TIMEPAC

Towards Innovative Methods
for Energy Performance Assessment
and Certification of Buildings

TIMEPAC GUIDELINE

Enhancing Energy Performance Certification:

Guidelines to create archetypes of the building stock from EPC data

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TIMEPAC aims to modernize building certification practices according to the latest Energy Performance of Buildings Directive (EPBD) review. The guidelines series provides recommendations for stakeholders involved in building certification to improve their working procedures to meet the objectives of the Directive.

Among the objectives of the Directive, the national building renovation plan is mandatory. Building archetypes, which are representative of clusters within the building stock, can significantly contribute to the formulation of a national building renovation plan. These archetypes encapsulate the diverse characteristics of the building stock, thereby improving the accuracy of urban energy models while simultaneously reducing their complexity, as to engage multiple stakeholders.

The guidelines aim to provide a methodology to conduct a statistical analysis on the EPC database, as a core source of information to create the archetypes and analyse the energy performance status of the building stock. An important phase is dedicated to check the quality of the data provided by the certificates that is crucial to assure the validity of the outcomes.

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TIMEPAC “Guidelines to create archetypes of the building stock from EPC data”

Authors:

Ilaria Ballarini, Matteo Piro

Politecnico di Torino, Turin, Italy

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1. Introduction to the guidelines

The guidelines provide the procedure to create reference buildings (archetypes) of the building stock from EPC data; they are subdivided into methodology (Section 1, this section) and application (Section 2). The latter refers to a subset of the EPC database of Piemonte Region (Italy), which has been used to validate the proposed methodology. In accordance with the flowchart shown in **Figure 1**, and considering the different steps of the methodology and the related application, the guidelines are structured into the following topics:

- EPC data selection (Sections 1.1 and 2.1),
- EPC data clustering (Sections 1.2 and 2.2),
- EPC data quality checking (Sections 1.3 and 2.3),
- Statistical analysis (Sections 1.4 and 2.4), and
- Identification of reference buildings (Sections 1.5 and 2.5).

For each topic, three sub-sections are provided: purpose, methods, and implementation. Even if the guidelines have been presented in such a way to provide a general methodological approach, not limited to a territorial context but applicable at EU level, however, references to the countries/regions involved in the TIMEPAC project are given to justify the choices behind the use of specific data and methods. In addition, the methodology has been developed in such a way to be flexible, adaptable to the specificities of the single countries and their own EPC databases. It allows to be implemented in different tools or procedures.

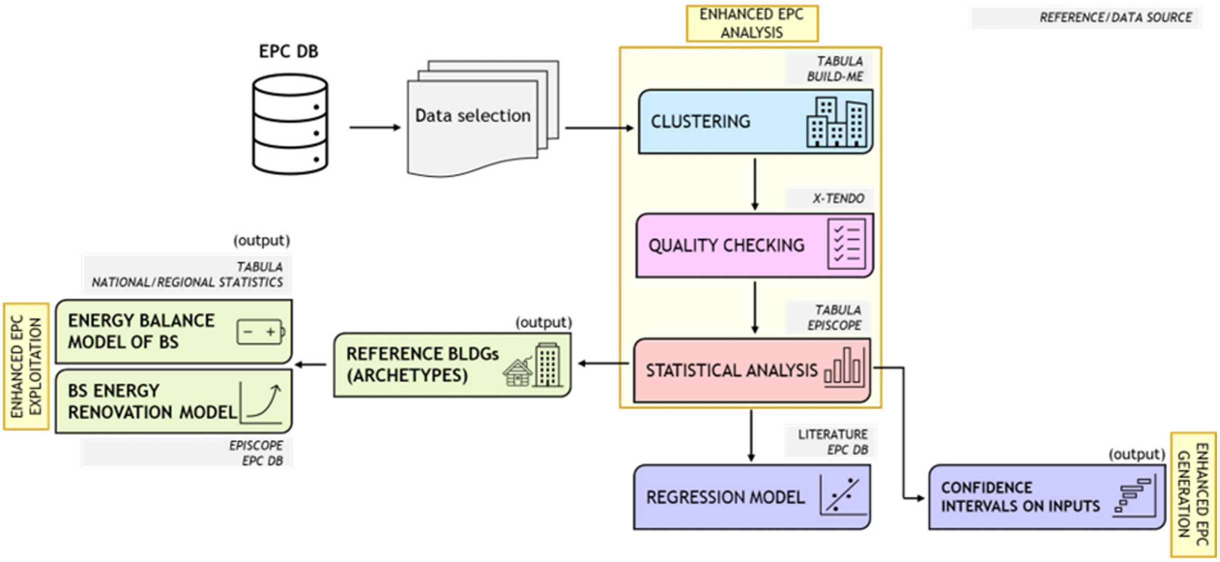

Figure 1. Methodology to create archetypes (i.e., shaped area related to "Enhanced EPC analysis") in the overall flowchart[1] of TIMEPAC

1.1 EPC data selection

1.1.1 Purpose

The purpose of the EPC data selection is the identification of the input and output metrics set, in this case common to the TIMEPAC countries. The parameters have been derived from the regional or national energy certificates to define a shared, harmonised, and replicable methodology to carry out the subsequent operative phases. The EPC databases considered in the analysis are the ZEUS database of the Salzburg region in Austria, the EPC databases of Croatia, of Cyprus, of the Piemonte Region (Italy), of Slovenia, and of the region of Catalonia (Spain). The equality between regional and national databases has been reported.

[1] The overall flowchart and the outcomes of the methodology for each of the six country partners involved in TIMEPAC are reported in https://timepac.eu/reports/procedures-and-services-to-undertake-large-scale-statistical-analysis-of-epcs-databases/ (TIMEPAC, 2023).

1.1.2 Methods

The EPC data selection originates from the outcomes of a previous task of the TIMEPAC project, where each country partner identified the data availability and the EPC data quality based on the source type and way of determination. The outcomes of a previous TIMEPAC task have been elaborated and presented in **Figure 2**, where the availability of the EPC data for each TIMEPAC country is reported. Further analysis regarding the availability of the non-renewable energy performance per energy service ($EP_{H/C/W;nren}$) in the EPC should be conducted for the countries/regions (like Austria, Croatia, Cyprus, and Slovenia) that did not provide this information. Otherwise, these EPC data would not appear in the reference building schema (see **Table 12**).

Data name	AUSTRIA	CROATIA	CYPRUS	ITALY	SLOVENIA	SPAIN	p-100%	p-83%	p-67%	p-50%	p-33%	p-17%
Assessed object	Yes	Yes	Yes	Yes	Yes	Yes	x					
Application type	Yes	Yes	Yes	Yes	No	Yes		x				
EPC ID code	Yes	Yes	Yes	Yes	Yes	Yes	x					
Building ~~address~~ city	Yes	Yes	Yes	Yes	Yes	Yes	x					
Number of building units	Yes	No	Yes	Yes	Yes	Yes		x				
Building typology	No	Yes	Yes	Yes	Yes	Yes		x				
Building constructive typology	Yes	No	Yes	Yes	Yes	Yes		x				
Building use	Yes	Yes	Yes	Yes	Yes	Yes	x					
Year of construction	Yes	Yes	No	Yes	Yes	Yes		x				
Climatic region	Yes	Yes	Yes	Yes	Yes	Yes	x					
Degree days	Yes	No	Yes	Yes	Yes	No			x			
Thermally conditioned floor area	Yes	Yes	Yes	Yes	Yes	Yes	x					
Thermally conditioned gross volume	Yes	Yes	No	Yes	Yes	Yes		x				
Compactness ratio	Yes	Yes	No	Yes	Yes	Yes		x				
Thermal envelope area	Yes	No	Yes	Yes	Yes	Yes		x				
Opaque thermal envelope area	Yes	No	Yes	Yes	Yes	Yes		x				
Transparent thermal envelope area	Yes	Yes	Yes	Yes	Yes	Yes	x					
Mean thermal transmittance of the total building envelope	Yes	Yes	Yes	Yes	Yes	No		x				
Mean thermal transmittance of opaque building envelope	Yes	No	Yes	Yes	Yes	No			x			
Mean thermal transmittance of transparent building envelope	Yes	No	Yes	Yes	Yes	No			x			
Energy services	Yes	Yes	Yes	Yes	Yes	Yes	x					
Technical building system (TBS) type of generator per ~~energy service~~ space heating	Yes	Yes	Yes	Yes	Yes	Yes	x					
TBS energy carrier per energy service	Yes	Yes	Yes	Yes	Yes	Yes	x					
TBS mean overall seasonal efficiency per energy service	Yes	No	Yes	Yes	No	Yes			x			
TBS nominal power per ~~energy service~~ space heating	Yes	Yes	Yes	Yes	Yes	Yes	x					
TBS subsystems efficiency per ~~energy service~~ space heating	Yes	No	Yes	Yes	Yes	No			x			
Energy need for space heating	Yes	Yes	Yes	Yes	Yes	Yes	x					
Energy need for space cooling	Yes	Yes	Yes	Yes	Yes	Yes	x					
Overall non-renewable energy performance	Yes	Yes	Yes	Yes	Yes	Yes	x					
Non-renewable energy performance per energy service	No	No	No	Yes	No	Yes					x	
Delivered energy per energy carrier	Yes	Yes	Yes	Yes	Yes	No		x				
Recommended energy efficiency measure (EEM)	Yes	Yes	Yes	Yes	Yes	Yes	x					

Figure 2. Cross-country comparison of I/O dataset related to EPC data

Table 1 shows the whole picture of the parameters involved in the subsequent analysis, common to the TIMEPAC country partners, accompanied by their data type. Mostly, the data types are classified into strings, numbers, and Boolean value groups. If a regional or a national energy certificate does not contain some metrics reported in **Table 1** (e.g., the heating degree days for Croatia and Spain, or the thermally conditioned gross volume for Cyprus, etc.), the introduction of some assumptions should be done or the findability of data from other sources or databases should be realised, where possible.

Table 1. EPC data types considered in the analysis

Data name	Data type
Assessed object	string
Application type	string
EPC ID code	string
Building city	string

Data name	Data type
Number of building units	number (integer)
Building typology	string
Building construction typology	string
Building category	string
Year of construction	number (integer)
Climatic region	string
Heating degree days	number (integer)
Thermally heated/cooled floor area	number (decimal)
Thermally heated/cooled gross volume	number (decimal)
Compactness ratio	number (decimal)
Opaque/transparent thermal envelope area	number (decimal)
Mean thermal transmittance of the total/opaque/transparent building envelope	number (decimal)
Heating/cooling/domestic hot water energy service	Boolean value
Energy carrier per space heating/cooling/domestic hot water	string
Main technical building system (TBS) type of space heating generator	string and/or number (decimal)
Overall mean seasonal efficiency of the heating/cooling/domestic hot water system	number (decimal)
Mean seasonal efficiency of the heating generation/distribution/control/emission sub-system	number (decimal)
Energy need for heating/cooling	number (decimal)
Overall non-renewable energy performance	number (decimal)
Delivered natural gas/electricity/ thermal energy from district heating	number (decimal)
Recommended energy efficiency measures	string and/or number (decimal)

1.1.3 Implementation

The metrics reported in **Table 1** are common to Austria, Croatia, Cyprus, Italy, Spain, and Slovenia. However, if some additional parameters are missing in the above table and are deemed to be influential for the subsequent phase of the analysis, they could be exploited anyway.

1.2 EPC data clustering

1.2.1 Purpose

The EPC data clustering aims to group buildings with similar thermo-physical properties of the opaque and transparent building envelope and comparable technical building systems (TBSs) characteristics. This procedure is based on assigning to an urbanised area real or theoretical, reference residential and non-residential buildings, with known characteristics and energy consumptions useful to assess the energy and environmental performance at a larger scale. The association is based on the climatic zone, building use category, year of construction, and building size and shape (the last only for residential buildings).

1.2.2 Methods

The methodology for clustering buildings has been derived from the outcomes of the TABULA project (Ballarini et al., 2014), aimed at harmonising the European building typology, and the follow-up EPISCOPE project focused on building stock monitoring (EPISCOPE, 2016). The clusters defined, as presented in **Figure 3**, are the climatic zone, the building use category, the year of construction, and the building size and shape for residential buildings.

The clustering approach is applicable to the EPCs following a sequential procedure: (1) to group buildings according to the climatic zone (each country/region could have more than one climatic zone), (2) within a climatic zone, to group buildings belonging to the same intended use (residential and non-residential) as to cover more building categories, (3) within each intended use cluster, to group buildings giving priority either to the construction period or the building size according to specific criteria (e.g., the amount of existing buildings represented, etc.), and (4) within the innermost cluster, a further grouping may be performed according to the scope (e.g., in function of the *U*-value range, the space heating generator type, etc.).

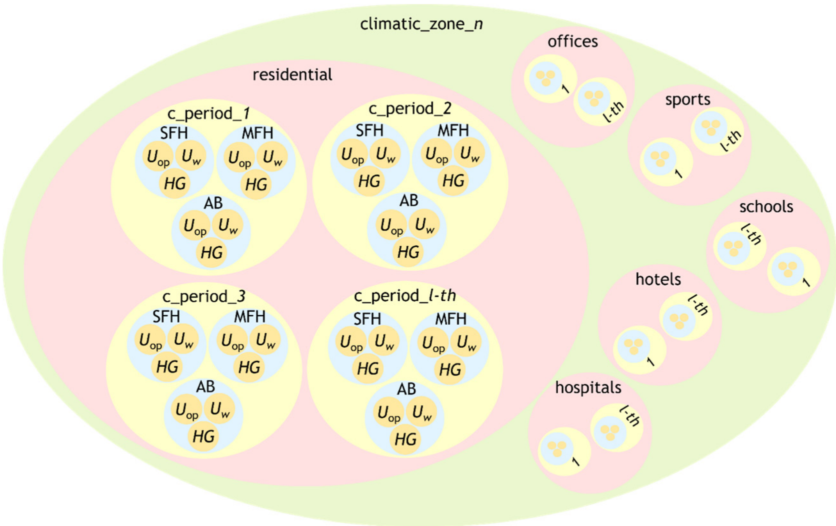

Figure 3. EPC data clustering

The building use categories have been deduced from the EN ISO 52000-1 (CEN, 2017) technical standards completed with the TABULA and EPISCOPE outcomes. The building categories, reported in **Table 2**, are the most representative to summarise the building stock. As regards the third cluster, the reference construction periods have been derived from TABULA and are listed in **Table 3**. In the TABULA and EPISCOPE projects, the majority of TIMEPAC countries are included, except for Croatia where the construction periods have been equalised to national legislation (see **Table 3**).

Table 2. Building categories (CEN, 2017)

Intended use	**Type**	**Description**
Residential	*BLDNGCAT_RES_SINGLE*	Single-family houses of different types
	BLDNGCAT_RES_APPBLOCK	Apartment blocks (multi-family houses included)
Non-residential	*BLDNGCAT_OFF*	Offices
	BLDNGCAT_EDUC	Educational buildings
	BLDNGCAT_HOSP	Hospitals

Intended use	Type	Description
	BLDNGCAT_HOTEL	Hotels and restaurants
	BLDNGCAT_SPORT	Sports facilities

Table 3. Construction periods (TABULA-EPISCOPE)

Country	Description
Austria	≤1918; 1919-1944; 1945-1960; 1961-1980; 1981-1990; 1991-2000; 2001-2010; >2010
Croatia	≤1940; 1941-1970; 1971-1980; 1981-1987; 1988-2005; ≥2006
Cyprus	≤1980; 1981-2006; 2007-2013; >2013
Italy	≤1900; 1901-1920; 1921-1945; 1946-1960; 1961-1975; 1976-1990; 1991-2005; >2005
Slovenia	≤1944; 1945-1970; 1971-1980; 1981-2002; 2003-2008; >2008
Spain	≤1900; 1901-1936; 1937-1959; 1960-1979; 1980-2006; >2006

1.2.3 Implementation

In accordance with the clustering approach introduced in Section 1.2.2, the following clusters have been defined in TIMEPAC:

- No. of climatic zones: n = (1, ..., 6) – because six are the TIMEPAC country partners,
- No. of building categories: m = (1, ..., 6) – because six are the maximum number of the building categories chosen. However, according to **Figure 3**, single-family houses (SFHs), multi-family houses (MFHs), and apartment blocks (ABs) are included in the same set, which is the residential buildings. The other clusters are offices, educational buildings, hospitals, hotels and restaurants, sports facilities,
- No. of construction periods: l = (1, ..., 8) – according to TABULA and EPISCOPE, the maximum number of construction periods is set to eight (i.e., Austria and Italy). This threshold value could be subject to changes,
- No. of building size: o = (1, ..., 3) – the building size and shape is considered only for residential building, especially considering single-family house (SFH), multi-family house (MFH), and apartment blocks (AB). However, the concept may be extended to non-residential buildings, and
- No. of key-values: k = (1, ..., 3) – in the case the energy assessor has to perform a further clustering (by space heating system type, or U-values), a further statistical analysis should be carried out to support the decision making of the technician in charge.

Some modifications per country to the year of construction (**Table 3**) or to other clusters could be formulated to take into account local, regional, or national legislation in the energy and environmental fields.

1.3 EPC data quality checking

1.3.1 Purpose

The EPC data quality checking procedure is a fundamental phase to have reliable energy certificates free of inaccuracies for carrying out large-scale energy analyses. The deep renovation of building stock, in order to achieve the EU 2030 and 2050 GHG emission reduction goals, goes through the reliable creation of the urban building's energy models. In this regard, the energy certificate represents a crucial source of data to build urban energy analysis. Undoubtedly, the EPC information should be enhanced, real-time upgradeable, implemented, and made interoperable. However, it is crucial to establish the validity of the EPC data already contained in the energy certificate.

The aim of the EPC data quality procedure is to derive only the reliable energy certificates, whose information will be processed in the subsequent phase of the analysis. This methodology draws inspiration from the X-tendo project (X-tendo, 2022), especially for the EPC data score attribution. The proposed procedure is applicable to the energy certificates still uploaded into the reference local, regional, or national EPC databases. Moreover, it can be implemented in the EPC database system in the future, as a support to validation and control bodies in identifying the errors contained in the document, but also as a support to energy certifiers in providing warnings on input data in the EPC generation phase.

1.3.2 Methods

The EPC data quality checking procedure provides the score attribution to parameters and values contained in the energy certificates. For each of the EPC data, a validity rule has been associated. For each rule, a score has been attributed to the non-respected rule. Therefore, the overall score, originating from summing the single score of each parameter, will be compared to the cut-off value. This value represents the acceptability threshold value for all energy certificate parameters. Whether the overall EPC data score is greater than the threshold value then all the EPC data will be neglected, and they will not appear in the subsequent phases (e.g., statistical analysis, reference buildings identification, and confidence intervals generation).

Some metrics have been defined as 'critical' (see **Table 4**), whose validity is considered fundamental for statistical analysis. The non-compliance rules for critical parameters give a score greater than the threshold value and thus every EPC data will be neglected. The inaccuracies of these parameters drastically affect the reliability of the entire procedure, so they will not be considered. The overall picture of EPC data involved in the energy certificate data quality checking procedure, rules, and scores is shown in **Table 4**.

Three groups of rules are summarised as follows:

- Data types of checks are the simplest control and represent that set of rules which evaluate the data types (i.e., integer, string, Boolean value, etc.) of the data analysed. For instance, the compactness ratio is a decimal number and not a string, or the year of construction of the building must be an integer and not a Boolean value. These rules have been associated with both critical and non-critical parameters,
- Physical impossibility checks represent that set of rules which evaluate the order of magnitude of EPC data comparing them with the physical admissibility for that parameter. For example, the thermal energy need for space heating cannot be a negative value, or the thermal transmittance of the building envelope opaque component cannot be greater than a threshold value (e.g., 4,5 W/(m^{2}K)). These rules have been associated with both critical and non-critical parameters,
- Consistency checks represent that set of rules which determine the validity of a parameter compared to another one. For example, the energy carrier for the space cooling service should be invalid or null whether the energy service flag for space cooling is set to "NO". The consistency checks could also refer to national regulations (e.g., the minimum average height of a building should not be less than reasonable values). These rules have been associated with both critical and non-critical parameters.

Considering n as the total number of EPC data and m as the total amount of critical parameters, the score for the non-critical parameter has been calculated as $s = 1/(n - m)$. Indeed, the invalidity score border, i.e., the threshold value beyond which an energy certificate, and all data contained therein, is considered rejected, is calculated as $e = (n \cdot s)/2$. So, whether the overall score of the EPC is greater (>) than e then the EPC is rejected and will not be considered in the subsequent statistical analysis. Instead, if the overall score of the EPC is less or equal (≤) to e then the energy certificate is considered valid with reliable EPC data. For this purpose, the score for the non-respected rule for critical parameters is set to 1, i.e., a value greater than the threshold one.

Obviously, the proposed procedure is a first check about the reliability of the EPC data, because energy certificates with respected rule outliers for some parameters may progress in the later stage of the work development. Mainly, the EPC data quality check procedure sets lower limits because a priori it is difficult to set upper limits.

1.3.3 Implementation

In **Table 4**, the rules and scores are attributed to the common EPC data of the six TIMEPAC countries. Additional country parameters could enrich the proposed list (e.g., the year of the last renovation, the no. of floor, or the overall renewable energy performance, in case of the Piemonte Region EPC). For the additional parameters, the recommendation is to encourage their introduction in the analysis, doing only a validity control on their data types. Moreover, these parameters should not be considered critical.

Table 4. Construction periods (TABULA-EPISCOPE)

Data name (Critical parameter*)	**Typology of rules**	**Rule**	**Respected rule (score)**	**Unrespected rule (score)**
Assessed object	D	string not null	0,000	$1/(n-m)$
Application type	D	string not null	0,000	$1/(n-m)$
EPC ID code*	D	string not null	0,000	1,000
Building city	D	string not null	0,000	$1/(n-m)$
Number of building units	D	string not null *or* integer ≥ 0	0,000	$1/(n-m)$
Building typology	D	string not null	0,000	$1/(n-m)$
Building constructive typology	D	string not null	0,000	$1/(n-m)$
Building category	D	string not null	0,000	1,000
Year of construction	D, P	integer > 0	0,000	1,000
Climatic region	D	string not null	0,000	$1/(n-m)$
Heating degree days	D, P	integer > 0	0,000	$1/(n-m)$
Thermally heated/cooled floor area	D, P, C	decimal > 0 if the space heating/cooling service exists	0,000	1,000
Thermally heated/cooled gross volume	D, P, C	decimal > 0 if the space heating/cooling service exists	0,000	1,000
Compactness ratio	D, P	decimal > 0	0,000	$1/(n-m)$
Thermal envelope area	D, P	decimal > 0	0,000	1,000
Opaque/transparent thermal envelope area	D, P, C	decimal > 0	0,000	$1/(n-m)$
Mean thermal transmittance of the total building envelope	D, P	decimal (0,0; 6,0] W/(m²·K)	0,000	$1/(n-m)$
Mean thermal transmittance of the opaque building envelope	D, P	decimal (0,0; 4,5] W/(m²·K)	0,000	$1/(n-m)$
Mean thermal transmittance of the transparent building envelope	D, P	decimal (0,0; 6,0] W/(m²·K)	0,000	$1/(n-m)$
Heating/cooling/domestic hot water energy service	D	Boolean value	0,000	$1/(n-m)$
Energy carrier per heating/cooling/domestic hot water	D, C	string not null if the heating/cooling/domestic hot water service exists	0,000	$1/(n-m)$

Data name (Critical parameter*)	Typology of rules	Rule	Respected rule (score)	Unrespected rule (score)
Main technical building system (TBS) type of space heating generator	D, C	string not null if the space heating service exists	0,000	$1/(n-m)$
Overall mean seasonal efficiency of the heating/cooling/domestic hot water system	D, P, C	decimal > 0 if the heating/cooling/domestic hot water service exists	0,000	$1/(n-m)$
Mean seasonal efficiency of the heating generation	D, P, C	decimal > 0 if the space heating service exists	0,000	$1/(n-m)$
Mean seasonal efficiency of the heating distribution/control/emission sub-system	D, P, C	decimal (0; 1] if the space heating service exists	0,000	$1/(n-m)$
Energy need for space heating	D, P, C	decimal ≥ 0 if the space heating service exists	0,000	1,000
Energy need for space cooling	D, P, C	decimal ≥ 0 if the space cooling service exists	0,000	$1/(n-m)$
Overall non-renewable energy performance	D, P	decimal ≥ 0	0,000	1,000
Delivered natural gas/electricity/ thermal energy from district heating	D, P, C	decimal > 0 if natural gas/electricity/thermal energy from district heating consumed	0,000	$1/(n-m)$
Recommended energy efficiency measures	D	string not null	0,000	$1/(n-m)$
D = data types of checks; P = physical impossibility checks; C = consistency checks				

1.4 Statistical analysis

1.4.1 Purpose

After the EPC data quality checking, the statistical analysis aims to extract the most probable data to generate representative buildings for the specific climatic zone. Reference buildings mean buildings with mean geometrical and technological characteristics, representative of the regional or national building stock. Therefore, the statistical observations (see examples reported in **Figure 4**) help to find the data necessary to create the national building typology.

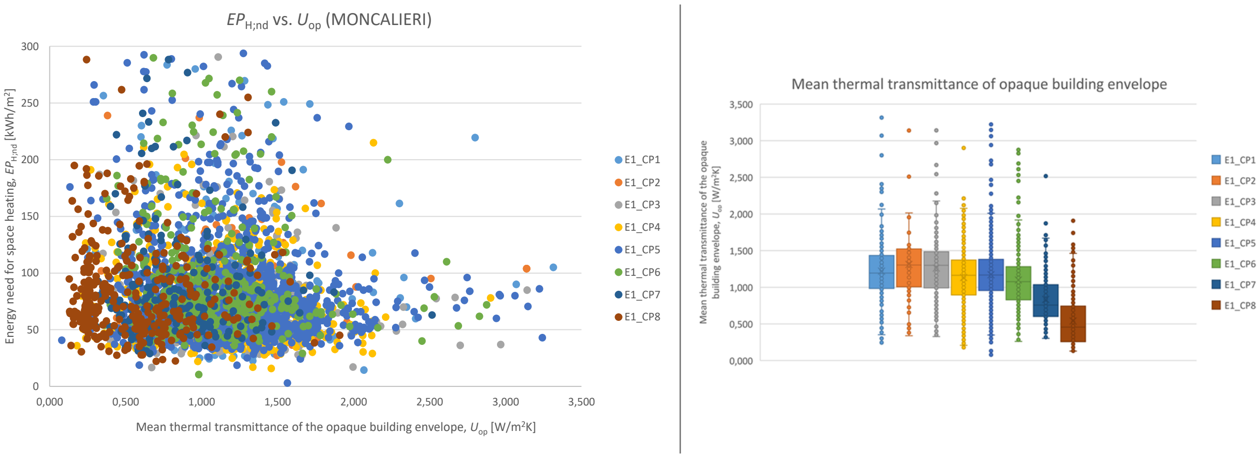

Figure 4. Statistical representations of parameters for a subset of the Piemonte Region (Italy) EPC database (example)

1.4.2 Methods

For quantitative parameters, the boxplot is a basic statistical description sufficient for the identification of the input and output EPC data to develop reference buildings. The five key elements of the boxplot are summarised as follows:

- the zero quartile Q_0, i.e., the minimum value,
- the first quartile Q_1, i.e., the first 25% of the statistical distribution,
- the second quartile Q_2, i.e., the median value,
- the third quartile Q_3, i.e., 75% of the data falls below the third quartile, and
- the fourth quartile Q_4, i.e., the maximum value.

The distance between the third quartile, Q_3, and the first quartile, Q_1 is called the interquartile range (IQR). Obviously, for the quantitative dataset outlier's removal, i.e., the elimination of the points greater than Q_4 and lower than Q_0, will decrease the dispersion between data.

Other qualitative data (e.g., energy carrier per space heating, energy efficiency measures recommendations, building constructive typology, etc.) can be represented considering absolute or relative frequency (see **Figure 5**).

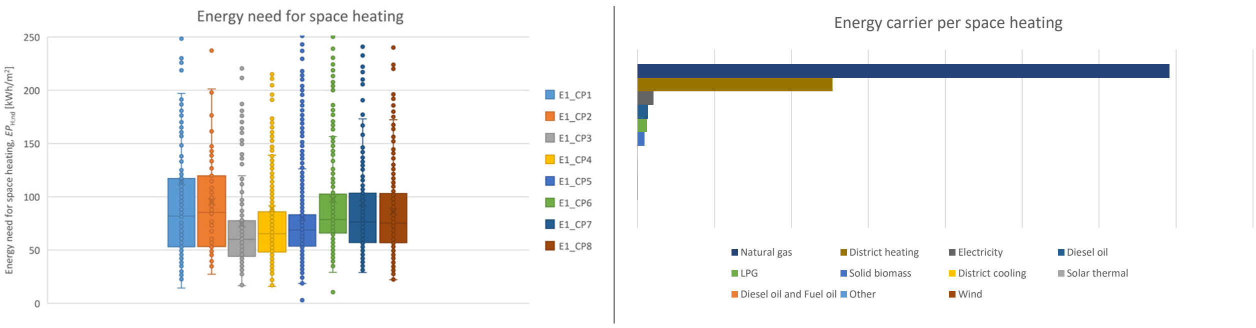

Figure 5. Boxplot and relative frequency graphs of parameters for a subset of the Piemonte Region (Italy) EPC database (example)

1.4.3 Implementation

Considering the innermost cluster (see Section 1.2.3), the types of statistical representation that can be provided are summarised in **Table 5**.

Table 5. Statistical representation of the EPC data

Data name	Qualitative or quantitative	Statistical representation
Number of building units	quantitative	boxplot or relative frequency

Data name	Qualitative or quantitative	Statistical representation
Building typology	qualitative	relative frequency
Building constructive typology	qualitative	relative frequency
Heating degree days	quantitative	not needed
Thermally heated/cooled floor area	quantitative	boxplot
Thermally heated/cooled gross volume	quantitative	boxplot
Compactness ratio	quantitative	boxplot
Thermal envelope area	quantitative	boxplot
Opaque/transparent thermal envelope area	quantitative	boxplot
Mean thermal transmittance of the total building envelope	quantitative	boxplot
Mean thermal transmittance of the opaque building envelope	quantitative	boxplot
Mean thermal transmittance of the transparent building envelope	quantitative	boxplot
Heating/cooling/domestic hot water energy service	qualitative	relative frequency
Energy carrier per heating/cooling/domestic hot water	qualitative	relative frequency
Main technical building system (TBS) type of space heating generator	qualitative	relative frequency
Overall mean seasonal efficiency of the heating/cooling/domestic hot water system	quantitative	boxplot
Mean seasonal efficiency of the heating generation	quantitative	boxplot
Mean seasonal efficiency of the heating distribution/control/emission sub-system	quantitative	boxplot
Energy need for space heating	quantitative	boxplot
Energy need for space cooling	quantitative	boxplot
Overall non-renewable energy performance	quantitative	boxplot

1.5 Identification of reference buildings

1.5.1 Purpose

The reference buildings have to reflect the most common geometrical characteristics, technical specifications of the building envelope, and technical building system typology, representing the average situation in a market segment. The identification of a library of reference buildings plays a crucial role, especially for the energy performance benchmarking of the national or regional building stock. The identification of the reference buildings should consider an adequate number of real and/or 'virtual' residential and non-residential buildings to cover the most spread building categories in a climatic zone.

The basic energy related parameters of the categories to be selected are (1) the geometrical data (e.g., compactness ratio, thermally heated/cooled floor area, heated/cooled volume, windows-to-wall ratio, etc.), (2) the thermo-physical properties of the opaque and transparent building envelope (e.g., mean thermal transmittance of the opaque building envelope, mean thermal transmittance of the transparent building envelope), and (3) the types and energy performance of the technical building systems (TBS).

1.5.2 Methods

The main reference for the definition of national building typologies in Europe is the TABULA project (Ballarini et al., 2014; EPISCOPE, 2016). For several European countries, a Building Typology Matrix was defined to represent residential building types categorised by climatic zone, construction year class, and size and shape class. Another reference is BUILD_ME (BUILD_ME, 2018), which developed a building typology database, reflecting the region's typical architecture and technical building systems of Egypt, Jordan, and Lebanon. The Prototype Building Models (PBM), created by the U.S. Department of Energy (DOE, 2013), instead, allowed associating a scorecard to the building model containing the key modelling input information.

The methodology is based on deriving from the statistical representation average parameters, representative of climatic zone, building use category, year of construction, and size and shape (see also Section 1.4.2).

1.5.3 Implementation

The statistical analysis allows the creation of reference buildings, according to Section 1.4.3. The reference building is represented by means of the median value of each characterising parameter; the values falling in the Interquartile ranges (*IQRs*) (Q_3 - Q_2 and Q_2 - Q_1) are admitted as well.

2. Example for a subset of the regional building stock of Piemonte (Italy)

This section provides an application of the methodology to create archetypes starting from a subset of the EPC data stored in the Piemonte Region energy certificates database and referred to the municipality of Moncalieri, in the metropolitan city of Torino. The proposed methodology, as described in Section 1, is replicable for other countries, regions or local contexts. The structure of this section follows the same structure as Section 1: (2.1) EPC data selection, (2.2) EPC data clustering, (2.3) EPC data quality checking, (2.4) statistical analysis, and (2.5) identification of reference buildings.

2.1 EPC data selection

The EPC data selection for the Piemonte Region provides the majority of energy certificate data presented in **Table 1** and **Table 4**. However, due to the lack of some EPC data, some adjustments and calculations, presented in **Table 6**, have been done to make available the required parameters.

Table 6. EPC data adjustments and calculations on the EPC database of Piemonte

Data name	**Note**
Heating degree days (*HDD*)	The parameter is not directly present in the Piemonte Region EPC. *HDD* is derived from another database linked through the building city.
Mean thermal transmittance of the total building envelope (U)	Calculated as the weighted average of the mean thermal transmittance of the opaque building envelope (U_{op}), the mean thermal transmittance of the transparent building envelope (U_{wi}), and the opaque (A_{op}) and transparent (A_{wi}) thermal envelope area.
Main technical building system (TBS) type of space heating generator	Theoretically, for an EPC ID, there can be an infinite number of heat generators installed (e.g., the EPC of an apartment block or a multi-family house with an autonomous boiler for each building unit). Therefore, only one space heat generator was identified for each EPC, i.e., the one with the highest nominal power.
Energy need for space cooling ($EP_{C;nd}$)	Calculated as the product between the overall mean seasonal efficiency of the space cooling system ($\eta_{s;C}$) and the total energy performance per space cooling ($EP_{C;tot}$).
Recommended energy efficiency measures (EEMs)	The recommended EEMs have been subdivided in: 1. Building fabric - Opaque building envelope 2. Building fabric - Transparent building envelope 3. Technical building system - Space heating 4. Technical building system - Space cooling 5. Technical building system - Other systems Technical building system - Renewable plants
Year of last renovation	Additional data (contained in the Piemonte Region EPC) to make further analysis.
No. of floor	Additional data (contained in the Piemonte Region EPC) to make further analysis.
Mean overall heat transfer coefficient by thermal transmission (H'_T)	Additional data (contained in the Piemonte Region EPC) to make further analysis.

Data name	Note
Energy need for domestic hot water ($EP_{W;nd}$)	Calculated as the product between the overall mean seasonal efficiency of the domestic hot water system ($\eta_{s;W}$) and the total energy performance per domestic hot water ($EP_{W;tot}$).
Non-renewable energy performance per space heating ($EP_{H;nren}$)	Additional data (contained in the Piemonte Region EPC) to make further analysis.
Non-renewable energy performance per space cooling ($EP_{C;nren}$)	Additional data (contained in the Piemonte Region EPC) to make further analysis.
Non-renewable energy performance per domestic hot water ($EP_{W;nren}$)	Additional data (contained in the Piemonte Region EPC) to make further analysis.
Overall renewable energy performance ($EP_{gl;ren}$)	Additional data (contained in the Piemonte Region EPC) to make further analysis.

2.2 EPC data clustering

Table 7 reports the set of clusters that identify the Piemonte Region-building typology matrix. According to DPR 412/93 (Italian Republic, 1993), in function of the heating-degree-days (*HDD*) of each municipality, Piemonte Region is divided into climatic zone E (2101 °C·d ≤ *HDD* ≤ 3000 °C·d) and climatic zone F (*HDD* ≥ 3001 °C·d). The municipality of Moncalieri belongs to the climatic zone E. The clusters are grouped into residential and non-residential buildings. The residential buildings have been divided into single family houses (SFHs) and building units in apartment blocks and in multi-family houses (BU(AB)). The most representative and common non-residential building use categories have been selected. The cells of the building typology matrix (**Table 7**) represent different groups of energy certificates according to climatic zone, building use category, year of construction, and size and shape. For each of the proposed clusters, at least one reference building should be defined, if the sample is representative.

Table 7. Piemonte Region building typology matrix (also used for Moncalieri)

Climatic zone E	Residential bldgs		Non-residential bldgs				
	Single-family house (SFH)	**Building unit (BU(AB))**	**Office**	**Educational building**	**Hospital**	**Sport facility**	**Hotel**
≤ 1900 (CP1)	...	...	...	...	...	...	...
1901-1920 (CP2)	...	...	...	...	...	...	...
1921-1945 (CP3)	...	...	...	...	...	...	...
1946-1960 (CP4)	...	...	...	...	...	...	...
1961-1975 (CP5)	...	...	...	...	...	...	...
1976-1990 (CP6)	...	...	...	...	...	...	...
1991-2005 (CP7)	...	...	...	...	...	...	...

Climatic zone E	Residential bldgs		Non-residential bldgs				
	Single-family house (SFH)	Building unit (BU(AB))	Office	Educational building	Hospital	Sport facility	Hotel
> 2005 (CP8)	...	...	...	...	...	...	...

The EPC data contained in the energy certificates have been processed with MS Excel. However, other similar tools (e.g., Python or MATLAB) could be used, especially whether the number of information increases. In the MS Excel environment, in order to reduce the computational effort, it is highly recommended to avoid links between different files.

The number of spreadsheets in the Excel file has been set consistently with the number of construction periods (CPs) per country (see **Table 3**). Thus, each Excel spreadsheet will contain the EPC data per intended use and construction period (e.g., RES_CP1, RES_CP2, ..., RES_CPn).

The cluster structure for Moncalieri is shown in **Figure 6.** The characters before the underscore symbol represent the residential building use category ("E1"), according to Italian legislation (Italian Republic, 1993).

Figure 6. MS Excel cluster's structure for Moncalieri (residential use)

The EPC data quality scoring procedure has been integrated into the MS Excel sheet. To facilitate the analysis, some cells have been coloured differently. The colour of the cells refers to the indications presented in **Figure 7**, and summarised as follows:

- Yellow cells provide a link to other MS Excel spreadsheets (the EPC Piemonte Region database),
- Red cells contain formulas that determine the result of the selected EPC parameter (e.g., EPC data quality score, *U*-value, $EP_{C;nd}$, etc.). As indicated in **Table 6**, some EPC parameters have been calculated for the Piemonte Region case, and
- Green cells provide additional Piemonte Region EPC data compared to the set presented in the EPC data selection (Section 1.1).

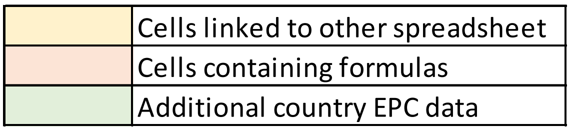

Figure 7. Colour caption of the MS Excel spreadsheet cells

As regards the MS Excel structure, each row represents a different energy performance certificate, and the EPC data are reported along the columns (see **Figure 8**).

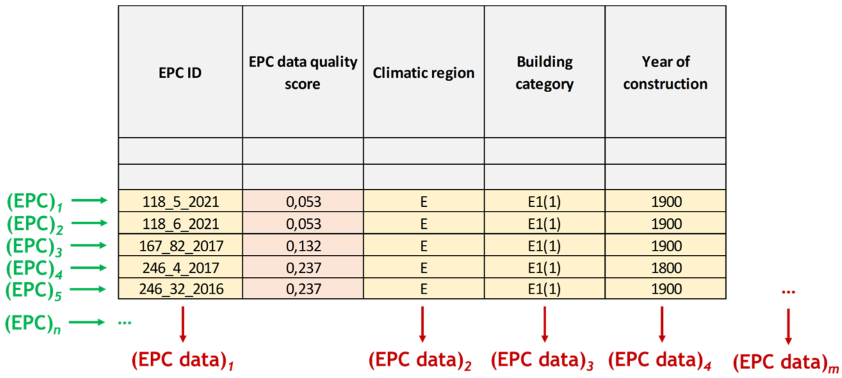

Figure 8. MS Excel spreadsheet structure per building typology (climatic zone E_residential_BU(AB)_CP1)

2.3 EPC data quality checking

The EPC data quality rules and scores, presented in **Table 8**, have been integrated into the MS Excel spreadsheet mentioned in the previous Section 2.2.

Table 8. EPC data adjustments and calculations on the EPC database of Piemonte

Data name (Critical parameter*)	Typology of rules	Rule	Respected rule (score)	Unrespected rule (score)
Assessed object	D	string not null	0,000	0,026
Application type	D	string not null	0,000	0,026
EPC ID code*	D	string not null	0,000	1,000
Building city	D	string not null	0,000	0,026
Number of building units	D	string not null *or* integer ≥ 0	0,000	0,026
Building typology	D	string not null	0,000	0,026
Building constructive typology	D	string not null	0,000	0,026
Building category	D	string not null	0,000	1,000
Year of construction	D, P	integer > 0	0,000	1,000
Climatic region	D	string not null	0,000	0,026
Heating degree days	D, P	integer > 0	0,000	0,026
Thermally heated/cooled floor area	D, P, C	decimal > 0 if the space heating/cooling service exists	0,000	1,000
Thermally heated/cooled gross volume	D, P, C	decimal > 0 if the space heating/cooling service exists	0,000	1,000
Compactness ratio	D, P	decimal > 0	0,000	0,026
Thermal envelope area	D, P	decimal > 0	0,000	1,000
Opaque/transparent thermal envelope area	D, P	decimal > 0	0,000	0,026
Mean thermal transmittance of the total building envelope	D, P	decimal (0,0; 6,0] W/(m²·K)	0,000	0,026
Mean thermal transmittance of the opaque building envelope	D, P	decimal (0,0; 4,5] W/(m²·K)	0,000	0,026
Mean thermal transmittance of the transparent building envelope	D, P	decimal (0,0; 6,0] W/(m²·K)	0,000	0,026
Heating/cooling/domestic hot water energy service	D	Boolean value	0,000	0,026

Data name (Critical parameter*)	Typology of rules	Rule	Respected rule (score)	Unrespected rule (score)
Energy carrier per heating/cooling/domestic hot water	D, C	string not null if the heating/cooling/domestic hot water service exists	0,000	0,026
Main technical building system (TBS) type of space heating generator	D, C	string not null if the space heating service exists	0,000	0,026
Overall mean seasonal efficiency of the heating/cooling/domestic hot water system	D, P, C	decimal > 0 if the heating/cooling/domestic hot water service exists	0,000	0,026
Mean seasonal efficiency of the heating generation	D, P, C	decimal > 0 if the space heating service exists	0,000	0,026
Mean seasonal efficiency of the heating distribution/control/emission sub-system	D, P, C	decimal (0; 1] if the space heating service exists	0,000	0,026
<u>Energy need for space heating</u>	D, P, C	decimal ≥ 0 if the space heating service exists	0,000	1,000
Energy need for space cooling	D, P, C	decimal ≥ 0 if the space cooling service exists	0,000	0,026
<u>Overall non-renewable energy performance</u>	D, P	decimal ≥ 0	0,000	1,000
Delivered natural gas/electricity/ thermal energy from district heating	D, P, C	decimal > 0 if natural gas/electricity/thermal energy from district heating consumed	0,000	0,026
Recommended energy efficiency measures	D	string not null	0,000	0,026
Year of last renovation	D, P	integer > 0	0,000	0,026
No. of floor	D, P	integer > 0	0,000	0,026
Mean overall heat transfer coefficient by thermal transmission (H'_T)	D, P	decimal ≥ 0	0,000	0,026
Energy need for domestic hot water ($EP_{W;nd}$)	D, P	decimal ≥ 0	0,000	0,026
Non-renewable energy performance per space heating ($EP_{H;nren}$)	D, P	decimal ≥ 0	0,000	0,026
Non-renewable energy performance per space cooling ($EP_{C;nren}$)	D, P	decimal ≥ 0	0,000	0,026
Non-renewable energy performance per domestic hot water ($EP_{W;nren}$)	D, P	decimal ≥ 0	0,000	0,026
D = data types of checks; P = physical impossibility checks; C = consistency checks				

Moreover, some additional rules (**Table 9**) of the consistency check categories have been introduced in the MS Excel spreadsheet.

Table 9. EPC data adjustments and calculations on the EPC database of Piemonte

Data name	Rule description
Thermally heated/cooled floor area ($A_{H/C;use;ztc}$) Thermally heated/cooled gross volume ($V_{H/C;g}$)	The thermally heated/cooled gross volume is divided by the thermally heated/cooled gross floor area. The average height calculated will be compared with the minimum height in Italian legislation. The following factor (UNI, 2008) to convert the thermally heated/cooled (net) floor area to the thermally heated/cooled gross floor area: • $f_n = 0{,}9761 - 0{,}3055 \cdot d_m$ • d_m represents the average thickness of the vertical closures (d_m = 45 cm)
Opaque/transparent thermal envelope area ($A_{op/wi}$)	In the Piemonte Region case, the thermal envelope area has been considered as a reference. Moreover, the A_{env} has not to be calculated starting from the sum between the opaque and the transparent thermal envelope area. So, the following are the admissibility ranges to be met: • ($A_{op} + A_{wi} \geq 0{,}85 \cdot A_{env}$) AND ($A_{op} + A_{wi} \leq A_{env}$)

For each I/O EPC data, the set of rules (**Table 8** and **Table 9**) have been introduced in each MS Excel spreadsheet (see **Figure 9**). For instance, according to **Figure 9**, the cells coloured in red represent the non-respected rule for a critical parameter (thermally cooled gross volume, $V_{C;g}$) with the attribution of the maximum score value. Instead, the yellow cells represent the non-respected rule for a non-critical parameter (opaque thermal envelope area, A_{op}). The acceptability threshold value, for the proposed example, corresponds to 0,631, namely equal to the sum of the score of halves of the EPC data considered in the analysis, thus neglecting the number of additional EPC parameters (i.e., $EP_{W;nd}$, $EP_{H;nren}$, $EP_{C;nren}$, etc.).

Summarising, the *i*-th EPC data will not appear in the statistical processing if one of the two following circumstances occurs:

- The overall EPC score is greater than 0,631 (acceptability threshold value), or
- The score for that specific EPC data is greater than 0.

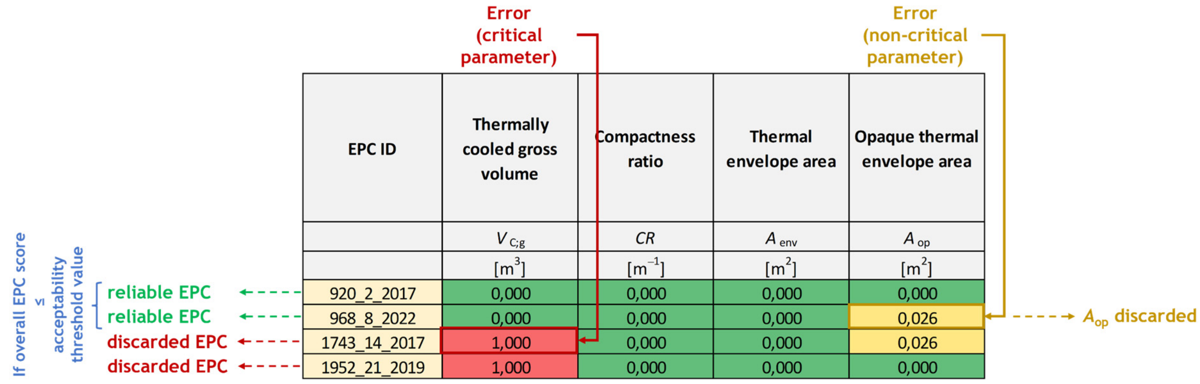

Figure 9. Set of scores for the Piemonte EPC database (example)

2.4 Statistical analysis

The statistical analysis described in 1.4 has been applied to the Piemonte Region case (Moncalieri) in the MS Excel environment. The analysed dataset is limited, and it is used to discover the applicability of the proposed methodology. In some cases, the sample is non-representative, i.e., the information is randomly distributed without identifying any general trend, resulting in wide interquartile ranges.

Table 10 presents the EPC input and output data necessary to create the reference buildings. If the goal is to create a representative apartment block from EPCs issued for building units, some hypotheses have to be formulated. For instance, some geometrical characteristics (i.e., compactness ratio, gross volume, etc.) could be derived from TABULA, in order to assemble the virtual representative apartment block or multi-family house. Otherwise, the defined reference building is referred to as the building unit archetype.

The main results for Moncalieri are shown from **Figure 10** to **Figure 31**.

Table 10. Reference building data definition (db = database)

Representative EPC data	**Single-family house (SFH)**	**Apartment block**
Building constructive typology	Piemonte EPC db	Piemonte EPC db
Building typology	Piemonte EPC db	TABULA
Compactness ratio, *CR*	Piemonte EPC db	TABULA
Thermally heated gross volume, $V_{H;g}$	Piemonte EPC db	TABULA
Thermally conditioned floor area, $A_{H;use;ztc}$	Piemonte EPC db	TABULA
Ratio between transparent thermal envelope area and thermal envelope area, A_{wi}/A_{env}	Piemonte EPC db	Piemonte EPC db
Mean thermal transmittance of opaque building envelope, U_{op}	Piemonte EPC db	Piemonte EPC db
Mean thermal transmittance of transparent building envelope, U_{wi}	Piemonte EPC db	Piemonte EPC db
Energy carrier per space heating	Piemonte EPC db	Piemonte EPC db
Energy carrier per space cooling	Piemonte EPC db	Piemonte EPC db
Energy carrier per domestic hot water	Piemonte EPC db	Piemonte EPC db
Mean seasonal efficiency of the heating generation sub-system per energy carrier	Piemonte EPC db	Piemonte EPC db
Utilisation efficiency, $\eta_{H;u}$ ($\eta_{H;d}$ x $\eta_{H;c}$ x $\eta_{H;e}$)	Piemonte EPC db	Piemonte EPC db
Energy need for space heating, $EP_{H;nd}$	Piemonte EPC db	Piemonte EPC db
Energy need for space cooling, $EP_{C;nd}$	Piemonte EPC db	Piemonte EPC db
Energy need for domestic hot water, $EP_{W;nd}$	Piemonte EPC db	Piemonte EPC db
Overall mean seasonal efficiency of the space heating system, $\eta_{s;H}$	Piemonte EPC db	Piemonte EPC db
Overall mean seasonal efficiency of the space cooling system, $\eta_{s;C}$	Piemonte EPC db	Piemonte EPC db
Overall mean seasonal efficiency of the domestic hot water system, $\eta_{s;W}$	Piemonte EPC db	Piemonte EPC db

Representative EPC data	Single-family house (SFH)	Apartment block
Non-renewable energy performance per space heating, $EP_{H;nren}$	Piemonte EPC db	Piemonte EPC db
Non-renewable energy performance per space cooling, $EP_{C;nren}$	Piemonte EPC db	Piemonte EPC db
Non-renewable energy performance per domestic hot water, $EP_{W;nren}$	Piemonte EPC db	Piemonte EPC db
Overall non-renewable energy performance, $EP_{gl;nren}$	Piemonte EPC db	Piemonte EPC db
Overall renewable energy performance, $EP_{gl;ren}$	Piemonte EPC db	Piemonte EPC db
Renewable Energy Ratio, RER ($EP_{gl;ren}/EP_{gl;tot}$)	Piemonte EPC db	Piemonte EPC db

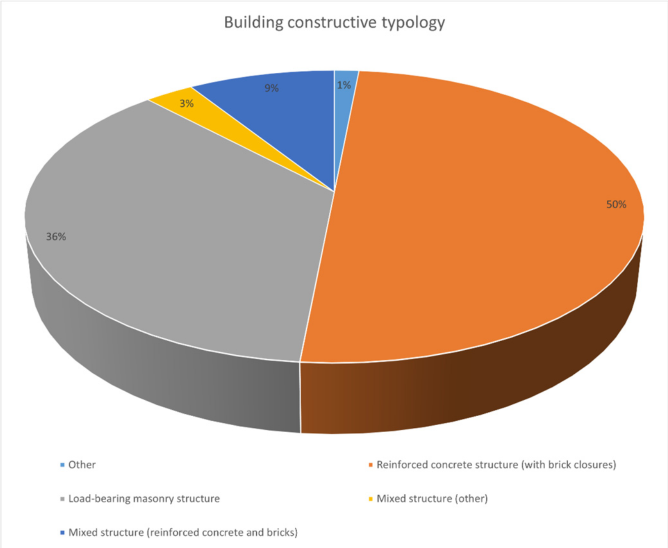

Figure 10. (SFH) Building constructive typology

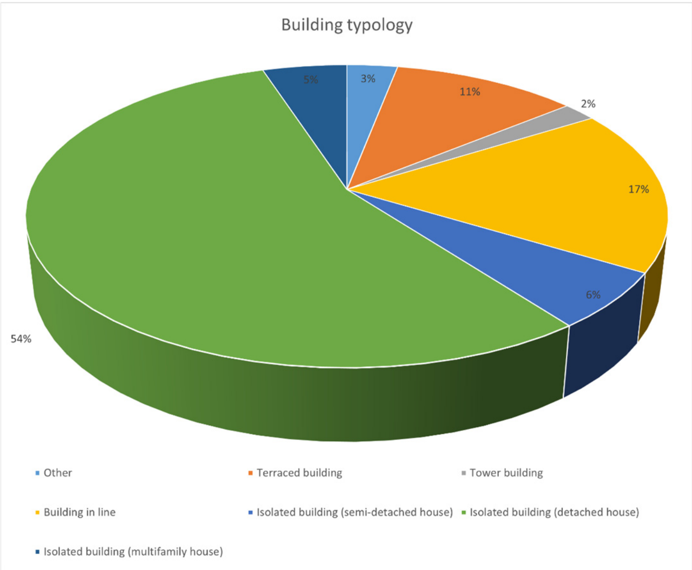

Figure 11. (SFH) Building typology

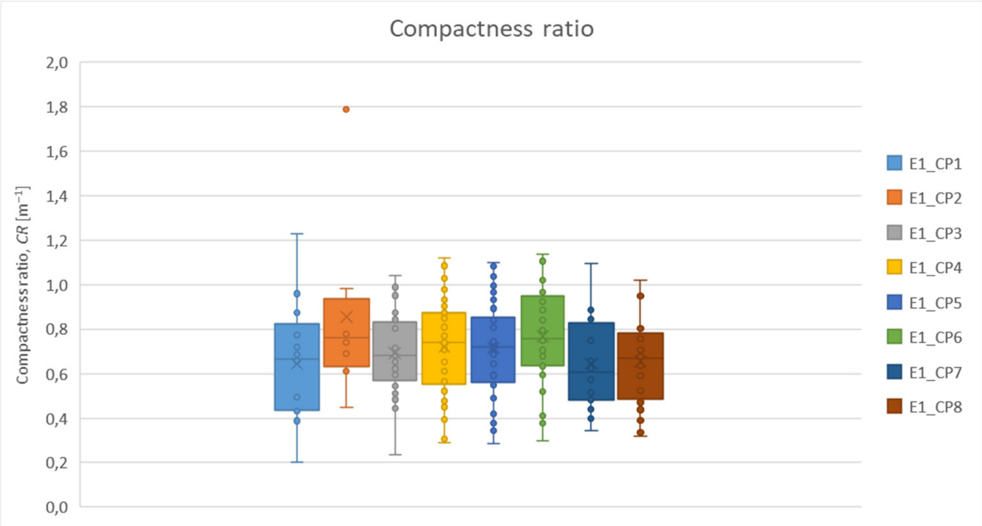

Figure 12. (SFH) Compactness ratio

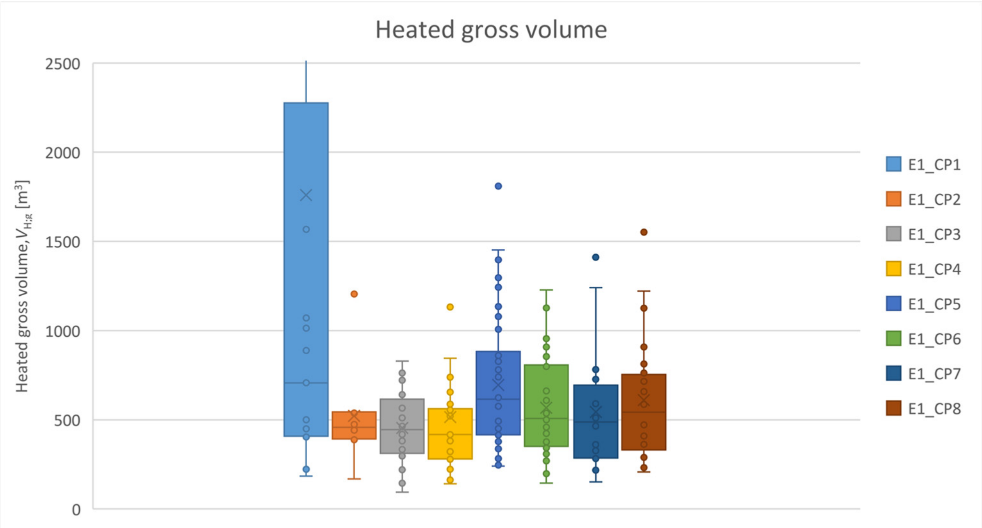

Figure 13. (SFH) Thermally heated gross volume (non-representative sample (i.e., CP1(SFH))

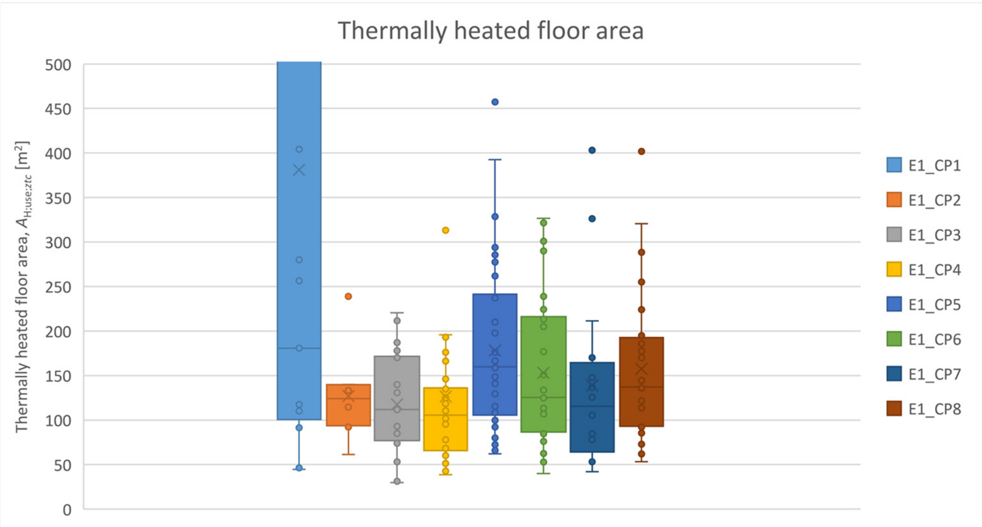

Figure 14. (SFH) Thermally heated floor area (non-representative sample (i.e., CP1(SFH))

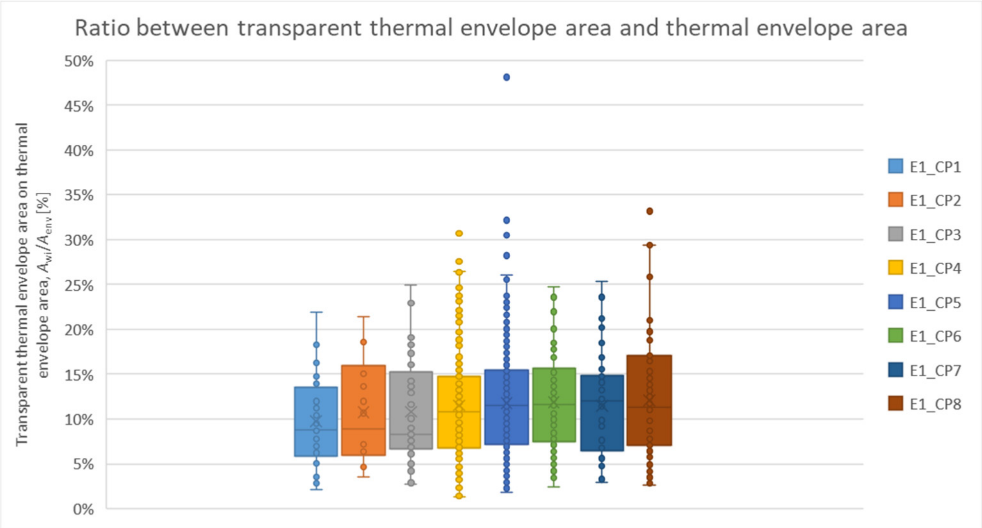

Figure 15. (BU(AB)) Ratio between transparent thermal envelope area and thermal envelope area

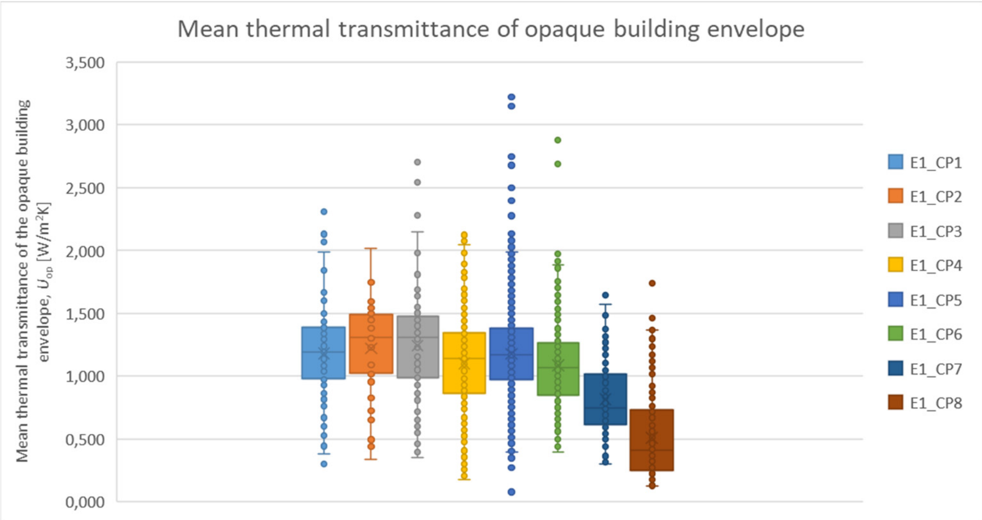

Figure 16. (BU(AB)) Mean thermal transmittance of opaque building envelope

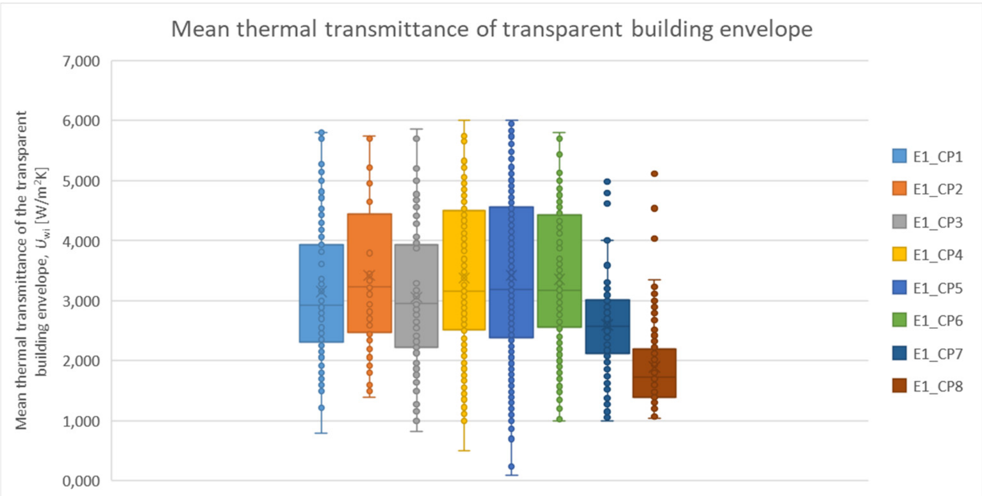

Figure 17. (BU(AB)) Mean thermal transmittance of transparent building envelope

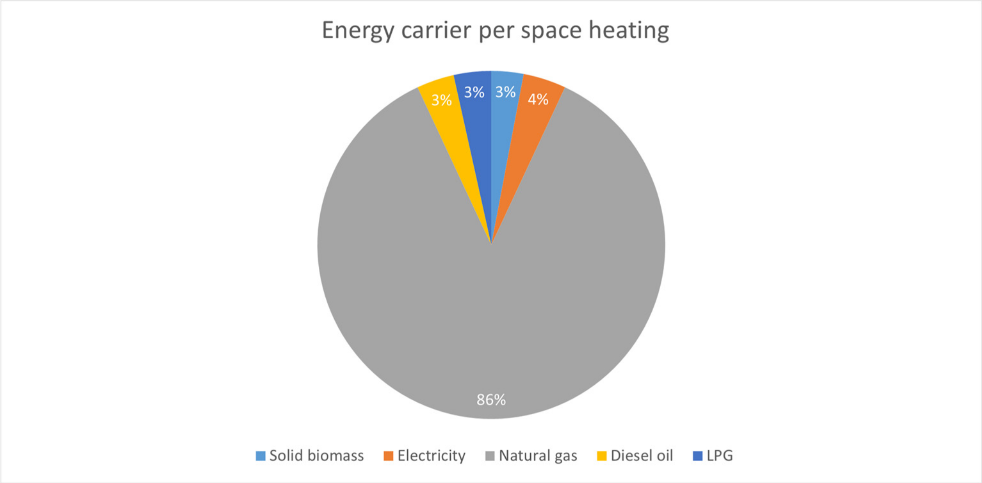

Figure 18. (SFH) Energy carrier per space heating

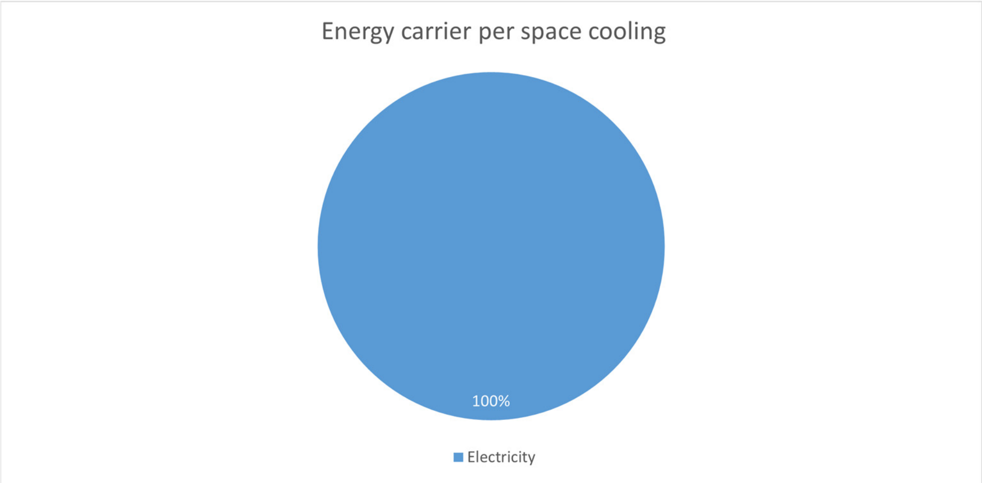

Figure 19. (SFH) Energy carrier per space cooling

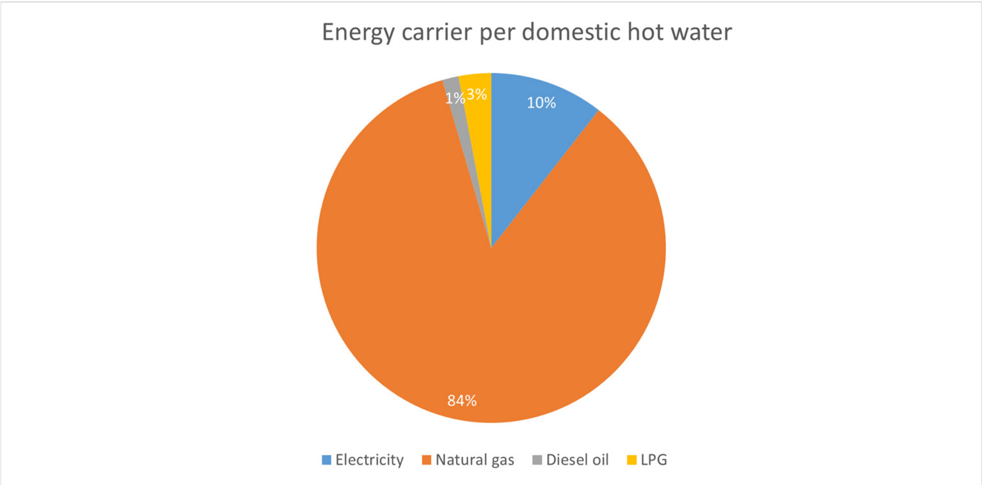

Figure 20. (SFH) Energy carrier per domestic hot water

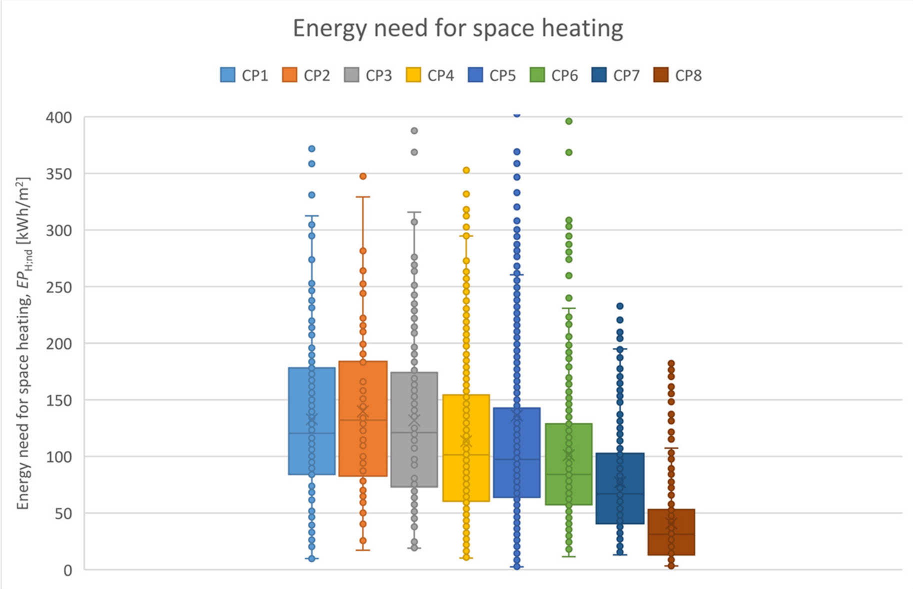

Figure 21. (BU(AB)) Energy need for space heating

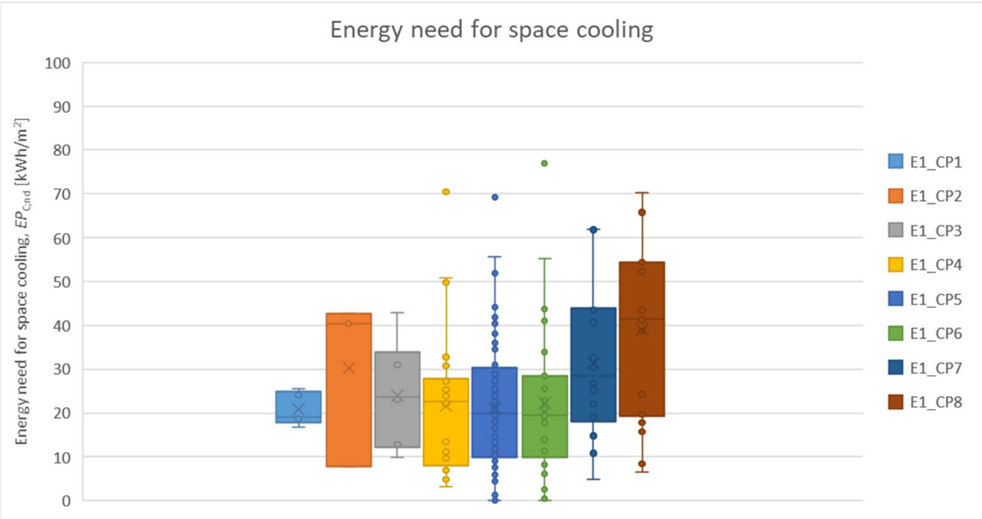

Figure 22. (BU(AB)) Energy need for space cooling (non-representative sample (i.e., CP2(BU(AB)), CP3(BU(AB)))

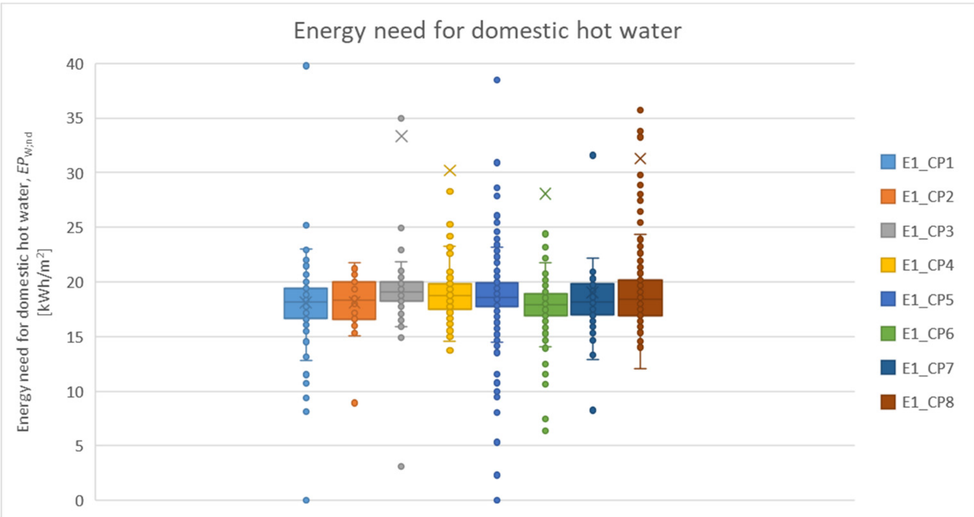

Figure 23. (BU(AB)) Energy need for domestic hot water

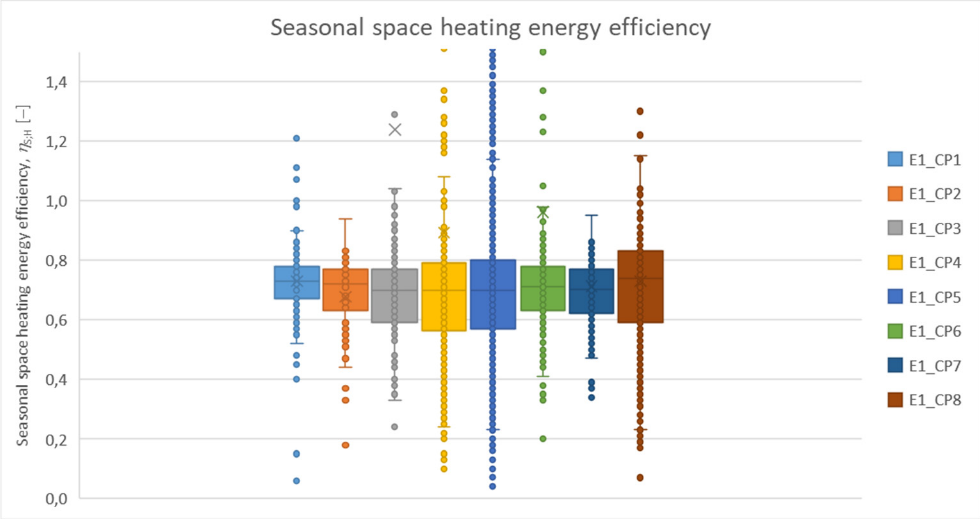

Figure 24. (BU(AB)) Overall mean seasonal efficiency of the space heating system

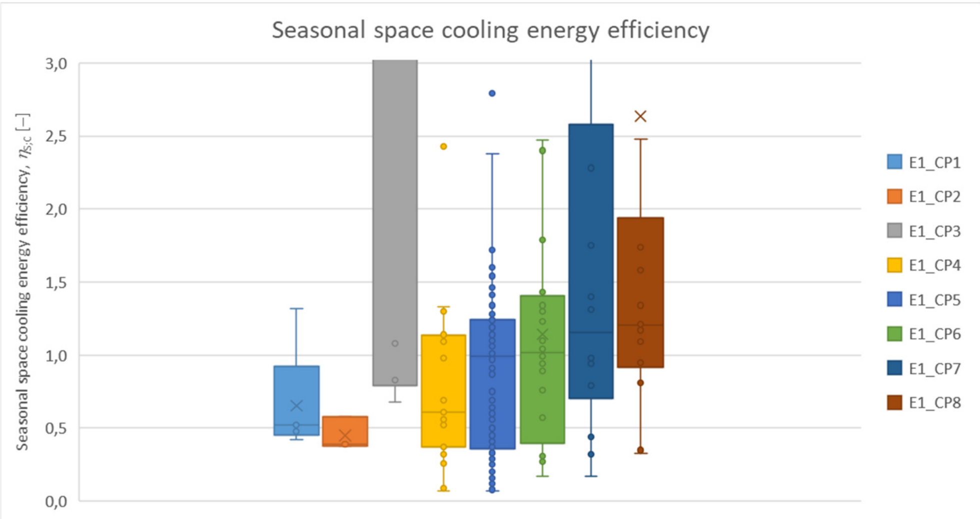

Figure 25. (BU(AB)) Seasonal efficiency of the space cooling system (non-representative sample (i.e., CP3(BU(AB)), CP7(BU(AB)))

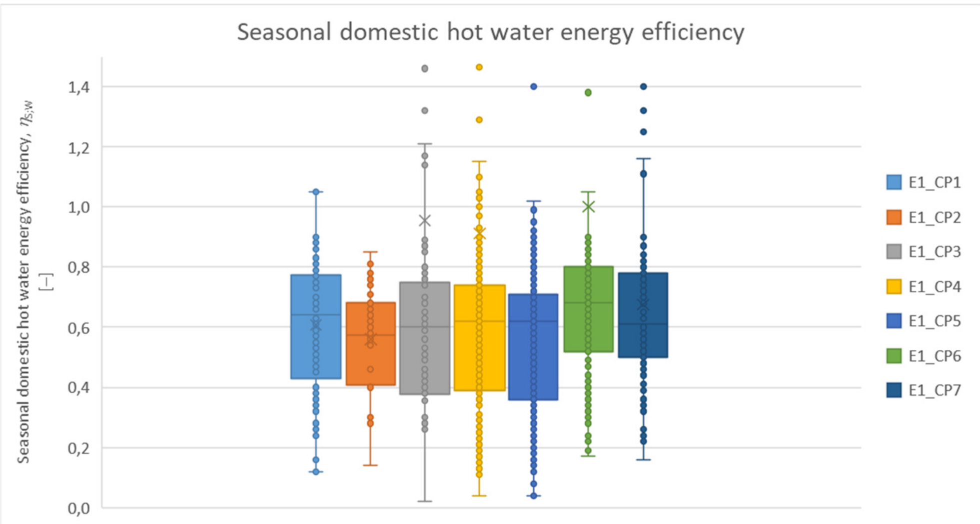

Figure 26. (BU(AB)) Seasonal efficiency of the domestic hot water system

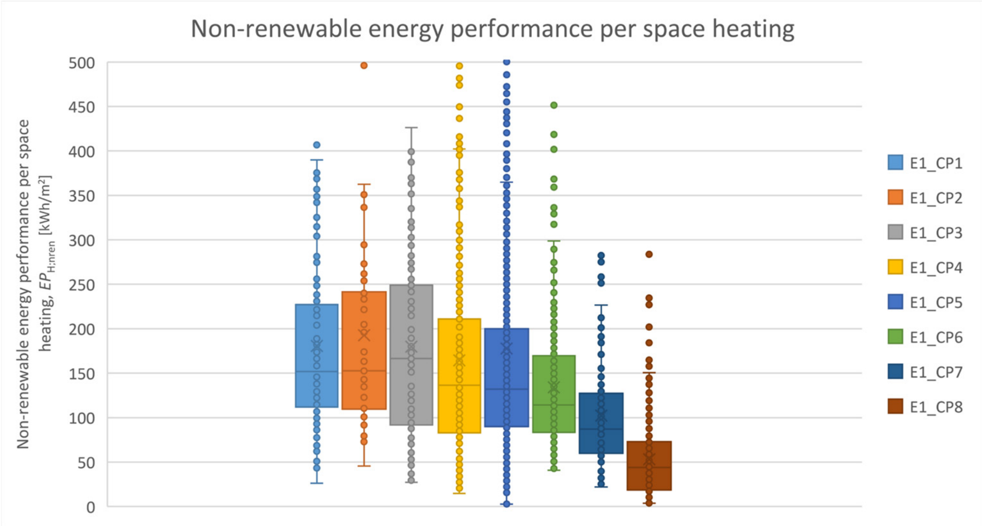

Figure 27. (BU(AB)) Non-renewable energy performance per space heating

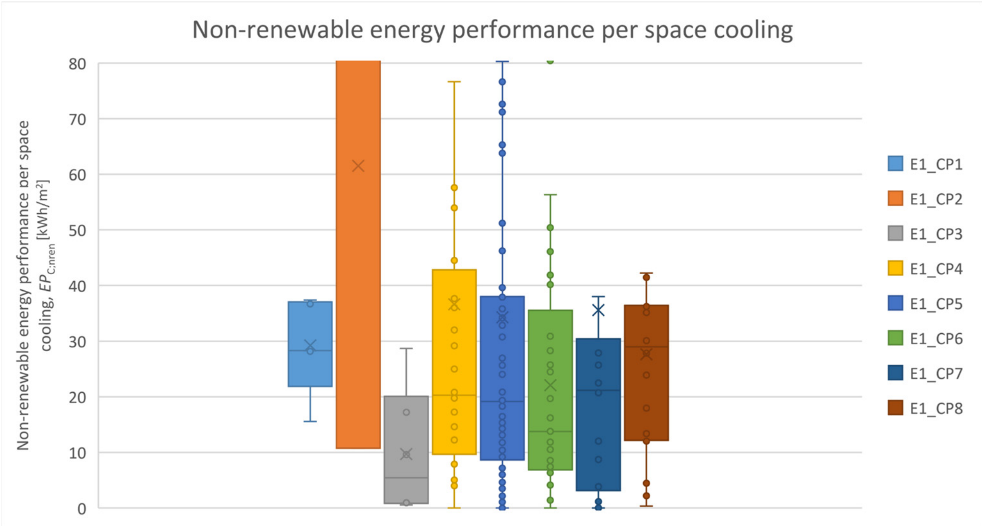

Figure 28. (BU(AB)) Non-renewable energy performance per space cooling (non-representative sample (i.e., CP2(BU(AB)))

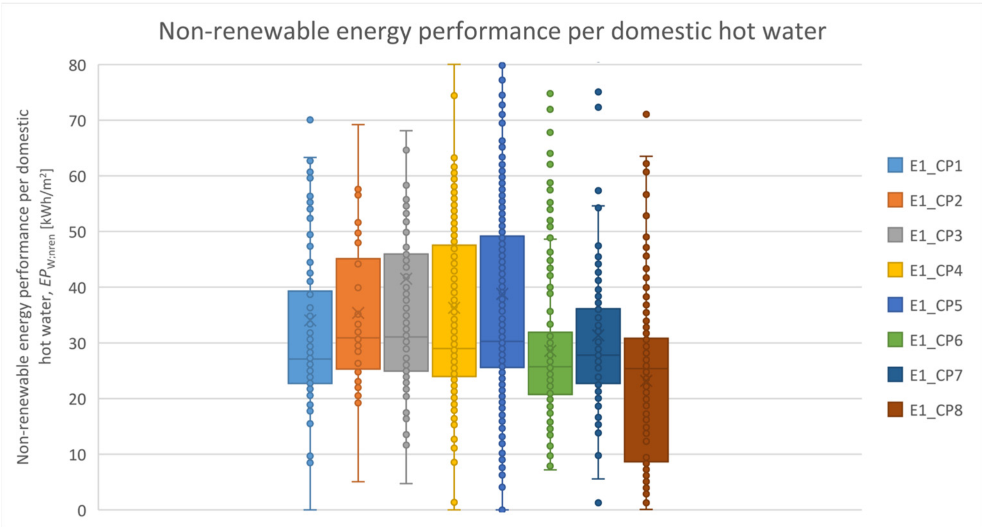

Figure 29. (BU(AB)) Non-renewable energy performance per domestic hot water

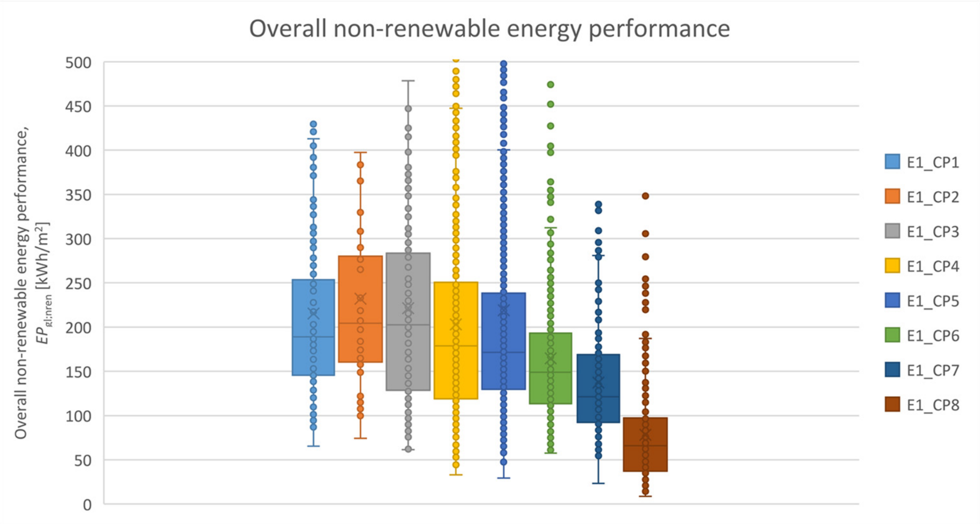

Figure 30. (BU(AB)) Overall non-renewable energy performance

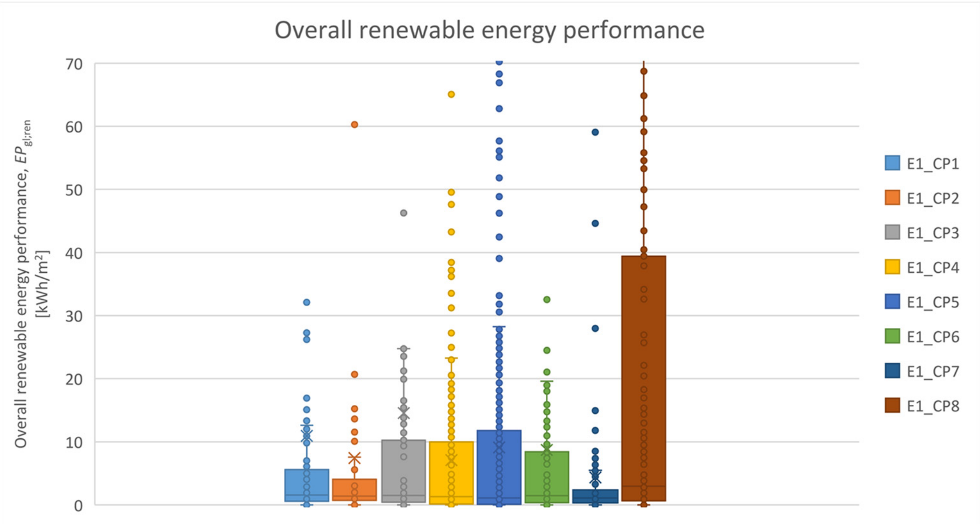

Figure 31. (BU(AB)) Overall renewable energy performance

2.5 Identification of reference buildings

As introduced in Section 2.4, the statistical representation of the proposed EPC parameters is essential for the reference building description. According to the limited sample analysed in this example of application, and in order to show the results of the general methodology, only an archetype is reported for Moncalieri; it refers to E_RES_CP6_SFH (**Table 11**).

The geometrical characteristics, the thermo-physical properties of the building envelope and of the technical building systems, and the energy indicators are reported for this archetype in **Table 12**, in the form of the median and the interquartile ranges (Q_3 - Q_2) and (Q_2 - Q_1).

The data related to the technical building system section of **Table 12** are independent on the year of construction, but dependent on the climatic region, building use category, and building size and shape (in the case of residential buildings).

Table 11. Representative building E_RES_SINGLE_CP6 in the building typology matrix of Piemonte

Climatic zone E	Residential bldgs		Non-residential bldgs				
	Single-family house (SFH)	**Building unit (BU(AB))**	**Office**	**Educational building**	**Hospital**	**Sport facility**	**Hotel**
≤ 1900 (CP1)	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
1976-1990 (CP6)	**E_RES_SINGLE_CP6**	...	...	...	...	...	...
...	...	...	...	...	...	...	...

Table 12. Building archetype for a subset of the building stock of Piemonte (Moncalieri)

MONCALIERI DATABASE – E_RES_SINGLE_CP6						
	Data	**Symbol**	**Unit of measure**	**Median**	**(Q_3 - Q_2)**	**(Q_2 - Q_1)**
Geometry	Compactness ratio	CR	m^{-1}	0,75	0,18	0,12
	Thermally heated gross volume	$V_{H;g}$	m^3	508	291	149
	Thermally heated floor area	$A_{H;use;ztc}$	m^2	125	86	34
	Transparent thermal envelope area on thermal envelope area	A_{wi}/A_{env}	%	6,55	3,24	1,58
Envelope	Mean thermal transmittance of opaque building envelope	U_{op}	$W/(m^2 \cdot K)$	0,924	0,302	0,164
	Mean thermal transmittance of transparent building envelope	U_{wi}	$W/(m^2 \cdot K)$	2,971	0,329	0,634
Technical building system	Energy carrier per space heating	Natural gas = 84%; electricity = 6% (of the analysed sample)				
	Energy carrier per space cooling	Electricity = 95%; natural gas = 5% (of the analysed sample)				
	Energy carrier per domestic hot water	Natural gas = 82%; electricity = 12% (of the analysed sample)				
	Mean seasonal efficiency of the heating generation sub-system (natural gas)	$\eta_{H;gn}$	-	0,800	0,085	0,040
	Mean seasonal efficiency of the heating generation sub-system (electricity)	$\eta_{H;gn}$	-	na (*)	na	na
	Utilisation energy efficiency	$\eta_{H;u}$	-	0,883	0,048	0,071
Energy indicators	Energy need for space heating	$EP_{H;nd;ztc}$	kWh/m^2	125	86	34
	Energy need for space cooling	$EP_{C;nd;ztc}$	kWh/m^2	14	3	5
	Energy need for domestic hot water	$EP_{W;nd;ztc}$	kWh/m^2	15	2	1
	Seasonal space heating energy efficiency	$\eta_{s;H}$	-	0,760	0,048	0,058
	Seasonal space cooling energy efficiency	$\eta_{s;C}$	-	na	na	na
	Seasonal domestic hot water energy efficiency	$\eta_{s;W}$	-	0,735	0,055	0,155
	Non-renewable energy performance per space heating	$EP_{H;nren}$	kWh/m^2	158	80	65
	Non-renewable energy performance per space cooling	$EP_{C;nren}$	kWh/m^2	na	na	na
	Non-renewable energy performance per domestic hot water	$EP_{W;nren}$	kWh/m^2	21	7	3
	Overall non-renewable energy performance	$EP_{gl;nren}$	kWh/m^2	197	61	85
	Overall renewable energy performance	$EP_{gl;ren}$	kWh/m^2	1,5	1,9	0,8
	Renewable Energy Ratio	RER	%	0,65	2,52	0,35
(*) The sample analysed does not allow the statistical representation of these parameters ($\eta_{H;gn}$, $EP_{C;nren}$, and $\eta_{s;C}$).						

3. References

1. Ballarini, I., Corgnati, S. P., Corrado, V. (2014). Use of reference buildings to assess the energy saving potentials of the residential building stock: The experience of TABULA project. Energy Policy, 68, 273-284. https://doi.org/10.1016/j.enpol.2014.01.027.
2. BUILD_ME. (2018). BUILD_ME: Towards a Low-Carbon Building Sector in the MENA Region - Building typology database. Retrieved November 26, 2022, from https://www.buildings-mena.com/typologies.
3. Department of Energy (DOE) of United States of America. (2013). Prototype Building Models. Retrieved November 26, 2022, from https://www.energycodes.gov/prototype-building-models.
4. EPISCOPE. 2016. Project website. Retrieved November 4, 2024, from https://episcope.eu/welcome/.
5. European Committee for Standardisation (CEN). (2017). EN ISO 52000-1: Energy performance of buildings —Overarching EPB assessment — Part 1: General framework and procedures.
6. eXTENDing the energy performance assessment and certification schemes via a modular approach (X-tendo). (2022). D4.4 Description of methodologies and concepts for the technical implementation of each feature regarding improved handling and use of EPC data in selected implementing countries.
7. Italian Organisation for Stardardisation (UNI). (2008). UNI/TS 11300-1: Energy performance of buildings - Part 1: Evaluation of energy need for space heating and cooling. UNI: Milan, Italy.
8. Italian Republic. (1993). DPR 26 August 1993, n. 412 - Regolamento recante norme per la progettazione, l'installazione, l'esercizio e la manutenzione degli impianti termici degli edifici ai fini del contenimento dei consumi di energia, in attuazione dell'art. 4, comma 4, della legge 9 gennaio 1991, n. 10.
9. TIMEPAC. (2023). Procedures and services to undertake large-scale statistical analysis of EPCs databases. Deliverable D2.5. Retrieved November 4, 2024, from https://timepac.eu/reports/procedures-and-services-to-undertake-large-scale-statistical-analysis-of-epcs-databases/.