PHD TESIS

CONTROL METHODOLOGIES OF ENERGY PERFORMANCE CERTIFICATES

DATA QUALITY ASSESSMENT IN THE BASQUE COUNTRY AND LEARNING FROM EXPERIENCE TO MAKE IMPROVEMENTS

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Abstract

The energy performance certificate (EPC) is the core source for the EU to obtain information about its building stock energy efficiency level and then plan the energy targets paths. In addition, it is used to declare the level of energy efficiency for building sale or rent, compliance with regulations and minimum requirements for obtaining renovation aids. For all of this, ensuring the EPC data quality is essential.

The EPBDs required Member States (MSs) to establish an independent control system for the EPC. In Spain, the autonomous regions are responsible for its regulation and thus, the Basque Country has its own system. The Laboratory for the Quality Control in Buildings (LCCE-*for its acronym in Spanish*) of the Basque Government is one of the accredited bodies for performing the control activity. It is from this laboratory numerous EPCs checks have been carried out for this thesis.

Despite initiatives to improve the quality of the EPCs, studies have shown that the inaccuracy of many of them is a fact. Without measures to enhance the EPCs quality, public distrust in European strategy could raise and the continuity of this could be at risk.

In consequence, in order to get better quality results in EPC database, this thesis aims to contribute improving the Basque Country independent control system and making the control procedures implementation more effective. For that purpose, it is necessary to learn from previous experience, to know the effectiveness of the system and to observe where there is potential for improvement.

Hence, a continuous and iterative methodology has been adopted in this thesis. After exposing the control performance of EPCs (Chapter 3), an exhaustive analysis of control results has been realized in order to obtain the feedback of the experience (Chapter 4, 5 and 6) and finally, some improvements proposals have been exposed.

At first, in Chapter 3, an overview of the control campaign in the 2014-2019 period has been presented. The control protocol stablished by LCCE, which is based on documentary review and on-site inspections, has been carried out in numerous EPCs and from them control results data have been collected in a representative 146 EPC sample.

After that, an accurate analysis of collected data has been performed in three parts. In the first part (Chapter 4), the EPC sample quality is assessed, and a statistical analysis has made possible to extrapolate sample results to the Basque Country EPC database. The results obtained prove that not only inaccuracy exists but also there is an increasing trend. Nevertheless, approximately as many EPCs present a positive deviation as EPCs have a negative one. It suggests that at least half of EPCs were not made deliberately by wrongdoing.

In the second part (Chapter 5), an assessment of EPC subsamples data quality has been carried out. By this study, some guidance for the most effective EPC control selection criteria have been achieved. It is impossible to control 100% of the EPCs, so it is necessary to have a selection criterion capable of filtering out the EPCs with most of the errors. The results suggest that the EPCs with the highest nrPEC (e.g. existing buildings or tertiary building) have the poorer quality. Moreover, it has been shown that the automatic checks methodology could be an effective way to filtering EPCs with potential errors.

The last part of the monitored EPC control analysis is focused on the qualitative, quantitative, and mixed research of nonconformities (NCs) issued in noncompliance reports. The analysis is carried out by cataloguing the type of NCs, exploring what underlies these NCs and what are the most appropriate and optimal ways to identify them. Several conclusions have been achieved, but two of them are worth mentioning. The NCs mainly occur given that qualified experts (QEs) fail in getting accurate data from project definition, from information exchange with project/construction management agents, etc as well as because EPCs are sometimes ill-defined. And the second main

conclusion, is that there is not a single detection form which is able to detect the most part of the NC types. A combination of different checking procedures is needed to get an effective control methodology.

Finally (Chapter 7), after the completion of the EPC control results analysis, this thesis has proposed various improvements for the system and verification procedures which are supported by conclusions of the previous chapter 4, 5 and 6. A preventive phase where the attachment of some documents will be required at the start of EPC registration in order to avoid some specific NCs is proposed. Besides, a new selection criterion is suggested based on a combination of a filtering by automatic checks and targeted criteria. At the end, organization of various steps in the verification protocol for controllers must be planned. Part of the last two measures consist of an automatic check-up program. Thus, validation rules for this aim have been determined.

With the last chapter a continuous-iterative procedure is proposed. Nevertheless, it is necessary to make clear that a continuous improvement involves initiating again the procedure with the future control results and new regulations.

Table of Contents

Nomenclature and Abbreviations

Abbreviations

ADENE	Agency for Energy and National Energy Agency (Portugal)
ANN	Artificial Neural Network
AT	Austria
BE	Belgium
BG	Bulgaria
BHB	Biomass Heat Boiler
BP	Building in Project
BR	Brussels Capital Region
CAT	Catalonia
CB	Condensate Boiler
CEN	European Committee for Standardization
CF	EPC Control File
CG	Cogeneration
CTE	Spanish Technical Building Code (for its acronym in Spanish)
CY	Cyprus
CZ	Czech Republic
DdP	Declaration of performance (for its acronym in Spanish)
DE	Germany
DK	Denmark
DHW	Domestic Hot Water
EB	Existing Building
EE	Estonia
ENG	England
EPBD	Energy Performance Building Directive
EPC	Energy Performance Certificate
ER	Emilia Romagna Region
ES	Spain
EU	European Union
EUS	Basque Country-Euskadi
EVE	Basque Energy Agency (for its acronym in Spanish)

FLM	Flemish Region
FI	Finland
FR	France
GIS	Geographical Information System
GR	Greece
HP-A	Aerothermal Heat Pump
HP-G	Geothermal Heat Pump
HR	Croatia
HU	Hungary
HULC	Herramienta Unificada Lider- Calener
ICAEN	The Catalonian Institute of Energy
IE	Ireland
IT	Italy
JE	Joule Effect
LB	Low-temperature Boiler
LCCE	Laboratory of Quality Control in Buildings (for its acronym in Spanish)
LT	Lithuania
LU	Luxembourg
LV	Latvia
MS	Member State
MT	Malta
MVHRS	Mechanical ventilation with heat recovery system
NAV	Foral Community of Navarra
NBB	New Built Building
NC	Nonconformity
NIE	Northern Ireland
NL	Netherlands
NO	Norway
NZEB	Nearly Zero Energy Buildings
OB	Oil Boiler
PEC	Primary Energy Consumption
PO	Poland
PT	Portugal
QE	Qualified Expert
R	Energy rating
RITE	Regulation of Thermal Installations in Buildings (for its acronym in Spanish)

RO	Romania
SB	Standard Boiler
SCT	Scotland
SE	Sweden
SI	Slovenia
SK	Slovakia
STS	Solar Thermal System
UK	United Kingdom
VA	Valencian Community
VEEI	Energy efficiency value of an installation (VEEI for its acronym in Spanish)
WAL	Wales
WL	Walloon Region

Nomenclature

A	Habitable area [m^2]
av	Average
$\boldsymbol{CI}$	Confidence Interval
$\widehat{\boldsymbol{CI}}$	Estimated Confidence Interval
$\boldsymbol{D_{DHW}}$	Domestic hot water demand
$d_{l,max}$	Distance from the farthest point and the trendline below it.
$d_{s,max}$	Distance from the farthest point and the trendline above it.
H_i	Hypothesis (statistics, see Chapter 4)
K_{mn}	Incidence in Relative Error of each nonconformity for each EPC CF (nrPEC or CO_2 emissions) [%]
K_m	Incidence mean in Relative Error of each nonconformity [%]
$K_{CO2,m}$	Average incidence in CO_2 emissions relative error of each nonconformity [%]
$K_{nrPEC,m}$	Average incidence in nrPEC relative error of each nonconformity [%]
max	Maximum
min	Minimum
N	Normal Distribution
NC_m	Nonconformity unit

n	Number of observations
nrPEC	Non-renewable Primary Energy Consumption
P	Probability
R^2	Correlation Coefficiente
RMS	Root Mean Square
S	Sample Standard Deviation
U	Overall heat transfer coefficient [W/m^2K]
v_d	Draft EPC calculation value
v_f	Final EPC calculation value
X_i	Frequency distribution of the relative error in the
$\bar{x}$	Sample Mean
$\tilde{x}$	Sample Median
Y_{mn}	Frequency of occurrence of each nonconformity in each EPC control file
Y_m	Frequency of occurrence of each NC
Z	Number of Standard Deviation

Greek symbols

β_m	Weight of each nonconformity in the sampling error
$\boldsymbol{\varepsilon_a}$	Absolute error
$\boldsymbol{\varepsilon_r}$	Relative error
$\boldsymbol{\alpha}$	Significance
λ	Thermal conductivity
$\boldsymbol{\sigma^2}$	Variance
$\boldsymbol{\mu}$	Population Mean
$\boldsymbol{\hat{\mu}}$	Estimated Population Mean
$\boldsymbol{\eta_t}$	Thermal efficiency of the heat recovery in MVHRS

1 Introduction

1.1. Background and motivation

Energy is the fundamental basis of this society. Our well-being and standard of living are totally linked to the energy consumption. This leads on the one hand to the depletion of fossil resources, and on the other hand to the climate change.

Our energy system is highly dependent on fossil fuels, since 80% of our energy consumption comes from them. This energy model is the responsible for the CO_2 emissions that generate the greenhouse effect, and consequently, for the climate change. A qualitative change in energy policies based on reducing emissions and increasing the use of renewable energy has become essential to avoid the serious consequences of climate change. Among all sectors, the construction is one with the greatest potential in the decarbonization of the society. Therefore, the European Union (EU) has issued several Energy Performance of Buildings Directives (EPBDs) [1]–[4] to member states (MSs) in recent years.

EPBDs introduce the building Energy Performance Certificate (EPC). It is the main policy tool of EU used to achieve the European Directive objectives [1], [4], the attainment of Nearly Zero Energy Buildings (NZEB) requirements and the renovation of existing housing.

Currently, EPC is the most widely used instrument to justify the compliance of these objectives in Europe.

Each MS has standardized the EPC calculation methods in conformity with its national building efficiency regulation. EPC is a mechanism to certify the energy efficiency rate of a building. Each MS has a database with the set of EPCs of the entire building stock, which makes available data to plan future energy policies.

Following the European principles, EPC is also employed for auditing the fulfillment of minimum requisites in new buildings or major renovation projects in most MSs [5]. Moreover, it is used in energy renovation aid programs [6], [7] to require the justification of the minimum conditions compliance. At last, the EPC's other function is to inform owners, buyers and tenants about their property's energy efficiency level and the possible improvement measures. A research [8] reviews EPC data applications. The study is based on 79 papers and it points out the widespread use of EPC data and the increasing trend on its applications.

Though EU's bet is quite serious, there is a lack of confidence in EPCs [9]–[12]. In the Qualicheck project [13]–[15], the quality and compliance of EPC schemes have been studied in 9 countries. The study covers the input data quality assessment, but not the correctness of the calculation method as such. This project reveals that inaccuracies exist in input data and, in consequence, in EPC results. The results of the Spanish case study within this project showed that only 13 out of 25 existing building EPCs analyzed had a correct energy efficiency rating [16]. According to the authors of the study, one of the reasons for those discrepancies is the absence of inspections. Under these circumstances, it is worth noting that if any measures are not taken to ensure the EPCs quality, public mistrust in EPC could increase and put the continuity of this instrument at risk.

The mechanism that EU has set up to ensure the quality of EPCs is the independent EPC control system. Article 18 of Directive 2010/31/EU [4] forces to MSs to guarantee the establishment of independent control systems for EPCs. According to this article, the independent control system must be implemented in accordance with Annex II of this document. Nevertheless, the specifications given regarding to the procedures to be followed are too general. In consequence, each MS has followed a different path in developing its own independent control system [10], [17]. However, literature about EPC quality assessment of a few methodologies are found [11], [17]–[22].

In turn, within Spain, each Autonomous Region has established its own system in a different manner [23]. As established by EPC regulations —Royal Decree 47/2007 [24] and more recently Royal Decree 235/2013 [25]—the functions of control, inspections and registration of EPCs are delegated to the Autonomous Regions.

Currently in the Basque Country, the Decree 25/2019 [26] regulates the procedure of the EPC Control. Independent accredited bodies, whose activity is regulated by this decree, carry out the EPC controls. One of the accredited bodies is the Laboratory of Quality Control in Buildings (LCCE *—for its acronym in Spanish—*) of the Basque Government. More than 200 controls have been carried out in the last 6 years by the LCCE. According to published data by EVE [27], approximately 10% of the total of EPCs registered with control in the Basque Country is conducted by the LCCE. This thesis is based on the results obtained during this control campaign at the LCCE.

Despite various efforts among all the countries and regions of Europe to control EPCs quality, studies confirm the general need to improve the effectiveness of the control systems to obtain the full impact of the control implementation [10], [28].

According to the literature [10], [29], [30] the improvements should be driven focusing on the following topics:

- monitoring the independent control system results
- reporting of common mistakes
- developing automatic input data validity checkings
- including not only the input data quality assurance, but also of the certifier bodies and EPC calculating software.
- guaranteeing the sufficient controlled sample size.

This thesis studies the EPC quality assurance in the Basque Country. The aim is to assess the effectiveness of the implemented control system during the last 6 years, to conclude by proposing improvements in methodology and procedure that could be replicated in other regions and MSs.

The main interest in the topic of this research comes from the fact that the European EPC database is the main source of information for identifying where we are and what measures must be taken to achieve the established energy efficiency objectives. Moreover, it is a widespread tool with other important applications, as it is explained before. Therefore, the assurance of quality and transparency EPC database is important not only for Public Administrations to plan future strategies, but also, for technicians to develop building energy renovation projects and for owners or tenants to have available more transparent data when they are buying or renting a property, etc.

1.2. Introduction to the Energy Performance Certificate (EPC)

1.2.1 Definition and objectives

EPC is a standardized method for assessing the energy efficiency grade of a property or an individual building. It allows an estimation of one or more energy efficiency indicators taking into account building physics characteristics and a normalized building operation. It is not based on a detailed energy simulation model since it is not its goal to precisely determine the energy consumption of the building. It may also include options for improving the energy characteristics of the building. All EPCs are performed under the same operating conditions and by following the same methodology which makes them a comparative tool and enables generating universal building stock results.

EPC is an important energy policy instrument with the aim of turning the real estate market and building sector toward high efficiency energy performance. It aims to be an information tool capable of creating an energy efficiency demand on the market.

Informing owners, occupiers and real estate actors about energy consumption and savings potential can make the EPC one more factor to consider in the decision of a real estate transaction, since it allows assessing and comparing the energy performance of the real estate. Moreover, the information provided by EPCs can also stimulate the building energy efficiency renovation. The greater the interest of buyers or tenants, the greater is the motivation of owners to make investments in energy efficiency measures in buildings. As such, EPC has the potential to generate a transformation in improving energy efficiency in new buildings and retrofitting existing buildings.

It is also a tool with a lot of potential for administrative purposes. Currently EPCs are the most important source of information regarding the efficiency level of the building stock in Europe [9]. Therefore, it can be a powerful tool to track the building stock energy consumption reduction and the impact of the energy planning and policies over time. It can also be a relevant and conditioning source of information to establish the minimum requirements in the future building codes.

1.2.2 EPCs in European Legislation Framework

EPC is an instrument that was introduced in European legislation framework through the first EPBD in 2002 [3]. This EPBD required all MS to implement an effective EPC scheme by 2009. Each MS had to apply its own national and normalized methodology for assessing each building energy performance. To this end, there was flexibility to adapt its own scheme to the regulatory context of each country. However, it has been seen that this was a complex task covering technical, social and economic aspects since at the time of the publication of the next Directive in 2010 [4] only 20 out of 28 MSs had managed to design and fully implement their system (see Table 1.1). Three years later, all MSs had already introduced it in their legislation framework in the absence of minor modifications (see Table 1.1).

With EPBD 2010 and EPBD 2018 [1], [4] transpositions, MSs were introducing new improvements in EPC systems in relation to data quality assurance, availability, and usability. More details are provided in Section 1.3.1.

Table 1.1. No. of Countries running EPC schemes (cumulative). [Source [9]].

	In some types of building	In all required buildings	
1995	1	0	
1996	1	0	
1997	2	0	
1998	2	0	
1999	2	0	
2000	2	0	
2001	3	0	
2002	4	0	Directive 2002/91/EC
2003	5	0	
2004	5	0	
2005	6	0	
2006	8	0	
2007	15	1	
2008	21	7	
2009	27	16	
2010	28	20	Directive 2010/11/EU
2011	28	24	
2012	28	27	
2013	28	28	

Today EPC is a widespread tool in Europe, nevertheless each MS has chosen different paths in terms of energy indicators, calculation procedures, establishment of a national database, EPC technical quality control system, Qualified Experts (QE)[1], etc.

1.2.3 Energy Performance Indicators

As Rey Martinez et al. stated, there is diversity within the EU when calculating the energy efficiency indicators [9], [10]. The indicators used, ordering from the most employed to the least, are the estimation of annual consumption, the indicator regarding the reference building, the potential for savings and the cost ratio. Although most countries' EPC schemes are based on annual energy consumption, this is also expressed in different ways depending on the country: in primary energy consumption (PEC) or in relation to CO_2 emissions. In addition,

[1] *Qualified Expert (QE): accredited professional to certify EPCs.*

the PEC indicator does not always include the consumption of the same building services. France, for example, considers the energy consumption of lighting in residential buildings, while Flanders does not, as is the case of Spain.

The indicators usually adopt the form of energy labels (e.g. A to G, where A is the most energy-efficient grade and G is the poorest energy-efficient grade) (see Figure 1.1(a)). Otherwise, few countries (Belgium-Flanders, Germany, Latvia, Luxembourg and Poland) use a sliding scale form [31] (see Figure 1.1(b)).

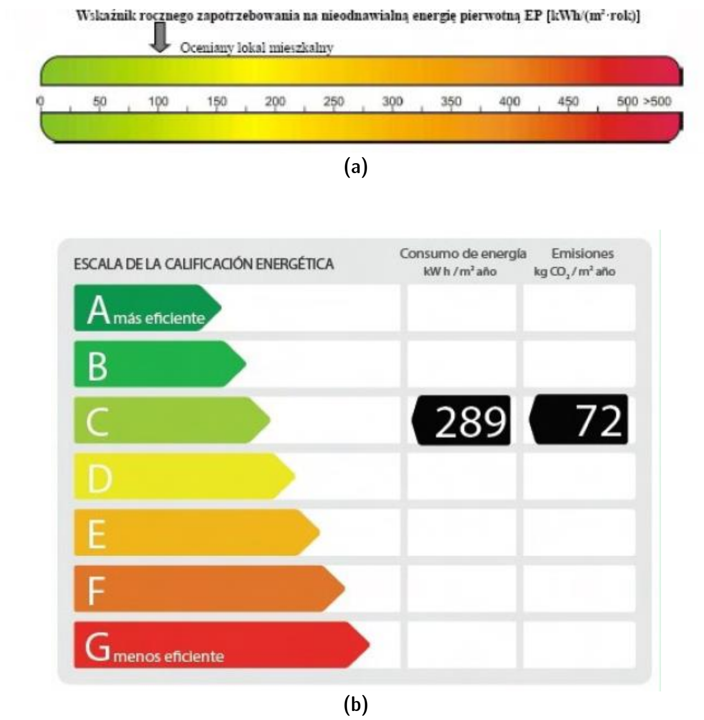


Figure 1.1. (a) Polish sliding scale form; (b) Spanish energy labels form.

1.2.4 Assess Methodology

EPBDs [1], [3], [4] drive MSs to stablish a methodology for calculating the energy efficiency of buildings taking into account the standards and methodologies for assessing the energy performance of buildings that the European Commission had entrusted to the European Committee for Standardization (CEN) through the mandates M 343-EN and M-480. Due to the short time interval between the date of the mandate and the deadline for the implementation of the EPBD, and since the CEN standards were still under development, practically all MSs chose to develop their own calculation methodology combined with some CEN standards [32]. Even if there is an intention to harmonize methodologies through CEN standards, there will still be differences that influence energy use due to such differences in air quality standards (ventilation rates), operational conditions, construction practices, etc [5]. Thus, the methodology of each country is in continuous development and improvement, adapting to the particularities of the country, the new standards and the new technologies.

Annex I of the EPBDs [1], [3], [4], in turn, expresses the two options for the energy performance evaluation: methodology based on the calculated energy consumption (asset rating) or on the measured energy consumption (operational rating).

The first one is based on the calculation of the amount of energy consumed annually to satisfy the different needs linked to its normal use (standardized), while the second takes into account the actual consumption of the building which is conditioned, among other aspects, by user's behavior and a possible misuse of equipment.

As Arcipowska et al. report [9], 14 out of 28 EU countries have adopted the methodology exclusively based on calculated energy consumption. In other countries, both asset rating and operational rating methodologies are employed, depending on the building type or building age.

To perform an EPC, a QE must collect the building characteristics, introduce them in the specific software which generates the EPC and make recommendations for energy renovation with their corresponding energy saving potentials.

The characteristics of the building to be considered for the calculation are defined in Annex I of the EPBDs. The quality of this data is essential to obtain reliable results. However, some MSs do not require a previous visit to the building before calculating the EPC (Austria, Czech Republic, Estonia, Italy, Poland and German) [9]. In addition, it is complicated to obtain some of the data cited in Annex I of the EPBD in existing buildings, since they correspond to hidden elements in the building. To solve this problem, many countries have chosen to develop their own catalogues for certifiers that detail typical values for material properties in building components depending on their age, as well as efficiency factors [32].

Regarding the software, it is worth noting that in some countries (e.g. Belgium, Croatia or Lituania) the development of EPC software is totally financed by public funds, while in others (e.g. Denmark and Portugal) several private software tools are available [28]. In these cases, the governments may require an approval of these tools. In Spain both ways of developing EPC calculating software are applied.

1.2.5 EPC database and register

The database is an electronic register where all the certificates issued are collected and updated over time. These data platforms not only provide issuing certificates, but also allow doing control checks, verifying specific EPCs as well as data mining with statistical purposes.

The presence of such databases is widespread through Europe: 24 out of 28 MSs already had a central database in 2015 [33], managed either by the nations or the regions.

According to this 2015 study [9], there are five MSs which follow the EPC database regional approach: Italy, UK, Spain, Austria and Belgium. Furthermore, few MSs established independent databases by building type; e.g. for new and existing buildings (Belgium-Flanders) or for residential and service buildings in the UK. It should be noted that this database variability can generate complexities for MSs when centralizing data from different databases.

The way to register an EPC also varies according to the MS scheme. There are three ways to upload EPC data [9]:

- An automatic upload of EPC data through standardized data protocol (e.g. XML, editable PDF) which can take place either before or after issuing the certificate.
- A manual upload of EPC data conducted (usually) through an input form on the online platform. In this case, the expert needs to manually retype the results of the EPC to the input forms.
- An electronic copy of the EPC is sent to the Central Secretariat, which is responsible for storing and/or transferring information to the EPC database.

In Europe, the QEs are responsible generally for registering the EPC in the database. In contrast, in the Basque Country, the EPC registration is the owner's responsibility, even if the proprietor can assign the representation to the QE [26].

Passing a data validation procedure is needed in several databases during the registration phase, after uploading the data and before issuing the final EPC. This procedure may require some corrections to the EPC before its issuing. These steps involve the certifier's participation in the registration.

Public access to the database ensures the transparency of the data. Nonetheless, in some states the data is available by searching for the address or postcode while in others accessing the data is permitted only for authorities, researchers or selected organizations [10]. In addition, the amount of data provided is also more or less limited depending on the country and the data applicant. Few databases are limited to owning only the EPC final result, whereas others contribute with energy characteristics of the certified building data [9].

Not only the public access improves the transparency of the data, the representativeness of the data also plays an important role. The more buildings are registered in the system, the greater the credibility of the conclusive data on the building stock. For example, by 2015, 82% of the buildings already had an EPC in Sweden [34]. In this manner, creating overview and validating model of the building stock is possible.

However, the greater the number of lodged EPCs, the greater the difficulty of ensuring the technical quality of the EPC data.

1.2.6 Data applicability

The EPC data is a valuable information source about building energy performance. It could be used as a single building information document for individuals, but also the EPC information can be utilized in other contexts, such as:

- Checking compliance with the energy performance requirements for new and renovated buildings. These are the key element of the EPBDs since MSs should adjust the requirements until the NZEB level is reached. Even though the main objective of certification in most MSs is associated with demonstrating the energy quality of buildings, many of them also use the EPC as a supporting document of compliance [5] .
- Energy policies and building renovation planning [35]–[37] Renovating the building stock and regulating the building code to meet NZEB requirements are the priorities of the MSs to meet the EPBDs standards. In this regard, the large data source for all the EPCs form a basis to provide useful information for energy-related policies and decision making, since this extensive information provides creating a representative picture of the energy performance level of the building stock.

Dall'O' et al. [20] provide indicators of energy performance of existing buildings of Lombardy Region in northern Italy which were obtained by integrating data from the energy cadastral (175.778 EPCs) with statistical data from the national census. These energy indicators which are characterized by building type and construction period and normalized as a function of Degree-Days, become an effective tool for energy planning at local and regional scales since they have been used to estimate the potential for energy retrofit of existing buildings.

Gupta et al. [38] show that mapping the EPC data (energy consumption and reduction potential) combined with others reliable databases by Geographical Information System (GIS) helps to identify suitable local areas and dwellings for installing energy retrofit measures. For example, it is possible to identify a certain area with the highest need of public investment to promote measures. Moreover, the local energy maps can be used for planning the energy retrofit measures at urban scale, in contrast to the usual interventions in individual buildings.

Moreover, Majcen [39] investigates the overall changes in the Dutch building stock in the 2008 – 2013 period by using the register as a basis to assess the energy renovation development.

Other example of EPC data utilization for planning energy policies is found in the UK, where a new policy was introduced in April 2018 for renting private properties. Homeowners in Wales and England must ensure that their buildings for renting have achieved a minimum EPC rating of "E", even there is no change in tenancy [10]. Scottish government has a similar planning. It plans to introduce regulations that will require all homes from 2020 onwards to meet an EPC "E" standard before they can be rented out, by 2022 this standard will rise to "D" and by 2024 minimum "C" standard will be needed before selling a residential property.

- Financial aids for energy renovation. EPC can be employed as a mandatory evidence document to obtain the financial subsidies or supports. Commonly it is asked both before and after renovation to evidence of the quality of the energy-related renovation.

By 2015, 10 MSs made used of this system [31]. For instance, several countries (e.g. Bulgaria, Portugal, Scotland) use the EPC as a loan prerequisite [40]. Scottish homeowners can, for example, access an interest-free loan for energy improvements if they present several supporting documents, one of which is the EPC. In addition, there is a requirement that a post-improvement EPC must be provided for all homes which benefit from the loans, to show how the home's energy performance has improved.

In Spain, with the PAREER II program [6], there is a requisite based on energy class for getting a non-refundable grant: raising the energy rating "A" or "B" on the CO_2 scale after renovation or increasing by two letters the initial energy rating is needed.

The last RENOVE program [7] for non-refundable subsidies in the Basque Country present a requisite on the same basis. It entails the raise of energy rating "C" in both CO_2 emissions and non-renewable primary energy consumption (nrPEC).

- Research. There is a study [8] that reviews existing applications of EPC data based on 79 papers and reveals an increase in these applications as well as in complexity of studies advanced in applied data analysis techniques.

1.2.7 Issues and challenges

The certificate was introduced with high expectations, claiming to be a relevant building document and an influential energy policy instrument in the transformation of the real estate market and the construction sector. Nevertheless, as we have seen in the previous sections, it has been implemented as well as possible, slowly and in a diverse way.

Li et al point out the many issues encountered, based on a review of 18 studies [10]; and they are listed below:

- EPC is a bureaucratic obligation for homeowners. They find it no useful.
- General unawareness of people.
- Little impact on the building renovation.
- Little impact on people's decision making to buy or rent properties.
- Not expected impact on the real-estate-market.
- Lack of reliability and confidence. There is a need to improve the quality.
- Calculations do not consider occupants' behavior and building smartness.
- Lack of energy labels in certain number of renting/selling advertisements.
- General lack of compliance in public buildings where there is the obligation to exhibit the energy label.

1.3. Legal Framework

1.3.1 European Legal Framework

The development of EPC schemes in Europe has been driven over the past few years by the EPBDs, which determine the guidelines to be followed by MSs in adapting their regulations to achieve the objectives imposed on energy efficiency in buildings.

In 1993 the EU published the first EPBD aimed at improving the energy efficiency of buildings: Directive 93/76/EEC (SAVE) [2]. It aimed to limit CO_2 emissions by establishing different programs, one of which is the energy certification.

A few years later, Directive 2002/91/EC [3] on the energy performance of buildings was published, obliging MSs to transpose it by January 2006, although allowing a three-year extension to implement the provisions of articles 7 (related to the EPC), 8 and 9. This Directive stated that MSs had to ensure that all constructed, sold or rented buildings should provide an EPC for the prospective buyer or tenant as it is the owner's obligation. The EPC should contain objective information on the energy characteristics of the building in favor of high efficiency buildings.

The next Directive in relation with EPCs came out in 2010 [4]. The main changes regarding to EPCs that occurred were:

- The introduction of an independent control system for EPCs. It had to be stablished in accordance with Annex II and separately or not from inspection system of heating and air-conditioning installations.
- Inclusion of an optional second indicator for energy performance, complementing the CO_2 emissions indicator with one for nrPEC.
- Extension of the application scope: buildings occupied by a public authority, larger than 500 m^2 and frequented by the public were included.
- Deepening in the recommendations of improvement that an EPC must have including aspects like relation of cost-effective or cost-optimal, estimation of the times of recovery or other reference data.
- Extension of EPC utilization for compliance check on minimum requirements in new buildings or renovation.

Recently, EPBD 2018 was published to modify some aspects of EPBD 2010. It is aimed at accelerating the renovation of the building stock and there are few changes on the EPC's topic:

- Ensuring the collection of data on measured or calculated energy consumption of at least all buildings containing an EPC and the openness of the data for statistical and research purposes and for the owner information.
- On the calculation of energy efficiency of buildings (Annex I): incorporation of the consumption related to ventilation, lighting and other technical installations to the consumption of heating,

cooling and DHW that were already contemplated in the previous version.

- About independent control systems for EPCs and inspection reports (Annex II):
    - Clarification of the random sample to be verified, having to be of sufficient size to ensure statistically significant compliance results.
    - Ensuring that the EPC database enables EPC data to be linked to the certifier/author data for monitoring and verification purposes.

1.3.2 Spanish Legal Framework

The Spanish regulation has been adapted to the guidelines published by Europe, both in the field of energy certification and in the regulation of the building code. This section includes the transposition related to energy certification and Table 1.2. also specifies the technical standards published with the minimum requirements of the building in response to its relative EPBD.

After the publication of Directive 93/76/EEC (SAVE) [2], no regulations were introduced that made it compulsory to have an EPC in Spain. However, the Directive was a precedent for the appearance of the first energy certification software: CALENER.

Subsequently, after the publication of EPBD 2002 [3] and in parallel to the publication of the Spanish Technical Building Code (CTE —*for its acronym in Spanish*—) [41], LIDER software was made available to technicians for the justification of the limitation of energy demand for the Energy Savings Basic Document. It was complementary to the CALENER certification software.

In 2007, the first regulations concerning EPC came out, RD47/2007 [24] partly transposing EPBD 2002 [3]. This document regulated the basic procedure for calculating the energy certification of new buildings and delegated some functions to the autonomous communities. Among them, there are the establishment of a quality assurance system, a registration system and a system that requires the promoters or the property owners to have an updated and public label.

This Royal Decree was abolished by Royal Decree 235/2013 [25] when the transposition of EPBD 2010 [4] was carried out. This decree modified the regulation of EPCs by considering the new European guidelines and the experience accumulated in the application of R.D. 47/2007 during the last five years.

1.3.3 Legal Framework in the Basque Country

According to the functions delegated by Spain, the control and registration in the EPC database have been regulated at regional level.

As a result of Royal Decree 47/2007, 240/2011 Decree [42] was published in 2011 which regulated the administrative functions for the correct application of the basic procedure for EPCs, located in the Basque Country. For the first time, the quality control of new building EPCs was implemented.

Chapter IV of the mentioned Decree regulates the external control of the energy efficiency certification, specifically, the bodies that are going to carry it out as well as the basic lines of the external control procedure. For more technical details it referred to the Order of 12 December 2012 [43]:

As of the publication of that Order in the official journal (BOPV) in January 22, 2013, the criteria of obligatory nature were established and the procedure was regulated for the first time. From the publication of the 240/2011 Decree until then the application of control was optional.

The publication of RD 235/2013 [25] at the state level also meant modifications in the autonomous regulations. Decree 226/2014 [44] was published regulating the certification of the energy efficiency of buildings and repealing the Decree 240/2011 [42]. It extends the scope of application to all buildings, including existing ones. Moreover, linked to this decree, later, the Order of March 16 was made public in 2015 [45]. It collected the prescriptions to define the control procedure as the registration in the EPC database. It further regulated the requirements to be met by accredited bodies, which would be entities or organisms duly accredited in the corresponding regulatory field, as well as the rights and obligations that they had in the exercise of this work. Finally, as far as control is concerned, the mechanism by which the control was going to be carried out was detailed, both for the certification of the building in project and for that of the new built building and the existing one, specifying the content that the control report should have.

Despite Decree 226/2014 already met the requirements of RD235/2013, the experience gained during its implementation showed that there were some aspects of the regulation that needed to be addressed or improved. With that objective, Decree 25/2019 [26] was published abrogating
Decree 226/2014 [44] and the Order of March 16, 2015 [45]. It is currently in force.

With regard to the external control of the existing building certificates, it should be noted that a system is configured with the following two main goals: on the one hand, avoiding that those individuals or legal entities that have already made a significant investment in order to achieve a very good energy rating, do not have an additional cost for having to perform the control; and on the other hand, allowing a more exhaustive control of those buildings that have been able to benefit from public aid based on the good energy rating obtained.

The following Table 1.2 gathers the milestones of the normative context at European, Spanish and autonomic level and explains the origin of the norms established to regulate the quality control of the energy certification in the Basque Country. With yellow shading the specific ones of EPCs and their control are indicated, and without any shading those related to the technical regulation of energy saving in building and thermal installations are shown.

Table 1.2. European, Spanish and Basque Country's Legal Framework. (In yellow specific regulation of energy certification and independent control system)

Legal Framework		
Europe	**Spain**	**Basque Country**
93/76/CEE (SAVE)	1st Official Software - Calener	
	RD1751/1998 (RITE)	
Directive 2002/91/CE	Royal Decree 314/2006. (CTE- BDHE)	
	Official Software- Lider (2006)	
	Royal Decree 1027/2007: (RITE)	
	Royal Decree 47/2007 (Energy Efficeincy Certification in New Buidlings)	Decree 240/2011
		ORDER of 12 December 2012
Directive 2010/31/EU	Orden FOM/1635/2013. CTE-DBHE update	
	Royal Decree 238/2013: RITE (modifications)	
	Royal Decree 235/2013	Decree 246/2014
		Order of 16 March 2015
		Decree 25/2019
Directive 2018/244	Royal Decree 732/2019. CTE- DBHE updaten	
	Royal Decree 178/2021 RITE updaten	

CTE: Spanish Technical Building Code; DB HE: Energy Savings Basic Document; RITE: Regulations of Thermal Installations in Buildings (for its acronym in Spanish)

1.4. EPC Control System and its implementation status in Europe

The EPC control system was introduced by EPBD 2010 [4] with the aim of ensuring the quality of EPCs in general and the correct reporting about compliance with requirements for new and renovated buildings.

In the first EPBD [3], EPC quality assurance requirements were not sufficiently developed [33]. EPBD recast [4], in Article 18 and Annex II, deepened in this area forcing all Member States to establish an independent control system. This fact opened new paths within the EPC schemes and great opportunities to improve the quality of EPCs.

Although the official deadlines for the implementation of the systems were not respected by all MSs, by 2014 twenty-seven countries had an operational system and the rest two were in the process of implementation [9], [10], [33]. Nevertheless, Annex II gave general specifications in concern to the procedures so that each MS developed the independent control system on its own way [23], [31] and with different degrees of implementation [9], [33].

In Spain, EPCs information is collected and registered in databases of each of the seventeen Autonomous Communities and in the two Autonomous Cities [21]. Even though the official documents state that an independent control system has been established in all regions and that each has done in a differential manner [21], [23], [31], [46], no information has been found on the procedures applied in some autonomous communities.

The last Directive, despite it hardly requires modifications or improvements in the independent control systems, emphasizes the need to compare and evaluate EPCs before and after the renovation works through a transparent or proportional system [1]. A widespread EPC control system allows ensuring a correct comparison between the EPC before and after renovation, especially in cases involving economic incentives [17]. Therefore, future modifications in the implementation of control systems can be expected to be influenced by that aim.

1.5. Control Systems Characteristics

The aim of this section is to collect the fundamental aspects that define a control system and describe how they have been solved in several regions and MSs.

Table 1.3 presents a summary of the main characteristics of these systems implemented throughout EU. The yellow shaded boxes represent the absence of data for the corresponding characteristic.

Table 1.3. Characteristics of Independent Control Systems in European regions and Member States. [Source: [17], [26], [31], [46]–[48]].

		EUS (ES)	NAV (ES)	VA (ES)	CAT (SP)	ER (IT)	BR (BE)	FLM (BE)	WLL (BE)	AT	BG	HR	CY
Quality Control based on:	EPCs	•	•	•	•	•				•	•		•
	QE						•	•	•				•
System Manag Adm.	Regional									•			
	National										•	•	•
Quality Control by:	Public Adm.	•			•	•	•	•			•		•
	Indep. third bodies	•	•	•			•			•		•	
	Profes. Adm.												
Type of Quality Control	Autom. checks (1rst lev)				•	• 100 %	•	•	•	•	• 100 %		
	Desk audits (2nd lev)	•	•	•		• 5%		•	•	•	• 32%	•	• 10%
	On site checks (3rd lev.)	•	•	•		• 2%	•	•			• 5%	•	• 21%
Building subject to control	Random sample						•	•	•	•		•	•
	Other selection criterio	•	•	•		•							
Sample Size [%]		2.1				100					100	0.5	22Q+ 31EPC
Compl. Rate [%]						20			31			85	
Allowed limit on deviation [%]		-										30	

EUS: Basque Country; NAV: Foral Community of Navarra; VA: Valencian Community; CAT: Catalonia; ER: Emilia Romagna; BR: Brussels Capital Region; FLM: Flemish Region; WL: Walloon Region; AT: Austria; BG: Bulgari; HR: Croatia; CY: Cyprus; QE: Qualified Expert; Adm: Administration; Indep: Independent; Profes: Professional; Lev: Level; Compl: Compliance

		CZ	DK	EE	FI	FR	DE	GR	HU	IE	IT	LV	LT	LU
Quality Control based on:	EPCs		•	•	•		•	•	•	•	•	•	•	•
	QE	•				•				•	•	•		
System Manag Adm.	Regional						•				•			
	National	•	•	•	•	•	•	•	•	•		•	•	•
Quality Control by:	Public Adm.	•	•	•	•		•	•	• 1 lev	•				•
	Indep. third bodies		•			•	•							
	Profes. Adm.								• 2+ 3 lev			•		
Type of Quality Control	Autom. checks (1rst lev)		• 100 %		• 100 %		• 5%	• 100 %	• 100 %			•	• 100 %	•
	Desk audits (2nd lev)		• 0.25 %		• 2%	•	• 0.25 %	• 1.25 %	• 2,5 %				• 0,28 %	
	On site checks (3rd lev)					•	• 0.25 %	• 1.25 %	• 0.5 %				• 0,03 %	
Building subject to control	Random sample	•	•	•			•	•		•			•	
	Other selection criteria					•				•	•			
Sample Size [%]		20	100	0.6	100	1	5	100		0.6	7		100	
Compl. Rate [%]		70							90					
Allowed limit on deviation [%]			10					5	2 rat. diff.					

CZ: Czech Republic; DK: Denmark; EE: Estonia; FI: Finland; FR: France; DE: Germany; GR: Greece; HU: Hungary; IE: Ireland; IT; Italy; LV: Latvia; LT: Lithuania; LU: Luxemburg; QE: Qualified Expert; Adm: Administration; Indep: Independent; Profes: Professional; Lev: Level; Compl: Compliance; rat: rating; diff: difference

		MT	NL	NO	PO	PT	RO	SK	SI	SE	ENG(UK)	WAL(UK)	NIE(UK)	SCT(UK)
Quality Control based on:	EPCs	•		•				•	•	•	•	•	•	
	QE	•	•			•	•							•
System Manag Adm.	Regional										•	•	•	•
	National	•	•	•	•	•	•	•	•	•				
Quality Control by:	Public Adm.	•				•	•	•	•	•	•	•	•	
	Indep. third bodies		•		•	•								•
	Profes. Adm.													
Type of Quality Control	Autom. checks (1rst lev)	•		•		• 100 %		•	•	•				
	Desk audits (2nd lev)	•				• 5%			•					•
	On site checks (3rd lev)	•	•			• 0.5%								
Building subject to control	Random sample	•	•			•		•			•	•	•	
	Other selection criterio					•				•				•
Control Sample Size [%]						100	10	0.04		1				2.53
Compli. Rate [%]			89-94											
Allowed limit on deviation [%]					10	5								5

MT: Malta; NL: Netherlands; NO: Norway; PO: Poland; PT: Portugal; SK: Slovakia; SE: Slovenia; ENG: England; UK: United Kingdom; WAL: Wales; NIE: Northern Ireland; SCT: Scotland; Adm: Administration; Indep: Independent; Profes: Professional; Lev: Level; Compl: Compliance.

1.5.1 Item subject to Control: EPC or QE

In some MSs and regions, as in the case of the Basque Country, the technical quality of the EPCs is controlled, independently of the technician who has signed it, following a selection criterion established by the system. Others base their EPC quality control system on checking the work quality of the QEs —WLL (BG), FLN (BG), FR, PT, RO, NL, SCT (UK) —. And in other countries, for example, in IE and LT, both the quality control of QE and EPC is performed in parallel, where the QE may receive penalty points in case of a wrong EPC. These points are cumulative and may lead to corrective training or suspension license [9], [31], [46].

1.5.2 Public Administration responsible for system managing

There are five countries —IT, ES, AT, UK, BG— which follow a regional approach regarding the quality check system of EPCs [46]. Thus, the regional government is the responsible for the control system. This is the case of the Basque Country. The other MSs and NO have a national approach system except for Germany. In Germany, the first level of control is conducted at the central level by the German Institute for Building Technology; detailed control is the responsibility of regional governments [46].

1.5.3 Bodies responsible for performing quality checks

Even though MSs can delegate implementation of the control system to third parties according to Article 18 of the EPBD [4], MS reports [31], [46] point out that in most of them checking are performed by the Public Administration. The responsible entity is usually the Central or Regional Government itself, as in the case of Slovakia [9], or even a governmental agency (energy or consumer agencies) as it happens in Emilia Romagna Region [17].

Among the countries that appointed a third party to run quality checks, there are differences. One the one hand, these third parties are often the same as the accredited bodies responsible for expert certification [33]. On the other hand, those are impartial accredited bodies with exclusive control function, such as the case of some regions in Spain —NAV, VA—[47], [48]. Moreover, in other countries, the third parties are the bodies responsible for the accreditation of QE —FR, UK, SE—[9]. Finally, there are independent control systems that have been structured so that checks are carried out by both the public administration and third bodies —EUS, PT, DK, DE, BR(BG)— [26], [31], [46]. In the Basque Country the control of EPCs corresponding to the new buildings regardless of their use is carried out by third parties (accredited bodies) as well as the control of existing buildings with tertiary use. Otherwise, EPCs of existing residential buildings are evaluated by the Public Administration [26]. In Denmark, in parallel to the quality control system performed by the government body, accredited companies follow an internal quality assurance system based on DS/EN ISO 9001 [9].

LV and HU make even more of a difference. The competence for quality control of EPCs is in the hands of professional organizations of engineers and architects [9], [31], [46]. These in turn delegate the quality checks to the independent experts from the Chamber.

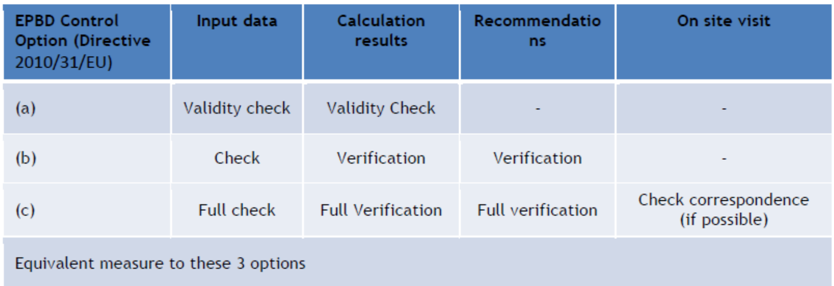
1.5.4 Quality Control verification options

Annex II of EPBDs [1], [4] gives 3 options for establishing a methodology for EPC verification, starting from the simplest to the most rigorous screening:

> *"The verification shall be based on the options indicated below or on equivalent measures:*
>
> *(a) validity check of the input data of the building used to issue the energy performance certificate and the results stated in the certificate;*
>
> *(b) check of the input data and verification of the results of the energy performance certificate, including the recommendations made;*
>
> *(c) full check of the input data of the building used to issue the energy performance certificate, full verification of the results stated in the certificate, including the*

> *recommendations made, and on-site visit of the building, if possible, to check correspondence between specifications given in the energy performance certificate and the building certified.”*

This report [30] helps to clarify the meaning of each option by the next Figure 1.2.



EPBD Control Option (Directive 2010/31/EU)	Input data	Calculation results	Recommendatio ns	On site visit
(a)	Validity check	Validity Check	-	-
(b)	Check	Verification	Verification	-
(c)	Full check	Full Verification	Full verification	Check correspondence (if possible)
Equivalent measure to these 3 options				

Figure 1.2. Definition of EPC control options [Source:[4]].

The validity check refers to the automatic validation rules which could be processed during the EPC definition in calculating software or during the EPC registration in EPC database. Experience showed that it can prevent errors that can have a huge influence on the final result (on the EPC level, as well as on recommendations for improvements) [30].

The validation rules consist in:

- Prohibition of impossible values;
- Detection and warning about out of range values;
- Consistency checks on the plausibility of different input values relating to the defined materials or equipment. (e.g., plausibility of the presence and the consumption of fans in comparison with the type of ventilation system).

As stated by MS’s official reports [46], simple input data validity checking is quite widespread among the countries. However, hardly any details have been found about the technical scope and the checking methodologies.

On the other hand, both desk-audits, as well on-site controls are used in options (b) and (c), though the level of detail of the control can vary a lot. In some cases, the control can be limited to only very specific elements. In other cases, all the elements of the EPC are controlled [30].

The few detailed descriptions about checking methodologies found are explained below in Section 1.7.

As can be seen in line 9-11 of Table 1.3, some countries have chosen only one option, while others carry out the controls combining different options.

1.5.5 Building Subject to Control

The general objective of the EPBD proposed independent control system is to reach an as high as possible quality of the EPCs. Therefore, EPBD proposes to control a statistically significant percentage of all EPCs randomly selected [4]. The random sample is recommended, but it is not compulsory.

The independent control system is also used to check the correct application of the different instruments and to check compliance with different requirements. They are called targeted controls.

Loncour X. and Roelens W. recommend both types of selection: targeted controls to use the resources in an efficient way for enforcement, and random selection to get a view on the global quality [30].

The followings are the most used criteria by MSs to select buildings subject to control [30]:

- EPCs with identified strange values;

- focus on the most active experts;
- control of the first certificate(s) of each expert;
- customer complaints (not considered in Table 1.3);
- experts frequently issuing EPCs with errors;
- experts that often revoke and replace EPCs;
- experts who make excessive use of the help desk;
- experts that fail to provide (sufficient) evidence or use stock photos;
- EPCs with specific results, e.g., by focusing on the best performing buildings, or on buildings presenting an EPC near to the minimum required energy quality, or on buildings meeting the necessary conditions to obtain subsidies.

The last one is the case of some regions in Spain —EUS, NAV, VA— where the best performing buildings are controlled [26], [47], [48].

Others mentioned criteria are related with QE's activity as also explained in Section 1.5.1. For example, in France, the certification body has to check at least 8 reports, during the first years of the QE's activity (detailed desk audit); and at least one EPC with an on-site visit of the building for each certification cycle (5 years) of each QE. In Portugal, also, the first EPC issued by the expert is controlled by an on-site visit [23].

All these criteria, except customer complaints, have been considered in row 13 "other selection criteria" of Table 1.3. Generally, MSs and regions carry out controls when there is a complaint from a citizen, nevertheless, as this is not a key distinguishing factor, it has been disregarded.

1.5.6 Control Sample Size

EPBD requires the annually control of a statistically significant percentage of all EPCs [4]. Randomly selected EPCs can provide information on the overall quality of the certificates. Therefore, according to population size, a random sample size necessary to ensure statistical confidence is established by the following table [33] (see Table 1.4).

Table 1.4. Sample size for a statistically significant random sample. [Source:[33]].

Population Size	Sample Size	Significant percentage
100	80	80%
200	132	66%
500	217	43.4%
1000	278	27.8%
2000	322	16.10%
5000	357	7.14%
10000	370	3.70%
20000	377	1.88%
50000	381	0.762%
100000	383	0.383%
200000	383	0.192%
500000	384	0.077%
1000000	384	0.038%

The minimum sample size should substantially increase if MSs want to obtain information on subsamples (e.g. regional differences, new vs existing buildings, etc.) [33].

The yellow shaded cells show the range of population size in the Basque Country per year according to the data provided by Economic Development, Sustainability and Environment Department of the Basque Government and therefore the reference percentage in EPCs that should be controlled is 0.762%-1.88%. For example, between years 2018-2019, 62436 EPCs have been issued and among them 1323 EPCs have been controlled (2.1%). The percentage is significant but does not correspond to the random sample, just to the targeted sample.

As can be seen in Table 1.3, the sample size is related to the checking methodology. The more comprehensive is the used methodology, the smaller the sample size is. This is the case of Emilia Romagna Region in Italy, where 100% of EPCs issued during the last campaign were checked by automatic control, of which about 5% with document verification and 2% through on-site inspections [17]. Similar tendency is declared in GR, HU, BG and PT as can be seen in Table 1.3.

Nevertheless, it is not enough to comply with the recommended minimum sample size. In order to consider the quality on the set of the EPCs, the Energy Performance of Buildings Committee recommend limits in terms of confidence interval and confidence level for the significant sample (see Table 1.4): confidence interval of 5% with a confidence level of 95%. This means that the result has a 95% probability that the sample gives a compliance rate at ±5% of the actual population compliance rate (which is unknown) [33].

1.5.7 Monitoring the EPC quality

Although MSs seriously intend to implement a credible, effective control system to satisfy EPBD, very few countries monitor the results obtained in their EPC control campaigns. This is evidenced by the scarce data found and showed in row 15 of Table 1.3.

Data were collected in [33] about the number of MSs that have information on the percentage of good quality EPCs as result of the independent control of a random sample. According to those data, 38% of MSs did not have this information at that time, 42% had this information but the rest of the CA participants did not know about it and 21% of MSs had that data yet had not made it public.

In addition to a lack of compliance rate data, there is few information in the available literature or in the MS reports about frequent errors or miscalculations in EPCs. PT [49] and MT [46] are the few exceptions. Information about DK and IE is more confusing. They state the existence of that good practice [46], nonetheless any details about common errors are found.

Not enough importance has been given to monitoring the results, however knowing the percentage of good quality EPCs is necessary. This information is vital to analyze the efficiency and efficacy of the independent control systems and identify current failures [30], [33]. Thus, according to these reports, monitoring and publishing the results should be required for all MSs.

Moreover, as MSs and researchers use different criteria to define EPC quality, among the quality indicators found there is a great variability. As can be seen in Table 1.3. MSs declare compliance ratings from 20% until 94%. Fabbri and Marinosci stated that nearly 80% of EPCs have at least one “noncongruity” which is detected during the on-site inspection [17]. Hardy and Glew show the results of system based on validity check. They found that 27% of EPCs display at least one flag to suggests it is incorrect and they estimate the true error rate to be between 36-62% [11]. López-González et al. used a Matlab algorithm in order to check the correctness of climate zone definition in La Rioja (Spain) and Aragón (Spain) databases and conclude that the compliance rate is of 50.29% and 58.03% in the corresponding order [35], [50]. The Qualicheck project analysis the EPC compliance focusing on the EPC input data quality [51]. Within this project, the Spanish case study [16] demonstrated that 12 out of 25 existing building EPCs had obtained an incorrect rating; the Austrian study showed that 25 out of 26 evaluated EPCs deviated from the original [51]; and the Romanian study concluded that 18 out of 26 cases had deviations larger than ± 5%, while 15 out of 26 analyzed EPCs presented deviations larger than ± 10% [51].

This versatility apparently is conditioned by the type of checking methodology and quality criteria. In consequence, it is difficult to compare the overall quality of the EPC scheme among MSs.

1.5.8 Quality Criteria. Allowed limit on deviation

Despite the European Building Performance Committee recommend a quality criterion (see Section 1.5.6) —confidence interval of 5% with a confidence level of 95%—, the criteria adopted by MSs are different between them.

Two main strategies have been identified among MSs on the deviation limit determination as can be seen in Table 1.3:

- Limitation of the deviation based on the energy class difference, such the case of HU. There is permitted until 2 rating deviation.
- Limitation of the deviation based on the calculated error. This is the most generalized criteria and varies between 5%-30% (Table 1.3).

The strategy chosen in Ireland is unique [52]. The impact of errors is sized to determine the evaluation outcome. There are 6 grades of severity of noncompliance (compliance, severity 3, severity 3 advisory, severity 2, severity 2 advisory and severity 1). Each outcome involves a number of penalty points and the severity 2 and 1 carries the revocation of the EPC. Thus, the noncompliance in various EPC registrations may lead to the accumulation of penalty points and in consequence, to the suspension of registration of an EPC QE in case of 10 penalty points or more are reached within the previous 2-year period.

However, in this section it should be noted that there is little information on the quality criteria taken by the MSs (see Table 1.3).

1.5.9 Control phases in new buildings

The control in new buildings has a double objective: verification of compliance with building regulation and the verification of the declared energy rating.

The majority of MSs undertake the checking both at the design stage and when the construction phase is finished [46]. This second check is crucial to ensure that the building, as it has been built, complies with the declared specifications in the design stage. Some independent control systems ask for proof of compliance at a certain point after construction was complete [33], while others require *in-situ* inspections during the construction works such as the case of EUS [26], NAV [47], VAL [48] and NL [46].

Anyway, carrying out or not in both phases is not a key distinguishing factor between the independent control systems. Therefore, this characteristic has not been included in Table 1.3.

1.6. Control Systems Case Studies

This section includes procedures or workflows applied in the independent control systems of Portugal and the Emilia Romagna Region.

1.6.1 Emilia Romagna Region

Fabbri et Marinosci described the procedure adopted in Emilia Romagna Region and the obtained results during the control campaign in 2016 and 2017 [17]. The results show the effectiveness of the system and its capability to identify two categories of bad professionals: negligent technicians (who make mistakes, do not have a full understanding of the legislation for the specific case, cannot find data, etc.) and pirates (who deliberately commit errors). That is because the system is focused on sharing technical culture by giving opportunities to certifiers to improve the EPC quality during the registration procedure as it is explained below.

The followings are the procedure main steps:

- The certifying body makes out the EPC data and signs and sends in order to perform a validity check.
- In case a non-congruity is detected a notification is sent to the QEs and asked if they want to continue with the registration even though their EPC probably contains nonconformities (NC) or if they prefer that it be reviewed by an expert controller. In both cases, a desk review is performed and an evaluation report

is sent to the QEs with the results. Thus, two scenarios are possible:
(a) there is no any NC that requires an on-site inspection. In this case, two other situations can also occur: i. In case of the EPC has not been signed previously (draft EPC), QE has to choose if continue with the registration without considering the observations (it can be re-checked) or cancel it to re-register the corrected EPC. ii. If it is an issued EPC, the procedure is finished.
(b) an on-site inspection is required. In this case, the procedure continues as described in the following steps.

- An inspector is assigned and the inspection is carried out.
- The inspector issues his report which may or may not contain any NC. Two other situations may result at this time:
  (a) Draft EPC: QE must choose if the registration goes on without considering the observations (it can be re-checked) or cancel it to re-register the corrected EPC in accordance with the instructions.
  (b) Issued EPC: there are two further possible cases: i. It does not contains NC. The procedure is concluded. ii. It contains NCs. Depending on its severity, it enters the sanctioning process or it is previously conceded a period of 10 days for the correction of the EPC.

1.6.2 Portugal

Two projects which are co-funded by the EU's program present the Portuguese case study as best practice in quality control [40], [49]. They describe the workflow of the system which is structured into two phases:

- Prevention phase
  - Automatic input validation of the EPC inserted in the database (100% of EPCs). This step aims to identify potentially erroneous values in the submitted EPC data. Inconsistencies or out of range values are identified in

this step and experts can correct the inputs when they receive the portal alerts.

- Correction phase
  - Simple quality checks. This is performed on a random sample of the EPCs issued daily and the sample covers 5-6% of the total EPCS. The analysis is carried out without the QE's participation, without any complex calculations and by crossing documents uploaded by the expert.
  - Detailed quality checks. This is applied to 0.5% of the registered EPCs. It includes the replication of the work performed by the QE. An on-site visit and calculations are performed and the results are compared with those of the EPC issued by the QE. If severe mistakes are found, fines can be applied.

Moreover, parallel to the control of the EPC and at the same time, ADENE (Agency for Energy and National Energy Agency) experts evaluate the QE's work quality [40]. They accompany the QE to an on-site visit before issuing the EPC and verify if the QE complies with the established technical and administrative procedure.

The procedure which is based on 4-level control system (validity check, simple verification, detailed verification, and QE quality control) is complete, but also the establishment of the quality criteria is remarkable. The system is quite developed in this aspect.

The limit allowed in the deviation, even if there is no modification in the letter, is 5% in the ratio of primary energy needs [49]. But in addition to that, other requirements need to be met. The lack of recommendations, the incorrect procedures or calculations, and the noncompliance with the overall quality of EPC in terms of its contents are considered NCs. Regarding the last one, the Portuguese regulation [53] determines acceptable deviations in the 74 input parameters for residential building EPCs verification and 68 parameters for tertiary buildings. They are used to quantify the number and severity of errors or mistakes that can exist in an EPC.

Finally, there is another distinguishing aspect with respect to the rest of MSs. Technical mistakes identified during the control process are registered in the central database related to QE data. This allows not only monitoring each QE's error rate development over time but also the most common mistakes the QE makes.

1.7. Verification methodologies

1.7.1 Validation rules

Checking by validation rules is the most widespread methodology. However, there is no much literature on the effectiveness and technical scope of systems based on this methodology. These best practices are worth further exploration and wider application [33]. In this section, few particularities of several systems based on this methodology are collected.

In Sweden, automatic controls are performed in the electronic certification system for all EPCs. These controls include, e.g., the level of energy performance, the heated area, the real-state information, and the climate-data verification [46].

Whereas, in general, the automatic input data check is used to detect out-of-range values, missing data and noncompliance with regulations, in Norway it is also used to detect false data. EPCs with an "A" rating require the submission of an air infiltration test report with a blower door test. The infiltration rate declared in this report is compared with the value defined in the EPC [46].

The Catalonian Institute of Energy (ICAEN), given the high volume of certificates, automated the review of EPCs. A warning system has been implemented to verify in the back office the coherence between the form data and the XML file generated by the energy certification tools, as well as to check the consistency of the XML file values. In total there are 90 configurable warnings. However, the level of exigency can be increased over time. If the data successfully passes the warnings, the energy efficiency label is automatically sent. Otherwise, a person from ICAEN's energy certification team reviews the EPC, sending requirements to the person who signed up for the procedure [54].

Hardy and Glew after analyzing UK public EPC data and studying them with professionals responsible for the training and certification of EPC assessors together, wrote a script with a 16 error code in order to detect potential errors [11]. The followings are the used validation rules:

Table 1.5. Validation Rules proposed by Hardy and Glew to evaluate the registered EPC data in UK. [Source: [11]].

Error group A) possible lodgement errors	Error code 1 - identical duplicates
	Error code 2 - EPCs with the same inspection date
	Error code 3 - EPCs lodged within a week
Error group B) building structure discrepancies	Error code 4 – differing floor type
	Error code 5 - differing wall type
	Error code 6 - disappearing pitched roof
Error group C) building design discrepancies	Error code 7 - differing property type
	Error code 8 - differing built-form
Error group D) discrepancies inflat parameters	Error code 9 - differing flat floor level
	Error code 10 - differing top storyflag
Error group E) reduced energy efficiency products	Error code 11 - reduced wall insulation
	Error code 12 - reduced glazing performance
	Error code 13 - decreased loft insulation
	Error code 14 - decreased energy efficiency rating
Error group F) random errors	Error code 15 – Random error on multiple EPCs for a single house
	Error code 16 – Random error on EPCs of neighbouring house

Dall’O’ et al. based on EPC data from Lombardi Region to develop their study [20]. However, previously they automatically checked the consistency of the public data by applying validation rules in order to ensure the data quality. The followings are the employed validation rules:

Table 1.6. Validation Rules used to filter the Lombardi Region EPC data. [Source: [20]].

Parameter description	Unreliability of the parameter
Net Floor Surface (A_n)	A_n<50 m^2
Net Volume (V_n)	V_n<120 m^3
Ratio of dispersant surface and heated volume (S/V_r)	S/V_r<0.2 or S/V_r>1.5
Calculated average heigh (V_n/A_n)	V_n/A_n<2.4m or V_n/A_n>6m
U-values for opaque surface	U<0.15W/m^2K or U>2.6W/m^2K
U-values for transparent surface	U<0.8W/m^2K or U>6W/m^2K
Heat demand indicator/primary energy indicator (ET_H/EP_H)	ET_H/EP_H<0.5 or ET_H/EP_H >1.5

They filtered out the 24.6% of the EPCs that contained information with risk factors that indicate the EPC may contain errors.

In conclusion, according to the information collected about the details of the checking systems based on validation rules it can be said that:

- The first validity checking helps EPCs reach the registry with higher quality. However, it is practically impossible to contrast the EPC input data with actual values. This means that if only this methodology is used for the overall control of EPCs, defining consistent input data, but not the actual one is possible. The example of air infiltration rate validation in Norway is an exception. Therefore, it is a methodology that optimizes the control system, but it would be desirable that it worked in combination with another methodology.
- The validation rules vary from one EPC scheme to another. It is necessary to adapt them to the available input data in each EPC scheme and calculating software.
- Some validation rules and their ability to detect EPCs with error potential are known, otherwise it is unknown how much is the limit to pass or fail the validation test in terms of EPC quality level.

1.7.2 Verification based on Artificial Neural Network

According to [18] and [55] another tool to perform EPC quality verification can be the Artificial Neural Network (ANN). They proved that it can be used for predicting indicators that are used as energy performance indicators in EPCs in a rapid manner.

Khayatian et al based on ANN to predict the heat demand indicator [55] regardless of plant specifications and renewable energy systems, due to the complexity involved. Five models were investigated, each one with an input number (12, 13, 15, 18, and 21). The choice of the most suitable model was based on the best relation between performance and computation time. The preferred model (12 inputs and 50 neurons) presented an acceptable regression of 0.95 with a mean absolute error of 16.03 kWh/m^{2}y.

Buratti et al. also applied ANN to predict energy labels based on 2000 energy certificates from the Umbria Region (IT) [18]. The proposed Neural Network demonstrated that it is possible to estimate the energy consumptions from specific parameters, evaluate the accuracy of data in EPCs, and identify EPCs with potential errors. It showed an error greater than 15 kWh/m^{2}y in only 3.6% of the cases.

Therefore, it is an useful tool in order to predict the result of an EPC based on some input data and compare it with the result presented by the QE. Nevertheless, the correctness of the input data is not considered by this methodology. That means that passing test is possible being the input data out of range or far from the actual value. It can be said that this tool tests the used calculating methodology in EPCs.

1.7.3 Manual verification

The point-by-point verification is the most complete methodology as it allows to evaluate: all input data crossing with supporting documents and collected data by onsite inspections; the used calculating methodology; the absence of data; and the compliance with building code requirements. Otherwise, the experience showed (see Table 1.3) that it requires more resources than automatic methodologies, and in consequence, a small number of EPCs have been controlled in this way.

For example, it is the methodology used in EUS [26] and VA for new buildings [48]. The procedure is defined in both cases. However the effectiveness of these systems is unknown as there is no monitorization of the obtained results. In addition, no verification protocols, neither their results, have been found in other regions or MSs that also partly employ this type of verification.

The procedure established in EUS is detailed in Chapter 3.

1.8. Future improvements in EPC Quality Assurance

As some studies show [10], [28], through this literature review it has been seen that there is a need to improve control systems to ensure that the full impact of these systems is achieved.

Li et al. suggest that the actions can be approached from three perspectives: (1) input data; (2) QE; (3) software-applied [10].

According to the report *Quality Control Schemes make the EPCs more reliable* [30] improving the quality of the EPC system should be a continuous-iterative process and every continuous improvement process requires the existence and functioning of a monitoring system of the quality of the scheme. The improvements should be driven by integrating the feedback of the monitorization results in EPC schemes.

Moreover, the authors [30] point out that making the central EPC database information accessible for research organizations can facilitate research and provide new ideas for the independent control systems.

The QualdeEPC project [29] has concluded the priorities of project participants in order to improve the independent control systems.

Taking into account the sharing of the total points, the first five priorities (from highest to lowest score) are as follows:

- Reporting errors or faulty procedures in a central database to create statistics of common mistakes for training purposes and identify assessors with high error rates.
- Deeper control and monitoring of renovation recommendations.
- Performing automatic validity check of EPC during the assessment and/or during upload to the central database.
- Quality Control of both EPCs and QEs.
- Sufficient sample size for verification and quality control.

1.9. Conclusions

This section aims to conclude some points identified in the literature review that are not fully developed yet.

The first conclusion drawn from the literature review is that there is a lack of reliability and confidence of EPCs. This means that the control systems are not working effectively and that there is a need to improve the effectiveness of these systems, so as to improve the quality of the EPCs and thus regain the trust of citizens. Otherwise, the continuity of the EPC may be at risk.

In order to improve the system in the Basque Country, practices from different MSs that have not been implemented in our system and that could be applied as long as their effectiveness is validated, have been reviewed. These practices are listed below:

- Introduction of a validity check system being complementary with the point-by-point control methodology. It can be entered either in the pre-registration phase or post-registration control.
    - Introduction of a prevention phase prior to the registration request through alarms that would allow the certifier to make its own corrections before sending the

request. Nowadays, there is not any prevention phase during the registration procedure.
    - Introduction of validity rules in a post-registration phase to identify EPCs with a high risk of errors.
- The selection criteria of the EPCs to be controlled can be modified as long as their effectiveness is proven. Currently, the buildings with the best energy performance are controlled, however, there are other selection options in other countries and regions. It is not proven which one is the most effective.
    - Random sample selection which is recommended by the EU.
    - Selection based on a number of EPCs per QE, so that the work of all QE's is evaluated.
- Introduction of a system that links the EPC data with the author's data for monitoring and verification purposes.
- Establish quality criteria for input data for EPC controller technicians, i.e., determine the tolerances that can be allowed for each type of input data. At present, in the point-by-point methodology, there are no tolerance criteria to determine whether an input value is valid or not. This practice allows all controllers to have the same quality criteria.
- Introduce the obligation to present test results to justify values defined in EPC. This is the example of Norway, which requires a blower door test to ensure the reliability of the air infiltration data defined in EPC. In the same way, it could be generalized to other types of tests.

On the other hand, the literature review has identified aspects that are to be developed in general, not only in the Basque Country but also in other countries.

- The monitoring of the results obtained in control systems. On the one hand, knowing the quality indicators of a sufficiently large sample allows generalizing the results to the whole set of registered EPCs. It is the first step to obtain feedback on the functioning of the implemented system and then to improve the system. On the other hand, the diffusion of the common errors that are detected makes it possible to improve the knowledge of the technicians and in a collateral way, the quality of the EPCs.

- No system has proven its effectiveness. If the objective is to reach the quality indicators proposed by the EU (confidence interval of ±5% in a 95% probability) it has not been demonstrated that the methodologies used in known systems are so effective that they can guarantee this level of quality. For example, a validity check is a widespread and diverse practice. But its effectiveness is not known in any of the countries where it has been implemented. That is, those who pass the automated rules test are assumed to be of sufficient quality to be recorded, however, they may contain a tolerated error. How much is tolerance allowed? 5%? 10%? It is not known for any of the cases.
- ANN systems have been proposed to automate the checking of EPCs, but no case study was found in which this was put into practice.

Finally, one of the general problems of EPC schemes that has been highlighted in several documents is the lack of homogeneity between the systems. Each state or region is making its own way in developing EPC schemes and its quality system. Therefore, EPC databases and quality control results are no longer comparable between different countries and regions and it is more complex to obtain global conclusions for all systems. In that sense, all research in the search for global solutions and their divulgation can contribute to the homogenization of systems..

2 Objectives, Methodology & Structure

2.1. Framework of the thesis

This line of research is included as part of the work carried out by the ENEDI group (UPV-EHU) in the Thermal Area of the LCCE (Basque Government) thanks to the collaboration agreement that exists between these two entities.

The Thermal Area-LCCE is one of the current 28 accredited bodies to perform EPC quality controls. From Thermal Area-LCCE, 239 EPC controls have been carried out between 2014-2019. According to data from the last year published by EVE, this is approximately 10% of the total of EPCs registered with accredited body's control in the Basque Country.

The main objective of the control is to improve the quality of the EPCs and the general knowledge of the technicians. However, in recent years no improvement has been perceived in these regards. In addition, the increase in the number of EPCs to be controlled has generated a need to optimize working procedures in order to control the maximum number of EPCs, with fewer possible resources and with as much detail as possible. These two factors have led us to investigate this line of research in order to bring about improvements in the procedure.

2.2. Objectives

The main objective of the thesis is to contribute to optimizing the control procedures and making their implementation more effective. For that, a deep analysis of the EPC quality control experience in LCCE will be made by assessing the effectiveness of the Basque Country's EPC control system and in order to check different issues of the procedure, thereby identifying its gaps and potentials. For this purpose, data of 146 EPC control sample carried out in LCCE will be gathered. The conclusion obtained in that analysis will help to propose improvements in the Basque Country's system.

To reach the final goal mentioned above, the following partial objectives are also identified.

The aim of the state-of-the-art in Chapter 1 is to learn about EPC quality control methodologies applied throughout other countries and regions. Likewise, to identify the others system features which are applicable in the Basque Country's system as well as other possible improvements which are not developed in any system.

The objective of Chapter 3 is to provide an overall description of the EPC sample control performance between 2014-2019, which will be the database for the study undertaken in this thesis. The followed procedure in the control performance of the sample is intended to be presented in the context of stablished regulation as well as the selected EPC sample description. The aim of the detailed report is to demonstrate its representativeness and have information about its features and their evolution, which could be useful for the next objectives.

The main goal of Chapter 4 is to assess the EPC quality. The study consists of the analysis of the error gap between the draft EPCs and final EPCs of the sample and nonconformities (NCs) found during the control. The analysis provides to conclude several tendencies of the population (Basque Country's EPC database). To reach this aim, the following objectives are proposed:

- To obtain the general results of an EPC large sample quality in terms of the deviation between draft and final EPC and required NCs.
- Analyze the evolution of deviation and NCs during the years of study.
- To assess the inaccuracy in EPC database by a statistics analysis of the sample deviation. For this purpose, it will be needed to fit the distribution of deviation frequency in the sample to a theoretical distribution.

The main target of Chapter 5 is to know the behavior of the error in different subgroups of the sample and to know the relationship of the common characteristics of the subsamples with the error presented by these sets of EPCs, in order to obtain guidance for the selection of EPCs to be controlled.

To reach this goal, the following objectives are formulated:

- To assess the appropriateness of the current control obligation criterion in the Basque Country by investigating whether there is a trend in the deviation as the energy rating scale improves.
- To assess the appropriateness of the control obligation criteria applied in others MSs and regions, based on the selection of EPCs by QE’s and the random sample.
- To identify which characteristics make an EPC more error prone.

- To identify which classification of subsamples has more impact on differentiating error behavior of subsamples.
- To conclude some guidelines, if it is necessary, to improve the current control obligation criterion in the Basque Country.

The aim of Chapter 6 is to performance an exhaustive analysis of collected NCs in noncompliance reports of the sample by cataloguing the type of NCs, exploring what underlies these NCs and what are the most appropriate and optimal ways to identify them. To achieve this purpose, the following objectives have been set:

- To identify which are the common mistakes and which are the most influencing in the resulting sampling error.
- To investigate why the mistakes do happen and in which technical area do they occur.
- To assess the optimal and most suitable way to check the definition of a building in an EPC, in order to detect the highest resulting sampling error possible.

Finally, the objective of Chapter 7 is to propose improvements in the control procedure based on the conclusions obtained in the previous chapters 4, 5 and 6 as they are the result of the experience gained in EPC control campaign during the period 2014-2019.

2.3. Methodology and structure of the thesis

The improvement of the procedure and the quality of the EPCs has to be a continuous and iterative process, as it has been demonstrated in the state-of-the-art. The improvements in the procedure must come from the feedback of the learning experience. For this, it is necessary to monitor of control results, which is not a common practice in MSs as seen in the previous chapter.

The methodology of this thesis is based on this continuous-iterative process (see Figure 2.1). It is structured in 3 consecutive sections: data collection from EPC sample control (Chapter 3), analysis of monitoring data of control results (Chapter 4, 5 and 6) and control methodology improvements proposal.

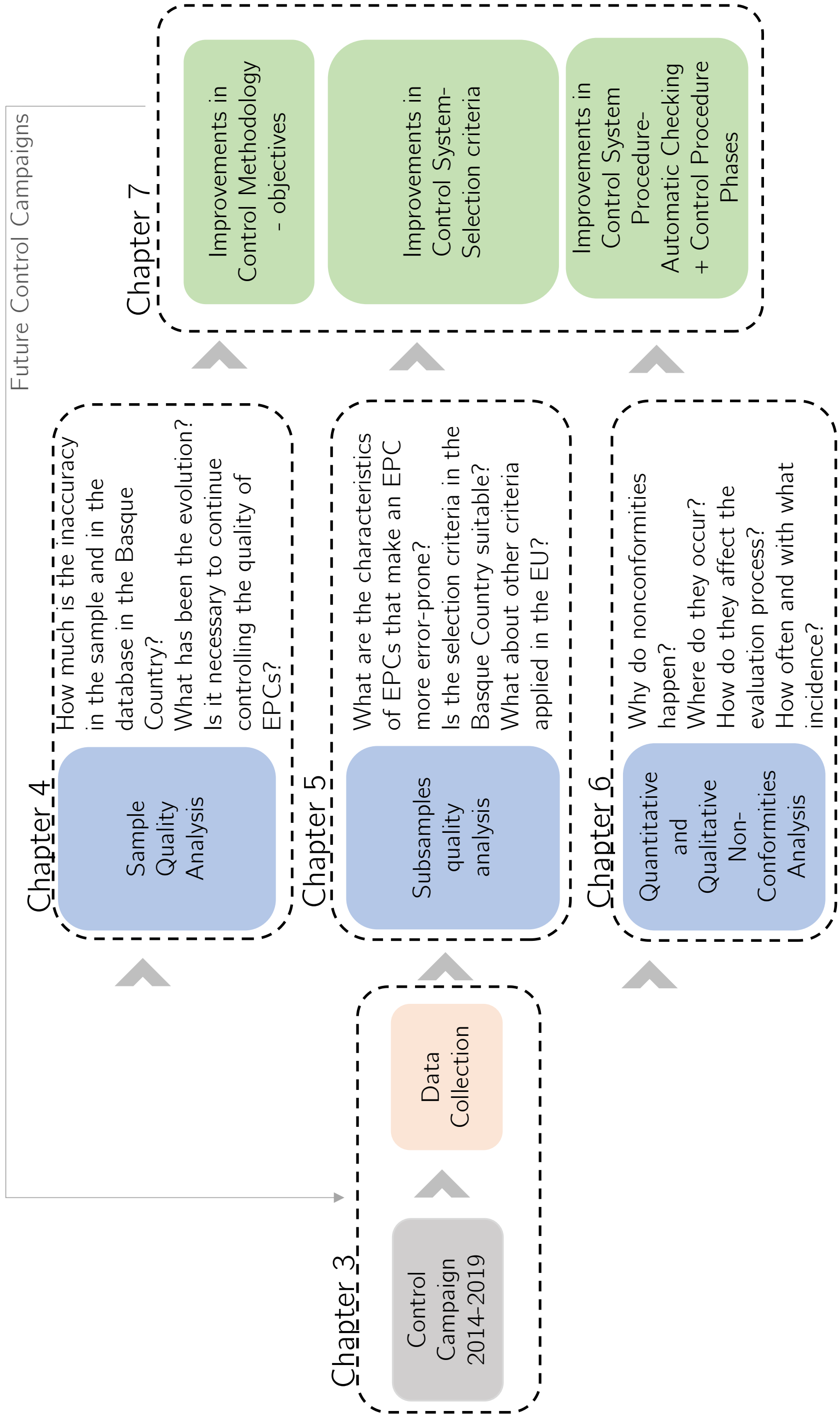


Figure 2.1. Continuous-iterative structure of the thesis.

The aforementioned sequence is reflected in the structure of the thesis. The first two chapters deal with the introduction of the thesis, the state-of-the-art of the research line (Chapter 1), and the global approach of this work (Chapter 2).

Chapter 3 presents an overview of the control campaign carried out between the years 2014-2019. A representative sample of EPCs controlled in LCCE has been selected for this thesis. These data are the basis of the study of this thesis, therefore, this chapter is intended to explain in detail its origin and validity. At first, the control methodology followed in these files has been reported going into detail about the Basque Country control system, control procedure for different types of EPCs, and means of data collection during the control. Next, the general, constructive, and active characteristics of the selected sample of 146 EPCs have been analyzed in order to prove its representativeness.

Chapter 4 analyzes the EPC sample quality in terms of the deviation identified between the first EPC and the last one after passing the control, the NCs issued and subsequently corrected during the process and the chronological development of the previous two points. After that, a statistical analysis of the sample deviation is carried out in order to extrapolate the sample results to the population (Basque Country EPC database). Thus, the inaccuracy of EPC outcomes has been assessed and some improvements key factors have been discussed.

Chapter 5 exposes the quality analysis of the various EPC subsamples. These subsamples have been structured following, on one hand, different EPC control selection criteria, and on the other hand, in line with hypothetical EPC features that could influence in the EPC inaccuracy. Assessing the pattern of error in each subsample of different classifications has allowed which are the features that make an EPC more error prone and which is the most error differentiating criteria in order to obtain guidance for make improvements in the criteria for the selection of EPCs to be controlled.

Chapter 6 analyzes the NCs recorded in during the controls of EPCs of the sample. Firstly, all collected NC types have been catalogued. After that, a qualitative, quantitative and mixed analysis of these NC types have been performed consecutively in order to investigate the reasons why they happen and the most appropriate and optimal forms to detect them.

Finally, Chapter 7 closes the cycle of continuous-iterative process of this thesis as it proposes improvements driven by the conclusions obtained in the 3 previous chapters. These improvements are proposed for three phases: for a prevention phase before EPC registration, for the selection criteria to choose EPCs to be controlled by the controller and finally, for the protocol of EPC evaluation checks. Two of the measures are based in an automatic check software so the validation rules for creating the software have been determined. Currently, the automatic check software is under development.

3 Quality Control Performance of EPC sample

3.1. Introduction

In this chapter the main material and methods to get data for this thesis are described. It is based on the data obtained from EPC controls which have been undertaken in the Thermal Area-LCCE as the task of an accredited control body.

During these years of study, 239 controls have been conducted and from these, a sample of 146 EPCs has been selected. All evaluations have been completed following the same procedure, established by the LCCE-Thermal Area and complying with the framework established by the control system in the Basque Country.

Therefore, the following sections show the methodology followed within the regulatory context, the description of the sample selected for study, and the main conclusions.

3.2. Methodology: Control Procedure

3.2.1 The Basque Country EPC Control System

EPC control is included as a further step in the EPC registration procedure. The EPC registration system is under the authority of the Directorate-General for Energy and it is managed by the Basque Energy Organization (EVE). However, the EPC Control Procedure is administered by a third party: accredited bodies or experts not hired by the Public Administration.

The control is mandatory for all EPCs with an A, B, or C non-renewable Primary Energy Consumption (nrPEC) rating. This means that 100% of new building EPCs and 0.5% of existing building EPCs have been issued with a previous control procedure between 2018-2019 according to the data provided by the Economic Development, Sustainability and Environment Department of the Basque Government. The control must be contracted to an accredited body with three exceptions:

- Private property residential existing building EPCs.
- Building renovations EPCs, intended exclusively for housing and property owners' associations.
- Public Administration existing building EPCs.

In the first two cases, the control is carried out by the competent Energy Department of the Basque Government and in the last case, it can be carried out by the competent technical staff of any of the Administration's services. However, the property or the Public Administration may also choose to hire one of the accredited bodies. Thus, among the EPCs analyzed in this study, there are some public buildings and existing residential buildings.

Regarding the procedure, in Spain [25] and therefore in the Basque Country [26], Directive 2010/31/EU [4] has been transposed according to option 1.c. of its Annex II. Decree 25/2019 [26] specifies the types of checks to be carried out during a control:

- Assess the calculation methodology.
- Examine the project documents: memory, quality control program of the work, construction elements and systems, and installations that affect the energy efficiency of the building.
- Visit the building.
- Complete technical tests and relevant measurements.

Nonetheless, the protocol and methodologies for its verification are open to the criteria of the accredited body. The following Sections 3.2.2 and 3.2.3 set out the protocol followed by the LCCE in the EPC controls that are the subject of this study.

3.2.2 Control Procedure

Complying with the sequence of actions dictated by the registration procedure, as far as the control phase is concerned, a protocol of verifications elaborated by the LCCE has been followed.

There are three modalities of EPCs (ref RD235/2013): (1) Building in Project EPC, (2) New Built Building EPC, and (3) Existing Building EPC. Hence, the procedure to be followed in the control is also adjusted to the reality of each mode. A control procedure scheme is presented for new buildings (see Figure 3.1(a)) and for existing buildings (see Figure 3.1(b)). The actions are drawn within its corresponding modality and represented with a certain geometrical shape for each actor involved in the procedure. The phases are described below.

Building in Project EPC (BP-EPC) Phases (See the first part of Figure 3.1(a)):

- *Initiation of registration and application for control*: Control begins during the project phase of the building. The certifier or the property developer uploads the draft documentation of the building in project EPC to the online application of the register and requests the control to an accredited body.

- *Documental verification*: The first step of the accredited body is the revision and documentary verification. On one hand, it is revised the description memory, construction elements, and systems description, plans, installations memory, and the regulation compliance memory. The quality control program of the work is also gone over to extract relevant information from the thermal performance quality checks that are planned for the construction phase. All data collected through documents are described in Table 3.1 in Section 3.2.3. After the project data is collected, all EPC input data is corroborated comparing with project data, and the definition methodology is evaluated.
- *Nonconformity (NC) or conformity report*: Once the review is completed, the accredited body draws up a conformity or NC report. If the report is compliant, it is added to the registration initiated by the requestor —the certifier or the promoter—, and then the requestor can continue with the next steps of the registration. On the other hand, if the report is not in conformity, the controller indicates in the report the corrections to be made by the certifier in the EPC. After that, the process is restarted until the EPC is completely correct.
- Finishing the registration procedure. When the accredited body uploads the compliant report to the registry application, the applicant must accept it and send the application, including the EPC and the compliant report. Finally, an EPC label is issued by EVE.

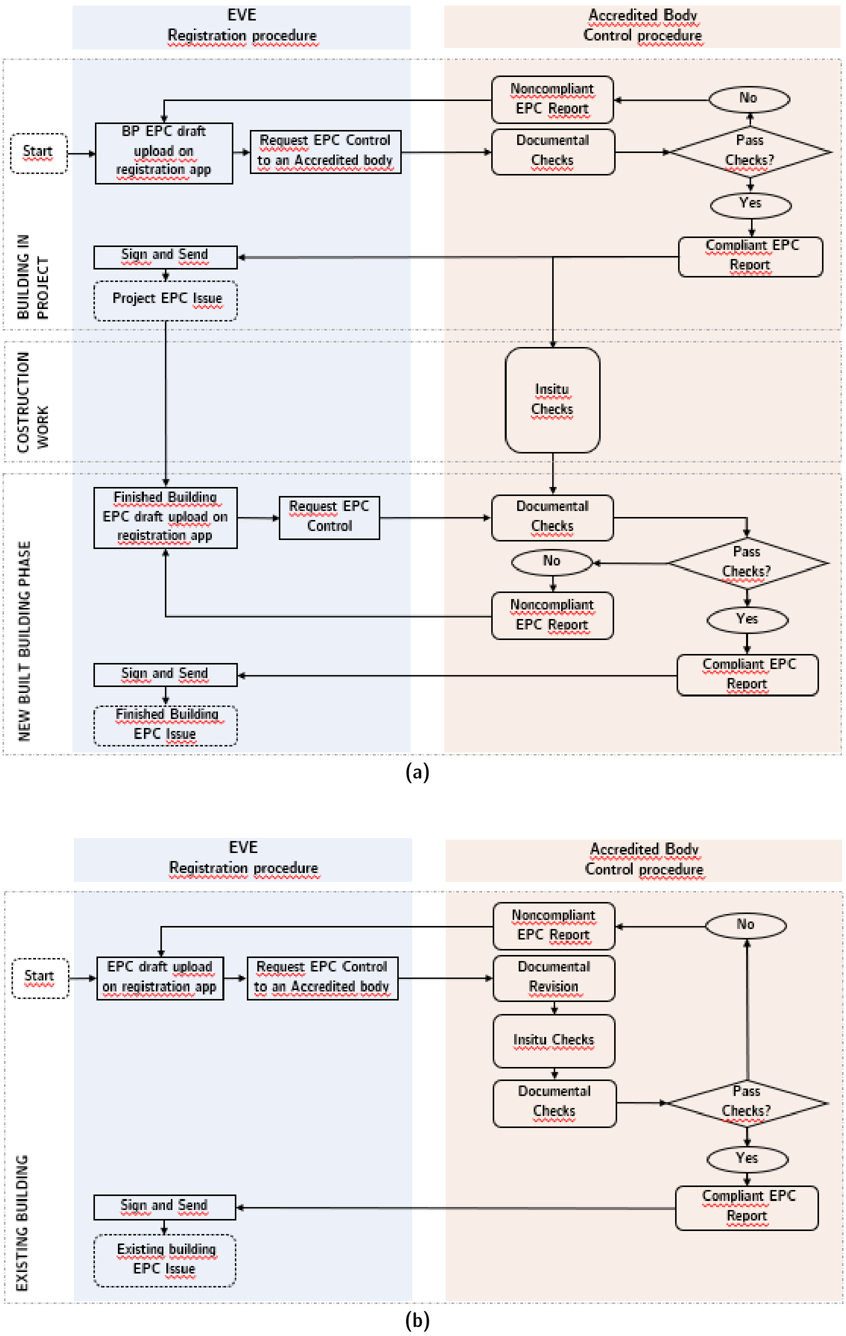


Figure 3.1. Control Procedure chart: (a) for a new building; (b) for an existing building.

New Built Building EPC (NBB-EPC) Phases (see last part of Figure 3.1.(a)):

- *In-situ Checks*: During the work phase, the accredited body makes 3 visits to the building to obtain as-built data that will be needed for the EPC evaluation at the end of the job. All collected types of data during the inspections are listed in Table 3.1 in Section 3.2.3. The first two visits to the site are made during the execution of the insulation to take the type, thermal conductivity, and thickness data of the executed insulations. Special attention is also paid to the execution of the insulation in constructive solutions adopted to break thermal bridges. The third visit is in the final phase of the construction and the rest of the characteristics are verified: windows, thermal installations, lighting, ventilation systems, conditioned and unconditioned spaces, etc.
- *Application for Registration and Control*: Once the work is completed, the certifier or developer updates the documentation of the New Built Building EPC with the changes that have occurred during the construction and re-applies for control with the updated documentation.
- *Documental Verification*: At this time, the controller already has the data collected during the construction phase. In this way, the technician evaluates the correspondence of the EPC input data with as-built characteristics. Furthermore, the controller reviews the documentation supporting EPC input data that is submitted by the applicant, e.g. calculations of thermal bridges, those of ventilation flows, or calculations of percentages of energy consumption covered by renewable systems that are not calculated by the EPC calculation program. Finally, in the same way as in the Building in Project EPC, EPC calculation methodologies and other configurations within the EPC adopted by the certifier are assessed.
- *NC or conformity report*: id. Building in Project EPC.

- *Finish the registration procedure*: id. Building in Project EPC.

Although the control decree has always established the obligation for new buildings to carry out the Building in Project EPC Control, it was not until 2019 that many of EPCs had registered in the New Built Building EPC Phase. These registration requests occurred once the construction had begun or on its completion. Therefore, they have missed the Building in Project Phase steps.

Requesting the control after the execution of the insulations makes it impossible for controllers to verify them through a visual inspection. Given the increase in this type of request, in 2016 the LCCE established as a criterion that *in-situ* verifications already established for existing buildings must be followed as well. That includes the performance of an *in-situ* thermal resistance test (see Figure 3.2(c)) according to ISO 9869-1:2014 —Thermal Insulation, building elements, and *in-situ* measurement of thermal resistance and thermal transmittance. Part1: Heat Flow meter method— [56].

Otherwise, the following are the steps involved in controlling an Existing Building EPC (see Figure 3.1(b)):

Existing Building EPC (EB-EPC) Phases (see Figure 3.1(b))

- *Initiation of registration and application for control*: id. new building EPC
- *Documental Revision*: This is a documentary revision prior to the visit to the building. On one side, the aim is to obtain the data of the building's characteristics that can be checked onsite with a visual inspection. On the other side, this step is intended to identify the enclosure types and possible test places to measure the thermal resistance *in-situ*.
- *In-situ verification*: The controller makes two visits to the building. In the first visit, the instrumentation of the test is placed and data recording is started. In addition, this visit is used for the rest of the verifications that must be done visually and by

means of the glass measuring device. These verifications can also be made on the second visit. However, doing them in the first one is considered convenient, since this makes it possible to leave some verification pending for the next visit if needed. The second visit takes place 7-10 days later as set out in the standard. In this visit it should be verified that the data have been recorded correctly, the test is then stopped and the instrumentation is removed.

- *Documental verification*: once in the LCCE premises, the recorded data are processed and the thermal resistance of each enclosure is calculated. Furthermore, as in other phases, the documentary evaluation is carried out which means the evaluation of input data from the EPC, supporting documents for the input data, and the calculation methodologies.
- *NC or conformity report*: id. Building in Project EPC or New Built Building EPC
- *Finish the registration procedure*: id. Building in Project EPC or New Built Building EPC

3.2.3 Data collection during Control

In order to be able to check the veracity of all the defined EPC input data, checked data are collected through project documents, end of work documents, technical sheets, visual inspections and tests. The following Table 3.1 shows the list of data collected and contrasted in each EPC and the way in how data are collected according to the phase and the EPC mode.

Table 3.1. List of data collected for each EPC and source of data depending on the type of EPC.

	BP-EPC	NBB-EPC and EB-EPC		
	Doc	Doc.	*In-situ* visual inspec.	Test
General Data				
Building use	x	x	x	
Conditioned/ Unconditioned area	x	x	x	
Shading elements	x	x	x	
Ventilation System				
Type of system (simple/ double-flux)	x	x	x	
Double-flux ventilation equipment	x	x	x	
Heat recovery system effiency	x	x		
Air flow rate calculation	x	x		
Insulation in envelope				
Type of insulation	x	x	x (Figure 3.2(a))	
Insulation thickness	x	x	x (Figure 3.2(a))	
Insulation thermal conductiviy (λ)	x	x	x (Figure 3.2(b))	x[1] UNE-EN 12667:2002
Envelope thermal transmittance (U)	x	x		x [2] ISO 9869-1:2014 (Figure 3.2(c))
Windows				
Glass thickness	x	x	x (Figure 3.2(e))	
Glass g-value	x	x		
Low emissivity glass	x	x	x (Figure 3.2(e))	
Glass air chamber filled with argon gas	x	x		
Glass thermal transmittance (U_g)	x	x		
Frame material	x	x	x	
Frame thermal transmittance (U_f)	x	x		
Percentage of the frame area in relation to the window area (%)	x	x	x	
Window frame air permeability	x	x		
Window global thermal transmittance (U_w)	x	x		x [1] UNE-EN ISO 12567-1:2011
Thermal Bridges				
Linear transmittance (ψ)	x	x		
Thermal Bridge length	x	x		
Constructive solution in thermal bridges	x	x	x	
Heating/Cooling system				
Type of heat/cool generation equipment	x	x	x (Figure 3.2(f))	
Equipment model	x	x	x (Figure 3.2(f))	
Installed nominal power	x	x	x (Figure 3.2(f))	

	BP-EPC	NBB-EPC and EB-EPC		
	Doc	Doc.	*In-situ* visual inspec.	Test
Equipment efficiency	x	x		
DHW thermal storage tank capacity	x	x	x	
DHW demand calculation	x	x		
Type of heating (radiant underfloor heating/radiators)	x	x	x	
Air processing units				
Heat battery power	x	x	x	
Cool battery power	x	x	x	
Supply air volume flow rate	x	x	x	
Heat recovery system	x	x	x	
Heat recovery system efficiency	x	x		
Solar thermal system				
Solar thermal collector model	x	x	x (Figure 3.2(d))	
Solar thermal collector absorber area	x	x	x (Figure 3.2(d))	
Number of collectors	x	x	x (Figure 3.2(d))	
Heat exchanger storage tank capacity	x	x	x	
Percentage of the DHW demand covered (%)	x	x		
PV system				
PV technology	x	x	x	
Number of PV panels	x	x	x	
Slope and Azimuth	x	x	x	
Installed peak PV power	x	x	x	
PV energy output (year)	x	x		
Lighting system (service buildings)				
Types and number of luminaires	x	x	x	
Installed power in each interior space	x	x		
IEEV in each interior space	x	x		

inspe.: Inspection; Doc,: Documental; PV: Photovoltaic; IEEV: Installation Energy Efficiency Value

[1] In case the quality control program of the work includes this test.

[2] When the insulation materials are hidden and it is not possible to verify its execution visually.

As an example, Figure 3.2 shows some photographs of the measurements and inspections carried out in some buildings.

Figure 3.2. *In-situ* visual inspections and measurements: (a) measurement of insulation thickness; (b) insulation label collected in building works; (c) *in-situ* thermal resistance test; (d) solar thermal collectors verification; (e) window glass thickness and low emissivity measurement; and (f) boiler label verification.

3.3. Sample Description

146 out of 239 EPC controls carried out in the LCCE between 2014 and 2019 (61%) have been chosen as a sample for this thesis. Appendix A lists all evaluated EPCs with all their data used for the analysis of the sample presented in this section.

To ensure the representativeness of the sample, EPCs have been selected to cover a wide range of constructive characteristics, age of buildings, locations, use and typologies, conditioned surfaces, degree of insulation of the enclosures, type of energy used, and configuration of the DHW installations and air conditioning and ventilation systems.

3.3.1 General characteristics of the sample

An annual distribution has been sought that is proportional to all the controls carried out in each year and a minimum sample number of 10% of the total sample (see Table 3.2). The analysis by years allows observing the trends in the characteristics of the buildings, which will be used in the subsequent chapters on quantitative and qualitative analysis and in the chapter on procedural proposals, making it possible in the latter to take into account especially the trends of recent years.

Table 3.2. Total of completed EPC controls per year.

	2014	2015	2016	2017	2018	2019	Total	%
No. of EPC controls	16	17	27	19	31	36	146	100%

As required by Decree 25/2019, all controlled EPCs have a nrPEC rating of “A·, “B”, or “C”. The 2.1% of EPCs are exceptions, since in draft they had a "C" qualification and after passing the control they have remained in a "D". The next graph (see Figure 3.3) shows that as years go by, more buildings have an "A" rating.

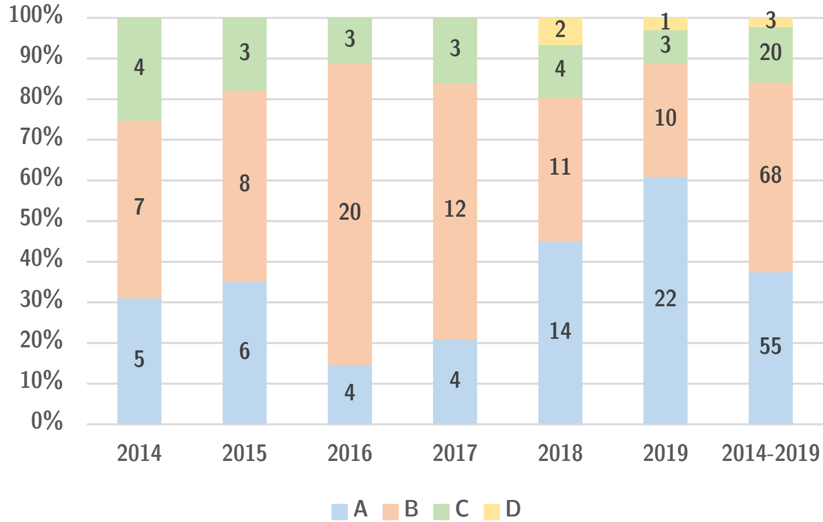


Figure 3.3. No. and percentage of EPCs per year according to the ratings obtained from the control.

All EPCs in the sample have been performed by 50 QEs. In the following Figure 3.4 the number of EPCs performed by each QE is presented, being the maximum number 18 and the minimum 1. A study [57] shows that the accuracy of EPCs is linked to their ability to understand and perform the procedure. In this paper, the authors have collected the results of EPCs of the same building made by 162 experts obtaining 4 different energy ratings and PEC results in a confidence interval of ±20 respecting average value. On the other hand, some MSs, such as France, have implemented their quality assurance system based on the control of EPCs by certifiers [23]. Therefore, it is an aspect to consider when analyzing the resulting deviations after passing the control procedure and this sample allows us to do so since there are 19 QEs with more than two EPCs to analyze the errors made by each QE.

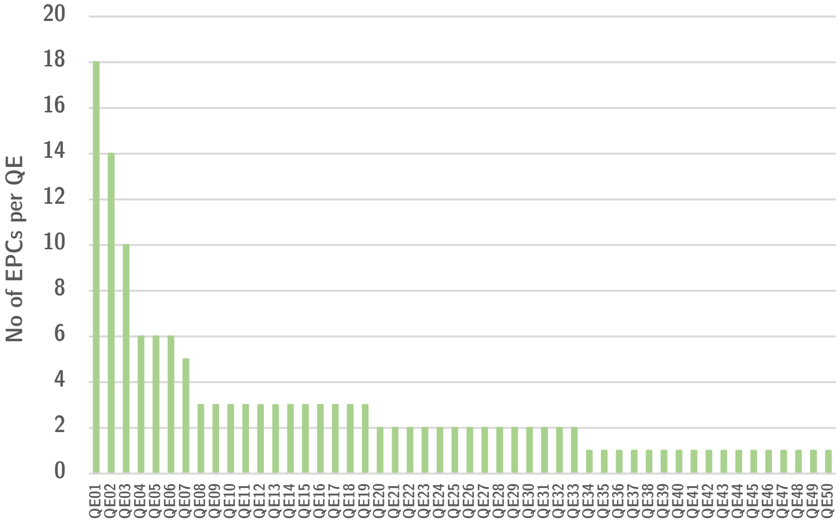


Figure 3.4. No. of EPCs performed by each QE.

Figure 3.5 shows the location of the buildings whose EPC has been verified. Most of the buildings are located in Vitoria-Gasteiz (south of the territory), followed by Bilbao (northwest of the territory) and its urban area. Probably, most of the control requests that have been received are from Vitoria-Gasteiz due to the LCCE location and from Bilbao, due to the population density in comparison with the rest of the Basque Country. However, the rest of the buildings are scattered throughout the territory including areas of low and moderate population density.

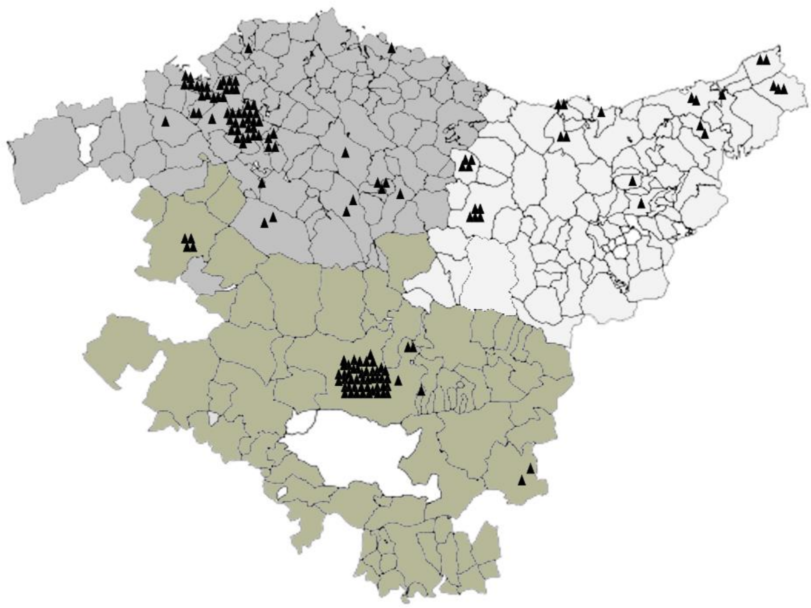


Figure 3.5. Location of the EPC sample.

The following Figure 3.6 displays the distribution of EPCs per year in each climate zone established by the Spanish Technical Building Code (CTE). The reference climate zone in the province of Bizkaia is C1, in Araba is D1, and in Gipuzkoa it is D1, the latter since the CTE—*for its acronym in Spanish*—) update in 2013. However, the calculation software was in a transition period until January 2016, so some EPCs in Gipuzkoa were calculated with the previous versions that considered Gipuzkoa as a C1 climate zone. This explains the superiority of the number of EPCs with climate zone C1 between the years 2014-2015 (see Figure 3.6). In addition, at altitudes above 500m in Araba and 400m in Gipuzkoa, the climate zone becomes E1. Very few geographical areas reach this altitude and consequently, the number of EPCs located in the E1 climate zone is also very low compared to the other two climate zones.

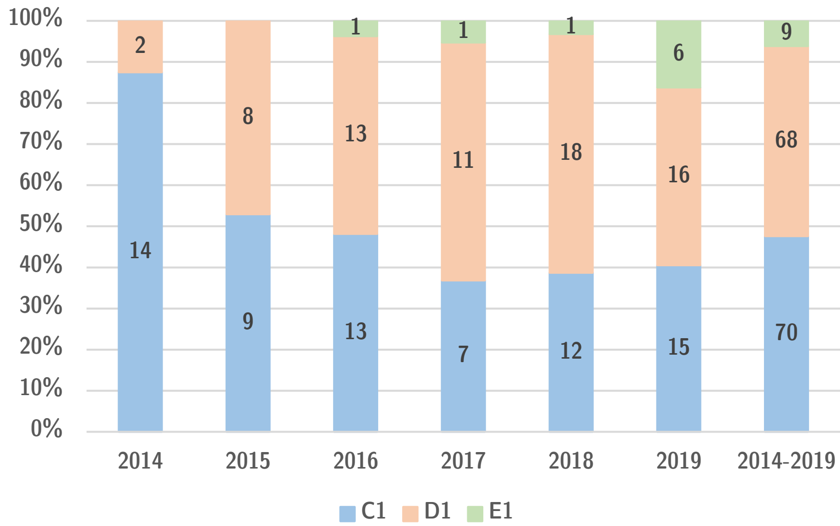


Figure 3.6. Number and percentage of EPC controls per year in each climate zone.

As seen in Section 3.2.2, there are 2 types of procedures in the EPC evaluation: one for new buildings and one for existing buildings. Most of the EPCs in the sample belong to new buildings, which include Building in Project EPCs (BP-EPC) and New Built Building EPCs (NBB-EPC) and are computed individually. Therefore, in some cases, two EPCs correspond to the same building.

54 new building files correspond to certificates made for the BP-EPC, while the rest, 73 are for the NBB-EPC. This difference has an explanation. As explained above, even though carrying out the new buildings control in both phases is an obligation established by control decree, until 2019, 53% of NBB-EPCs have only been registered in the last phase without previous recording of BP-EPC.

As for the existing building EPCs included in the sample, it should be noted that they belong to rehabilitated buildings or buildings constructed a few years before 2014 and certified in 2014. That is why in 2014, the existing building EPCs almost reach the number of new buildings (see Table 3.3).

Table 3.3. Number of new and existing building EPC controls per year.

	2014	2015	2016	2017	2018	2019	Total	%
No. of EPC controls	16	17	27	19	31	36	146	100%
New Building EPC	9	14	27	17	26	34	127	87.0%
Existing Building EPC	7	3	0	2	5	2	19	13.0%

The analyzed certified buildings have different uses (see Figure 3.7). 80% of the EPCs correspond to residential buildings, where you can find single-family and collective buildings of between 1 and 190 dwellings. Approximately the remaining 20% corresponds to tertiary buildings. The predominant use in these tertiary buildings is educational, but in the last three years, the sample also includes buildings for other uses such as social, health, residential, offices, etc.

As can be seen in the following Figure 3.7, the distribution of residential and tertiary EPCs by year has not been maintained and there is an upward trend in tertiary EPCs in the last three years.

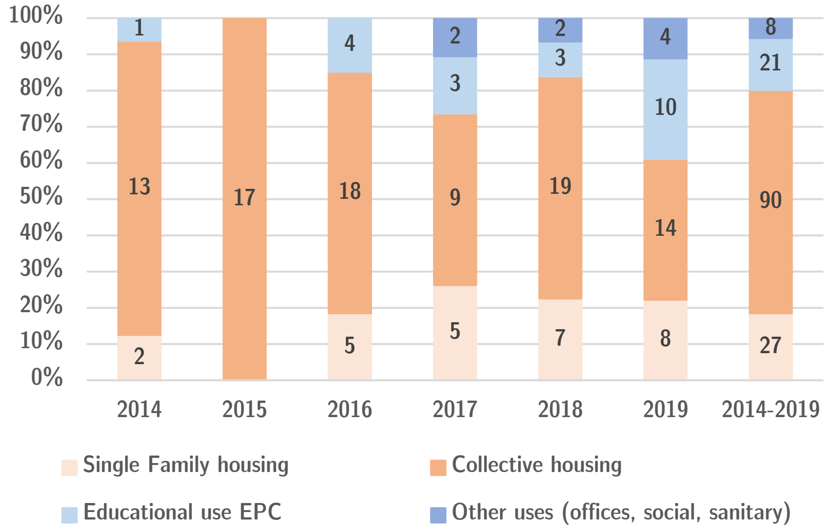


Figure 3.7. Number and percentage of EPC controls per building use during the 2014-2019 period.

The following Figure 3.8, also demonstrates the typological variety of the buildings certified for the sample, since there are buildings of different scales between 70 m^2 and 19,645 m^2. Almost 50% of EPCs have an area of fewer than 2,000 m^2. In addition, as can be seen in the last bar (period 2014-2019) as the surface range increases, the number of EPCs decreases. In the last two years, along with the increase in the number of controlled tertiary buildings, the number of EPCs with raised surfaces has also increased.

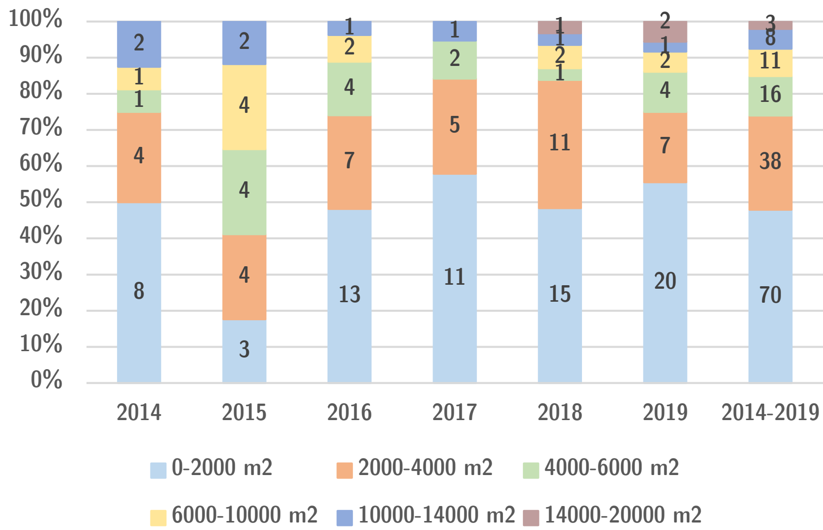


Figure 3.8. Number and percentage of EPC controls in each conditioned area range during the 2014-2019 period.

On the other hand, another characteristic of the EPCs in the sample is the type of property. As shown in the following Table 3.4, approximately half is privately owned and the other half is public, although this percentage of distribution has not been maintained every year.

Table 3.4. Number of EPC controls for each type of property and per year.

	2014	2015	2016	2017	2018	2019	Total	%
No. of EPC controls	16	17	27	19	31	36	146	100%
Property								
Public Administration	12	12	13	7	17	14	75	51.4%
Private Property	4	5	14	12	14	22	71	48.6%

3.3.2 Constructive and active characteristics of the sample

After describing the general characteristics of the sample, the constructive characteristics (see Figure 3.9 and Table 3.5) and active characteristics (see Figure 3.10; Figure 3.11; Figure 3.12 and Table 3.6) of the certified buildings are shown below.

Figure 3.9 shows the average (av), maximum (max), and minimum (min) U-value evolution in each type of enclosure in new construction. Although during these years there have been no regulatory changes regarding the limitation of energy demand, nor in U-values, there is a general decreasing trend of U-values, in some components more accentuated than in others.

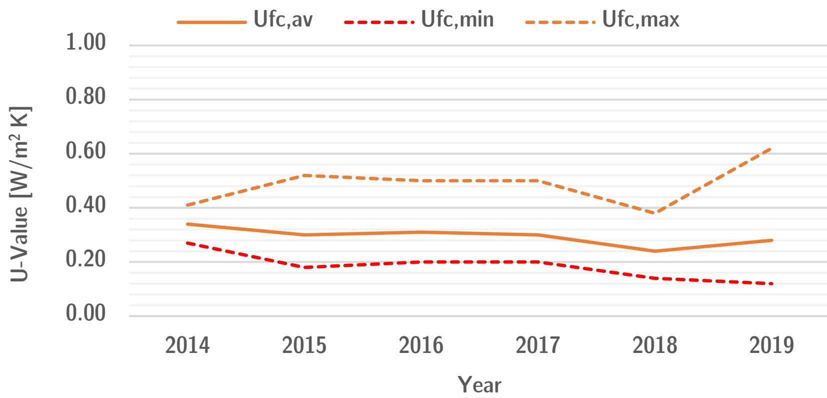
The most notable decrease is in windows (see Figure 3.9(h)). As this is the construction element that most affects demand, it can be seen that the sector has focused on improving this element, with a reduction in heat transfer coefficient of 65%.

The constructive element *wall in contact with the ground* (see Figure 3.9(d)) and *horizontal partitioning with unconditioned space* (see Figure 3.9(g)) are also types of enclosures that have been improved over the period studied, around 27% and 32% of the average value in the corresponding order.

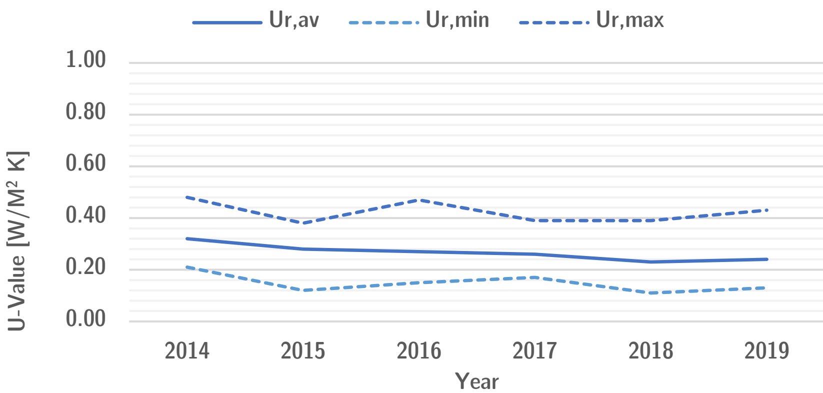
The decrease in the facade and the roof have been lighter; that may be a sign that a techno-economical optimal value is being reached and will not change much in the following years. It should be noted that in the graph of the facade, last year there was a rise in the maximum U-value and as a consequence, in the U-value average as well. In the sample, there is an EPC of the year 2019 that corresponds to a building wholly rehabilitated and that for EPC purposes is considered as a new building since it is an integral renovation. In this project, there was a municipal requirement for the conservation of the façade. Hence the U-value of 0.61 W/m^{2}K, which is out of the usual range for new buildings.

The U-value of the external floor can practically be said to have remained at around 0.3 W/m^{2}K. Finally, graphs in Figure 3.9(e) and Figure 3.9(f) do not show any trend They are inconclusive, probably because the number of EPCs with this type of enclosure may not be sufficient.

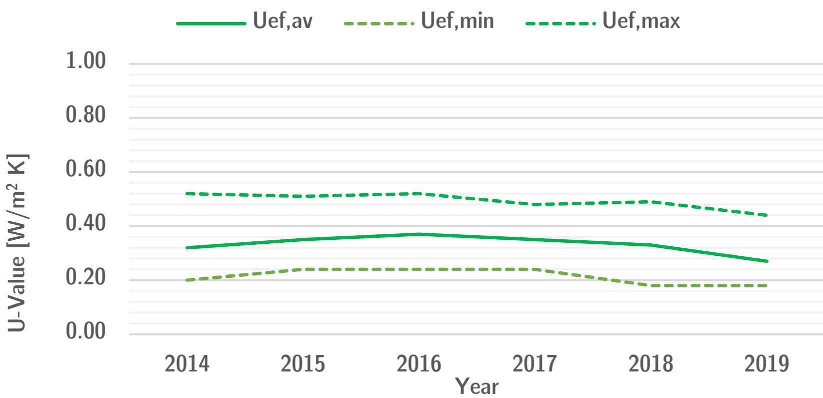
The widest range between the minimum and maximum U is given in *horizontal partitioning with unconditioned space.* This is understandable as it is an enclosure whose proportion in surface to the rest of the enclosure can vary depending on the project and when the surface is insignificant, its effect on the energy demand is minimal and allows a reduction in the degree of insulation or vice versa. In the *facade, roof,* and *external floor* (see Figure 3.9(a)(b)and(c)), the range between the minimum and the maximum is quite similar and regular during the whole period of study.



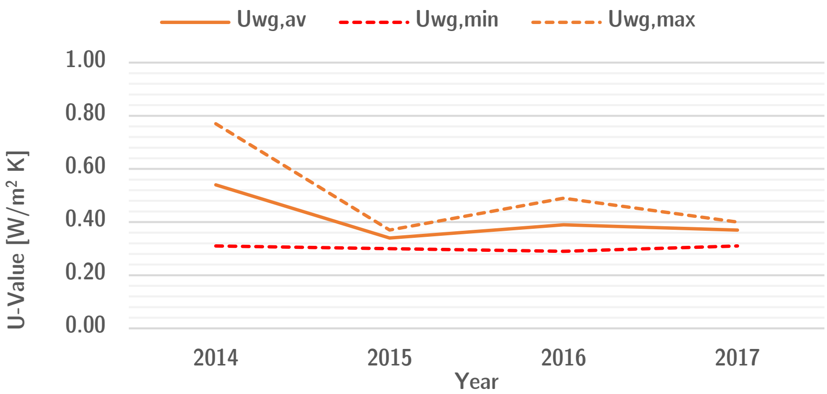
(a) Façade [fc]



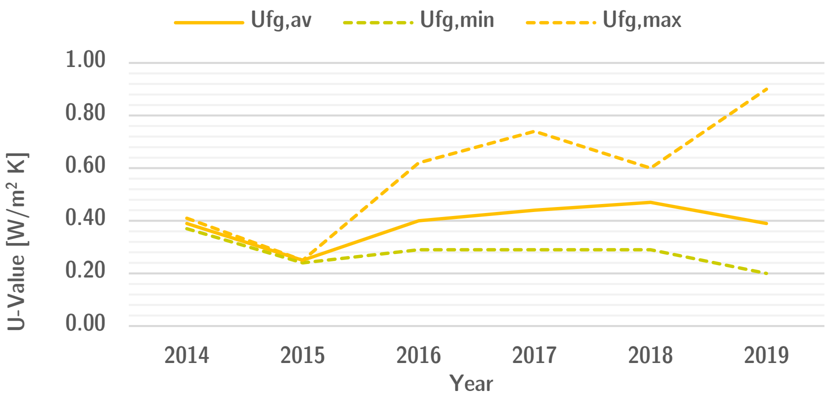
(b) Roof [r]



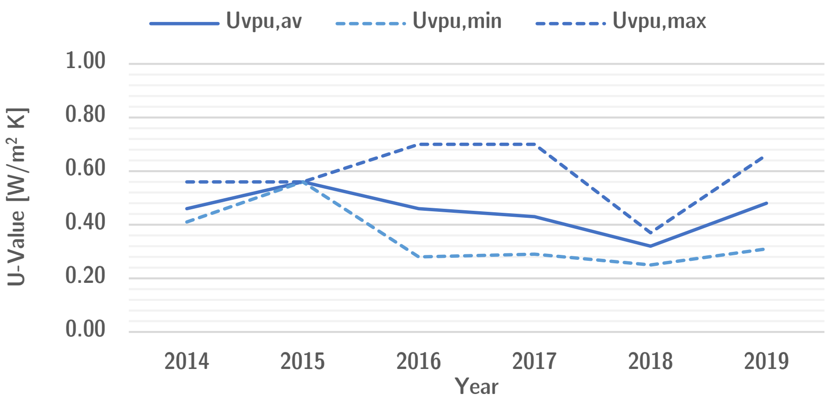
(c) External Floor [ef]



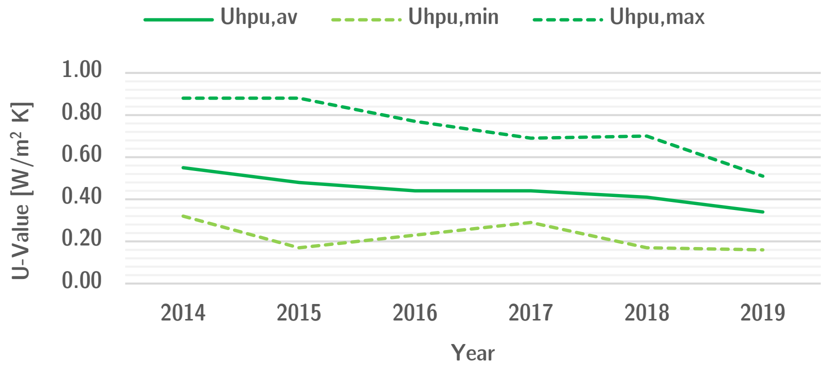
(d) Wall in contact with the ground [wg]



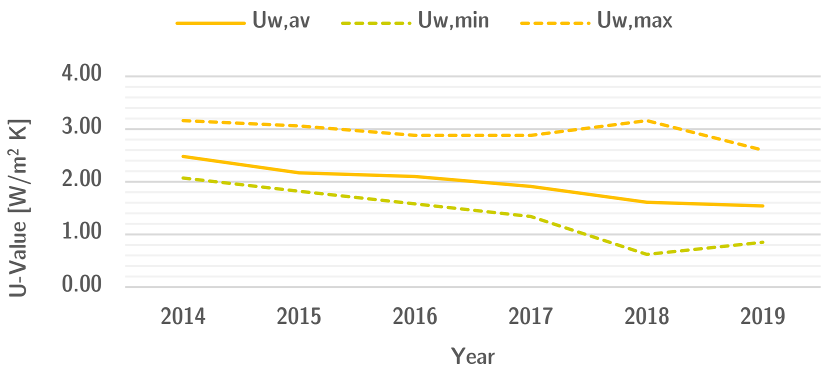
(e) Floor in contact with the ground [fg]



(f) Vertical partitioning with unconditioned space [vpu]



(g) **Horizontal partitioning with unconditioned space [hpu]**



(h) Window [w]

Figure 3.9. Average, minimum and maximum U-values of envelope elements for each year during the 2014-2019 period.

In addition to the constructive characteristics in new building, U-values in existing buildings have been analyzed. As mentioned above, the existing buildings certified for the sample have been built in recent years (before 2014) or are retrofitted buildings, so these buildings have a certain degree of insulation. Heat transfer coefficients are in order of 33%-64% times higher than the new construction's one depending on the constructive element (see Table 3.5).

Table 3.5. Average, minimum and maximum U-values of envelope elements for each year during the 2014-2019 period in existing building.

	U_{fc}	U_r	U_{ef}	U_{fg}	U_{wg}	U_{vpu}	U_{hpu}	U_f	U_g	U_w
Av	0.48	0.36	0.52	0.64	-	0.45	0.70	3.11	2.52	2.69
Min	0.23	0.14	0.20	0.61	-	0.32	0.27	1.30	1.00	1.06
Max	1.69	0.79	0.82	0.66	-	0.58	2.42	4.20	3.30	3.62

fc: facade; r: roof; ef: external floor; fg: floor in contact with the ground; wg: wall in contact with the ground; vpu: vertical partitioning with unconditioned space; hpu: horizontal partitioning with unconditioned space; f: frame; g: glass; w: window

The following Figure 3.10 illustrates the variability in the type of heating and DHW installation. Each color represents a heat generation system configuration, consisting of one or two pieces of equipment. A total of 16 different configurations have been found. In addition, in some tertiary buildings the heat generation system is also associated with the primary air ventilation system, although this has not been taken into account in this graph.

The most repeated configuration during the study period was the system composed of a gas condensing boiler and a solar thermal installation for partial renewable solar coverage of DHW. Nonetheless, from 2015 onwards this type of systems have been declining in favor of installations based on electrical energy sources (HP-A; CB+HP-A; BHB+HP-A; HP-G; HP-G+ JE; HP-A+JE; CB+JE) (see Figure 3.10 and Figure 3.11).

Secondly, condensing boiler without any additional equipment is quite common in retrofitted buildings and in tertiary buildings without DHW demand. In Figure 3.10 it is observed that its presence is maintained during the study period.

Next, there is the combination of condensing boiler with aerothermal heat pump for partial renewable coverage of DHW. This configuration is more and more frequent especially in collective housing, using the aerothermal heat pump for DHW preheating and condensing boiler for heating and for DHW, reaching high performances in the heat pump.

Two other facilities that appear throughout the study period, quite regularly, are the geothermal heat pump and the biomass boiler, in most cases in single-family homes.

In a smaller percentage, there is the combination of condensing boiler and cogeneration for the renewable coverage of DHW and aerothermal heat pump without any complementary equipment. Although the first appears during the whole period of study, the second emerges in the last two years, coinciding with the electrification trend of thermal installations (see Figure 3.10 and Figure 3.11) and in low-temperature heating installations.

Finally, the rest of the configurations are very scarce and mostly appear in the last two years. It is due to the search for alternative solutions to the solar thermal installation to justify the renewable coverage of DHW since the maintenance and operation problems of the solar installation have led many technicians to consider other systems. These systems are increasingly particular, as well as more and more projects are linked to the primary air system which enhances their complexity. However, EPC calculation software is designed for certain conventional systems, making it difficult to define unusual systems. Therefore, it is an important factor in analyzing the errors that occur in EPCs in the following chapters.

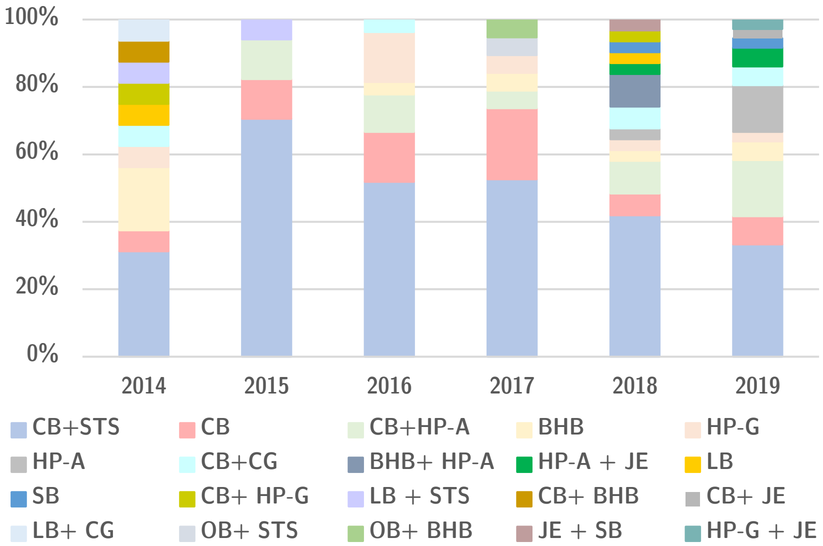


Figure 3.10. Types of configuration of heating and DHW installations and percentage of EPCs within each configuration by year. *(BHB: Biomass Heat Boiler; CB: Condensate Boiler; CG: Cogeneration; HP-A: Aerothermal Heat Pump; HP-G: Geothermal Heat Pump; JE: Joule Effect; LB: Low temperature boiler; OB: Oil boiler; SB: Standard Boiler; STS: Solar Thermal System)*

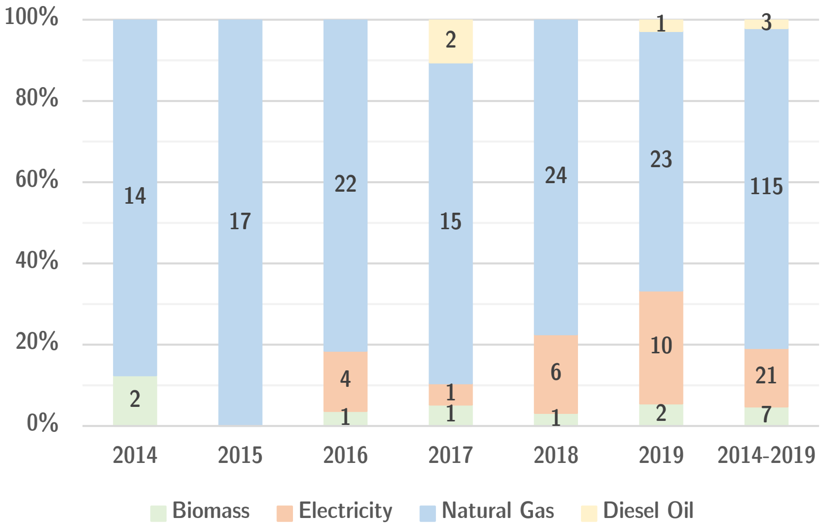


Figure 3.11. Main Energy Source used in certified buildings.

As for ventilation systems, two types have been differentiated: single flow extraction or double flow systems with heat recovery. The latter includes individual systems in dwellings, centralized systems in collective housing and tertiary buildings, and air conditioners that incorporate heat recovery in tertiary buildings. As it can be seen in the following Figure 3.12, there has been a clear growing evolution of the systems with heat recovery in ventilation. In fact, in the last year of the study, the number of buildings with mechanical ventilation with heat recovery systems (MVHRS) has been higher than those without heat recovery. Being one of the factors that most affect the energy demand, its definition in the EPC requires exhaustive control.

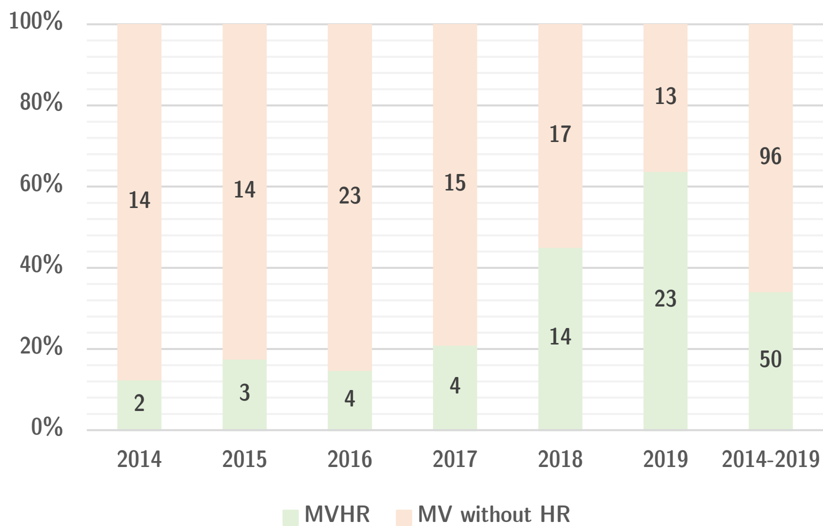


Figure 3.12. Percentage of EPCs with MVHR and mechanical ventilation without heat recovery by year and during the 2014-2019 period.

Finally, Table 3.6 shows the number of certified buildings with a photovoltaic installation. It should be noted that all these buildings are schools.

Table 3.6. Number of EPCs with PV system during the 2014-2019 period.

	year						Period 2014-2019	
	2014	2015	2016	2017	2018	2019	No.	%
PV system	1	0	1	2	1	2	7	4.8%

3.4. Conclusions

To carry out a study on the effectiveness of the EPC control methodology implemented in the Basque Country, it is first necessary to carry out an exhaustive analysis of a representative sample of EPCs.

This chapter, in Section 3.2., has described the procedure followed in the control of the selected sample based on 146 EPCs. It is a procedure based on a point-by-point verification. Each EPC is completely verified:

- The administrative data and 49 types of input data defined in the EPC are contrasted based on the project and end of work documents, and also by means of a field study.
- The building configuration defined in the EPC calculation software is evaluated: a building model (geometry, thermal zones, types of spaces, and types of enclosures) and the configuration of the facilities are set up.
- The suitability of the software used is evaluated.

However, an EPC control system based on such a comprehensive control does not allow to reach a large number of EPCs. In the Basque Country all EPCs that have an energy rating "A", "B" or "C" in nrPEC are controlled. That means that between 2018 and 2019 100% of new buildings were controlled and only 0.5% of existing buildings which is 1.7% of registered EPCs.

In comparison with the quite generalized characteristics that have been collected from control systems of other MSs and regions, the control system in the Basque Country does not have:

- Checking validation.
- Control per QEs. The control results of each certifier are not recorded.

In addition, the experience obtained during these six years has allowed knowing the problems that occur from the moment of the control request until its end:

- EPCs are registered in the New Built Building phase without having been previously registered in Building in Project phase, although the regulations require the registration of both phases.
- The delay between control request and the start of control in modalities of New Built Building phase and Existing Building control. The registry application is designed so that the application is made once the building is completed. That is why sometimes the request for control does not occur until the work is completed. On-site inspections, however, have to be started at the same time as the insulation execution. Once the work is completed, the characteristics of the insulation cannot be visually checked and a test is required to determine the thermal resistance of the enclosure. In the protocol established by the Thermal Area-LCCE, the thermal resistance *in-situ* measurement test has been chosen following the ISO 9869-1:2014 standard [56].

On the contrary, the thermal resistance *in-situ* measurement test also has its limitations compared to visual inspection:

- It is only checked at specific points, and the result may have been affected by an undetected thermal bridge.
- It is necessary to perform with a minimum temperature difference between indoor and outdoor; $\Delta T_{min} \cong 15ºC$. Therefore, it is not applicable in enclosures that delimit a conditioned space from an unconditioned one. Furthermore, it is a test that cannot be carried out during the summer period, which generates delays in the registration.

- It cannot be applied to external envelopes with ventilated chambers, such as a ventilated facade or a ventilated tile roof.

In conclusion, it follows that finding solutions for data collection of thermal performance of enclosures is necessary. Other tests that have been carried out, such as testing the thermal transmittance of windows or the use of glass meters on-site, have proved effective.

In Section 3.3 the representativeness of the sample has also been demonstrated, showing the variability in all the differentiating characteristics of the sample.

These characteristics have been analyzed chronologically since it is necessary to know what the current situation is and what the trends are for the study of proposals to improve the control methodology. The main trends that have been detected are the following:

- Increase in the number of tertiary building controls.
- An overall decrease in the heat transfer coefficient of the enclosures. In some, such as the facade, roof, and external floor, there is a tendency to stabilize the values. The decrease is more accentuated in windows.
- Increase in installations based on electrical energy sources.
- Increase in the variability and complexity of thermal facilities, to the detriment of conventional facilities such as condensing boilers with solar thermal for renewable coverage of DHW.

3.5. Referred Appendices

The Appendix related to this Chapter is:

- Appendix A. Characteristics of the controlled EPCs

4 EPC Sample Quality Analysis

4.1. Introduction

The national EPC database provides a picture of the energy efficiency level of the building stock to plan future energy strategies [35], [36]. Not only EPC database information is important for this reason, but also because it is used in renting or selling real estate properties, as well as it is a core resource for technicians and researchers.

Despite its widespread scope, studies show that public distrust exists [10]. Various specific studies have shown inaccuracies in EPCs [11], [16], [17], [35], [50], [51]. However, very few countries monitor the results obtained in their EPC quality control campaigns or they do not publish them (see Table 1.3 in Chapter 1). The knowledge of monitoring data is vital, since in additional to providing transparency and improving public opinion, it allows to obtain feedback from experience which may improve the system and consequently the quality of EPCs.

The only reference quality indicator found is the one proposed as the acceptable limit by the *The Energy Performance of Building Committee* of the EU Commission. They estimated that a confidence interval of 5% of the actual population with a confidence level of 95% would be suitable for independent control [33]. Nevertheless, it is not known whether the results of the different MSs and regions are above or below this indicator. It is also not an indicator used to establish the limit of tolerated deviation in EPC controls. As seen in chapter 1 Table 1.3, there are MSs which determine the limits basing on energy class differences and others which are based on percentage error set the limit between 5-30% [46].

In the absence of follow-up on results, actually it is not known whether it is necessary in each case to continue controlling or not, and whether the systems in place are working properly or need to be changed to improve their effectiveness. These data are also unknown in the Basque Country.

Therefore, the main questions to be answered in this chapter are as follows:

- What is the real scenario of the quality of EPCs in the Basque Country database?
- How much is the inaccuracy?
    - And is it within the acceptable limit proposed by the EU Commission?
    - Changes in the system are necessary to improve the results of the current system?

To find the answers, firstly, the overall results of the sample have been analyzed, regarding the deviation identified between the first EPC and the last one after passing the control; the NCs issued and subsequently corrected during the process; and the chronological development of the previous two points.

Secondly, a statistical analysis of the sample deviation is performed. Thanks to statistics, it is possible to extrapolate the conclusions obtained from the analysis of a representative sample, as in this case, to the population (the whole EPC database). In this manner, the inaccuracy of the declared CO_2 emissions and nrPEC in the set of EPCs can be known and, if it exceeds the proposed limits, taking measures to improve the system which should assure the EPC quality.

4.2. Methodology

During the process of emission of energy certificates, frequently nonconformity (NC) reports are issued and, consequently, the EPCs are corrected and a deviation is occurred in the results of nrPEC, CO_2 emissions and energy rating between the first and the last EPC. The study in this chapter is based on the analysis of these deviations of the EPCs as well as the found NCs.

For this aim, at first the following variables are recorded in each control file (CF) (see Table 4.1):

Table 4.1. Recorded variables in each CF.

Draft EPC	**Issued NCs**
	nrPEC result
	CO_2 emissions result
	Energy rating in nrPEC
Final EPC	**nrPEC result**
	CO_2 emissions result
	Energy rating in nrPEC

The issued NCs, on one hand, have been counted in each EPC, and on the other hand, all variety of them have been catalogued in Appendix B. With other recorded variables the deviation is calculated in 3 different ways: absolute error, relative error and energy rating deviation. The first two are calculated for both, nrPEC and CO_2 emissions results.

- NCs: are the faults found in the EPC, which need to be corrected (see Appendix B). The consequence of these corrections is the resulting deviation between the draft and final EPC.

- Energy rating[2] deviation: It is the variation in the energy rating scale (from A to G). Measured in number of letters scaled up or down.
- Absolute error, ε_a (See Eq. 4.1): It is the difference between the measurement value (draft EPC result in this case), v_d, and the exact value (final EPC result in this case), v_f. It can be positive or negative, depending on whether the draft result is higher or lower than the final value. It has units, the same as those of the measurement.
- Relative error, ε_r (See Eq. 4.2): It is the quotient (the division) between the absolute error and the value of the final EPC result. Multiplying by 100 provides the percent (%) error. Like absolute error, it can be positive or negative and has no units.

$$\varepsilon_a = v_f - v_d \qquad \text{Eq. 4.1}$$

$$\varepsilon_r = \frac{v_f - v_d}{v_f} \times 100 \qquad \text{Eq. 4.2}$$

Where,
ε_a: Absolute error
ε_r: Relative error
v_d: Draft EPC qualification value
v_f: Final EPC qualification value

Once these parameters have been calculated for each of the EPCs in the sample, these data are analyzed for the sample as a whole.

In Section 4.3.1, Section 4.3.2 and Section 4.3.3 the overall results of the sample deviation are presented. It shows a general picture of the

[2] The EPC includes two EPC ratings (letter). One of them referring to CO_2 emissions scale and the other one to nrPEC scale. Throughout the Thesis, EPC rating refers to the nrPEC scale.

evaluated EPCs quality, regarding the general NCs results, the general deviation results, and the chronological evolution of both.

Secondly (Section 4.4.4), a statistical analysis of the relative error in nrPEC of the whole sample is performed in order to adjust the frequency distribution of this statistic to a theoretical distribution. Extrapolating the results obtained in the sample to the population is possible thanks to the adjustment to a theoretical distribution and in this way, conclusions can be drawn for the whole of the EPC database in the Basque Country. Therefore, a comparison of the result obtained with the acceptable limits proposed by the EU Commission is carried out.

4.3. Results

4.3.1 Nonconformities General Results

Once an EPC has been reviewed in draft version, a report is issued, which in case of noncompliance, indicates the corrections to be made in order to obtain a compliant report. Appendix B lists all types of NCs that have been requested during the study period. In total there are 75 types and 70 of them appear in more than one EPC, with a total of 642 NCs detected in 146 EPCs.

Figure 4.1 in green represents the number of NCs reported in each EPC. The EPC with the highest number of corrections has 22 and the one with the lowest number of corrections has 0. Specifically, the number of EPCs that do not contain any errors is 32, 21.9% of the total sample (see Figure 4.2). The average of NCs per EPC, which is in purple line (see Figure 4.2), is 4.4.

Fabbri and Marinosci [17] in their research showed that in Emilia Romagna Region 80% of EPCs contained at least one error. This is similar to the percentage obtained in our sample (78.1%). In contrast, the study by Hardy and Glew [11] revealed that in UK at least one NC was found in 27% of EPCs. The control methodology in the first case is based on point-by-point control and *in-situ* checks, as in the Basque Country. On the opposite, the second is based on a control of automatic checks.

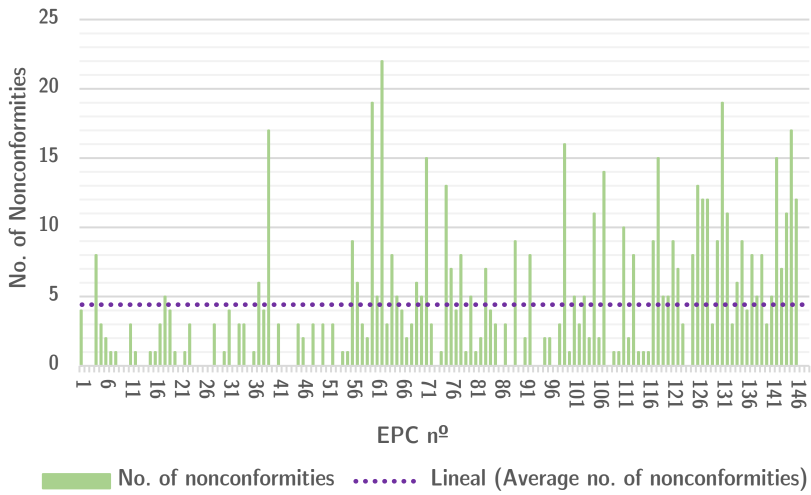


Figure 4.1. No. of NCs in each EPC and the average.

Figure 4.2 shows the relation between number of EPCs vs no. of NCs per EPC. A clear trend is observed: the higher the number of NCs, the lower the number of EPCs. And as the number of NCs increases, the decrease in the number of EPCs becomes less and less significant. The probability for an EPC to contain less than 3 NCs is 60%; below 9 NCs, 87%; below 15, 96%; and, finally, below 21, 99%.

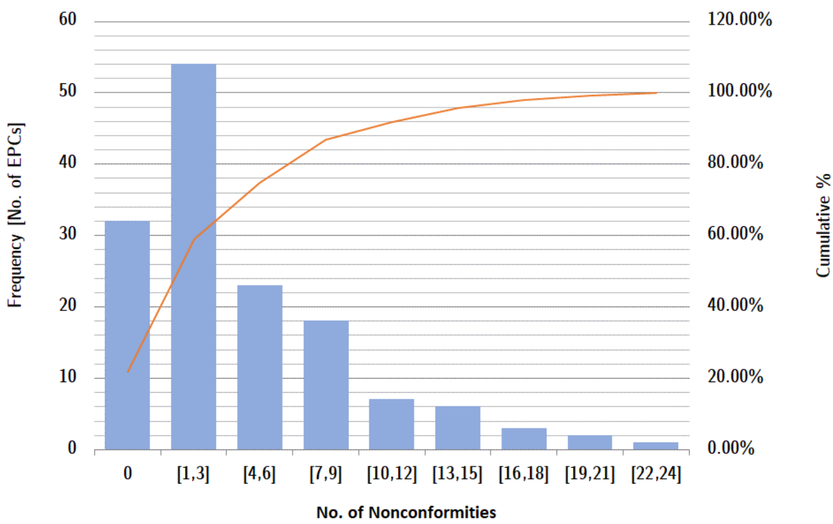


Figure 4.2. The frequency (no. of EPC) versus no. of NCs and the cumulative percentage of no. of EPCs.

4.3.2 Deviation General Results

The deviation is calculated in three energy efficiency indicators: EPC rating, nrPEC result and CO_2 emissions result. Figure 4.3 displays the distribution of EPCs based on whether they have had a positive or negative deviation once they have passed the control.

As detailed in the following paragraphs, the main result is that the deviation is not always unfavorable to the final result. Approximately as many EPCs worsen their rating as EPCs improve. This means that many of the QEs make mistakes in EPC for the mere reason of being conservative without acting in bad faith, when they could declare better ratings.

Letter changes have been observed in 20% of the buildings evaluated (see Figure 4.3). Of these changes, 54% have led to an improvement in the letter of energy certification. Among the EPCs that underwent a change in the energy rating, only one of them dropped 2 letters, the rest scaled up or dropped a single letter.

Without taking into account the change in the rating letter and only focusing on the difference in the results of nrPEC and CO_2 emissions between draft and final EPC, the number of EPCs than finally have poorer outcomes are slightly higher, the opposite of what happens in the change of the letter: 32.2% of EPCs improve their result in nrPEC and 29.5% in CO_2 emissions and, conversely 37.0% worsen in nrPEC results and 38.4% in CO_2 emissions. Even so, the differences between improving and worsening EPCs are not significant in either case.

In the previous sections, it has been seen that 21.9% of the sample passed checks without any correction requirement. In the results shown above (see Figure 4.3.), it has been observed that 30.8% of the cases have not been affected in nrPEC outcomes and neither the 32.1% of them in CO_2 emissions outcomes. This means that approximately 9% of the sample presents at least one incongruity but it does not alter the result in nrPEC and CO_2 emissions.

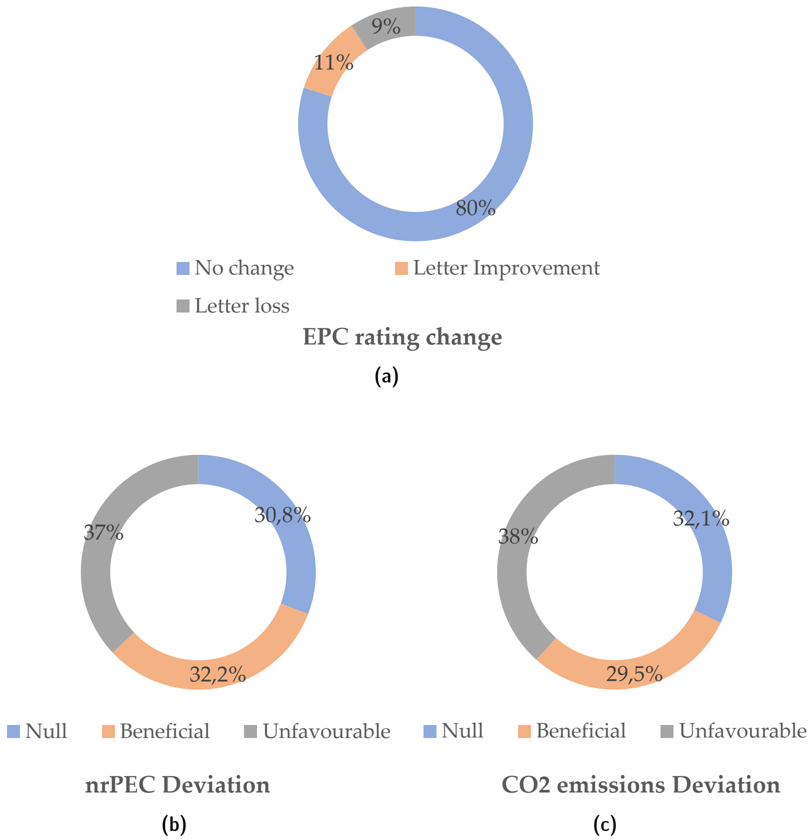
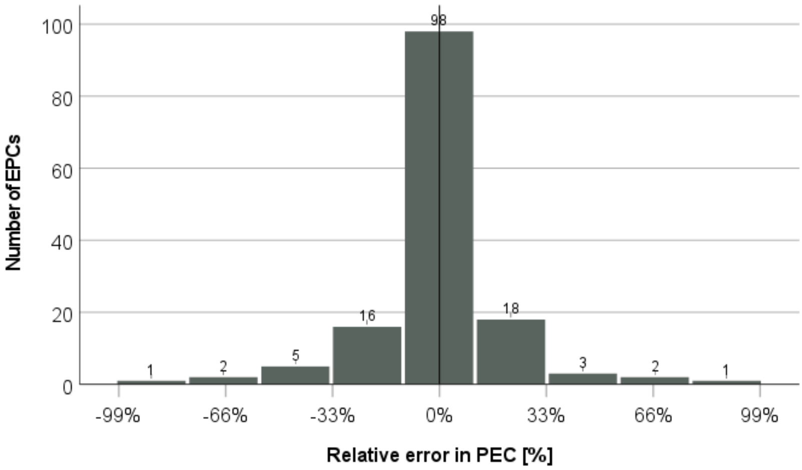
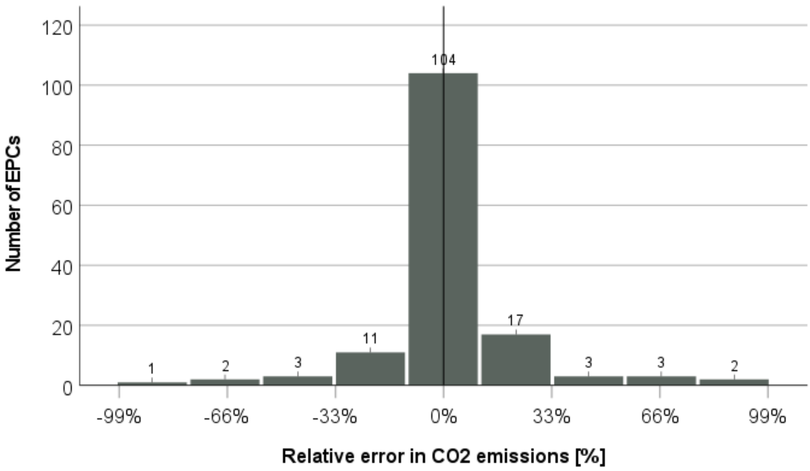


Figure 4.3. EPC result deviation after control in: (a) EPC rating (letter), (b) nrPEC and (c) CO_2 emissions.

Figure 4.4 shows the number of EPCs corresponding to each relative error range. The graph points out a certain symmetry to the y-axis (0%) and the number of EPCs decreases further the error range is from the y-axis. Otherwise, the maximum relative error in nrPEC is 93.8% and in CO_2 emissions 92.1%. However, as can be seen in Figure 4.4, such high errors are very rare, only in 2 or 3 cases respectively.



(a)



(b)

Figure 4.4. Frequency distribution of relative error in: (a) nrPEC and (b) CO_2 emissions.

Table 4.2 summarizes the results of the absolute error in nrPEC and CO_2 emissions for the entire sample.

Table 4.2. Absolute error in nrPEC and CO_2 emissions in the sample.

	$\sum \varepsilon_{a,i}$	$\sum \lvert\varepsilon_{a,i}\rvert$	$\sum \varepsilon_{a,i}/_n$	$\sum \lvert\varepsilon_{a,i}\rvert/_n$	$\sum v_{f,i}$	$\sum v_{f,i}/_n$
nrPEC [MWh/y]	**207.17**	**2'412.71**	**1.41**	**16.53**	**23'115.32**	**158.32**
CO_2 emissions [$TnCO_2$/y]	**-6.90**	**555.95**	**0.05**	**3.81**	**4'558.06**	**31.21**

The sum of the absolute error of the whole sample is shown, both compensating for absolute errors of different signs, $\lvert \varepsilon_{a,i} \rvert$, and disregarding the sign, $\varepsilon_{a,i}$. Thus, it is observed that the absolute error of the whole sample, $\sum \varepsilon_{a,i}$, is 0.9% and 0.2% respectively of the sum of all final EPCs in nrPEC and CO_2 emissions, $\sum v_{f,i}$. Nevertheless, if the sign is not considered in the absolute error, $\sum\lvert\varepsilon_{a,i}\rvert$, this percentage increases to 10% in nrPEC and 12% in CO_2 emissions. The first is the deviation that differentiates the sample scenario in draft and final version, however, it is more favorable that the second one since the negative errors are compensated by the positive ones. On the other hand, the second defines the absolute amount incorrect in the computation of draft EPCs. This means that 10% of the initially declared nrPEC and 12% CO_2 emissions are overestimated or underestimated.

The average absolute error of each EPC in the sample, 16.53MWh/y, may be used to estimate the absolute inaccuracy in the entire database of EPCs. Being 7,230 the number of EPCs controlled in Euskadi between 2014-2019 (1.3% of the registered EPCs), the total estimated absolute error in the whole database in that period will be 119.51 GWh/y, which is the approximately the 0.6% of the nrPEC per year of the total Building Stock (18519.96 Gwh/y in 2018).

4.3.3 Evolution of Deviation and Nonconformities during the studied period (2014-2019)

Finally, Figure 4.5 shows the evolution of the absolute error detected in the sample, ε_a, during the study period. It is displayed by the total absolute error per year and the absolute error average per EPC and per year. The main result is that after a few ups and downs in the first

3 years, there has been a considerable increasing since 2017, reaching the maximum values in the last year 2019, which doubles the values of the previous year 2018 in both measurements, unitary absolute error and total absolute error per year.

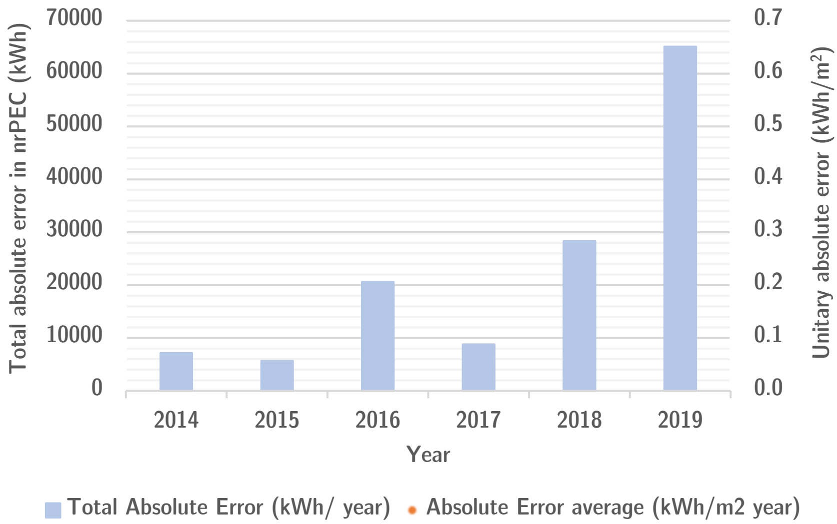


Figure 4.5. Total absolute error [kWh/y] and unitary absolute error [kWh/m^{2}y] in nrPEC per studied year.

Similar tendency is observed in Figure 4.6 and Figure 4.7 where the evolution of number of NCs per year is presented. The results divided by categories (see Figure 4.6) point out that the increment does not depend on the use or type of building, residential-service or new-existing building. They all follow the same trend i.e. an increase since 2017. However, Figure 4.7 shows that the cause of the increase from 2017 is the significant rise in NCs on systems, in construction data and in definition of the building model categories. It is also important to highlight that "others" category is the only one that decreases, since it refers to those certificates that do not report any kind of correction, that is, they are correct and they decrease in the last period of study (2017-2019). This last point shows that errors in the certificates increase in a generalized way and it is dismissed that errors are concentrated in a specific number of certificates.

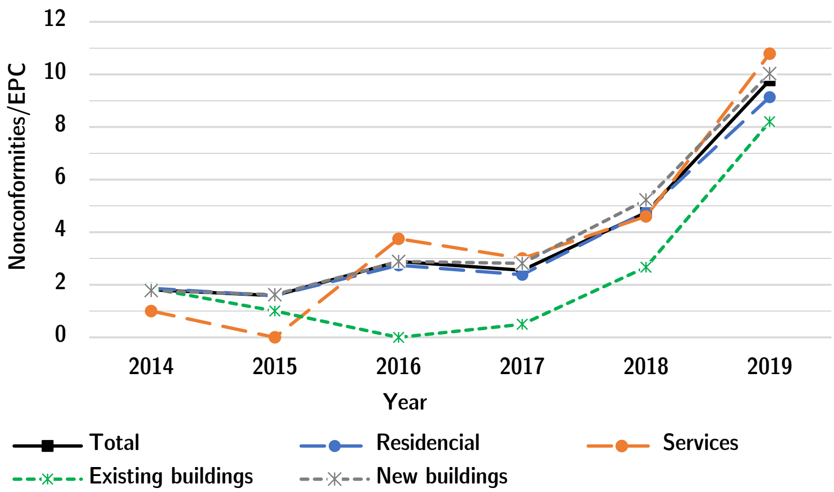


Figure 4.6. Evolution in total NCs per EPC by years.

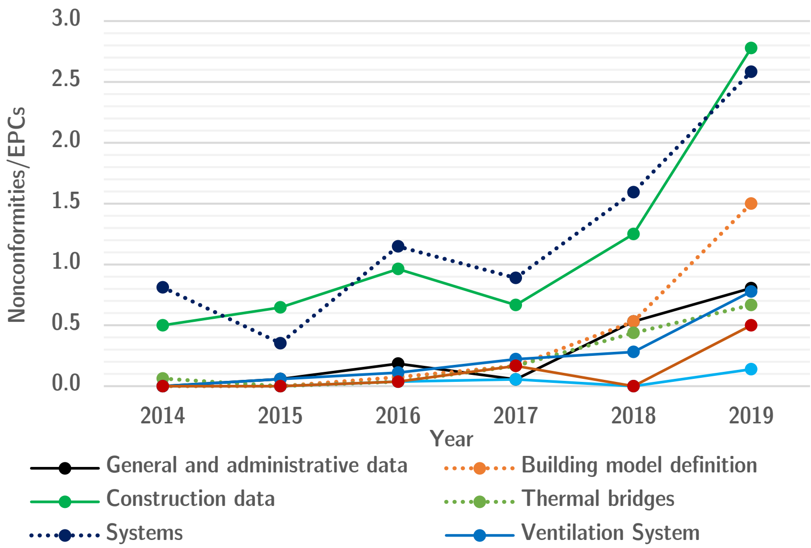


Figure 4.7. Evolution in NCs types per EPC by years.

4.3.4 Statistical Analysis of Sample Deviation

Since the distribution shows signs of symmetry with respect to the center of the distribution, which is where most of the values are concentrated and has an inverted bell shape, it leads to the hypothesis that the relative error in the sample may follow a normal distribution. The representativeness of the sample and the confirmation of this distribution would make it possible to extrapolate the results obtained in the sample to the population (all the EPCs in the database) and thus compare the quality indicators obtained with those proposed by the EU Commission.

The verification of the theoretical distribution is performed with the results obtained in the nrPEC deviation, excluding the deviation obtained in CO_2 emissions. Either of the two parameters would be valid since the distribution follows approximately the same pattern.

Table 4.3 below shows the descriptive statistics for the relative error data set in nrPEC calculated using SPSS software [58]. It includes measures of central tendency, measures of variability and measures of shape. Of particular interest here are bias and kurtosis, which can be used to determine whether the sample is from a normal distribution. The bias measures whether the tail of the distribution is longer to the right or to the left, i.e., how skewed or asymmetric the curve of the data distribution might be. The kurtosis, on the other hand, is a measure of "pointing" of the distribution, in colloquial terms it reflects the height of the curve. Value of the standardized bias is within the expected range for data from a normal distribution [-2,2]. However, the standardized kurtosis value is not expected for data from a normal distribution, it is considerably away from the 3 value.

Table 4.3. Descriptive Statistics of the nrPEC relative error distribution.

Count	146
Average	-0.0038
Standard Deviation	0.20420
Minimum relative error	-0.94
Maximum relative error	0.89
Range	1.83
Standardized Bias/ Asymmetry coefficient	0.163
Kurtosis	6.509

In addition, the nonparametric Kolmogorov-Smirnov test [59] was performed to test whether the distribution conforms to a normal distribution (null hypothesis) or not (alternative hypothesis).

$$H_0: Xi \approx N(\mu, \sigma^2)$$ **Eq. 4.3**

$$H_1: Xi \neq N(\mu, \sigma^2)$$ **Eq. 4.4**

Where,

H_0 *and* H_1: **null and alternative hypothesis**

x_i: **Distribution of the relative error in the sample**

$N(\mu, \sigma^2)$: **Normal distribution for a population with mean μ and a variance** σ^2

The test was performed for a significance α=0.05. In order to accept the null hypothesis, the following condition must be met:

$$H_0: p - value \geq \alpha$$ **Eq. 4.5**

According to calculations performed by SPSS software the p-value is <0.05, therefore the null hypothesis is rejected, it does not fit the normal distribution.

One of the solutions when the distribution does not fit the normal distribution, in case of large samples (n>30), is to work with methods that do not require assumptions about the distribution of the data. These methods are called nonparametric tests and are based on certain characteristics of the data such as signs or signed ranges.

The sign test and the signed-rank test (see Eq. 4.6 and Eq. 4.7) conclude that the hypothesis that the median, $\tilde{x}$, is equal to 0 at the 95% confidence level cannot be rejected (see Table 4.4).

$$H_0 : \tilde{x} \cong 0 \quad \text{Eq. 4.6}$$

$$H_1 : \tilde{x} \neq 0 \quad \text{Eq. 4.7}$$

Where,
H_0 *and* H_1: **null and alternative hypothesis**
$\tilde{x}$: **Sample median value**

Table 4.4. Sign and Signed-rank test results.

Sign Test	
Number of values below the hypothetical median	48
Number of values greater than the hypothetical median	54
Statistician for large samples	0.4951 (continuity correction applied)
P- value	0.6205
Signed-rank test	
Mean range of values lower than the hypothetical median	53.2083
Mean range of values greater than the hypothetical median	49.9815
Statistician for Large Samples	0.2403 (continuity correction applied)
P- value	0.8101

In both cases the P-value is >0.05, so the null hypothesis is not rejected for $\alpha = 0.05$.

On the other hand, the T-student test evaluates the hypothesis that the mean of the data set equals 0 vs the alternative hypothesis that the mean does not equal 0 (see Eq. 4.8 and Eq. 4.9). Because the P-value for this test is greater than 0.05, the null hypothesis cannot be rejected. In other words, at a 95.0% confidence level ($\alpha = 0.05$) it fits the T-distribution (see Table 4.5).

$$H_0: \bar{x} \cong 0$$ **Eq. 4.8**

$$H_1: \bar{x} \neq 0$$ **Eq. 4.9**

Where,
H_0 *and* H_1: **null and alternative hypothesis**
$\bar{x}$: **Sample mean value**

Table 4.5. T- Student test results.

T-student test	
Statistician t	-0,226
P- value	0.821

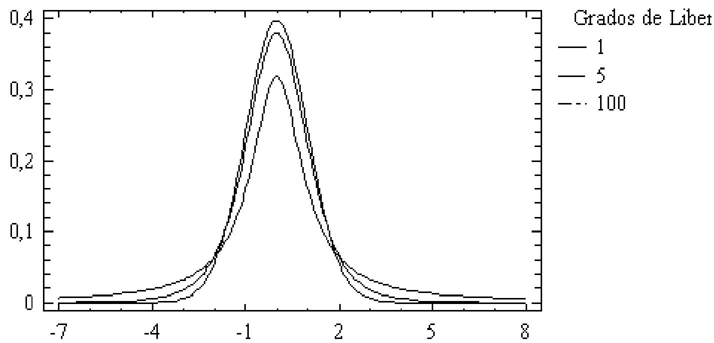


Figure 4.8. T- Student theoretical distribution.

Figure 4.8 illustrates an example of the T-distribution plot. It can be observed that it is symmetrical with respect to the origin of ordinates, so that, as in the standard normal distribution, the mean, mode and median of this distribution are equal to zero. Its shape is similar to that of the normal curve, improving the approximation as the value of n (no. of observations) increases. For large values of n, the T-Student distribution approximates the Normal distribution. The approximation is considered acceptable for $n > 30$, as is the case ($n = 146$). Therefore, it is concluded that the distribution under analysis is approximately normal. And the fact that it is a large sample $(n > 30)$ allows estimates to be made for the population with descriptive statistics for the sample.

As explained in the previous chapters, the EU Commission services estimated that a confidence interval of 5% with a confidence level of 95% would be suitable for the independent control results. This means that the result should have a 95% probability that the sample gives a relative error at ±5% of the actual population relative error.

The relative error of the actual population is not known, so the estimated population mean, $\hat{\mu}$, with its confidence interval, $\widehat{CI}$, is taken as a reference value of the population relative error. It is calculated by the following equation (Eq. 4.10):

$$\widehat{CI}\ (1-\alpha): \hat{\mu} \in \left\{\bar{x} \pm Z_{\frac{\alpha}{2}} \frac{S}{\sqrt[2]{n}}\right\} \qquad \textbf{Eq. 4.10}$$

Where,
$\widehat{CI}$: **estimated Confidence Interval**
α: **significance**
$\hat{\mu}$: **estimated population mean**
$\bar{x}$: **sample mean**
S: **sample standard deviation**
$Z_{\frac{\alpha}{2}}$: **number of standard deviations for a significance α**

Considering that the mean relative error in the sample, $\bar{x}$, is 0% (T- Student test), the confidence interval of the mean is -3.3%<$\hat{\mu}$<3.3% with a probability of 95%.

Therefore, assuming as a starting point the confidence interval of the population mean, in the sample results 95% of EPCs should give a relative error ±8.3% for the quality of EPCs to be satisfactory.

However, the confidence interval of the sample relative error is 39.98%<ε_r <39.98% with a reliability of 95%. That is, assuming that the sample is representative of the population and approximately normal, at a probability of 95%, any uncontrolled file in the EPC database will contain a relative error that is in the range ±39.98%, almost 5 times greater than the appropriate range proposed by the EU Commission (see Figure 4.9).

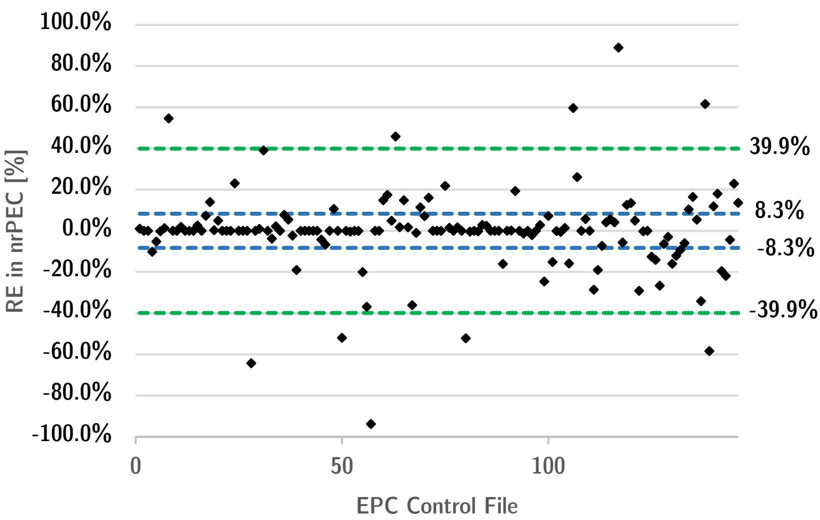


Figure 4.9. Relative error in nrPEC of 146 EPCs with its confidence interval at a probability of 95% compared with the proposed confidence interval by the EU Commission.

4.4. Discussion

4.4.1 Symmetry of Error distribution

This chapter has analyzed the deviation resulting from the control procedure. The first result obtained is that, although there is a fairly high percentage with zero or almost zero deviation, among the EPCs that vary, approximately half worsen their initial result and the other half improve.

This means that in EPCs that obtain favorable control results, there is no malfeasance on the part of the certifier. Otherwise, mistakes are made due to lack of technical knowledge or because they are conservative.

Although at first one may think that a favorable result is not an error because it is not a fraud, from the Thermal Area of the LCCE these NCs have been treated with the same requirement of correction as in the opposite case. These are errors that distort the real energy efficiency level of both a single building and the building stock as a whole. And, consequently, the greatest possible transparency has been sought in the final result of each EPC, either to the detriment of the result or vice versa.

Furthermore, the fact of analyzing the positive errors has pointed out that there is a need to make an effort to improve the technical knowledge of certifiers in the Basque Country. It could be one of the objectives when establishing improvements in the control system.

4.4.2 The increase of the error in the last 3 years

Another noteworthy result is the significant increase in error over the last 3 years, especially in the systems, in constructive elements and in building model definition data. This could have happened for several reasons.

It should be mentioned that the increase of NCs in systems and ventilation also match with a CTE (Spanish Building Technical Code) change in 2017. Since this modification, there has been an increase in the variability of systems, meaning more buildings with ventilation systems with heat recovery and alternative systems to thermal solar panels are presented for the justification of renewable coverage in DHW (see Chapter 3); therefore, this could also be the cause of the increment. This modification in regulation also affected the EPC calculation tools. They were updated and structural changes were made. Therefore, this could also be another reason for the increase in errors.

The increase in NCs corresponding to the construction data can be related to the start of the R *in-situ* test used to check the thermal performance of the envelope, since this verification was introduced in the protocol from the beginning of 2017.

Another possible cause is the experience acquired by the control technicians since the beginning of the activity until nowadays. As the years have gone by, the ability of Thermal Area technicians to detect errors has increased, and with this, it is possible that the level of demand has also increased. This, in part, could be solved by using objective criteria of tolerances in input data to determine whether a value is correct or not. The PT case is the only example that has been found [53].

4.4.3 Relation between the criteria to decide when is an EPC correct or incorrect and the compliance rate

The system should determine if the controlled EPC is correct or not. The decision criteria for this conclusion are different according to MS [30]. The evaluation criterion of some of the MSs is based on the limitation of the energy rating difference; otherwise, other MSs limit the impact of errors on the results. Therefore, depending on the adopted standard the compliance rate would be different. In the Basque Country there are no criterion to determine whether an EPC is correct or not. For this reason, the Thermal Area-LCCE has adopted its own rule, which is quite rigorous compared to those established in other MSs. This rule establishes that any inconsistency found in the EPC through comparison with the project documentation or actual building characteristics, regardless of its impact on the EPC outcome or energy rating, leads to a noncompliant report. However, if other criterion used in other MSs is applied [31], [46] to the sample studied in this thesis, it is observed that the compliance rate given by the same sample varies significantly (see Table 4.6).

Table 4.6. Comparison of compliance rate given by the sample for different quality criteria.

Independent EPC Control System	Adopted Criterion			Compliance rate for the studied sample
	Relative error limitation	Energy rating difference Limitation	No. of NC limitation	
Thermal Área-LCCE	-	-	>1 NC	21.9%
HR	30%	-	-	95.8%
PO, DK	10%	-	-	82.1%
PT, SCT, GR	5%	-	-	76.7%
HU	-	2 energy rating difference	-	99.3%

This makes the results of different MSs with respect to each other not comparable. Therefore, there is a clear need to standardize this criterion throughout Europe. The quality criterion proposed by the EU (a confidence interval of 5% with a confidence level of 95%), being the only existing global index, could be a reference to be followed. Therefore, in this study, the quality of the sample has been evaluated based on this reference.

4.4.4 Improvements on the Independent Control System

The results have shown a high error rate in the sample and population. Moreover, the evolution of the last few years is not at all encouraging, but shows that there is a need for constant monitoring, since changes in regulations, software, the use of new technologies in buildings, etc. can alter the error trend of previous years.

The control is targeted to achieve the best possible result with the available resources and the general objective is to reach an as high as possible compliance rate [30]. To meet this objective, it is necessary to implement improvements in the control system that improve the quality of the EPC data set. Two ways to do this are discussed below:

- Control and correct the EPCs with the largest deviations and the highest number of NCs. To achieve this objective, it is necessary to have an optimal EPC selection criterion capable of detecting the EPCs with the greatest potential to contain errors. It is a way to achieve the best possible results with the same resources that have been used up to now. In the Basque Country with the existing accredited control agents there is a capacity to control 1.3% of the registered EPCs by point-by-point and with *in-situ* checks. By controlling the same amount of EPCs, but those that contain greater errors, correcting a greater amount of error in the EPC database would be possible.

- Increasing the number of controlled EPCs. The point-by-point methodology and *in-situ* checks applied in the Basque Country, as shown in the results, is a methodology with a high error detection capacity. Nonetheless, the rate of controlled EPCs achieved is low (1.3% of EPCs). It is necessary to achieve higher control rates and, to this end, to have an optimal screening methodology. One way would be to employ an automated checking methodology. Probably, as seen in examples from other MSs (see Section 1.6.), this methodology would not be able to reduce errors 100%, but it could be applied to the whole database and could be complementary to the point-by-point and *in-situ* checks methodology.

Control can be carried out in a preventive and corrective phase. In the Basque Country, there are currently no preventive measures in force.

The first measure proposed is a corrective measure, subsequent to the registration. It would not change the deviation that EPCs have prior to registration.

The increase in the number of EPCs to be controlled, on the other hand, can occur in both phases. Applied at a pre-registration stage on a preventive basis, it gives the certifier an option to review and correct its EPC based on the warnings resulting from the automatic check. This measure would make it possible to partially correct the deviation and improve, in part, the quality of the set of EPCs entering the registry.

Another way would be to apply it after registration and correct, if necessary, all EPCs after registration. In this case, it would be a corrective measure. It would not make it possible to reduce the deviation of incoming EPCs in the registry.

4.5. Conclusions

This chapter describes the EPC deviation and required number of NCs in the EPC sample. This exhaustive analysis has allowed, on the one hand, to evaluate the quality of the EPCs in the sample and in the EPC database.

One of the first conclusions of this chapter is that deviations exist in EPCs of the sample in two manners: not only sometimes being unfavorable for the final result, but also other times improving it. Approximately as many EPCs worsen their rating as EPCs improve, so that in the final balance of the sample the positive deviations are practically offset by the negative ones. However, this does not detract from the fact that 10% and 12% of the initially declared nrPEC and CO_2 emissions are overestimated or underestimated, nor does it detract from the fact that the average deviation of each EPC is ±16.53 kWh/m^{2}y. In addition, 78.1% of the EPCs contain at least one error and some contain up to 22 NCs. These data are evidence of inaccuracy in EPCs.

Further on, using a theoretical statistical distribution it has been possible to estimate the quality level of the EPCs for the whole population (EPC database) with the statistical data of the sample. The frequency distribution of the relative error in nrPEC points out a certain symmetry to the y-axis (0%) and the number of EPCs decreases further the error range is from the y-axis, taking the form of an inverted bell. Furthermore, since the tests performed do not reject the hypothesis that the mean and median can have the same value 0 and that the sample is large ($n>30$), the hypothesis that the distribution is approximately normal has not been rejected. This has allowed to estimate a confidence uncertainty of the relative error in the population of ±39.98% for a probability of 95%. This quality index is well above the appropriate value proposed by the EU Commission. This proves that there is a need to improve the control system with the aim of enhancing the quality of the EPCs.

In addition, it has been observed that the deviation is not a static value, since it has undergone an evolution during the 5 years of the study. In this evolution, the significant increase in deviation in the last 3 years is noteworthy as well as in number of NCs. Therefore, it is necessary to continue controlling EPCs in the most effective and efficient way possible.

Finally, in Section 4.4. the results obtained in the analysis of deviation and NCs have been discussed. This led to the conclusion of several possible objectives that should be taken into consideration in order to improve the control system and achieve the most efficient and optimal system possible:

- Improving the knowledge of technicians through the control system.
- Establish input data tolerances to be able to objectively decide whether the data is correct or not.
- Establish a uniform quality criterion among different MSs to be able to objectively decide whether an EPC is correct or not.
- Establish a selection criterion for the selection of EPCs to be controlled capable of selecting the EPCs with the greatest potential to contain errors.
- Increase the number of controlled EPCs.

4.6. Referred Appendices

The Appendices related to this Chapter are:

- Appendix B. Catalog of nonconformities.

5 EPC Subsamples Quality Analysis: identifying the EPC groups with the highest error pattern.

5.1. Introduction

As stated in Section 1.5.5, one of the relevant features of a control system is the selection system of EPCs subject to control. Due to the limited resources available for the control activity, not all EPCs are checked by an independent control system in MSs, at least not exhaustively —by documentary checking or by *in-situ* checks— (see Table 1.3), and therefore, a selection of EPCs subject to control is needed.

As discussed in the previous Chapter 4, in order to achieve a more effective reduction of the deviation in the set of EPCs, one of the ways could be to stablish the selection criterion with the highest capacity to detect the EPCs that contain greatest errors. In this manner, the corrected error will be greater than by any other type of EPC selection with the same number of controlled certificates.

The existing selection criteria throughout EU for the choice of EPCs to be controlled are varied (see Section 1.5.5.). In the Basque Country, the selection criterion is based on the rating obtained in the EPC. All EPCs with an Energy Rating of "A", "B" or "C" in nrPEC must undergo a control procedure. NAV and VA also have a similar criterion [26], [48]. Some other MSs —WLL (BG), FLN (BG), FR, PT, RO, NL, SCT (UK) — have a system of selection of EPCs to be controlled that is somehow associated with the activity of the Qualified Expert (QE) [23], [31], [46] and other systems are based in random samples [31], [46].

Nonetheless, the effectiveness of different selection criteria applied in different MSs have not been evaluated regarding to their capability to detect the EPCs with the highest error. In consequence, it is not known which one is the most suitable and well-functioning.

In addition, it is possible that the EPCs with the highest errors are characterized by some common features. Knowing what these features are can be useful in determining the most appropriate selection criteria, which may be different from some of the existing ones in different MSs.

Therefore, in this chapter is intended to answer the following research questions:

- Is the current selection criterion in the Basque Country which is based on the best energy ratings, the most suitable for detecting the EPCs with the highest error?
- How effective are other criteria used in other MSs which are based on QE's activity or on the random sample?
- Is any characteristic that make the EPC potentially error prone?
    - Use of the building?
    - Building typology?
    - EPC modality?
    - Used EPC calculating software?

To answer these questions, firstly, some subsamples have been organized according to different existing selection criteria. Others have been classified according to hypothetical characteristics that could make a difference in the error of the EPCs. After performing the subsample classification, the deviation and number of NCs in each subsample have been analyzed.

In this way, it will be known what is the pattern of error that these subsamples of EPCs follow and it will be confirmed whether the error can be directly related to the features that distinguish these subgroups. At the same time, it will be confirmed which of the criteria used to classify the subgroups most strongly differentiates the subsamples error. The one that is the most subsample error differentiator will be the one that has the highest capacity to identify the EPCs with the greatest errors.

5.2. Methodology

In this chapter, an evaluation of different criteria for the selection of EPCs to be controlled and of the features that make an EPC more error prone has been realized.

For this aim, a specific methodology for this chapter is employed. The deviation and NCs in each EPC that have been calculated in the previous chapter are also used in this chapter, but they are now used to obtain results about different subsamples deviation and NCs in order to determine the trends in each one of them.

Some subsamples have been classified according to two points of view: 1) different existing selection criteria (see Table 5.1) and 2) hypothetical characteristics that could make a difference in the error of the EPCs (see Table 5.2).

Table 5.1. Subsample classification based on most used selection criteria in Europe.

The most used selection criteria	Subsamples classification criterion	Subsample
Random Sample [30];	-	Subsample = Studied Sample (146 EPCs)
EPCs with specific results, e.g., by focusing on the best performing buildings, or on buildings presenting an EPC near to the minimum required energy quality, or on buildings meeting the necessary conditions to obtain subsidies [30];	Classification 1: Energy rating	Energy rating A
		Energy rating B
		Energy rating C
EPCs with identified strange values [30];	Classification 2: Qualified Experts (QE) activity	QE01
		QE02
		QE03
focus on the most active experts [30];		QE04
		QE05
		QE06
control of the first certificate(s) of each expert [30];		QE07
		QE08
		QE09
experts frequently issuing EPCs with errors [30];		QE10
		QE11
		QE12
experts that often revoke and replace EPCs [30];		QE13
		QE14
		QE15
experts who make excessive use of the help desk [30];		QE16
		QE17
experts that fail to provide (sufficient) evidence or use stock photos [30];		QE18
		QE19

Table 5.2. Subsample classification based on characteristics that could make a difference in the error of the EPCs.

Classification criterion characteristic	Subsample	Differential aspects between subsamples
Classification 3: Use of the Building	Residential Tertiary	- Operating conditions. Energy demand is higher in tertiary buildings. - Thermal and ventilation installations are more complex in tertiary buildings
Classification 4: Building Typology	Residential building: single family housing Residential: Collective housing Tertiary building: Educational Centre Tertiary building: Other Service Building*	- Building scale. - Operational conditions vary between residential and tertiary buildings, but also between different typologies of tertiary buildings.
Classification 5: EPC modality	Existing Building (EB) Building in Project (BP) New Built Building (NBB)	- Different ways of obtaining building data. In BP, there is often uncertainty about the thermal performance of some elements of the building. The way to obtain data in NBB is more accurate than in other modalities. And in EB, some data cannot be obtained with certainty; approximations are made. - Higher energy demand in existing building.
Classification 6: EPC calculating software**	Herramienta Unificada Lider-Calener (HULC)-Calener VyP Cerma Cypetherm HE Plus Ce3x***	- Different ways of defining the certificate. - Some programs are more open than others; greater possibility of cheating - Software complexity.

** This subsample includes more varied typologies (health centers, office building, small offices, social center, etc.), but none of them has enough items to consider as a subsample*

*** EPCs calculated with HULC-Calener GT and Líder-Calener VyP are excluded, since there is only one EPC calculated with HULC-Calener GT and because Líder-Calener VyP is a program that is not currently in force.*

**** Included in this subsample are several EPCs calculated with Ce3x and the add-on for new buildings.*

When choosing the classification criteria, the aspects that would differentiate the subsamples within the same classification have been considered (see 3rd column in Table 5.2). In this manner, a discussion of the relationship between the differences in the error of each subsample and the possible reasons for this will be performed.

In each subsample the calculated and analyzed parameters are:

- Root Mean Square (RMS) of the relative error of the deviation in nrPEC as well as of the deviation in CO_2 (See Eq. 5.1).
- RMS of the absolute error of the deviation in nrPEC as well as the deviation in CO_2 (See Eq. 5.2).
- Linear correlation of nrPEC and CO_2 results between draft and final EPC.
- Average of no. of NCs.

The relative error, ε_r, (see Eq. 4.2 in previous Chapter 4) and the absolute error, ε_a, (see Eq. 4.1 in previous Chapter 4) take positive and negative values. Hence the interest in collecting a type of average that does not include the effects of the sign to represent the global error of each subsample and sample, in this case, the Root Mean Square (RMS).

$$\varepsilon_{r,RMS} = \sqrt{\frac{{\varepsilon_{r,1}}^2 + {\varepsilon_{r,2}}^2 + \cdots + {\varepsilon_{r,n}}^2}{n}} \qquad \text{Eq. 5.1}$$

$$\varepsilon_{a,RMS} = \sqrt{\frac{{\varepsilon_{a,1}}^2 + {\varepsilon_{a,2}}^2 + \cdots + {\varepsilon_{a,n}}^2}{n}} \qquad \text{Eq. 5.2}$$

Where,
$\varepsilon_{r,RMS}$: **The RMS of the relative error**
$\varepsilon_{r,n}$: **The relative error of each observation**
$\varepsilon_{a,RMS}$: **The RMS of the absolute error**
$\varepsilon_{a,j}$: **The absolute error of each observation**
n: **Number of observations**

The RMS has the same units as the measured variable. Therefore, the $\varepsilon_{a,RMS}$provides an average value of the effect that the error made in the EPC has on the absolute amount of energy or CO_2. It is a comparative parameter between subsamples from the point of view of their effect on the total consumption of EPCs database. It is not an indicator that allows comparison of the quality of various subsamples of EPCs. In other words, before analyzing the results, it is predictable that the subsamples that usually have higher consumption, with the same level of quality as the rest of the subsamples, may have a higher $\varepsilon_{a,RMS}$.

In contrast, the $\varepsilon_{r,RMS}$ provides information on the average error in each EPC in percentage, with no effect of the degree of consumption or the amount of CO_2 corresponding to each EPC. As such, it is a parameter that compares the quality level of EPCs.

Finally, the results are presented in 3 subsections. Subsection 5.3.1 reports the average of NCs per EPC in each subsample. After that, Subsection 5.3.2 displays the results of the deviation in each subsample. And finally, Subsection 5.3.3 resumes and links the results of Subsections 5.3.1 and 5.3.2. All these results are discussed in Section 5.4. and the main conclusions are provided in Section 5.5.

5.3. Results

5.3.1 Subsamples Nonconformities Results

In this subsection the error of the subsamples is measured in average number of NCs per EPC. The results are presented below (see Table 5.3).

The most approximate result for a random sample selection criterion would be the whole sample result, as the sample has been randomly selected from all EPCs audited in the period 2014-2019. The average number of NCs per EPC in the sample is the reference value to assess the result in the rest of the subsamples (see Table 5.3).

In classification 1 a relationship between the order of the rating and the decrease in the average of NCs appears. The better the rating, the more NCs are issued. In fact, the NCs in rating "A" are above the sample average, and in ratings "B" and "C", they are below.

Table 5.3. No. of NCs average per EPC in each subsample.

	Subsample	No. EPC	Sample Percentage [%]	No. of NCs per EPC
-	All the sample	146	100	4.4
Classification 1	Rating A	53	36.3	5.4
	Rating B	72	49.3	4.0
	Rating C	21	14.4	3.6
Classification 2	QE01	18	12.3	3.2
	QE02	14	9.6	3.1
	QE03	10	6.8	6.3
	QE04	6	4.2	4.5
	QE05	6	4.2	3.7
	QE06	6	4.2	1.5
	QE07	5	3.4	8.0
	QE08	3	2.1	1.0
	QE09	3	2.1	7.0
	QE10	3	2.1	2.0
	QE11	3	2.1	6.7
	QE12	3	2.1	8.0
	QE13	3	2.1	4.7
	QE14	3	2.1	1.7
	QE15	3	2.1	1.0
	QE16	3	2.1	3.3
	QE17	3	2.1	6.0
	QE18	3	2.1	2.3
	QE19	3	2.1	5.7
Classification 3	Residential	117	80.1	3.8
	Tertiary	29	19.9	7.0
Classification 4	Single Family Housing	27	11.6	4.2
	Collective Housing	90	61.7	3.7
	T-E	21	14.4	7.2
	T others	8	5.5	6.3
Classification 5	EB	19	13.0	2.4
	BP	53	36.3	4.7
	NBB	74	50.7	4.8
Classification 6	H.U.L.C. – Calener VyP	76	52.1	5.16
	Cerma	21	14.4	5.42
	Cypetherm HE Plus	3	2.1	7.5
	Ce3x	15	10.3	3.2

The most important differences between subsamples are found in classification 2, followed by 6 and 4. The subsamples with the highest number of NCs per EPC are QE07 and QE12 —8 NCs per EPC, 1.81 times more than the sample average—, and with the lowest number of

NCs per EPC are QE15 and QE08 —1 NC per EPC, 4.4 times less than the sample average—. The four subsamples belong to classification 2.

The most remarkable point in the results of classification 3 is that the NCs of tertiary buildings almost double those of residential buildings. The same conclusion can be drawn from the results of classification 4. However, in the latter, the variation between different typologies of the same use is not so pronounced.

In classification 5 the dissimilarity between EPCs corresponding to existing buildings and those corresponding to new buildings (subsamples BP and NBB) is identified. These last two subsamples show similar results —4.7 and 4.8 NCs per EPC—, in contrast to 2.4 NCs of subsample EB.

And finally, in classification 6, it can be seen that the software that generates the most difficulty for technicians is Cypetherm HE Plus —7.5 NCs per EPC—. On the opposite side is the software Ce3x with 3.2 NCs per EPC. The result in this subsample is related to that of the EB subsample of the previous classification, since most of the EPCs calculated with Ce3x are existing buildings.

5.3.2 Subsamples Deviation Results

In this section, error results for various subsamples are presented below. The error of each subsample has been measured in RMS of the relative error as well as the linear correlation between the result in the draft and final corrected EPC is analyzed. In the latter, only the graph corresponding to the nrPEC is shown, ignoring the graph of CO_2 emissions, since the graphs obtained for both cases are almost identical. The subsamples analyzed have been described in Section 5.2.

Before presenting the results of the subsamples, Table 5.4 describes the statistical parameters (see Eq. 5.1 and Eq. 5.2 in Section 5.2) for the entire sample. They serve as reference values for later analysis of the subsamples. These are the results that are closest to the ones that a selection based on random sample could give, since the entire sample has been randomly created.

Table 5.4. RMS of relative error and absolute error in the sample.

	No. EPC	Sample Percentage [%]	RMS			
			$\varepsilon_{r,nrPEC}$ [%]	$\varepsilon_{r,CO2}$ [%]	$\varepsilon_{a,nrPEC}$ [Kwh/m^{2}y]	$\varepsilon_{a,CO2}$ [KgCO$_2$/m^{2}y]
Sample	146	100	20.3	22.0	12.2	2.4

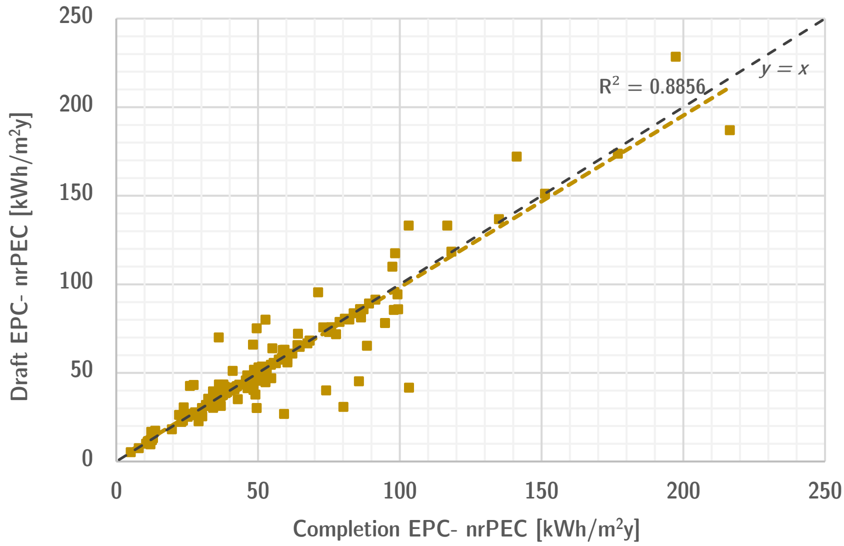


Figure 5.1. Linear Correlation between nrPEC results of Draft and Completion EPC (Sample).

The line $x = y$ (see Figure 5.1) shows the reference line representing the hypothetical result of a sample whose deviation between draft and final versions is zero or whose positive deviations are offset by negative ones. It is observed that the linear trend of the sample is close to and slightly below the $x = y$ line. This means that the sample in the draft version tends to underreport nrPECs very slightly. In addition, the higher the consumption, the larger the deviation, since the yellow line moves farther away from the reference line as consumption increases.

Subsamples in classification 1. EPC rating: “A”, “B” and “C”

This category of subsamples has been chosen based on the selection criteria of EPCs to be controlled established in the Basque Country, where all EPCs in draft version that have an "A", "B" or "C" rating in the initial version must undergo a quality control [26].

Table 5.5. RMS of the relative error and absolute error in subsamples classification 1.

Subsample	No. EPC	Sample Percentage [%]	RMS			
			$\varepsilon_{r,nrPEC}$ [%]	$\varepsilon_{r,CO2}$ [%]	$\varepsilon_{a,nrPEC}$ [Kwh/m^2y]	$\varepsilon_{a,CO2}$ [$KgCO_2/m^2y$]
Rating A	53	36.3	15.7	19.6	9.7	1.6
Rating B	72	49.3	22.8	23.6	14.1	2.8
Rating C	21	14.4	21.7	21.8	10.5	2.2

Table 5.5 demonstrates that the rating "A" subsample is the group with the highest accuracy in both the RMS of the relative error and the absolute error. In other words, it is the group with the highest quality and the one that has the least impact on the absolute consumption of the EPC database. In addition, comparing with the reference RMS of the sample (see Table 5.4), lower values are found. The next two subsamples display a larger error than the rating "A" subsample and the whole sample. Between the two, the rating "B" subsample has a slightly higher error.

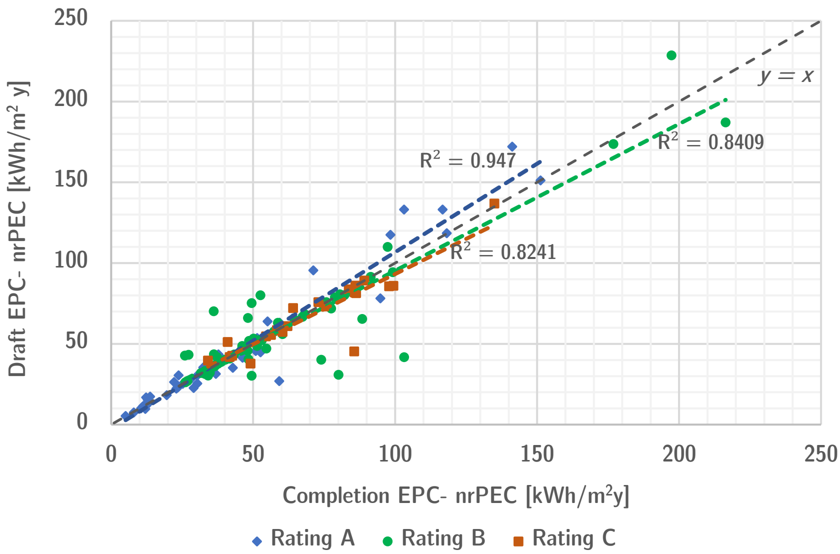


Figure 5.2. Linear Correlation between nrPEC results of Draft and Completion EPC (Subsample classification 1).

In Figure 5.2, we can see that, besides being the group with the lowest deviation, subsample rating "A" is also the group that tends to report the nrPEC above the real value, since the blue trend line is above the $x = y$ reference line. The opposite are the subsamples rating "B" (green line) and "C" (orange line) results. These are below the reference line, making them more "cheatable" subsamples. Although the deviation is greater in subsample rating "B" than in "C" (see Table 5.5), Figure 5.2 shows that its trend line of rating "B" is scarcely above that of subsample rating "C". This is because in the case of the subsample rating "B", positive errors are compensated by negative errors more than in the subsample rating "C". Therefore, the worse the rating, the more "cheating" errors predominate over "conservative" errors.

Subsamples in classification 2. EPC groupings by Qualified Experts (QE)

Results of the error in the EPCs of each QE are presented in this section. The 146 EPCs in the sample have been issued among 50 QEs: 17 QEs have calculated only one EPC and the one with the highest number of EPCs has issued 18 EPCs. For this analysis, only the QEs with 3 or more EPCs have been selected, totaling 19 QEs (see Table 5.6).

Table 5.6.RMS of the relative error and absolute error in subsamples classification 4.

Subsample	No. EPC	Sample Percentage [%]	RMS			
			$\varepsilon_{r,nrPEC}$ [%]	$\varepsilon_{r,CO2}$ [%]	$\varepsilon_{a,nrPEC}$ [Kwh/m^{2}y]	$\varepsilon_{a,CO2}$ [KgCO$_2$/m^{2}y]
QE01	18	12.3	5.4	6.7	2.0	0.5
QE02	14	9.6	20.2	19.8	10.4	2.1
QE03	10	6.8	24.4	36.0	10.6	1.9
QE04	6	4.2	18.2	19.4	8.8	1.9
QE05	6	4.2	15.3	16.5	4.6	1.2
QE06	6	4.2	11.1	11.1	5.6	1.2
QE07	5	3.4	12.2	14.5	8.4	2.2
QE08	3	2.1	4.7	3.9	0.5	0.1
QE09	3	2.1	13.9	14.5	4.3	0.8
QE10	3	2.1	1.6	1.6	0.4	0.1
QE11	3	2.1	14.9	15.3	24.6	4.4
QE12	3	2.1	10.1	10.1	5.6	1.2
QE13	3	2.1	9.2	13.0	18.0	4.8
QE14	3	2.1	0.0	0.0	0.0	0.0
QE15	3	2.1	2.2	2.1	1.6	0.3
QE16	3	2.1	3.0	1.9	1.8	0.2
QE17	3	2.1	11.5	13.0	10.8	1.9
QE18	3	2.1	37.1	39.3	9.6	2.4
QE19	3	2.1	37.8	40.8	38.0	7.2

Table 5.6 presents notable differences between different subsamples both in relative errors and absolute errors. The QE with the lowest relative error is QE14 —0% in nrPEC and CO_2 emissions— and the QE with the highest relative rrror is QE19 —37.8% in nrPEC and 40.8% in CO2 emissions—. The same pattern is found in RMS of $\varepsilon_{a,nrPEC}$ and $\varepsilon_{a,CO2}$: The QE14 is the subsample that had the lowest result —0% in nrPEC and CO_2 emissions— and QE19 is the one that presented the highest error —38.0 kWh/m^{2}y in nrPEC and 7.2kgCO_2/m^{2}y in CO_2 emissions—.

If the results are compared with the RMS obtained for the entire sample, only three of the QEs exceed the RMS of the relative error of the sample —QE03, QE18 and QE19— and besides QE19, two other QEs exceed the RMS of the absolute error —QE11 and QE13—. That is, 5 QEs are the ones that exceed the RMS of the total sample.

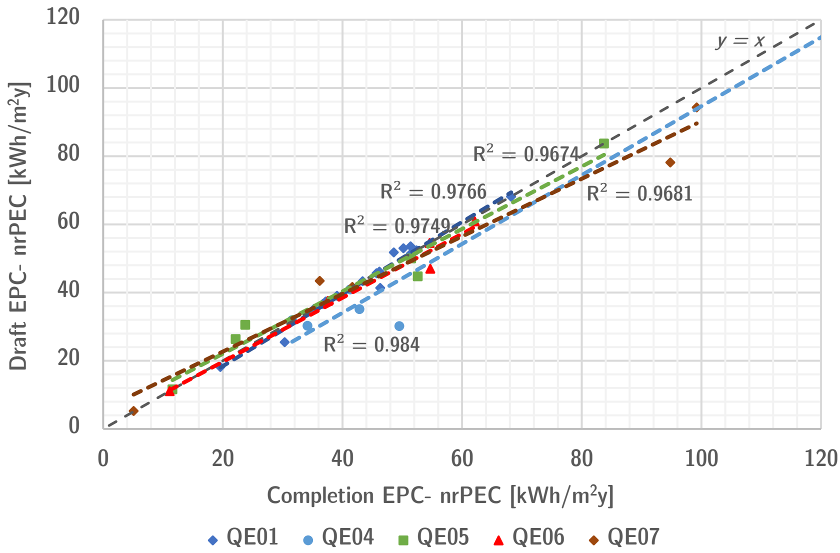


Figure 5.3. Linear Correlation between nrPEC results of Draft and Completion EPCs (Subsample classification 2).

Table 5.7. Correlation coefficient R^2 between draft and final EPC outcomes in nrPEC of each subsample.

	QE01	QE02	QE03	QE04	QE05	QE06	QE07
R^2	0,977	0,638	0,635	0,984	0,967	0,974	0,968

Figure 5.3, as in the previous classification, shows the relationship between draft and final version of each EPC and the trend lines of each subsample —in this case QEs—. As can be noticed, the data for all the QEs represented in Table 5.6 have not been plotted. QE02 and QE03 have been excluded, as the R^2 of these trend lines were below 0.80 (see Table 5.7) and therefore they have not been considered conclusive. On the other hand, from subsamples QE08 to QE19 only 3 points are available for each EPC group. This number of observations has also not been deemed sufficient to obtain conclusive trend lines. Therefore, all subsamples between QE08 and QE19 have also been disregarded.

Nevertheless, only with the analysis of 5 QEs it can be said that it is an effective tool to reflect the differences between the trends of the 5 QEs, since each line presents a different behavior.

The QE01 line practically coincides with the $x = y$ axis, which means that the negative errors are counterbalanced by the positive ones. In addition, the proximity of the points to the axis and the results obtained in Table 5.6. indicate that the deviations are not significant.

QE04, on the other hand, is one of the farthest from the $x = y$ axis along its entire length and in parallel below it. In other words, the deviations that have been detected in this QE in all cases are "cheating" and therefore, since there is no compensation between negative and positive ones, it is the QE that is furthest away from correct results.

QE05, QE06 and QE07 have similar behavior to each other: in EPCs of low nrPEC they are "conservative" and of high nrPEC they become "cheaters". This behavior is more accentuated in the case of QE07 and less pronounced in the case of QE05. QE06 is not as "conservative" at low nrPEC values since it reflects more accurately than the other QEs in EPCs of nrPEC below 40 kWh/m^{2}y.

Subsamples in classification 3. Building use: tertiary or residential

Two main subsamples have been distinguished: tertiary and residential buildings (see Table 5.8 and Figure 5.4).

Table 5.8. RMS of the relative error and the absolute error in subsamples classification 3.

Subsample	No. EPC	Sample Percentage [%]	RMS			
			$\varepsilon_{r,nrPEC}$ [%]	$\varepsilon_{r,CO2}$ [%]	$\varepsilon_{a,nrPEC}$ [kWh/m²y]	$\varepsilon_{a,CO2}$ [kgCO₂/m²y]
Tertiary	29	19.9	21.7	22.9	21.0	3.9
Residential	117	80.1	20.0	21.8	8.8	1.8

Table 5.8 demonstrates that there are no major differences in the RMS of the relative error of the two subsamples and that they are similar to those obtained in the whole sample. However, the difference in the RMS of the absolute error is significant. This is because the consumption and CO_2 emissions in tertiary buildings are higher than in residential buildings as the energy demand is higher in tertiary buildings. Thus, with the same level of quality in the two subsamples, the effect on total consumption and emissions is considerably higher in tertiary buildings.

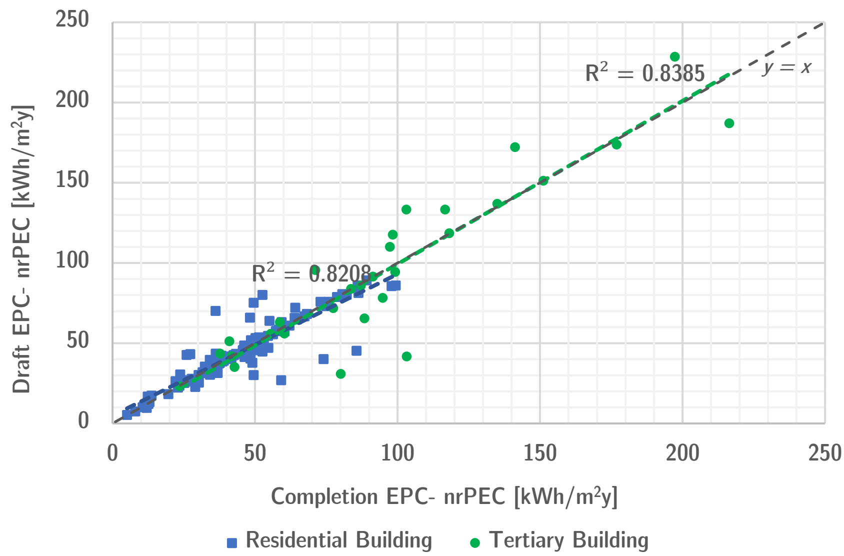


Figure 5.4. Linear Correlation between nrPEC results of Draft and Completion EPCs (Subsample classification 3).

Figure 5.4 represents the relationship between the draft and final results in each EPC of Residential and Tertiary Building subsamples. The blue line is the trend line for EPCs corresponding to residential buildings and the green line is the line for tertiary buildings. The blue line (residential) extends up to approximately 100 kWh/m^{2}y, the maximum consumption recorded in residential buildings. On the other hand, the green line is more extended since the maximum consumption of tertiary buildings is more than twice as high as the maximum in residential. On the one hand, in the first subsample, it is worth noting that the line crosses the reference line, being in its first half above the line and in the second half below it. In other words, this analysis also reveals that the EPCs with the best ratings are those that report results above the correct values. On the other hand, in the subsample tertiary buildings everything indicates that the positive errors are balanced by the negative ones.

Subsamples in classification 4. Building typology

Another adopted classification characteristic is the building typology (see Table 5.2 in Section 5.2) where 4 subcategories are distinguished. The residential buildings are divided into two subsamples: single-family housing and collective housing (see Table 5.9 and Figure 5.5). Both groups include detached buildings and those located between party walls, although these typologies have been differentiated in the description of the sample in Annex A.

The tertiary buildings as well are partitioned in two subsamples: educational centers and other use tertiary buildings (see Table 5.10 and Figure 5.6). Most of the controlled tertiary buildings are educational centers and this differentiation allows to know the behavior of the deviation in this type of buildings compared to the rest.

Table 5.9. RMS of the relative error and the absolute error in single-family housing and collective housing subsamples (Classification 4).

Subsample	No. EPC	Sample Percentage [%]	RMS			
			$\varepsilon_{r,nrPEC}$ [%]	$\varepsilon_{r,CO2}$ [%]	$\varepsilon_{a,nrPEC}$ [kWh/m²y]	$\varepsilon_{a,CO2}$ [kgCO₂/m²y]
Single Family Housing	27	11.6	25.6	26.5	11.8	2.3
Collective Housing	90	61.7	17.9	20.1	7.6	1.6

Table 5.9 shows that there are significant differences between the two residential typologies in the RMS of the relative and absolute errors, with single-family housing being the subsample with the worst data. Although in the RMS of the absolute error it is close to the reference values of the sample (see Table 5.4), in the RMS of the relative error it is well above.

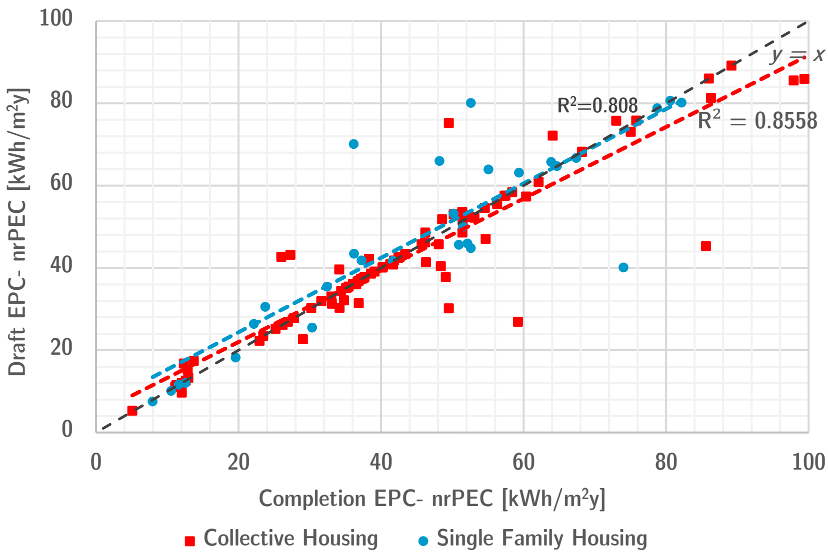


Figure 5.5. Linear Correlation between nrPEC results of Draft and Completion EPC in Single Family Housing and Collective Housing subsamples (classification 4).

Even though the results in Table 5.9 are favorable for the collective housing subsample, Figure 5.5 demonstrates that the ratings for single housing are more conservative than for collective housing. Moreover, in buildings with higher consumption in collective housing, the deviations exceed the most unfavorable point of the single-family housing.

Table 5.10. RMS of the relative error and the absolute error RMS in educational center and other tertiary building subsamples (classification 4).

Subsample	No. EPC	Sample Percentage [%]	RMS			
			$\varepsilon_{r,nrPEC}$ [%]	$\varepsilon_{r,CO2}$ [%]	$\varepsilon_{a,nrPEC}$ [kWh/m^{2}y]	$\varepsilon_{a,CO2}$ [kgCO$_2$/m^{2}y]
T-E	21	14.4	19.1	20.8	19.0	3.8
T others	8	5.5	27.5	27.5	25.4	4.3

Even though no major differences have been found between residential and tertiary buildings, as in the case of residential typologies, there are significant differences between tertiary typologies. The subsample of educational buildings presents similar relative errors and higher absolute errors than the whole sample, with no relevant errors to be highlighted. In contrast, the rest of the tertiary buildings have substantially higher relative and absolute errors.

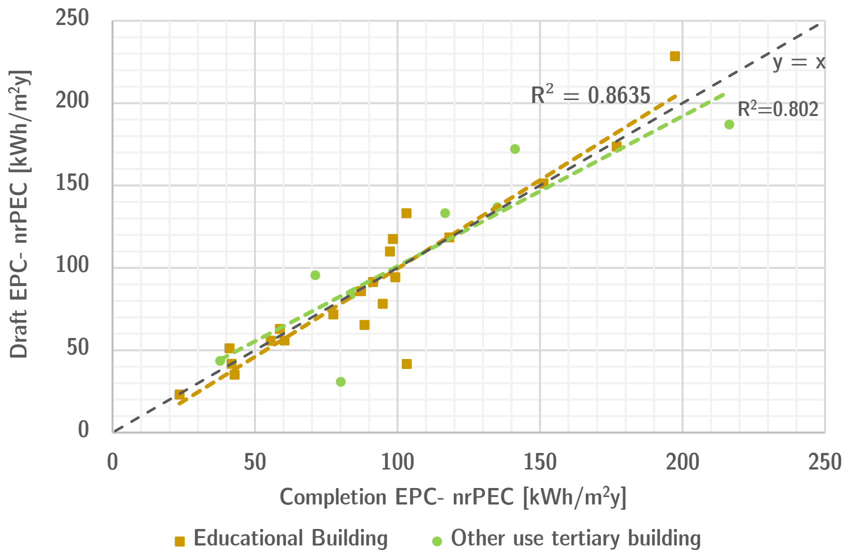


Figure 5.6. Linear Correlation between nrPEC results of Draft and Completion EPC in Tertiary Building subsamples (classification 4).

Figure 5.6 illustrates that the trend line of the tertiary building subsample practically overlaps with the $x = y$ reference line. Figure 5.6 zooms into the tertiary buildings EPC group and shows different trends for educational centers and the rest of the tertiary buildings. The trend lines are positioned at a very small distance from the axis, opposite and almost symmetrical to the x=y axis, so that they offset each other. The trend line of the educational centers subsample has a behavior contrary to what has been seen so far in general in most of the subsamples i.e. EPCs with lower consumptions are more "cheating" than EPCs with higher consumptions.

Subsamples in classification 5. EPC modality: EB-EPC, BP-EPC and NBB-EPC.

The fifth classification is based on the type of EPC (see Section 5.2).

Table 5.11. RMS of the relative error and the absolute error in subsamples classification 5.

Subsample	No. EPC	Sample Percentage [%]	RMS			
			$\varepsilon_{r,nrPEC}$ [%]	$\varepsilon_{r,CO2}$ [%]	$\varepsilon_{a,nrPEC}$ [kWh/m^{2}y]	$\varepsilon_{a,CO2}$ [kgCO_2/m^{2}y]
EB	19	13.0	26.3	27.1	11.4	2.5
BP	53	36.3	17.1	20.0	13.3	2.4
NBB	74	50.7	20.7	21.8	11.5	2.3

Table 5.11 indicates the differences in the deviation of the three subsamples to be analyzed. The relative error in BP-EPCs is lower than the reference value of the sample, in NBB-EPC subsample is similar and in EB-EPC subsample is much higher. However, no such notable differences are found in the absolute error.

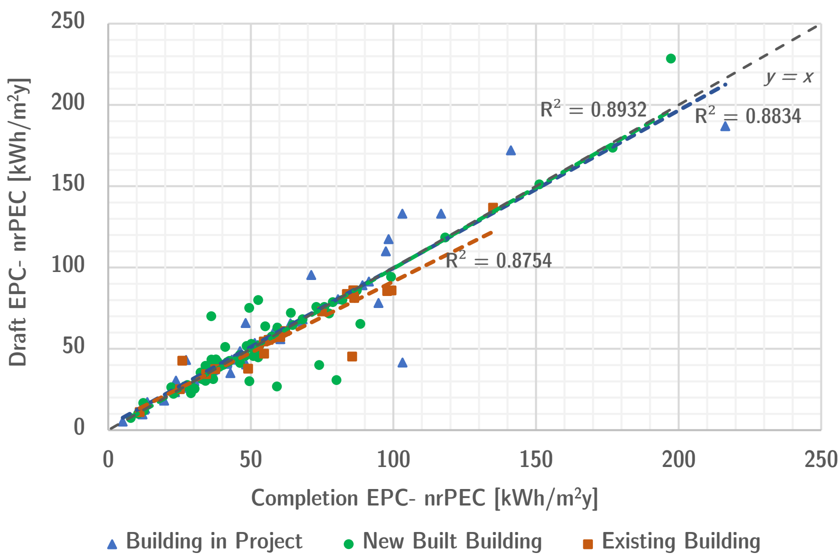


Figure 5.7. Linear Correlation between nrPEC results of Draft and Completion EPCs (Subsample classification 5).

It is observed in Figure 5.7 that the NBB and BP-EPC subsample lines are close to or almost overlapping the $x = y$ axis. In the other hand, the trend line of the EB-EPC subsample is steeper and located below the $x = y$ reference line. This means that EB-EPCs under-report their values and that the higher the consumption, the greater the increase in deviation is, more than in other subsamples.

Subsamples in classification 6. EPC calculating software

Classification 6 is based on the calculation program used by the certifier (see Section 5.2). The 146 EPCs have been calculated by 6 types of software, 4 of them have been included in the analysis.

Table 5.12. RMS of the relative error and the absolute error in subsamples classification 6.

Subsample	No. EPC	Sample Percentage	RMS			
		[%]	$\varepsilon_{r,nrPEC}$ [%]	$\varepsilon_{r,CO2}$ [%]	$\varepsilon_{a,nrPEC}$ [kWh/m^{2}y]	$\varepsilon_{a,CO2}$ [kgCO$_2$/m^{2}y]
H.U.L.C. – Calener VyP [60]	76	52.1	20.4	20.7	12.9	2.5
Cerma [61]	21	14.4	18.0	26.6	8.3	1.8
Cypetherm HE Plus[62]	3	2.1	15.6	19.8	13.7	3.4
Ce3x [63]	15	10.3	30.4	30.7	19.5	3.7

The most prominent deviation in classification 6 is the RMS of the relative error of the Ce3x subsample, which almost doubles the values in the Cypetherm HE Plus subsample (see Table 5.12). This result is related to the result of classification 3, where the EB subsample stands out, since most of the EPCs calculated with Ce3x are existing buildings. As for the RMS of the absolute error, it is also the Ce3x subsample that shows a spike in the error compared to the rest of the subsamples. A positive result is observed in the Cypetherm HE Plus subsample, which, although they are the result of a new way of working, the deviation is not significant and the RMS of the relative error is below the values of the sample.

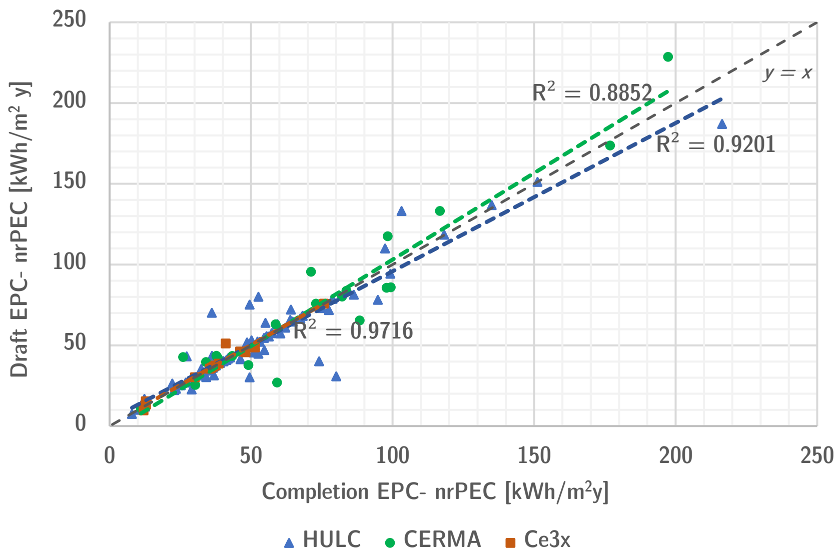


Figure 5.8. Linear Correlation between nrPEC results of Draft and Completion EPCs (Subsample classification 6).

As in other classifications, Figure 5.8 displays de correlation of the Draft and Completion EPCs outcomes. Although the RMS of the relative and absolute errors of the HULC and Cerma subsamples are similar and close to the sample means, differences are found in the correlation between them. Both trend lines are approximately symmetrical with respect to the $x = y$ axis, with the Cerma subsample showing "conservative" results and HULC showing "cheating" results. On the other hand, the Ce3x subsample, although it presents high deviations (see Table 5.12), it is observed that the negative ones are compensated with the positive ones, since the trend line is above the $x = y$ reference line.

5.3.3 Results Resume

Table 5.13 shows the results presented in Sections 5.3.1. and 5.3.2. except those related to the draft and final EPC correlations. In order to better understanding, the values in each column are ordered by colours; from green (the lowest values) to red (the highest values).

Table 5.13. Results resume of Section 5.3.1 and 5.3.2.

		No. of NCs per EPC	RMS			
			$\varepsilon_{r,nrPEC}$ [%]	$\varepsilon_{r,CO2}$ [%]	$\varepsilon_{a,nrPEC}$ [kWh/m^{2}y]	$\varepsilon_{a,CO2}$ [kgCO_2/m^{2}y]
	Sample	4.4	20.3	22	12.2	2.4
Classification 1	Rating A	5.4	15.7	19.6	9.7	1.6
	Rating B	4	22.8	23.6	14.1	2.8
	Rating C	3.6	21.7	21.8	10.5	2.2
Classification 2	QE01	3.2	5.4	6.7	2	0.5
	QE02	3.1	20.2	19.8	10.4	2.1
	QE03	6.3	24.4	36	10.6	1.9
	QE04	4.5	18.2	19.4	8.8	1.9
	QE05	3.7	15.3	16.5	4.6	1.2
	QE06	1.5	11.1	11.1	5.6	1.2
	QE07	8	12.2	14.5	8.4	2.2
	QE08	1	4.7	3.9	0.5	0.1
	QE09	7	13.9	14.5	4.3	0.8
	QE10	2	1.6	1.6	0.4	0.1
	QE11	6.7	14.9	15.3	24.6	4.4
	QE12	8	10.1	10.1	5.6	1.2
	QE13	4.7	9.2	13	18	4.8
	QE14	1.7	0	0	0	0
	QE15	1	2.2	2.1	1.6	0.3
	QE16	3.3	3	1.9	1.8	0.2
	QE17	6	11.5	13	10.8	1.9
	QE18	2.3	37.1	39.3	9.6	2.4
	QE19	5.7	37.8	40.8	38	7.2
Classification 3	Tertiary	7	21.7	22.9	21	3.9
	Residential	3.8	20	21.8	8.8	1.8
Classification 4	Single Family Housing	4.2	25.6	26.5	11.8	2.3
	Collective Housing	3.7	17.9	20.1	7.6	1.6
	T-E	7.2	19.1	20.8	19	3.8
	T others	6.3	27.5	27.5	25.4	4.3
Classification 5	EB	2.4	26.3	27.1	11.4	2.5
	BP	4.7	17.1	20	13.3	2.4
	NBB	4.8	20.7	21.8	11.5	2.3
Classification 6	H.U.L.C. – Calener VyP	5.16	20.4	20.7	12.9	2.5
	Cerma	5.42	18	26.6	8.3	1.8
	Cypetherm HE Plus	7.5	15.6	19.8	13.7	3.4
	Ce3x	3.2	30.4	30.7	19.5	3.7

Relationship between quality measurement in number of nonconformities and in deviation.

The main result at first sight (see Table 5.13) is that the level of quality of the subsamples measured in NCs does not present a direct relationship with the measurement in relative error or absolute error. Otherwise, there would be a correlation in the color palette of different columns.

Furthermore, if this relationship is analyzed in each classification, examples of subsamples are identified where not only there is no correlation, but also the values presented in deviation and number of NCs are extreme within the classification and antagonistic to each other. These are some examples:

- Subsample energy rating "A" (Classification 1): it has the lowest deviations in RMS of the relative error and absolute error among the subsamples of that classification, but at the same time, it presents the highest values in number of NCs measurement.
- Subsample EB (Classification 5): although it presents the lowest number of NCs, it has the higher RMS of the relative error value.
- Subsample Cypetherm HE Plus (Classification 6): the highest number of NCs vs the lowest RMS of the relative error.
- Subsample Ce3x (Classification 6): the lowest number of NCs vs the highest RMS of the relative error and the absolute error.

The results of classification 3 are an exception, where there is a certain relationship between the degree of quality measured in NCs and deviation. Subsamples QE08, QE10, QE14 and QE15 in classification 2 are also exceptions.

The most differentiating classification

The classification that most distinguishes the differences between subsample's errors is classification 2. In other words, the criterion most capable of identifying the worst quality EPCs and the best quality EPCs is related to QE's activity. In this classification are the subsamples with the best results in terms of deviation (in green), corresponding to QE08, QE10, QE14. The results for the number of NCs also show the most extreme values in that classification: in green QE06, QE07, QE14 and QE15 vs in red QE07 and QE12.

Subsamples with the worst quality index

In addition to the QEs with the worst quality indexes, the following subsamples should be highlighted, which also present notable inaccuracies:

- All Tertiary Buildings (T-E and T-others) in number of NCs and in RMS of the relative error and the absolute error.
- Single-Family housing in RMS of the relative error.
- Existing Buildings in RMS of the relative error.
- EPCs made by Cypetherm HE Plus in number of NCs.
- EPCs made by Ce3x in RMS of the relative error and the absolute.

5.4. Discussion

5.4.1 The best energy rating, the best quality performance

In order to evaluate the suitability of the criteria which are based on the best energy ratings (targeted control) the results of the classification 1 subsamples have been obtained. This type of selection criterion is applied in the Basque Country [26] where all EPC with rating "A", "B" or "C" are controlled. Similar system is established also in VA or NAV.

Although Loncour and Roelens [30] confirm that EPCs with errors are usually over-represented in the EPCs selected via targeted control, this study has shown the opposite. It has been shown that the better the rating, the higher the accuracy of the EPCs. Moreover, the best energy rating EPCs declare overestimated outcomes. On to the contrary, EPCs with higher energy demands (tertiary buildings and existing buildings) show greater deviations.

This means that it may not be the most appropriate selection criterion, as long as the objective is to correct as much error as possible in the set of controlled EPCs. Nevertheless, if the aim should be to verify compliance with a minimum level of energy efficiency through the veracity of the EPCs in buildings that receive aid for renovation, deductions in property taxes, etc., it would be a totally valid criterion. Nonetheless, this is not the case for all buildings with energy rating "A", "B" or "C". Thus, the results obtained do not support this selection criterion.

5.4.2 Factors that determine differences between the error of the subsamples

Other research questions of this Chapter were how effective are other MSs criteria based on QE's activity, random sample, etc. and whether there are any EPC common characteristics that make the EPC potentially more error prone.

In classification 2, based on the differentiation of the exercise of the QEs, subsamples with maximum and others with minimum errors can be found at the same time, both in deviation and NCs (see Table 5.13). This is the most subsamples differentiating classification. Therefore, it has been proven that it is the most effective classification in order to detect the most error prone EPCs. Nonetheless, the classification 2 summarizes the different selection criteria that exist (see Table 5.1). These are some criteria to be taken into account when proposing improvements in the selection system of EPCs to be controlled, and therefore, some of their attributes are discussed in the following table:

Table 5.14. Comparative discussion of different selection criteria based on QEs activity.

	The system...		
	...performs a first quality review of the EPC	...pursues technicians who display signs of lack of knowledge (1) and signs of negligence (2)	...requires more resources
EPCs with identified strange values	Yes	(1); (2)	Yes. Automatic Checking software
EPCs corresponding to the most active experts	No	(2)	No
First EPC of each expert	No	Partly (1) and (2). The fact that the first EPC is correct does not mean that the rest are correct.	No
EPCs corresponding to the experts frequently issuing EPCs with errors	No	(1); (2)	Monitoring of the errors made by each QE and its evolution.
EPCs corresponding to the experts that often revoke and replace EPCs	No	(1); (2)	Monitoring the QE's activity in registration app.
EPCs corresponding to experts who make excessive use of the help desk	No	(1)	Monitoring the QE's activity in registration app.
EPCs corresponding to experts that fail to provide (sufficient) evidence or use stock photos	Yes	(2)	Yes. Automatic Checking software

Table 5.14 compares the qualities of each EPC selection system to be controlled. Among all the criteria, the first one is the most complete, since in addition to selecting the most suspicious EPCs, it makes it possible to perform a first review of all the EPCs and filter by means of a check the EPCs that are at least almost correct. It is true that it requires more resources in addition to those that currently exist, such as those based on automatic checking software. But this tool has another advantage, since it may also be able to detect those EPCs that do not present evidence to justify the input data (see the last row of the table).

In addition to classification 2, classification 3 and 4 on the one hand, and classification 5 and 6 on the other, have also been effective in identifying subsamples with significant errors.

In classification 3 and 4, the error in tertiary buildings is higher than in residential buildings. The main aspects that differentiate these two types of buildings are (see Table 5.2) the energy demand and, on the other hand, the complexity of the thermal and ventilation installations, both of which are higher in tertiary buildings. Within the tertiary (classification 4), in addition, other tertiary buildings subsample presents substantially higher relative and absolute error than educational buildings. This difference is probably also due to the greater singularity and complexity of thermal and ventilation installations in other tertiary buildings, since in educational buildings the installations are more repetitive.

In classification 5, the EB subsample is the one with the highest errors and in classification 6 it is the Ce3x subsample. The two may be related, as most of the EPCs calculated using Ce3x are for existing residential buildings. Ce3x is a simpler program than HULC and Cypetherm HE Plus in the definition of the building, so complexity and lack of knowledge of the program do not seem to be the reason for the errors. However, it is a program that allows more manipulation of geometric definition data. Moreover, in EB it is not easy to determine the exact input data, since in general there are no technical data sheets available, nor visibility of the insulation, etc. This uncertainty may influence the incorrect definition of the building. But, finally, there is another factor, which, as in tertiary buildings, can affect the increase in error, overall, existing buildings have a higher energy demand than new buildings.

Once again, it is observed that the higher the consumption, the greater the error. In addition to this factor, others influencing the error can be the complexity of the systems in tertiary buildings and the lack of definition or uncertainty in the input data of existing buildings certificate.

5.5. Conclusions

In this chapter, subsamples quality analysis has been performed in order to assess the suitability of different EPC control selection criteria and the EPC features that make an EPC more error prone. It has been demonstrated that by analyzing the errors of various subsamples classified according to different features, it is possible to know from highest to lowest which types of EPCs are most likely to contain errors and which tend to report "conservative" or "cheating" values.

The quality of the EPC groups has been quantified by measuring the number of NCs and the deviation in relative error and absolute error. Both analyses show unequal results. It has been concluded that there is no direct relationship between the number of NCs and the deviation. This shows that the weight that each NC has on the impact of the final result of the EPC is very varied. Therefore, it is concluded that only measuring the number of NCs is not enough to assess the quality of the EPCs unless the impact of each one of them on the final result of the EPC is known.

Consequently, by focusing on the results of the deviation, some general guidelines have been concluded that should be taken into account when establishing criteria for the selection of EPCs to be controlled:

- In general, in the subsamples it has been found that the higher the consumption declared in the EPC, the greater is the deviation detected. Similarly, EPCs with an "A" rating have lower deviations than subsamples rated "B" and "C". This conclusion questions the effectiveness of the system of selecting EPCs to be controlled established in the Basque Country and elsewhere, based on the targeted sample and checking the buildings with the best ratings.

- The better the declared rating, the more conservative are the detected deviations. This can be seen in the comparison of the trend lines of the "A", "B" and "C" rating subsamples. It is also appreciable in the trend lines of most of the subsamples crossing the $x = y$ line, with the first part being on the "conservative" side and the second part on the "cheating" side. This point, as well as the previous one, questions the effectiveness of the EPC selection system established in the Basque Country and elsewhere in Europe.
- Among the 6 classifications of subsamples investigated, classification 2 (classification by QEs) is the one that most determines the differences between subsamples. In addition, the subsamples also present errors both under and over the results provided by the rest of the analyzed subsamples in the other classifications. Criteria for selecting EPCs to control based on QEs exist in many MSs and this analysis demonstrates that it can be an effective way to identify the most inaccurate EPCs.
- Other subsamples with relevant errors are: all tertiary buildings, existing buildings, or EPCs calculated by Ce3x software and single-family housing.

5.6. Referred Appendices

The Appendix related to this Chapter is:

- Appendix B. Catalog of nonconformities.

6 Qualitative and Quantitative analysis of nonconformities

6.1. Introduction

This is the last chapter tackling the analysis of the monitored EPC control results of the sample. In this case, all NCs issued in non-compliance reports are examined and through this analysis two issues identified in the literature review are dealt with, as in the previous chapters.

The state of the art has identified that one of the aspects to be developed in control systems, in general, is the monitoring of the NCs issued in EPC controls (see Section 1.9.). In addition, the QualdeEPC project [29] has established some priorities in order to improve independent control systems of which the first priority is to report NCs and create statistics of common mistakes.

Besides, Chapter 4 has shown that there is a problem in the quality of the EPCs, that it is necessary to continue with their verification and that one of the possible actions to improve quality could be aimed at increasing the number of EPCs checked. To this end, it is necessary to optimize the control check methodology. Nevertheless, the effectiveness of different procedures and measures implemented in other independent control systems is unknown (See Section 1.9.).

The need to solve these two problems gives rise to the research questions in this chapter:

- What are the common mistakes in EPCs and why do they happen?
    - In what technical area do they occur (building model definition, constructive definition, others)?
    - Which could be the QE's motivation to commit errors?
    - What type of errors are detected (lack of input data, software inconsistencies...)?
- What is the optimal and most suitable way to check the definition of a building in an EPC?
    - Are automatic checks methodology effective enough in order to substitute the current methodology stablished in LCCE?
    - Is it possible to discriminate some checks to simplify the current point-by-point methodology?
    - How effective are the building *in-situ* checks?

In order to answer these questions, an exhaustive analysis of detected NCs is performed. In this way, we have tried to know the types of NCs, what underlies these NCs and what the most appropriate and optimal ways to identify them are. Responses have been measured according to their importance or weight in the resulting sampling error.

6.2. Methodology

In this chapter, a qualitative, quantitative and mixed analysis [64] of registered NCs during the sample EPCs control process has been carried out in order to answer the questions stated at the beginning of this study.

For this aim, a specific methodology for this chapter is employed. Before starting the qualitative and quantitative analysis, it has been catalogued all the NCs recorded in the 146 sample control file (CF). This cataloguing is based on an iterative process, where the types of NCs that group more specific NCs are formed as they are collected. The following Table 6.1 shows an example. The final catalogue of NCs is listed in Appendix B.

Table 6.1. Example of the creation of a catalogued NC.

EPC CF Code	*Recorded NC*	*Catalogued NC*
RN057F	*Correct the definition of the type of insulation from mineral wool to extruded polystyrene as verified on site*	*NC.3.11. Correct the type of the thermal insulation*
RN102P	*Correct the definition of the type of insulation from extruded polystyrene to expanded polystyrene as defined in the project*	

Once the NCs have been catalogued, the methodology of this chapter is divided into three consecutive parts to arrive at the responses according to their weight in the sampling error. It is explained in the following subsections:

1. Qualitative Analysis of NCs.
2. Quantitative Analysis of NCs.
3. Mixed research of NCs: Quantifying the Qualitative Results

6.2.1 Qualitative Analysis

The first step is the performance of the qualitative investigation. It is a methodology oriented to pose questions that help us to understand the phenomenon. That is why, in this study, it is employed to understand why, where and how NCs occur, i.e., to discover what underlies the results in NCs.

Qualitative analysis involves organizing the qualitative information available to draw conclusions, and in this work, this is carried out in 3 phases: categorization, organization of data in a matrix, and finally, qualitative data analysis.

Categorization

The categorization is intended to answer the nonquantifiable questions raised at the beginning of the study (see Section 6.1.): Why do errors occur in EPCs that lead to NCs? What are the most suitable and optimal ways to detect errors?

In qualitative analysis, these questions are the rules of categorization and, in this study, the categories emerge from these questions and reflections as possible answers in each NC.

Therefore, once the categorization rules have been established, then the categories have been generated. Obtaining relevant categories, as well as cataloguing NCs, is not a linear process, but rather it is an iterative and gradually refining process. Once the NCs have been analyzed, new categories are added and then fragmented, grouped, discarded, etc. until the final categorization is reached. The final categorization used in the following phases is as follows (Table 6.2 to Table 6.6):

Table 6.2. Rules and codes for the Categorization Rule 1.

Categorization rule	Category code	Category
Q1. In which section of the EPC the error occurs?	Q1a.	General and administrative data definition
	Q1b.	Building geometric model definition
	Q1c.	Envelope constructive definition
	Q1d.	Thermal bridges definition
	Q1e.	DHW and heating and cooling systems definition
	Q1f.	Ventilation system definition
	Q1g.	Photovoltaic system definition
	Q1h.	Lighting system definition

Table 6.3. Rules and codes for the Categorization Rule 2.

Categorization rule	Category code	Category
Q2. Of which type is the error?	Q2a.	Out-of-range input data (when there is a requirement for correction).
	Q2b.	Lack of data in EPC (when it is necessary to define in the calculation software and it has not been defined).
	Q2c.	Building definition inconsistency in the calculation software
	Q2d.	Divergence between EPC definition and data collected from documents (project, "end of work" documents, technical data sheets, etc.), visits to the building or calculations performed by controllers.
	Q2e.	Lack of contrasting information (strange values, absence of calculation, inconsistencies among different contrasting information, etc.). In the case of strange values, these would be possible values, but optimistic values.
	Q2f.	Noncompliance with regulation

Table 6.4. Rules and codes for the Categorization Rule 3.

Categorization rule	Category code	Category
Q3. Which is apparently the QE's motivation for making an error?	Q3a.	Lack of knowledge of concepts in general and of the EPC calculation software.
	Q3b.	Lapse of concentration.
	Q3c.	Lack of accuracy in EPC definition, in project definition, in the exchange of information between the project/construction management and the QE, etc.
	Q3d.	Of a deliberate nature (either cheating or conservative deliberation).

Table 6.5. Rules and codes for the Categorization Rule 4.

Categorization rule	Category code	Category
Q4. Of how much is the priority in the detection of the requirement?	Q4a.	1st priority. Additional information is required. Therefore, it does not make any sense start with the control procedure since in the future, when all information is available, it could lead to more NCs.
	Q4b.	2nd priority. Complete correction of the EPC is required. Thus, it does not make any sense to continue with the more detailed aspects in the EPC definition since they must be evaluated again in the corrected version.
	Q4c.	3rd priority. When partial correction of EPC is required (a complete Section of the EPC) or when the correction affects to other EPC definitions as well. In these cases, it does not make any sense continue with the affected input data evaluation since they can be modified in the next EPC version.
	Q4d.	4th priority. Modification of an input data is required.
	Q4e.	5th priority. No correction is required, it is an observation.

Table 6.6. Rules and codes for the Categorization Rule 5.

Categorization rule	Category code	Category
Q5. What possible forms of detection can be used for each NC?	Q5a.	Identification of the error by means of the input data automatic check.
	Q5b.	Partial error identification by the input data automatic error check (alarm for strange values).
	Q5c.	By review of the methodology and configuration used to define the building.
	Q5d.	By contrast to documentary data without a visit to the building.
	Q5e.	Data contrast through visits to the building during the works is needed apart from the contrast of documentary data.
	Q5f.	Data contrast through visits to the building at the end of the works is needed apart from the contrast to documentary data.

Obtaining the matrix of qualitative data

In this phase, in addition to the categorization rules and categories, the units of NCs come into play. Each question is applied to each NC previously catalogued so that depending on the response each unit is placed in one or more categories within each rule. These responses are recorded in the form of a matrix. (see Table 6.7).

Table 6.7. Matrix to record the qualitative data.

	Q1				Q2				…			Qn			
	Q1a	Q1b	…	Q1z	Q2a	Q2b	…	Q2z	…	…	…	Qna	Qnb	…	Qnz
NC_1		▪				▪					▪			▪	
NC_2				▪				▪	▪	▪			▪		
….			▪				▪				▪	▪			▪
NC_m											▪			▪	

The information to obtain the qualitative data is collected from the history of each CF —review of documents and review of registered e-mails—. The answers to questions Q1, Q2, Q4 and Q5 are wholly objective. However, answers to questions Q3 may become more subjective, since the researcher's observation becomes relevant.

Qualitative data analysis: Identification of possible links between categories

Once the complete matrix was available, links between the results of the categories of Q2, Q3 and Q4 with the categories of Q5 were looked for by Sankey diagrams, so that it could be analyzed whether there is a connection between the underlying characteristic of the NC and the way of detecting these errors.

6.2.2 Quantitative Analysis

Once the qualitative analysis is completed, it is proceed with the quantitative analysis of the NCs in order to quantify the incidence of each NC in the computation of the sampling error.

Frequency of occurrence of each NC

First, through the review of the noncompliance reports, information has been extracted on the files in which each NC is given. These data have been recorded in a quantitative data matrix (see Eq. 6.1) so that it is possible to measure the frequency of occurrence of each NC.

	CF_1	CF_2	CF_3	...	CF_n	Y_m
NC_1	Y_{11}	Y_{12}	Y_{13}	...	Y_{1n}	$\sum_{i=1}^{n} Y_{1i}$
NC_2	Y_{21}	Y_{22}	Y_{23}	...	Y_{2n}	$\sum_{i=1}^{n} Y_{2i}$
...	...	...	...	...	...	...
NC_m	Y_{m1}	Y_{m2}	Y_{m3}	...	Y_{mn}	$\sum_{i=1}^{n} Y_{mi}$

Eq. 6.1

where,
NC_m: **Nonconformity** m
CF_n: **EPC Control File** n
Y_{mn}: **Frequency of occurrence of NC** m **in EPC CF** n.
Y_m: **Frequency of occurrence of NC** m.

Average incidence of each NC in the outcomes of an EPC

Subsequently, the average incidence that each NC has on the outcomes of an EPC —both in nrPEC and CO_2 emissions— has been calculated.

The same procedure was followed for each NC. At least 3 and a maximum of 10 EPCs containing the NC under calculation have been taken. The correction has been applied to the selected EPCs and the relative error of this modification has been calculated for each EPC in nrPEC and CO_2 emissions. There are some NCs that are repeated <3 times. In these NCs, one or more other EPCs (up to a minimum of 3) have been randomly selected and the modification that the NC entails in this EPC has been calculated. Once the minimum number of data has been obtained, the arithmetic means of the relative errors are calculated in both, nrPEC and CO_2 emissions (see Eq. 6.2).

	CF_1	CF_2	CF_3	...	CF_n	K_m
NC_1	$\lvert K_{11} \rvert$	...	$\lvert K_{13} \rvert$	...	$\lvert K_{1n} \rvert$	$\frac{\sum_{i=1}^{n} \lvert K_{1i} \rvert}{n}$
NC_2	...	$\lvert K_{22} \rvert$	...	...	$\lvert K_{2n} \rvert$	$\frac{\sum_{i=1}^{n} \lvert K_{2i} \rvert}{n}$
...	...	...	...	...	...	...
NC_m	...	$\lvert K_{m2} \rvert$	$\lvert K_{m3} \rvert$	...	$\lvert K_{mn} \rvert$	$\frac{\sum_{i=1}^{n} \lvert K_{mi} \rvert}{n}$

Eq. 6.2

where,
NC_m: **Nonconformity unit** m
CF_n: **EPC Control File** n
K_{mn}: **Incidence in Relative Error of NC** m **for EPC CF** n **(nrPEC or** CO_2 **emissions).**
K_m: **Average incidence mean in Relative Error of each NC** m

Weight of each NC in the sampling error computation

The incidence and frequency of each NC both affect the computation of the sampling error. Accordingly, a factor β is proposed, which represents the weight of each NC in the computation of the sampling error and considers both the effect of the average incidence of each NC and its frequency (see Eq. 6.3).

$$\beta_m = \frac{(K_{nrPEC,m} \times Y_m + K_{CO2,m} \times Y_m)}{2} \quad \textbf{Eq. 6.3}$$

where,
β_m: **Weight of each NC m in the sampling error computation**
$K_{nrPEC,m}$: **Average incidence in nrPEC relative error of NC m**
$K_{CO2,m}$: **Average incidence in CO_2 emissions relative error of NC m**
Y_m: **Frecuency of occurrence of NC m**

6.2.3 Mixed research: Quantifying the Qualitative Results

With the qualitative and quantitative analysis completed, with the mixed research is proceed. In this phase, the qualitative data is transformed through the quantitative data obtained in the previous phase. This phase is a weighting of qualitative research. In this way it is possible to conclude the weight or importance of each category analyzed in the sampling error.

This weighting is carried out in two ways: by taking into account only the frequency of each NC as well as by means of the β factor calculated in the previous phase. The first is denominated Weighting 1 (see Eq. 6.4) and the second Weighting 2 (see Eq. 6.5).

Weighting 1

	Q1				…			Qn			
	Q1a	Q1b	…	Q1z	…	…	…	Qna	Qnb	…	Qnz
NC_1		$Y_{NC1,Q1b}$					…	$Y_{NC1,Qna}$		…	
NC_2				$Y_{NC2,Q1z}$	…	…			$Y_{NC2,Qnb}$		
….			…				…	…			
NC_m	$Y_{NCm,Q1a}$	$Y_{NCm,Q1b}$	…	$Y_{NCm,Q1z}$	…	…	…	$Y_{NCm,Qna}$	$Y_{NCm,Qnb}$	…	$Y_{NCm,Qnz}$
	$\sum Y_{Q1a,i}$	$\sum Y_{Q1b,i}$		$\sum Y_{Q1z,i}$	…	…	…	$\sum Y_{Qna,i}$	$\sum Y_{Qnb,i}$		$\sum Y_{Qnz,i}$

Eq. 6.4

where,

$Y_{NCm,Qnz}$: **Frequency of occurrence of NC m and which corresponds to category Q nz.**

Weighting 2

	Q1				…			Qn			
	Q1a	Q1b	…	Q1z	…	…	…	Qna	Qnb	…	Qnz
NC_1		$\beta_{NC1,Q1b}$					·	$\beta_{NC1,Qna}$		…	
NC_2				$\beta_{NC2,Q1z}$	·	·			$\beta_{NC2,Qnb}$		
….			…				·	…			
NC_m	$\beta_{NCm,Q1a}$	$\beta_{NCm,Q1b}$	…	$\beta_{NCm,Q1z}$			·	$\beta_{NCm,Qna}$	$\beta_{NCm,Qnb}$	…	$\beta_{NCm,Qnz}$
	$\sum \beta_{Q1a,i}$	$\sum \beta_{Q1b,i}$		$\sum \beta_{Q1z,i}$				$\sum \beta_{Qna,i}$	$\sum \beta_{Qnb,i}$		$\sum \beta_{Qnz,i}$

Eq. 6.5

where,

$\beta_{NCm,Qnz}$: **The weight of each NC_m in the sampling error computation and which corresponds to category Q_{nz}.**

6.3. Results

The presentation of the results also reflects the structure of the followed methodology steps.

6.3.1 Qualitative results

The following two subsections show the results of the qualitative research.

Following the methodology described in the previous sections, the Qualitative data matrix has been obtained, which can be found in Table C.1. in Appendix C. The Sankey diagrams in Figure 6.1, Figure 6.2, and Figure 6.3 have been obtained from their values. The mentioned Sankey diagrams show how and how many times the categories corresponding to the categorization rules Q2-Q5, Q3-Q5 and Q4-Q5 are related to each other. In other words, how many NCs correspond to both a category corresponding to one categorization rule and another category of another categorization rule. If a consolidated coincidence between categories is observed, it can be deduced that there is a relationship between them.

The Q1-Q5 relationship has not been analyzed, since the Q1 rule differentiates the categories by technical areas and each technical area comprises NCs of all types. At a glance at the matrix, it is already clear that there is no strong relationship between categories.

As the objective is to detect strong relationships, connections that only occur $<1\%$ of the total number of connections have been excluded. In this way, it is intended to obtain a clearer and more visual diagram.

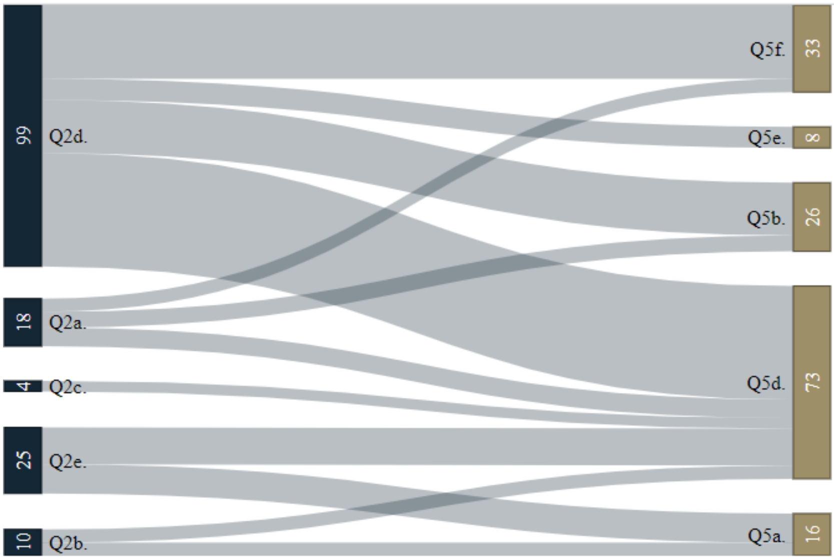


Figure 6.1. Relationships between the categories corresponding to rules Q2 and Q5.

Figure 6.1 displays the connections between the categories corresponding to rules Q2 and Q5. It can be seen that most connections happen between the categories Q2d —divergence between EPC definition and available contrasting data— and Q5d —by contrast to documentary data without on-site inspection—. In fact, 43 types of NCs corresponding to Q2d types can be detected by documentary contrast and the other 36 types of NCs by on-site inspections in addition to documentary contrast (Q5f+Q5e).

Another reading, regarding the Q2d category, is that through document review, EPC review and building visits, all types of NCs can be found, but only 25% of them can be partially identified, in the form of alarms for outliers, through the automatic check.

Another aspect to highlight is that the types of NCs catalogued that correspond to the Q2c category— building definition inconsistency in the calculation software—, though they are few in number, can only be detected through Q5d —by contrast to documentary data without on-site inspection—.

Finally, NCs of type Q2e —lack of contrasting information— can be detected by either Q5d —by contrast to documentary data without on-site inspection— or Q5a —identification of the error by means of the input data automatic check—.

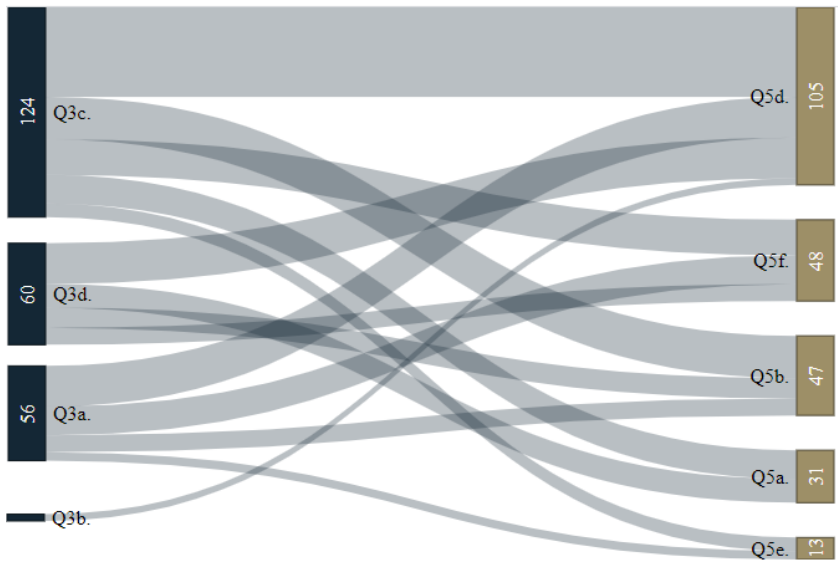


Figure 6.2. Relationships between the categories corresponding to rules Q3 and Q5.

In Figure 6.2, in general, it can be appreciated that the connections between categories are more multiple than in the previous diagram (see Figure 6.1). The diagram points out that the most repeated connection is between the type of NCs which are due to the category Q3c — lack of accuracy in EPC definition, in project definition, in the exchange of information between the project/construction management and the QE, etc— and the way of detection Q5d —by documentary contrast—. This is the only solid correlation that can be noticed in Figure 6.2.

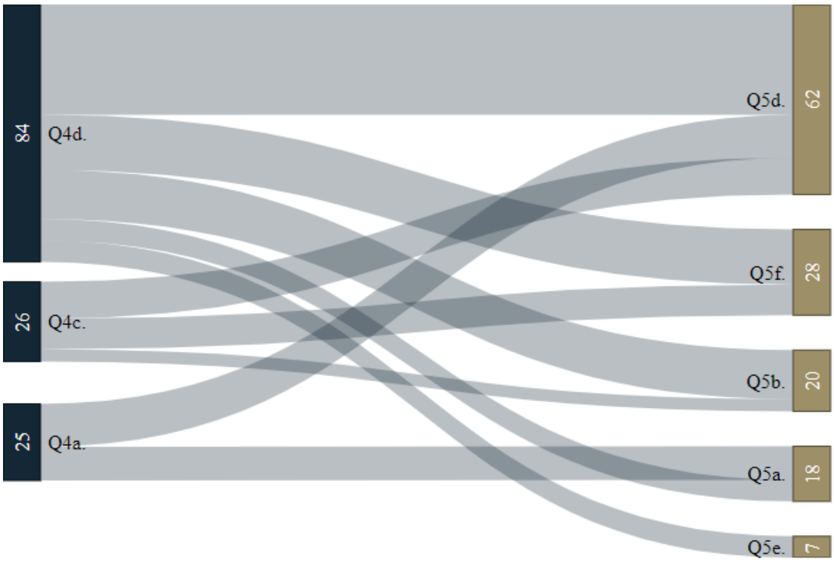


Figure 6.3. Relationships between the categories corresponding to rules Q4 and Q5.

Figure 6.3 presents the matches that occur between Q4 and Q5. The category with the most relationships, both in number and variety, is the Q4d. This category includes those types of NC of 4th priority, i.e, the requirements of input data modification. The 43% of the connections happen with the Q5d detection way —by contrast of documentary data without on-site inspection— and 30% with detection forms based on building visits (Q5e+ Q5f). The connections between Q4d and automatic checks ways (Q5a + Q5b) are less. They only represent 27% of the relationships.

Besides, there is another aspect to highlight. The type of NCs which correspond to the category Q4a —requirement of additional information of 1st priority— can be identified either by an automatic check or by documentary review, since they present approximately the same grade of connections. Therefore, both options are equally valid, but the first option has the advantage of requiring fewer human or time resources.

To conclude with the analysis of Figure 6.3, it should be noted that the types of NCs involving partial correction of the EPC, Q4c, are connected to the way of automatic partial detection, Q5b, in only 18% of all the relationships in this category. Furthermore, there is no connection with the way of full identification by means of the automatic check, Q5a.

Hence, as a summary of the analysis of these three diagrams, Table 6.8 shows the 10 strongest relationships, in descending order, found between categories of Q2, Q3 and Q4 with those of Q5.

Table 6.8. The 10 strongest relationships found between categories in descendent order.

Category of rule Q2, Q3 or Q4 (NC character)	Category of rule Q5 (way of detection)
Q3c. Lack of accuracy in EPC definition, in project definition, in the exchange of information between the project/construction management and the QE, etc.	Q5d. By contrast to documentary data without a visit to the building.
Q2d. Divergence between EPC definition and data collected from documents, visits to the building or calculations performed by controllers.	Q5d. By contrast to documentary data without a visit to the building.
Q4d. 4th priority. Modification of an input data is required.	Q5d. By contrast to documentary data without a visit to the building.
Q2d. Divergence between EPC definition and data collected from documents, visits to the building or calculations performed by controllers.	Q5f. Data contrast through visits to the building at the end of the works is needed apart from the contrast of documentary data.
Q3c. Lack of accuracy in EPC definition, in project definition, in the exchange of information between the project/construction management and the QE, etc.	Q5b. Partial error identification by the input data automatic error check (alarm for strange values).
Q3d. Of a deliberate nature (either cheating or conservative deliberation)	Q5d. By contrast to documentary data without a visit to the building.
Q3a. Lack of knowledge of concepts in general and of the EPC calculation software.	Q5d. By contrast to documentary data without a visit to the building.is not needed.
Q3c. Lack of accuracy in EPC definition, in project definition, in the exchange of information between the project/construction management and the QE, etc.	Q5f. Data contrast through visits to the building at the end of the works is needed apart from the contrast of documentary data.
Q2d. Divergence between EPC definition and data collected from documents, visits to the building or calculations performed by controllers.	Q5b. Partial error identification by the input data automatic error check (alarm for strange values).
Q4d. 4th priority. Modification of an input data is required.	Q5f. Data contrast through visits to the building at the end of the works is needed apart from the contrast of documentary data.

6.3.2 Quantitative results

As explained in the methodology (Section 6.2), after qualitative analysis, it is proceed with quantitative analysis. The results in this section are analyzed in 3 consecutive subsections: frequency of occurrence of each NC, average incidence of each NC in the outcomes of an EPC and the weight of each NC in the sampling error computation. All the raw data obtained in this phase are displayed in Table C-2. in Appendix C.

Frequency of occurrence of each NC

The first step of quantitative analysis has been to quantify the frequency of occurrence of each NC type. 2 of the NC types only occur in one EPC, otherwise the NC found in most EPCs was in 37 EPCs. In total, 645 NCs of 73 types were identified.

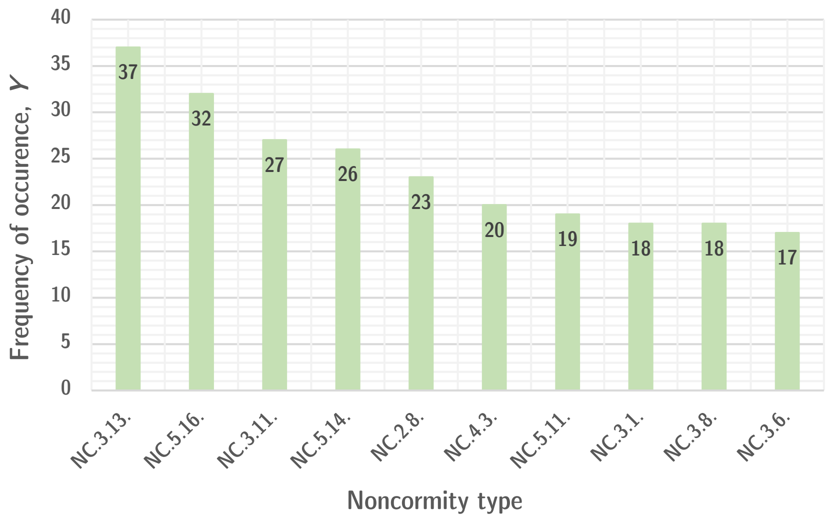


Figure 6.4. The 10 most repeated NCs.

Table 6.9. Description of the 10 most repeated NCs.

NC.3.13.	Correct the thermal insulation thickness.
NC.5.16.	Correct the equipment efficiency.
NC.3.11.	Correct the type of thermal insulation.
NC.5.14.	Correct the power of equipment.
NC.2.8.	Define the building surrounding shadows and shading elements in windows.
NC.4.3.	Correct the length of the thermal bridge.
NC.5.11.	Correct the storage capacity of the DHW (storage tank or electric boiler).
NC.3.1.	Correct the percentage of the frame with respect to the total area of the window.
NC.3.8.	Correct the type of constructive element (from facade to dividing wall...).
NC.3.6.	Justify the thermal characteristics of the glass or frame and the air permeability.

Figure 6.4 puts the 10 most repeated NCs on display which are detailed below in Table 6.9. Half of them are related to the constructive elements description, 3 of them to conditioning and DHW systems, 1

to geometric building model definition, and the other one to thermal bridges.

Average incidence of each NC in the outcomes of an EPC

Once the frequency of occurrence of each NC type is calculated, the calculations have been continued with the average incidence of each NC in the outcomes of an EPC, both in nrPEC and CO_2 emissions (see Section 6.2.2).

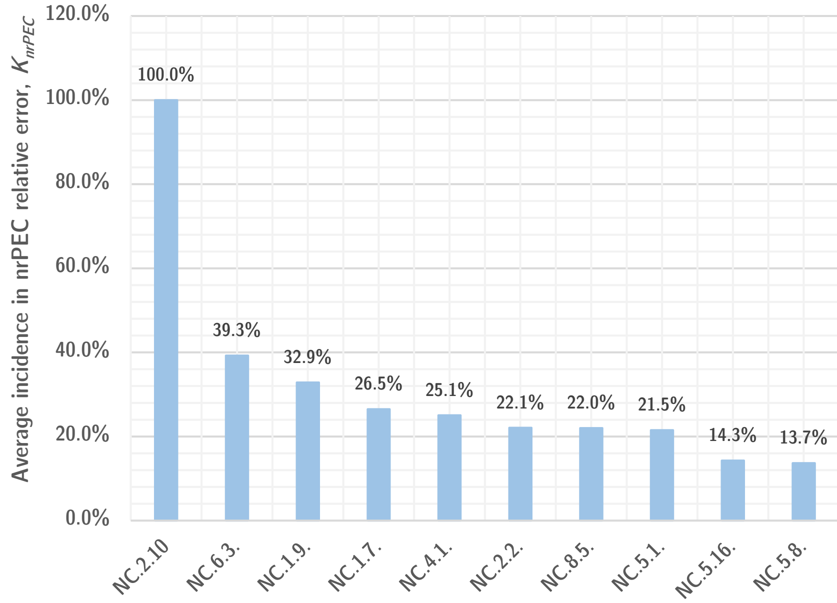


Figure 6.5. The 10 NCs with the highest average incidence in the outcome in the nrPEC of an EPC.

Table 6.10. Description of the 10 NCs with the highest average incidence in the nrPEC outcome of an EPC.

NC.2.10.	The software cannot carry out the calculation because of errors in the building model.
NC.6.3.	Define mechanical ventilation with heat recovery systems (MVHRS).
NC.1.9.	Correct the definition of the type of building in terms of its use (residential/service building) or age (existing/new construction building).
NC.1.7.	Correct the climate zone definition.
NC.4.1.	Define thermal bridges.
NC.2.2.	Correct the building model geometry definition- thermal zones floor areas.
NC.8.5.	Define the lighting systems in one or more conditioned thermal zones.
NC.5.1.	Correct the general definition of the system configuration- the type of system.
NC.5.16.	Correct the equipment efficiency.
NC.5.8.	Correct the percentage of renewable coverage in DHW.

Figure 6.5 shows the average incidence in the nrPEC outcome of an EPC of the 10 NCs with the highest values. These mentioned NCs are described in Table 6.10.

In the same way, the average incidence of each NC in the CO_2 emissions outcome is also calculated. The results are shown in the following Figure 6.6 and Table 6.11.

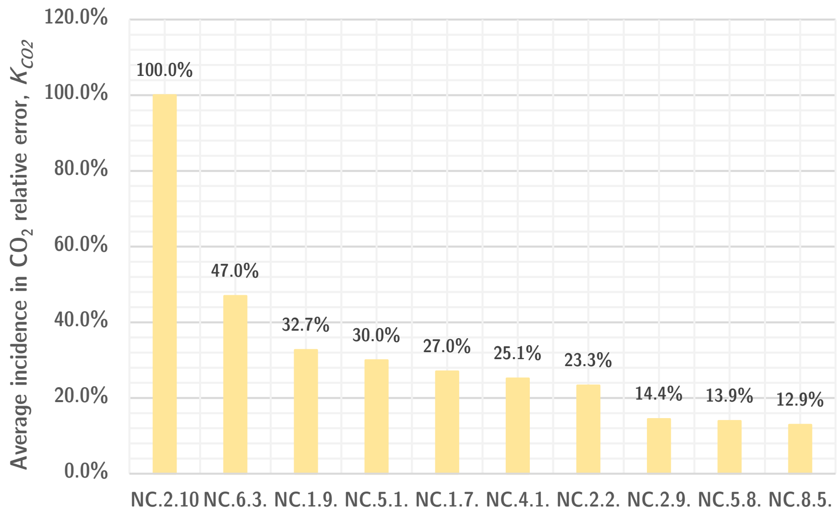


Figure 6.6. The 10 NCs with the highest average incidence in the CO_2 emissions outcome of an EPC.

Table 6.11. Description of the 10 NCs with the highest average incidence in the CO_2 emissions outcome of an EPC.

NC.2.10.	The software cannot carry out the calculation because of errors in the building model.
NC.6.3.	Define mechanical ventilation with heat recovery systems (MVHRS).
NC.1.9.	Correct the definition of the type of building in terms of its use (residential/service building) or age (existing/new construction building).
NC.5.1.	Correct the general definition of the system configuration- the type of the system.
NC.1.7.	Correct the climate zone definition.
NC.4.1.	Define thermal bridges.
NC.2.2.	Correct the building model geometry definition- thermal zones floor areas.
NC.2.9.	Correct the type of thermal zone definition: conditioned/not conditioned and habitable/non-habitable.
NC.5.8.	Correct the percentage of renewable coverage in DHW.
NC.8.5.	Define the lighting systems in one or more conditioned thermal zones.

From the results obtained in these first two subsections, it is worth noting that among the 10 NCs that occur in most EPCs and the 10 with the highest incidence in nrPEC and CO_2 emissions, there is only one coincidence. This is the case of NC 5.16. which can be found both among the top 10 in the frequency of occurrence (see Table 6.9 and Figure 6.4) and also among the top 10 in average incidence in the outcome in the nrPEC of an EPC (see Table 6.10 and Figure 6.5). Nevertheless, it is not among the top 10 in average incidence in the CO_2 emissions. (see Table 6.11 and Figure 6.6). Consequently, the most frequently repeated errors, in general, are not the errors that most affect the final result of the EPC.

On the other hand, the results obtained in the average incidence in nrPEC and CO2 emissions are similar. The same NCs can be found in both results, with a slight variation in the order of the NCs. Only one difference has been found: In the top 10 of the CO_2 emissions results is the NC.2.9. (see Table 6.11) which is not listed in the nrPEC results. Otherwise, as noted in the previous paragraph, NC.5.16. is in the top 10 of the nrPEC results (see Table 6.10) and not in the list of CO_2 emissions results (see Table 6.11). In addition, the values obtained, measured in relative error are also similar in both in nrPEC and CO_2 emissions (see Figure 6.5 and Figure 6.6).

Weight of each NC in the sampling error computation

This subsection presents the results obtained from the weight of each NC in the sampling error computation which integrates into a variable the number of occurrences and the average incidence in nrPEC and CO_2 emissions (see Eq. 6.3 in Section 6.2.2). The results are given in the same form as in the previous subsections (see Figure 6.7 and Table 6.12).

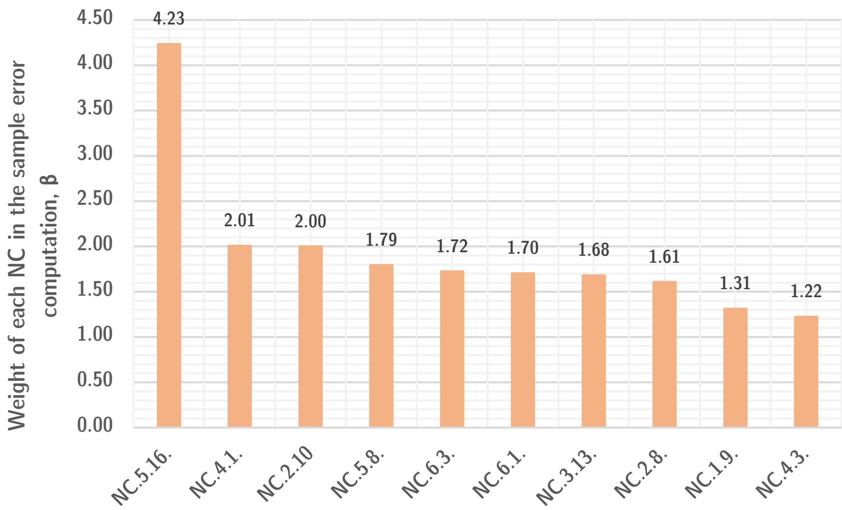


Figure 6.7. The 10 NCs with the highest weight in the sampling error computation.

Table 6.12. Description of the 10 NCs with the highest weight in the sampling error computation.

NC.5.16.	**Correct the equipment efficiency.**
NC.4.1.	**Define thermal bridges.**
NC.2.10.	**The software cannot carry out the calculation because of errors in the building model.**
NC.5.8.	**Correct the percentage of renewable coverage in DHW.**
NC.6.3.	**Define mechanical ventilation with heat recovery systems (MVHRS).**
NC.6.1.	**Correct the defined value of the air change rate of the mechanical ventilation.**
NC.3.13.	**Correct the thermal insulation thickness.**
NC.2.8.	**Define the building surrounding shadows and shading elements in windows.**
NC.1.9.	**Correct the definition of the type of building in terms of its use (residential/service building) or age (existing/new construction building).**
NC.4.3.	**Correct the length of the thermal bridge.**

Figure 6.7 points out the weight in the sampling error of the 10 NC with the highest values. NC.5.16., at the top of the list, stands out considerably from the other NCs. It has a weight greater than two times that of the preceding NC.4.1. Among the remaining 9 NCs, differences are not as evident as in the first two NCs.

Moreover, only one out of 10 NCs on the list has not appeared in the results of either of the two previous subsections: the NC.6.1. (see Table 6.9, Table 6.10 and Table 6.11). Apart from it, the rest of the NCs listed in Table 6.12 can be found in the top ten of the frequency of occurrence (see Table 6.9) or average incidence (see Table 6.10 and Table 6.11).

6.3.3 Mixed research: Quantifying the Qualitative Results

As indicated in the section on methodology (Section 6.2), once the qualitative and quantitative results are achieved, the qualitative ones are weighted through the quantitative data in this phase which is denominated mixed research.

The weighting 1 and 2 results are obtained by data matrix (see Eq. 6.4 and Eq. 6.5). The data collected in these matrices are presented in Table C.3. and C.4. in Appendix C. In addition, the final results are organized by categorization rules including the weighting 1 and 2 results in each one.

Q1 categories

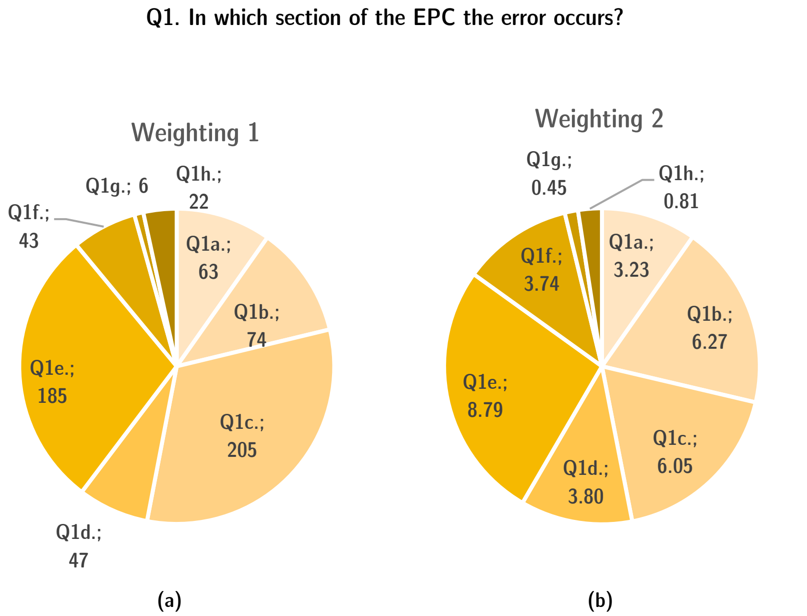


Figure 6.8. Mixed analysis results for Q1 categories. (a) Weighting 1 based on NCs frequency of occurrence values, *Y*, and (b) Weighting 2 based on the NCs weight in the sampling error computation, β.

Figure 6.8 displays the weight of Q1 categories in the whole sampling error. The two previous graphs indicate that the NCs and their weight in the sampling error are not concentrated mainly in one category. The number of NCs and, in particular, the weight in the sampling error is fairly evenly distributed among categories.

Even then, the categories with the greatest number of NCs and the highest weight in the sampling error computation are the categories Q1e —DHW and heating and cooling systems—, Q1c —envelope constructive definition— and Q1b —Building geometric model definition—. Among the three categories, the Q1c category is worth mentioning. Although in the weighting 1 graph it is the category with the largest fraction, when weighted by its weight in the resulting error of the sample, this fraction is considerably reduced. The opposite is true for Q1b. In addition, while Q1e approximately maintains its proportion in both graphs, the second graph reports that it is the category that has the greatest weight in the resulting sampling error.

Q1a NCs correspond to those occurring in the general and administrative data definition section. Despite having a similar proportion in the graph in both weightings, in the second weighting it loses positions with respect to the first weighting, and therefore loses relevance in the second graph. This is because this section includes some errors, such as building identification data, certifier data, etc. that do not affect the final result. Even though they do not affect the outcome of the EPC, they are necessary data to record the EPC, and therefore, as important as the rest of the input data of the EPC.

In addition, categories Q1f and Q1d group together the NCs occurring in the ventilation systems and thermal bridges sections in the corresponding order. In terms of the number of NCs, these are not the categories that stand out the most; however, their weight in the sampling error is considerable. NCs in these sections of the EPC greatly affect the outcome of the EPC.

Finally, Q1g —photovoltaic system definition— and Q1h —lighting system definition— are the categories with fewer repetitions and with less weight in the resulting sampling error. This is because these are errors that cannot occur in all EPCs, as they are definitions that only occur in tertiary buildings and in the case of Photovoltaic Systems no in all tertiary buildings.

Q2 categories

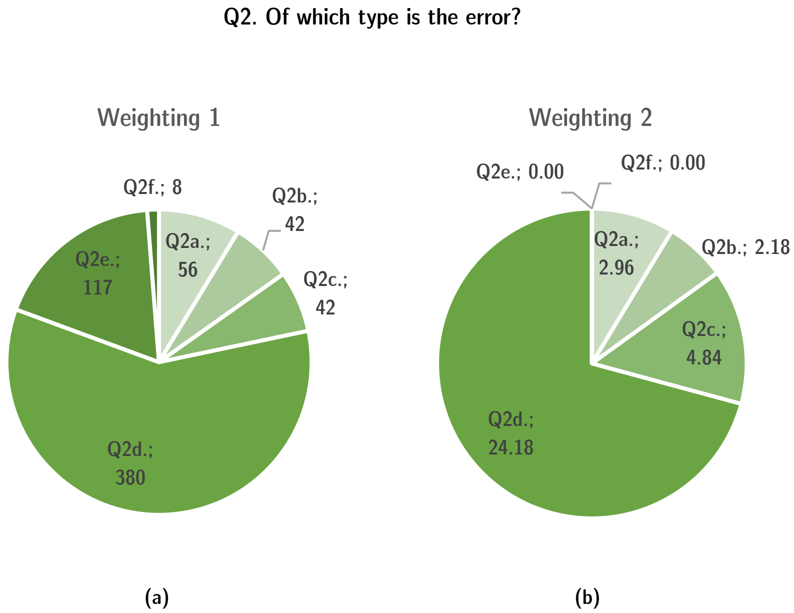


Figure 6.9. Mixed analysis results for Q2 categories. (a) Weighting 1 based on NCs frequency of occurrence values, *Y*, and (b) Weighting 2 based on the NCs weight in the sampling error computation, β.

Figure 6.9 shows the pertinence of Q2 categories in the whole sampling error. It shows that among all the categories there is one that stands out in both graphs; it is the Q2d category that integrates those NCs that are due to divergences between EPC definition and data collected from documents (project, "end of work" documents, technical datasheets, etc.), visits to the building or calculations performed by controllers. Moreover, its relevance is even greater in Weighting 2 due to the high incidence of NCs of this category in EPC outcomes.

The second most relevant category in weighting 1 is Q2e —lack of contrasting information—. Nevertheless, when weighted by its weight in the sampling error computation, it disappears from the graph, since the incidence of NCs corresponding to this category is null. This case is similar to category Q1a in the previous analysis. Although it is composed of NCs with zero incidences, they are NCs that must be required and corrected in order to continue with the control process. The same happens with category Q2f —Noncompliance with regulation—. The control agent cannot require its correction, since it does not fall within the competence of the control activity, but is obliged to notify in the control report in the form of observation.

Another category with moderate significance in both weighting 1 and weighting 2 is Q2c —Building definition inconsistency in the calculation software—. Nonetheless, it should be noted that it includes NCs with a high incidence since in weighting 2 it takes on greater importance with respect to the rest of the categories than in the first weighting.

Finally, the most relevant categories in the 3rd and 4th position are Q2a— out-of-range input data— and Q2b — lack of data in EPC—. I only have to mention that they maintain approximately the same proportion in the two graphs.

Q3 Categories

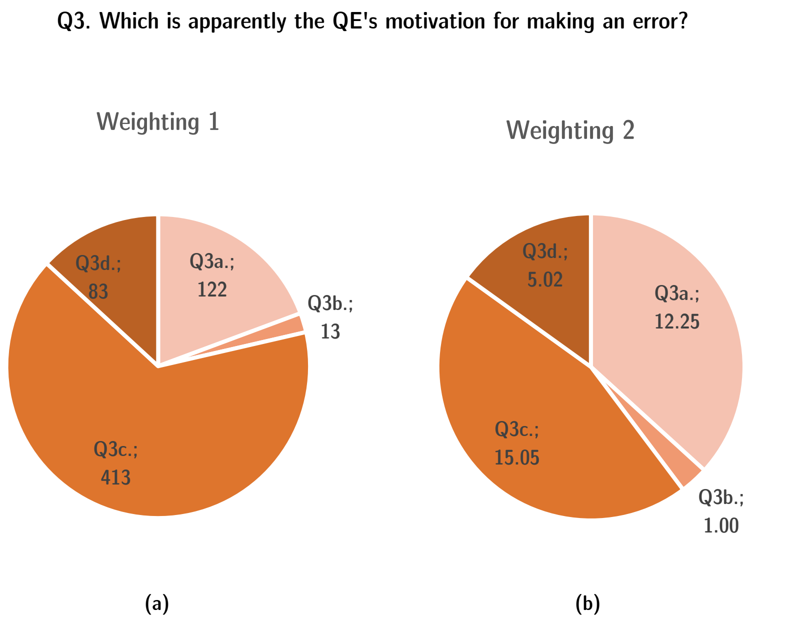


Figure 6.10. Mixed analysis results for Q3 categories. (a) Weighting 1 based on NCs frequency of occurrence values, *Y*, and (b) Weighting 2 based on the NCs weight in the sampling error computation, β.

Figure 6.10 demonstrates the relevance of Q3 categories in the whole sampling error. The two graphs in Figure 6.10 illustrate the same order of relevance of categories. The most prominent category is Q3c — lack of accuracy in EPC definition, in project definition, in the exchange of information between the project/construction management and the QE, etc— and is preceded in the following order by Q3a —lack of knowledge of concepts in general and of the EPC calculation software—, Q3d —of a deliberate nature— and, lastly, Q3b —lapse of concentration—.

The first graph weighting 1 displays that more than half of the NCs are due to lack of accuracy. However, taking into account its weight in the resulting error of the sample, its relevance is reduced with respect to the rest of the categories, although it continues on leading the list. The opposite is true for NCs due to a lack of knowledge of concepts in general and of the EPC calculation software. They are significantly less than in the first category, but the weight in the resulting error in the sample is close to that of Q1a. Thus, these are the two main aspects to take into account in this categorization, since NCs that have a deliberate nature, Q3d, or are committed by lapse of concentration, Q3b, together comprise only 15% and 18% of the graphs in the corresponding order.

Q4 Categories

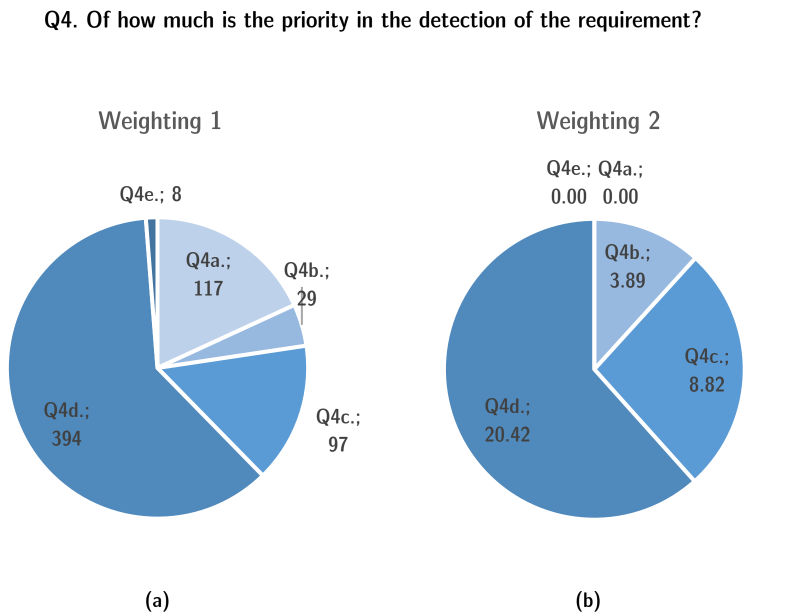


Figure 6.11. Mixed analysis results for Q4 categories. (a) Weighting 1 based on NCs frequency of occurrence values, Y, and (b) Weighting 2 based on the NCs weight in the sampling error computation, β.

Figure 6.11 reveals the importance of Q4 categories in the whole sampling error. In this categorization there is a distinguished category which is Q4d —4th priority NCs which require a modification of inputs data—.

There are other two categories with a significant number of NCs, however as their incidence in EPC results is null, their values in weighting 2 also are nulls. They are Q4a —1^{st} priority NCs which require additional information— and Q4e —5^{th} priority NCs which do not require correction, they are observations—. Though these NCs do not affect the final error, they cannot be ignored. NCs corresponding to Q4a, being 1st priority, although they do not directly modify the final result, in the future, when they are answered, they may lead to other NCs. Additionally, NCs belonging to category Q4e, although they cannot be required to be corrected by the control agent, the agent is obliged to report them in the control report in the form of observation.

In addition, with respect to category Q4b, despite the fact that it does not present a very significant number of NCs, they are of second priority and their relevance increases with respect to the rest of the categories in weighting 2.

Hence, it is observed that the weight of categories Q4a to Q4d in the resulting sampling error is inverse to their order of priority. The first priority is the least weighted and the fourth priority are the most weighted.

Q5 Categories

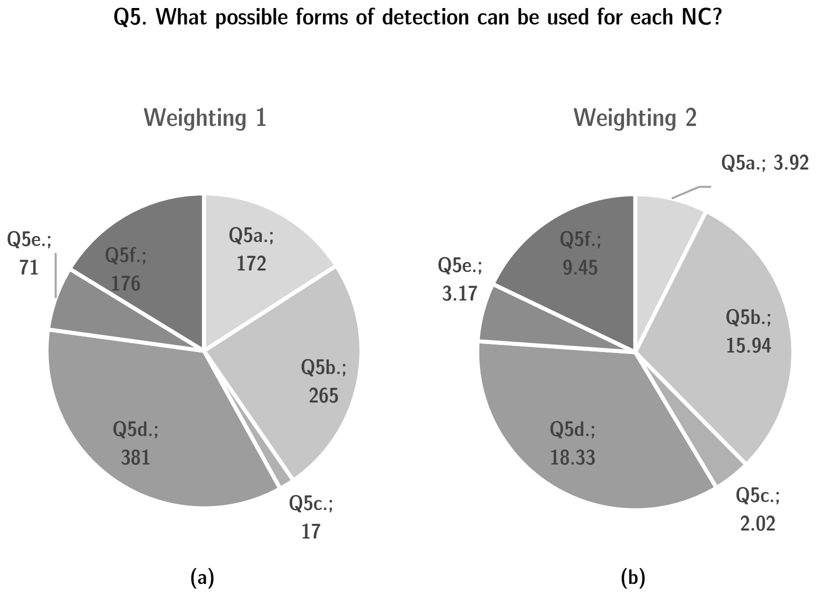


Figure 6.12. Mixed analysis results for Q5 categories. (a) Weighting 1 based on NCs frequency of occurrence values, *Y,* and (b) Weighting 2 based on the NCs weight in the sampling error computation, β.

Figure 6.12 displays the relevance of Q5 categories in the whole sampling error. At first glance and in comparison with Q2, Q3 and Q4 categories, it can be seen that in this case there is no category that stands out from the others. The weight among categories is more evenly distributed. This proves that there is no one way of detecting errors that stands out from the others in terms of its error detection capacity.

Q5d —by contrast to documentary data without a visit to the building— and Q5b —partial error identification by the input data automatic error check— are the two categories with the highest error detection capacity in terms of both number and weight of NCs.

Q5b together with Q5a —identification of the error by means of the input data automatic check— are the two forms of automatic checking. Q5b is only able to detect illogical values, which does not directly mean that they are incorrect. Or else, it may not detect non-real input data because it is within a reasonable range. Consequently, although it is able to check many types of NCs whose weight is significant in the final error count, it cannot replace with the same efficiency other forms of detection. In contrast, Q5a is able to detect NCs with the same result as other identification forms. This category is able to review a significant number of NCs, however, its ability to detect errors in the final computation of the sample is reduced as shown in graph (b) weighting 2. This is because most of the NCs that are placed in this category are also placed in categories Q4a and Q2e (see Section 6.3.1). Considering that putting together the ways of detecting Q5c, Q5d, Q5e and Q5f can detect all types of NCs as done in sample control during the period 2014-2019, it can be said that Q5a alone is able to detect 12% of the total error in the sample and Q5b has the potential to generate an alarm on NCs that can generate 48% of the sampling error.

Finally, it should be noted that categories Q5f and Q5e, which correspond to the ways of detecting NCs in the building *in-situ*, present approximately the same proportion in both graphs. They are capable of detecting approximately 25% of the NCs, both in number and weight in the resulting sampling error. If they are compared between them, in the visit carried out at the end of the building, more NCs are detected, both in number and in their resulting weight, than in the first two visits carried out during the execution of the works.

6.4. Discussion

6.4.1 Investigating the reasons for nonconformities

The main nonconformities performance causes

One of the premises set out at the beginning of the study is to understand the reasons for the errors that weigh most heavily on the final result of the sample, in particular how they happen and what may be the main reason for the QE to make these mistakes. The categorization rules focused on finding the answer have been Q2 and Q3.

The interpretation of the results in this sense is quite obvious since in the mixed analysis of the Q2 and Q3 categories there are two categories that stand out above the others.

- Q2d. Divergences between EPC definition and data collected from documents (project, "end of work" documents, technical datasheets, etc.), visits to the building or calculations performed by controllers.
- Q3c. Lack of accuracy in EPC definition, in project definition, in the exchange of information between the project/construction management and the QE, etc.

The evidence suggests that the two categories have a conclusive relationship, i.e., that Q2d may be the consequence of Q3c. Then the real problem is the lack of precision in different essential instruments of the project:

- Lack of specification of passive and active thermal performance of the building in the execution project.
- Simplifications and data omissions in the EPC.
- Communication failures in the exchange of information between different project/work agents.

Among the apparent reasons for QE in the second order is the lack of knowledge of concepts in general and the EPC calculation software (Q3a). It should be recalled that one of the results obtained in chapter 4 suggested this motive. And the fact that the errors are mostly deliberate with intent to cheat or be conservative (Q3d) can be ruled out since their weight in the sampling error is 3 times less than the first motive Q3c and twice less the second motive Q3a (see Figure 6.10).

Future role of BIM in EPC quality

As can be seen in the previous subsection, the results prove that the category Q3c —Lack of accuracy in EPC definition, in project definition, in the exchange of information between the project/construction management and the QE, etc— is the main reason to happen errors in EPCs.

At present, in general, the QE is not the same person who drafts a building. In consequence, the procedure of defining an EPC involves some inconveniences leading to errors of Q3c category in EPCs:

- The Project does not define all the sufficient data that are necessary to define and justify the inputs data of an EPC and therefore default values or invented in EPCs are adopted.
- It is not only necessary to define the building model characteristics in different programs according to the purpose of the calculation, but also they usually are defined by different technicians.
- Lack of interoperability between different software used in a building project definition.
- An exchange of data between the person or group drafting the project and the QE is necessary.
- Time-consuming for the QE to collect the data necessary to define the EPC in detail. This time is not usually compensated by the market price of the service.

Hope is pinned on the full implementation of BIM which is an instrument with a huge potential advantage in order to solve the aforementioned problems and to thus avoid mistakes of the Q3c type. Data access for defining buildings in EPC calculation software could be different since a fully develop building model would contain all data, interoperability between different software would be possible, BIM objects should be able to provide information about all product characteristics, BIM models of existing buildings would provide data of hidden elements in the buildings such as insulations, etc.

Therefore, the theoretical potential of BIM to improve the EPC quality is considerable and everything indicates that it will be a line to be taken into account in future research in the field of EPC and its quality.

6.4.2 Optimizing the control methodology

The rest of the questions stated in the introduction are oriented to get results in order to optimize the control methodology. This section interprets these results.

The most optimal error detection methodology

The analysis of question Q5 seeks to know the form of error detection most capable of detecting NCs with greater frequency and with greater impact on the outcome of the EPCs.

Figure 6.12 reveals that there is no methodology that stands out from the rest since the weight among categories is quite evenly distributed. Accordingly, it is not sufficient to establish a single way of detecting NCs in the control protocol.

In order to find the best combination, the forms of control that show the best results in terms of detection capacity of both number and weight of NCs are as follows:

- Q5d. By contrast to documentary data without a visit to the building.
- Q5b. Partial error identification by the input data automatic error check.

Furthermore, focusing on the intermediate results obtained in the qualitative analysis, it is noticed that Q5d is the option that presents the strongest relationships with other categories, being the main form of detection of NCs corresponding to categories Q3c, Q2d, Q4d, Q3d, and Q3a. This already gives us signs of the potential of the Q5d form of detection.

The second option Q5b is part of an automatic check methodology and is discussed in the next section.

Effectiveness of automatic check

Automatic check is a widespread methodology in control systems established in MSs and regions of Europe, although it has not yet been implemented in the Basque Country. Additionally, in Chapter 4 and 5 it has been shown that it is a methodology that has the potential to improve the control system. For all these reasons, this option has been considered and its effectiveness has been studied.

As seen in the previous sections, there are two forms of automatic check: Q5a —identification of the error by means of the input data automatic check— and Q5b —partial error identification by the input data automatic error check— and, as such, have been studied independently.

The error detection form Q5a is able to detect NCs with the same result as other identification forms. It identifies the incorrect input data with absolute certainty.

As results in mixed research proved, Q5a alone is able to detect 12% of the total error in the sample. Therefore it is not enough to substitute the conventional procedures established nowadays in LCCE (Q5c, Q5d, Q5e and Q5f). However, as can be seen in intermediate results of qualitative analysis, this error detection form is able to substitute the Q5d form in certain types of NCs:

- NCs which correspond to category Q2e —lack of contrasting information—.

- NCs which correspond to category Q4a —requirement of additional information of 1st priority—.

In these mentioned two groups, both options, Q5a and Q5b, are equally valid, but the form of the automatic checks form, Q5a, has the advantage of requiring fewer human and time resources.

In contrast, the partial identification by automatic checks form, Q5b, is able to revise a higher number of NCs with higher incidence in the sampling error, but it is only able to detect illogical values, which does not directly mean that they are always incorrect ones. Or else, it may not detect non-real input data because it is within a reasonable range. This means that its function could not be to replace with the same efficiency other forms of detection, but it can generate alarms that make the controller or the QE to review the input data that generated the alarm.

The results in mixed research have shown (see Figure 6.12) that this detection form has the potential to identify alarms on NCs that can reach 48% of the sampling error.

The qualitative results anticipated that this methodology could detect alarms in 25% of the NC types corresponding to the Q2d category and in 27% of the NC types belonging to the Q4d category. Nevertheless, as seen in the previous section, after weighting the qualitative results by the frequency and weight in the sampling error of each NC type, the results are more favorable for this type of procedure.

This means that not only it could be a helpful control instrument in combination with other control procedures, but it can also be an error filtering instrument in order to reduce a part of the errors in each EPC.

Optimization through check discrimination

Another question raised in the introduction was whether there is a possibility of optimizing the methodology through the discrimination of certain specific checks in the current point-by-point methodology established in the LCCE protocol. Is it necessary to control 100% of the EPC data? This subsection interprets the results obtained to answer this question.

If we look at the results obtained in the mixed research Q1 categories (see Figure 6.8), one can see that the errors are not concentrated in one or a few sections of the EPC definition. The weight in the sampling error is fairly evenly distributed among categories, being two categories with little weight in the final tally. Nevertheless, this is because these NCs cannot occur in most EPCs. The definition of the lighting system, Q1h, is only performed in tertiary buildings, which total 58 EPCs (see Figure 3.7) and of these 58 EPCs, 22 have been found to have an NC. In the case of the photovoltaic definition, the percentage of NC is higher. There are only 7 buildings with a photovoltaic system (see Table 3.6) and 6 of them have an NC. Accordingly, it can be said that no section can be discriminated, when checking the definition of an EPC.

On the other hand, through the mixed research results, it has been seen that there are NCs categories with a null weight in the computation of the sampling error. These categories are as follows:

- Q2e. Lack of contrasting information.
- Q2f. Noncompliance with regulation.
- Q4a. 1st priority NCs which require additional information.
- Q4e. 5th priority NCs which do not require correction; they include only observations.
- Several NCs correspond to the Q1a category.

Although the type of NCs placed in Q2e and Q4a categories have zero incidences, they are NCs that must be required and corrected in order to continue with the control process, as when they are answered they may lead to other NCs. Hence, they cannot be ignored during the control process.

In the case of Q2f and Q4e the control agent makes an observation, not a requirement. Nevertheless, it is mandatory to include the observation in the report. Thus, they are not groups that can be omitted even if their incidence is zero.

The scenario is similar for a large part of the Q1a category. This category integrates those NCs that occur in the general and administrative data definition section. Data in the EPC such as building identification data, certifier data, etc. frequently are not defined or are defined incorrectly. They do not affect the outcome of an EPC, but they are necessary data to register the EPC in the Basque Country database, and therefore, as important as the rest of the input data of the EPC.

Moreover, the Q4 categorization allows analyzing NCs according to their priority in an evaluation process. The detection of a first priority NC makes it meaningless to continue with lower priority checks, since the correction of a first priority NC may modify the rest of the lower priority data. This classification raises the question of the order in which NCs should be checked and the possibility of discriminating checks of NC types from the last priorities. Nonetheless, Figure 6.11 demonstrates that the weight of categories Q4a to Q4e in the resulting sampling error is inverse to their order of priority. NCs of first priority are the least weighted and of fourth priority are the most weighted by far. Consequently, the control procedure cannot be limited to the checking of first priority groups while discriminating completely the checks of fourth priority NCs.

As a result, if the discrimination of some types of NCs is wished, it cannot be done by categories, but only by particular NCs that are not integrated into any of the mentioned categories and in such a way that the sum of their average incidences in the EPC outcomes is less than 5%, so that the resulting error of an EPC is within the reference tolerance proposed by the EU Commission (see Section 1.5.8). All the incidences calculated and presented in Table C-2 in Appendix C could be used for this purpose.

Building in-situ checks

The control protocol established by the LCCE includes 3 visits to the building in the case of NBB- EPC, or 2 visits to perform the thermal resistance measurement test in the case of completed works or EB-EPC. The check carried out in this test is the equivalent of the first two visits made during the construction work, which is when the building's constructive characteristics are checked. Hence, NCs that are detected in these two ways (by testing or on the two on-site visits) are included in category Q5e and the rest of the checks that are performed in the building are included in category Q5f.

According to the results presented in Figure 6.12, Q5e and Q5f categories, both together, are capable of detecting approximately 25% of the NCs in both, number and weight in the resulting sampling error. But in the first two visits or through the thermal resistance measurement test, only the identification of 10% of the NCs in both, number and weight in the resulting sampling error is solved.

As such, Q5e is one of the forms of error detection with the least ability to influence the resulting sampling error. However, it is probably the most resource-intensive instrument, because it requires:

- continuous follow-up of the building works to know at any time at which stage the work is in progress.
- increased communication with site agents.
- 2 trips to the construction site.
- In case it is necessary, following the criteria of the protocol established in the LCCE, the performance of the thermal resistance measurement test, which implies a considerable increase in cost for the control applicant.

6.5. Conclusions

In this chapter, NCs issued during the sample EPC control process have been analyzed in order to obtain key factors to improve EPC checking procedures.

At first, NCs recorded in the studied EPC sample have been catalogued and are provided in Appendix B. In the subsequent analysis, the most frequent NCs and those having the greatest impact on the final result of the EPC have been reported. The reporting could be useful in order to improve the technician's knowledge, as well as being one of the means to achieve the objectives of this chapter.

The available qualitative data of NCs is organized and analyzed. Then, the quantitative data about NCs is obtained and it is also analyzed. Finally, putting together the two previous phase results, the qualitative attributes of NCs have been quantified in terms of their frequency of occurrence and their weight in the sampling error resultant.

Interpretation of the intermediate results (first two investigation phases) and the final results (the last investigation phase) has allowed for answering the research questions stated at the start of the studio in order to explain the underlying of the NCs and conclude some guidance to optimize the error detection procedures. As a result, the followings are the main conclusions of this chapter:

- NCs mainly happen because the QEs fail in getting accurate data from the project definition, from information exchange with project/construction management agents, etc. as well as because EPCs are sometimes not defined in sufficient detail. In consequence, the main type of NCs found in the analysis are divergences between EPC definition and data collected by the controller from documents, building or calculations performed by itself. The solution for this type of NCs may be directly related to the expected future full implementation of BIM.

- There is not a single detection form that is able to detect most part of the NC types. A combination of different checking procedures is needed to get an effective control methodology.
- The checking procedures which present the best results in terms of their detection capacity in both, number and weight of NCs, are Q5d —by contrast to documentary data without a visit to the building— and Q5b —partial error identification by the input data automatic error check—.
- The automatic check methodologies (Q5a+ Q5b) are not enough to completely substitute the procedures which are established nowadays in LCCE (Q5c+ Q5d+Q5e+Q5f). Q5a is capable of detecting 12% of the sampling error and Q5b has the potential to identify extraneous data, which is likely to be incorrect but not guaranteed to be incorrect, and therefore, may represent between 0-48% of the sampling error. Consequently, even though the automatic check does not prove to be sufficiently effective as a single form of detection, it can be an error filtering instrument in order to reduce a part of the errors in each EPC and effective in combination with other procedures.
- The automatic check methodology Q5a can substitute Q5d form NC types corresponding to Q2e —lack of contrasting information— and Q4a —requirement of additional information of 1st priority—.
- The simplification of the current procedure reducing the number of checks should not be done in discriminating the NC types which correspond to categories Q2e, Q2f, Q4a, Q4e and Q1a. Although their incidence is null, the checking of these NCs is essential. The only way to reduce the number of NC checks is to discriminate those NCs whose average occurrences do not add up to 5% so as the relative error deviation of an EPC will be within the range ±5% proposed tolerance by the EU Commission.
- The building *in-situ* checks (Q5e+ Q5f) are the ones with the least ability to influence the resulting sampling error. Furthermore, the comparison of the results presented by both

categories has shown that Q5f is capable of detecting 1.5 times the number of NC types and errors in the sample of the Q5e. However, Q5e currently is performed by two visits during the construction works or *in-situ* thermal resistance measurement test and Q5f by one visit at the end of the works. Q5e is the most resource-intensive instrument not only comparing with Q5f but also with the rest of the error detection methodologies.

6.6. Referred Appendices

The Appendices related to this Chapter are:

- Appendix B. Catalog of nonconformities.
- Appendix C. Results of nonconformities analysis. Data table.

7 Proposed control methodology improvements

7.1. Introduction

As seen in the literature review (see Section 1.8), improving the quality of the EPC system should be a continuous-iterative process [30] and every continuous improvement process requires monitoring of the quality of the scheme, which is not a common practice in control schemes throughout Europe (see Section 1.5.7). The improvements should be driven by the conclusions obtained from the feedback of the monitorization results in EPC schemes.

The methodology structure of this thesis is based on this continuous-iterative process as described in Section 2.3 (see Figure 2.1). Chapter 3 described the control campaign in the Basque Country in the period 2014-2019 and the sample of EPCs base for this thesis. Chapters 4, 5, 6 are the monitoring of the results obtained with the system used in the control campaign, and the conclusions obtained in these three chapters are the learning experience that is intended to guide the improvements in the Control Scheme of the Basque Country. Accordingly, as a consequence of the work done in the previous chapters, Chapter 7 proposes improvements in the control system and control check procedures, thus closing the first cycle of the continuous-iterative process. It should be made clear that the proposed methodology should also be adapted and improved based on its results in the future, following the principle of continuous improvement.

7.2. Objectives for proposing improvements in control methodology

The objective of this chapter is to propose improvements in the control procedure based on the conclusions obtained in the previous chapters. The conclusions of Chapter 4 provided the general approach that the EPC control scheme should have. The conclusions of Chapter 5 contributed guidance to follow when establishing the criteria for selecting the EPCs to be controlled. And finally, the analysis in Chapter 6 provided guidelines for defining the most efficient possible methodology for checking. Consequently, following these conclusions, this section states the objectives that should be met by the control scheme (see Table 7.1).

Table 7.1. List of conclusions from chapters 4, 5 and 6 related to the proposed objectives to improve the control scheme.

Conclusions of the previous chapters		Objectives to improve the control system and control procedures
Chapter 4	Increase the number of controlled EPCs.	- To develop an automatic checks procedure that is able to revise the 100% of EPC. - New targeted selection criteria that reach a higher percentage of EPCs to be checked by means of point-by-point documentary and *in-situ* checks. - To optimize the accredited body's control procedure so that they can achieve a greater number of controlled EPCs.
Chapter 4	One of the control objectives should be to improve the knowledge of the technicians through control.	- To allow the option to review, correct or justify to the QE the results obtained in an automatic check before the EPC is sent to register.
Chapter 4& 6	A combination of different checking procedures is needed to get an effective control methodology	- To combine the automatic checks procedure and point-by-point methodology based on documental and *in-situ* verifications.
Chapter 6	Even though the automatic check does not prove to be sufficiently effective as a single form of detection, it can be an error filtering instrument in order to reduce a part of the error in each EPC and effective in combination with other procedures.	
Chapter 6	The checking procedures which present the best results in terms of their detection capacity in both, number and weight of NCs are Q5d —by the contrast of documentary data without a visit to the building— and Q5b —partial error identification by the input data automatic error check—	
Chapter 5	The most selective criterion for detecting groups of EPCs with greater errors is based on the activity of the QEs, but in addition, there are specific groups with considerable errors: tertiary buildings, existing buildings and single-family homes. In general, the higher the consumption, the more errors are found.	- To develop a selection criterion combining the filtering of EPCs by means of an automatic check applicable to 100% of EPCs (based on the detection of bad practices of the QEs) with a targeted criterion that establishes the obligation to pass the check with control by an Accredited Agent or, when applicable, by the energy department, for some types of EPCs.
Chapter 6	Although the incidence of NCs categorized in Q2e, Q2f, Q4a and Q4f are null, the checking of these NCs is essential	- To add a preventive phase to avoid the occurrence of NCs corresponding to categories Q2e and Q4a. Q2f and Q4f categories have been already solved

Conclusions of the previous chapters			Objectives to improve the control system and control procedures
			with the checks of the last update of HULC software.
Chapter 6	The main reason for NCs happening is the fails in lack of accuracy in project definition, information exchange with project/construction management agents or in EPC input data definition.	-	To implement a measure that obliges QEs or designers to define and calculate all EPC input data (in absence of the full implementation of BIM).
Chapter 6	There are NCs with different priorities according to their level of correction requirement -Q4 categorization-.	-	To put an order in the checks of the possible NCs in practice according to the priority of each one of them
Chapter 6	The *in-situ* check way Q5e is the one with the least capability to influence on the resulting sample error even if it may be the most resource-intensive instrument	-	To determine a criterion for assessing whether to carry out the thermal resistance measurement test in case visual checks of the insulation could not be made during its execution.

7.3. Control methodology scheme proposal

The objectives set out in the previous section are materialized in a proposal consisting of 3 main phases during the registration of the EPC: the preventive phase where it is requested to attach supporting documentation of the input data; phase of selection of EPCs to be controlled by an accredited body or, when applicable, energy department; and finally, the phase of control procedure carried out by the controller (see Figure 7.1).

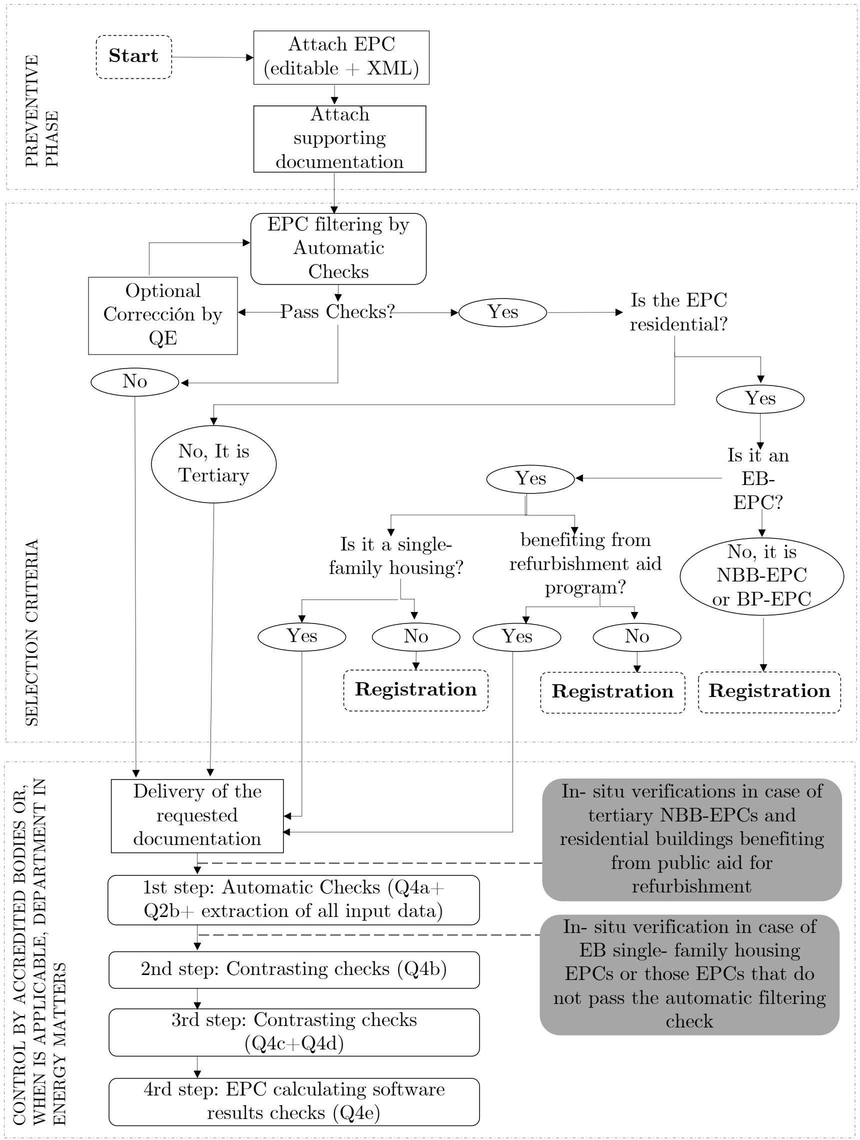


Figure 7.1. Outline of the proposed procedure: preventive phase, selection criteria and control check procedure.

7.3.1 Attach input data supporting documents

In the cataloguing of NCs, it has been seen that some of them, even if they have a null incidence, are necessary to continue with the verification procedure, such as those corresponding to the categories defined in the previous chapter Q2e —lack of contrasting information— and Q4a —additional information is required, NCs of 1st priority—. In order to avoid this type of NCs, it is proposed to establish a preventive measure at the beginning of the registration, which consists of attaching specific documentation that justifies the input data defined in the EPC.

This measure has two advantages. On the one hand, having this documentation available at any time during the procedure allows for a continuous check without having to stop the procedure due to lack of information and restart it later. On the other hand, it implies that the QE will perform more precise calculations instead of adopting default or undefined values, as well as will have a more exhaustive control of the real features that have been executed on site. Hence, it can help reduce errors categorized as Q3c —lack of accuracy in EPC definition, in project definition, in the exchange of information between the project/construction management and the QE, etc— which is the main reason for NCs.

Table 7.2 lists the NCs corresponding to categories Q2e and Q4a with the specific documents proposed to be requested.

Table 7.2. Supporting documents to be submitted and related NCs catalog.

Supporting Document to be submitted	Related NC
Declaration of Performance (DdP) or UNE-EN ISO 12567-1:2011 test result for windows.	NC.3.6.
Constructive definition of layers in all the defined type of envelopes and constructive sections of the project or end of work documentation.	NC.3.14.
Manufacturer's DdP or UNE-EN 12667:2002 thermal conductivity test of the insulation type in case of BP-EPC or NBB-EPC.	NC.3.15.
Supporting calculations of the linear thermal transmittance values of the thermal bridges in case they have been defined by *user-defined values.*	NC.4.4.
Calculation of DHW renewable coverage in the case of an aerothermal heat pump.	NC.5.6.
Justifying calculation of DHW renewable coverage in case a solar thermal panel system is available.	NC.5.7.
Supporting calculation of DHW demand.	NC.5.9.
Technical data sheets for heating, cooling and DHW generation equipment	NC.5.17.
Calculation of the air renewal flow according to CTE DBHS3 or RITE in case the certified building was built after 2006	NC.6.2.
ErP datasheet for mechanical ventilation equipment	NC.6.5.
Calculation of electricity production and self-consumption (monthly balance sheet) in photovoltaic systems.	NC.7.1.
Lighting calculation (installed power and VEEI) for each zone defined in the EPC (applicable only in tertiary buildings).	NC.8.2.
Data and calculation of the installed electrical power for the entire certified unit (applicable only in tertiary buildings).	NC.8.6.

CTE: Spanish Technical Building Code (for its acronym in Spanish); DBHS: Basic Document on Salubrity; DdP: Declaration of Performance; ErP: Energy Related Products Directive: RITE: Regulations of Thermal Installations in Buildings (for its acronym in Spanish); VEEI: Energy efficiency value of an installation (for its acronym in Spanish)

In addition to the documents mentioned in the table, one more supporting document related to a new item in the latest version of the regulation is added. The latest version of the technical code [65], and consequently, the latest version of HULC [66] also introduces a new input data to define the targeted building or dwelling: air permeability of the envelope, n50 [ACH]. Up to this moment, no NC has been found related to this input data since EPCs in the sample correspond to buildings and dwellings constructed based on the previous regulations.

There are two options for defining this parameter in the new HULC 2019, either by default or by test value. The default value is calculated by the EPC calculation program itself and, therefore, it is not considered necessary to require its justification. Nevertheless, if defined by test value, it is proposed to require the test report performed according to method B of UNE-EN 13829:2002 *Determination of air permeability of buildings. Fan pressurization method* [67] together with the documents listed in Table 7.2.

7.3.2 Selection criteria

In Chapter 5, conclusions were drawn to help determine the selection criteria in order to detect the EPCs with the greatest errors. It is a selection criterion so that the selected EPCs are controlled in as much detail as possible. Summarizing the conclusions of chapter 5, these are some criteria to follow when establishing the selection criteria:

- The higher the rating and the lower the consumption, the better the outcome accuracy of EPCs. Therefore, the criterion should not be aimed at detecting EPCs with the best rating.
- The suitable system for detecting EPC groups with higher and lower error is one based on the activity of the QEs. There are different selection criteria based on the activity of QEs (see Section 5.4.2), but filtering by automatic checks is the most complete way to select QEs (see Section 5.4.2).
- Other groups with relevant errors are tertiary buildings, existing buildings and single-family houses.

Following these orientations, this chapter proposes the implementation of a combined selection criterion (see Figure 7.1). First, all EPCs are filtered by automatic checks. Those that do not successfully pass the filtering process will go directly to a more exhaustive control by means of the controller. All tertiary buildings, even if they meet the filtering stage, will undergo the control procedure by an accredited body or the department in energy. Among the residential buildings that overcome the first screening, on the other hand, only BP-EPC, NBB-EPC, existing residential buildings in residential blocks may be registered directly, provided that they are not registered in any public aid program for renovation. The rest of the residential buildings will have to be checked more exhaustively by an accredited body or, if the case may be, by the department in charge of energy matters.

Through this way of selecting EPCs, it is estimated that at least around 20% of EPCs will have to undergo a control by an accredited body or, if applicable, by the energy department. This estimate has been made using data from the EPC registers of recent years provided by the Department of Economic Development, Sustainability and Environment and statistical data from EUSTAT [68].

This type of filtering, in addition to having a selective function, is also part of the EPC control procedure since this system improves the quality of EPCs. EPCs that do not pass the first automatic-check have the option to review and correct NCs and alarms generated in this check. This initiative is intended to respond to one of the main theses concluded in Chapter 4, which states that one of the objectives of control should be to improve the knowledge of technicians through the control procedure. This measure is intended to make QE more involved in the correction process and improve its training during these reviews. In addition, EPCs that pass the filtering after the review but are obliged to pass the control through the controller, thanks to this system will be received by the controller with fewer errors. If recalling the results of Chapter 6, the error reduction can be as much as 48%.

7.3.3 Control check procedure

Once the selection criteria defined in the previous section have been applied, those selected will proceed to the next phase, which consists of a more exhaustive control process with the accredited body or, if applicable, with the energy department.

The reference procedure is the control that is currently applied to all new buildings with a nrPEC energy rating of A, B or C by an accredited body and to existing residential buildings with the same rating by the department of energy, as determined by the regulation [26]. The proposal made in this section is based on improvements to the referral system and the protocol that we have been applying in the LCCE, which is a procedure based on point-by-point documentary check and *in-situ* inspections.

Before starting the procedure, together with the acceptance of the work, the EPC submitter must provide the controller with the documentation requested as it is done in the currently implemented scheme, in addition to the documentation provided that should have already been attached at the beginning of the registration.

In the protocol applied for the EPC evaluation procedure so far, no order of checks has been defined. However, in chapter 6, it was seen that there are NCs with different priorities depending on their level of correction requirements. For example, the correction of a first priority NC may lead to a second, third or fourth priority NC. Therefore, it makes no sense to review possible NCs of subsequent priorities before correcting the NCs found of higher priority. In view of this, a check order is proposed as a protocol improvement (see Figure 7.1). As a general rule in the protocol, the impossibility of continuing with the control until the QE makes the modifications in each phase should be established and a statement of this procedure should be made prior to the acceptance of the work by the applicant. In the event that one or more NCs exist between different phases, it is proposed to issue partial reports to require their correction.

Stage 1 will be carried out by means of automatic checking. The first priority NCs —category Q4a NCs— and the missing data to be defined in the EPC —category Q2b NCs— will be verified. An extraction of all the EPC data contained in the EPC XML file will be performed, instead of doing it data by data manually as it has been done so far. This data extraction will be used for the verification of possible Q4a NCs. Specifically, it will be verified if there are thermal bridges defined by user values, if there is a renewable contribution in DHW and of what type, which is the generation equipment defined in the EPC, which are the values of air renewal flow rate, in constructions after 2006 which is the ventilation equipment and if there is photovoltaic energy production. In these mentioned cases, documentation should have been attached in the preventive phase of the registration (see Section 7.2.1). Therefore it shall be checked that all the necessary calculations are available to continue with the control. The verification of possible NCs corresponding to category Q2b is detailed in Section 7.4.2.

In the second stage, possible NCs corresponding to the second priority category Q4b will be reviewed. These possible NCs can be verified by reviewing the building configuration defined in the EPC and contrasting general plans (floor plans, elevations and sections) of the project or end of construction document in case of new buildings, as well as by collecting data on the building configuration *in-situ* in existing buildings, in addition to the documentation provided by the QE.

In the third stage, possible third priority —Q4c category— and fourth priority —Q4d category— NCs will be verified. Before this phase, all the necessary data had to be collected *in-situ* in case of NBB-EPC or EB-EPC, and with all the available data all the point-by-point verifications are performed in the LCCE.

Finally, once all the corrections have been made, before issuing the final favorable report, a check will be made to ensure that there is no NC of 5th priority —category Q4e—. In chapter 6 it was seen that the possible NCs corresponding to this category can be detected by means of the automatic check; however, this is an aspect that has been solved by the latest version of the HULC software, since when calculating the building, it verifies all the requirements of the latest version of the CTE DB HE 2019 standard.

On-site checks in the building

The way of selecting EPCs to be checked by documentary verifications and on-site inspections (see Section 7.3.2) and the order of checks proposed in this section may alter the way and timing of building visits and checks. Nowadays, the regulation [26] obliges the applicant of the finished building control to contract the work sufficiently in advance to the construction of those elements associated with the result of the qualification obtained, for their control and verification on site by the controller. With the proposal of Section 7.3.2, this obligation can continue to be applied in new tertiary buildings and in existing residential buildings that benefit from public aid for their renovation, since in these cases, even if they pass the automatic check filtering without NCs or alarms, it is proposed that they must be checked by an accredited body or, where appropriate, by the department responsible for energy matters. Nonetheless, NBB-EPCs that are selected from the automatic check filtering will reach the hands of the controller once the works are completed, since the registration will be initiated with the end of works documentation. In these cases, the first two site visits to verify the insulation visually, as has been done up to now, will not be possible.

Thus, in the case of new tertiary buildings and existing residential buildings benefiting from public subsidies for renovation, three visits will be made —two for insulation checks and one at the end of the works— as currently determined by the protocol established in the LCCE (see Section 3.2.2). These visits will take place prior to the first phase of check-ups.

In existing single-family residential buildings and those completed residential new construction EPCs that reach the controller by screening the automatic check, it is proposed to set criteria to assess whether the thermal resistance measurement test [56] really be worth it. In the previous chapter, it was shown that *in-situ* verifications of the thermal performance of the envelope, being one of the most resource-consuming forms of verification, is one of the least capable of detecting errors in the computation of the sample. Furthermore, it is estimated that this may be the case in at least 7% of the registered EPCs, which makes it impossible to apply the test to such many EPCs. Regardless of whether the test is performed, the necessary visits to the building shall be made between stage 1 and stage 2 of the protocol defined in Section 7.2.3.

As the criteria to decide if the thermal resistance measurement test will be performed or not, it is proposed an inflexion value for the percentage of the heating demand due to heat losses through the envelope. If this percentage is higher than 50%, it is proposed to perform the test, otherwise, documents justifying the definition of the enclosures to the QE will be requested. This percentage can be adjusted according to the resources available for the test and the workload of the controllers.

7.4. Automatic check

As explained in the previous section, the use of automatic checks is proposed both in the pre-registration phase and during the check with the Accredited Agent or, if applicable, the energy department. As the objective of the automatic check is different in both phases, the checks to be carried out will not be the same either, as described in Sections 7.4.1 and 7.4.2.

All the established rules are described in Appendix D and the following Table 7.3, Table 7.4, Table 7.5 and Table 7.6 define which ones would be used in the pre-registration phase and which ones would be used in the first step of the control by the accredited body or, if applicable, the energy department. In addition, these tables indicate to which NCs in the catalog each of the rules corresponds.

The automatic checks are performed on the XML file generated by the EPC calculation program. It should be noted that the proposed rules have been adapted to the latest version of the CTE DB HE, which is the current energy-saving regulation and, as a consequence, they have also been adapted to the XML files generated by the latest version of the HULC 2019 software. These rules are also replicable to other EPC calculation software, although it has been seen that they will probably require some minor adaptation in each case.

Currently, although the rules have been defined (see Appendix D), the testing software is in the development phase. The appearance of the program is shown below (see Figure 7.2):

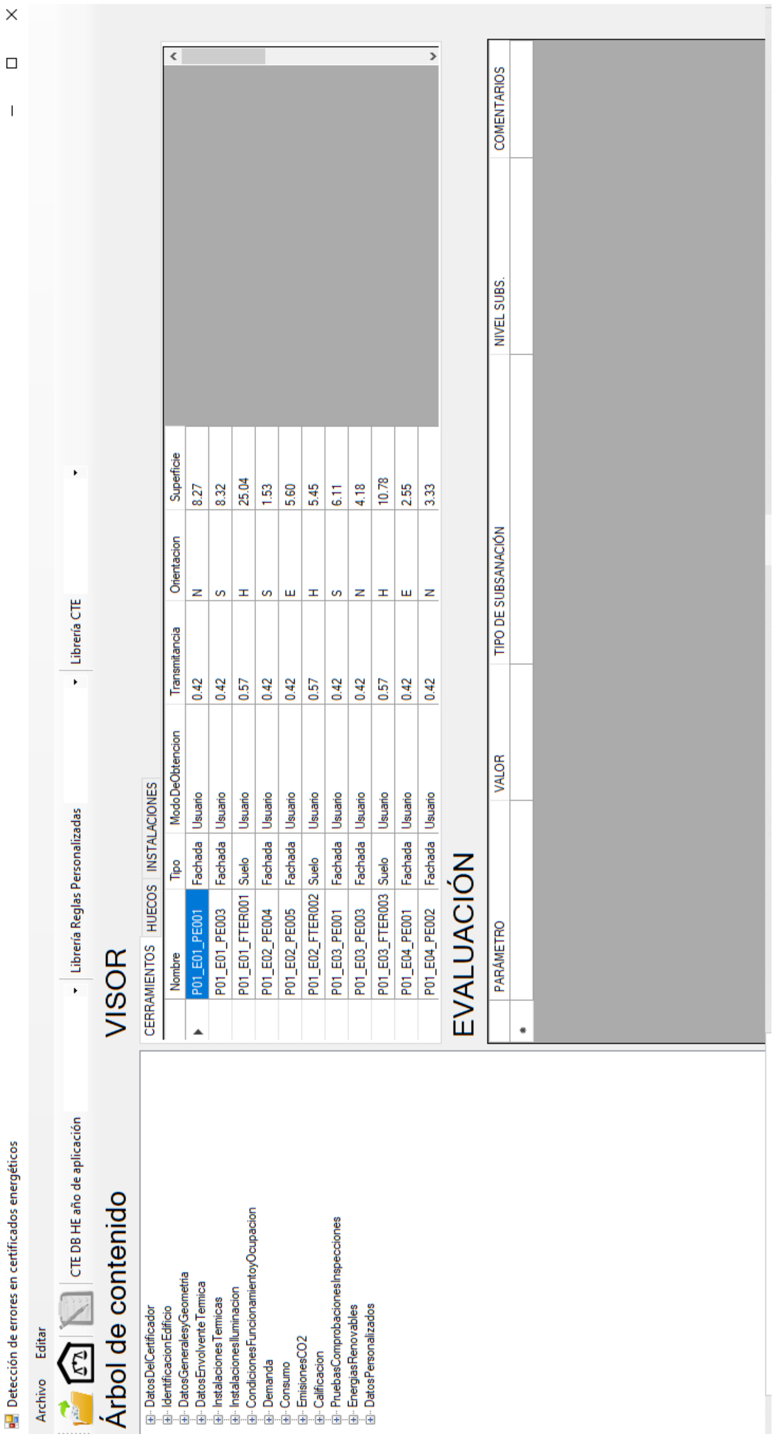


Figure 7.2. The automatic check software which is currently in development.

7.4.1 Automatic checks in filtering phase (selection criteria)

The followings are the validation rules proposed for automatic checks applied in the filtering process as EPC selection criteria: those that are able to identify NCs corresponding to category Q1a that have a null incidence but are necessary to be able to register (see Table 7.3), those that are able to identify an NC corresponding to category Q5a with total certainty (see Table 7.4) and those that detect unreliable inputs data corresponding to category Q5b (see Table 7.5). In addition, the relationship with the NC types solved by each rule is indicated in the aforementioned tables.

Table 7.3. Validation rules for identifying NCs with a null incidence in the error, but which correspond to data necessary to EPC registration.

Validation Rule Code	Validation Rule (description can be found in Appendix D)	Related NC code (description can be found in Appendix B)
R1	Expired EPC issuance date	NC.1.1.
R2	Lack of definition of postal address	NC.1.3.
R3	Lack of cadastral reference definition	NC.1.4.
R4	Lack of building description	NC.1.5.
R5	Lack of QE's data definition	NC.1.6.

Table 7.4. Validation rules for identifying NCs.

Validation Rule Code	Validation Rule (description can be found in Appendix D)	Related NC code (description can be found in Appendix B)
R6	Wrong definition of the climatic zone	NC.1.7.
R7&R8	Expired EPC calculating software version	NC.1.8.
R9	Lack of thermal bridges definition	NC.4.1.
R10	Lack of installed lighting power definition (tertiary buildings)	NC.8.5.

Table 7.5. Rules for identifying unreliable input data (alarms).

Validation Rule Code	Validation Rule (description can be found in Appendix D)- Unreliable input data	Related NC code (description can be found in Appendix B)
R11-R20	Nominal efficiency input data of the energy production equipment	NC.5.16
R21	Air change rate (in new residential buildings)	NC.6.1.
R22	Air change rate (in residential buildings built with the ventilation regulation CTE DB HS3 2006)	NC.6.1.
R23	Air change rate (in residential buildings built before the ventilation regulation CTE DB HS3 2006)	NC.6.1.
R24-R26	Type of building definition	NC.1.9.
R27-R29	Window thermal transmittance	NC.3.1.; NC.3.2.; NC.3.3.
R30&R31	Installed lighting power	NC.8.1.
R32	DHW demand	NC.5.10.
R33-R36	Fraction of glazed area	NC.2.6.
R37	MVHRS efficiency	NC.6.4.
R38-R42	Thermal conductivity, λ, of insulation material	NC.3.12.

7.4.2 Automatic checks in control process by an accredited body or department in the energy area

As explained in Section 7.3.3, in the first step of the proposed control protocol, an automatic check is included to verify the possible related NCs corresponding to categories Q4a and Q2b and, moreover, an extraction of all the EPC data contained in the EPC XML file will be carried out. The verification of NCs corresponding to category Q4a is based on the data extracted in this automatic review, so there are no specific validation rules for this type of NCs. Accordingly, Table 7.6 below shows the validation rules related to the possible NCs of category Q2b.

Table 7.6. Validation rules for identify lack of input data in EPC definition.

Validation Rule Code	Validation Rule (description can be found in Appendix D)- Unreliable input data	Related NC code (description can be found in Appendix B)
R1	Expired EPC issuance date	NC.1.1.
R2	Lack of definition of postal address	NC.1.3.
R3	Lack of cadastral reference definition	NC.1.4.
R4	Lack of building description	NC.1.5.
R5	Lack of QE's data definition	NC.1.6.
R9	Lack of thermal bridges definition	NC.4.1.
R10	Lack of installed lighting power definition (tertiary buildings)	NC.8.5.

8 Conclusions & Future Works

This last chapter contains the main contributions of this thesis, as well as the conclusions and a proposal for future lines of work.

8.1. Contribution

EPC is the main policy tool to attain the European Directive objectives: the fulfilment of NZEB requirements and the renovation of the building stock. That is why ensuring the data quality of EPCs is essential and that is the main objective of the independent control system.

In this line, the main objective of this thesis has been to contribute to improve the independent control system of the Basque Country and to optimize the control procedures in order to make their implementation more effective, and in consequence, improve the EPC quality and its reliability.

Thus, the fundamental contribution of this thesis has been the improvement proposals for the control system and checking methodologies which are supported by the conclusions obtained from the EPC sample control results monitorization analysis. These proposals are suited to the Basque Country independent control system, however, they may be replicable at least to other Spanish autonomous systems since the same EPC calculating procedures and standards are applied. Even if each state or region is making its own way in developing EPC schemes and its quality system, all research in the area and its divulgation can contribute to the homogenization of systems.

Though the principal benefit of enhancing quality control assurance systems is the improvment of data accuracy in the EPC database, this leads to co-benefits for several agents like policy-makers, technicians, researchers, investors, promoters or tenants, not only at a financial level but also in an environmental and social level. Some of them are mentioned in the following paragraphs.

The EPC database is a useful resource for decision making in energy-related policies as this extensive information provides creating a representative picture of the actual energy performance level of the building stock. Therefore, the higher the accuracy in EPC data, the more realistic energy planning will be carried out by policy-makers for the benefit of society as a whole.

At the financial level, the reliability of EPCs empowers the potential real estate buyers, investors or tenants to make better-informed buying decisions. It also incentives the owners or the investors to renovate the building stock. Thus, the credibility of data promotes investments and stimulates the real estate market.

Finally, the greater EPC database transparency, the higher accuracy in researchers and technicians projects. The applicability of EPC data in research and building retrofit works is proven (see Section 1.2.6). In this manner, the data quality in their work will improve and the energy savings calculations will be optimized for the benefit of the environment.

8.2. Conclusions

This thesis has begun with an analysis of data quality in the Basque Country EPCs. Inaccuracy has been demonstrated, so it is necessary to improve its quality and optimize quality control methodologies. To this end, a series of objectives have been drawn up, which have been achieved throughout the chapters of the thesis. The following is a list of the conclusions obtained related to the determined objectives:

Objective 1: Analysis of quality control methodologies applied throughout other countries and regions. Identify the other system features which are applicable in Basque Country's system and other possible improvements which are not developed in any system.

Practices from different MSs that have not been implemented in the Basque Country independent control system, that could be applied as long as their effectiveness is validated, are:

- Introduction of a validity check system being complementary with the point-by-point control methodology. It can be entered either in the pre-registration phase or post-registration control.
- The selection criteria of the EPCs to be controlled can be modified as long as their effectiveness is proven. Currently, the buildings with the best energy performance are controlled; however, there are other selection options in other countries and regions. It is not proven which one is the most effective.
- Introduction of a system that links the EPC data with the author's data for monitoring and verification purposes.
- Establishment of quality criteria for input data for EPC controller technicians.
- Introduction the obligation to present test results to justify values defined in EPC.

Aspects that are to be developed in general, not only in the Basque Country but also in other countries, are:

- The monitoring of the results obtained in control systems.
- Proving the effectiveness of the implemented system.
- Introduction of an ANN system to automate the checking of the EPCs.

Objective 2: EPC sample control performance between 2014-2019: followed control protocol as well as the representativeness of the selected EPC sample.

- The quality control procedure has been performed in a sample compounded by 146 EPCs.
- During the control, the building definition in the EPC calculation software is evaluated as well as the suitability of the chosen software.
- Only 100% of new buildings and 0.5% of existing buildings are controlled in the Basque Country database which is 1.7% of registered EPCs.
- The representativeness of the sample has also been demonstrated, showing the variability in all the differentiating characteristics of the sample.
- The main last year's trends in the EPC sample feature that have been detected are the following:
    - Increase in the number of tertiary building controls.
    - Overall decrease in heat transfer coefficient of the enclosures, especially, in windows.
    - Increase in installations based on electrical energy sources.
    - Increase in the variability and complexity of thermal installations, to the detriment of conventional installations such as condensing boilers with solar thermal for renewable coverage of DHW.

Objective 3: Analysis of the EPC sample data quality and subsequent statistical analysis of the sample deviation in order to extrapolate the sample results to the population (Basque Country EPC database).

- The results show that inaccuracy exists in EPCs.
- The deviations exist in EPCs not only sometimes being unfavorable for the final result, but also other times improving it. Approximately as many EPCs worsen their rating as EPCs improve.
- A confidence uncertainty of the relative error in the population of ±39.98% for a probability of 95% has resulted. This quality index is well above the appropriate value proposed by the EU Commission.
- A significant increase in deviation in the last 3 years is noteworthy as well as in the number of NCs. Therefore, it is necessary to continue controlling EPCs in the most effective and efficient way possible.

Objective 4: Analysis of the EPC subsamples data quality in order to assess the appropriateness of different existing EPC control selection criteria and features that could make an EPC more error prone. This aims to obtain guidance for the determination of the most effective EPC control selection criteria in terms of the capability to select the EPCs with the highest errors.

- The higher the consumption declared in the EPC, the greater is the deviation detected. Similarly, EPCs with an "A" rating have lower deviations than subsamples rated "B" and "C". This conclusion questions the effectiveness of the system of selecting EPCs to be controlled established in the Basque Country which is based on a selection of EPCs with the best rating.
- The better the declared rating, the more conservative are the detected deviations.
- Criteria for selecting EPCs to control based on QE' activity can be an effective way to identify the most inaccurate EPCs since the subsamples classification based on QEs has been the most error differentiator criteria.

- Other subsamples/attributes that present relevant errors are all tertiary buildings, existing buildings or EPCs calculated by Ce3x and single-family housing.

Objective 5: Qualitative, quantitative and mixed research analysis of collected NCs in noncompliance reports of the sample by cataloguing the type of NCs, exploring what underlies these NCs and what are the most appropriate and optimal ways to identify them.

- NCs recorded in the studied EPC sample have been catalogued. The reporting could be useful in order to improve the technician's knowledge.
- The NCs mainly happen because the QEs fail in getting accurate data from the project definition, from information exchange with project/construction management agents, etc as well as because EPCs are sometimes not defined in sufficient detail. In consequence, the main type of NCs founds in the analysis are divergences between EPC definition and data collected by the controller from documents, building or calculations performed by itself. The solution for this type of NCs may be directly related to the expected future full implementation of BIM.
- There is not a single detection form that is able to detect most part of the NC types. A combination of different checking procedures is needed to get an effective control methodology.
- The checking procedures which present the best results in terms of their detection capacity in both, number and weight of NCs are the checks by the contrast of documentary data without a visit to the building and the unreliable input data detection by automatic checks.
- The automatic check methodologies are not enough to completely substitute the procedures which are established nowadays in LCCE (point by point methodology based on EPC revision, documentary contrast and building inspections). They can detect 12% of the sampling error and of detecting unreliable values,

which may represent between 0-48% of the sampling error. Consequently, though the automatic check does not prove to be sufficiently effective as a single form of detection, it can be an error filtering instrument in order to reduce a part of the error in each EPC and effective in combination with other procedures.

- The building *in-situ* checks are the ones with the least ability to influence the resulting sample error. Furthermore, the comparison of the results presented by both categories has shown that the inspection, which is performed at the end of works, is capable of detecting 1.5 more times the number of NC types and error in the sample than the two first inspections, which are done during the isolation materials execution or at the end of the works by means of a thermal resistance measurement test.

Objective 6: Independent control system and control protocol improvements proposal based on the conclusions obtained in the previous chapters 4, 5 and 6 as they are based on the experience gained in the EPC control campaign during the period 2014-2019.

- The main proposals are:
  - Introduction of a preventive phase in EPC pre-registration where the attachment of some documents will be required. This measure is able to avoid 13 NC types.
  - Implementation of a combined selection criterion (see Figure 7.1) of filtering by automatic checks and targeted criteria.
  - Implementation of a control protocol for controllers organized in stages in accordance with NC types priority.
  - Validation rules proposal for automatic check methodology in selection criteria and in the first stage of controller's protocol.
- A continuous-iterative cycle of this thesis has been closed with this methodology proposal. It should be made clear that the

proposed methodology should also be adapted and improved based on its results in the future, following the principle of continuous improvement.

8.3. Future works

The following are some ideas in which this line of research could be further deepened, in addition to expanding on some of the work that has already been initiated as a result of this research.

In the first chapter, which identified practices of different independent control systems that have not been implemented in the Basque Country as well as other aspects that are yet to be developed, in general, in all systems, some possible improvements were mentioned. Nevertheless, their effectiveness has not been tested in this thesis and, therefore, no proposal has been made based on these practices.

One of these lines is to evaluate and propose quality criteria to assess whether input data or EPC outcome can be considered valid or not. This would help to standardize the criteria for all controllers. A possible way to obtain real data on the existing differences between controllers today could be an inter-accredited body so that all control agents would perform the evaluation of the same EPCs and the results obtained would be compared. A simile could also be made between different persons exercising the control activity in the same accredited body, for example, between LCCE colleagues.

Another possible line of action is the development of an ANN system to automate the checking of EPCs and the evaluation of its effectiveness in order to compare it with the methodologies implemented so far in the LCCE and proposed in this thesis. To date, there are few articles with proposed methodologies, but no implemented cases have been found.

On the other hand, as the implementation of BIM methodology advances in the field of design, construction, and operation of buildings, it will probably also play an important role in the quality control of EPCs and in the implemented methodologies. In particular, it is expected to facilitate a more in-depth definition of the passive and active thermal performance of the building and also the exchange of information between different calculation software and between different project agents. Therefore, it is an aspect to be taken into account in the next steps of research on the subject of the quality of EPCs.

In addition to those identified in the state of the art, Chapter 7 has initiated the development of an automatic checking software, which will be continued in the coming months. 42 validation rules have been established, but this number could be extended or adapted as more data becomes available from monitoring control results in the coming years. The continuous-iterative process, as has been done in this thesis, requires starting the cycle again with the analysis of the monitoring of the results of the controls carried out from 2020 onwards to continue improving the system and protocols in force.

9 References

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Appendices

Appendix A: Characteristics of the controlled EPCs

The EPCs of the analyzed sample is shown with their corresponding characteristics in each table:

- Table A-1 shows the general characteristics: use and typology of the building, EPC modality (Building in Project EPC, New Built Building EPC or Existing Building EPC), date of issue, type of property and location.
- Table A-2 provides the EPC results in nrPEC and CO_2 emissions. In new building EPCs, both in Building in Project EPC and in the New Built Building EPC, the difference obtained in the final results of both phases is also indicated.
- Table A-3 gives the U-values of the building envelope elements and of exterior windows.
- Table A-4 contains the characteristics of heating and DHW systems: generation equipment, installed power, efficiency, etc.
- Finally, table A-5 defines the type of ventilation system for each building and, if applicable, the installed power of the photovoltaic installation.

Table A-1. General features of the sample EPCs.

Control File Code				Use - Typol.	EPC modality	Date of issue		Property	Location	
					BP-EPC/ NBB-EPC/ EB-EPC	Year	Month	Private:0 / Public:1	Municipality	Climate zone (CTE)
R	N	001	P	R-SF	BP-EPC	2014	2	0	Bilbo	C1
R	N	002	F	R-SF	NBB-EPC	2014	9	0	Bilbo	C1
R	N	003	P	R-CH	BP-EPC	2014	5	1	Bilbo	C1
R	N	004	F	R-CH	NBB-EPC	2018	10	1	Bilbo	C1
R	N	005	P	R-CH	BP-EPC	2014	4	1	Eibar	C1
R	N	006	F	R-CH	NBB-EPC	2016	3	1	Eibar	D1
R	N	007	F	R-CH	NBB-EPC	2014	4	1	Bilbo	C1
R	N	008	F	R-CH	NBB-EPC	2014	10	1	Durango	C1
R	N	009	F	R-CH	NBB-EPC	2015	8	1	Basauri	C1
R	N	010	F	R-CH	NBB-EPC	2015	6	1	Barakaldo	C1
R	E	011	R	R-CH	EB-EPC	2014	3	1	Sestao	C1
R	E	012	E	R-CH	EB-EPC	2014	3	1	Santurtzi	C1
R	E	013	E	R-CH	EB-EPC	2014	6	1	Durango	C1
R	E	014	E	R-CH	EB-EPC	2014	7	1	Barakaldo	C1
R	E	015	E	R-CH	EB-EPC	2014	4	0	Vitoria- Gasteiz	D1
T	N	016	P	T-E	BP-EPC	2014	5	1	Ugao- Miraballes	C1
T	N	017	F	T-E	NBB-EPC	2017	10	1	Ugao- Miraballes	C1
R	E	018	E	R-CHD	EB-EPC	2014	9	1	Bilbo	C1
R	N	019	F	R-CH	NBB-EPC	2015	9	1	Hernani	C1
R	N	020	F	R-CH	NBB-EPC	2015	10	1	Leioa	C1
R	N	021	P	R-CHD	BP-EPC	2014	10	0	Vitoria- Gasteiz	D1
R	N	022	F	R-CHD	NBB-EPC	2015	6	0	Vitoria- Gasteiz	D1
R	N	023	F	R-CH	NBB-EPC	2014	11	1	Bilbo	C1
R	E	024	E	R-CH	EB-EPC	2015	2	1	Barakaldo	C1
R	N	025	F	R-CH	NBB-EPC	2015	1	0	Vitoria-Gasteiz	D1
R	N	026	F	R-CH	NBB-EPC	2015	4	0	Vitoria-Gasteiz	D1
R	E	027	E	R-CHD	EB-EPC	2014	11	1	Tolosa	C1
R	E	028	E	R-CH	EB-EPC	2015	4	1	Vitoria-Gasteiz	D1
R	E	029	E	R-CH	EB-EPC	2015	10	1	Vitoria-Gasteiz	D1
R	N	030	P	R-CH	BP-EPC	2015	4	1	Eibar	C1
R	N	031	F	R-CH	NBB-EPC	2016	4	1	Eibar	D1
R	N	032	P	R-CH	BP-EPC	2015	10	1	Irun	C1
R	N	033	F	R-CH	NBB-EPC	2016	7	1	Irun	D1
R	N	034	P	R-CH	BP-EPC	2015	9	1	Leioa	C1
R	N	035	F	R-CH	NBB-EPC	2016	4	1	Leioa	C1
R	N	036	P	R-CH	BP-EPC	2015	7	1	Leioa	C1
R	N	037	F	R-CH	NBB-EPC	2016	6	1	Leioa	C1
R	N	038	P	R-CH	BP-EPC	2015	11	1	Hondarribia	D1
R	N	039	F	R-CH	NBB-EPC	2018	12	1	Hondarribia	D1
R	N	040	P	R-CH	BP-EPC	2016	4	1	Sestao	C1
R	N	041	F	R-CH	NBB-EPC	2017	12	1	Sestao	C1
R	N	042	F	R- GASF	NBB-EPC	2016	7	0	Vitoria- Gasteiz	D1
R	N	043	P	R-CH	BP-EPC	2015	10	0	Amurrio	D1
R	N	044	F	R-CH	NBB-EPC	2016	7	0	Amurrio	D1
R	N	045	P	R-CHD	BP-EPC	2015	10	0	Vitoria- Gasteiz	D1
R	N	046	F	R-CHD	NBB-EPC	2016	7	0	Vitoria- Gasteiz	D1
R	N	047	P	R-CHD	BP-EPC	2016	1	0	Vitoria- Gasteiz	D1
R	N	048	F	R-CHD	NBB-EPC	2017	1	0	Vitoria- Gasteiz	D1
R	N	049	F	R-CH	NBB-EPC	2016	6	1	Bilbo	C1
R	N	050	F	R-CH	NBB-EPC	2016	7	0	Vitoria- Gasteiz	D1
R	N	051	F	R-CHD	NBB-EPC	2016	1	0	Donostia	D1

Control File Code				Use - Typol.	EPC modality	Date of issue		Property	Location	
					BP-EPC/ NBB-EPC/ EB-EPC	Year	Month	Private:0 / Public:1	Municipality	Climate zone (CTE)
T	N	052	P	T-E	BP-EPC	2016	1	0	Trapagaran	C1
T	N	053	F	T-E	NBB-EPC	2016	10	0	Trapagaran	C1
R	N	054	P	R- GASF	BP-EPC	2016	3	1	Billbo	C1
R	N	055	F	R- GASF	NBB-EPC	2017	12	1	Billbo	C1
R	N	056	P	R-SF	BP-EPC	2016	3	0	Vitoria- Gasteiz	D1
R	N	057	F	R-SF	NBB-EPC	2017	4	0	Vitoria- Gasteiz	D1
R	N	058	P	R-CH	BP-EPC	2016	3	1	Errenteria	D1
R	N	059	F	R-CH	NBB-EPC	2016	6	1	Bilbo	C1
R	N	060	F	R-CH	NBB-EPC	2019	1	1	Donostia	D1
T	N	061	P	T-E	BP-EPC	2016	11	1	Bilbo	C1
T	N	062	F	T-E	NBB-EPC	2019	1	1	Bilbo	C1
R	N	063	F	R-SF	NBB-EPC	2016	7	0	Orozko	C1
T	N	064	F	T-E	NBB-EPC	2016	9	1	Vitoria-Gasteiz	D1
R	N	065	F	R-SF	NBB-EPC	2016	10	0	Ibarrangelua	C1
T	N	066	F	T-E	NBB-EPC	2017	12	0	Trokoniz	D1
R	N	067	F	R-CH	NBB-EPC	2018	12	1	Bilbo	C1
R	N	068	P	R-CH	BP-EPC	2016	11	1	Leioa	C1
R	N	069	F	R-CH	NBB-EPC	2018	7	1	Leioa	C1
R	N	070	P	R-SF	BP-EPC	2016	12	0	Arrazua-Ubarrundia	E1
R	N	071	F	R-SF	NBB-EPC	2019	4	0	Arrazua-Ubarrundia	E1
R	N	072	P	R-CH	BP-EPC	2016	11	0	Vitoria- Gasteiz	D1
R	N	073	F	R-CH	NBB-EPC	2017	12	0	Vitoria- Gasteiz	D1
R	N	074	F	R-SF	NBB-EPC	2016	12	0	Dima	C1
R	N	075	F	R-CH	NBB-EPC	2018	9	1	Bilbo	C1
T	N	076	F	T-E	NBB-EPC	2017	11	1	Hernani	D1
R	N	077	P	R-CHD	BP-EPC	2017	2	0	Vitoria- Gasteiz	D1
R	N	078	F	R-CHD	NBB-EPC	2018	3	0	Vitoria- Gasteiz	D1
R	N	079	P	R- GASF	BP-EPC	2017	2	0	Vitoria- Gasteiz	D1
R	N	080	F	R- GASF	NBB-EPC	2018	6	0	Vitoria- Gasteiz	D1
R	N	081	F	R-CH	NBB-EPC	2017	8	0	Vitoria- Gasteiz	D1
R	N	082	F	R-CHD	NBB-EPC	2017	1	0	Vitoria- Gasteiz	D1
R	N	083	F	R-CH	NBB-EPC	2018	11	1	Santurtzi	C1
R	N	084	F	R-SF	NBB-EPC	2017	4	0	Dima	C1
R	N	085	F	R-SF	NBB-EPC	2017	11	0	Kanpezu	E1
R	N	086	P	R-CH	BP-EPC	2018	3	0	Amurrio	D1
R	N	087	F	R-CH	NBB-EPC	2018	5	0	Amurrio	D1
R	N	088	P	R-CH	BP-EPC	2017	11	1	Basauri	C1
R	N	089	F	R-CH	NBB-EPC	2019	4	1	Basauri	C1
T	E	090	E	T-O	EB-EPC	2017	12	1	Abadiño	C1
R	N	091	P	R-CH	BP-EPC	2018	10	1	Vitoria- Gasteiz	C1
R	N	092	P	R-CH	BP-EPC	2019	6	1	Bilbo	C1
R	N	093	F	R-CH	NBB-EPC	2019	9	1	Bilbo	C1
T	E	094	E	T-O	EB-EPC	2017	11	0	Vitoria- Gasteiz	D1
R	N	095	P	R-CH	BP-EPC	2017	11	1	Barakaldo	C1
R	N	096	P	R-CH	BP-EPC	2018	1	1	Irun	D1
R	N	097	P	R-CH	BP-EPC	2018	1	1	Santurtzi	C1
R	N	098	F	R-CH	NBB-EPC	2019	9	1	Santurtzi	C1
T	N	099	F	T-E	NBB-EPC	2019	3	1	Bilbo	C1
T	N	100	P	T-E	BP-EPC	2018	8	1	Bilbo	C1
T	N	101	F	T-H	NBB-EPC	2018	3	1	Zornotza	C1
R	N	102	P	R-CH	BP-EPC	2017	12	0	Vitoria- Gasteiz	D1
R	N	103	F	R-CH	NBB-EPC	2018	7	0	Vitoria- Gasteiz	D1

Control File Code				Use - Typol.	EPC modality	Date of issue		Property	Location	
					BP-EPC/ NBB-EPC/ EB-EPC	Year	Month	Private:0 / Public:1	Municipality	Climate zone (CTE)
R	E	104	E	R-CH	EB-EPC	2018	1	0	Bilbo	C1
T	N	105	F	T-E	NBB-EPC	2019	5	1	Bergara	D1
T	N	106	P	T-E	BP-EPC	2018	8	1	Zestoa	D1
T	N	107	F	T-E	NBB-EPC	2019	2	1	Zestoa	D1
T	N	108	F	T-E	NBB-EPC	2018	4	1	Güeñes	C1
R	E	109	E	R-CH	EB-EPC	2018	5	0	Bergara	D1
R	E	110	E	R-CH	EB-EPC	2018	4	0	Bergara	D1
R	N	111	P	R-SF	BP-EPC	2018	5	0	Durango	C1
R	N	112	F	R-SF	NBB-EPC	2019	3	0	Durango	C1
T	N	113	P	T-E	BP-EPC	2019	6	1	Vitoria- Gasteiz	E1
R	N	114	F	R-SF	NBB-EPC	2018	5	0	Jungitu	D1
R	N	115	F	R-SF	NBB-EPC	2018	5	0	Jungitu	D1
R	N	116	F	R-SF	NBB-EPC	2018	5	0	Jungitu	D1
R	E	117	E	R-CHD	EB-EPC	2019	3	0	Bilbo	C1
R	N	118	F	R-CHD	NBB-EPC	2019	5	0	Vitoria- Gasteiz	D1
R	E	119	E	R-CH	EB-EPC	2018	12	0	Bergara	D1
R	E	120	E	R-CH	EB-EPC	2018	12	0	Bergara	D1
R	E	121	E	R-CH	EB-EPC	2019	5	0	Bilbo	C1
T	N	122	P	T-E	BP-EPC	2019	3	1	Zumaia	D1
T	N	123	F	T-E	NBB-EPC	2019	11	1	Zumaia	D1
R	N	124	P	R-CHD	BP-EPC	2018	9	0	Vitoria- Gasteiz	D1
R	N	125	F	R-CHD	NBB-EPC	2019	12	0	Vitoria- Gasteiz	D1
T	N	126	P	T-S	BP-EPC	2018	10	1	Vitoria- Gasteiz	D1
R	N	127	P	R-CH	BP-EPC	2019	4	1	Basauri	C1
R	N	128	F	R- GASF	NBB-EPC	2018	12	0	Vitoria- Gasteiz	E1
R	N	129	P	R- GASF	BP-EPC	2019	5	0	Vitoria- Gasteiz	E1
R	N	130	F	R- GASF	NBB-EPC	2019	12	0	Vitoria- Gasteiz	E1
R	N	131	P	R-CH	BP-EPC	2019	10	0	Vitoria- Gasteiz	D1
R	N	132	F	R-CH	NBB-EPC	2019	12	0	Vitoria- Gasteiz	D1
R	N	133	P	R- GASF	BP-EPC	2018	12	0	Vitoria- Gasteiz	D1
R	N	134	F	R- GASF	NBB-EPC	2019	12	0	Vitoria- Gasteiz	D1
R	N	135	P	R-CH	BP-EPC	2019	7	0	Vitoria- Gasteiz	D1
R	N	136	F	R-CH	NBB-EPC	2019	2	0	Vitoria- Gasteiz	D1
T	N	137	P	T-O	BP-EPC	2019	2	1	Bilbo	C1
T	N	138	F	T-O	NBB-EPC	2019	7	1	Bilbo	C1
R	N	139	P	R-CH	BP-EPC	2019	8	1	Zarautz	D1
R	N	140	P	R-SF	BP-EPC	2019	5	0	Orbiso	E1
T	N	141	P	T-E	BP-EPC	2019	9	1	Bilbo	C1
T	N	142	P	T-E	BP-EPC	2019	7	1	Alkiza	D1
T	N	143	P	T-S	BP-EPC	2019	5	1	Elorriaga	D1
R	N	144	P	R-CH	BP-EPC	2019	6	1	Ortuella	C1
T	N	145	P	T-E	BP-EPC	2019	12	1	Lemoiz	C1
T	N	146	P	T-R	BP-EPC	2019	12	1	Gasteiz	D1

BP-EPC: Building in Project EPC; EB-EPC: Existing Building EPC; NBB-EPC: New Built Building EPC; R- CH: Residential Building- Collective housing; R- CHD: Residential Building- Collective housing between dividing walls; R-GASF: Residential Building- Group of adjacent Single Family housing; R-SF: Residential Building- Single Family housing; T-CO: Tertiary Building- Commercial Office; T-E: Tertiary Building- educational center; T-H: Tertiary Building- Health Center; T-O: Tertiary Building- Office building; T-R: Tertiary Building- Residence; T-S: Tertiary Building- Social Center

Table A-2. Results in nrPEC and CO_2 emissions of the EPCs in the sample.

Control File Code				Heated Area	nrPEC				CO_2 emissions			
				[m^2]	[KWh/ m^2y]	R	$\Delta_{BP\text{-}NBB}$ [kWh/ m^2y]	$\Delta_{BP\text{-}NBB}$ [R]	[$KgCO_2$/ m^2y]	R	$\Delta_{BP\text{-}NBB}$ [$kgCO_2$/ m^2y]	$\Delta_{BP\text{-}NBB}$ [R]
R	N	001	P	153.5	67.40	B	-2.7	=	13.60	B	-0.6	=
R	N	002	F	153.5	64.70	B			13.00	B		
R	N	003	P	3984.0	12.60	A	25.71	from A to B	2.50	A	5.34	from A to B
R	N	004	F	3984.0	38.31	B			7.84	B		
R	N	005	P	2173.5	46.20	B	11.27	=	9.40	B	2.77	=
R	N	006	F	2173.5	57.47	B			12.17	B		
R	N	007	F	11251.3	36.50	B	-	-	7.90	B	-	-
R	N	008	F	10910.0	59.20	A	-	-	9.68	A	-	-
R	N	009	F	12265.6	40.25	B	-	-	8.33	B	-	-
R	N	010	F	7792.1	42.44	B	-	-	8.66	B	-	-
R	E	011	R	1593.7	62.11	C	-	-	12.96	C	-	-
R	E	012	E	1496.2	54.57	C	-	-	11.37	C	-	-
R	E	013	E	1730.2	37.56	B	-	-	9.27	B	-	-
R	E	014	E	2927.4	11.11	A	-	-	2.76	A	-	-
R	E	015	E	70.3	75.04	C	-	-	15.71	C	-	-
T	N	016	P	3661.2	91.40	B	-13.9	=	16.40	B	-3	=
T	N	017	F	3661.2	77.50	B			13.40	B		
R	E	018	E	4392.6	54.68	C	-	-	11.52	C	-	-
R	N	019	F	11274.5	40.20	B	2.01	=	8.76	B	0.7	=
R	N	020	F	7495.8	48.10	C	-	-	10.00	B	-	-
R	N	021	P	1726.2	68.20	B	0	=	15.00	B	0	=
R	N	022	F	1726.2	68.20	B			15.00	B		
R	N	023	F	6053.8	27.80	A	-	-	5.60	A	-	-
R	E	024	E	4994.8	49.09	C	-	-	10.55	C	-	-
R	N	025	F	4152.8	35.20	A	-	-	7.10	A	-	-
R	N	026	F	2281.1	75.80	B	-	-	15.30	B	-	-
R	E	027	E	1503.0	34.40	A	-	-	7.40	A	-	-
R	E	028	E	2369.0	26.00	A	-0.80	=	6.20	A	-0.20	=
R	E	029	E	2369.0	25.20	A			6.00	A		
R	N	030	P	5410.5	41.30	B	8.22	=	8.70	B	1.76	=
R	N	031	F	5410.5	49.52	B			10.46	B		
R	N	032	P	2975.0	58.40	C	14.59	=	12.20	C	3.26	=
R	N	033	F	2975.0	72.99	C			15.46	C		
R	N	034	P	8992.4	41.70	B	-8.67	=	8.40	B	-1.44	=
R	N	035	F	8992.4	33.03	B			6.96	B		
R	N	036	P	9947.4	34.80	B	-1.70	=	7.40	B	-0.50	=
R	N	037	F	9947.4	33.10	B			6.90	B		
R	N	038	P	5264.8	12.95	A	-0.09	=	3.00	A	-0.69	=
R	N	039	F	5733.5	12.86	A			2.31	A		
R	N	040	P	13081.6	36.06	B	-0.60	=	7.62	B	-0.56	=
R	N	041	F	13081.6	35.46	B			7.06	B		
R	N	042	F	696.6	78.78	B	-	-	16.58	B	-	-
R	N	043	P	1601.6	36.70	A	2.40	from A to B	7.70	A	0.60	=
R	N	044	F	1601.6	39.10	B			8.30	A		
R	N	045	P	1438.4	51.40	A	-2.83	from A to B	10.80	A	-0.74	from A to B
R	N	046	F	1438.4	48.57	B			10.06	B		
R	N	047	P	2863.4	45.70	B	0.60	=	9.90	A	0.10	=
R	N	048	F	2863.4	46.30	B			10.00	A		
R	N	049	F	2800.0	42.60	C	-	-	9.00	C	-	-

Control File Code				Heated Area	nrPEC				CO_2 emissions			
				[m^2]	[KWh/ m^2y]	R	$\Delta_{BP\text{-}NBB}$ [kWh/ m^2y]	$\Delta_{BP\text{-}NBB}$ [R]	[$KgCO_2$/ m^2y]	R	$\Delta_{BP\text{-}NBB}$ [$kgCO_2$/ m^2y]	$\Delta_{BP\text{-}NBB}$ [R]
R	N	050	F	2280.0	49.50	B	-	-	10.30	B	-	-
R	N	051	F	560.0	36.90	B	-	-	6.90	B	-	-
T	N	052	P	670.7	55.50	B	-13.70	=	12.80	B	-6.50	=
T	N	053	F	670.7	41.80	B			6.30	B		
R	N	054	P	1964.6	41.65	B	-5.44	=	8.79	B	-1.21	from B to A
R	N	055	F	1964.6	36.21	B			7.58	A		
R	N	056	P	270.9	48.21	A	-12.04	=	8.23	A	-2.00	=
R	N	057	F	270.9	36.17	A			6.23	A		
R	N	058	P	3043.0	30.20	A	-	-	6.10	A	-	-
R	N	059	F	5829.0	26.92	B	-	-	5.70	B	-	-
R	N	060	F	4647.0	36.86	A	-	-	7.45	A	-	-
T	N	061	P	3103.1	94.80	B	4.41	=	15.49	C	3.89	from C to B
T	N	062	F	2736.7	99.21	B			19.38	B		
R	N	063	F	174.2	74.03	C	-	-	12.76	C	-	-
T	N	064	F	5519.1	176.90	B	-	-	25.50	B	-	-
R	N	065	F	330.6	52.60	B	-	-	9.50	B	-	-
T	N	066	F	1347.6	23.50	A	-	-	4.30	A	-	-
R	N	067	F	15418.0	12.33	A	-	-	2.61	A	-	-
R	N	068	P	5024.0	31.61	B	2.56	=	6.49	B	1.08	=
R	N	069	F	8849.1	34.17	B			7.57	B		
R	N	070	P	162.4	19.60	A	-	-	3.30	A	-	-
R	N	071	F	254.6	30.34	A	-	-	5.63	A	-	-
R	N	072	P	1844.4	52.39	B	-0.96	=	10.97	B	-0.27	=
R	N	073	F	1844.4	51.43	B			10.70	B		
R	N	074	F	124.6	11.60	A	-	-	2.50	A	-	-
R	N	075	F	2752.9	29.02	B	-	-	5.27	A	-	-
T	N	076	F	2385.0	87.20	A	-	-	15.80	A	-	-
R	N	077	P	911.8	52.29	B	0.81	=	11.04	B	0.13	=
R	N	078	F	908.7	53.10	B			11.17	B		
R	N	079	P	696.6	80.60	B	-27.99	from B to A	16.97	B	-5.95	from B to A
R	N	080	F	696.5	52.61	A			11.02	A		
R	N	081	F	2280.0	57.32	B	-	-	11.81	B	-	-
R	N	082	F	430.4	38.60	B	-	-	7.60	A	-	-
R	N	083	F	3548.5	37.68	B	-	-	7.83	B	-	-
R	N	084	F	113.0	51.50	B	-	-	12.10	B	-	-
R	N	085	F	216.5	82.18	B	-	-	21.08	A	-	-
R	N	086	P	2101.8	43.37	B	2.8	=	9.14	B	-0.3	=
R	N	087	F	2101.8	46.17	B			8.84	B		
R	N	088	P	5956.5	35.10	B	-0.97	=	7.30	B	-0.65	=
R	N	089	F	5956.5	34.13	B			6.65	B		
T	E	090	E	286.8	83.72	C	-	-	13.08	B	-	-
R	N	091	P	8145.1	26.18	B	-	-	5.39	A	-	-
R	N	092	P	19645.0	12.03	A	0	=	2.55	A	0	=
R	N	093	F	19645.0	12.03	A			2.55	A		
T	E	094	E	376.5	135.00	C	-	-	27.00	B	-	-
R	N	095	P	5992.6	41.80	C	-	-	8.60	B	-	-
R	N	096	P	2493.5	11.27	A	-	-	2.24	A	-	-
R	N	097	P	2885.5	23.45	A	-0.51	=	4.09	A	-0.1	=
R	N	098	F	2885.5	22.94	A			3.99	A		
T	N	099	F	3389.9	41.06	B	-	-	7.90	A	-	-
T	N	100	P	2587.4	60.35	B	-	-	10.64	B	-	-

Control File Code				Heated Area	nrPEC				CO_2 emissions			
				[m^2]	[KWh/ m^2y]	R	$\Delta_{BP\text{-}NBB}$ [kWh/ m^2y]	$\Delta_{BP\text{-}NBB}$ [R]	[KgCO_2/ m^2y]	R	$\Delta_{BP\text{-}NBB}$ [kgCO_2/ m^2y]	$\Delta_{BP\text{-}NBB}$ [R]
T	N	101	F	3894.7	37.80	A	-	-	6.60	A	-	-
R	N	102	P	3986.3	37.38	A	-0.2	=	7.77	A	-0.03	=
R	N	103	F	3986.3	37.18	A			7.74	A		
R	E	104	E	11131.0	56.30	C	-	-	11.90	C	-	-
T	N	105	F	13748.7	197.36	B	-	-	37.41	A	-	-
T	N	106	P	947.4	103.23	B	-14.80	=	18.28	B	-2.36	=
T	N	107	F	947.4	88.43	B			15.92	B		
T	N	108	F	3468.8	151.20	A	-	-	25.83	A	-	-
R	E	109	E	1102.0	86.30	D	-	-	17.70	C	-	-
R	E	110	E	757.3	86.00	C	-	-	17.70	C	-	-
R	N	111	P	214.8	23.76	A	-1.61	=	5.03	A	-0.34	=
R	N	112	F	199.3	22.15	A			4.69	A		
T	N	113	P	5381.5	58.72	B	-	-	10.74	A	-	-
R	N	114	F	178.0	10.54	A	-	-	1.88	A	-	-
R	N	115	F	168.0	7.95	A	-	-	1.45	A	-	-
R	N	116	F	130.0	12.56	A	-	-	2.22	A	-	-
R	E	117	E	3145.9	85.60	D	-	-	18.10	C	-	-
R	N	118	F	1192.7	50.19	B	-	-	10.53	B	-	-
R	E	119	E	1037.9	97.90	C	-	-	19.80	C	-	-
R	E	120	E	1037.3	99.40	C	-	-	20.10	C	-	-
R	E	121	E	2788.5	60.35	C	-	-	12.55	C	-	-
T	N	122	P	801.8	103.15	A	15.05	=	16.60	A	2.60	=
T	N	123	F	801.8	118.20	A			19.20	A		
R	N	124	P	691.3	89.17	D	-25.08	from D to C	18.38	C	-5.33	=
R	N	125	F	784.4	64.09	C			13.05	C		
T	N	126	P	464.6	116.74	B	-	-	18.17	B	-	-
R	N	127	P	5701.8	13.72	A	-	-	2.63	A	-	-
R	N	128	F	507.2	59.36	A	-	-	12.60	A	-	-
R	N	129	P	760.8	63.89	A	-8.81	=	13.58	A	-1.88	=
R	N	130	F	760.8	55.08	A			11.70	A		
R	N	131	P	629.5	37.27	A	-4.85	=	7.51	A	-0.91	=
R	N	132	F	629.5	32.42	A			6.60	A		
R	N	133	P	1362.6	50.19	A	0.73	=	10.51	A	0.14	=
R	N	134	F	1362.6	50.92	A			10.65	A		
R	N	135	P	2615.5	48.38	B	3.03	=	10.14	B	0.64	=
R	N	136	F	2615.5	51.41	B			10.78	B		
T	N	137	P	1472.0	71.20	A	8.9	=	12.10	A	1.5	=
T	N	138	F	1472.0	80.10	A			13.60	A		
R	N	139	P	8920.5	27.28	A	-	-	5.77	A	-	-
R	N	140	P	145.8	52.13	A	-	-	8.83	A	-	-
T	N	141	P	1725.0	42.86	B	-	-	8.05	A	-	-
T	N	142	P	764.9	15.04	A	-	-	98.34	A	-	-
T	N	143	P	449.9	141.23	A	-	-	22.70	A	-	-
R	N	144	P	6462.0	5.09	A	-	-	1.55	A	-	-
T	N	145	P	708.0	97.37	A	-	-	15.09	A	-	-
T	N	146	P	547.2	216.40	C	-	-	41.80	B	-	-

$\Delta_{BP\text{-}NBB}$: *Deviation from Building in Project EPC to New Built Building EPC; R: Energy Ratiing*

Table A-3. U-values of envelope elements and windows of the EPCs in the sample.

Control File Code	Envelope								Windows		
	U_{fc} [W/ m²K]	U_r [W/ m²K]	U_{ef} [W/m²K]	U_{wg} [W/m²K]	U_{fg} [W/m²K]	U_{vpu} [W/m²K]	U_{hpu} [W/m²K]	U_m [W/m²K]	U_f [W/m²K]	U_g [W/m²K]	U_w [W/m²K]
R N 001 P	0.38	0.34	-	-	0.41	0.41	-	-	4.00	2.80	3.16
R N 002 F	0.38	0.34			0.37	0.41	-	-	4.00	1.40	2.18
R N 003 P	0.32	0.28	0.29	-	-	-	0.44	-	3.70	2.80	3.12
R N 004 F	0.26	0.33	0.29	-	-	-	0.44	-	2.70	2.80	2.77
R N 005 P	0.41	0.29	0.52	-	-	-	0.52	-	4.00	2.24	2.67
R N 006 F	0.41	0.29	0.52	-	-	-	0.52	-	4.00	1.90	2.49
R N 007 F	0.31	0.48	-	-	-	-	0.72	0.37	2.80	2.10	2.25
R N 008 F	0.27	0.35	0.27	-	-	-	0.61	-	2.90	1.80	2.30
R N 009 F	0.35	0.38	0.43	-	-	-	0.41	-	4.00	1.74	1.91
R N 010 F	0.39	0.23	0.43	-	-	-	0.64	-	4.00	2.12	2.69
R E 011 R	0.44	0.14	0.41	-	-	-	0.45	-	4.00	3.00	3.30
R E 012 E	0.38	0.45	0.57	-	-	-	0.47	-	4.00	2.80	3.16
R E 013 E	0.31	0.35	0.66	-	-	0.32	0.41	-	4.00	2.80	3.16
R E 014 E	0.59	0.54	0.39	-	-	-	0.34	-	4.00	2.80	3.16
R E 015 E	0.36	-	-	-	-	-	-	0.44	3.80	1.80	2.30
T N 016 P	0.4	0.39	-	-	0.39	-	0.38	-	3.20	1.60	2.08
T N 017 F	0.4	0.39	-	-	0.56	-	0.38	-	1.90	1.40	1.55
R E 018 E	0.57	0.42	0.82	-	-	-	0.68	1.4	4.00	2.80	3.22
R N 019 F	0.26	0.38	0.51	-	-	-	0.51	-	2.47	1.80	2.04
R N 020 F	0.52	0.3	0.3	-	-	-	0.61	-	4.00	2.20	2.83
R N 021 P	0.3	0.21	0.3	-	-	0.56	0.88	0.62	3.20	2.10	2.49
R N 022 F	0.3	0.21	0.3	-	-	0.56	0.88	0.62	3.20	2.10	2.49
R N 023 F	0.32	0.24	0.2	-	-	-	0.32	-	3.30	1.40	2.07
R E 024 E	0.29	0.32	0.35	-	-	-	0.48	-	4.00	2.80	3.22
R N 025 F	0.43	0.36	-	-	-	-	0.42	-	2.90	1.40	1.93
R N 026 F	0.33	0.35	0.36	-	-	-	0.48	-	2.70	2.80	2.77
R E 027 E	0.56	0.29	0.73	-	-	-	0.73	1	2.86	1.60	2.04
R E 028 E	0.24	0.15	0.29	-	0.25	-	-	-	1.90	1.30	1.51
R E 029 E	0.22	0.19	0.25	-	0.24	-	-	-	1.90	1.30	1.51
R N 030 P	0.32	0.32	-	-	-	-	0.62	-	2.10	1.80	1.91
R N 031 F	0.32	0.31	-	-	-	-	0.43	-	1.91	1.40	1.58
R N 032 P	0.24	0.31	0.39	-	-	-	0.77	-	4.00	2.55	3.06
R N 033 F	0.24	0.28	0.39	-	-	-	0.77	-	4.00	1.30	2.25
R N 034 P	0.27	0.26	0.24	-	-	0.56	0.28	-	2.70	2.00	2.25
R N 035 F	0.27	0.26	0.24	-	-	0.56	0.52	-	2.70	1.70	2.05
R N 036 P	0.26	0.34	0.38	-	-	-	0.38	-	4.00	1.80	2.57
R N 037 F	0.27	0.34	0.4	-	-	-	0.38	-	2.74	1.60	2.00
R N 038 P	0.18	0.12	-	-	-	-	0.17	-	1.30	0.61	0.82
R N 039 F	0.18	0.13	-	-	-	-	0.17	-	1.30	1.10	1.16
R N 040 P	0.5	0.15	0.38	-	-	0.29	0.7	-	3.20	2.70	2.88
R N 041 F	0.5	0.17	0.38	-	-	0.29	0.37	-	3.20	2.70	2.88
R N 042 F	0.26	0.38		-	0.4	0.28	0.68	0.34	2.70	1.60	1.99
R N 043 P	0.27	-	-	-	-	-	0.26	-	3.20	1.80	2.29
R N 044 F	0.21	-	-	-	-	-	0.27	-	3.20	1.80	2.29
R N 045 P	0.24	0.23	0.29	-	-	-	0.29	0.31	3.20	1.60	2.16
R N 046 F	0.24	0.23	0.29	-	-	-	0.29	0.37	2.90	1.40	1.93
R N 047 P	0.24	0.23	-	-	-	-	0.29	0.31	2.30	1.60	1.85
R N 048 F	0.24	0.23	-	-	-	-	0.29	0.31	2.30	1.40	1.72
R N 049 F	0.4	-	0.5	-	-	-	0.55	-	3.20	2.70	2.88
R N 050 F	0.33	0.33	0.33	-	-	-	0.48	-	2.70	2.80	2.77

Control File Code	Envelope								Windows		
	U_{fc} [W/m²K]	U_r [W/m²K]	U_{ef} [W/m²K]	U_{wg} [W/m²K]	U_{fg} [W/m²K]	U_{vpu} [W/m²K]	U_{hpu} [W/m²K]	U_m [W/m²K]	U_f [W/m²K]	U_g [W/m²K]	U_w [W/m²K]
R N 051 F	0.34	0.29	-	-	-	-	0.23	0.56	3.20	2.50	2.75
T N 052 P	0.26	0.2	-	-	-	-	0.31	-	3.20	1.40	1.85
T N 053 F	0.26	0.2	-	-	-	-	0.3	-	3.20	1.40	1.85
R N 054 P	0.2	-	0.3	-	-	0.5	0.35	0.39	2.20	1.40	1.68
R N 055 F	0.2	-	0.3	-	-	0.5	0.35	0.33	1.90	1.40	1.58
R N 056 P	0.32	0.22	-	-	0.34	0.31	0.36	-	3.20	1.60	2.16
R N 057 F	0.31	0.22	-	-	0.34	0.31	0.36	-	3.20	1.60	2.16
R N 058 P	0.24	0.21	-	-	-	0.51	0.3	-	1.70	1.60	1.64
R N 059 F	0.41	0.47	-	-	-	0.5	0.63	0.5	4.00	2.00	2.70
R N 060 F	0.25	0.26	-	-	-	-	0.43	-	1.30	1.40	1.37
T N 061 P	0.33	0.16	-	0.31	0.29	0.31	0.34	-	2.56	1.63	1.82
T N 062 F	0.32	0.2	-	0.31	0.27	0.31	0.34	-	2.56	1.63	1.82
R N 063 F	0.42	0.3	-	-	0.62	0.41	-	-	4.00	1.40	2.44
T N 064 F	0.36	0.36	0.48	-	0.49	0.5	0.48	-	3.80	1.40	2.00
R N 065 F	0.49	0.4	0.39	-	-	-	0.53	-	2.20	1.80	1.94
T N 066 F	0.27	0.19	0.31	-	0.31	-	-	-	3.10	1.60	1.90
R N 067 F	0.2	0.19	-	-	-	-	0.31	-	0.57	1.03	0.87
R N 068 P	0.22	0.23	-	-	-	-	0.47	-	2.20	1.50	1.75
R N 069 F	0.22	0.23	-	-	-	-	0.47	-	1.98	1.98	1.98
R N 070 P	0.3	0.22	-	-	0.33	0.59	0.35	-	3.20	0.90	1.71
R N 071 F	0.33	0.2	-	-	0.21	0.47	0.39	-	0.97	0.97	0.97
R N 072 P	0.27	0.23	0.35	-	-	0.55	0.45	-	2.30	1.40	1.72
R N 073 F	0.27	0.23	0.35	-	-	0.55	0.45	-	2.30	1.40	1.72
R N 074 F	0.32	0.22	0.26	0.77	0.36	0.7	0.45	-	2.20	1.40	1.68
R N 075 F	0.31	0.17	0.45	-	-	-	0.5	-	2.39	2.70	2.59
T N 076 F	0.39	0.35	-	0.37	0.55	0.48	0.45	-	2.70	1.00	1.34
R N 077 P	0.24	0.21	0.3	-	0.29	0.32	0.47	3.08	2.70	1.60	1.99
R N 078 F	0.24	0.2	0.3	-	0.29	0.34	0.23	3.08	2.70	1.60	1.99
R N 079 P	0.28	0.38	0.48	-	0.4	-	-	-	2.70	1.55	1.95
R N 080 F	0.27	0.38	0.42	-	0.36	-	-	-	2.70	1.44	1.88
R N 081 F	0.28	0.33	0.32	-	-	-	0.48	-	2.70	2.80	2.77
R N 082 F	0.29	0.29	0.45	-	0.74	-	0.69	0.37	2.70	1.50	1.92
R N 083 F	0.32	0.22	0.33	0.29	-	-	0.48	-	3.20	1.40	2.03
R N 084 F	0.3	0.17	-	-	-	0.7	0.53	-	2.20	1.80	1.94
R N 085 F	0.29	0.22	-	0.3	0.29	0.36	0.54	-	1.80	1.10	1.35
R N 086 P	0.24	-	0.31	-	-	-	0.32	-	3.20	1.80	2.29
R N 087 F	0.28	-	0.33	-	-	-	0.36	-	1.20	1.40	1.33
R N 088 P	0.3	0.28	0.24	-	-	-	0.31	-	1.97	1.51	1.67
R N 089 F	0.26	0.28	0.24	-	-	-	0.33	-	1.97	1.51	1.67
T E 090 E	0.27	0.22	-	-	0.61	0.58	0.52	0.29	2.20	3.30	2.92
R N 091 P	0.3	0.36	-	-	-	-	0.5	-	1.90	1.60	1.68
R N 092 P	0.2	0.195	-	-	-	-	-	-	0.57	1.03	0.87
R N 093 F	0.2	0.19	-	-	-	-	-	-	0.57	1.03	0.87
T E 094 E	1.69	0.38	-	-	0.66	-	-	-	4.00	3.30	3.48
R N 095 P	0.23	0.2	0.48	-	-	-	0.5	-	2.70	1.40	1.86
R N 096 P	0.29	0.29	0.22	-	-	-	0.48	-	1.60	1.40	1.47
R N 097 P	0.21	0.23	0.29	-	-	-	0.29	-	1.13	1.13	1.12
R N 098 F	0.21	0.23	0.2	-	-	-	0.28	-	1.70	1.20	1.38
T N 099 F	0.26	0.16	-	0.4	0.46	-	0.43	-	1.50	1.15	1.26
T N 100 P	0.24	-	-	-	0.59	-	0.31	-	2.70	1.09	1.41
T N 101 F	0.38	0.3	0.33	-	0.55	-	0.59	-	2.00	1.00	1.30
R N 102 P	0.27	0.24	0.29	-	-	0.37	-	-	2.40	2.00	2.14
R N 103 F	0.24	0.24	0.29	-	-	0.37	-	-	2.40	2.00	2.14

Control File Code	Envelope								Windows		
	U_{fc} [W/m^{2}K]	U_r [W/m^{2}K]	U_{ef} [W/m^{2}K]	U_{wg} [W/m^{2}K]	U_{fg} [W/m^{2}K]	U_{vpu} [W/m^{2}K]	U_{hpu} [W/m^{2}K]	U_m [W/m^{2}K]	U_f [W/m^{2}K]	U_g [W/m^{2}K]	U_w [W/m^{2}K]
R E 104 E	0.31	0.27	0.31	-	-	-	-	-	4.20	3.30	3.62
T N 105 F	0.46	0.43	0.44	-	-	-	-	-	2.20	2.70	2.55
T N 106 P	0.17	0.14	-	-	0.47	-	0.16	-	2.70	1.09	1.44
T N 107 F	0.23	0.14	-	-	0.36	-	0.16	-	2.70	1.09	1.44
T N 108 F	0.35	0.31	0.49	0.49	0.51	-	0.7	-	4.00	2.80	3.16
R E 109 E	0.39	0.31	0.46	-	-	-	-	-	3.10	3.30	3.23
R E 110 E	0.39	0.52	0.64	-	-	-	-	-	3.10	3.30	3.23
R N 111 P	0.2	0.21	0.18	-	0.42	-	-	-	3.20	1.40	1.89
R N 112 F	0.22	0.16	0.18	-	0.42	-	-	-	3.20	1.40	1.90
T N 113 P	0.26	-	-	-	-	-	0.17	-	3.20	1.90	2.19
R N 114 F	0.14	0.11	-	-	0.6	-	-	-	1.00	0.60	0.62
R N 115 F	0.14	0.11	-	-	0.6	-	-	-	1.00	0.60	0.62
R N 116 F	0.14	0.11	-	-	0.6	-	-	-	1.00	0.60	0.62
R E 117 E	0.79	0.79	0.75	-	-	-	-	0.78	4.00	3.30	3.55
R N 118 F	0.62	0.29	-	-	0.51	0.66	0.51	0.63	3.20	1.40	2.03
R E 119 E	0.28	0.31	0.2	-	-	-	1.42	-	2.20	2.00	2.07
R E 120 E	0.28	0.31	0.2	-	-	-	2.42	-	2.20	2.00	2.07
R E 121 E	0.23	0.36	-	-	-	-	0.35	-	3.00	1.60	2.07
T N 122 P	0.43	0.33	-	-	0.31	-	-	-	2.70	1.40	1.54
T N 123 F	0.43	0.35	-	-	0.31	0.48	-	-	2.70	1.40	1.54
R N 124 P	0.57	0.23	0.56	-	-	-	-	0.63	1.45	2.70	2.26
R N 125 F	0.46	0.21	0.56	-	-	-	-	0.51	1.40	2.50	2.12
T N 126 P	0.24	-	-	-	-	-	0.64	0.45	1.00	1.00	1.00
R N 127 P	0.2	0.24	0.32	-	-	-	0.32	-	1.20	0.85	0.97
R N 128 F	0.25	0.14	-	-	0.38	0.25	0.25	-	0.90	1.00	0.97
R N 129 P	0.26	0.14	-	0.38	0.38	-	0.29	-	0.90	1.00	0.97
R N 130 F	0.27	0.14	-	0.38	0.38	-	0.23	-	0.90	1.00	0.97
R N 131 P	0.24	0.23	-	-	-	-	0.24	-	1.90	1.80	1.82
R N 132 F	0.24	0.25	-	-	-	-	0.23	-	1.90	1.40	1.56
R N 133 P	0.25	0.39	0.36	-	0.31	-	-	0.31	2.70	1.55	1.95
R N 134 F	0.25	0.39	0.36	-	0.31	-	0.33	0.33	2.70	1.40	1.86
R N 135 P	0.22	0.16	0.23	-	-	-	0.41	0.47	2.70	1.49	1.91
R N 136 F	0.22	0.21	0.19	-	-	-	0.41	0.47	2.70	1.49	1.91
T N 137 P	0.4	-	-	-	-	-	0.27	-	1.30	1.00	1.06
T N 138 F	0.43	-		-	-	-	0.53	-	2.50	1.00	1.30
R N 139 P	0.26	0.22	0.32	-	-	-	0.48	-	2.20	1.60	1.81
R N 140 P	0.31	-	-	-	0.32	-	0.28	-	1.90	0.64	1.08
T N 141 P	0.27	0.33	0.3	-	0.6	-	0.5	1	1.80	1.50	1.60
T N 142 P	0.22	0.13	0.2	-	0.2	-	-	0.29	2.30	1.00	1.42
T N 143 P	0.25	0.2	-	-	0.9	-	-	-	1.90	1.20	1.40
R N 144 P	0.19	0.29	-	-	-	-	0.37	-	2.00	1.50	1.68
T N 145 P	0.22	0.19	0.2	-	0.34	-	-	-	1.20	0.70	0.85
T N 146 P	0.33	0.28	-	-	-	-	0.25	-	1.90	2.80	2.60

Table A-4. Characteristics of the DHW and heating installations in the EPCs sample.

Control File Code				Heating System				DHW system					Renewable DHW system		
				Gen.	P [kW]	η*	C/ I **	Gen.	P [kW]	η*	Sto. [l]	C/ I **	STS/ AS	AS	Ren. range [%]
R	N	001	P	BHB	30.0	0.80	C	BHB	30.0	0.80	200	C	AS	BHB	100%
R	N	002	F	BHB	30.0	0.80	C	BHB	30.0	0.80	212	C	AS	BHB	100%
R	N	003	P	CB	75.0	0.98	C	CB	75.0	1.05	667	C	AS	CG	69%
R	N	004	F	CB	228.0	0.90	C	HP-A	15.6	2.06	2000	C	AS	HP-A	68%
R	N	005	P	CB	360.0	0.98	C	CB	360.0	0.98	-	C	STS	-	76%
R	N	006	F	CB	295.0	0.98	C	CB	295.0	0.98	500	C	STS	-	75%
R	N	007	F	LB	690.0	0.94	C	LB	690.0	0.94	2000	C	STS	-	60%
R	N	008	F	LB	1000.0	0.96	C	LB	1000.0	0.96	3000	C	AS	CG	50%
R	N	009	F	CB	742.0	0.95	C	CB	742.0	0.95	9000	C	STS	-	35%
R	N	010	F	CB	702.0	0.97	C	CB	702.0	0.97	7000	C	STS	-	30%
R	E	011	R	LB	253.0	0.92	C	LB	253.0	0.92	200	C	-	-	-
R	E	012	E	CB	130.0	0.98	C	CB	130.0	0.98	1000	C	STS	-	32%
R	E	013	E	HP-G	17.2	4.00	C	CB	115.9	0.92	2000	C	AS	HP-G	74%
R	E	014	E	HP-G	221.0	2.79	C	HP-G	221.0	4.46	3000	C	AS	HP-G	100%
R	E	015	E	CB	24.0	0.96	C	CB	24.0	0.96	-	C	STS	-	32%
T	N	016	P	CB	570.0	0.95	C	CB	570.0	0.95	1000	C	-	-	-
T	N	017	F	CB	286.0	0.95	C	CB	286.0	0.95	1000	C	-	-	-
R	E	018	E	CB	583.0	0.90	C	CB	583.0	0.90	2000	C	STS	-	44%
R	N	019	F	CB	1200.0	0.98	C	CB	1200.0	0.98	-	C	STS	-	60%
R	N	020	F	CB	752.4	0.98	C	CB	752.4	0.98	9000	C	AS	HP-A	75%
R	N	021	P	CB	428.4	0.97	I	CB	428.4	0.97	588	I	STS	-	34%
R	N	022	F	CB	428.4	0.97	I	CB	428.4	0.97	588	I	STS	-	34%
R	N	023	F	CB	120.0	0.97	C	CB	120.0	0.97	1500	C	AS	BHB	34%
R	E	024	E	CB	463.0	0.98	C	CB	463.0	0.98	2400	C	STS	-	30%
R	N	025	F	CB	340.0	0.98	C	CB	340.0	0.98	1000	C	STS	-	32%
R	N	026	F	LB	503.2	0.92	I	LB	503.2	0.92	-	I	STS	-	30%
R	E	027	E	CB	279.0	0.98	C	CB	279.0	0.98	-	C	-	-	-
R	E	028	E	CB	705.0	0.98	I	CB	705.0	0.98	-	I	-	-	-
R	E	029	E	CB	705.0	0.98	I	CB	705.0	0.98	-	I	-	-	-
R	N	030	P	CB	522.0	0.95	C	CB	522.0	0.95	1000	C	STS	-	60%
R	N	031	F	CB	522.0	0.95	C	CB	522.0	0.95	1000	C	STS	-	60%
R	N	032	P	CB	1644.8	0.95	I	CB	1644.8	0.95	-	I	STS	-	61%
R	N	033	F	CB	1920.0	0.97	I	CB	1920.0	0.97	-	I	STS	-	46%
R	N	034	P	CB	560.0	0.93	C	CB	560.0	0.93	2000	C	STS	-	52%
R	N	035	F	CB	600.0	0.97	C	CB	600.0	0.97	2000	C	STS	-	51%
R	N	036	P	CB	570.0	0.95	C	CB	570.0	0.95	4000	C	STS	-	60%
R	N	037	F	CB	480.0	0.97	C	CB	480.0	0.97	4000	C	AS	HP-A	
R	N	038	P	CB	188.0	0.98	C	HP-A	30.0	3.48	4000	C	AS	HP-A	30%
R	N	039	F	CB	200.0	0.98	C	HP-A	29.0	3.50	2000	C	AS	HP-A	48%
R	N	040	P	CB	844.0	0.95	C	CB	844.0	0.95	-	C	STS	-	60%
R	N	041	F	CB	882.0	0.95	C	CB	882.0	0.95	13000	C	AS	HP-A	
R	N	042	F	CB	157.8	0.92	I	CB	157.8	0.92	-	I	STS	-	30%
R	N	043	P	CB	489.6	0.97	I	CB	489.6	0.97	672	I	STS	-	32%
R	N	044	F	CB	400.0	0.98	I	CB	400.0	0.98	720	I	STS	-	32%
R	N	045	P	CB	428.4	0.97	I	CB	428.4	0.97	588	I	STS	-	30%
R	N	046	F	CB	428.4	0.97	I	CB	428.4	0.97	588	I	STS	-	30%
R	N	047	P	CB	795.6	0.98	I	CB	795.6	0.98	1092	I	STS	-	35%
R	N	048	F	CB	795.6	0.98	I	CB	795.6	0.98	1092	I	STS	-	48%
R	N	049	F	CB	214.0	0.95	C	CB	214.0	0.95	1500	C	STS	-	30%
R	N	050	F	CB	520.2	0.98	I	CB	520.2	0.98	714	I	STS	-	30%

Control File Code				Heating System				DHW system					Renewable DHW system		
				Gen.	P [kW]	η*	C/ I **	Gen.	P [kW]	η*	Sto. [l]	C/ I **	STS/ AS	AS	Ren. range [%]
R	N	051	F	CB	364.0	0.97	I	CB	364.0	0.97	-	I	-	-	-
T	N	052	P	CB	65.0	0.95	C	-	-	-	-	-	-	-	-
T	N	053	F	CB	65.0	0.95	C	-	-	-	-	-	-	-	-
R	N	054	P	CB	25.0	0.95	I	CB	25.0	0.95	-	I	STS	-	51%
R	N	055	F	CB	25.0	0.95	I	CB	25.0	0.95	-	I	STS	-	50%
R	N	056	P	HP-G	3.0	3.47	C	HP-G	3.0	2.48	200	C	AS	HP-G	100%
R	N	057	F	HP-G	3.0	3.23	C	HP-G	3.0	2.31	165	C	AS	HP-G	100%
R	N	058	P	CB	170.0	0.95	C	CB	170.0	0.95	1000	C	AS	HP-A	68%
R	N	059	F	CB	270.0	0.97	C	CB	270.0	0.97	2000	C	STS	-	30%
R	N	060	F	CB	234.0	0.97	C	CB	234.0	0.97	5000	C	AS	HP-A	35%
T	N	061	P	CB	200.0	0.98	C	CB	200.0	1.00	1000	C	-	-	-
T	N	062	F	CB	214.0	0.85	C	CB	214.0	0.95	930	C	-	-	-
R	N	063	F	HP-G	4.5	2.23	C	HP-G	4.5	2.23	200	C	AS	HP-G	100%
T	N	064	F	CB	460.0	0.98	C	CB	460.0	0.98	1000	C	AS	HP-A	30%
R	N	065	F	HP-G	2.6	2.65	C	HP-G	2.6	1.89	435	C	AS	HP-G	100%
T	N	066	F	BHB	151.0	0.94	C	BHB	151.0	0.94	204	C	AS	BHB	100%
R	N	067	F	CB	1150.0	0.98	C	CB	1150.0	0.98	2000	C	AS	CG	36%
R	N	068	P	CB	313.0	0.90	C	CB	313.0	0.98	1000	C	AS	CG	50%
R	N	069	F	CB	430.0	0.98	C	CB	430.0	1.00	1000	C	AS	CG	50%
R	N	070	P	HP-G	12.0	5.46	C	HP-G	12.0	4.20	-	C	AS	HP-G	100%
R	N	071	F	HP-G	11.0	2.34	I	HP-G	11.0	2.98	165	I	AS	HP-G	100%
R	N	072	P	CB	350.0	0.92	I	CB	350.0	0.92	420	I	STS	-	30%
R	N	073	F	CB	350.0	0.92	I	CB	350.0	0.92	420	I	STS	-	30%
R	N	074	F	BHB	20.0	0.91	C	BHB	20.0	0.91	140	C	AS	BHB	100%
R	N	075	F	HP-G	154.8	5.34	C	HP-G	154.8	5.34	800	C	AS	HP-G	100%
T	N	076	F	CB	250.0	0.98	C	CB	250.0	0.98	1000	C	-	-	-
R	N	077	P	CB	236.7	0.96	I	CB	236.7	0.96	-	I	STS	-	30%
R	N	078	F	CB	253.8	0.95	I	CB	253.8	1.01	-	I	STS	-	30%
R	N	079	P	CB	177.6	0.96	I	CB	177.6	0.96	-	I	STS	-	30%
R	N	080	F	CB	146.4	0.93	I	CB	146.4	0.97	-	I	STS	-	39%
R	N	081	F	CB	408.0	0.92	I	CB	408.0	0.92	-	I	STS	-	34%
R	N	082	F	CB	25.0	0.94	I	CB	100.0	0.94	168	I	STS	-	48%
R	N	083	F	CB	210.0	0.97	C	CB	210.0	0.97	750	C	STS	-	30%
R	N	084	F	OB	23.0	0.75	C	OB	23.0	0.86	160	C	AS	BHB	30%
R	N	085	F	OB	28.0	0.97	I	OB	28.0	0.99	130	I	STS	-	40%
R	N	086	P	CB	539.7	0.87	I	CB	539.7	0.87	882	I	STS	-	30%
R	N	087	F	CB	539.7	0.91	I	HP-A	14.6	2.83	2130	I	AS	HP-A	67%
R	N	088	P	CB	420.0	0.98	C	CB	420.0	0.98	2000	C	STS	-	60%
R	N	089	F	CB	420.0	0.99	C	CB	420.0	0.99	1000	C	AS	HP-A	46%
T	E	090	E	CB	28.0	0.93	C	CB	28.0	0.93	-	C	-	-	-
R	N	091	P	CB	466.0	0.98	C	CB	466.0	2.00	3000	C	STS	-	71%
R	N	092	P	CB	1150.0	0.98	C	CB	1150.0	0.98	2000	C	AS	CG	35%
R	N	093	F	CB	1150.0	0.98	C	CB	1150.0	0.98	2000	C	AS	CG	35%
T	E	094	E	CB	51.3	0.91	C	CB	51.3	0.91	-	C	-	-	-
R	N	095	P	CB	527.4	0.95	C	CB	527.4	0.95	-	C	STS	-	60%
R	N	096	P	BHB	99.0	0.79	C	BHB	99.0	0.83	500	C	AS	BHB	100%
R	N	097	P	HP-A	90.0	1.03	C	HP-A	90.0	1.03	3000	C	AS	HP-A	100%
R	N	098	F	HP-A	90.0	1.05	C	HP-A	90.0	2.28	3000	C	AS	HP-A	100%
T	N	099	F	CB	170.0	1.52	C	CB	400.0	0.95	750	C	-	-	-
T	N	100	P	CB	300.0	1.01	C	CB	300.0	1.01	-	C	STS	-	30%
T	N	101	F	CB	205.0	0.99	C	CB	205.0	0.99	772	C	AS	HP-G	70%
R	N	102	P	CB	340.0	0.94	C	CB	340.0	1.01	500	C	STS	-	33%

Control File Code				Heating System				DHW system					Renewable DHW system		
				Gen.	P [kW]	η*	C/ I **	Gen.	P [kW]	η*	Sto. [l]	C/ I **	STS/ AS	AS	Ren. range [%]
R	N	103	F	CB	340.0	0.93	C	CB	340.0	1.01	765	C	STS	-	33%
R	E	104	E	LB	725.0	0.88	C	LB	219.0	0.92	715	C	-	-	-
T	N	105	F	CB	762.0	1.20	C	HP-A	11.0	0.94	1000	C	AS	HP-A	31%
T	N	106	P	CB	230.0	0.90	C	CB	230.0	1.05	-	C	STS	-	30%
T	N	107	F	CB	230.0	0.90	C	CB	230.0	0.88	500	C	STS	-	30%
T	N	108	F	CB	36.0	0.97	C	CB	36.0	0.97	750	C	STS	-	34%
R	E	109	E	SB	312.0	0.78	I	SB	312.0	0.78	-	I	-	-	-
R	E	110	E	JE	192.0	0.80	I	SB	240.0	0.80	-	I	-	-	-
R	N	111	P	CB	25.0	0.85	I	CB	25.0	0.85	150	I	STS	-	32%
R	N	112	F	CB	25.0	0.98	I	CB	25.0	0.98	162	I	STS	-	32%
T	N	113	P	CB	400.0	0.89	C	HP-A	16.0	2.86	500	I	AS	HP-A	52%
R	N	114	F	BHB	9.0	0.85	C	HP-A	0.4	3.80	300	C	AS	HP-A	37%
R	N	115	F	BHB	9.0	0.85	C	HP-A	0.4	3.75	285	C	AS	HP-A	37%
R	N	116	F	BHB	9.0	0.85	C	HP-A	0.4	3.75	300	C	AS	HP-A	37%
R	E	117	E	SB	360.0	0.83	C	SB	360.0	0.83	1000	I	-	-	-
R	N	118	F	CB	236.7	0.95	I	CB	236.7	0.95	-	I	STS	-	35%
R	E	119	E	CB	552.0	0.95	I	CB	552.0	0.95	-	I	-	-	-
R	E	120	E	CB	552.0	0.95	I	CB	552.0	0.95	-	I	-	-	-
R	E	121	E	CB+ JE	1110.0	0.98	I	CB+ JE	1110.0	0.98	-	I	-	-	-
T	N	122	P	HP-A	69.0	6.85	C	HP-A	69.0	3.01	200	C	AS	HP-A	100%
T	N	123	F	HP-A	69.0	6.85	C	HP-A	69.0	3.01	187	C	AS	HP-A	100%
R	N	124	P	CB	210.4	1.02	I	CB	210.4	1.02	-	I	STS	-	34%
R	N	125	F	CB	218.4	1.01	I	CB	218.4	1.01	-	I	STS	-	34%
T	N	126	P	HP-A	54.0	1.15	I	JE	4.8	0.90	315	I	AS	HP-A	
R	N	127	P	CB	271.6	0.97	C	CB	271.6	0.97	2500	C	AS	HP-A	35%
R	N	128	F	CB	140.0	0.98	I	CB	140.0	0.98	-	I	STS	-	54%
R	N	129	P	CB	210.0	0.98	I	CB	210.0	0.98	900	I	STS	-	30%
R	N	130	F	CB	210.0	0.98	I	CB	210.0	0.98	870	I	STS	-	44%
R	N	131	P	CB	105.0	0.87	I	CB	105.0	0.95	-	I	STS	-	23%
R	N	132	F	CB	120.0	0.86	I	CB	120.0	0.96	-	I	STS	-	30%
R	N	133	P	CB	268.4	0.92	I	CB	268.4	0.97	-	I	STS	-	50%
R	N	134	F	CB	268.4	0.92	I	CB	268.4	0.97	-	I	STS	-	40%
R	N	135	P	CB	576.0	0.81	I	CB	576.0	0.91	10	I	STS	-	30%
R	N	136	F	CB	732.0	0.85	I	CB	732.0	0.85	168	I	STS	-	30%
T	N	137	P	HP-A	63.0	2.30	C	JE	4.5	1.00	150	C	-	-	-
T	N	138	F	HP-A	170.0	2.30	C	JE	6.0	1.00	150	C	-	-	-
R	N	139	P	CB	400.0	0.87	C	CB	400.0	0.98	2000	C	STS	-	36%
R	N	140	P	HP-A	7.9	2.68	I	HP-A	7.9	2.77	177	I	AS	HP-A	100%
T	N	141	P	CB	428.0	1.02	C	-	-	-	-	-	-	-	-
T	N	142	P	BHB	119.7	1.10	C	-	-	-	-	-	-	-	-
T	N	143	P	HP-A	45.0	1.57	I	HP-A	5.4	4.43	477	C	AS	HP-A	100%
R	N	144	P	BHB	300.0	0.70	C	BHB	300.0	0.84	5000	C	AS	BHB	100%
T	N	145	P	HP-G	42.0	1.79	C	HP-G	5.5	0.90	500	I	AS	PV	30%
T	N	146	P	CB	50.0	0.84	C	CB	50.0	0.90	-	C	AS	HP-A	54%

AS: Alternative System; BHB: Biomass heat boiler; C: Centralized; CB: Condensing boiler; CG: Cogeneration; Gen: Generation; HP-A: Aerothermal Heat Pump; HP-G: Geothermal Heat Pump; I: Individualized; JE: Joule Effect; LB: Low- temperature boiler; OB: Oil boiler; P: Installed Power; PV: Photovoltaic Panels; SB: ren.: renewable; Standard Boiler; Sto.: Storage; STS: Sollar Thermal System

** Generation equipment efficiency: rendimiento de combustion o en el caso de la bomba de calor, COP.*

*** Cuando el edificio se compone de una única unidad (por ejemplo una vivienda unifamiliar o un edificio terciario de un único uso/propiedad, la instalación se considera siempre centralizada.*

Table A-5. Characteristics of the ventilation system and power installed in photovoltaic panels in each EPC of the sample.

Control File Code				Mechanical Ventilation System			Air Handling Unit					PV
				SFE/ DB	airflow rate $[(m^3/h)/m^3]$	C/ I	Total heating power	Total cooling power	AC (yes:1/no: 0)	heat recovery (yes:1/ no:0)	heat recovery η	P (kWp)
R	N	001	P	SFE	0.80	C	-	-	-	-	-	-
R	N	002	F	SFE	0.80	C	-	-	-	-	-	-
R	N	003	P	SFE	1.00	C	-	-	-	-	-	-
R	N	004	F	SFE	0.24	C	-	-	-	-	-	-
R	N	005	P	SFE	1.00	C	-	-	-	-	-	-
R	N	006	F	SFE	0.63	C	-	-	-	-	-	-
R	N	007	F	SFE	0.60	C	-	-	-	-	-	-
R	N	008	F	SFE	0.90	C	-	-	-	-	-	-
R	N	009	F	SFE	1.00	C	-	-	-	-	-	-
R	N	010	F	SFE	0.70	C	-	-	-	-	-	-
R	E	011	R	SFE	0.90	C	-	-	-	-	-	-
R	E	012	E	SFE	0.80	C	-	-	-	-	-	-
R	E	013	E	DF	0.85	C	-	-	0	1	0.65	-
R	E	014	E	SFE	0.86	C	-	-	-	-	-	-
R	E	015	E	SFE	0.83	C	-	-	-	-	-	-
T	N	016	P	SFE	1.13	I			0	1	-	8.84
T	N	017	F	SFE	1.13	I			0	1	-	8.50
R	E	018	E	SFE	0.77	C	-	-	-	-	-	-
R	N	019	F	SFE	0.90	C	-	-	-	-	-	-
R	N	020	F	SFE	1.00	C	-	-	-	-	-	-
R	N	021	P	SFE	0.80	C	-	-	-	-	-	-
R	N	022	F	SFE	0.80	C	-	-	-	-	-	-
R	N	023	F	SFE	0.80	C	-	-	-	-	-	-
R	E	024	E	SFE	0.85	C	-	-	-	-	-	-
R	N	025	F	SFE	0.90	C	-	-	-	-	-	-
R	N	026	F	SFE	1.00	C	-	-	-	-	-	-
R	E	027	E	SFE	0.49	C	-	-	-	-	-	-
R	E	028	E	DF	0.90	I	-	-	0	1	0.85	-
R	E	029	E	DF	0.90	I	-	-	0	1	0.85	-
R	N	030	P	SFE	1.00	C	-	-	-	-	-	-
R	N	031	F	SFE	0.63	C	-	-	-	-	-	-
R	N	032	P	SFE	0.90	C	-	-	-	-	-	-
R	N	033	F	SFE	0.63	C	-	-	-	-	-	-
R	N	034	P	SFE	0.60	C	-	-	-	-	-	-
R	N	035	F	SFE	0.63	C	-	-	-	-	-	-
R	N	036	P	SFE	0.70	C	-	-	-	-	-	-
R	N	037	F	SFE	0.63	C	-	-	-	-	-	-
R	N	038	P	DF	0.60	I	-	-	0	1	0.92	-
R	N	039	F	DF	0.63	I	-	-	0	1	0.70	-
R	N	040	P	SFE	0.52	C	-	-	-	-	-	-
R	N	041	F	SFE	0.52	C	-	-	-	-	-	-
R	N	042	F	SFE	0.63	I	-	-	-	-	-	-
R	N	043	P	SFE	0.60	C	-	-	-	-	-	-
R	N	044	F	DF	0.63	C	-	-	0	1	0.85	-
R	N	045	P	SFE	0.60	C	-	-	-	-	-	-
R	N	046	F	SFE	0.63	C	-	-	-	-	-	-
R	N	047	P	SFE	0.60	C	-	-	-	-	-	-
R	N	048	F	SFE	0.60	C	-	-	-	-	-	-
R	N	049	F	SFE	0.63	C	-	-	-	-	-	-

Control File Code				Mechanical Ventilation System			Air Handling Unit					PV
				SFE/ DB	airflow rate [(m³/h)/m³]	C/ I	Total heating power	Total cooling power	AC (yes:1/no: 0)	heat recovery (yes:1/ no:0)	heat recovery η	P (kWp)
R	N	050	F	SFE	0.63	C	-	-	-	-	-	-
R	N	051	F	SFE	0.40	C	-	-	-	-	-	-
T	N	052	P	SFE	1.00	C	-	-	-	-	-	-
T	N	053	F	DF	1.00	C	-	-	0	1	0.85	-
R	N	054	P	SFE	0.63	I	-	-	-	-	-	-
R	N	055	F	SFE	0.40	I	-	-	-	-	-	-
R	N	056	P	SFE	0.84	C	-	-	-	-	-	-
R	N	057	F	SFE	0.84	C	-	-	-	-	-	-
R	N	058	P	DF	0.87	C	-	-	0	1	0.85	-
R	N	059	F	SFE	0.51	C	-	-	-	-	-	-
R	N	060	F	SFE	0.60	C	-	-	-	-	-	-
T	N	061	P	SFE	0.80	C	-	-	-	-	-	-
T	N	062	F	DF	1.00	C	17	-	1	1	0.82	-
R	N	063	F	SFE	0.44	C	-	-	-	-	-	-
T	N	064	F	SFE	1.00	C	67	-	1	1	0.65	5
R	N	065	F	SFE	1.00	C	-	-	-	-	-	-
T	N	066	F	SFE	0.70	C	-	-	-	-	-	-
R	N	067	F	DF	1.00	I	-	-	0	1	0.85	-
R	N	068	P	SFE	0.21	C	-	-	-	-	-	-
R	N	069	F	SFE	0.24	C	-	-	-	-	-	-
R	N	070	P	DF	0.71	C	-	-	0	1	0.81	-
R	N	071	F	DF	0.71	C	-	-	0	1	0.84	-
R	N	072	P	SFE	0.63	C	-	-	-	-	-	-
R	N	073	F	SFE	0.63	C	-	-	-	-	-	-
R	N	074	F	SFE	0.65	C	-	-	-	-	-	-
R	N	075	F	DF	0.63	I	-	-	0	1	0.83	-
T	N	076	F	SFE	1.00	C	5.5	0	1	1	-	3.75
R	N	077	P	SFE	0.63	C	-	-	-	-	-	-
R	N	078	F	SFE	0.63	C	-	-	-	-	-	-
R	N	079	P	SFE	0.63	I	-	-	-	-	-	-
R	N	080	F	SFE	0.37	I	-	-	-	-	-	-
R	N	081	F	SFE	0.22	C	-	-	-	-	-	-
R	N	082	F	DF	0.63	C	-	-	0	1	0.85	-
R	N	083	F	SFE	0.63	C	-	-	-	-	-	-
R	N	084	F	SFE	0.63	C	-	-	-	-	-	-
R	N	085	F	DF	0.46	C	-	-	0	1	0.87	-
R	N	086	P	DF	0.63	I	-	-	0	1	0.90	-
R	N	087	F	DF	0.63	I	-	-	0	1	0.90	-
R	N	088	P	SFE	0.63	C	-	-	-	-	-	-
R	N	089	F	SFE	0.63	C	-	-	-	-	-	-
T	E	090	E	DF	2.3	C	0	0	0	1	0.70	-
R	N	091	P	SFE	0.65	C	-	-	-	-	-	-
R	N	092	P	DF	0.63	I	-	-	0	1	0.74	-
R	N	093	F	DF	0.63	I	-	-	0	1	0.74	-
T	E	094	E	SFE	0.8	C	-	-	-	-	-	-
R	N	095	P	SFE	0.43	C	-	-	-	-	-	-
R	N	096	P	SFE	0.49	C	-	-	-	-	-	-
R	N	097	P	SFE	0.63	C	-	-	-	-	0.70	-
R	N	098	F	DF	0.63	C	-	-	0	1	0.70	-
T	N	099	F	DF	0.80	C	76.00	-	1	1	0.65	9.75
T	N	100	P	DF	1	C	39.83	-	1	1	0.70	-

Control File Code				Mechanical Ventilation System			Air Handling Unit					PV
				SFE/ DB	airflow rate [(m³/h)/m³]	C/ I	Total heating power	Total cooling power	AC (yes:1/no: 0)	heat recovery (yes:1/ no:0)	heat recovery η	P (kWp)
T	N	101	F	SFE	0.8	C	93.70	75.30	1	1	-	-
R	N	102	P	SFE	0.63	C	-	-	-	-	-	-
R	N	103	F	DF	0.93	C	-	-	0	1	0.84	-
R	E	104	E	SFE	0.86	C	-	-	-	-	-	-
T	N	105	F	DF	1.88	C	236.58	-	1	1	0.71	-
T	N	106	P	DF	1	C	-	-	0	1	0.68	-
T	N	107	F	DF	1	C	-	-	0	1	0,86	-
T	N	108	F	DF	1.67	C	-	-	1	1	0.69	5
R	E	109	E	SFE	0.63	C	-	-	-	-	-	-
R	E	110	E	SFE	0.63	C	-	-	-	-	-	-
R	N	111	P	SFE	0.63	I	-	-	-	-	-	-
R	N	112	F	DF	0.68	I	-	-	0	1	0.83	-
T	N	113	P	DF	1	C	-	-	1	1	0.44	-
R	N	114	F	DF	0.06	C	-	-	0	1	0.93	-
R	N	115	F	DF	0.06	C	-	-	0	1	0.93	-
R	N	116	F	DF	0.08	C	-	-	0	1	0.93	-
R	E	117	E	SFE	0.63	C	-	-	-	-	-	-
R	N	118	F	SFE	0.441	C	-	-	-	-	-	-
R	E	119	E	SFE	0.6	I	-	-	-	-	-	-
R	E	120	E	SFE	0.6	I	-	-	-	-	-	-
R	E	121	E	SFE	0.63	C	-	-	-	-	-	-
T	N	122	P	DF	1	C	-	-	0	1	0.67	-
T	N	123	F	DF	1.00	C	-	-	0	1	0.67	0
R	N	124	P	SFE	0.63	C	-	-	-	-	-	-
R	N	125	F	SFE	0.30	C	-	-	-	-	-	-
T	N	126	P	DF	1.37	C	-	-	0	1	0.67	-
R	N	127	P	DF	0.77	C	-	-	0	1	0.82	-
R	N	128	F	SFE	0.54	C	-	-	-	-	-	-
R	N	129	P	SFE	0.54	I	-	-	-	-	-	-
R	N	130	F	SFE	0.54	I	-	-	-	-	-	-
R	N	131	P	SFE	0.53	I	-	-	0	1	0.66	-
R	N	132	F	SFE	0.53	I	-	-	0	1	0.66	-
R	N	133	P	SFE	0.63	I	-	-	-	-	-	-
R	N	134	F	DF	0.63	I	-	-	0	1	0.85	-
R	N	135	P	SFE	0.36	C	-	-	-	-	-	-
R	N	136	F	SFE	0.36	C	-	-	-	-	-	-
T	N	137	P	DF	0.8	C	-	-	0	1	0.75	-
T	N	138	F	DF	0.8	C	-	-	0	1	0.75	-
R	N	139	P	SFE	0.15	C	-	-	-	-	-	-
R	N	140	P	DF	0.63	C	-	-	0	1	0.6	-
T	N	141	P	DF	0.8	C	37.56		1	1	0.74	-
T	N	142	P	DF	1	C	-	-	0	1	0.6	-
T	N	143	P	DF	1.60	C	-	-	0	1	0.66	-
R	N	144	P	DF	0.63	I	-	-	0	1	0.95	-
T	N	145	P	DF	0.80	C	-	-	0	1	0.84	8
T	N	146	P	DF	0.75	C	-	-	0	1	0.658	-

AC: Air conditioning; C: Centralized; DF: Double Flow; I: Individualized; P: Installed Power; PV: Photovoltaic Panels; SFE: Single Flow Extraction.

Appendix B: Catalog of nonconformities

The aim of this Appendix is to present the EPC sample control results in cataloguing all the nonconformities (NC) recorded in the 146 control file (CF) sample. In Section 6.2. the process to cataloguing NCs is explained and the final result is shown below in the following tables.

- Table B-1 shows the NC types registered about general and administrative data definition.
- Table B-2 provides the NC types found in building model definition.
- Table B-3 gives the NC types identified in envelope constructive definition.
- Table B-4 contains the NC types detected in thermal bridges definition.
- Table B-5 collects the NCs types catalogued in DHW and conditioning system definition.
- Table B-6 presents the NCs types recorded about ventilation system definition.

- Table B-7 shows the NCs types registered about photovoltaic system definition.
- Table B-8 provides the NCs types found in lighting system definition.
- Table B-9 gives the NCs types identified related to noncompliance with regulation.

B-1. NCs in general and administrative data definition.

NC Code	NC description
NC.1.1.	Update the date of EPC Issue and present the report generated by the software.
NC.1.2.	Correct the construction year and applicable regulation.
NC.1.3.	Define the building identification data- postal address.
NC.1.4.	Define the building identification data- the cadastral reference.
NC.1.5.	Define the building identification data- the project description data.
NC.1.6.	Define the QE's data.
NC.1.7.	Correct the climate zone definition.
NC.1.8.	Update the Calculation tool (outdated version, no correspondence with the type of EPC).
NC.1.9.	Correct the definition of type of building in terms of its use (residential/service building) or age (existing/new construction building).
NC.1.10.	Correct operational conditions (thermal loads and set point temperatures).

B-2. NCs in building model definition.

NC Code	NC description
NC.2.1.	Correct the building model geometry definition- Number of floors/building heigh.
NC.2.2.	Correct the building model geometry definition- thermal zones floor areas.
NC.2.3.	Correct the building model geometry definition- matching of the envelope with the thermal zone.
NC.2.4.	Correct the building model geometry definition- envelope/constructive element area.
NC.2.5.	Correct the building model geometry definition- Define other thermal zone/s.
NC.2.6.	Correct the building model geometry definition- the window area.
NC.2.7.	Correct the building orientation.
NC.2.8.	Define the building surrounding shadows and shading elements in windows.
NC.2.9.	Correct the type of thermal zone definition: conditioned/not conditioned and habitable/non habitable.
NC.2.10	The software cannot carry out the calculation because of errors in building model.
NC.2.11.	Correct the definition of the envelope line

B-3. NCs in envelope constructive definition.

NC Code	NC description
NC.3.1.	Correct the percentage of frame with respect to the total area of the window.
NC.3.2.	Correct the thermal transmittance of the glass based on the project definition/built.
NC.3.3.	Correct the thermal transmittance of the frame based on the project definition/built.
NC.3.4.	Correct the global thermal transmittance of the window based on the result of the test (UNE-EN ISO 12567-1:2011/UNE-EN ISO 8990:1997).
NC.3.5.	Correct the g-value based on the project definition/built.
NC.3.6.	Justify the thermal characteristics of the glass or frame and the air permeability.
NC.3.7.	Correct the type of window (e.g. from door to window).
NC.3.8.	Correct the type of constructive element (from facade to dividing wall...).
NC.3.9.	Define other types of enclosures/constructive element.
NC.3.10.	Correct the definition of the layers or the thermal transmittance of a constructive element based on the project definition or as built.
NC.3.11.	Correct the type of the thermal insulation.
NC.3.12.	Correct the thermal insulation thermal conductivity.
NC.3.13.	Correct the thermal insulation thickness.
NC.3.14.	Justify the existence of the thermal insulation.
NC.3.15.	Justify the thermal insulation characteristics by technical datasheets.

B-4. NCs in thermal bridges definition.

NC Code	NC description
NC.4.1.	Define the thermal bridges.
NC.4.2.	Correct the linear thermal transmittance of the thermal bridge.
NC.4.3.	Correct the length of the thermal bridge.
NC.4.4.	Justify the linear thermal transmittance of the thermal bridge.

B-5. NCs in DHW and conditioning system definition.

NC Code	NC description
NC.5.1.	Correct the general definition of the system configuration- type of the system.
NC.5.2.	Correct the general definition of the system configuration - definition of the renewable source (heat pump for the DHW...).
NC.5.3.	Correct the general definition of the system configuration- equipment order (based on real demand order).
NC.5.4.	Correct the general definition of the system configuration-Divide a system in two (heating/DHW or DHW1/DHW2).
NC.5.5.	Define other conditioning or DHW system.
NC.5.6.	Justify the renewable coverage in DHW - aerothermal heat pump.
NC.5.7.	Justify the renewable coverage in DHW - solar collectors.
NC.5.8.	Correct the percentage of renewable coverage in DHW.
NC.5.9.	Justify the defined DHW demand.
NC.5.10.	Correct the defined DHW demand.
NC.5.11.	Correct the storage capacity of the DHW (storage tank or electric boiler).
NC.5.12.	Define a storage tank.
NC.5.13.	Define other conditioning or DHW equipment.
NC.5.14.	Correct the power of equipment.

NC Code	NC description
NC.5.15.	Correct the power of terminal units.
NC.5.16.	Correct the equipment efficiency.
NC.5.17.	Justify the characteristics of equipment by technical datasheet.
NC.5.18.	Present the systems Project (more data is needed to make checks).
NC.5.1.	Correct the general definition of the system configuration- type of the system.
NC.5.2.	Correct the general definition of the system configuration - definition of the renewable source (heat pump for the DHW...).
NC.5.3.	Correct the general definition of the system configuration- equipment order (based on real demand order).
NC.5.4.	Correct the general definition of the system configuration-Divide a system in two (heating/DHW or DHW1/DHW2).

B-6. NC in ventilation system definition.

NC Code	NC description
NC.6.1.	Correct the defined value of air change rate of the mechanical ventilation.
NC.6.2.	Justify the defined value of air change rate of the mechanical ventilation.
NC.6.3.	Define the mechanical ventilation with heat recovery systems (MVHRS).
NC.6.4.	Correct the MVHRS efficiency.
NC.6.5.	Justify the characteristics of mechanical ventilation equipment by technical datasheet.

B-7. NCs in photovoltaic system definition.

NC Code	NC description
NC.7.1.	Justify the defined electricity production.
NC.7.2.	Define or correct the electricity production.

B-8. NCs in lighting system definition.

NC Code	NC description
NC.8.1.	Correct the definition of the installed power.
NC.8.2.	Justify the definition of the installed power in conditioned thermal zones.
NC.8.3.	Correct the defined energy efficiency value of an installation (VEEI for its acronym in Spanish).
NC.8.4.	Present the lighting project (more data is needed in order to make checks).
NC.8.5.	Define the lighting systems in one or more conditioned thermal zones.
NC.8.6.	Define the building total electric power installed value.

B-9. NCs because of noncompliance with regulation.

NC Code	NC description
NC.9.1.	Renewable coverage of DHW (CTE DB HE4).
NC.9.2.	the constructive elements thermal characteristics doesn't meet with the regulation requirements (air permeability of the window, thermal transmittance of the constructive element,...).

Appendix C: Results of nonconformities analysis. Data tables

The raw data related to Chapter 6 results are provided in this Appendix C by following tables:

- Table C-1 shows the qualitative data matrix for Section 6.3.1. The codes shown in the table corresponding to the categories and the categorization rules are defined in Section 6.2. The codes of the NCs, on the other hand, are defined in Appendix B.
- Table C-2 displays all quantitative data results obtained for the Section 6.3.2. The quantified parameters are defined in Section 6.2. The codes of the NCs, on the other hand, are defined in Appendix B.
- Tables C-3 and C-4 provides all data of mixed research results obtained for Section 6.3.3. The codes of the NCs, on the other hand, are defined in Appendix B.

Table C-1. Nonconformities qualitative data results matrix.

	Q1								Q2						Q3				Q4					Q5					
	Q1a	Q1b	Q1c	Q1d	Q1e	Q1f	Q1g	Q1h	Q2a	Q2b	Q2c	Q2d	Q2e	Q2f	Q3a	Q3b	Q3c	Q3d	Q4a	Q4b	Q4c	Q4d	Q4e	Q5a	Q5b	Q5c	Q5d	Q5e	Q5f
NC.1.1.	*								*								*					*		*			*		
NC.1.2.	*											*					*					*					*		
NC.1.3.	*									*							*					*		*			*		
NC.1.4.	*									*							*					*		*			*		
NC.1.5.	*									*							*					*		*			*		
NC.1.6.	*									*							*					*		*			*		
NC.1.7.	*										*					*						*		*			*		
NC.1.8.	*										*				*					*				*			*		
NC.1.9.	*											*					*				*				*		*		
NC.1.10.	*											*					*	*				*					*		
NC.2.1.		*										*			*		*			*					*		*		*
NC.2.2.		*										*					*	*		*							*		
NC.2.3.		*									*				*						*					*			
NC.2.4.		*										*			*		*	*		*					*		*		
NC.2.5.		*										*			*		*			*							*		*
NC.2.6.		*										*					*	*			*				*		*		*
NC.2.7.		*										*				*						*					*		*
NC.2.8.		*										*					*				*				*		*		*
NC.2.9.		*										*			*						*						*		*
NC.2.10		*									*				*					*						*			
NC.2.11.		*										*			*						*						*		*
NC.3.1.			*						*			*					*	*				*			*		*		*
NC.3.2.			*						*			*			*		*	*				*			*		*		*
NC.3.3.			*						*			*			*		*	*				*			*		*		*
NC.3.4.			*									*					*					*					*		
NC.3.5.			*									*					*					*					*		*
NC.3.6.			*										*				*	*	*					*			*		

	Q1								Q2						Q3				Q4					Q5					
	Q1a	Q1b	Q1c	Q1d	Q1e	Q1f	Q1g	Q1h	Q2a	Q2b	Q2c	Q2d	Q2e	Q2f	Q3a	Q3b	Q3c	Q3d	Q4a	Q4b	Q4c	Q4d	Q4e	Q5a	Q5b	Q5c	Q5d	Q5e	Q5f
NC.3.7.			*									*				*						*					*		
NC.3.8.			*								*				*							*					*		*
NC.3.9.			*									*			*		*				*						*	*	
NC.3.10.			*									*			*		*					*			*		*	*	
NC.3.11.			*									*					*					*					*	*	
NC.3.12.			*						*			*			*		*	*				*			*		*	*	
NC.3.13.			*									*					*					*					*	*	
NC.3.14.			*										*				*	*	*					*			*		
NC.3.15.			*										*				*		*					*			*		
NC.4.1.				*						*							*	*				*		*			*		
NC.4.2.				*								*					*	*				*					*	*	
NC.4.3.				*								*					*	*				*					*		*
NC.4.4.				*									*				*		*					*			*		
NC.5.1.					*							*			*						*						*		*
NC.5.2.					*							*			*						*						*		*
NC.5.3.					*							*			*						*						*		*
NC.5.4.					*						*				*						*						*		*
NC.5.5.					*							*			*						*						*		*
NC.5.6.					*								*				*	*	*					*			*		
NC.5.7.					*								*				*	*	*					*			*		
NC.5.8.					*							*			*		*	*				*			*		*		*
NC.5.9.					*								*				*		*						*		*		
NC.5.10.					*							*				*	*	*				*			*		*		*
NC.5.11.					*							*				*	*					*			*		*		*
NC.5.12.					*							*					*					*			*		*		*
NC.5.13.					*							*			*		*					*					*		*
NC.5.14.					*							*					*					*			*		*		*

	Q1								Q2						Q3				Q4					Q5					
	Q1a	Q1b	Q1c	Q1d	Q1e	Q1f	Q1g	Q1h	Q2a	Q2b	Q2c	Q2d	Q2e	Q2f	Q3a	Q3b	Q3c	Q3d	Q4a	Q4b	Q4c	Q4d	Q4e	Q5a	Q5b	Q5c	Q5d	Q5e	Q5f
NC.5.15.					*							*					*					*			*		*		*
NC.5.16.					*				*			*			*		*	*				*			*		*		*
NC.5.17.					*								*				*		*					*			*		
NC.5.18.					*								*				*		*								*		
NC.6.1.						*						*			*		*					*			*		*	*	
NC.6.2.						*							*				*	*	*					*			*		
NC.6.3.						*						*			*		*				*						*		*
NC.6.4.						*			*			*			*		*	*				*			*		*	*	
NC.6.5.						*							*				*		*					*			*		
NC.7.1.							*						*				*		*					*			*		
NC.7.2.							*					*			*		*	*				*					*		*
NC.8.1.								*				*					*	*				*			*		*		*
NC.8.2.								*					*				*		*					*			*		
NC.8.3.								*				*					*					*			*		*		*
NC.8.4.								*					*				*		*								*		
NC.8.5.								*		*							*				*			*					
NC.8.6.								*					*				*		*						*				
NC.9.1.					*									*				*					*	*		*			
NC.9.2.			*											*				*					*	*		*			

Table C-2. Nonconformities quantitative results.

	Y	K_{nrPEC}	K_{CO2}	β
NC.1.1.	5	0.0%	0.0%	0.00
NC.1.2.	3	0.0%	0.0%	0.00
NC.1.3.	11	0.0%	0.0%	0.00
NC.1.4.	16	0.0%	0.0%	0.00
NC.1.5.	3	0.0%	0.0%	0.00
NC.1.6.	3	0.0%	0.0%	0.00
NC.1.7.	4	26.5%	27.0%	1.07
NC.1.8.	10	13.1%	9.1%	1.11
NC.1.9.	5	32.9%	32.7%	1.64
NC.1.10.	3	0.3%	0.3%	0.01
NC.2.1.	4	0.0%	0.0%	0.00
NC.2.2.	4	22.1%	23.3%	0.91
NC.2.3.	5	0.4%	0.4%	0.02
NC.2.4.	5	2.7%	2.4%	0.13
NC.2.5.	3	0.2%	0.1%	0.00
NC.2.6.	10	2.0%	4.4%	0.32
NC.2.7.	2	6.4%	8.4%	0.15
NC.2.8.	23	7.0%	6.9%	1.61
NC.2.9.	9	13.1%	14.4%	1.24
NC.2.10	3	100.0%	100.0%	3.00
NC.2.11.	6	7.6%	7.1%	0.44
NC.3.1.	18	4.1%	2.5%	0.59
NC.3.2.	16	7.1%	7.6%	1.18
NC.3.3.	12	0.7%	0.8%	0.09
NC.3.4.	5	3.1%	2.5%	0.14
NC.3.5.	2	0.1%	0.1%	0.00
NC.3.6.	17	0.0%	0.0%	0.00
NC.3.7.	3	0.1%	0.1%	0.00
NC.3.8.	18	4.3%	4.2%	0.77
NC.3.9.	11	3.2%	3.6%	0.37
NC.3.10.	15	0.5%	0.5%	0.08
NC.3.11.	27	3.3%	3.8%	0.95
NC.3.12.	9	4.5%	0.3%	0.22
NC.3.13.	37	4.5%	4.6%	1.68
NC.3.14.	8	0.0%	0.0%	0.00
NC.3.15.	5	0.0%	0.0%	0.00
NC.4.1.	8	25.1%	25.1%	2.01
NC.4.2.	7	6.8%	12.2%	0.66
NC.4.3.	20	6.1%	6.2%	1.22
NC.4.4.	12	0.0%	0.0%	0.00
NC.5.1.	5	21.5%	30.0%	1.29
NC.5.2.	8	6.7%	10.6%	0.69
NC.5.3.	2	0.5%	0.5%	0.01
NC.5.4.	2	5.1%	8.8%	0.14
NC.5.5.	6	1.2%	0.8%	0.06
NC.5.6.	16	0.0%	0.0%	0.00
NC.5.7.	10	0.0%	0.0%	0.00

NC.5.8.	13	13.7%	13.9%	1.79
NC.5.9.	1	0.0%	0.0%	0.00
NC.5.10.	9	5.3%	5.5%	0.48
NC.5.11.	19	0.5%	0.5%	0.10
NC.5.12.	5	2.0%	2.1%	0.10
NC.5.13.	7	0.4%	0.4%	0.03
NC.5.14.	26	0.1%	0.1%	0.02
NC.5.15.	3	6.8%	7.6%	0.22
NC.5.16.	32	14.3%	12.2%	4.23
NC.5.17.	13	0.0%	0.0%	0.00
NC.5.18.	2	0.0%	0.0%	0.00
NC.6.1.	14	11.9%	12.4%	1.70
NC.6.2.	11	0.0%	0.0%	0.00
NC.6.3.	4	39.3%	47.0%	1.72
NC.6.4.	7	4.4%	4.6%	0.32
NC.6.5.	7	0.0%	0.0%	0.00
NC.7.1.	2	0.0%	0.0%	0.00
NC.7.2.	4	11.7%	10.8%	0.45
NC.8.1.	5	13.5%	11.8%	0.63
NC.8.2.	3	0.0%	0.0%	0.00
NC.8.3.	3	0.0%	0.0%	0.00
NC.8.4.	4	0.0%	0.0%	0.00
NC.8.5.	1	22.0%	12.9%	0.17
NC.8.6.	6	0.0%	0.0%	0.00
NC.9.1.	6	0.0%	0.0%	0.00
NC.9.2.	2	0.0%	0.0%	0.00

Table C-3. Mixed investigation results. Weighting 1.

	Q1								Q2						Q3				Q4					Q5					
	Q1a	Q1b	Q1c	Q1d	Q1e	Q1f	Q1g	Q1h	Q2a	Q2b	Q2c	Q2d	Q2e	Q2f	Q3a	Q3b	Q3c	Q3d	Q4a	Q4b	Q4c	Q4d	Q4e	Q5a	Q5b	Q5c	Q5d	Q5e	Q5f
NC.1.1.	5								5								5					5		5			5		
NC.1.2.	3											3					3					3					3		
NC.1.3.	11									11							11					11		11			11		
NC.1.4.	16									16							16					16		16			16		
NC.1.5.	3									3							3					3		3			3		
NC.1.6.	3									3							3					3		3			3		
NC.1.7.	4										4					4						4		4			4		
NC.1.8.	10										10				10					10				10			10		
NC.1.9.	5											5					5				5				5		5		
NC.1.10.	3											3					1	1				3					3		
NC.2.1.		4										4			2		1			4					4		1		3
NC.2.2.		4										4					1	2		4					4		4		
NC.2.3.		5									5				5						5					5			
NC.2.4.		5										5			2		1	1		5					5		5		
NC.2.5.		3										3			1		1			3							1		2
NC.2.6.		10										10					4	6			10				10		1		9
NC.2.7.		2										2				2						2					0		2
NC.2.8.		23										23					23				23				23		9		14
NC.2.9.		9										9			9						9						5		4
NC.2.10		3									3				3					3						3			
NC.2.11.		6										6			6						6						2		4
NC.3.1.			18						16			2					8	10				18			18		11		7
NC.3.2.			16						6			10			4		5	7				16			16		4		12
NC.3.3.			12						7			5			3		5	4				12			12		5		7
NC.3.4.			5									5					5					5					5		
NC.3.5.			2									2					2					2					0		2
NC.3.6.			17										17				9	8	17					17			17		

	Q1								Q2						Q3				Q4					Q5					
	Q1a	Q1b	Q1c	Q1d	Q1e	Q1f	Q1g	Q1h	Q2a	Q2b	Q2c	Q2d	Q2e	Q2f	Q3a	Q3b	Q3c	Q3d	Q4a	Q4b	Q4c	Q4d	Q4e	Q5a	Q5b	Q5c	Q5d	Q5e	Q5f
NC.3.7.			3									3				3						3					3		
NC.3.8.			18								18				18							18					9		9
NC.3.9.			11									11			3		8				11						4	7	
NC.3.10.			15									15			1		14					15			15		9	6	
NC.3.11.			27									27					27					27					14	13	
NC.3.12.			9						5			4			3		4	2				9			9		0	9	
NC.3.13.			37									37					37					37					15	22	
NC.3.14.			8										8				6	1	8					8			8		
NC.3.15.			5										5				5		5					5			5		
NC.4.1.				8						8							2	5				8		8			8		
NC.4.2.				7								7					4	2				7					4	3	
NC.4.3.				20								20					15	5				20					9		11
NC.4.4.				12									12				12		12					12			12		
NC.5.1.					5							5			5						5						3		2
NC.5.2.					8							8			7						8						4		4
NC.5.3.					2							2			1						2						0		2
NC.5.4.					2						2				2						2						1		1
NC.5.5.					6							6			6						6						3		3
NC.5.6.					16								16				13	3	16					16			16		
NC.5.7.					10								10				4	1	10					10			10		
NC.5.8.					13							13			6		5	2				13			13		6		7
NC.5.9.					1								1				1		1						1		1		
NC.5.10.					9							9				2	6	1				9			9		3		6
NC.5.11.					19							19				2	17					19			19		6		13
NC.5.12.					5							5					5					5			5		2		3
NC.5.13.					7							7			4		3					7					3		4
NC.5.14.					26							26					26					26			26		5		21

	Q1								Q2						Q3				Q4					Q5					
	Q1a	Q1b	Q1c	Q1d	Q1e	Q1f	Q1g	Q1h	Q2a	Q2b	Q2c	Q2d	Q2e	Q2f	Q3a	Q3b	Q3c	Q3d	Q4a	Q4b	Q4c	Q4d	Q4e	Q5a	Q5b	Q5c	Q5d	Q5e	Q5f
NC.5.15.					3							3					3					3			3		1		2
NC.5.16.					32				12			20			3		21	8				32			32		14		18
NC.5.17.					13								13				13		13					13			13		
NC.5.18.					2								2				2		2								2		
NC.6.1.						14						14			11		3					14			14		7	7	
NC.6.2.						11							11				8	3	11					11			11		
NC.6.3.						4						4			4		1				4						4		0
NC.6.4.						7			5			2			2		4	1				7			7		3	4	
NC.6.5.						7							7				7		7					7			7		
NC.7.1.							2						2				2		2					2			2		
NC.7.2.							4					4			1		2	1				4					2		2
NC.8.1.								5				5					4	1				5			5		4		1
NC.8.2.								3					3				3		3					3			3		
NC.8.3.								3				3					3					3			3		2		1
NC.8.4.								4					4				4		4								4		
NC.8.5.								1		1							1				1				1	1			
NC.8.6.								6					6				6		6						6		6		
NC.9.1.					6									6				6					6	6		6			
NC.9.2.			2											2				2					2	2		2			
Total Y_{Qi}	63	74	205	47	185	43	6	22	56	42	42	380	117	8	122	13	413	83	117	29	97	394	8	172	265	17	381	71	176

Table C-4. Mixed investigation results. Weighting 2.

	Q1								Q2						Q3				Q4					Q5					
	Q1a	Q1b	Q1c	Q1d	Q1e	Q1f	Q1g	Q1h	Q2a	Q2b	Q2c	Q2d	Q2e	Q2f	Q3a	Q3b	Q3c	Q3d	Q4a	Q4b	Q4c	Q4d	Q4e	Q5a	Q5b	Q5c	Q5d	Q5e	Q5f
NC.1.1.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NC.1.2.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NC.1.3.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NC.1.4.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NC.1.5.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NC.1.6.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NC.1.7.	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.00	0.00	0.00	0.00	0.80	0.00	0.00	0.00	0.00	0.00	0.80	0.00	0.80	0.00	0.00	0.80	0.00	0.00
NC.1.8.	1.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.11	0.00	0.00	0.00	1.11	0.00	0.00	0.00	0.00	1.11	0.00	0.00	0.00	1.11	0.00	0.00	1.11	0.00	0.00
NC.1.9.	1.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.31	0.00	0.00	0.00	0.00	1.31	0.00	0.00	0.00	1.31	0.00	0.00	0.00	1.31	0.00	1.31	0.00	0.00
NC.1.10.	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00
NC.2.1.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NC.2.2.	0.00	0.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.68	0.00	0.00	0.00	0.00	0.23	0.45	0.00	0.68	0.00	0.00	0.00	0.00	0.68	0.00	0.68	0.00	0.00
NC.2.3.	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
NC.2.4.	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.05	0.00	0.03	0.03	0.00	0.10	0.00	0.00	0.00	0.00	0.10	0.00	0.10	0.00	0.00
NC.2.5.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NC.2.6.	0.00	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.32	0.00	0.00	0.00	0.00	0.13	0.19	0.00	0.00	0.32	0.00	0.00	0.00	0.32	0.00	0.03	0.00	0.29
NC.2.7.	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.07
NC.2.8.	0.00	1.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.61	0.00	0.00	0.00	0.00	1.61	0.00	0.00	0.00	1.61	0.00	0.00	0.00	1.61	0.00	0.63	0.00	0.98
NC.2.9.	0.00	1.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.10	0.00	0.00	1.10	0.00	0.00	0.00	0.00	0.00	1.10	0.00	0.00	0.00	0.00	0.00	0.55	0.00	0.55
NC.2.10	0.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	0.00	0.00	0.00	2.00	0.00	0.00	0.00	0.00	2.00	0.00	0.00	0.00	0.00	0.00	2.00	0.00	0.00	0.00
NC.2.11.	0.00	0.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.37	0.00	0.00	0.37	0.00	0.00	0.00	0.00	0.00	0.37	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.29
NC.3.1.	0.00	0.00	0.59	0.00	0.00	0.00	0.00	0.00	0.53	0.00	0.00	0.59	0.00	0.00	0.00	0.00	0.26	0.33	0.00	0.00	0.00	0.59	0.00	0.00	0.59	0.00	0.36	0.00	0.23
NC.3.2.	0.00	0.00	1.18	0.00	0.00	0.00	0.00	0.00	0.44	0.00	0.00	1.18	0.00	0.00	0.30	0.00	0.37	0.52	0.00	0.00	0.00	1.18	0.00	0.00	1.18	0.00	0.30	0.00	0.89
NC.3.3.	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.09	0.00	0.00	0.02	0.00	0.04	0.03	0.00	0.00	0.00	0.09	0.00	0.00	0.09	0.00	0.04	0.00	0.05
NC.3.4.	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.11	0.00	0.00

	Q1								Q2						Q3				Q4					Q5					
	Q1a	Q1b	Q1c	Q1d	Q1e	Q1f	Q1g	Q1h	Q2a	Q2b	Q2c	Q2d	Q2e	Q2f	Q3a	Q3b	Q3c	Q3d	Q4a	Q4b	Q4c	Q4d	Q4e	Q5a	Q5b	Q5c	Q5d	Q5e	Q5f
NC.3.5.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NC.3.6.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NC.3.7.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NC.3.8.	0.00	0.00	0.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.77	0.00	0.00	0.00	0.77	0.00	0.00	0.00	0.00	0.00	0.00	0.77	0.00	0.00	0.00	0.00	0.38	0.00	0.38
NC.3.9.	0.00	0.00	0.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.37	0.00	0.00	0.10	0.00	0.27	0.00	0.00	0.00	0.37	0.00	0.00	0.00	0.00	0.00	0.13	0.24	0.00
NC.3.10.	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.01	0.00	0.07	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.08	0.00	0.05	0.03	0.00
NC.3.11.	0.00	0.00	0.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.95	0.00	0.00	0.00	0.00	0.95	0.00	0.00	0.00	0.00	0.95	0.00	0.00	0.00	0.00	0.49	0.46	0.00
NC.3.12.	0.00	0.00	0.22	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.00	0.10	0.00	0.00	0.07	0.00	0.10	0.05	0.00	0.00	0.00	0.22	0.00	0.00	0.22	0.00	0.00	0.22	0.00
NC.3.13.	0.00	0.00	1.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.68	0.00	0.00	0.00	0.00	1.68	0.00	0.00	0.00	0.00	1.68	0.00	0.00	0.00	0.00	0.68	1.00	0.00
NC.3.14.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NC.3.15.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NC.4.1.	0.00	0.00	0.00	2.01	0.00	0.00	0.00	0.00	0.00	2.01	0.00	0.00	0.00	0.00	0.00	0.00	0.50	1.25	0.00	0.00	0.00	2.01	0.00	2.01	0.00	0.00	2.01	0.00	0.00
NC.4.2.	0.00	0.00	0.00	0.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.57	0.00	0.00	0.00	0.00	0.38	0.19	0.00	0.00	0.00	0.57	0.00	0.00	0.00	0.00	0.38	0.19	0.00
NC.4.3.	0.00	0.00	0.00	1.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.22	0.00	0.00	0.00	0.00	0.92	0.31	0.00	0.00	0.00	1.22	0.00	0.00	0.00	0.00	0.55	0.00	0.67
NC.4.4.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NC.5.1.	0.00	0.00	0.00	0.00	1.03	0.00	0.00	0.00	0.00	0.00	0.00	1.03	0.00	0.00	1.03	0.00	0.00	0.00	0.00	0.00	1.03	0.00	0.00	0.00	0.00	0.00	0.77	0.00	0.26
NC.5.2.	0.00	0.00	0.00	0.00	0.61	0.00	0.00	0.00	0.00	0.00	0.00	0.61	0.00	0.00	0.61	0.00	0.00	0.00	0.00	0.00	0.61	0.00	0.00	0.00	0.00	0.00	0.26	0.00	0.35
NC.5.3.	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
NC.5.4.	0.00	0.00	0.00	0.00	0.14	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.00	0.00	0.14	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.07
NC.5.5.	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.03
NC.5.6.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NC.5.7.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NC.5.8.	0.00	0.00	0.00	0.00	1.79	0.00	0.00	0.00	0.00	0.00	0.00	1.79	0.00	0.00	0.83	0.00	0.69	0.28	0.00	0.00	0.00	1.79	0.00	0.00	1.79	0.00	0.83	0.00	0.97
NC.5.9.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NC.5.10.	0.00	0.00	0.00	0.00	0.48	0.00	0.00	0.00	0.00	0.00	0.00	0.48	0.00	0.00	0.00	0.11	0.32	0.05	0.00	0.00	0.00	0.48	0.00	0.00	0.48	0.00	0.16	0.00	0.32
NC.5.11.	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.01	0.09	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.10	0.00	0.03	0.00	0.07
NC.5.12.	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.08	0.00	0.02	0.00	0.06

	Q1								Q2						Q3				Q4					Q5					
	Q1a	Q1b	Q1c	Q1d	Q1e	Q1f	Q1g	Q1h	Q2a	Q2b	Q2c	Q2d	Q2e	Q2f	Q3a	Q3b	Q3c	Q3d	Q4a	Q4b	Q4c	Q4d	Q4e	Q5a	Q5b	Q5c	Q5d	Q5e	Q5f
NC.5.13.	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.02	0.00	0.01	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.01	0.00	0.02
NC.5.14.	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.02	0.00	0.00	0.00	0.02
NC.5.15.	0.00	0.00	0.00	0.00	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.00	0.00	0.00	0.00	0.22	0.00	0.00	0.00	0.00	0.22	0.00	0.00	0.22	0.00	0.07	0.00	0.14
NC.5.16.	0.00	0.00	0.00	0.00	4.23	0.00	0.00	0.00	1.59	0.00	0.00	2.65	0.00	0.00	0.40	0.00	2.78	1.06	0.00	0.00	0.00	4.23	0.00	0.00	4.23	0.00	1.85	0.00	2.38
NC.5.17.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NC.5.18.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NC.6.1.	0.00	0.00	0.00	0.00	0.00	1.70	0.00	0.00	0.00	0.00	0.00	1.70	0.00	0.00	1.34	0.00	0.36	0.00	0.00	0.00	0.00	1.70	0.00	0.00	1.70	0.00	0.85	0.85	0.00
NC.6.2.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NC.6.3.	0.00	0.00	0.00	0.00	0.00	1.72	0.00	0.00	0.00	0.00	0.00	1.72	0.00	0.00	1.72	0.00	0.43	0.00	0.00	0.00	1.72	0.00	0.00	0.00	0.00	0.00	1.72	0.00	0.00
NC.6.4.	0.00	0.00	0.00	0.00	0.00	0.32	0.00	0.00	0.23	0.00	0.00	0.09	0.00	0.00	0.09	0.00	0.18	0.05	0.00	0.00	0.00	0.32	0.00	0.00	0.32	0.00	0.14	0.18	0.00
NC.6.5.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NC.7.1.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NC.7.2.	0.00	0.00	0.00	0.00	0.00	0.00	0.45	0.00	0.00	0.00	0.00	0.45	0.00	0.00	0.11	0.00	0.22	0.11	0.00	0.00	0.00	0.45	0.00	0.00	0.00	0.00	0.22	0.00	0.22
NC.8.1.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.63	0.00	0.00	0.00	0.63	0.00	0.00	0.00	0.00	0.51	0.13	0.00	0.00	0.00	0.63	0.00	0.00	0.63	0.00	0.51	0.00	0.13
NC.8.2.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NC.8.3.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NC.8.4.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NC.8.5.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.00
NC.8.6.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NC.9.1.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NC.9.2.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total β_{Qi}	3.2	6.3	6.1	3.8	8.8	3.7	0.5	0.8	3.0	2.2	4.8	24.2	0.0	0.0	12.3	1.0	15.0	5.0	0.0	3.9	8.8	20.4	0.0	3.9	15.9	2.0	18.3	3.2	9.5

Appendix D: Validation Rules

In this Appendix D the validation rules stablished for the automatic checks in Section 7.4. are provided. They are organized in the following three groups:

D.1. Validation rules for identify NCs with a null incidence in the error, but which correspond to data necessary to EPC registration.

D.2. Validation rules for identify NCs. The errors are detected with absolute certainty by this type of rules.

D.3. Validation rules for identify unreliable input data. They make it possible to detect the potential, because the EPC has one or more suspicious inputs that suggest it may contain errors and they generate alarms.

D.1. Validation rules for identify NCs with a null incidence in the error, but which correspond to data necessary to EPC registration.

R1. Expired EPC issuance date

If the date of issue is more than two 2 months prior, correction is required. This rule responds to NC.1.1.

The data required for the check can be found in the XML code as follows:

<DatosDelCertificador>
    <Fecha>22/02/2021</Fecha>
<DatosDelCertificador>

R2. Lack of definition of postal address

If any or more of the building identification data (Address, Municipality, Postal Code, Province or Autonomous Community) is undefined, it is required to complete its definition. This rule responds to NC.1.3.

The data required for the check can be found in the XML code as follows:

<IdentificacionEdificio>
    <Direccion>- </Direccion>
    <Municipio>- </Municipio>
    <CodigoPostal/>
    <Provincia>- </Provincia>
    <ComunidadAutonoma>- </ComunidadAutonoma>
<IdentificacionEdificio>

R3. Lack of cadastral reference definition

If the cadastral reference is not defined in the identification of the building, its definition will be required. This rule responds to NC.1.4.

The data required for the check can be found in the XML code as follows:

Código XML:

```
<IdentificacionEdificio>
        <ReferenciaCatastral>ninguno</ReferenciaCatastral>
<IdentificacionEdificio>
```

R4. Lack of building description

If some or more data of the building description (building use, number of floors above ground, number of floors below ground, floor area, roof area, total height, image data and site plan data) is undefined, it is required to complete its definition. This rule responds to NC.1.5.

Código XML: The data required for the check can be found in the XML code as follows:

```
<DatosGeneralesyGeometria>
      <NumeroDePlantasSobreRasante>8</NumeroDePlantasSobreRasante>
      <NumeroDePlantasBajoRasante>0</NumeroDePlantasBajoRasante>
<DatosGeneralesyGeometria>
```

R5. Lack of QE's data definition

If any or more of the certifier's data (name and surname(s), NIF, Company Name, Address, Municipality, Postal Code, Province, Autonomous Community, Email, Qualification, Telephone) is undefined, it will be required to complete its definition. This rule responds to NC.1.6.

The data required for the check can be found in the XML code as follows:

```
<DatosDelCertificador>
```

<NombreyApellidos>NombresApellido1Apellido2</Nombrey Apellidos>
<NIF>CIF</NIF>
<RazonSocial>Razón Social</RazonSocial>
<NIFEntidad/>
<Domicilio>Nombre calle</Domicilio>
<Municipio>Localidad</Municipio>
<CodigoPostal>Codigo postal</CodigoPostal>
<Provincia>- Seleccione de la lista -</Provincia>
<ComunidadAutonoma>- Seleccione de la lista </ComunidadAutonoma>
<Email>-</Email>
<Titulacion>-</Titulacion>
<Telefono>-</Telefono>
</DatosDelCertificador>

D.2. Validation rules for identify NCs

R6. Wrong definition of the climatic zone

To check the definition of the climate zone, a search is made in the XML file for the municipality and the climate zone. The database entered in the program is used to check if they correspond to each other. To build the database to be entered in the program, the climate zone corresponding to all the municipalities of the Basque Country that are in the HULC 2019 database (see table D-1) has been searched. This rule responds to NC.1.7.

The data required for the check can be found in the XML code as follows:

<IdentificacionEdificio>
<Municipio>Irun</Municipio>
<ZonaClimatica>D1</ZonaClimatica>
<IdentificacionEdificio>

Table D-1. Climatic Zones of each municipality of the Basque Country according to CTE DB HE 2019.

Province	Municipality	Altitude (m)	CTE DB HE 2019
Gipuzkoa	Abaltzisketa	370	D1
	Aduna	130	D1
	Aia	311	D1
	Aizarnazabal	58	D1
	Albiztur	278	D1
	Alegia	94	D1
	Alkiza	341	D1
	Altzaga	279	D1
	Altzo	217	D1
	Amezketa	215	D1
	Andoain	65	D1
	Anoeta	77	D1
	Antzuola	236	D1
	Arama	169	D1
	Aretxabaleta	260	D1
	Arrasate	236	D1
	Asteasu	142	D1
	Astigarraga	25	D1
	Ataun	197	D1
	Azkoitia	113	D1
	Azpeitia	80	D1
	Baliarrain	294	D1
	Beasain	173	D1
	Beizama	485	E1
	Belauntza	213	D1
	Berastegi	403	E1
	Bergara	155	D1
	Berrobi	163	D1
	Bidegoian (Bidania- Goiatz desde 2013)	489	E1
	Deba	10	D1
	Donostia	6	D1
	Eibar	121	D1
	Elduain	246	D1
	Elgeta	462	E1
	Elgoibar	44	D1
	Errenteria	12	D1
	Errezil	304	D1
	Eskoriatza	279	D1
	Ezkio (1)- Itsaso (2)	450 (1)- 400(2)	E1
	Gabiria	418	E1
	Gaintza	444	E1
	Gaztelu	454	E1
	Getaria	18	D1
	Hernani	44	D1

Province	Municipality	Altitude (m)	CTE DB HE 2019
	Hernialde	302	D1
	Hondarribia	16	D1
	Ibarra	72	D1
	Idiazabal	210	D1
	Ikaztegieta	113	D1
	Irun	20	D1
	Irura	74	D1
	Itsasondo	173	D1
	Larraul	239	D1
	Lasarte- Oria	20	D1
	Lazkao	157	D1
	Leaburu	297	D1
	Legazpi	408	D1
	Legorreta	124	D1
	Leintz- Gatzaga	456	E1
	Lezo	18	D1
	Lizartza	138	D1
	Mendaro	12	D1
	Mutiloa	246	D1
	Mutriku	49	D1
	Oiartzun	84	D1
	Olaberria	320	D1
	Oñati	230	D1
	Ordizia	150	D1
	Orendain	391	D1
	Orexa	417	E1
	Orio	14	D1
	Ormaiztegi	196	D1
	Pasaia	4	D1
	Segura	247	D1
	Soraluze/ Placencia de las armas	111	D1
	Tolosa	74	D1
	Urnieta	56	D1
	Urretxu	355	D1
	Usurbil	29	D1
	Villabona	62	D1
	Zaldibia	168	D1
	Zarautz	4	D1
	Zegama	296	D1
	Zerain	329	D1
	Zestoa	72	D1
	Zizurkil	115	D1
	Zumaia	4	D1
	Zumarraga	357	D1
Araba	Alegria- Dulantzi	568	D1
	Amurrio	219	D1
	Añana	531	D1

Province	Municipality	Altitude (m)	CTE DB HE 2019
	Aramaio	333	D1
	Armiñón	467	D1
	Arraia-Maeztu	658	E1
	Artziniega	210	D1
	Asparrena	602	E1
	Ayala/Aiara	325	D1
	Baños de Ebro/Mañueta	425	D1
	Barrundia	548	E1
	Berantevilla	471	D1
	Bernedo	710	D1
	Campezo/Kanpezu	575	E1
	ElBurgo/Burgelu	547	E1
	Elciego	451	D1
	Evillar/Bilar	581	D1
	Harana/Valle de Arana	825	E1
	Iruña Oka/Iruña de Oca	500	D1
	Iruraiz-Gauna	634	E1
	Kripan	691	E1
	Kuartango	594	D1
	Labastida	554	D1
	Lagrán	756	E1
	Laguardia	630	E1
	Lanciego/Lantziego	542	D1
	Lantarón	482	D1
	Lapuebla de Labarca	444	D1
	Laudio/Llodio	130	D1
	Legutiano	575	D1
	Leza	569	D1
	Moreda de Álava	460	D1
	Navaridas	535	D1
	Okondo	277	D1
	Oyón-Oion	440	D1
	Peñacerrada-Urizaharra	752	E1
	Rivera Alta/Erriberagoitia	545	D1
	Rivera Baja/Erribera Beitia	482	D1
	Salvatierra/Agurain	605	E1
	Samaniego	572	D1
	San Millán/Domeniliaga	600	E1
	Urkabustaiz	633	E1
	Valdegobía	553	D1
	Villabuena de Álaba/Eskuernaga	483	D1
	Vitoria-Gasteiz	525	D1
	Yécora/Iekora	694	E1
	Zalduondo	612	E1
	Zambrana	459	D1
	Zigoitia	585	D1
	Zuia	617	E1

Province	Municipality	Altitude (m)	CTE DB HE 2019
Bizkaia	Abadiño	144	C1
	Abanto y Ciérvana/Abanto Zierbena	100	C1
	Ajangiz	37	C1
	Alonsotegi	32	C1
	Amorebieta-Etxano	90	C1
	Amoroto	184	C1
	Arakando	244	C1
	Arantzazu	95	C1
	Areatza	140	C1
	Arrankudiaga	112	C1
	Arratzu	42	C1
	Arrieta	205	C1
	Arrigorriaga	58	C1
	Artea	125	C1
	Artzentales	342	C1
	Atxondo	162	C1
	Aulesti	89	C1
	Bakio	6	C1
	Balmaseda	147	C1
	Barakaldo	39	C1
	Barrika	65	C1
	Basauri	64	C1
	Bedia	68	C1
	Berango	46	C1
	Bermeo	11	C1
	Berriatua	35	C1
	Berriz	158	C1
	Bilbao	19	C1
	Busturia	24	C1
	Carrantza Harana/Valle de Carranza	155	C1
	Derio	72	C1
	Dima	133	C1
	Durango	119	C1
	Ea	10	C1
	Elantxobe	80	C1
	Elorrio	183	C1
	Erandio	23	C1
	Ereño	281	D1
	Ermua	166	C1
	Errigoiti	241	C1
	Etxebarri	41	C1
	Etxebarria	106	C1
	Forua	6	C1
	Fruiz	59	C1
	Galdakao	50	C1
	Galdames	165	C1

Province	Municipality	Altitude (m)	CTE DB HE 2019
	Gamiz-Fika	55	C1
	Garai	300	D1
	Gatika	89	C1
	Gautegiz-Arteaga	50	C1
	Gernika-Lumo	10	C1
	Getxo	47	C1
	Gizaburuaga	42	C1
	Gordexola	73	C1
	Gorliz	122	C1
	Güeñes	78	C1
	Ibarrangelu	116	C1
	Igorre	90	C1
	Ispaster	113	C1
	Iurreta	112	C1
	Izurtza	146	C1
	Kortezubi	13	C1
	Lanestosa	287	D1
	Larrabetzu	73	C1
	Laukiz	53	C1
	Leioa	31	C1
	Lekeitio	9	C1
	Lemoa	70	C1
	Lezama	60	C1
	Loiu	26	C1
	Mallabia	323	D1
	Mañaria	192	C1
	Markina-Xemein	84	C1
	Maruri-Jatabe	23	C1
	Mendata	245	C1
	Mendexa	186	C1
	Meñaka	154	C1
	Morga	205	C1
	Mundaka	8	C1
	Mungia	28	C1
	Munitibar-Arbatzegi Gerrikaitz	188	C1
	Murueta	32	C1
	Muskiz	21	C1
	Muxika	29	C1
	Nabarniz	347	D1
	Ondarroa	6	C1
	Orozko	156	C1
	Ortuella	65	C1
	Otxandio	560	D1
	Plentzia	21	C1
	Portugalete	10	C1
	Santurtzi	6	C1
	Sestao	48	C1
	Sondika	27	C1

Province	Municipality	Altitude (m)	CTE DB HE 2019
	Sopelana	62	C1
	Sopuerta	86	C1
	Sukarrieta	31	C1
	Trucios-Turtzioz	152	C1
	Ubide	568	D1
	Ugao-Miravalles	70	C1
	Urduliz	76	C1
	Urduña-Orduña	275	D1
	Valle de Trápaga/Trapagaran	35	C1
	Zaldibar	210	C1
	Zalla	92	C1
	Zamudio	50	C1
	Zaratamo	172	C1
	Zeanuri	243	C1
	Zeberio	121	C1
	Zierbena	84	C1
	Ziortza-Bolivar	150	C1

R7 y R8. Expired EPC calculating software version.

Two types of rules have been established to respond to the NC.1.8: R7 y R8.

The first of these, R7, refers to the HULC 2019 update versions. In the certificates produced in HULC 2019, in order to be able to make the verification, the issue date of the EPC is related to the version used, in the following manner:

If the issue date is after December 30, 2020, versions prior to HULC CTE-HE and CEE Version 2.0.2149.1160 dated December 29, 2020 will not be accepted. The followings are the aforementioned not accepted versions:

- HU CTE-HE y CEE Versión 2.0.2080.1160, de fecha 16-oct-2020
- HU CTE-HE y CEE Versión 2.0.2078.1160 (fecha de actualización 6 de octubre de 2020).
- HU CTE-HE y CEE Versión 2.0.2072.1160 (fecha de actualización 30 de septiembre de 2020)

- HU CTE-HE y CEE Versión 2.0.2039.1160 (fecha de actualización 24 de junio de 2020)
- HU CTE-HE y CEE Versión 2.0.1960.1156 (fecha de actualización 29 de enero de 2020)

If the issue date is after March 18, 2021, in addition to the list of versions indicated above, the HU CTE-HE and CEE Version 2.0.2149.1160 (update date December 29, 2020) will also not be admitted.

The data required for the check can be found in the XML code as follows:

```
<DatosDelCertificador>
        <Fecha>02/03/2021</Fecha>
</DatosDelCertificador>
<IdentificacionEdificio>
        <Procedimiento>HU CTE-HE y CEE Versión 2.0.2080.1160, de fecha
        16-oct-2020</Procedimiento>
<IdentificacionEdificio>
```

On the other hand, rule R8 is established to detect those EPCs produced with HULC of the previous CTE DB HE 2013 standard. This check is applicable (see Figure D-1) to certificates whose purpose is to verify CTE DB HE in addition to certifying the building. For EPCs whose purpose is only to certify, versions prior to HULC 2019 can still be used, since as of April 2021 its regulation has not yet been established.

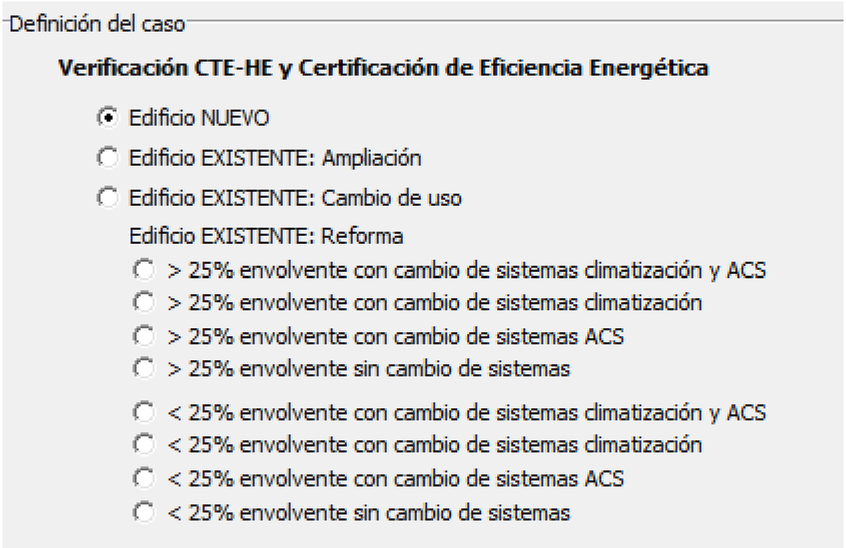

Figure D-1. Types of EPCs in which the R8 rule is applicable.

The latest CTE DB HE 2019 must be applied in projects with a construction license after 23/09/2020, since the transitional period expired on this date. Consequently, as of that date, the use of HULC 2019 became mandatory. This does not mean that it is not possible to register an EPC with an issue date after 09/23/2020, since it has been possible to obtain the construction license before this date and complete the works later. Therefore, EPCs produced with the version prior to HULC 2019 -HU CTE-HE and CEE Version 1.0.1564.1124, dated 3-mar-2017- may carry out the registration as long as they submit the building permit as supporting document. In these cases, R8 will require the provision of this document and the lack of response from the EPC submitter will lead to a NC.

The data required for the check can be found in the XML code as follows:

<DatosDelCertificador>

<Fecha>02/03/2021</Fecha>

</DatosDelCertificador>

<IdentificacionEdificio>

<Procedimiento> HU CTE-HE y CEE Versión 1.0.1564.1124, de fecha 3-mar-2017</Procedimiento>

<IdentificacionEdificio>

R9. Lack of thermal bridges definition

To check whether thermal bridges have been defined or not, check whether the length definition is found with a null value or not. It is possible that there are types of thermal bridges with null value because in the building or dwelling being certified there is no such type of thermal bridge. However, some typologies, such as the contour of the opening or slab front, must always be defined. Accordingly, the verification will be carried out in three ways:

- In case all types of thermal bridges have an input data "0" in the length, it means that they have not defined any thermal bridge and the automatic check program will generate a NC requiring the definition of all thermal bridges.
- In case the type of thermal bridge of the opening contour or slab front has not been defined, a NC will also be generated requiring the definition of all thermal bridges.
- Nonetheless, if any other type of thermal bridge has not been defined, the program will generate alarms for each one of them for the QE to review or justify, since it is possible that in the building or dwelling being certified there are no thermal bridges of this type.

The data required for the check can be found in the XML code as follows:

<DatosEnvolventeTermica>

<PuentesTermicos>

<Elemento>

<Nombre>FRENTE_FORJADO</Nombre>

<Tipo>FRENTE_FORJADO</Tipo>

<Longitud>746.73</Longitud>

<Transmitancia>0.08</Transmitancia>

<ModoDeObtencion>Usuario<
/ModoDeObtencion>

</Elemento>

<Elemento>

<Nombre>UNION_ CUBIERTA</Nombre>

<Tipo>UNION_ CUBIERTA</Tipo>

<Longitud>148.34</Longitud>

<Transmitancia>0.24</Transmitancia>

<ModoDeObtencion>Usuario<
/ModoDeObtencion>

</Elemento>

<Elemento>

<Nombre>ESQUINA_ CONVEXA_ FORJA
DO< /Nombre>

<Tipo>ESQUINA_ CONVEXA_ FORJADO
</Tipo>

<Longitud>92.41</Longitud>

<Transmitancia>0.22</Transmitancia>

<ModoDeObtencion>Usuario<
/ModoDeObtencion>

</Elemento>

<Elemento>

<Nombre>ESQUINA_ CONVEXA_ CERRA
MIENTO< /Nombre>

<Tipo>ESQUINA_ CONVEXA_ CERRAMI
ENTO< /Tipo>

<Longitud>108.00</Longitud>

<Transmitancia>0.05</Transmitancia>

<ModoDeObtencion>Usuario</
ModoDeObtencion>

</Elemento>

<Elemento>

<Nombre>PILAR</Nombre>

<Tipo>PILLAR</Tipo>

<Longitud>1.00</Longitud>

<Transmitancia>0.02</Transmitancia>

<ModoDeObtencion>Usuario<
/ModoDeObtencion>

</Elemento>

```
        <Elemento>
            <Nombre>UNION_ SOLERA_ PAREDEXT< /Nombre>
            <Tipo>UNION_ SOLERA_ PAREDEXT</Tipo>
            <Longitud>90.61</Longitud>
            <Transmitancia>0.27</Transmitancia>
            <ModoDeObtencion>Usuario</ModoDeObtencion>
        </Elemento>
        <Elemento>
            <Nombre>HUECO_ VENTANA</Nombre>
            <Tipo>HUECO_ VENTANA</Tipo>
            <Longitud>1397.00</Longitud>
            <Transmitancia>0.07</Transmitancia>
            <ModoDeObtencion>Usuario</ModoDeObtencion>
        </Elemento>
    </PuentesTermicos>
</DatosEnvolventeTermica>
```

R10. Lack of installed lighting power definition (in tertiary buildings).

To check whether the installed power in tertiary building spaces has been defined, the data defining the installation are observed. If the data in several or all the rooms are the default data of the program, it leads to think that the QE has not calculated or defined the values that correspond to each room. The default values are the installed power 4.4 W/m2; the VEEI 7.00 W/m2100 lux; and the VEEI limit 10 W/m2100 lux.

The data required for the check can be found in the XML code as follows:

```
<Espacio>
    <Nombre>P04_ E15</Nombre>
    <PotenciaInstalada>4.40</PotenciaInstalada>
    <VEEI>7.00</VEEI>
    <IluminanciaMedia>200.00</IluminanciaMedia>
```

</Espacio>

D.3. Validation rules for identify unreliable input data (alarms)

The validation rules for identify unreliable input data have been ordered from highest to lowest incidence in the sample error.

R11 a R20. Unreliable nominal efficiency input data of the energy generation equipment

To verify the plausibility of the efficiency of the defined equipment, acceptable limits are established for each type of equipment. If a value higher than the set limit is defined in the EPC, the program will generate an alarm. A rule is determined for each type of generation equipment (see Table D-2). To establish the acceptable limits, the efficiencies presented in the EPCs of the sample (see Appendix A) are taken as a reference. Although higher heat pump efficiencies can be found in the sample, those proposed in the table are considered to be high efficiencies and therefore, if they are higher, their review or modification will be required. These validation rules respond to NC.5.16.

D-2. Upper acceptable limit in nominal efficiency.

	Type of energy production equipment	Default nominal efficiency	Nominal efficiency upper acceptable limit
R11	Electric boiler	0.90	1.00
R12	Conventional boiler	0.85	0.85
R13	Low temperature boiler	0.90	0.92
R14	Condensating boiler	0.95	0.98
R15	Biomass boiler	0.75	0.80
R16	HP Air- Water DHW	2.72	4.00
R17	autonomous equipment only cold-AirAir-	2.50	3.50
R18	Autonomous equipment HP AirAi	2.50 cooling/ 2.50 heating	3.50
R19	Autonomous Outdoor Unit	2.50 cooling/ 2.50 heating	3.50
R20	Electric heating	1.00	1.00

The data required for the check can be found in the XML code as follows:


```
<GeneradoresDeCalefaccion>
<Generador>
        <Nombre>SIS1_EQ1_EQ_ED_UnidadExterior-Defecto</Nombre>
        <Tipo>Unidad exterior en expansión directa</Tipo>
        <RendimientoNominal>3.20</RendimientoNominal>
</Generador>
```


R21. Unreliable air change rate (in new residential buildings)

This verification is applicable to new residential buildings. To check whether the defined ventilation flow rate is within a logical range or not, the minimum and maximum reference flow rates are calculated using the latest version of CTE DB HS3, published in June 2017. This rule responds to NC.6.1.

The ventilation flow rate in the XML is given in ACH (see XML Code), therefore, in order to make the check, the range is calculated in this unit (see Table D-3).

Table D-3. Reference flow rate range according to CTE DB HS3 of 2017 for standard housing types.

No. of bedrooms	Flow rate according to table 2.1. of CTE DB HS3 in force [l/s]	Reference housing area [m^2].	Volume [m^3]	Flow rate range in ACH
1	14	40-50	108-135	0.37-0.47
2	24	50-65	135-175.5	0.49-0.64
3 o 4	33	70-120	189-324	0.37-0.63

In consequence, if a flow rate out of range 0.37-0.64 is defined, an alarm will be generated and a review will be required.

The data required for the check can be found in the XML code as follows:


```
<IdentificacionEdificio>
        <AlcanceInformacionXML>CertificacionVerificacionNuevo</Alcance
```

InformacionXML>
</IdentificacionEdificio>
<DatosGeneralesyGeometria>
<VentilacionTotal>0.40</VentilacionTotal>
</DatosGeneralesyGeometria>

R22. Unreliable air change rate (in residential buildings built with the ventilation regulation CTE DB HS3 2006)

This verification is valid for existing residential buildings constructed in accordance with the CTE 2006 standard. Thus, all existing EPCs that define post-2006 construction will have to comply with the R21 rule. This rule, as the R20, responds to NC.6.1.

To check whether the defined ventilation flow rate is within a logical range or not, the minimum and maximum reference flow rates are calculated using the latest version of the CTE DB HS3, published in DB HS3 of March 2006.

The ventilation flow rate in the XML is given in ACH (see XML Code), thus, in order to make the check, the range is calculated in this unit (see Table D-4) in the same way as in R20.

Table D-4. Rango de caudal de referencia según CTE DB HS3 del 2006 para tipos de vivienda estándar.

No. of rooms	No. of occupants	No. of wet rooms (excluding kitchen)	Flow rate according to table 2.1. of CTE DB HS3 2006 [l/s]	Reference housing area [m^2]	Volume [m^3]	Flow rate range in ACH
1	2	1	17	40-50	108-135	0.45-0.57
2	3	1	18	50-60	135-162	0.4-0.48
2	3	2	32	60-70	162-189	0.60-0.71
3	4	2	32	70-95	189-256.5	0.45-0.61
4	5	2	32	95-105	256.5-283.5	0.41-0.45
4	5	3	47	105-140	297-378	0.45-0.57

In consequence, the acceptable flow rate range is set at 0.40-0.71. Any value defined outside this range will generate an alarm and will require to be revised.

The data required for the check can be found in the XML code as follows:

```
<IdentificacionEdificio>
        <AnoConstruccion>2006- 2013</AnoConstruccion>
</IdentificacionEdificio>
<DatosGeneralesyGeometria>
        <VentilacionTotal>0.40</VentilacionTotal>
</DatosGeneralesyGeometria>
```

R23. Unreliable air change rate (in residential buildings built before the ventilation regulation CTE DB HS3 2006)

This rule is established for existing residential buildings constructed before 2006 CTE came into force. All residential buildings built with standards prior to CTE 2006 do not have mechanical ventilation. Therefore, a minimum flow rate of 0.8 ren/h (default value in the energy certificate programs) is established as a limit. If a ventilation rate lower than this value is defined, the program will generate a NC. This rule also responds to a NC.6.1.

The data required for the check can be found in the XML code as follows:

<IdentificacionEdificio>
<NormativaVigente>NBE-CT-79</NormativaVigente>
<AlcanceInformacionXML> CertificacionExistente</Alcance InformacionXML>
</IdentificacionEdificio>
<DatosGeneralesyGeometria>
<VentilacionTotal>0.40</VentilacionTotal>
</DatosGeneralesyGeometria>

R24-R26. Unreliable type of building definition

To verify if the EPC type is existing building or new construction, three rules are established with the information available in the XML (see Table D-5). The information available is detailed below in the XML code description. These three rules respond to NC.1.9.

Table D-5. Validation rules R23 a R25.

	If... (condition)	The type of case can be...
R23	the construction date is prior to 2013	• Existing Building: Building Extension • Existing Building: Use change • Existing Building: Renovation • Existing Building: certification only
R24	the current standard is CTE2006, NB-CT-79 or another one	• Existing Building: certification only
R25	Current estandard is CTE HE 2019	• New Building • Existing Building: Building Extension • Existing Building: Use change • Existing Building: Renovation

The data required for the check can be found in the XML code as follows:

<IdentificacionEdificio>
<AnoConstruccion>1979 - 2006</AnoConstruccion>

<NormativaVigente>NBE-CT-79</NormativaVigente>
<AlcanceInformacionXML> CertificacionExistente</Alcance InformacionXML>
</IdentificacionEdificio>

R27-R29. Unreliable window thermal transmittance

The XML file, as can be seen below in the XML code, does not have the thermal performance data of the glass and frames independently. Even though in the EPC definition both of them are defined separately with their thermal transmittances, Ug and Uf, and the frame area fraction, the XML code provides only the global thermal transmittance of the window, Uw. Consequently, only the overall thermal transmittance of the window, Uw, can be checked. Thus, Validation rules R26 and R27 respond to more than one NC, specifically to NC3.1; NC.3.2; NC.3.3.

Different validation rules are defined for EPCs whose purpose in addition to certifying is to verify compliance with CTE —R26 for climate zone C1 and R27 for climate zone D1 and E1— or for EPCs of existing buildings whose purpose is only to certify —R28—. In each of them, the lower and upper limit of the thermal transmittance of the window is determined (see Table D-6). The values of the cells in yellow are limits established by CTE DB HE 2019 and the rest of the data are obtained from the sample data of the last year 2019 studied. (see Appendix A or Section 3.3). As R28 is applicable to existing buildings whose only purpose is to certify, it is expected to find windows of all types, from the best on the market to the worst existing ones.

D-6. Upper and lower limit values in validation rules R27, R28 and R29.

Case	Climate zone	Validation Rule Code	Window $U_{lim, max}$	Window $U_{lim, min}$
Verification of CTE and Energy Efficiency Certification	**C1**	**R27**	**2.1**	**0.95**
Verification of CTE and Energy Efficiency Certification	**D1 o E1**	**R28**	**1.8**	**0.95**
Energy Efficiency Certification only	**C1, D1 o E1**	**R29**	**5.7**	**0.95**

The data required for the check can be found in the XML code as follows:


```
<IdentificacionEdificio>
    <ZonaClimatica>C1</ZonaClimatica>
    <AlcanceInformacionXML>CertificacionExistente</AlcanceInformacionXML>
</IdentificacionEdificio>
<HuecosyLucernarios>
    <Elemento>
        <Tipo>Hueco</Tipo>
        <Transmitancia>1.83</Transmitancia>
    </Elemento>
</HuecosyLucernarios>
```


R30 y R31. Unreliable installed lighting power.

This validation rule applies to new tertiary buildings. On the one hand, the upper limit is established by CTE 2019 differentiating spaces whose average horizontal illuminance is ≤600 lux with spaces whose average horizontal illuminance is >600 lux. In the first case, the maximum acceptable installed power is 10 W/m^2 and in the second case 25 W/m^2. On the other hand, to establish the lower limit of the range, the installed lighting power of 87 random rooms of the sample EPCs registered in the last year has been collected and are represented in Figure D-2 below. For both type of rooms, the minimum value presented is chosen, since no extreme value is found in the lower part of the whisker.

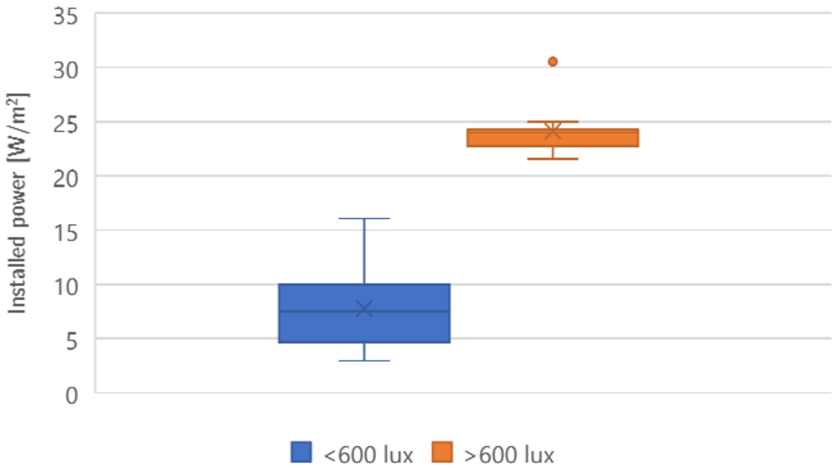

Figure D-2. Lighting installed power in rooms of sampled EPCs registered in the last year of analysis.

Therefore, the two validation rules, R30 and R31, are as follows (see Table D-7). The cells in yellow show the limits established by CTE DB HE 2019.

D-7. Valores límite superior e inferior en las reglas R29 y R30.

iluminancia media horizontal de la estancia	Código Regla	U_{lim} superior del hueco	U_{lim} inferior del hueco
≤600 lux	R30	10	2.9
>600 lux	R31	25	21.5

The data required for the check can be found in the XML code as follows:

<Espacio>

<Nombre>P04_E15</Nombre>

<PotenciaInstalada>5.00</PotenciaInstalada>

<VEEI>3.00</VEEI>

<IluminanciaMedia>200.00</IluminanciaMedia>

</Espacio>

This validation rule could be replicated in existing tertiary buildings; however, since there is not enough data in the sample as a reference to establish the limits, it has only been defined for new tertiary buildings.

R32. Unreliable DHW demand

This validation rule is implementable to residential buildings where the DHW demand is calculated using the standards defined in CTE DB HE4. To verify whether the defined demand is a logical value or not, an analysis is made of 27 residential EPCs in the sample relating their living area to DHW demand. (see Figure D-3). The correlation of these two variables gives us a reference value of the DHW demand for a value of habitable area and the distance between the point furthest from the trend line and the line provides a range where all the calculated points fall. In this way, when verifying an EPC, the range is automatically calculated by the software according to the habitable area, A, (see Eq. D-1), and check if the defined DHW demand falls within the calculated range or not.

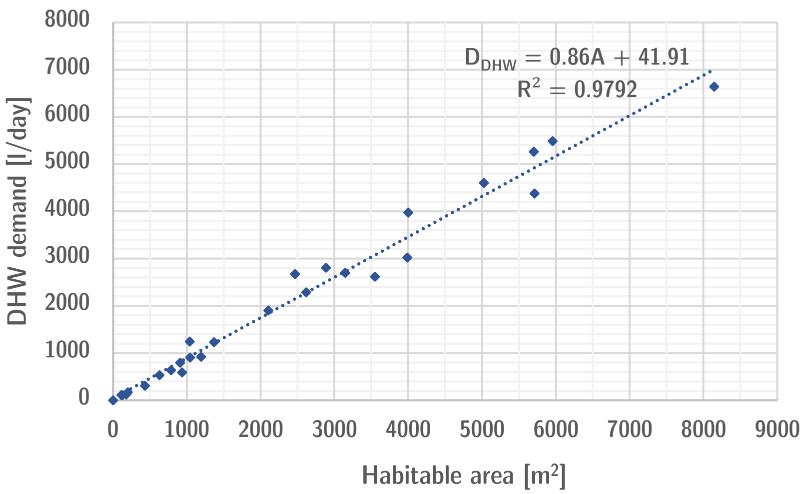

Figure D-3. Relation between habitable area and DHW demand in 27 residential EPCs in the sample.

$$0.86A + 41.91 - d_{l,max} \leq D_{DHW} \leq 0.86A + 41.91 + d_{s,max} \qquad \textbf{Eq. D-1.}$$

Where,
A: **Habitable Area [m^2].**
$d_{l,max}$: **Distance from the farthest point and the trendline below it.**
$d_{s,max}$: **Distance from the farthest point and the trendline above it.**
D_{DHW}: **Domestic hot water demand.**

The farthest point above the trend line is at $d_{s,max} = 545.5$. On the other hand, the farthest point below the trend line is at $d_{l,max} = 523.2$. Hence, the acceptable range for a DHW demand is: $0.86A - 481.3 \leq D_{DHW} \leq 0.86A + 587.4$.

The data required for the check can be found in the XML code as follows:

<DatosGeneralesyGeometria>
<SuperficieHabitable>102.38</SuperficieHabitable>
<DemandaDiariaACS>150.00</DemandaDiariaACS>
<DatosGeneralesyGeometria>

R33-R36. Unreliable fraction of glazed area

This rule is established only for residential buildings since the glazing fraction in commercial buildings is much more varied depending on the use of each building and each space in the building. The NC related to this validation rule is the incorrect definition of the glazed surface in one or more facades. Even if this validation rule does not detect incorrect definitions of glazed surfaces, it allows to establish a logical range of glazed surface fraction, so that values below it, are detected as strange values and those above the range are detected so that in case of a point-by-point control the controller will focus on the glazed part of the envelope, since its impact on the heating and cooling demand will be relevant.

To determine the range, data are collected on glazing fractions of facades of different orientations in 40 residential EPCs in the sample as a reference. The data collected are presented in Figure D-4 below.

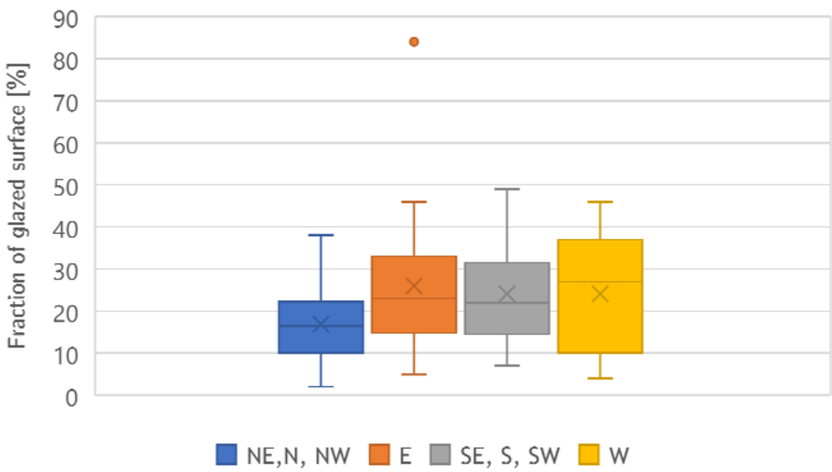

Figure D-4. Fraction of glazing on facades of different orientations collected from 40 residential EPCs.

With these data, the following ranges are established (Table D-8). To define the lower limit, the minimum value found in the sample is adopted. On the other hand, to determine the upper limit, the value of quartile 3 is adopted since it is not intended to find incorrect values, but rather critical points of the building configuration that considerably may affect the EPC result.

Table D-8. Glazing fraction ranges for facades of each orientation in residential buildings.

Facade	Rule Code	Lower limit [%]	Upper limit [%]
NE, N, NW	R31	2	22.25
E	R32	5	33
SE, S, SW	R33	7	31.5
W	R34	4	37

The data required for the check can be found in the XML code as follows:

<DatosGeneralesyGeometria>

<PorcentajeSuperficieAcristalada>
<NE>32</NE>
<SE>14</SE>
<SO>30</SO>
<NO>39</NO>
</PorcentajeSuperficieAcristalada>
</DatosGeneralesyGeometria>

R37. Unreliable efficiency of mechanical ventilation equipment with heat recovery.

The input of the recuperator efficiency required in the EPC definition in HULC 2019 is the thermal efficiency of the recuperator which is calculated according to EN 308 under dry reference conditions (Eq. D-2).

$$\eta_t = \frac{t_{22} - t_{21}}{t_{11} - t_{12}} \qquad \text{Eq. D-1.}$$

Where,
η_t: **Thermal efficiency of heat recovery in MVHRS.**
t_{11}: **Exhaust air inlet temperature.**
t_{12}: **Exhaust air outlet temperature.**
t_{21}: **Supply air inlet temperature.**
t_{22}: **Supply air outlet temperature.**

The manufacturers' data sheets state thermal efficiencies up to 0.95. Values above 0.90 are considered high efficiencies, so it is proposed to determine this value as the upper limit. If the automatic software check finds an input data higher than 0.90, it will generate an alarm and require review, modification, or justification.

R38-R42. Unreliable thermal conductivity of insulation material

In order to verify the thermal conductivity, λ, adopted for the different insulation types, acceptable ranges are established for each type and each of them determines a validation rule (R37 to R40). The values are determined on the basis of data sheets and labels collected in the building on-site verifications.

Table D-9. Thermal conductivity, λ, input data ranges for each type of insulation material.

		Keyword for search in the *XML code*	$\lambda_{lim,min}$ [W/mK]	$\lambda_{lim,max}$ [W/mK]
R38	**PUR**	*PUR; Poliuretano Proyectado; Panel Sandwich*	**0.028**	**0.032**
R39	**XPS**	*XPS; Poliestireno extruido; XPS-FOAM*	**0.032**	**0.036**
R40	**EPS**	*EPS; Poliestireno expandido*	**0.032**	**0.037**
R41	**MW**	*MW; Lana Mineral; Alpharock; Rockwool; Ultracoustic; Ursa Terra Vento;*	**0.032**	**0.038**
R42	**Any type of isolation that is not defined with the above keywords**	-	**0.03**	-

Any value defined out of range will generate an alarm and must be reviewed, corrected or justified by means of a manufacturer's DdP or UNE-EN 12667:2002 thermal conductivity test.

In order to find the necessary data in the XML code, some keywords used in sample EPCs are collected to name the isolation. In case no name related to any of these keywords is found, but some material with thermal conductivity $\lambda \leq 0.03$ W/mK, revision, modification or justification by a manufacturer's DdP or thermal conductivity test is also required UNE-EN 12667:2002 (R41).

The data required for the check can be found in the XML code as follows:

```
<Elemento>
        <Nombre>P01_E04_PE003</Nombre>
        <Tipo>Fachada</Tipo>
        <Superficie>2.51</Superficie>
```

```
<Orientacion>O </Orientacion>
<Transmitancia>0.42</Transmitancia>
<ModoDeObtencion>Usuario</ModoDeObtencion>
<Capas>
    <Capa>
        <Material>MW Lana mineral [0.04 W/[mK]]</Material>
        <Espesor>0.0800</Espesor>
        <ConductividadTermica>0.040</ConductividadTermica>
        <Densidad>40.00</Densidad>
        <FactorResistenciaVapor>0.20</FactorResistenciaVapor>
        <CalorEspecifico>1000.00</CalorEspecifico>
    </Capa>
</Capas>
</Elemento>
```

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