ePANACEA

Smart European Energy Performance Assessment & Certification

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Evaluation of the ePANACEA methodology

Report on the evaluation of the ePANACEA energy assessment and certification methodology

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OVERVIEW OF THE EPANACEA PROJECT

After 10 years of track record, the current EPC schemes across the EU face several challenges which have led to a not full accomplishment of their initial objectives: lack of accuracy, a gap between theoretical and real consumption patterns, absence of proper protocols for inclusion of smart and novel technologies, little convergence across Europe, lack of trust in the market and very little user awareness related to energy efficiency.

The objective of the ePANACEA project is to develop a holistic methodology for energy performance assessment and certification of buildings that can overcome the above-mentioned challenges. The vision of ePANACEA is to become a relevant instrument in the European energy transition through the building sector.

ePANACEA comprises the creation of a prototype (the Smart Energy Performance Assessment Platform) making use of the most advanced techniques in dynamic and automated simulation modelling, big data analysis and machine learning, inverse modelling or the estimation of potential energy savings and economic viability check.

A relevant part of the project is to have a fluent dialogue with European policy makers, certification bodies, end-users and other stakeholders through two types of participatory actions: a feedback loop with policy makers, carried out through the so-called Regional Exploitation Boards (REBs) covering EU-27+UK+Norway on the one hand, and dialogue with end-users, established by means of specific thematic workshops, on the other.

Thanks to these participatory actions, the acceptance of the ePANACEA approach was tested and validated in order to become aligned with and meet the needs of national public bodies, end-users and other stakeholders.

ePANACEA's target is to demonstrate and validate reliability, accuracy, user-friendliness and cost-effectiveness of its methodology through 15 case studies in 5 European countries.

EXECUTIVE SUMMARY

This report presents the findings and outcomes of testing of the three energy performance assessment methods developed in the ePANACEA project. The objective of testing was to assess the effectiveness and applicability of these methods in various real-case scenarios across the ePANACEA partners' countries through study buildings. The report provides an overview of the selected cases, outlines the methodology and validation process, presents the outputs and compares the values derived through the current national EPC methodology with those derived through the three ePANACEA assessment methods.

In order to perform a comparison between the three methods and the national EPC methodology, each country selected three existing buildings of various types, local geographical areas, sizes, and ages, and collected all important buildings' data. A total of 15 buildings was selected from Austria, Belgium, Finland, Greece and Spain. First, an energy performance assessment was carried out using the existing national EPC calculation procedure. Then, the three methods developed within the ePANACEA project were applied and outputs were compared against those derived through the current EPC process. Differences between the various methods' outputs and the outputs derived from the current EPC were identified, as were the number and the quality of the outputs. The purpose was to perform a qualitative and quantitative cross-analysis of results in the pilot countries.

For each case study, the input data used for the EPC calculation and the related output were documented so that a direct comparison with the corresponding outputs of the three developed methods was possible.

As proves from the comparison, the number of values derived through the three ePANACEA methods is always greater and the outputs more detailed than those of the EPC. The testing outputs show deviations between the EPC method and the methods developed in ePANACEA. The EPC assessment methodology uses simplified data and predefined values for many parameters while the three methods developed in ePANACEA use detailed data, real data for energy consumption, well-defined profiles for user behaviour, etc. Accordingly, the results between the EPC methodology and the three methodologies are, in most cases, different. Additionally, the lack, in certain cases, of data or the lack of qualitative data, i.e., poor quality of measurement input data, absence of monthly consumption data, use of different conversion factors depending on the fuel type, etc., lead to low resolution outputs.

The main conclusions from concept development and testing through study cases are the following:

- Method 1 is easy to implement and complements the current EPC methodology.
- Method 2 utilises a monthly calculation basis provided by the standard 52016, implementing different functionalities to improve the whole process in terms of accuracy and cost-effectiveness via a web platform, such as advanced models of the occupation profiles and a calibration procedure.
- Methods 1 and 2 have been integrated into the SEPAP tool, which allows building an inventory of projects, storage of input data, calculation, and visualisation of results.
- Method 3 uses an advanced & automated simulation modelling based on hourly calculations and its calibration procedures covering all the needs of the next generation of energy assessment and certification, and beyond. The whole procedure is implemented in a local software called SEPAP tool including OpenStudio server application that allows the parametric analyses to be performed in the cloud.

Conclusively, Method 3 is the most detailed one but at the same time the most complicated one, requiring previous experience on white-box building energy models and/or additional training to understand the auto-calibration procedures. On the other hand, appropriate tools, such as the SEPAP tool, significantly reduce the work associated with similar energy performance assessments.

Finally, the decision matrix implemented in the SEPAP tool supports users in their decision about which assessment method to choose, i.e., which is the most suitable according to the availability and quality of building and energy data, and the level of outputs' detail needed.

GLOSSARY

The following abbreviations are used in this report

ach	Air Changes per Hour
AT	Austria
BACS	Building Automation and Control System
BE	Belgium
BEM	Building Energy Model
BMS	Building Management System
CA	Calculated Actual
CDD	Cooling Degree Days
CV(RMSE)	Coefficient of the Variation of the Root Mean Square Error
DHW	Domestic Hot Water
EEMs	Energy Efficiency Measures
EPB	Energy Performance of Buildings
EPBD	Energy Performance of Buildings Directive
EPC	Energy Performance Certificate
FI	Finland
GFA	Gross Floor Area
GR	Greece
GHG	Greenhouse Gases
HDD	Heating Degree Days
HVAC	Heating, Ventilation and Air Conditioning
MA	Measured Actual
MS	Measured Standard
NMBE	Normalized Mean Bias Error

OBM	on-board monitored
RES	Renewable Energy Sources
ROV	Range Of Variation
SHGC	Solar Heat Gain Coefficient
SP	Spain
TDB	Testing and Demonstration Board

1 OVERVIEW OF CURRENT EPC NATIONAL SCHEMES

This section presents an overview of the national EPC certification schemes for the ePANACEA member countries that validated the ePANACEA energy assessment methodology, i.e., Austria, Belgium, Finland, Greece and Spain.

As presented in the tables below (*Table 1* - *Table 5*) there is a variety of conditions and requirements in terms of the current EPC methodology applied in the five countries. Indicatively:

In the Austrian region of Styria, energy retrofit recommendations and their economic feasibility are optional for new buildings but mandatory for existing ones. As regards the energy services to be calculated, these are heating, cooling, DHW and ventilation for residential buildings, while for non-residential buildings, also lighting is calculated. Dynamic (hourly) to quasi stationary (monthly or hourly) methods are possible for the calculation of the energy performance, however the quasi-stationary method is implemented in common EPC software tools where multi-zone is considered.

In Belgium, recommendations for energy retrofit are mandatory for existing buildings, both residential and non-residential. In the current EPC methodology, an estimation of the costs is provided for each retrofit measure, although the costs are not accurate. The energy services to be calculated are identical to those in Austria. For the calculation of the energy performance and energy classification of buildings, the monthly no multi-zone method is used with some exemptions (see *Table 2*).

In Finland, there are 9 different building categories for new and existing buildings. The energy retrofit recommendations are mandatory only for existing buildings while their economic feasibility is not calculated, since it implies that recommended measures are cost-efficient. In contrast to the other countries, the energy services considered are heating, cooling, DHW, ventilation, lighting and other services, for both new and existing buildings. As regards the energy performance calculation, hourly dynamic simulation is used for buildings with cooling systems, otherwise monthly calculation is allowed. Multi-zone models can be used, however single-zone is common.

In Greece, recommendations for energy retrofit and their economic feasibility are optional only for new buildings. The energy services calculated are heating, cooling and DHW for residential buildings, additionally lighting for non-residential buildings. As regards the energy performance calculation, the monthly method and multi-zone models can be used for all buildings.

In Spain, energy retrofit recommendations are mandatory only for existing buildings and the calculation of their economic feasibility is optional. As in Austria and Belgium, the calculated energy services are heating, cooling, DHW and ventilation for residential buildings. For non-residential buildings, also lighting is calculated. Simplified methods based on indirect dynamic calculations and also dynamic methods can be used for the energy performance calculation however it is not mandatory. Multi-zone models can be considered only with dynamic methods, although these models are not mandatory.

Table 1: EPC certification scheme – Austria/Styria

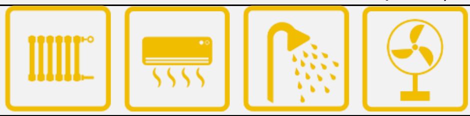
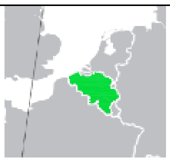
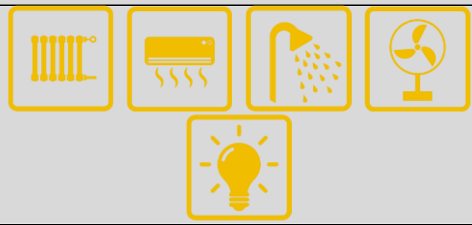
AUSTRIA/STYRIA 	RESIDENTIAL BUILDINGS		NON RESIDENTIAL BUILDINGS	
	NEW	EXISTING	NEW	EXISTING
Recommendations for energy retrofit	Optional	Mandatory	Optional	Mandatory
Economic feasibility of retrofit measures	Optional	Mandatory (the recommendations for energy retrofit should be feasible from an economic perspective- however no specific economic calculation is required)	Optional	Mandatory (the recommendations for energy retrofit should be feasible from an economic perspective- however no specific economic calculation is required)
Energy Services				
Calculated energy rating	YES		YES	
Measured energy rating	NO		NO	
Complexity	Dynamic methods (hourly) to quasi stationary (monthly or hourly) possible, however the quasi-stationary method is implemented in common EPC software tools			
Multi-zone	YES		YES	
Global Energy Performance Indicators	• Specific energy needs for space heating (HWB Ref,RK) based on given standardised climatic conditions [kWh/m² year] • Specific energy needs for space heating (HWB Ref,SK) based on the local climate conditions [kWh/m² year] • Primary energy demand (energy required to provide heating, hot water and electricity for a building), in total and separated for renewable and non-renewable energy [kWh/m² year] • CO_2 emissions created to meet the overall energy demand of the building [kg/year or kg/m² year] • total energy efficiency factor (fGEE) (ratio between the final energy demand of the present building and the final energy demand of a reference building)			
Additional indicators	All indicators calculated for standardised climate conditions and local climate conditions of the building. The following are expressed in kWh/year and/or kWh/m² year: • "WWWB": Hot water demand • "HEB": Energy requirements for heating and hot water preparation taking into account losses from generation, storage, distribution and transfer, as well as possible auxiliary energy • "HHSB": Household electricity demand • "EEB": final energy demand (incl. electricity demand; delivered energy)		Same indicators as for residential buildings. Additional factors for non-residential buildings: • "KB": energy needs for cooling • "KEB": energy needs separated for the heating, cooling and ventilation system • "BefEB": humidification energy demand • "BelEB": energy demand for lighting • "BSB": operational electricity consumption	

Table 2: EPC certification scheme – Belgium

 BELGIUM	RESIDENTIAL BUILDINGS		NON RESIDENTIAL BUILDINGS	
	NEW	EXISTING	NEW	EXISTING
Recommendations for energy retrofit	N/A	Mandatory	N/A	For small non-residential buildings: mandatory For large non-residential buildings: method in development For public buildings: mandatory
Economic feasibility of retrofit measures	N/A	N/A	N/A	N/A
Energy Services				
Calculated energy rating	YES		YES	YES (exception: public buildings)
Measured energy rating	NO		NO	NO (exception: public buildings)
Complexity	Monthly	Monthly	Monthly	Monthly
Multi-zone	NO (except for ventilation for air flow per room and ventilation sectors (per system type) and for heating and cooling by definition of energy sectors)	NO (except for heating subdivision in clusters and for cooling: share of volume that is actively cooled)	NO (except subdivision for functional units and further subdivision for ventilation for air flow per room and ventilation sectors (per system type) and for heating, cooling and humidification by definition of energy sectors)	For small non-residential buildings: NO (except for heating and for cooling subdivision in clusters) For large non-residential buildings: in development For public buildings: NO
Global Energy Performance Indicators	• E-peil (Energy Performance level; normalised characteristic, primary, annual specific energy use) • Specific annual primary characteristic energy use • Annual CO_2-emission	• Annual, characteristic, primary, specific energy use, annual CO_2 emission	• E-peil (Energy Performance level; normalised characteristic, primary, annual specific energy use) • Specific annual primary characteristic energy use • Annual CO_2-emission • Share of renewable energy	For small non-residential buildings: Annual, characteristic, primary, specific energy use, annual CO_2 emission For large non-residential buildings: in development For public buildings: Annual, characteristic, primary, specific energy

	• Share of renewable energy		(Energy Performance level denominator based on concept of national building approach)	use, annual CO_2 emission
Additional indicators	• Net energy demand, gross, final and primary energy consumption for heating, humidification, cooling, lighting, DHW, auxiliary systems. • Specific net energy demand for space heating • Specific annual renewable energy produced and or used (renewables originating from heat pump, solar thermal system, PV, biomass, external thermal energy delivery) • K-peil (Global thermal insulation of building), thermal insulation of building envelope parts • Ventilation system and flow rates • Energy balance on an annual basis	Net energy demand, gross, final and primary energy consumption for heating, cooling, DHW, auxiliary systems. Specific net energy demand for space heating S-peil (Indicator for energy efficiency of building envelope) Efficiency of systems for heating and cooling Indicator for risk for overheating	• Net energy demand, gross, final and primary energy consumption for heating, humidification, cooling, lighting, DHW, auxiliary systems. • Specific net energy demand for space heating • Specific annual renewable energy produced and or used (renewables originating from heat pump, solar thermal system, PV, biomass, external thermal energy delivery) • K-peil (Global thermal insulation of building), thermal insulation of building envelope parts • Ventilation system and flow rates • Energy balance on an annual basis	For small non-residential buildings: Net energy demand, gross, final and primary energy consumption for heating, cooling, DHW, auxiliary systems; Specific net energy demand for space heating; S-peil (Indicator for energy efficiency of building envelope); Efficiency of systems for heating and cooling; Indicator for risk for overheating For large non-residential buildings: method in development For public buildings: None

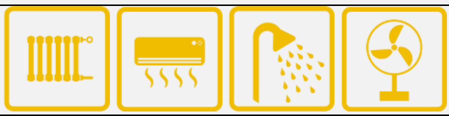
Table 3: EPC certification scheme – Finland

 **FINLAND**	**NEW BUILDINGS (9 different categories)**	**EXISTING BUILDINGS (9 different categories)**
Recommendations for energy retrofit	N/A	Mandatory
Economic feasibility of retrofit measures	N/A	Not required (but implies that recommended measures are cost-efficient)
Energy Services		
Calculated energy rating	YES	YES
Measured energy rating	NO	NO
Complexity	Hourly dynamic simulation for buildings with cooling systems / otherwise monthly calculation allowed	Hourly dynamic simulation for buildings with cooling systems / otherwise monthly calculation allowed
Multi-zone	NO (YES allowed)	NO (YES allowed)
Global Energy Performance Indicators	• primary energy [kWh/m² year]	• primary energy [kWh/m² year]
Additional indicators	N/A	N/A If measured history exists, it must be reported

Table 4: EPC certification scheme – Greece

 GREECE	RESIDENTIAL BUILDINGS		NON RESIDENTIAL BUILDINGS	
	NEW	EXISTING	NEW	EXISTING
Recommendations for energy retrofit	Optional	Mandatory	Optional	Mandatory
Economic feasibility of retrofit measures	Optional	Mandatory	Optional	Mandatory
Energy Services				
Calculated energy rating	YES		YES	
Measured energy rating	NO		NO	
Complexity	Monthly		Monthly	
Multi-zone	YES		YES	
Global Energy Performance Indicators	• Non-renewable primary energy of reference building [kWh/m²year] • Non-renewable primary energy [kWh/m² year] • CO_2 emissions [kgCO_2/m² year]		• Non-renewable primary energy of reference building [kWh/m² year] • Non-renewable primary energy [kWh/m² year] • CO_2 emissions [kgCO_2/m² year]	
Additional indicators	• Non-renewable primary energy for heating, cooling, DHW [kWh/m²year] • Renewable and CHP primary energy [kWh/m²year]		• Non-renewable primary energy for heating, cooling, DHW, lighting [kWh/m²year] • Renewable and CHP primary energy [kWh/m²year]	

Table 5: EPC certification scheme – Spain

 SPAIN	RESIDENTIAL BUILDINGS		NON RESIDENTIAL BUILDINGS	
	NEW	**EXISTING**	**NEW**	**EXISTING**
Recommendations for energy retrofit	N/A	Mandatory	N/A	Mandatory
Economic feasibility of retrofit measures	N/A	Optional	N/A	Optional
Energy Services				
Calculated energy rating	YES		YES	
Measured energy rating	NO		NO	
Complexity	HULC, SG SAVE and CYPETHERM HE Plus are dynamic methods CE3X, CERMA are simplified methods based on indirect dynamic calculations.	HULC, SG SAVE and CYPETHERM HE Plus are dynamic methods CE3X, CE3 and CERMA are simplified methods based on indirect dynamic calculations.	HULC, SG SAVE and CYPETHERM HE Plus are dynamic methods CE3X is a simplified method based on indirect dynamic calculations.	HULC, SG SAVE and CYPETHERM HE Plus are dynamic methods CE3X and CE3 are simplified methods based on indirect dynamic calculations.
Multi-zone	Dynamic methods: YES (No Mandatory) Simplified Methods: NO		Dynamic methods: YES (No Mandatory) Simplified Methods: NO	
Global Energy Performance Indicators	• Non-renewable primary energy [kWh/m² year] • CO_2 emissions [kgCO_2/m² year]		• Non-renewable primary energy [kWh/m² year] • CO_2 emissions [kgCO_2/m² year]	
Energy performance rating scales	Single Family Houses: 13 energy rating scales (one for each climatic zone) + Apartment Blocks: 13 energy rating scale (one for each climatic zone)		Energy rating is granted as compared to a reference building.	
Additional indicators	• Energy need for: heating, cooling [kWh/m² year] • Non-renewable primary energy for: heating, cooling, DHW [kWh/m² year] • CO_2 emissions for: heating, cooling, DHW [kgCO_2/m² year]		• Energy need for: heating, cooling [kWh/m² year] •Non-renewable primary energy for: heating, cooling, DHW, lighting [kWh/m² year] • CO_2 emissions for heating, cooling, DHW, lighting [kgCO_2/m² year]	

2 OVERVIEW OF THE EPANACEA METHODOLOGY

The holistic, accurate, flexible and modular methodology for building energy performance assessment and certification developed under the ePANACEA project is based on three energy assessment methods (Figure 1) plus a decision matrix (see section 6 Decision matrix):

i. Assessment method 1 (M1): Smart & performance data-driven energy performance assessment

ii. Assessment method 2 (M2): Simplified method based on monthly calculation (ISO 52016) interval and its calibration

iii. Assessment method 3 (M3): Advanced & automated simulation modelling based on hourly calculation and its calibration.

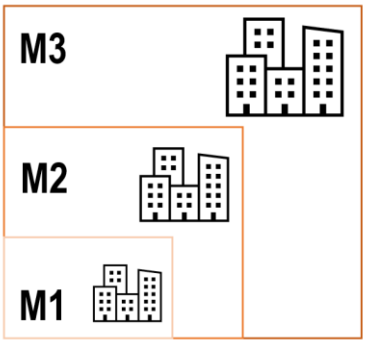


Figure 1: The relation between ePANACEA's three assessment methods

The vision for the modular and flexible methodology development is an evolution of the three assessment methods from the more simplistic to the more complex one, according to the building and/or assessment requirements, e.g., innovative energy assessment with compliance of accuracy and standard requirements, integration of smart and novel technologies or use of real measured data. A graphical overview of the three methods is shown in Figure 2.

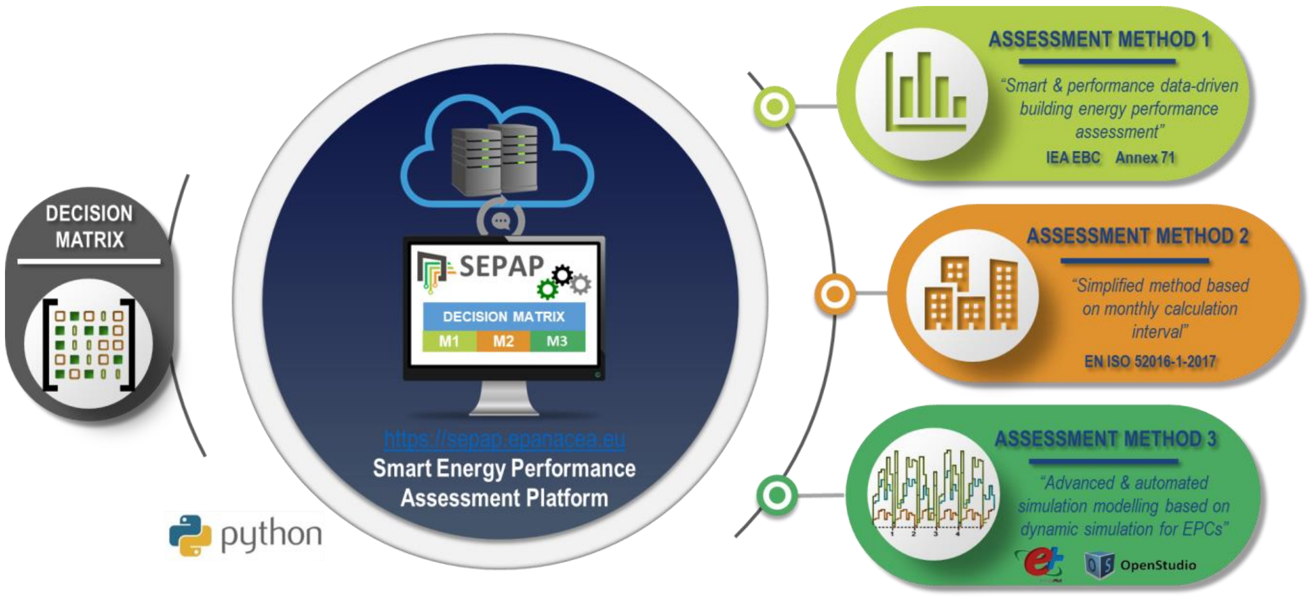


Figure 2: Overview on ePANACEA's three assessment methods. (Source: CENER, May 2023)

Each assessment method can include techniques stemming from a lower complexity level. The following synergies between the three assessment methods are exploited:

- Use of monitoring data

- Data acquisition
- Advanced user behaviour modelling
- Sensitivity analysis
- Semi-automated calibration based on machine learning techniques
- Inclusion of novel and smart technologies

2.1 Assessment method 1

Specifically, assessment method 1 uses on-board monitored (OBM) data, leveraging the increasing smart dimension of the energy management systems of the buildings, and inverse modelling approaches to assess the building energy performance. Theoretical values are calculated within the SEPAP tool using input data such as the geometrical and physical parameters of the building. The theoretical values (refer to Figure 3) are calibrated using energy bills and HDD and CDD if indoor temperature is available. If indoor temperature is not available, it is assumed that indoor temperature equals to the desired set point for heating or cooling. Having these inputs, the decomposed energy is calculated. The results are the monthly energy data (see Figure 4).

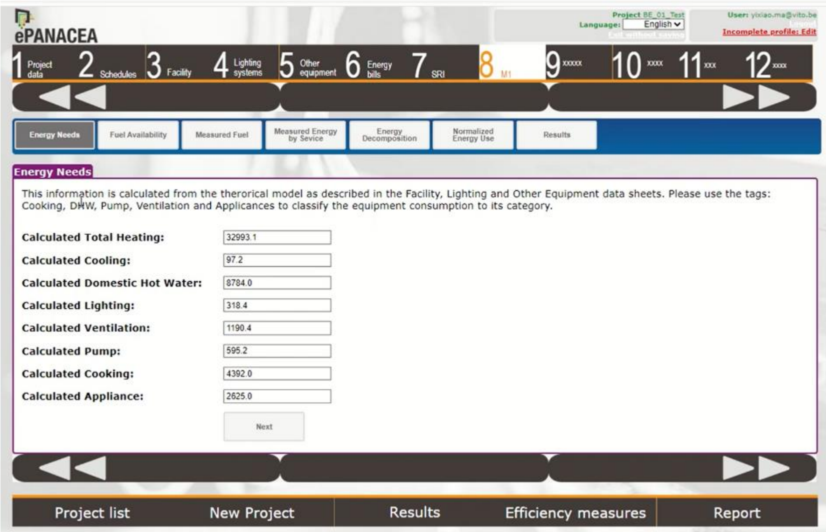
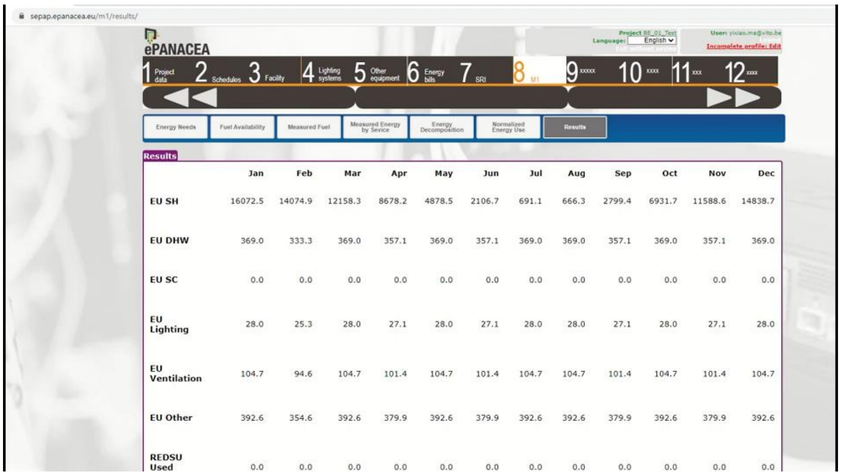


Figure 3. The theoretically calculated energy use



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
EU SH	16072.5	14074.9	12158.3	8678.2	4878.5	2106.7	691.1	666.3	2799.4	6931.7	11588.6	14838.7
EU DHW	369.0	333.3	369.0	357.1	369.0	357.1	369.0	369.0	357.1	369.0	357.1	369.0
EU SC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EU Lighting	28.0	25.3	28.0	27.1	28.0	27.1	28.0	28.0	27.1	28.0	27.1	28.0
EU Ventilation	104.7	94.6	104.7	101.4	104.7	101.4	104.7	104.7	101.4	104.7	101.4	104.7
EU Other	392.6	354.6	392.6	379.9	392.6	379.9	392.6	392.6	379.9	392.6	379.9	392.6
REDSU Used	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Figure 4. Indicative results of assessment method 1

2.2 Assessment method 2

Assessment method 2 is based on the monthly method of ISO 52016, considering that smart technologies, artificial intelligence and machine learning for automated assessments as well as advanced models for occupation profiles are increasingly present in the buildings.

General data, such as location, floor area, and construction type of the building are entered into the SEPAP tool (Figure 5). A list of weather data stations, and heating and cooling schedules are predefined, but the user can also edit if different data are available. Envelope data and data related to HVAC systems, as well as data related to lighting systems, other equipment (not included in the EPB service, such as washing machines), DHW and data from energy bills are also filled in by the user/assessor. The Smart Readiness Indicator (SRI) can be calculated by entering the functionality level for various services (e.g., heating/cooling emission control, flexibility and grid interaction, etc.). The final and primary energy consumption are presented annually in kWh (Figure 6). In addition, energy indicators are provided by services, energy sectors and energy components on an annual basis (Figure 7) while heating and cooling demands on a monthly basis (see Figure 8).

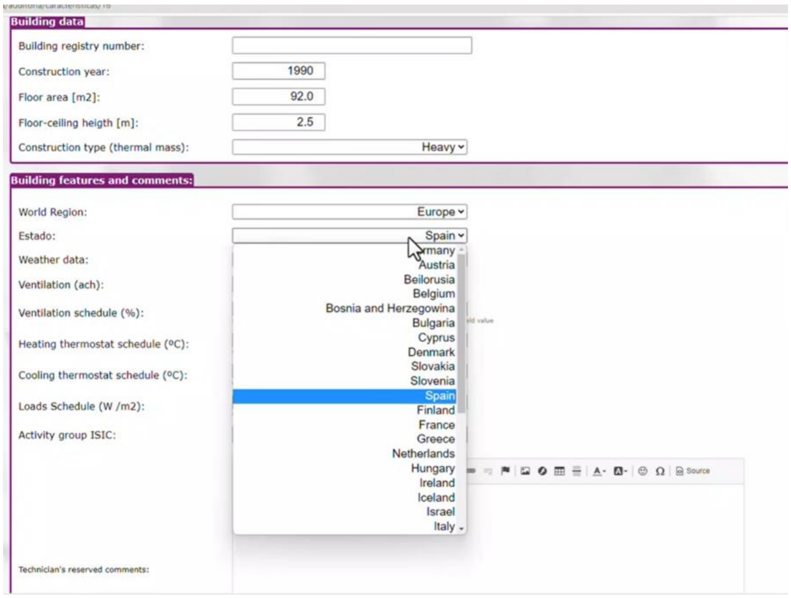


Figure 5. General data (M2)

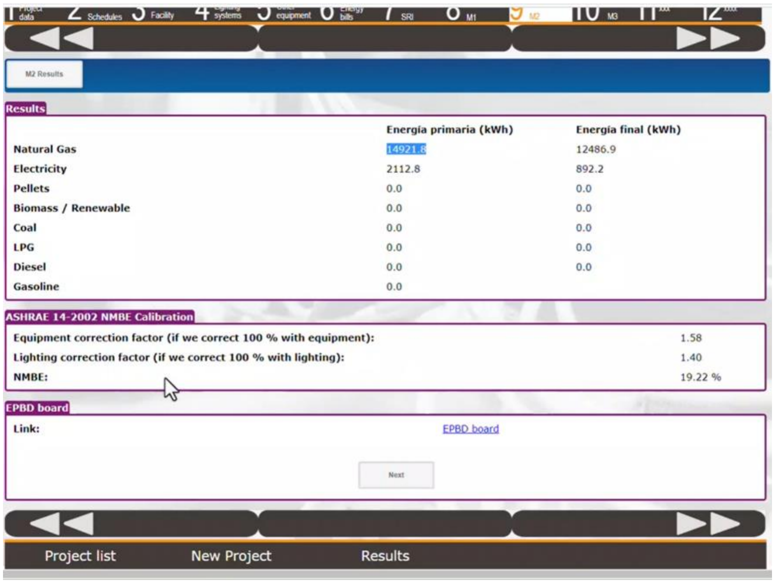


Figure 6. Indicative results of assessment method 2

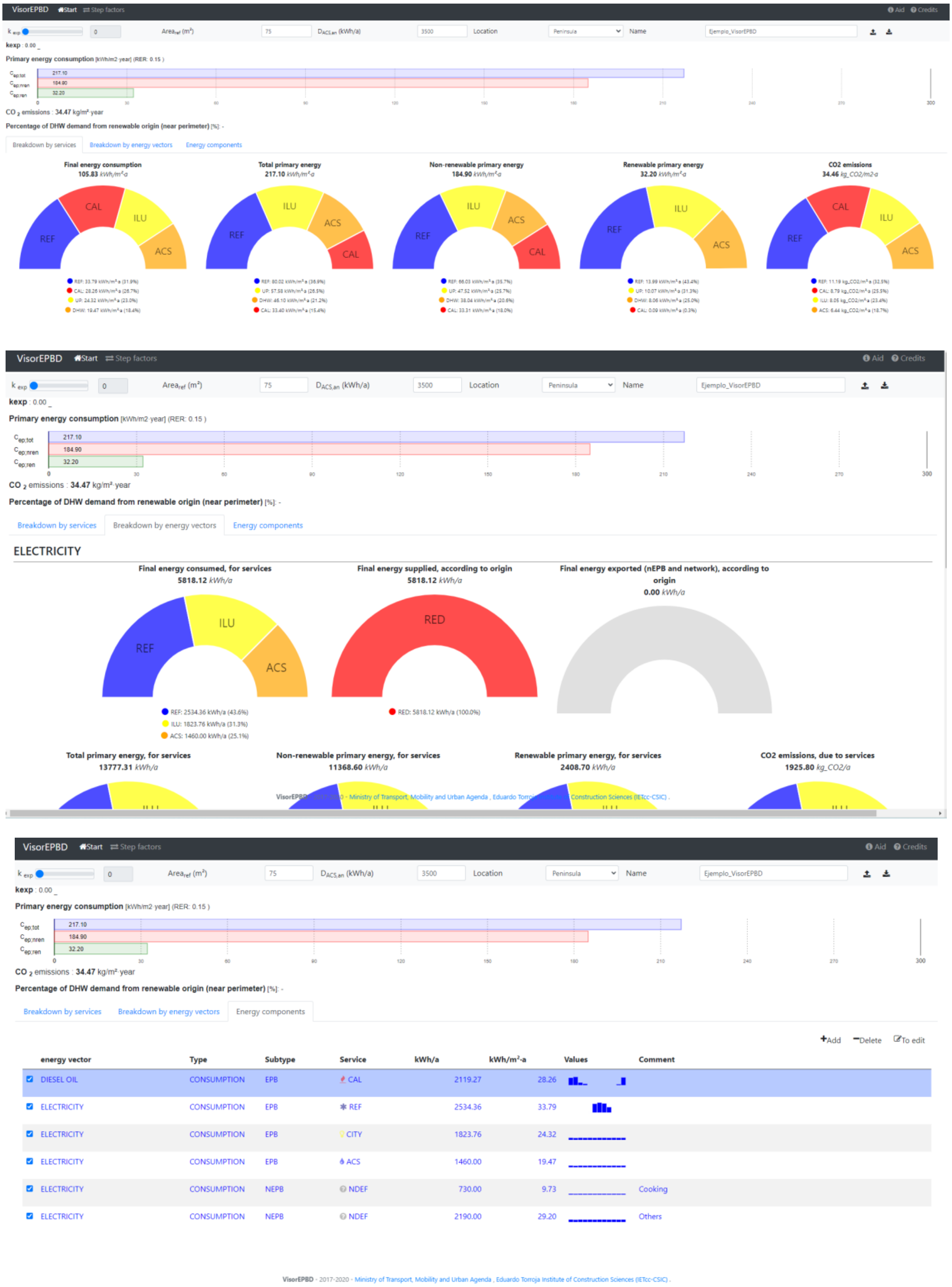


Figure 7. Indicative results of assessment method 2 (EPBD board)

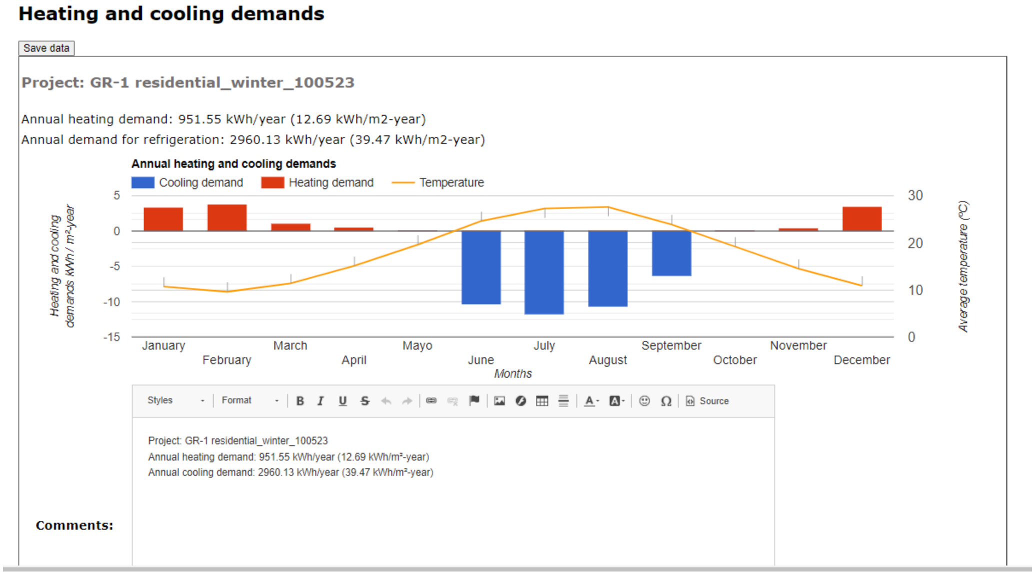


Figure 8. Indicative results for heating/cooling demands of assessment method 2

2.3 Assessment method 3

Finally, the third and more complex method of the ePANACEA methodology is the advanced & automated simulation modelling which is based on the auto-calibration of white-box BEM (Building Energy Models). Advanced dynamic simulation techniques allow a high level of accuracy as well as qualitative outputs, including:

(i) The prediction of building energy performance (e.g., corrected by climate)

(ii) Disaggregation of consumption per energy service and/or type of fuel

(iii) Identification of energy efficiency measures

(iv) Quantification of potential energy savings and economic viability calculation.

The overall concept of the suggested EPC methodology is summarised in *Figure 9*, the so-called “EPC cycle”. This approach implements a sequential structure that allows obtaining a calibrated model based on actual consumption patterns (i.e., EPC in use) at the same time that it will provide a more accurate standard EPC after correction by climate and use. This approach covers two different perspectives for the EPC:

- on the one hand, it improves the information provided to end-users based on their actual consumption patterns through the “EPC in use”;
- on the other hand, the “Standard EPC” will fulfil the administration's requirements for an objective comparison of the building stock.

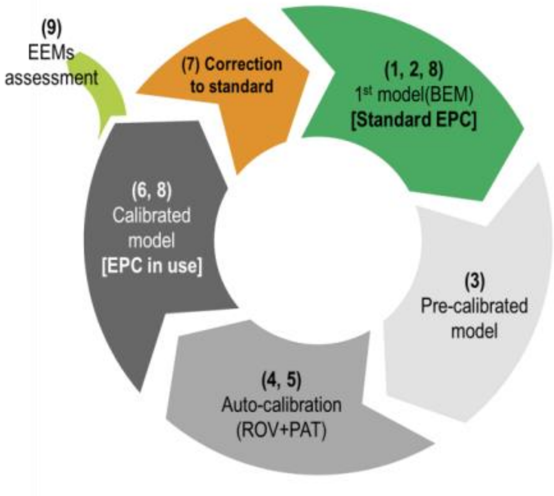


Figure 9. The "EPC cycle": the proposed methodology for EPCs based on the assessment method 3

The "EPC cycle" consists of the following steps:

1. Data gathering: building documentation, utility bills, monitoring data from BMS, spot measurements, actual weather data, etc.
2. Development of a first version of the building energy model (BEM) with dedicated tools
3. Definition and adjustment to actual peak loads and operational schedules
4. Classification of data sources to define calibration variables and their ROV (range of variation in percentage);
5. Auto-calibration: use of parametric assessments and optimisation algorithms
6. Selection of the final calibrated model (i.e., values for calibration variables)
7. Correction to standard: weather data, operational schedules, peak loads, etc.
8. Results: overall performance indicators, partial indicators, monthly disaggregation per fuel and service
9. EEMs based on actual use (i.e., calibrated BEM).

This method uses three assessment options according to ISO 52000-1 (see Report on the use of innovative certification schemes and its implementation (zenodo.org)) as presented below (*Table 6*).

Table 6: Assessment method 3 assessment options

Type	Subtype	Input data			Type of application
		Use	Climate	Building	
Calculated	As built	Standard	Standard	Design	EPC, regulation (only option for new buildings)
	Actual	Actual	Actual	Actual	Validation
Measured	Actual	Actual	Actual	Actual	Monitoring and energy audit
	Standard	Corrected to standard	Corrected to standard	Actual	EPC, regulation

Calculated

The calculated assessment is mainly based on calculation under standard operational conditions. It usually shows a high performance gap in comparison to actual consumption patterns but it is the only way for a quantitative assessment of the energy performance in the case of new buildings during their design phase, when there is no actual consumption data available. The calculation intervals (e.g., hourly, monthly, seasonal or yearly) will be consistent throughout the whole calculation.

Measured actual

The measured actual assessment is based on actual consumption data. It is only valid for existing buildings in the use phase and needs to have an associated specific rating system, since it does not imply any data correction (i.e., neither by weather nor operation). The output of the method is in principle the same as the output of the calculated energy performance (e.g., primary energy use) but with restrictions regarding parameters that cannot be measured (e.g., contribution of RES).

Measured standard

Within the measured standard method, the assessment is again based on actual consumption data but this time, the measured energy amounts need corrections and /or extrapolations in order to correct actual to standard operational conditions. Although this method presents the best potential in relation to accuracy and multi-target assessments, it also requires a tailored approach and expert knowledge in order to develop corrections with a reasonable accuracy.

In addition, a local installation package, called the SEPAP tool, based on OpenStudio®, has been developed to carry out assessment method 3, which is based on the auto-calibration of white-box BEMs (Building Energy Models). OpenStudio is a cross-platform collection of software tools to support whole-building energy modelling using the EnergyPlus simulation engine. This cross-platform integrates different open source applications that have been adapted to meet the objectives of the proposed methodology through the SEPAP tool. Among them, the SEPAP tool integrates OpenStudio SketchUp plug-in, OpenStudio application, PAT (Parametric Analysis Tool) and OpenStudio Server (Figure 10).

The user/assessor enters the building geometric and thermal performance, HVAC and profile data in the 3D design software. In addition, they fill in energy consumption data from the energy bills. The simulation results are compared with the real energy consumption data and the user runs the calibration by implementing actual behavioural patterns. Recommendations and energy savings quantification based on actual use (i.e., calibrated model) can be used to quantify actual energy savings with a high accuracy level based on the implementation of energy efficiency measures.

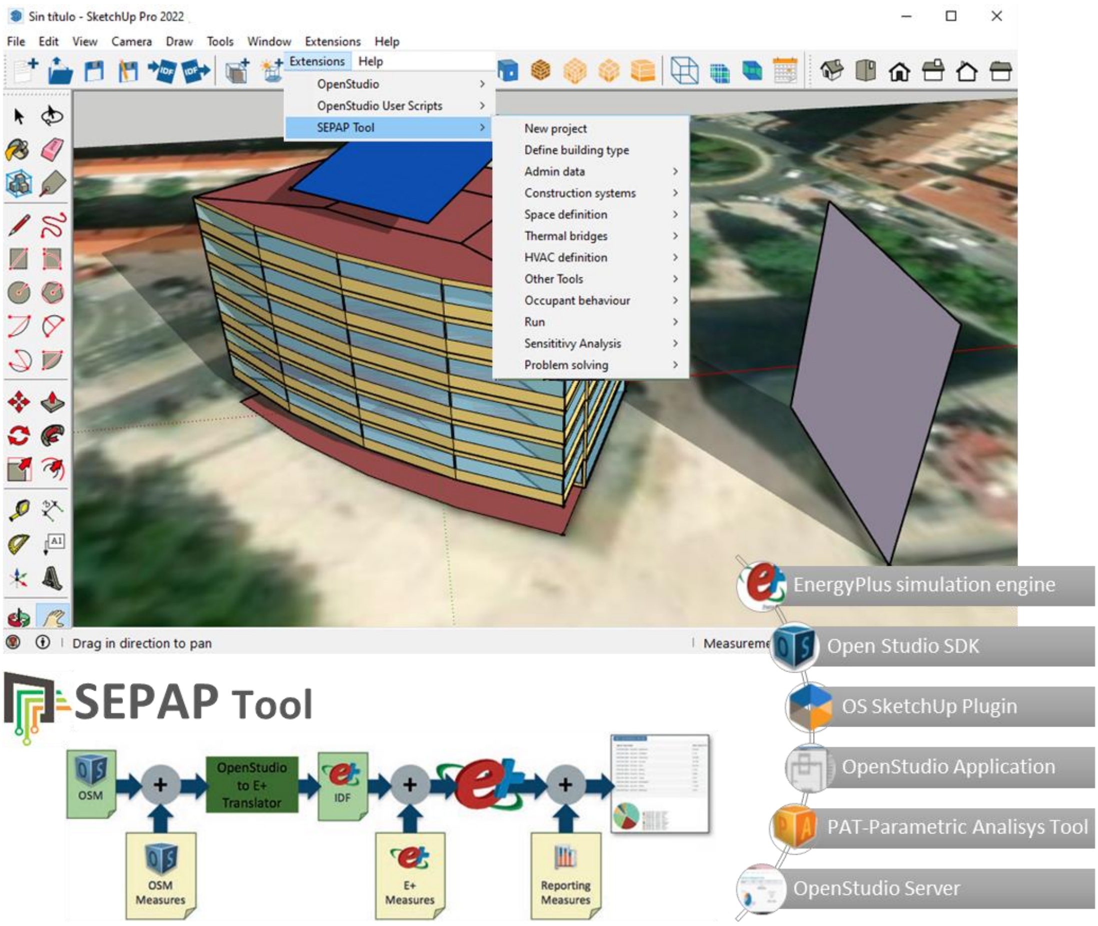


Figure 10. The SEPAP tool for conducting the assessment method 3. Source: CENER, May 2023

Concluding the above, the capabilities of the three ePANACEA method 3 assessment methods are presented in the table below (Table 8).

Table 7: Assessment method 3 assessment options

	Option 1	Option 2	Option 3
Calculated As Built	Not provided	If "standard operational conditions" are used in the SEPAP M2	the 1st approach (first model developed within the SEPAP tool): step 2 of the "EPC cycle"
Calculated Actual	Not provided	If "actual operational conditions" (i.e., adaptation of default schedules) are used in the SEPAP M2	Pre-calibrated model with actual operational conditions (i.e., seed model uploaded to the PAT): step 3 of the "EPC cycle"
Measured Actual	Not provided	Values obtained by applying the correction factor to the Actual Calculated model to calibrate the model with the actual values of the bills.	The calibrated model: step 6 of the "EPC cycle"
Measured Standard	Data-driven method is used and the results come from a correction to standard procedure		Standard model from SEPAP tool: step 7 of the "EPC cycle"

3 OVERVIEW OF THE SELECTED CASE STUDIES

All three assessment methods (M1, M2, M3), developed in ePANACEA were tested in each pilot country through three case studies, using the SEPAP, in a total of 15 buildings.

The selection of the real case studies was done taking into account the requirements of the ePANACEA methodology and in close cooperation with the building owners. Several criteria and data requirements were set in order to cover a board range of building typologies among participating countries and to create validated assessment methods with high reliability and broad applicability (see Table 8). The criteria set for the case study selection are described in detail in the report "Compendium of Testing and Demonstration Board (TDB) Meetings"[1].

Table 8: Overview of building characteristics of the 15 selected case studies.

Building characteristics		Pilot Country				
		AT	BE	FI	GR	SP
Climate	Atlantic		x			x
	Mediterranean				x	
	Continental	x		x		
	Boreal			x		
	Pannonian	x				
Size (GFA)	<500 m^2	x	x		x	x
	500-2.000 m^2	x			x	x
	>2.000 m^2			x	x	x
Building Type	Single-family houses		x			x
	Multi-family apartments	x			x	x
	Offices	x		x	x	x
	Educational buildings			x		
Construction type	Light	x				x
	Moderate	x		x		
	Heavy		x	x	x	
Energy need	Heating (& DHW)	x	x	x		x
	Heating (& DHW) & Cooling			x	x	x
HVAC	Low complexity		x			x
	Medium complexity	x		x	x	x
	High complexity			x	x	
RES on site	No	x	x	x	x	x
	Yes	x		x	x	x

[1] Available at the project website: RESULTS – ePANACEA Horizon 2020 project

BACS	Low complexity		x		x	x
	Medium complexity	x			x	x
	High complexity	x		x		
Data availability	Low				x	x
	Medium		x	x		
	High			x		x
	Very high	x		x		

***GFA**: gross floor area, **HVAC**: low complexity - covering heating and DHW demand with only one system (e.g., individual boilers or central heating boiler), high complexity - covering heating, cooling and DHW demand with a mix of different technologies with different fuels; **Data availability**: 1) low - design data, medium - design data, utility bills, weather data, 2) high - design data, utility bills, weather data, short-term measurements, 3) very high - design data, utility bills, weather data, short-term measurements, smart meters data; **RES on site**: Renewable energy sources on site; **BACS**: Building automation and control system*

For the development of the ePANACEA methodology it was agreed to collect data from at least one case study per pilot country with high data availability until the end of May 2021 or August 2021, depending on the availability of historical measurement data.

The length of collection of the energy consumption data (electricity, heating fuels, etc.) depends on the measurement frequency of the data. For high resolution data (less than 1 hour), a 4 weeks period would be sufficient. Energy consumption with a daily or weekly frequency should be collected for a period of 15 weeks. If energy consumption data are available on a monthly basis, it would be sufficient to have approx. 2-3 years of data. The period and frequency of data availability will imply short-term or long-term calibration processes as well as different levels of accuracy. For testing assessment method 1, the data (electricity, gas, solar radiation, indoor and outdoor temperature, etc.) need to be available for the same period with the same frequency (either monthly, daily or hourly data). The other methods will be able to deal with longer data time periods.

The following tables (Table 9 - Table 13) list all selected case studies of the individual countries that meet the criteria. These case studies have been selected by the TDB and have been considered as the most suitable to develop and test the ePANACEA methods.

Table 9: Selected case studies, Austria

Austria

Case study number	AT-01	AT-02	AT-03
Picture of building	 © Ditz Fejer	 © Forschung Burgenland	 © KooWo Volkersdorf
Name of building	Multi-family building	Office building	Community building

Building address	AT-8063 Eggersdorf	AT-7423 Pinkafeld	AT-8063 Eggersdorf
Year of construction	2018	2015	2018
EPC rating for primary energy demand	B (106,65 kWh/m²year)	B (222,40 kWh/m²year)	B (191,30 kWh/m²year)
Climate	Continental	Pannonian	Continental
Building typology	Multi-family house	Office building	Office building
General data availability	Very high (less than 1 hour)	Very high (less than 1 hour)	Very high (less than 1 hour)

Table 10: Selected case studies, Belgium

Belgium			
Case study number	BE-01	BE-02	BE-03
Picture of building	 © Google Maps	 © Google Maps	 © Google Maps
Name of building	single-family house (Vinkenhof)	Multi-family building - flat	Terraced house
Building address	2590 Berlaar	2290 Vorselaar	9040 Gent
Year of construction	1982	1979	1904
EPC rating for primary energy demand	D-306 kWh/m²year	B-141 kWh/m² & A-83 kWh/m²	B-156 kWh/m²year

Climate	Atlantic	Atlantic	Atlantic
Building typology	Single family house	Multi-family house	Single family house
General data availability	Low (monthly data)	Low (monthly data)	Very high (less than 1 hour)

Table 11: Selected case studies, Finland

Finland

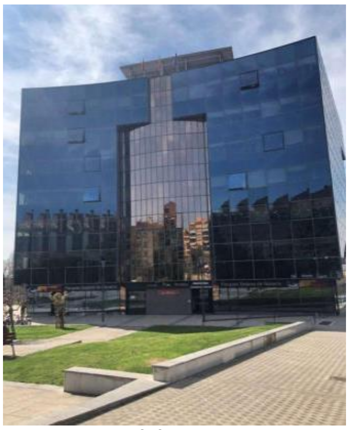
Case study number	FI-01	FI-02	FI-03
Picture of building	 © VTT	 © VTT	 © VTT
Name of building	Energy efficient office building	School Eklöfska skolan	School (Keinutien ala-aste)
Building address	00940 Helsinki	06750 Tolkkinen Porvoo	00940 Helsinki
Year of constructio n	2011	2019	2016
EPC rating for primary energy demand	A, 72 kWh/m^2, 2018	B, 99 kWh/m^{2}year	B, 130 kWh/m^2, 2013
Climate	Boreal	Boreal	Boreal
Building typology	Office building	Educational building	Educational building
General data availability	Very high (less than 1 hour)	High (1 hour for all data)	High (1 hour for all data)

Table 12: Selected case studies, Greece

Greece			
Case study number	GR-01	GR-02	GR-03
Picture of building	 © CRES	 © CRES	 © CRES
Name of building	Apartment in Multi Family Building – 2nd floor	Office building	Municipal Office building
Building address	17341, Ag. Dimitrios - Attiki	190 09, Pikermi – Attiki	17343 Ag. Dimitrios – Attiki
Year of construction	1976	2001	1970
EPC rating for primary energy demand	Class: C 197,6 kWh/m^2 year	Class: B 170,8 kWh/m^2 year	Class: D 369kWh/m^2 year
Climate	Mediterranean	Mediterranean	Mediterranean
Building typology	Multi-family house	Office building	Office building
General data availability	Low (monthly data)	Low (monthly data)	Low (monthly data)

Table 13: Selected case studies, Spain

Spain

Case study number	SP-01	SP-02	SP-03
Picture of building	 © CENER	 © CENER	 © CENER
Name of building	Public office building	Private residential building (single family home)	Private residential building (multifamily block)
Building address	Tomás Caballero, 1, 31006 Pamplona (Navarra)	31486 Egües (Navarra)	31006 Pamplona (Navarra)
Year of construction	1994	2005	2009
EPC rating for primary energy demand	Class C: 386,59 kWh/m^{2}year	Class C: 148,43 kWh/m^{2}year	Class C: 15,2 kgCO_2/m^{2}year
Climate	Atlantic	Atlantic	Atlantic
Building typology	Office building	Single family house	Multi-family house
General data availability	High (1 hour for all data)	Low (monthly data)	Low (monthly data)

4 METHODOLOGY FOR EVALUATION

Based on the demonstration and validation results, as described in the report "Testing the ePANACEA methodology", the evaluation of the ePANACEA energy assessment and certification methodology is presented in this section as part of the third testing phase of the ePANACEA project (see *Figure 11*).

The focus was on the outputs of the three ePANACEA methods, and their comparison with the outcomes of the current EPC reports in terms of quality and quantity at national level. Fifteen (15) real case studies have been tested using real-measured and theoretical data as required for each assessment method.

The outputs provided from each national EPC report are used as the basis for the evaluation of the three ePANACEA methods. Values/outputs that were not given directly from the methods, were calculated so as to make a comprehensive analysis of the data.

Method 1 uses monitored data and gives outputs only for energy needs. Therefore, in order to compare between the national current EPC and the Method 1 data, national conversion factors for primary energy and CO_2 emissions were used, as described in the following sections.

Method 2 provides energy values such as energy use, total, renewable and non-renewable primary energy per energy services, as well as CO_2 emissions. These values are compared with the national current EPC data, as described in the following sections.

As regards Method 3, it provides energy related values (energy use per energy services) and partial indicators (e.g., heat transfer coefficient of building components) for the energy assessment options according to ISO 52000-1; specifically, these are Calculated Actual (CA), Measured Actual (MA) and Measured Standard (MS). The analysis and comparison with the national current EPC data requires calculations based on conversion factors as defined in each pilot country. It is noted that the Measured Standard (MS) option is based on the Spanish technical specifications.

Figure 11: ePANACEA's testing phases

5 EVALUATION PER COUNTRY

As presented below, each country has its national EPC certification scheme in place and therefore different assessment results. This section presents the current EPC report results for the 15 case studies and the outputs of the three ePANACEA assessment methods.

5.1 Austria

In Austria, the main performance indicator is the total primary energy use (PEtot in kWh/m²year). The energy classification of the building, the CO_2 emissions, the energy need for space heating and the energy efficiency factor (comparing the efficiency of the current building with a reference building from 2007) are also provided in the EPC report. The overall energy performance is represented by the non-renewable and renewable primary energy use in kWh/m²year. There are partial indicators based on the greenhouse gas emissions (GHG) and the characteristics of the building envelope; specifically, these concern GHG emissions for heating and for DHW, lighting (only for non-residential buildings) or other services (only for residential buildings). The current Austrian EPC report also displays the heat transfer coefficient of walls, roofs, floors and windows as well as of the thermal envelope in W/m²K and the solar heat gain coefficient (SHGC) of windows. All the values provided are calculated based on the national assessment methodology. The total number of outputs displayed in the EPC reports of the case studies - depending on the building type (residential or non-residential) - ranges between 17 and 19.

Table 14 presents the current EPC data for the Austrian case studies (AT-01, AT-02, and AT-03), which are a multi-family building, an office building and a community building.

Table 14: Current EPC report outputs in Austria

Category	Definition	Units	AT-01	AT-02	AT-03
Energy performance rating	Classification (label/class A-G)	-	B	B	B
	Total primary energy use	kWh/m²year	106,6	222	191,3
	GHG emissions	$kgCO_2$/m²year	7,55	37,5	18,1
	Energy need for space heating	kWh/m²year	33,4	38,8	33,6
	f gee (energy efficiency factor)	-	0,725	1,07	0,95
Overall numerical indicators	Non-renewable primary energy use	kWh/m²year	38,2	191,0	82,7
	Renewable primary energy use	kWh/m²year	68,4	31,1	108,6
Partial indicators	GHG emissions for heating	$kgCO_2$/m²year	0,23	15,47	0,18
	GHG emissions for DHW	$kgCO_2$/m²year	4,67	5,77	0,06
	GHG emissions for lighting	$kgCO_2$/m²year	-	17,89	29,94
	GHG emissions for other services	$kgCO_2$/m²year	4,11	-	1,33
	Heat transfer coefficient of walls (weighted average)	W/m²K	0,153	0,149	0,12
	Heat transfer coefficient of roofs (weighted average)	W/m²K	0,123	0,136	0,15

	Heat transfer coefficient of floors (weighted average)	W/m²K	0,209	0,198	0,19
	Heat transfer coefficient of windows (weighted average)	W/m²K	0,82	0,85	0,88
	Heat transfer coefficient of the thermal envelope (weighted average)	W/m²K	-	-	0,22
	SHGC of windows (weighted average)	fraction (0-1)	0,52	0,50	0,58

5.1.1 Method 1

As described in section 2.1, Method 1 uses OBM data which is entered into the SEPAP tool by the user. The method provides two types of values, i.e., values directly provided by the method (extracted) and values which are calculated for evaluation purposes. The following figure (Figure 12) presents the number of current EPC outputs, the number of outputs extracted from the method and the total number of outputs (extracted and calculated) for each case study (AT-01, AT-02, AT-03). The number of Method 1 outputs range from 4 to 32, while the EPC number of outputs lies between these two.

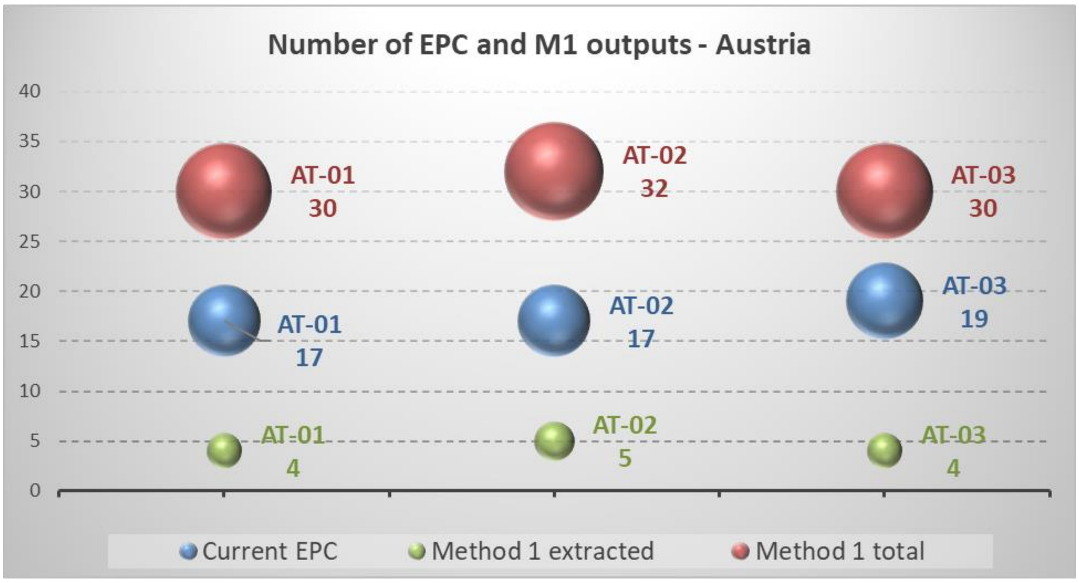
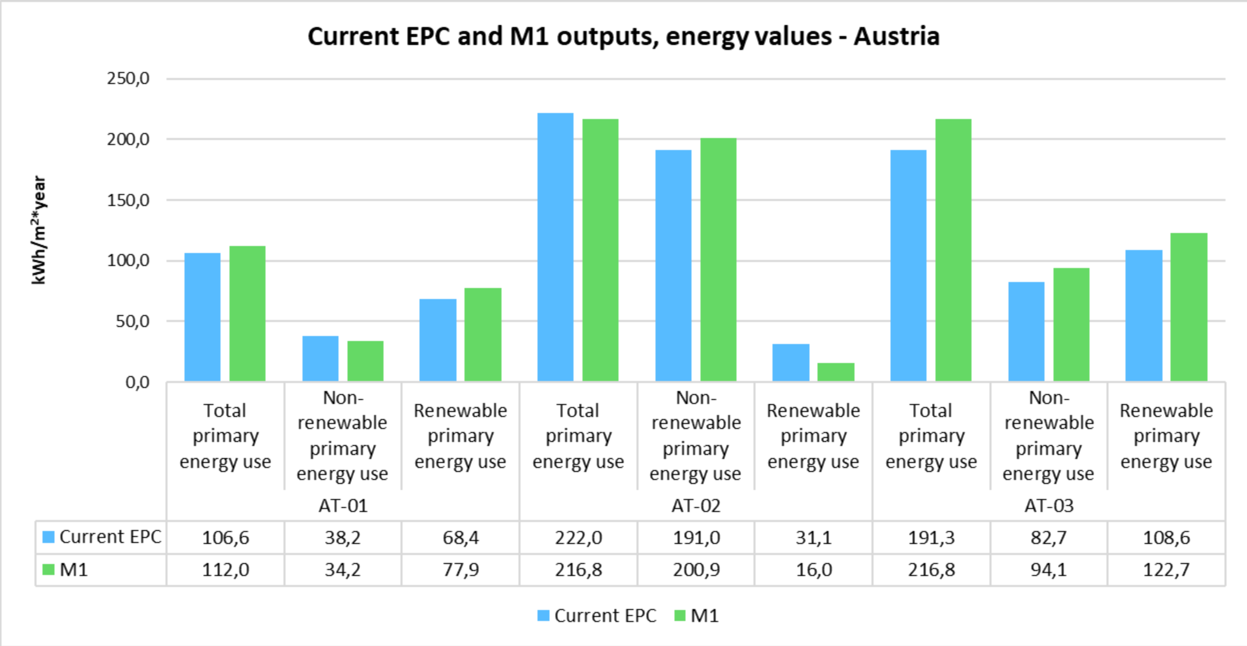


Figure 12: EPC and M1 outputs - Austria

Method 1 values are presented in the figures below (Figure 13, Figure 14); these include Total primary energy use, Non-renewable primary energy use, Renewable primary energy use and CO_2 emissions. As noted above, these values have been calculated using the Austrian conversion factors.



	AT-01			AT-02			AT-03		
	Total primary energy use	Non-renewable primary energy use	Renewable primary energy use	Total primary energy use	Non-renewable primary energy use	Renewable primary energy use	Total primary energy use	Non-renewable primary energy use	Renewable primary energy use
Current EPC	106,6	38,2	68,4	222,0	191,0	31,1	191,3	82,7	108,6
M1	112,0	34,2	77,9	216,8	200,9	16,0	216,8	94,1	122,7

Figure 13: EPC and M1 energy values – Austria

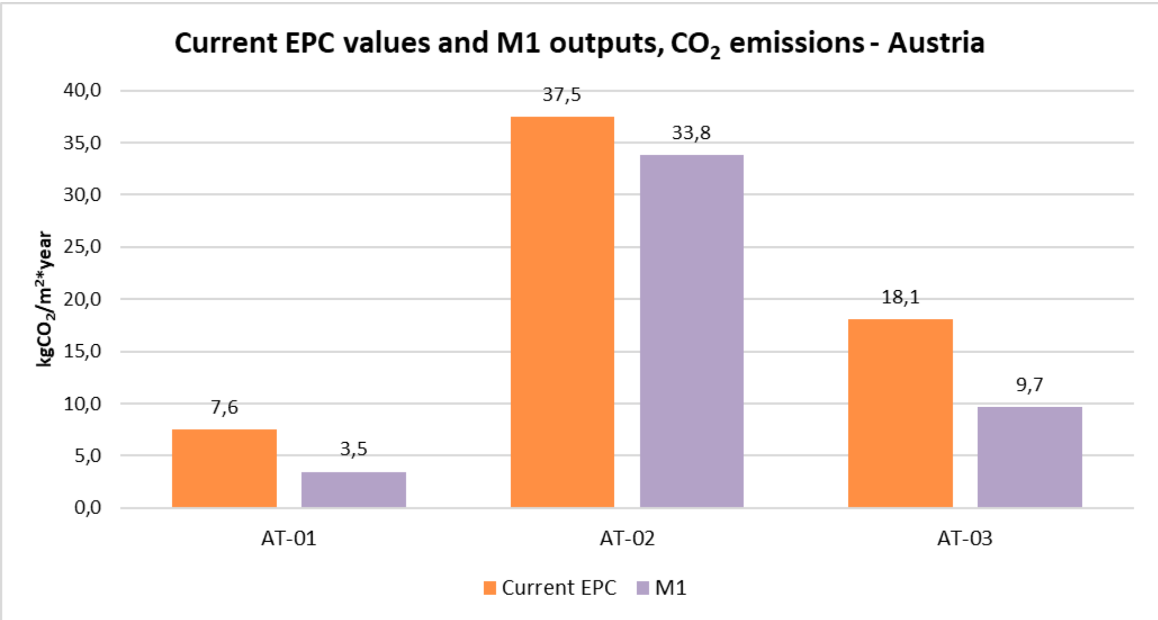


Figure 14: EPC and M1 CO_2 emissions – Austria

It is shown that the energy values (total, non-renewable and renewable primary energy) of Method 1 are close to those of the current EPC and the average deviation rate is approx. 13%. As regards CO_2 emissions, current EPC values are almost double for AT-01 and AT-03.

5.1.2 Method 2

As described above, Method 2 values are directly taken from the SEPAP tool. The number of Method 2 outputs depends on the buidling type (AT-01, AT-02, AT-03) (Figure 15).

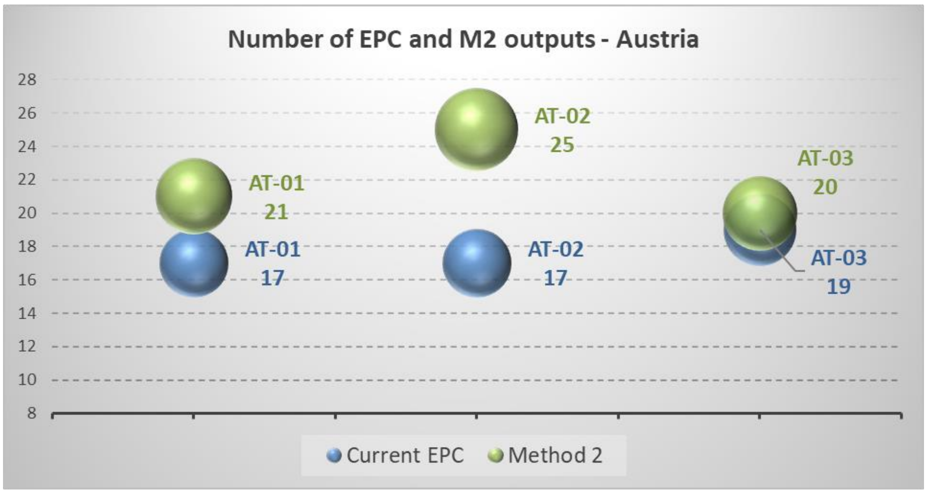
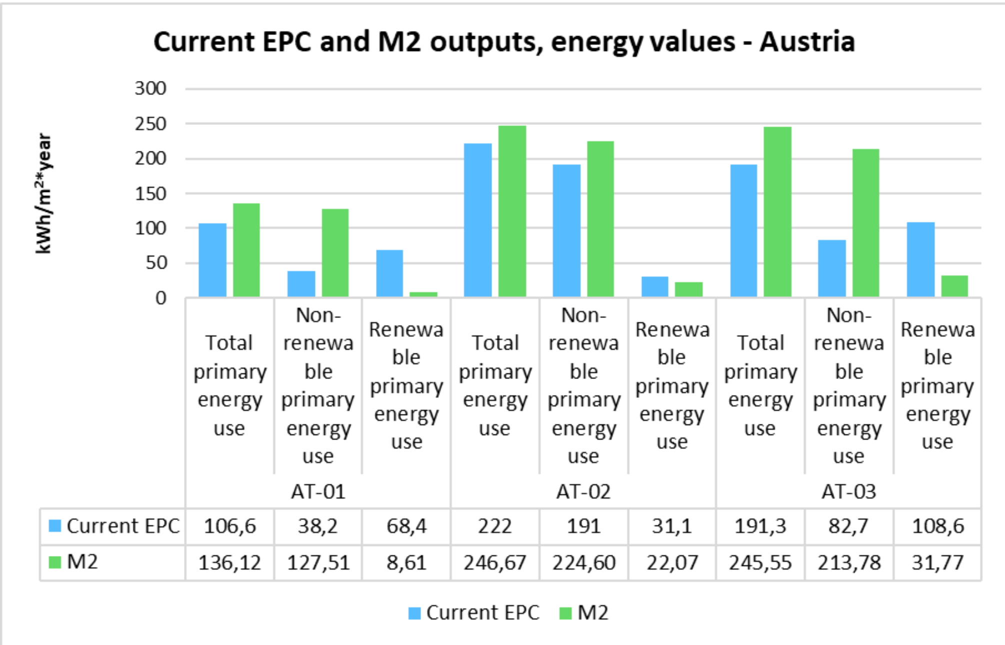


Figure 15: EPC and M2 outputs - Austria

Method 2 values are presented in the figures below (Figure 16, Figure 17); these include Total primary energy use, Non-renewable primary energy use, Renewable primary energy use and CO_2 emissions.



	AT-01 Total primary energy use	AT-01 Non-renewable primary energy use	AT-01 Renewable primary energy use	AT-02 Total primary energy use	AT-02 Non-renewable primary energy use	AT-02 Renewable primary energy use	AT-03 Total primary energy use	AT-03 Non-renewable primary energy use	AT-03 Renewable primary energy use
Current EPC	106,6	38,2	68,4	222	191	31,1	191,3	82,7	108,6
M2	136,12	127,51	8,61	246,67	224,60	22,07	245,55	213,78	31,77

Figure 16: EPC and M2 energy values – Austria

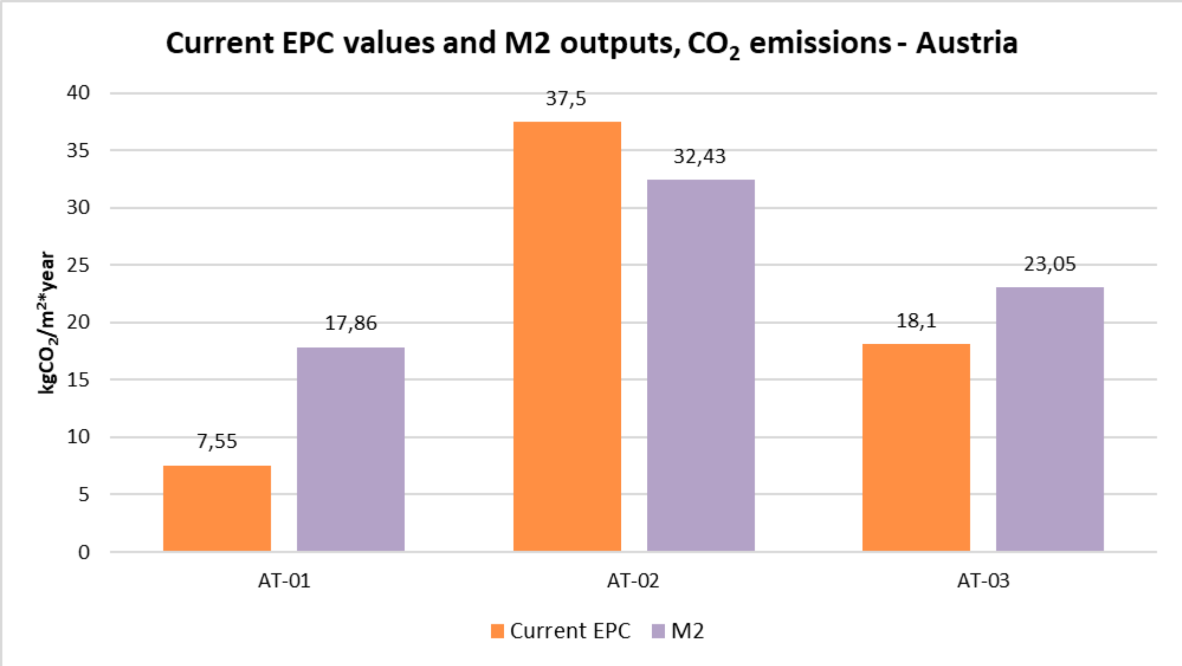


Figure 17: EPC and M2 CO_2 emissions – Austria

It is shown that the energy values (total, non-renewable and renewable primary energy) of Method 2 and current EPC for AT-02 are quite similar, in contrast to the corresponding values for AT-01 and AT-03. Regarding CO_2 emissions, the values do not show similar patterns; AT-01 and AT-03 have less CO_2 emissions in the current EPC whilst for AT-02 the opposite is true. This is probably due to the different conversion factors taken into account for the CO_2 emissions calculations in the Austrian EPC and the respective one for Method 2.

5.1.3 Method 3

Method 3 is the most complex method and provides more values than the other methods. As in Method 1, the values fall under one of the following two types, values provided directly by the method (extracted) and values calculated for evaluation purposes. The number of outputs of the three Method 3 options (CA, MA, MS) of each case study (AT-01, AT-02, AT-03) is presented in Figure 18.

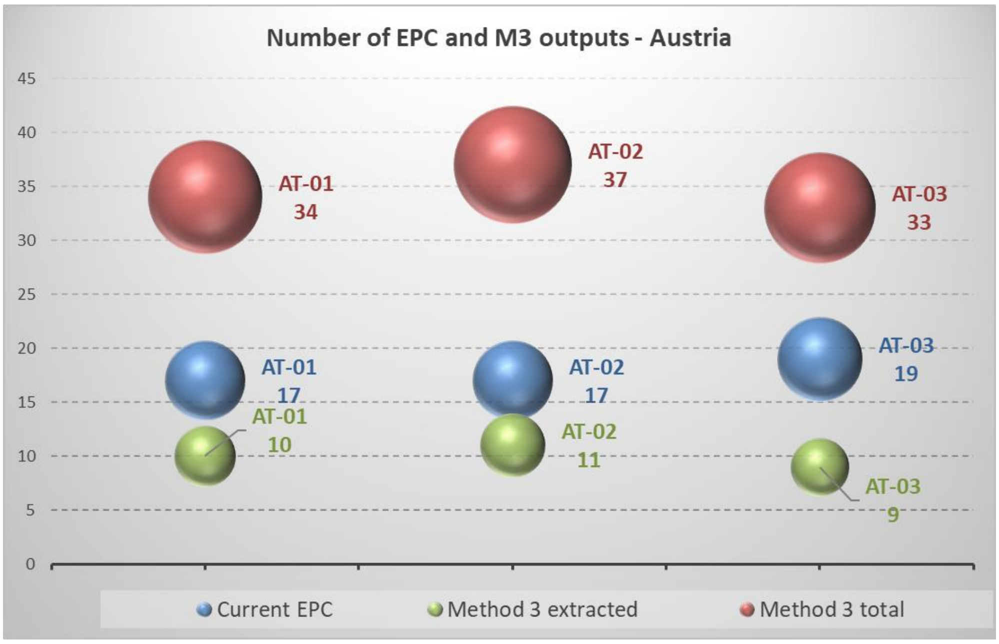
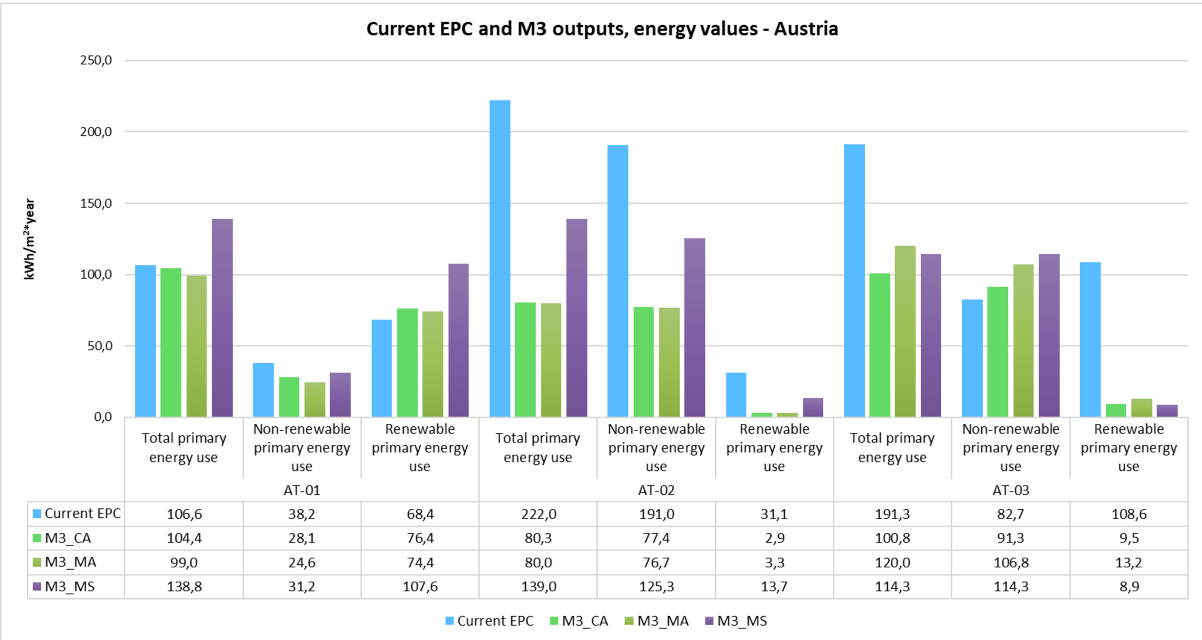


Figure 18: EPC and M3 outputs - Austria

Figure 19 and Figure 20 present the values of Method 3 outputs compared with the current EPC ones.



	AT-01			AT-02			AT-03		
	Total primary energy use	Non-renewable primary energy use	Renewable primary energy use	Total primary energy use	Non-renewable primary energy use	Renewable primary energy use	Total primary energy use	Non-renewable primary energy use	Renewable primary energy use
Current EPC	106,6	38,2	68,4	222,0	191,0	31,1	191,3	82,7	108,6
M3_CA	104,4	28,1	76,4	80,3	77,4	2,9	100,8	91,3	9,5
M3_MA	99,0	24,6	74,4	80,0	76,7	3,3	120,0	106,8	13,2
M3_MS	138,8	31,2	107,6	139,0	125,3	13,7	114,3	114,3	8,9

Figure 19: EPC and M3 energy values – Austria

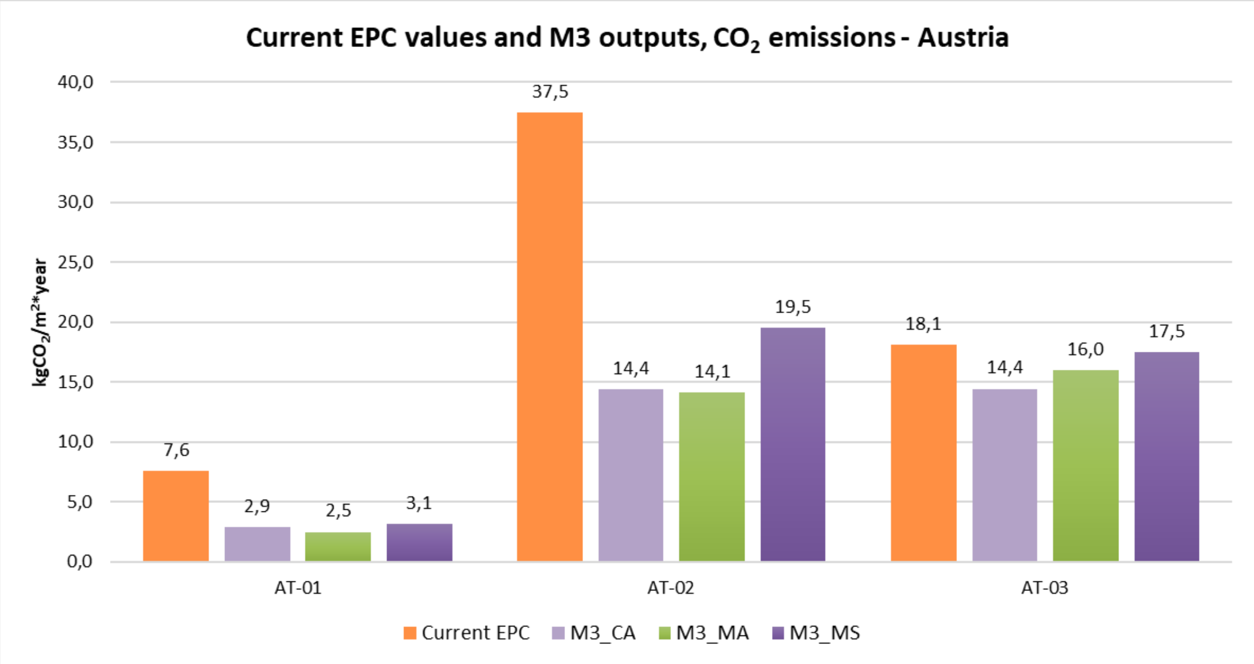


Figure 20: EPC and M3 CO_2 emissions – Austria

It is noticeable that the Method 3_MS option for AT-01 and AT-02 provides values that are higher than those of the current EPC for all energy related values, which is probably due to a more realistic user behaviour and better values for the thermal building envelope (were only estimated for some superstructures) than assumed in the model. As for the CO_2 emissions, the values of the current EPC are higher than the ones of Method 3 for all case studies.

5.1.4 Country results

The following table (Table 15) shows the possible outputs provided by the Austrian EPC report and the ePANACEA assessment methods 1, 2 and 3. It is noted that all methods have more outputs (extracted and calculated) than the national EPC report. All data provided by Method 2 are directly extracted whilst Method 1 and 3 provide values which are mostly calculated. Method 3 provides the most data, including thermal performance characteristics of the building elements which are also provided in the EPC report.

Table 15: Current EPC and M1, M2, M3 outputs in Austria

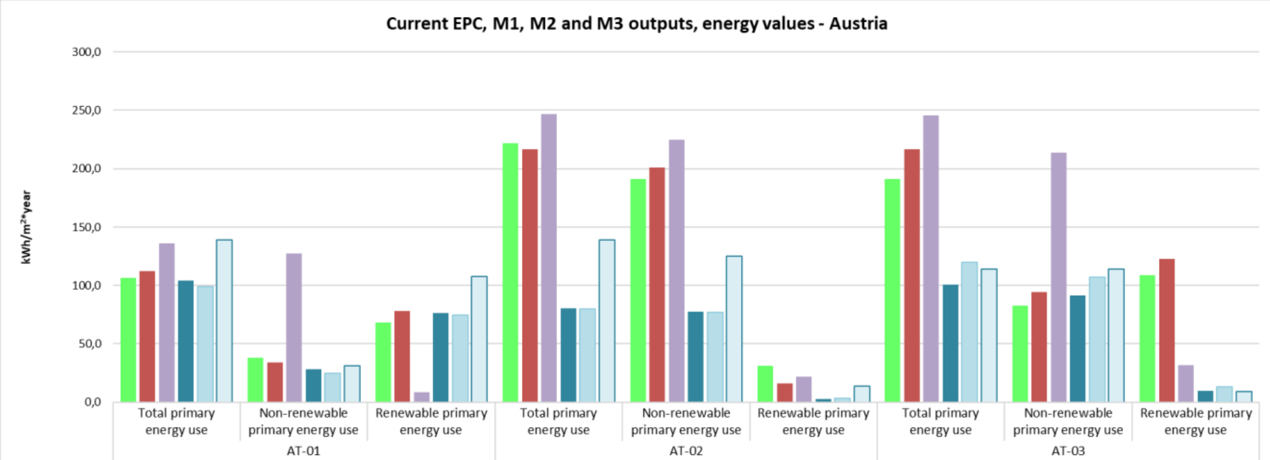
Category	Definition	Current EPC	M1	M2	M3_CA	M3_MA	M3_MS
Energy performance rating	Classification (label/class A-G)						
	Total primary energy use [kWh/m²year]	*(provided below) **					
	GHG emissions [kgCO2/m²year]						
	HWB (energy need for space heating) [kWh/m²year]						
	Energy efficiency factor (f gee) [fraction (0-1)]						
Overall numerical indicators (main	*Total primary energy use (EPBD services) [kWh/m²year]		C	E	C	C	C
	Non-renewable primary energy use (EPBD services) [kWh/m²year]		C	E	C	C	C

Category	Definition	Current EPC	M1	M2	M3_CA	M3_MA	M3_MS
performance indicators)	Renewable primary energy use (EPBD services) [kWh/m²year]		C	E	C	C	C
	*GHG emissions (EPBD services) [kgCO_2/m²year]		C	E	C	C	C
	Renewable energy ratio (EPBD services) [% or fraction (0-1)]		C	E	C	C	C
	Total primary energy use (All services) [kWh/m²year]		C		C	C	C
	Non-renewable primary energy use (All services) [kWh/m²year]		C		C	C	C
	Renewable primary energy use (All services) [kWh/m²year]		C		C	C	C
	GHG emissions (All services) [kgCO_2/m²year]		C		C	C	C
	Renewable energy ratio (All services) [% or fraction (0-1)]		C		C	C	C
Partial indicators	*Energy need for space heating [kWh/m²year]			E			
	Energy use for heating [kWh/m²year]		E	E	E	E	E
	Energy use for cooling [kWh/m²year]		E	E	E	E	E
	Energy use for DHW [kWh/m²year]		E	E	E	E	E
	Energy use for lighting [kWh/m²year]		E	E	E	E	E
	Energy use for ventilation [kWh/m²year]				E	E	E
	Energy use for other services [kWh/m²year]		E		E	E	E
	Electric energy from RES used on-site [kWh/year, kWh/m²year]						
	GHG emissions for heating [kgCO_2/m²year]		C	E	C	C	C
	GHG emissions for cooling [kgCO_2/m²year]		C	E	C	C	C
	GHG emissions for DHW [kgCO_2/m²year]		C	E	C	C	C
	GHG emissions for lighting [kgCO_2/m²year]		C	E	C	C	C
	GHG emissions for other services [kgCO_2/m²year]		C		C	C	C
	Non-renewable primary energy use for heating [kWh/m²year]		C	E	C	C	C
	Non-renewable primary energy use for cooling [kWh/m²year]		C	E	C	C	C
	Non-renewable primary energy use for DHW [kWh/m²year]		C	E	C	C	C
	Non-renewable primary energy use for lighting [kWh/m²year]		C	E	C	C	C
	Non-renewable primary energy use for other services[kWh/m²year]		C		C	C	C
	Total primary energy use for heating[kWh/m²year]		C	E	C	C	C
	Total primary energy use for cooling[kWh/m²year]		C	E	C	C	C
	Total primary energy use for DHW [kWh/m²year]		C	E	C	C	C
	Total primary energy use for lighting [kWh/m²year]		C	E	C	C	C
	Total primary energy use for other services [kWh/m²year]		C		C	C	C
	Renewable primary energy use for heating [kWh/m²year]		C	E	C	C	C
	Renewable primary energy use for cooling [kWh/m²year]		C	E	C	C	C
	Renewable primary energy use for DHW [kWh/m²year]		C	E	C	C	C

Category	Definition	Current EPC	M1	M2	M3_CA	M3_MA	M3_MS
	Renewable primary energy use for lighting [kWh/m²year]		C	E	C	C	C
	Renewable primary energy use for other services [kWh/m²year]		C		C	C	C
	Heat transfer coefficient of walls (weighted average) [W/m²K]				E	E	E
	Heat transfer coefficient of roofs (weighted average) [W/m²K]				E	E	E
	Heat transfer coefficient of floors (weighted average) [W/m²K]				E	E	E
	Heat transfer coefficient of windows (weighted average) [W/m²K]				E	E	E
	Heat transfer coefficient of the thermal envelope (weighted average) [W/m²K]						
	SHGC of windows (weighted average) [fraction (0-1)]				E	E	E

C: Calculated, E: Extracted

In terms of quantitative analysis, as shown in Figure 21, the Method 1 energy values of the Austrian case studies are close to the ones of the national EPC report. The deviation rates of the total primary energy use of Method 1 and Method 2 from the national EPC report are 7% and 15%, respectively, while the average deviation rate of Method 3 is 30%.



	AT-01 Total primary energy use	AT-01 Non-renewable primary energy use	AT-01 Renewable primary energy use	AT-02 Total primary energy use	AT-02 Non-renewable primary energy use	AT-02 Renewable primary energy use	AT-03 Total primary energy use	AT-03 Non-renewable primary energy use	AT-03 Renewable primary energy use
Current EPC	106,6	38,2	68,4	222,0	191,0	31,1	191,3	82,7	108,6
M1	112,0	34,2	77,9	216,8	200,9	16,0	216,8	94,1	122,7
M2	136,12	127,51	8,61	246,67	224,60	22,07	245,55	213,78	31,77
M3_CA	104,4	28,1	76,4	80,3	77,4	2,9	100,8	91,3	9,5
M3_MA	99,0	24,6	74,4	80,0	76,7	3,3	120,0	106,8	13,2
M3_MS	138,8	31,2	107,6	139,0	125,3	13,7	114,3	114,3	8,9

Current EPC ■ M1 ■ M2 ■ M3_CA ■ M3_MA ■ M3_MS

Figure 21: EPC and M1, M2, M3 energy values – Austria

5.2 Belgium

In Belgium, the main performance indicator is the total primary energy use (PEtot in kWh/m²year) and the energy classification of the building. The overall energy performance is represented by the Greenhouse Gas emissions (GHG) in kgCO_2/m²year. There are partial indicators based on the characteristics of the building envelope and the technical building systems. Specifically, the heat transfer coefficient of walls, roofs, floors and windows in W/m²K and the efficiency of the heating system are presented on the current Belgian EPC report. All the values provided are calculated based on the national assessment methodology. The total number of outputs displayed in the EPC reports of the Belgian case studies is 10. Moreover, the Belgian EPC provides an estimate of the required costs for proposed renovation measures.

The table below (Table 16) presents the current EPC data for the Belgian case studies (BE-01, BE-02, and BE-03), which are two single-family houses and one multi-family house.

Table 16: Current EPC report outputs in Belgium

Category	Definition	units	BE-01	BE-02	BE-03
Energy performance rating	Classification 7 classes (A+-F)	-	B	B	B
	Total primary energy use	kWh/m²year	140	141	156
Overall numerical indicators	GHG emissions	$kgCO_2/m^2year$	27	36	28,59
Partial indicators	Heat transfer coefficient of walls (weighted average)	W/m²K	0,24	1	0,98
	Heat transfer coefficient of roofs (weighted average)	W/m²K	0,73	0,85	0,22
	Heat transfer coefficient of floors (weighted average)	W/m²K	0,65	0,85	0,49
	Heat transfer coefficient of windows (weighted average)	W/m²K	1,29	3,5	1,95
	Heat transfer coefficient of the thermal envelope (weighted average)	W/m²K	0,39	0,86	0,69
	Efficiency of heating system	-	80	91	92
EEMs and energy savings quantification / economic feasibility	EEM based on improving the building envelope (e.g., thermal insulation of opaque envelope, windows substitution, etc.)	kWh/year, $kgCO_2$/year, €/year Payback	Improving floor insulation, adding solar panels	N.A.	Windows, facade, roof

5.2.1 Method 1

As in Austria, Method 1 provides two types of data; values directly provided by the method (extracted) and values which are calculated for evaluation purposes. As presented in the following figure (Figure 22) – which shows the number of current EPC outputs, the outputs extracted from the method and the total number of outputs (extracted and calculated) – , the number of Method 1 output values for each case study (BE-01, BE-02, BE-03) range from 4 to 20, while the EPC outputs lie between these two.

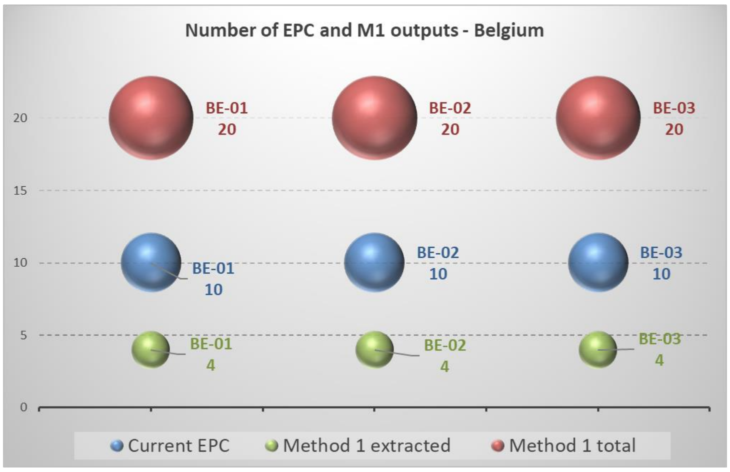


Figure 22: EPC and M1 outputs – Belgium

The values of Method 1 are presented in the figures below (Figure 23, Figure 24); these include Total primary energy use and CO_2 emissions. As noted above, these values have been calculated using the Belgian conversion factors.

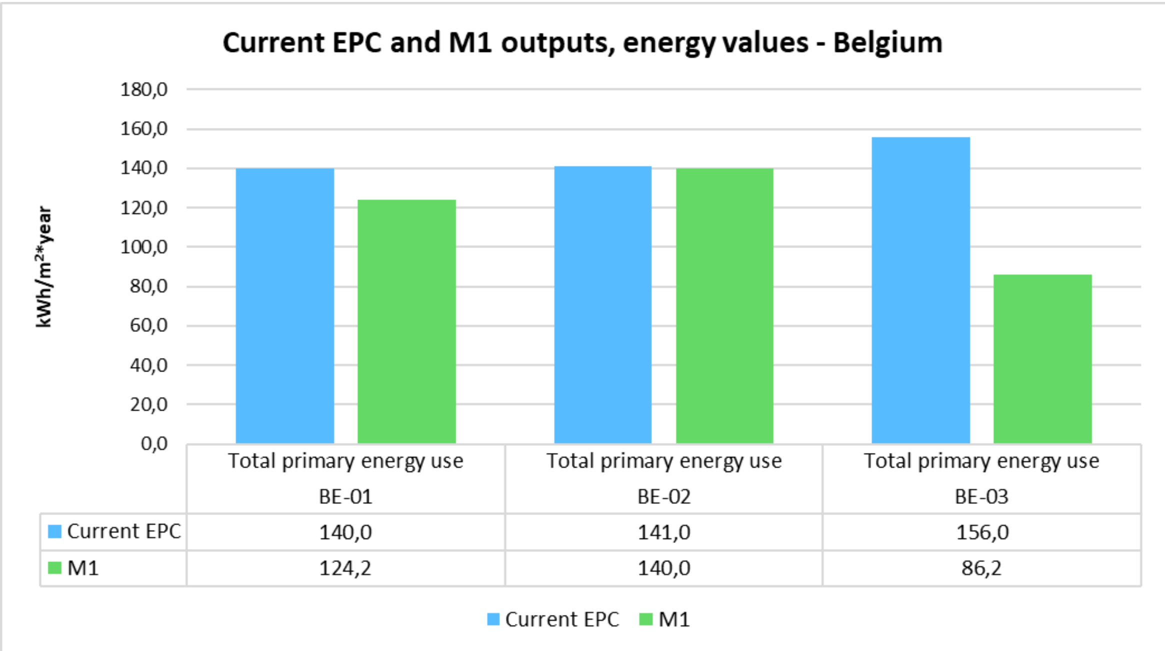


Figure 23: EPC and M1 energy values – Belgium

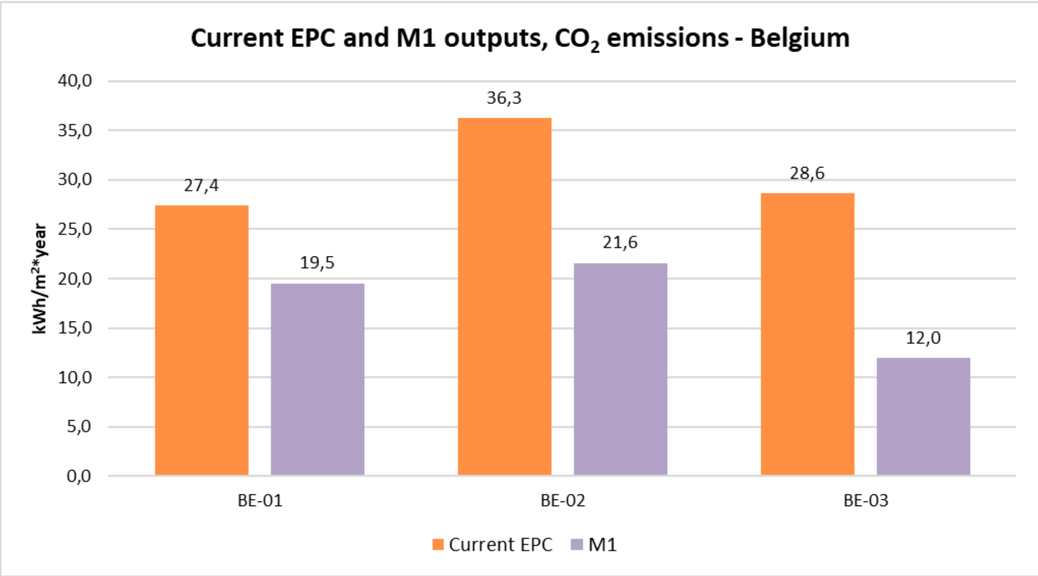


Figure 24: EPC and M1 CO_2 emissions – Belgium

It is shown that the total primary energy values of Method 1 are the same with those of the current EPC values for BE-02, close to current EPC values for BE-01 and almost half of current EPC values for BE-03. As regards CO_2 emissions, the values of the current EPC are double as much as those of Method 1 for BE-03 and close to those of Method 1 for BE-01 and BE-02.

5.2.2 Method 2

As described above for the Autrian case studies, the number of Method 2 outputs are the same for all case studies (BE-01, BE-02, BE-03) (Figure 25).

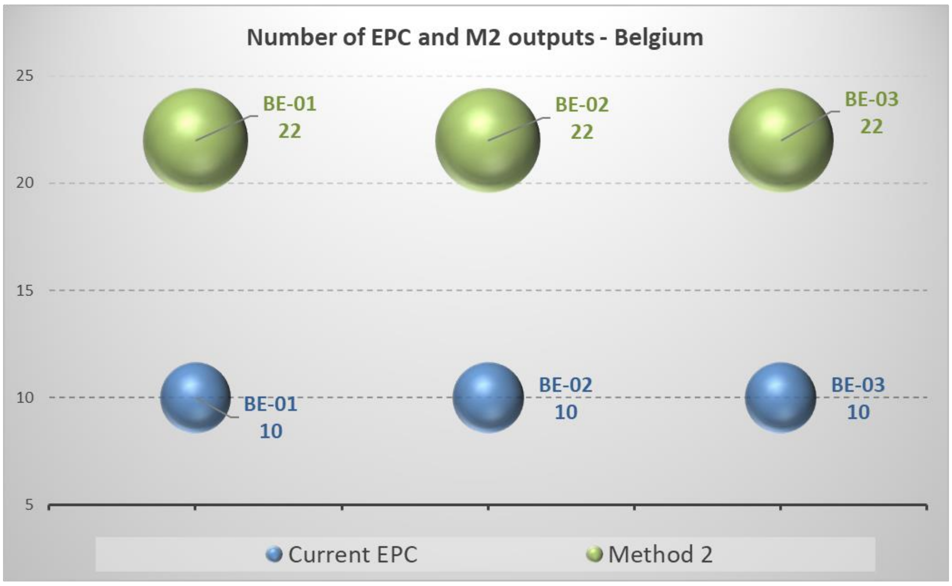


Figure 25: EPC and M2 outputs – Belgium

Method 2 values are presented in the figures below (Figure 26, Figure 27); these are Total primary energy use and CO_2 emissions.

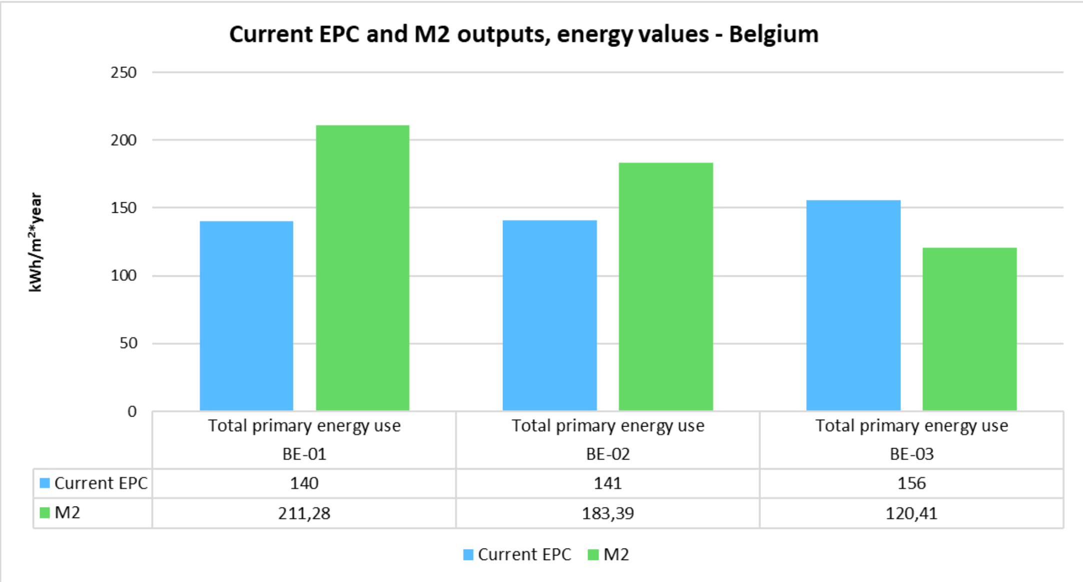


Figure 26: EPC and M2 energy values – Belgium

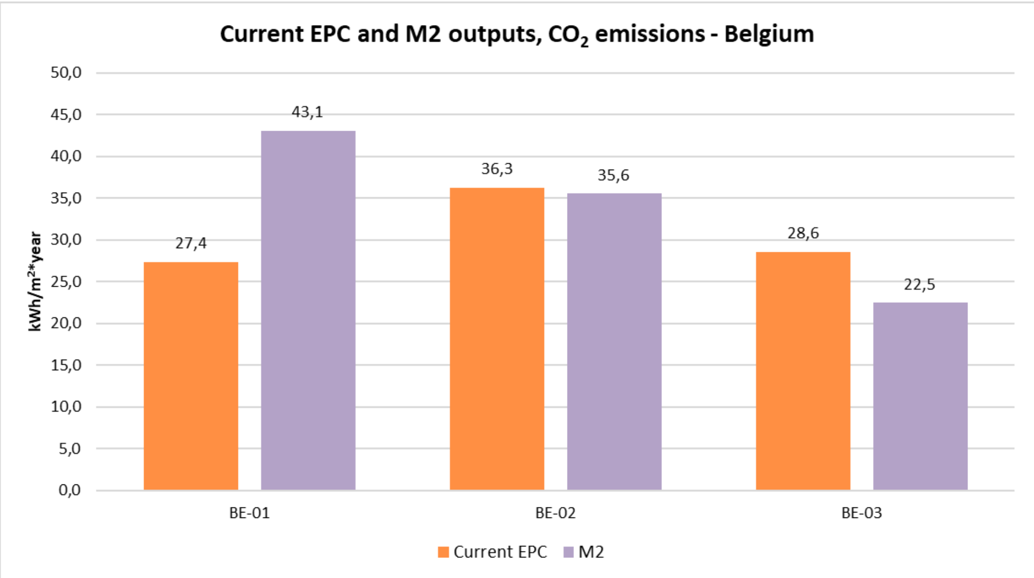


Figure 27: EPC and M2 CO_2 emissions – Belgium

Method 2 total primary energy values for BE-01 and BE-02 show a similar pattern, in contrast to the respective values for BE-03. Regarding CO_2 emissions, the Method 2 values for BE-02 are similar with those of the current EPC. The Method 2 values for BE-01 are higher than those of the current EPC values and the contrary implies for BE-03.

5.2.3 Method 3

Method 3 is the most complex method and provides more values than the other methods. The values are either directly provided by the method or calculated for evaluation purposes. The number of outputs of the three Method 3 options (CA, MA, MS) for each case study (BE-01, BE-02, BE-03) is presented in Figure 28.

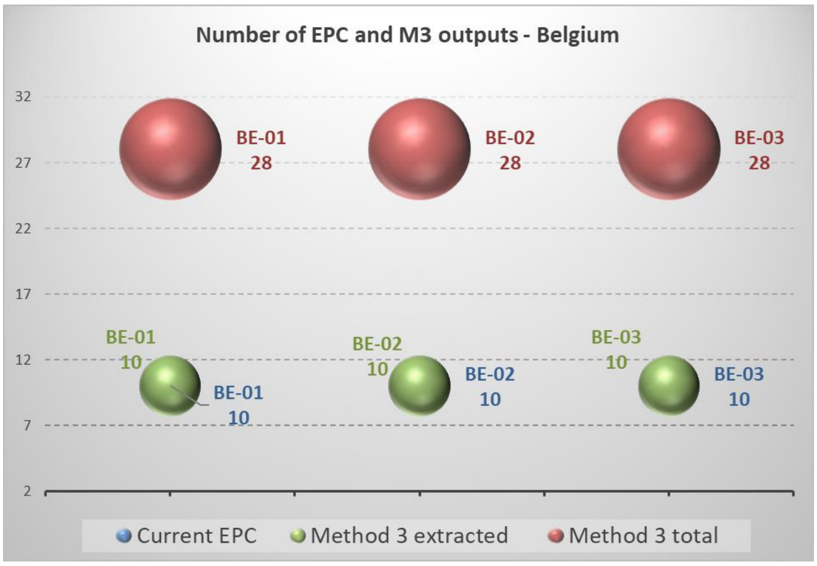
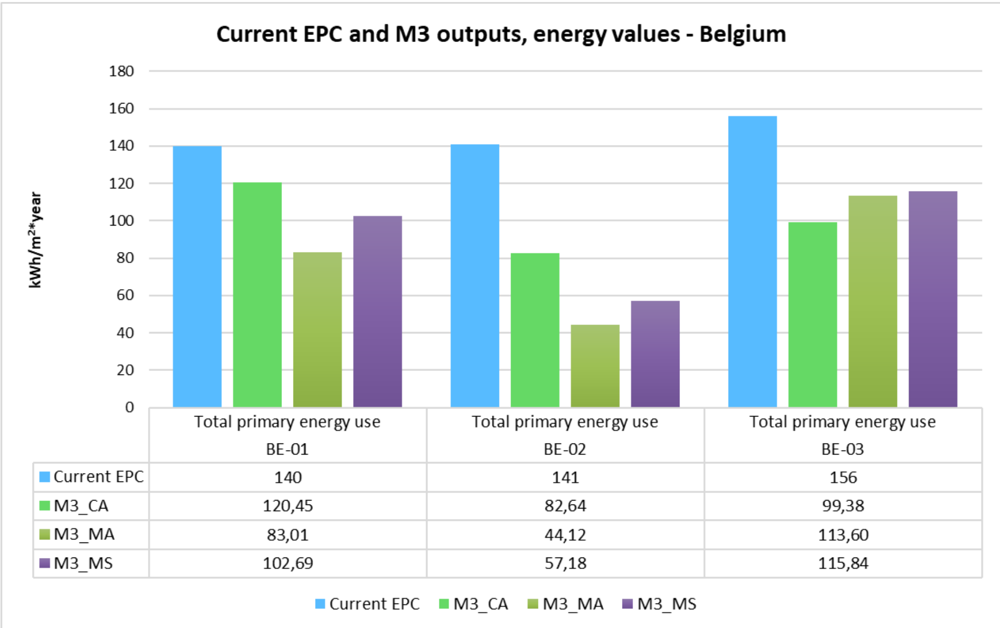


Figure 28: EPC and M3 outputs - Belgium

Figure 29, Figure 30 and Figure 31 present the values of Method 3 outputs compared with the current EPC ones.



	Total primary energy use BE-01	Total primary energy use BE-02	Total primary energy use BE-03
Current EPC	140	141	156
M3_CA	120,45	82,64	99,38
M3_MA	83,01	44,12	113,60
M3_MS	102,69	57,18	115,84

Figure 29: EPC and M3 energy values – Belgium

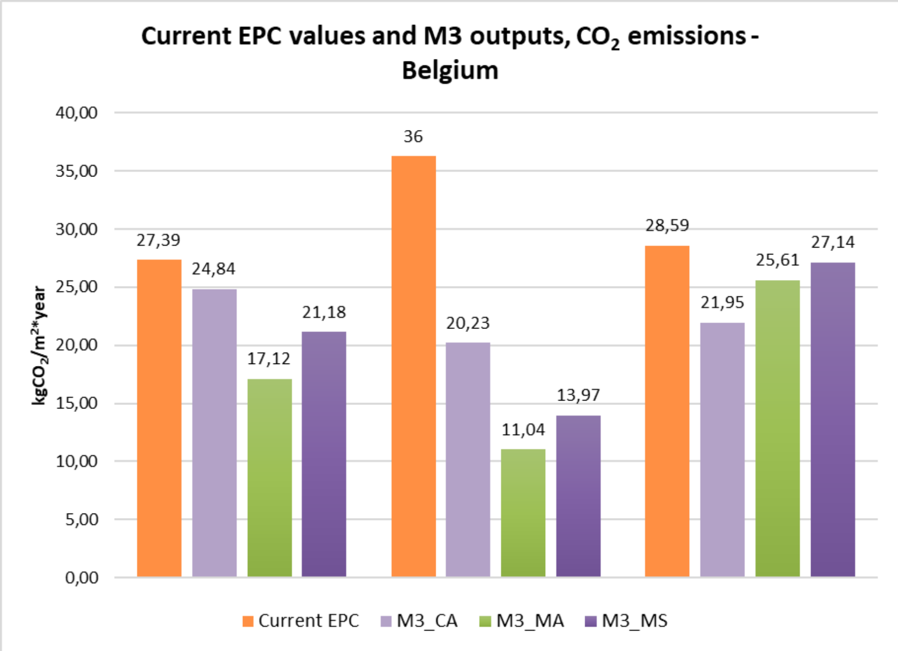
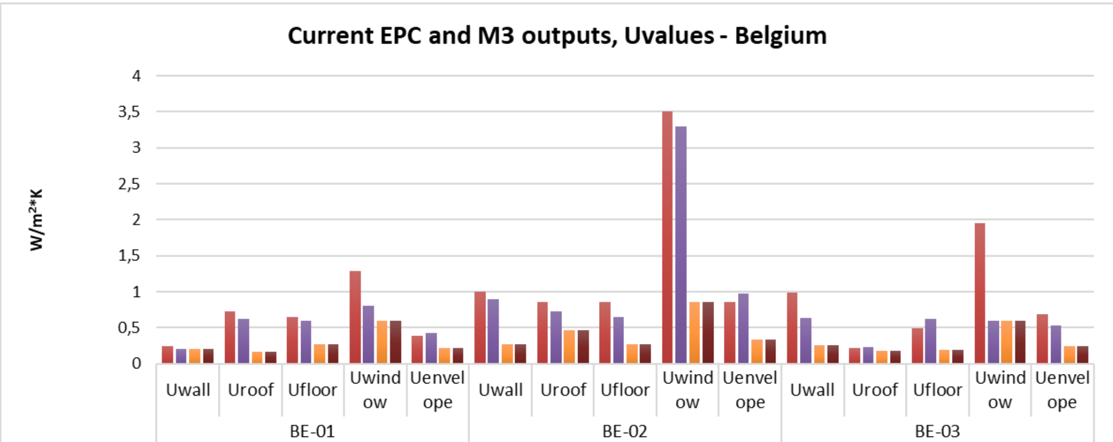


Figure 30: EPC and M3 CO_2 emissions – Belgium



	BE-01					BE-02					BE-03				
	Uwall	Uroof	Ufloor	Uwindow	Uenvelope	Uwall	Uroof	Ufloor	Uwindow	Uenvelope	Uwall	Uroof	Ufloor	Uwindow	Uenvelope
Current EPC	0,24	0,73	0,65	1,29	0,39	1	0,85	0,85	3,5	0,86	0,98	0,22	0,49	1,95	0,69
M3_CA	0,21	0,63	0,60	0,81	0,43	0,90	0,73	0,65	3,30	0,98	0,64	0,23	0,62	0,60	0,52
M3_MA	0,21	0,16	0,27	0,60	0,21	0,27	0,47	0,27	0,85	0,34	0,26	0,18	0,19	0,60	0,24
M3_MS	0,21	0,16	0,27	0,60	0,21	0,27	0,47	0,27	0,85	0,34	0,26	0,18	0,19	0,60	0,24

Figure 31: EPC and M3 U-values – Belgium

It is noticed that the values for the three case studies, as given in the three figures above, are similar or very close to each other; an exception to this being the U-values of the windows which, however, is not considered significant.

5.2.4 Country results

The following table (Table 17) shows the possible outputs provided by the Belgian EPC report and the ePANACEA assessment methods 1, 2 and 3. It is noted that there is a limited number of outputs which are common among the national EPC report and the three methods, except for Method 3 which is the most complex one and provides heat transfer values similar to those in the national EPC report. The total primary energy use and the GHG emissions are common for both the EPC report and the three ePANACEA methods.

Table 17: Current EPC and M1, M2, M3 outputs in Belgium

Category	Definition	Current EPC	M1	M2	M3_CA	M3_MA	M3_MS
Energy performance rating	Classification (label/class A-G)						
	Total primary energy use [kWh/m²year]	*(provided below) **					
Overall numerical indicators (main performance indicators)	*Total primary energy use (EPBD services) [kWh/m²year]		C	E	C	C	C
	Non-renewable primary energy use (EPBD services) [kWh/m²year]			E	C	C	C
	Renewable primary energy use (EPBD services) [kWh/m²year]			E			
	GHG emissions (EPBD services) [kgCO₂/m²year]		C	E	C	C	C
	Renewable energy ratio (EPBD services) [% or fraction (0-1)]			E			
	Total primary energy use (All services) [kWh/m²year]		C	E	C	C	C
	Non-renewable primary energy use (All services) [kWh/m²year]			E	C	C	C
	Renewable primary energy use (All services) [kWh/m²year]			E			
	GHG emissions (All services) [kgCO₂/m²year]		C	E	C	C	C
	Renewable energy ratio (All services) [% or fraction (0-1)]			E			
Partial indicators	Energy need for space heating [kWh/m²year]			E			
	Energy need for space cooling [kWh/m²year]			E			
	Energy use for heating [kWh/m²year]		E	E	E	E	E
	Energy use for DHW [kWh/m²year]		E	E	E	E	E
	Energy use for lighting [kWh/m²year]		E	E	E	E	E
	Energy use for other services [kWh/m²year]		E		E	E	E
	GHG emissions for heating [kgCO₂/m²year]		C	E	C	C	C
	GHG emissions for DHW [kgCO₂/m²year]		C	E	C	C	C
	GHG emissions for lighting [kgCO₂/m²year]		C	E	C	C	C
	GHG emissions for other services [kgCO₂/m²year]		C		C	C	C
	Non-renewable primary energy use for heating [kWh/m²year]		C	E	C	C	C
	Non-renewable primary energy use for DHW [kWh/m²year]		C	E	C	C	C
	Non-renewable primary energy use for lighting [kWh/m²year]		C	E	C	C	C
	Non-renewable primary energy use for other services[kWh/m²year]		C		C	C	C
	Total primary energy use for heating [kWh/m²year]		C	E	C	C	C
	Total primary energy use for DHW [kWh/m²year]		C	E	C	C	C
	Total primary energy use for lighting [kWh/m²year]		C	E	C	C	C
	Total primary energy use for other services [kWh/m²year]		C		C	C	C

Category	Definition	Current EPC	M1	M2	M3_CA	M3_MA	M3_MS
	Renewable primary energy use for heating [kWh/m²year]			E			
	Renewable primary energy use for DHW [kWh/m²year]			E			
	Renewable primary energy use for lighting [kWh/m²year]			E			
	Heat transfer coefficient of walls (weighted average) [W/m²K]				E	E	E
	Heat transfer coefficient of roofs (weighted average) [W/m²K]				E	E	E
	Heat transfer coefficient of floors (weighted average) [W/m²K]				E	E	E
	Heat transfer coefficient of windows (weighted average) [W/m²K]				E	E	E
	Heat transfer coefficient of the thermal envelope (weighted average) [W/m²K]				E	E	E
	SHGC of windows (weighted average) [fraction (0-1)]				E	E	E
	Efficiency of heating system [fraction (0-1)]						
EEMs and energy saving quantification/economic feasibility	EEM based on improving building envelope (e.g., thermal insulation of opaque envelope, windows substitution…) [kWh/year, $kgCO_2$/year, €/year Payback]						

C: Calculated, E: Extracted

In terms of quantitative analysis as seen in Figure 32, the Method 3 energy values of the Belgian case studies are lower than the ones of the national EPC report. The deviation rate for the total primary energy use of Method 1 from the national EPC report is approx. 25%, of Method 2 35% and of Method 3 38%, respectively.

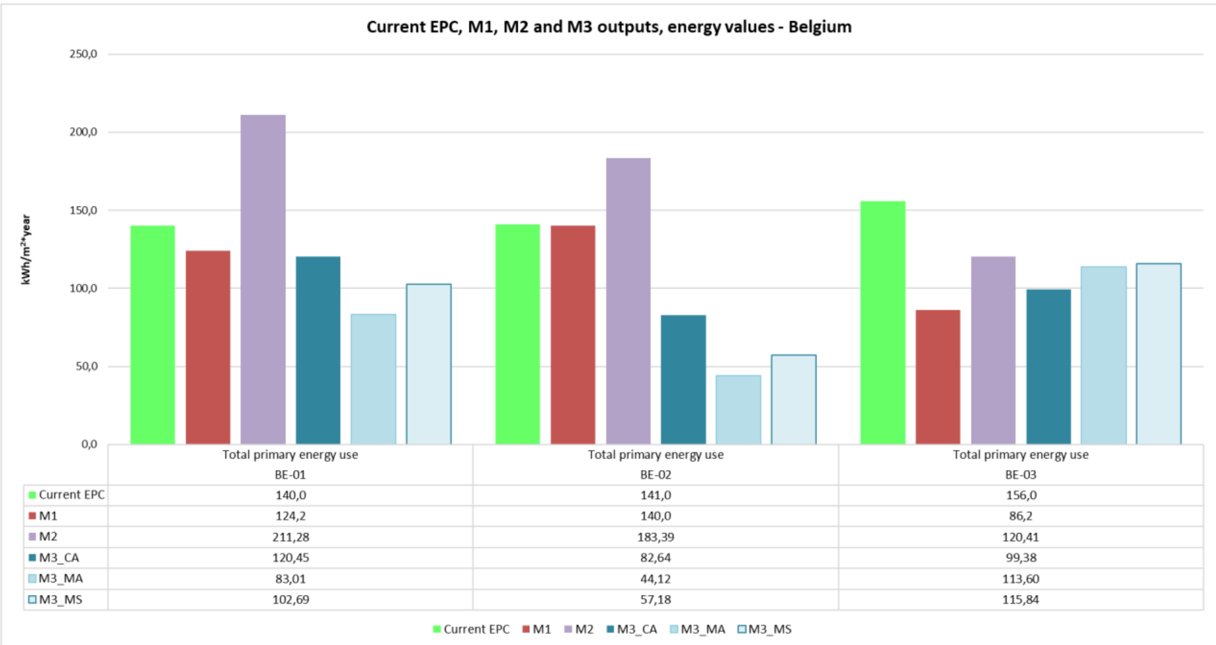


Figure 32: EPC and M1, M2, M3 energy values – Belgium

5.3 Finland

Based on the current EPC scheme in Finland, the main performance indicator is the non-renewable primary energy use (PEnonren in kWh/m²year) and also the energy classification of the building. As partial indicators are considered the energy need for space heating and cooling. Indicators based on energy use, i.e., energy use for heating, cooling, DHW, ventilation, other services and the electricity from RES used on-site, are displayed on the EPC report. There are partial indicators based on the characteristics of the building envelope and the technical building systems, specifically, the heat transfer coefficient of walls, roofs, floors and windows as well as the SHGC of windows. As regards technical systems, the Finnish EPC report displays the efficiency of the heating, DHW and cooling systems. All values are calculated based on the national assessment methodology.

Table 18 presents the current EPC data for the Finnish case studies (FI-01, FI-02, and FI-03), which are one office building, and two educational buildings. The total number of outputs displayed on the EPC report is 21 for FI-01, and 20 for FI-02 and FI-03 due to the absence of a cooling system.

Table 18: Current EPC report outputs in Finland

Category	Definition	Units	FI-01	FI-02	FI-03
Energy performance rating	Classification (label/class A-G)	-	A2018	B2018	B2013
	Non-renewable primary energy use	kWh/m²year	62	99	130
Partial indicators	Energy need for space heating	kWh/m²year	11	81	71
	Energy need for space cooling	kWh/m²year	6	no cooling	no cooling
	Energy use for heating	kWh/m²year	9,1	73,3	65,1
	Energy use for cooling	kWh/m²year	6,5	no cooling	no cooling
	Energy use for DHW	kWh/m²year	9	20,2	20,5
	Energy use for ventilation	kWh/m²year	3,3	17,5	12,8
	Energy use for other services	kWh/m²year	32,9	27,5	19,7
	Electric energy from RES used on-site	kWh/year	32.319	20.000	32.933
	Heat transfer coefficient of walls (weighted average)	W/m²K	0,13	0,19	0,17
	Heat transfer coefficient of roofs (weighted average)	W/m²K	0,1	0,12	0,21
	Heat transfer coefficient of floors (weighted average)	W/m²K	0,09	0,2	0,29
	Heat transfer coefficient of windows (weighted average)	W/m²K	0,8	1,07	1
	SHGC of windows (weighted average)	fraction (0-1)	0,36	0,6	0,62
	Efficiency of heating system: Heating production	-	0,97	0,97	0,97
	Efficiency of heating system: distribution	-	0,9	0,86	0,9

	Efficiency of heating system: Heat recovery efficiency	-	0,78	0,6	0,71
	Efficiency of DHW system: production	-	0,97	0,97	0,97
	Efficiency of DHW system: distribution	-	0,85	0,89	0,86
	Efficiency of cooling system	-	1	no cooling	no cooling

5.3.1 Method 1

As mentioned above, Method 1 uses OBM data which is entered into the SEPAP tool by the user. The method provides two types of values; i.e., values directly provided by the method (extracted) and values which are calculated for evaluation purposes. The following figure (Figure 33) presents the number of current Finnish EPC outputs, the number of outputs extracted from Method 1 and the total number of outputs of Method 1 (extracted and calculated) of each case study (FI-01, FI-02, FI-03). The number of Method 1 values ranges from 5 to 17, while the EPC number of outputs is 20 to 21.

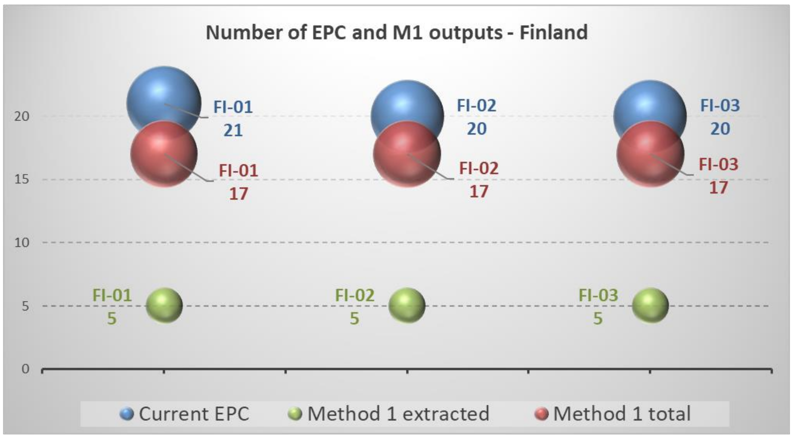


Figure 33: EPC and M1 outputs - Finland

Method 1 values are presented in the figures below (Figure 34, Figure 35); these include Non-renewable primary energy use, Energy use for heating, cooling, DHW and other services. Based on the Finnish regulation, the Non-renewable primary energy use is calculated since the corresponding weighting factors are used (as defined in EN ISO 52000-1:2017).

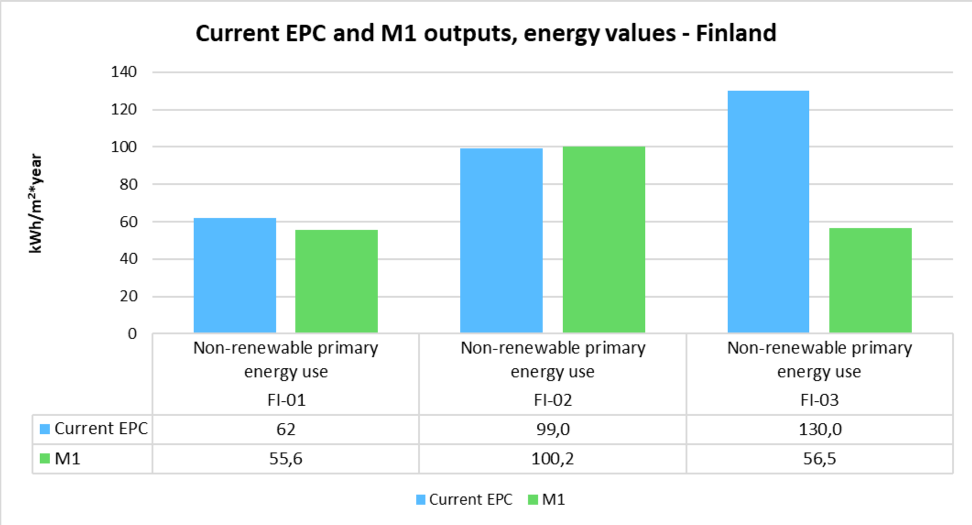


Figure 34: EPC and M1 energy values – Finland

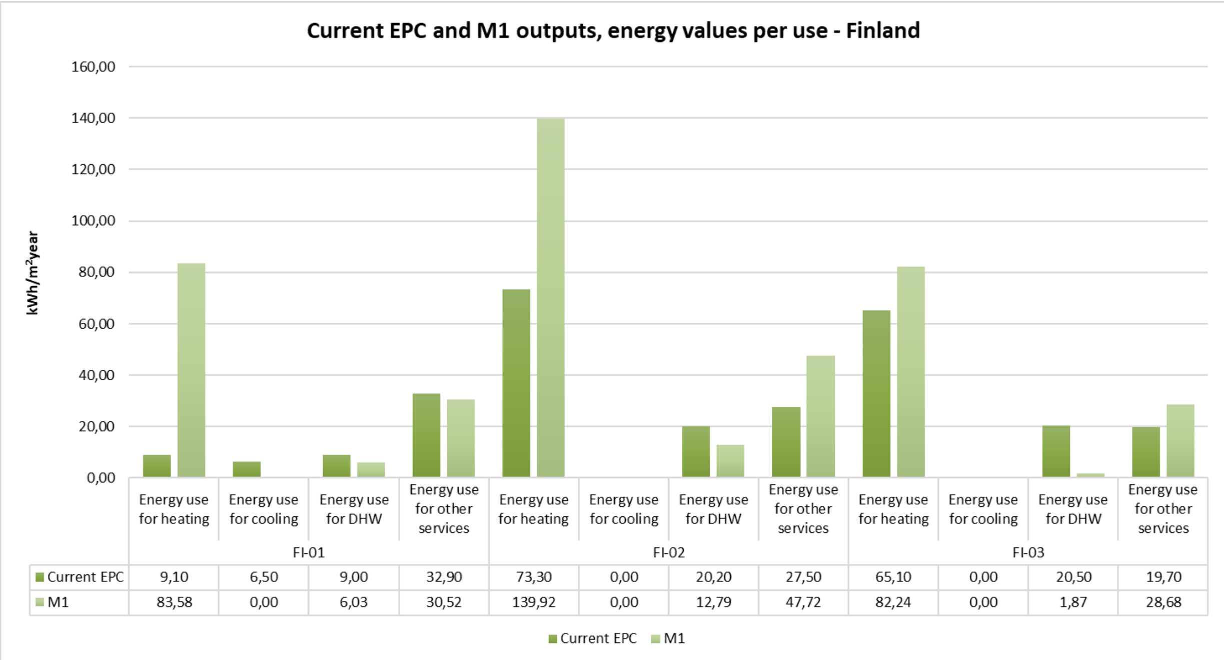


Figure 35: EPC and M1 energy values per energy use– Finland

Although the Non-renewable primary energy use outputs of Method 1 for FI-01 and FI-02 are almost the same with those of the current EPC outputs, the values for Energy use for heating are higher than the current EPC values.

5.3.2 Method 2

The number of outputs of Method 2, which are directly taken from the SEPAP tool, are shown in Figure 36. It is seen that the outputs of the current EPC report and Method 2 are 20 to 21 and 22, respectively.

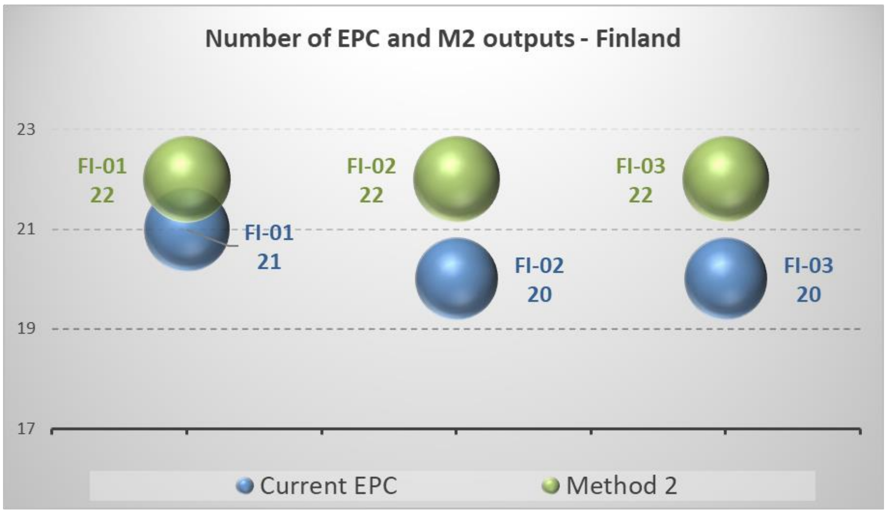
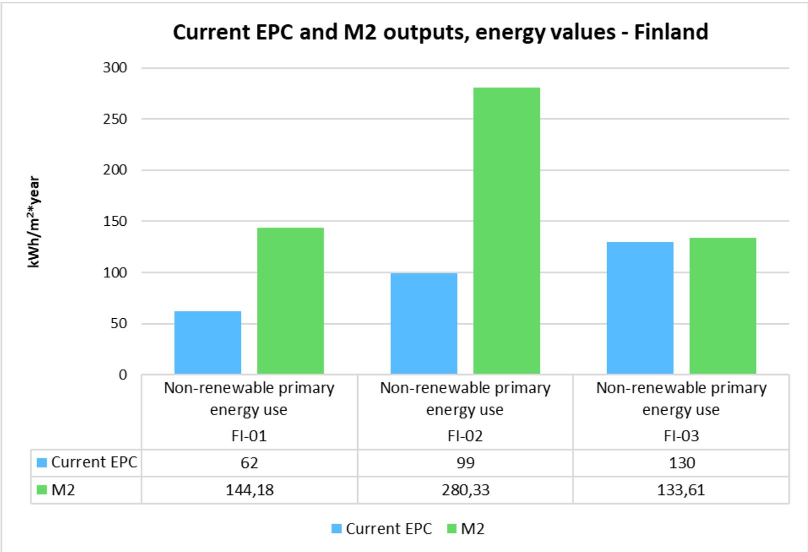


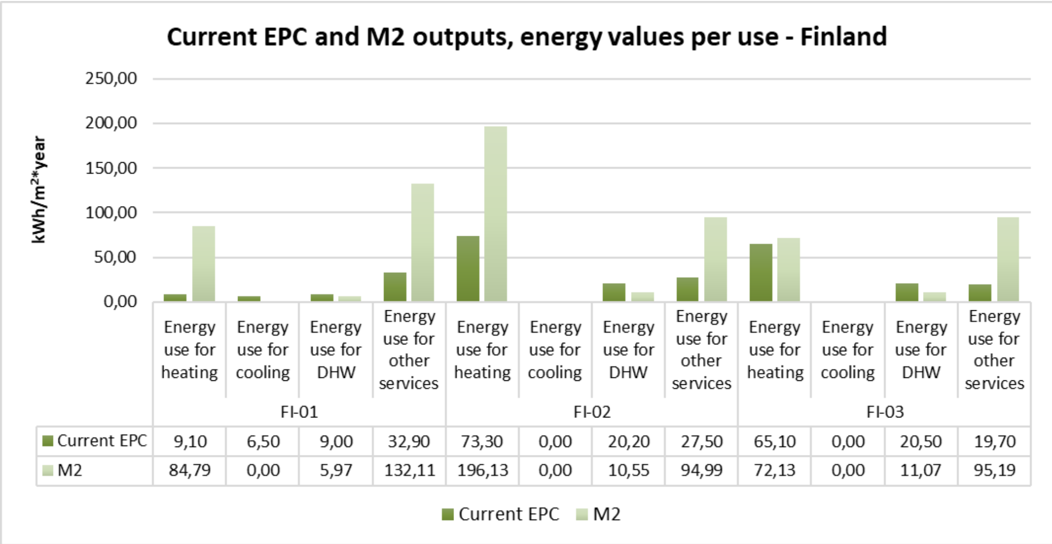
Figure 36: EPC and M2 outputs - Finland

Figure 37 presents the Non-renewable primary energy use values of Method 2 and Figure 38 shows the energy values per use for each case study.



	Non-renewable primary energy use FI-01	Non-renewable primary energy use FI-02	Non-renewable primary energy use FI-03
Current EPC	62	99	130
M2	144,18	280,33	133,61

Figure 37: EPC and M2 energy values – Finland



	FI-01				FI-02				FI-03			
	Energy use for heating	Energy use for cooling	Energy use for DHW	Energy use for other services	Energy use for heating	Energy use for cooling	Energy use for DHW	Energy use for other services	Energy use for heating	Energy use for cooling	Energy use for DHW	Energy use for other services
Current EPC	9,10	6,50	9,00	32,90	73,30	0,00	20,20	27,50	65,10	0,00	20,50	19,70
M2	84,79	0,00	5,97	132,11	196,13	0,00	10,55	94,99	72,13	0,00	11,07	95,19

Figure 38: EPC and M2 energy values per energy use - Finland

The above figures show similar energy values with the current EPC only for FI-03, in contrast to the corresponding values of FI-01 and FI-02. As regards the energy values per use, they are very different, especially the energy use for heating.

5.3.3 Method 3

The outputs of the three Method 3 options (CA, MA, MS) of each case study (FI-01, FI-02, FI-03) are presented in Figure 39. It is obvious that the total number of outputs of Method 3 are more than those of the current Finnish EPC report.

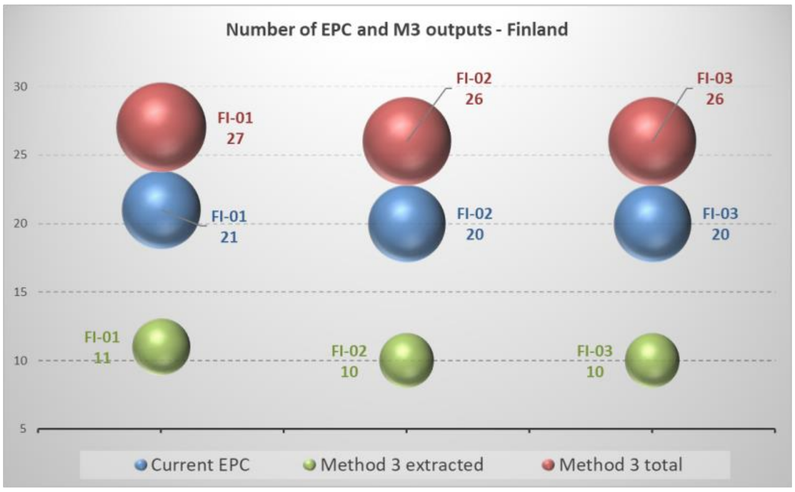


Figure 39: EPC and M3 outputs - Finland

Figure 40 and Figure 41 present the values of Method 3 outputs compared with the current EPC ones.

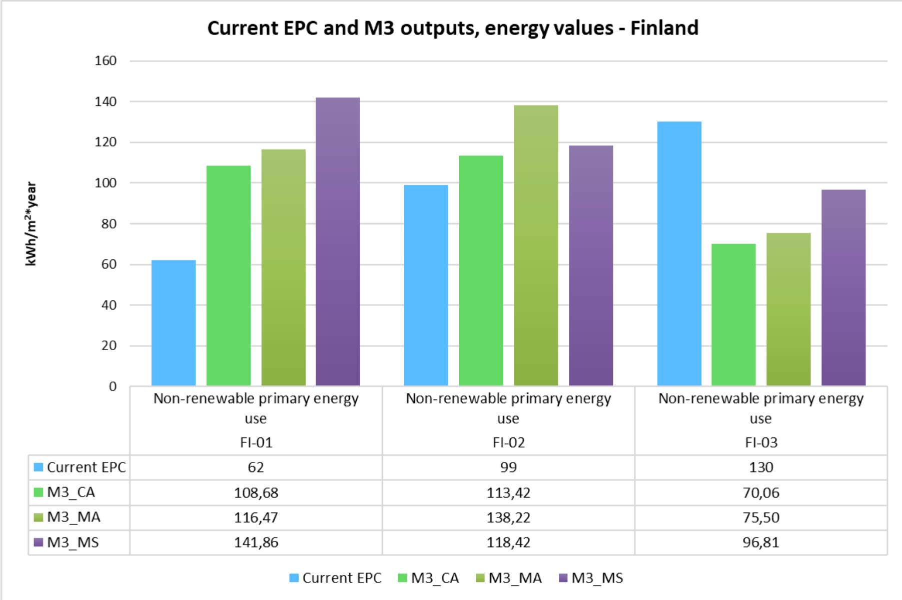


Figure 40: EPC and M3 energy values – Finland

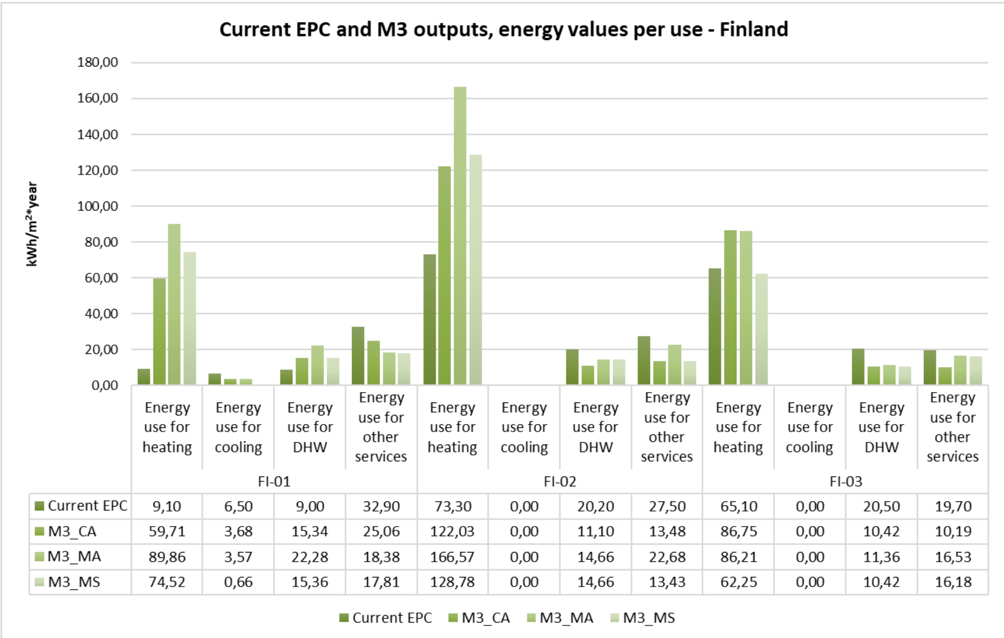


Figure 41: EPC and M3 energy values per energy use – Finland

The energy use for heating as calculated in Method 3 is higher than the EPC report's value and especially the M3_MA values; this is in contrast to the energy use for other services, where the current EPC value is the highest compared with the methodology options (CA, MA, MS) of Method 3.

5.3.4 Country results

The following table (Table 19) shows the possible outputs provided by the Finnish EPC report and the ePANACEA assessment methods 1, 2 and 3. According to the Finnish regulation, the calculated values concern the Non-renewable primary energy use.

As regards Method 2 which only has extracted values, it provides values for non-renewable, total and renewable primary energy use due to the ePANACEA methodology using common factors for all pilot countries. It is noted that Method 1 provides less values than the EPC (21 and 17, respectively).

Table 19: Current EPC and M1, M2, M3 outputs in Finland

Category	Definition	Current EPC	M1	M2	M3_CA	M3_MA	M3_MS
Energy performance rating	Classification (label/class A-G)						
	Non-renewable primary energy use [kWh/m²year]	*(provided below) **					
Overall numerical indicators (main performance indicators)	Total primary energy use (EPBD services) [kWh/m²year]			E			
	*Non-renewable primary energy use (EPBD services) [kWh/m²year]		C	E	C	C	C
	Renewable primary energy use (EPBD services) [kWh/m²year]			E	C	C	C
	GHG emissions (EPBD services) [$kgCO_2/m^2year$]		C	E	C	C	C
	Renewable energy ratio (EPBD services) [% or fraction (0-1)]		C		C	C	C
	Non-renewable primary energy use (All services) [kWh/m²year]		C		C	C	C
	GHG emissions (All services) [$kgCO_2/m^2year$]		C		C	C	C
Partial indicators	Energy need for space heating [kWh/m²year]			E			
	Energy need for space cooling [kWh/m²year]			E			
	Energy use for heating [kWh/m²year]		E	E	E	E	E
	Energy use for cooling [kWh/m²year]		E	E	E	E	E
	Energy use for DHW [kWh/m²year]		E	E	E	E	E
	Energy use for lighting [kWh/m²year]		E	E	E	E	E
	Energy use for ventilation [kWh/m²year]				E	E	E
	Energy use for other services [kWh/m²year]		C	E	E	E	E
	Electric energy from RES used on-site [kWh/year, kWh/m²year]						
	GHG emissions for heating [$kgCO_2/m^2year$]		C	E	C	C	C
	GHG emissions for cooling [$kgCO_2/m^2year$]				C	C	C
	GHG emissions for DHW [$kgCO_2/m^2year$]		C	E	C	C	C
	GHG emissions for lighting [$kgCO_2/m^2year$]		C	E	C	C	C
	GHG emissions for ventilation [$kgCO_2/m^2year$]				C	C	C
	GHG emissions for other services [$kgCO_2/m^2year$]		C		C	C	C
	Non-renewable primary energy use for heating [kWh/m²year]		C	E	C	C	C
	Non-renewable primary energy use for cooling [kWh/m²year]				C	C	C
	Non-renewable primary energy use for DHW [kWh/m²year]		C	E	C	C	C
	Non-renewable primary energy use for lighting [kWh/m²year]		C	E	C	C	C
	Non-renewable primary energy use for ventilation [kWh/m²year]				C	C	C

Category	Definition	Current EPC	M1	M2	M3_CA	M3_MA	M3_MS
	Non-renewable primary energy use for other services[kWh/m2year]		C		C	C	C
	Total primary energy use for heating[kWh/m2year]			E			
	Total primary energy use for cooling[kWh/m2year]						
	Total primary energy use for DHW [kWh/m2year]			E			
	Total primary energy use for lighting [kWh/m2year]			E			
	Renewable primary energy use for heating [kWh/m2year]			E			
	Renewable primary energy use for cooling [kWh/m2year]						
	Renewable primary energy use for DHW [kWh/m2year]			E			
	Renewable primary energy use for lighting [kWh/m2year]			E			
	Heat transfer coefficient of walls (weighted average) [W/m2K]				E	E	E
	Heat transfer coefficient of roofs (weighted average) [W/m2K]				E	E	E
	Heat transfer coefficient of floors (weighted average) [W/m2K]						
	Heat transfer coefficient of windows (weighted average) [W/m2K]				E	E	E
	SHGC of windows (weighted average) [fraction (0-1)]				E	E	E
	Efficiency of heating system						
	Efficiency of DHW system						
	Efficiency of cooling system						

C: Calculated, E: Extracted

In terms of quantitative analysis as seen in Figure 42, the Method 1 energy values for FI-01 and FI-02 are close to the ones of the national EPC report (deviation rates of 10% and 1%, respectively). Method 2 provides similar values with the current EPC only for FI-03 (deviation rate of 3%).

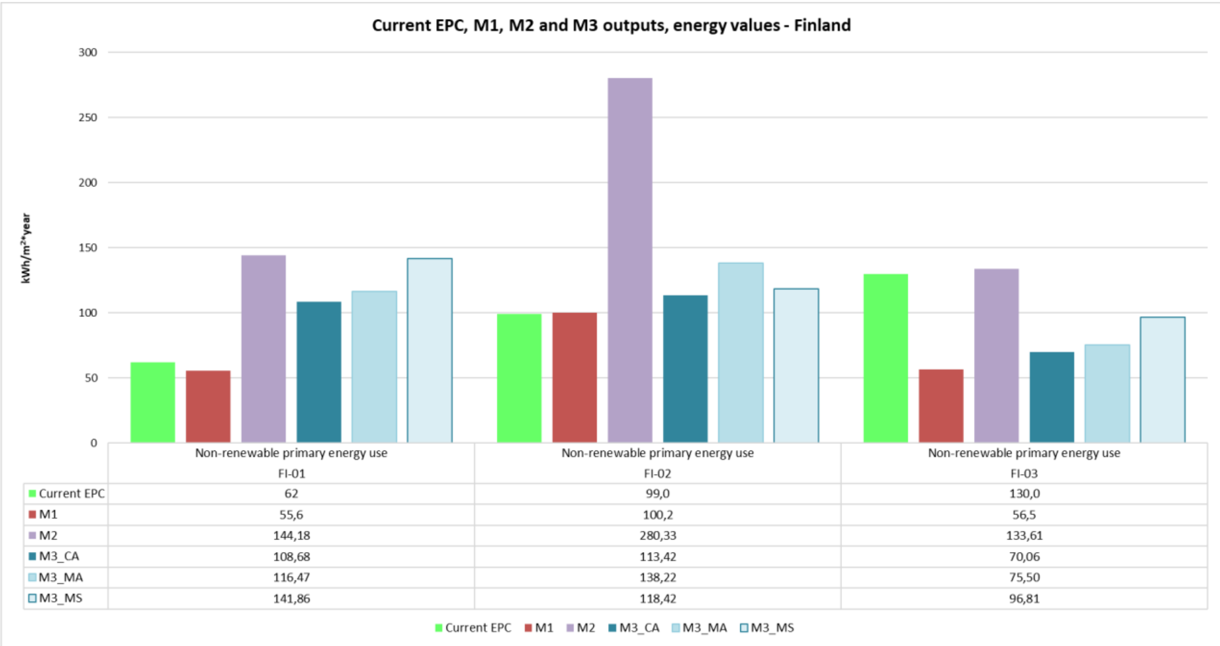


Figure 42: EPC and M1, M2, M3 energy values – Finland

5.4 Greece

In Greece, based on the current EPC scheme, the main performance indicator is the total primary energy use (PEtot in kWh/m^{2}year) and the energy classification of the building. The overall energy performance is represented by the Greenhouse Gas emissions (GHG) in kgCO_2/m^{2}year. There are partial indicators which are based on the energy need, i.e., energy need for space heating and cooling, and those which are based on the energy use, i.e., energy use for heating, cooling, DHW and (only for non-residential buildings) lighting. The electricity from RES used on-site is also provided. Energy saving recommendations (i.e., the investment cost, the energy saving in kWh/m^2, €/kWh, %, CO_2 emissions reduction, payback period, potential energy category) can be presented on the EPC report. The actual consumption data for electricity and thermal energy are also optional, as are comfort and other indoor environmental quality parameters (e.g., thermal comfort, acoustics, lighting and air quality) that are provided only through a tick-box based on the subjective evaluation of the EPC assessor. The total number of outputs displayed on the EPC reports of the Greek cases varies - depending on the building type (residential or non-residential) - and ranges between 13 and 14.

The table below (*Table 20*) presents the current EPC data for the Greek case studies (GR-01, GR-02, and GR-03), which are an apartment, an office building, and a municipal office building.

Table 20: Current EPC report outputs in Greece

Category	Definition	Units	GR-01	GR-02	GR-03
Energy performance rating	Classification (label/class A-G)	-	C	B	D
	Total primary energy use	kWh/m^{2}year	197,6	170,8	369,0
Overall numerical indicators	GHG emissions	kgCO_2/m^{2}year	49,9	58,3	120,9

Partial indicators	Energy need for space heating	kWh/m²year	87,8	19,2	13,6
	Energy need for space cooling	kWh/m²year	33,8	47,2	83,4
	Energy use for heating	kWh/m²year	158,1	16,4	31,9
	Energy use for cooling	kWh/m²year	4,7	16,5	55,1
	Energy use for DHW	kWh/m²year	2,9	0	0
	Energy use for lighting	kWh/m²year	0	27,8	59,5
	Electric energy from RES used on-site	kWh/m²year	0	1,8	0

5.4.1 Method 1

As presented in the following figure (Figure 43) – which shows the number of current EPC outputs, the number of outputs extracted from the method and the total number of outputs (extracted and calculated) - , the Method 1 output values for each case study (GR-01, GR-02, GR-03) vary from 4 to 19, while the EPC output values lie between those two.

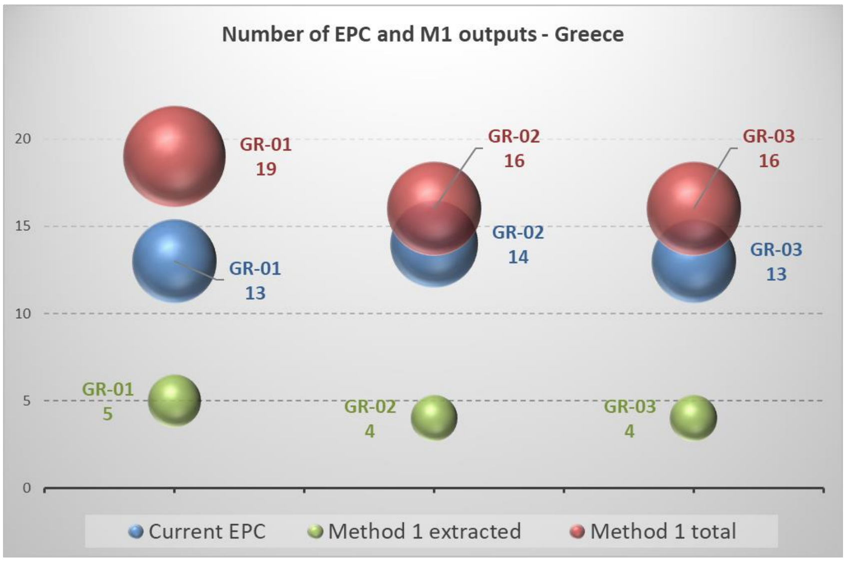


Figure 43: EPC and M1 outputs – Greece

The values of Method 1 are presented in the figures below (Figure 44, Figure 45); these concern Total primary energy use and CO_2 emissions. As noted above, these values have been calculated using the Greek conversion factors (primary and CO_2). The calculation of the energy use for both heating and cooling is not provided by a single model. Therefore, it was necessary to run two models taking into account different measurement periods, one for summer and one for winter.

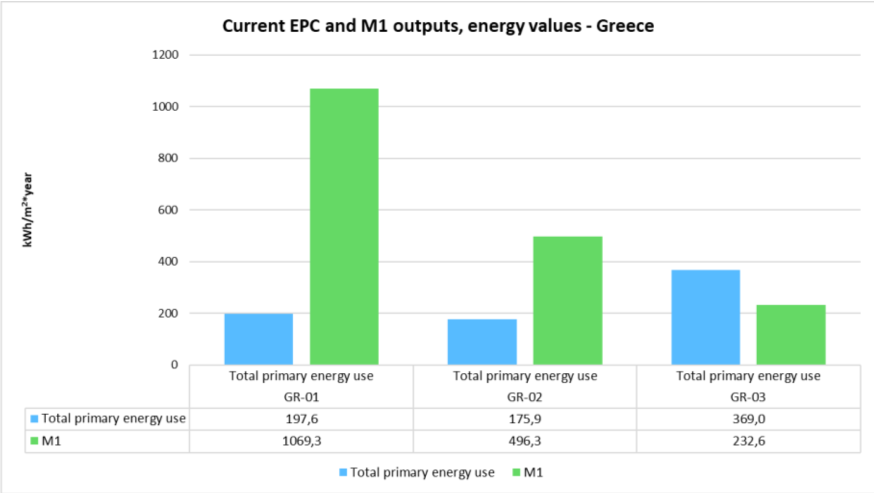


Figure 44: EPC and M1 energy values – Greece

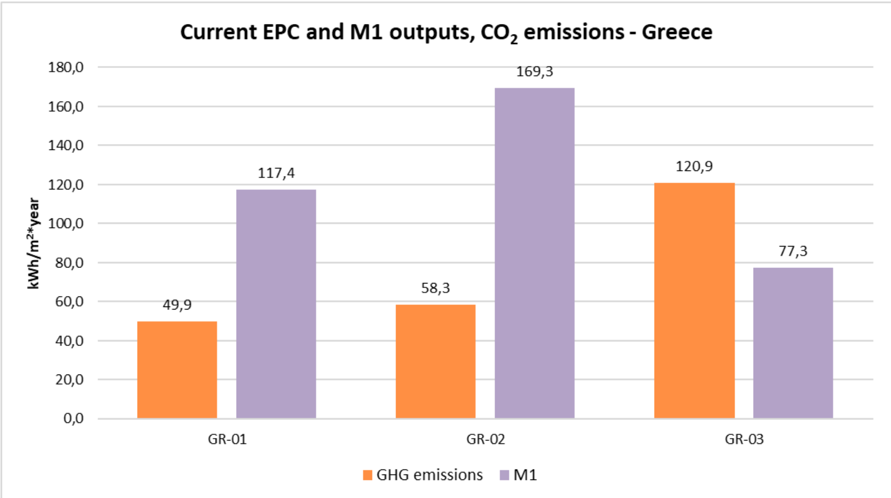


Figure 45: EPC and M1 CO_2 emissions – Greece

It is shown that the total primary energy values of Method 1 have significant deviations from the current EPC values due to the inadequacy of the methodology to calculate energy use both for heating and cooling in one model; the values are thus considered out of range, especially for GR-01. As regards the CO_2 emissions, the deviation differs probably due to the different conversion factors depending on the fuel type (i.e., oil, electricity, natural gas).

5.4.2 Method 2

As seen in the figure below (Figure 46), the number of Method 2 outputs is higher than the EPC ones for all case studies (GR-01, GR-02, GR-03).

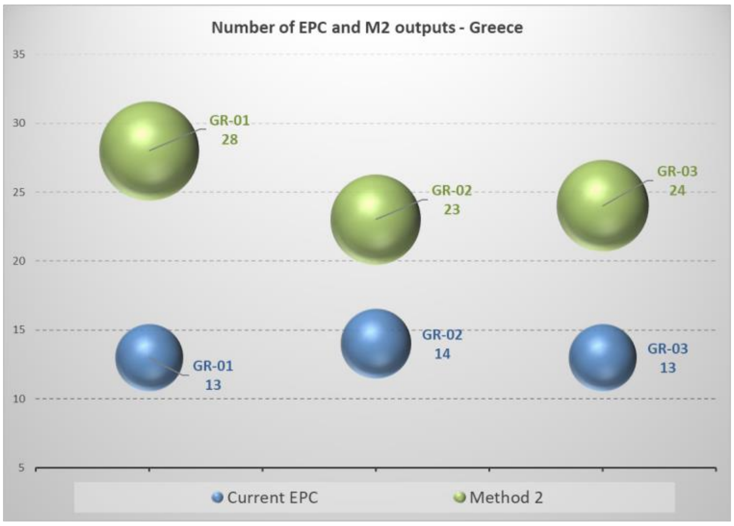
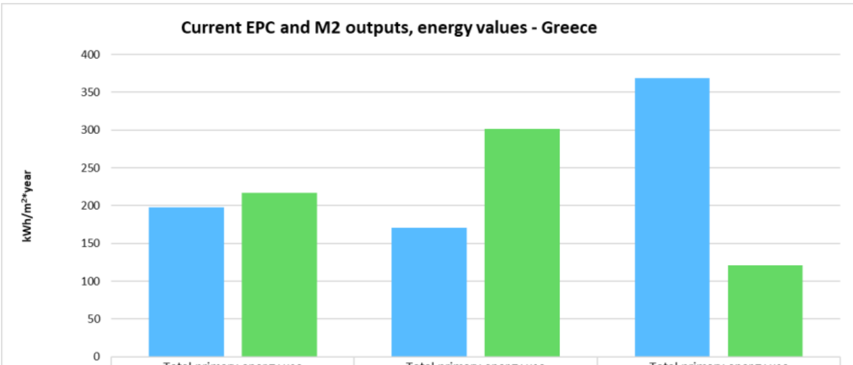


Figure 46: EPC and M2 outputs – Greece

Method 2 results are presented in the figures below (Figure 47, Figure 48); these are Total primary energy use and CO_2 emissions.



	Total primary energy use GR-01	Total primary energy use GR-02	Total primary energy use GR-03
Current EPC	197,6	170,8	369
M2	217,10	301,18	120,61

Figure 47: EPC and Method 2 energy values – Greece

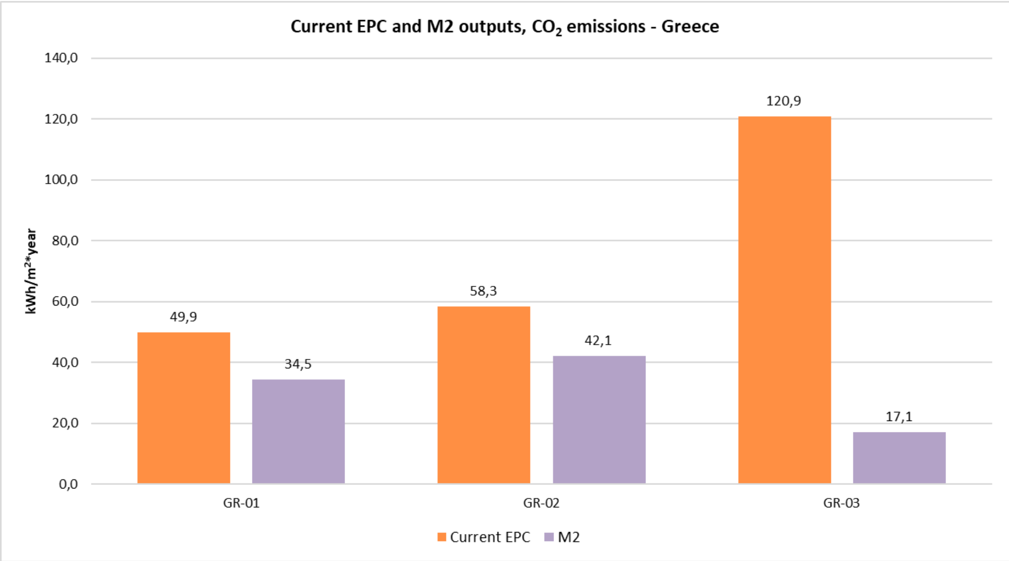


Figure 48: EPC and M2 CO_2 emissions – Greece

It is shown that the total primary energy values of Method 2 and the EPC for GR-01 are close; in contrast, for GR-02 the Method 2 values are higher and for GR-03 the Method 2 values are lower. This is probably due to the different conversion factors taken into account for the calculations in the Greek EPC against the respective ones used in Method 2. For the same reason, there are differences in the CO_2 emissions.

5.4.3 Method 3

In the complex Method 3, the values are provided either directly by the method or calculated for evaluation purposes. The number of outputs of the three Method 3 options (CA, MA, MS) for each case study (GR-01, GR-02, GR-03) is presented in Figure 49.

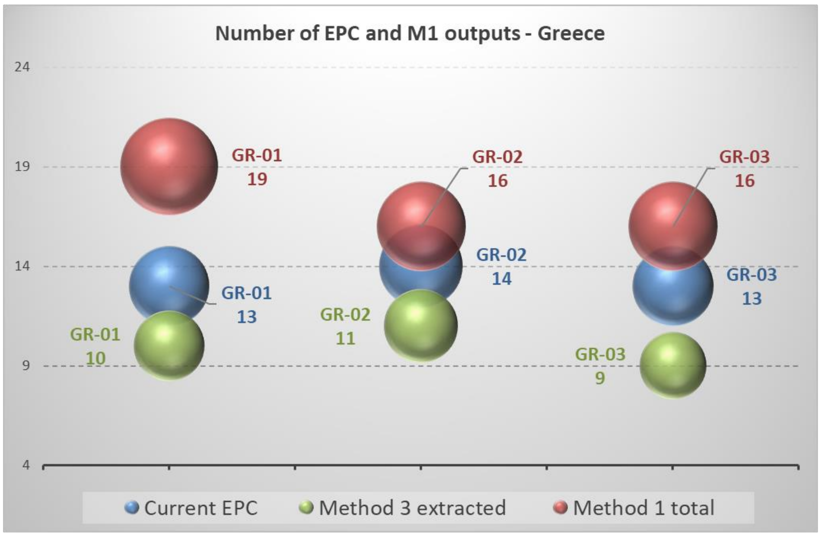
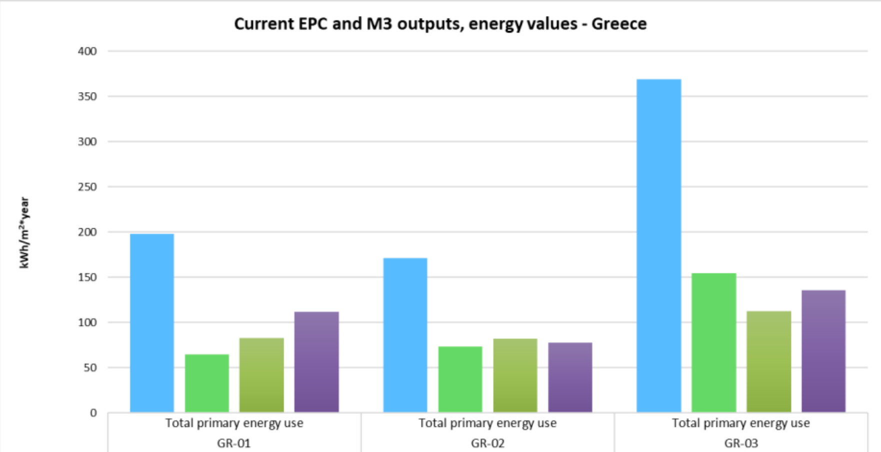


Figure 49: EPC and M3 outputs - Greece

Figure 50, Figure 51 and Figure 52 present the values of Method 3 outputs compared with the current EPC ones.



	Total primary energy use GR-01	Total primary energy use GR-02	Total primary energy use GR-03
Current EPC	197,6	170,8	369
M3_CA	64,73	72,98	154,70
M3_MA	82,57	82,34	112,57
M3_MS	111,70	77,48	135,44

Figure 50: EPC and M3 energy values – Greece

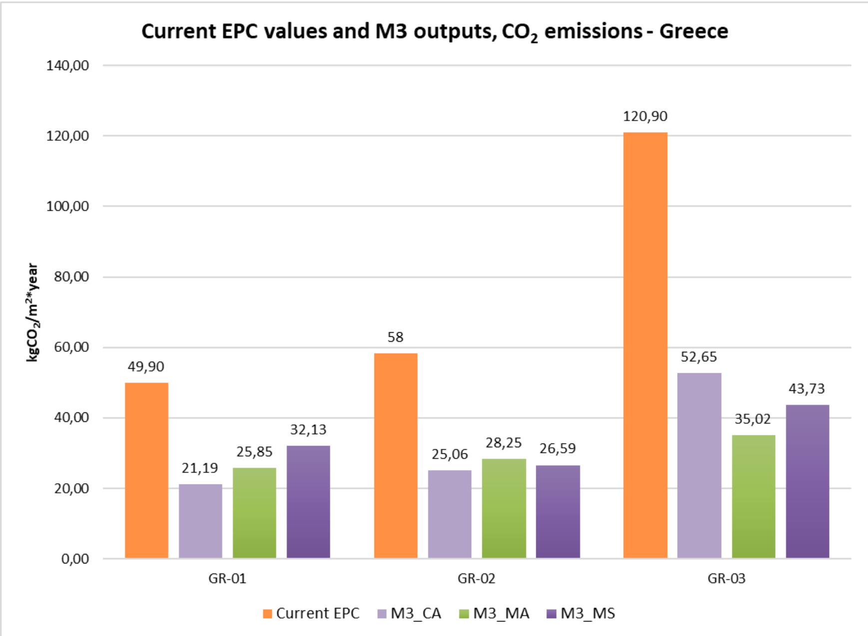


Figure 51: EPC and M3 CO_2 emissions – Greece

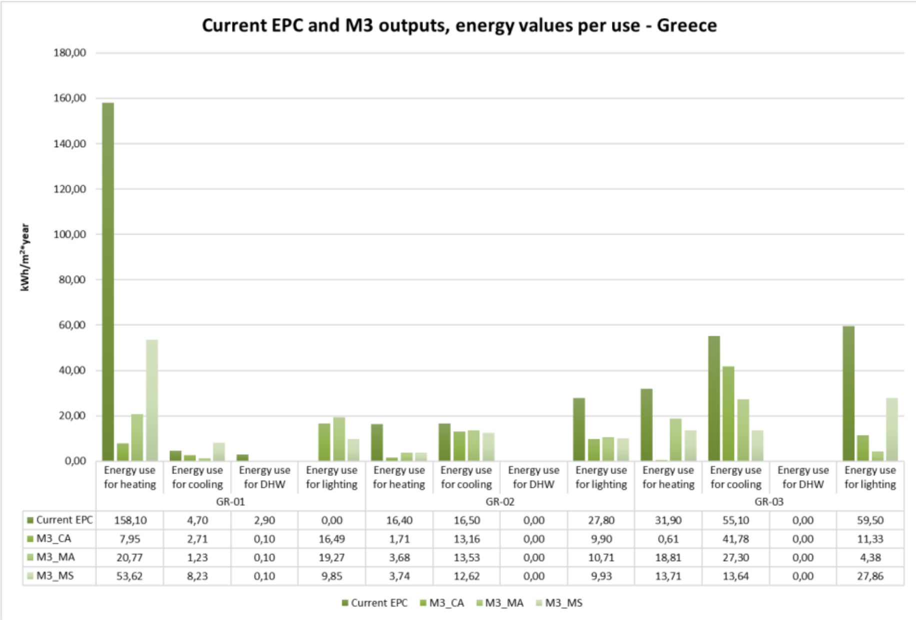


Figure 52: EPC and M3 energy values per use – Greece

It is noticed that the values of the current EPC are higher than the ones' of the three Method 3 methodology options. The difference between the EPC values and the corresponding values of Method 3 is probably due to the fact that, according to the national energy assessment, building operation and use profile are predefined based on technical guidelines (standard values), while in Method 3 the building operation and use profile is determined by the SEPAP user.

5.4.4 Country results

The following table (Table 21) shows the possible outputs provided by the Greek EPC report and the ePANACEA assessment Methods 1, 2 and 3. It is noted that there is a limited number of outputs which are common among the national EPC report and the three methods. Energy use for heating, cooling, DHW and lighting outputs are common between the current national EPC and all three methods.

Table 21: Current EPC and M1, M2, M3 outputs in Greece

Category	Definition	Current EPC	M1	M2	M3_CA	M3_MA	M3_MS
Energy performance rating	Classification (label/class A-G)						
	Total primary energy use (EPBD services) [kWh/m²year]	*(provided below) **					
Overall numerical indicators (main performance indicators)	*Total primary energy use (EPBD services) [kWh/m²year]		C	E	C	C	C
	Non-renewable primary energy use (EPBD services) [kWh/m²year]			E	C	C	C
	Renewable primary energy use (EPBD services) [kWh/m²year]			E	C	C	C
	*GHG emissions (EPBD services) [kgCO₂/m²year]		C	E	C	C	C
	Renewable energy ratio (EPBD services) [% or fraction (0-1)]		C		C	C	C
	Total primary energy use (All services) [kWh/m²year]		C		C	C	C

Category	Definition	Current EPC	M1	M2	M3_CA	M3_MA	M3_MS
	Non-renewable primary energy use (All services) [kWh/m²year]				C	C	C
	Renewable primary energy use (All services) [kWh/m²year]						
	GHG emissions (All services) [kgCO₂/m²year]		C		C	C	C
	Renewable energy ratio (All services) [% or fraction (0-1)]		C		C	C	C
Partial indicators	Energy need for space heating [kWh/m²year]			E			
	Energy need for space cooling [kWh/m²year]			E			
	Energy use for heating [kWh/m²year]		E	E	E	E	E
	Energy use for cooling [kWh/m²year]		E	E	E	E	E
	Energy use for DHW [kWh/m²year]		E	E	E	E	E
	Energy use for lighting [kWh/m²year]		E	E	E	E	E
	Energy use for ventilation [kWh/m²year]				E	E	E
	Energy use for other services [kWh/m²year]		E	E	E	E	E
	Electric energy from RES used on-site [kWh/year]				E	E	E
	GHG emissions for heating [kgCO₂/m²year]		C	E	C	C	C
	GHG emissions for cooling [kgCO₂/m²year]		C	E	C	C	C
	GHG emissions for DHW [kgCO₂/m²year]		C	E	C	C	C
	GHG emissions for lighting [kgCO₂/m²year]		C	E	C	C	C
	GHG emissions for ventilation [kgCO₂/m²year]				C	C	C
	GHG emissions for other services [kgCO₂/m²year]		C		C	C	C
	Non-renewable primary energy use for heating [kWh/m²year]			E			
	Non-renewable primary energy use for cooling [kWh/m²year]			E			
	Non-renewable primary energy use for DHW [kWh/m²year]			E			
	Non-renewable primary energy use for lighting [kWh/m²year]			E			
	Total primary energy use for heating [kWh/m²year]		C	E	C	C	C
	Total primary energy use for cooling [kWh/m²year]		C	E	C	C	C
	Total primary energy use for DHW [kWh/m²year]		C	E	C	C	C
	Total primary energy use for lighting [kWh/m²year]		C	E	C	C	C
	Total primary energy use for ventilation [kWh/m²year]				C	C	C
	Total primary energy use for other services [kWh/m²year]		C		C	C	C
	Renewable primary energy use for heating [kWh/m²year]			E			
	Renewable primary energy use for cooling [kWh/m²year]			E			
	Renewable primary energy use for DHW [kWh/m²year]			E			
	Renewable primary energy use for lighting [kWh/m²year]			E			
	Heat transfer coefficient of walls (weighted average) [W/m²K]				E	E	E

Category	Definition	Current EPC	M1	M2	M3_CA	M3_MA	M3_MS
	Heat transfer coefficient of roofs (weighted average) [W/m²K]				E	E	E
	Heat transfer coefficient of floors (weighted average) [W/m²K]				E	E	E
	Heat transfer coefficient of windows (weighted average) [W/m²K]				E	E	E
	SHGC of windows (weighted average) [fraction (0-1)]				E	E	E
EEMs and energy saving quantification/economic feasibility	EEM based on improving building envelope, HVAC, control systems and dynamic envelope (e.g., thermal insulation of opaque envelope, temperature set points,…) [kWh/year, $kgCO_2$/year, €/year Payback]						

C: Calculated, E: Extracted

In terms of quantitative analysis as seen in Figure 53, the Method 3 energy values of the Greek case studies are lower (<50%) than the ones of the national EPC report. Beyond the reasons mentioned in the methods separately, the deviation is also caused by other reasons. Specifically, the poor quality of input data, such as the limited measurement period (2-3 weeks) for Method 1 and the absence of monthly consumption data for Method 3, led to low accuracy results. This is illustrated in the figure, in which a scaling is observed among the three case studies, i.e., from poor quality of the input data of GR-01 (oil consumption data on an annual basis) to detailed input data of GR-03 (electricity and natural gas consumption data on a monthly basis).

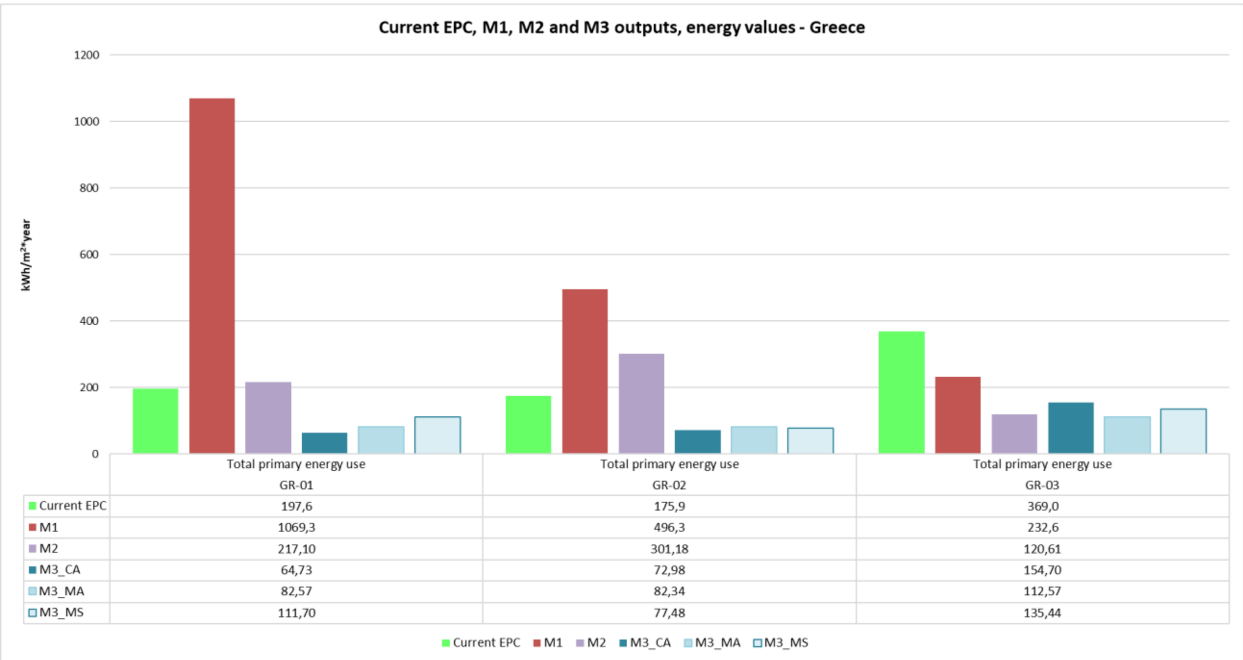


Figure 53: EPC and M1, M2, M3 energy values – Greece

5.5 Spain

In Spain, based on the current EPC scheme, the main performance indicator is the non-renewable primary energy use (PEnonren in kWh/m²year) as well as the energy classification of the building, and the CO_2 emissions (in kgCO_2/m²year). There are partial indicators based on the energy need, which are the energy need for space heating and cooling. The GHG emissions for heating, cooling, DHW and (only for non-residential buildings) lighting are also provided in the EPC report. As regards the non-renewable primary energy use, partial indicators for heating, cooling, DHW and (only for non-residential buildings) lighting are also given. The total number of outputs displayed in the EPC reports of the Spanish case studies is 11 and 13.

The table below (Table 22) presents the current EPC data for the Spanish case studies (SP-01, SP-02 and SP-03), which are a public office building, a single-family house and an individual dwelling in a multi-family building block.

Table 22: Current EPC report outputs in Spain

Category	Definition	Units	SP-01	SP-02	SP-03
Energy performance rating	Classification (label/class A-G)	-	B	D	B
	Non-renewable primary energy use	kWh/m²year	132,00	132,30	54,00
	GHG emissions	kgCO_2/m²year	24,50	34,40	11,30
Partial indicators	Non-renewable primary energy use	kWh/m²year	132,40	132,31	54,00
	Energy need for space heating	kWh/m²year	36,20	92,50	13,40
	Energy need for space cooling	kWh/m²year	34,70	non-qualifying	non-qualifying
	GHG emissions for heating	kgCO_2/m²year	10,44	28,02	3,71
	GHG emissions for cooling	kgCO_2/m²year	4,18	1,42	0,47
	GHG emissions for DHW	kgCO_2/m²year	0,76	5,01	7,13
	GHG emissions for lighting	kgCO_2/m²year	8,05	--	--
	Non-renewable primary energy use for heating	kWh/m²year	49,31	132,31	17,53
	Non-renewable primary energy use for cooling	kWh/m²year	24,68	8,37	2,77
	Non-renewable primary energy use for DHW	kWh/m²year	4,47	23,64	33,68
	Non-renewable primary energy use for lighting	kWh/m²year	47,52	--	--

5.5.1 Method 1

Figure 54 presents the number of current EPC outputs, the outputs extracted from the method and the total number of outputs (extracted and calculated) for each case study (SP-01, SP-02, SP-03). They vary from 4 to 37. The large number of total outputs is due to the fact that there are renewable and non-renewable conversion factors apart from CO_2 conversion factors which are used for the national assessment method.

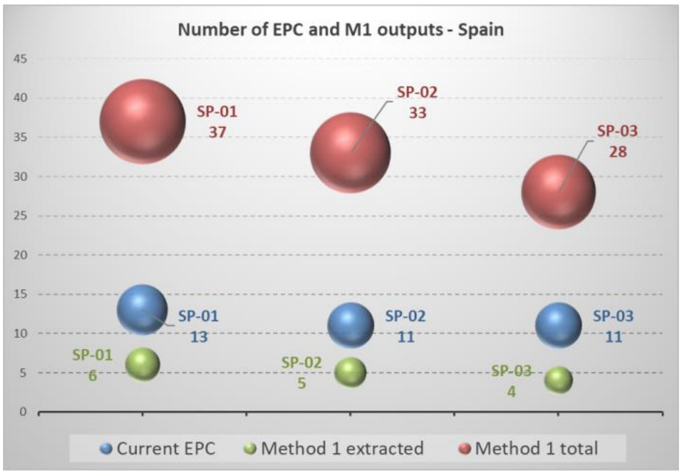
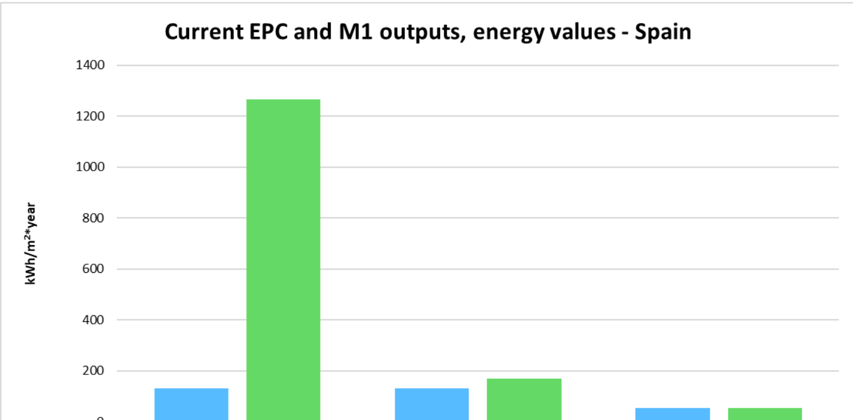


Figure 54: EPC and M1 outputs – Spain

The values of Method 1 are presented in the figures below (Figure 55, Figure 56); these relate to Non-renewable primary energy use and CO_2 emissions. Like in the Greek case studies, it was necessary to run two models, one for heating and one for cooling. It is seen that SP-01 Method 1 presents high values, which are considered out of range, compared to the values of the other two case studies. One reason for these out of range values is that cooling needs increase the non-renewable energy use.



	Non-renewable primary energy use SP-01	Non-renewable primary energy use SP-02	Non-renewable primary energy use SP-03
Current EPC	132,4	132,3	54,0
M1	1267,21	170,3	55,4

Figure 55: EPC and M1 energy values – Spain

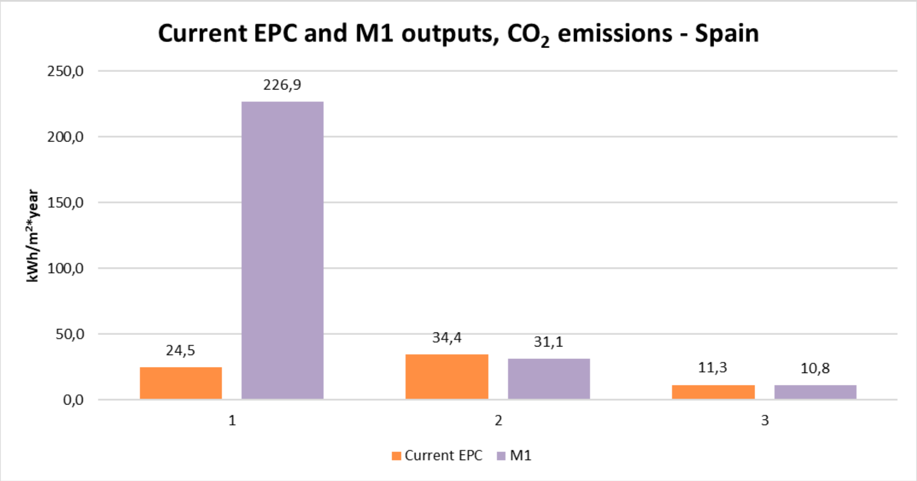


Figure 56: EPC and M1 CO_2 emissions – Spain

Deviations related to CO_2 emissions show similar patterns as those of the energy values.

5.5.2 Method 2

The number of outputs of Method 2 are more than the Spanish EPC outputs for all case studies (SP-01, SP-02, SP-03), as can be seen in Figure 57.

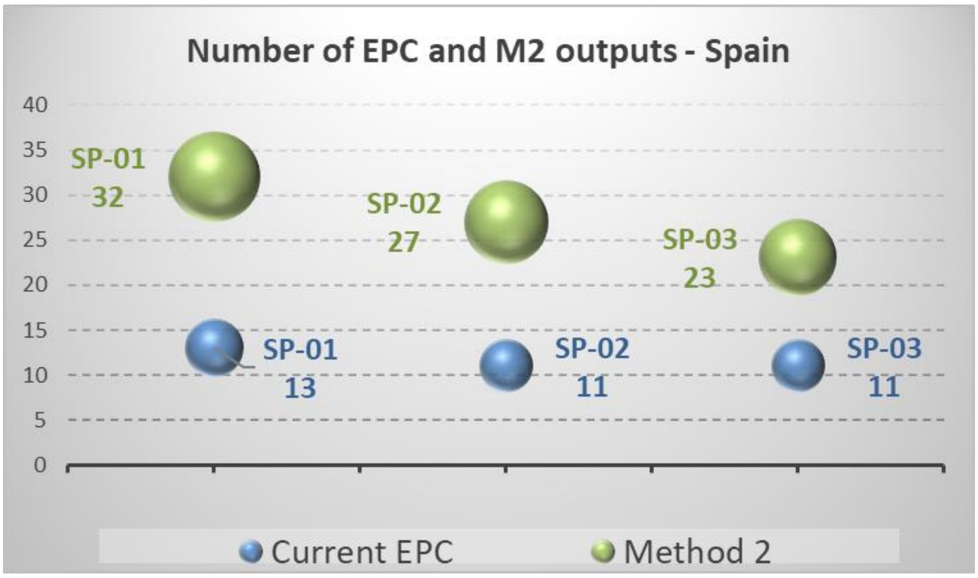


Figure 57: EPC and M2 outputs – Spain

The Method 2 results are presented in the figures below (Figure 58, Figure 59); these refer to Non-renewable primary energy use and CO_2 emissions.

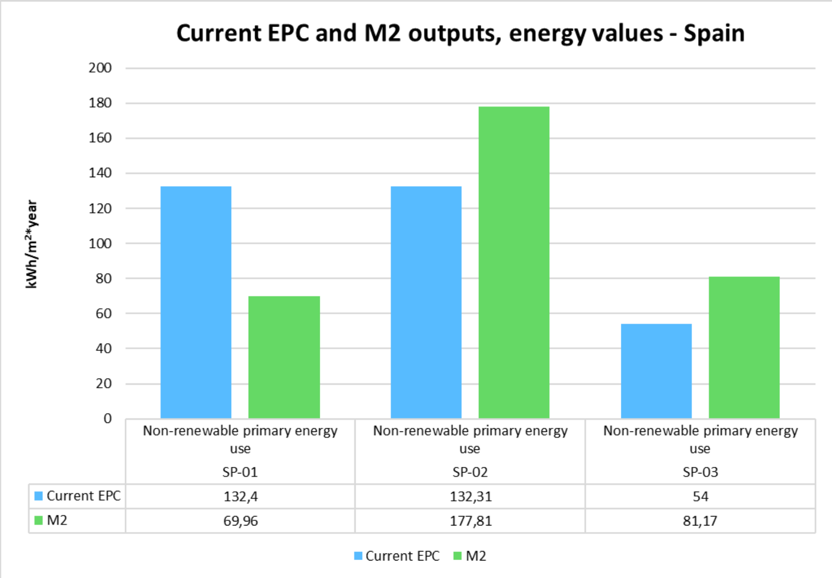


Figure 58: EPC and M2 energy values – Spain

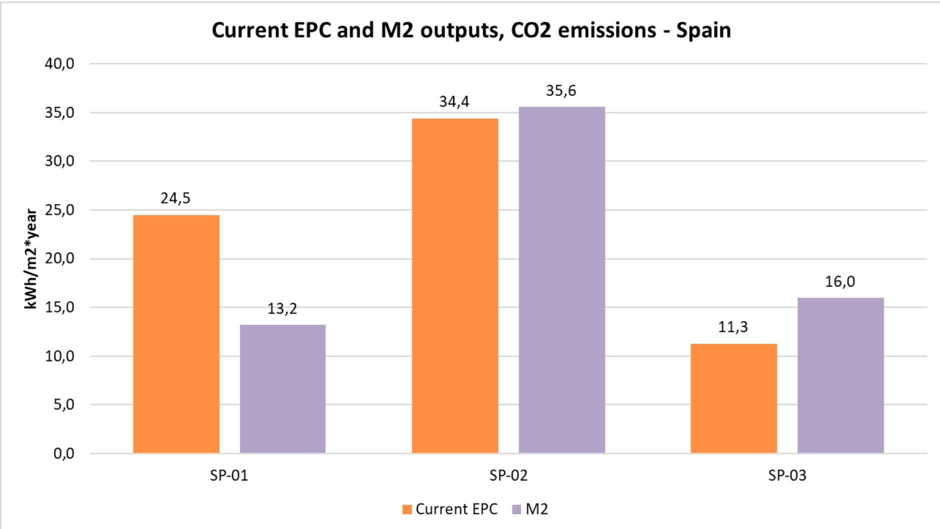


Figure 59: EPC and M2 CO_2 emissions – Spain

It is shown that the energy values of Method 2 for SP-02 and SP-03 are higher than the ones of the Spanish EPC report while the opposite occurs for SP-01. This may be due to the different building typologies (residential vs office). As regards the CO_2 emissions, the values of SP-02 are similar with the current EPC. The Method 2 values of SP-01 are lower than those of the current EPC values and the contrary is the case for SP-03.

5.5.3 Method 3.

The outputs of the three Method 3 options (CA, MA, MS) for each case study (SP-01, SP-02, SP-03) are presented in Figure 60. The extracted values of Method 3 are close to the current EPC report values.

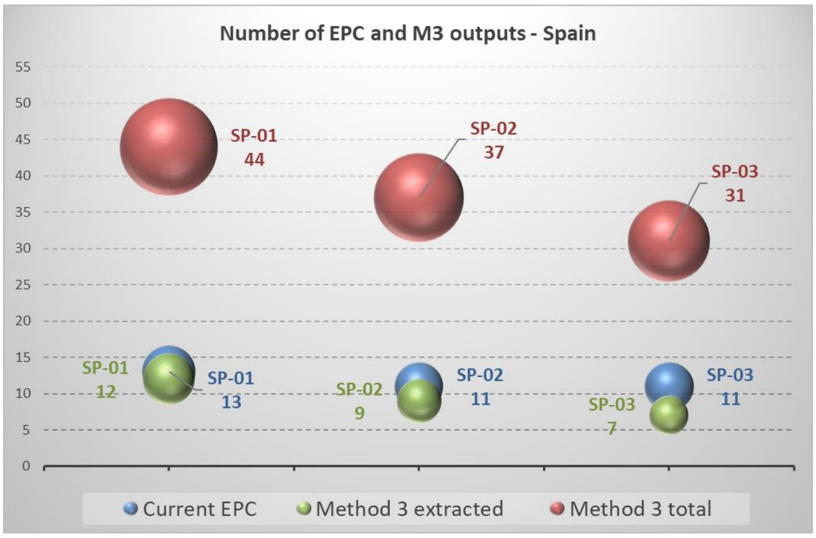
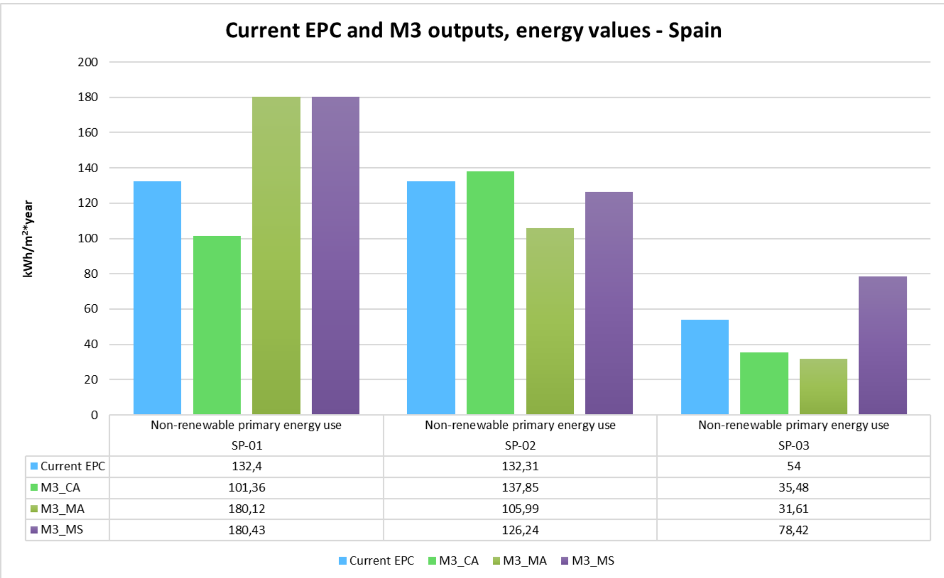


Figure 60: EPC and M3 outputs - Spain

Figure 61, Figure 62 and Figure 63 present the values of Method 3 outputs compared with the current EPC ones.



	Non-renewable primary energy use SP-01	Non-renewable primary energy use SP-02	Non-renewable primary energy use SP-03
Current EPC	132,4	132,31	54
M3_CA	101,36	137,85	35,48
M3_MA	180,12	105,99	31,61
M3_MS	180,43	126,24	78,42

Figure 61: EPC and M3 energy values – Spain

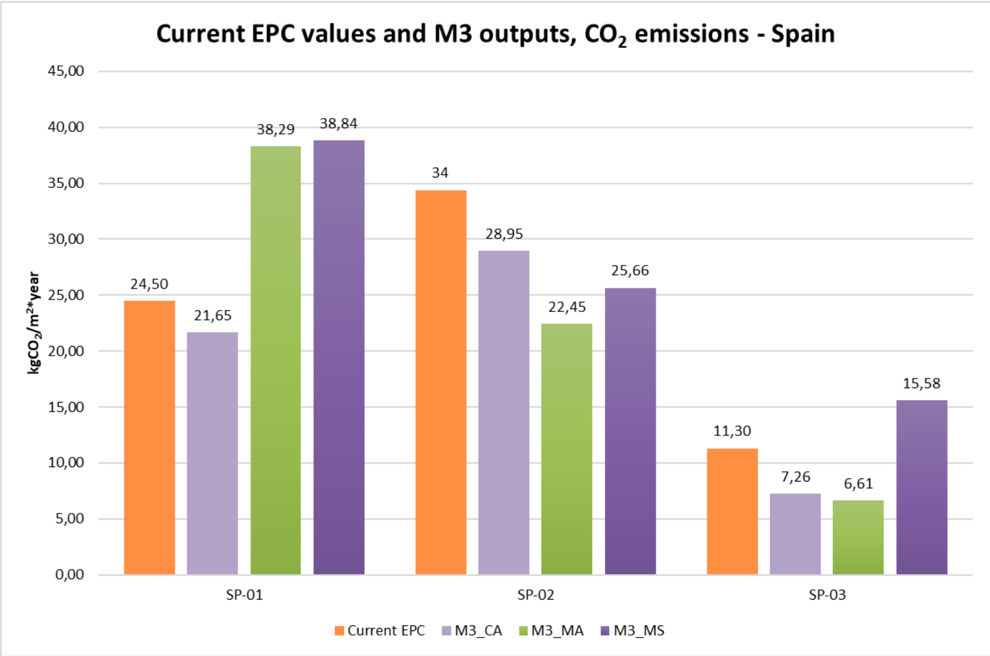
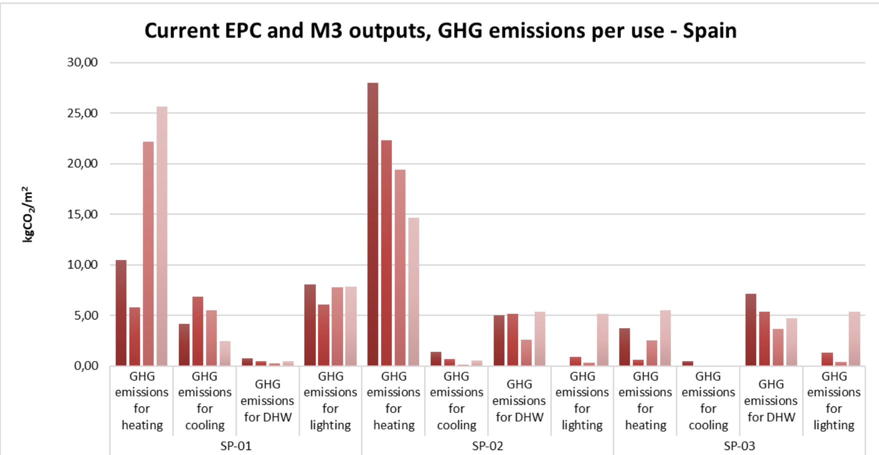


Figure 62: EPC and M3 CO_2 emissions – Spain



	SP-01				SP-02				SP-03			
	GHG emissions for heating	GHG emissions for cooling	GHG emissions for DHW	GHG emissions for lighting	GHG emissions for heating	GHG emissions for cooling	GHG emissions for DHW	GHG emissions for lighting	GHG emissions for heating	GHG emissions for cooling	GHG emissions for DHW	GHG emissions for lighting
Current EPC	10,44	4,18	0,76	8,05	28,02	1,42	5,01	0,00	3,71	0,47	7,13	0,00
M3_CA	5,76	6,86	0,45	6,08	22,28	0,65	5,15	0,87	0,62	0,00	5,33	1,31
M3_MA	22,20	5,50	0,26	7,76	19,43	0,13	2,58	0,31	2,55	0,00	3,63	0,43
M3_MS	25,63	2,47	0,45	7,85	14,62	0,55	5,33	5,16	5,47	0,00	4,73	5,38

Figure 63: EPC and M3 U-values – Spain

As seen from the figures above, the Non-renewable primary energy use calculated from Method 3_CA is close to the respective value of the current EPC (deviation rate of approx. 18%). The same pattern is shown for GHG emissions (deviation rate of approx. 21%).

It is important to highlight the fact that this comparison is only based on EPB services and, because of that, in some cases the global indicators of Method 3 and the current EPC are similar. E.g., if the electric equipment peak load has been sub- or over-estimated, this implies a high gap in partial indicators such as heating and cooling; even though the sum could be the same, in practice it is not the case.

5.5.4 Country results

The following table (Table 23) shows the possible outputs provided by the Spanish EPC report and the ePANACEA assessment methods 1, 2 and 3. It is noted that Method 1 has a large number of outputs, however the renewable primary energy use values are not accurate due to the inability to extract electric energy from RES used on-site even if the actual radiation values are considered in the method inputs. All EPC report outputs can be compared with these of the methods.

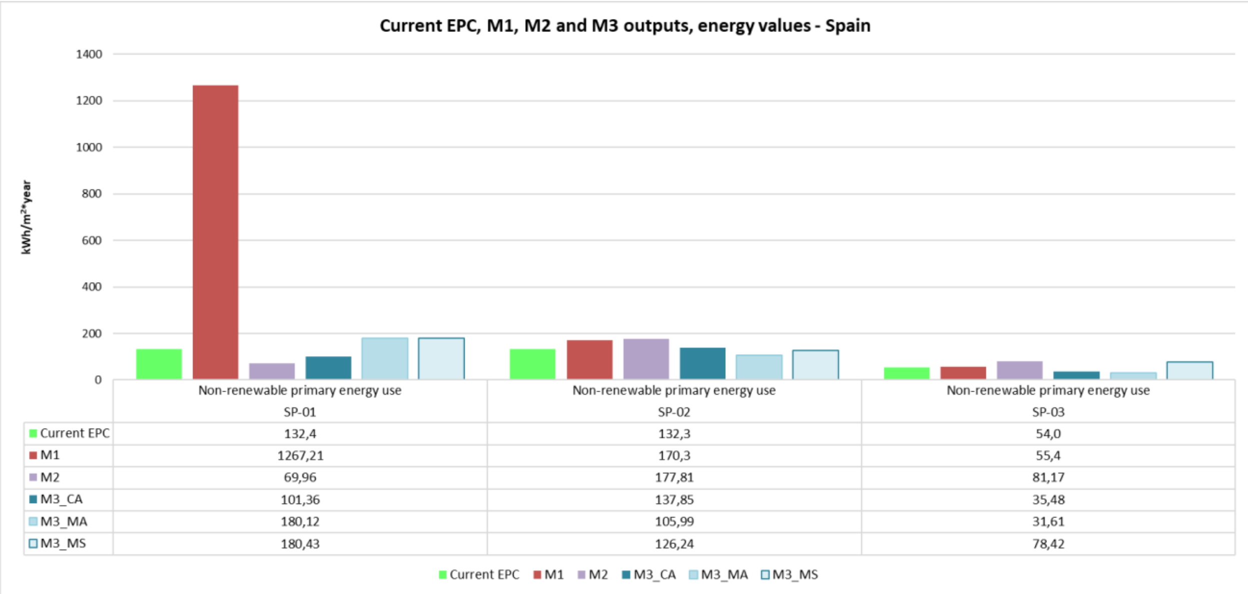
Table 23: Current EPC and M1, M2, M3 outputs in Spain

Category	Definition	Current EPC	M1	M2	M3_CA	M3_MA	M3_MS
Energy performance rating	Classification (label/class A-G)						
	Non-renewable primary energy use (EPBD services) [kWh/m^2year]	*(provided below) **					
	GHG emissions (EPBD services) [kgCO_2/m^2year]						
Overall numerical indicators (main performance indicators)	Total primary energy use (EPBD services) [kWh/m^2year]		C	E	C	C	C
	*Non-renewable primary energy use (EPBD services) [kWh/m^2year]		C	E	C	C	C
	Renewable primary energy use (EPBD services) [kWh/m^2year]		C	E	C	C	C
	* GHG emissions (EPBD services) [kgCO_2/m^2year]		C	E	C	C	C
	Renewable energy ratio (EPBD services) [% or fraction (0-1)]						
	Total primary energy use (All services) [kWh/m^2year]		C		C	C	C
	Non-renewable primary energy use (All services) [kWh/m^2year]		C		C	C	C
	Renewable primary energy use (All services) [kWh/m^2year]		C		C	C	C
	GHG emissions (All services) [kgCO_2/m^2year]		C		C	C	C
	Renewable energy ratio (All services) [% or fraction (0-1)]		C		C	C	C
Partial indicators	Energy need for space heating [kWh/m^2year]			E			
	Energy need for space cooling [kWh/m^2year]			E			
	Energy use for heating [kWh/m^2year]		E	E	E	E	E
	Energy use for cooling [kWh/m^2year]		E	E	E	E	E
	Energy use for DHW [kWh/m^2year]		E	E	E	E	E
	Energy use for lighting [kWh/m^2year]		E	E	E	E	E
	Energy use for ventilation [kWh/m^2year]		E	E	E	E	E
	Energy use for other services [kWh/m^2year]		E	E	E	E	E
	Electric energy from RES used on-site [kWh/year]				E	E	E
	GHG emissions for heating [kgCO_2/m^2year]		C	E	C	C	C
	GHG emissions for cooling [kgCO_2/m^2year]		C	E	C	C	C
	GHG emissions for DHW [kgCO_2/m^2year]		C	E	C	C	C
	GHG emissions for lighting [kgCO_2/m^2year]		C	E	C	C	C
	GHG emissions for ventilation [kgCO_2/m^2year]		C	E	C	C	C
	GHG emissions for other services [kgCO_2/m^2year]		C		C	C	C
	Non-renewable primary energy use for heating		C	E	C	C	C

Category	Definition	Current EPC	M1	M2	M3_CA	M3_MA	M3_MS
	[kWh/m²year]						
	Non-renewable primary energy use for cooling [kWh/m²year]		C	E	C	C	C
	Non-renewable primary energy use for DHW [kWh/m²year]		C	E	C	C	C
	Non-renewable primary energy use for lighting [kWh/m²year]		C	E	C	C	C
	Non-renewable primary energy use for ventilation [kWh/m²year]		C	E	C	C	C
	Non-renewable primary energy use for other services [kWh/m²year]		C		C	C	C
	Total primary energy use for heating [kWh/m²year]		C	E	C	C	C
	Total primary energy use for cooling [kWh/m²year]		C	E	C	C	C
	Total primary energy use for DHW [kWh/m²year]		C	E	C	C	C
	Total primary energy use for lighting [kWh/m²year]		C	E	C	C	C
	Total primary energy use for ventilation [kWh/m²year]		C	E	C	C	C
	Total primary energy use for other services [kWh/m²year]		C		C	C	C
	Renewable primary energy use for heating [kWh/m²year]		C	E	C	C	C
	Renewable primary energy use for cooling [kWh/m²year]		C	E	C	C	C
	Renewable primary energy use for DHW [kWh/m²year]		C	E	C	C	C
	Renewable primary energy use for lighting [kWh/m²year]		C	E	C	C	C
	Renewable primary energy use for ventilation [kWh/m²year]		C	E	C	C	C
	Renewable primary energy use for other services [kWh/m²year]		C		C	C	C
	Heat transfer coefficient of walls (weighted average) [W/m²K]				E	E	E
	Heat transfer coefficient of roofs (weighted average) [W/m²K]				E	E	E
	Heat transfer coefficient of floors (weighted average) [W/m²K]				E	E	E
	Heat transfer coefficient of windows (weighted average) [W/m²K]				E	E	E
	SHGC of windows (weighted average) [fraction (0-1)]				E	E	E

C: Calculated, E: Extracted

Figure 64 illustrates the energy values of all methods for the three Spanish case studies. Excluding the results for SP-01 of Method 1, the percentage of deviation of the ePANACEA methodologies' values from the national EPC report values is 15%. Regarding Method 2, for all case studies, the respective deviation rate ranges from 34% to 50% and for Method 3 the deviation percentages are 18% for Method 3_CA, 8% for Method 3_MA and 25% for Method 3_MS.



	Non-renewable primary energy use SP-01	Non-renewable primary energy use SP-02	Non-renewable primary energy use SP-03
Current EPC	132,4	132,3	54,0
M1	1267,21	170,3	55,4
M2	69,96	177,81	81,17
M3_CA	101,36	137,85	35,48
M3_MA	180,12	105,99	31,61
M3_MS	180,43	126,24	78,42

Figure 64: EPC and M1, M2, M3 energy values – Spain

6 DECISION MATRIX

Work performed during this task and presented in this report, including quantitative and qualitative data from the 15 case studies across the five pilot countries, conducted with the three assessment methods, has also guided the development of the ePANACEA decision matrix ("Decision matrix for the recommendation of the most suitable method").

The decision matrix establishes an automatic procedure to provide recommendations on the assessment method most suitable to use by the EPC assessor according to 7 input criteria:

1. Building type
2. Energy needs
3. HVAC complexity
4. BACS presence
5. RES presence
6. Assessment objective
7. Current background of the energy assessor

Each of these criteria includes a list of elements that have been classified according to each assessment method with a code of three levels:

- "+" ➔ highly recommended
- "-" ➔ possible
- "o" ➔ not recommended

The final objective is a recommendation about which method would be the most suitable to use; this would be represented by a "triple" check symbol like in the example below:

	Assessment method		
	M1	M2	M3
Check list	data-driven building energy performance assessment	Simplified method based on monthly calculation interval ISO 52016	Advanced and auto calibrated white-box BEMs

Total count:

	Check list	10					
+	>>>>	✗	3	!	5	✓	10
-	>>>>	!	4	!	3	✓	0
o	>>>>	✗	3	✗	2	✓	0

Figure 65. Schematic results from the "Decision Matrix"

6.1 Examples of application of the decision matrix

Figure 66 and Figure 67 show examples of the application of the decision matrix to two of the 15 project case studies.

As can be seen, the decision matrix would recommend the use of the Method 3 for the SP-01 related to an office building of 5.000 m^2 located in Pamplona (Spain) but it would recommend the use of Method 2 (and possibly Method 1) for the case study BE-01 related to a single-family house in Belgium.

Leyend:

+	high recommended
-	possible
o	not recommended
	input "x" when applicable

	Check list	Assessment method M1: data-driven building energy performance assessment	Assessment method M2: Simplified method based on monthly calculation interval ISO 52016	Assessment method M3: Advanced and auto calibrated white-box BEMs
1. Building type				
New buildings		o	+	+
Existing buildings	x	+	+	+
Residential		+	+	+
Tertiary	x	-	+	+
2. Energy needs				
Heating	x	+	+	+
Cooling	x	-	+	+
DHW	x	+	+	+
3. HVAC complexity				
NO HVAC modelling required		+	+	+
Basic HVAC modelling		o	-	+
Advanced/detailed HVAC modelling	x	o	o	+
4. BACS presence				
Not present		+	+	+
Lighting Dimming control by natural light	x	o	o	+
Automatic Window blinds		o	o	+
5. RES presence				
Not present		+	+	+
PV	x	-	-	+
ST		o	-	+
Heat Pump (H&DHW)		o	-	+
6. Assessment objective				
EPC standard - Regulation		+	+	+
Detailed EPC - EEMs based on actual use	x	o	-	+
EPC + Basic Energy audit		o	+	-
EPC + Detailed Energy audit		o	o	+
Comfort and IAQ		o	o	+
7. Current backgrounf/trainning of the energy assessor				
None		+	o	o
Basic backgrounf on energy assessments		-	+	o
High expertise on dynamic simulation	x	-	-	+

Total count:

	Check list: 10	M1	M2	M3
+	>>>>	✗ 3	! 5	✓ 10
-	>>>>	! 4	! 3	✓ 0
o	>>>>	✗ 3	✗ 2	✓ 0

Figure 66. Example of the “Decision Matrix” application to SP-01

Leyend:

+	high recommended
-	possible
o	not recommended
	input "x" when applicable

	Check list	Assessment method M1: data-driven building energy performance assessment	Assessment method M2: Simplified method based on monthly calculation interval ISO 52016	Assessment method M3: Advanced and auto calibrated white-box BEMs
1. Building type				
New buildings		o	+	+
Existing buildings	x	+	+	+
Residential	x	+	+	+
Tertiary		-	+	+
2. Energy needs				
Heating	x	+	+	+
Cooling		-	+	+
DHW	x	+	+	+
3. HVAC complexity				
NO HVAC modelling required	x	+	+	+
Basic HVAC modelling		o	-	+
Advanced/detailed HVAC modelling		o	o	+
4. BACS presence				
Not present	x	+	+	+
Lighting Dimming control by natural light		o	o	+
Automatic Window blinds		o	o	+
5. RES presence				
Not present	x	+	+	+
Photovoltaic		-	-	+
Solar thermal		o	-	+
Heat Pump (H&DHW)		o	-	+
6. Assessment objective				
EPC standard - Regulation	x	+	+	+
Detailed EPC - EEMs based on actual use		o	-	+
EPC + Basic Energy audit		o	+	-
EPC + Detailed Energy audit		o	o	+
Comfort and IAQ		o	o	+
7. Current backgrounf/trainning of the energy assessor				
None		+	o	o
Basic backgrounf on energy assessments	x	-	+	o
High expertise on dynamic simulation		-	-	+

Total count:

	Check list: 9	M1	M2	M3
+	>>>>	8	9	8
-	>>>>	1	0	0
o	>>>>	0	0	1

Figure 67. Example of the "Decision Matrix" application to BE-01

7 CONCLUSIONS

Besides the country-specific results, as presented in the previous sections, general conclusions can be drawn considering the main objective of the ePANACEA methodology which is to reduce the performance gap between theoretical and actual consumption (i.e., current EPC report values and actual energy use data).

The ePANACEA assessment methods aim to cover different levels of building data, from a simple to a more advanced and finally a complex one. In specific, Method 1 is a simple, easy to use, and no time-consuming method that complements the current EPC. In fact, it is the easiest to use method. However, it shows some constrains such as a lack of accurate modelling for cooling performance which is critical for certain countries like Greece and Spain but not relevant for northern countries like Finland. Method 2 provides a basic calibration with two variables as correction factors (equipment and lighting) whereas Method 3 is a global approach which covers all possible combinations in terms of building uses, types, complexity, etc.

The ePANACEA assessment methods provide different achievements from a qualitative and quantitative point of view. For instance, Method 1 energy values for BE-02 and FI-02 are similar with the national EPC values with a deviation of approx. 1%. Method 2 energy values for FI-03 show a 3% deviation from the Finnish EPC data. As for Method 3, the deviation in energy values for AT-01 is 2% and for SP-02 4%, respectively. Regarding the quantitative analysis, the number of Method 1 outputs of the case studies range from 4 (outputs directly extracted from the method) to 37 (total number of outputs). The Method 2 outputs range from 22 to 32, and Method 3 outputs range from 7 to 44.

In terms of GHG emissions, there is high potential to realistically estimate CO_2 emissions because the latter are very sensitive to the local energy supply conditions and the developed methods provide means to include updated CO_2 conversion factors.

However, it is also important to highlight the fact that similar global indicators do not mean equal or similar outcomes, since the global indicator includes energy consumption by service (e.g., heating, cooling, DHW, lighting, etc.). In some cases, the global indicator can suffer from the “compensation effect“, which basically means that a lower energy use of one service can be compensated with a higher energy result of another service. It is also important to note that an appropriate energy use decomposition is more important than the global indicator itself, since it is intimately linked to a proper energy saving quantification from the implementation of energy efficiency measures.

Specifically focusing on assessment method 3, additional conclusions are:

- Accurate calibration requires high quality input data (i.e., good quality energy bills, actual values for at least 12 months) and correct implementation of occupant behaviour (i.e., schedules and set points closer to actual).
- The development of accurate models that reduce the current performance gap between theoretical and actual consumption is possible with cost-effective procedures (e.g., 2-3 working days for complex buildings).
- With the appropriate tools, it is possible and feasible to extrapolate the methodology based on auto-calibrated white-box models, from the scientific to the commercial environments.
- Multi-objective optimisation based on genetic algorithms plus parametric analysis in the cloud allows to reduce the computational cost of the calibration process.
- The automation of the workflow based on available computational tools will reduce the need for professional training in terms of cost and time.
- If the estimation of energy savings resulting from the implementation of energy efficiency measures is not based on the actual energy use of the building (i.e., calibrated model), accuracy cannot be guaranteed.
- The use of calibrated models within EPC schemes would reduce the uncertainty of some parameters, also used for the "EPC standard", such as envelope thermal transmittance or outdoor air infiltration (air changes per hour - ach).

- End-users show a higher level of engagement with energy efficiency when the EPC information is based on their occupant behavioural patterns (i.e., actual energy use) and they perceive this information as helpful in making decisions about investments.
- The calibration is performed for one calendar year, which means that two different winter seasons are covered (i.e., January-February and October-December). This can lead to discrepancies due to occupant behaviour, as different behaviour may be due to economic/political issues (e.g., war in Ukraine, energy efficiency policies, high fuel prices). A different behaviour can be translated into different set points between the seasons (e.g., 1 – 2 ^{o}C); this will make the auto calibration difficult in terms of meeting the CV(RMSE) requirement (<15%) because the auto calibration is based on a variation of the heating set point constant throughout the year. This scenario means that an acceptable calibration can be achieved by simply meeting NMBE<5%. This problem is more frequent in the residential typology. It seems that in this scenario a school year makes more sense than a calendar year.

Concluding, the purpose of the three developed ePANACEA assessment methods is to support the EPC and provide more data for the energy performance of the building. The selection of the method depends on the needs of each building case, the building typology and complexity, the climate, the input data available and the level of detail of the required outputs.

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