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Data Descriptor

Progress in the Cost-Optimal Methodology Implementation in Europe: Datasets Insights and Perspectives in Member States

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Abstract: This data article relates to the paper "Review of the cost-optimal methodology implementation in Member States in compliance with the Energy Performance of Buildings Directive". Datasets linked with this article refer to the analysis of the latest national cost-optimal reports, providing an assessment of the implementation of the cost-optimal methodology, as established by the Energy Performance of Building Directive (EPBD). Based on latest national reports, the data provided a comprehensive update to the cost-optimal methodology implementation throughout Europe, which is currently lacking harmonization. Datasets allow an overall overview of the status of the cost-optimal methodology implementation in Europe with details on the calculations carried out (e.g., multi-stage, dynamic, macroeconomic, and financial perspectives, included energy uses, and full-cost approach). Data relate to the implemented methodology, reference buildings, assessed cost-optimal levels, energy performance, costs, and sensitivity analysis. Data also provide insight into energy consumption, efficiency measures for residential and non-residential buildings, nearly zero energy buildings (NZEBs) levels, and global costs. The reported data can be useful to quantify the cost-optimal levels for different building types, both residential (average cost-optimal level 80 kWh/m^{2}y for new, 130 kWh/m^{2}y for existing buildings) and non-residential buildings (140 kWh/m^{2}y for new, 180 kWh/m^{2}y for existing buildings). Data outline weak and strong points of the methodology, as well as future developments in the light of the methodology revision foreseen in 2026. The data support energy efficiency and energy policies related to buildings toward the EU building stock decarbonization goal within 2050.

Dataset: Data directly related to this article are provided in the Supplementary Materials.

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Keywords: Energy Performance of Buildings Directive; cost-optimal methodology; Member States; energy efficiency; costs; energy policy; building decarbonization

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1. Summary

Buildings are at the core of the European strategy towards a zero-emission and fully decarbonized stock by 2050 [1]. A key priority at the European level is to make the energy performance of buildings more efficient in the Member States [2,3]. Important policy provisions for a long-term improvement of the EU building stock are contained in the Energy Performance of Buildings Directive recast (2010/31/EU—EPBD [4]) and its recent revision [5]. As assessed in [6], The implementation of the cost-optimal methodology marked a novel approach to the establishment of the minimum energy performance requirements for new and existing buildings. Member States have to calculate and establish cost-optimal levels of minimum energy performance requirements for new and existing buildings following the established comparative methodology framework [7] and related guidelines [8].

As regards the application, the cost-optimal methodology is an efficient and complete decision-making tool for building designs that considers both energy and economic evaluations. Its introduction signaled an important milestone towards the renovation of the existing building stock and a substantial transformation towards a zero-carbon society.

Starting from the definition of the reference buildings, the methodology comprises the establishment of technical variants and measures or packages of measures to be compared in terms of costs and energy performance in the global cost curve. In 2012, the Commission provided the Delegated Regulation 244/2012 (European Commission, 2012a), related to the comparative methodology framework of cost-optimal levels, to be used by Member States to benchmark their building standards.

The calculation approach can be summarized in six steps:

1. Establishment of reference buildings by selecting real or virtual buildings representing the building stock. Member States shall define them for at least three building categories, both for new and existing buildings (residential single-family, residential multi-family, and offices). According to Regulation 244, Annex I, Member States must also define reference buildings for other building categories for which specific energy performance requirements exist. For new buildings, the energy performance standard in force can be assumed as the base case. For the existing stock at least two reference buildings have to be considered, which can be established on the basis of size, age, cost, structure, construction material, use pattern, or climatic zone;
2. Identification of the energy efficiency and renewable measures to be implemented in new or existing buildings, including different packages of measures or measures of different levels (e.g., different insulation levels), which must respect the EU and national legislation on construction products, comfort criteria indoors and indoor environmental quality;
3. Calculation of the (net) primary energy consumption based on the current national or CEN standards methodologies for each selected building variant;
4. Calculation of the global cost at each step using the Net Present Value based on 30 years for residential and 20 years for non-residential buildings. The included cost categories are initial investment costs, running costs (i.e., energy, operational, maintenance, and replacement costs), disposal costs, final value, and the cost associated with CO_2 emissions (only for the macroeconomic perspective);
5. Identification of cost-optimal levels for each reference building expressed in primary energy consumption (kWh/m^{2}y or in the relevant unit). Cost-optimal levels can be calculated for both macroeconomic and financial perspectives, but they are normally derived from the second one;
6. Evaluation of the gap with current minimum energy performance requirements. If the difference is more than 15%, Member States are asked to justify the gap or define a plan to reduce the gap.

The calculation of the (net) primary energy consumption should be based on the current National or CEN standards, while the cost-optimal levels can be calculated from both macroeconomic and financial perspectives.

Energy efficiency is associated with increased costs and, generally, the more efficient the measures are, the higher the expense. This is because the only benefit, normally monetized, is the energy cost savings from a financial perspective.

The financial calculation of the global costs assumes that all costs are paid by the customer (i.e., including all applicable taxes, VAT, and charges). In addition, the calculation includes the subsidies for different measures or measure packages. The following equation is applied:

$$C_g(\tau) = C_I + \sum_j \left[\sum_{i=1}^{\tau} (C_{a,i}(j) \times R_d(i)) - V_{f,\tau}(j) \right]$$

where τ is the calculation period; $C_g(\tau)$ is the global cost (referring to starting year τ_0) over the calculation period; C_I is the initial investment cost for a measure or a set of measures

j; $C_{a,i}(j)$ is the annual cost in the year i for a measure or a set of measures j; $V_{f,\tau}(j)$ is the residual value of the measure or set of measures j at the end of the calculation period (discounted to the starting year τ_0); $R_d(i)$ is the discount factor for year i, based on the discount rate r.

The included cost categories are initial investment costs, running costs (i.e., energy, operational, maintenance, and replacement costs), disposal costs, final value, and the cost associated with CO_2 emissions (only for the macroeconomic perspective). The gap is between the NZEBs levels and the current minimum energy performance requirements. If the difference is more than 15%, Member States are asked to justify the gap or define a plan to reduce it. Key calculation parameters in the cost-optimal calculation are the discount/interest rate, and the annual increase of energy prices, as well as primary energy factors associated to different fuels.

The cost-optimal methodology appears very effective both to upgrade the energy performance requirements in force at the national level and to assess the effects of policy measures to achieve the mandatory target of near-zero energy buildings (NZEBs) [9–12]. A recent study [13] showed that the majority of Member States seems to adopt the cost-optimal approach in an appropriate way and use it to define NZEBs requirements.

From an early assessment of the cost-optimal methodology, a heterogeneous situation characterized European countries as each building type and climate presented varying cost-optimal levels [14]. Moreover, since its release, the methodology spread mainly theoretically at government and scientific levels, but not yet sufficiently among professionals.

Regardless of comparison issues among cost-optimal levels and a non-uniform application across Europe [15], it is generally agreed that it represents an efficient and complete decision-making tool for building design that considers both energy and economic evaluations. The importance of this assessment is highlighted by the efforts in the literature to develop the methodology. However, studies mainly focus on a specific climate or building type, but a comprehensive methodology implementation is still missing and undoubtedly necessary to assess its progress with strengths and weaknesses and possible future developments. Moreover, this assessment can guide the revision of the cost-optimal methodology that is foreseen in 2026 according to the revision of the EPBD [5].

The first cost-optimal reports were released and analyzed in 2013. A joint, consistent and comparable level of ambition was desirable after the first assessment [16]. A heterogeneous situation is characterized by European countries as each building type and climate presented varying cost-optimal levels [17]. Furthermore, comparison issues emerged among cost-optimal levels, adopting a non-uniform application across Europe.

The comparison between the cost-optimal levels obtained with the two calculation rounds shows that, for almost all building types, lower values were obtained in 2018 with respect to the 2013 values. The comparison between the cost-optimal levels (consolidated version) and the latest NZEB levels reveals that many countries are introducing NZEB energy requirements which are lower (about −50%) than cost-optimal. In fact, the NZEB levels for new buildings result in substantially higher cost-optimal levels only for four countries.

The revised reports were submitted by Member States in 2018–2021 but have not been assessed yet [18]. This data paper provides the first datasets related to the assessment of these reports. Data on energy price, discount rate, and primary energy factors are provided for each Member State for different residential and non-residential buildings. Data on cost-optimal levels for building types are also included in the datasets as well as the gaps with the previous reports both at building and element levels. Considered reference buildings and energy efficiency measures are also extracted from the reports and available. The conformity and plausibility of the Member States' reports are assessed in the linked datasets.

In addition to summarizing the progress of the cost-optimal methodology implementation in European Member States, the data are useful to compare the latest reports submitted with the previous ones, as well as for further analysis. Within this perspective, the outcomes of this cost-optimal review assume a strategic value, since they allow a comprehensive comparison among Member States assessing the progress and related strengths and weaknesses. Its future development and implementation will be crucial for the renovation of existing buildings and a zero-carbon society in 2050.

2. Data Description

Data were collected from the latest cost-optimal reports that Member States submitted to the European Commission to comply with the Energy Performance of Building Directive.

The methodology is based on the principle of the cost-benefit analysis, and it shall be calculated from two economic perspectives: the financial and the macroeconomic, which refer to different discount rates (lower in the macroeconomic one) and cost items. While the financial perspective includes taxes, macroeconomics considers greenhouse gas emission costs.

The first step of the current assessment has been the reports' collection, and their official translation [6]. To harmonise the data collection, an assessment template has been developed to summarise the different steps of the cost-optimal methodology. The data collection can be summarised in the following sections that reflect the developed template:

- establishment of reference buildings,
- identification of energy efficiency measures,
- measures based on renewable energy sources and/or packages and variants of such measures for each reference building,
- calculation of the primary energy demand,
- calculation of the global cost in terms of net present value for each reference building,
- sensitivity analysis,
- derivation of a cost-optimal level of energy performance for each reference building.

In relation to the analyzed reports, the magnitude of this study can be also perceived by the total reports' pages to be analyzed (5238) and related annexes (3971). Although Member States were contacted to provide additional information when possible, frequently information was missing or not extractable due to non-clear translations, provided units, tables, figures, or explained methodology.

Data on cost-optimal reports are attached to this paper in the form of an excel spreadsheet (named "Cost-optimal datasets"). It is composed of different sheets:

In Sheet 1 (named "report overview"), the information in Table 1 is available for each Member States.

Table 1. Reported information in Sheet 1 for Member States.

Sheet 1 "Report Overview"	Name	Explanation
1	Reference buildings	Which type of building representing the national stock has been considered
1.1	New residential	Considered new residential building
1.2	New non-residential	Considered New non-residential building
1.3	Existing residential	Considered Existing residential building
1.4	Existing non-residential	Considered Existing non-residential building
1.5	Virtual or existing	Considered Virtual or existing building
2	Measures	Energy efficiency and renewable measures to be implemented in new or existing buildings
2.1	Average number new	Number of measures for new buildings

Table 1. *Cont.*

Sheet 1 "Report Overview"	Name	Explanation
2.2	Average number existing	Number of measures for existing buildings
2.3	Fair competition	Evaluation of measures
3	Energy	Calculation (calculation of the net primary energy consumption based on the current National or CEN standards for each selected building variant);
3.1	Methods	Methods in the calculation
3.2	Multi-stage	Multi-stage approach details
3.3	Dynamic	Dynamic approach details
3.4	All energy uses residential	Accounted energy uses in the residential sector
3.5	All energy uses non-residential	Accounted energy uses in the non-residential sector
4	Cost calculation	Calculation of the global cost using the Net Present Value based on 30 years for residential and 20 years for non-residential buildings
4.1	All costs	Accounted costs
4.2	Both perspectives	Accounted perspective
4.3	Reference year	Year of reference for the calculation
4.4	Full cost approach	If a full cost approach has been accounted
5	Sensitivity analysis	Performed sensitivity analysis
5.1	Available	If sensitivity is available
5.2	Number of parameters	How many parameters are given
6	Derivation of cost-optimal	Identification of cost-optimal levels for each reference building as primary energy consumption, calculated for both macroeconomic and financial perspectives
6.1	Cost-optimal range	Identification of a cost-optimal range
6.2	Reference perspective	Accounted perspective
6.3	Results available	Details on the provided results
7	Gap analysis	Evaluation of the gap with current minimum energy performance requirements
7.1	With current requirements	Gap with current requirements
7.2	With future/NZEB requirement	Details on future/NZEB requirements
7.3	Gap between cost-optimal and NZEBs levels > 15%?	If the gap is higher than 15%
7.4	Justifications	Justification of a gap that is higher than 15%
7.5	Plan	Plan to reduce the gap

In Sheet 2 (named "PEF, discount rate, energy price"), the information in Table 2 is available for each Member States.

Table 2. Reported information in Sheet 2 for Member States.

Sheet 2 "PEF, Discount Rate, Energy Price"	Name	Explanation
1	Primary energy factors	Provided Primary energy factors
1.1	Electricity	Provided Primary energy factors for Electricity
1.2	Biomass	Provided Primary energy factors for Biomass
1.3	Gas	Provided Primary energy factors for Gas
1.4	Oil	Provided Primary energy factors for Oil
1.5	District heat	Provided Primary energy factors for District heat
2	Discount rate	Provided discount rate
2.1	Financial Residential	Provided discount rate for the Financial Residential
2.2	Financial non-Residential	Provided discount rate for the Financial non-Residential
2.3	Macro Residential	Provided discount rate for the Macro Residential
2.4	Macro Non-residential	Provided discount rate for the Macro Non-residential
3	Energy price calculation [EUR/kWh]	Calculation of energy price from Financial perspective
3.1	Residential	Calculation of energy price from Financial perspective in the residential
3.1.1	Electricity	Energy price for Electricity
3.1.2	Gas	Energy price for Gas
3.1.3	Oil	Energy price for Oil
3.1.4	District heat	Energy price for District heat
3.1.5	Biomass	Energy price for Biomass
4	Annual increase of energy price [EUR/kWh]	Given annual increase of energy price from Financial perspective
4.1	Residential	Energy price from Financial perspective in the residential
4.2	Non-Residential	Energy price from Financial perspective in the non-residential
4.2.1	Electricity	Energy price for Electricity
4.2.2	Gas	Energy price for Gas
4.2.3	Oil	Energy price for Oil
4.2.4	District heat	Energy price for District heat

In Sheet 3 (named "Cost-optimal levels, gaps"), the information in Table 3 is available for each Member States:

Table 3. Reported information in Sheet 3 for Member States.

Sheet 3 "Cost-Optimal Levels, Gaps"	Name	Explanation
1	Cost-optimal levels	Derived cost-optimal levels
1.1	New SFH	New single-family house
1.1.1	PE [kWh/m^{2}y]	Primary energy
1.1.2	GC [EUR/m^2]	Global costs
1.2	New MFH	New multi-family house
1.2.1	PE [kWh/m^{2}y]	Primary energy
1.2.2	GC [EUR/m^2]	Global costs
1.3	New Office	New office building
1.3.1	PE [kWh/m^{2}y]	Primary energy
1.3.2	GC [EUR/m^2]	Global costs
1.4	New Other non-residential	New other non-residential building
1.4.1	PE [kWh/m^{2}y]	Primary energy

Table 3. *Cont.*

Sheet 3 "Cost-Optimal Levels, Gaps"	Name	Explanation
1.4.2	GC [EUR/m^2]	Global costs
1.5	Existing SFH	Existing single-family house
1.5.1	PE [kWh/m^{2}y]	Primary energy
1.5.2	GC [EUR/m^2]	Global costs
1.6	Existing MFH	Existing multi-family house
1.6.1	PE [kWh/m^{2}y]	Primary energy
1.6.2	GC [EUR/m^2]	Global costs
1.7	Existing Office	Existing office building
1.7.1	PE [kWh/m^{2}y]	Primary energy
1.7.2	GC [EUR/m^2]	Global costs
1.8	Existing other non-residential	Existing other non-residential building
1.8.1	PE [kWh/m^{2}y]	Primary energy
1.8.2	GC [EUR/m^2]	Global costs
2	Gaps	Identified gap
2.1	Building level	Primary energy difference (%) between 2013 and 2018 levels
2.1.1	New SFH	New single-family house
2.1.2	New MFH	New multi-family house
2.1.3	New Office	New office building
2.1.4	New Other Non-Residential	New other non-residential building
2.2	Element level	U-value
2.2.1	Existing SFH	Existing single-family house
2.2.2	Existing MFH	Existing multi-family house
2.2.3	Existing Office	Existing office building
2.2.4	Existing Other Non-Residential	Existing other non-residential building

In Sheet 4 (named "conformity-plausibility"), the information in Table 4 are available and summarized:

Table 4. Reported information in Sheet 4 for Member States.

Sheet 4 "Conformity-Plausibility"	Name	Explanation
1	Conformity	Evaluation of the report as it conforms to the different steps of the methodology
1.1	Scope	Conformity in relation to the scope of the methodology
1.	Reference buildings	Conformity in relation to the establishment of reference buildings
1.3	Measures	Conformity in relation to the selection of energy efficiency measures
1.	Calculation P	Conformity in relation to the calculation of the primary energy demand
1.	Sensitivity analysis	Conformity in relation to the carried out sensitivity analysis
1.6	Cost-optimal level	Conformity in relation to the derivation of cost-optimal levels

Table 4. *Cont.*

Sheet 4 "Conformity-Plausibility"	Name	Explanation
1.7	Gap analysis	Conformity in relation to the analysis of gap
2	Plausibility	Evaluation of the report as plausible in the different steps of the methodology
2.1	Reference buildings	Plausibility in relation to the establishment of reference buildings
2.2	Measures	Plausibility in relation to the selection of energy efficiency measures
2.3	Calculation PE	Plausibility in relation to the calculation of the primary energy demand
2.4	Sensitivity analysis	Plausibility in relation to the carried out sensitivity analysis
2.5	Cost- optimal level	Plausibility in relation to the derivation of cost-optimal levels
2.6	Gap analysis	Plausibility in relation to the analysis of gap

In Sheet 5 (named "Gap"), the information in Table 5 is available for each Member States:

Table 5. Reported information in Sheet 5 for Member States.

Sheet 5 "Gap"	Name	Explanation
1	Gap 2013	Quantification of the gaps in 2013 for the different building types
1.1	Virtual or Existing	Gap identification for virtual or existing buildings
1.2	New SFH	Gap quantification in New multi-family house
1.3	New MFH	Gap quantification in New multi-family house
1.4	New Office	Gap quantification in New office building
1.5	New Other non-Res	Gap quantification in New other non-residential building
1.6	Existing SFH	Gap quantification in Existing single-family house
1.7	Existing MFH	Gap quantification in Existing multi-family house
1.8	Existing Office	Gap quantification in Existing office building
1.9	Existing Other non- Res	Gap quantification in Existing other non-residential building
2	Gap 2013 vs. 2018	Comparison of the gaps in 2013 and 2018 for the different building types
2.1	New SFH	Gap quantification in New multi-family house
2.2	New MFH	Gap quantification in New multi-family house
2.3	New Office	Gap quantification in New office building
2.4	New Other non-Res	Gap quantification in New other non-residential building
2.5	Existing SFH	Gap quantification in Existing single-family house
2.6	Existing MFH	Gap quantification in Existing multi-family house
2.7	Existing Office	Gap quantification in Existing office building
2.8	Existing Other non-Res	Gap quantification in Existing other non-residential building

Finally, in Sheet 6 (named "Best practices"), best practices are identified for Member States in relation to the different aspects of the assessment (Establishment of reference buildings, Identification of energy efficiency measures, Calculation of the primary energy demand, Calculation of the global cost in terms of net present value, Sensitivity analysis, Derivation of a cost-optimal level of energy performance, and Plan to reduce the gap).

3. Methods

All Member States submitted to the Commission their report on the implementation of the cost-optimal methodology between 2018 and 2021.

Data linked to this paper allow for visualizing the cost-optimal levels for new and existing buildings (Figures 1 and 2). This data paper also provides comprehensive review progress of the implementation of the cost-optimal methodology in Member States to assess strengths and weaknesses, and future possible developments in the light of the recent policy developments. The assessed values were related to new and existing Single-Family Houses (SFH), Multi-Family Houses (MFH), Offices and other non-residential (N-R) buildings. The last one is the least covered category, for which Member States are free to select the reference type. In some cases, these results refer to a particular type (often an educational building), in others to an average among different building types (e.g., school, commercial and hospital).

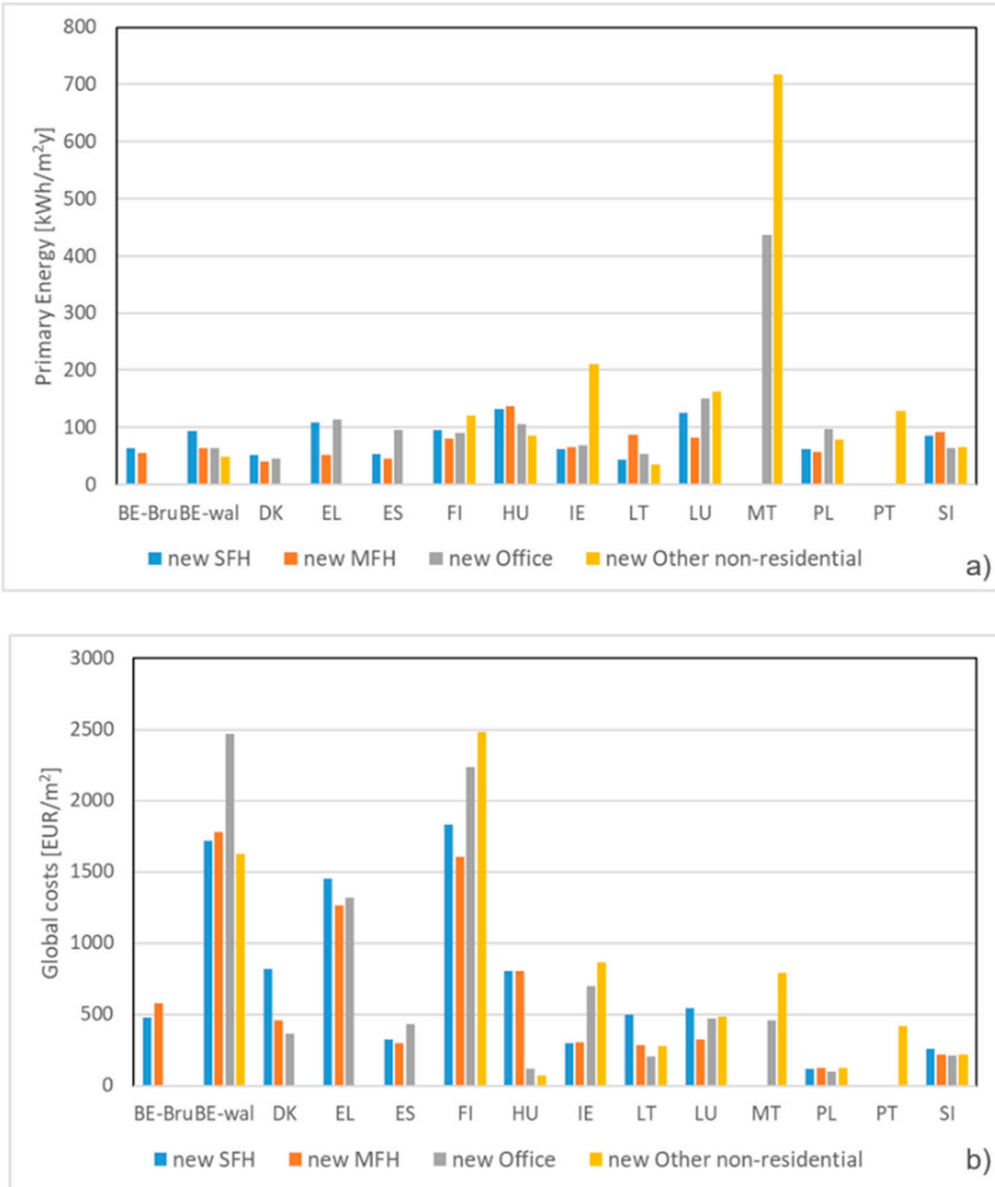

Figure 1. Cost-optimal levels for new buildings: (**a**) primary energy, (**b**) global costs (data extracted from sheet "Cost-optimal levels, gaps" of the linked dataset).

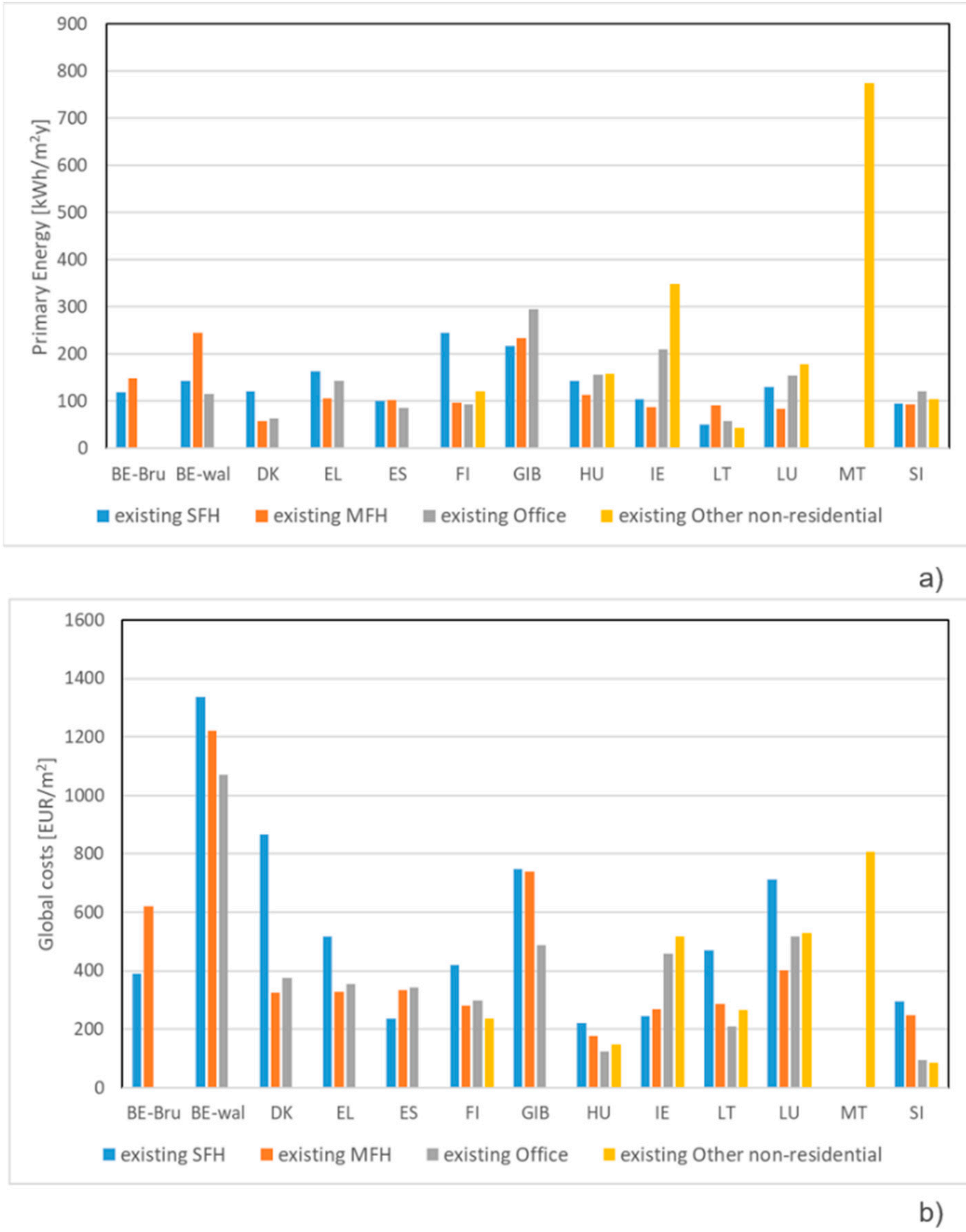

Figure 2. Cost-optimal levels for existing buildings: (**a**) primary energy, (**b**) global costs (data extracted from sheet "Cost-optimal levels, gaps" of the linked dataset).

For new buildings, the majority of cost-optimal points fell between 50 and 100 kWh/m^{2}y, with an average of 80 kWh/m^{2}y for the residential sector and 140 kWh/m^{2}y for the non-residential sector. Associated global costs are often lower than 1500 EUR/m^2, with an average of 925 EUR/m^2 for the residential and 800 EUR/m^2 for the non-residential sector. For existing buildings, the majority of cost-optimal levels fell between 75 and 175 kWh/m^{2}y, with an average of 130 kWh/m^{2}y for the residential and 180 kWh/m^{2}y for the non-residential sector. For existing buildings, the global costs are generally lower than 600 EUR/m^2, with an average of 500 EUR/m^2 for the residential and 385 EUR/m^2 for the non-residential sector. However, from the reports analyzed it has been not possible to extract all the cost-optimal levels for all Member States, as half of them did not derive them in a clear and complete way. It is interesting to observe that in almost all cases the primary energy consumptions associated to cost-optimal levels are lower in the cold zones. Global costs are lower in the Continental zone, which includes the States of Eastern Europe.

The evaluation of the gaps between cost-optimal levels and current requirements represents a relevant step of the calculation since it should provide useful indications for the update of existing energy performance regulations. National minimum energy performance requirements should not be higher than 15% compared to the outcome of the cost-optimal levels. A plan should be defined to reduce the gaps that cannot be strongly justified. Datasets linked to this paper provide a clear indication of the gap with current requirements for about half of the cost-optimal reports. The most covered building categories are those of new residential buildings (17 gaps for Single-Family Houses and 18 gaps for Multi-Family Houses were extracted), while only few data were available for the existing non-residential (11 gaps for office and -11 gaps for other types were extracted). An example of the visualisation of the gaps is provided in the graphs of Figures 3 and 4. Green histograms represent the cases for which the gaps are negative (current requirements are more stringent than cost-optimal levels), the orange ones indicate the cases where the gaps are between 0% and 15%, and the red ones indicate gaps higher than 15%.

Figures 3 and 4 show that 3–6 Member States provided gaps higher than 15% (red histograms) for each building type. The picture is more critical for new multi-family buildings. Romania is the country with higher gaps for almost all building typologies.

The gap quantification allows comparing results among countries, reference building types, and requirements for renovation of buildings or components. Therefore, it is important to note that the results are not fully comparable among Member States since they were free to choose the macroeconomic or financial perspective for deriving the cost-optimal levels and apply different national standards to calculate the energy performance of buildings. Other differences (e.g., related to investment costs) should reflect national market conditions and are thus not a limit to, but an integral part of the comparison. Scarce information was obtained for the gaps with current requirements for building elements under renovation (Figure 5). Only one third of Member States clearly provided this analysis. Among them, Poland, Ireland, and Lithuania reported gaps higher than 15%.

With the introduction of NZEB requirements for all new buildings from January 2021, the main ambit of application of cost-optimal references becomes the existing building stock. On this field, a very challenging match will be played in the coming years, since the EU zero-carbon target by 2050 cannot be achieved without a deep renovation of the majority of existing buildings [19–23].

A key implication of this aspect for a future revision of the methodology is accounting for the developments of the construction market as well as the technological innovation of building products, considering the evolution of energy prices, primary energy factors and materials. Another important implication is the identification of the most suitable renovation packages that Member States should consider achieving ZEBs [24–27].

As another example of data visualization, Table 6 shows the reference buildings that each Member State established in their cost-optimal report.

Regarding the establishment of reference buildings, 15 reports covered all four building categories required by the official methodology (Table 6), while most of the remaining reports (10) have not covered the non-residential buildings.

Strengths: Most Member States covered all building categories required by the official methodology. Moreover, two countries explicitly provided a wide range of non-residential buildings subcategories while another two countries provided a detailed description of building types.

Weaknesses: The main weakness is that the analysis of non-residential buildings is incomplete in many national reports. In most of these cases, a second non-residential reference building is not considered. In addition, in some cases, the reference building for existing buildings is missing. In some cases, the methodology is applied for individual apartments, not for the entire apartment block or multi-family building.

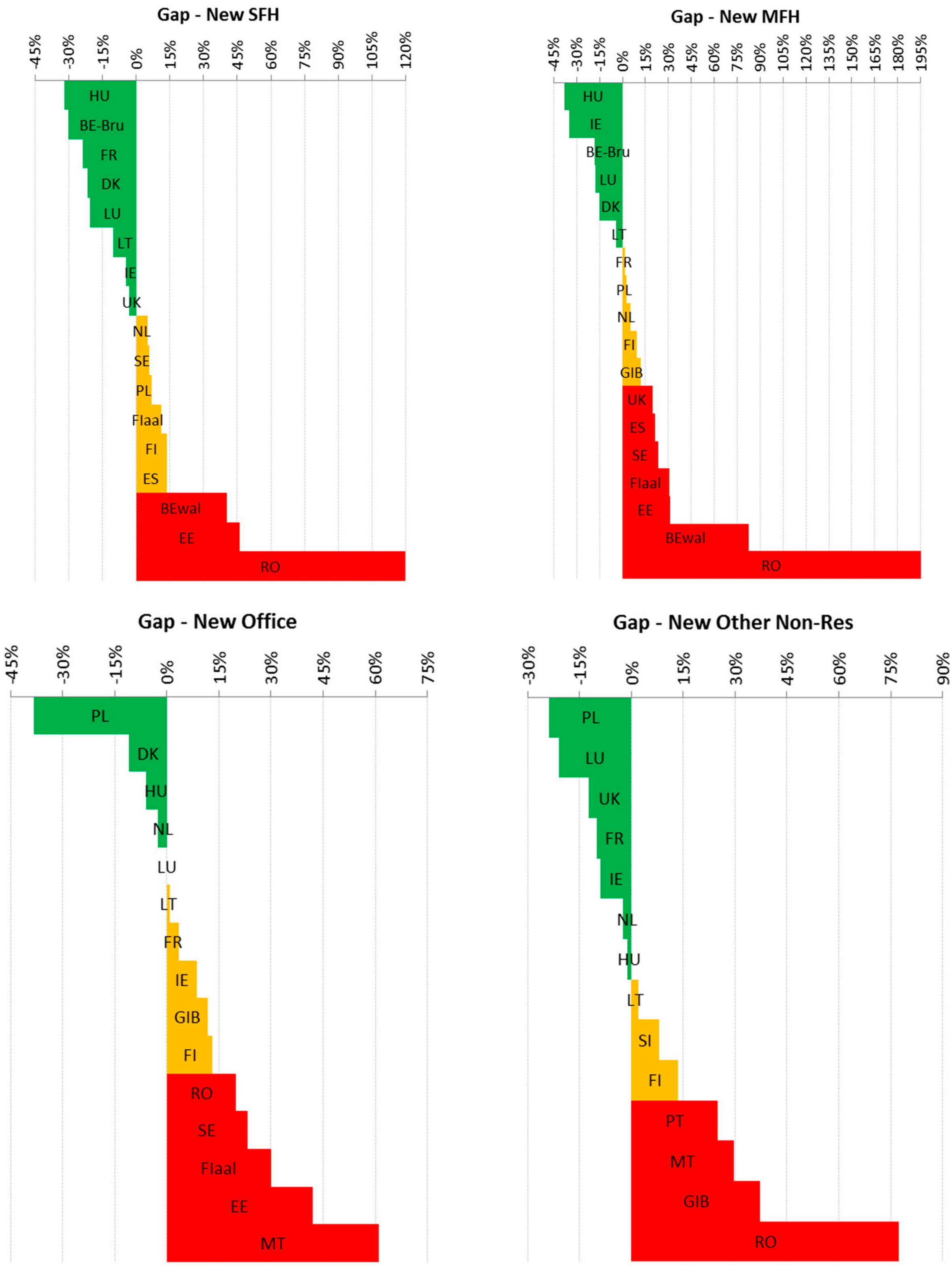

Figure 3. Overview of gaps between current requirements and cost-optimal levels for new constructions (SFH: Single-Family Houses, MFH: Multi-Family Houses) (data extracted from sheet “Cost-optimal levels, gaps” of the linked dataset).

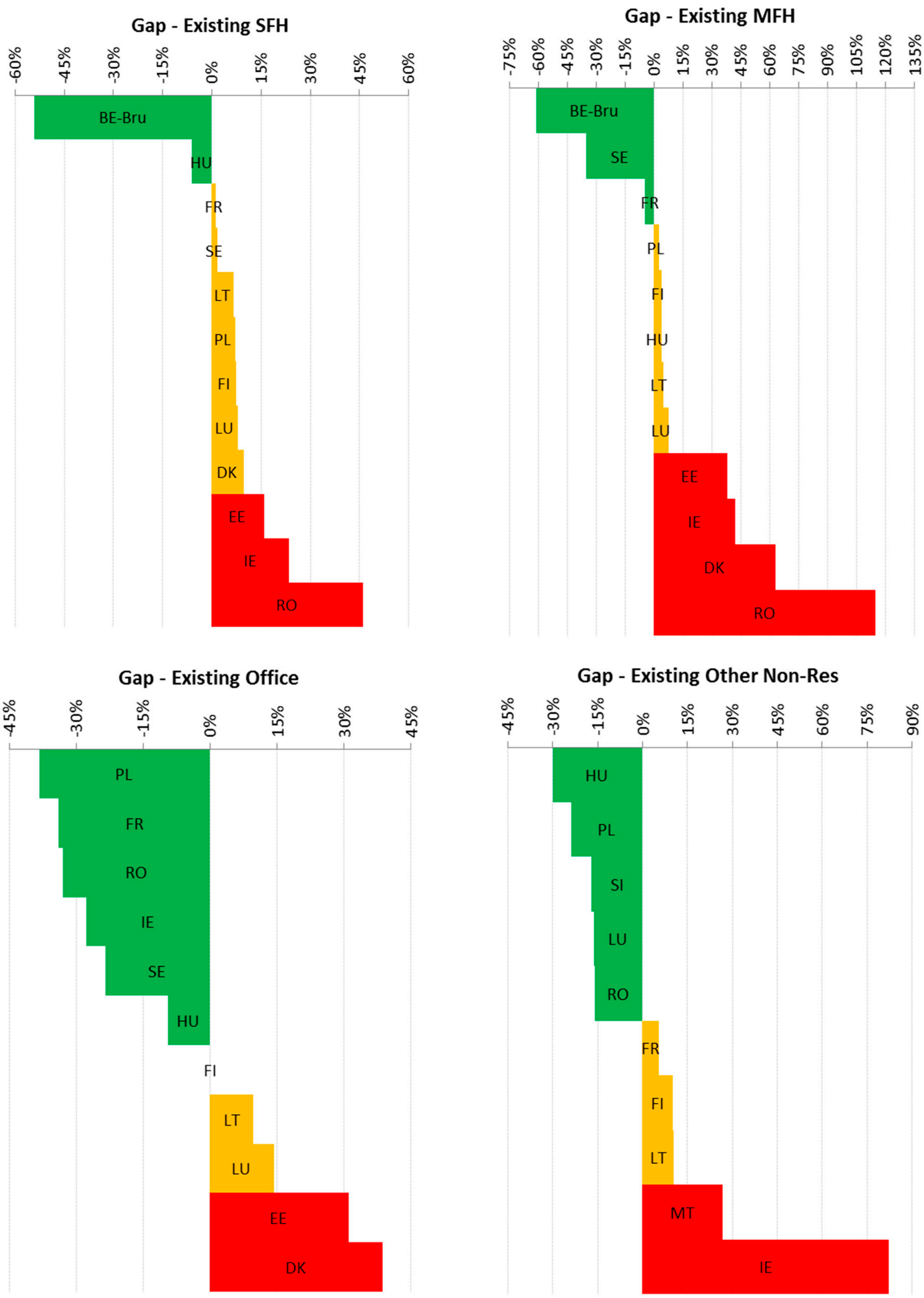

Figure 4. Overview of gaps between current requirements and cost-optimal levels for existing buildings (SFH: Single-Family Houses, MFH: Multi-Family Houses) (data extracted from sheet "Cost-optimal levels, gaps" of the linked dataset).

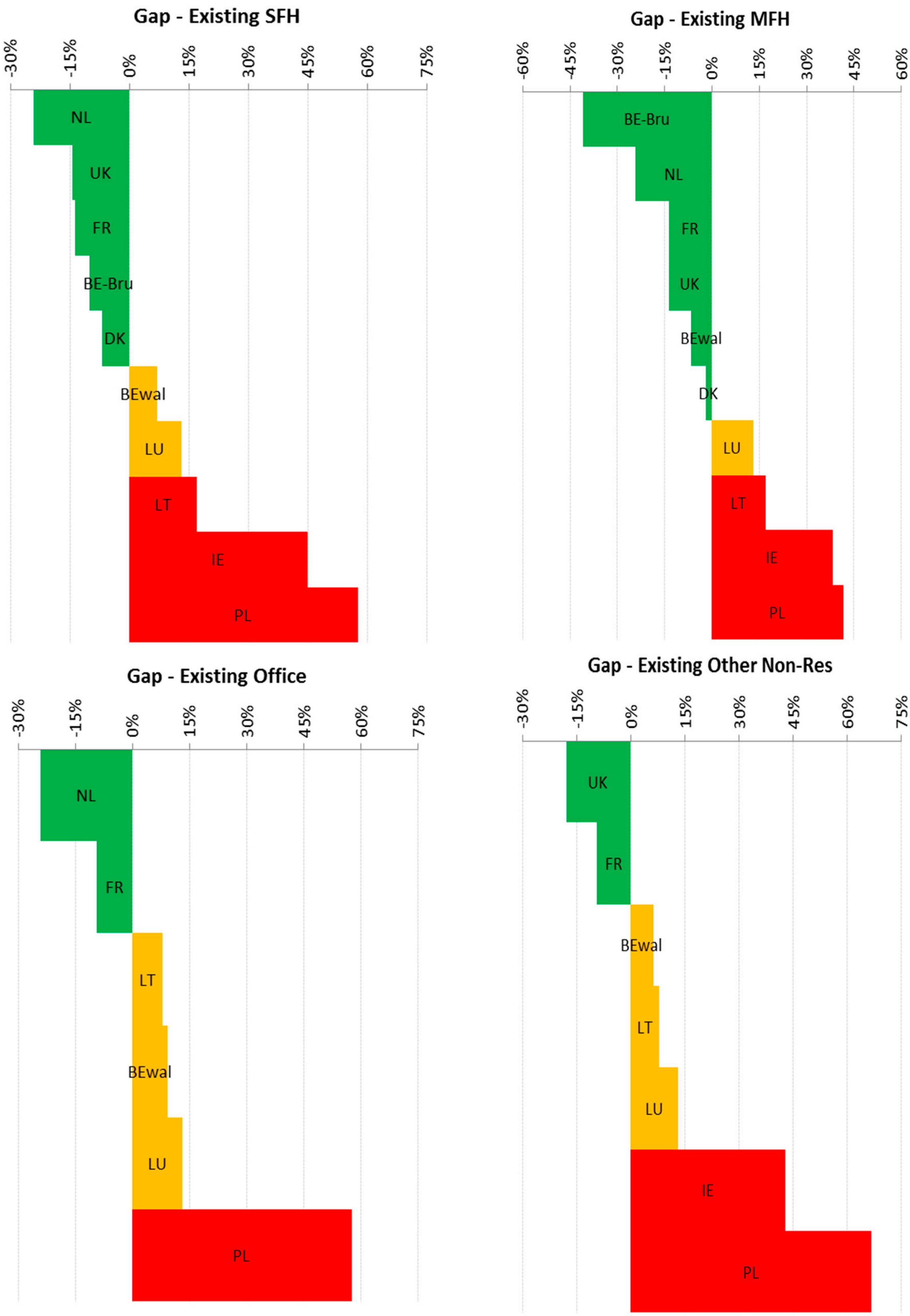

Figure 5. Overview of gaps between current requirements and cost-optimal levels for renovated building elements (SFH: Single-Family Houses, MFH: Multi-Family Houses) (data extracted from sheet “Cost-optimal levels, gaps”).

Table 6. Established reference buildings by Member States (data extracted from sheet "report overview" of the linked dataset).

	New Residential	New Non-Residential	Existing Residential	Existing Non-Residential
AT	yes	no	yes	no
BEbru	yes	no	yes	no
BEfla	yes	yes	no	yes
BEwal	yes	yes	yes	yes
CY	yes	yes	yes	yes
CZ	yes	yes	yes	yes
DE	yes	yes	no	no
DK	yes	no	yes	no
EE	yes	no	yes	no
EL	yes	no	yes	no
ES	yes	no	yes	no
FI	yes	yes	yes	yes
FR	yes	yes	yes	yes
HU	yes	yes	yes	yes
IE	yes	yes	yes	yes
IT	yes	no	yes	yes
LT	yes	yes	yes	yes
LV	yes	yes	yes	yes
LU	yes	yes	yes	yes
MT	no	yes	no	no
NL	yes	yes	yes	no
PL	yes	yes	yes	yes
PT	no	no	no	no
RO	yes	yes	yes	yes
SE	yes	no	yes	no
SI	yes	yes	yes	no
SK	yes	no	yes	no
UK	yes	yes	yes	yes

Table 7 provides a summary of the number of solutions taken into account and the level of competition achieved by the calculation method adopted by each Member State.

Table 7. Coverage of energy efficiency measures and synthetic judgment about the competition among them.

MS	Average Number for New Buildings	Average Number for Existing Buildings	Competition between Measures
AT	medium	medium	enough
BEbru	very high	very high	certainly
BEfla	very high	very high	enough
BEwal	very high	very high	certainly
CY	medium	medium	not much
CZ	high	medium	enough
DE	high	n/a	not clear
DK	medium	low	not much
EE	low	low	enough
EL	n/a	n/a	certainly
ES	low	low	enough
FI	medium	medium	not much
FR	medium	medium	not much
HU	medium	medium	enough
HR	medium	medium	enough
IE	very high	very high	certainly
IT	n/a	n/a	not clear
LT	medium	medium	not much
LV	n/a	n/a	not clear
LU	medium	medium	none
MT	medium	medium	enough
NL	medium	medium	not much
PL	medium	high	enough
PT	medium	medium	enough
RO	medium	medium	none
SE	medium	low	not much
SI	medium	high	certainly
SK	medium	medium	not much

The ranges used in Table 7 were clarified according to the number of solutions chosen: higher than 100: very high; between 10 and 50: medium; between 50 and 100: high; and less than 10: low. More in detail, according to the Guidelines implementing the Directive, the measures to be implemented need to be at least 10. It was decided to judge the number low when less than 10. The other criteria were progressively established considering the overall number of implemented measures in all countries.

Strengths: Most countries provided a wide number of energy efficiency measures in their assessments. Among these, four reports include a comprehensive selection of energy efficiency measures for the building envelope.

Weaknesses: The main weaknesses were identified in relation to RES technologies since, in some reports, the identification is not addressed adequately and, in many cases, there is poor competition between system technologies. In addition, in some cases, the number of identified energy efficiency measures is quite low for some building types.

Table 8 shows an overview of choices made by Member States for the calculation of the primary energy level, associated with the building variants. The CEN standards were used in 10 cases, while dynamic simulation was documented in the other 7 reports. However, a significant number of countries do not consider all energy uses required by the European regulation, particularly in the case of residential buildings [28–30].

Table 8. Calculation of energy demand approaches.

MS	Method	Multi-Stage Approach	Dynamic Simulation	All Energy Uses Residential	All Energy Uses Non-Residential
AT	National standard	no	no	yes	not clear
BEbru	Not clear	yes	not clear	yes	not clear
BEfla	National standard	not clear	no	no	yes
BEwal	Not clear	no	not clear	no	yes
CY	Dynamic simulation and Other	no	yes	yes	yes
CZ	National standard	no	no	no	yes
DE	Not clear	not clear	not clear	not clear	not clear
DK	CEN standard	no	not clear	not clear	not clear
EE	Dynamic simulation and National standard	no	yes	no	yes
EL	CEN standard	not clear	no	yes	yes
ES	Dynamic simulation and National standard	no	yes	yes	yes
FI	Dynamic simulation and National standard	no	yes	yes	yes
FR	Not clear	no	not clear	yes	yes
HU	Not clear	no	not clear	no	yes
HR	Dynamic simulation	no	yes	yes	yes
IE	CEN standard	no	no	yes	yes
IT	National standard	yes	no	yes	yes
LT	CEN standard and	no	not clear	yes	yes
LV	CEN standard	not clear	not clear	yes	yes
LU	National standard	yes	no	no	yes
MT	CEN standard/national standard	yes	no	yes	yes
NL	National standard	no	not clear	no	not clear
PL	National standard	no	no	no	no
PT	CEN standard	no	yes	not clear	no
RO	Not clear	no	not clear	no	yes
SE	Dynamic simulation	no	yes	not clear	not clear
SI	Dynamic simulation	no	yes	no	yes
SK	CEN standard	not clear	no	no	yes

Strengths: Many Member States performed dynamic energy simulations. In addition, one report includes a detailed study on lighting consumption reduction while in another report, the method, model and primary energy factors are presented with a degree of details.

Weaknesses: The weaknesses identified regard the details scarcity on the calculation methods (i.e., the starting year, specific method of ISO used, absence of cooling systems, and not clear method for primary energy levels).

Table 9 provides a summary on the choices made by Member States about the calculation of global costs associated with each building variant. In eight cases, not all cost categories were taken into account, while almost in all analyses both perspectives were evaluated.

Table 9. Calculation of the global cost approaches.

MS	All Cost Categories	Both Perspectives	Reference Year	Full-Cost Approach
AT	no	no	n/a	yes
BEbru	yes	no	2018	not clear
BEfla	yes	yes	Not clear	no
BEwal	not clear	yes	2017	not clear
CY	yes	yes	n/a	not clear
CZ	no	not clear	2016	yes
DE	not clear	no	2020	yes
DK	not clear	yes	2017	not clear
EE	no	yes	n/a	not clear
EL	no	yes	2016	yes
ES	yes	yes	2015	yes
FI	not clear	yes	n/a	yes
FR	not clear	yes	2018	not clear
HU	not clear	yes	2017	not clear
HR	not clear	yes	2020	not clear
IE	not clear	yes	2018/2019	not clear
IT	not clear	not clear	n/a	yes
LT	no	yes	2017	yes
LV	not clear	yes	2018	not clear
LU	yes	yes	2016	yes
MT	yes	yes	2018/2020	yes
NL	not clear	yes	2018	not clear
PL	no	yes	2017	not clear
PT	not clear	yes	2014/2016	yes
RO	no	yes	2017	not clear
SE	not clear	yes	2017	not clear
SI	no	yes	2017	yes
SK	not clear	yes	not clear	not clear

Strengths: The strengths regard mainly the robustness and level of detail of the analysis of costs and energy prices for different technologies.

Weaknesses: Many reports do not clearly specify which category of costs is included in the calculation. In addition, it is not always clear whether the full cost approach is employed. In some cases, the units of measure are not clear. Finally, some calculation approaches do not define the final values of the building variants.

Table 10 provides indications on the availability of sensitivity analyses and the number of calculation parameters as varied by Member States. The overall picture is quite positive, since only five cost-optimal calculations overlooked the sensitivity analysis.

Table 10. Sensitivity analysis approaches.

MS	Analysis Available	Number of Parameters Considered
AT	yes	4
BEbru	yes	2
BEfla	yes	4
BEwal	no	0
CY	yes	3
CZ	yes	3
DE	no	1
DK	yes	2
EE	yes	2
EL	yes	3
ES	yes	4
FI	yes	4
FR	yes	4
HU	yes	3
HR	yes	3
IE	yes	4
IT	not clear	0
LT	yes	3
LV	yes	3
LU	yes	3
MT	yes	3
NL	yes	3
PL	no	0
PT	yes	4
RO	yes	2
SE	yes	5
SI	yes	4
SK	no	0

Strengths: The inclusion of a deep sensitivity analysis or the coverage of all perspectives and input parameters is considered as a strength. Particularly, one Member State defines and applies six scenarios and discusses the impact of subsides.

Weaknesses: In many reports, the results of the sensitivity analysis are not discussed.

Table 11 shows a summary of the Member States' choices regarding the derivation of cost-optimal levels associated with each building type. Here, the general judgement has not been positive, since only in a few cases (five) the cost-optimal range has been applied, and almost two-thirds of the reports provided none or just a few results. Currently, fewer than half of the Member States select as reference perspective the macroeconomic one, despite the fact that it is the most relevant for the optimisation at a societal level.

Table 11. Derivation of cost-optimal level approaches.

MS	Cost-Optimal Range	Reference Perspective?	Results Available
AT	no	financial	few
BEbru	not clear	financial	few
BEfla	no	macroeconomic	few
BEwal	no	macroeconomic	yes
CY	not clear	not clear	no
CZ	not clear	financial	no
DE	not clear	financial	few
DK	no	financial	some
EE	yes	not clear	few
EL	no	macroeconomic	some
ES	no	financial	some
FI	no	financial	yes
FR	no	financial	few
HU	no	financial	yes
HR	yes	macroeconomic	some
IE	no	macroeconomic	yes
IT	not clear	not clear	no
LT	no	both	yes
LV	not clear	macroeconomic	no
LU	no	financial	yes
MT	yes	macroeconomic	yes
NL	yes	financial	no
PL	no	macroeconomic	few
PT	no	financial	yes
RO	not clear	macroeconomic	few
SE	no	not clear	few
SI	no	financial	yes
SK	yes	macroeconomic	few

Strengths: Among the strengths, the pareto front optimization approach is identified. In addition, two Member States have covered all the reference buildings and all the categories in the definition of the cost-optimal level of energy performance.

Weaknesses: A common weakness is the absence of a cost-optimal range. In some cases, the economic perspective used is not clear or one of the perspectives is not considered. In some other cases, only the methodology was described, but no results or very few results are presented. On the contrary, sometimes the method used to derive the results was not clear. Finally, in some reports, the current requirements are not clear.

Table 12 provides an overview of the comparison between the cost-optimal levels and the current or future requirements in each country, as well as the recognition of gaps and the definition of plans to reduce the gaps.

Table 12. Comparison with current/future requirements and availability of plans to reduce the gaps.

MS	Comparison with Current Requirements	Comparison with Future/NZEB Requirements	Gaps > 15%	Justification Provided	Plan Provided
AT	not clear	no	not clear	n/a	n/a
BEbru	yes	no	no	no	n/a
BEfla	no	no	not clear	no	no
BEwal	yes	yes	yes	no	no
CY	not clear	no	not clear	no	n/a
CZ	yes	no	not clear	no	no
DE	no	no	not clear	no	no
DK	yes	yes	yes	no	no
EE	yes	yes	yes	yes	yes
EL	yes	no	yes	no	no
ES	yes	yes	yes	no	yes
FI	yes	no	not clear	no	no
FR	yes	yes	yes	no	no
HU	yes	yes	no	yes	no
HR	yes	yes	not clear	no	no
IE	yes	no	yes	yes	no
IT	not clear	no	not clear	n/a	n/a
LT	yes	yes	no	no	no
LV	yes	no	yes	yes	yes
LU	yes	no	yes	yes	no
MT	yes	no	yes	no	yes
NL	yes	no	no	n/a	n/a
PL	yes	yes	yes	no	no
PT	yes	yes	yes	yes	yes
RO	yes	no	yes	yes	not clear
SE	yes	no	yes	no	no
SI	yes	no	no	no	no
SK	no	no	not clear	no	no

Strengths: Five Member States included in their analysis a plan to reduce the gaps between the cost-optimal level and current requirements.

Weaknesses: In most reports, the plan to reduce the gap is missing or not detailed. In addition, the comparison of cost-optimal levels with future (NZEB) requirements is not addressed in most calculations. In addition, in most reports, the calculation of the gaps is not clearly described.

Data linked to this paper allow for showing the conformity of the Member States' calculations with the EPBD Regulation. The same criteria used for the first cost-optimal calculations were considered for the conformity assessment, with additional criteria for situations of insufficient information.

The following definitions were applied to assess each reference category in Figure 1 [6]:

- Conform: all the aspects considered by the guiding questions were assessed as conform.

- Not fully conform: one or more criteria of the corresponding category were assessed, not conform.
- Not conform: major deviation from regulatory requirements (e.g., a missing item, such as a missing reference building or missing plan to reduce the gap, or a wrong implementation, such as a calculation not performed according to the global cost methodology).
- Further information needed: not sufficient information about the method and/or data used for a specific step of the calculation.

As shown in Figure 6, the overall status about the conformity with requirements can be assessed as rather positive, although the following gaps were registered:

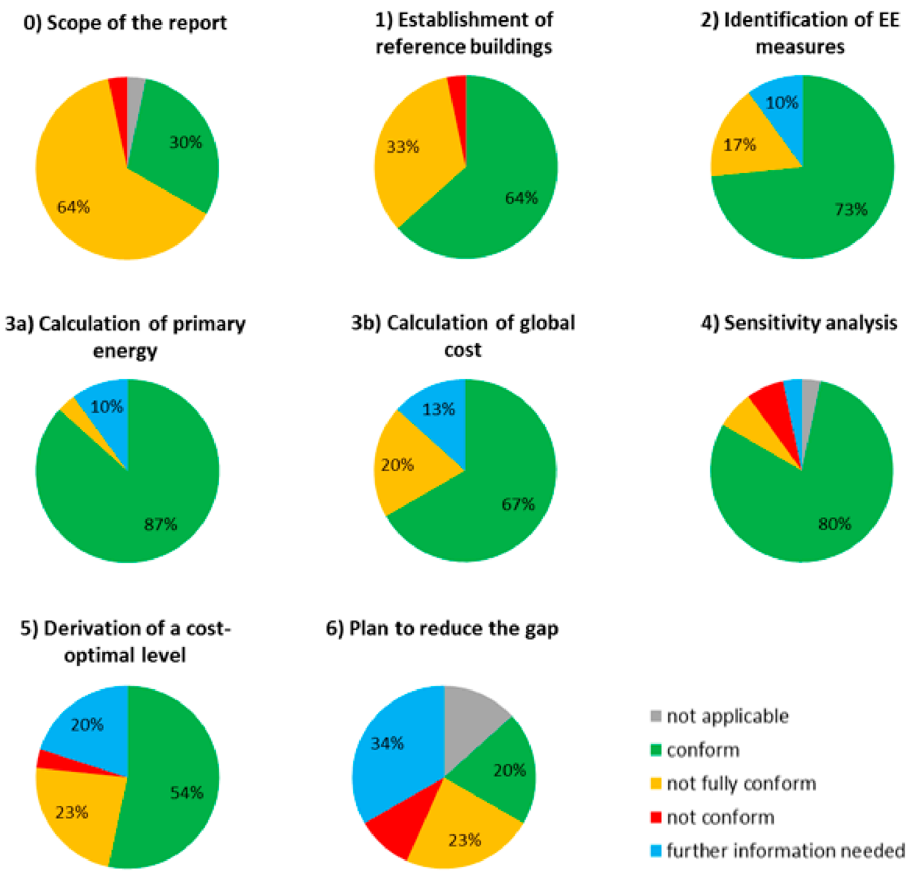

Figure 6. Overview of the conformity of the 2018 country reports per category (data extracted from sheet "Conformity-plausibility" of the linked dataset).

The calculation scope (zero): almost two-thirds of Member States failed to cover one or more objectives, such as a required building type or the cost-optimal levels for building elements installed in existing buildings.

The derivation of cost-optimal levels (five): almost half of Member States applied derivation methodologies judged not fully conform or did not provide sufficient information to assess this calculation step.

The definition of a plan to reduce the gap (six): many Member States did not provide convincing explanations about the existing gaps, did not provide clear plans to reduce them, or did not even discuss the gaps with current requirements. Only in a few cases a comparison with NZEB requirements was available.

Data also relate to the plausibility of input parameters and cost-optimal levels, following the same reasoning of the conformity assessment, The plausibility refers to key numeric input data (e.g., building geometries, primary energy factor, energy prices, investment costs) and outputs (e.g., calculated cost-optimal levels, global costs), also taking into account methodological choices which can affect the comprehensiveness of achieved results (e.g., multi-stage optimisation approach and use of a cost-optimal range). Data are shown in Figure 7.

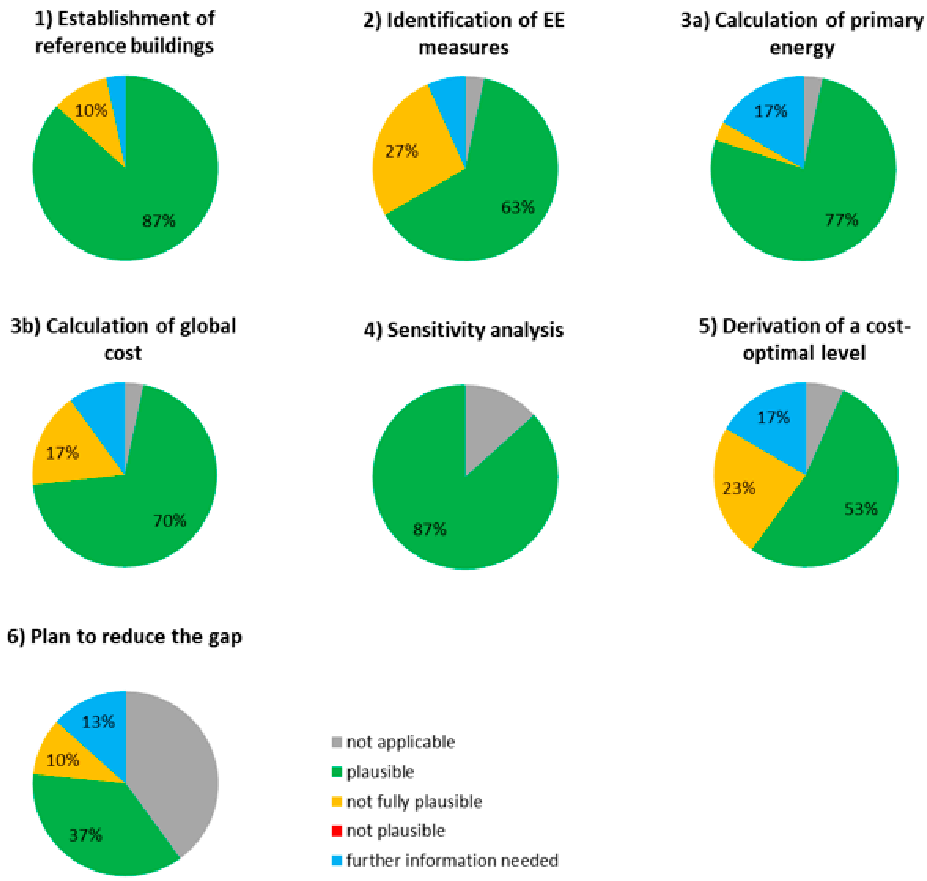

Figure 7. Overview of the plausibility of the 2018 country reports per category (data extracted from sheet "Conformity-plausibility" of the linked dataset).

In relation to the plausibility of input parameters and results, the assessment is rather positive, since no report has been assessed as not plausible, as shown in Figure 7. Additionally, in this case the most critical reference categories are the last ones (derivation of cost-optimal levels and plan to reduce the gap). However, some Member States missed covering all significant technological options and also in the selection of energy efficiency measures [31–33].

4. Conclusions

Reducing the energy demand in buildings is a requisite to meet Europe's energy efficiency and GHG emissions reduction targets. This data article gave a comprehensive assessment of the cost-optimal methodology in Member States based on the latest submitted reports. The reported data are useful to assess the implementation progress of the cost-optimal methodology, as foreseen in the Energy Performance of Buildings Directive (EPBD).

In summary, the average cost-optimal level is assessed at 80 kWh/m^{2}y for the new residential and 140 kWh/m^{2}y for the new non-residential sector, while it is 130 kWh/m^{2}y for the existing residential and 180 kWh/m^{2}y for the existing non-residential sector. Energy efficiency measures bring not only energy and cost savings but contribute to climate change mitigation by reducing greenhouse gas emissions. In addition, energy efficiency positively affects the comfort, well-being, and productivity of residents and users as well as the aesthetics of the building. Such benefits can be grouped into social, environmental, and financial benefits. However, the current methodology overlooks these benefits except for the environmental impact of CO_2 emissions due to operational energy use.

Furthermore, for almost all building types, the primary energy consumptions associated with cost-optimal levels are lower in the cold regions, while global costs are normally lower in countries with warm and mild climates. As the cost-optimal methodology will be revised in 2026, it is important to suggest future developments based on the assessment of the latest reports. The assessment outlines weak and strong points, as well as future developments based on the overall policy framework. The introduction of the methodology at the district level is also crucial as in the revision of the Energy Performance of Buildings Directive much emphasis is given on a larger scale of buildings, such as district, regional, and communities. Furthermore, the introduction of externalities also will be considered as topics, such as health and indoor environmental quality are of growing importance in the field. Research is ongoing on the inclusion of wider benefits in the global cost formula, the introduction of cost-optimality at district level, and historical buildings, comfort, and indoor air quality, the inclusion of wider energy efficiency benefits, such as reduced import dependency and a positive impact on economy. Monetization is identified as the biggest challenge since it is context-dependent and usually, there is no straightforward approach for determining single monetised values. In addition, the quantification of the various co-benefits requires great efforts in data collection and homogenization from various sectors.

The provided data offers inputs for the methodology update foreseen in 2026. Currently, the energy efficiency measures mainly target the reduction of operational energy use and operational GHG emissions, while the incorporated energy and GHG emissions are overlooked. Highly energy-efficient buildings (such as NZEBs) imply the use of a higher amount of materials (notably insulation materials) compared to conventional ones, the installation of more complex technical systems and, in case of renovation, the removal and treatment of old materials, leading to higher embodied impacts of buildings. In addition, as operational emissions are being reduced, the importance of embodied emissions rises, dominating the life-cycle emissions of a building. It is estimated that the upfront carbon emissions (i.e., emissions released before the use of the building) will represent about 50% in the life-cycle emissions of new buildings in the next decades.

Updating the calculations of the cost-optimal levels will have to be monitored, considering the update of the NZEB definitions for new and renovated buildings, the introduction of energy requirements and incentive mechanisms for existing buildings in line with the Renovation Wave Strategy, and the environmental targets to 2030 and the carbon neutrality to 2050 for the building sector. A limitation of the analysis is linked to the evolving nature of specific fields, such as energy prices and measures, so that cost-optimal levels may be subject to quick variations. It is expected that the research area and related data will continue evolving. Future research may account for more condensed data as the available information and related policies are continuously updated. As current methodological status, an overall positive development can be derived from the assessment. The outcomes of the analysis assume a crucial relevance towards the ambitious energy efficiency targets established by Europe.

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Abbreviation

MS	Member States
EU	European Union
EPBD	Energy Performance of Building Directive
EPC	Energy performance certificate
LTRS	Long-term renovation strategy
RES	Renewable Energy Sources
PED	Primary Energy Demand
NZEBs	Nearly zero energy buildings
c-o	Cost-optimal
AT	Austria
BE-BRU	Belgium-Brussels region
BE-FLA	Belgium- Flemish region
BE-WA	Belgium- Wallonia
BG	Bulgaria
CY	Cyprus
CZ	Czech Republic
DE	Germany
DK	Denmark
EE	Estonia
EL	Greece
ES	Spain
FI	Finland
FR	France
HR	Croatia
HU	Hungary
IE	Ireland
IT	Italy
LT	Lithuania
LU	Luxemburg
LV	Latvia
MT	Malta
NL	Netherlands
PL	Poland
PT	Portugal
RO	Romania
SE	Sweden
SI	Slovenia
SK	Slovakia
UK	United Kingdom

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