TIMEPAC

Towards Innovative Methods
for Energy Performance Assessment and Certification of Buildings

Deliverable 2.2

Enhancing EPC schemas through operational data integration

Transversal Deployment Scenario 2

Lead Beneficiary: Politecnico di Torino (POLITO)

Date: 29.09.2023

Version: 2.0

Dissemination level: Public

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This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grand agreement Nº 101033819.

Document description

Deliverable No.	2.2
Dissemination level	Public
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Contributors	All consortium members have provided content for this document
Due date of deliverable	30.06.2023
Actual submission date	29.09.2023

Version	Date	Beneficiary	Author
V0.1	24.05.2023	POLITO	Vincenzo Corrado
V0.2	26.06.2023	POLITO	Vincenzo Corrado
V0.3	10.07.2023	POLITO	Vincenzo Corrado
V0.4	24.07.2023	POLITO	Vincenzo Corrado
V0.5	24.07.2023	EIHP	Ružica Jurjević (internal review)
V1.0	31.07.2023	POLITO	Vincenzo Corrado (draft submission)
V1.1	17.09.2023	POLITO	Anthony Suppa (proof reading)
V1.2	28.09.2023	FUNITEC	Leandro Madrazo, Álvaro Sicilia
V2.0	29.09.2023	POLITO	Vincenzo Corrado (final submission)

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Executive Summary

This report summarizes to the work performed in Task 2.2 "TDS 2- Enhancing EPC schemas through operational data integration" of Work Package 2 "Transversal Deployment Scenarios". This work package is concerned with the creation of future scenarios with the aim of deploying and delivering new methods to implement enhanced EPCs schemas. Different partner profiles (e.g., certification bodies, software developers, and research groups) are involved in the deployment of these methods, which embrace the techno-scientific, operational, legislative, and standardisation levels. The aim of Task 2.2 is to devise new methods and tools to implement enhanced EPC schemas which focuses on the enhancement of EPC schemas through operational data integration.

TIMEPAC partners performed an energy performance assessment of a cluster of buildings applying new analysis procedures and evaluating their strengths and weaknesses. This assessment was carried out using a share methodology to select the buildings for the analyses, to collect and gather the data, and to perform the energy performance assessment. These procedures are described in Annex A "Guidelines for data collection" and B "Guidelines for data analysis".

The following analyses of selected buildings in each partner were performed using the shared procedures:

- standard energy performance assessment
- tailored energy performance assessment
- model calibration against monitored data
- indoor environmental quality assessment (for thermal comfort and indoor air quality)
- economic evaluation of energy efficiency measures
- assessment of building automation and control system improvement on the energy performance of the building

These analyses were performed using of ad hoc calculation sheets. Through the application of the analyses on different case studies, TIMEPAC partners were able to assess the relevance of the procedures, propose possible enhancements, and underline application issues.

The outcomes of the enhancement of EPC schemas through operational data integration will be deployed and tested in WP3 "Verification Scenarios" to demonstrate the feasibility of the new developed methods and tools.

1 Introduction

1.1 Purpose and target group

According to the European Commission, the building sector today is the largest consumer of energy in the EU; it is responsible for 40 percent of energy consumption and 36 percent of greenhouse gas emissions, and approximately 75 percent of the building stock is energy inefficient. Concerning the above-mentioned data, the European Union intervenes through political actions aimed at the realisation of deep renovation and energy requalification interventions. Proposed policy actions include the European Green Deal, the Renovation Wave, and the proposed revision of the Energy Performance of Buildings Directive (EPBD), all aimed at achieving the political and environmental targets set for 2050.

From this perspective, the Energy Performance Certificate (EPC) represents an essential document to identify the buildings that need to be upgraded, the interventions to be performed, and the best methodology to be applied. The project "Towards Innovative Methods for Energy Performance Assessment and Certification of Buildings" (TIMEPAC) aims to identify faults in the current energy performance certificates and to improve current energy certification processes from single, static certification to more holistic and dynamic approaches.

The aim of WP2 "Transversal Deployment Scenarios" (TDSs) is to deploy and deliver new methods to implement enhanced EPCs schemas, which will be then implemented in the Verification Scenarios to be carried out in WP3. Different partner profiles — certification bodies, software developers, research groups — have been involved in the deployment of these methods, which embrace the technical, scientific, operational, legislative, and standardisation levels.

WP2 includes five TDSs:

- TDS1 – Generating enhanced EPCs with BIM data.
- TDS2 – Enhancing EPC schemas through operational data integration.
- TDS3 – Creating Building Renovation Passports from data repositories.
- TDS4 – Integration of Smart Readiness Indicators and sustainability indicators in EPC.
- TDS5 – Large scale statistical analysis of EPC databases.

The TDS referred to from now on will be TDS2, the subject of this paper. TDS2 - "Enhancing EPC schemas through operational data integration" aims to specify procedures and services specifically addressing the enhancement of EPC schemas through operational data integration. This task involves the collection of actual energy consumption data, occupancy data and user profiles for selected representative buildings. Afterwards, methodologies and tools will be applied to the collected data to carry out model calibration and analysis of uncertainties in the energy performance assessment, assess indoor environmental quality (IEQ), enhance the effectiveness of the energy retrofit measures suggested in the EPC, by identifying cost-optimal energy efficiency measures, also taking into account the impact of the user behaviour; quantify the impacts of innovative technologies (e.g., BACS), propose related indicators to be integrated in the enhanced EPC scheme. In Figure 1 a schema of the TIMEPAC approach is presented.

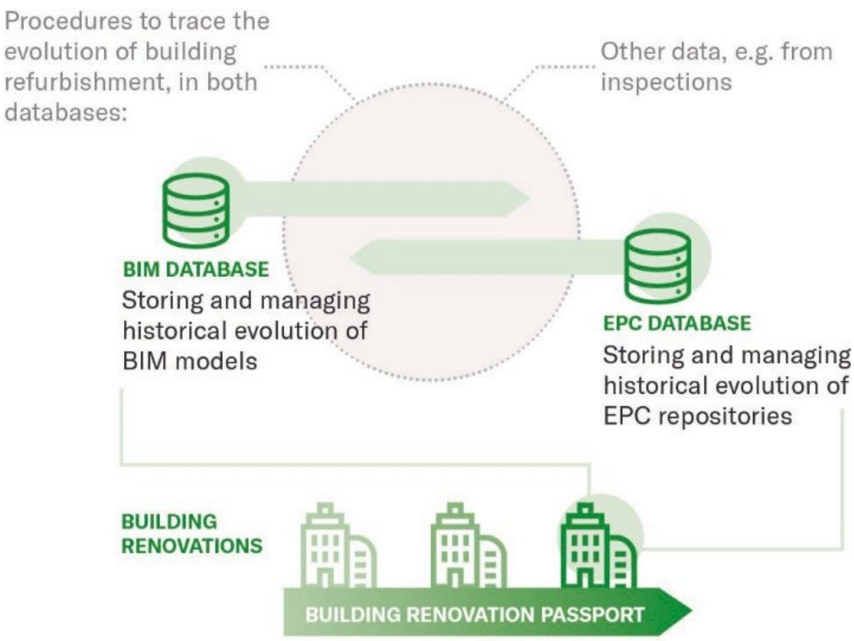

Figure 1. TIMEPAC approach

1.2 Deliverable structure

The present deliverable has been structured into seven main sections, as follows. Section 1 provides the introduction, focusing on: the purpose of TDS2 (1.1), the deliverable structure (1.2), the contribution of TIMEPAC partners (1.3); and the relations to the other project activities (1.4). Section 2 presents the TIMEPAC vision related to data integrated enhanced EPCs, the main topic of TDS2. Section 3 presents a literature review on the topic of energy performance assessment, calibration, and possible analysis that can be performed in EPCs. The main technical standards and the relevant sister projects are detailed, and the possible interactions are highlighted. Section 4 describes the methodology used in the three main phases: building selection (4.1), data collection (4.2), and data analysis (4.3). Section 5 presents the procedures applied by each partner for the data collection (5.1) and the data analysis (5.2). Section 6 presents the main findings of TDS2 application for each partner (for data collection and data analysis respectively in Section 6.1 and Section 6.2) comparing the results in Section 6.3. Section 7 provides the conclusions.

1.3 Contribution of partners

TDS2 analyses were carried out by POLITO with the contribution of the TIMEPAC consortium. The document was developed by POLITO in collaboration with SERA, EIHP, CEA, CUT, JSI, and ICAEN.

The project partners, grouped by participating country/region (SERA for Austria, EIHP for Croatia, CEA and CUT for Cyprus, POLITO and EDIC for Italy, JSI for Slovenia, and ICAEN and CYPE for Spain), performed the proposed analyses for the respective cluster of buildings, discussing the outcomes of the application of said procedures and highlighting pros and cons of their application.

1.4 Relations to other project activities

Task 2.2 addresses the use of operational data and analyses to enhance EPCs and has relations to the other project activities, as follows.

- Generating enhanced EPCs with BIM data (Task 2.1). The results of the tasks will be used to create the enhanced EPC. The BIM model generated in Task 2.1, for the provided buildings, were used to create building energy models (BEMs).
- Creating Building Renovation Passports from data repositories (Task 2.3). The results of the tasks will be used to create the enhanced EPC. The Energy Conservation Measures analysed in Task 2.2 were used for BRP scenarios determination.
- Integration of Smart Readiness Indicators and sustainability indicators in EPC (Task 2.4). The results of the tasks will be used to create the enhanced EPC. The Energy Conservation Measures results of Task 2.2 were used for the Life Cycle Assessment in Task 2.4.
- Large scale statistical analysis of EPC databases (Task 2.5). The results of the tasks will be used to create the enhanced EPC.

The outputs of the analysis carried out in this task will be deployed in the verification scenarios (WP3) to demonstrate the feasibility of the new analyses.

2 TIMEPAC vision

TIMEPAC fosters the implementation of a more holistic approach to energy certification by considering: a) the overall cycle of EPC-related data, from generation to storage, to analysis and exploitation, throughout all the building lifecycle, from design, to construction and operation b) that buildings are part of a larger ecosystem which includes energy and transport networks, and the built environment and c) that buildings are dynamic entities, continuously changing over time.

The building is a complex object made of building fabric, technical building systems (TBSs), and occupants; it is a dynamic entity subjected to continuous changes throughout its lifetime. For instance, the TBSs operation is related to the occupants' psychophysical well-being in the four comfort domains: thermal, visible, acoustic, and indoor air quality (IAQ). Therefore, even the next-generation EPC should be intended as a dynamic object rather than a static and non-updatable entity.

The next-generation energy performance certificate (EPC) must no longer be conceived as a paper-based document, but rather as a digital source of integrated information. According to the TIMEPAC vision, the enhanced energy certificate will meet the following requirements:

1. Data quality
2. Data enrichment and integration (Smart Readiness (SRI), sustainability indicators, real consumption data, etc.)
3. Dynamicity (i.e., through-life updatable)
4. Flexibility (i.e., tailored for different purposes and target groups)

The quality check of data processed and displayed in an enhanced EPC requires specifying data sources and levels of uncertainty. To increase the EPC reliability, confidence intervals on those input data that most affect the energy performance shall be specified and applied in the EPC generation.

The enhanced EPC will contain a wider set of parameters and information to broaden its scope. It will:

- Encompass the information stored in BIM models, to improve the quantity of available data
- Add operational data (e.g., real consumption data, occupancy schedules, environmental measurements, etc.) to apply models tailored to the actual users and to perform model calibration
- Address an integrated performance according to a holistic approach, which should be at the same time: Multiscale (e.g., from single building to urban context), Multi-domain (e.g., thermal analysis, lighting, CFD, acoustics, etc.), and Multi-object (e.g., energy performance, indoor environmental quality, smartness, climate resilience, environmental sustainability, cost-effectiveness)
- Address social, environmental, and economical aspects (e.g., highlighting local, regional or national fiscal incentive programmes to encourage occupant awareness about renovation activities)

The dynamicity and flexibility of the enhanced EPC should not invalidate the legal value of the document, which should capture both the standard energy performance status of the building or building unit and the continuous changes throughout its lifetime. It is not probable that all aforementioned parameters could be included in a mandatory scheme, but more likely some of them could be drafted on a voluntary basis. Currently, the actual EPC is a document mainly addressed to the end-users with limited and, in most cases, unreliable technical data. Thus, the enhanced EPC should have multiple functions becoming a central document for different target groups (e.g., end-users, energy certifiers, local, regional, and national authorities, etc.). Therefore, the next-generation energy certificate should be customised for intended audiences and final purposes (Figure 2).

Moreover, the enhanced EPC should improve information interoperability, i.e., the capability of data exchange between different environments, with local, regional, and national databases (e.g., cadastre database, geographical database, statistical database, thermal plant registers, digital building logbooks, etc.). Information should be centralised in the respective databases to which documents or data sources refer. For instance, the information on the technical building systems should appear just in the thermal plant register and the EPC should refer to those values, specifying the database origin and the data extracted.[1]

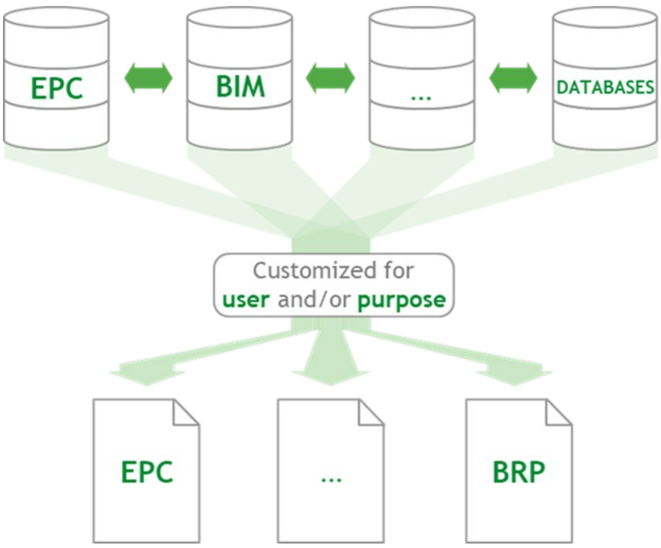

Figure 2. Enhanced EPC architecture

[1] The concepts presented in this paragraph are in line with the introduction of digital building logbooks in the proposal for the revision of the EPBD. A 'digital building logbook' is defined as a common repository for all relevant building data, including data related to energy performance such as energy performance certificates, renovation passports and smart readiness indicators, which facilitates informed decision making and information sharing within the construction sector, among building owners and occupants, financial institutions, and public authorities.

3 Recent developments

3.1 General

The enhancement of the EPC schema through the integration of operational data within TDS2 will be addressed by the proposal of new key performance indicators (KPIs). These will be selected from the results of different analyses performed on the selected buildings. Specifically, the analyses to be performed are the following:

1. Standard energy performance assessment (SEPA)
2. Tailored energy performance assessment (TEPA)
3. TEPA calibration against monitored data (CAL)
4. Economic evaluation of energy efficiency measures (ECM)
5. Indoor environmental quality evaluation (IEQ)
6. Building Automation and Control System impact assessment (BACS)

All of these analyses require the creation of a building energy model (BEM), as described in Annex B.

3.2 Sister projects

There are other projects in the literature that share the goal of improving certification systems, namely the Sister Projects. These are:

- COLLECTiEF - Using collective intelligence to improve the energy performance of buildings and contribute to global climate and energy goals,
- crossCert - Creating a product testing methodology for the new Energy Performance Certificates approaches,
- D2EPC - Setting the grounds for the next generation of dynamic Energy Performance Certificates for buildings,
- E-DYCE - Increasing the reliability of the energy performance assessment process through dynamic Energy Performance Certification,
- ePANACEA - Creating a Smart Energy Performance Assessment Platform to overcome the challenges to the current Energy Performance Certificates schemes,
- EPC RECAST - Supporting the development, implementation, and validation of a new generation of Energy Performance Assessment and Certification, with a focus on existing residential buildings,
- EUBSuperHub - Constructing common energy assessments for buildings,
- iBRoad2EPC - Integrating building renovation passports into Energy Performance Certification schemes for a decarbonised building stock,
- QualDeEPC - Increasing the quality and cross-EU convergence of Energy Performance Certificate schemes and enhancing the link between EPCs and deep renovation,
- SER - Maximising social impact and increasing clean energy investments in sustainable renovation,
- U-CERT - Introducing the next generation of user-centred Energy Performance Assessment and Certification Schemes to value buildings in a holistic and cost-effective manner,
- X-tendo - Providing public authorities and implementing agencies with improved compliance, reliability, usability, and convergence of next-generation energy performance assessment and certification.

Among the above-mentioned projects, only those with similarities and common objectives with TIMEPAC's TDS2 are highlighted herein, including D^{2}EPC, E-DYCE, ePANACEA, EUBSuperHub, U-CERT e X-tendo.

The overall objective of the D^{2}EPC project is to lay the foundation for the next generation of dynamic Energy Performance Certificates (EPCs) for buildings. One of the objectives of the project is to integrate a new set of indicators covering different aspects to improve EPC schemes, a common goal with TIMEPAC's TDS2. The indicators proposed by the D^{2}EPC project can be divided into four categories: Energy Performance and LCA, Smart Readiness (SRI), Financial and LCC, and Comfort and Well-being (IAQ and thermal comfort). TDS2 also focuses the search for new indicators on some of the areas addressed by the D^{2}EPC, i.e., the financial and the well-being areas, generating for the financial indicators the Net Present Value (NPV) and the Discounted Payback Period (DPP), while for thermal comfort the Percentage Discomfort Hours (PDH) and the minimum air flow rate requirement for indoor air quality (qIAQ).

The E-DYCE project involves the use of dynamic EPCs that can minimise the gap in the energy performance of buildings by capturing their dynamic behaviour. One main objective is to capture dynamic behaviour of buildings on an ongoing basis. According to the project, "static" EPCs have limited reliability in predicting energy savings from renovations, and the implementation of new indicators (KPIs) within energy certifications, as also proposed by TIMEPAC's TDS2. The new indicators proposed by E-DYCE can be classified into four categories: energy, energy-signature, comfort and quality, and free-running operation (i.e., buildings without heating or cooling systems). Among these categories, only one related to user comfort is also analysed by TDS2; in particular, both projects focus on the importance of indoor air quality (IAQ) and thermal comfort. The last common aspect is the proposal of financial KPIs.

The objective of the EUBSuperHUB project is to support the creation of a harmonised certification process within the EU by developing a scalable methodology to visualise, assess, and monitor buildings throughout their lifecycle, thanks to the presence and utilisation of operational data. This latter aspect is a common point with TDS2 since it also utilises operational data. Concerning the EUBSuperHub project, a CEN Workshop has been activated, entitled "A Harmonisation of KPIs for the next generation of EPCs", which aims to take the concepts of the EUBSuperHub project and provide the contents for the new generation of EPCs, defining unique and shared indicators and calculation methodologies based on existing technical standards, legislative devices, and sustainability assessment protocols. The introduction of new KPIs is also a shared aspect with TDS2.

The purpose of the ePANACEA project is to develop a holistic methodology for the energy assessment and certification of buildings. One of the aims of the project is to create an inventory of data that can be used to supplement or replace existing EPCs (e.g., geometric data, envelope data, occupant comfort data, etc.); this includes data that can be monitored, controlled, and estimated in a building. All possible data is first collected and then only those data variables that may be relevant to be incorporated into the EPC are specifically selected and analysed. Both ePANACEA and TDS2 use monitored data, the first one to build the list of data variables and the second one as one of the preliminary steps for applying the calibration procedure.

The objective of U-CERT is to introduce a new generation of user-centred energy performance assessment and certification schemes to evaluate buildings holistically and cost-effectively. The structure of the U-CERT EPCs focuses on four indicator dimensions: Energy Performance, IEQ, Smart Readiness (SRI), and Costs. TDS2 also considers the user comfort category - focusing on thermal comfort and indoor air quality (IAQ) - and the financial domain. Both projects propose the implementation of new indicators. Regarding the definition of IAQ indicators and specifically thermal comfort, the U-CERT project is based on the use of discomfort indicators such as Summer Thermal Comfort and Winter Thermal Comfort, which indicate the hours of discomfort when the indoor temperature is above or below a certain reference temperature. A similar approach is also used in TDS2 as here, too, the hours of comfort and discomfort are used to define the new indicator.

The objective of the X-tendo project is to improve energy performance certificates through the implementation of new indicators (KPIs), a common aspect with TDS2. In particular, the project develops 10 'next-generation EPC characteristics', equally divided into two categories: innovative EPC indicators and innovative handling EPC data. Regarding the first category, the project proposes the following new indicators: smart readiness, comfort, outdoor air pollution, real energy consumption, and district energy. In addition to the common objective between the X-tendo project and TIMEPAC's TDS2 concerning the implementation of new KPIs, both projects refer to the "adaptive comfort" method for the definition of the related indicators.

The analyses carried out in TDS2 are based on technical reference standards. To increase the scenario of standards in the guideline references, other possible standards are proposed below to refer to for the topics analysed in TDS2.

3.3 Technical standards

The reference standards relevant to the EPC and to its possible enhancement are listed below.

EN 15378-3:2017 - *Energy performance of buildings - Heating and domestic hot water systems - Part 3: Measured energy performance, Modules M3-10, M8-10.*

The standard specifies methods for assessing the energy delivered for space heating and domestic hot water energy performance of a building based on measurements during operation and occupancy.

EN 15459-1:2018 - *Energy performance of buildings - Hydronic heating and cooling systems in buildings - Part 1: Economic evaluation procedure for energy systems in buildings, Module M1-14.*

This standard provides a calculation method for economic issues of heating systems and other systems that are involved in building energy demand and consumption; it applies to all types of new and existing buildings.

EN 15643:2010 - *Sustainability of construction works - Sustainability assessment of buildings - Part 1: General framework.*

The purpose of the document is to provide a framework with principles, requirements and guidelines for assessing the sustainability of buildings in terms of environmental, social and economic performance.

ISO 15686-5:2011 - *Buildings and constructed assets - Life planning - Part 5: Life cycle costs.*

It provides requirements and guidelines for performing LCC analysis of new and existing buildings and constructed assets and their parts.

EN 15978:2011 - *Sustainability of construction works - Assessment of the environmental performance of buildings - Calculation method.*

It specifies the calculation method, based on life cycle assessment (LCA) and other quantified environmental information, for assessing the environmental performance of a building (new or existing) and provides the means for reporting and communicating the results of the assessment.

EN 16309:2014 - *Sustainability of construction works - Assessment of the social performance of buildings - Calculation methodology.*

It provides specific methods and requirements for the assessment of the social performance of buildings, considering their technical and functional characteristics; it applies to both new and existing buildings.

EN 16627:2015 - *Sustainability of construction works - Assessment of the economic performance of buildings - Calculation methodology.*

The standard establishes the calculation methods, based on Life Cycle Cost (LCC) and other quantified economic information, for assessing the economic performance of a building, and provides guidelines for reporting and communicating the results of the assessment; it applies to both new and existing buildings as well as those undergoing renovation.

EN 16798-1:2018 - *Energy performance of buildings - Ventilation for buildings - Part 1: Indoor environment input parameters for the design and assessment of the energy performance of buildings with respect to indoor air quality, thermal environment, lighting and acoustics - Module M1-6.*

It specifies the requirements for indoor environmental parameters for the thermal environment, indoor air quality, lighting and acoustics and indicates how to establish these parameters for building system design and energy performance calculation.

CEN/TR 16978-2:2019 - *Energy performance of buildings - Ventilation for buildings - Interpretation of the requirements of EN 16798-1 - Indoor environmental input parameters for the design and assessment of the energy performance of buildings in relation to indoor air quality, the thermal environment, lighting and acoustics (Module M1-6).*

The document deals with indoor environmental parameters for the thermal environment, indoor air quality, lighting, and acoustics. It also explains how to use EN 16798-1 to specify indoor environmental parameters for the design of building systems and the calculation of energy performance and specifies methods for the long-term assessment of the indoor environment obtained as a result of calculations or measurements.

EN ISO 52000-1:2017 - *Energy performance of buildings - Holistic EPB assessment - Part 1: General framework and procedures.*

The standard establishes a systematic, comprehensive and modular framework for assessing the energy performance of new and existing buildings (EPB) in a holistic manner.

EN ISO 52003-1:2017 - *Energy performance of buildings - Indicators, requirements, ratings and certificates - Part 1: General aspects and application to overall energy performance.*

This standard provides private actors and legislative authorities (and all actors involved in the regulatory process) with a general overview of how to use partial and global indicators - derived from procedures for assessing the energy performance of buildings - for different purposes.

EN ISO 52016-1:2016 - *Energy performance of buildings - Energy needs for heating and cooling, indoor temperatures, and sensible and latent heat loads - Part 1: Calculation procedures.*

The standard defines calculation methods for assessing energy needs for heating and cooling (on an hourly or monthly basis), calculation methods for indoor temperatures and for sensible and latent heat loads (on an hourly basis).

EN ISO 52120-1:2022 - *Energy performance of buildings - Contribution of building automation, control and technical management - Part 1: General framework and procedures.*

The standard specifies both a structured list of building control, automation and technical management functions that contribute to the energy performance of the building; the functions have been classified and structured according to the building services and their automation and control (BAC); and a method for defining minimum requirements or any other specifications regarding building control, automation and technical management functions that contribute to its energy efficiency.

4 Methodology

The aim of the Task 2.2 is to enhance EPC schemas through operational data integration. The task is structured in four subtasks:

a. Analysis of 45 representative buildings (case studies)
b. Evaluation of energy efficiency measures
c. Support in the assessment of energy management system
d. Proposal and evaluation of new indicators

Task 2.2 workflow and the connection between subtasks and TDSs are presented in Figure 3.

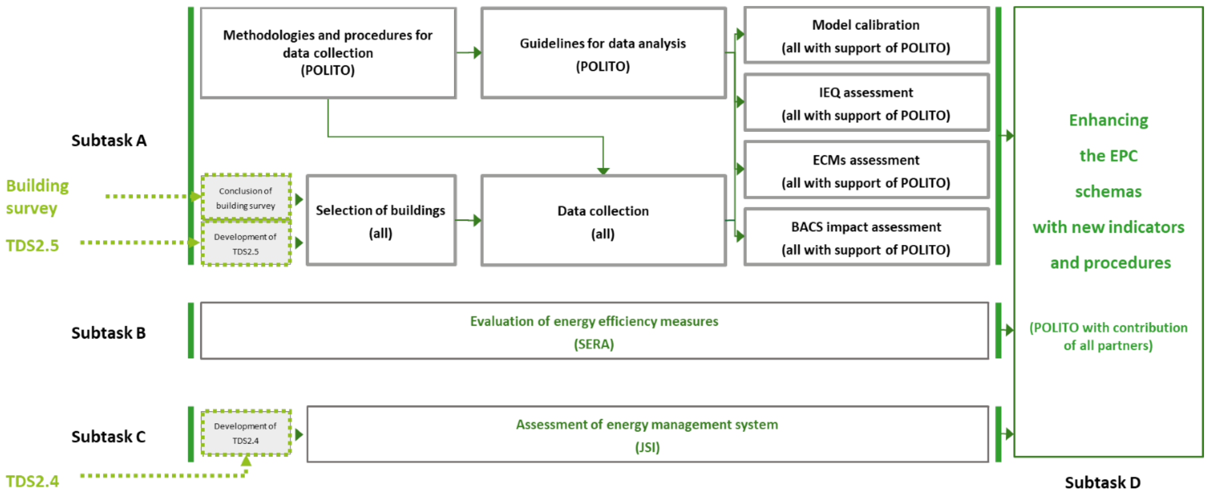

Figure 3. TDS2 workflow and subtasks connection

In this specific case, the focus is on subtask A, in which the objectives are the development of methodologies and procedures for data collection, with consequent drafting of "*Guidelines for data collection*" (Annex A) and "*Guidelines for data analysis*" (Annex B). Data collection takes place after selecting the representative buildings to be analysed based on specific criteria.

Both guidelines are based on the following steps:

- Standard energy performance assessment (SEPA)
- Tailored energy performance assessment (TEPA)
- Building energy model calibration against monitored data (including monthly/seasonal and hourly calibration scenarios) (CAL)
- Evaluation of energy efficiency measures (ECM)
- Indoor environmental quality evaluation –including thermal comfort and indoor air quality– (IEQ)
- Building automation and control system impact assessment (BACS).

The purpose of subtask A, as well as the other subtasks defined above, is to improve EPC schemes through new indicators and procedures.

4.1 Building selection

Following the procedure presented in Section 4, the first step was the selection of the buildings. A survey of possible building to be deployed in WP2 was carried out by all the partners and the findings, divided by nation, were grouped and categorised.

The building selection procedure was pursued deploying a specific tool to allow a comparison between the available buildings and the selection of the most suitable ones for TDS2 analyses. This is composed of 4 sections:

- Item –containing the building identifying code defined in the building survey (Figure 4),
- Building general properties– including the building use category and the period of construction. This latter was defined country by country as a function of the national specificities (Figure 4) and is a result of TDS5 analyses,
- TDS2 relevant parameters availability – containing the availability of data from three main domain, i.e., user schedule, energy, and environment measurements (Figure 5), and
- Representative building relevant parameters compliance – including mean thermal transmittance values for opaque and transparent components. These comes from TDS5 results and were defined for residential representative buildings as a function of the period of construction and the nation (Figure 6).

Item		**Building general properties**	
Identifying code for the building in the building survey	*Note*	*Use category* *List*	*Period of construction* *List*
<Choice from list>	*<Free text>*	*<Choice from list>*	*<Choice from list>*
IT-01		apartment block	1961-1975
IT-02		apartment block	1901-1920
IT-03		apartment block	1961-1975
IT-05		educational building	1961-1975
IT-09		apartment block	> 2005
IT-11		apartment block	1991-2005

Figure 4. Building selection tool (part 1)

TDS2 relevant parameters availability		
Energy measurements *Available (✓)* *Not available (✗)*	*Environment measurements* *Available (✓)* *Not available (✗)*	*User schedules* *Available (✓)* *Not available (✗)*
Yes/No>	*<Yes/No>*	*<Yes/No>*
✗	✗	✗
✗	✗	✗
✗	✗	✗
✗	✗	✗
✓	✓	✓
✓	✗	✗

Figure 5. Building selection tool (part 2)

Representative building relevant parameters compliance						
Mean U value range for external walls		*Compliance with representative building mean U value for external walls* *Compliant (✓)* *Non-compliant (✗)*	*Mean U value range for windows*		*Compliance with representative building mean U value for windoes* *Compliant (✓)* *Non-compliant (✗)*	*Note* *(optional)*
<Fixed value>		*<Yes/No>*	*<Fixed value>*		*<Yes/No>*	*<Free text>*
,1 - 3,4	[$Wm^{-2}K^{-1}$]	✗	Range: 4,9 - 5,7	[$Wm^{-2}K^{-1}$]	✗	
,02 - 2,4	[$Wm^{-2}K^{-1}$]	✓	Range: 4,9 - 5,7	[$Wm^{-2}K^{-1}$]	✗	
,1 - 3,4	[$Wm^{-2}K^{-1}$]	✓	Range: 4,9 - 5,7	[$Wm^{-2}K^{-1}$]	✗	
lot defined	[$Wm^{-2}K^{-1}$]		Range: Not defined	[$Wm^{-2}K^{-1}$]		
,34 - 0,42	[$Wm^{-2}K^{-1}$]	✗	Range: 2 - 2,4	[$Wm^{-2}K^{-1}$]	✗	
,59 - 0,74	[$Wm^{-2}K^{-1}$]	✗	Range: 2 - 3,7	[$Wm^{-2}K^{-1}$]	✗	

Figure 6. Building selection tool (part 3)

4.2 Data collection

The enhancement of the EPC schema through the integration of operational data within Transversal Deployment Scenario 2 (TDS2) was addressed by the proposal of new key performance indicators (KPIs). These were selected from the results of different analyses performed on the selected buildings. All the analyses, which are further detailed in sub-section 4.3, require the development of a building energy model. To this purpose, different input data needs to be collected. Additionally, specific input data are required to conduct various analyses. The following list presents the categories of data to be collected for building energy model creation and analysis execution:

1. **Geographical and climatic data,** required to define the geographical location of the building and of its neighbour (e.g., presence of external obstacles), and the outdoor environmental parameters (e.g., air temperature, solar irradiance, etc.),
2. **Geometrical characteristics**, required to define the dimensions of the building (e.g., floor area, internal height, etc.) and of its components (e.g., external opaque and transparent components, internal partitions),
3. **Thermal properties of building components**, required to define the thermal parameters (e.g., thermal transmittance, thermal capacity, etc.) of the external opaque and transparent components, and of internal partitions,
4. **Technical building systems (TBSs) characteristics**, required to define the presence, typology, and properties of the TBSs for each energy service,
5. **Operating conditions**, required to define the user behaviour in terms of presence in the building/room, control of the TBSs, use of appliances, windows openings, and use of solar shading devices, etc.,
6. **Monitored data on building performance**, including indoor environmental data, performance parameters of the TBS components, and energy consumptions for each energy service and/or energy carrier,
7. **Economic data** in terms of cost of each energy carrier and cost of refurbishment.

In Annex A the main procedures for the data collection are explained.

4.3 Data analysis methods and tools

By assessing the selected buildings, it is possible to achieve the objective of TDS2, which is to improve EPC schemes through the integration of operational data and the introduction of new key performance indicators. In particular, the following analyses were carried out:

1. Standard energy performance assessment (SEPA),
2. Tailored energy performance assessment (TEPA),
3. TEPA calibration against monitored data (CAL),
4. Economic evaluation of energy efficiency measures (ECM),
5. Indoor environmental quality evaluation (IEQ),
6. Building Automation and Control System impact assessment (BACS).

All the analysis to be performed require the creation of a building energy model.

The following paragraphs will explain the methods and tools specific to each analysis performed.

4.4 Standard/tailored energy performance assessment

The evaluation of the two methods - standard and tailored - starts with the development of an energy model of the building. The input data required for the creation of the building energy model are listed and described in the "Annex A" of this deliverable.

For these assessments there are not specific mandatory tool, but we referred to specific standards: EN ISO 52016-1, EN ISO 52000-1, and EN ISO 52003-1.

4.5 Model calibration

The process of calibrating a building energy model involves adjusting the simulation inputs to closely align the predicted energy consumption (or environmental parameters) with the observed values. The suggested approach is a manual calibration method that involves iteratively modifying the model parameters affected by uncertainties. These parameters can be adjusted individually or in combination. The overall workflow for calibrating the building energy model is illustrated in Figure 7.

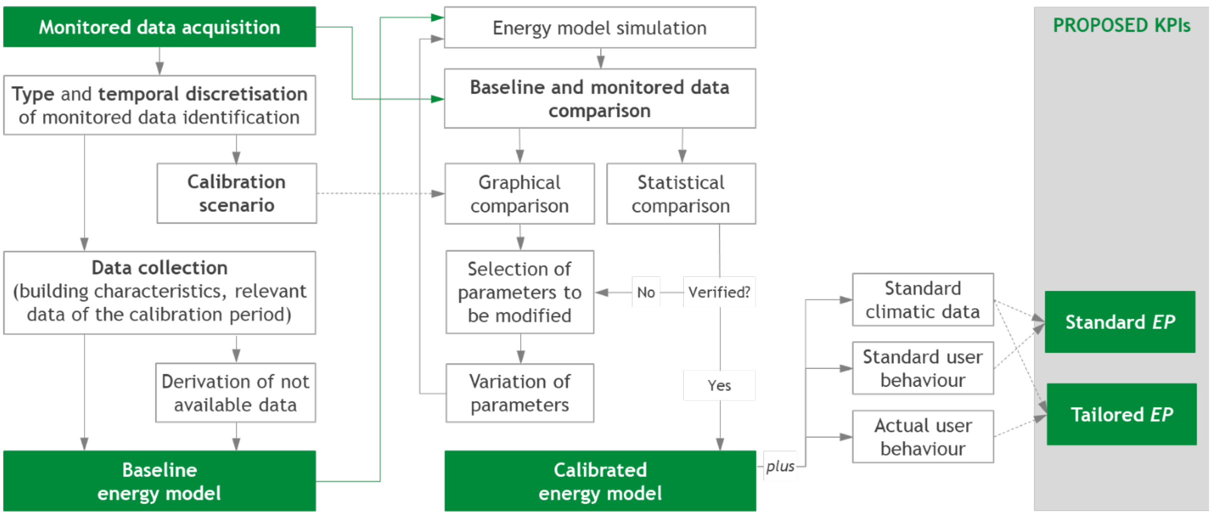

Figure 7. Building energy model calibration workflow

Before implementing the manual calibration procedure, several preliminary steps are necessary. These steps include:

1. Analysis of the available monitored data
2. Identification of the calibration scenario
3. Selection of the calibration period
4. Creation of the building energy model

More details about model calibration, the description of the preliminary phases, and the show of the scenarios are described in point B3 of Annex B of this deliverable.

4.6 IEQ assessment

Indoor Environmental Quality (IEQ) refers to the overall conditions and characteristics of the indoor environment within a building, specifically related to the well-being, comfort, and satisfaction of its occupants. It encompasses various factors that can affect the indoor environment, including air quality, thermal comfort, lighting, acoustics, and ergonomics. IEQ plays a crucial role in occupant health, productivity, and overall satisfaction in indoor spaces.

Two different domains are considered for the indoor environmental quality (IEQ) assessment: thermal comfort and indoor air quality (IAQ).

The IEQ assessment will be carried on following the procedures specified in EN ISO 16798-1 and CEN/TR 16798-2.

Standard preliminary phases are necessary for all the IEQ domains under consideration. These steps involve:

1. Selection of representative spaces of the considered building
2. The IEQ assessments were carried out on representative spaces, which can be individual rooms or thermal zones
3. Identification of the IEQ comfort category

According to the intended use, an IEQ comfort category (EN ISO 16798-1) is associated to each of the chosen representative spaces.

4.6.1 Thermal comfort

The assessment of IEQ is based on the adaptive comfort theory, which assumes that occupants of a non-air-conditioned environment tend to adapt if they can freely operate micro-climate control according to their own habits. Therefore, it can be applied only to buildings without mechanical cooling.

The evaluation will be carried out considering a standard (standard weather data and users) or a tailored (standard weather data and actual users) energy model. Both standard and tailored models can be created starting from the calibrated energy model (if available).

After the preliminary steps, the evaluation of thermal comfort according to the adaptive theory consists of the following steps (Figure 8):

1. Selection of the evaluation period
2. Calculation of the running mean outdoor temperature
3. Definition of the operative temperature comfort range
4. Calculation of the thermal comfort index
5. Definition of the thermal comfort quality index (proposed KPI)

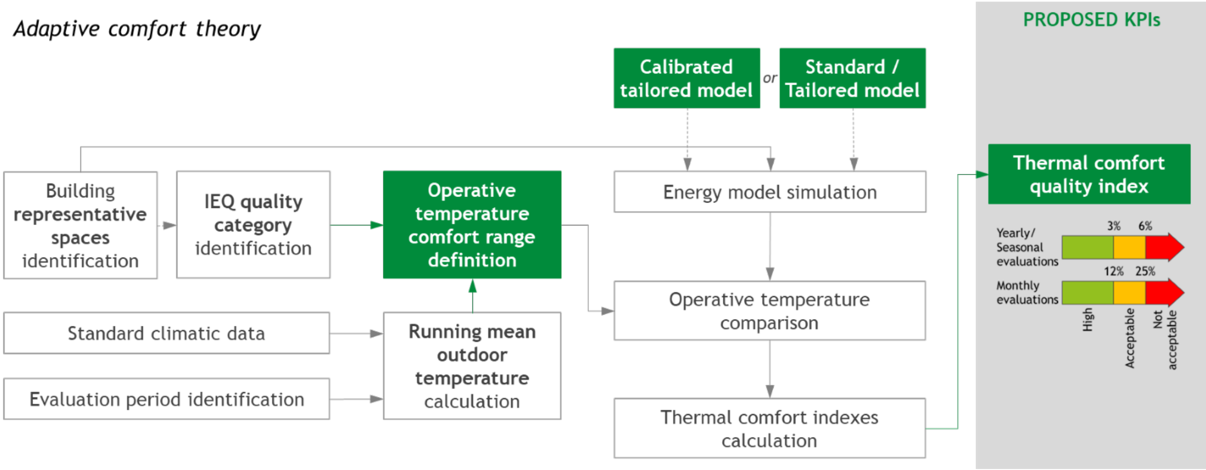

Figure 8. Thermal comfort assessment procedure

More details about the thermal comfort assessment and its outputs are described in point B5.1 of Annex B of this deliverable.

4.6.2 Indoor air quality assessment

The indoor air quality evaluation was carried out as a simple comparison between the actual external air flow rate (which can be either measured or a design value) with the minimum to guarantee the indoor air quality. This will be automatically calculated within an MS Excel file provided by POLITO (uploaded to the SharePoint platform), following the specification of EN ISO 16798-1 (method A).

For each representative space, the inputs required are:

- Comfort category (defined as specified above)
- Intended use
- Building polluting level
- Conditioned net floor area
- Conditioned net volume
- Number of occupants
- Measured or design external air flow rate

More details about the indoor air quality assessment and its outputs are described in point B5.2 of Annex B of this deliverable.

4.7 Economic evaluation of energy efficiency measures

The economic evaluation of the energy efficiency measures is carried out analysing the building in the original state (baseline) and the various scenarios of energy efficiency measures (EEMs) following these steps:

1. Determination of the general parameters,
2. Determination of the specific case parameters,
3. Calculation of economic cost analysis indicators.

In Figure 9, the above steps are detailed.

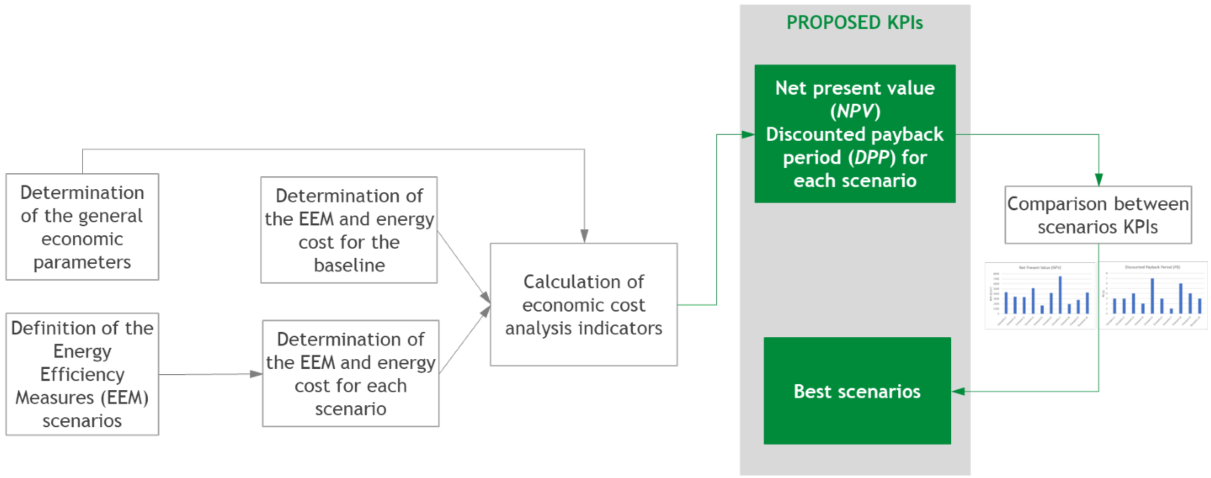

Figure 9. Economic evaluation of energy efficiency measures workflow

The analysis is performed with a calculation period of thirty years and the economic indicators are calculated from a financial perspective according to EN 15459-1.

More details about the indoor air quality assessment and its outputs are described in point B4 of Annex B of this deliverable.

4.8 BACS impact assessment

To determine the building automation and control system (BACS) impact, the proposed procedure focuses on specific function determined using the following procedure, as presented in Figure 10.

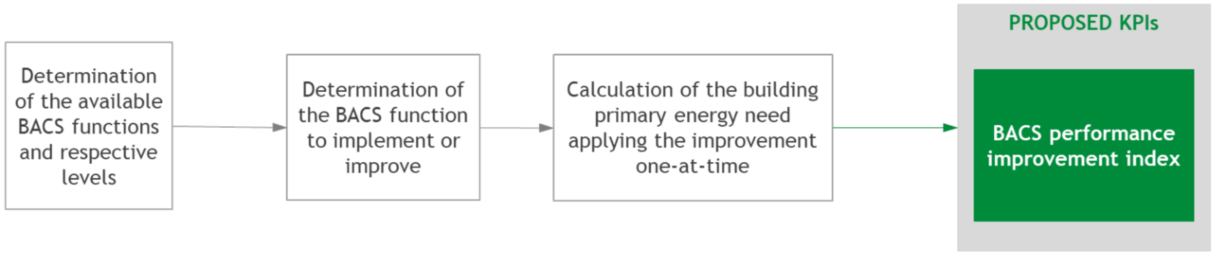

Figure 10. Evaluation of BACS impact workflow

For the assessment of BACS impact, reference is made to EN ISO 52120-1.

For further details on the methodology used for BACS refer to Section B6 of Annex B of this deliverable.

5 Application

In this section the options deployed for the application of the proposed methods is presented for each partner.

5.1 Data collection

In the following sections the application of the data collection methods is presented. The buildings defined through the building selection procedure are briefly described. A brief explanation of the collection procedures is outlined as well.

5.1.1 Austria

The original plan was to analyse five multi-unit residential buildings in the province of Salzburg. However, in order to better meet the objectives of TDS2 and the requirements for the data, the range of building types and also the range of provinces is expanded (Salzburg, Carinthia, Lower Austria). In terms of conclusions for the EPC scheme, this leads to an advantage regarding the dissemination of project results because 6 of 9 federal states now use the ZEUS EPC database, including the province of Lower Austria since 1 July 2022.

Aware that access to data is a major challenge, case study buildings with good documentation were selected from voluntary building certification and research projects. With the resources available in the project, it was not possible to undertake more extensive primary data collection apart from interviews and site visits. However, the available monitoring data was provided in a form that was not very useful for the project, and in one case the original commitment was cancelled for personal data protection reasons.

In contrast to other TIMEPAC partner countries, energy audit reports are only available for large non-residential buildings and not at all for most buildings. The reason is that energy audits are covered by the legislation related with the Energy Efficiency Directive, which is transposed at federal level, while the technical part of the Energy Performance of Buildings Directive is transposed as part of the building regulations at province level.

Inspection reports of technical building systems are not accessible because inspections are carried out under the Clean Air Act, which is the responsibility of another department of the province administration, and there is no link between the different databases.

In the ZEUS EPC database, metered data can be stored in addition to the EPC. The original idea was to identify buildings with energy performance certificates and measured energy data in the database and compare the energy data. This had to be abandoned due to concerns about personal data protection. However, it also turned out that the possibility to store measured energy consumption data together with the energy performance certificate is not often used, or only under certain conditions in connection with a subsidy.

The data uncertainty levels of the data sources as shown in Table 1 based on the reference provided by TIMEPAC and adjusted to the specific situation of the Austrian case study. Level 1 represents the maximum uncertainty. In Table 2 the uncertainty levels for the not available data are presented.

Table 1. Data uncertainty levels – Available data

	Datum source	Way of determination		
		C	M	T
Available data	Interview	-	3	-
	Building energy design verification report (corresponds with completion EPC)	3	3	1
	XML database	3	3	1
	EPC	3	3	1
	EPC database: metered energy consumption	-	3	-
	Open access database: baubook (materials and building products database)	2	3	-
	BIM model (for AT-04, AT-06, AT-08 as part of TIMEPAC)	2	3	-
	Technical descriptions	3	3	-
	Research reports	3	3	-
	Documentation from voluntary building assessments	2	3	-
C = calculation, M = measurement, T = tabulated values				

Table 2. Data uncertainty levels – Not available data

	I	D	Ts	Ti
Not available data	3	2	1	1
D = derived from other data, I = interviews, Ts = tabulated values from standards, Ti = tabulated values from inference rules				

A detailed description of data used is provided in the paragraphs below.

Geographical data are determined by the address and the GIS -portal, "*Geoinformationssystem*" (e.g., KAGIS for Carinthia, SAGIS for Salzburg). The presence and characteristics of external shading obstacles (height and position) is determined by means of project documentation and site visit. Possible future developments are checked by means of interviews with owners and by consulting the municipal development plan and in particular the land use plan (zoning plan) for the building site.

Climatic regions and climate data models are defined by Austrian Standard ÖNORM B 8110-5 and are part of the EPC calculation software (Thermal insulation in building construction — Part 5: Model of climate and user profiles). Aggregated climatic data (heating degree days, cooling degree days) are also included in the EPC calculation software. Tables for municipalities are also available as part of the training material provided for energy advisors[2]. Weather data and climatic data are available from Geosphere Austria[3].

Geometrical characteristics are collected based on existing EPCs, technical documentation, and site visits.

Thermal properties of opaque and transparent building components based on layers and materials are identified based on existing EPCs and technical documentation submitted as part of the *klimaaktiv* buildings declaration which is a green building assessment like Level(s). Since many years, *klimaaktiv* has been the official national climate protection programme of the Austrian government[4]. Characteristics of materials are available in the *baubook* database which is also connected with the officially approved EPC calculation software programmes[5].

Technical building systems (TBSs) characteristics: While the building envelope with all its properties can be mapped very well in the energy performance certificate, the input options for the technical building systems are still incomplete for energy-efficient new developments and deep renovations. Therefore, the existing EPC alone will not provide sufficient information. Additional documentation such as submission documents for the *klimaaktiv* declaration or technical reports prepared within the framework of funding or research projects are consulted. Especially new real estate developments or ambitious renovations with very energy-efficient building envelopes make use of energy supply concepts that use innovative technologies, function at neighbourhood level and are operated by ESCOs (Energy Service Companies).

Operating conditions: User profiles are defined by Austrian Standard ÖNORM B 8110-5 and are part of the EPC calculation software (Thermal insulation in building construction — Part 5: Model of climate and user profiles). Actual operating conditions can be determined for building uses with a clear user profile (in terms of occupancy, operating hours, and indoor temperature) such as an educational building (Kindergarten). Determination of actual operating conditions is difficult for multi-unit residential buildings, as tenants and user behaviour change, as well as user occupancy and user behaviour of the same tenants over time (visitors, growing children, children moving out, pets, fluctuation of family income).

Monitored data on building performance are collected based on research reports done for other projects or as part of a funding requirement.

Economic data - Specific cost for each energy carrier: The economic crisis following the COVID-19 pandemic and the war in Ukraine has changed the price structure completely and estimates are difficult. This is also true for specific cost of energy efficiency measures (EEMs, see paragraph below). Cost information for energy carriers is included in the EPC calculation software and available from E-Control[6].

Economic data - Specific cost of different energy efficiency measures (EEMs): In Austria, BKI – *das Baukosteninformationszentrum Deutscher Architektenkammern*[7] can be used for orientation. However, isolated energy efficiency measures are not listed, but types of renovations, considering

[2] https://arge-eba.net

[3] https://www.geosphere.at/

[4] https://www.klimaaktiv.at/bauen-sanieren.html

[5] https://www.baubook.info/en/welcome-to-baubook?set_language=en

[6] https://www.e-control.at/

[7] https://bki.de/

the general condition of the building before renovation. This is reasonable, because in badly maintained buildings, other repair works must be carried out before energy efficiency measures can be implemented. This backlog in maintenance and repair is a big challenge in providing realistic cost estimates for implementing energy efficiency measures in existing buildings. Cost information for isolated energy efficiency measures is included in the EPC calculation software, and cost data for orientation are also included in the material provided for energy advisors. However, even before the economic crisis, price estimates were problematic because in tenders the offers were normally in a range with 25% fluctuation.

Finally, the Austrian buildings analysed are shown in Table 3.

Table 3. Austrian buildings analysed

Building code	Use category	Period of construction	Building type	Conditioned floor area [m^2]	Building energy services
AT-01	Apartment block	2016-2021	Multifamily building	1912	H, W, V, L
AT-04	Apartment block	1976-1990	Multifamily building	873	H, W, V, L
AT-06	Educational building	1976-1990	Kindergarten	1120	H, W, V, L
AT-07	Educational building	1976-1990	Dormitory of a boarding school	618	H, W, V, L
AT-08	Educational building	Up to 1900	Event/seminar centre	330	H, W, L
H = heating, C = cooling, W = domestic hot water, V = ventilation, L = lighting					

5.1.2 Croatia

Implementing the described methodology for data collection posed several challenges, requiring additional work beyond the standard energy auditing and EPC process. One of the primary challenges was obtaining access to relevant data. Building owners or managers may not always have readily available data, such as historical energy consumption records, building plans, or equipment specifications. Obtaining data from multiple sources and in different formats can be time-consuming and necessitate coordination with various stakeholders.

The TIMEPAC process required data from various sources, as mentioned earlier. Integrating data from different systems and formats proved to be challenging due to variations in data protocols, units, and time intervals. Data integration efforts involved data cleansing, transformation, and standardisation to ensure compatibility and consistency. The required data was primarily derived from measurements (energy bills), followed by data stated in the EPC and energy audit reports, and if necessary, additional interviews with building owners and users.

The accuracy and completeness of the collected data were crucial for reliable energy auditing. Inaccurate or incomplete data can lead to incorrect assessments and recommendations. Some data, such as occupancy patterns, weather conditions, or equipment performance, had to be estimated or directly measured, introducing uncertainties. It is important to emphasise that data collection in energy auditing involves handling sensitive information related to building operations and occupant behaviour. Ensuring privacy and data security is essential to safeguard the confidentiality of personal and proprietary information. Compliance with data protection regulations, implementing secure data transmission and storage practices, and obtaining informed consent from occupants are vital considerations.

Incomplete or missing data can significantly impact the accuracy of energy audits. Data gaps can occur due to equipment malfunctions, data transmission errors, or the lack of historical records. Identifying missing data and taking appropriate steps to fill those gaps is important. This may involve the use of estimation techniques, statistical analysis, or additional measurements. Estimation techniques were primarily used for occupancy patterns and equipment runtime, while weather data was estimated based on historical trends. Human error during data collection, entry, or processing can also affect data accuracy. To minimise the risk of errors, data from energy audits and EPC reports were cross-checked against expected values, and any deviations were verified with building owners. The accuracy of data can be enhanced through verification processes, and the previously described methodology was employed to address uncertainty levels.

When selecting buildings for TDS2 analysis, the following procedure was applied. Firstly, a variety of buildings with different uses were chosen, including at least one residential and several non-residential buildings. For residential buildings, the single-family house was chosen since collecting energy bills in multi-apartment buildings is nearly impossible. The next step involved considering the available data from previously developed documents such as building drawings, EPC reports, energy audits, BEMs, BIMs, and others, along with their quality. This assessment was conducted qualitatively as introducing numerical weighting was challenging. Lastly, the potential for obtaining additional data and the response time for acquiring that information were taken into account. The implemented process allowed for flexibility in possible approaches and the performance of different methodologies and analysis variances.

Ultimately, the data collection efforts were resource-intensive in terms of time, personnel, and equipment but were kept within reasonable limits. This expanded on the standard energy auditing time consumption and resource usage by improving the reliability and consistency of data and results while optimising input efforts and output outcomes.

Table 4 presents the levels of data uncertainty for available data, focusing on the case of Croatia, while Table 5 displays the levels of data uncertainty for not available data.

Table 4. Data uncertainty levels – Available data: case for Croatia

	Datum source	Way of determination		
		C	M	T
Available data	Energy audit report	3	3	1
	Interview	-	2	-
	Inspection report	2	3	1
	Building energy design verification report	3	3	1
	XML database	3	3	1
	EPC	3	3	1
	BIM model	3	3	1
	BEM model	3	3	1
	Other	-	-	-
C = calculation, M = measurement, T = tabulated values				

Table 5. Data uncertainty levels – Not available data

	I	D	Ts	Ti
Not available data	3	2	1	1
D = derived from other data, I = interviews, Ts = tabulated values from standards, Ti = tabulated values from inference rules				

The data collection procedure was applied to 5 Croatian buildings, as shown in Table 6. These buildings differ in terms of use category, construction period, envelope, and technical systems features.

Table 6. Croatian buildings analysed

Building code	Use category	Period of construction	Building type	Conditioned floor area [m^2]	Building energy services
HR-01	Offices	1975	Office	2061	H, C, W, L
HR-02	Educational buildings	1972	Kindergarten	1048	H, C, W, L
HR-03	Other buildings	1906	Library	2028	H, C, W, L
HR-04	Single-family house	2012	Single-family house	150	H, C, W, L
HR-05	Educational buildings	1976	Primary school	3446	H, C, W, L
H = heating, C = cooling, W = domestic hot water, L = lighting					

5.1.3 Cyprus

Data Collection Sources

Our data collection sources are shown in Table 7.

Table 7. Analysed buildings in Cyprus

TIMEPAC Code	Building usage	Build year	Heated floor area [m^2]	Data collection resources	Building use
CY-01	Primary school Aglatzia	2007-2013	1297,98	EPC, Energy audit, electricity bills, building drawings, smart meters	educational building
CY-02	Primary school Lakatamia	1981-2006	1760,82		educational building
CY-03	CEA offices Building 1	≤1980	173,00		offices
CY-04	CEA offices Building 2	≤1980	169,00		offices
CY-05	Primary school Larnaca(Leivadia)	1981-2006	792,48		educational building

Data of the buildings were collected from:

- Energy Audits done on previous projects,
- We created energy models for the Cyprus Energy Agency buildings from scratch and collected data from there (using the software mentioned above),
- Some of the building drawing plans we had received had inaccuracies which we had to redo to correctly calculate the building geometry.

Data were also received from:

- Interviews with building managers, building owners and employees (i.e., for heating methods in schools),
- EPC Reports, Energy Audits (if available), electricity bills, electricity smart meters and temperature and humidity sensors (internal readings),
- External temperatures collected from https://statics.teams.cdn.office.net/evergreen-assets/safelinks/1/atp-safelinks.html.

Data Collection Difficulties

For the data collection we encountered difficulties in finding the measured data for the indoor hourly temperatures and hourly power consumptions. For example:

- In the case of the school buildings (CY-01, CY-02, CY-05), we only had values for a few weeks,
- In the case of the CEA buildings (CY-03, CY-04), we had values for the electric consumption for last three months and for the indoor temperatures for ten months.

It is important to state that the collection of the data, analysis and transformation into meaningful and usable data was a time-consuming process. The measurements from most of meters and sensors were typically collected every minute (or in irregular patterns) and part of our analysis and a transformation procedure was to convert them into hourly measures.

The data uncertainty levels of the data sources as shown in Table 8 based on the reference provided by TIMEPAC and adjusted to the specific situation of the Cypriot case study. Level 1 represents the maximum uncertainty.

Table 8. Data uncertainty levels – Available data; case for Cyprus

	Datum source	Way of determination		
		C	M	T
Available data	Energy audit report	3	3	1
	Interview	-	1	-
	Inspection report	2	2	2
	Building energy design verification report	2	2	1
	XML database	3	3	1
	EPC	3	3	1
	BIM model	3	3	1
	Other	-	-	-
C = calculation, M = measurement, T = tabulated values				

5.1.4 Italy

The selection of buildings for TDS2 analysis was carried out according to the following procedure.

First, different buildings were chosen different from use purposes, construction period and systems type. The next step was to examine the available information from previous documents, such as drawings of buildings, EEC reports, audits of energy efficiency, BEMs, BIM, and other documents, and their quality, and to determine the quality of the data. Ultimately, the possibility of obtaining supplementary data and the response time for obtaining that information were taken into consideration. The implementation process allowed flexibility in the possible approaches, and in the performance and analysis of different methods and analyses. The availability of operational data was considered as the most important parameter in the building determination process, due to its relevance for TDS2 analyses.

The first step in the data collection was the analysis of the possible input data following the procedures currently in force in Italy and Europe. These procedures are detailed in Section 5.2.4

In case of available data, for each combination of datum source and way of determination, a data uncertainty level was defined, as a function of the typical Italian source features, and is presented in Table 9. Following the same procedure, in case of data not available but useful for TDS2 analyses, four possible content derivation procedures were determined along with a level of uncertainty, as presented in Table 10.

The data uncertainty level thus defined was used as a reference and in some case changed in function of the specificity of the analysed building.

Table 9. Data uncertainty levels – Available data

	Datum source	Way of determination		
		C	M	T
Available data	Energy audit report	3	3	1
	Interview	-	3	-
	Inspection report	2	3	1
	Building energy design verification report	2	3	1
	XML database	3	3	1
	EPC	3	3	1
	Open access database	2	3	1
	BIM model	3	3	1
	Other	-	-	-
C = calculation, M = measurement, T = tabulated values				

Table 10. Data uncertainty levels – Not available data

	I	D	Ts	Ti
Not available data	3	2	1	1
D = derived from other data, I = interviews, Ts = tabulated values from standards, Ti = tabulated values from inference rules				

The data collection procedure was applied to 10 Italian buildings.

These are presented in Table 11, and differ for use category, construction period, envelope and technical systems features. The buildings were defined from the available ones defined in a building survey from the Italian partners.

Table 11. Italian buildings analysed

Building code	Use category	Period of construction	Building type	Conditioned floor area [m^2]	Building energy services
IT-01	Apartment block	1961-1975	Mid-rise condos	5974	H, W, L
IT-02	Apartment block	1901-1920	Mid-rise condos	2018	H, W, L
IT-03	Apartment block	1961-1975	Mid-rise condos	6449	H, W, L
IT-05	Educational building	1961-1975	Low-rise school building	1306	H, W, L
IT-09	Apartment block	> 2005	Apartment block	820	H, C, W
IT-11	Apartment block	1991-2005	Apartment block	3500	H, W
IT-12	Educational building	1961-1975	School	669	H, W, L
IT-13	Educational building	1961-1975	School	3693	H, W, L
IT-14	Educational building	1961-1975	School	3154	H, W, L
IT-15	Educational building	1991-2005	School	1674	H, W, L
H = heating, C = cooling, W = domestic hot water, L = lighting					

5.1.5 Slovenia

The implementation of the described method of data collection presented several challenges and required additional work in addition to the standard process for energy audits and the EPC creation process. One of the primary challenges was obtaining additional data that enable to create detailed models. Building proprietors or overseers may not always possess immediate data, such as past energy utilisation records, building sketches, or equipment specifications. Data from a variety of sources and formats can take a long time and require coordination with the various stakeholders involved.

The integration of data from a variety of systems and data formats was a challenge due to the differences in data protocol, units and time periods. Data integration efforts included data cleansing and transformation, as well as standardisation, in order to ensure compatible and consistent data. The required data were primarily obtained from the energy bills, which were followed by the data contained in the Energy Audit Reports and, when necessary, further interviews with the owners of the building and the users of the building.

The accuracy and totality of the data collected were crucial to a reliable audit of energy consumption. Inaccuracies or incomplete information can lead incorrectly to the assessment and recommendation. Some data, e.g., patterns of occupancy, weather or performance of equipment, were estimated or measured directly, thereby introducing uncertainty. It is important that the collection of data in the context of energy audits involves the handling of sensitive information relating to the operation of the building and the behaviour of the occupants. Compliance with the Data Protection Regulations, the implementation of secure data storage and transmission practices and the obtaining of the informed consent of the occupant are vital factors.

Incomplete or missing information can significantly affect accuracy of audits of energy consumption. Data gaps can arise due to malfunctions in equipment, transmission errors or the absence of historical data. Estimation methods, statistical calculations, or more observations might be required. The estimation techniques were used primarily for the pattern of occupancy and the running time of the equipment, while the weather data were estimated on the basis of historical data. The accuracy of the data can improve through the verification process and the above-described methodology was used to address the level of uncertainty.

The selection of buildings for TDS2 analysis was carried out according to the following procedure:

First, different buildings were chosen for different use purposes. The focus was on non-residential buildings, since a sufficient amount of data can be gained for those. The next step was to examine the available information from previous documents, such as drawings of buildings, EEC reports, audits of energy efficiency, BEMs, BIM, and other documents, and their quality, and to determine the quality of the data. Ultimately, the possibility of obtaining supplementary data and the response time for obtaining that information were taken into consideration. The implementation process allowed flexibility in the possible approaches, and in the performance and analysis of different methods and analyses.

The first step in the data collection was the analysis of the possible input data following the procedures currently in force in Slovenia. These procedures are described in section 5.2 In the case of the availability of data, the uncertainty level of the datum source and way of determination was defined for each of the combinations of the datum source and way of determination in relation to the data source, which was based on the characteristic Slovenian sources, as described in Table 12. In the same way, in the case of not available data, but useful to TDS2, four possible methods for the determination of the content were determined, along with the uncertainty level as described Table 13.

The data uncertainty level thus defined was used as a reference and in some case changed in function of the specificity of the analysed building.

Table 12. Data uncertainty levels – Available data; case for Slovenia

	Datum source	Way of determination		
		C	M	T
Available data	Energy audit report	3	3	1
	Interview	-	3	-
	Inspection report	2	3	1
	Building energy design verification report	2	3	1
	XML database	3	3	1
	EPC	3	3	1
	BIM model	3	3	1
	Other	-	-	-
C = calculation, M = measurement, T = tabulated values				

Table 13. Data uncertainty levels – Not available data

	I	D	Ts	Ti
Not available data	3	2	1	1
D = derived from other data, I = interviews, Ts = tabulated values from standards, Ti = tabulated values from inference rules				

The data collection procedure was applied to 10 Slovenian buildings. These, as presented in Table 14, differ for use category, construction period, envelope and technical systems features.

Table 14. Analysed buildings in Slovenia

TIMEPAC Code	Building usage	Build year	Heated floor area [m^2]	Data from	BEM
SI-01	School	1976	3174	Energy audit, EPC, building design documentation	Yes, hourly in IDA ICE and monthly in KI Energija
SI-02	Health care facility	1980	3630		Yes, hourly in IDA ICE and monthly in KI Energija

SI-03	Office building	1956	605		Yes, hourly in IDA ICE and monthly in KI Energija
SI-04	School	1880	501		Yes, hourly in IDA ICE and monthly in KI Energija
SI-05	School	1675	2527		Yes, hourly in IDA ICE and monthly in KI Energija
SI-06	School	1954	1066		Yes, hourly in IDA ICE
SI-07	Kindergarten	1960	470		Yes, hourly in IDA ICE
SI-08	School	1960	3977		Yes, hourly in IDA ICE and monthly in KI Energija
SI-09	Cultural home	1928	325		Yes, hourly in IDA ICE
SI-10	School	1980	681		Yes, hourly in IDA ICE

5.1.6 Spain

As mentioned before in the Italian case, the first step in the data collection was the analysis of the possible input data following the procedures currently in force in Spain and Europe. These procedures are detailed in Section 5.2.6. In the case of available data, for each combination of datum source and way of determination, a data uncertainty level was defined, as a function of the typical Spanish source features, as presented in Table 15. In Table 16 the uncertainty levels for the not available data are presented.

The implementation of the described data collection method posed several challenges and necessitated extra effort beyond the standard procedures for the EPC creation. A key obstacle revolved around acquiring supplementary data to develop comprehensive models. Building owners or managers may not always have readily available information, such as historical energy usage records, or equipment specifications. Gathering data from diverse sources and formats can be time-consuming and necessitate coordination with multiple stakeholders. Regarding energy consumption, the required data were primarily obtained from the energy bills, followed by data already contained in some of the EPCs and, moreover, further interviews with the owners of the building and the users of the building. In order to enhance our comprehension of the building itself, site visits were carried out in selected buildings, providing us with a broader perspective and deeper insights. Due to the unavailability of certain data, three buildings were modified as elaborated in the subsequent section to conclude the study.

The data uncertainty level thus defined was used as a reference and in some cases changed in function of the specificity of the analysed building.

Table 15. Data uncertainty levels – Available data

	Datum source	Way of determination		
		C	M	T
Available data	Energy audit report	3	3	-
	Interview	3	3	1
	Inspection report	3	3	1
	Building energy design verification report	3	3	1
	XML database	2	3	1
	EPC	3	3	1
	BIM model	3	3	1
	Other	-	-	-
C = calculation, M = measurement, T = tabulated values				

Table 16. Data uncertainty levels – Not available data

	I	D	Ts	Ti
Not available data	3	2	1	1
D = derived from other data, I = interviews, Ts = tabulated values from standards, Ti = tabulated values from inference rules				

The selection process for the buildings involved considered the opportunity to choose diverse building types from various construction periods, thereby ensuring a broader spectrum and increased diversity in the study. There were several factors considered when selecting these buildings. Firstly, a primary criterion was the availability of data that we could gather from the owners, particularly real data on consumption patterns. Secondly, we aimed to incorporate a diverse range of uses, including educational institutions, office spaces, nursing homes, and residential areas. Lastly, in order to make the project more captivating, we took into account the inclusion of buildings constructed in different years, showcasing a variety of architectural styles and historical contexts.

Furthermore, a crucial aspect of the potential data collection led to modifications in the initially chosen buildings. Finally, an enriched analysis was achieved by incorporating buildings from different climatic zones into the study. The following Table 17 summarises the buildings selected.

Table 17. Spanish buildings analysed

Building code	Use category	Period of construction	Building type	Conditioned floor area [m^2]	Building energy services
ES-01	Educational building	2016-2021	School building	2279	H, C, W, L
ES-02	Offices	2016-2021	Office	4316	H, C, W, L
ES-03	Home for the elderly	2016-2021	Home for elderly and disabled people	3577	H, C, W, L
ES-04	Apartment block	1976-1990	Apartment block	627	H, C, W, L
ES-05	Apartment block	1921-1645	Apartment block	360	H, C, W, L
ES-06	home for the elderly	2006-2015	Nursing home	1924	H, C, W, L
ES-07	Apartment block	2023	Apartment block	3223	H, C, W, L

ES-08	Apartment block	1961-1975	Apartment block	2352	H, C, W, L
ES-09	Apartment block	1961-1975	Apartment block	2355	H, C, W, L
ES-10	Apartment block	Up to 1900, refurbished 2022	Apartment block	774	H, C, W, L
H = heating, C = cooling, W = domestic hot water, L = lighting					

5.2 Data analysis

In the following sections the application of the data analysis methods is presented. For each of the six proposed analyses the applied procedures are detailed for each partner; the specific analysis performed for each of the analysed building is presented as well.

5.2.1 Austria

Standard energy performance assessment (SEPA) and Tailored energy performance assessment (TEPA): The energy model for the EPC is based on a standard user behaviour by law. The model is adjusted during energy advisory and renovation planning in a module of the EPC software. The adjusted model is not a valid EPC. The relevant standards for SEPA and TEPA are presented in Table 18.

Table 18. Relevant standards for SEPA and TEPA

Object	Standard(s) (official English translation)
Climate model and occupancy	ÖNORM B 8110-5 Thermal insulation in building construction — Part 5: Model of climate and user profiles
Energy demand for heating and cooling (useful energy)	ÖNORM B 8110-6-1 Thermal insulation in building construction — Part 6-1: Principles and verification methods — Heating demand and cooling demand
Energy demand for ventilation technology (useful energy)	ÖNORM H 5057-1 Energy performance of buildings — Part 1: Energy use for ventilation systems of residential and non-residential buildings
Energy needs (Energy performance factor and final energy requirements based on reference equipment, as well as primary energy demand and carbon dioxide emissions) (final energy)	ÖNORM H 5050-1 Energy performance of buildings — Part 1: Calculation of the energy performance factor
Energy need for heating (final energy)	ÖNORM H 5056-1 Energy performance of buildings — Part 1: Energy use for heating systems
Energy need for cooling (final energy)	ÖNORM H 5058-1 Energy performance of buildings — Part 1: Energy use for cooling systems
Energy need for lighting (final energy)	ÖNORM H 5059-1 Energy performance of buildings — Part 1: Energy use for lighting (National amendment referring to ÖNORM EN 15193) — Fast track procedure

SEPA was done with the Hottgenroth ETU Software package covering EPC calculation tools for all Austrian provinces according to regional legislations. TEPA was done by means of the same software package which includes the so-called energy advisory module. The set-up is similar like the EPC calculation tool, but standard conditions can be changed, and consumption values can be considered.

Cype software tools were tested for comparison, also regarding the tasks T2.1 and T2.3. It is not a business-as-usual procedure to perform hourly simulation for small and medium sized buildings. Hourly simulations are usually only done in research projects and for large complex buildings. Hottgenroth ETU Software is based on the monthly method.

TEPA calibration against monitored data (CAL): The suggested procedure according to guidelines for data analysis was applied only for one building because monitoring data collected for other buildings were not in a suitable format.

Monitoring versus EPC performance is being used to detect deficiencies (technical and user behaviour) after handing over a new building or after completion of a deep renovation. Monitoring is required as part of funding schemes, the *klimaaktiv* declaration, and as part of research projects.

Indoor environmental quality evaluation (IEQ): Thermal Comfort and Indoor Air Quality: Thermal comfort is not assessed because the monthly method is applied. Indoor Air Quality is assessed based on the guidelines for data analysis.

The economic evaluation of energy conservation measures (ECM) is carried out according to guidelines for data analysis.

Building Automation and Control System impact assessment (BACS) is carried out according to guidelines for data analysis. The actual energy consumption data from the monitoring report are used, before and after improving the BACS functionality.

For the selected buildings, the types of data analysis are applied as shown in Table 19.

Table 19. Analyses performed on the Austrian buildings

Item	Building general properties		Performed analyses					
Identifying code for the building in the building survey	*Use category* *List*	*Period of construction* *List*	*SEPA* *Performed (✓)* *Not feasible (✗)*	*TEPA* *Performed (✓)* *Not performed (✗)*	*CAL* *Performed (✓)* *Not performed (✗)*	*IEQ* *Performed (✓)* *Not performed (✗)*	*ECM* *Performed (✓)* *Not performed (✗)*	*BACS* *Performed (✓)* *Not performed (✗)*
<Choice from list>		*<Choice from list>*	*<Yes/No>*	*<Yes/No>*	*<Yes/No>*	*<Yes/No>*	*<Yes/No>*	*<Yes/No>*
AT-01	apartment block	>2010	✓	✓	✓	✓	✗	✗
AT-04	apartment block	1961-1980	✓	✓	✗	✓	✗	✗
AT-06	educational building	1961-1980	✓	✓	✗	✓	✓	✓
AT-07	hotel/restaurant	1945-1960	✓	✓	✗	✗	✓	✗
AT-08	educational building	≤1918	✓	✓	✗	✓	✓	✗

5.2.2 Croatia

Building data analysis offers numerous opportunities to gain insights and optimise energy management. Data quality is crucial for accurate analysis. Incomplete, inaccurate, or inconsistent data can lead to unreliable results. Data may have gaps, errors, or inconsistencies due to measurement issues, human error, or data integration challenges. Data cleansing, validation, and normalisation are necessary steps to address these issues. In this regard systematic approach using an Excel template provided by POLITO was utilised taking all available sources. As stated, building data analysis often requires integrating data from various sources, such as energy meters, sensor networks, weather data, and maintenance records. Building systems are highly interconnected and analysing data across multiple systems requires understanding the complex relationships between different parameters. Identifying cause-effect relationships, correlations, and dependencies can be challenging, especially when dealing with large and diverse datasets. To correctly understand interconnectable relationships, different tools have been used, optimising overall process in one coherent methodological approach.

The data was extracted from various available sources, including the EPC, energy audit report, and energy bills, to gather comprehensive information. Building energy models (BEMs) were developed for all the buildings under consideration. Two of the buildings were analysed using an hourly method, while the rest were analysed using a monthly method.

The hourly method was implemented using the DesignBuilder Energy simulation tool, whereas the monthly method utilised the KI Expert Plus tool, which is specifically designed for EPC calculations in Croatia. This approach was adopted to compare the results obtained from both methods and ensure their consistency.

Subsequently, the BEMs were compared with the actual energy consumption data derived from bills, energy measurements, or indoor temperature monitoring. Each approach underwent rigorous testing and calibration, with three buildings being calibrated based on monthly energy consumption (bills), one based on hourly energy consumption, and the final one based on hourly temperature readings.

Calibration using the monthly method was relatively straightforward since the data was more robust, although the results were less reliable compared to the hourly method. The hourly calibration required a significant number of interventions due to unpredictable periods of usage fluctuations, which were either difficult to predict or unfamiliar to the building owner. This calibration process was only possible because there was extensive familiarity with the buildings being analysed. To verify the calibration, the TEPA calibration tool provided by POLITO was employed as a final check. In the last stage, energy efficiency measures identified in the EPC and energy audit reports were recalculated using the BEMs and updated energy and investment prices. The BACS and ECM assessment tool provided by POLITO facilitated the final evaluation of the buildings. Furthermore, the assessment of indoor environmental quality (IEQ) was conducted following the methodology outlined in Annex B. The data analyses performed in the Croatian case studies are presented in Table 20 and Table 21.

Table 20. Data analysis process in Croatia

TIMEPAC Code	Building usage	Data from	BEM	Calibration	BACS and ECM assessment	IEQ assessment
HR-01	Office	Energy audit, EPC, other	Yes, hourly in DesignBuilder	Yes, Scenario 2En	Yes, cost-optimal analysis	Thermal comfort and indoor air quality

HR-02	Kindergarten	Energy audit, EPC, other	Yes, monthly in KI Expert Plus	Yes, Scenario 1	Yes, recalculated for TIMEPAC with new prices	Indoor air quality
HR-03	Library	Energy audit, EPC, other	Yes, monthly in KI Expert Plus	Yes, Scenario 1	Yes, recalculated for TIMEPAC with new prices	Indoor air quality
HR-04	Single-family house	Energy audit, EPC, other	Yes, hourly in DesignBuilder	Yes, Scenario 2Temp	Yes, recalculated for TIMEPAC with new prices	Thermal comfort and indoor air quality
HR-05	Primary school	Energy audit, EPC, other	Yes, monthly in KI Expert Plus	Yes, Scenario 1	Yes, recalculated for TIMEPAC with new prices	Indoor air quality

Table 21. Analyses performed on the Croatian buildings

Item	Building general properties		Performed analyses					
Identifying code for the building in the building survey	*Use category* *List*	*Period of construction* *List*	*SEPA* *Performed (✓) Not feasible (✗)*	*TEPA* *Performed (✓) Not performed (✗)*	*CAL* *Performed (✓) Not performed (✗)*	*IEQ* *Performed (✓) Not performed (✗)*	*ECM* *Performed (✓) Not performed (✗)*	*BACS* *Performed (✓) Not performed (✗)*
<Choice from list>		*<Choice from list>*	<Yes/No>	<Yes/No>	<Yes/No>	<Yes/No>	<Yes/No>	<Yes/No>
HR-01	offices	1971-1980	✗	✓	✓	✓	✓	✓
HR-02	educational building	1971-1980	✗	✓	✓	✓	✓	✓
HR-03	educational building	<1945	✗	✓	✓	✓	✓	✓
HR-04	single-family house	≥2009	✗	✓	✓	✓	✓	✓
HR-05	educational building	1971-1980	✗	✓	✓	✓	✓	✓

5.2.3 Cyprus

The data analysis process is the analysis, filtering and transformation of the input data received from our resources using the various methodologies analysed in the data collection section and prepare the necessary reports and graphs.

For the data collection for the buildings, we had to create the energy models of buildings using the below software.

- Integrated Environmental Solutions (IES),
- SketchUp Sefaira energy efficient design software.

During our data analysis process, we encountered and resolved the issues noted below. These issues were affecting the accuracy of our data, and accordingly we corrected or adjusted them where possible.

- Building Plans: any changes made to buildings due to renovations were not updated on the building plans. We had to update the building plans accordingly.
- School Building Indoor Temperature Values: we did not have consecutive hourly readings for indoor temperature of buildings for long periods of time since the thermal comfort of buildings is not required to be captured and reported by building owners. We used the readings from humidity and temperature sensors that were installed for a previous E.U. project, providing only a few weeks of data. We could not install sensors on our end as we required the permission from the building manager.
- School Building Electricity Consumption Measurements: for the electricity consumption we only had monthly readings which were provided by the Electricity Authority of Cyprus. For the hourly readings we used the readings made by power meters which were installed in buildings as part of a previous E.U. project. We could not install power meters on our end as we required the permission from the building manager.
- Energy Performance Certificate (EPC) Issues: inaccuracies with the stated EPC values due to software limitations.
- For Photovoltaic (PV) systems instead of inputting in the software the installed power of the PV system, one must input the PV area and the system calculates the energy output using its own algorithms which are not accurate. To correct the energy output in the software they are often stating different PV areas.
- Hot Water Solar Panels: for the hot water solar panels we assumed that their performance is static across all the buildings. (~90% performance).
- Heating Boilers: the value for the performance of the heating boilers was provided by the building managers. We compared the values that the building managers provided with those found in the market and found similar results.
- Air Conditioning (A/C) Units: the value for the performance of the A/C Units was provided by the building managers. We compared the values that the building managers provided with those found in the market and found similar results.
- Energy Efficiency measures: The proposed energy efficiency measures arise from identifying primary challenges affecting buildings in Cyprus and considering their implementation costs. One major issue is the discomfort caused by high temperatures during the hot summer months, as indoor conditions are affected by the high temperatures. Using mechanical systems like air conditioning is currently the most common solution to this problem. In our simulations and suggested renovation scenarios, we explore various combinations, including enhancing wall and ceiling insulation and installing photovoltaic systems. These measures aim to create a more comfortable and energy-efficient indoor environment.

The data analysis performed on the buildings lead to the following results.

Standard and tailored energy performance assessment (TEPA) and Model Calibration: To calibrate the model, we had to use as an input the simulated energy consumption data from TEPA, the electricity bills, measured electricity consumption, indoor temperature measures and meteorological data for outdoor temperatures from a weather website.

To conduct the **Model calibration (CAL)** analysis, we needed to gather data from various sources such as electricity meters, electricity bills, humidity and temperature sensors, and information from building managers. However, the data we gathered was in different formats, so we had to convert them into hourly formatting. The analysis and calibration were performed using two software programs: Integrated Environmental Solutions (IES) for the schools and SketchUp Sefaira energy efficient design software for CEA1 (CY-03) and CEA2 (CY-04).

The **Indoor Environmental Quality Assessment (IEQ)** required us to utilise our existing resources, including data from electricity meters, electricity bills, humidity and temperature sensors, as well as information provided by building managers. Additionally, we had to make assumptions about how the building is being used. For instance, in the case of the CEA buildings (CY-03 and CY-04), we had to factor in the four-day work schedule of office personnel when conducting the proposed thermal comfort assessment procedure. We used the hourly indoor temperatures obtained from humidity and temperature sensors. As mentioned earlier, we also sourced meteorological data for outdoor temperatures from weather website. For our analysis, we selected a representative space from each building and employed the analysis tool from TDS2, as previously presented.

When assessing **energy conservation measures (ECM),** an analysis is conducted to evaluate the investment's actual cost and turnover. In most cases, the best energy and cost-efficient investments involve utilising solar energy, which is abundant in Cyprus. Examples of such measures include installing or replacing the domestic hot water (DHW) generator with high-efficiency technologies and implementing photovoltaic systems.

The **Building Automation and Control Systems Assessment (BACS)** assessment was consistent for the majority of the buildings. More specifically, in school cases, the BACS were very similar because the construction, implementation, and maintenance fall under the Cyprus Ministry of Education. Similarly, for the CEA buildings, both are identical structures, and they had the same BACS. For the analysis, we utilised the tool as previously presented.

Regarding **Building automation and control systems assessment (BACS)**, analysis reveals that popular systems are widely used throughout the island of Cyprus. Domestic hot water generation often involves high-efficiency technologies like solar panels. Cooling methods primarily rely on split unit air conditioning systems, and heating is achieved through split unit air conditioners or oil heating boilers in some buildings. When available, air ventilation systems typically employ simple on/off controls. The analyses performed on the Cypriot case studies are presented in Table 22.

Table 22. Analyses performed on the Cypriot buildings

Item	**Building general properties**	**Performed analyses**					
Identifying code for the building in the building survey	*Use category* *List*	*SEPA* *Performed (✓)* *Not feasible (✗)*	*TEPA* *Performed (✓)* *Not performed (✗)*	*CAL* *Performed (✓)* *Not performed (✗)*	*IEQ* *Performed (✓)* *Not performed (✗)*	*ECM* *Performed (✓)* *Not performed (✗)*	*BACS* *Performed (✓)* *Not performed (✗)*
<Choice from list>		<Yes/No>	<Yes/No>	<Yes/No>	<Yes/No>	<Yes/No>	<Yes/No>
CY-01	educational building	✓	✗	✓	✓	✓	✓
CY-02	educational building	✓	✗	✓	✓	✓	✓
CY-03	offices	✓	✓	✓	✓	✓	✓
CY-04	offices	✓	✓	✓	✓	✓	✓
CY-05	educational building	✓	✗	✓	✓	✓	✓

5.2.4 Italy

Standard and tailored energy performance assessment (SEPA and TEPA): The determination of the building energy performance was pursued following the standards currently in force in Italy and Europe, as presented in Table 23.

Table 23. Relevant standards for SEPA and TEPA

Object	Standard(s)
Energy needs for heating and cooling	UNI EN ISO 52016-1 (hourly procedure)
Occupancy	UNI EN 16798-1
Energy demand for heating	UNI/TS 11300-2
Energy demand for cooling	UNI/TS 11300-3
Energy demand for lighting	UNI EN 15193-1

The whole energy performance procedure was pursued deploying the software developed by Edilclima s.r.l., EC700.

Model calibration (CAL): The calibration was performed deploying the procedure presented in Annex B. The meteorological data were derived from an open database (from the Regional Environmental Protection Agency of Piemonte, ARPA Piemonte), the simulated energy consumption from the TEPA and the measured consumption from monthly energy bills.

Energy conservation measures (ECM): The economic assessment evaluated energy conservation measures considering the main building shortcomings in terms of energy efficiency to determine the possible measures. These were analysed both one at time and combined, and the energy consumption was evaluated through a SEPA or a TEPA. The costs of energy, the interest rate, the measure investment, and maintenance cost were determined using values provided by Italian national agencies and from regional and national price lists. The tool developed in TDS2, as presented in Annex B, was deployed in the analyses.

Indoor environmental quality assessment (IEQ): The indoor environmental quality assessment was performed using hourly operative temperatures derived from the SEPA or TEPA, and outdoor temperatures from the typical meteorological years developed by the Italian Thermotechnical Committee (CTI). For the indoor air quality, a representative space was defined and the main geometrical, occupation and ventilation features were determined from the data already used in the energy assessment. The tool developed in TDS2, as presented in Annex B, was deployed in the analyses.

Building automation and control systems assessment (BACS): The BACS assessment was performed using the SEPA or TEPA procedures following TDS2 methods and tools, as presented in Annex B.

In Table 24 the analyses performed on each building are presented.

Table 24. Analyses performed on the Italian buildings

Item	Building general properties		Performed analyses					
Identifying code for the building in the building survey	*Use category* *List*	*Period of construction* *List*	*SEPA* *Performed (✓) Not feasible (✗)*	*TEPA* *Performed (✓) Not performed (✗)*	*CAL* *Performed (✓) Not performed (✗)*	*IEQ* *Performed (✓) Not performed (✗)*	*ECM* *Performed (✓) Not performed (✗)*	*BACS* *Performed (✓) Not performed (✗)*
<Choice from list>		*<Choice from list>*	<Yes/No>	<Yes/No>	<Yes/No>	<Yes/No>	<Yes/No>	<Yes/No>
IT-01	apartment block	1961-1975	✓	✗	✗	✓	✓	✓
IT-02	apartment block	1901-1920	✓	✓	✓	✓	✓	✓
IT-03	apartment block	1961-1975	✓	✗	✗	✓	✗	✓
IT-05	educational building	1961-1975	✓	✗	✗	✓	✗	✓
IT-09	apartment block	> 2005	✗	✓	✓	✗	✗	✗
IT-11	apartment block	1991-2005	✓	✗	✗	✓	✗	✗
IT-12	educational building	1961-1975	✓	✓	✓	✓	✓	✓
IT-13	educational building	1961-1975	✓	✗	✗	✓	✓	✓
IT-14	educational building	1961-1975	✓	✗	✗	✓	✗	✗
IT-15	educational building	1991-2005	✗	✓	✓	✓	✓	✗

5.2.5 Slovenia

PURES: The determination of the building energy performance was pursued following the standards currently in force in Slovenia and Europe. The main legislation is Rules on efficient use of energy in buildings with a technical guideline (PURES) that defines standards and guidelines for calculation of energy needs and overall renewable and non-renewable energy performance. The last version was updated and adopted in late 2022, which mean the majority of all already performed calculation for buildings are not according to the latest legislation.

Model calibration (CAL): The calibration was performed deploying the procedure presented in Annex B. The meteorological data were derived from an open database, the simulated energy consumption from the TEPA and the measured consumption from monthly energy bills.

Energy conservation measures (ECM): The economic assessment evaluated energy conservation measures' considering the main building shortcomings in terms of energy efficiency to determine the possible measures. These were analysed both one at time and combined, and the energy consumption was evaluated. The costs of energy, the interest rate, the measure investment, and maintenance cost were determined using values provided by national agencies and from regional and national price lists. The tool developed in TDS2, as presented in Annex B, was deployed in the analyses.

Indoor environmental quality assessment (IEQ): The indoor environmental quality assessment was performed using hourly operative temperatures derived from IDA ICE, and outdoor temperatures from the typical meteorological years developed by the Slovenian Environmental Agency. For the indoor air quality, a representative space was defined and the main geometrical, occupation and ventilation features were determined from the data already used in the energy assessment. The tool developed in TDS2, as presented in Annex B, was deployed in the analyses.

Building automation and control systems assessment (BACS): The BACS assessment was performed using the SEPA or TEPA procedures following TDS2 methods and tools, as presented in Annex B.

Table 25 shows the analyses performed on Slovenian buildings.

Table 25. Analyses performed on the Slovenian buildings.

Item	**Building general properties**		**Performed analyses**					
Identifying code for the building in the building survey	*Use category* *List*	*Period of construction* *List*	*SEPA* *Performed (✓) Not feasible (X)*	*TEPA* *Performed (✓) Not performed (X)*	*CAL* *Performed (✓) Not performed (X)*	*IEQ* *Performed (✓) Not performed (X)*	*ECM* *Performed (✓) Not performed (X)*	*BACS* *Performed (✓) Not performed (X)*
<Choice from list>		*<Choice from list>*	*<Yes/No>*	*<Yes/No>*	*<Yes/No>*	*<Yes/No>*	*<Yes/No>*	*<Yes/No>*
SI-01	educational building	1971-1980	X	✓	✓	✓	✓	✓
SI-02	hospital	1971-1980	✓	✓	✓	✓	✓	✓
SI-03	offices	1971-1980	✓	✓	✓	✓	✓	✓
SI-04	offices	<1945	X	✓	✓	✓	✓	✓
SI-05	educational building	1971-1980	X	✓	✓	✓	✓	✓
SI-06	educational building	1945-1970	X	✓	✓	✓	✓	✓
SI-07	educational building	1945-1970	X	✓	✓	✓	✓	✓
SI-08	educational building	1945-1970	X	✓	✓	✓	✓	✓
SI-09	trade services building	<1945	X	✓	✓	✓	✓	✓
SI-10	educational building	1945-1970	X	✓	✓	✓	✓	✓

5.2.6 Spain

Standard and tailored energy performance assessment (SEPA and TEPA): The determination of the building energy performance was pursued following the standards currently in force in Spain and Europe, as presented in Table 26.

Table 26. Relevant standards for SEPA and TEPA

Object	Standard(s)
Energy needs for heating and cooling	CTE DB-HE, UNE-EN ISO 52000-1:2019 // UNE-EN ISO 52016-1
Occupancy	CTE DB-HE, UNE-EN ISO 52000-1:2019 // UNE-EN ISO 52016-1
Energy demand for heating	CTE DB-HE, UNE-EN ISO 52000-1:2019 // UNE-EN ISO 52016-1
Energy demand for cooling	CTE DB-HE, UNE-EN ISO 52000-1:2019 // UNE-EN ISO 52016-1
Energy demand for lighting	CTE DB-HE, UNE-EN 12464-1:2022
Indoor environmental quality assessment	CTE DB-HS-3, EN ISO 16798-1

The whole energy performance procedure was pursued by deploying the software developed by CYPE. The CYPETHERM HE Plus tool has been used for the energy simulation by means of an hourly method using the EnergyPlus calculation engine. The geometric models have been defined using CYPE programs such as CYPECAD MEP, IFC Builder and CYPE Architecture.

Model calibration (CAL): The calibration was performed deploying the procedure presented in Annex B. The meteorological data were derived from an open database, the simulated energy consumption from the TEPA and the measured consumption from monthly energy bills. Part of the procedure was based on generating iterations with the models developed in CYPETHERM HE Plus taking into account some regulatory constraints. For example, the real use of the building every month and its use at the regulatory level had to be changed for the calibration. On the other hand, the other electrical consumption values not included in the energy simulation, such as the use of equipment, lifts and other energy uses, have been evaluated.

Energy conservation measure (ECM): The economic assessment evaluated energy conservation measures considering the main building shortcomings in terms of energy efficiency to determine the possible measures. The costs of energy, the interest rate, the measure investment, and maintenance cost were determined using values provided by the Catalan database from The Catalonia Institute of Construction Technology price lists.

Indoor environmental quality assessment (IEQ): The indoor environmental quality assessment was performed using hourly operative temperatures derived from the SEPA or TEPA, and outdoor temperatures from the typical meteorological years. For the indoor air quality, a representative space was defined and the main geometrical, occupation and ventilation features were determined from the data already used in the energy assessment. The tool developed in TDS2, as presented in Annex B, was deployed in the analyses.

Building automation and control systems assessment (BACS): The BACS assessment was performed using the SEPA or TEPA procedures following TDS2 methods and tools, as presented in Annex B.

In Table 27 the analyses performed on each building are presented.

Table 27. Analyses performed on the Spanish buildings

Item	Building general properties		Performed analyses					
Identifying code for the building in the building survey	*Use category* *List*	*Period of construction* *List*	*SEPA* *Performed (✓)* *Not feasible (X)*	*TEPA* *Performed (✓)* *Not performed (X)*	*CAL* *Performed (✓)* *Not performed (X)*	*IEQ* *Performed (✓)* *Not performed (X)*	*ECM* *Performed (✓)* *Not performed (X)*	*BACS* *Performed (✓)* *Not performed (X)*
<Choice from list>		*<Choice from list>*	*<Yes/No>*	*<Yes/No>*	*<Yes/No>*	*<Yes/No>*	*<Yes/No>*	*<Yes/No>*
ES-01	educational building	≥2007	✓	✓	✓	✓	X	X
ES-02	offices	≥2007	✓	✓	✓	✓	X	X
ES-03	home for elderly and disabled people	≥2007	✓	✓	✓	✓	✓	✓
ES-04	apartment block	1980-2006	✓	✓	✓	X	✓	X
ES-05	apartment block	1901-1936	✓	✓	✓	✓	✓	X
ES-06	home for elderly and disabled people	≥2007	✓	X	X	✓	X	X
ES-07	apartment block	≥2007	✓	X	X	✓	X	X
ES-08	apartment block	≥2007	✓	X	X	✓	X	X
ES-09	apartment block	≥2007	✓	X	X	X	✓	X
ES-10	apartment block	≥2007	✓	X	X	X	✓	X

6 Results and discussion

In this section, the main findings are presented together with some consideration regarding the effectiveness of the procedures explaining any possible issues related with their application.

6.1 Data collection

In the following sections the results of the data collection methods are presented.

6.1.1 Austria

In Austria, EPCs are issued for zones with the same type of use, meaning that for multi-unit residential buildings there is usually one EPC for the building, and not individual EPCs for the apartments.

Regarding information about the surroundings of the building, the necessary level of detail is not always available, and plans are sometimes difficult to access. The challenge is being addressed by a national research project[8] aiming at improving access to spatial planning information which is relevant at the building level.

For the task in TDS2, buildings with an EPC and additional documentation were chosen. Regarding existing buildings, there are always issues with plans and documentation which deviate from the actual situation. The potential of scanning existing buildings (Scan to BIM) as basis for developing 3D models was investigated and it seems that this technology is already quite advanced and will soon become economically competitive[9].

In general, it is noted that more attention needs to be given to the presence and characterisation of solar shading devices (movable), which is gaining importance due to climate change.

It became evident that the documentation needed for the *klimaaktiv* declaration is helpful but not always easily accessible and should also be stored in the EPC database environment ZEUS which is now being used by 6 of the 9 Austrian provinces. Technically, this is possible, however, it will be necessary to specify access rights accordingly. The *klimaaktiv* declaration is becoming more and more widespread, especially because it is used for housing subsidy schemes and to prove conformity with the Taxonomy Regulation. However, it is also a finding of the work that the documentation of technical building systems could be improved, and the corresponding criteria should be developed for this purpose.

Monitoring of energy consumption is required by *klimaaktiv*, but there is no standardised protocol. Reports about the results of monitoring energy consumption are available and used to optimised building performance. However, these reports are seldom written in such a way that they can be used for other purposes, such as to calibrate standardised building energy models (monthly basis). Monitoring data that need to be recorded as part of a funding programme cannot be easily used either, because errors need to be excluded and data must be processed which causes additional effort. Detailed monitoring data at apartment level were not provided to be further processed by the TIMEPAC team with reference to personal data protection and General Data Protection Regulation (GDPR).

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[8] transFORMAT-Link - Den Transformationsprozess unterstützen: Verknüpfung von NEKP-Planung und dessen Berichtslegung mit der Projektumsetzung auf kommunaler Ebene. Information is available at: https://sera.global/#projects (27.06.2023)

[9] https://www.ecoplus.at/newsroom/5-bim-stammtisch (27.06.2023)

The EPC database environment ZEUS already allows for recording metered energy consumption and production data. This functionality is provided for building owners who can make data accessible to third parties for specific purposes. This feature has great potential but is currently rarely used.

To summarize the topic of monitoring, the EPC database environment ZEUS offers potential that still needs to be exploited. In addition, a standardised monitoring protocol that can be used for various purposed is needed, and this topic has been taken up by a DECA working group (DECA is the Austria association of ESCOs). To avoid issues related with the protection of personal data, for multi-unit residential buildings the installation of central building energy meters (root meter) is recommended. In case of abnormal deviations between EPC and consumption, energy advice could be offered to the individual apartments.

In conclusion, and with a view to the building logbook envisaged in the proposed recast EPBD, access to data for certain professions must be regulated to overcome the obstacles related to the protection of personal data. These reservations are often not based on good reasons, but on uncertainties about the scope for interpretation and possible legal consequences. Sometimes they are just used as an excuse.

Different sources were available for the buildings, as presented in Table 28. In case of multiple sources available for the same data, the priority order presented in Table 1 was deployed.

Table 28. Available data sources

	Data sources					
	Interview/ onsite visit	Technical report based on onsite visit	Monitoring report	EPC including BEM	Open access database *baubook*	Documentation for Voluntary building assessment *klimaaktiv*
AT-01		x	x	x		x
AT-04		x	not provided	x		x
AT-06		x	x	x		
AT-07			x	x	x	x
AT-08	x			x		x

6.1.2 Croatia

Ensuring data accuracy and completeness is crucial in energy auditing, and it can be achieved by adhering to standardised data collection protocols, conducting regular quality checks, using reliable measurement equipment, and implementing data validation and verification processes. Leveraging advanced technologies and automation can also minimise human error and enhance the overall accuracy of the energy auditing process. One of the challenges encountered was accessing relevant data from various sources, which can be a complex task.

Building owners often store data in different systems and formats, making it difficult to gather a comprehensive dataset. Overcoming data accessibility issues requires collaboration with multiple stakeholders such as building owners, designers, auditors, and others, while also addressing privacy concerns. Ensuring the accuracy, completeness, and consistency of the collected data poses a significant challenge. Inaccurate or incomplete data can lead to unreliable analysis and decision-making. Data quality issues can arise from measurement errors, data entry mistakes, or inconsistencies in data formats and units. This challenge becomes particularly relevant when considering occupancy schedules, as precise data on occupancy patterns is essential for accurate energy analysis. Integrating data from different sources and systems can be a time-consuming effort.

Building data is often sourced from energy meters, building management systems, weather stations, sensors, and other sources. However, a large amount of data may not be stored in easily readable digital formats, leading to the repetition of work that has already been done in the past. In addition, undocumented changes can result in incorrect conclusions and require detailed data checking. To achieve comprehensive data collection, it is necessary to ensure seamless data integration, standardise formats, and address interoperability challenges. However, it should be noted that these tasks extend beyond the scope of the current project, given the complexity involved. Even when performing detailed energy analysis, challenges needed to be overcome, and different tools had to be utilised to meet the requirements of the multi-layered analysis task. This highlights the need for flexibility and adaptability in the face of challenges encountered during data collection process.

When discussing opportunities, the integration of multiple data sources has significantly enhanced the accuracy of energy data collection. Energy audits provide detailed insights into building systems and energy usage patterns, while energy consumption data from bills offers actual figures of energy consumed. Occupancy data provides valuable information regarding building usage patterns, and EPCs offer standardised energy performance ratings. By combining these sources, a more precise and comprehensive understanding of the building is achieved, thereby improving the Building Energy Model (BEM). The integration of data from different sources also allows for benchmarking and performance comparison. By comparing energy consumption data with similar buildings or industry standards, energy inefficiencies can be identified. Occupancy data can be utilised to normalise energy consumption and identify anomalies or deviations from expected patterns. Energy modelling tools heavily rely on assumptions and estimations. By comparing the modelled energy performance with actual energy consumption data, the accuracy and reliability of these energy models can be validated, further enhancing their effectiveness. Ultimately, the availability of comprehensive energy data empowers evidence-based decision-making.

Different sources were available for the buildings, as presented in Table 29. In case of multiple sources available for the same data, the priority order presented in Table 4 was deployed.

Table 29. Available data sources: case for Croatia

	Data sources								
	Energy audit report	Interview	Inspection report	Building energy design verification report	XML database	EPC	Open access database	BIM model	Other
HR-01	X	X	X	X		X		X	BEM
HR-02	X					X			BEM
HR-03	X					X			BEM
HR-04	X					X			BEM
HR-05	X					X			BEM
BEM = building energy model									

6.1.3 Cyprus

The analysis of the data collected from the buildings has led to the following conclusions.

The Cyprus climate, characterised by mild winters and hot dry summers, helps us to correctly calculate the expected level of thermal comfort in each building.

In the case of the school buildings (CY-01, CY-02, CY-05), which all have similar heating and cooling systems, daily usage patterns, and are all geographically close to each other (even though the schools are in separate cities, Cyprus is a relatively small island with a shared climate across all cities), we notice a low level of thermal comfort especially during the hot months. This is because most classrooms lack mechanical cooling systems and rely only on central heating which is only used during winter. Given that temperatures begin to rise as early as March, these findings match our expectations.

In the case of the Cyprus Energy Agency (CEA) buildings, we noticed a different trend. Both buildings (CY-03 and CY-04) have identical mechanical systems, with air conditioning (A/C) units installed in all zones for both cooling and heating. Both buildings share the same orientation (facing north) which has an impact on the indoor conditions. Due to these factors the thermal comfort of these buildings is more efficient and more favourable than those of the school buildings (CY-01, CY-02, and CY-05).

During our data collection we encountered challenges that affected our analysis that we had to overcome:

- Limited Data Availability: In some cases, the available data that we had was limited (monthly or weekly instead of hourly) making it difficult to get a complete picture which would have resulted in a more accurate analysis.
- Building Access: Communicating with building managers proved to be challenging as access to the buildings was restricted. This limited our ability to install our own sensors and meters inside the buildings to acquire additional data.
- Inadequate Regulations: current regulations to ensure optimal thermal comfort are not very strict for existing buildings and only apply to new ones. This corresponds to the suboptimal thermal comfort observed in some buildings especially those of the school buildings (CY-01, CY-02, and CY-05).
- Insufficient Records: building owners are not required to keep records of consumption (as in the case of thermal comfort) which limited the depth of our analysis.
- Energy Performance Certificates (EPC) procedure: the software and procedure used to issue the EPC certificates is outdated and needs to be updated with the current standards and practices to ensure the accurate assessment of energy consumption and thermal comfort in buildings.

In conclusion, our analysis of the data collected from the buildings shows the importance of consistent, periodical, and comprehensive data collection which are vital in understanding and improving the energy performance of buildings. While the results between the CEA and school buildings varied, both posed the same challenges such as data availability, building accessibility, lack of mandatory record keeping and outdated regulations. We need to address these challenges and implement the necessary procedures which will then lead to the improvement of the energy performance of buildings throughout Cyprus.

Different sources were available for the buildings, as presented in Table 30. In case of multiple sources available for the same data, the priority order presented in Table 8 was deployed.

Table 30. Available data sources

	Data sources								
	Energy audit report	Interview	Inspection report	Building energy design verification report	XML database	EPC	Open access database	BIM model	Other
CY-01	X	X			X			X	
CY-02	X	X			X			X	
CY-03		X	X		X	X		X	
CY-04		X	X		X	X		X	
CY-05	X	X			X			X	
BEM = building energy model									

6.1.4 Italy

The data collection procedure applied to the ten analysed buildings showed similar results in typology of data required. This is related to the use of the same calculation procedures for all buildings. The main differences in required data were in the systems due to buildings differences (e.g., a building with boiler as generator for heating requires a different set of information from a building with a heat pump as generator).

Different sources were available for the buildings, as presented in Table 31. In case of multiple sources available for the same data, the priority order presented in Table 9 was deployed.

Table 31. Available data sources

	Data sources								
	Energy audit report	Interview	Inspection report	Building energy design verification report	XML database	EPC	Open access database	BIM model	Other
IT-01							X	X	BEM
IT-02							X	X	BEM
IT-03							X	X	BEM
IT-05							X	X	BEM
IT-09	X	X		X	X	X	X	X	BEM
IT-11	X								BEM
IT-12	X						X		BEM
IT-13	X						X		BEM
IT-14	X						X		BEM
IT-15	X						X		BEM
BEM = building energy model									

Concerning data collection, two main scenarios were encountered in the data gathering procedure: either a lack or an overabundance of data.

In the first case, a possible way to fill the gap in information is to use standards or other consolidated data. This procedure is often very easy and fast to be applied but the results might have a not-negligible difference from the real ones. On the other hand, the data can be derived through an interview with actors related to the analysed building (e.g., owner or energy manager), or additional research could lead to the finding of new data sources. This procedure is more time-consuming but is better in terms of data quality and is the only way to obtain certain data, such as operational data, that cannot be derived from standards.

In case there is data surplus, i.e., if the same data can be simultaneously obtained from several sources, this leads to two possibilities. If the data are the same in all sources, they can be used directly in the energy performance assessment and in the other analyses, with a reasonable level of safety. When data vary across different sources, it is advisable to prioritize the more reliable sources when collecting data for analysis. A more in-depth analysis could also be performed to ensure the correctness of the data.

6.1.5 Slovenia

Ensuring data accuracy and completeness is crucial in energy auditing, and it can be achieved by adhering to standardised data collection protocols, conducting regular quality checks, using reliable measurement equipment, and implementing data validation and verification processes. Leveraging advanced technologies and automation can also minimise human error and enhance the overall accuracy of the energy auditing process. One of the challenges encountered was accessing relevant data from various sources, which can be a complex task. Building owners often store data in different systems and formats, making it difficult to gather a comprehensive dataset.

Overcoming data accessibility issues requires collaboration with multiple stakeholders such as building owners, designers, auditors, and others, while also addressing privacy concerns. Ensuring the accuracy, completeness, and consistency of the collected data poses a significant challenge. Inaccurate or incomplete data can lead to unreliable analysis and decision-making.

Data quality issues can arise from measurement errors, data entry mistakes, or inconsistencies in data formats and units. This challenge becomes particularly relevant when considering occupancy schedules, as precise data on occupancy patterns is essential for accurate energy analysis. Integrating data from different sources and systems can be a time-consuming effort. Building data used is often sourced from energy meters, building management systems, weather stations, sensors, and other sources.

However, a large amount of data may not be stored in easily readable digital formats, leading to the repetition of work that has already been done in the past. In addition, undocumented changes can result in incorrect conclusions and require detailed data checking. To achieve comprehensive data collection, it is necessary to ensure seamless data integration, standardise formats, and address interoperability challenges. However, it should be noted that these tasks extend beyond the scope of the current project, given the complexity involved. Even when performing detailed energy analysis, challenges needed to be overcome, and different tools had to be utilised to meet the requirements of the multi-layered analysis task. This highlights the need for flexibility and adaptability in the face of challenges encountered during data collection process.

When considering prospects, merging multiple data sources has significantly increased the accuracy of energy data gathering. Energy audits give thorough information on building systems and how energy is utilised, while data from energy bills reveal accurate numbers of energy consumed. Occupancy data provide valuable information about building usage, and the Energy Performance Certificates offer standard energy performance. By combining the two sources, we achieve a better and more detailed understanding of a building, thus improving the building energy model. Through analysing energy consumption data relative to similar buildings or industry standards, energy inefficiencies can be exposed. Occupancy records can be applied to normalise energy expenditure and pinpoint anomalies or departures from predicted patterns. Energy modelling tools are largely dependent on assumptions and estimations. By comparing modelled data on energy performance to actual data on energy consumption, the reliability and accuracy of these models of energy consumption can be verified, further strengthening their efficiency. Ultimately, the access to comprehensive data on energy can lead to decisions based on evidence. The data collection procedure applied to the ten analysed buildings showed similar results in typology of data required. This is related to the use of the same calculation procedures for all buildings. The main differences in the required data were in the systems due to buildings differences (e.g., a building with boiler as generator for heating requires a different set of information from a building with a heat pump as generator). Different sources were available for the buildings, as presented in Table 32.

Table 32. Available data sources

	Data sources								
	Energy audit report	Interview	Inspection report	Building energy design verification report	XML database	EPC	Open access database	BIM model	Other
SI-01	X	X		X	X	X	X		BEM
SI-02	X	X		X	X	X	X		BEM
SI-03	X	X	X	X	X	X	X	X	BEM
SI-04	X	X		X	X	X	X		BEM
SI-05	X	X		X	X	X	X		BEM
SI-06	X	X		X	X	X			BEM
SI-07	X	X		X	X	X	X		BEM
SI-08	X	X		X	X	X	X		BEM
SI-09	X	X		X	X	X	X		BEM
SI-10	X	X		X	X	X	X		BEM
BEM = building energy model									

6.1.6 Spain

It is crucial to highlight that in Spain, the requirement for conducting an energy audit does not apply to all buildings, which underscores the need for a broader perspective on this matter.

In particular, Spanish standard (RD56/2016) makes energy audits compulsory only for companies that are considered large companies, meaning those that employ at least 250 people, or those that have annual business income exceeding 50 million euros and, at par, a balance sheet exceeding 43 million euros. On the other hand, Catalonia applies the Climate Change law (*Llei 16/2017*) so energy audits are also required for all public buildings owned by the Catalan Government.

In the present research, none of the buildings included in our study fall under the aforementioned categories, meaning energy audits were not required for the buildings studied. As a result, obtaining accurate and comprehensive information emerged as the pivotal challenge in our endeavour. That means that all information for the buildings was gathered through collaboration with various stakeholders, including building owners, designers, certifiers, and others, was crucial for addressing data accessibility issues and addressing privacy concerns. A significant challenge lies in ensuring the accuracy, completeness, and consistency of the collected data, as inaccurate or incomplete data can result in unreliable analysis.

Extensive analysis has been conducted on the information gathered from the buildings, encompassing meticulous study, harmonisation, thorough examination, and dedicated effort. Through this comprehensive process, we have identified instances of information mismanagement and occasional data loss within the intricate network of numerous stakeholders involved in the chain. Data quality issues can arise due to various factors such as measurement errors, inaccuracies during data entry, or inconsistencies in data formats and units. This challenge becomes even more crucial when analysing occupancy schedules because precise information regarding occupancy patterns is vital for conducting accurate energy analysis. For instance, determining occupancy can be particularly challenging in residential buildings where multiple dwellings coexist. Additionally, when considering energy consumption, relying on data from small buildings proves to be more reliable due to the similarity in dwelling characteristics. As a result, it is more practical to focus on smaller residential buildings, which offer greater ease in data collection, or focus on public buildings which have undergone energy audits.

The data collection procedure applied to the ten analysed buildings showed similar results in typology of data required. This is related to the use of the same calculation procedures for all buildings. The main differences in the required data were in the systems due to various building differences.

Different sources were available for the buildings, as presented in Table 33.

Table 33. Available data sources

	Data sources								
	Energy audit report	Interview	Inspection report	Building energy design verification report	XML database	EPC	Open access database	BIM model	Other
ES-01		X		X	X	X		X	BEM
ES-02		X		X	X	X		X	BEM
ES-03		X		X	X	X		X	BEM

ES-04		X						X	BEM
ES-05		X						X	BEM
ES-06		X			X	X			
ES-07		X		X	X	X		X	
ES-08		X			X	X		X	
ES-09		X			X	X		X	
ES-10		X			X	X		X	
BEM = building energy model									

6.2 Data analysis

In the following sections the results of the application of the data analysis methods are presented. For each of the six proposed analysis the results are detailed for each partner; the specific results for each of the analysed building is presented as well.

6.2.1 Austria

Standard energy performance assessment (SEPA) and Tailored energy performance assessment (TEPA): Currently, the tailored energy performance assessment is applied as part of the energy advisory process and renovation project development process managed by the regional governments and linked to funding schemes related with improving building energy performance.

All case study buildings were analysed with SEPA and TEPA procedures, partly based on assumptions, depending on the availability of information. An exemplary presentation is shown in Figure 11. Regarding TEPA, the main factors causing deviations from SEPA are the following: indoor temperatures in the cold season that are higher (due to comfort requirements) or lower (due to poverty); opening windows in addition to mechanical ventilation (with heat recovery); switching off the mechanical ventilation (with heat recovery) and opening the windows for ventilation instead; and higher domestic hot water consumption. In terms of electricity consumption, the deviations are due to user behaviour (purchase and use of electrical appliances and lighting). Recently, the use of cooling appliances in summer has become an issue.

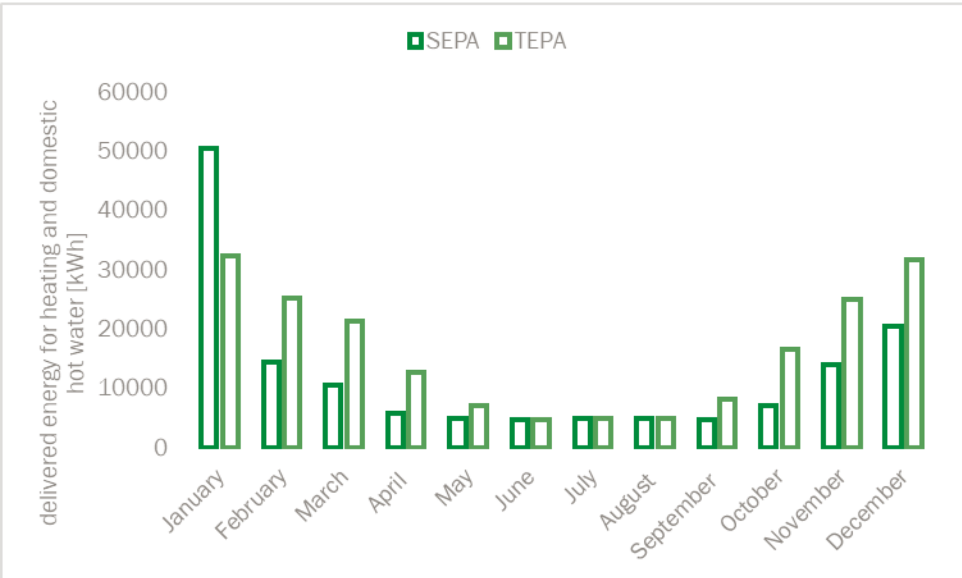

Figure 11. SEPA and TEPA comparison for building AT-01

About tailored energy performance assessment, in buildings such as offices and educational buildings, user profiles and indoor conditions are standardised and controllable, in contrast to the situation in multi-unit residential buildings. Challenges regarding the development of tailored energy models of multi-unit residential buildings are for example:

- Different thermal conditions in different parts of the building (e.g., top floor, ground floor), because the EPC usually refers to a building, not to a building unit.
- Different user behaviour in different apartments (e.g., small children, old people, single, long vacations abroad, home office, pets, etc.).
- People move in and move out, flats are empty for a while, family income can change and influence user behaviour, i.e., more or less energy consumption.

- Regarding heating: the more efficient the building envelope, the more important becomes the hot water consumption in terms of overall heat consumption.
- It is not possible to differentiate space heating and domestic hot water in the energy bills if there is the same source of heating.

In comparison, single family buildings are much easier to deal with. Occupants and their user profile can be clearly identified. However, in Austria, around 50% of apartments are located in multi-unit residential buildings, and therefore, it is crucial to find a feasible solution how to deal with these buildings in terms of improving energy efficiency. The question arises if the apartment-specific EPC would bring any advantages. The answer would be probably not for the case of deep renovation, as the building envelope needs to be addressed, and many of these buildings have a central heating system. Energy advice at apartment level will only address the heating system if the heating system is decentralised, and the optimisation of lighting and appliances, as well as automation and control systems. The apartment-specific EPC in addition to the EPC for the whole building could provide additional benefits, especially regarding comparing standard energy performance with the specific energy performance, to detect deficiencies in technology or user behaviour at apartment level. For this purpose, household energy bills are used or, even better, smart meter data if available. To make the process easier, smart meter data need to be made accessible to energy assessors and energy advisors on a regular basis and in a useful format. In addition, a method is needed to avoid additional cost for EPCs at apartment level, maybe through a BIM approach.

TEPA calibration against monitored data (CAL): Usually, monitoring data are used at building level for innovative projects on a temporary basis to detect technical deficiencies and room for improvement with reference to the user behaviour after handing over a new building or after implementation of a deep renovation. In such a case, a monitoring concept must be developed, and recorded data must be processed and cleaned to provide useful insight.

For building AT-01, a monitoring study had been carried out that was used for TIMEPAC. The results of this study are in line with the results of other monitoring projects. The monitoring showed that the heat generation systems, heat distribution and heat delivery systems function according to the state of the art and that the users are therefore mainly responsible for the level of heat consumption, which consists of space heating and hot water supply. Due to the sometimes relatively high deviations from the forecast values, various information campaigns were launched to draw attention to the possibilities for saving energy. After two years of monitoring, however, it can be said that residents have made little use of the offers. A further in-depth look at the flat level shows that the specific heat consumption per flat is relatively different. When presented and analysed in a different form, it shows that the median heat consumption of the individual flats in 2020 and 2021 is around 76 and 79 kWh/m² of floor area, respectively, and that ten to ninety percent of all specific heat consumption is in the range between 35 and around 130 kWh/m² of floor area per year.[10] That means it is either overestimated or underestimated, depending on the actual user behaviour. The calibration results for building AT-01 are presented in Figure 12.

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[10] https://smartcities.at/projects/monitoring-sglimberg-evaluierung-der-bereiche-energie-mobilitaet-und-soziales-in-den-ersten-zwei-jahren-nach-bezug/ (27.06.2023)

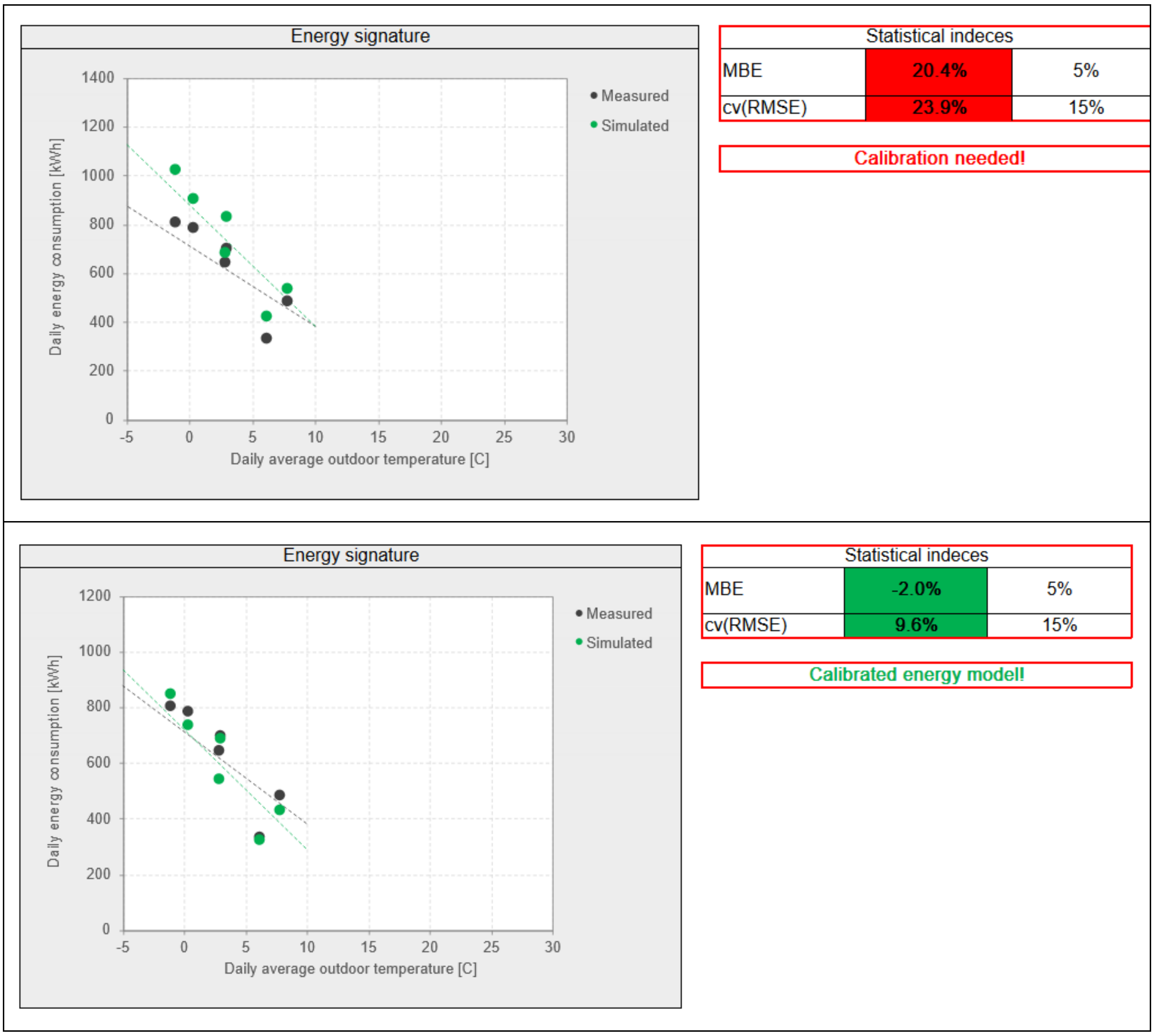


Figure 12. Calibration results for building AT-01 (Monthly method)

Table 34. Calibration results for the analysed building AT-01

Building code	Calibration procedure	MBE [%]			cvRMSE [%]		
		Limit	Uncalibrated model	Calibrated model	Limit	Uncalibrated model	Calibrated model
AT-01	Monthly - Energy demand	±5	20,4	-2,0	15	23,9	9,6

For Austria, the benefit of calibrating the TEPA simulation model based on hourly simulation methods with monitoring data for multi-storey residential buildings is not clear. The monthly calculation method is quite sufficient for the cold climate with the prevailing heating energy demand, and energy bills provide sufficient information as the basis for energy advisory services. It is possible that hourly simulations will become important with the shift to a greater weight of cooling energy demand in summer due to climate change. However, this implies a change in procedures, software and qualification and needs to be evaluated in terms of costs and benefits.

It would be helpful if energy meter identification information were included in the EPC and professionals were given access to smart meter data based on their professional accreditation.

The economic evaluation of energy conservation measures (ECM) is carried out according to guideline for data analysis. The main results are presented in Table 35. ECM results for the analysed building AT-06. It must be noted that costs are based on data collections from the past and do not reflect changes due to the current economic crisis. It is observed that exported electricity from photovoltaic systems cannot be considered according to the method provided. In Austria, tools for this type of economic evaluation have been developed in the past and integrated into EPC calculation software. However, it is always problematic to consider energy efficiency measures only in isolation, as buildings usually have a high maintenance and repair backlog, and thus isolated cost estimates tend to be underestimated. Therefore, such calculations can provide a rough orientation, but are not suitable for the development of refurbishment projects. For example, AT-06 was renovated because more space was needed and the building in general needed refurbishment. In this situation, it was decided to also upgrade the building in terms of energy efficiency. The scenarios presented below are examples done for the analysis in TIMEPAC and mainly based on cost data available in the energy performance calculation program. Cost assessment of the ventilation system with heat recovery was not done although this measure was implemented in the specific case, because calculated energy savings can be changed by opening the windows under operating conditions. It is also difficult to assess the contribution of solar systems to reducing the amount of delivered energy; probably specific simulations would be necessary to come up with reliable numbers. In Austria, economic information is provided to occupants/building owners in the course of energy advisory services for rough orientation only. It is not so easy to introduce a euro amount into the EPC, as this could lead to liability under the legal provisions of the real estate industry. The isolated assessment of BACS functions can be misleading because improved BACS installations can lead to energy cost savings which are outweighed by an increase in operating costs (IT services, maintenance and repair) for short-life BACS components.

Table 35. ECM results for the analysed building AT-06

Scenarios	Energy conservation measures	NPV/A_f [€/m^2]	*DPP* [a]
Scenario 1	External wall thermal insulation Roof (or upper slab) thermal insulation Floor (or lower slab) thermal insulation Windows replacement	615	13
Scenario 2	Windows replacement	326	11
Scenario 3	Windows replacement Installation of a photovoltaic system	426	10
Scenario 4	Installation of a photovoltaic system	120	10

Scenario 5	External wall thermal insulation	714	12
	Roof (or upper slab) thermal insulation		
	Floor (or lower slab) thermal insulation		
	Windows replacement		
	Installation of a photovoltaic system		

Indoor environmental quality evaluation (IEQ): Thermal comfort is not assessed because the monthly calculation method is applied. Indoor Air Quality is assessed based on the guideline for data analysis. The main results are presented in Table 36. IEQ results for the analysed buildings The indoor pollution level is determined based on the information available from the *klimaaktiv* declaration. *Klimaaktiv*, like other green/sustainable building assessment schemes offers methods how to prove a defined level of Indoor Air Quality based on material quality because it is most effective to avoid building materials causing indoor emissions such as Volatile Organic Compounds (VOC). In the operational phase, indoor air quality in existing buildings is dominated by furniture, the type of cleaning products used, and other occupancy behaviour. Energy-efficient buildings usually have a low air flow rate by design, but this can be overridden by opening the windows for ventilation.

Table 36. IEQ results for the analysed buildings

	Comfort category	Building polluting level	Design / Measured external air flow rate [h^{-1}]	Minimum external air flow rate [h^{-1}]
AT-01	III	Very low	0,45	0,40
AT-04	III	Very low	0,40	0,40
AT-06	IV	Very low	0,20	0,30
AT-08	II	Very low	1,80	1,30

In terms of indicators and reference area, there are different definitions of square metres of floor area, depending on whether standards are used in the field of energy, facility management or real estate management. This is a potential source of errors.

Building Automation and Control System impact assessment (BACS) is carried out according to guideline for data analysis. For AT-06 (educational building with clear user profile and occupancy), a monitoring and evaluation report is available that shows substantial energy savings potential through installation and optimisation of time programmes that regulate the operation of all building services systems according to daily operating times and holiday and weekend reductions. Higher BACS functionality levels would not improve energy efficiency in a way that justifies cost and effort. In Table 37 in Table 38 respectively the BACS levels for the analysed building and the BACS assessment results are presented.

Table 37. BACS levels for the analysed building AT-06

BACS levels							
Building code	Whole building	Heating control	Domestic hot water supply control	Cooling control	Ventilation and air-conditioning control	Lighting control	Blind control
AT-06	C	C	D	-	C	D	-

Table 38. BACS Total primary energy improvement for the analysed building AT-06

Building code	Building service	Original BACS function	Improved BACS function	E_P reduction [%]
AT-06	Heating control	Automatic control – time program	Automatic control – optimised time program based on occupancy; individual room control	15
AT-06	Ventilation control	Automatic control – time program	Automatic control – optimised time program based on occupancy	1

Building AT-08 (small community centre, seminar, and event hall) uses the architectural concept of passive design for the renovation of the building. The concept of passive design was chosen for its comfort benefits and, in this case, primarily also because it allows building automation and control to be dispensed with as much as possible to save on investment and operating costs.

With regard to the results of the monitoring report available for AT-01 (multiunit residential building), the question arises if a higher BACS functionality level could help to reduce energy consumption. However, the practical experience of housing cooperatives constructing and operating multi-unit residential buildings shows that residents hardly use regulation and control systems which are currently implemented. The research carried out by Aspern Smart City GmbH[11] over the last eight years has shown that BACS must be as simple as possible to be used in households at all. The experiences from the energy consultancy show that time programmes can be a problem if short power cuts are not noticed, and the programmes are not corrected.

[11] https://www.ascr.at/en/smart-user/ (27.06.2023)

6.2.2 Croatia

The standard EPC process in Croatia involves the development of a monthly Building Energy Model (BEM) for EPC calculations. All the necessary input data should be included in an energy audit report, which serves as an addendum to the EPC. The energy audit report addresses energy consumption and calculates energy efficiency measures based on a recalibrated model adjusted to real consumption. In essence, the Standard Energy Performance Assessment (SEPA) is the usual procedure in Croatia, while the Tailored Energy Performance Assessment (TEPA) is also used but with a larger margin of error. However, the introduction of the TIMEPAC process brought about changes in the mean error by imposing stricter statistical requirements. The goal is to achieve a more accurate calibrated BEM (CAL), which enables a more reliable identification of energy efficiency opportunities.

By analysing energy usage patterns in conjunction with building characteristics and occupant behaviour, potential areas for improvement can be easily identified. This includes recognising opportunities for retrofitting and optimising system operations to reduce energy consumption and enhance overall building performance.

For the analysed buildings in Croatia, the SEPA was initially developed as part of the standard process, and TEPA served as an intermediate step in the development of the CAL model. CAL models were developed for all buildings, with Scenario 2A (temperature calibration) used in one case, Scenario 2B (energy calibration) in another case, and Scenario 1 (monthly method) in the remaining three cases. The results for the CAL models can be summarised as follows:

- Calibration was achieved by incorporating real occupancy schedules. Calibration using Scenario 2B yielded the most accurate model. The major challenge in calibration was accounting for deviations from average real occupancy schedules. Building operations knowledge played a crucial role, as calibration would likely not have been achieved without the use of advanced optimisation algorithms. Calibration using Scenario 2A proved to be accurate but with a higher error rate compared to Scenario 2B (around 10%). The robust model with Scenario 1 had the largest error, primarily affecting cooling energy needs, but it was the least time-consuming.
- The CAL model facilitates the identification and calculation of energy efficiency measures, resulting in savings that align more closely with real impact.
- Implementing the CAL model for Scenario 2 is a time-consuming process, and it raises the question of whether the improved data accuracy justifies the workload. The answer may lie in applying machine learning algorithms.
- For the time being, the CAL model for Scenario 1 can be seen as the optimal solution.

For instance, in Figure 13 the energy signature of the measured energy consumption, and of the simulated energy consumption before and after the calibration procedure, are presented. In Table 39 is presented the calibration procedure pursued, highlighting the time step (e.g., hourly, monthly) and the analysed parameter (e.g., indoor temperature or energy consumption), as well as the statistical indices before and after the calibration.

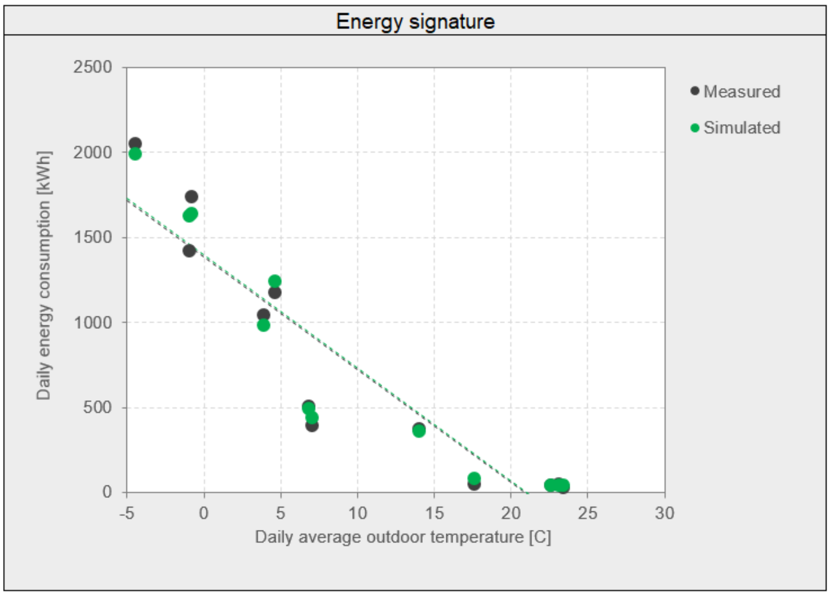


Figure 13. Calibration results for building HR-02

Table 39. Calibration results for the analysed buildings: case for Croatia

Building code	Calibration procedure	MBE [%]			cvRMSE [%]		
		Limit	Uncalibrated model	Calibrated model	Limit	Uncalibrated model	Calibrated model
HR-01	Hourly - Heat Energy demand	±5	10	0,6	15	30	4,0
HR-01	Hourly - Electricity Energy demand	±5	10	-1,0	15	30	1,6
HR-02	Monthly - Energy demand	±5	5	1,3	15	15	10,1
HR-03	Monthly - Energy demand	±5	5	-4,4	15	15	8
HR-04	Monthly - Energy demand	±5	10	0,1	15	10	0,1

HR-05	Monthly – Energy demand	±5	5	1,4	15	15	4,0

The ECM assessment revealed the potential for energy savings. Based on the CAL model and energy audit, various energy efficiency measures were identified, and their savings calculated. These measures were categorised into different scenarios, and economic parameters were calculated using Net Present Value (NPV) and Discounted Payback Period (DPP). In general, deep renovations that include building envelope improvements showed the best results in terms of net present value. On the other hand, smaller investments, such as lighting system upgrades, yielded the best results in terms of DPP. The ECM assessment builds upon the current method, which relies on simple payback period, and provides better conclusions in the long run. It should be noted that the current EPC process only employs the simple payback period, so the improved approach represents a clear upgrade with limited additional effort. Table 40 summarises all energy efficiency measures across analysed Croatian buildings.

Table 40. ECM results for the analysed buildings: case for Croatia

Building code	Scenario	Energy efficiency measures	NPV/A_f [€/m^2]	*DPP* [a]
HR-01	1	External wall thermal insulation, roof (or upper slab) thermal insulation	8	30
	2	Scenario 1 + installation or replacement of the combined generator for heating, DHW and cooling with high efficiency technologies	341	19
	3	Installation of a photovoltaic system, installation, or replacement of the lighting system with high efficiency technologies	345	11
	4	Scenario 2 + Scenario 3	653	17
HR-02	1	External wall thermal insulation, roof (or upper slab) thermal insulation, windows replacement	80	25
	2	Installation or replacement of the lighting system with high efficiency technologies	-7	>30
	3	Scenario 1 + Scenario 2	58	27
HR-03	1	External wall thermal insulation, roof (or upper slab) thermal insulation, windows replacement	3114	14

	2	Installation or replacement of the combined generator for heating, DHW and cooling with high efficiency technologies	136	30
	3	Installation or replacement of the lighting system with high efficiency technologies	3540	2
	4	Scenario 1 + Scenario 3	6286	10
	5	Scenario 4 + Scenario 2	6055	16
HR-04	1	Installation of a photovoltaic system	23	28
	2	Installation or replacement of the control system with high efficiency technologies	4	30
	3	Scenario 1 + Scenario 2	21	29
HR-05	1	Installation or replacement of the control system with high efficiency technologies	22	29

The assessment of indoor environmental quality (IEQ) was conducted using an IEQ tool. Thermal comfort evaluation was only possible for buildings with hourly BEM data. The results were as expected, with non-residential buildings performing better in terms of discomfort levels, as residential buildings are more closely tied to user experience. Indoor air quality assessment was carried out for all buildings, and the results indicated that buildings in need of deep renovation exhibited inadequate results. However, a clear link between energy efficiency and indoor environmental quality cannot be asserted (more analysis needed), only implied. Table 41 summarises all IEQ results for analysed Croatian buildings.

Table 41. IEQ results for the analysed buildings: case for Croatia

	Comfort category	Thermal discomfort hours [%]	Building polluting level	Design / Measured external air flow rate [h^{-1}]	Minimum external air flow rate [h^{-1}]
HR-01	II	2	Very low	1,0	0,5
HR-02	II	-	Very low	0,6	5,0
HR-03	II	-	Very low	1,2	1,0
HR-04	II	9	Very low	0,7	1,0
HR-05	II	-	Very low	1,0	0,8

The final assessment focuses on the impact of Building Automation and Control Systems (BACS). The results indicate that there is potential to achieve savings through the implementation of these systems. Furthermore, there is a clear connection between energy efficiency improvements and the need for control system enhancements, which should be implemented in tandem.

In conclusion, the data analysis conducted can be applied in certain cases within the standard EPC process in Croatia, although this is quite rare and typically only when building owners have predefined future plans. This methodical approach ultimately yields higher-quality output, leading to a better understanding of the specific problems and potential solutions for each building. However, it is important to note that the workload and time required can increase significantly in some cases, resulting in higher costs for the final products (EPC and energy audit). To address this, significant automation of the process will be necessary in the future.

In Table 42 in Table 43 respectively the BACS levels for the analysed buildings and the BACS assessment results are presented.

Table 42. BACS levels for the analysed buildings

BACS LEVEL							
Building code	Whole building	Heating control	Domestic hot water supply control	Cooling control	Ventilation and air-conditioning control	Lighting control	Blind control
HR-01	-	D	-	D	-	D	-
HR-02	-	D	-	-	-	-	-
HR-03	-	D	-	D	-	-	-
HR-04	-	D	-	-	-	-	-
HR-05	-	D	-	-	-	-	-

Table 43. BACS Total primary energy improvement for the analysed buildings

Building code	Building service	Original BACS function	Improved BACS function	Reduction of E_P [%]
HR-01	Heating control	Individual modulating room control with communication	Individual modulating room control with communication and occupancy detection (not applied to slow reacting heating emission systems, e.g., floor heating)	5
		On off control	Variable speed pump control (external demand signal)	2

	Cooling control	Individual modulating room control with communication	Individual modulating room control with communication and occupancy detection (not applied to slow reacting heating emission systems, e.g., floor cooling)	2
		Variable temperature control depending on outside temperature	Variable temperature control depending on the load	2
		On off control	Variable speed pump control (external demand signal)	2
	Lightning control	Manual on/off switch	Automatic detection (manual on)	3
HR-02	Heating control	No automatic control	Individual room control	3
		On off control	Variable speed pump control (pump unit (internal) estimations)	1
HR-03	Heating control	No automatic control	Individual room control	4
		On off control	Variable speed pump control (pump unit (internal) estimations)	2
	Cooling control	Central automatic control	Individual room control	1
HR-04	Heating control	Central automatic control	Individual modulating room control with communication	3
		No automatic control	Demand based control	5
HR-05	Heating control	Individual room control	Individual modulating room control with communication and occupancy detection (not applied to slow reacting heating emission systems, e.g., floor heating)	5
		Outside temperature compensated control	Demand based control	3
		Variable temperature control depending on outside temperature	Variable temperature control depending on the load	2

6.2.3 Cyprus

In Cyprus, the energy performance certification procedure follows a static approach, with energy experts certified by the Ministry of Energy. These experts consider various factors, including the building's geometry divided into zones, the cooling and heating system's energy performance, window specifications, and the presence of renewable energy sources.

To conduct the **Model calibration (CAL)** analysis, we needed to gather data from various sources such as electricity meters, electricity bills, humidity and temperature sensors, and information from building managers. However, the data we gathered was in different formats, so we had to convert them into hourly formatting. The analysis and calibration were performed using two software programs: Integrated Environmental Solutions (IES) for the schools and SketchUp Sefaira energy efficient design software for CEA1 (CY-03) and CEA2 (CY-04).

The **Indoor Environmental Quality Assessment (IEQ)** required us to utilise our existing resources, including data from electricity meters, electricity bills, humidity, and temperature sensors, as well as information provided by building managers. Additionally, we had to make assumptions about how the building is being used. For instance, in the case of the CEA buildings (CY-03 and CY-04), we had to factor in the four-day work schedule of office personnel when conducting the proposed thermal comfort assessment procedure. The main results are presented in Table 44.

When assessing **energy conservation measures (ECM),** an analysis is conducted to evaluate the investment's actual cost and turnover. In most cases, the best energy and cost-efficient investments involve utilising solar energy, which is abundant in Cyprus. Examples of such measures, as presented in Table 45, include installing or replacing the domestic hot water (DHW) generator with high-efficiency technologies and implementing photovoltaic systems.

Regarding **building automation and control system assessment (BACS),** analysis reveals that popular systems are widely used throughout the island. Domestic hot water generation often involves high-efficiency technologies like solar panels. Cooling methods primarily rely on split unit air conditioning systems, and heating is achieved through split unit air conditioners or oil heating boilers in some buildings. When available, air ventilation systems typically employ simple on/off mechanical systems.

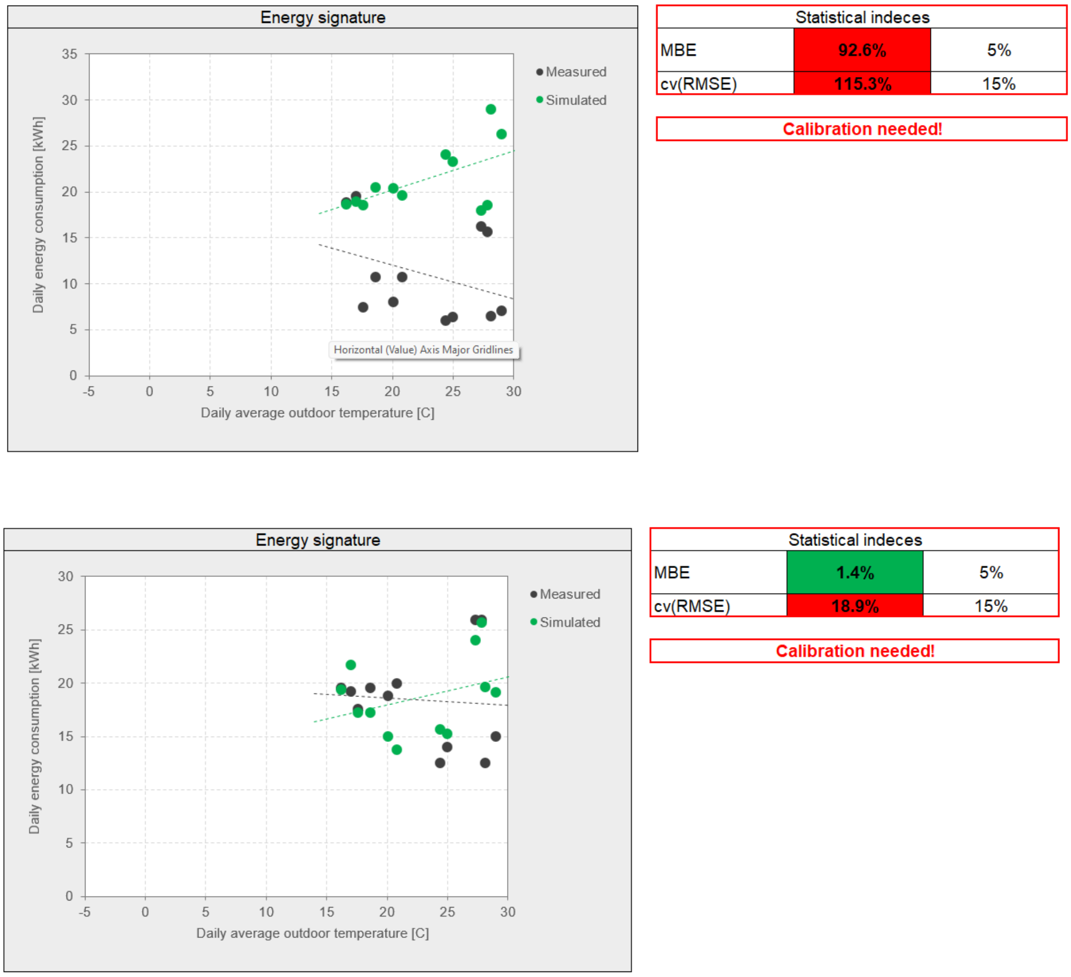


Figure 14. Calibration results for building CY-03

Table 44. IEQ results for the analysed buildings

	Comfort category	Thermal discomfort hours [%]	Building polluting level
CY-01	I	70	Very low
CY-02	I	97	Very low
CY-03	I	60	low
CY-04	I	57	Very low
CY-05	I	78	Very low

Table 45. ECM results for the analysed buildings

Building code	Scenario	Energy efficiency measures
CY-01	1	External wall thermal insulation
	2	Roof (or upper slab) thermal insulation
	4	Windows replacement
	11	Installation of a thermal solar system
	12	Installation of a photovoltaic system
CY-02	1	External wall thermal insulation
	2	Roof (or upper slab) thermal insulation
	4	Windows replacement
	11	Installation of a thermal solar system
	12	Installation of a photovoltaic system
CY-03	1	External wall thermal insulation
	11	Installation of a thermal solar system
	12	Installation of a photovoltaic system
CY -04	1	External wall thermal insulation
	11	Installation of a thermal solar system
	12	Installation of a photovoltaic system
CY -05	1	External wall thermal insulation
	2	Roof (or upper slab) thermal insulation
	4	Windows replacement
	12	Installation of a photovoltaic system

6.2.4 Italy

Standard and tailored energy performance assessment (SEPA and TEPA): The buildings were analysed with SEPA and/or TEPA procedures, depending on the availability of building information. For a case study, IT-12, both procedures were performed and compared in Figure 15.

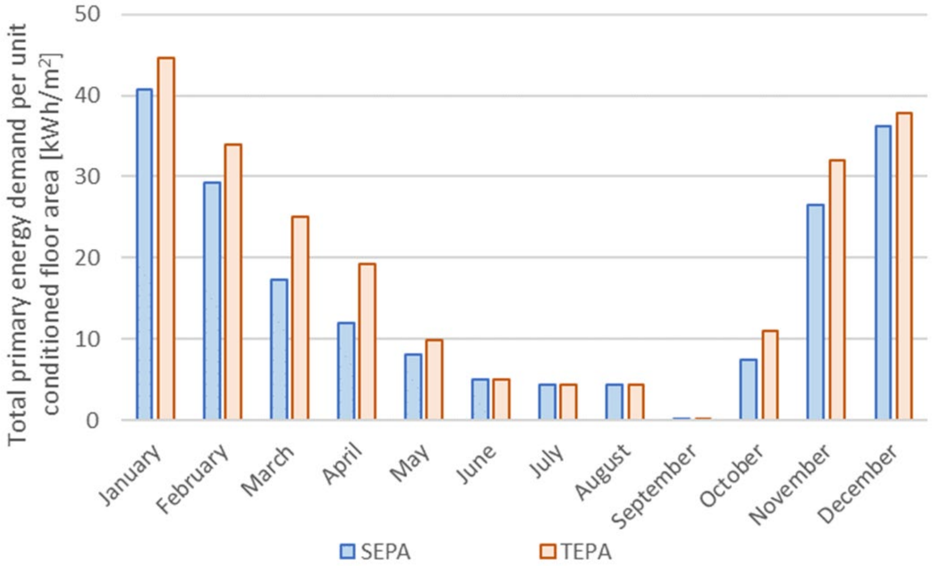


Figure 15. SEPA and TEPA comparison for building IT-12

Model calibration (CAL): The calibration procedure was pursued on the buildings provided with suitable measurements. Figure 16 and Figure 17 present the energy signature of the measured energy consumption, and of the simulated energy consumption before and after the calibration procedure. Table 46 presents the calibration procedure pursued, highlighting the time step (e.g., hourly, monthly) and the analysed parameter (e.g., indoor temperature or energy consumption), as well as the statistical indices before and after the calibration. For one building, IT-02, due to the lack of a sufficient amount of measured data, the calibration was not effective.

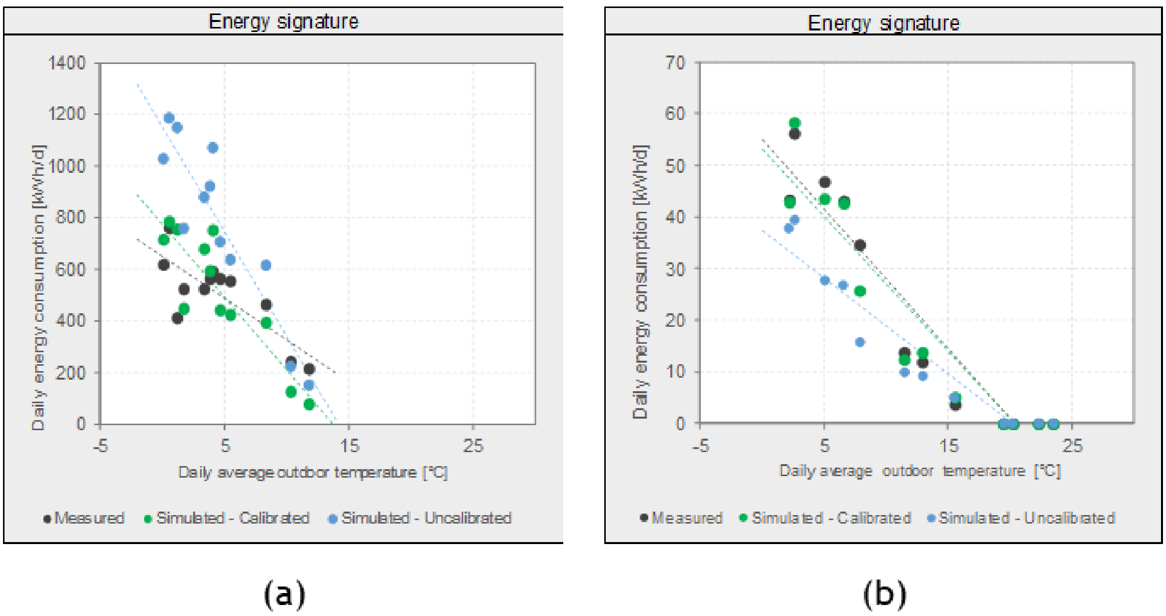
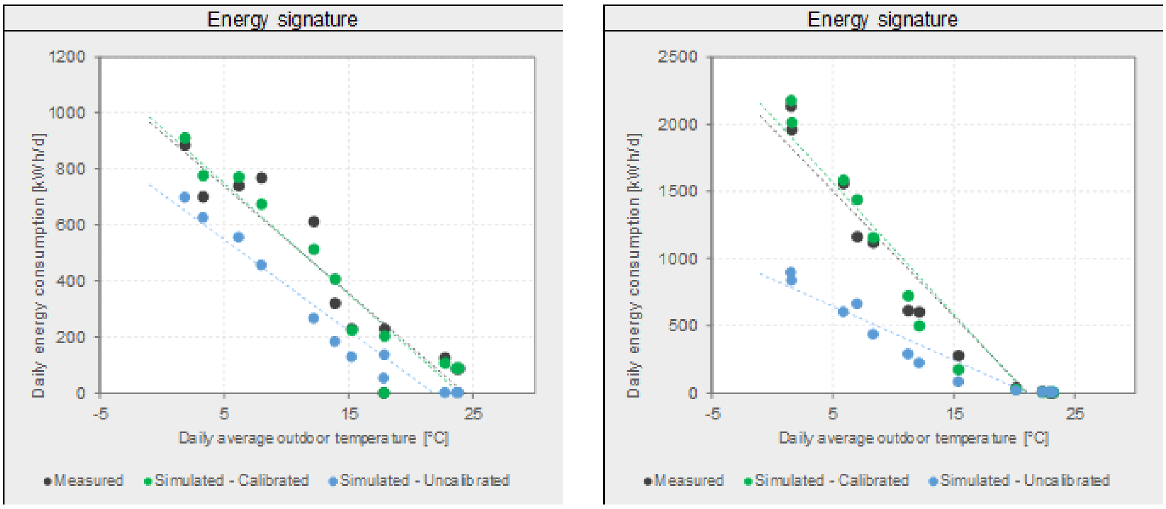


Figure 16. Calibration results for building IT-01 (a) and IT-02 (b)



(c) (d)

Figure 17. Calibration results for building IT-12 (c) and IT-15 (d)

Table 46. Calibration results for the analysed buildings

Building code	Calibration procedure	MBE [%]			cvRMSE [%]		
		Limit	Uncalibrated model	Calibrated model	Limit	Uncalibrated model	Calibrated model
IT-01	Monthly - Energy demand	±5	-27,7	-3,6	15	46,3	14,0
IT-02	Weekly - Energy demand	±5	59,8	2,6	15	75,4	28,8
IT-12	Monthly - Energy demand	±5	-39,3	-0,5	15	51,8	13,4
IT-15	Monthly - Energy demand	±5	-56,2	3,4	15	78,3	12,3

Energy conservation measure assessment (ECM): The energy conservation measure assessment results are presented in Table 47.

Table 47. ECM results for the analysed buildings

Building code	Scenario	Energy efficiency measures	*NPV/A*$_f$ [€/m^2]	*DPP* [a]
IT-01	1	External walls and roof insulation, windows replacement	-212	>30
	2	Heating emission control replacement	-9	10
	3	Scenario 1+ Scenario 2	-227	>30
IT-02	1	External walls insulation	131	9
	2	Roof insulation	5	30
	3	Floors insulation	25	25
	4	Windows replacement	-5	>30
	5	Heat generator replacement (heat pump)	18	18
	6	Scenario 1 + Scenario 2 + Scenario 3 + Scenario 4	96	19
	7	Scenario 5 + Scenario 6	106	19
	8	Scenario 7 + PV system installation	95	23
IT-12	1	External walls and roof insulation, windows replacement	260	19
	2	Heat generator replacement (heat pump), PV system installation	-263	>30
	3	Scenario 1 + Scenario 2	-231	30
IT-13	1	External walls and roof insulation	-12	>30
	2	Windows replacement	-288	>30
	3	Scenario 1 + Scenario 2	683	30
	4	Scenario 3 + Heating emission control replacement	135	21
IT-15	1	Windows replacement	-115	>30
	2	Scenario 1 + external walls insulation	-176	>30
	3	Scenario 1 + Scenario 2 + Heat generator replacement (heat pump)	-920	>30

Indoor environmental quality assessment (IEQ): The indoor environmental quality assessment results are presented in Table 48.

Table 48. IEQ results for the analysed buildings

	Comfort category	Thermal discomfort hours [%]	Building polluting level	Design / Measured external air flow rate [h^{-1}]	Minimum external air flow rate [h^{-1}]
IT-01	II	42	Very low	0,60	0,60
IT-02	II	76	Low	0,15	0,70
IT-03	II	56	Low	0,28	1,30
IT-05	II	65	Low	0,78	4,20
IT-11	II	49	Very low	0,80	0,80
IT-12	II	42	Low	6,44	4,80
IT-13	II	32	Low	4,32	4,30
IT-14	II	49	Low	1,32	5,00
IT-15	II	35	Very low	3,41	4,30

Building automation and control system assessment (BACS): The level for each service and for the whole building in the original state of all the buildings are presented in Table 49, while the BACS impact assessment results are shown in Table 50.

Table 49. BACS levels for the analysed buildings

BACS levels							
Building code	Whole building	Heating control	Domestic hot water supply control	Cooling control	Ventilation and air-conditioning control	Lighting control	Blind control
IT-01	D	D	D	-	-	-	-
IT-02	D	D	D	-	-	-	-
IT-03	D	D	D	-	-	-	-
IT-05	D	D	D	-	-	D	-
IT-09	D	D	C	D	D	C	-

IT-11	D	D	-	-	-	C	-
IT-12	D	D	-	-	-	D	-
IT-13	D	D	D	-	-	D	-
IT-14	D	D	D	-	-	D	-
IT-15	D	D	-	-	-	D	-

Table 50. BACS Total primary energy improvement for the analysed buildings

Building code	Building service	Original BACS function	Improved BACS function	Reduction of E_P [%]
IT-01	Heating control	Emission control - No automatic control	Emission control - Individual room control	12
IT-02	Heating control	Emission control - No automatic control	Emission control - Individual room control	14
	Heating control	Control of distribution network hot water temperature (supply or return) – No automatic control	Control of distribution network hot water temperature (supply or return) – Demand based control	34
	Ventilation and air-conditioning control	Supply air flow control at the room level (e.g. fan on/off) – No automatic control	Supply air flow control at the room level (e.g. fan on/off) – Occupancy based control	12
IT-03	Heating control	Emission control - No automatic control	Emission control - Individual room control	23
IT-05	Heating control	Emission control - No automatic control	Emission control - Individual room control	10
IT-12	Heating control	Emission control - No automatic control	Emission control - Individual room control	4
IT-13	Heating control	Emission control - No automatic control	Emission control - Central automatic control	9
	Heating control	Emission control - No automatic control	Emission control - Individual room control	12

	Lighting control	Occupancy control - Manual on/off switch	Occupancy control - Automatic detection (auto on)	0

The application of the proposed procedures showed interesting results, in particular:

- SEPA calculation is always feasible due to the massive use of standard data instead of user-based data.
- TEPA calculation is feasible only when user-based data is available. In case of recent energy audits that can be used as data sources, this procedure is always feasible.
- CAL procedure requires a significant amount of information. This information can be contained in the energy audit but is not always ready to be used. E.g., energy consumption values are often presented as aggregated data, therefore investigation of bills can be required to gather the needed information.
- IEQ – Indoor thermal comfort procedure can only be applied in case of availability of hourly data, therefore such an application is only possible when the energy performance procedure is based on an hourly calculation.
- IEQ – Indoor air quality procedure, in order to be applicable for all partners, is based on the minimum requirements of EN 16798-1. These can suffer variations based on the national annex, for this reason in some cases even if the standard procedure for the energy performance was pursued, the compliance turned out to be non-verified.
- ECM analysis – Currently in Italy the economic indicators are not required in detail, since only a not discounted payback period is required. New indicators, such as the proposed ones can give useful information to the end-user.
- BACS analysis – In Italy there is no indication in the EPC regarding the BACS status in the building. Furthermore, the BACS level is defined for the whole building as the minimum value of all the considered services. BACS information should be embedded in the energy certificate and should be detailed for each service in order to give suitable information to the user regarding the areas that need enhancement.

6.2.5 Slovenia

Standard and tailored energy performance assessment (SEPA and TEPA): The buildings were analysed with SEPA and/or TEPA procedures, depending on the availability of building information. For a case study, SI-03, both procedures were performed and compared in Figure 18.

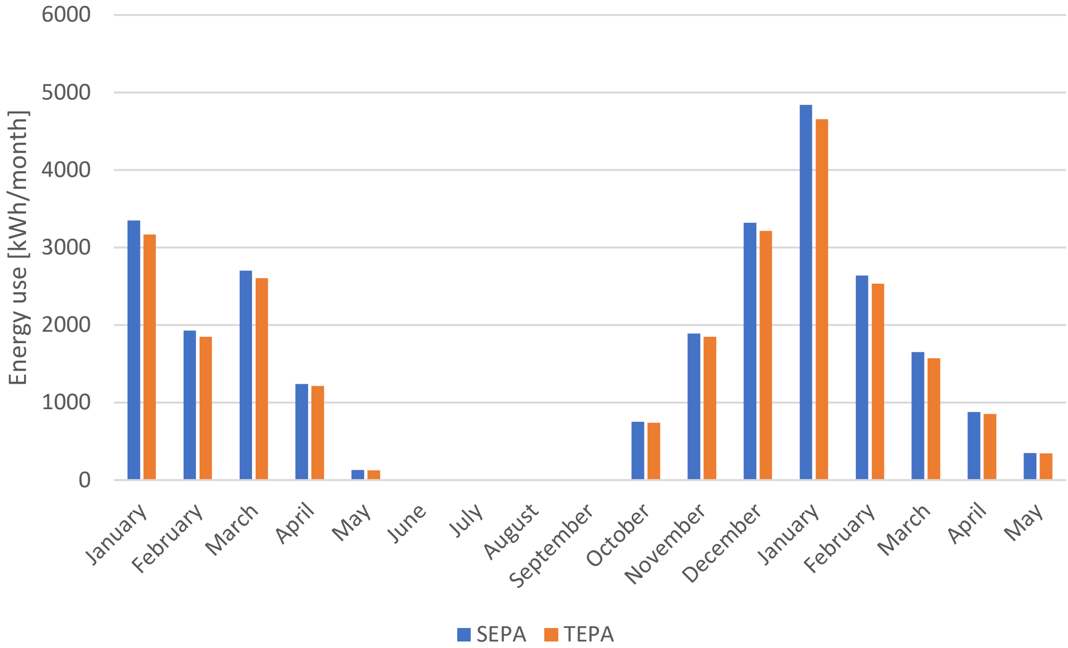


Figure 18. SEPA and TEPA comparison for building SI-03

Model calibration (CAL): The calibration procedure was pursued on the buildings provided with suitable measurements. Figure 19 presents the energy signature of the measured energy consumption, and of the simulated energy consumption before and after the calibration procedure. Table 51 presents the calibration procedure pursued, highlighting the time step (e.g., hourly, monthly) and the analysed parameter (e.g., indoor temperature or energy consumption), as well as the statistical indices before and after the calibration.

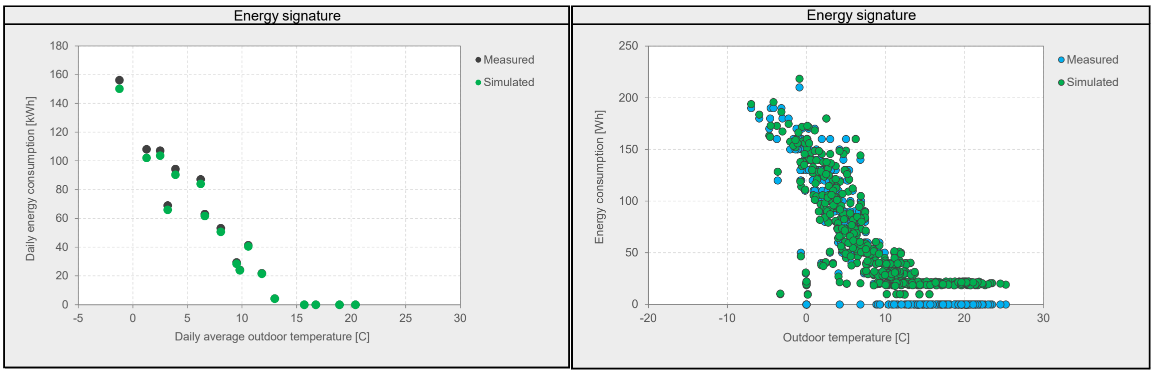


Figure 19. Calibration results for building SI-02

Table 51. Calibration results for the analysed buildings

Building code	Calibration procedure	MBE [%]			cvRMSE [%]		
		Limit	Uncalibrated model	Calibrated model	Limit	Uncalibrated model	Calibrated model
SI-01	Monthly - Energy demand	±5	+15,2	+4,1	15	+78,1	+12,1
SI-02	Hourly - Energy demand	±5	+43,8	+3,5	15	+65,2	+13,2
SI-03	Hourly - Energy demand	±5	-35,8	-4,2	15	+23,8	+8,9
SI-04	Hourly - Energy demand	±5	-65,2	-2,8	15	+48,2	+15,6
SI-05	Monthly - Energy demand	±5	-81,2	+4,1	15	+56,3	+12,1
SI-06	Monthly - Energy demand	±5	+15,2	+4,2	15	+30,1	+8,2
SI-07	Monthly - Energy demand	±5	+22,3	+3,2	15	+44,8	+11,2
SI-08	Monthly - Energy demand	±5	-18,4	-2,3	15	+35,2	+13,8
SI-09	Monthly - Energy demand	±5	-35,2	-4,5	15	+41,2	+12,2
SI-10	Monthly - Energy demand	±5	+35,2	+3,2	15	+23,2	+14,1

Energy conservation measure assessment (ECM): The energy conservation measure assessment results are presented in Table 52.

Table 52. ECM results for the analysed buildings

Building code	Scenario	Energy efficiency measures	*NPV/A*$_f$ [€/m^2]	*DPP* [a]
SI-01	1	Installation of the energy management system	358	3
	2	1 + Renovation of lighting system	256	8
	3	2 + Installation of PV system	128	16
	4	3 + Thermal insulation of external walls	35	29
	5	4 + Thermal insulation of the ceiling towards the attic and basement	-235	>30
	6	5 + Windows replacement	-502	>30
	7	6 + Reconstruction of the HVAC system	-683	>30
SI-02	1	Upgrade of the energy management system	403	3
	2	1 + Installation of PV system	235	16
	3	2 + Renovation of lighting system	102	21
SI-03	1	Upgrade of the energy management system	435	2
	2	1 + Installation of PV system	285	12
	3	2 + Renovation of lighting system	205	16
	4	3 + Reconstruction of the HVAC system	-135	>30
SI-05	1	Upgrade of the energy management system	315	2
	2	1 + Renovation of lighting system	275	6
	3	2 + Installation of PV system	133	15
	4	3 + Thermal insulation of external walls	-45	>30
	5	4 + Thermal insulation of the ceiling towards the attic and basement	-135	>30
	6	5 +Windows replacement	-468	>30
	7	6 + Reconstruction of the HVAC system	-785	>30
SI-08	1	Upgrade of the energy management system	277	3
	2	1 + Installation of PV system	95	15

Indoor environmental quality assessment (IEQ): The indoor environmental quality assessment results are presented in Table 53. In each building a representative room was analysed and subjected to IEQ analysis.

Table 53. IEQ results for the analysed buildings

	Comfort category	Thermal discomfort hours [%]	Building polluting level	Design / Measured external air flow rate [h^{-1}]	Minimum external air flow rate [h^{-1}]
SI-01	II	15	Very low	1,00	0,50
SI-02	II	8	Low	3,10	4,20
SI-03	II	23	Low	1,65	1,40
SI-04	II	14	Very low	1,20	0,50
SI-05	II	6	Low	2,30	0,65
SI-06	II	8	Low	4,80	1,40
SI-07	II	12	Low	3,50	0,70
SI-08	II	23	Low	6,20	1,20
SI-09	II	15	Low	3,20	0,65
SI-10	II	5	Very low	4,20	0,80

Building automation and control system assessment (BACS): The level for each service and for the whole building in the original state of all the buildings are presented in Table 54, while the BACS impact assessment results are shown in Table 55.

Table 54. BACS levels for the analysed buildings

BACS LEVEL							
Building code	Whole building	Heating control	Domestic hot water supply control	Cooling control	Ventilation and air-conditioning control	Lighting control	Blind control
SI-01	D	D	D	-	-	-	-
SI-02	D	D	D	-	D	D	-
SI-03	D	D	D	-	-	D	-

SI-04	D	D	D	-	-	-	-
SI-05	D	D	D	-	-	-	-
SI-06	D	D	D	-	-	-	-
SI-07	D	D	D	-	-	-	-
SI-08	D	D	D	-	D	-	-
SI-09	D	D	D	-	-	-	-
SI-10	D	D	D	-	-	-	-

Table 55. BACS Total primary energy improvement for the analysed buildings

Building code	Building service	Original BACS function	Improved BACS function	Reduction of E_P [%]
SI-01	Heating control	Emission control - No automatic control	Emission control - No automatic control	5
SI-02	Heating control	Emission control - No automatic control	Emission control - No automatic control	6
SI-03	Heating control	Emission control - No automatic control	Emission control - No automatic control	3
SI-04	Heating control	Emission control - No automatic control	Emission control - No automatic control	8
SI-05	Heating control	Emission control - No automatic control	Emission control - No automatic control	10
SI-06	Heating control	Emission control - No automatic control	Emission control - No automatic control	6
SI-07	Heating control	Emission control - No automatic control	Emission control - No automatic control	11
SI-08	Heating control	Emission control - No automatic control	Emission control - No automatic control	6
SI-09	Heating control	Emission control - No automatic control	Emission control - No automatic control	7
SI-10	Heating control	Emission control - No automatic control	Emission control - No automatic control	5

For the analysed buildings in Slovenia, the SEPA was initially developed as part of the standard process, and TEPA served as an intermediate step in the development of the CAL model. CAL models were developed for all buildings. The results for the CAL models can be summarised as follows: (1) calibration was achieved by incorporating real occupancy schedules. The major challenge in calibration was accounting for deviations from average real occupancy schedules. Building operations knowledge played a crucial role, as calibration would likely not have been achieved without the use of advanced optimisation algorithms, (2) the CAL model facilitates the identification and calculation of energy efficiency measures, resulting in savings that align more closely with real impact.

The ECM assessment revealed the potential for energy savings. In general, the most effective results were achieved with the most extensive renovations, which included the improvement of the building envelope. On the other hand, smaller investments, such as lighting system upgrades, yielded the best results in terms of DPP. The ECM assessment builds upon the current method, which relies on simple payback period, and provides better conclusions in the long run. It should be noted that the current EPC process only employs the simple payback period, so the improved approach represents a clear upgrade with limited additional effort.

In conclusion, data analysis can be carried out in some cases within a standard process of EPC, although it is very rare and usually only if the building owner has a predetermined future plan. This methodical approach ultimately leads to higher quality output, resulting in a greater understanding of specific problems, and possible solutions for the individual buildings. However, it should be noted that the amount of work and the time required may increase in certain cases, leading to a higher cost of the final product (e.g., EPC and Energy Audit).

6.2.6 Spain

Standard and tailored energy performance assessment (SEPA and TEPA): The buildings were analysed with SEPA and/or TEPA procedures, depending on the availability of building information.

Model calibration (CAL): The calibration procedure was pursued on the buildings provided with suitable measurements. Figure 20 presents the energy signature of the measured energy consumption, and of the simulated energy consumption before and after the calibration procedure. Table 56 presents the calibration procedure pursued, highlighting the time step (e.g., hourly, monthly) and the analysed parameter (e.g., indoor temperature or energy consumption), as well as the statistical indices before and after the calibration.

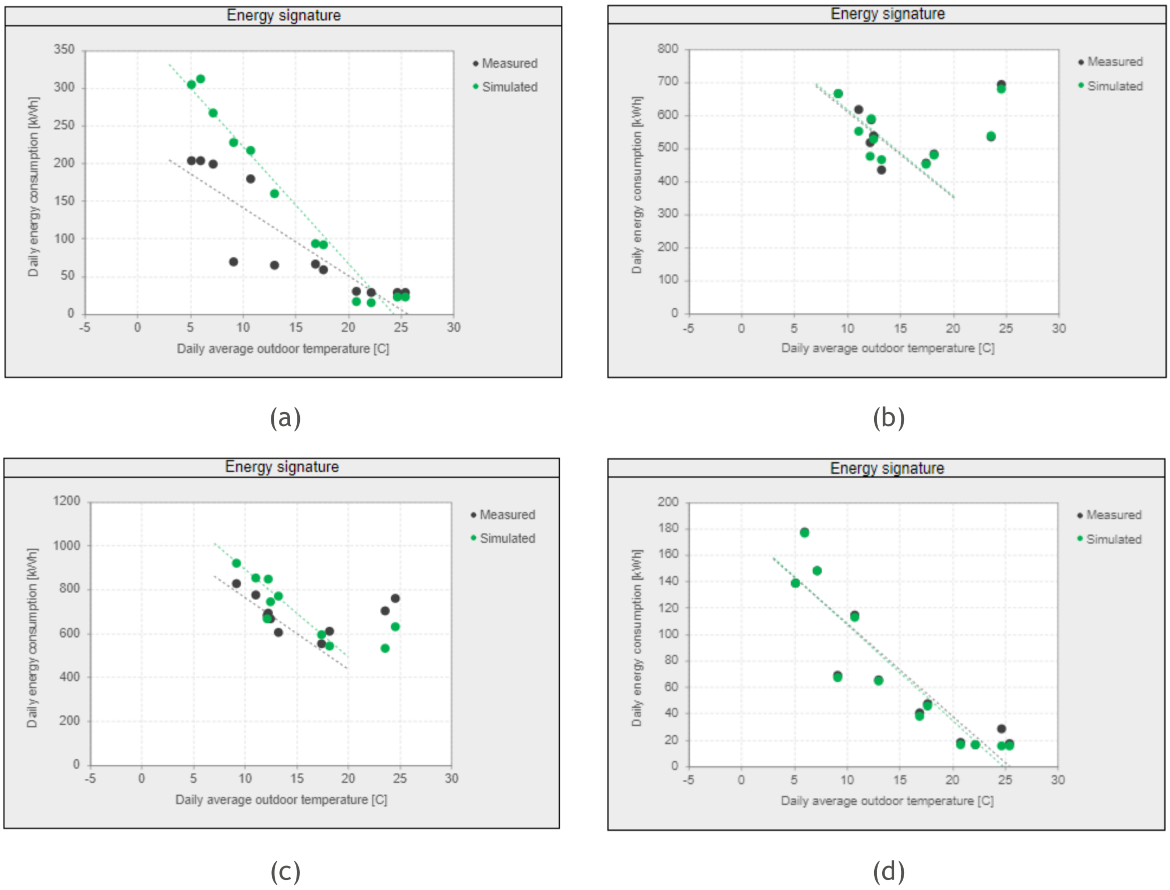


Figure 20. Calibration results for building ES-03 (a) before calibration, (b) after calibration, and ES-05 (c) before calibration and (d) after calibration

Table 56. Calibration results for the analysed buildings

Building code	Calibration procedure	MBE [%]			cvRMSE [%]		
		Limit	Uncalibrated model	Calibrated model	Limit	Uncalibrated model	Calibrated model
ES-03	Monthly – Energy demand	±5	3,2	-1,8	15	23,6	7,1
ES-05	Monthly – Energy demand	±5	50,9	-3,0	15	75,9	5,4

Energy conservation measure assessment (ECM): The energy conservation measure assessment results are presented in Table 57.

Table 57. ECM results for the analysed buildings

Building code	Scenario	Energy efficiency measures	NPV/A_f [€/m^2]	DPP [a]
ES-03	1	Installation or replacement of the combined generator for heating, DHW and cooling with high efficiency technologies and Installation of a photovoltaic system	36,9	13
ES-04	1	External wall thermal insulation, Roof (or upper slab) thermal insulation, Windows replacement, Installation or replacement of solar shading devices, Installation or replacement of the combined generator for heating, DHW and cooling with high efficiency technologies, Installation of a photovoltaic system	-96,9	>30
ES-05	1	External wall thermal insulation, Roof (or upper slab) thermal insulation, Windows replacement	-27,8	>30
	2	Installation or replacement of the combined generator for heating, DHW and cooling with high efficiency technologies, Installation of a photovoltaic system	18,8	30
	3	External wall thermal insulation, Roof (or upper slab) thermal insulation, Windows replacement, Installation or replacement of the combined generator for heating, DHW and cooling with high efficiency technologies, Installation of a photovoltaic system	43,1	28
ES-09	1	Installation or replacement of the combined generator for heating, DHW and cooling with high efficiency technologies, Installation of a photovoltaic system	430,1	8
	2	External wall thermal insulation, Roof (or upper slab) thermal insulation, Windows replacement, Installation or replacement of solar shading devices, Installation or replacement of the combined generator for heating, DHW and cooling with high efficiency technologies, Installation of a photovoltaic system	587,3	8
ES-10	1	External wall thermal insulation, Roof (or upper slab) thermal insulation, Floor (or lower slab) thermal insulation, Windows replacement, Installation or replacement of solar shading devices, Installation or replacement of the combined generator for heating, DHW and cooling with high efficiency technologies, Installation of thermal solar system, Installation or replacement of the heat recovery for the mechanical ventilation system with high efficiency technologies	-240,0	>30

Indoor environmental quality assessment (IEQ): The indoor environmental quality assessment results are presented in Table 58.

Table 58. IEQ results for the analysed buildings

	Comfort category	Thermal discomfort hours [%]	Building polluting level	Design / Measured external air flow rate [h^{-1}]	Minimum external air flow rate [h^{-1}]
ES-01	III	10	Very low	0,8	1,2
ES-02	III	41	Low	1,4	0,9
ES-03	I	23	Very low	0,69	1,8
ES-05	II	33	Low	0,8	2,7
ES-06	II	28	Low	0,95	1,4
ES-07	II	16	Low	0,54	1,5
ES-08	II	45	Low	0,63	1,7

Building automation and control system assessment (BACS): The level for each service and for the whole building in the original state of all the buildings are presented in Table 59, while the BACS impact assessment results are shown in Table 60.

Table 59. BACS levels for the analysed buildings

BACS LEVEL							
Building code	Whole building	Heating control	Domestic hot water supply control	Cooling control	Ventilation and air-conditionin g control	Lighting control	Blind control
ES-01	B	B	B	B	B	A	B
ES-02	A	A	-	A	A	C	C
ES-03	A	A	A	A	A	A	A
ES-04	D	D	D	D	-	D	D
ES-05	D	D	D	D	-	D	D
ES-06	B	B	B	B	B	B	B
ES-07	A	A	A	A	A	A	A

ES-08	D	D	D	D	D	D	D
ES-09	D	D	D	D	D	D	D
ES-10	D	-	D	-	-	D	D

Table 60. BACS Total primary energy improvement for the analysed buildings

Building code	Building service	Original BACS function	Improved BACS function	Reduction of E_P [%]
ES-03	Cooling control	Emission control - Individual room control	Individual modulating room control with communication and occupancy detection (not applied to slow reacting heating emission system	3
	Heating control	Emission control - Individual room control	Individual modulating room control with communication and occupancy detection (not applied to slow reacting heating emission system)	3
	Ventilation and air-conditioning control	Supply air flow control at the room level – time control	Occupancy based control	15

The application of the proposed procedures showed interesting results, in particular:

- CAL procedure requires a significant amount of information. As mentioned in the Italian remarks, this information can be contained in the energy audit but are not always ready to be used. E.g., energy consumptions are often presented as aggregated data, therefore investigation of bills can be required to gather the needed information. The calibration has been done with the software CYPETHERM.
- IEQ – Indoor thermal comfort procedure showed that Spanish standards are different (less restrictive) compared to the minimum requirements of EN 16798-1.
- ECM analysis – The Spanish study was done with the Catalan database.
- BACS analysis – In Spain there is no indication in the EPC regarding the BACS status in the building.

6.3 Cross country comparison

The analysis of the data sources for the analysed buildings, as presented in Figure 21, shows different available sources from country to country. The graph does not provide a representative sample, especially due to the uneven number of buildings used by the individual countries for the analyses, but rather an idea of the current state of available data sources per section in each country. Regarding source availability, in this representation, Slovenia is the only country with data available for all the listed sources and the one with the highest data availability. As for the other countries, however, each of them has one or more unavailable data source. Four out of six partners also had building energy models available as data sources.

The number of analyses performed on the selected buildings by each partner among the six proposed, are presented in Figure 22 and Figure 23.

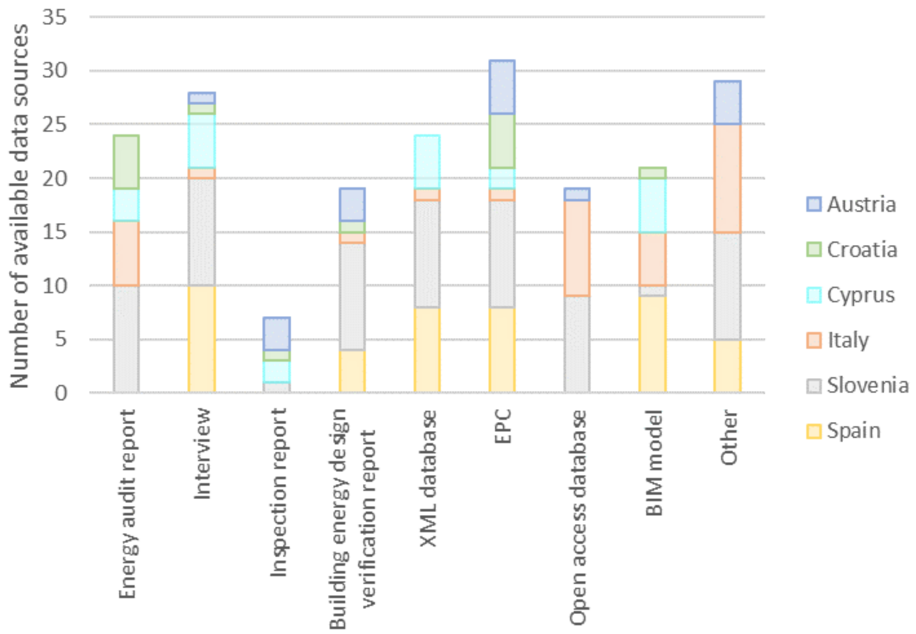


Figure 21. Data sources for TDS2 analysed buildings

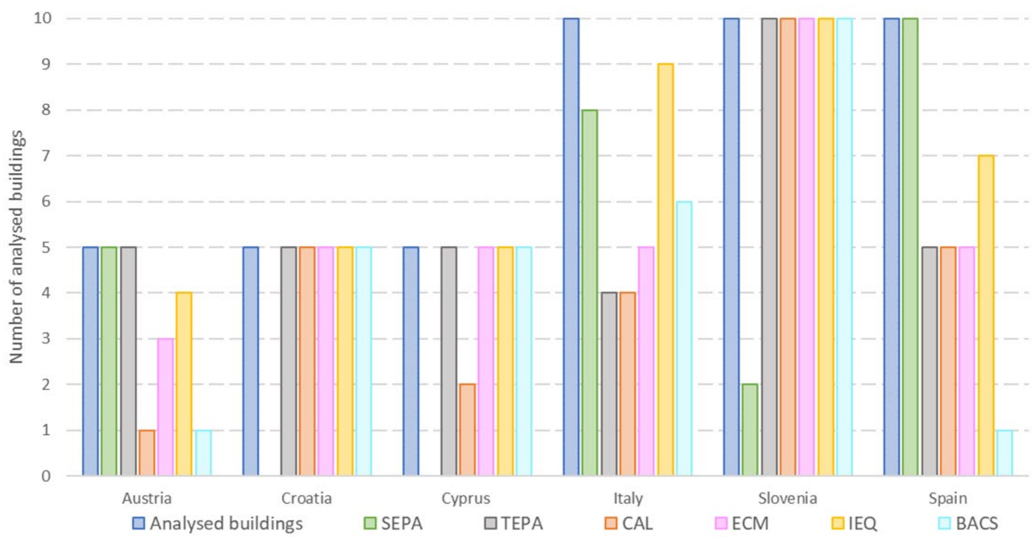


Figure 22. Number of analyses performed grouped by country

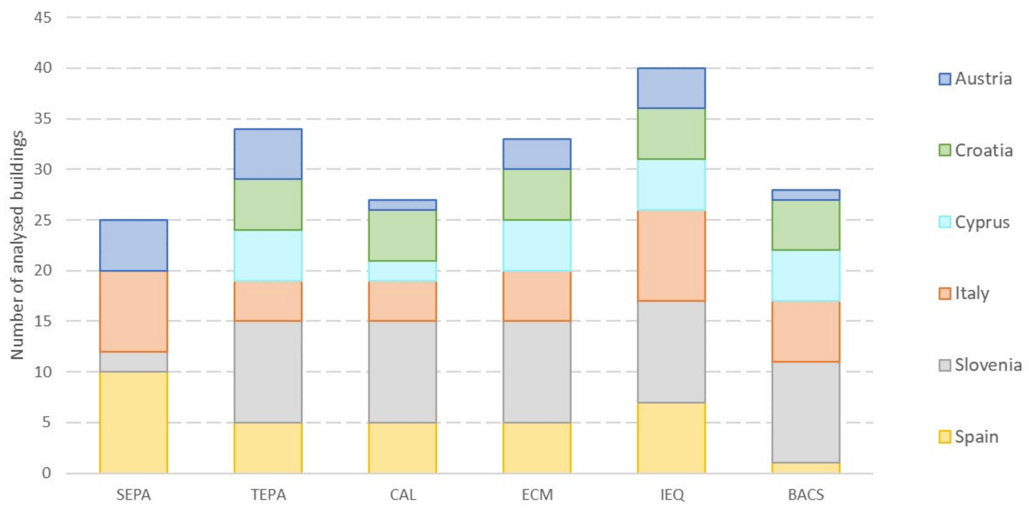


Figure 23. Number of analyses performed grouped by analysis type

The main purpose of the analyses performed in different countries was to investigate the effectiveness of the different procedures and to define possible issues associated with their application, rather than comparing numerical results.

The following considerations can be made from the cross-country comparison.

Standard energy performance assessment (SEPA)

The SEPA is the basis of the EPCs. For its specificities it is easy to perform, since only standard information is required. On the other hand, differences in the results can be detected from country to country. This can be attributed to the different procedures deployed in the different countries: e.g., in some countries monthly quasi-steady state method is applied, while in others simplified or detailed dynamic hourly models are deployed.

Tailored energy performance assessment (TEPA)

The TEPA can only be performed when the actual occupancy and building use are known, through interviews or monitoring. Therefore, its application is not always feasible. Nevertheless, non-negligible differences in the results can be detected from SEPA. For this reason, the introduction of such results in the EPC can provide useful information to the final user.

Model calibration (CAL)

The model calibration procedure has the potentiality to significantly reduce the model error in the energy performance assessment procedure. The performed analyses highlighted two major issues related to this procedure. The first is connected to the required data: plenty of information is mandatory (i.e., operative data and climatic data) or quasi-mandatory (i.e., occupancy profiles, system operation schedules, etc). These data, for various reasons, are not always available. The second issue is related to the complexity of the procedure. In some cases, it may require a high number of repetitions to reach the required calibration indicators levels. This can be very time-consuming, both for the simulation time and the time needed to implement the changes in the model.

Energy conservation measure assessment (ECM)

The ECM analysis proved to be of interest due to its simplicity. In several countries similar procedures are already applied and the introduction of discounted indicators and/or new indicators turned out to be potentially effective.

Indoor environmental quality assessment (IEQ)

The proposed thermal comfort assessment procedure is only applicable in case of hourly calculation procedures; therefore, its application may be limited in specific countries. The air quality assessment, on the other hand, was based on the standard values proposed in EN 16798-1. Since National annexes are in force, the values need to be changed country by country.

Building automation and control system assessment (BACS)

The assessment of the improvement of BACS functions proved to be effective, even if standardised procedures need to be added to technical standards to properly determine the effects of BACS on the energy performance. Currently in the EPC of several countries there is no information to describe buildings status regarding the control and automation systems. Due to the relevance of this topic new indicators should be implemented in the EPC schema.

7 Conclusions

The activity carried out in Task 2.2 of TIMEPAC WP2 analysed possible procedures to enhance the current Energy Performance Certificate. The innovation in the adopted approach comes from the integration of new indicators, currently not included in EPC schemas, able to enhance the quality of the result but also expand the range of information including indices from different domains (e.g., economic and IEQ).

An in-depth analysis of the available procedures was performed, and six procedures were chosen. These are the standard energy performance assessment, the tailored energy performance assessment, the model calibration against monitored data, the indoor environmental quality assessment (for thermal comfort and indoor air quality), the economic evaluation of energy efficiency measures, and the assessment of building automation and control system improvement on the energy performance of the building.

The application of these procedures was explained, and some tools to ease their application were developed in MS Excel. Two guidelines to clarify the best practices for the data collection and the data analysis were drafted.

The implementation of the proposed procedures in the EPC was tested in different countries analysing a group of 45 buildings different for many factors (e.g., building use, period of construction, location, technical building systems, etc.).

Starting from the numerical result and the knowledge derived from the application, the partners proposer several remarks on the procedures, analysing the feasibility of the proposed methods in terms of easiness of application and quality of the results.

The analyses carried out and the drafting of guidelines on data collection and data analysis aim to improve the current status of energy performance certificates (EPCs). The proposed analyses are a good starting point to develop an enhanced EPC since they allow both to increase the quality of the certificate and to generate information on a multi domain. Nevertheless, as presented in the results, there are some aspects that should be improved or modified. In particular, to implement these analyses, energy performance certificates are required to become a digital source of integrated information and no longer just a paper document, in accordance with the TIMEPAC vision. This approach is fully consistent with the introduction of the Digital Building Logbook, as foreseen in the revised EPBD.

Thanks to through-life updatable EPCs, it will be possible to enhance the validity of the certificates over time. Since it is not reasonable to ask technicians to manually modify, update, and generate new EPCs, a change of paradigm is mandatory. Open-source databases of building information (e.g., BIM, BEM, etc.) and an increase in building smartness to automatise the data gathering process will be needed.

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Annex A - Guidelines for data collection

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A1 Introduction

The enhancement of the EPC schema through the integration of operational data within Transversal Deployment Scenario 2 (TDS2) will be addressed by the proposal of new key performance indicators (KPIs). These will be selected from the results of different analysis that will be performed on the selected buildings. Specifically, the analysis to be performed are the following:

1. Standard energy performance assessment (SEPA)
2. Tailored energy performance assessment (TEPA)
3. TEPA calibration against monitored data (CAL)
4. Economic evaluation of energy efficiency measures (ECM)
5. Indoor environmental quality evaluation (IEQ)
6. Building Automation and Control System impact assessment (BACS)

All the analysis to be performed require the creation of a building energy model. To this purpose, different input data needs to be collected. Moreover, specific input data are required to carry out different analysis; in the following list, the categories of data to be collected for the creation of the building energy model and for carrying out the analysis are presented:

1. *Geographical and climatic data*, required to define the geographical location of the building and of its neighbour (e.g., presence of external obstacles), and the outdoor environmental parameters (e.g., air temperature, solar irradiance, etc.),
2. *Geometrical characteristics*, required to define the dimensions of the building (e.g., floor area, internal height, etc.) and of its components (e.g., external and internal opaque and transparent components),
3. *Thermal properties of building components*, required to define the thermal parameters (e.g., thermal transmittance, thermal capacity, etc.) of the external and internal opaque and transparent components,
4. *Technical building systems (TBSs) characteristics*, required to define the presence, typology, and properties of the TBSs for each energy service,
5. *Operating conditions*, required to define the user behaviour in terms of presence in the building/room, control of the TBSs, use of appliances, windows openings, and use of solar shading devices, etc.,
6. *Monitored data on building performance,* including indoor environmental data, performance parameters of the TBS components, and energy consumptions for each energy service and/or energy carrier,
7. *Economic data* in terms of cost of each energy carrier and cost of refurbishment.

According to the availability of the input data, and to the analysis to be performed, the required input data can be either *real* data, *conventional* (standard) data, which are data derived from technical standards, and/or *reference* data, which are data derived from similar buildings. The use of real, conventional, or reference data is presented in Table A. 1.

Table A. 1. Type of data to be used for the different analyses

	Standard EP assessment	Tailored EP assessment	Model calibration	ECM assessment	IEQ assessment	BACS impact assessment
General information	Real	Real	Real	Real	Real	Real
Geographical and climatic data	Conventional (standard)	Conventional (standard)	Real	Conventional (standard)	Conventional (standard)	Conventional (standard)
Geometrical characteristics	Real	Real	Real	Real	Real	Real
Thermal parameters of building components	Real or reference	Real or reference	Real or reference	Real or reference	Real or reference	Real or reference
TBSs characteristics	Real or reference	Real or reference	Real or reference	Real or reference	Real or reference	Real or reference
Operating conditions	Conventional (standard)	Real	Real	Real or conventional	Real or conventional	Real or conventional
Monitored data on building performance	/	/	Real	/	/	/
Economic data	/	/	/	Real or reference	/	/

A2 Geographical and climatic data

A2.1 Data to be collected

The geographical and climatic data are requested in order to define the characteristics of analysed building's neighbour – specifically the presence of external obstacles that may shade the building, and the outdoor driving forces (environmental parameters).

The **geographical data** to be collected include, but are not limited to, the following parameters:

- Geographical location (latitude, longitude, and altitude), and/or building address
- Presence and characteristics of external shading obstacles (height and position)

The **climatic data** to be collected include, but are not limited to, the following parameters:

- Climatic region
- Aggregated climatic data (e.g., heating degree days, cooling degree days, etc.)
- Weather data (e.g., outdoor air temperature, etc.)

A2.2 Data sources and data collection procedure

Generally, the required geographical data could be derived from any provided documentation (i.e., existing energy performance certificate, a BIM model, etc.) or from web mapping platforms.

Among the geographical data, the collection of the altitude of the analysed building is of foremost importance for the (possible) correction of the weather data (detailed later in the guideline). In case of unavailability of latitude, longitude, and altitude in any provided documentation, these can be extracted through web mapping platforms starting from the building address (this is not mandatory, and it can be omitted for the sake of privacy issues).

The characterisation of the building's surroundings is relevant as well; specifically, it is necessary to identify the presence of any object that may shadow the analysed building (other buildings, trees, etc.), and to characterise them. The data sources and the procedure for the collection of these data are provided in Section A2.2.1.

Among the climatic data, the climatic region (if necessary) may be derived from the specific National documentation, depending on the city in which the analysed building is place. As for the weather data, it would be preferable to collect the specific weather data, thus avoiding the aggregated ones; the data sources and the procedure for the collection of the specific weather data are provided in Section A2.2.2.

A2.2.1 Characterisation of the building's surrounding

The presence of external shading obstacles, and their characterisation (height and distance from the analysed building), may be derived through the following (but not limited to) data sources:

1. City (or district) plans
2. Web mapping platforms (e.g., Google Maps)
3. In site inspections
4. In field measurements

The easiest way to determine the presence of external shading obstacles and their characterisation is through city (or district) plans. However, generally these plans only provide useful information regarding the surrounding buildings; for other objects, such as trees, other data sources should be considered.

In most cases, city and district plans (Figure A. 1. Example of city (or district) plan with indication of the buildings' number of storeys) provides the number of storeys of the buildings that surrounds the analysed one; assuming an average storey height (typical for the specific context, nation, etc.), it is possible to determine the height of the surrounding buildings. If the city (or district) plan is provided in a digital form (e.g., CAD), it is possible to easily derive the distance of the surrounding buildings from the analysed one (in absence of specific information in the plan) by measuring the distance directly in the plan. If the city (or district) plan is provided in a printed form, it would be useful to copy the plan in a digital form, and then derive the distance from the digital drawing.

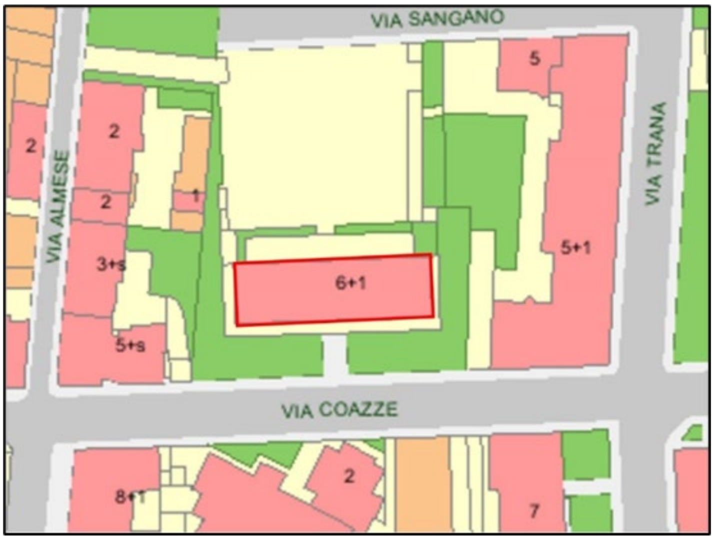

Figure A. 1. Example of city (or district) plan with indication of the buildings' number of storeys

In absence of city (or district) plans (and for different external obstacles rather than buildings), web mapping platforms may be used. Specifically, by the use of such platforms it is possible to determine the presence of external shading obstacles and to derive their characteristics. From 2D views, it is possible to determine both the presence and the distance of the objects from the analysed building; the 2D view should be transformed in a digital drawing (e.g., CAD) to allow the measuring of the distance of the objects from the analysed building. From 3D views, instead, it is possible to derive the number of storeys of the surrounding buildings, and thus their height; similarly, it is possible to determine the height of other obstacles by defining an "apparent" number of storeys.

In the unfortunate case of absence of 2D or 3D views in the web mapping platforms, it is possible to derive the required information by means of in site inspections (presence of external shading obstacles, number of storeys) and in field measurements (distance and height).

Finally, it should be useful to verify the correspondence of the collected data with reality through in site inspections.

A.2.2.2 Weather data

The climatic data (generally) required are the external air temperature (dry and/or dew bulb), the solar irradiance (horizontal and for each orientation), relative humidity, wind speed, and wind direction. These may be derived through the following (but not limited to) data sources:

1. In field measurements (real data recorded on the building site),
2. Meteorological stations (real data recorded nearby the building, or at the building location),
3. Technical standards (standard data for the building location).

In case of real data recorded on the building site (by means of in field measurements), the recorded data needs to be elaborated to be consistent with the temporal discretisation of the calculation method (beside a check for errors in the recordings). For example, if an hourly calculation method is adopted and the weather data are recorded with a sub-hourly timestep (e.g., 10 min), these should be elaborated to derive hourly data; specifically, a single value can be assumed as reference for each hourly timestep (e.g., the recording at 12:00 may be representative of the hourly timestep from 12:00 to 13:00), or an average over the recording of a specific timestep may be assumed as representative for that timestep.

If data recorded from meteorological stations or derived from technical standards, some preliminary verifications need to be performed. Specifically, **the climatic data should be derived from the nearest (as the crow flies) available climatic station (or location for standard climatic data) to the analysed building**. Moreover, the climatic data derived from meteorological stations or technical standard should be corrected to account for differences in the altitude of the desired location (of the analysed building) and the climatic station (or location). Usually, the procedures for the correction of the climatic data are provided by the National standards. Finally, also in this case the consistency in the temporal discretisation of the climatic data and the calculation method needs to be checked.

For model calibration activities, the climatic data **must** be real data, either recorded on site or taken from nearby meteorological stations. Moreover, it is mandatory that the recorded weather data cover each measurement interval considered for the model calibration. For example, if monitored energy consumptions are referred to the heating season from October 2017 to April 2018, the climatic data required should cover the range from October 2017 to April 2018. Moreover, also in this case the consistency in the temporal discretisation of the climatic data and the calculation method needs to be checked.

Generation of customised .epw weather file

1. It is suggested to start from an EnergyPlus weather file for the location of the analysed building. This can be found at the following link: https://energyplus.net/weather-region/europe_wmo_region_6. Once selected the country, you should select the city. In most cases, different weather file sources are available for the same city; it is recommended to select the **IWEC** weather file source (Figure A. 2), and download the **epw** weather file (Figure A. 3).

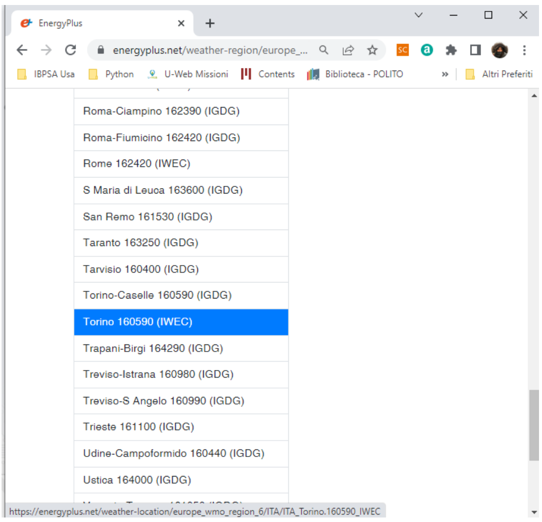

Figure A. 2. IWEC weather file source

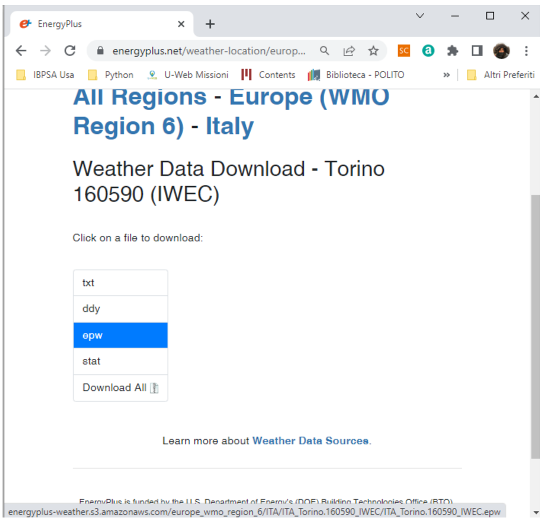

Figure A. 3. epw weather file

2. For the following steps, it is mandatory to set Excel with dots (.) as decimal separator, and commas (,) as column separator, and to set the PC's date and hour format as U.S. format (e.g., hh:mm AM/PM, month/data/year).
3. Open the EnergyPlus's **Weather Statistics and Conversions** tool – automatically installed with EnergyPlus (Figure A. 4), then:
    a. Select the file to be converted: this is the downloaded **.epw weather file**,
    b. Data type: it automatically detects the **EnergyPlus / ESP(r) format**,
    c. Select Output Format: select **CSV format of EPW data**,
    d. Then **Save File As…**

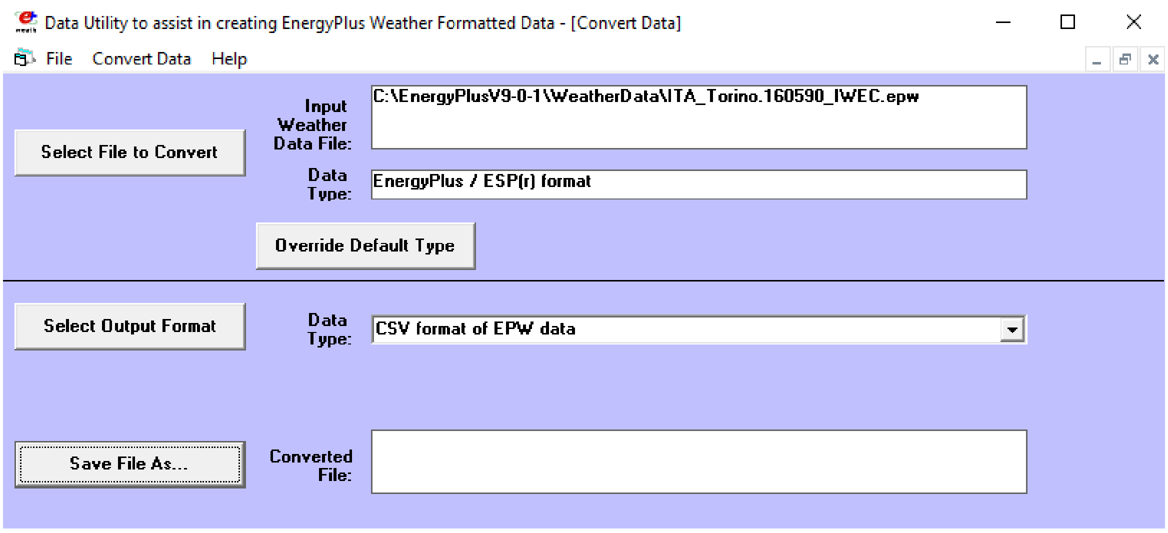

Figure A. 4. EnergyPlus Weather Statistics and Conversions tool

4. Open the .csv file in Excel, and override the available recorded weather data (for the specific periods), and save the file. For not available weather data, keep the values present in the csv file.
5. Once the csv weather file is modified, it has to be converted in .epw format. For this purpose, open again the Weather Statistics and Conversions tool, then:
    a. Select the file to be converted: this is the modified **.csv weather file**. Once opened the .csv file, an error message will appear (Figure A. 5),

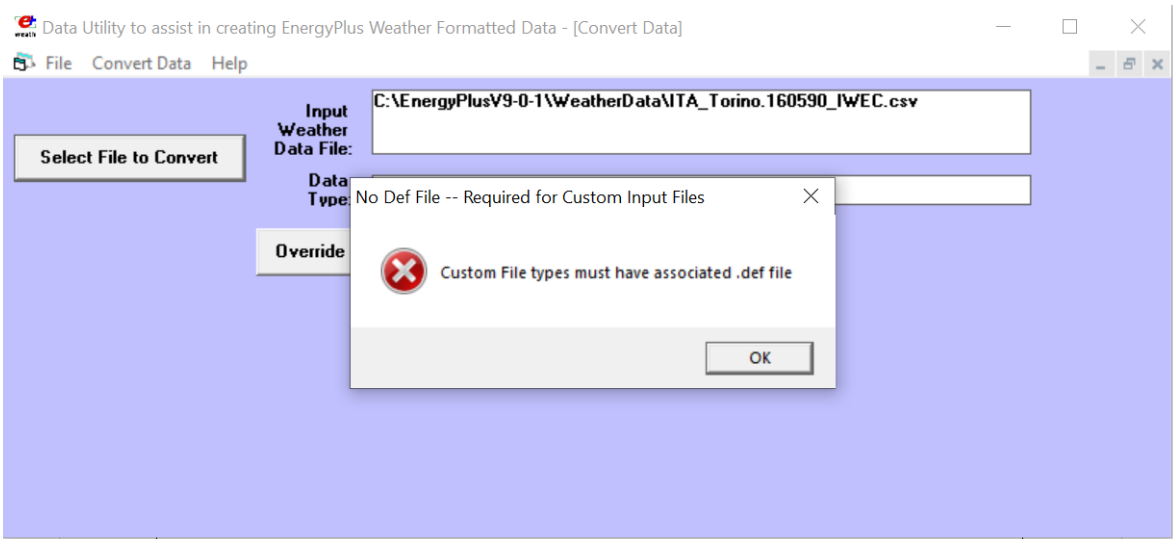

Figure A. 5.EnergyPlus Weather Statistics and Conversions tool error message

    b. Override default data type: select **EnergyPlus Comma Separated Variable (CSV)** format,
    c. Select Output Format: select **EnergyPlus weather format (EPW),**
    d. Then **Save File As…**
6. Now the .epw weather file is available, and can be used in the EnergyPlus simulations. The Excel format(s) and date/hour format can be set to the default one.

A3 Geometrical characteristics

A3.1 Data to be collected

The geometrical characteristics are requested in order to define the geometrical features of the building. The geometrical data to be collected include, but are not limited to, the following parameters:

- Gross and net floor area (at least for each thermal zone),
- Floor-to-ceiling height,
- Gross heating space volume,
- Envelope area,
- Envelope components dimensions (for each opaque and transparent component),
- Envelope components orientation (for each opaque and transparent component),
- Presence of fixed solar shading devices, such as overhangs or side fins (for each opaque and transparent building envelope component).

A3.2 Data sources and data collection procedure

All the required information derived through the following (but not limited to) data sources:

1. Provided documentation (e.g., building plans, EPC, BIM, etc.),
2. In site inspections plus in field measurements (real data recorded on building site).

The first one, more straightforward and less time-consuming, is based on the analysis of the available documentation of the building (e.g., building plans, EPC, BIM, etc.). While this procedure is quite simple to be applied it can lead to issues related to possible wrong information in the analysed documents. The second one is based on inspection and on in field measurement of the relevant information; this procedure is surely the most reliable but also the most time and cost-consuming.

Moreover, according to the calculation procedure, the geometrical characteristics can be defined as gross external, gross internal, and net internal dimensions (Figure A. 6).

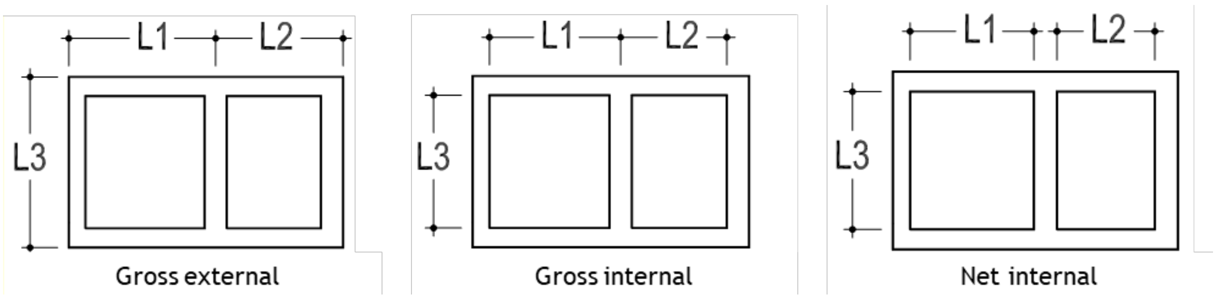

Figure A. 6. Different geometrical characteristic dimensions

A4 Thermal properties of building components

A4.1 Data to be collected

The thermal properties of the building components are requested to define the thermal parameters of the external and internal opaque and transparent components. The geometrical data to be collected include, but are not limited to, the following parameters:

- Thermal properties of the opaque building components, specifically:
  - Thermal parameters of each opaque component,
  - Layers and materials composing each opaque component,
  - Thermal properties of the layers' materials.
- Thermal properties of the transparent building components (window plus solar shading devices), specifically:
  - Thermal parameters of each transparent component,
  - Presence and characterisation of solar shading devices (movable).

A4.2 Data sources and data collection procedure

To easily collect all the required data related to the building envelope, it is suggested to firstly create an abacus of all the components characterising the building envelope, considering both the opaque and the transparent envelope. Basically, the abacus consists in the identification of all the present components, namely each type of wall, door, roof, floor, window, etc.; it is also suggested to complement the abacus with the geometrical information for each component (e.g., area, orientation, presence of external shading obstacles, etc.), and with the presence of any solar shading devices, their type and position, for the transparent components.

A4.2.1 Opaque component characterisation

According to the calculation method adopted, the characterisation of opaque envelope components may be provided as:

- Aggregated thermal parameters (e.g., thermal transmittance),
- Definition of the layers (materials) composing each opaque component.

The aggregated thermal parameters of each opaque component can be derived through the following (but not limited to) data sources:

1. Calculation (simplified)
2. Provided documentation or technical sheets
3. Inference rules
4. In field measurements

The calculation of the aggregated thermal parameters requires the knowledge of the layers and materials composing the components (if the layers are unknown, please refer to the following paragraphs), and should follow the specifications of the EN 6946 technical standards. Alternatively, the aggregated thermal parameters may also be derived from the building documentation, such as design documentation, energy audit reports, etc.; the data derived from the provided documentation should be checked to avoid the use of values which are beyond physically understandable ranges.

If only general information about the components is known, inference rules may be applied to derive the thermal properties. This consists in identifying a component, or a building, like the one to be described (in terms of year of construction, building typology, construction typology, etc.), and to take from that component or building the required information.

Finally, the thermal parameters may also be derived through in field measurements, by means of calorimeter or heat flow meter method. Both methods consist in monitoring for long periods the specific thermal flow through the walls and the surface temperatures.

The layers and materials composing each opaque component can be derived through the following (but not limited to) data sources:

1. Provided documentation or technical sheets
2. Inference rules
3. In site inspection

Specifically, the layers and materials may be found in design documentation, energy audit reports, existing BIM models, XML data, etc. As for the aggregated thermal parameters, the layers can be derived by means of inference rules. Alternatively, two alternative procedures can be applied to derive the layers through in site inspections, namely (i) to make a small hole to establish the layers using an endoscope, and (ii) to perform a core drill and directly determine the material characteristics.

Finally, if the thermal properties of the materials are unknown these can be derived from technical sheets or technical standards.

A4.2.2 Transparent component characterisation

According to the calculation method adopted, the characterisation of transparent envelope components may be provided as:

- Aggregated thermal parameters (thermal transmittance, g-value or SHGC),
- Definition of the layers (glass, gap) composing each transparent component.

The aggregated thermal parameters of each transparent component can be derived through the following (but not limited to) data sources:

1. Calculation (simplified)
2. Provided documentation or technical sheets
3. Inference rules
4. In field measurements

The calculation of the aggregated thermal parameters requires the knowledge of the layers and materials composing the components (if the layers are unknown, please refer to the following paragraphs), and should follow the specifications of the EN ISO 10077-1 technical standards. Alternatively, the aggregated thermal parameters may also be derived from the building documentation, such as design documentation, energy audit reports, etc.; the data derived from the provided documentation should be checked to avoid the use of values which are beyond physically understandable ranges.

If only general information about the components is known, inference rules may be applied to derive the thermal properties. This consists in identifying a component, or a building, similar to the one to be described (in terms of year of construction, building typology, construction typology, etc.), and to take from that component or building the required information.

Finally, the thermal parameters may also be derived through in field measurements, by means of calorimeter or heat flow meter method. Both methods consist in monitoring for long periods the specific thermal flow through the walls and the surface temperatures.

The layers and materials composing each opaque component may be found in design documentation, in energy audit reports, in existing BIM models, in XML data, etc. As for the aggregated thermal parameters, the layers can be derived by means of inference rules. Finally, if the thermal properties of the materials are unknown these can be derived from technical sheets or technical standards.

Finally, the presence of solar shading devices should also be identified and characterised. The characteristics of the solar shading devices could be derived from technical sheets, provided documentation, or technical standards according to the type of device (e.g., internal, or external shades, blinds, or others).

A5 Technical building systems (TBSs) characteristics

A5.1 Data to be collected

The technical building systems (TBSs) characteristics are needed to properly define the actual behaviour of all the components that manage the various services in the building. The first step in the analysis of the TBSs is to define the macro-categories of systems; these can be associated with the available services, such as heating, cooling, lighting, and so on. For every service, it is then necessary to define all properties related to emission, control, distribution and the time the different components are operating as well.

A5.2 Data sources and data collection procedure

The main ways to gather data for the technical building systems are two: inspection and analysis of building documentation. The specific data sources and procedures may differ depending on the level of analysis and are explained in the following sections.

A5.2.1 Type of TBSs installed in the building

The first step for the specification of the technical building systems installed is to analyse the services available in the building. This can be performed either through an inspection of the building itself or by an analysis of the available documentation. The services can be divided into two macro-categories: the ones related to the hygrothermal control of the building (such as heating, cooling, domestic hot water, etc.) and the ones not related (e.g., lighting, people transport, etc.).

A5.2.2 Characteristics of the sub-systems for each TBS

The study of each single TBS includes the analysis of all the sub-systems that are available. For each technical building system, several sub-systems can be found such as emission, control, distribution, storage, and generation. Each TBS can present one or more sub-systems, depending on the specific conformation of the TBS itself. The storage sub-system is not always available while the generation can be shared between different TBSs (e.g., for heating and domestic hot water, or for heating and cooling in case of a reversible heat pump) and can be either on-site, nearby or off-site.

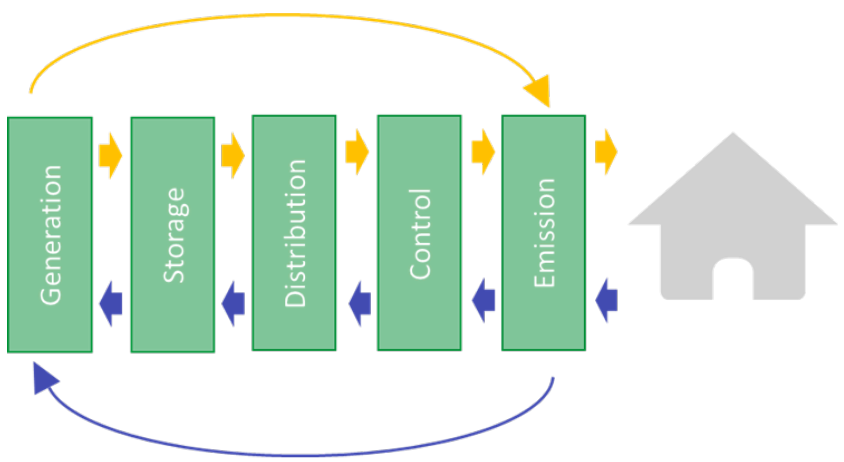

Figure A. 7. The analysis direction of the main TBSs sub-systems

The procedure to determine the specific properties of the sub-systems should be carried out analysing one TBS at a time, starting either from the emission and going up to the generation sub-system or going in the other direction (Figure A. 7).

The procedure to determine the sub-system properties is again twofold, it can be determined by an inspection, or through the analysis of the documentation.

The first procedure can precisely assess the specific technologies available in the building and, through measurement, is able to determine the correct properties of the sub-systems. On the other hand, the measurements can be quite difficult to be carried out due to the cost, the time needed to perform them on every technical building sub-system, and the possible complication associated with the inspection of sub-systems integrated into the building (e.g., distribution pipes in walls or floors).

The second procedure, based on the analysis of the building documentation (e.g., building plans, EPC, etc.) can be more straightforward since is able to lead to the determination of the required properties in a very direct and efficient way. The drawback is that the results do not take into account the properties variation associated with the ageing of the systems and furthermore can lead to wrong assumptions in case the selected documentation is not updated.

In case the collected data only contains general information regarding the sub-system (such as the component name) the technician should obtain the technical sheets (e.g., through internet research or asking directly the component producer) and derive the relevant data there.

In case of refurbishment scenarios, the relevant information should be derived from technical sheets.

A6 Operating conditions

A6.1 Data to be collected

The operating conditions are requested in order to define the user behaviour in terms of presence in the room, thermal zone, or building, control of the technical building systems, the use of the appliances, the windows opening, the use of solar shading devices, etc. The operating conditions to be collected include, but are not limited to, the following parameters:

- Occupancy, specifically:
    - Number of occupants (or occupant heat gains) for each room, thermal zone, or whole building
    - Occupancy schedule for each room, thermal zone, or whole building
- Windows opening (natural ventilation), specifically:
    - Ventilation air flow rate for each room, thermal zone, or whole building
    - Windows opening schedule for each room, thermal zone, or whole building
- Use of appliances, specifically:
    - Heat gains derived from the use of the appliances for each room, thermal zone, or whole building
    - Occupancy schedule for each room, thermal zone, or whole building
- Solar shading devices and shutters management, specifically:
    - Solar shading devices activation schedule (for each room, thermal zone, or whole building, or orientation)
    - External shutters activation schedule
- TBSs management, specifically:
    - Operational time
    - Internal set-points

A6.2 Data collection procedure

A6.2.1 Occupancy

According to the calculation method adopted, the definition of the occupancy may be performed as number of occupants or as internal heat gains. If the number of occupants is required, it should be defined for each room, thermal zone, or whole building, according to the modelling requirements. The number of occupants can be derived through the following (but not limited to) data sources:

1. Provided documentation,
2. Interviews with the users or the building energy manager,
3. Technical standards (EN ISO 16798-1).

Generally, the number of occupants reported in the provided documentation is a design value (design number of occupants), which is usually assumed as maximum number of occupants for each room, thermal zone, or whole building. The derivation of the number of occupants by means of interviews with the users or the building energy manager gives the possibility to get a more realistic number of occupants, in relation also to the distribution of the occupants over the operational time of the building. Finally, if any realistic information can be derived, the maximum number of occupants can be derived from the technical standards, according to the building use. It is suggested to refer to the EN ISO 16798-1 technical standard.

In case of hourly or sub-hourly calculation methods, the occupancy schedule is required, and it can be derived through the following (but not limited to) data sources:

1. Interviews with the users or the building energy manager,
2. Technical standards (EN ISO 16798-1).

Generally, if an interview with the users is allowed, it is useful to ask for how many hours the room, thermal zone, or whole building is occupied (e.g., from 8 a.m. to 5 p.m. for an office building), and for other useful information (e.g., if the building is occupied during the lunchbreak in an office building). In Figure A. 8, an example of questionnaire to the users of an office building is reported, used to derive the occupancy schedule.

Floor	Working hours					Midday hours				
	Monday	Tuesrday	Wednesday	Thursday	Friday	Monday	Tuesrday	Wednesday	Thursday	Friday
1	8 or more	8 or more	8 or more	8 or more	8 or more	Yes	Yes	Yes	Yes	Yes
1	8 or more	6	8 or more	6	6	Yes	Yes	Yes	Yes	Yes
1	8 or more	6	8 or more	6	6	Yes	Yes	Yes	Yes	Yes
1	8 or more	8 or more	8 or more	8 or more	8 or more	Yes	Yes	Yes	Yes	Yes
1	8 or more	7	8 or more	7	7	Yes	Yes	Yes	Yes	Yes
1	8 or more	6	8 or more	6	6	Yes	Yes	Yes	Yes	Yes
1	8 or more	6	8 or more	6	6	Yes	Yes	Yes	Yes	Yes
1	8 or more	6	8 or more	6	6	No	No	No	No	No
1	8 or more	6	8 or more	6	6	Yes	Yes	Yes	Yes	Yes
1	8 or more	6	8 or more	6	6	Yes	No	Yes	No	No
1	8 or more	7	8 or more	7	6	Yes	Yes	Yes	Yes	Yes

Figure A. 8. Questionnaire answers in terms of number of working hours and presence during the lunchbreak

The occupancy schedule should be generated from the results of the questionnaires, following these steps:

1. Derivation of the maximum number of occupants in each room, thermal zone, or building, with an hourly (or sub-hourly) timestep for each weekday (or a typical weekday) and for each weekend day (or a typical weekend day)
2. Calculation of the occupancy fraction for each timestep, as the fraction between the number of occupants in a specific timestep and the maximum number of occupants

3. **It is suggested to create two schedules: one for a typical weekday and one for a typical weekend day**, thus an average of the occupancy fraction for each timestep in each day should be performed (if the data are available for each day)

The temporal discretisation of the schedules must be coherent with the calculation method timestep.

If interviews are not allowed, the occupancy schedules can be derived from the technical standards, according to the building use. It is suggested to refer to the EN ISO 16798-1 technical standard.

A6.2.2 Natural ventilation

According to the calculation method adopted, the definition of natural ventilation may be performed by defining the air flows (air changes per hours, etc.) or the windows opening profiles. If the ventilation air flow is required, it should be defined for each room, thermal zone, or whole building, according to the modelling requirements. The ventilation airflow rate can be derived through the following (but not limited to) data sources:

1. In field measurements
2. Technical standards (minimum airflow rate for indoor air quality)

The most accurate way to derive the ventilation airflow rate is by means of in field measurements. However, it is more common to assume the operational airflow rate as the minimum airflow rate for indoor air quality. This can be derived from the technical standards, according to the building use. It is suggested to refer to the EN ISO 16798-1 technical standard.

In case of hourly or sub-hourly calculation methods, the ventilation schedule is required, and it can be derived through the following (but not limited to) data sources:

1. Interviews with the users or the building energy manager
2. Assumed equal to the occupancy schedule

Generally, if an interview with the users is allowed, it is useful to ask for how many hours the windows are kept open and in which part of the day (e.g., 1 hour in the morning). Starting from these results, the ventilation schedule can be generated following the steps presented in Section 6.2.1 (Occupancy). If interviews are not allowed, the ventilation schedule can be assumed equal to the occupancy schedule.

A6.2.3 Use of appliances

Generally, the definition of the use of appliances is performed by defining the internal heat gains (from the use of the appliances) and the use of appliances schedules. The internal heat gains can be derived through the following (but not limited to) data sources:

1. Calculated from the number and type of appliances installed in the room
2. Technical standards

The number and type of appliances installed in the room can be derived from the provided documentation or from interviews with the users. Then, the heat gains derived from the use of such appliances can be calculated taking the specific heat gain of each type of appliance (e.g., from the ASHRAE Fundamentals). In another way, the heat gains derived from the use of the appliances can be derived from the EN ISO 16798-1 technical standard.

In case of hourly or sub-hourly calculation methods, the use of appliances schedule is required, and it can be derived through the following (but not limited to) data sources:

1. Interviews with the users or the building energy manager
2. Assumed equal to the occupancy schedule
3. Technical standards (EN ISO 16798-1)

Generally, if an interview with the users is allowed, it is useful to ask for how many hours the appliances are used at full power or kept in stand-by (e.g., 1 hour in the morning of full power, and 6 hours in stand-day). Starting from these results, the ventilation schedule can be generated following the steps presented in Section 6.2.1 (Occupancy). If interviews are not allowed, the use of appliances schedule can be assumed equal to the occupancy schedule, or it can be derived from the technical standards, according to the building use. It is suggested to refer to the EN ISO 16798-1 technical standard.

A6.2.4 Solar shading devices and shutters management

The definition of the use of solar shading devices is of foremost importance for the control of solar heat gains. Generally, only the schedule of activation of the solar shading devices is required. This can be derived through the following (but not limited to) data sources:

1. Rule-based activation (provided documentation, or interviews with the users)
2. Interviews with the users or the building energy manager
3. Technical standards

The most accurate way to model the activation of the solar shading devices is by considering different criteria that rules their activation. These can be simple rules (such as a threshold for the incident solar irradiance on the window) or complex rules that consider different domains (e.g., visual and thermal comfort). The adoption of a specific rule can be derived from the provided documentation (design documentation of the shading devices) or, most commonly, from interviews with the users.

If the solar shading devices are not rule-based activated, a schedule of activation can be derived from interviews with the users. According to the information derived from the interviews, it is possible to create the schedules of activation. Finally, if interviews are not allowed, the activation schedule can be derived from the technical standards.

On the other hand, the external shutters are generally assumed to be activated during the night hours. In absence of any solar shading devices installed in the building, the shutter may be used as shading devices, and modelled according to the procedures presented above.

A6.2.5 TBSs management

The management of the technical building systems is generally performed by controlling the operational time and the set-points (temperatures, humidity, etc.).

The operation time can be determined by the analysis of the actual use through either survey performed on the users, or the analysis of the energy consumed by each TBS. While these procedures can provide high-quality data, they both present some possible issues. The surveys are based on user-given information and therefore the reliability can be low. The energy consumption analysis, on the other hand, may be available not differentiated by each TBS but by energy carrier and, in case of more than one TBS using the same energy carriers the operation time can be impossible to derive from it. In case these procedures are not followable information and standard values can be derived both from the legislation (e.g., if the length of the heating/cooling seasons is mandatory by national law) or from international standards (e.g., in the EN 16798-1 technical standard the daily operation profiles can be determined as a function of the building intended use).

As regards the set-points, these can be derived through the following (but not limited to) data sources:

1. Provided documentation
2. Interviews with the users or the building energy manager
3. Technical standards
4. In field measurements

In case of model calibration activities, the set-points should be obtained for each measurement interval of the energy carriers within the heating or cooling season.

A7 Monitored data on building performance

A7.1 Data to be collected

Monitoring different data and parameters on the building performance is required specifically for the model calibration activity. The monitored data on the building performance to be collected for the sake of calibration activities include, but are not limited to, the following parameters:

- Indoor environmental data
- Performance parameters of TBSs components
- Energy consumptions

A7.2 Data sources and data collection procedure

Generally, the monitoring of data on the building performance may be used for different scopes, including the derivation of the required input data, as presented in the previous sections, or for the sake of the model calibration. However, the monitoring procedure depends on the specific data to be monitored; therefore, only the specific procedure for the collection of the energy consumptions is presented in this guideline (Section 7.2.1).

A7.2.1 Energy consumption

The energy consumption information is needed to determine the actual energy expenses of the building also in the perspective of a calibration procedure. It is important, in order to be able to properly deploy these data, to distinguish the consumption for each energy service and each energy carrier.

Generally, the energy consumption can be determined through meter readings (e.g., planned readings, maintenance reports, inspection reports, logbooks, and BACS records), bill analysis or through estimation techniques. In case the source is an invoice, it is fundamental to verify the period the consumption is referred to since the bill and the consumption dates can differ. On the second hand is also important to verify if the consumption is based on readings or is a forecast.

In case the data is needed for calibration purposes, the estimation techniques as well as the forecasts, cannot be deployed.

In order to guarantee a check on the data quality, a minimum number of three years should be covered by the measurement period. For proper data collection for the energy consumption, it is important to first identify the supplied generator, devices and appliances including the ones not related to the energy performance of buildings.

A8 Economic data

A8.1 Data to be collected

The economic data collection is addressed to the definition of the costs for the economic analysis. In order to do that it is mandatory to define the prices related to the energy carriers, and to the different energy efficiency measures planned in the refurbishment scenarios.

A8.2 Data sources and data collection procedure

The main ways to gather economic data are two: market analysis and the study of local or national documentation. The specific data sources and procedures may differ depending on the level of analysis and are explained in the following sections.

A8.2.1 Specific cost for each energy carrier

The first procedure to determine the specific cost for the energy carrier is through the analysis of the building energy bills. This process is the most reliable one since it can properly evaluate the actual energy cost related to the building characteristics (e.g., geographical location, TBSs dimension, etc.). Another available procedure is to perform a market analysis studying the invoices and the expenses of buildings similar in dimension, use, and climatic data to the considered building.

The third procedure is to determine the energy carrier cost through the analysis of the local or national reports containing information on the energy use and cost. These reports often indicate mean energy carriers cost which are useful to determine the cost magnitude but are ineffective to perform a precise assessment.

A8.2.2 Specific cost of different energy efficiency measures (EEMs)

The specific cost of the different energy efficiency measures is fundamental to properly assess the refurbishment scenarios.

To determine the EEMs cost two procedures are available: the use of local or national price lists or the deployment of market analysis. The first procedure is the most straightforward one since it is able to directly determine the single intervention cost knowing the specific measure characteristics, but, since these price lists are not always updated, they are not always able to properly determine the EEMs cost. In order to solve this issue market analysis can be deployed. These procedures, which are of course more time-consuming, are able to properly determine the EEMs cost but can be negatively influenced by market variation and therefore the results have a short applicability in time.

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European Committee for Standardisation (CEN). (2017d). EN ISO 10077-1: Thermal performance of windows, doors and shutters - Calculation of thermal transmittance - Part 1: General.

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European Committee for Standardisation (CEN). (2018b). EN 15316-4-1: Energy performance of buildings - Method for calculation of system energy requirements and system efficiencies - Part 4-1: Space heating and DHW generation systems, combustion systems (boilers, biomass), Module M3-8-1, M8-8-1.

European Committee for Standardisation (CEN). (2018c). EN 15316-4-2: Energy performance of buildings - Method for calculation of system energy requirements and system efficiencies - Part 4-2: Space heating generation systems, heat pump systems, Module M3-8-2, M8-8-2.

European Committee for Standardisation (CEN). (2018d). EN 15316-4-3: Energy performance of buildings - Method for calculation of system energy requirements and system efficiencies - Part 4-3: Heat generation systems, thermal solar and photovoltaic systems, Module M3-8-3, M8-8-3, M11-8-3.

European Committee for Standardisation (CEN). (2018e). EN 15316-4-5: Energy performance of buildings - Method for calculation of system energy requirements and system efficiencies - Part 4-5: District heating and cooling, Module M3-8-5, M4-8-5, M8-8-5, M11-8-5.

European Committee for Standardisation (CEN). (2018f). EN 15459-1: Energy performance of buildings - Economic evaluation procedure for energy systems in buildings - Part 1: Calculation procedures, Module M1-14.

European Committee for Standardisation (CEN). (2018g). EN 16798-5-1: Energy performance of buildings - Ventilation for buildings - Part 5-1: Calculation methods for energy requirements of ventilation and air conditioning systems (Modules M5-6, M5-8, M6-5, M6-8, M7-5, M7-8) - Method 1: Distribution and generation.

European Committee for Standardisation (CEN). (2018h). EN 16798-5-2: Energy performance of buildings - Ventilation for buildings - Part 5-2: Calculation methods for energy requirements of ventilation systems (Modules M5-6, M5-8, M6-5, M6-8, M7-5, M7-8) - Method 2: Distribution and generation.

European Committee for Standardisation (CEN). (2018i). EN 16798-13: Energy performance of buildings - Ventilation for buildings - Part 13: Calculation of cooling systems (Module M4-8) – Generation.

European Committee for Standardisation (CEN). (2019). EN 16798-1: Energy performance of buildings. Ventilation for buildings. Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics. Module M.

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International Organization for Standardization (ISO). (2018). ISO 18523-2: Energy performance of buildings — Schedule and condition of building, zone and space usage for energy calculation — Part 2: Residential buildings.

Annex B - Guidelines for data analysis

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B1 Introduction

The enhancement of the EPC schema through the integration of operational data within TDS2 will be addressed by the proposal of new key performance indicators (KPIs). These will be selected from the results of different analyses that will be performed on the selected buildings. Specifically, the analysis to be performed are the following:

1. Standard energy performance assessment (SEPA)
2. Tailored energy performance assessment (TEPA)
3. TEPA calibration against monitored data (CAL)
4. Economic evaluation of energy efficiency measures (ECM)
5. Indoor environmental quality evaluation (IEQ)
6. Building Automation and Control System impact assessment (BACS)

All the analysis to be performed require the creation of a building energy model (BEM).

B2 Standard vs. tailored energy performance assessment

The standard and tailored energy performance (EP) assessment starts with the creation of the energy model of the building to be analysed. The input data required for the creation of the building energy model are listed and described in the “Guidelines for data collection”.

The difference between the standard and the tailored energy performance assessment is related to the definition of the user behaviour and of the climate. This should follow the criteria shown in Table B.1.

Table B. 1. Standard vs. tailored EP assessment

EP assessment	User	Climate
Tailored	Real (actual)	Standard
Standard	Standard	Standard

B3 Calibration against monitored data

Requirements for building energy model calibration:	
1. Monitored data	Monthly/seasonal energy consumptions, or hourly indoor temperatures, or hourly energy consumptions
2. Weather data	Real data for the calibration period

Building energy model calibration is the process of fine-tuning the simulation inputs so that the observed energy consumptions (or environmental parameters) closely match those predicted by a simulation program. The proposed methodology is a manual calibration procedure, which consists in the iterative modification of the model parameters affected by uncertainties; these can be modified one-at-a-time or combining them together. The general building energy model calibration workflow is presented in Figure B. 1.

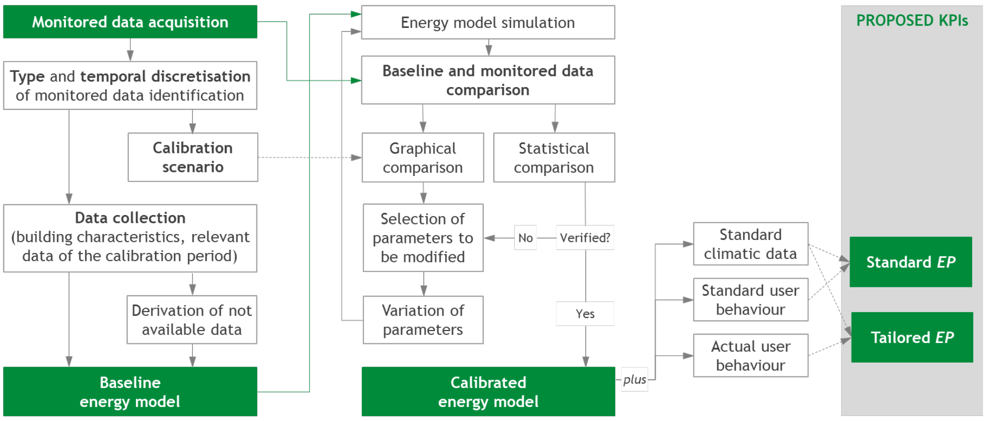


Figure B. 1. Building energy model calibration workflow

In preparation for the application of the manual calibration procedure, different preliminary phases are required. These steps consist in:

1. Analysis of the available monitored data. It is necessary to firstly analyse available monitored data to identify their type and temporal discretisation. The most common monitored data are indoor temperatures and energy consumption (for different energy carriers). Moreover, these can be either on a daily, weekly, monthly, seasonal, or hourly data.
2. Identification of the calibration scenario. According to the type and temporal discretisation of the available monitored data, three different calibration scenarios can be identified. These are the following:
    - Scenario 1, in case of daily, weekly, monthly, or seasonal monitored energy consumptions
    - Scenario 2A, in case of hourly monitored temperatures
    - Scenario 2B, in case of hourly monitored energy consumptions

    The applicability of the different scenarios is presented in Table B. 2. The procedures to follow to carry on the building energy model calibration according to Scenario 1, 2A, and 2B are presented respectively in Section B3.1, B3.2, and B3.3.

Table B. 2. Calibration scenarios

Temporal discretisation	Energy consumptions	Hourly temperatures
Hourly	Scenario 2B	Scenario 2A
Daily	Scenario 1	-
Weekly	Scenario 1	-
Monthly	Scenario 1	-
Seasonal	Scenario 1	-

3. Selection of the calibration period. The calibration period is derived from the analysis of the monitored data as well; this is required to identify and derive the specific input data for the building energy model creation (e.g., climatic data).
4. Creation of the building energy model. The last preliminary step consists in the creation of the building energy model, namely the base model. For its creation, several input data are required and must be real (actual data). These are:
    - General information about the building
    - Geographical and climatic data (climatic data must be referred to the identified calibration period, and must be consistent with the calculation timestep)
    - Geometrical characteristics
    - Monitored data

    If real data related to the above input data are not available, the model calibration cannot be performed.
    In absence of real data, the other input data required for the creation of the building energy model may be derived from similar buildings or standard values can be assumed. This is valid for the following input data:
    - Thermal properties of the building components,
    - Technical building systems characteristics, and
    - Operating conditions (e.g., user behaviour, set-point temperatures, etc.).

    For more accurate results, it is highly recommended to use real data.

B3.1 Scenario 1: daily/weekly/monthly/seasonal energy consumptions

After the preliminary phases presented, the calibration scenario 1 (for daily, weekly, monthly, or seasonal energy consumptions) consists in the following steps:

1. Energy simulation for the base model and extraction of the outputs (energy consumptions for the available energy carriers)
2. Comparison between monitored and simulated outputs
3. Verification of compliance with statistical indexes
4. (If statistical indexes are not verified), modification of the base energy model and repetition of steps from 1 to 4, until statistical indexes are verified

The energy simulation outputs required for the model calibration are the *energy consumption values* for selected calibration period.

Step 1: Energy simulation for the base model and extraction of outputs

The base model must be simulated considering the real external climatic data. Once simulated, it is required that the outputs, which include energy consumption for scenario 1, are extracted (or elaborated) with the same temporal discretisation as the monitored data.

For example, if the monitored energy consumption values are available as shown in Figure B. 2, it is mandatory that simulated energy consumption values follow the same temporal discretisation. In this case, since the variable temporal discretisation as the monitored data, the base model should be simulated considering an hourly (or at least a daily) calculation timestep; then, the simulated hourly energy consumption should be elaborated in order to get the aggregated energy consumption for the specific time intervals.

From	To	Number of days [d]	Monitored energy consumption [kWh]
10/14/2019	10/21/2019	7	399
10/21/2019	10/30/2019	9	807
10/30/2019	11/11/2019	12	2199
11/11/2019	11/18/2019	7	2184
11/18/2019	11/25/2019	7	1917
11/25/2019	12/2/2019	7	1855
12/2/2019	12/9/2019	7	2439
12/9/2019	12/16/2019	7	2565
12/16/2019	12/23/2019	7	2025
12/23/2019	1/7/2020	15	5681
1/7/2020	1/13/2020	6	2280
1/13/2020	1/27/2020	14	5551
1/27/2020	2/3/2020	7	2254
2/3/2020	2/17/2020	14	4426
2/17/2020	3/2/2020	14	4013
3/2/2020	3/9/2020	7	2175
3/9/2020	3/30/2020	21	4905
3/30/2020	4/6/2020	7	1696
4/6/2020	4/14/2020	8	973
4/14/2020	4/20/2020	6	640
4/20/2020	4/27/2020	7	804
4/27/2020	5/4/2020	7	712
5/4/2020	5/12/2020	8	303

Figure B. 2. Example of output extraction

Step 2: Comparison between monitored and simulated outputs

The comparison between monitored and simulated outputs can be done by means of either statistical or graphical comparisons. It is suggested to perform both comparisons; these were implemented in a dedicated MS Excel file ("Scenario1" sheet) provided by POLITO. The inputs (Figure B. 3) required by this file are:

- Beginning and end of the temporal intervals of the monitored data
- Daily average outdoor air temperature for the temporal intervals of the monitored data
- Measured energy consumption values
- Simulated energy uses

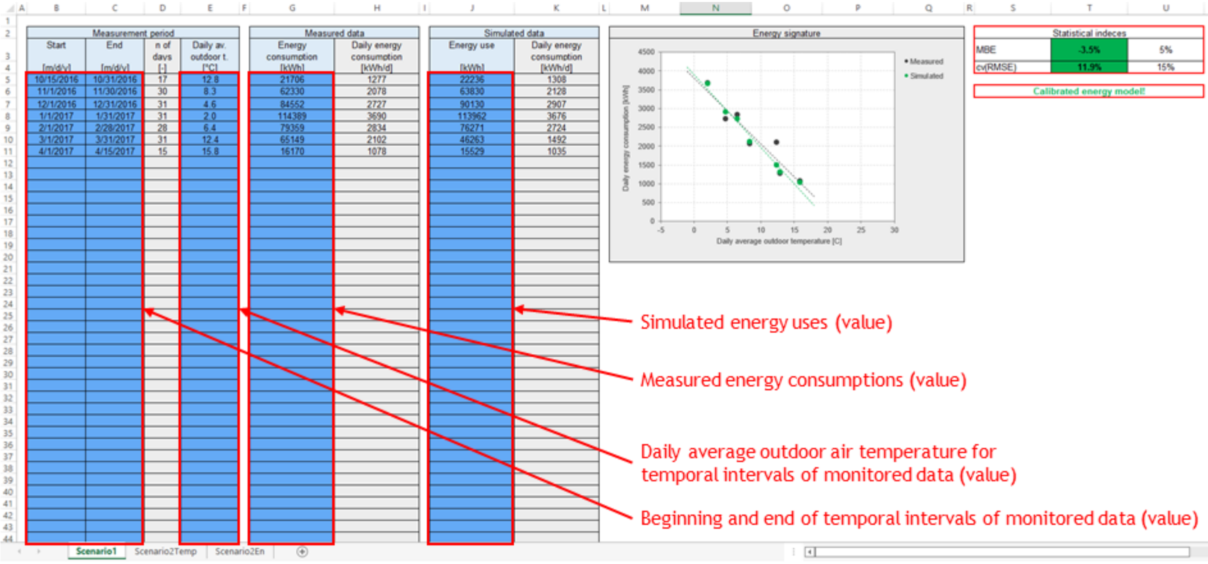


Figure B. 3. Inputs for statistical and graphical comparison for calibration scenario 1

As for the beginning and end of the temporal intervals of the monitored data, these must be inserted in a month/day/year or day/month/year format in order to derive the number of days of each temporal interval. The daily average outdoor temperature is mandatory for the graphical comparison. This should be calculated for each specific temporal intervals of the monitored data. The simulated energy consumption must respect the temporal discretisation and temporal intervals of the monitored data, as specified above.

Step 3: Verification of compliance with statistical indexes

The verification of statistical indexes is automatically calculated within the provided MS Excel file (Figure B. 4). Two statistical indexes were considered for calibration scenario 1, namely:

- Mean Bias Error (*MBE*), for which the limit value is assumed equal to ±5%
- Coefficient of variation of the root-mean-square error [*cv(RMSE)*], for which the limit value is assumed equal to 15%

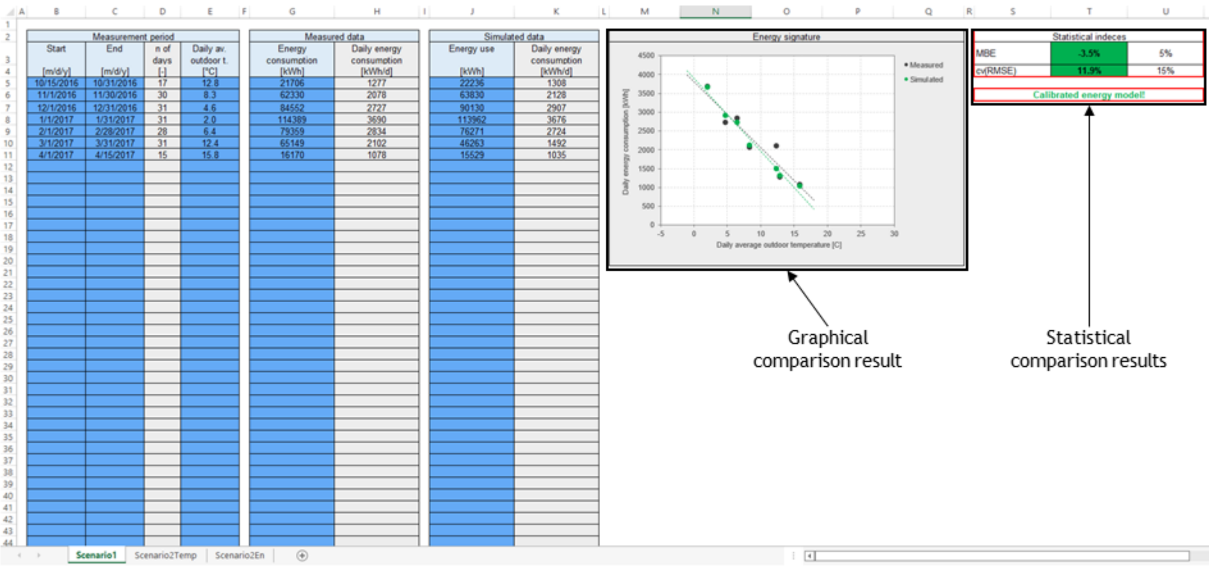


Figure B. 4. Outputs for statistical and graphical comparison for calibration scenario 1

If both the *MBE* and the *cv(RMSE)* are within the limit values, the building energy model can be considered as calibrated. In this case, the proposed procedure ends. Otherwise, it continues to the next step (step 4).

Step 4: Modification of base model

When the statistical indexes are not verified, the base energy model must be modified. The choice of the parameters to be modified in the model should be guided by the graphical comparison (Figure B. 4). Specifically, it consists in the comparison between the trend lines representative of both the monitored and simulated data. The following situations may occur:

1. Differences in the trend line slopes. In this case, the parameters to be modified are the ones influenced by the temperature difference between the indoor and outdoor environments. These includes:
    - Thermal properties of building component
    - Thermal bridges linear thermal transmittance
    - Ventilation/Infiltration rates
2. Shift between trend lines. In this case, the parameters to be modified are the ones not influenced by the difference between indoor and outdoor temperature. These includes:
    - Internal heat gain load and/or profiles,
    - Heating/cooling set-points
    - HVAC technical specifications
    - HVAC operation profile

Following these indications, the choice of the parameters to be modified should firstly focus on those input data for which high uncertainties were identified in the creation of the building energy model (e.g., standard or reference data).

Once the base model is modified, the procedure should continue again from step 1 to step 4, until the statistical indexes are verified.

B3.2 Scenario 2A: hourly temperatures

After the preliminary phases presented, the calibration scenario 2A (for indoor temperatures) consists in the following steps:

1. Energy simulation for the base model and extraction of the outputs (hourly indoor air temperatures)
2. Comparison between monitored and simulated outputs
3. Verification of compliance with statistical indexes
4. (If statistical indexes are not verified), modification of the base energy model and repetition of steps from 1 to 4, until statistical indexes are verified

The energy simulation outputs required for the model calibration are the *hourly values of indoor temperature* for the selected calibration period.

Step 1: Energy simulation for the base model and extraction of outputs

The base model must be simulated considering the real external climatic data. Once simulated, it is required that the outputs, which are hourly values of indoor air temperature for scenario 2A, are extracted with the same temporal discretisation as the monitored data (hourly).

Step 2: Comparison between monitored and simulated outputs

The comparison between monitored and simulated outputs can be done by means of either statistical or graphical comparisons. It is suggested to perform both comparisons; these were implemented in a dedicated MS Excel file (“Scenario2Temp” sheet) provided by POLITO. The inputs (Figure B. 5) required by this file are:

- Date and time of the monitored data (not mandatory)
- Hourly outdoor air temperature for each measurement timestep
- Measured hourly indoor air temperature (for each measurement timestep)
- Simulated hourly indoor air temperature (for each measurement timestep

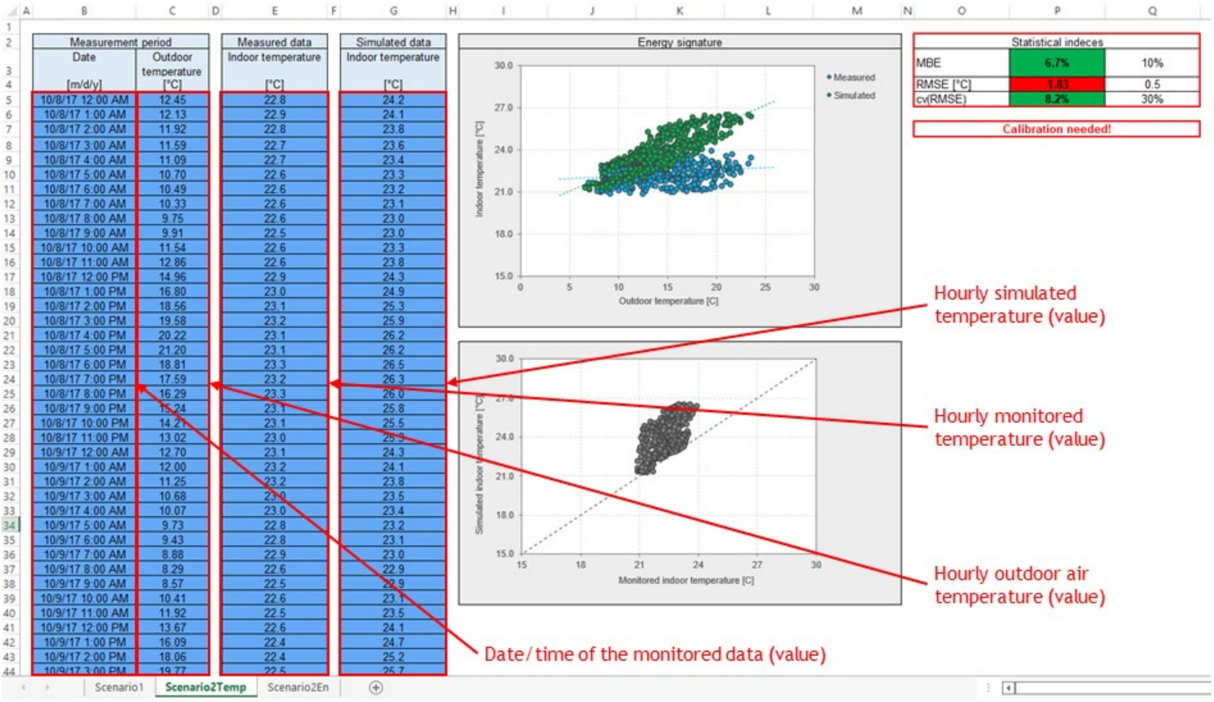


Figure B. 5. Inputs for statistical and graphical comparison for calibration scenario 2A

The hourly outdoor temperature is mandatory for the graphical comparison. The simulated hourly indoor temperatures must respect the temporal discretisation of the monitored data, as specified above.

Step 3: Verification of compliance of statistical indexes

The verification of statistical indexes is automatically calculated within the provided MS Excel file (Figure B. 6). Two statistical indexes were considered for calibration scenario 1, namely:

- Mean Bias Error (*MBE*), for which the limit value is assumed equal to ±10%
- Root-Mean-Square error (*RMSE*), for which the limit value is assumed equal to 0,5 °C
- Coefficient of variation of the root-mean-square error [*cv(RMSE)*], for which the limit value is assumed equal to 30%

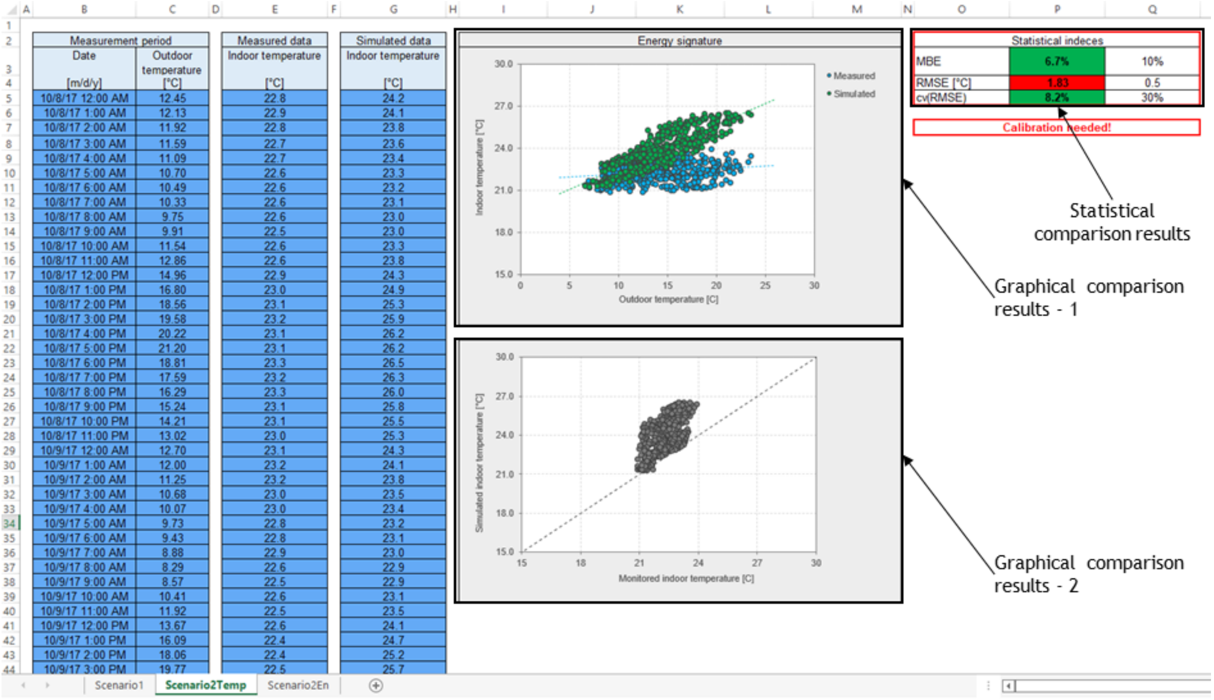


Figure B. 6. Outputs for statistical and graphical comparison for calibration scenario 2A

<u>**When both the *MBE*, the *RMSE*, and the *cv(RMSE)* are within the limit values, the building energy model can be considered as calibrated**</u>. In this case, the proposed procedure ends. Otherwise, it continues to the next step (step 4).

Step 4: Modification of base model

When the statistical indexes are not verified, the base energy model must be modified. The choice of the parameters to be modified in the model should be guided by the graphical comparison (Figure B. 6). Specifically, the first graphical comparison (energy signature) consists in the comparison between the trend lines representative of both the monitored and simulated data. The following situations may occur:

1. <u>Differences in the trend line slopes</u>. In this case, the parameters to be modified are the ones influenced by the temperature difference between the indoor and outdoor environments. These includes:
    - Thermal properties of building components
    - Thermal bridges linear thermal transmittance
    - Ventilation/Infiltration rate
2. <u>Shift between trend lines</u>. In this case, the parameters to be modified are the ones not influenced by the difference between indoor and outdoor temperature. These includes:
    - Internal heat gain load and/or profiles
    - Heating/cooling set-points
    - HVAC technical specifications
    - HVAC operation profile

The second graphical comparison, instead, shows the direct comparison between the monitored and the simulated hourly temperatures. The line in the graph represents the perfect equality between the simulated and monitored. When the points in the graph are above the dashed line, this means that simulation is overestimating the indoor temperatures, and vice versa.

Following these indications, the choice of the parameters to be modified should firstly focus on those input data for which high uncertainties were identified in the creation of the building energy model (e.g., standard or reference data).

Once the base model is modified, the procedure should continue again from step 1 to step 4, until the statistical indexes are verified.

B3.3 Scenario 2B: hourly energy consumption

After the preliminary phases presented, the calibration scenario 2B (for hourly energy consumption) consists in the following steps:

1. Energy simulation for the base model and extraction of the outputs (hourly energy consumption for the available energy carriers)
2. Comparison between monitored and simulated outputs
3. Verification of compliance with statistical indexes
4. (If statistical indexes are not verified), modification of the base energy model and repetition of steps from 1 to 4, until statistical indexes are verified

The energy simulation outputs required for the model calibration are the *hourly energy consumption values* for identified calibration period.

Step 1: Energy simulation for the base model and extraction of outputs

The base model must be simulated considering the real external climatic data. Once simulated, it is required that the outputs, which are energy consumption values for scenario 2B, are extracted with the same temporal discretisation as the monitored data.

Step 2: Comparison between monitored and simulated outputs

The comparison between monitored and simulated outputs can be done by means of either statistical or graphical comparisons. It is suggested to perform both comparisons; these were implemented in a dedicated MS Excel file (“Scenario2En” sheet) provided by POLITO. The inputs (Figure B. 7) required by this file are:

- Date and time of the monitored data (not mandatory)
- Hourly energy consumption values for each measurement timestep
- Measured energy consumption values (for each measurement timestep)
- Simulated energy uses (for each measurement timestep)

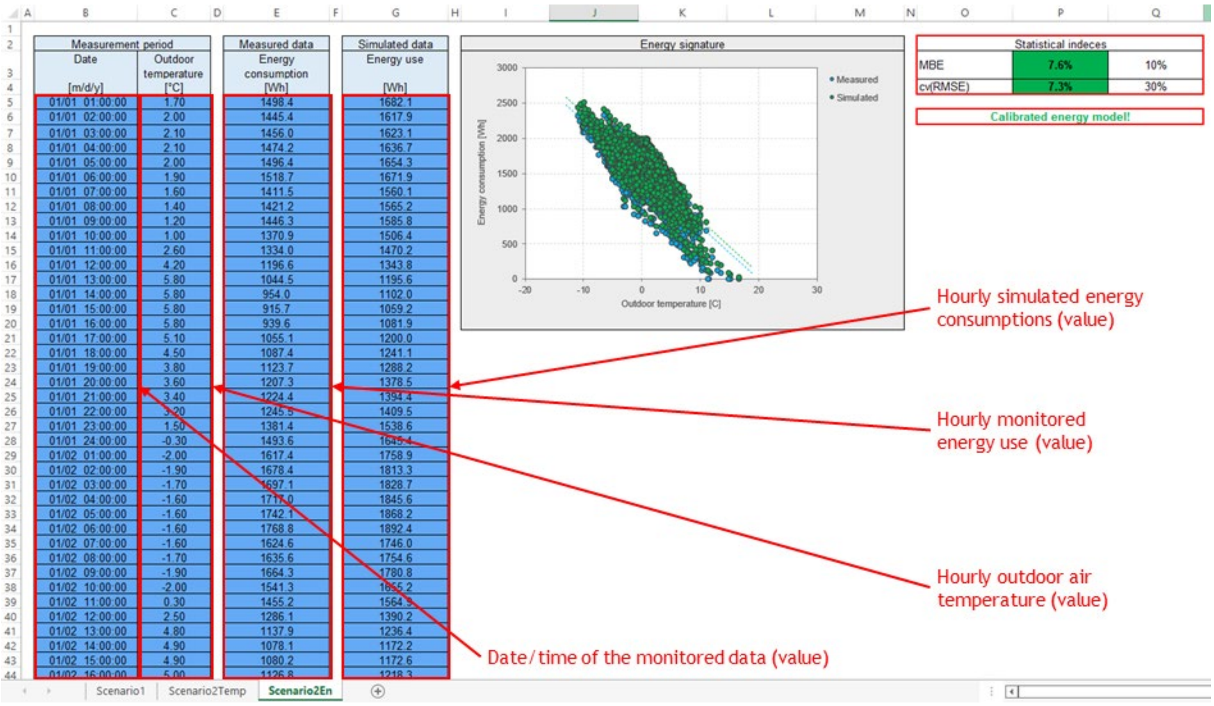


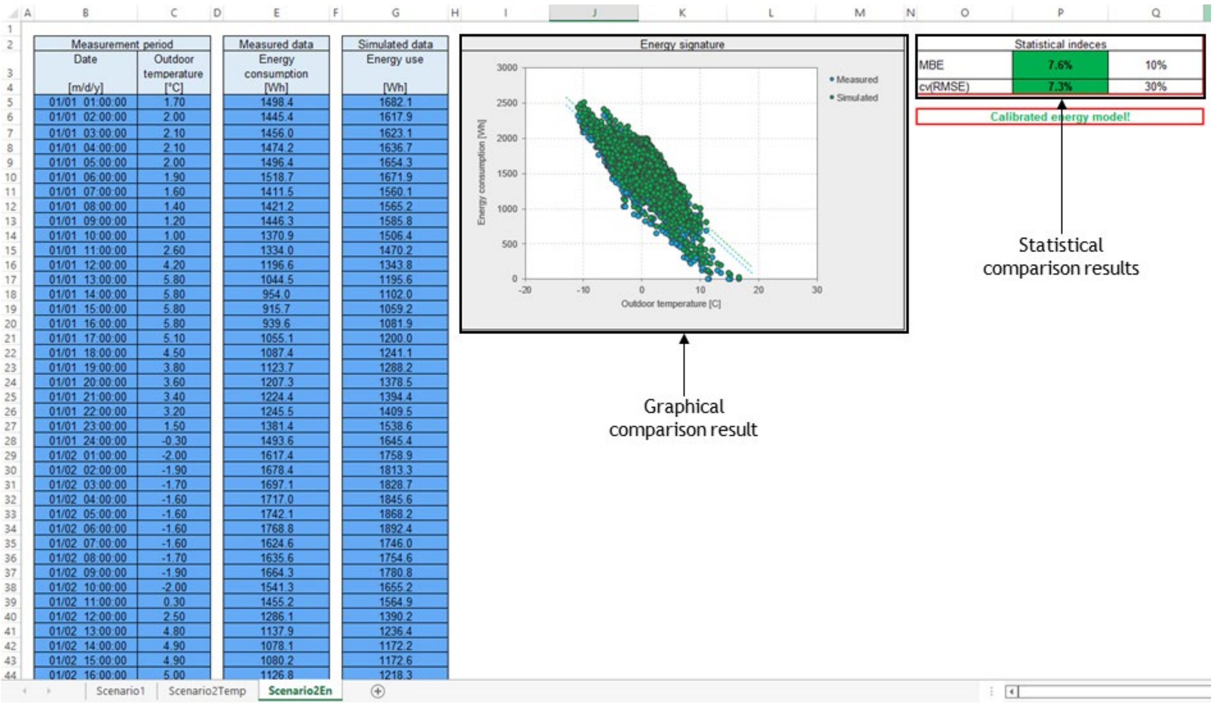
Figure B. 7. Inputs for statistical and graphical comparison for calibration scenario 2B

The hourly outdoor temperature is mandatory for the graphical comparison. The simulated energy consumption must respect the temporal discretisation of the monitored data, as specified above.

Step 3: Verification of compliance with statistical indexes

The verification of statistical indexes is automatically calculated within the provided MS Excel file (Figure B. 8). Two statistical indexes were considered for calibration scenario 1, namely:

- Mean Bias Error (*MBE*), for which the limit value is assumed equal to ±10%
- Coefficient of variation of the root-mean-square error [*cv(RMSE)*], for which the limit value is assumed equal to 30%



Measurement period		Measured data	Simulated data
Date [m/d/y]	Outdoor temperature [°C]	Energy consumption [Wh]	Energy use [Wh]
01/01 01:00:00	1.70	1498.4	1682.1
01/01 02:00:00	2.00	1445.4	1617.9
01/01 03:00:00	2.10	1456.0	1623.1
01/01 04:00:00	2.10	1474.2	1636.7
01/01 05:00:00	2.00	1496.4	1654.3
01/01 06:00:00	1.90	1518.7	1671.9
01/01 07:00:00	1.60	1411.5	1560.1
01/01 08:00:00	1.40	1421.2	1565.2
01/01 09:00:00	1.20	1446.3	1585.8
01/01 10:00:00	1.00	1370.9	1506.4
01/01 11:00:00	2.60	1334.0	1470.2
01/01 12:00:00	4.20	1196.6	1343.8
01/01 13:00:00	5.80	1044.5	1195.6
01/01 14:00:00	5.80	954.0	1102.0
01/01 15:00:00	5.80	915.7	1059.2
01/01 16:00:00	5.80	939.6	1081.9
01/01 17:00:00	5.10	1055.1	1200.0
01/01 18:00:00	4.50	1087.4	1241.1
01/01 19:00:00	3.80	1123.7	1288.2
01/01 20:00:00	3.60	1207.3	1378.5
01/01 21:00:00	3.40	1224.4	1394.4
01/01 22:00:00	3.20	1245.5	1409.5
01/01 23:00:00	1.50	1381.4	1538.6
01/01 24:00:00	-0.30	1493.6	1645.4
01/02 01:00:00	-2.00	1617.4	1758.9
01/02 02:00:00	-1.90	1678.4	1813.3
01/02 03:00:00	-1.70	1697.1	1828.7
01/02 04:00:00	-1.60	1717.0	1845.6
01/02 05:00:00	-1.60	1742.1	1868.2
01/02 06:00:00	-1.60	1768.8	1892.4
01/02 07:00:00	-1.60	1624.6	1746.0
01/02 08:00:00	-1.70	1635.6	1754.6
01/02 09:00:00	-1.90	1664.3	1780.8
01/02 10:00:00	-2.00	1541.3	1655.2
01/02 11:00:00	0.30	1455.2	1564.9
01/02 12:00:00	2.50	1286.1	1390.2
01/02 13:00:00	4.80	1137.9	1236.4
01/02 14:00:00	4.90	1078.1	1172.2
01/02 15:00:00	4.90	1080.2	1172.6
01/02 16:00:00	5.00	1126.8	1218.3

Figure B. 8. Outputs for statistical and graphical comparison for calibration scenario 2B

When both the *MBE* and the *cv(RMSE)* are within the limit values, the building energy model can be considered as calibrated. In this case, the proposed procedure ends. Otherwise, it continues to the next step (step 4).

Step 4: Modification of base model

When the statistical indexes are not verified, the base energy model must be modified. The choice of the parameters to be modified in the model should be guided the results of the graphical comparison (Figure B. 8). Specifically, this consists in the comparison between the trend lines representative of both the monitored and simulated data. The following situations may occur:

3. Differences in the trend line slopes. In this case, the parameters to be modified are the ones influenced by the temperature difference between the indoor and outdoor environments. These includes:
    - Thermal properties of building components
    - Thermal bridges linear thermal transmittance
    - Ventilation/Infiltration rates
4. Shift between trend lines. In this case, the parameters to be modified are the ones not influenced by the difference between indoor and outdoor temperature. These includes:
    - Internal heat gain load and/or profiles
    - Heating/cooling set-points
    - HVAC technical specifications
    - HVAC operation profile

Following these indications, the choice of the parameters to be modified should firstly focus on those input data for which high uncertainties were identified in the creation of the building energy model (e.g., standard or reference data).

Once the base model is modified, the procedure should continue again from step 1 to step 4, until the statistical indexes are verified.

B4 Economic evaluation of energy efficiency measures

The economic evaluation of the energy efficiency measures is carried out analysing the building in the original state (later referred as “baseline”) and the various scenarios of energy efficiency measures (EEMs) (later referred as “scenario”) following these steps, as detailed in Figure B. 9:

1. Determination of the general parameters,
2. Determination of the specific case parameters,
3. Calculation of economic cost analysis indicators.

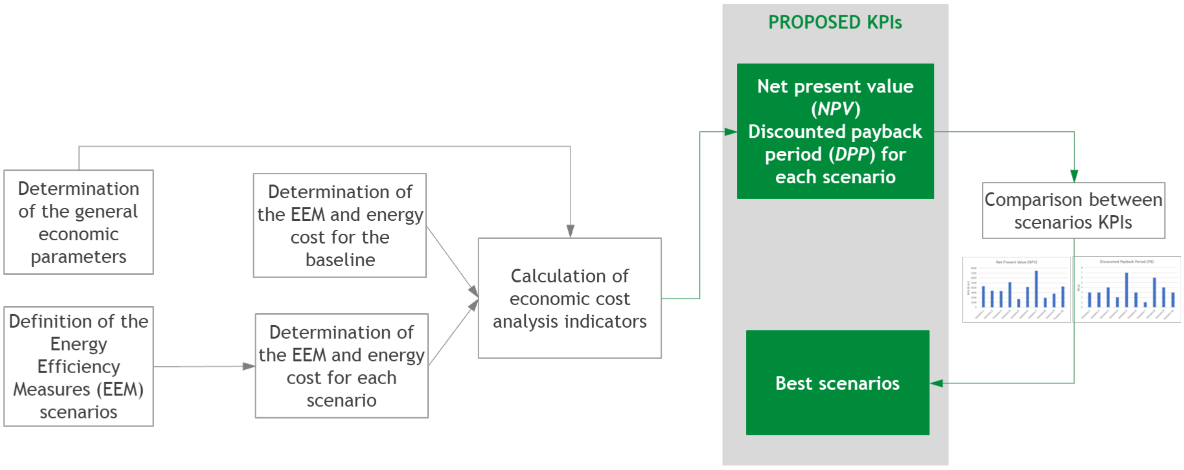


Figure B. 9. Economic evaluation of energy efficiency measures workflow

The analysis is performed with a calculation period of thirty years and the economic indicators are calculated from a financial perspective according to EN 15459-1.

B4.1 Determination of the general parameters

Two main activities must be performed before the economic assessment of each single case.

The first one is the determination of the economic general parameters such as the interest rate and the energy carrier yearly increment cost, as presented in Figure B. 10. While the first is defined as a constant value, the second one need to be defined for each energy carrier used in the baseline or in the scenarios for each year of the calculation period. The conditioned net floor area needs to be defined as well, in order to perform a normalisation of the results.

	Default value (Italy)	Used value
Interest rate [%]	4%	4%
Calculation period [a]	30	30
Conditioned floor area [m^2]	-	100
Number of considered scenarios	-	5

Year	Electricity yearly increment cost			Natural gas yearly increment cost		
	Default value (Italy)	Used value	Cost evolution	Default value (Italy)	Used value	Cost evolution
2023	0,0%	0,0%	1,0000	0,0%	0,0%	1,0000
2024	3,4%	3,4%	1,0338	3,2%	3,2%	1,0323
…	…	…	…	…	…	…
2053	3,4%	3,4%	2,7069	1,2%	1,2%	1,4892

Figure B. 10. Main general data

The second activity regards the definition of the number of scenarios of application of EEM, indicated in Figure B. 10, and the specific EEMs applied in each scenario. This specific procedure is a result of TDS3, therefore the explanation of the determination procedure will be contained in the specific deliverable.

B4.2 Determination of the specific case parameters

Both for the baseline and for each scenario, the relevant information regarding time and costs that has to be determined, as represented in Figure B. 11 and Figure B. 12.

For each EEM and each associated technology, characteristic years are predefined; they represent the number of years a technology, existing or subjected to an EEM, can last before it needs to be replaced. These values are predetermined for each specific technology differentiating, where necessary, the main technical building sub-system affected by the measure.

			Energy efficiency measures																			
			EEM 1	EEM 2	EEM 3	EEM 4	EEM 5	EEM 6	EEM 6	EEM 7	EEM 7	EEM 8	EEM 9	EEM 9	EEM 10	EEM 10	EEM 11	EEM 12	EEM 13	EEM 14	EEM 15	TOTAL
Investment cost [€]			0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	**0**
Annual maintenance cost [€]			1920,00	138,60	0,00	0,00	0,00	1920,00	0,00	58,30	244,55	138,60	0,00	0,00	0,00	0,00	0,00	0,00	244,55	0,00	0,00	**2361**
Repl./Disposal costs [€]			24000,00	0,00	0,00	0,00	0,00	24000,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	**24000**
New technology life [a]			30	30	30	30	30	15	15	20	15	20	20	15	15	15	20	20	20	20	15	**TOTAL**
isting tech. year of replacement			0	0	0	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	
2023	0	1,000	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	**0**
2024	1	0,962	1846,15	133,27	0,00	0,00	0,00	1846,15	0,00	56,06	235,15	133,27	0,00	0,00	0,00	0,00	0,00	0,00	235,15	0,00	0,00	**4485**
2025	2	0,925	1775,15	128,14	0,00	0,00	0,00	1775,15	0,00	53,90	226,10	128,14	0,00	0,00	0,00	0,00	0,00	0,00	226,10	0,00	0,00	**4313**
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	**...**
2053	30	0,308	7991,62	42,73	0,00	0,00	0,00	591,97	0,00	17,98	75,40	42,73	0,00	0,00	0,00	0,00	0,00	0,00	75,40	0,00	0,00	**8838**
TOTAL			**40600**	**2397**	**0**	**0**	**0**	**46527**	**0**	**1008**	**4229**	**2397**	**0**	**0**	**0**	**0**	**0**	**0**	**4229**	**0**	**0**	**101387**

Figure B. 11. Main data for baseline or scenario (EEM)

		Energy carriers				
		Electric	Natural gas	District heating	Other	**TOTAL**
Annual cost [€/a]		1101	10276	0	0	**11377**
Year						
2023	0	1101	10276	0	0	**11377**
2024	1	1138	10607	0	0	**11746**
2025	2	1177	10934	0	0	**12110**
2026	3	1217	11065	0	0	**12281**
2027	4	1258	11198	0	0	**12455**
2028	5	1300	11332	0	0	**12632**
2029	6	1344	11459	0	0	**12803**
2030	7	1389	11588	0	0	**12978**
2031	8	1436	11745	0	0	**13181**
2032	9	1485	11895	0	0	**13379**
2033	10	1535	12046	0	0	**13581**
2034	11	1586	12200	0	0	**13786**
2035	12	1640	12346	0	0	**13986**

Figure B. 12. Main data for baseline or scenario (energy carriers)

As presented in Figure B. 11, the investment cost, the annual maintenance cost, the replacement, or disposal cost have to be determined for all the cases and for each EEM or each technology associated with it. In case of the baseline, since the building is the existing one, the investment section should be all equal to zero, while the other sections must be filled in with the correct values.

For all the cases the annual costs for all the energy carriers deployed in the analysed building must be filled in as presented in Figure B. 12. These costs are the results of the combination of the energy needs derived from the energy calculation procedure and multiplied by the energy carrier cost determined country by country.

B4.3 Calculation of economic cost analysis indicators

The main calculation procedures are performed in the baseline and in the scenarios sheets. For each EEM or associated technology, and for each energy carriers, the annual actualised costs are calculated in the reference time period, as presented in Figure B. 13.

For each scenarios the annual cash flow derived from the comparison with the baseline, the sum of cash flows, the actualised Net Present Value (*NPV*), and the Discounted Payback Period (*DPP*).

Year [a]		Cash Flow [€]	Sum of cash flows [€]
2023	0	11622,80	11622,80
2024	1	12000,48	23623,28
2025	2	12375,39	35998,67
...	...	...	...
2053	30	19620,90	477850,10

NPV	[€]	**477850,1**
	[€/m^2]	**4778,5**
DPP	[a]	**1**

Figure B. 13. Scenario results and calculations

In the results sheets, for the whole set of scenarios, the net present value normalised on the conditioned floor area and the payback period are then indicated. Both these parameters are presented in both a table and a graph.

B5 Indoor environmental quality evaluation

Two different domains are considered for the indoor environmental quality (IEQ) assessment. The IEQ assessment will be carried on following the procedures specified in EN ISO 16798-1 and -CEN/TR 16798-2.

The following domains will be considered:

1. Thermal comfort
2. Indoor air quality (IAQ)

Common preliminary phases are required for all the considered IEQ domains. These steps consist in:

1. Selection of representative spaces of the considered building. For the sake of simplicity, the IEQ verifications will be carried out for representative spaces, which can be single rooms or thermal zones. The choice for the representative spaces should address the following criteria:
   - Different intended uses
   - Different occupancy density
   - Different sizes and orientation
   - Different storeys of the building

Identification of the IEQ comfort category. According to the intended use, an IEQ comfort category is associated to each of the chosen representative spaces. The categories specified in the EN ISO 16798-1 are presented in Table B. 3.

These are related to the level of expectations the occupants may have. A normal level is generally assumed as “medium” (Cat. II), while a higher level may be selected for occupants with special needs (such as children, elderly, persons with disabilities, etc.). A lower level will not provide any risk but may decrease comfort.

Table B. 3. Categories of indoor environmental quality (EN ISO 16798-1)

Category	Level of expectation
IEQ_{I}	High
IEQ_{II}	Medium
IEQ_{III}	Moderate
IEQ_{IV}	Low

Most of intended uses, such as offices, residentials, etc. are generally associated to Category II; however, the choice of the comfort category should address the specific needs of the considered building.

B5.1 Thermal comfort evaluation

Requirements for thermal comfort evaluation:	
1. Hourly energy model	Either calibrated or not
2. Hourly occupancy profiles	Either actual or standard
3. Climatic hourly data	Standard

The thermal comfort evaluation will be carried out according to the adaptive comfort theory. Therefore, it can be applied only to buildings without mechanical cooling.

The evaluation will be carried out considering a standard (standard weather data and users) or a tailored (standard weather data and actual users) energy model. Both standard and tailored models can be created starting from the calibrated energy model (if available).

After the preliminary phases presented, the thermal comfort assessment following the adaptive theory consists in the following steps (Figure B. 14):

1. Selection of the evaluation period
2. Calculation of the running mean outdoor temperatur
3. Definition of the operative temperature comfort range
4. Calculation of the thermal comfort index
5. Definition of the thermal comfort quality index (proposed KPI)

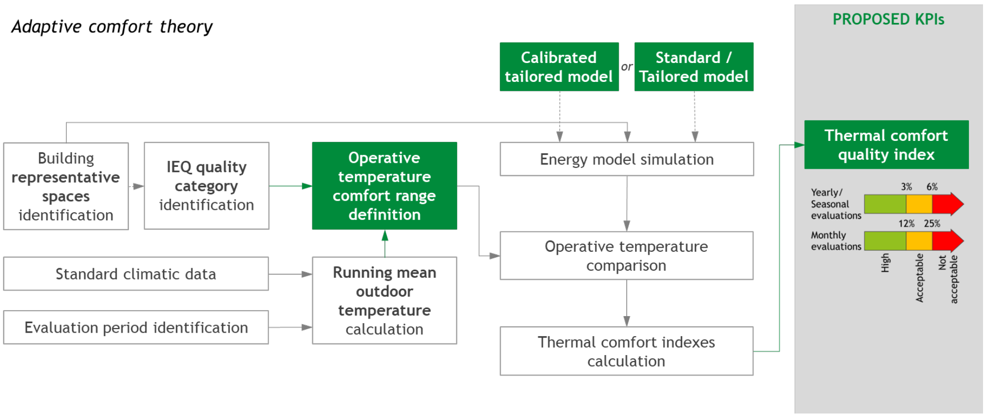


Figure B. 14. Thermal comfort assessment procedure

The thermal comfort evaluation is carried out by means of an MS Excel file provided by POLITO. For each representative space, the inputs (Figure B. 15) required by this file are:

- Comfort category (defined as specified above
- Hourly external air temperature (standard weather data)
- Hourly occupancy profile (standard or actual user)
- Hourly indoor operative temperature
- Beginning and end of the evaluation period

The only energy simulation outputs required for the thermal comfort assessment is the *hourly indoor operative temperature* for the identified representative spaces.

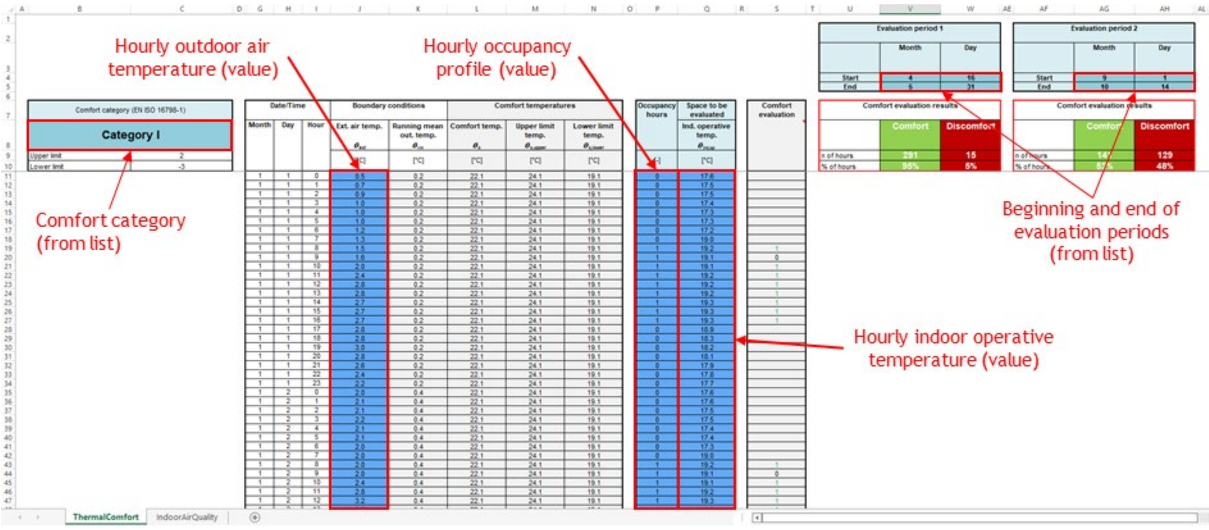


Figure B. 15. Input data for the thermal comfort assessment

Step 1: Selection of the evaluation period

As introduced, the adaptive comfort theory applies to buildings without mechanical cooling. Therefore, this theory may be applied to the non-conditioned months, namely in the shoulder seasons (spring and autumn) and summer , only if the considered space is not served by a cooling system.

In case of buildings without mechanical cooling, one evaluation period should be considered. This should start at the end of the heating season, and it should end at the beginning of the following heating season. For example, for such a building sited in Northern Italy (for which the heating season is from 15th October to 15th April), the evaluation period should start the 16th April and it should end the 14th October.

In case of buildings with mechanical cooling, two evaluation periods should be considered. The first period should start at the end of the heating season, and it should end at the beginning of the cooling season; the second period should start, instead, at the end of the cooling season, and it should end at the beginning of the following heating season.

Step 2: Calculation of the running mean outdoor temperature

The running mean outdoor temperature is automatically calculated within the provided Excel file, using only the hourly outdoor air temperatures as input data (Figure B. 15).

Step 3: Definition of the operative temperature comfort range

The operative temperature comfort ranges are automatically calculated within the provided MS Excel file, according to the selected thermal comfort category (Figure B. 15) and the running mean outdoor temperature. The operative temperature comfort range represents the interval in which a variation of the indoor operative temperature is allowable.

Step 4: Calculation of the thermal comfort index

The thermal comfort index for the identified evaluation periods is automatically calculated within the provided Excel file. For the sake of this calculation, the hourly occupancy profile and the simulated hourly indoor operative temperatures are required (Figure B. 15). Specifically, the occupancy profile should be filled in with the following criteria:

- A value equal to 0 means that the representative space is not occupied, and

- A value equal to 1 means that the representative space is occupied (with at least one person).

The comfort index calculation is carried on only for the occupied hours. Two comfort indexes are considered, namely the <u>percentage of comfort (*PCH*)</u> and <u>discomfort hours (*PDH*)</u> (Figure B. 16). The former is calculated as the percentage of occupied hours in which the indoor operative temperature is within the thermal comfort range. The latter, instead, is calculated as the percentage of occupied hours in which the indoor operative temperature exceeds the thermal comfort range.

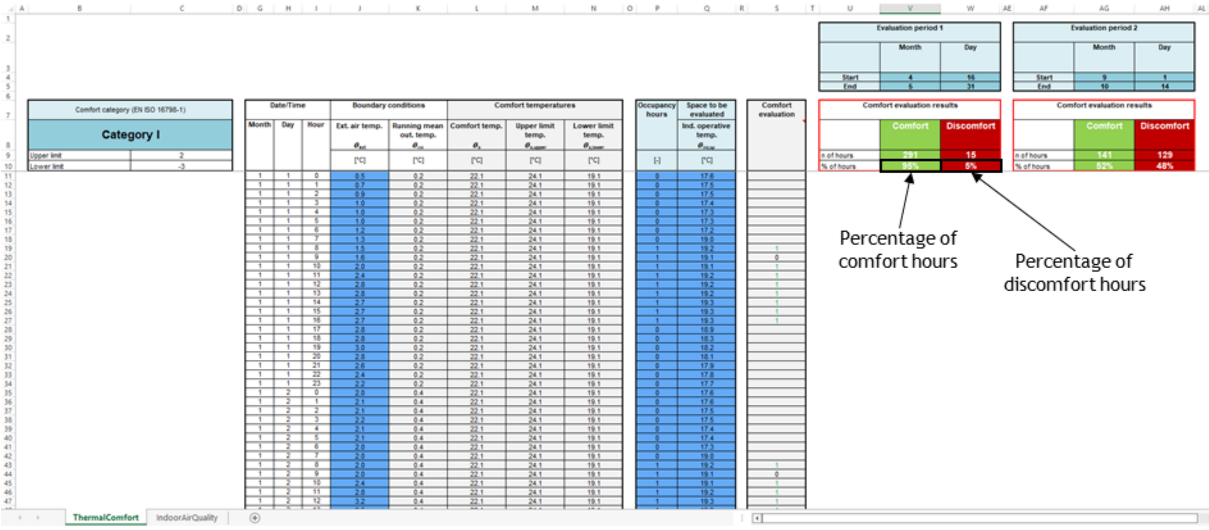


Figure B. 16. Outputs for the thermal comfort assessment Excel file

Step 5: Definition of the thermal comfort quality index (proposed KPI)

The proposed KPI is a qualitative index that identified the level of thermal comfort expected in the analysed representative spaces. This is defined by means of the percentage of discomfort hours, as follows (CEN/TR 16798-2):

- If *PDH*≤3%, then a **<u>high</u>** thermal comfort level is expected
- If 3%<*PDH*≤6%, then an **<u>acceptable</u>** thermal comfort level is expected
- If *PDH*>6%, then a **<u>not acceptable</u>** thermal comfort level is expected

B5.2 Indoor air quality assessment

Requirements for indoor air quality evaluation:	
1. **External air flow rate**	Measured or design value, either from natural or mechanical ventilation

The indoor air quality evaluation will be carried out as a simple comparison between the actual external air flow rate (which can be either measured or a design value) with the minimum to guarantee the indoor air quality. This will be automatically calculated within an MS Excel file provided by POLITO, following the specification of EN ISO 16798-1 (method A).

For each representative space, the inputs (Figure B. 17) required by this file are:

- Comfort category (defined as specified above)
- Intended us
- Building polluting level
- Conditioned net floor area
- Conditioned net volume
- Number of occupants
- Measured or design external air flow rate

<u>No energy simulation outputs are required for the indoor air quality assessment</u>.

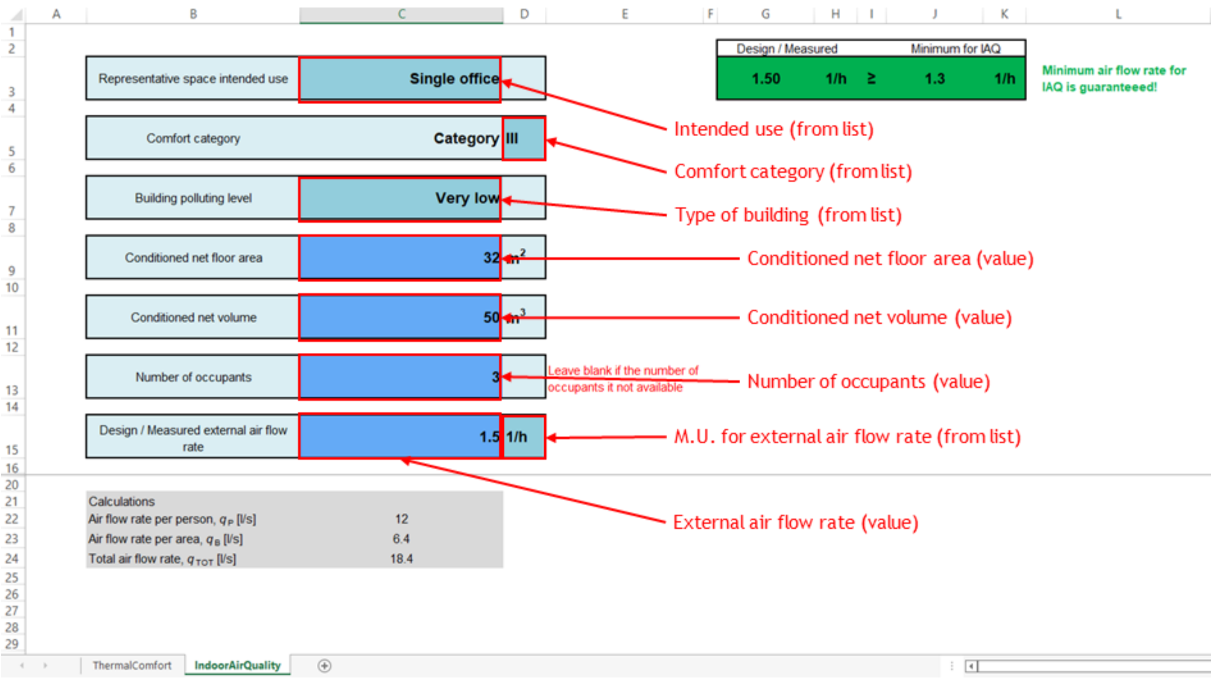


Figure B. 17. Inputs data for the indoor air quality assessment

As for the representative spaces intended use, the Partner may choose between the ones specified by the EN ISO 16798-1 technical standard, namely single office, landscaped office, conference room, auditorium, restaurant, class-room, kindergarten, department store, conference room, auditorium, and classroom.

As for the building polluting level, the building may be either very low-, low-, or not low-polluting. These are defined as follows (EN ISO 16798-1):

- Very low-polluting building: "building where predominantly very low-emitting materials and furniture are used, activities with emission of pollutants are prohibited and no previous emitting sources (like tobacco smoke, from cleaning) were present"
- Low-polluting building: "building where predominantly low emitting materials are used and materials and activities with emission of pollutants are limited"
- Not low-polluting building: "building where no effort has been done to select low-emitting materials and where activities with emission of pollutants are not limited or prohibited"

The datum regarding the number of occupants in the representative space is not mandatory. It can be left blank if not available; in this case, the calculations will be carried one considering a standard occupancy density (in relation to the intended building use). On the other hand, if this datum is available, it is preferable to consider the actual number of occupants to guarantee more accurate results.

Finally, the measured or the design value for the external air flow rate ($q_{m/d}$) is a mandatory datum (since the present analysis is based on the comparison between this value and the minimum requirement). Beside the specification of the value, the Partner is also asked to specify the measurement unit (MU) of the provided value. The available MU are l/s, l/h, m^3/s, m^3/h, and h^{-1} (ACH). In case the air flow rate is provided in h^{-1}, the specification of the conditioned volume is mandatory.

The proposed KPI is a qualitative index that identifies if the minimum air flow rate requirement for indoor air quality (q_{IAQ}) is guaranteed (Figure B. 18). This is defined as follows:

- If $q_{m/d} < q_{IAQ}$, then the minimum air flow rate for IAQ is not guaranteed
- If $q_{m/d} \geq q_{IAQ}$, then the minimum air flow rate for IAQ is guaranteed

Figure B. 18. Outputs data for the indoor air quality assessment

B6 Building Automation and Control System impact assessment

For the determination of the BACS impact the proposed procedure focuses on specific function determined using the following procedure, as presented in Figure B. 19.

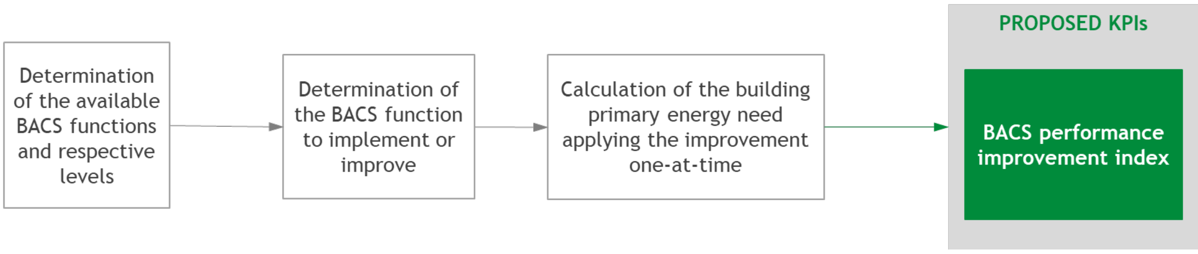


Figure B. 19. Building Automation and Control System impact assessment workflow

At first for the whole set of function presented in EN ISO 52120-1, the user should determine if the function is installed at any level or if it cannot be installed in that specific building; then for the available function the specific level describing the actual BACS should be determined.

The second step is the definition of the function interested by the procedure. The user should exclude the functions that cannot be installed in the building (e.g., if there are no thermally activated building structures, also known as TABS, in the building the heating emission control for TABS cannot be installed), and the functions already at maximum level.

The chosen functions should be analysed one-at-time, improving their BACS level by one and implementing their effect on the energy calculation procedure and assessing the effect on the primary energy need.

A simple “BACS performance improvement” index should be then calculated as follows:

$$E_{\mathrm{BACS}} = \frac{EP_0 - EP_i}{EP_0}$$

Where:

$EP_{,0}$ is the primary energy need for the building in the original state,

$EP_{,i}$ is the primary energy need for the building with the function improvement *i* implemented.

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