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1 Executive Summary

For the last 20 years energy performance certificates (EPCs), on one hand, have proven their place for labelling energy performance of new and existing building while, on the other hand, the same EPCs still reflect significant capacity for improvement that will unlock their potential, win better acceptance and improve reliability. Numerous reviews of current situation across different EU Member States report different level of advancement of EPC with respect, for example: calculation tools, quality check, price, users acceptance/trust and results usability. Still, tendency is rather clear – with age EPCs gain their significance and they evolve by seeking novelty to be integrated within their scope. At the same time, building owners, research and industry related to buildings and especially energy in buildings become more and more aware of evident performance gap between theoretical and real energy performance of building stock – so called performance gap. Major challenges of today are related to the inherent inability of steady-state EPCs to capture and reflect the dynamic conditions of building operation. Authors believe that EPCs could be more actively used to communicate and predict the actual building energy performance to the user/building owner and by that accelerate actual energy optimization of buildings. Moreover, assessment of energy performance in EPC should integrate measured energy, key parameters of indoor environment and results from tools able to take account for passive and active building systems. Among key innovative use of EPC indicators pointed out in *X-tendo* project [1] can be found smart readiness, comfort and real energy consumption, which all are aligned with the key objectives of E-DYCE project.

1.1 Aim and concept of E-DYCE

In E-DYCE, innovative approaches will be combined with established and available tools to create a methodology capable of implementing scalable, adaptable and accurate dynamic energy performance certification (DEPC). Moreover, the objective of E-DYCE is to propose labelling methodology that will deliver a living outcome that will be able to follow the operational performance of the building. The ultimate goal is to obtain a scenario in which savings and other benefits triggered by DEPC could incentivise building owner effort to reach out for DEPC.

The key objectives of E-DYCE are listed below. The objectives also indicate the added value of DEPC comparing to current steady-state EPC.

SO1. To deliver a methodology for dynamic certification of buildings based on openly available resources and tools for technology and service providers, effectively creating an evolving, technology-neutral ecosystem.

SO2. To generate substantial savings of 30kWh/m^2 (+1 energy class) in buildings certified through a dynamic scheme, benefiting owner, tenant and the service provider and thus incentivising all three.

SO3. To leverage the savings generated and reinvest into energy-efficient refurbishments and optimisation, scaling up the number of buildings certified to the level that can provide policymakers with meaningful data.

Other important aspects that are aimed to be addressed by E-DYCE are:

- In the current iteration of steady-state EPCs, the free-running potential of buildings is not considered, leading to buildings operating dependent on mechanical, energy-consuming systems instead of passive solutions.

- E-DYCE focuses on more realistic, trustworthy certification, with minimal investment from the end-user. Assessing and labelling a building's energy performance based on its free-running potential in combination with dynamic simulations is innovative, only by virtue of being a drastically different approach from conventional steady-state EPCs. Frequent measurements of performance (minute or hour resolution) or real-time data collection is the most consistent guarantee of reliability, especially once the models are optimised.

- Smart dimension of buildings will be illustrated for both passive operation and simple but smart metering and actuating of building systems. E-DYCE is designed for applicability throughout the smartness spectrum, also considering traditional, heritage, low-income and other "low-tech" buildings.

- Evaluation of the buildings will be carried out with respect to its thermal envelope quality, systems (heating and cooling) demand, operation time and efficiency and readiness for simple but efficient smart metering and actuation. Since the method allows to take account for buildings dynamic operation the share of free-running operation will be determined. As a consequence, the feedback about the building expected demand can be provided to the electrical and heating network for optimisation of their operation.

- Evaluation will be based on agreed parameters and key performance indicators, including energy and comfort aspects.

- E-DYCE will also contribute to recommendations for standards and compliance tools, including free-running buildings.

1.2 Objective of the report

Objective of this report is to elaborate on the current situation of national EPCs with particular focus on calculation tools and methods and their compliance with the objectives of recast EPBD goals for EPCs.

In this task (D1.1), the National EPCs will be listed along with the **policies and legislative initiatives** of the corresponding Member States with regards to energy performance certification. Moreover, **mapping of national tools (static/dynamic) qualified to calculate EPC** will be performed to understand advancement across EU Member State. This activity will allow the Consortium to **detect shortcomings of existing EPC schemes** and define the expected advantages of E-DYCE in far greater detail. Where possible risks related **to legislative, regulatory certification bottlenecks** of implementation at Member State and European level will be identified when current EPC were implemented over the recent years. Collected information will provide necessary lesson learned – what could be the challenges that have to be taken into account when moving from design to implementation of proposed E-DYCE certification concept.
Emerging EPCs and building standards: Innovations in these areas will be listed, and a list of actions to monitor the most prevalent advancements will be drafted, in order to enable E-DYCE to remain relevant in the EPC ecosystem with special regards to ISO/CEN M/480.

The findings that are collected and elaborated in this deliverable provide inputs to WP2 – WP5 activities and lay a foundation for future activities in the project.

1.3 Key conclusions

- In Europe, it was seen in the last years a great effort to improve the energy efficiency in buildings in order to decrease European energy consumption. From this effort, the Energy Performance Certificate (EPC) was originated to assess the building's energy performance.
- The current EPCs have several shortcomings, and its impact on increasing the EU existing buildings' energy performance has not been as positive as initially predicted.
- A new EPC scheme is proposed in E-DYCE project, in order to solve the limitations present in the current EPCs.
- E-DYCE aims to combine innovative approaches with established and available tools to create a methodology capable of implementing scalable, adaptable and accurate dynamic energy performance certification (DEPC).
- The DEPC methodology will consider, contrary to the EPC scheme, the innovative elements of real energy usage measurements, smart readiness indicator, interaction with district energy systems, passive solutions assessment and highly dynamic technologies assessment.
- The E-DYCE Members involved in this project and described as examples on this report are Denmark, Switzerland, Italy and Greece.

2 Focal points of the recast of Energy Performance of Buildings Directive with respect to E-DYCE objectives

In this chapter are listed the focal points of EPBD recast (Directive 2010/31/EU) concerning objectives and ambitions set for the future buildings EPCs.

The Energy Performance of Buildings Directive (EPBD) was originated by the Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002. This Directive is an EU legislation that aimed to require from the EU Member States (MS) to stimulate the improvement and development of the energy performance of buildings. To improve their performance, it was considered to take into account the outdoor climate and local conditions of each MS as the indoor climate requirements and cost-effectiveness. In the EPBD 2002/91/EC, it was also specifically required to develop and apply the following criteria:

• The creation at the national or regional level, a general methodology framework for the calculation of the energy performance of buildings, while considering the parameters and definitions given by the Directive and standards or norms present in the Member State legislation.

• The application of the minimum demands on the energy performance for new and renovated large existing buildings according to the methodology used.

• Ensure that an energy performance certificate is attributed to all buildings that are constructed, rented or sold, and it must be available to the owner and by the owner to the prospective buyer or tenant.

• Mandatorily inspect boilers and air-conditioning systems installed in buildings, where all the heating installations with more than 15 years must be assessed.

In 2010, the European Parliament reformulated the EPBD 2002/91/EC and broadened its scope by creating the Directive 2010/31/EU, also known as the EPBD recast. This new Directive deepened the concepts and methodology requirements present in the first Directive, as well as introduced the concept of Nearly Zero-Energy Buildings (NZEB), meaning buildings that have high energy performance where renewable sources meet their low energy demands. In the EPBD recast, it was established that all Member States should plan the increase of NZEB in their regions, by stipulating that in 2018 the new buildings occupied and owned by public authorities, shall be NZEB. Furthermore, in 2020, the recast specified that all new buildings should be NZEB. All of these requirements from the EPBD 2010/31/EU must be considered and executed, taking into account by the Member States the cost-optimal balance between the investment and the consequent energy savings brought from the EPCs. The 2010 Directive also further developed the EPC standards presented initially in the 2002 EPBD, to promote its implementation in the Member States as well as avoiding possible ambiguities when transposed to their national context. In 2016, the European Commission revised the 2010 EPBD, as the Energy Efficiency Directive (EED), and in 2018 published the new Directive (EPBD 2018/844/EU). The 2018 EPBD consists of new amendments of the former Directive, and it aims to stimulate and accelerate the renovation rate of the existing buildings and decarbonise the building stock by the year 2050 [2]. In order to achieve this goal, the present EPBD focus on the implementation of smart technologies in buildings, stimulation of the electric mobility, increase the transparency and quality of the energy performance certificates, improve the health and well-being of the building users and liberate more funds to promote these new set of measures.

To achieve a highly energy-efficient and decarbonised building stock and to ensure that the long-term renovation strategies deliver the necessary progress towards the transformation of existing buildings into nearly zero-energy buildings, in particular by an increase in deep renovations. Member States should provide clear guidelines and outline measurable, targeted actions as well as promote equal access to financing, including for the worst performing segments of the national building stock, for energy-poor consumers, for social housing and for households subject to split-incentive dilemmas, while taking into consideration affordability. To further support the necessary improvements in their national rental stock, **Member States should consider introducing or continuing to apply requirements for a certain level of energy performance for rental properties, in accordance with the energy performance certificates**.

E-DYCE DEPC: Concept in its initial adoption phase expects higher acceptance and interests first from professional building owners, such as municipalities, building associations, pension funds that have large building rental portfolio. The professional building owners are expected to be more aware of potential benefits brought by DEPC, such as, for example, lower operational costs, lower maintenance costs, higher price and better competitiveness, better and continuously updated overview of the energy performance of building portfolio, possibility for ongoing monitoring of performance and rapid identification of benefits due to changes/renovation implementation.

To meet the objectives of energy efficiency policy for buildings, the **transparency of energy performance certificates should be improved** by ensuring that all necessary parameters for calculations, both for certification and minimum energy performance requirements, are set out and applied consistently. Member States should adopt adequate measures to ensure, for example, that the performance of installed, replaced or upgraded technical building systems, such as for space heating, air-conditioning or water heating, is documented in view of building certification and compliance checking.

E-DYCE DEPC: One of the focal points in E-DYCE is to set a number of necessary KPIs addressing respectively defined end-users: tenants, building owners, building administrator/energy consultants with regards to new features and levels (asset, design, operational, hybrid) of DEPC scheme. This task is in detail, addressed in **Task 1.2 - Definition of dynamic and operational EPC specifications**. The transparency and data representation is addressed in **Task 2.4 Certification protocol consolidation**. Use and test of developed protocols will be performed on demonstration buildings within E-DYCE duration.

To ensure that financial measures related to energy efficiency are applied in the best way in building renovation, they should be linked to the quality of the renovation works in light of the targeted or achieved energy savings. Those measures should therefore be linked to the performance of the equipment or material used for the renovation, to the level of certification or qualification of the installer, to an energy audit, or to the **improvement achieved as a result of the renovation, which should be assessed by comparing energy performance certificates issued before and after the renovation, by using standard values or by another transparent and proportionate method**.

E-DYCE DEPC: The presentation of improvement achieved versus theoretical is incorporated in DEPC labelling schemes by comparing the result of design rating versus operational rating. However, this approach's main drawback is a very long time required to collect, analyse measured data and incorporate corrections if necessary. **In E-DYCE this drawback is overpassed by hybrid rating that aims at making the comparison possible thanks to detailed modelling results that should be able to predict building energy and indoor climate performance with adequate resolution.**

The current independent control systems for energy performance certificates can be used for compliance checking and should be strengthened to ensure that certificates are of good quality. Where the independent control system for energy performance certificates is complemented by an optional database going beyond the requirements of Directive 2010/31/EU as amended by this Directive, **it can be used for compliance checking and for producing statistics** on the regional or national building stocks. High-quality data on the building stock is needed, and this could be partially generated by the databases that almost all Member States are currently developing and managing for energy performance certificates.

E-DYCE DEPC: The main drawback of current EPCs is that majority of them is issued only at a selling-buying occasion or at renting occurrence, and their validity is very long, of up to 10 years. The renovation actions and operational changes introduced to the building in the meantime may therefore not be updated in the statistics built based on issued EPCs making these statistics outdated and not able to reflect on legislative changes with regards to building energy performance. Consequently, a conclusion about the uptake of actions triggering renovation actions and improvement of operational energy performance may be overlooked due to large inertia and delay of data reported through EPCs. **In its most advanced level DEPC aims at a label that follows building energy performance and is almost instantaneously updated both taking accounts for actual weather condition, comfort and energy use.**

3 EPBD and EPCs across member states in EDYCE

In this chapter are described the initiatives, policies, methodologies and consequences of the application of the EPBD recast in EU Member States participants of EDYCE consortium, these are Denmark, Switzerland, Italy and Greece.

3.1 Denmark

3.1.1 Policies and legislative initiatives

In Denmark, the implementation of the Energy Performance Building Directive is carried out by the Danish Energy Agency (DEA). It is also DEA that is responsible for the implementation of EPC and the central database. EPC statistics are publicly available on www.sparenergi.dk. And according to [3], approximately 60.000 EPC are issued each year in Denmark.

In 2014 in Denmark has been established Strategy for Energy Renovation [4]. The strategy consists of 21 initiatives to promote and improve the energy performance of existing buildings and establishes a framework for energy efficiency up to 2050 with the goal of 35% energy reduction in buildings. Among these initiatives can be found several actions to strengthen EPCs. As stated in Danish Strategy for Energy Renovation [4], the Minister for Climate, Energy and Building will maintain an effective and targeted energy-labelling scheme for buildings. Following objectives are listed:

- Increase the use of energy labelling of buildings by setting up a website where building owners and tenants can use the energy labels to gain an overall view of the energy-saving potential in their buildings and obtain specific information and guidance on carrying out energy renovations.

- Provide background data on buildings from the energy labels via the Danish Energy Agency website.

- Draw up guidelines and examples of how energy labelling can assist with building maintenance and the renovation of property portfolios.

- Strive for constant improvements in the quality of the energy labels for buildings, simplify the rules and reduce the costs of energy labelling.

- Pursue the dialogue with building owners, tenants, consultants, tradespeople, energy companies, financial institutions and other market operators on ways in which energy labelling can best support energy-saving efforts.

Since 2006, requirements for new buildings have been reduced gradually by 25% by each iteration with the aim of in total 75% reduction by 2020 with respect to 2006 requirements. The final, so-called "Building class 2020, at ≈25 kWh/m^{2}year", that is equivalent to NZEB level, is currently still voluntary, mainly due to economic barriers hindering that ambitious energy performance from being set as obligatory.

Danish national plan to progress towards NZEB is a combination of requirements set by Building Regulation, promotion actions to increase awareness and significant stimulus to subsidise renovation actions. Whereas requirements apply for newly constructed buildings, the renovation targets (so-called renovation classes) are voluntary.

Following examples of strategies and policies can be indicated in Denmark:

- Building Regulation – being updated towards ambitious energy performance. Building regulation sets requirements for new constructions and defines renovation levels for existing buildings. Renovation levels are currently only voluntary.

- NZEB level for the new buildings is mostly advertised by information and promotion campaigns spread by architects, energy consulting engineers, municipalities, contractors, universities and research organisations, energy ministry and other organisations created to support the transition towards zero CO2 communities.

- Public initiatives to reduce energy use in public buildings – savings up to 14% by 2020 compared to 2006.

- Ban on the installation of oil boilers/gas boilers enforces installation of renewable solutions, for example, heat pumps, PVs, collectors.

Strategy for energy renovation of buildings 2014 – action plan developed by the Danish Ministry of Energy, Climate and Buildings outlining incentives and programs supporting the renovation of buildings. The plan is aimed at different types of buildings, where some of the strategies are highlighted:

- **Upgrade the energy requirements for the buildings' envelope, windows and installations** – All of these building's characteristics have a significant effect on its total energy consumption. Therefore by increasing their requirements, it will contribute significantly to the improvement of the indoor climate as well the lowering of energy consumption.

- **Improve better compliance with the Buildings Regulations** – This will be reached by assuring that the regulations are clear and accessible for all the parties, by improving the collaboration in the execution of information materials with relevant organisations and also by implementing yearly surveys to verify if the regulations are being applied.
- **Introduce voluntary energy classes for existing buildings and upgrade the energy requirements for the new buildings** – By having these voluntary classes for existing buildings, the building owners will have a tangible goal to achieve the low-energy classes and consequently indicating it to the potential buyers. Moreover, by establishing these requirements for the new buildings, it will comply with the Danish target of reducing by 75% in total energy consumption by 2020.
- **Increase the use of energy-labelling schemes** – As studies reveal, there is a relationship between a property price and its energy certificate. Therefore by emphasising this relationship and also by improving the quality, simplifying the rules and reducing the costs of the energy labelling, it will increase the number of these labelling schemes.
- **Develop better data and tools for the decision in energy renovation** – By developing a methodology capable of calculating and documenting the energy savings from a renovation and by analysing data from different sources that supports energy renovation in buildings it will offer to the building's owners solid information to help in their decisions of in energy renovation.
- **Promote these strategies through financial funding** – When offered good financial conditions for energy renovations, it increases the acceptance and the owner's financial safety in proceeding with the renovation. As an example, in Denmark, there are several building fundings as the "Håndværkerfradrag" where it is deducted from the taxes some of the costs of energy renovations when applied to rental/owner-occupied housing or holiday housing. Furthermore, the "Varmepumpe på abonnement", which is a financial subsidy to support the costs of installing a heat pump instead of using an oil or natural gas boiler.

Moreover, when considering specifically private homes, the highlights are:

- **Promote renovation of single-family houses via 'Bedre Bolig' scheme** – approval scheme where a certified specialist is authorised to advise home-owners on ways of carrying out and manage energy renovation. The accreditation course for the professionals allows them to evaluate existing condition and advice on choice of solutions, suppliers, documentation, quotes etc.
- **Promote alternatives to oil and gas-fired boilers based on renewable energy** – Since 2013 no oil and gas-fired boilers can be installed in new buildings; since 2016, it is not possible to install oil-fired systems in existing buildings in areas where natural gas or district heating is a possibility.
- **Programs supporting new business models** where Energy Company owns and operates heat pumps for building owner while they pay a fixed amount for heating, similarly to district heating.

3.1.2 General information about EPC

All EPCs are registered at central database administrated by Danish Energy Agency (DEA). EPC database stores input data file provided by the certified EPC consultant and report for the building owner. EPC upload to the database is the responsibility of EPC consultant, and the procedure is carried out through automatised and standardised data protocol.

Danish EPC rates buildings with respect to energy efficiency scale, which ranges from A (high-energy efficiency) to G (low-energy efficiency), see Table 1. Moreover, class A is divided into three sub-categories A2020, A2018, A2010 reflecting ongoing progress of energy efficiency in BR updates since 2006 until the present.

Table 1: Danish EPC rating.

EPC rating	Criteria for each class [kWh/m^2year]	
	Residential	Non-residential
A2020	20	25
A2015	≤30.0+1,000/A	≤41+1,000/A
A2010	≤52.5+1,650/A	≤71.3+1,650/A
B	≤70.0+2,200/A	≤95+2,200/A
C	≤110+3,200/A	≤135+3,200/A
D	≤150+4,200/A	≤175+4,200/A
E	≤190+5,200/A	≤215+5,200/A
F	≤240+6,500/A	≤265+6,500/A
G	>240+6.500/A	>265+6.500/A

The key information, among others that can be found in EPC, are as follows:

- The general data about the building
- Description of the building
- The energy efficiency rating, see

- Calculated energy use
- Calculated CO_2 emissions
- List of recommended improvements per activity with investment estimate (if possible), energy saving, CO_2 saving, money-saving.

Practicalities

The energy survey needed to produce an EPC is performed by an assessor who visits the property, examines essential items such as roof insulation, boiler, hot water tank, radiators, windows for double glazing, areas, and other. The assessor is responsible for writing the observations into a **software program which performs the calculation of energy efficiency**. The program gives a single number for the rating of energy efficiency, and a list of recommended actions for improvement of rating. Recommendations are split into these with payback time shorter than the life expectancy of component (rentable) and payback time longer than the life expectancy of component (not rentable).

Exceptions are allowed, and the assessor must visit not all buildings in order to issue certification. Single-family buildings not older than 25 years can be labelled remotely. In such case-building owner must provide energy use from invoices and the address to find the building information in the Danish Building Database.

The exercise is entirely non-invasive so that the software will make assumptions on the insulation properties of various elements of the property based on age and construction type. The assessor has the ability to over-ride these assumptions if visual or written evidence is provided to support the presence of insulation which may have been subsequently installed.

Who is allowed to perform EPC?

Firstly, the company must be certified. The certification must be carried out by a certification body which is accredited by DANAK (Danish Accreditation) or an equivalent body in another EU country affiliated with the EU's accreditation organisation EA (European Cooperation for Accreditation).

Once the company has been certified, the company must be registered with the Danish Energy Agency. Please also note that energy-labelling assignments may only be carried out by individuals who meet the Danish Energy Agency's requirements – containing the requirements to perform as an energy consultant. At the time of writing this report, 96 companies in Denmark are accredited to issue energy certificates (among them are also large consulting offices and architecture companies). List of accredited organisations is available publicly.

3.1.3 Tools & methods

Current EPC scheme consists of two parts. Part 1 – small buildings and Part 2 – large buildings with area higher than 1.500 m^2. Both are certified with calculated energy performance and not measured energy rating. There is one central database for Part 1 and 2. Tool interface may be different, but the calculation engine must operate in accordance with the methodology and the calculations performed in Be18 energy compliance tool. The methodology is in detail elaborated in SBi Direction 213. The tool calculates total energy need for the building and compares it with the allowed maximum energy frames given in kWh/m^2 year. The energy frames are different for residential buildings and other buildings, for example, offices, schools, daycare buildings. The calculation tool takes into account: insulation properties of the building envelope, building orientation, daylight, monthly weather condition, heating source and heating system, building heat capacity, mechanical and natural ventilation, cooling, solar loads and solar shading and indoor condition. With regards to building energy need, the tool can take into account renewable energy production from solar cells, solar collectors, windmill and heat pump. **Be18 tool [5] is a steady-state calculation tool that performs monthly calculations for the entire building**. Be18 energy performance calculation applies for residential and all other buildings for people occupancy. Be18 integrate also simplified hourly summer comfort model to investigate thermal comfort condition. However, this model is available only to residential buildings. Thermal comfort documentation of other than residential types of buildings requires the use of a dynamic simulation, but Danish Building Regulation does not refer to the specific tool. However, before commercialisation, the tool must be approved by the Danish Energy Agency.

Currently on the market are available two commercial online and offline tools (interfaces) which allow issuing EPC calculation, Energy10 [6] and Ek-Pro [7]. Use of the tool is free, and EPC issuer pays fee whenever EPC is published. The fee is constant but varies depending on the building type being certified (single-family house, multi-apartment building, office building) and if the floor area is lower or larger than 1500 m^2.

Tools must fulfil demands stated in:

- Handbook for energy consultants HB2019 [8]
- Danish Building Regulation [9]
- Listed standards and Sbi reports, see below.

The energy label is based on calculated energy use. The calculation is performed for standard weather condition, standard use time, family size and use profile. Technical specifications taken into account when issuing energy certification are based on the following Danish Standards/guidelines:

- **DS 418** – Dimensioning heat loss calculation
- **DS 439** – Standard for domestic water installations
- **DS 452** – Thermal insulation
- **DS 469** – Heating and cooling installations in buildings
- **DS 447** – Ventilation in buildings – Mechanical, natural and hybrid ventilation systems
- **DS/EN 12464-1** – Light and lighting - Lighting of workplaces - Part 1: Indoor workplaces
- **SBI-anvisning 213** – Building energy demand, Guide for Be18 (Danish energy compliance tool)

3.1.4 Use of data from EPCs

EPC results, to some extent, are publicly available. For example, a map with all buildings being labelled in Denmark can be accessed at https://sparenergi.dk/demo/addresses/map. After selecting a particular building, several more information on the building and recommendation for energy efficiency improvement stated in the EPC report can be obtained.

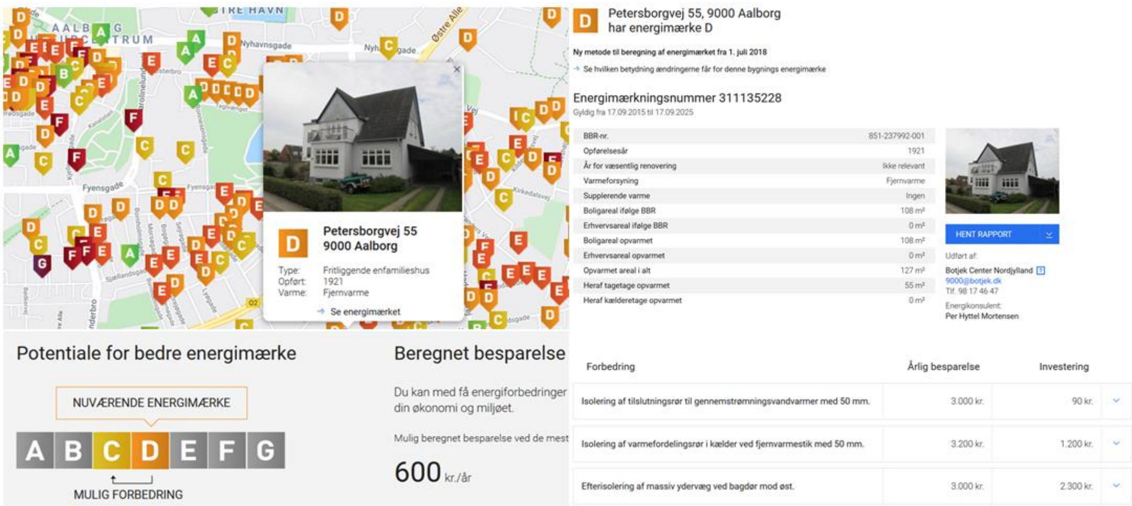

Figure 1: Digital access to an EPC rating of Danish buildings.

However, access to the EPC database is not publicly accessible. Research institutions, though, may have access to the database to perform statistics and analysis on:

- Potential energy savings
- Costs savings/expenditure
- Prognosis and historical analysis of political initiatives to promote energy efficiency, renovation actions.
- To predict role out the potential of specific political/legislative measures.

3.1.5 Major shortcomings of current EPC and effort to progress towards DEPC

3.1.5.1 Shortcomings

Energy labelling in its current form is performed with respect to standard boundary condition and use and evaluates building energy efficiency quality. The actual energy use of the building may vary significantly from the calculated rating obtained in the EPC scheme due to multiple reasons, and the most important are:

- User behaviour and operation of the building is different from the standard
- Weather condition is different from the standard weather file used for calculation
- Calculation methodology is performed as steady-state while the operation of the building is dynamic

Among major shortcoming of today's energy labels can be listed

- They do not provide sufficient information to take active and ongoing measures to correct energy operation of the building. Moreover, EPCs do not reward optimisation of building energy operation, for example, balancing of the hydronic system, optimisation of working point for pumps, or more aware definition of setpoints that would result in a decrease of actual energy use is not taken into account.

- Statistics indicate that actual energy use in low energy building is significantly higher than estimated, calculated energy use (so-called performance gap).

- EPC is based on steady-state calculations and has limited possibility to account for passive solutions, for example, ventilative cooling and thermal mass utilisation.

- They provide the only fraction of information on renovation rate of existing building stock as they are issued/updated only when the building is advertised for sell or rent - the process of monitoring energy transition of the building stock. EPCs are valid for up to 10 years and do not take account for building energy improvements unless the building is sold or rented again. As a result, there might be a large gap between actual building stock condition and conclusions based on statistics that rely on EPCs inputs.

3.1.5.2 Effort to progress towards DEPC

The DEPC proposed in E-DYCE is a parallel labelling scheme to current EPC scheme that addresses propagation of awareness of energy use, fault detection, smarter operation of buildings/building stock, ability to track operational changes. Users of DEPC are expected to be the ones who do not find current EPC sufficient to address their needs. In Denmark, it is expected that the first followers/users of DEPC would be social housing associations that are responsible for administration, operation, maintenance and planning of renovation of their building stock. For Danish social housing associations, DEPC could be proposed as a tool that could replace EPC for being more proper to assess actual energy performance and as well as a tool to support renovation plans. DEPC scheme is considered to be a voluntary scheme.

In Denmark, progress towards DEPC would require the active involvement of the Danish Energy Agency and development of required structures to support the approach. E-DYCE role is seen as work that could pave the way to indicate solutions for several key questions that have to be answered, such as:

- With respect to modelling: the selection of modelling software is expected to be arbitrary yet with some restrictions indicated by E-DYCE. For example, the possibility to use various weather data sets, ability to communicate with the weather forecast, required minimum standard input and output parameters, minimum result frequency (hourly, daily, weekly), ability to deliver specified KPIs, ability to communicate results to end-users, ability to take account for technologies and passive solutions, validation and performance according to standards/best test case.

- With respect to monitoring: the selection of indoor environment parameters to be monitored, selection of energy use to be monitored, data logging frequency, data transfer protocols, level of sub-metering, location of sensors.

- With respect to quality check: due to the increased number of parameters and complexity of calculation and metering data analysis, current quality procedures for EPC would not be sufficient and proper. E-DYCE DEPC is expected to rely on trust and close cooperation between customer (building association/professional building owner) and DEPC assessor specialist.

3.2 Switzerland

3.2.1 Policies and legislative initiatives

With its 1.64 million residential properties, the Swiss construction industry offers great potential for increasing energy efficiency and using renewable energies. According to Art. 89 para. 4 of the Federal Constitution, the cantons are primarily responsible for measures relating to the energy consumption of buildings. Historically, due to the Swiss executive federalism, the Confederation assumed a distant coordinating role and supported the harmonisation of cantonal measures elaborated by the inter-cantonal sublevel (e.g. development of norms and standards, model energy regulations of the cantons "MoPEC", harmonised promotion model (subsidies) or cantonal energy certificate for buildings "CECB"). However, due to the environmental and most specifically climate issues, the federal government tends to regain control over the formulation and design of energy policy for buildings. This dynamic was quite clear during the recent formulation of the new climate policy (currently subject to a referendum deadline) and the major constraining policy instruments devolved to the buildings (Limit values for CO2 emissions, art. 9 "Loi sur le CO2 postérieure à 2020", available at: https://www.parlament.ch/centers/eparl/curia/2017/20170071/S4%20F.pdf).

Thus, since 1979, the 26 members of the cantonal governments dealing with "Energy" have come together in the Conference of Cantonal Energy Directors (EnDK, "Energiedirektoren konferenz"). The EnDK is the cantons' joint energy competence centre. It promotes and coordinates cooperation between the cantons on energy issues and defends the common interests of the cantons. The Conference of Cantonal Energy Services (EnFK, "Energiefachstellenkonferenz"), which deals with specific technical issues, is attached to the EnDK.

This institutional organisation largely determines the framework of Swiss energy policy. In this respect, it is not uninteresting to mention the fact that these different institutional 'levels' (federal, intercantonal, cantonal, even communal) are all arenas for formulating more or less formal public policy programmes, and therefore grounds in which actors play their political games. Thus, the field of energy in Switzerland will be the result of those parameters, and in comparison to our UE partners, it will produce some specificities. For example, cantonal public authorities but also semi-public actors are central actors in the implementation of EPCs.

Therefore, cantonal public authorities are happy to make use of non-binding legal instruments and refer to private standards if they do not have the power to issue regulations in a particular area. This is a skilful procedure since tangible effects can follow it, but in this case, it raises the question of the legitimacy of such instruments. Classically observed in Switzerland, semi-public and private actors traditionally self-regulate and to more or less formally enshrine their rules in the legal order. Finally, yet importantly, European directives in the field of energy performance in the buildings also contributed to implementing EPC schemes in the Swiss legal order. It is precisely in this context that the instrument for energy certification of buildings (CECB, "Certificat énergétique cantonal des bâtiments") and the implementation of energy performance in the building emerge (the canton of Geneva is an exception, as it will be discussed later).

Therefore, the policy acts ruling energy certification and energy performance of buildings at the national level were issued in 2016 in the Energy Act in the federal corpus of energy laws (RS 730.0, LEne, available at https://www.admin.ch/opc/fr/classified-compilation/20121295/index.html). A central rule specifies that cantons have to produce uniform regulations on the indication of the energy consumption of buildings (energy certificate for buildings). They may decide that the certificate is compulsory on their territory and, if so, under what conditions (art. 45, LEne).

Before the introduction in 2016 of the Energy Act, the EnDK promulgated as said the model energy regulations of the cantons "MoPEC" in 2014 (available at https://www.endk.ch/fr/documentation/batiments-mopec). The certificate is also anchored in the guiding principles of the EnDK, in particular Guideline 13: Information, advice, training and further training. The cantons promote the basic and further training of professionals, enabling them to acquire new knowledge on the economical use of energy and on local solutions for producing energy from small renewable sources linked to specific objects. Through the provision of information and advice, they stimulate consumer interest in energy-efficient use of energy and the demand for renewable energy and energy efficiency applications. Through the provision of information and advice, they stimulate consumer interest in energy-efficient use of energy and the demand for renewable energy and energy efficiency applications.

3.2.2 General information about EPC

As mentioned above, the EnDk did not wait for the federal level to introduce CECB. A dedicated chapter in the MoPEC (section N) specifies: "The CECB is not compulsory for owners. However, it is intended to encourage them to insulate their buildings better and/or to renovate their heating or hot water installations. It provides mainly, and independently of the users, indications on the state of the building and its overall energy efficiency. It also informs the owner about first steps it can take to optimise its consumption." (MoPEC 2014: 55ss).

Contrary to some other UE members, there is no indication whether EPCs are registered at a central database and whether it is possible to monitor the penetration of EPCs in regional or cantonal comparison. However, an EPC manual mentions that data projects and the electronic reports are stored centrally in a national database. The conditions of access for public authorities are not specified or even discussed. Structurally, the management of the EPCs is carried out under the responsibility of the CECB association.

Members of cantonal authorities in charge of energy policy compose the latter. Operationally, experts certified by the CECB Association managed to establish EPCs and the related reports. The association offers three products:

- a standard product (CECB): a constitutive report indicates the energy performance of a building regarding thermal building envelope and overall energy efficiency;
- a premium product (CECBplus): in addition to the above, the latter product adds a report with additional advice for energy efficiency renovation;
- a "new building" EPC (CECB Nouveau Bâtiment): regarding new construction, this product sets energy efficiency targets to be achieved when planning for new construction or replacement.

The CECB energy label gives two indications: the first, performance of the thermal envelope evaluates the heat requirements for space heating; the second, the overall weighted energy performance evaluates the total heat plus electricity energy consumption of the building as well as the ecological impact of the energy vectors using weighting coefficients. (x 1 for fossil fuel, x 2 for electricity, x 0.6 for wood boiler, x 0.4 to x 1 for district heating depending on the renewable part). In some region in Switzerland, CECB is mandatory for a new building or in case of high consumption building, in case of replacement of fuel heating, or in case of building selling, as discussed hereafter. By definition, all new construction is Class A or B in all regions that apply the MoPEC 2014 or equivalent.

The association rates buildings with respect to the building envelope efficiency and global energy efficiency scales which ranges from A to G, see Table 2.

Table 2: Swiss EPC rating and description.

EPC rating	Building envelope efficiency	Global energy efficiency	Values
A	Excellent thermal insulation (roof, facade, cellar), windows with triple glazing	High-efficiency building installations for heating and domestic hot water, efficient lighting and equipment; use of renewable energy and clean electricity production	performance < 50% of the limit for new construction
B	New constructions meeting the criteria of category B according to the legislation in force	Envelope and technical installations in accordance with new building standards, use of renewable energy sources	performance < the limit for new construction. Indicative values for collective housing 40 kWh/m2 for heating needs and 115 kWh/m2 (weighted energy) for the total energy
C	Old building whose envelope has undergone a complete rehabilitation	Completely renovated building (envelope and installations techniques), most often combined with the use of renewable energies	performance <150% the limit for new construction
D	Old building that later benefited from good insulation, but with	Building largely rehabilitated, but with some shortcomings or without the use of renewable energy sources.	performance <200% the limit for new construction

	thermal bridges still remaining.		
E	Old building with improved thermal insulation, incl. new insulating glass panes	Partially renovated old building, e.g. with new heat generator and possibly new appliances and lights	performance <250% the limit for new construction
F	Partially thermally insulated building	Building with various new elements (building envelope, technical installations, lighting, etc.).	performance <300% the limit for new construction
G	Old building without insulation or with insufficient subsequent insulation, with high renovation potential	Old building with outdated technical installations, without renewable energies, and with a high potential for improvement	performance>300% the limit for new construction

The Swiss EPC method is based on the SIA 2031 standard determining the methods for energy certification. This standard is based on other standards, like SIA 380/1, which is used throughout Switzerland to calculate the heat requirement for heating the building, SIA 382/1 to calculate cooling and ventilation energy demand, SIA 387/1 for lighting energy demand, and 380/4 for other electricity use demand. Generally, these norms are referring to the corresponding EN norms, and SIA 2031 itself is harmonised with the European Directive EPBD and the EU EPC's. The calculation of the total energy requirement also takes into account the building technology in a simplified form. For the calculation, the EPC is based on the heated area and the actual energy consumption (invoices and meter readings) for heating, hot water and electrical technical equipment (ventilation, the lighting of common areas, etc.).

The major information, in comparison to the other UE countries (e.g. Italy) that can be found in EPC (standard product) are as follow:

- General building data: the data of the evaluated object; representation of the energy efficiency class of the building envelope and the overall energy efficiency under standard operating conditions; Energy and CO2 indices under standard operating conditions; actual energy consumption of the building.
- Technical description, evaluation and brief indications for a renovation: Description of the building and the current technical installations; actual consumption data; gross evaluation of the individual building elements and technology, as well as information on their current state; Information on the renovation.
- Measures to be taken and recommendations: recommendations on technical energy measures; description of the building envelope, heating, hot water production and other electricity consumers; comments on user behaviour.
- Cost/utility analysis: the report offers a clear and simple cost/utility ratio for the property owner.

Practicalities

The EPC analysis is produced and undertaken by an EPC expert. The latter expert collects all relevant data concerning the building envelope and overall energy efficiency. The owner of the building shall provide data on the consumption of heating, hot water and electricity over a period of at least three years, if available. The expert then calculates the EPC (standard product) using the online tool and prepares the official four-page document, as well as, for an EPC premium (CECBplus), the supplementary advice report indicating the proposed improvement measures.

Cantonal specificities in the Swiss federalist context:

As mentioned above, the Swiss federalist system allows room for manoeuver to local authorities regarding how to implement EPCs in their policy regimes. For example, in the Canton of Vaud, since 2017, EPC is compulsory in the case of:

- Sale of an existing residential building;
- Replacement of a heating system with new gas, oil or coal-fired system. This obligation applies to buildings such as individual dwellings, collective dwellings, administrative buildings and schools.

The canton of Geneva shows another example of creativity regarding EPCS schemes. In the 90s, the local authority in charge of energy policy developed a specific scheme in order to monitor the consumption of energy heating in the buildings (incl. sanitary hot water). Called "Heat consumption index" (Indice de dépense de chaleur), this tool differs from EPCs (CECB).

It differentiates between buildings by their consumption in MJ/m^2.year of heated area and sets efficiency thresholds. These thresholds define obligations for renovations to be undertaken by owners. In order to have a common monitoring language with all the cantons, the Geneva authority has developed a method for converting the results of the index into energy classes on the basis of the SIA 2031 standard. Some quantitative specifications will be discussed hereafter about the Genevan exception.

As the Swiss model explained above showed, experts must follow a certain logic of membership in order to certify. The certification is carried out by a regional certification body which is member of the Swiss EPC association. Contrary to the case of Denmark, for example, there is not a nationally accredited body or an equivalent body such as the Federal office of energy.

Thus, the right to practice is undertaken by an individual person most often. Once the expert has been certified, she/he is registered with the regional association. So, the energy-labelling assignments are being carried out by individuals who meet the central association's requirements – containing the requirements to perform as an energy consultant. At time of writing this report, there is no indication about companies who employed EPCs experts in Switzerland that are accredited to issue energy certificates (but we know that there are large consulting offices, engineering and architecture companies). List of accredited organisations is not available publicly but has to be asked to the central association.

3.2.3 Tools & methods

Use of CECB web base platform is mandatory for CECB labelling, Only registered expert has access to this platform and must follow some courses to remain in the expert database. CECB can be applied to the following categories of buildings :

- Collective and individual housing
- Administration and school
- Hotel
- Commerce
- Catering

Calculations for heating demand are based on a steady-state calculation tool that performs monthly calculations for the entire building based on ISO 13790. The assumptions and thresholds for the passing from heating and cooling demand to energy consumption, as well as the weighting energy factors, are determined in MoPEC 2014. Calculations for heating system and loss and electricity consumption are based on a complete description of the installation by the expert and can be compared with the measured energy for benchmark and validation. However, measured energy is not taken into account the calculations. In the standard SIA 2031, a methodology explains how to establish an operational rating. However, the CECB has not adopted the methodology.

In Switzerland, there are other ways of thresholding and monitoring real energy consumption. Many public administrations use the EU initiative display (http://www.display-campaign.org). As mentioned, in the canton of Geneva, all buildings of a certain dimension need to declare their heat energy consumption to the public authority. This indicator called IDC for Indice de Dépense de Chaleur (heat consumption index) is simply the yearly specific heat consumption per unit surface. There is a methodology of how to calculate this index and normalise it according to a standard meteorological year. These data are available since 1991 for several thousands of buildings, but since 2010 almost all the buildings of the canton are declared.

3.2.4 Use of data from EPCs

Ten years after the start of the CEBS programme and almost five years after the creation of the CECB association, the milestone of 80,000 EPC (standard product) and 25,000 CECBPlus (premium product) has been reached. In 2019, 19,226 EPCs were published, of which 3,604 updates. In addition, 7,716 advisory reports have been produced. A total of 137 new experts were certified out of a total of 1,529 experts active throughout Switzerland. These experts were offered more than 30 continuing education courses in order to maintain their status, just as the association monitored the work of 150 of them in the context of our quality control activities.

CECB data are not publicly available, use of database results are unknown for now and are probably aiming policies maker in Switzerland. However, the owner or the expert may export the CECB data from the tool. Additionally, he or she may import data from other tools. In Switzerland, there are other private tools calculating heat demand and provide facilities to export results to the CECB tool (LesoSai is one of these private tools for calculating heating, cooling and ventilation demand, able to perform also dynamic and other simulations with the same building). For the owner or the buyer, this EPC may help to identify what are the best works to do to achieve energy saving. However, building owners need to know if the operation of their building conforms to expectations and the legal authorities need to know whether a building consumes really according to the permitted energy threshold by the law.

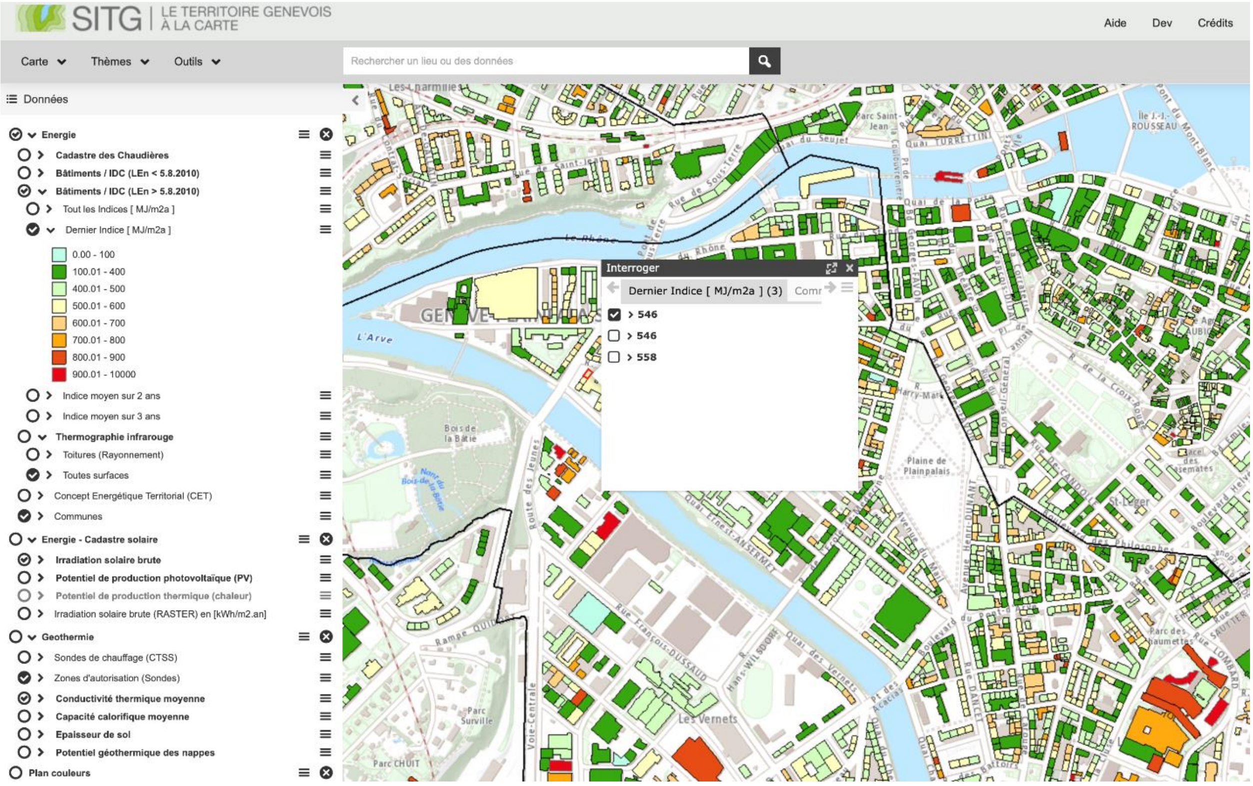

Figure 2: Geneva Gis open and public system showing the heat consumption index for all buildings for the last 20 years.

Geneva geographical information system (GIS system) offers the possibility to download public data or to get them by an API. This enables public administration, private companies or researchers to analyse individual building, group of buildings, a particular owner building stock or the whole canton heat consumption.

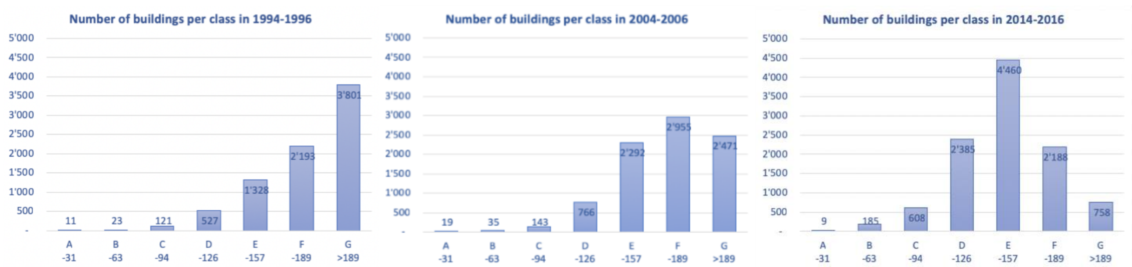

Figure 3: Number of buildings per class regarding three temporal cohorts.

Using the Genevan public heat consumption data, it was possible to produce graphs illustrating the distribution of buildings in energy classes from 1994 until today.

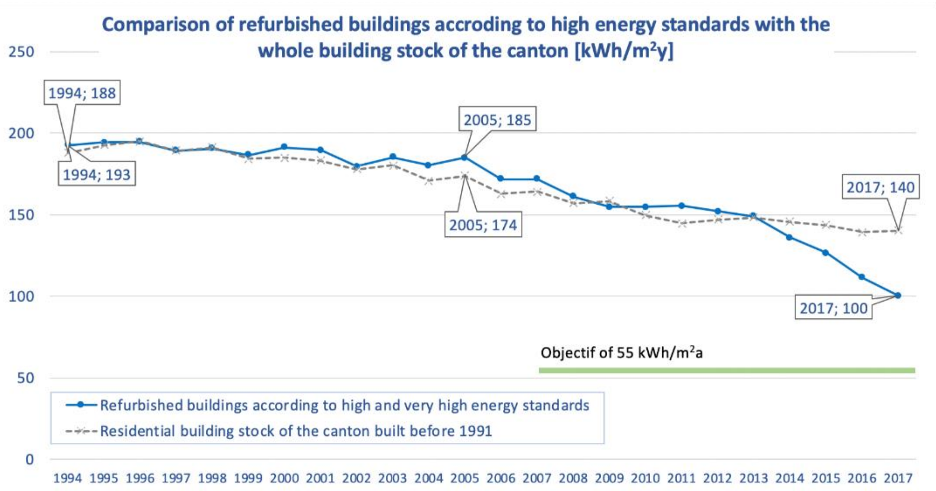

Figure 4: Comparison of refurbished buildings regarding the whole building stock of the canton.

Again, using the Genevan public heat consumption data, it was possible to produce graphs quantifying the performance gap of high energy performance deep refurbishment. In grey dote line, the evolution of the heat consumption index of the whole canton building stock and with the continuous blue line the evolution of 59 identified deep refurbished buildings.

The public authority of energy in the canton of Geneva differs from other cantonal authorities basing their public policy on theoretical EPC's. Although this exceptionalism could isolate the canton of Geneva from harmonised practices between cantons, it allowed researchers to well documented the crucial problem of the "performance gap". This concept embodies the idea of discrepancies between theoretical values of energy performances as documented during the administrative examination of the dossiers by the implementing authority, in one hand and, in the other hand, the real performances of the buildings. Translated from the point of view of policy analysis, this observation is nothing less than an implementation deficit. Having in the toolbox such a valuable tool, the cantonal energy authority wants to push legislation towards compulsory control of the performance gap problem or actions for buildings consuming over a certain limit.

One of the reasons for the conservatory keeping of the EPC data in contrary to the Geneva GIS energy consumption data is the Geneva law making the energy consumption of a building public. For the other cantons, publishing the EPC data is under data protection clauses limiting publishing them. This is a major difference compared to the Italian case, where it is possible to have a better understanding of EPCs penetration in a regional perspective and then address corrective public measures (e.g. information campaign, regionally targeted actions, etc.)

3.2.5 Major shortcomings of current EPC and effort to progress towards DEPC

3.2.5.1 Shortcomings

Current EPC major shortcomings are the following:

- EPC is a picture of the energy quality of the building when the EPC is established under standard conditions. This does not represent the real energy consumption of the building.
- The building energy quality under standard conditions is a good tool for the authorities to control the design choices (insulation and window U values, building capacity, ventilation heat losses, lighting system choice, heating system theoretical performance etc.) However, the way the

system operates cannot be controlled; thus, regulatory cantilevers cannot push the owners towards virtuous strategies in this domain.

- Although model and calculation tool precision evolved positively since the first version, EPC results still show low precision. As in other countries, they overestimate the energy consumption of existing buildings, and they are too optimistic about new buildings.
- Albeit Swiss EPC gives some economic information (cost/utility ratio), it does not give us a better understanding of economic indicators whereas they are critical. Obviously, having the capacity to assess the economic and energy cost-benefit ratio is important, but decision-makers (owners and their external agents) may decide to embark on renovations if they have a better view of the economic profitability.
- Despite the model simplicity, the EPC results are still too depended on experts' assumptions. In the figure below we can see the results of a classroom of 18 official experts with several years experience the results of 6 groups of 3 for the same building with two scenarios. In the first column, we can see that even for the heating reference area there is large spam of answers varying from 353 to 382 m^2 ± 4% while global energy performance varies between 187 and 335 kWh/m^{2}year (factor 1.8).

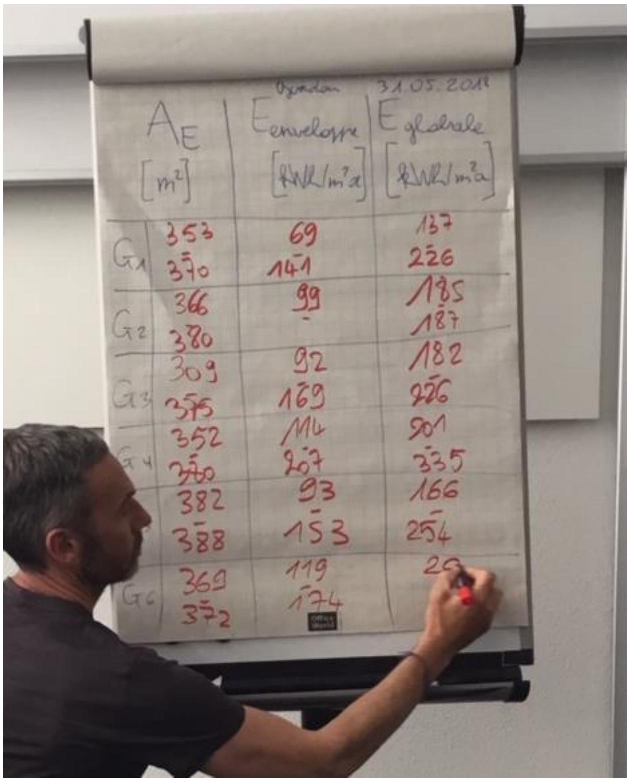

Figure 5: Results of 6 groups of certified experts who established and EPC for the same simple single-family house.

Other shortcomings of the EPCs is the poor quality of the report content, mostly due to unsatisfactory experts and their lack of experience or skills. Indeed, a qualitative analysis undertaken by the Federal office of energy showed major problems and disparities regarding the quality of the aforementioned reports. Nonetheless, the tool is generating automatic texts to help as edition aid for the users, but the users keep the default texts, and finally, we get the same EPC description for the buildings of the whole country. It arrived at the editor to analyse the EPCs of 15 buildings and find the same description for the building component characteristics and for the expert recommendations. In this regard, it was the tool default values.

3.2.5.2 Effort to progress towards DEPC

The ambition of the Swiss DEPC is to bring together the advantages of the real energy consumption operational labelling with and those of the design labelling with the DEPC dynamic operational labelling. This label will not reflect both theoretical and real performance of the building, but also it will indicate the difference between the two in real-time. This real-time theoretical and real energy performance indicator is destined as a tool for building monitoring and optimisation. A reliable DEPC based on metering and simulation must integrate the following points:

- Simulation tool: The description of the building must be as simple as possible but as detailed as necessary to avoid big disparities between identical modelled building. Standard dynamic simulations are very complex to perform with actuals tools in the market.
- Assessor specialist: The assessor must have the expertise and competencies needed to have reliable results. Thus, DEPC labelling cannot be mandatory. As said in the Danish Chapter, EDYCE DEPC is expected to rely on trust and close cooperation between customer (building association/professional building owner) and DEPC assessor specialist.
- Metering: Definition of minimal dynamic metering for energy input and a more detailed level in option with indoor air quality to make it possible to limit investment for owners
- Economic indicators: The simulation tool must integrate new information in order to simulate economic indicators such as rents and change in rents, charges and change in charges and consider the following simple arithmetical equation to assess, e.g. indicator of "Profitability of a renovation project" as equal to change in rents - change in charges/amount of investment.

  Territorial information: Perhaps utopian, but the DEPC must interact with territorial information, and integrate constraints and opportunities the surrounding perimeters show. Indeed, in the context of urbanised territories such as cities, energy and buildings law have to include environmental (air, mobility, etc.), building heritage, and many other policies. In order to get rid of frustrating and time-consuming processes, a simulation as close as possible to reality is preferable.

3.3 Italy

3.3.1 Policies and legislative initiatives

Policies related to the implementation of Energy Performance Building Directive in Italy follow a double track, following the legislative changes at the end of the past century that increased the autonomy of Regions respect to the State for several aspects, including the one here described. The Ministry of Economic Development (former Ministry of Industry) is responsible for the implementation at central level; Regions, as well as the Provinces of Bolzano and Trento, can follow the national scheme or autonomously implement their own scheme. ENEA is in charge to prepare the annual EPC report, the latest version, available at www.efficienzaenergetica.enea.it/pubblicazioni/rapporto-annuale-sulla-certificazione-energetica-degli-edifici-2020.html, is based on 4.5 million EPCs referring to the 2016-19 period (more than one million per year).

The policy acts ruling the energy performance of buildings at the national level were issued in 2015; they include:

- The national guidelines on EPC, also dealing with the relevant issue of instruments of reconciliation between the State and the Regions for the presentation of EPC
- The minimum requirements of the energy performance of buildings, including requirements for NZEBs and of the new calculation methodology, based on the introduction of the national building to assess the energy performance and classes of the building.
- Formats and templates for the technical design reports aimed at the implementation of requirements for EPCs.

The cited ministry published the national action plan to increase nearly zero energy buildings in 2016 (www.mise.gov.it/images/stories/normativa/all_decreto_interministeriale_19_giugno_2017_panzeb.pdf), listing a number of measures to achieve the objective. The plan includes the action aimed to strengthen the EPC actions coupled with economic incentives to support the energy renovation of buildings. In parallel, several Regions promoted similar programs to incentivise the plan at the local level.

The *integrated national energy and climate plan*, published in 2020 (https://www.mise.gov.it/images/stories/documenti/it_final_necp_main_en.pdf), set ambitious objectives with time target 2030, among them: -0.8%/year final energy use savings, -43% primary energy use respect to PRIMES 2007 scenario, +1.3%/year renewable energy share in final energy use.

Following examples of strategies and policies can be indicated in Italy:

- Building Regulation. Building regulation sets requirements for new constructions and defines renovation levels for existing buildings. Renovation levels are currently only voluntary.
- All new and deep renovated buildings will NZEB since January 2021.
- Initiative to reduce the energy use in at least 3% of the total useful area of public buildings each year (PREPAC scheme).
- Minimum contribution of renewable energy in new or deep renovated buildings (50%), set by a dedicated decree and implemented in the national guidelines.
- Tax reduction schemes for building renovation of single energy (related) components and deep renovation (up to 110% of eligible costs).

3.3.2 General information about EPC

As indicated above, the EPC system is managed at the national level by the Regions that do not implement their own method; the legislative system asks local authorities to forward their data to a central system: SIAPE (Informative System for Energy Performance Certificates) is the informative system, which contains the all the country EPC database. This is, in fact, the EPC cadastre and it is managed by the Department for Energy Efficiency of ENEA. The bridging between the regional and the national schemes takes place through an XML file, unique and shared for each EPC. The file containing the EPC is uploaded by the accredited consultant that carried out the work. Current status on Region applying for SIAPE is summarised in Figure 6.

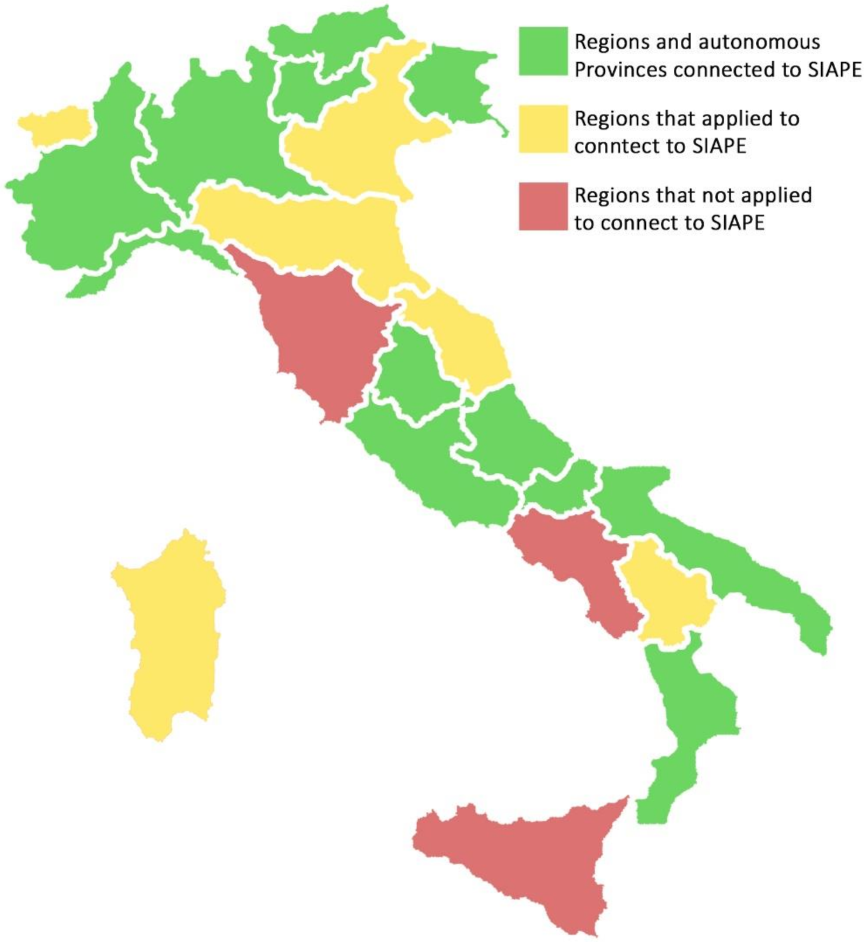

Figure 6: Regional application status for the Italian EPC informative system. Green regions are part of SIAPE, yellow regions applied for, red regions did not.

The Italian EPC method is based on the comparison of the given building versus its reference building, which is a theoretical building with same use and geometry of the given building, and with assigned reference envelope and energy system performances. The energy class is achieved by comparison of the non-renewable global primary energy performance indicator (EP_{gl}) in standard conditions, as summarised in

Table 3. The relevant indicator to assess and classify building energy performance is the kilowatt-hour per square meter of useful surface. If the minimum requirement of renewable energy is reached (50%), the building gets the NZEB class, and it will be indicated in a dedicated box in the energy certificate. The EPC in the residential sector is implemented at the single flat level, and not the whole building.

Table 3: Italian scale for primary energy use in EPC, obtained by comparison of a given building versus its reference building.

Lower limit	Class	Upper limit
	A4	≤ 0,40 EPgl
0,40 EPgl <	A3	≤ 0,60 EPgl
0,60 EPgl <	A2	≤ 0,80 EPgl
0,80 EPgl <	A1	≤ 1,00 EPgl
1,00 EPgl <	B	≤ 1,20 EPgl
1,20 EPgl <	C	≤ 1,50 EPgl
1,50 EPgl <	D	≤ 2,00 EPgl
2,00 EPgl <	E	≤ 2,60 EPgl
2,60 EPgl <	F	≤ 3,50 EPgl
	G	> 3,50 EPgl

The key information, among others that can be found in EPC, are as follows:

- The general data about the building/flat (use, climatic data, geometry, cadastral data)
- Primary non-renewable global energy performance and the associated class
- Primary and final, renewable and non-renewable energy use, with the indication of energy sources and the used/produced energy for each of them
- Calculated CO2 emissions
- Recommended measures for energy renovation, simple payback time and related energy class improvement
- Other performance indicators (periodic transmittance, net energy for heating, etc.)
- Details of present energy systems
- Details of the professional in charge of the EPC and used software's

Additionally, Italy is subdivided into six climate zones according to the local heating Degree-Day, with 20°C base temperature. Climate zones are defined according to DPR 412–93 and further upgrades and integrations, listing the zone for each Italian Municipality – see Annex A of the DPR and the 2018 upgrade. Zones are used to define the local heating season and to set minimum requirements for the global thermal transmission coefficient and related requirements of envelope performances (U-value) for new construction and renovation. Figure 7 shows the distribution of Italian Municipalities and population in relation to the climate zone, while Table 4 reports the maximum thermal transmittance values for climate zones, data referred to building requalification, the period 2019-20.

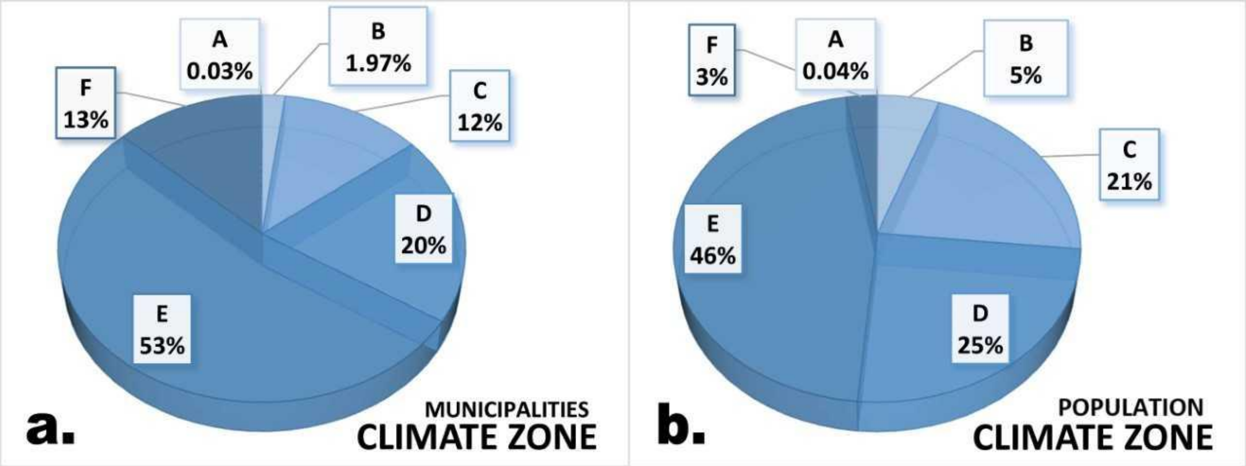

Figure 7: Percentage distribution of Italian Municipalities for climate zone, left: Percentage of No. municipalities and right: Percentage of population.

Table 4: Sample representation of minimal requirements – maximal U-values for envelope components according to local climate classes (2019-20, DM 26.06.2015)

		Building components			
		Roof	Ground floor	Wall	Window
Climate zone	A/B	0.32	0.42	0.40	3.0
	C	0.32	0.38	0.36	2.0
	D	0.26	0.32	0.32	1.8
	E	0.24	0.29	0.28	1.4
	F	0.22	0.28	0.26	1.0

Practicalities

The energy survey needed to produce an EPC is performed by an accredited consultant (national laws provide the title required to do this activity), who visits the property, examines key items such as geometry, structures, energy systems, use, measures to improve the energy performances, etc. The data are then reversed in a certified software, which performs calculations, assigns the energy class and produce the standard energy diagnosis for renovation.

EPC is not necessary for buildings with a useful area smaller than 50 m^2, and a number of other very specific cases, statically not relevant. According to national laws, it is mandatory at least a visit to the building. The assessor providing false declaration is subject to sanctions.

Who is allowed to perform EPC?

The EPC is performed by a professional, working in a company or as an individual. National and regional laws allow many professional figures to operate as an EPC assessor. Two main classes exist:

- Professionals with university degrees (Engineering, Architecture, Planning, etc.) or technical secondary school diplomas devoted to the building/construction/mechanical/energy sectors. In this case, no additional and specific training is required. However the professional must register as an assessor in the Regional cadasters.
- Professionals with university degrees or technical secondary school diplomas from other sectors have to go through specific EPC training and final exam to get the accreditation.

3.3.3 Tools & methods

EPC is based on asset rating, with a quasi-steady state method with monthly heat balance and utilisation factors for the calculation of energy needs. Calculations are carried out in standard conditions for energy uses and users' profiles. The Italian technical standards implement the relevant CEN standards; a set of dedicated standards adapt those standards to the EPC purposes. They are following listed:

- UNI/TS 11300-1:2014 Energy performance of buildings - Part 1: Evaluation of energy need for space heating and cooling

- UNI/TS 11300-2:2019 Energy performance of buildings - Part 2: Evaluation of primary energy need and of system efficiencies for space heating, domestic hot water production, ventilation and lighting for non-residential buildings

- UNI/TS 11300-3:2010 Energy performance of buildings - Part 3: Evaluation of primary energy and system efficiencies for space cooling

- UNI/TS 11300-4:2016 Energy performance of buildings - Part 4: Renewable energy and other generation systems for space heating and domestic hot water production

- UNI/TS 11300-5:2016 Energy performance of buildings - Part 5: Evaluation of energy performance for the classification of building

- UNI/TS 11300-6:2016 Energy performance of buildings - Part 6: Evaluation of energy need for lifts, escalators and moving walkways

Being UNI the Italian Body for Standardisation, the standards are elaborated by CTI (Italian Thermo-technical Committee), a private body federated to the above mentioned UNI.

EPC schemes in Italy are based on the following energy services: space heating (alternative references are given in the dwellings do not have any installed system), domestic hot water, mechanical ventilation, space cooling, electric lighting, transport of people and/or goods (the latter two do not apply to residential buildings).

In Italy there is not only one certified tool to calculate the buildings' Energy Performance, leaving to institutions and commercial software houses the possibility to develop their own solution. A crucial requirement for candidate software is that EP on reference buildings cannot differ more than 5% respect to that calculated according to the relevant standards. CTI governs the verification and accreditation process. The verification process follows the regulation included in art.7 of the DM of the 26th June 2015, the D.Lgs 192/05, and the Verification Rules for APE software currently in use (last integration 2nd of December 2019) – see [10 - 11]. All positively verified software and instruments are included in the official

Register of the National Tool (Registro dello strumento nazionale), that is publicly accessible. Furthermore, the producers receive a certification of conformity to be mentioned in the software. The National Tool Register currently includes tools listed in Table 5:

Table 5: Register of National Tool – from CTI website

List of informatics tools (valid from 29th June 2016)			
Producer	**Denomination**	**Protocols No.**	**Certify No.**
Blumatica S.r.l.	Blumatica Energy	n. 69 (29/06/2016)	n. 64 (15/03/2017)
Logical Soft S.r.l.	Termolog EpiX	n. 70 (29/06/2016)	n. 65 (15/03/2017)
Namirial S.p.A.	Namirial Termo	n. 71 (29/06/2016)	n. 66 (15/03/2017)
Acca Software S.p.A.	TerMus	n. 72 (29/06/2016)	n. 67 (15/03/2017)
Analist Group S.r.l.	TermiPlan	n. 73 (29/06/2016)	n. 68 (15/03/2017)
Italsoft Group S.r.l.	Termiko One	n. 74 (29/06/2016)	n. 69 (15/03/2017)
Cype Ingenieros S.A.	Cypetherm C.E.	n. 75 (29/06/2016)	n. 70 (15/03/2017)
Geo Network S.r.l.	Euclide Certificazione Energetica	n. 76 (29/06/2016)	n. 71 (15/03/2017)
Mc4Software Italia S.r.l.	Mc4 Suite	n. 77 (29/06/2016)	n. 72 (15/03/2017)
Topoprogram & Service di	Energetika 2000	n. 78 (29/06/2016)	n. 76 (03/07/2017)
Edilclima S.r.l.	EC 700 calcolo prestazioni energetiche degli edifici	n. 79 (01/07/2016)	n. 73 (15/03/2017)
Watts Industries Italia S.r.l.	Stima10/TFM	n. 80 (01/07/2016)	n. 74 (15/03/2017)
Mc4Software Italia S.r.l.	www.ape-online.it	n. 81 (01/07/2016)	n. 77 (03/07/2017)
Aermec S.p.A.	Masterclima MC 11300	n. 82 (05/07/2016)	n. 75 (15/03/2017)
ing. S. Daniele Alberti e ing. Antonio Mazzon	Lex10 Professional	n. 84 (19/07/2016)	n. 79 (03/07/2017)
Tep s.r.l.	Leto	n. 85 (19/07/2016)	n. 80 (03/07/2017)
Acca Software S.p.A.	TerMus	n. 87 (26/06/2018)	N. 82 (11/10/2018)

Beside commercial standard, the simplified institutional software DOCET [12] (developed by ENEA and ITC-CNR) is freely available for existing residential buildings EPCs, only if the net area is smaller than 200 m^2. The tool is able in printing the calculated APE, export simplified XML v.12 and the complete Italian XML v.5. Furthermore, it supports the definition of retrofitting suggestions

According to the country framework, some Regions developed their own reference software's, which however do not present significant differences with respect to the national ones, concerning the calculation methodologies. Examples include:

- CENED in Lombardia Region
- Celeste in Liguria Region
- BeauClimat in Valle d'Aosta Region
- CasaClima in Bolzano Province

The producer of a tool may update its software and maintain the validity of the verification procedure if it guarantees that the new version maintains the conformity to previously mentioned regulations. CTI has the possibility to verify this congruence.

Considering the above-mentioned list of tools, it is possible to mention that three of them have a free version (or can be freely downloaded by certifiers in a specific Region), while 89% are Commercial (in one case both versions are available). The licence cost is highly variable, considering that producers offer different commercial approaches, i.e. annual subscriptions, on-demand tickets, perpetual licences of the software, or even being available to members of the developer association. Furthermore, some of the tools are stand-alone module, while others are integrated into a software platform. These tools also differ for additional potential technical supports, such as the possibility to calculate thermal bridges or suggested retrofitting solutions automatically.

3.3.4 Use of data from EPCs

EPCs are publicly available; the mentioned SIAPE will be the national platform where all the certificates will be available. However, this step will be fulfilled in a not near future. Some Regions, conversely, have already implemented the platform, which allows for public access to APE data via their informative system.

Atypical example is SIPEE (Informative System on Buildings' Energy Performance), is the informative system of Piedmont Region, part of Sistemapiemonte provided by CSI Piemonte, the informative regional system. The system allows private citizens to have access to some EPC, in particular: 1) list of EPC assessors, 2) open consultancy of existing EPCs, using both a specific identification of the certificate or a free-searching engine. The last one lists EPCs according to locations (not GIS-based), addresses, and/or cadastre information. Each obtained record may be visualised, having access to registry data, general technical data, EP results, energy class, renewable energy sources (if present), GHG emissions, and others. This list of information may be downloaded in *.pdf or *.xls. Nevertheless, the system does not allow to visualize or download the certification report. This information detail is similar to most of the Italian Regions, for the sake of brevity and repetitiveness they are not here reported.

SIRAPE, the EPC informative system of Friuli Venezia Giulia Region, provides additional information to citizens. Each record of the EPC cadastre comes along with a photo of the building, besides general data of the building itself and EPC assessor. Also, the system provides statistics of the plus 200,000 regional EPCs; they include disaggregated data referring to EPC figures, energy class, energy performance, space heating generators, renewable sources. The informative region of Lazio Region aims, a unique case in the country, at a geo-referenced visualisation of EPC for citizens; however, this section of the platform is still under development, while some aggregated statistics until 2016 are available

3.3.5 Major shortcomings of current EPC and effort to progress towards DEPC

3.3.5.1 Shortcomings

As in most EU countries, energy labelling in its current form is performed with respect to standard boundary condition and use to evaluate the building energy efficiency quality. The actual energy use of the building may significantly vary from calculated EPC methodology due to multiple reasons, and the most important are:

- user behaviour, and operation of the building and its energy system is different from standard conditions
- weather condition is different from the standard weather file used for calculation
- calculation methodology is performed as quasi-steady state, which cannot accurately reproduce the dynamic of real use operation

Among major shortcoming of today's energy labels can be listed

- They do not provide information to take active and ongoing measures to correct energy operation of the building. Moreover, EPCs do not reward optimization of building energy operation, for example, balancing of the hydronic system, optimization of working point for pumps, or more aware definition of setpoints that would result in the decrease of actual energy use is not taken into account.
- It is widely recognised that actual energy use in low energy building is significantly higher than estimated, calculated energy use, while the opposite happens in poor energy performance buildings (so-called performance gap).
- EPC for cooling based on the mean monthly method can lead to severe errors in the energy performance assessment. Moreover, the quality of the built environment in buildings without an active cooling system is assessed by indicators, often not accurate enough to provide reliable information.
- EPC is based on quasi-steady state calculations and has limited possibility to account for passive solutions, for example, ventilative cooling, dynamic solar shading and thermal mass utilization.
- The potential of energy renovation measures is expressed in a simplified way

3.3.5.2 Effort to progress towards DEPC

The Ministry of Economic Development, together with the relevant stakeholders, is setting up a number of implementing decrees aimed at the operative implementation of EPBD III (Energy performance of buildings directive III) after the National Decree 48 of 10/06/2020 formally transposed the Directive in the country.

In parallel, dedicated bodies are working on updating the current standards for EPC (the before mentioned UNI TS 11300 series) with the implementation and national transposition of the new ISO 52000 family standards, related to the energy performance of buildings.

The Ministry funds ENEA and relevant Universities to compare and assess EPC using: 1) the current monthly mean method, 2) the hourly method implemented in the standard ISO 52016-1:2017 - Energy performance of buildings — Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads — Part 1: Calculation procedures, 3) a detailed dynamic method developed by the Polytechnic of Milan. The results of the process will lead to the EPC requirements to be officially implemented in the forthcoming decrees. Informal discussions with some involved experts highlight that it might be possible to maintain a simpler approach for residential buildings and a more accurate one for not-residential ones; while no discussions are on the floor about the operational rating for the time being. In any case, findings of the study may create room for the penetration of DEPC in Italy.

Application of DEPC in Italy may follow two tracks:

- Be introduced (even partially) in the normative framework. This would give the method the character of officialdom. This approach appears difficult to be pursued since the DEPC introduces news and advanced contents hard to be accepted in the framework set up by the relevant Ministry.

- Be adopted by relevant stakeholders. The push towards the renovation of the obsolete national building stock, the birth of energy communities and the development and spread of smart buildings/cities technology call for a more accurate prediction of energy use, comfort for occupants and optimisation of maintenance. This framework creates favourable conditions for DEPC application for Energy Service Company, and energy and facility management. DEPC may, in fact, help the development of new models based on a more realistic assessment of the building energy response and more benefits of the occupants.

- The DEPC proposed in EDYCE is a parallel labelling scheme to current EPC scheme that addresses propagation of awareness of energy use, fault detection, smarter operation of buildings/building stock, ability to track operational changes. Users of DEPC are expected to be the one who does not find current EPC sufficient to address their needs.

3.4 Greece

3.4.1 Policies and legislative initiatives

The responsibility of the implementation of the EPBD in Greece lies with the Ministry of Environment and Energy (YPEN). The EPBD was transposed to the national legislative framework with the Law 3661 of 2008 and was given effect by the Greek government through the 'Regulation on Energy Performance in the Building Sector' (KENAK) in 2010. Then it was updated in 2013 (Law 4122) in harmonization with the EPBD re-form. Through this legislation, Energy Performance Certificates (EPCs) became a legal requirement in Greece in 2011 for rental properties, and in 2012 for property sales. All EPCs are produced automatically (and stored) on a web-based platform (available at www.buildingcert.gr)

Regarding existing buildings, the definition of major renovation is set in Law 4122/2013, after being amended in Law 4409/2016, Article 49 (A’ 136). A renovation is considered as major when the total cost relating to the building envelope or the TBS is higher than 25% of the value of the building, excluding the value of the land upon which the building is situated.

The YPEN approved, in December 2015, the study of the long-term strategy for mobilizing investment in the renovation of the national stock of residential and commercial buildings (according to the provisions of EED, Article 4). The basic goal set out by this study for the year 2050 is that 80% of the existing building stock will be of high-energy performance. Five different scenarios have been examined. These scenarios consist of different mixtures of renovation types and renovation rates. More specifically, four different renovation types have been introduced:

- Low renovation that achieves 20% savings;
- Medium renovation with 40% savings;
- Total renovation with 60% savings;
- NZEB renovation with 80% savings.

New buildings or building units must meet minimum energy performance requirements set out in the “Regulation on the Energy Performance of Buildings” (KENAK) (class B). In combination with the obligation set in Law 4122/2013, these regulations ensure that every new building of the public sector, from 1 January 2019 should be NZEB. This obligation also applies to all new buildings constructed after 1 January 2021.

The preparation of a national plan for increasing the number of NZEB (according to Directive 2010/31/EU, Article 9) is on-going. The study for the definition of NZEB will:

• Define the technical characteristics of buildings with almost zero-energy consumption, taking into account national, regional or local conditions, and including a numerical indicator of primary energy use in kWh/m^{2}year;

• Set intermediate targets for improving the energy efficiency of new buildings;

• Provide information on the policies and financial or other measures taken to promote NZEB, including details of national requirements and measures concerning the use of energy from RES in new buildings and existing buildings which undergo a major renovation.

The study will provide:

- The characteristics of the national building stock;
- The evolution, through time, of the national requirements related to the energy performance of buildings;
- The energy characteristics of the buildings with nearly zero-energy consumption;
- Policies and measures to encourage improvements in the energy efficiency of buildings so as to meet the requirement that, from 1 January 2021, all new buildings are to be NZEB;
- Policies and measures to transform existing buildings through deep renovation to NZEB.

3.4.2 General information about EPC

The legal requirement in Greece that an EPC must accompany each new rental or sale transaction still remains. The only change, according to Law 4342/2015, Article 58, paragraph 3, is that from 9 November 2015, all new rentals must adhere to the unique protocol number of the EPC being inserted into the electronic platform of the General Secretariat of Information Systems of the Ministry of Finance (www.gsis.gr).

Until the end of 2016, a total number of 946,700 EPCs have been issued according to the Energy Inspections Department. In 2015 alone, 282,462 EPCs were issued. The number of EPCs, according to the reason for issuance, is presented in Table 6. The Departments of Energy Inspection has developed a web platform, which provides statistical data of the issued EPCs (available at http://www.ypeka.gr/Default.aspx?tabid=907&language=el-GR) see Figure 8.

Table 6: EPCs according to the reason for issuance.

Reason of issuance	Number of EPCs	Total area (m^2)
Sale	135,282	16,522,900.20
Rent	647,999	66,405,197.51
New and renovated building	4,556	1,473,126.44
Existing residential buildings: first energy audit for “Energy Savings in Households” program	99,374	10,703,829.78
Existing residential buildings: second energy audit for “Energy Savings in Households” program	47,354	5,135,641.40
Public school buildings: first energy audit	155	230,009.51
Public school buildings: second energy audit	30	64,009.02
Local public buildings program	2,242	1,608,124.71
Other reason	9,708	4,677,981.50
Total	946,700	106,820,820

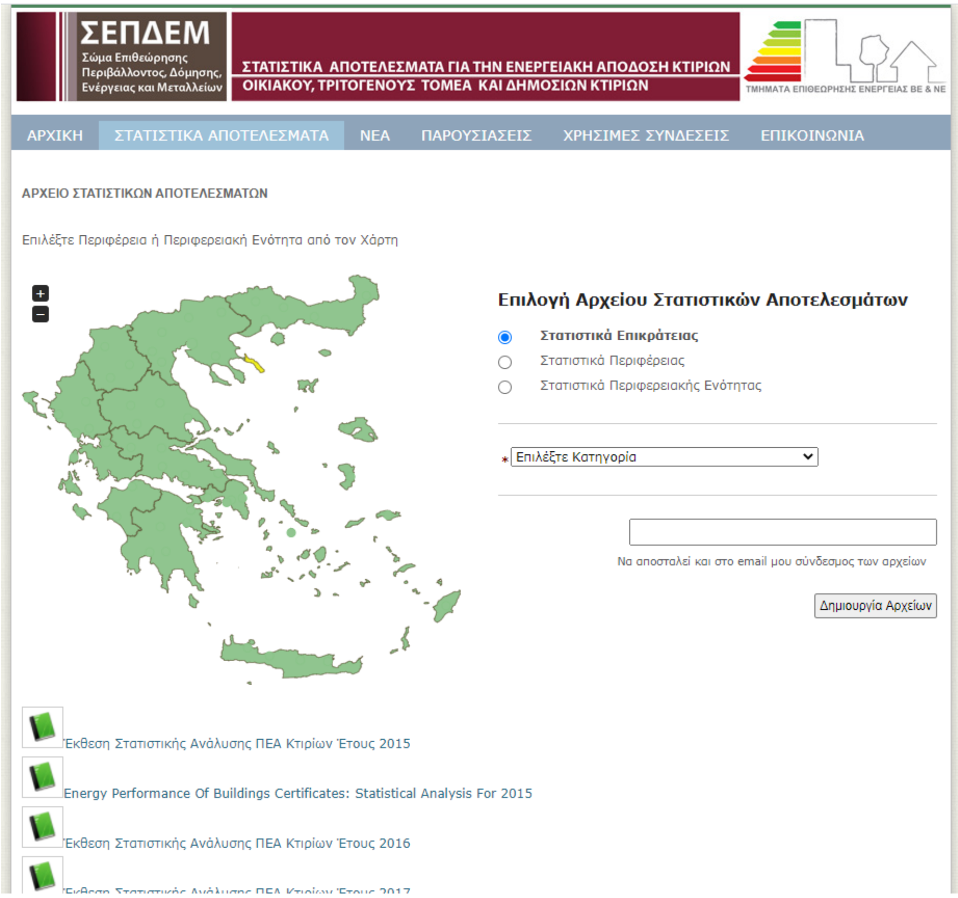

Figure 8: Statistics on EPCs (YPEN website).

In Greece, there are four different climate zones, as is shown in Figure 9. The rating of the EPC is based on these zones. An example of the EPC rating for a building block located in the A zone is shown in Table 7.

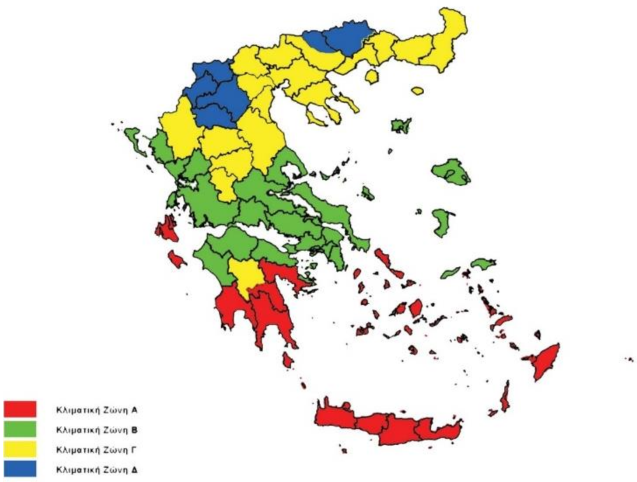

Figure 9: Climate zones of Greece

Table 7: EPC rating of a building block located in A zone

	Minimum and Maximum values of energy consumption [kWh/m²year]	
	Building Block	
	Climate Zone A	
	Minimum	Maximum
A+	55	
A	70	60
B+	95	75
B	120	105
C	135	130
D	155	150
E	185	165
F	220	200
G		240

The key information, among others that can be found in EPC, are as follows:

- The energy efficiency rating
- Energy consumption of the building
- Identify potential losses
- Recommend cost-effective practices to improve or optimize the energy efficiency
- Calculated CO2 emissions

It was decided to nationally adopt the inspection scheme (model A) for heating systems. The inspectors for heating systems perform the on-site inspection and prepare a report to assess the system characteristics, operation, size and efficiency. They also provide instructions and recommendations regarding the maintenance/ replacement of the heating system or parts of it, and other alternatives. The inspection reports are submitted on-line to the same platform used for the registration of the EPCs. Quality control procedures for heating systems inspection reports are the same as those for EPCs.

Who is allowed to issue EPCs?

Qualified energy auditors, registered in the national database of energy auditors, issue EPCs. Qualifications of auditors are defined by law; they need to be licensed engineers, Members of the Hellenic Technical Chamber or graduate engineers of technological institutes. They are classified into three categories, depending on their qualifications and proven experience in energy audits.

• Energy experts classified in the cat. A have the right to conduct energy audits in (only) residential buildings up to 250 m^2 and heating or cooling systems up to 50 kW

• Energy experts classified in the cat. B have the right to conduct energy audits, in buildings of a total surface area of 250-1,000 m^2, and Heating or AC systems of a total power of 50-400 kW. Energy experts of the cat. A can upgrade their category to the cat. B and be registered in category B, if records of at least 30 energy audits of class A are provided.

• Energy experts classified in category C have the right to conduct energy audits in all buildings, independently of size. Energy experts of the cat. B can upgrade their category to the cat. C and be registered in category C, if records of at least ten energy audits of class B are provided.

The required qualification of energy auditors and their classification in three categories was recently set with Law 4409/2016 (part 3, Article 52), approved by parliament on 28 July 2016. According to this law, the energy auditors are classified in three categories: Class A, Class B and Class C. Class A: energy auditors/inspectors that belong to Class A can perform audits and inspections for the following categories:

• Building audits for buildings or building units with a total area lower than 250 m^2;

• Heating systems inspections for heating systems with a heating capacity lower than 50 kW;

• AC system inspections for AC systems with a cooling capacity lower than 50 kW.

Eligible: all auditors/inspectors already registered in the national registry. Class B: auditors/inspectors in Class B can perform audits and inspections for:

• Buildings or building units from 250 m^2 to 1,000 m^2;

• Heating systems with a heating capacity from 50 kW to 400 kW;

• AC systems with a cooling capacity from 50 kW to 400 kW

Eligible: auditors falling under class A who have conducted at least 30 audits of Class A, 20% of which for non-residential buildings with heating systems or AC systems larger than 15 kW. Class C: auditors in Class C can perform audits and inspections for:

• Buildings or building units above 1,000 m^2;

• Heating systems with a heating capacity above 400 kW;

• AC systems with a cooling capacity above 400 kW.

Eligible: auditors that have successfully passed the examination foreseen by Presidential Decree 100/2010, in Article 9 or auditors that fall under Class B who have already conducted at least 10 Class B audits. At the end of 2016, the total number of energy auditors/inspectors registered in the National Registry for Energy Auditors was 16,858. Table 8 classifies them by type of inspections.

Table 8: Energy auditors/inspectors by type of inspections.

Category	Quantity
Building energy auditors	13,635
Inspectors for heating systems	2,589
Inspectors for AC systems	2,012

3.4.3 Tools & methods

The energy inspector electronically submits the EPC data (including all relevant information, e.g. building drawings, calculation method owner's contact details, etc.) to the Ministry of Environment and Energy, before issuing the EPC. The Ministry of Environment and Energy publishes annual reports on EPC statistics.

For buildings undergoing major renovations requiring a building permit (and also for new buildings), energy checks are performed upon completion to assure that the building is in line with the initial assessment [13]. The building must be compliant with class B or higher. In case this is not achieved, the owner is given a year to upgrade the energy performance of the building according to the recommendations provided by the energy inspector. After the upgrade is complete, a second check takes place. In case of non-compliance, the building owner receives a penalty. Only when the building meets the minimum energy requirements, it is connected to utility networks (e.g. electricity, water).

According to Article 15 of KENAK, an energy check/inspection includes the following stages: (i) the building owner assigns the check to an energy expert/inspector; (ii) the energy inspector registers the building online; (iii) before the inspection, the inspector collects the building shell and installations (architectural drawings, electrical and mechanical building installations, electricity consumptions etc.) relevant information; (iv) during the inspection, the energy auditor visits the site, collects information about the building and double-checks information that was provided by the owner; (v) calculations and analysis of the results are performed, and an energy classification based on the results is provided; (vi) the energy inspector electronically submits the data (in XML) to the Special Secretariat for the Environment and Energy Inspectorate of the Greek Ministry of Environment and Energy.

The TEE KENAK software [14], provided by the Technical Chamber of Greece, is used by the energy inspectors to issue the Energy Performance Certificates. It is also used for buildings' energy efficiency studies either for issuing a licence permits for new buildings or major renovation works. TEE KENAK was developed by the Institute for Environmental Research and Sustainable Development of the National Observatory of Athens.

Several commercial software tools (4MKENAK, Buildingsoft GoEnergy CAD-PRO, Civiltech Energy Certificate CAD, etc.), using the calculation engine of TEE KENAK, are used to reduce the workload for energy inspectors by integrating shading calculations and building drawings.

3.4.4 Use of data from EPCs

Through the development of the information system www.buildingcert.gr where the energy inspectors of buildings are entering the data of the EPCs issued, it is possible to derive national statistical results. Thus, the Ministry of Environment & Energy developed the online platform "Archive of Statistics of EPC" for the energy efficiency of the residential, the tertiary sector, and the public buildings in Greece.

3.4.5 Major shortcomings of current EPC and effort to progress towards DEPC

3.4.5.1 Shortcomings

The non-uniform application of the EPCs results in their limited reliability, compliance and market penetration, as well as their reduced acceptance by the end-users unless forced to comply, putting thus obstacles to the increase in energy renovations. Major violations were identified after on-site and electronic audits as the entry of inaccurate data, the submission of inaccurate supporting documents and the incorrect fulfilment of scientific and professional duties and incompatibilities of energy inspectors.

Some of the main barriers are:

- Low level of awareness and interest of building owners in EPC information
- Low level of credibility and acceptance of EPC as an efficient tool for building renovation
- Low fees of energy audits resulting in low quality of EPC
- Lack of regular promotional-awareness activities on EPCs and deep building renovation
- Lack of monitoring of compliance with the existing legislation on EPCs in real estate advertisement – no sanctions foreseen
- Limited funding boosting deep renovation of the building stock

3.4.5.2 Effort to progress towards DEPC

Unfortunately, there are no signs that any progress has been made towards introducing DEPCs in the sector. Nevertheless, the discussion is already in the air regarding the expected outcome of the new project funded by the Horizon 2020 Programme "X-tendo" - "*eXTENDing the energy performance assessment and certification schemes via a mOdular approach*" [1], where the National Laboratory of CRES is participating. The project aims to improve compliance, reliability, usability and convergence of EPCs, through the new generation of energy efficiency assessment and certification, expected to introduce new ideas and methods also.

Some main success factors are:

- Quality control of EPCs and energy auditors
- Competences of energy auditors / Regular training
- EPC databases allowing for implementation monitoring and identification of gaps

- Friendliness of EPC
- The usefulness of EPCs recommendations in deep renovations
- National programmes providing incentives (financial / fiscal) for building renovation

3.5 Summary on EPC in E-DYCE member states

3.5.1 Policies and legislative initiatives

In the four Member States that partake in E-DYCE, all of them have made several initiatives to follow the European Directives and to reach the ambitious goals set by these same Energy Directives. In some of the E-DYCE Members, these new energetic policies are imposed in national level, as it happens in Denmark and Greece, but in Switzerland and Italy, the implementation of the new legislation is a responsibility of the countries autonomous regions and cantons. It is seen in all Members a strive to improve the EPC schemes and implement stricter rules in order to reach the EPBD and national goals of energy efficiency. Also worth mention, that national plans of the different E-DYCE countries are moving towards NZEB, renewable energy sources and to increase the renovation rate on their existing buildings stock, through public subsidies and reducing taxes.

3.5.2 General information about EPC

In all E-DYCE Members, the EPC always meant to inform the owner about the building's energy efficiency and its impact on the billing as well as to encourage him to undertake in renovation measures to increase the efficiency. In Denmark, Italy and Greece, the EPCs when performed are uploaded to a central database, where it stores all the information from the assessment. In Switzerland, it is mentioned in the guidelines that there is a central database, but the details regarding this national recording process are not clear. For the case of Denmark and Greece, the data regarding the EPC data is single managed by a national association by following the same national protocol. Where in Italy, its Regions can have their own method or follow the national EPC scheme, but all the audited EPCs are sent to a central database managed by the Department for Energy Efficiency of ENEA.

Concerning the key information present in the EPCs:

- Denmark displays in its EPCs the general building's information and description, e.g., owners name, year construction, type of building, etc. The energy efficiency rating is a label with a letter where A represents the best energy performance and G the worst energy performance on the EPC rating scale, calculated energy usage, calculated CO2 emissions and a list of recommended improvements and the estimated cost to undertaking them.
- Switzerland has three types of EPCs (known as CECB), the standard CECB, the CECBplus and the CECB Nouveau Bâtiment. The main difference between them is that the first two are used to assess existing buildings, and the last one is to be used to evaluate new constructions. The CECBplus is similar to the standard CECB but has appended in the report additional advice for renovations to be taken. The CECB, similarly with the Danish EPC, presents a similar energy efficiency rating from A (best performance) to G (worst performance). Most of the information provided by the Swiss EPC is similar to the Danish EPC but more detailed.

The Italian and Greek EPCs are similar to the other Members in terms of displayed and calculated parameters, e.g., CO2 emissions, energy consumption, list of recommended measures of improvement for a renovation, etc. Also, both countries are divided into groups in terms of the different weather conditions measured in the areas, and for each group, the building characteristics requirements and energy consumption intervals for labels are different. The difference of these countries is that Greece, as the Danish case, determines its energy rating label regarding the buildings energy consumption per m^2 per year. Where the Italian case, the EPC is performed by comparing the assessed building with a reference building with the same geometry, and the rating is attributed by calculating the primary non-renewable global energy performance indicator of the building and comparing with the reference one.

3.5.3 Tools & methods

In Denmark, the EPC scheme consists of two parts, Part 1 – small buildings and Part 2 – large buildings with more than 1,500 m^2. The calculation of the energy performance follows the methodology of the SBi and the different Danish standards. The result is given in kWh/m^2year, and the energy label is attributed regarding consumption by the type of building assessed, e.g., residential house, office, hospital, daycare, etc. The tools used to perform the calculation are Be18 [5], Energy10 [6] or Ek-Pro [7]. The tool used to determine the energy efficiency must be approved before by the Danish Energy Agency.

In Switzerland, the EPC (known as CECB) is calculated in a building regarding its categories, e.g. hotel, residential (individual and collective), school, etc. The EPC methodology varies in the different cantons, where the Geneva canton is known for the calculation of the heat consumption index, IDC standing for *Indice de Dépense de Chaleur*, which is the yearly specific heat consumption per m^2 of the heated surface.

Regarding Italy, the EPC methodology is based upon the Italian technical standards to calculate the building’s heat balance by considering the space heating, domestic hot water, mechanical ventilation, space cooling, electric lighting, transport of people and goods (the latter two do not apply to residential buildings). Due to the inexistence of a certified national tool, several institutions and companies can develop their own tool, if verified and accredited by the Italian authorities according to the energy requirements. Besides these commercial tools, it is also freely available a simplified institutional software DOCET [12], that can be used to issue EPCs for small existing residential buildings. Some of the different Italien regions also have their own software, which does not have significant differences from the existing national commercial software.

In Greece, the EPC is performed and issued with TEE KENAK software [14], a national tool provided by the Technical Chamber of Greece. Besides this software, there are other commercial tools available, that integrate the calculation engine of the TEE KENAK and combine it with other calculation engines, in order to upgrade the EPC algorithm with other features, e.g., solar shading calculations and uploading the building drawings.

3.5.4 Use of data from EPCs

In Denmark, the EPC results are publicly available. The information displayed is the energy label, as some general information of the building and the investment costs to undertake an energetic renovation and predicted energy label that will be achieved after the renovations. The complete dataset of the EPCs can be only fully available to research institutions and EPC assessors.

In Switzerland, the information displayed in the EPCs is not publicly available, the access of the information of a specific building it is only disclosed to the owner and the EPC assessors. In Geneva, for example, it is only possible to access public geographical data from the buildings, e.g. energetic indices, enabling, therefore, the public administration, private companies or researchers to analyse individual buildings, group of buildings, a particular owner building stock or the whole canton heat consumption.

Concerning the Italian EPCs, they are publicly available, and it is currently being developed a national platform where it will standardise and store all regions EPC information in one place. This due to the different Italian regions presents this information on different levels of detail. In Greece, it is possible to consult the statistical studies derived from the EPCs issued in the different Greek regions, for different types of buildings.

3.5.5 Major shortcomings of current EPC and effort to progress towards DEPC

3.5.5.1 Shortcomings

Respecting to the Danish case, it is identified significant differences between the predicted energy consumption from the EPCs and the real consumption. This difference has different causes, where the most significant are the user behaviour, different system's operation than predicted, the considered weather conditions for the calculation are not the same as the real weather conditions, and the steady-state methodology is not accurate enough to quantify the dynamic building's operation. It is also demonstrated that the current EPCs do not provide enough information to correct the building's systems operation, e.g. balancing the hydronic system, change of the working setpoints, etc., are not able to estimate accurately the impact of passive solutions which are an important component on the NZEB buildings and have large validation period (10 years), where during this timespan other building refurbishments might be undertaken and therefore increasing even further the difference between the predictions and the real energy use. The other E-DYCE Members also mentioned these shortcomings from the EPCs. However, it is also highlighted by some the lack of information regarding the economic advantages of an energetic renovation for the case of existing buildings the EPCs are too much based on experts' assumptions and experience, which will affect the final result. Moreover, it is also mentioned the poor quality that some EPCs are issued, by being mostly made of default comments and values, instead of real on-site/building descriptions and measurements by the assessors.

The current EPCs also present limited reliability and non-acceptance by the end-users in the Member countries, due to violations by the EPC certifiers and inaccuracies with the inserted EPC parameters, causing a reduced renovation rate.

3.5.5.2 Effort to progress towards DEPC

Regarding the DEPC, due to the considerable shortcomings mentioned above regarding the current EPCs, a parallel labelling scheme is proposed in E-DYCE where it addresses propagation of awareness of energy use, fault detection, smarter operation of buildings/building stock, ability to track operational changes.

To implement in Denmark this new scheme it is required an active involvement of the Danish Energy Agency to develop the required structures to support the approach. From the DEPC scheme, it is predicated to deeper the knowledge concerning energy modelling, increase the monitoring features and their quality. It is purposed that the first entities to integrate this scheme, as a voluntary approach, are the social housing associations to improve the building energy assessments and renovation plans. In the other E-DYCE Members, it also has been advancements from the government and the authorities to fund research programs to improve the EPC scheme, e.g. Italy. In Switzerland and Greece, it is not mentioned any real proposal, but it is revealed that this type of scheme is already being discussed in terms of what can bring for the future of the energy performance assessment.

4 Emerging EPCs - innovations and future of EPC

In this chapter is described the on-going initiatives which aim to improve the current EPCs. It is listed some European programs and their published reports.

4.1 Innovative elements

Since the Energy Performance of Buildings Directive 2002/91/EC was released, the EPCs were used in the several EU Member States, where different methodologies were designed according to the Directive standards. These standards were updated, and its requirements become stricter and more holistic after each Directive amendment. Still, according to relevant studies and the response received by the different countries, it is seen that the EPCs that are used currently must be updated to contribute for the real decrease of the country's energy consumption and solve the shortcomings listed above. To reach the improvement of the EPCs, several methodologies are being studied and developed; these new solutions are the following:

4.1.1 Real energy consumption

In most of the EPCs, the building's energy performance is assessed by considering all the energy consumed and produced. In a building, the major energy consumers are building-related utilities, e.g. heating/cooling, ventilation, lighting, domestic hot water (DHW) production as well as plug loads and electric vehicle charging spots. In the studies [15,16] it is shown that a significant difference between the measured energy performance and the calculated energy performance exists, this difference is defined as "performance gap". In Figure 10, it is observed the performance gap in the EPCs of several houses in a Danish [16] and Swiss [17] study-case:

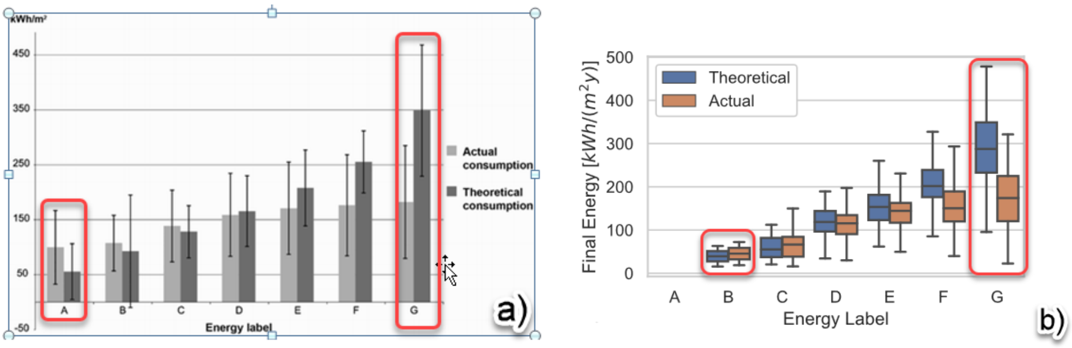

Figure 10: Performance gap observed from a large sample of buildings a) Danish case-study [16]; b) Swiss case-study [17].

Firstly, in the figure, it can be observed that the most significant difference between theoretical (EPC) and actual energy performance (measured) occur either for the very well performing buildings or for the very bad energy performing buildings. Secondly, statistics indicate that bad performing buildings actual performance is significantly better than theoretical and therefore, actual energy savings due to energy renovation should be anticipated lower. In these buildings, thermal comfort and use of the building is expected compromised to compensate for high energy bills. The same conclusion was also withdrawn for a Dutch case study [18], where the theoretical and actual measurements of energy consumption through gas and electricity were compared, and it seemed that buildings with poor energy performance had smaller energy usage and the high-efficient buildings were consuming more than predicted.

For the third, NZEB buildings (category A) perform in reality significantly worse than expected. In principle, it is not expected to energy renovate these buildings as they represent state-of-the-art thermal performance. Here more focus should be paid to malfunction of systems and correct operation of the building, including training user behaviour towards energy performance awareness. In these buildings, thermal comfort is expected higher than assumed in standard calculations.

For the forth, buildings in the middle of the labelling range, that is category C, D and E represent a relatively good agreement between theoretical and actual energy performance. In these buildings a compromise between cost operation of the building and maintained thermal comfort reflect good agreement with boundary assumptions for standard calculations. Still rebound effect related to energy renovation of these buildings should be closely observed. Another interesting observation is that energy, although the performance of these buildings is very similar (both theoretical and actual), these buildings end up in three different energy labels. Especially for the actual energy performance of these building, one could shift their place, e.g., from label E to D or opposite respectively rewarding or punishing positive and negative energy performance in operation.

The “X-tendo” report [19] highlighted that the occupant behaviour, the lack of measurements of the outdoor conditions regarding the period when it was calculated the energy performance and the difference between the technical installation/characteristics used in the design phase and the actual one at as-built phase are the main reasons for the existence of the performance gap. It is also pointed out that another factor that leads to this difference is the usage of default, or standardised, values by the experts when elaborating the EPC instead of using the real required values. This conclusion is also corroborated by the German study-case [20], where it was investigated on the site three buildings, where all have in total 90 apartments. The study was based on high-resolution measurements of the thermal indoor environmental conditions, air quality conditions and energy usage in different building’ levels in order to measure the energy performance gap and detect which are reasons to such a difference between the theoretical and measured values. In Figure 11, it is seen a schematic of the expected and real values before and after the refurbishments and the main reasons found behind the performance gap.

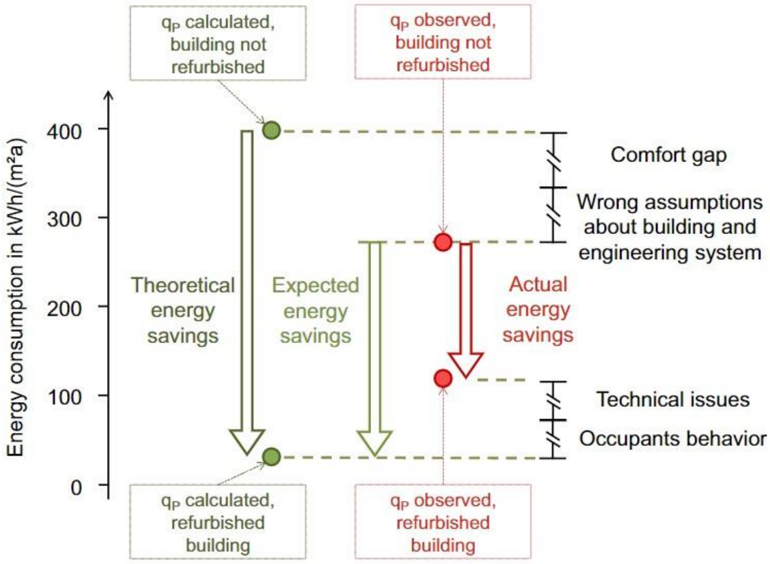

Figure 11: Schematic of the performance gap observed in the German study [20].

As seen, the study concluded that the different energy usage before the renovation was mainly due to users' behaviour (they prefer to save energy and money instead of being comfortable, therefore consuming less than predicted – comfort gap) and wrong assumptions regarding the installed systems or building's characteristics. Moreover, the performance gap encountered after refurbishment was justified by technical issues, e.g., water calcification of the DHW heat exchanger, high DHW distribution losses and malfunction of one the installed heat pumps, and also occupants preference on certain system conditions, e.g., higher DHW temperature setpoint than designed.

One of the solutions for the performance gap problem is by integrating the actual energy consumption in the EPC, allowing to achieve a deeper understanding of a building's energy performance as well as assessing other possible solutions to increase the overall correct performance. The data can be withdrawn from the smart energy meters, building energy monitoring systems (BEMS) and recorded energy bills. By having these information datasets, it is also possible to aggregate them with other information datasets, e.g. weather, building and installation characteristics, socioeconomic traits of the occupants, to analyse and correlate them with the performance results.

4.1.2 Smart readiness indicator

One of the new parameters that can be displayed in the EPCs is the smart readiness indicator (SRI). This indicator was introduced in the 2018 amendment of the EPBD [21]. However, the planning of using smart metering devices was already introduced in the EPBD 2012/27/EU and is idealized to measure the buildings' capacity to adapt its operation regarding the users and grid demands by using the information from its installed measuring devices. In the EPBD 2018/844, it was established that by December of 2019 the Commission should supplement the Directive with an optional Union scheme for rating the smart readiness of buildings. The indicator shall take into consideration the aspects of energy savings, benchmarking and system's flexibility, enhanced functionalities resulting from more interrelated and intelligent devices. Regarding its methodology, it may have the following functionalities:

- Maintain the energy performance and building's operation through the adaptation of energy consumption using energy from other sources.

- According to the occupant demands, adapt its systems' operation while maintaining healthy indoor climate conditions, being user-friendly available and able to report the energy use.
- Adjust the building's overall electricity demand in relation to the grid, by using active and passive as well as implicit and explicit demand response.
- Positively influence of existing communication networks, in particular the existence of high-speed-ready in-building physical infrastructure, such as the voluntary 'broadband ready' label, and the existence of an access point for multi-dwelling buildings, in accordance with Article 8 of Directive 2014/61/EU of the European Parliament and of the Council.
- Be interoperable with the different systems installed, e.g. smart meters, building and control systems, built-in home appliances, self-regulating devices of indoor air temperature and indoor air quality sensors and ventilations.

In June of 2020, the European Commission published a final report [22] where it presents a set of two studies that provide technical support to establish a common methodology and an implementation of the SRI by European Commission and the Member States. The results of this work is a flexible and modular multi-criteria assessment methodology to evaluate a building's SRI by its technical scope and its impact on the building. The result from this report is three methods (A, B and C) that can be used to calculate the SRI of a building. The two first methodologies differentiate in complexity where methodology A is more straightforward to implement due to the assessment is less detailed, which is destined for residential buildings. Moreover, methodology B is a more thorough evaluation, and it is aimed to be used in non-residential buildings. These methodologies were applied to different facilities in several EU countries, and the results were mostly positive. Both methods had similar overall SRI results when used on the same building, in which some of the impact scores evidenced high differences between methods. Both methodologies when applied may take less than 4 hours, according to feedback received, but this is without considering commuting to the building site, administration, intake discussions as well as most of the assessors were familiar with the buildings, and it was not a requirement to collect evidence or documentation to append in the SRI assessment. As the general result of the methodologies testing, it was considered positive, but further studies and applications are required. The method C was not developed in [22], but it was idealized as a metered/measured dependent methodology that self-reports the building's systems functionalities, quantifies the actual building's performance and assists the methods A and B. From E-DYCE, the resulting outcomes can be used as knowledge for the future development of this method C of the SRI, due to its connection with smart meter data.

The approach used to evaluate the smart readiness of a building must be simple enough to facilitate its aggregation and application on an EPC, it has to provide concise information regarding the buildings while presenting solutions that will increase the SRI and consequently its energy performance. It must also be versatile to be applied to different types of buildings.

4.1.3 Interaction with district energy system – smart meters role

According to [23,24] the district energy solution integrated with other renewable energy systems is one of the best alternatives to replace the fossil fuel-based systems; therefore this is a feature that most of EU Member States are planning to execute. Due to its importance, it is necessary to attach to the EPC schemes, indicators that assess the interaction between the building and the district network and on increasing the awareness of the building owners, tenants, builders or designers for the implementation of this type of solution.

With the integration of smart energy meters and by having access to the real energy consumption complemented, it is possible to display in the future EPCs, the building's interaction with the district energy system.

The report "X-tendo" [19] presented two different sets of indicators to measure the impact of the district energy system has on the energy performance certificate. The first set consists of three indicators, which are the primary energy factor (PEF), the renewable energy factor (REF) and the carbon emission factor (CEF). These three indicators provide information on the DEPC concerning the impact of the building's heating and cooling demands on its primary energy consumption, renewable energy production and carbon emissions.

These three factors can be calculated through the equation (1) given by the standard EN 15316-4-5:2017 or through other methodologies used in other European countries:

$$f_{we;des} = \frac{\sum_{cr} E_{in;cr} * f_{we;cr} - E_{exp} * f_{we;exp}}{\sum E_{del}} \quad (1)$$

$f_{we;des}$	Weighting factor of the energy system
$E_{in;cr}$	Energy content of the energy carrier supplied to the system (cr)
$f_{we;cr}$	Weighting factor of the energy carrier (cr)
E_{exp}	Energy emitted to an external system or external network
$f_{we;exp}$	Weighting factor of external energy
E_{del}	Total delivered energy

The second set consists of three indicators, which are three measured district energy system parameters, necessary supply temperature and expectable return temperature in the distribution system flow and the measured flow rate. These three parameters are used to point out the efficiency of the heat supply system in the building.

All in all, the first set is used to understand the building's energy performance indirectly, but also it is useful to measure the performance of the district network. The second set is more focused on the end-user categorisation, due to its dependency on the building characteristics and heat distribution/transfer systems, as seen in Table 9:

Table 9: Indicators to assess the existing interaction with the district energy system.

Set	Indicator	Description
District network performance	Primary Energy Factor (PEF)	Measures the impact of the building's heating and cooling demands on its primary energy consumption.
	Renewable Energy Factor (REF)	Measures the impact of the building's heating and cooling demands on its renewable energy production.

	Carbon Emission Factor (CEF)	Measures the impact of the building's heating and cooling demands on its carbon dioxide emissions.
Building's energy performance	Supply temperature	Measured supply temperature.
	Return temperature	Measured return temperature.
	Fluid flow rate	Measured fluid flow rate.

4.1.4 Passive solution assessment

Another feature that must be taken into account when evaluating a building's energy performance is the designed passive solutions in a building and their impact on the overall energy consumption. A passive solution in a building is based on the concept of using the natural resources to guarantee the building/users demands in terms of heating, cooling, ventilation and lighting. In the following list is presented some possible passive solutions where the energy performance is dependent:

- Solar heating: this solution meets the heating needs by warming the building taking into the advantage of an indoor greenhouse effect. By having large glazing areas (windows) that absorb the incident solar radiation, most of the heat will be accumulated indoors, which will increase the room temperature. This solution is dependent on the building's orientation, outdoor/indoor shading and the glazing characteristics.
- Natural ventilation: it is based on the outside air that enters the building through the opening of windows, allowing to renovate the indoor air and cooling the room. The efficiency of this solution is based on the building's architectural layout, outside-inside pressure and temperature difference, amount of air openings and their size and the building's location.
- Daylight: this solution takes into consideration the dispersal of outside light into the building. This solution is highly dependent on the building's architectural layout and geographical location, the type and size of the windows, external conditions, outdoor/indoor shading and interior surface. By guaranteeing adequate levels of daylight, it will promote the less use of artificial lighting, e.g. lamps, decreasing, therefore, the energy consumption.
- Thermal mass: This solution is not a passive system, but is complemental with the other solutions, e.g. solar heating and natural ventilation. The thermal mass is a building's characteristic based on the properties of its construction materials and enables the building to accumulate energy, as inertia, against the outside temperature fluctuations. By determining, in the EPC, the building's thermal mass will lead to a better comprehension of the energy performance throughout a period of time.

Due to the high focus on the nearly zero-energy buildings, where the energy consumption is significantly low, it is necessary to integrate as much as possible of passive systems while ensuring that the energy and indoor quality needs are met. By having several passive solutions designed in a building and because all of them are connected to each other and with other active systems that might exist, it is crucial to assess all of these systems and the impact they have on the energy performance.

4.1.5 Highly dynamic technologies assessment

These types of solutions are highly dependent on the building's layout design as well as the outdoor microclimate conditions, which makes every building individually singular and holistically dynamic, in terms of energy. Therefore an EPC scheme must be developed where it is possible to assess all these particularities in a building and evaluate dynamically how the different active/passive solutions interact with each other. In passive solutions, which use natural resources, are often used dynamic technologies that act accordingly with the outdoor climate changes. The devices that are usually installed in the buildings are the following:

- Dynamic shading: Constituted by indoor/outdoor blinders or facades, which change their position according to the solar radiation and/or the temperature to control energy consumption and daylight.
- Double skin facades / Ventilated walls: This solution underlies on controlling the admission of outdoor air or the extraction of indoor air by a space gap between two windows (double skin facades) or a window and a wall (ventilated wall). Often these solutions are constituted of dynamic openings (dampers) that open/close regarding the indoor/outdoor temperature difference, solar radiation or ventilation needs.
- A phase change material (PCM) as thermal mass: This passive dynamic solution is based on the building's thermal mass definition by using a PCM material. This type of material besides storing sensible heat it also accumulates the latent energy, responsible for the phase changing process. By installing this material in buildings, it reduces, even more, the indoor temperature difference fluctuations and has a significant positive impact on energy consumption.

On top of these, with the implementation of these solutions or other HVAC systems, it is incorporated a system control strategy which is difficult to mimic in dynamic simulations for EPC purposes. As seen, all of these dynamic technologies are highly advantageous in terms of energy performance and indoor comfort, but they all have the disadvantage of being extremely difficult to calculate or implement in a dynamic simulation tool.

Therefore for the EPC scheme, it is mandatory to understand the impact that these solutions have on the overall energy performance, this can be achieved by a set of benchmarked factors that can be applied to all kind of assessed buildings and by drawing meaningful conclusions from the measured data. These factors will depend on which adopted solution, system or control strategy is in the building and represents the weight that has on the energy performance. Moreover, the assessment of these technologies and their correctness of operation can be quantified indirectly, for example, by analysis of indoor climate parameters and energy use of heating/cooling system operation (or opposite by free-running mode (FRM) operation of the building – no activation or no need for installation of mechanical systems).

5 Usability of current EPC

In this chapter is described the usability of the current EPCs schemes in the different Member States, highlighting the main advantages and disadvantages of the EPC application in terms of energy consumption prediction, financial impact before and after retrofit and owners/tenants influence in the renovation process.

As stated before, the EPBD is a European Directive that was published in 2002 and required from the Member States to implement the given requirements in their national level accordingly with their legislation. From the Directive, the EPCs have been used to analyse the energy efficiency of buildings, and due to being mandatory the attribution of an EPC when a building is constructed, sold or rented to a new tenant or that it is a building where a total useful area is over 250 m^2 occupied by a public authority and frequently visited by the public. Then numerous EPCs were issued until present contributing to have a deeper level of information regarding the building's energy performance. Since the implementation of these new set of regulations, several studies were carried on to investigate the methodology, results and impact that the energy performance certificates have in the different European countries.

In Amecke (2012) [25], it is explored how effective is the EPCs to support the German house owners to decide to incorporate energy efficiency as a decision factor for their purchasing and identify the factors that corroborate the current positive and negative results for the EPC. In other words, it is investigated how the EPCs influence the owners in purchasing a house**. The study revealed that most of the owners had a high general understanding of the EPCs, but few of them used the energy certifications when considering to buy a residential property**. The main reasons for the owners to not consider the EPC when buying a house are:

- **the lack of trust in the certificate's information**

- **the absence of information regarding the financial implication that a high energy-efficiency building has, compared with a low energy-efficiency one** (the buyers usually consider that energy efficiency has small importance compared with other criteria, e.g., location, investment price, building layout, etc. in the overall decision).

The study focused on a sample of owners that purchased existing buildings until 2009, but it is stated that the influence of the EPCs might have increased when the EPBD 2010 is fully implemented in Germany.

In Denmark, Christensen et al. (2014) [26] investigated if the EPCs issued in the country had an influence on the practices of Danish homeowners regarding energy retrofits. From a sample of 743 cases, it was concluded that the **EPC is reliable and easy to understand** by the owners **but not useful as an information source for home renovation**. The study stated that an EPC is considered to have **too much general information, and it does not present practical advice** that can be used to implement in the building. Therefore the EPC is incapable of encouraging the renovation of buildings. The study also presented that usually the renovations made in a building improve the energy efficiency, however, **the reason behind the retrofit was not related with the energy consumption, but the user's comfort, aesthetics, etc**. From this work, it was suggested to improve on the EPC by estimating the renovation's investment cost, to append a list of reliable tradespersons to undertake the renovation and to present several measures that are based in comfort and buildings' aesthetics which will promote the increase of energy efficiency.

In Hardy and Glew (2019) [27] was investigated the errors detected in the EPCs issued in the United Kingdom. The study was based on the fact that the UK issued over 15 million EPCs in the country, but has the reputation of containing **different types of errors in the certificates**. As seen in the studies before, one of the **important aspects of an EPC impact is the level of trust of the population regarding the certificates**, in which by having a bad reputation, it might affect the public openness negatively to undertake a building renovation. In this work, the detected anomalies were categorized into five different groups, where each of them is divided into subgroups. These groups are concerning EPCs with duplicated data, buildings that have different characteristics comparing with former issued EPCs, reduced energy-efficient components on the new EPCs, etc. From this study, it was discovered that many of the mistakes are due to the certifiers disagree on building characteristics, e.g., floor type, wall type, etc. It was also discovered that the type of building that has more mistakes is the flat and maisonettes. Regarding the true error rate in an EPC, it is estimated to be between 36 to 62%. By analyzing the EPCs, it was also estimated that a building with errors might impact the Energy Efficiency Rating by ±4 points, which means that 30% of the buildings might have the wrong energy label. By having mistakes in the building and systems characterization and wrong labels, it induces in the creation of a wrong list of possible retrofit recommendations. The study proposed several measures to overcome this issue by changing the current criteria of the EPC audit to more specific cases, the creation of a system that checks the information given in an EPC with the former information to detect any discrepancy and the use of Machine Learning algorithms to detect and change these errors. These errors that are stated in this work have significant consequences in the list of recommendations that are usually appended in an EPC as well as the energy performance gap, which has been detected in last years when comparing the theoretical energy values with the overall measured consumption.

From the recommendation list of measures (RLM), it was investigated by Gonzalez-Caceres et al. (2020) [28] the barriers and challenges of the RLM under the EPBD scheme in Denmark. The recommendation list proved to be an indispensable tool to contribute to the building retrofit and its increase in energy efficiency. It also showed, even though it is a great tool, it does not have a common format in the Member States, as well as the new EPBD, did not improve this EPC component. These studies also corroborate the arguments made in [26] by naming the main reasons why the EPC is not having a significant impact on promoting building renovations. The complexity associated with a retrofit, lack of awareness in the retrofit benefits and the lack of trust in possible financial benefits is some of these reasons. The study highlighted some barriers that the current RLM has, where is seen the low quality of recommendations, the existence of the performance, informational and financial gaps and the lack of enforcement. It is found that some of the RLM are too obvious and general, which consequently do not present a clear plan for the renovation. The **several gaps mentioned as barriers are the performance gap (the high difference between the energy consumption estimated by the EPC and the real consumption measured by smart meters and energy bills), information gap (some of the presented terms in an EPC are too technical for the owner) and the financial gap (the absence of financial analysis in the RLM concerning the recommended implementations, in terms of costs, incentives and payback time)**. And also, the distrust of banks regarding the EPC being a documented insurance to attribute a loan for retrofit. The lack of enforcement is also highlighted as an obstacle to overcome, due to some EPCs are issued without any recommendation list of measures; therefore the list should be enforced in the future EPCs to improve their quality. This study also presented some improvements for the RLM that should be taken into account for the future of the EPCs. It was stated that the RLM should have some generic recommendations; however, it should also have some tailored-made suggestions of renovations for the building assessed. It was also suggested to overcome the performance gap by the creation of guidelines in the EPBD to set minimum requirements regarding the EPC assessor training, the field inspections, to control the EPC assessment costs (for not being too low compromising, therefore, the assessment's quality) and the tools used to perform an EPC, e.g., software used. It is also proposed the creation of financial schemes to promote the investment in building retrofitting and the execution of detailed profitability analysis in the EPC.

Regarding the energy performance gap, several studies were made to investigate in the depth of this subject. It was found that the **main reasons for the existence of this difference between estimative and calculated values are the lack or inaccurate knowledge of input variables of building physics by the**

certifiers, the uncertainty regarding the weather measurements and a poor occupancy behaviour model for the type of building. Behind these reasons, it can also be listed several inaccuracies during the EPC calculation, e.g., expected indoor temperature, U-values in the building facades, ventilation air change rate, airtightness level, default values for the space heating, building's thermal inertia (thermal mass), solar gains and its solar shading system/control and ultimately, the existing faults and malfunctioning of the systems integrated into the building. By having this level of uncertainty in the EPC calculations, it increases the uncertainty of the possible energy savings consequently after a renovation, as well as the measures described in the RLM and the retrofit's payback time.

In Cozza, et al. (2020) [17] it was investigated the existing performance gap from the Swiss Cantonal Energy Certificate for Buildings database (CECB). In this study, it was used a sample of 1172 buildings where their data (theoretical and measured) is respecting before and after retrofitting. From the given dataset, it was seen that the existing gap before retrofitting is -23%, meaning the actual consumption is lower than the estimated. It is also seen that the highly-efficient buildings (B and C labels) have a lower difference between the values and the gap between the low-efficiency buildings (F and G labels) is higher, where the actual energy consumption is much lower than the one predicted by the EPCs. In this study, it was also assessed how some variables in the CECB database influence the performance gap. It was concluded from this analysis that the variables strongly predict the theoretical consumption, but do not sufficiently predict the actual building's energy consumption. This might mean that the variables are inaccurate or that **other hidden variables have a more substantial influence to estimate the actual performance**. The building's energy label, heating system, the different façade components' U-value are some of the variables used in the regression analysis. From the results, it was concluded that energy labels cause great uncertainty to predict the energy consumption tending to overestimate the actual consumption. It was also seen that the **heating system is a variable that does not cause a performance gap**. And in the building characteristics level, **it was concluded that the U-values from the opaque envelope contribute more for the performance gap than the U-values of the windows**. This might be, due to the level of detailed information required before retrofit of the opaque elements is much lower, causing, therefore, a higher uncertainty, than of the glazed elements.

6 Economic studies regarding EPCs and building renovations

6.1 Premises

The knowledge of the real estate market, in terms of demand and supply behaviours dynamics and pricing processes, represents fundamental support for energy-environmental-economic sustainability.

Recently, some studies focus on exploring the effects of the technological and physical-technical characteristics, and, furtherly, of the buildings energy performances (these last represented for example through the EPC) on the pricing processes and consumers' demand behaviours. The dynamics of consumers' behaviour are deeply analysed in the scientific literature and the real estate economics researches, given the importance of their impact on the market, not only in terms of willingness to pay for buying/renting houses but also in terms of availability to invest in retrofit interventions. For example, Charalambides et al. (2019) [29], implemented a study for exploring the effects of EPC on buildings' renovation: the authors investigated upon aspects able to act as "key drivers " or "barriers" in retrofit investments mobilisation. More specifically, as illustrated the authors, in the context of the European

Project ENERFUND (Horizon 2020 Programme), two online questionnaires were submitted to European citizens of twelve Member States; from these emerged that (among other aspects) on average EPCs are able to influence the rent/buy decisions and renovation intervention decisions in the residential segment. The results of the survey showed that EPC plays a limited role (the authors deeply discuss the reasons), considering that the results, as underlined in the article, are sensibly variables between the different countries and according to the age of the groups. As reported among the results, male respondents indicated “Energy cost/efficiency” (with another parameter), as the main reason for home renovation.

Widely explored is the potential influence of the buildings energy performance as a green attribute on the real estate properties prices - assuming of course that the location attribute confirms its great importance as emerges, traditionally, in the real estate analysis literature.

On the background, studies and researches on topic assume the European regulatory framework, starting from the first European Directive 2002/91/EC (Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings, Official Journal of the Communities), or Energy Performance of Buildings Directive – EPBD, up to the last European Directive 2018/844/EU (Directive 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency).

Notice that, among these regulations, the Directive 2010/31/EU with the Guidelines accompanying Commission Delegated Regulation (EU) n. 244/2012 of 16 January 2012 (supplementing the Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings by establishing a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements), is particularly interesting under an economic viewpoint. In fact, by introducing a comparative methodological framework for calculating the optimal levels in the function of costs for minimum requisites of the energy performance of buildings and building elements, it opens the way to studies aimed at exploring the application of the optimal cost methodology, assuming the Global Cost calculation as a fundamental step. In some of these studies, EPC labels calculation in relation to the energy and economic performance of buildings is considered (see, for example, Becchio et al. 2016 [30]).

6.2 Literature

The literature about the effects of EPCs on the real estate market prices and dynamics is consistent and, at the time being, the topic is widely explored as the growing literature demonstrates.

In the following subsections, some studies and researches are mentioned, with reference to the European/international context. For a matter of clearness, the studies are presented in two groups: a first one includes references which refer to a “first-period” of literature production (approximately concentrated after the publication of the EPBD), and a second group refers to the most recent years’ literature.

6.2.1 First-period literature

From the literature produced in the first period, closest to the publication of the norms and regulations on the energy performance of buildings, the following considerations emerge.

In general, in some studies emerges that “not energy-efficient” buildings have lower selling/rental prices than the “energy-efficient” ones. In other studies, the researches reveal that energy performance had not the effects on market prices/rents as it would be expected.

Brounen and Kok (2011) [31], in the Netherlands, in their study, presented the first evidence about the economic impacts of EPC in the European Union. The relationship between EPC label and sale price was studied at large scale, by considering a dataset of 177,000 housing transactions. Summarizing the illustrations of the authors, the results showed that dwellings with a “green” label were sold with a premium of 3.6%, in relation to “non-green labels” dwellings. Afterwards, Kok and Jennen (2012) [32] presented a study focused on rental prices for commercial properties in the Netherlands. As reported by the authors (among the other results), the buildings with an EPC label lower than D had 6.5% less than energy-efficient buildings with labels A, B or C. Rodrigues et al. (2012) [33] in their study showed that, in the UK residential market, the EPC had started to impact on the market, even if – as underlined by the authors - consumers were not yet willing to pay for energy-efficient building. Successively, a report produced by the European Commission (2013) [34], presents the results of several researches focused on the effect of EPC on prices in the real estate residential sector. The Authors of the report underlined that in several European countries and increase in prices/rents was associated with how long the EPCs were mandatory and that in general was found an increase in prices in relation to EPC labels. Afterwards, Eichholtz et al. (2013) [35], in their study, referred to commercial properties in the United States’ real estate market. As they reported, the study demonstrated that, for green buildings, an increase in energy efficiency was monetized into rents/asset values. Hyland et al. (2013) [36], referring to the Ireland real estate market, presented a study on the effect of energy efficiency levels on selling/rental prices. As the authors reported, the study showed that energy efficiency had a positive effect on prices. Furthermore, the authors underlined that they found a stronger effect of the energy rating in the case of worse market conditions (notice that, as indicated in the article, it was the first study considering, among other aspects, the market conditions). Cajias and Piazolo (2013) [37] produced research in which, as illustrated, the energy price premium in the German residential segment is quantified: as reported in the article, “the authors provide evidence that energy efficiency in the residential sector is a relevant factor affecting both tenant investment decisions and consequently the performance of investor portfolios”. Högberg (2013) [38] analysed a sample of houses in Sweden and found that better energy performance influenced positively selling prices. The author highlighted that EPCs “provide new information and measure energy performance more exactly than many earlier (proxy) variables”. Kholodilin and Michelsen (2014) [39] by analysing the same market segment in Germany showed that energy efficiency savings were monetized into prices/rents. Cerin et al. (2014) [40] explored the contribution to price premiums of mandatory EPC of residential properties, in Sweden. As the authors evidenced, it was found a property price premium for energy performance for houses built before 1960, and for houses with a lower transaction price. Davis et al. (2015) [41] measured the effect of EPCs on residential property values in Ireland: among the other results, the authors reported that “the results indicate a small but positive relationship between better energy performance and higher selling prices”. Fuerst et al. (2015) [42] underlined that their study allowed to found a positive relationship between the mandatory EPCs and the transaction price related to a large-scale dwelling sample, in England. Furthermore, Fuerst et al. (2016) [43] explored the effect of EPC on residential prices in Wales. As reported by the authors, “statistically significant positive price premiums are estimated for dwellings in EPC bands A/B (12.8%) and C (3.5%) compared to houses in-band D. For dwellings in band E (−3.6%) and F (−6.5%) there are statistically significant discounts”, and also “Such effects may not be the result of energy performance alone”.

Contrarily, in previous studies by Fuerst and McAllister (2011) [44], the authors found no evidence of the EPC label effect on market rent/prices, for the commercial segment. Amecke (2012) [25] analysed the support of EPCs for including energy efficiency into the buying decisions in Germany and found that the effect of EPCs is limited. Feige et al. (2013) [45] analysed rental prices of residential dwellings in Switzerland: as reported, they found a negative relationship between energy efficiency and rental prices. Murphy (2014) [46] explored the real estate market in the Netherlands; as the authors reported, the results showed a weak influence, particularly in the phase before the transaction. Zalejska-Jonsson (2014) [47] explored the Sweden context: as the authors illustrated, environmental (and energy) building performance had a low impact on the selling/renting decisions.

In a broader international context, Deng et al. (2012) [48] analysed transactions in the Singapore housing market involving green and non-green properties in the residential segment, showing that economic revenues to green buildings were substantial. Deng and Wu (2014) [49] investigated the price effects of the Green Mark certification in Singapore between 2000 and 2010. As the authors illustrated, they found that the market premium was not far from 10% at the resale stage, and to about 4% during the presale stage.

In Italy, in the first period here considered, the impact of the EPC on prices is poorly studied, and even fewer studies are conducted on the impact of EPC on transaction (selling) prices (notice that in Italy transaction prices are not public information and are difficult to observe).

Morri and Soffietti (2013) [50] analysed the market premium in Italy through an online questionnaire. They found that the importance of green buildings was recognized, even if the greatest part of respondents conceived a correlation between increases in rent/price premiums and an increase in costs. Bonifaci and Copiello (2015) [51] studied the impact of EPC on listing prices of residential properties in the city of Padua (Northern Italy). They found a positive relationship between buildings with higher EPC and residential prices, but a stronger relationship between lower EPC labels, than between higher ones.

Other studies are focusing on the city of Turin (Northern Italy). Two of them are developed in the context of the activities of the Turin Real Estate Market Observatory of the Politecnico di Torino (Curto and Fregonara, 2016; 2019 [52,53]). In the first Study, Fregonara et al. (2014) [54] aimed at investigating the economic effects related to the energy performance of building on listing behaviours. The study tried to measure the impact of the EPC labels on listing prices, for analyzing it as a significant aspect able to influence dwelling prices. The work started from preliminary assumptions: listing prices and dwellings characteristics are the initial and fundamental information considered by sellers/buyers during a first preliminary analysis; the real estate advertisements can be considered as the first step of a house transaction (Robertson and Doig, 2010 [55]; Semeraro and Fregonara, 2013 [56]). A data sample (577 listing prices collected in Turin in the year 2012) was analyzed through a log-linear Hedonic Regression Model, applied through Hedonic Regression Analyses[1]. The results demonstrated that for a low level of EPC (EPC label F), is found a significant influence, even if low; the same results are confirmed by modelling

[1] For describing and interpreting the real estate market dynamics, and for detecting the influence of buildings/dwellings features on pricing processes, the Hedonic approaches solved through the Multiple Regression Models are well explored by the scientific communities. From the second half of the Sixties, a widespread literature is produced for exploring the Hedonic Prices Method, starting from the fundamental work by Rosen (1974) [59] in which the author explores the Hedonic function, for detecting the price determinants in the real estate housing properties.

EPC labels clusters. In the following study (Fregonara et al., 2017 [57]) the impact of the EPC was analysed not only on dwelling prices, but also on market liquidity, considering the time on the market, and the difference between listing prices and transaction prices ("delta prices"). A subsample of old buildings (879 transactions of old apartments in Turin in the period 2011-2014) was considered. The study showed that low EPC labels (E, F and G) were priced in the market but explaining only 6-8% of price variation. Including the principal dwelling characteristics in the model, EPC labels had no impact on prices (the G label is weakly significant). A final focus on buildings of the period 1940-1989 confirmed the previous results.

The results of the two mentioned Turin's experiences suggest the presence of latent variables able to catch the explicative power of EPC. In the second study emerges clearly the influence of the building construction period on pricing processes and on-demand/supply dynamics, obviously jointly to the assets location. This point is even present in recent literature, as mentioned below.

6.2.2 Recent literature

In recent years, a growing literature on the topic has been produced. Some representative studies, according to a methodological and analytical viewpoint, are mentioned below[2].

Chen and Marmolejo-Duarte (2019) [58] presented a Spatial Error Hedonic model for analysing prices of multifamily houses in Barcelona (Spain), in the period 2014-2016. The study explored the differences between dwellings whose energy efficiency impacts on prices formation and dwellings whose energy efficiency does not influence pricing processes. It was assumed that in some studies, the increase in the relevance (marginal price) of EPC ratings is not constant but variable in view of the specific EPC label. They analysed the differences in terms of architectural and location attributes between dwellings that present an increase in EPC marginal prices, and houses for which EPC seems not relevant on pricing. The following points summarize some of the aspects (among the others) emerging from the study, illustrated and discussed by the authors:

- in general, there is a correlation between spatial and houses characteristics, and the attributes can reveal a weight varying in function of the building location (spatial effects)
- the energy premium is not uniform when in the presence of a segmented market: the impact of energy characteristics is different in different submarket (these last have to be preventively defined)
- buildings for which the price increases as it increases the energy performance rating are characterized by sets of attributes that are different from the buildings non-affected by the energy performance rating, in different submarkets: specific attributes in different submarkets have a different impact on dwelling prices
- architectural attributes and location contributions to the green premium must be carefully explored
- there is a correlation between the EPC rating influence on prices and the dwelling quality.

[2] According to a methodological viewpoint, recent studies are exploring the use of Spatial Econometrics, by means of Spatial Regression Models (Spatial Lag Models or Spatial Error Models), and spatial autocorrelation analyses (i.e. Moran's Index, Local Indicator of Spatial Association – LISA), due to the presence of "spatial effects". Centrality is posed on the treatment of the spatial dependence in data and on the criticalities generated by spatial autocorrelation. Several studies compare the results obtained through traditional Hedonic Models and Spatial Econometric Models.

Dell'anna et al. (2019) [60] presented a work developed in two research projects[3]: a comparison between two European cities - Barcelona (Spain) and Turin (Italy) – which belong to two different climate zones. Listing prices of residential properties were analyzed with Hedonic Prices Method and Spatial Econometric Models (Spatial Autoregressive Model and Spatial Error Model), with the aim to explore the contribution of green attributes on marginal prices. Different results were obtained and illustrated in the study; for example, in Italy, EPC is more relevant than in Spain, where single characteristics are more appreciated. The authors of the paper deduced, from the results and the literature analysis conducted, important aspects. The following points summarize some of these aspects (among the others), illustrated and discussed by the authors:

- it is difficult to compare the impacts of EPC on prices in different European countries. The implementation of EPC schemes is still irregular in the European States.
- the consumers' behaviours related to the EPC are variable, according to different factors (building stock, economy, time, location, climate zones)
- methodologically, the introduction of location effects in analyzing green labels is confirmed as a fundamental step (necessity to integrate the Hedonic Prices Model with Spatial Econometric Models)
- the Hedonic Prices Method should guarantee a high level of completeness, even if the sampling problem limits the comparability of the results
- the literature that presents studies on the influence of EPC on the real estate properties prices, by means of Hedonic Methods, is wider in Northern European countries than in Southern European countries
- a limited number of studies consider the effect of location on the real estate market prices in exploring green labels (the authors define EPC as "a synthetic indicator of intrinsic variables" that is spatially variable)
- the greatest part of the literature considered (referring to the results presented in it) reveals the presence of a willingness to pay by consumers for houses' green attributes, and a limited number of studies reveal low/null EPC effects: a green premium for buildings in best energy labels exists
- the effect of EPC on prices is different in European countries.

Besides, other recent studies can be mentioned. For example, Bisello et al. (2020) [61] analyzed a dataset of residential listing prices in Bolzano (Northern Italy) aiming at exploring if local real estate markets react to EPCs, by means of a Hedonic Prices Method and its spatial specification. They found an increment in prices (price premium) of 6% moving from EPC label G to EPC label A (being equal all the other attributes). They also found a spillover effect on the nearby real estate properties (defined by the authors in terms of "additional co-benefit of retrofitting"). Still, in Northern Italy, a study conducted in the city of Milan (Tagliabue et al. 2019 [62]), explored the EU Directives capacity, as the authors said, "to steer the real estate market" through the attribution of an energy rating to buildings, as was done by energy-efficient products. The results, as reported by the authors, showed that in Milan, a significant correlation, even though low, between location, energy consumptions and prices of residential buildings is present. In Marmolejo-Duarte et al. (2020) [63], the authors investigated the motivations upon which a green

[3] Research Project "EnerValor - How much do we care about the residential energy performance? An analysis of the level of EPC understanding, perceived confidence, and impact on residential preferences and values", Universitat Politecnica de Catalunya, Barcelona, Spain. Research Project "VALIUM - Valuation for Integrated Urban Management", Politecnico di Torino).

premium for energy-efficient dwellings founds. Through the Contingent Valuation approach applied for analysing the willingness to pay by consumers in Barcelona (Spain), they found that generally, people are not aware of the EPC scheme. Furthermore, as underlined by the authors, they found that people tend to consider dwellings' energy performance and architectural quality as the same. Besides, they underlined the importance of EPC communication. The necessity to increase awareness and dissemination about EPC policy is confirmed in Khazal and Sønstebø (2020) [64], in a study on the EPC in the residential rental market in Norway, in which the authors found as they illustrated, a premium in prices (increasing by increasing the EPC label). Furthermore, Wilkinson and Sayce (2020) [65] through a paper review of the literature/quantitative studies developed in Europe, found that the greatest part of the studies has been conducted by means of Hedonic Prices Methods. The studies considered by the authors allowed them, as they reported, to deduce that the academic studies show, generally, a positive relationship between EPC (considered as a proxy for efficiency) and market prices, even if the outcomes are variable. The authors explained that "whilst there is some evidence that energy efficiency is beginning to impact on value, it is small compared to other value drivers".

There are also other studies that even though not published yet, they seem promising to correlate the economic perspective on the EPC and buildings renovation. In Geneva, it has been developed a formulation to measure the rentability of a refurbishment in this Swiss canton, taking into consideration all the expenses, fiscal incentives and public subsidies. By calculating the renovation's rentability, it can be displayed in the EPC this value and be used consequently to convince the owner to undertake in the renovation. Also at Aalborg University, it has been developed a study where it is evaluated the investment cost of different renovation measures and the actual decrease in energy consumption. With this methodology, it will be possible to highlight which are the best refurbishment measures in terms of low investments cost and high energy savings and therefore present them to the owner.

6.3 Conclusions

In conclusion, given that the before mentioned studies start from real estate market prices (which can reflect real estate property values), the results represent a different perspective in comparison to other studies based on typological elements, and in which the structural, technological and physical-technical viewpoint prevails.

For stimulating investments for the energy retrofit of buildings the information about energy consumptions is fundamental, and, for this reason, the EPC could play a key role for buyers/producers/developers in their decisions.

7 Conclusions and recommendation

In Europe, it was seen in the last years a great effort to improve the energy efficiency in buildings in order to decrease European energy consumption. From these efforts, it was released several European Directives, Energy Performance in Buildings Directive (EPBD) and Energy Efficiency Directive (EED), that set high the energy and constructive requirements in the building sector for the different Member States. In these new requirements, it was originated the Energy Performance Certificate, that is an evaluative methodology designed to estimate a building's conditions, in terms of, yearly energy consumption, CO2 emissions, renewable and non-renewable energy share, etc. and therefore catalogue and distinguish it regarding its overall operating performance.

Since the implementation of the EPCs in the different Member States countries, several studies have been developed to understand the impact of this assessment on the European and national level. These studies have been showing that even though the EPCs a good tool to be used, it has several shortcomings, and its impact on increasing the EU existing buildings' energy performance has not been as positive as initially predicted. The shortcomings found in the EPCs can be listed below:

- The actual energy use in low-energy buildings is significantly higher than estimated, and for high-energy buildings is significantly lower than calculated, this phenomenon is known as the energy performance gap.
- EPC is based on steady-state calculations and has limited possibility to account for passive solutions, for example, ventilative cooling and thermal mass utilisation.
- They do not provide sufficient information to take active and ongoing measures to correct energy operation of the building.
- They provide the only fraction of information on renovation rate of existing building stock as they are issued/updated only when the building is advertised for sell or rent. As a result, there might be a large gap between actual building stock condition and conclusions based on statistics that rely on EPCs inputs.
- The EPC is too simplified and dependent on several expert assumptions and national standards that might not be the correct ones.
- The lack of economic indicators, e.g. profitability, that may assist the owners in the process of decision-making of embarking in the building's renovation.

Therefore, due to the numerous shortcomings of the current EPCs, a new scheme is necessary in order to reach the ambitious European energy goals. One of the existing projects that aim to develop this new EPC scheme is E-DYCE**. In E-DYCE, innovative approaches will be combined with established and available tools to create a methodology capable of implementing scalable, adaptable and accurate dynamic energy performance certification (DEPC). Moreover, the objective of E-DYCE is to propose labelling methodology that will deliver a living outcome that will be able to follow the operational performance of the building. The ultimate goal is to obtain a scenario in which savings and other benefits triggered by DEPC could incentivise building owner effort to reach out for DEPC.** The E-DYCE Member countries are **Denmark, Switzerland, Italy and Greece**. Where in all of these countries it has been identified several of the current EPC's shortcomings, but as well as developed several studies and projects that will contribute to the DEPC scheme. The main characteristics of the DEPC are:

- Focused on **more realistic, trustworthy certification, with minimal investment from the end-user.** Assessing and labelling a building's energy performance **based on its free-running potential in combination with dynamic simulations is innovative**, only by virtue of being a drastically different approach from conventional steady-state EPCs. **Frequent measurements of**

performance (minute or hour resolution) or real-time data collection is the most consistent guarantee of reliability, especially once the models are optimised.

- **Smart dimension of buildings will be illustrated for both passive operation and simple but smart metering and actuating of building systems.** E-DYCE is designed for applicability throughout the smartness spectrum, also considering traditional, heritage, low-income and other "low-tech" buildings.

- **Evaluation of the buildings will be carried out with respect to its thermal envelope quality, systems (heating and cooling) demand, operation time and efficiency and readiness for simple but efficient smart metering and actuation.** As a consequence, the feedback about the building expected demand can be provided to the electrical and heating network for **optimisation of their operation.**

- **Evaluation will be based on agreed parameters and key performance indicators, including energy and comfort aspects.**

- **Will contribute to recommendations for standards and compliance tools, including free-running buildings.**

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