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An Integrated Design Approach for Planning the Measurement and Verification of Zero Energy Settlements

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ABSTRACT

Building design is undergoing a paradigm shift with the introduction of the IDP. The IDP is an inclusive and iterative design process that requires involvement and collaboration of various professionals from the start of a project. The IDP in contrast to the conventional design process follows through the operational phase of the project with the intention to monitor, measure and verify the project's in use performance and subsequently assess the implemented sustainable design strategies and energy conservation measures, identify weaknesses and as far as possible improve performance. A variety of actions has to be coordinated before and during the actual implementation of a project's the measurement and verification. These actions are specified and documented in an M&V Plan. Experience from the Zero-Plus project has revealed that the development of an M&V plan is closely related to the steps and development of the IDP. The present paper identifies this correlation which will support the development of solid M&V plans that in the long-term will benefit the projects' in-use performance monitoring and assessment.

Keywords

integrated design process, measurement and verification, zero energy buildings, zero energy settlements.

1. INTRODUCTION

The realisation that the building sector is a major energy consumer has forced building design to enter a new era so as to produce energy efficient, less energy consuming and more sustainable buildings. Globally, building codes and standards have been launched to guide design towards improved environmental performance and energy efficiency [1].

The creation of sustainable/low energy/nearly zero energy buildings can best be achieved through a revised approach to design and construction which has been identified under the term Integrated Design Process (IDP). IDP is widely recognized as the means towards creating high performance, sustainable buildings [2], [3], [4], [5], [6], [7], [8] and can be defined as an inclusive and iterative design process that requires involvement and collaboration of various professionals from the start of a project. A critical step of the IDP that greatly differentiates it from the conventional design process is building monitoring after construction. The EPBD also encourages the installation of smart metering and BEMS that should assist in energy saving. To this aim, a monitoring scheme is indispensable part of building design and operation.

Energy saving and improved energy efficiency is the overarching aim of monitoring [9]. Building monitoring is becoming essential for the transition from traditional energy distribution grids to smart grids. Within a smart grid, building monitoring and BEMS become a part of the wider energy management system of the grid through which energy flows are regulated and optimized with the application of suitably designed controls [10]. Monitoring also provides feedback to occupants, thus assisting the transition of occupant behavior to an energy conscious mindset and therefore enhancing the success of the applied energy strategies [9], [11]. Under this scope, monitoring is essential for measuring, evaluating and verifying actual building performance as well as for identifying causes and mitigating the performance gap.

The success of a measurement and verification process depends on the design and implementation of a reliable monitoring scheme as well as on planning of all actions that should be performed for measuring and verifying performance. These are part of an M&V Plan of the project. In the present work the phases of an M&V Plan preparation are correlated to the steps of the IDP process. To the knowledge of the authors this is the first attempt to introduce the M&V Plan in the context of the IDP and correlate their design and development. The M&V Plan of the Zero-Plus project is used as basis for this correlation.

The paper is organised as follows. Section 2 sets the background of the Integrated Design Process, its development and its steps. Also in section 2 is given the background of the Measurement and Verification Protocols that dictate the development of an M&V Plan. In section 3 is presented the case study, its IDP attributes and the process of its M&V plan development. In this section are also presented a Problem Identification Procedure and the Web-GIS platform that have been designed for measuring, verifying and monitoring the case study. Section 4 discusses the case study and the correlations that can be deduced. Finally section 5 presents the concluding remarks.

2. BACKGROUND

2.1 The Integrated Design Process

The IDP for building design emerged as sustainable building practices and the green, low–energy and recently nearly-zero energy building concepts evolved. Through practice and collection of data from case study buildings it was recognized that sustainable building design requires a revised design approach where considerable design effort is transferred to the beginning of

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a project with the collaboration of various building practitioners that share expertise and set a comprehensive design basis on which the project will evolve and will be optimized. The details, benefits, weaknesses and elaboration of the process have been suggested to be subject of research and development for the IPD [6]. Indeed the work that has been identified in literature has focused on these topics with the aim to assist the building industry through this paradigm shift in building design.

The characteristics and steps of the process have been a subject for investigation in recent years. Various projects and organizations have worked towards the formulation of a clearly defined process [2],[7],[12],[13]. The implications of this new process to project contracting have also been investigated [13],[14]. In [2] is given a comprehensive roadmap of the process. The drivers and the principles of the process are analyzed and detailed guidance step by step for successfully implementing IDP is presented supported by relevant case studies. The IEA Task 23 also provides a comprehensive guide for implementing IDP that is supported by an IDP navigator tool [7]. Interviews with industry professionals and consultation with experts assisted the development of the Guide to Integrated Design and Delivery document where specific attention is also given to the contractual requirements of the process [16].

In Table 1 the steps for implementing an IDP, as these have been suggested in literature, have been identified. It is observed that the number of steps may vary from 4 to 20; however the actions related to the process are common.

Table 1. The steps of the IDP

<table>
<tr><th>[2]</th><th>[7]</th><th>[13]</th><th>[8]</th></tr>
<tr><td rowspan="2">Pre-design</td><td>Basics</td><td>Basics</td><td>Basics (steps 1 - 3)</td></tr>
<tr><td>Pre-design</td><td>Pre-design</td><td>Pre-design (steps 4 & 5)</td></tr>
<tr><td>Schematic</td><td>Concept design</td><td>Schematic</td><td>Concept design (step 6)</td></tr>
<tr><td>Design development</td><td rowspan="2">Design development</td><td rowspan="2">Design development</td><td rowspan="2">Design development (steps 7 – 14)</td></tr>
<tr><td>Construction documentation</td></tr>
<tr><td rowspan="2">Bidding-construction-commissioning</td><td rowspan="2">Construction</td><td rowspan="4">Construction and operation</td><td>Construction (steps 15 – 17)</td></tr>
<tr><td>Commissioning (step 18)</td></tr>
<tr><td>Building operation (startup)</td><td rowspan="2">Operation</td><td rowspan="2">Operation (steps 19 & 20)</td></tr>
<tr><td>Post-occupancy</td></tr>
</table>

Implementation of an IDP requires a diverse team of professionals that will collaborate from the beginning of the project. Furthermore, it is fundamental that the client is involved from the beginning of the process along with the team. Purpose of the initial meeting between the team and the client is the definition of the project's aspirations, the identification of potentialities or problems and goal setting. The assembly of the team and meeting with the client in order to set the launching base of the project are the actions that compose the first step of an IDP that is characterized as the "basics" step or "pre-design 1".

The following step, characterized as "pre-design" or "pre-design 2" includes exploration of design strategies and identification of synergies for producing a refined energy and sustainability targets' plan for the project. This plan will be the basis upon the "schematic" or "concept design" will be built; that is the third step. At the third step, design alternatives are evaluated while design strategies and targets are reevaluated and become more concrete. The schematic design that will result from this process will be further developed at the next step, the "design development". This step may include a number of iteration loops where the design choices, the energy strategies and combined performance of all systems are evaluated and optimized before moving to the "construction" step. The construction step also involves the commissioning process and in some cases construction has been grouped with "operation" as one step.

The final step of an IDP is the "operation" or "post-occupancy". As opposed to the conventional process, where the project ends after construction is completed, the IDP continues into the operation phase. The operation phase includes continuous monitoring of the building, collection of data relating to its performance, evaluation of the performance and indoor environmental quality as well as actions for improving and further optimizing performance. This final iterative loop is invaluable not only for continuous improvement of the specific project but also for verifying the result of the implemented design strategies, identifying weaknesses and methods to be overcome as well as gaining experience and knowledge for future projects.

Although operation is the final step its successful implementation in support of a project's measurement and verification requires preparation and planning from the beginning of the project which is documented in an M&V Plan for the project [15],[16]. Specifically, as experience from the Zero-Plus project has revealed, preparation of a project's M&V Plan should develop in phases that match the phases of IDP.

2.2 Measurement And Verification Protocols

The preparation and implementation of a monitoring scheme for measuring and verifying the performance of a project requires planning and coordination of various actions including the definition of performance indicators, the metrics to be measured in relation to the performance indicators, the baseline of performance, the monitoring equipment to be used, the placement of the monitoring equipment, the connection of the monitoring system, the assignment of monitoring responsibilities, the method for analyzing data and evaluating performance. The complexity of the process as well as the variety of actions to be coordinated has led to the composition and release of measurement and verification guideline documents where the details and actions for devising an M&V Plan, and ultimately implementing a robust measurement and verification, are specified.

The first document of such purpose was released in 1996 titled "North American Energy Measurement and Verification Protocol," which evolved into the "International Performance Measurement and Verification Protocol" [IPMVP] [17], [18]. The IPMVP comprised three volumes. Volume I outlined the framework for measuring and verifying the savings of ECM applied on existing buildings. Volume II focused on IEQ assessment and Volume III addressed specific issues for measuring and verifying new buildings [18], [19]. Recently the

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IPMVP Core concepts replaced the three volumes into one comprehensive document [15]. A more technical guidance on measurement and verification that complements IPMVP is provided by the ASHRAE Guideline 14. ASHRAE Guideline 14 specifically addresses measurement and verification of retrofit ECM and provides detailed guidelines on savings calculation, uncertainty evaluation, instrumentation selection and calibration as well as data management [16].

In [20] a measurement and verification protocol for performance-based contracts is provided. In a performance-based contract a third party contractor guarantees the performance of the implemented energy saving measures and the installed equipment. Thus risk allocation and responsibilities between the contractor and the customer is in the core of a measurement and verification process for performance-based contracts. The IEA Task 40 produced a measurement and verification protocol specifically for net-ZEB. In this protocol are presented the steps for planning, installing and operating a monitoring system for a net-ZEB. The document addresses strategies for monitoring energy, IEQ as well as data prost processing procedures. The contents and structure of a measurement and verification report are also detailed [21].

The protocols outline fundamental contents of an M&V Plan which may be supplemented by project specific measurement and verification instructions. The development of the M&V plan is a process that should start from the beginning of a project and evolve along the project [19]. Specifically, the steps for developing an M&V Plan can be correlated to the IDP steps. The M&V plan that has been prepared for the Zero-Plus project has followed this approach as will be presented in the following section.

3. CASE STUDY

The Zero-Plus project involves the design and construction of four pilot settlements across Europe. Through the project the concept of nZEB is applied on settlement level thus achieving lower investment costs compared to single nZEB. The four pilot settlements are located in Cyprus, France, Italy and UK and each settlement comprises residential buildings, energy production technologies and energy conservation technologies. The three targets that the Zero-Plus settlements aim to achieve are:

- Regulated energy consumption up to 20kWh/m²/year
- Renewable energy production at settlement level of at least 50kWh/m²/year
- Investment cost reduced by at least 16% compared to current costs for single nZEBS

The steps of the project, match the steps of the IDP starting with goal-setting and team assembly in pre-design. For the Zero-Plus project a broad team of experts from both industry and academia, including the settlement developers, has been assembled and has worked collaboratively from the beginning of the project. Following, schematic design and design development were supported by simulations and an optimization process. At the design development stage, along with the buildings and the technologies, microclimatic improvements were also studied and LCA was performed. The design has been reviewed and evaluated through progress meetings of the team as well as through two dedicated review workshops with the participation of external experts. After construction and commissioning, monitoring and POE will be implemented so as to evaluate performance and draw conclusions and guidelines for wider implementation of the Zero-Plus concept. It can be concluded that the process that has been adopted for the design of the Zero-Plus settlements possesses the attributes of the IDP (Table 2) as these have been identified in literature [3],[8],[15].

Table 2. The IDP attributes of the Zero-Plus project

IDP	Zero Plus
Inclusive	yes
Iterative	yes
Holistic thinking	yes
Broad -team	yes
Goal -driven	yes
Optimised	yes

3.1 The M&V Plan of Zero Plus

Monitoring is imperative for Zero-Plus project in order to verify the achievement of the project's energy related targets as well as to assess the IEQ of the Zero-Plus buildings. An M&V plan describes the steps that will be followed for measuring and verifying the actual performance of the Zero-Plus case studies. The M&V Plan of the project was built in relation to the phases of the project. These have been identified as follows:

1st phase: Pre-Design

2nd phase: Design (schematic and design development)

3rd phase: Construction/Installation

4th phase: Post-Construction/Post-Installation – Pre-occupation

5th phase: Post-occupation

At the pre-design phase the foundation for the M&V plan was set with the establishment of clearly defined targets which should be measured and verified through monitoring. Furthermore a partner with expertise in monitoring was selected to lead the process supported by partners with individual expertise of the various M&V components. During the schematic design were drawn the definitions, decisions and planning that have to be elaborated during design development. These include the boundaries of assessment, expected energy performance and baseline of analysis, the energy definitions and data that will be monitored. Following, the monitoring equipment that will be installed was specified as well as the connections and communications of the monitoring schema. The contents of the design section of the M&V Plan are updated and reevaluated along with the design development.

The third phase comprises the measurement and verification procedures that have to be followed during construction of the settlements and installation of the technologies and monitoring equipment. These will be commissioning procedures intended to ensure proper installation and function of the technologies and monitoring equipment. Similarly, during the fourth phase, measurement and verification procedures include commissioning after construction of the settlements and installation of the technologies and monitoring equipment. These procedures will be intended to monitor both the simultaneous and individual performance of the systems and evaluate it against the project's targets.

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The fifth phase is the post-occupation phase. At this phase building and technology monitoring is in progress along with POE (social science surveys). Procedures for data post-processing and analysis as well as for troubleshooting will be applied. Data analysis and savings estimation will allow the verification of the design, thus appropriate savings estimation method and data analysis methods have to be decided and applied. Furthermore, quality control procedures should be in place for defining post-construction monitoring responsibilities, evaluation of measurements and results and troubleshooting.

The preparation and organizing of an M&V plan according to the above described logic can be correlated to the IDP as demonstrated in Table 3:

Table 3. M&V Planning correlated to the IDP

IDP	Zero Plus M&V Plan	M&V actions	M&V methods
Pre-design	Pre-design	Targets and team formation including a monitoring leader Budgeting	
Schematic	Design process	Energy definitions Baseline definition Data to be monitored Monitoring technology (product, placement, connection) Quality control	
Design development			
Construction & Commissioning	Construction / Installation	Proper installation and functional tests	Physical testing of technologies
	Post-Construction / Post-Installation – Pre-occupation	Commissioning Pre-occupation monitoring	Building diagnostics Monitoring Physical testing of technologies
Operation	Post-occupation	Post-occupation monitoring Questionnaires/Interviews Data post-processing and analysis Reporting Quality control	Building diagnostics Monitoring Social science surveys

3.1.1 Problem Identification

A Problem Identification procedure has also been designed as part of the quality control for the post-occupation phase the Zero-Plus M&V Plan. Since it is possible that measurement and verification results might reveal poor-performance, it is critical to have a means of identifying the cause. The developed Problem Identification procedure is a protocol of steps that are suggested to be followed and implemented should performance is not as expected for a defined period. The first step (Figure 1) searches for exogenous causes of unexpected performance (i.e. extreme weather). The subsequent steps try to identify poor fabric performance, poor technologies' performance, occupants' interaction with the building, and finally possible false data.

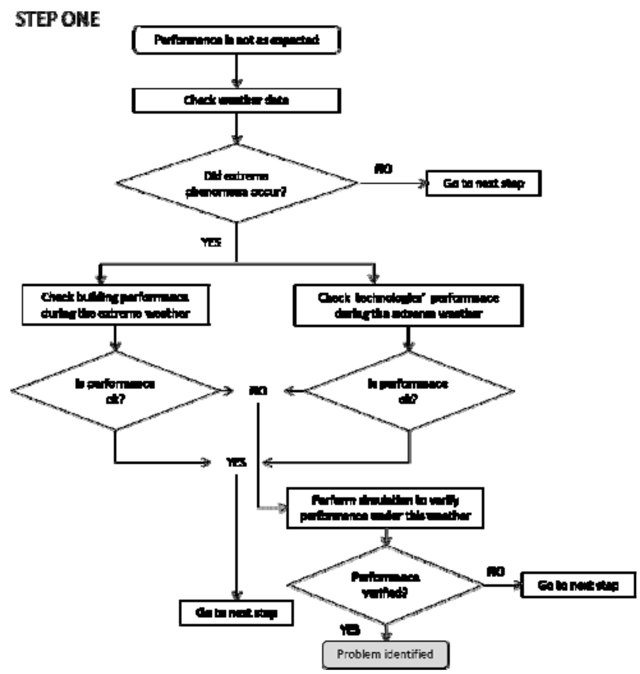

Figure 1. The first step of the Problem Identification Procedure

3.1.2 Web-GIS Platform

A Web-GIS platform has been created in order to support effective monitoring and, by extension, measurement and verification of the ZERO-PLUS case studies. The Web-GIS platform is the core component of the ZERO-PLUS monitoring scheme. On the platform all the information from the various sources (sensors inside rooms, energy monitoring of RES etc.) is gathered, stored, analyzed and presented to the users. The overall layout of the platform is depicted in Figure 2 and comprises:

- The monitoring devices and data acquisition units at building and at settlement level.
- The Cloud Server which incorporates:

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o The database for storing the monitoring data of each settlement.

o The spatial database for the geographical data of each settlement.

o The GeoServer for displaying the geographical data.

o The Application Server which communicates the data to the end user and the Front End of the ZERO PLUS monitoring platform.

• The Communication system between the data acquisition units and the Cloud Server.

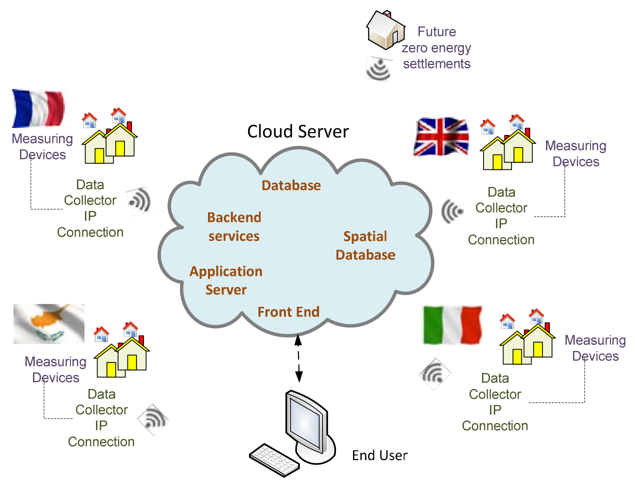

Figure 2. Overall layout of the Web-GIS monitoring platform

The Web-GIS platform has been designed in four levels for each case study as follows (Figure 3):

• Level 1: The 1st level of the Web-GIS platform provides information on the IEQ of the buildings, i.e. on thermal comfort, visual comfort and air quality.

• Level 2: The 2nd level of the Web-GIS platform provides information about the energy consumption of the buildings and the district.

• Level 3: The 3rd level of the Web-GIS platform is dedicated to the monitoring of the energy production from the ZERO-PLUS energy technologies.

• Level 4: The Case Studies Integrated Resources Management Level and Dashboard.

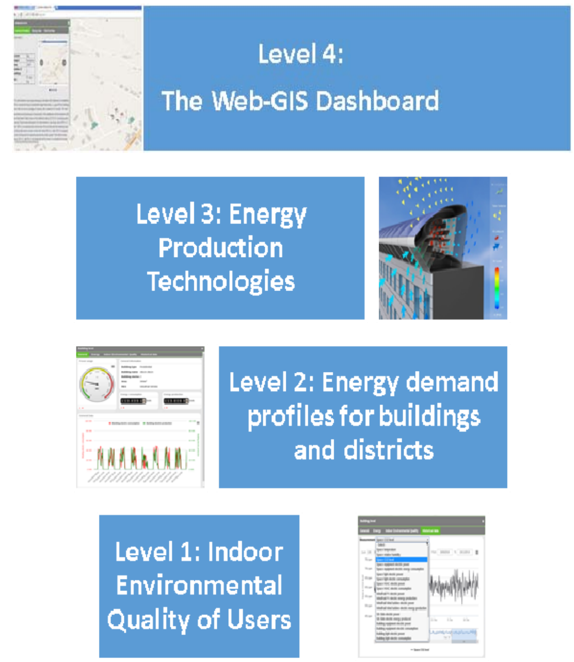

Figure 3. The four levels of the Web-GIS platform

4. DISCUSSION

The Zero-Plus project has applied the IDP at settlement level for the integration of buildings, energy production technologies and energy conservation technologies. A measurement and verification plan has been devised with the intention to assess the final performance of the settlements. Planning the measurement and verification of a project is a complex process integral to IDP and the approach that has been followed for the M&V Plan of the Zero-Plus project demonstrates how its development is related to each of the steps although it is intended to serve the last step of the process.

Experience form the Zero-Plus project revealed that the design of monitoring for measurement and verification is closely related to the design development and optimization of the project. During design development the placement of the building sensors is considered along interior and electrical design. Similarly, the location of a weather station in the settlement is decided at this stage. Therefore, at the end of this phase a set of plans indicating location of the equipment should be prepared and be included in the M&V Plan. Furthermore, the electrical drawings should include the monitoring installation. The design of the monitoring schema at this phase can be further supported by the employment of BIM tools. As demonstrated in [22], BIM can support the integration of monitoring equipment in building design and though post-construction management of the facility. This possibility aligns with the fact that BIM is indispensable tool for implementing IDP [14].

Finally, there is a link between the Commissioning plan and the M&V plan. Construction, installation and commissioning procedures are also part of the measurement and verification. Commissioning is closely related to measurement and verification because it guarantees functionality of the technologies and the monitoring schema and provides a solid basis for comparison of initial performance after installation, therefore allowing the elimination of “procurement” as a possible reason of poor

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performance when considering a Problem Identification procedure.

5. CONCLUSIONS

The present work has discussed the planning of a project's measurement and verification in correlation to the IDP. The M&V plan of the Zero-Plus project has been used as basis for this correlation. The IDP constitutes a paradigm shift in building design emerging from the requirement to produce sustainable, low energy, and recently zero-energy buildings and a critical step of the process is the operation phase that involves the measurement and verification of the project's objectives.

The Zero-Plus project has implemented the IDP at settlement level and an M&V Plan has been prepared along with the implementation of the IDP. It is expected that this parallel development and integration of the M&V planning in the loops of the IDP will provide a solid basis for monitoring, measuring and verifying the project's performance in the operation phase thus supporting the credibility of the obtained assessment results. A Problem Identification procedure should further assist in identifying and correcting the causes of poor performance.

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