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E-DYCE - Dynamic approach to the dynamic energy certification of buildings

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Abstract. The energy performance certification (EPC) scheme, introduced in the European Union approximately 20 years ago, has become the focus of the upcoming revision of the Energy Performance of Buildings Directive (EPBD). Despite its widespread use, the current EPC scheme has several shortcomings that need to be addressed. The Energy flexible DYnamic building Certification (E-DYCE) project has developed a dynamic approach to address these issues. The methodology includes a dynamic assessment of a building's energy needs and comfort conditions under standard and different from standard conditions of building use to support Performance Gap (PG) analyses. The E-DYCE approach includes a dynamic building performance simulation with comfort and energy-related key-performance indicators (KPIs) measured and calculated according to E-DYCE DEPC methodology. These KPIs can inform end-users about indoor environmental quality conditions decisive for building energy performance, aid building managers in detecting dysfunctions resulting in PG, and include energy performance indexes for heating, cooling, lighting, domestic hot water, and more. Overall, the E-DYCE approach offers dynamic, reliable, and customer-tailored information and optimization possibilities to end-users while potentially resolving known shortcomings of the existing EPC schemes.

1. Introduction

Energy used in buildings accounts for 40% of the total energy use in the European Union (EU) and takes a significant share of the carbon emissions in the European Union (EU) [1]. The Energy Performance Certification (EPC) schema for buildings was introduced by the Energy Performance of Buildings Directive (EPBD) about two decades ago as a mean to provide transparent information with respect to the energy performance of the building stock [2]. Since then, the EPC has grown in importance due to continuous evolution upon EPBD recasts. In 2010 EPC was a mandatory requirement when constructing, selling, or renting a building or dwelling. Then, in 2012 it was added the requirement for EPC when advertising any property placed on the market for sale or rent, and in 2018 it was issued an amendment to Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency to improve transparency and quality of EPC.

Despite its widespread adoption, the current EPC schemas also have shortcomings that need to be addressed [2]. This work aims at introducing the dynamic approach to energy performance certification of buildings developed within the Energy flexible DYnamic building Certification (E-DYCE) project, which can potentially resolve known shortcomings of the existing EPC schema and, at the same time, offer dynamic, reliable, and customer-tailored information and optimization service to the end-user. Due to the space limitation, only the key elements of the E-DYCE approach will be introduced in this paper. First, a short literature review summarizes the shortcomings of current EPC schemes and highlights the potential of moving towards more dynamic evaluation schemas. It is then followed by the methodology, which describes the overall structure of the E-DYCE approach and the function of its specific elements in resolving some of the shortcomings. Finally, the implications of the E-DYCE approach are presented in the conclusion section.

2. Literature review

Energy labeling schemas that rely on steady-state calculation modesl have clear advantages. They require minimal information and rely on standardized procedures, which reduces the risk of assumption errors and they can provide comparable and reproducible results without ambiguities in algorithms and input/output data [3] and without an extensive simulation effort. Nevertheless, the implementation of EPC varies significantly across EU Member States, resulting in its limited reliability, compliance, various market penetration and user acceptance [4]. In this regard, the main open issues are identified in recent publications and are related to their inability to address the free-running potential of buildings where mechanical systems (cooling/heating/ventilation) are not installed [5]. This refers to heritage buildings, residential and small office buildings in southern Europe and other building typologies in the periods when the mechanical systems are switched off. In this regard EN ISO 52016–1 and EN 15265 regulations already suggest incorporating dynamic simulation tools, such as EnergyPlus or similar into the evaluation of buildings' energy performance to enable a more accurate assessment of a building's energy efficiency.

The effectiveness of building automation and smart technologies in reducing energy demand in buildings has been demonstrated by research [2]. However, most national energy performance certification tools do not account for the impact of these technologies and innovative systems [6]. The potential contribution of smart technologies can take on various forms, such as providing data to differentiate between space heating (SH) and domestic hot water (DHW) production, while the total use is normally metered and reported within the current EPC schema [7]. In addition to reducing energy demand, smart meters can provide insights into the performance of building systems, such as measuring return temperature in heat networks to determine the effectiveness of heat transfer in end-devices and much more. They can also gather data on the indoor environment to introduce new key performance indicators (KPIs) that cover aspects of indoor environmental quality, which are currently underrepresented in EPCs [2], but appear in high demand among the end-users [4]. Other studies also indicate an end-users need to see an EPC that presents the real energy consumption rather than an estimated value [4].

Furthermore, the performance gap within EPC schemas, is another aspect that deserves mentioning. Multiple studies address it in terms of definition, but also as a "prebound" and "rebound" effects [8]. Though in general, it is linked to the adoption of simplified steady-state approaches, the use of standardized data in simulations and interaction between occupants and technologies.

Finally, the fact that EPC cannot explain the development of the building energy performance over time makes it unable to support the evaluation of the measures planned to optimize the energy performance of a building [1] and have shown to be insufficient to motivate renovation among the end-users [2]. The above-mentioned shortcomings of current steady-state labeling approaches (EPBD 2018 Directive) are addressed in E-DYCE DEPC framework which is introduced in the following sections of this manuscript.

3. Methodology

The E-DYCE certification is proposed as a voluntary schema, which is anchored in existing EPC legislation and focuses on Performance Gap (PG) detection and actions to its' subsequent reduction by comparing operational building performance against the simulated performance upon selected performance indicators, including energy, indoor environmental quality, and free running. Furthermore, the E-DYCE methodology opens up a possibility to address the building's energy performance development over time; therefore, it can better support evaluating the renovation measures planned for the building. All of these functionalities of the E-DYCE DEPC scheme and the data-flow are managed through an E-DYCE platform by connecting calculation and elaboration modules. The platform is essential for managing operational ratings and evaluations and supports the performance gap detection, including semi-real time results. The platform is developed using the FusiX middleware and includes a web-service and a mobile app returning to monitored and simulated outputs and KPIs to different categories of end-users.

Two main profiles of the end-user are considered. (1) Experts, e.g. engineers performing energy certification analyses, professional building owners, and building operators with sufficient technical background). The E-DYCE framework will augment certifier capabilities to perform dynamic analyses on the energy behavior of buildings. Meanwhile, the professional building owners and administrators/operators often hold the same or nearly the same competencies as the energy certification party and represent large housing associations, where the tasks of energy analyses and optimization of the building operation are performed in-house rather than outsourced. (2) non-experts, e.g. tenants and owners of small buildings and single flats. These end-users will benefit from the E-DYCE framework by receiving information about the building's actual operation, push notifications on semi-realtime operational suggestions and recommendations about planning renovation actions.

3.1. PREDYCE

PREDYCE (Python semi-Realtime Energy DYnamics and Climate Evaluation) is a Python library that can act as a dynamic simulation platform, adopting EnergyPlus as simulation engine [9]. Its architecture is based on EU H2020 project E-DYCE (893945), while extra functionalities and scenarios of use are based on project PRELUDE (958345). It comprises three core modules and an EPW compiler, which allow flexible automatic handling of weather and building model inputs thanks to a managing input JSON file and to compute a large set of KPIs also on structured, monitored data.

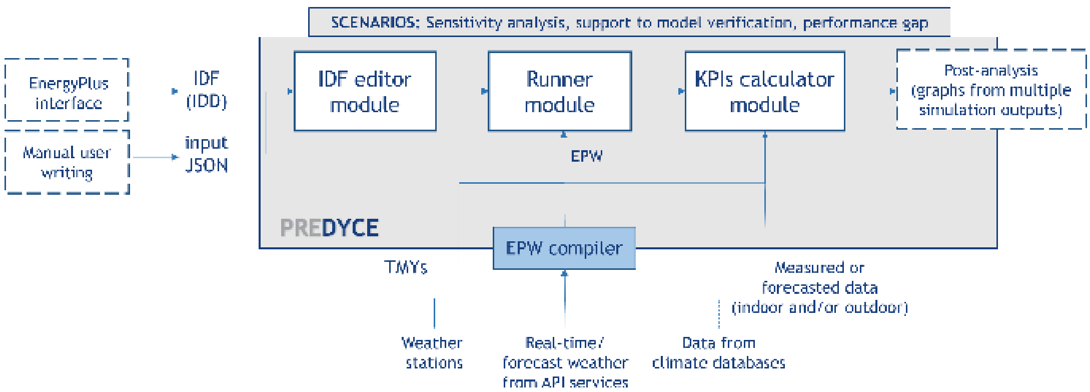

Figure 1. Overview of PREDYCE structure.

Figure 1 highlights how these modules are organised in pre-defined scenarios, including sensitivity analysis, support to model verification, and performance gap detection. Two main outputs in CSV format are returned reporting period-aggregated and timeseries KPIs, with definable timestep, e.g., hourly, including the ones needed for the DEPC application. At present, the library cannot perform geometrical changes, not including a CAD interface. Hence, it requires an initial IDF generated through one of the available EnergyPlus interfaces as input. Finally, even if automatic graphical outputs are provided for some KPIs, more complex graphical elaborations could come from post-analyses based on the library outputs.

Inside the E-DYCE project, PREDYCE acts as a dynamic simulation platform connected to both the project Middleware and manual REST API functionalities. It is used for sensitivity analyses supporting model verifications and retrofitting studies. Furthermore, it allows performing performance gap calculations connecting verified models with monitored data inside the FusiX platform.

3.2. Performance Gap and adapted conditions

The performance gap is defined as the difference between the operational (real) and theoretical (simulated) performance of a building. The reduction of PG in E-DYCE is addressed in two steps. First, is the application of the dynamic calculation engine EnergyPlus to overcome the current inability of steady-state energy labeling approaches to accurately reflect the dynamic conditions inside and outside the building. Second, the differentiation of occupancy, loads, schedules and set-points in the models is introduced to better describe the dynamic behavior within the building.

In E-DYCE, if nothing is known about the building use and operation, standard conditions (acc. to EN ISO 52000-1 and EN 16798-1) are assumed for computing PG. However, if additional information about the building use is available, then the model can be adapted accordingly, and the PG is then calculated for a more representative scenario of the building use and operation, in this publication named as *adapted conditions*. These are defined as conditions that, to a certain degree, anticipate the actual building use and operation (Figure 2). The adapted conditions can be established by, for example, incorporating the knowledge about the national or local operational tradition from national standards or guidelines, performing an inspection of the building, conducting a survey, or extracting the information from the smart meters in the building (i.e. settings for the set-points). In E-DYCE, the definition of the *adapted conditions* is supported by the inspection plan.

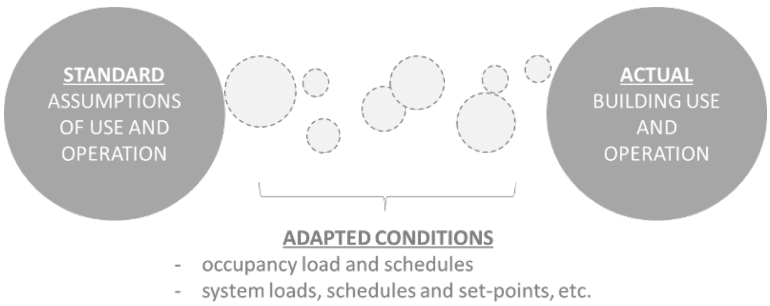

Figure 2. An illustration of adapted conditions in relation to standard assumptions and the actual building use and operation.

3.3. Inspection and monitoring plan

The inspection and additional data collection methods in E-DYCE are introduced to ensure any building can be submitted for E-DYCE procedure. The primary function of the inspection plan is to ensure that any supplementary information compulsory for setting up an EnergyPlus (dynamic) model for the building is available. The inspection plan systematises the information so that standard EPC calculation can also be performed to serve as a reference. The outcome of the inspection has a format of several Excel sheets describing different elements of the building, such as general building information, building envelope and its relevant properties and dimensions, building systems and their characteristics, etc. The novelty in the E-DYCE inspection plan lies within its systematic inclusion of information on the dynamic parameters of buildings, which can be collected either for the entire building or broken into individual rooms/spaces.

Availability of the operational data is the key to the E-DYCE concept and PG assessment. Therefore, the degree of building instrumentation defines the extent of achievable PG analysis for certain KPIs. If existing monitoring solutions are insufficient, additional instrumentation of the building must be considered according to guidelines within E-DYCE monitoring plan.

3.4. Key Performance Indicators

E-DYCE DEPC must be able to provide necessary information to the end-users, to emplace the above-mentioned capabilities. Several families of KPIs are selected for the E-DYCE DEPC process (energy operation, energy signature, comfort/quality and free-running operation). Nevertheless, the E-DYCE DEPC approach is dedicated to accurate energy performance evaluation. Meanwhile, the primary purpose of comfort/quality KPIs lies in identifying conditions that cause the performance gap, which can potentially be eliminated. Optimally, the performance gap caused by operational thermal conditions is evaluated using the energy signature. On the other hand, the presence of over-or underventilation is undesirable in buildings. Thus, the air quality-related KPIs can, for example, support identifying these issues within the building and adjusting its operation to eliminate the PG.

- *Energy operation KPIs* include the energy needs in the building in a distributed format to identify which type of energy needs causes the performance gap. Given the nature of the simulation tools and modules used in E-DYCE, only the energy demand for heating/cooling and the electricity demand for lighting and for running (some) technical systems in the building can be calculated. Calculating the energy demand for Domestic Hot Water (DHW) is not possible in Energy Plus models nor in most other similar tools. However, the operational energy from DHW for dwellings can be estimated using the methodology developed in E-DYCE [7], where the monitored data from the smart heat meters are separated into two shares: energy demand for heating and the energy demand for domestic hot water.
- *The energy signature of a building* (or building zone) to ease the evaluation of the performance gap and the seasons it occurs by identifying, in parallel, the critical spaces or spaces with drifting behavior.
- *Comfort/quality KPIs* include thermal comfort and air quality characteristics during the heating, cooling, and intermediate seasons. Besides the time-series of operative temperature in the spaces, the thermal comfort is evaluated using Predicted Mean Vote for the heating/cooling season (calculated acc. to ISO7730). In the intermediate season, when no mechanical cooling or heating is used (or in buildings that are not equipped with HVAC systems), the adaptive comfort model, according to ISO EN 16798, is used to calculate the number of hours in the different comfort categories for each space (room, apartment, or the whole building). The air quality is characterized by the time-series of monitored/calculated CO2 concentration. In addition, two KPIs are introduced to characterize the number of hours the occupied space is exposed to overventilation (i.e. CO2 level below 600 ppm) and/or underventilation (i.e. CO2 level is above 900 ppm).
- *Free-running operation* KPIs [9] can address issues in the certification of low-tech buildings but also can be used to support passive strategies application in all types of buildings (also mechanically operated buildings).

3.5. Renovation roadmaps

The availability of verified dynamic model(s) of the building allows performing retrofitting studies using the PREDYCE tool, where a large pool of simple retrofitting actions can be tested with regards to the above-mentioned KPIs and can support the users in selecting, planning and financing the renovation actions.

4. Conclusions and policy implications

The E-DYCE DEPC was developed using the existing assessment schemas (EN ISO 52000-1) and by employing the static EPC as a benchmark. The anchoring in the current EPC rating means that the E-DYCE methodology can serve as a supplement to the existing certification schema rather than a competitor. As a result, E-DYCE certification does not create a new label but instead aims to identify causes of the performance gap (PG) and support improvements for energy demand reduction, which can ultimately lead to PG elimination.

In the E-DYCE DEPC approach, the total energy demand becomes less important, as the focus is shifted towards the distributed demands, such as energy demand for heating, cooling, domestic hot water, artificial lighting, etc. These demands can be evaluated with a different degree of detail or can even be left out if the data necessary for their specific evaluation is absent, ensuring high flexibility of the methodology.

The E-DYCE DEPC process generates information to augment certifier capabilities to perform dynamic analyses on the energy demand of buildings, to provide an incitement for the potential improvements of the building, to detect faults in operation and drifting behaviours, and to recommend renovation actions. The information generated through the E-DYCE DEPC process varies depending on the information that is fed in but also depends on what information is actually valuable for the end-user. Overall, the E-DYCE DEPC has the possibility to address some of the significant shortcomings of static EPC schemas.

Presently E-DYCE methodology is being tested with the project and applied in several demonstration buildings, whereby the information fed in and generated upon application of the E-DYCE DEPC procedure is under evaluation. Thus, test results will help refine the approach and ensure its effectiveness.

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