Next generation energy performance assessment methods for EPCs using measured energy data

Jan Verheyen [a,b], *Evi* Lambie [c,d], *María* Fernández Boneta [e], *Iná* Maia [f], *Lukas* Kranzl [g], *Theresa* Urbanz [h], *David* Frick [i].

[a] Unit Smart Energy and Built Environment, VITO, Mol, Belgium, jan.verheyen@vito.be

[b] EnergyVille, Thor Park, Genk, Belgium, jan.verheyen@energyville.be

[c] Unit Smart Energy and Built Environment, VITO, Mol, Belgium, evi.lambie@vito.be

[d] EnergyVille, Thor Park, Genk, Belgium, evi.lambie@energyville.be

[e] Energy in Buildings Department, National Renewable Energy Centre, Navarra, Spain, mfboneta@cener.com

[f] Technische Universität Wien, Austria, maia@eeg.tuwien.ac.at

[g] Technische Universität Wien, Austria, kranzl@eeg.tuwien.ac.at

[h] Energie Agentur Steiermark gGmbH, Graz, Austria, theresa.urbanz@ea-stmk.at

[i] Energie Agentur Steiermark gGmbH, Graz, Austria, david.frick@ea-stmk.at

Abstract. The European Union (EU) aims at net-zero greenhouse gas emissions by 2050, with intermediate quantified targets in 2030. To achieve these long-term objectives, the renovation rates in the building sector should be increased. Therefore, as part of the European Green Deal, the EU has initiated the renovation wave initiative with the ambition to at least double the annual renovation rate and to foster deep renovation. An important tool to raise awareness regarding the building energy performance and the need for renovation is the energy performance of buildings certification (EPC). The EPC was already introduced in the Energy Performance of Buildings Directive (EPBD) in 2002 (2002/91/EC) and is a specific focus of the upcoming revision of the EPBD. Currently, EPCs are mostly based on calculation of theoretical performance. Despite challenges such as correction for actual occupant behaviour and weather conditions, the inclusion of measured data of building energy use may lead to additional benefits, improve the quality, reliability and usability of next-generation EPCs. On the one hand, energy performance indicated based on actual energy use data relates better with non-experts understanding of energy consumption and bills. On the other hand, the actual energy use data can attribute to a more efficient and accurate reflection of the actual energy performance of a building. Such aspects are important for augmenting user acceptance and increasing trust in the market, which in turn may lever renovation rates.
This paper presents energy performance indicators based on measured building energy use, either to replace or to supplement EPC indicators currently in use. First, state of the art approaches for energy performance evaluation based on data of measured energy use or related parameters are described. Next, implementation cases are presented that are being developed in the frame of EU H2020 research projects ePANACEA and X-Tendo. Finally, the outline of future work within these projects is given.

Keywords. Energy performance certification, Measured energy performance, Operational rating, Smart buildings, Data driven modelling.
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1. Introduction

The EU has set forward the ambition to attain net-zero greenhouse gas emissions by 2050, with intermediate quantified targets in 2030, which were recently updated and aim at a reduction of the CO_2 emission with 55% by 2030 compared to 1990 levels. Since buildings are responsible for approximately 40% of energy consumption and 36% of CO_2 emissions in the EU [1], the energy performance in the building sector needs to be improved to achieve the long-term objectives. Policy

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measures in relation to new or thoroughly renovated buildings have been deployed, expanded and tightened throughout the recent 1,5 decade, but efforts to reduce the greenhouse gas (GHG) emissions in the existing building stock need to accelerate. Currently only 1% of European building stock undergoes energy-efficient renovation every year [2], while an average annual renovation rate – expressing the (equivalent) share of building stock that undergoes deep renovation - of more than 3% is required [3]. Therefore, as part of the European Green Deal launched in 2020, the EU has initiated the Renovation Wave initiative with the ambition to at least double the annual renovation rate in the next 10 years and to foster deep renovation.

An important tool to raise awareness regarding the building energy performance and the need for renovation is the energy performance of buildings certification (EPC), which was already introduced in the Energy Performance of Buildings Directive (EPBD) in 2002 (2002/91/EC), followed by implementation starting from 2006. EPCs could effectively instigate renovation in the EU if the full potential was explored [4]. There is a need to provide an improved and more reliable service tailored to the end-users [4] [5]. A report by Buildings Performance Institute Europe (BPIE) published in 2014 indicates that EPCs are mostly based on a theoretical calculation [6], a situation that barely changed since [4]. Despite challenges such as correction for actual occupant behaviour and weather conditions, the inclusion of measured data of building energy use or related aspects may lead to additional benefits, improve the quality, reliability and usability of next-generation EPCs. On the one hand, energy performance indicated based on actual energy use data relates better with non-experts understanding of energy consumption and bills. On the other hand, the actual energy use data can attribute to a more efficient and accurate reflection of the actual global or part energy performance of the building and more accurate energy assessments of energy efficiency measures. Such aspects are important for augmenting user acceptance and increasing trust in the market, which in turn may lever renovation rates.

It is shown that significant differences between energy use determined on calculation and actual energy use can occur, a phenomenon known as the ‘energy performance gap’ [7] [8] [9] [10] [11]. The actual energy use in buildings could be as much as 2,5 times the predicted or simulated energy use [11], but no clear or definitive quantification is available [10]. The most important causes contributing to the energy performance gap can be attributed to occupant behaviour (the use of thermostats, windows, blinds, etc…), micro-environment (outdoor climatic conditions) and design versus as-built issues [11] including the use of conservative default values as an input in case of missing or incompliant information [12]. There is also the aspect of modelling; calculation methods and simulation tools – especially the simplified ones – do not accurately represent the full details of physical reality. Apart from this inaccuracy of such EPC assessment methods, the resulting indicators also cause confusion for the end-users because of the difference with metering or billing information and the expression in primary energy instead of final energy.

In order to explore the potential of advanced performance assessment methods and to evolve towards next-generation EPCs, a call for proposals was launched on “Next-generation of Energy Performance Assessment and Certification” as part of the H2020 program [13]. This paper is based on synergies and discusses the results in relation to introducing energy consumption data in ‘next generation EPCs’ investigated in two co-funded projects, X-tendo, “eXTENDing the energy performance assessment and certification schemes via a mOdular approach”, https://x-tendo.eu/ and ePANACEA, “Smart European Energy Performance AssessmeNt And CErtificAtion”, https://epanacea.eu/.

X-tendo aims to support public authorities in the transition to next-generation EPC schemes, including improved compliance, reliability, usability and convergence. X-tendo envisions a toolbox as a key output: a freely available online knowledge hub that will contain 10 innovative EPC features that can be implemented in addition to existing EPC practices. The 10 innovative features are categorized into two main groups. Group one consists of the innovative EPC indicators, including smart readiness, comfort, outdoor air pollution, real energy consumption and district energy. Group two comprises the Innovative EPC data handling functionalities, including EPC databases, building logbook, enhanced recommendations, financing options, and one-stop-shops.

ePANACEA aims to overcome the current EPC challenges with a special focus on the performance gap between calculated and actual consumption patterns, incorporation of the user dimension and the improvement of clarity of the information provided by the EPC. ePANACEA develops a holistic methodology based on three different energy assessment methods and its decision matrix, covering technical building innovations and the use of actual building data for energy modelling. The whole methodology will be integrated on a prototype online platform SEPAP (Smart Energy Performance Assessment Platform). The vision is ePANACEA becoming a relevant instrument in the European energy transition through the building sector.

2. State of the art approaches for energy performance assessment based on measured energy use

Distinction between approaches that include measured data in energy performance assessment can be made according to different categorization aspects. The approaches can be categorized according to for instance the mathematical calculation principles applied, the type of corrections that are implemented, the resulting output(s) or the purpose they serve.

A review of approaches using measured data in (part) energy performance assessment methods is included in the X-tendo deliverable 3.1. Table 1, adopted from the publication, gives an overview of characteristics of energy performance assessment methods, categorized according to the type of method applied. In view of selecting approaches suitable for integration in EPC practices, the approaches are categorized in the report according to three types; Building-level simple approach; Building-level detailed approach and Stock-level model development. Further details on the approaches can be found in the X-tendo deliverable report D3.1 [12].

Tab. 1 – Overview of energy performance assessment methods and characteristics [12].

Method	Inputs	Accuracy	Applications	Restrictions
Engineering calculations	Simplified building information	Variable	Design, end-use evaluations, Highly flexible	Limited accuracy
Simulation	Detailed building information	High	Design, Compliance, Complex buildings, Cases where high accuracy is necessary	Dependent on user skill and significant data collection
Statistical	Dataset of existing buildings	Average	Benchmarking systems, Simple evaluations	Dependent on statistical data, Limited accuracy
Machine learning	Large dataset	Average to high	Buildings with highly detailed data collection, Complex problems with many parameters	Model construction is complicated, Do not consider direct physical characteristics
Limited postprocessing	Data of measured energy use	Variable	Simple evaluation, Historical benchmark	Including non-standard influences

In EN 52000-1 [7] distinction is made within the measured energy performance approaches between actual, climate corrected, use corrected and standard measured energy performance, depending on what corrections are applied to the measured energy use input data.

Energy performance assessment methods based on measured energy use data vary from very simple to relatively complex approaches. In its simplest form, the energy use data of a previous one-year period of the in-use building is directly included in an EPC after some limited processing of the data. Such processing consists of essential corrections required to consider the resulting output as an energy performance indicator [7]. These corrections mainly aim to exclude the non-EPC related energy uses and correct for non-standard influences of user behaviour and climate for the purpose of inter-building comparison and comparison of the energy performance over time.

Statistical techniques are implemented in data-driven modelling [14], using data of energy use complemented by other data such as the outdoor climatic conditions. These can be further subdivided in black-box modelling (including machine learning [15]), in which the structure of the model and the model parameters are determined solely from the measurement data, and grey-box modelling, a hybrid approach that combines a mathematical description of the building's physical model with data-driven statistical modelling techniques [16]. Such approaches are also implemented for the characterization of parameters related to the energy performance of the building or components of it. These parameters can serve directly as a part energy performance indicator or as an accurate input of (simplified) energy performance calculation methods. An example of such approaches to determine a part energy performance parameter is the whole building heat loss coefficient characterization [17]. In addition to these characterization methods, specific data-driven modelling techniques exist that enable the disaggregation of energy use across its constituent parts, such as the separation between gas use for domestic hot water and for space heating, or the quantification of electrical energy use for appliances [18] [19].

The energy performance of a building may also be determined by detailed dynamic energy balance simulation models that are calibrated based on measurements of the building energy use [20]. Such approach is currently considered less suitable for integration in EPC frameworks because of its complexity and related issues [12].

3. Implementation

3.1 X-tendo MEPI method

In the X-tendo project an EPC indicator is developed that expresses the energy performance of a building unit based on measured energy use and related data; Measured Energy Performance Indicator (MEPI). It can be applied to most types of buildings; residential single family houses, individual apartment units, multi-family houses, commercial and public buildings. It is not intended to be applied to industrial buildings. The MEPI can be used for certification potentially replacing existing energy performance indicators or it may solely serve informative purposes for instance for use in addition to existing EPC indicators currently applied in practice.

The MEPI determination method follows the general principles as described in EN 52000-1 series [7] and is inspired by other methods, such as the Swedish energy performance determination method based on measured energy used data [21].

The main input on the building level consists of measurement data of energy delivered to and exported from the building unit per energy carrier and per application. The meters required in the monitoring infrastructure can consist of electricity, gas, oil, heat meters or several of those. The number, type and location of the (sub)meters depend on the system and building architectural configuration. It is expected that availability, prevalence and quality of low cost sensor devices will increase substantially in the upcoming years. It was nevertheless acknowledged within the X-tendo consortium that the required monitoring infrastructure in most cases is not present in the existing building stock. The calculation tool is therefore complemented by a report with options to process real energy use data to represent part or global energy performance that may be used in cases with limited amount or detail of information or in very complex buildings (e.g., malls, hospitals) where the theoretical approach would be time consuming and costly. This additional report is planned to be published in the upcoming months.

Default corrections are applied to the space heating and cooling energy delivered to the building unit for external climatic conditions by means of heating degree-days and cooling degree-days method. Correction methods for solar irradiation, for domestic hot water energy and for indoor temperature are included optionally, with the default choice to also implement these corrections.

In the calculation procedure, a distinction is made between two types of energy carriers for the reason that energy carriers delivered from on-site are restricted in the amount of energy available for delivery to the building and obtain priority, while others are considered to be able to deliver the remaining energy that is required within normal conditions of climate and use.

The output of the MEPI methodology contains more than one indicator member states can choose from to adopt within their existing EPC practices. The default indicator is the non-renewable primary energy performance EPnren for the case Minus exported on-site produced electrical energy. This represents the annual specific primary standard measured energy performance calculated using the non-renewable primary energy conversion factors and taking into account the electrical energy produced on site and exported. The latter is accounted for as a reduction of the primary energy use by the avoided impact of electricity from the grid. Also as default indicators, the Renewable energy ratio RER and specific CO_2 equivalent emissions CO2eq both for the case Minus exported on-site produced electrical energy are reported.

A calculation spreadsheet [22] with accompanying guidelines [23] of the measured energy performance indicator including a description of the calculation algorithms is available on the X-tendo website (www.X-tendo.eu).

3.2 ePANACEA methodology

Within ePANACEA, several methods are developed to identify the energy performance based on on-board-monitoring data. Hereto, the data of 15 real-life cases (both residential and non-residential) is used to iteratively validate and improve the developed methodologies. One of the methods developed within ePANACEA elaborates the MEPI tool of X-tendo, which is possible because of the availability of more detailed high frequency (sub-)hourly data. Three alterations/additions are applied;

1) The heating and cooling degree days are calculated from measured high frequency outdoor and indoor temperatures, by comparing with the outdoor temperature of no heating/cooling required. In the MEPI tool, heating degree days (HDD) and cooling degree days (CDD) are calculated with a default indoor temperature and national or regional monthly outdoor temperatures. Correction for a deviating average indoor temperature during heating season is optional.

2) The domestic hot water is corrected for the number of default occupants and then extrapolated to the full year by means of the number of days. In the MEPI tool, in case the system efficiency is known, the energy demand for domestic hot water (DHW) is replaced by a calculated average value for the respective building characteristics. If efficiency is not known, the measured energy delivered for domestic hot water is corrected to the actual occupancy rate.

3) Self-consumption is derived based on the actual hourly measurement of the PV generation, which is linearly extrapolated and calibrated to the full year by means of solar radiation hourly profile from a standard year. In the MEPI tool, correction for actual solar irradiation is optional. In case the option is not retained, the measured energy yield from solar systems is recalculated to a full year based on standard national or regional values for solar irradiation.

Often the consumption for final energy usage per application (e.g. heating, DHW, cooling) is not measured separately. Instead, it is available as an energy carrier quantity (e.g. gas, oil, electricity). Depending on the frequency of the measurement, several methods are specifically developed and investigated in ePANACEA for disaggregation of energy carrier quantity data to the final energy uses of the various applications.

The ePANACEA methods allow to derive input parameters from measured values to replace theoretical inputs in existing energy performance calculation methods or enable the determination of additional energy performance indicators. The methods can thus be implemented to increase accuracy and reliability of the EPC indicator in use in local practice or as an extra energy performance indicator providing valuable additional information.

3.3 example with virtual buildings

The specifications, the technical functionalities, the usability and sensitivity of the calculation procedure were analysed by executing the calculation procedure of the MEPI with all options included for a set of theoretically composed residential reference buildings for 3 locations in Europe (Palermo, Bratislava and Helsinki).

Definitions of the climatic zones for Northern (N), Central (C) and Southern (S) EU are adopted from the Aldren project [24].

A reference single family house (SFH) and a reference apartment unit (APT), adopted from ISO/TR 52016-2 [25] - example 1 and 2 respectively - are used in the verification calculations. For each building case, two variants were considered; one to represent low energy performance level of the current building stock (Old) and one to represent a new or renovated building energy performance level (New). Missing characteristics to complete MEPI calculation inputs are further specified, such as system specifications. These include for the New cases good airtightness, a demand controlled mechanical exhaust ventilation system, PV and a new air/water heat pump for space heating and domestic hot water. Old cases have stock representative thermophysical properties and system efficiencies, natural ventilation and no PV. The actual number of inhabitants is set to 4 for SFH and 2 for APT. The annual energy use data per energy carrier and per application are based on building stock net energy use indicators from JRC IDEES library [26] (data of 2018) for the location of Belgium and translated to the three climatic zone locations using HDD for space heating energy use, CDD for space cooling energy use and solar irradiation for PV delivered electrical energy estimation.

The results of these verification calculations are included in table 2 and evaluated based on expert judgement to be in line with what in general can be expected.

Tab. 2 – MEPI verification calculation results.

Case	EPnren [kWh/(m^2.a)]	RER [-]	C2_eq [kg/(m^2.a)]
SFH_New_N	141	0,36	26
SFH_Old_N	309	0,00	61
APT_New_N	125	0,40	23
APT_Old_N	394	0,00	77
SFH_New_C	53	0,51	10
SFH_Old_C	175	0,01	35
APT_New_C	29	0,67	5
APT_Old_C	179	0,01	35
SFH_New_S	19	0,73	3
SFH_Old_S	113	0,05	22
APT_New_S	-7	1,15	-1
APT_Old_S	119	0,05	24

The energy gap is clearly present in the results from the table. The prebound effect- occupants use on average less energy compared to the calculated energy use and this increases with increasing calculated energy use [27] - is shown: the energy performance of old cases is better (lower EPnren values) than estimated by calculations. Vice versa, the rebound effect – occupants tend to use more energy compared to calculated energy use in low energy buildings [27] - is identified for the new cases, which perform not as good (higher EPnren values) as expected, although part of it is also explained by the fact that energy use data originate from 2015 and energy performance requirements have evolved since.

The insulation levels were not adapted to the climatic zones, which is reflected in poorly performing building cases in Northern EU climate. The new building variants in this climate perform rather poorly compared to those in the other climatic zones, which can be partly explained by a low efficiency of the heat pump: the air source heat pump efficiency depends on the outdoor air temperature .

When exported energy outweighs the delivered energy in the balance – which also is reflected in a RER value exceeding 1 – EPnren (default case is Minus exported on-site produced electrical energy) show negative values. Old cases in Central and Southern EU do not have heat pumps nor PV but also have RER values higher than one due to the space cooling air-conditioner outdoor condenser that contributes to ratio of renewable energy RER. In Northern EU climatic zone, energy delivered for space cooling is assumed equal to zero, so RER for Old cases there is equal to zero.

The verification outcomes do not reveal errors, anomalies or unexpected outcomes. The analysis described above verifies the outcomes which confirms correct implementation of the MEPI calculation method in the calculation tool. The results of the findings on aspects of functionalities, usability and clarity of the calculation tool from the verification calculations were used to improve the calculation and guideline tools, currently released as a beta version of the MEPI Calculation tool.

3.4 real-life case examples

The Within ePANACEA measurement data of 15 real-life cases located in 5 European countries are used to develop, improve and validate the three assessment methods. In this paper, the results of the EPANACEA method 1 for a Belgian case (BE) and an Austrian case (AT) are shown as an example and compared to results of the X-tendo MEPI tool. In the MEPI-tool, we opted to correct for (1) an indoor temperature that deviates from the default value, (2) DHW with known system efficiency and (3) the default solar radiation. Importantly, the X-tendo MEPI method is applied although the data does not comply to the requirements of duration of monitoring period; only two month period data are available, while MEPI requires uninterrupted period of at least 12 entire months. It is decided to proceed with these short period datasets within the context of this paper to enable comparison.

The Belgian case is a terraced house located in the city of Ghent, which was originally constructed in 1904 and renovated in 2017. For the period from the 1st of December 2017 until the 31st of January 2018 measurements were performed for a set of parameters, amongst others: the energy use, indoor climate, outdoor climate and user behaviour. As a result, an average indoor temperature of 18.8°C and outdoor temperature of 5.7°C was defined for the monitoring period, and additionally the total gas consumption was found to be 3006.8 kWh and the electricity consumption 511 kWh. To be able to split the gas consumption into energy use for space heating and domestic hot water (DHW), a questionnaire was performed to get insight in occupant-related characteristics, which enabled to estimate the energy use for DHW. It should be noted that there is no renewable energy system in this case.

The Austrian case is a newly built terraced house constructed in 2018, which is part of a multi-family building block. Measurement data was available from the 17th of October 2019 till the 31st of December 2019 for a similar set of parameters as the Belgian case. For the monitoring period, the average indoor temperature in the living room was 22.5°C, while the average outdoor temperature was 5.1°C. The total electricity use of the building was found to be 561.1 kWh, while for space heating 1318.8 kWh and for domestic hot water 405.3 kWh was used for a biomass boiler.

Starting from this monitoring data, the corrected energy use for a full year could be estimated, using the X-tendo and the ePANACEA correction methods respectively. Hereby the default outdoor climate and a constant indoor temperature of 18°C were considered as boundary conditions. The results are summarized in Fig. 1.

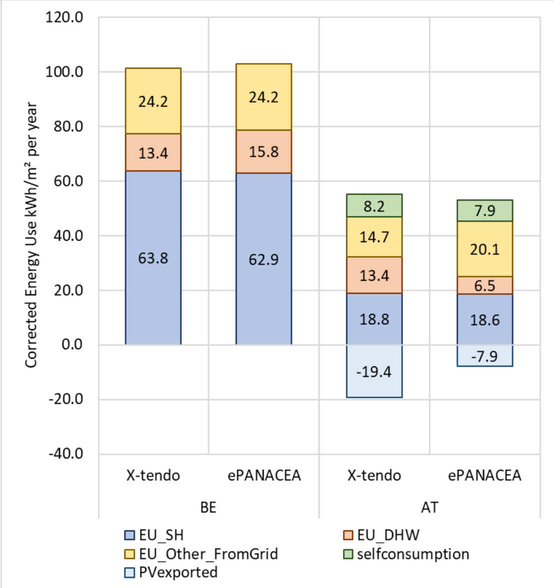

Fig. 1 - Results of the correction of the two real-life cases of ePANACEA and X-tendo (Belgian case BE and Austrian case AT). Note that the X-tendo method is applied using short period data, which does not comply to the requirements of duration of the monitoring period.

Fig. 1 distinguished different types of energy uses: space heating (EU_SH), domestic hot water (EU_DHW), electricity from the grid for other appliances (EU_Other_FromGrid), the generated electricity that is consumed on site (selfconsumption) and the generated electricity that is exported to the mains grid (PVexported). This shows that for the Belgian case the results of the two methods are very similar for space heating and the electricity use from the grid, but not for the domestic hot water. For the electricity from the grid there is no difference (since the same method is used), while for space heating the difference is only 2%. For the energy use of domestic hot water the difference is more significant (18%), since the energy demand for DHW is replaced by a default value within the MEPI methodology, while the ePANACEA method corrects the measured energy demand.

For the Austrian case, on the other hand, only the energy use for space heating is similar for the two methods while for the other energy flows the differences are more significant. The energy use for space heating differs with only 1%, while the energy use for domestic hot water is 50% lower for the ePANACEA method, and the electricity use from the grid is about 30% higher. The generated electricity exported to the main grid also differs significantly

(60% lower for the ePANACEA method).

This indicates that incorporating the heating degree day method at a higher frequency has rather a limited impact on the correction results, while calculating the energy use for domestic hot water based on the number of occupants and a detailed self-consumption calculation have a large impact. However, it is impossible to quantify the accuracy of the two methods. Furthermore, the impact of the use of short term monitoring data instead of a minimum duration of monitoring of an entire year for the X-tendo MEPI method is not quantified. As the X-tendo method should only be applied for data of a monitoring period of at least one year, the magnitude of the comparative results from X-tendo and ePANACEA methods should be interpreted considering a possible and likely bias as a result of this, as well as the very limited number of cases (2). Which method should be preferred strongly depends on the implementation context and correction parameters.

4. Conclusions

State of the art methods and implementation examples of energy performance assessment methods based on actual energy use data as developed in EU H2020 research projects X-tendo and ePANACEA are presented together with theoretical and real-life cases. Results from the example cases contribute to verification of the method's results and hint at extending the real-life case analysis programme in the next steps. As it is known that inclusion of actual energy used data in EPC may improve the quality, reliability and usability of EPCs, such methods support public authorities in the transition to next-generation EPC schemes.

5. Outline of future developments

In a next step of the presented approach, there is a need for validating the methods by applying them on a larger set of case studies. These real life cases should also include long-term monitoring period for correct implementation of the X-tendo MEPI method and also more cases need to be included to compare results from both X-tendo and ePANACEA methods. Currently the MEPI methodology also is tested in actual buildings in 4 countries.

Within ePANACEA, the developed methods are demonstrated and validated with regard to their reliability, accuracy, user-friendliness and cost-effectiveness through 15 case studies in 5 European countries (Austria, Belgium, Finland, Greece and Spain). These methods will be implemented in the Smart Energy Performance Assessment Platform. Additionally, a decision matrix will be developed in order to provide guidance or recommendation on the most suitable method to use with reasonable accuracy and uncertainty levels. Beyond ePANACEA, the SEPAP is a customizable tool that could be adapted to particularities and requirements at member state level. It also allows the joint implementation of energy performance certification with other policy instruments. The digitalization of information through the use of common data bases, including actual building data, easily accessible through web platforms, like the SEPAP, that also allow implementing different assessments is a key aspect to build the link between all of these policy instruments. Then, a common use of data sources can be established for all of them, also ensuring common data formats (interoperability) for information exchange between different platforms.

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7. Data access statement

The datasets generated during and/or analysed during the current study are not available because the privacy of the inhabitants must be respected (GDPR regulations) but the authors will make every reasonable effort to publish them in near future.

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