Advancing energy efficiency at the urban scale: perspectives on reliable information in the next-generation Energy Performance Certificates

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Exploiting data through innovative services can significantly enhance the energy and environmental performance assessment of the building stock. Key factors for success include data availability, accessibility, and quality. Within the H2020 TIMEPAC project, emphasis has been placed on enhancing the usability, reliability, and enrichment of Energy Performance Certificate data to effectively support urban-scale energy analysis.

Editorial Team

Authors

Ilaria Ballarini, Politecnico di Torino, Department of Energy, Turin | LinkedIn profile
Vincenzo Corrado, Politecnico di Torino, Department of Energy, Turin | LinkedIn profile
Matteo Piro, Politecnico di Torino, Department of Energy, Turin | LinkedIn profile

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Introduction

The recently issued Energy Performance of Buildings Directive (EPBD) recast (2024/1275) [1] requires each Member State to establish 'a national building renovation plan to ensure the renovation of the national stock of residential and non-residential buildings, both public and private, into a highly energy efficient and decarbonised building stock by 2050, with the objective to transform existing buildings into zero-emission buildings'. National renovation plans rely on national and/or local databases to gather information about **building stock** characteristics, enabling the development of **effective energy** refurbishment scenarios based on reliable knowledge of the current baseline. Among the available data sources, the Energy Performance Certificate (EPC) database represents a core resource. It can be exploited to develop energy models of **building stocks**, by applying various methods provided by the scientific community, such as the adoption of reference buildings (archetypes), that represent the average condition of specific building stock segments.
The quality of the data within these databases is crucial to ensure the validity of such models. However, most of the European countries and regions report that a significant share of the EPCs stored in their databases present reliability issues. Thus, **increasing the data quality of EPCs is fundamental to effectively guide public decision-making processes**, particularly in targeting the renovation of the most energy-intensive segments of the building stock.

In this context, the European H2020-TIMEPAC research project aimed to enhance building energy certification practices by developing procedures and services for undertaking large-scale statistical analyses of EPCs databases. These analyses allowed the prioritisation and resolution of data quality issues, as to increase the reliability of **building stock data** and to enable energy balance assessments.

Limits and constraints of the Energy Performance Certificate

The European Directive 2002/91/EC [2], along with its subsequent amendments and recasts, introduced the EPC as a mandatory document for buildings or building units that are constructed, sold, or leased. The directive's primary aim is **to establish a unified framework for energy-saving initiatives within the building sector across EU Member States**, contributing to the energy efficiency targets for the building stock. EPCs serve as transparent tools in the property market, enabling the comparison and assessment of buildings' energy efficiency. They provide reference values, including legal standards and benchmarks, to assist owners and tenants in evaluating the energy performance of a property.

EPCs are key sources of information, reflecting the **energy performance of building stocks**, levels of fuel poverty, and progress in national or regional energy renovation programmes. The quality of the data contained in EPCs significantly affects the reliability, adequacy, plausibility, coherence, and accuracy of this information. The accuracy of EPCs is strongly influenced by the quality of the input data, the methodologies and tools applied, and the expertise of energy assessors. The assessor's competence is paramount for ensuring data validation, the correct application of calculation methods, and the effective use of **building energy simulation tools.**

EPCs are often perceived by end-users as administrative burdens rather than valuable energy-related documents. However, the next-generation EPCs envisioned in the revised EPBD [1] seek to transcend this limited role. Future EPCs are expected to adopt a holistic approach, assessing buildings from multiple perspectives, including economic, environmental, and social dimensions. To achieve this, their dataset must be enriched with new Key Performance Indicators (KPIs) that complement standard theoretical energy performance data with metrics reflecting the actual building use.

New research is expected to focus on enhancing the credibility and functionality of future EPCs, highlighting potential improvements, modernisation, and better integration with national and regional information systems. A key issue with current EPCs is the low quality of data, which limits their reliability and effectiveness. Addressing this issue requires robust validation processes to verify data quality, either through integration with building energy simulation tools or within EPC databases.
At present, the poor quality of EPC data undermines their effectiveness for both individual building analyses and broader, city-scale assessments. However, at the urban scale, EPCs are essential for evaluating and ranking the energy performance of building stocks.

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Enhanced Energy Performance Certificate

The H2020 TIMEPAC Project

TIMEPAC (Towards Innovative Methods for Energy Performance Assessment and Certification) [3] is an EU-funded project under the Next Generation EPC Horizon2020 cluster, aimed at enhancing current EPCs. The project envisioned a holistic, flexible, and through-life certification process for EPCs to facilitate a continuous flow of data across all phases of energy performance certification: generation, storage, analysis, and exploitation (Figure 1). This integrated approach seeks to deliver more efficient and reliable EPCs.

The Transversal Deployment Scenarios (TDSs) constituted the core of TIMEPAC; they drove the development of standardised procedures and tools across six partner countries: Austria, Croatia, Cyprus, Italy, Spain, and Slovenia. These TDSs address specific stages of the EPC process and involve diverse objectives, methodologies, and target groups, including energy certifiers, energy agencies, energy auditors, architects, engineers, real estate agencies, construction companies, and public authorities.

The TDSs are interconnected and focus on improving all aspects of EPCs. Five TDSs were developed under TIMEPAC, as follows:

- **Generating Enhanced EPCs with Building Information Modelling (BIM) Data.** This scenario established a connection between EPC generation and BIM models by enabling interoperability between BIM and the **Building Energy Model (BEM)**. This integration facilitates more accurate and efficient certification processes.

- **Enhancing EPC schemas through operational data integration**. By incorporating operational data from energy monitoring systems (e.g., actual energy consumption) and additional assessment domains, such as indoor environmental quality (IEQ), economics, and sustainability, this scenario aimed to improve the accuracy and reliability of EPCs.

- **Creating Building Renovation Passports (BRPs) from Data Repositories**. This scenario focused on BRPs to assess and track the progression of a building's performance over time. BRPs provide comparisons of energy performance and the associated costs for various energy efficiency measures, supporting informed decision-making for building renovations.

- **Integrating Smart Readiness Indicators (SRIs) and Sustainability Indicators in EPCs**. This scenario incorporated indicators from the Level(s) framework to assess the **smartness and sustainability of buildings**. It evaluated the building's ability to maintain indoor comfort and deployed new and existing indicators to enhance EPCs.

- **Large-Scale Statistical Analysis of EPC Databases**. By analysing regional and national EPC databases, this scenario demonstrated how to exploit the wealth of data for driving **deep renovation of the building stock**. It also focused on improving EPC data quality to support broader energy efficiency objectives. This research activity is described in detail in the following section of this article.

TIMEPAC's comprehensive approach to EPC enhancement, supported by these TDSs, paves the way for a **new generation of energy certificates**, that are not only **more accurate and reliable but also aligned with the European Union's sustainability and energy efficiency goals.**

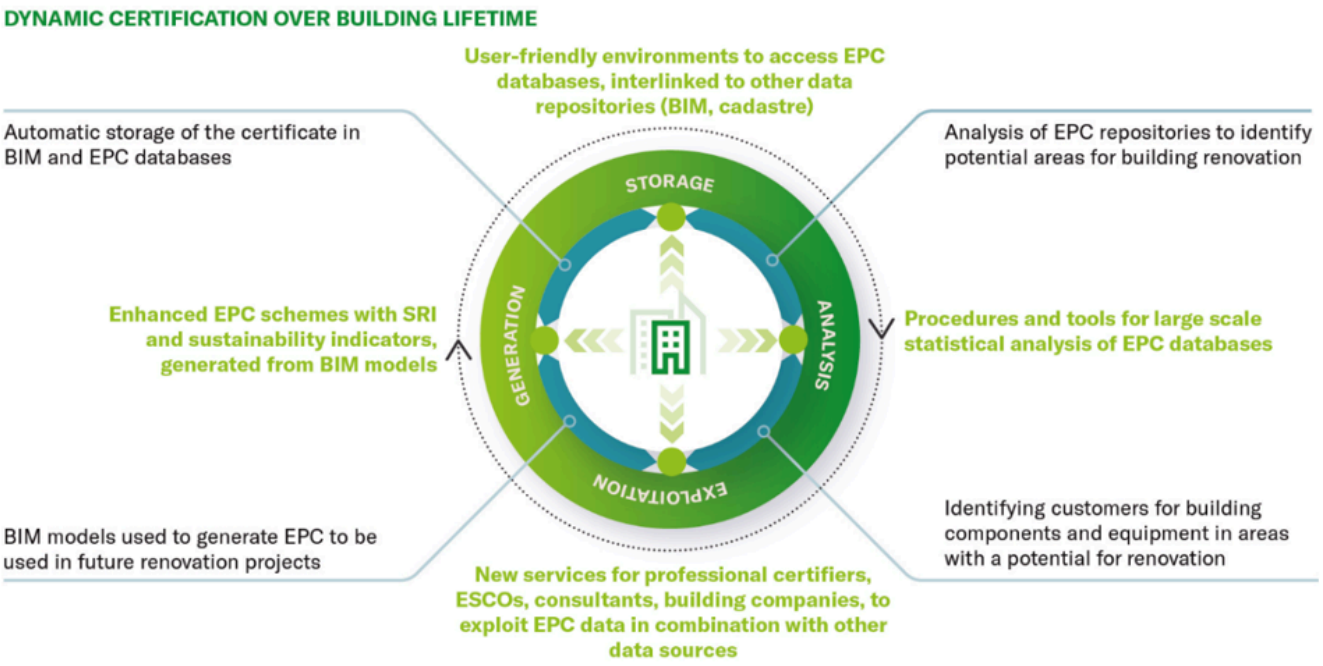

Figure 1. TIMEPAC project flow [4]

Large-scale statistical analysis of Energy Performance Certificate databases

The exploitation of EPC databases is the starting point of the research work carried out in the TIMEPAC Transversal Deployment Scenario dedicated to building stock data, 'Large-Scale Statistical Analysis of EPC Databases'[5], as shown in Figure 2. The envisioned enhancement of EPC focused on improving data quality by introducing a set of control rules designed to confine inconsistencies in EPC databases and identify inaccuracies during the EPC generation process. These improvements aim to produce reliable EPCs, which can be then utilised to create building archetypes to be adopted in the well-recognised Urban Building Energy Modelling (UBEM). This enhancement process involves the following **key steps:**

- **Establishing standardised quality rules for EPCs**
  Standardised rules are defined to verify EPC quality and create building archetypes. Customised data quality-checking procedures are adopted, employing tailored rules and scoring systems, assessing the reliability of EPC data. These interconnected objectives highlight that high-quality EPC data are essential for generating reliable building archetypes, which are vital for developing accurate building stock energy models and refurbishment scenario analyses.

- **Leveraging EPCs for benchmarking and energy performance planning**
  EPCs are used to benchmark, plan, and assess the improvement of the building stock's energy performance. By associating urban buildings with archetypes that capture key attributes, such as climatic zone, building use, construction period, and size, their energy performance can be forecast effectively.

- **Implementing input data controls to enhance future reliability**
  Controls on EPC input data are implemented using confidence intervals, which estimate the true value of a parameter based on a sample. These intervals quantify the uncertainty associated with the estimation, contributing to more reliable EPC data.

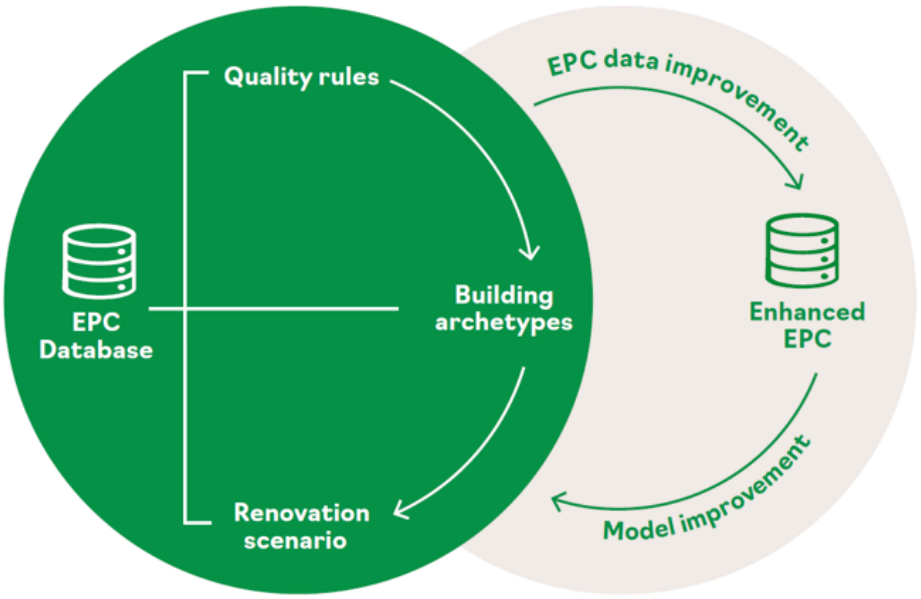

Figure 2. Flowchart of the EPC database exploitation in TIMEPAC [6]

In TIMEPAC, the quality-checking process, outlined in the following section of this article, involved evaluating the reliability of EPC data using a scoring method and implementing various levels of control, including checks for data type, physical inconsistencies, and overall coherence. Inconsistent EPCs were filtered out, and statistical analysis was then performed to create building archetypes that represent the typical technology and characteristics of specific building stock segments. These representative buildings, derived from EPC data, serve as inputs to assess the energy performance of the building stock and support efforts to improve the **energy efficiency of the built environment.**

A shared, harmonised, and flexible methodology for archetype creation was developed and documented in the Guidelines, which are available on the TIMEPAC website [3]. The Guidelines provide a comprehensive description of the building archetype schema and outline key performance indicators (KPIs) that reflect the energy status of the building stock. These KPIs are categorised into geometric data, thermo-physical properties of the building envelope, technical characteristics of technical building systems, and energy indicators.
Additionally, confidence intervals for selected EPC data were established, offering a valuable tool for certifiers during the EPC generation process.

Energy Performance Certificate data quality

In TIMEPAC, the quality assurance process began with a selection of EPC data. This activity involved harmonising input and output metrics across different countries, including Austria, Croatia, Cyprus, Italy, Spain, and Slovenia, to facilitate cross-country comparisons. The process continued with clustering buildings based on shared characteristics, such as climatic zone, building use category (e.g., residential or non-residential), construction period, and the size and shape of **residential buildings** (e.g., single-family houses and multi-family units). The clustering methodology was inspired by the outcomes of the TABULA project, which established a unified typology for European residential buildings.

To ensure the reliability of EPC data, a quality-checking procedure was applied [7]. This process involved assessing the data against a maximum error threshold, beyond which certificates are considered invalid. The methodology was inspired by the **TIMEPAC sister project X-tendo** [8] and **involved the definition of rules and the assignment of scores to evaluate data quality**. Critical parameters, which significantly impact on the usability of the EPC, were treated differently from non-critical parameters. For each parameter, specific validity rules were applied, and divided into the following three categories:

- data type checks, ensuring that data conform to logical and mathematical formats
- physical impossibility checks, verifying that parameters fall within physically feasible ranges
- consistency checks, evaluating the coherence of related parameters

Violations of these rules result in scores that increase as more issues are identified. Critical parameters carry greater weight in the scoring system, and if the total score surpasses the defined threshold, the certificate is deemed unreliable. Certificates with non-critical parameter violations may still be partially usable, provided their overall score remains below the threshold.

Overall, the EPC databases from the various countries/regions involved in TIMEPAC proved to be valuable data sources, despite current limitations in data quality. As a result of the process described above, a significant number of EPCs had to be excluded, e.g., approximately 20-30 % removed in the regions of Piedmont (Italy) and Catalonia (Spain) [5].

Conclusion

The Energy Performance Certificates play a pivotal role in multiple applications, especially in large-scale analyses that require significant data volumes. **Reliable EPCs help bridge data uncertainty gaps and support the creation of building archetypes, which represent typical characteristics of building stocks.** These archetypes, in turn, serve as inputs for developing national building renovation plans and assessing the energy (in-)efficiency of building stocks. By providing validated, high-quality data, EPCs improve energy modelling, enable the development of effective refurbishment strategies, and support the long-term enhancement of the built environment energy performance.

While current EPC data reliability remains a challenge, it is expected that data quality will be increased in the future with the enhanced EPC envisioned in the **EU Directive 2024/1275** [1], also leveraging the methodology and the outcomes of the TIMEPAC project.

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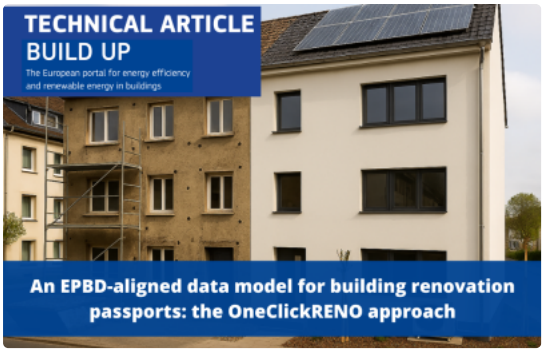

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