cooling systems can use technology that takes advantage of enthalpy to optimize the energy recovered.
Waste heat exchangers can be installed on any equipment that exhausts hot air or water including computer servers, clothes dryers, air conditioning and cooling systems. Flue heat recovery technologies can be installed on any equipment that burns a fuel for heat. Drain heat recovery systems can recover significant heat from waste water just before it leaves the building and goes into the public drainage system.

Sensors on all energy recovery systems will provide data to measure and optimize the re-use of the considerable waste energy that is produced by building services and equipment.

3.13 Energy Storage

Energy storage is a useful strategy to reduce the demand for energy by storing recovered, excess, waste and renewable energy produced in a building. The stored energy can then be used in different parts of the building at different times from where and when it was recovered or produced. This reduces the total energy demand from conventional sources.

The storage medium for thermal energy needs to have high thermal mass and be relatively cheap to keep the energy storage system cost effective. Water and the earth below the building are the two most common mediums. “Energy piles” in new buildings use the piled foundations as cost effective heat exchangers to the surrounding ground as a heat sink for cooling or for storing heat in an inter-seasonal heat storage system.

The structure of a building can be designed as a thermal store if it has high thermal mass (masonry or concrete) and is externally insulated with no thermal bridges. Integrating water pipes into this heavy structure for heating and cooling the building reduces the need for high temperatures for heating and cooling. Low temperature heating and cooling systems are most suitable with renewable and low carbon energy sources and result in very efficient buildings.

Heat pumps can increase or decrease the stored thermal energy to the desired temperature for use in the building. Battery technologies for storing renewable electricity, or for a back-up supply, are increasing their efficiency and performance while reducing their environmental impacts due to intense R&D in this area.

Energy storage systems integrated into the building design need sensors and monitoring so that the amount of energy available to the building is known and the effectiveness of the systems can be analysed and optimized.

3.14 Renewable Energy Systems

Integrating renewable energy systems into new building designs can significantly reduce the costs of installation compared to a retrofit. Many jurisdictions require a minimum percentage of a new building's energy use to be provided by renewable energy and this requirement will increase over time with new EU directives and national regulations.

To ensure the renewable energy systems are installed and perform correctly sub-meters and sensors should be installed to monitor the performance.

3.15 Controls

Effective controls on the services in a building can significantly reduce the amount of energy used and improve the Indoor Environmental Quality (IEQ). Research in Europe has found that most BMS (Building Management Systems) do not work or are not used properly in 90%[1] of buildings due to lack of knowledge and training, loss of critical instructions over time, lack of maintenance and lack of seasonal commissioning. BMS systems are often proprietary for the major systems installed during construction and they can be difficult to adapt when changes in the building are undertaken.

A greater level of control is possible with a more detailed layer of low cost sensors and actuators installed directly on equipment and in more spaces in a building. The technology of sensors has developed significantly in the past 15 years and low cost sensors and actuators are commercially available. When deployed across a building to capture a more detailed and fine-grained view of how a building, its equipment and systems are performing it is possible to provide feedback to the control system

[1] Cited by Mills, but unable to verify source reference. EU2 Analysis and Market Survey for European Building Technologies in Central & Eastern European Countries – GOPA ; also Carbon Trust UK Report 2007 : *CTV 032 Building Controls*.

so that it automatically controls the building for greater comfort and energy efficiency.
Wired or wireless sensors and actuators in more locations to provide a greater number of controlled spaces, or zones, will enable more specific control of spaces for greater comfort. There are now building control software platforms available in the cloud for integrating these sensors and actuators and allowing control from remote locations. The software also provides dashboards for reporting filtered information to selected Users.

3.16 Monitoring

A comprehensive monitoring system should be integrated into the design of a building so that the managers and users get feedback on the performance of the systems in their building during occupation. The greater the number of sensors and sub-meters the more fine-grained the data and feedback will be about the performance of the building. The more data that is available to manage the building the more the use and control of the building can be fine-tuned to optimize performance. The monitoring system should be integrated with the control system as outlined above for as much automatic feedback to the control system as possible.

A large and diverse database of monitored data collected over a long period of time can also be analysed with 'machine learning' tools to discover latent intelligence about how the building is being used and is performing. This type of data analysis can inform management about useful refinements and guide decisions about the control systems and use of the building.

The technology for monitoring buildings has been evolving rapidly over the past few years as the IoT (Internet of Things) concept and related technologies have been developed. There are now cost effective, wireless, batteryless, power harvesting sensors which can be deployed to monitor individual pieces of equipment and individual spaces for IEQ and IAQ. Essential to their use is an effective wireless communications system within the building with a gateway so the data can be exported to the cloud for viewing on a remote computer or device. The wireless sensors make installation in existing buildings cost effective as retrofitting any wiring is avoided.
See www.enocean-alliance.org .

A suitable M&T (Monitoring and Targeting) programme should be developed and implemented by the building's management based on the data provided by the monitoring system to make best use of the data available. The information generated by the monitoring system can be used to support designated *'energy champions'* in the building who lead behaviour change to improve performance of the building.

The monitoring system can also provide data and alerts for a Predictive Maintenance system which can reduce maintenance costs and the 'downtime' of any system in the building. For example vibration sensors on pumps can alert management that a pump needs maintenance that prevents failure up to 5 months before the pump would require costly replacement.

3.17 Soft Landings

"Soft Landings" is a framework for the successful handover of a building to the owner and users from the design and construction teams to ensure the owner and users know how to control and use the building as it was designed so that it performs well and satisfies their requirements in the first years of occupation.
https://www.bsria.co.uk/services/design/soft-landings

Essentially *Soft Landings* extends the contracts for the design and construction team beyond Practical Completion, usually for at least the first year of occupation. The Soft Landings framework was developed when it was realized that the new generation of low energy buildings were not achieving their designed performance targets because the managers and users of the buildings didn't know how to operate the buildings optimally.

The *Soft Landings* methodology is implemented in stages which are congruent with the principles of the *Integrated Design Process (IDP)* and the *Integrated Design and Delivery Service (IDDS).* These stages are :

1. **Inception and Briefing**
    - Define Roles and responsibilities
    - Review past experiences
    - Plan for intermediate evaluations and reality checks
    - Set environmental and other performance targets
    - Set up decision making gateways
    - Incentives for performance results

2. **Design Development**
    - Review past experience
    - Design Reviews
    - Tender documentation and Evaluation

3. **Pre-Handover Checklist**
    - Environmental and energy monitoring review
    - Building Readiness programme
    - Commissioning Records check
    - Maintenance Contract
    - Training
    - BMs interface completion and demonstration
    - Migration planning
    - Aftercare team home
    - Occupant Guide
    - Technical Guide
    - O&M Manual Review

4. **Aftercare Service**
    - On-site Attendance
    - Aftercare Team Workstation
    - Introductory Guidance for Users
    - Technical Guidance
    - Communications
    - Walkabouts

5. **Extended Aftercare Years 1-3**
    - Aftercare Review Meetings
    - Monitoring environmental and energy performance
    - Systems and energy review
    - Fine tune systems
    - Record fine tuning and use changes
    - Communications
    - Walkabouts
    - Post Occupancy Evaluation
    - End of Year Reviews

The details of how Soft Landings is implemented will vary for each project and client. By including the outline of the framework into the VCMP we will encourage, support and facilitate the use of these techniques for improving the performance of a building in the occupation stage.

3.18 Overall Performance

Ultimately the objective of the B2S project is to improve the overall performance of a building. Comparing the actual monitored performance of the building with the initial design stage whole building energy model and simulations will provide the quantitative results and one measure of the success of the building.

Equally important is the qualitative measure of the satisfaction of the occupants, users and owner of the building as it is of course the health and well-being of people who matter more than the energy that is used. A Post Occupancy Evaluation (POE) of the occupied building after at least one year of occupation is a methodology for capturing a subjective, qualitative assessment of the experience of using the building from the building's occupants.

The POE methodology developed by Building Use Studies is one of the longest established methodologies and thus has the most experience and largest database of buildings upon which its assessments are based.
(http://www.busmethodology.org)

Providing feedback to the design team, the construction team and clients is the best way for building design and construction to improve in the long term. If one succinct definition of sustainability is simply "taking a long term view", then measuring the overall performance of a building, both quantitatively and qualitatively, to provide feedback to the design process, is essential to achieving better buildings and closing the 'performance gap' in the long term.

The 18 Key Energy Efficiency Measures were selected after careful consideration of the issues in building design, construction and occupation which have the most impact on a building's indoor environmental quality and energy performance. The descriptions above outline the reasons why these measures were selected as fundamental to energy efficiency.

4.0 Building Regulations Standards for Energy Efficiency

Each of the *Key Energy Efficiency Measures* needs a measurable target to measure success and optimize performance. Some of the performance targets are determined by minimum standards of the Building Regulations in the jurisdiction of the site. To provide a source of these minimum standards and performance targets the 7 partners in T5.1 each summarized their national Building Regulations with the standards relevant to the Key Energy Efficiency Measures. The Passivhaus standards were also summarized and all are included in the "D5.1 Building Regulations for EE and RE" spreadsheet included in this Deliverable. These standards include references to ISO and EN standards where they are relevant.

These summaries of the Building Regulations will be uploaded and available as a resource in the Standards Datastore being developed in T6.8. The intention is that when a project's location details are put into the VCMP the Building Regulations standards for that jurisdiction will be linked to the checks and tests selected by the Administrator of the project. One of the useful outputs of the VCMP for project teams can be confirmation by the system that a building complies with the relevant Building Regulations for the project's location which is backed-up with detailed evidence from the construction stage.

Country	Permeability or Air change rate		Pressure difference (Pa)	Property type
Germany	3.0 (Natural ventilation) 1.5 (Mechanical ventilation) 0.6 (Passive house)	h^{-1}	50	Domestic dwelling
Ireland	10	$m^3/m^2 \cdot h$	50	Domestic dwelling
Switzerland	0.75	$m^3/m^2 \cdot h$	4	Domestic dwelling
Spain	50 (Southerly, warmer area) 27 (Northerly, cooler area)	$m^3/m^2 \cdot h$	100	Domestic dwelling
France	0.6 (single family house) /0.8 (Multi-family building)	$m^3/m^2 \cdot h$	4	Domestic dwelling
Italy	10	$m^3/m^2 \cdot h$	98	Schools
Netherlands	0.2	m^3/s	10	Domestic dwelling
	0.2 per 500 m^3	m^3/s	10	Non-residential building
United Kingdom	10	$m^3/m^2 \cdot h$	50	Domestic dwelling

Eg. Summary Table of the Building Regulation standards for 'airtightness' in partner countries

Some clients may have performance targets for projects which are not covered by the Building Regulations or which exceed the minimum standards of the Building Regulations. There are a number voluntary systems for low energy and more sustainable buildings that have been developed such as BREEAM, LEED, the Living Building Challenge and Net Zero Energy Buildings (NZEB) and some of these systems have local or regional definitions. All of these standards can be accommodated in the VCMP by uploading their requirements and standards into the Standards Datastore of the VCMP.

5.0 B2S Innovative Testing Technologies

In addition to the 18 Key Energy Efficiency Measures there are five innovative technologies for testing and analysing a building's performance which are being developed within the project. The B2S Innovative Technologies are listed in the table below:

B2S INNOVATIVE TESTING TECHNOLOGIES		
19	Thermal Imaging	WP2
20	Pulse Airtightness Testing	WP3
21	Indoor Air Quality Testing	WP3
22	Acoustic Quality Testing	WP3
23	Smart Materials	WP4

User Stories, Workflow Diagrams and Item of Work descriptions have been prepared in detail for these five technologies .

Some of these technologies are still being developed by the technology partners so the User Stories, Workflow Diagrams and Items of Work developed in T5.1 may change as the technologies are integrated into the VCMP in WP6. WP6 started in January 2017 and the Pulse Airtightness Testing and IAQ technologies have already been integrated into the VCMP. The acoustic testing technology is close to having its integration completed by VRM at the time of completing this report in mid-June 2017.

The BIM integration functionality is included in all User Stories for all aspects of the VCMP. Any information being used in the VCMP can be linked to a BIM model of a building and vice versa. We have learned during the project that BIM is not yet being used widely in the building industry and it is difficult to get access to BIM models to work with as most BIM models are privately developed and the information is private or commercially sensitive.

6.0 User Stories, Items of Work and Workflow Diagrams

VRM and Ecofix wrote a set of instructions for the consortium describing the format and reasoning for using the User Stories, Items of Work and Workflow Diagrams to develop the VCMP. These methods are standard in the software development industry but new to most of the partners in B2S so it was essential to guide the partners in this process so that they could communicate the functionality they wanted in the VCMP to the VRM software development team working in WP6.

Below is the description of instructions and guidance provided to the partners.

"A User Story is a simple description of what functionality is required of the VCMP broken down into a series of complete sentences in the format:

" **As a** < type of user >, **I want** < state your goal > **so that** < state your reason > "

An example of a complete sentence in a User Story is :
"**As an** Architect **I want** to take photos of all window to wall junctions **so that** I record the airtightness details of this critical junction in the VCMP."

The following critical information needs to be included in the User Story:

- **Who** is to perform the checks?
- **What** are the checks trying to achieve?
- **When** are the checks to take place?
- **Where** will the check be used?
- **Why** is the data important ?

User Stories need to include all three stages of a building's life from Design through Construction and including Occupation.

Workflow Diagrams
Once the *User Story* has been written it should be obvious how the workflow will have to be structured in order to provide complementary and supporting information on what actions need to be taken and where data is to go. We have seen various examples of workflow diagrams presented at our Project Meetings by UNOTT, TNO and ourselves which are available in presentations on EmDesk.

Items of Work
The *Evidence of Use* app is one of the strongest features of the VCMP and is used to collect digital data about a building using a mobile device. A smartphone camera can take photos, scan barcodes and the information can be sent to selected people or stored in specified parts of the VCMP.

The detailed step by step process for each quality check or test needs to be described as an *Item of Work* (IoW) and listed in the logical order of the process in an Excel spreadsheet. This is the correct place to detail what the User Story has described in an overall story format.

An IoW is a logical task, generally a single operation in a series of operations to complete an identifiable stage in the building process. An IoW could be the requirement for a selected User to take a photo of a specific part of the building at a specific stage of construction. The IoW will be displayed on the User's smartphone as a simple, short description of 'work' that must be completed before the next IoW is displayed to the User.

The sequence of the IoW's must be logical and practical for the process. The sequencing of IoW's also forces a User to complete each IoW task or they will very clearly be seen by other users of the VCMP that they are not doing their job properly. A notification can be sent to their superior so that the issue of a User's incorrect or incomplete use of the VCMP can be addressed.

The 4 key pieces of information that are typically required for each IoW are:

1. the IoW Description
2. the Standard
3. the Metric
4. the Evidence required.

If all of the above steps are followed we will have the step by step processes for the test and quality checks in a format that the software developers can work with to develop the VCMP."

Example for Airtightness

Below is an example of a *User Story* from the ***Airtightness*** measure:

"As a member of the design or construction team I want to take detailed progress photos on site of the airtightness seals, tapes and membranes being used to achieve airtightness in all parts of the building."

The *Item of Work* related to this User Story is below:

"Take progress photos of installation of airtightness system seals in all locations."

This instruction will be displayed on the selected User's mobile device when he/she starts using the VCMP. In this example the User was an Ecofix employee responsible for achieving the airtightness target on a new build housing site in Dublin.

The photos shown on the next page are automatically stored in the VCMP for this job and this project. The houses on this project are achieving an average airtightness of 0.24 ACH which is well below the global 'gold standard' of the Passivhaus Institute of 0.649 ACH. The Site Manager believes the excellent results and consistency of the airtightness test results are due in part to the use of the software system by the workers.

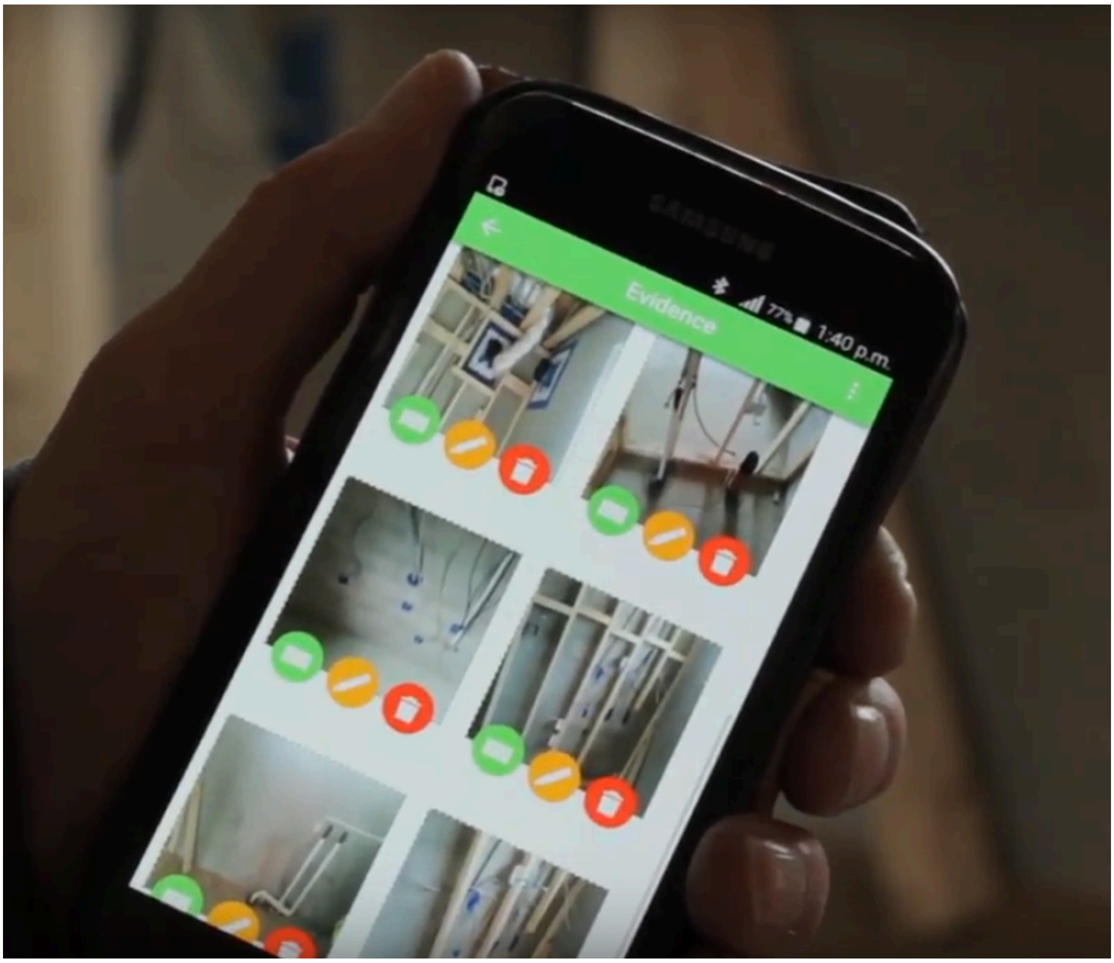

Photo of smartphone screen showing on site evidence photos of *Items of Work* for airtightness taken using a trial version of the VCMP on a new housing project

7.0 Conclusion

Task 5.1 has defined the ***Key Energy Efficiency Measures*** which affect the energy efficient performance of buildings. The detailed step-by-step processes for the quality checks for these 18 measures have been described in a format so that the VCMP can be developed in WP6 to integrate these quality checks. The ***User Stories, Items of Work*** and ***Workflow Diagrams*** of all 18 Key Energy Efficiency Measures have been compiled in a series of spreadsheets in Excel.

The VCMP will allow Users to define specific detailed quality checks for their specific project using the Key Energy Efficiency Measures as an overall guide to support and encourage an integrated approach to the design, construction and occupation of the building which will deliver energy efficiencies and an improved indoor environment.

The detailed step-by-step testing processes for the innovative testing technologies being developed within the project have been described in the same format for WP6. The testing methodologies and technology for the Pulse system and the IAQ system have already been integrated into the VCMP and the acoustic testing system is currently being integrated in WP6.

An integrated approach to the three stages of design, construction and occupation has been fundamental to the development of these quality checks and tests. The principles of the *Integrated Design Process*, the *Integrated Design and Delivery Service* and the *Soft Landings framework* are referred to in the 18 Measures and the associated quality checks.

The focus of the project is to introduce technology onto the building site to collect data and record quality checks and tests so that evidence of the quality assurance process and testing is available in real-time and in the future. By setting numeric targets wherever possible for each measure of performance the results of the checks and tests will be automated as much as possible. Confirmation of compliance with regulations and standards will be a useful output from the VCMP based on the Building Regulations information collated in this Deliverable.

There is a practical limit to the amount of time and resources a construction team can spend on recording the construction work they do and at a certain point there will be additional costs to the building project which a client may or may not be prepared to pay. There is a balance to be struck between the costs of a comprehensive quality assurance system on site during construction and the improvement in performance of the occupied building.

A significant improvement is necessary to the quality of work on site to close the performance gap in most buildings. Using the VCMP and the B2S methodology for quality assurance, self-inspection techniques and testing should provide a robust methodology for achieving this objective. The industry should be able to learn how to achieve the right balance using the flexibility that is being built into the B2S VCMP to develop unique quality checks suitable for the detailed design and specification of a building project.