Improving energy performance through an energy measurement and monitoring plan

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Keywords
measurements, control and monitoring devices, voluntary guidelines, buildings, industry, energy management system

Abstract
Organizations are able to better control their energy costs and increase their competitiveness by setting up energy performance actions. Voluntary energy management standards, such as ISO 50001, often refer to the measurement of energy as an important improvement of energy performance, but do not detail how a measurement and monitoring plan should be implemented in practice. The impact of having an efficient measurement system has been demonstrated by different studies, however, in practice it remains very difficult to define, measure, record and analyse the data related to energy performance evaluation due to the lack of standard protocols.

This article presents the state-of-the-art methodology currently being developed as a new standard with a CEN-CENELEC joint working group, for the industry and building sectors. The case study, which consists in a student accommodation of 148 flats, is used to show the improvements that could be obtained by setting up the previously introduced methodology.

Introduction
For many organizations, energy costs can represent an important part of their budget. The international, regional, and local energy management policies and standards provide guidelines and rules to reduce energy consumption and increase energy efficiency [Gruffaz1, 2016]. Studies show that knowledge obtained from an energy measuring system allow organizations to take action on their energy consumption and make energy and money savings. In 2014, the French agency for energy management and environment (ADEME) issued a book [ADEME, 2014] grouping 6 studies implementing a measurement plan in practice. The results showed a decrease of energy consumption of 15 to 25 %. In the scope of the ComptIAA project, an experiment was conducted with 20 small agro-industrial companies in France and the impact of implementing an energy measurement system was analysed [CETIAT, 2014]. Participants observed a sustainable reduction of their annual consumption between 5 and 15 %. Besides, the return on investment was proven to be quick, since it was less than 2 years. Moreover, the BESS (Benchmarking and Energy Management Schemes in SMEs) European program supported by Intelligent Energy – Europe [EIE, 2007], assessed the impact of energy conservation plans based on energy management and measurement plans on at least 55 companies from the food & drink industries in 11 European countries. Pilot companies adopting actions reported an increase of 3 to 10 % of profit and energy related costs savings.

Hence, the advantage and interest in setting up an energy measurement plan to reduce energy consumption has been widely observed, for both supply and demand sides [Gruffaz2, 2016]. Yet the methodologies developed in different cases require a broad range of expertise, covering the fields energy management, metrology and information system technology. The complexity makes it difficult to achieve superior energy performance in most cases, especially for smaller organisations. In order to be efficient, the measurement and monitoring plan and the system installed should be able to accurately measure energy consumption and performance to allow its monitoring based on factors that influence its operation. Cost is a significant parameter to take into account when implementing such plans. A general rule is that the average annual cost for the implementation and maintenance of a measurement and monitoring plan should be inferior to 10 % of the verified average cost savings over the year [Xia, 2013]. Besides, the accuracy of the measurement and monitoring plan is considered good if 90/10 criterion (i.e. minimum requirement of 90 % confidence within 10 % precision) is achieved.

In addition, the level of metering – or sub-metering – has an influence on the potential energy and cost savings: the basic installation of meters can generate savings of about 2 %, while the setup of an accurate and effective sub-metering program can lead to savings up to 45 % [GSA, 2016]. Sub-metering means installing specific sensors to measure selected areas of energy use, and allows a better understanding of where energy is used, and where it would be possible to make savings [Carbon Trust, 2012]. There are five methods of sub-metering, the most accurate and reliable (but more expensive) being the direct metering, and the least being the estimating power method which predicts energy consumption (used in most cases for office equipment or other appliances and utilities). More particularly, in the building and residential sector, early users of sub-metering earned savings over the years, and have gained experience on such projects. They can then have a better vision of the costs and advantages in terms of energy and costs savings [Baier, 2011]. This knowledge also showed the limits of sub-metering, including the maintenance costs of metering equipment, the addition of man-hours into the budget for analysing the acquired data and suggesting the proper actions. Beyond sub-metering, energy performance indicators also require other relevant variables (e.g. weather, building surface area …) in order to better understand the consumption profiles and define improvement plans.

State of the art

Existing energy management standards often refer to the measurement of energy as an important improvement of energy performance, but do not detail how a measurement and monitoring plan should be implemented in practice. In particular, the ISO 50001 4-6-1 standard states: "an energy measurement plan appropriate to the size and complexity of the organization and its monitoring and measurement equipment shall be defined and implemented" [ISO50001, 2011], but gives no guidelines on how to design or implement it in practice. In specific cases, an energy audit requires to get specific data measurement, as for instance in the norm EN 16247-1 § 5-2 b), 5-3, 5-5 [NF_EN_16247-1, 2012]. Besides, energy efficiency services have to be based on collected data according to the standard EN 15900 4-1 b [NF_EN_15900, 2010].

Within the scope of implementing an energy management program, measurement and verification (M&V) methodologies help to determine and systematically validate the improvement of the energy performance. Several guidelines issued by various bodies have been issued to approach the subject [EVO, 2012], [ASHRAE, 2014], [FEMP, 2015], [SEP, 2012], [AEPCA, 2004], [ISO-NE, 2014], [TecMarket, 2006], [SLEEAN, 2012] or [PJM, 2016]. Indeed, as specified in the ISO 50015 5.2 [h), k), l), m)] [ISO50015, 2014], a M&V process is based on a series of measurements without giving the methodology on how to organize them. Therefore, to ensure the quality of these measurements, (reliability, accuracy as well as applicability) a "measurement plan" is needed.

However, there is a lack of a homogeneous methodology for implementing this measurement system that should allow the definition, measurement, recording and evaluation of the benefits as well as the potential issues that may occur, and that could profit the organisation implementing them [ACEEE, 2015]. Indeed, when confronted to planning the implementation of a measurement system, it can be difficult or impractical to achieve precise, reliable and relevant measurements. As a matter of fact, none of the previously mentioned voluntary standards give any recommendation or methodology on how these measurement systems should be set up, and which kind of data should be monitored. Organizations deal with this lack of procedures when taking actions to comply with these standards.

Proposal for a measurement and monitoring plan

Based on the regulation for buildings in the UK, particularly the 'The Building Regulations 2000 – Part L2', the Chartered Institution of Building Services Engineers (CIBSE) issued a general information leaflet as a guide for designers willing to meet the regulations requirements [CIBSE, 2002]. This document recommends, as best practice, a method to develop a metering strategy that enables on one hand the optimisation of costs and savings, and on the other hand the improvement of the overall comprehension of the building by its users and managers. Other governmental organisations issued such guidelines and best practices providing directions to companies and managers involved in processes or projects that require to comply with the in-place regulations or standards [Doyle, 2010], [PNNL, 2015].

For a widespread dissemination of best practices, the French standardisation body published a "Measurement plan for energy performance monitoring – Design and implementation" document [AFNOR, 2015]. This work is being extended as a European standard by CEN CENELEC [CEN_CENELEC, 2016]. The global aim is to allow a precise and common identification of terminology, to define a realistic and easy to use methodology following specific steps for all kind of organisations, including SMEs, but also to be applicable for both new projects (as for instance the case study that will be presented afterwards) and already existing sites or companies with the improvement of what is available and already set up. As explained, this methodology is divided into steps that are schematically represented in Figure 1.

The first step is to set and define the objective for the implementation of a measurement and monitoring plan, which can be for instance to comply with a regulation or to adopt a standard. Then, the following phase consists in analyzing the available means that the person in charge of this plan has, or the already considered solutions. It is recommended to identify a person responsible for the management of the whole methodology, with technical knowledge to understand both the concept of data acquisition and its practical use. Based on this analysis phase, it is possible to suggest several plans with different levels of accuracy and monitoring capabilities. During the following phase of realization, the selected plan is implemented and followed up in the final step of operation and maintenance.

Figure 1. Schematic representation of the steps describing the methodology.

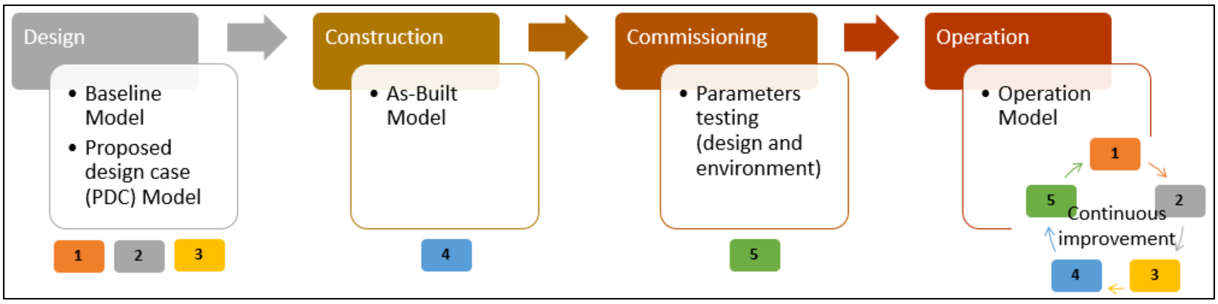

Figure 2. Schematic representation of the link between the methodology presented in Figure 1 and a project.

The way that this kind of methodology is integrated in a project (new building for example) is described in Figure 2 [Zhao, 2015].

During the design phase, the project can be modeled globally with a set of assumptions and overall parameters. Based on several hypotheses or choices, different models can be suggested, following the same assumptions that have been stated previously. At the end of this phase, the selected model can be updated according to the final design decision. Then, in the construction phase, the model can be adapted to the real case as it is built, to allow a better representation of it. At the later stage of commissioning of the project, the initial parameters and assumptions can be tested to allow the calibration of the model based on the first real data measured and acquired. Finally, during the last phase, the model is influenced by the operation. The measurement plan thus allows the comparison of initial predicted values with of consumption and production. with the real ones.

The aim of this article is to evaluate the relevance for such a framework on a real case. For this purpose, a case study on a project for which a measurement plan has been set up and implemented, but not according to the suggested methodology, is presented in the next section. Nonetheless, a retro-fitting of the implementation of the suggested methodology shows that improvements can be made by following it.

Case study

PROJECT INTRODUCTION

The case study is a student accommodation of 148 flats (147 student accommodations and 1 accommodation for the building manager) located in Guyancourt, France. This project, called the "Response" residence, was initiated by the urban conglomeration of Saint Quentin en Yvelines (SQY) and the city of Guyancourt with the aim of increasing student accommodation on their urban area with highly energy efficient buildings. In fact, the building has been labelled upon construction as a BEPOS-Effinergie building which is a French label for Energy-plus-houses [Effinergie, 2015]. This label defines design requirements about energy consumptions (low non-renewable energy consumption and high locally produced renewable energy) not exceeding a given amount established according to the localisation and general building characteristics. In order to raise awareness to energy savings and environment-friendly behaviours among the students, a university and the building manager will also participate in the project in order to monitor closely the building consumptions during operation. Besides, this monitoring will allow to study, take actions, and communicate with the occupants with the objective to keep low enough consumptions to guarantee that the BEPOS-Effinergie label is kept through time.

In this project, all the measured data will be collected and delivered on a web-based energy management software to the different users according to their profile. The users will be able to access to the desired and relevant information and monitor energy consumption and production. Two reports of consumption monitoring will also be delivered: one for the BEPOS label, and the other for the energy review of the building. The building is to be delivered before August 2017, for the first students to move in before September 2017. Twice a year, for a duration of five years, all the contributors of the project will meet to discuss the results in terms of energy consumptions and production, as well as the impact of the actions that have previously been decided. Therefore, this project needs an energy measurement system through various sensors and probes with a good enough accuracy to obtain reliable data and perform a relevant monitoring for each energy usage. Indeed, all the decisions and actions will be based on the collected data and the conclusions related to its analysis.

Building equipment includes renewable energy production, with 372.6 m^2 of solar PV panels set up on the roof. The base load for domestic hot water (DHW) is provided by a waste water-source heat pump. The peak load is covered by a gas boiler, which also produces the energy necessary for space heating. For the monitoring of building consumptions, each room is equipped with electricity, hot and cold water sensors, and 25 sample rooms have temperature sensors. The general water, electricity and gas consumption are also monitored, as well as the solar PV, DHW and space heating energy production. Electricity consumption includes auxiliary equipment such as lifts, ventilation, lighting or laundry room equipment. All this data will be acquired and collected via field protocols, aggregated through low-level gateways which will send the data every hour to a small local appliance. This appliance will in turn upload the data to a remote server in the cloud, which will be in charge of storing the historical data and serving it through a user-friendly web application. Several field protocols will be used, the main one being is Modbus (mainly used for the room sensors). Due to the high number of sensors, RTU and IP intermediate Modbus gateways will be chained on each floor. All these intermediate gateways will be connected through IP to the main gateway, which will be probing each individual sensor and sending the data to the local appliance. All the temperature sensors will be probed through one KNX link, and collected by the same main gateway as the Modbus-probed sensors. The different data obtained from the heating controller (general water and gas, DHW energy demand from the heat pump and space heating demand from the boiler) will also be collected through KNX, mainly due to the type of heating controller chosen. Lastly, some specific protocols will be used regarding the needs: electricity consumed from the general network will be probed via a TIC protocol; more complete data from PV production will directly be collected from the uninterruptible power supply that is in front of the PV panels, via an XML. As previously mentioned, all the collected data will be pushed every hour to the local appliance, in a custom json format. This appliance will be in charge of data capture in case of a network failure, and upload it to a cloud-based server. The analysis heavy-lifting is done on the server, either interactively through the application interface, or automatically.

Hence, the "Response" residence is equipped with many sensors to monitor energy consumption and production, with the objective of taking action on these consumptions and follow up on the influence of those actions. The separate monitoring for the consumption of each accommodation allows to give financial incentives (compensation on the bill) to the students with the lowest consumption over the year. This economic compensation will be covered by a part of the revenues from selling the additionally produced electricity (electricity produced from the PV panels, not directly consumed in the building, and sold to the main grid through a buying contract).

LINK WITH SUGGESTED MEASUREMENT AND MONITORING PLAN

Previously presented methodology for the implementation of a measurement plan did not exist at the time of the planning and construction of this building. Therefore, the measurement plan created and used for this project was not based on it. However, improvements in the design and implementation of the measurement plan could have been done by following the new standard, specifically the steps listed below and presented in Figure 1:

1. *Objective:* The set objective for this project is to have a BEPOS-Effinergie building (Energy-plus-house). This implies to be able to measure and compare to a previously determined level the amount of energy consumed according to their specific usage (for example space heating, lighting or DHW energy consumption converted to primary energy according to the type of energy used). Hence, there is a specific list of data that needs to be collected to comply with this requirement.
2. *Analysis:* This step consists in analysing what is already installed or planned. For the case of a new building, it has to comply with the regulations in place (for France, it is the RT2012), and can be based on building specifications, on building thermal analysis and on the measurement synoptic. For existing buildings, this analysis can be based on energy audits.
3. *Plan:* Several measurement plans are formulated and classified by cost and precision. In the case of this project, one measurement plan included controllable valves for each accommodation in order to remotely regulate water consumption (in case of excessive consumption for instance). For economic reasons, this plan (including the valves) was not selected and the previously described plan (project description in the above subsection) was preferred.
4. *Realization:* This step is the one in progress at the moment, according to the previously chosen measurement plan. During this phase, a regular follow up is organized once a week to make sure that all the contributors are doing their part on time and as planned.
5. *Operation and maintenance:* These steps will be effective around August 2017 with a monitoring of consumptions as previously described.

By rigorously following these steps, the creation and implementation of the measurement plan would have been more efficient, and would have helped to reduce mistakes or missing of relevant sensors. Nevertheless, it requires the implication of all concerned participants from the very first step.

Conclusion

This paper first shows the lack of and the need for a standard measurement plan to monitor energy consumption in order to improve energy performance and efficiently comply with global energy management standards, as ISO 50001 or ISO 50015. Then it explains the proposal to fill this gap with the CEN-CENELEC joint working group for a European standard "Energy measurement plan for organisations". Finally, it explains how the suggested methodology can be implemented in practice on a student residence of 148 flats to monitor energy consumption and maintain strict energy standards (positive energy house with the BEPOS-Effinergie label).

In practice, the main difficulties of implementing this measurement plan is to make all the contributors of the project to work together from the very first steps, as observed in the case study. This issue is mainly due to a lack of knowledge and training of the contributors and their teams on this subject. Besides, in the case of building construction and smart buildings, there is a need to develop a new and distinct work package for these systems taking into account its specific characteristics (including security of data). Moreover, this kind of project gives the opportunity to resort to commissioning in order to ensure that the building requirements are met throughout all the steps of the project, both in terms of quality and of efficiency.

Concerning the "Response" residence project, the building operation in the next years will allow the academic researchers of the partner university to access the data that will be collected through the measurement and monitoring plan and study of resident behaviours and actions regularly taken on the energy consumption.

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Acknowledgements

The authors are grateful to the members of the “Response” residence project (the urban conglomerate of SQY, the city of Guyancourt, the University of Versailles Saint Quentin, the ARPEJ company and Valophis Group) for letting us use this building as a case study and for allowing us to share data and information on this project.

For the building mentioned in the case study, the project owner is the Valophis Sarepa group and the project supervisors are the architecture firm Atelier Pascal Gontier, the design offices BATISERF and LBE Fluides, and the economist Bureau Michel Forgue. The construction is managed by the Les Maçons Parisiens company.