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Long-Term Monitoring Strategies for Increasing EPCs Reliability †

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Abstract: Energy retrofit strategies for buildings represent a major challenge for the achievement of EU decarbonization goals. In 2002, the Energy Performance of Building Directive introduced energy certificates to measure and compare building energy performance, to frame the more suitable renovation actions, and develop financing schemes. However, since its implementation, this instrument remained quite unexploited. In this framework, the EPC RECAST H2020 project aims at developing a new generation of EPCs with a focus on existing residential buildings. Within the project, the paper focuses on the monitoring strategy that has been defined and tested to validate, with real data, what is declared in Energy Performance Certificates.

Keywords: Energy Performance Certificate; EPC; EPC reliability; EPC validation; monitoring strategy; EPC RECAST; H2020; residential buildings

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1. Introduction

In 2002 the Energy Performance of Building Directive (EPBD) [1] introduced the Energy Performance Certificates (EPCs) as a tool to (i) measure and compare the building energy performance, (ii) frame the most suitable renovation actions, and (iii) develop financing schemes. Despite the high potential impact on the construction industry, the instrument remains largely unexploited due to different reasons influencing the confidence and thus the reliability of the whole process.

Trust is a key determinant for attitudes to EPCs [2], and their credibility depends on the principal interested parties' perceptivity and involvement in building energy efficiency. If we ignore these aspects, the EPC's supporting character may be lost causing a sub-optimal policy implementation. Experts argue that most of the EPCs are based on uncertain or incorrect data [3] and that the theoretical energy demand declared does not reflect the actual consumption [4]. Most of the detected errors are caused by EPC assessors disagreeing on building parameters or by the absence of data information [5]. Considering the uncertainty of EPCs data, it is hence crucial to assess and improve the data quality.

In this framework, the EPC RECAST H2020 project aims to support assessors to achieve improved EPC reliability, comparability between assets, user-friendliness, and to actively involve owners and occupants in the path to efficient energy retrofit. Within the project purposes, the paper focuses on the demonstration and impact evaluation activities, proposing a method to verify the evaluation strategies of the EPC RECAST approach.

2. Materials and Methods

In order to validate and improve the credibility of the new EPCs, the work focuses on the verification of the energy consumptions reported in EPCs. For this purpose, several demonstration sites in different EU countries have been recruited within the project Consortium partners, as summarized in Figure 1.

Figure 1. Summary of the demonstration sites that have been recruited within the Consortium.

Considering the different typologies of buildings involved, the work has led to a necessary definition of a monitoring strategy that could be suitable for all dwellings. To that end, six different configuration types have been identified, according to different building and systems characteristics. For each configuration, the monitoring approach was then customized as described in Section 3.2.

Monitoring Methods

The monitoring approach can be different according to the specific goals and type of building under analysis. On that base, the two main methods proposed by this work are:

- Utility meter monitoring, based on the measurement of the energy flow delivered to the building, collected either manually or via utility meters (e.g., gas or electricity);
- Sub-metering, used for centralized energy production systems: the energy flow absorbed for each dwelling must be gathered through dedicated sub-metering systems.

Once the most suitable approach has been selected, the main steps to be considered before starting the monitoring activities can be summarized as follows:

1. Planning (i.e., set the monitoring goals, collect building data, identify boundaries and suitable sensors and data acquisition systems);
2. Installation (i.e., assessment of the technical feasibility, and final plan and implementation);
3. Operation (i.e., data quality check, data post-processing, and reporting).

Based on the specific goals, different levels of building energy monitoring can be considered. The minimum level involves the data needed for the balance verification, including climate data and boundaries. The estimation of a specific load, instead, requires additional relevant meters: this means moving from a whole-building approach to a sub-metering approach. According to the time resolution, measurements are divided as follows:

- Spot measurement (up to one day of operation), to instantaneously detect the value of a metric or to quickly check the functioning of a subsystem;
- Short-time measurement (usually a week or month-based), to check the profile of metrics that vary with time;
- Long-time measurement (more than one year), to assess metrics that are influenced by variations in weather, occupants' behavior, or other operating conditions.

In general, monitoring systems and devices can be divided into two main categories:

- Measurement of energy consumption, using, for example, building meters, sub-metering, and plug-load measurements;

- Measurement of occupants' comfort and activity, using temperature, occupancy, humidity, CO_2, and air quality.

3. Monitoring Approach and Scenarios

In the context of EPC RECAST, the monitoring approach has been developed considering different building typologies, defined according to the presence of independent or centralized power generation systems. In particular, the three main typologies that have been identified are: (i) a single house with independent systems, (ii) an apartment in a multifamily building with independent systems, and (iii) an apartment in a multifamily building with one or more shared systems.

On that base, three main levels of monitoring have been defined, depending mainly on the typology of energy generation (centralized or independent) and of energy metering (electromechanical or smart): (i) Basic Level—BL, (ii) Medium Level—ML, and (iii) Advanced Level—AL. These three levels have been then associated with different building configurations, as furtherly discussed below, differentiating the respective data gathering methodologies in terms of thermal and electrical demand, as summarized in Table 1.

Table 1. Levels of monitoring, according to the assessment method of each building energy vector.

Level of Monitoring	Energy Generation	Thermal Energy Assessment	Electrical Energy Assessment
Basic Level (BL)	Independent	Utility bills	Utility bills
Medium Level (ML)	Independent	Utility bills/Metering [1]	Utility bills/Metering [1]
Advanced Level (AL)	Only partially centralized Centralized	Metering [1] + Sub-metering Sub-metering	Metering [1] + Sub-metering Sub-metering

[1] If the dwelling is equipped with smart utility meters, as suggested by the Energy Efficiency Directive (EED) [6,7] to trigger energy savings, the energy consumption can be assessed by using optical utility meter pulse sensors, that can be easily stuck to the front of any smart meter to measure the energy absorbed.

The three monitoring levels have then been linked to different building configurations, identified by taking into account the standard EU building stock in order to include the most recurrent typologies in terms of building systems and energy supply/generation.

Configuration n.1, as summarized in Table 2, represents a generic dwelling with fully independent systems. In sub-configuration 1.a, electricity powers appliances and a generic split cooling unit, while gas is used for the production of domestic hot water and heating (either radiators or heated floors). In sub-configuration 1.b, instead, the appliances and heated/cooled floors are powered by the electricity grid, while gas is used only for domestic hot water production. In both sub-configurations, consumptions are assessed by utility meters (either electromechanical or smart), and the total amount of final energy is obtained from the utility bills. For the monitoring of indoor/outdoor temperature and relative humidity, the approach foresees the installation of specific data loggers. Hence, the BL of monitoring does not require the implementation of any meters or sub-meters.

In Configuration n.2, suitable for all residential dwellings with fully independent systems as presented in Table 3, the energy consumption is measured through the latest generation of smart meters, by implementing optical utility meter pulse sensors. In sub-configuration 2.a, the heating (either radiators or heated floors) is powered by gas, while in configuration 2.b it is electrical. In both cases, utility bills would still be a valid option for assessing the total consumption, but, since the aim of the ML of monitoring is a more specific assessment on a shorter time base, the possibility of having the old electromechanical meters must be excluded.

Table 2. Basic Level (BL) of monitoring, configuration n.1.

Building Configuration	Energy Monitoring				Environmental Monitoring	
	Heating (H)	Cooling (C)	Domestic Hot Water (DHW)	Electricity (E)	Indoor RH/T	Outdoor RH/T
Configuration n.1 **Independent systems:** H, C, DHW, E **Centralized systems:** - **Electricity meter:** Electromechanical/Smart **Gas meter:** Electromechanical/Smart	1.a—Utility bills (gas)	1.a—Utility bills (electricity)	Utility bills (gas)	Utility bills (electricity)	Metering	
	1.b—Utility bills (electricity)					

Table 3. Medium Level (ML) of monitoring, configuration n.2.

Building Configuration	Energy Monitoring				Environmental Monitoring	
	Heating (H)	Cooling (C)	Domestic Hot Water (DHW)	Electricity (E)	Indoor RH/T	Outdoor RH/T
Configuration n.2 **Independent systems:** H, C, DHW, E **Centralized systems:** - **Electricity meter:** Smart **Gas meter:** Smart	2.a—Metering (gas)	2.a—Metering (electricity)	Metering (gas)	Metering (electricity)	Metering	
	2.b—Metering (electricity)					

Whenever a dwelling is provided with at least one centralized power generation system, the AL of monitoring is required. To that end, all centralized systems have dedicated sub-meters that allow the evaluation of the energy consumption of the single dwelling. The installation of mass flow meters and temperature sensors allow the assessment of the total energy consumption for heating, cooling, and/or domestic hot water, depending on the four main configurations (n.3, n.4, n.5, and n.6) identified. The monitoring of the independent systems, instead, can be performed by installing meter sensors as in ML of monitoring. The four above mentioned configuration are listed in Table 4.

Configuration n.3 refers to a dwelling with a centralized heating system, while the other services are independent; the difference between sub-configurations 3.a and 3.b refers to different typologies of heating systems: with radiators (3.a) a sensor can be installed directly on the emission system, while with heated floors (3.b) the mass flow and temperature sub-metering should be implemented directly on the pipes.

Configuration n.4 has both heating and domestic hot water as centralized systems. The sub-metering approaches for sub-configuration 4.a (radiators) and 4.b (heated floors) are as explained in the previous paragraph. For the sub-metering of the domestic hot water system, instead, a temperature sensor and a mass flow meter should be installed on the pipes.

Configuration n.5 has only heating and cooling systems as centralized services, while the domestic hot water and electricity production are independent and can be therefore metered with optical sensors on the electricity meter. The sub-metering of both heating and cooling systems can be performed by implementing specific sensors directly on the pipes, as explained for sub-configuration 3.b.

In Configuration n.6 the dwelling is provided with an independent electricity system, that can be therefore metered according to the ML of monitoring. All other systems are centralized and can be monitored by implementing specific sensors directly on the pipes, as explained for sub-configuration 3.b.

Table 4. Advanced Level (AL) of monitoring, configurations n.3-n.4-n.5-n.6.

Building Configuration	Energy Monitoring				Environmental Monitoring	
	Heating (H)	Cooling (C)	Domestic Hot Water (DHW)	Electricity (E)	Indoor RH/T	Outdoor RH/T
Configuration n.3 **Independent systems:** C, DHW, E **Centralized systems:** H **Electricity meter:** Smart **Gas meter:** Smart	3.a—Sub-metering (energy) 3.b—Sub-metering (temperature + mass flow)	Metering (electricity)	Metering (gas)	Metering (electricity)	Metering	
Configuration n.4 **Independent systems:** C, E **Centralized systems:** H, DHW **Electricity meter:** Smart **Gas meter:** Smart	4.a—Sub-metering (energy) 4.b—Sub-metering (temperature + mass flow)	Metering (electricity)	Sub-metering (temperature + mass flow)	Metering (electricity)	Metering	
Configuration n.5 **Independent systems:** DHW, E **Centralized systems:** H, C **Electricity meter:** Smart **Gas meter:** Smart	Sub-metering (temperature + mass flow)	Sub-metering (temperature + mass flow)	Metering (gas)	Metering (electricity)	Metering	
Configuration n.6 **Independent systems:** H, C, DHW **Centralized systems:** E **Electricity meter:** Smart **Gas meter:** Smart	Sub-metering (temperature + mass flow)	Sub-metering (temperature + mass flow)	Sub-metering (temperature + mass flow)	Metering (electricity)	Metering	

3.1. Primary Energy Calculation Method

Considering the different monitoring levels and building configurations, two main energy calculation processes must be considered to allow the comparability between measured and calculated non-renewable energy consumption.

In the case of BL or ML of monitoring, where the energy consumption is obtained directly from the energy supply meters or the energy bills, the measured final energy consumption must be converted into primary energy demand using the respective primary energy factors for each pilot country. As regards the AL of monitoring, instead, when the building energy needs are assessed through the installation of sub-metering at different boundaries, two major steps are required to assess the final energy demand: (i) conversion from useful energy, measured by the sub-metering sensors, to final energy; (ii) conversion from final energy to primary energy, by applying the respective primary energy factors for each pilot country.

3.2. Application of the Approach on a Case Study (Lecco, IT)

The demo site that has been identified in Italy is a residential dwelling, part of a residential complex located in Lecco and completed in 2012. The apartment is composed of a big living room with a kitchen, one bedroom, and one bathroom. Being a recently built apartment in a multifamily building, most of the building systems (heating, cooling, and domestic hot water) are shared amongst all the residential units, as defined for Configuration n.6 (Figure 2).

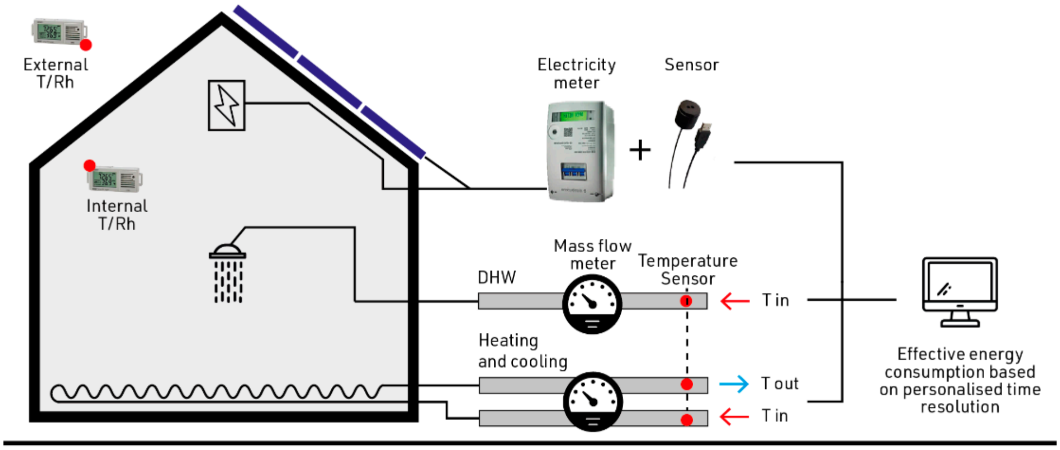

Figure 2. Schematic representation of the Configuration n.6 monitoring for the Italian case study.

Based on this configuration, the following sensor set-up has been defined: (i) to evaluate the electricity consumption, a pulse sensor needs to be installed on the smart meter; (ii) for the domestic hot water, heating, and cooling systems, the mass flow and the temperature difference will be monitored through two ultrasonic flow meters and two contact temperature probe sensors; (iii) two data loggers are required to track the internal/external temperatures and relative humidity; and (iv) a gateway is needed to collect and transfer all data. In this same way, all demo sites have been analyzed and provided with the necessary equipment and sensor kits.

4. Discussion and Conclusions

The EPC RECAST project aims at defining the testing and evaluation strategies approach, individuating the Key Performance Indicators to assess the EPC RECAST interest and reliability. In that context, the present paper frames and describes the status of the testing approach that will be implemented for the EPC RECAST demonstration and impact evaluation.

The document, in particular, describes the monitoring strategy that has been developed within the project, based on different building and systems typologies, by introducing the concept of "levels of monitoring". Three main levels have been set: (i) Basic Level—BL, (ii) Medium Level—ML, and (iii) Advanced Level—AL, mainly depending on the power generation system (centralized or independent) and the type of energy metering for the different energy vectors (electromechanical or smart). These monitoring levels have finally been linked to different building configurations, representative of the majority of the existing EU building stock.

The definition of standard cases and approaches allowed to structure a model that can be useful every time long-term monitoring is required, especially since the approach considers a wide range of possibilities according to the building type and systems.

The adoption of different levels of monitoring, in particular, has been introduced to increase the technical and economic feasibility of the overall monitoring activity. Collecting data from utility meters is the easiest way for assessing real building performance. The option of installing optical sensors on smart meters is also a non-invasive method, affordable in terms of cost, installation time, and minimum users disruption. Although, this method is not suitable in the case of centralized energy generation systems, and a more complex approach (sub-metering) must be implemented in those cases.

Starting from the general concept above, the specific EPC RECAST long-term monitoring approach will be personalized for each demonstration site, taking into account both the cost and the technical feasibility of the activity, as presented in Section 3.2.

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Informed Consent Statement: Not applicable.

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