Ref. Ares(2024)3418702 - 13/05/2024

D2.4 Asset methodology assessment in building level v2

Project Acronym:	SmartLivingEPC
Project Full Title:	Advanced Energy Performance Assessment towards Smart Living in Building and District Level
Grant Agreement:	101069639
Project Duration:	36 months (01/07/2022 – 30/06/2025)

D2.4

Asset methodology assessment in building level v2

Work Package:	WP2 - Smart Living EPCs Framework Asset Methodology
Task:	T2.1 SRI analysis and integration to SmartLivingEPC T2.2 Energy and non-energy resources analysis and integration to SmartLivingEPC T2.3 Environmental life-cycle assessment and integration to SmartLivingEPC T2.4 Technical audits and inspections integration to SmartLivingEPC
Document Status:	v1.0
File Name:	SmartLivingEPC_D2.4_Asset methodology assessment in building level v2
Due Date:	29.02.2024
Submission Date:	10.05.2024
Lead Beneficiary:	FRC

Dissemination Level	
Public	☒
Confidential, only for members of the Consortium (including the Commission Services)	☐

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Version History

v	Author	Date	Brief Description
0.1	Christos Kythreotis, Paris Fokaides	15.01.2024	First draft version of the document
0.2	Paul Waide	12.02.2024	Input from WSEE
0.3	Pablo Carnero	16.02.2024	Input from REHVA
0.4	Catalin Lungu	23.04.2024	Input from REHVA
0.5	Christos Kytheotis, Paris Fokaides	09.05.2024	Deliverable finalization

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Executive Summary

SmartLivingEPC aims to deliver a holistic smart Energy Performance Certificate (EPC) spanning relevant life-cycle performance aspects of the built environment. The certificate's scope will transcend energy performance, including the certification procedure's smartness, sustainability, and inspection dimension. Consequently, the smart energy performance certification scheme shall integrate the Smart Readiness Indicator (SRI) assessment, Life Cycle Analysis (LCA), and Life Cycle Cost (LCC) assessment, as well as additional human-centric indicators (e.g., Indoor Environmental Quality, thermal comfort, etc.), and others within the Level(s) framework. Furthermore, *SmartLivingEPC* will produce a dual enhanced methodology based on the existing CEN standards for delivering asset and operational ratings. These assessments will be applicable at both the building and the district scale.

The smart EPCs shall be issued with the use of digital tools and retrieving quality input data from BIM literacy, energy audits, and technical inspections, including enriched energy and sustainability-related information for the as-designed and actual performance of the building. Compatibility with Digital Building Logbooks (DBL) protocols will be ensured. The project will also use the digital twin approach to integrate BIM and inverse modeling by employing operational data to ensure that building models are enhanced and evolved in accordance with their actual performance during the complete life cycle. To that end, data coming from sensors and smart meters, as well as innovations related to the Internet of Things (IoT) and Artificial Intelligence (AI), will be leveraged.

Within WP2, “SmartLivingEPC Framework Asset Methodology”, the actions for the establishment of the smart EPC asset methodology will be performed. In short, smartness, sustainability, and audit and technical inspection aspects are integrated into one uniform rating system of the energy performance of buildings as well as the introduction of a new rating scheme at a building complex level. In that sense, the building level classification will result in a weighted average of four other indicators: the SRI, the Level(s), the energy performance rating, and the results from technical audits.

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List of Acronyms, Abbreviations and other Terms used in the document

Term	Description
AC	Air-conditioning
AHU	Air-handling unit
API	Application Programming Interfaces
BAC	Building automation and control Products, software, and engineering services for automatic controls, monitoring and optimization, human intervention, and management to achieve energy-efficient, economical, and safe operation of building services equipment. “Control” does not imply that the system or device is restricted to input/output, processing, optimization, management, and operator functions. Processing of data and information is possible.
BACS	Building automation and control system **BACS** is also referred to as **BMS** (building management system) **BEMS** (building energy management system) is part of a **BMS**
BAPV	Building Attached Photovoltaics
BEMS	Building energy management system Comprises data collection, logging, alarming, reporting, and analysis of energy usage, etc. The system is designed to reduce energy consumption, improve utilization, increase reliability, and predict the performance of the technical building systems, as well as optimize energy usage and reduce its cost.
BES	Building Energy Simulation
BESS	Battery Energy Storage Systems
BIM	Building Information Modelling
BIPV	Building Integrated Photovoltaics
BM	Building management The totality of services involved in the management operation and monitoring of buildings (including plats and installations). Building management can be assigned as part of facility management.
Building fabric	All physical elements of a building, excluding technical building systems. It is often described as the building as such. It includes elements both inside and outside the thermal envelope, including the thermal envelope itself.
Building service	Service is provided by technical building systems and by appliances to provide acceptable indoor environment conditions, domestic hot water, illumination levels, and other services related to the use of the building. The services included in EPB assessments are referred to as “EPB services”. Contrarily those not included as “non-EPB services”.
CA	Concerted Action (of the EPBD)
CAV	Constant Air Volume
CB	Chilled Beams
CE	"Conformité Européenne" (European conformity marking)
CEN	French: Comité Européen de Normalisation; English: European Committee for Standardization
CENELEC	French: Comité Européen de Normalisation Électrotechnique; English: European Committee for Electrotechnical Standardization
COP	Coefficient of Performance
DBL	Digital Building Logbook
DC	Direct Current
DCV	Demand-Controlled Ventilation
Distant	Not on-site nor nearby.
DG	Directorate-General
DHW	Domestic Hot Water

DR	Demand Response
DX	Direct Expansion
EC	European Commission
ED	Ecodesign Directive
EED	Energy Efficiency Directive
EEI	Energy Efficiency Index
EER	Energy Efficiency Ratio
ELR	Energy Labelling Regulation
EMS	Energy Monitoring System
EN	European Norm
ENER	Directorate-General for Energy
EPB	Energy performance of Buildings (Directive)
EPBD	Energy Performance of Buildings Directive
EPC	Energy Performance Certificate
EPREL	European Product Database for Energy Labelling
EU	European Union
EU27	27 Member countries of the EU
EU28	The former 28 Member countries of the EU
EUR	Euro (currency)
FCU	Fan Coil Unit
FM	Facility Manager
FP	Flue Pipe
Functionality level	As a term within the SRI calculation methodology, means the level of smart readiness of a smart-ready service.
GHG	greenhouse gases
H2020	Horizon 2020
HIU	Heat Interface
HP	Heat Pump
HR	Heat Recovery
HRS	Heat Recovery System
HVAC	Heating, Ventilation, and Air-Conditioning
HVAC&R	Heating, Ventilation, Air-Conditioning, and Refrigeration
IA	Integrated Assessment
IAQ	Indoor Air Quality
ICT	Information and Communications Technology
IEC	International Electrotechnical Committee
IEQ	Indoor Environmental Quality
IFC	Industry Foundation Classes
ISO	International Organization for Standardization
IT	Information Technology
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
LCC	Life Cycle Cost
LENI	Lighting Numerical Indicator
LPHE	Liquid-to-liquid Plate Heat Exchangers
lx	Lux
MFH	Multi-Family Housing
MS	Member State
MSA	Market Surveillance Authority
Nearby	On the local or district level
NECP	National energy and climate plans
NZEB	Nearly Zero-Energy Building
O&M	Operation & Maintenance
OJ	Official Journal (of the EU)

On-site	Premises and the parcel of land on which the building(s) is located and the building itself. On-site defines a strong link between the energy source (localization and interaction) and the building.
PDI	Lighting Power Density
PI	Performance Indicator
PMV	Predicted Mean Vote
PR	Performance Ratio
PSFP	Average Specific Fan Power
PV	Photovoltaic
QR	QR code
RA	Risk Assessment
RAC	Room Air Conditioner
RE	Renewable Energy
RES	Renewable Energy Systems/Sources
RT	Rooftop
SEER	Seasonal Energy Efficiency Ratio
SFP	Specific Fan Power
SLCA	Social Life Cycle Assessment
Smart-ready service	A term within the SRI calculation methodology; means a function or an aggregation of functions provided by one or more technical components or systems. A smart-ready service makes use of smart-ready technologies and orchestrates them into higher-level functions.
Smart-ready technology	A term within the SRI calculation methodology; means a technological enabler for one or more smart-ready services.
SRI	Smart Readiness Indicator
STC	Standard Test Conditions
TABS	Thermally activated building system Massive building fabric is actively heated or cooled by integrated air- or water-based systems.
TBM	Technical building management Processes and services related to the operation and management of building and technical building systems through the interrelationships between the different disciplines and trades.
TBS	Technical building systems Technical equipment for heating, cooling, ventilation, humidification, dehumidification, domestic hot water, lighting, and electricity production. A technical building system is composed of different subsystems.
TC	Technical Committee
Technical domain	As a term within the SRI calculation methodology, it means a collection of smart-ready services that, together, realize an integrated and consistent part of the services expected from the building or building unit.
TES	Thermal Energy Systems
Thermal envelope area	The total area of all elements of a building that enclose thermally conditioned spaces through which thermal energy is transferred, directly or indirectly, to or from the external environment. The thermal envelope area depends on whether internal, overall internal, or external dimensions are being used.
TRV	Thermostatic Radiator Valves
VAV	Variable Air Volume
VRF	Variable Refrigerant Flow
WHO	World Health Organization

The terms and definitions outlined above reflect those used in standardization. ISO and IEC maintain terminological databases at the following addresses:

1. ISO online browsing platform: available at https://www.iso.org/obp
2. IEC Electropedia: available at https://www.electropedia.org/

1 Introduction

1.1 Work package and Task description

The built environment constitutes a substantial proportion of global energy consumption and greenhouse gas emissions. Recognizing the urgency to mitigate climate change and reduce energy usage, the *Advanced Energy Performance Assessment towards Smart Living in Building and District Level – SmartLivingEPC* project—a transformative initiative aimed at enhancing energy efficiency in buildings. The central tenet of this project is the development of a novel Energy Performance Certificate (EPC) framework that goes beyond conventional energy rating systems.

Work Package 2 (WP2) assumes a pivotal role in establishing the asset methodology assessment at the building level by addressing several pressing challenges that have impeded the holistic evaluation of energy performance in buildings. Traditionally, energy ratings have been based solely on energy consumption data, neglecting other essential aspects that contribute to buildings' overall sustainability and performance. By incorporating cutting-edge practices and integrating diverse evaluation parameters, this integrated approach aims to create a comprehensive and harmonized rating system. Such a system will enable stakeholders, including property owners, investors, and policymakers, to make informed decisions, promote sustainable practices, and facilitate the transition toward a low-carbon future. This integrated approach embraces various aspects that significantly influence building performance and occupant satisfaction by implementing its tasks (T). Notably, it emphasizes the incorporation of additional critical characteristics, such as (SRI) – T2.1, energy and non-energy aspects – T2.2, LCA tools – T2.3, and introduction of a new building complex level rating scheme through technical audits and inspections – T2.4.

Conventional energy rating systems have undoubtedly played a critical role in fostering awareness of energy consumption in buildings. However, their narrow focus on energy usage fails to capture the broader spectrum of factors influencing a building's environmental impact and overall performance. As the global focus shifts towards sustainable development and responsible resource utilization, there is an imperative to rethink the current evaluation methodologies and develop a more inclusive approach. The asset methodology assessment at the building level seeks to address this need by encompassing a multifaceted evaluation paradigm. Integrating the principles of SRI analysis enables a more comprehensive understanding of a building's environmental, social, and governance implications. Concurrently, LCA tools facilitate a holistic examination of a building's environmental footprint over its entire life cycle, from construction to end-of-life considerations. Additionally, the incorporation of non-energy aspects, such as indoor air quality, thermal comfort, and occupant well-being, ensures a people-centric approach to building assessment.

A critical facet of this deliverable is the introduction of a new scheme building rating at the complex level. Recognizing that buildings rarely function in isolation, the Asset Methodology Assessment aims to extend its impact to encompass entire building complexes. This novel approach fosters more accurate and relevant ratings by evaluating the collective energy performance and sustainability attributes of interconnected structures.

1.2 Background and Objectives

Buildings account for a substantial portion of total energy consumption in Europe, and enhancing their energy performance is pivotal in achieving sustainability goals and combating climate change. Despite various existing rating systems and assessment tools, a coherent, comprehensive, and uniform methodology is still lacking to gauge the energy performance of buildings accurately. Moreover, the available frameworks often fail to consider vital non-energy aspects and fail to integrate multiple evaluation parameters into a single, cohesive rating system. With the integration of SRI analysis, LCA tools, technical audits, and inspections into a unified system, the project aspires to develop an all-encompassing assessment scheme that not only measures energy efficiency but also encompasses sustainability, environmental impact, and overall building performance.

1.3 Scope of the deliverable

This deliverable is an integral part of WP2, aiming to establish a unified and comprehensive approach to assess the energy performance and sustainability of buildings at individual and complex levels.

T2.1 - *SRI analysis and integration into SmartLivingEPC* focuses on examining smart technologies in buildings and analyzing SRIs with the aim of integrating them into the energy certification methodology of buildings. The first step involves conducting a detailed overview of the current status of SRIs, including their definition and methodologies. The examination will encompass the capacity of buildings to adapt their operation to occupants' needs, energy efficiency, and overall performance based on SRI schemes. SRIs will be classified according to the Energy Performance of Buildings Directive (EPBD) recast, categorizing aspects like heating, cooling, lighting, and more. The task also entails linking SRI certifications with EPC data, enabling the extraction of SRI information from intelligent Building Information Modeling (BIM) documents, thus facilitating the integration of SRI results into the new SmartLivingEPCs.

T2.2 - *Energy and non-energy resources analysis and integration into SmartLivingEPC* seeks to incorporate both energy performance and non-energy aspects into the classification of buildings. Building upon the technical documentation derived from the EN52000 standards series and other energy-related standards, this task aims to develop an integrated asset-based methodology for assessing building energy performance. The procedures developed will encompass the building's life cycle, integrate energy-related performance data, and data concerning non-energy resource consumption, such as water, noise, and acoustic quality issues. The assessment will be conducted in the BIM environment, leading to the development of necessary Application Programming Interfaces (APIs) to support the process. The expected outcome is a comprehensive energy and non-energy asset assessment of buildings, which will be further integrated into the SmartLivingEPC rating scheme.

The objective of T2.3 - *Environmental life-cycle assessment and integration into SmartLivingEPC* is to analyze the environmental life-cycle assessment and sustainability aspects of buildings to include sustainability ratings in the SmartLivingEPC rating procedure. Building and construction sustainability tools and technical standards, including the Level(s) scheme, will be employed to achieve this. The task will primarily focus on defining specific sustainability indicators for quantifying the environmental impact of buildings during their design and construction stages, utilizing a cradle-to-gate rationale. BIM documents will be utilized for the environmental assessment of buildings, necessitating the development of appropriate APIs to extract relevant building information from the IFC documents. The deliverable's outcome will consist of defined indicators and calculation processes, enabling the integration of life cycle performance aspects into the SmartLivingEPC calculation procedures.

T2.4 - *Technical audits and inspections integration into SmartLivingEPC* aims to integrate the findings from technical audits and inspections into the EPCs. It acknowledges the significance of up-to-date data on building systems' performance and its relevance to the energy rating process. By analyzing the input and outcomes of technical audits for building systems, such as the EN 15378, EN 16798, EN 16946, and EN 16947 standards series, this task seeks to identify relevant findings that can be utilized for energy classification. The outcome will be the development of necessary procedures and methodologies to incorporate the periodic audit findings of building systems into the process of calculating the asset energy class of the building, complementing the tasks in T2.1, T2.2, and T2.3.

The deliverable’s scope aims to revolutionize the evaluation of energy performance and sustainability of buildings by creating an integrated approach that includes SRIs, energy and non-energy aspects, LCA, and technical audits. Once integrated into the SmartLivingEPC rating procedure, this comprehensive assessment scheme will pave the way toward more energy-efficient and environmentally responsible buildings throughout Europe.

2 SRI analysis and integration to SmartLivingEPC

In this chapter, a detailed description of the SRI assessment is included. The remaining is structured as follows: Section 2.1 includes a documentation of current practices for SRI; Section 2.2 discusses the SRI certificate; Section 2.3 deals with the data and parameters for SRI analysis; and Section 2.4 outlines the SRI indicators used in the scope of the SmartLivingEPC project.

In future updates of this document the link between the SRI and EPB assessments and certification schemes and the extraction of data from IFC files to serve as an input for the SRI assessment will be dealt with.

2.1 Documentation of current practices for SRI

This Section aims to facilitate the integration of the SRI calculation into the SmartLivingEPC asset rating calculation methodology at the building, concerning the development, methodologies, and related procedures for the issuance of SRI certification. The process is to describe the SRI assessment methodology in detail, outlining the relevance at the building level. Certain conclusions are drawn, and possible future advances are outlined.

2.1.1 Context

The amendment of Directive 2010/31/EU on the energy performance of buildings (EPBD) [1] outlined the impact of energy system digitalization in the energy landscape, from the integration of renewables to smart grids and smart-ready buildings. As a result, smart-ready systems and digital solutions in the built environment are to be promoted through the provision of targeted incentives. Consequently, the Smart Readiness Indicator was introduced as a common European scheme for rating the smart readiness of buildings.

The power to adopt acts to supplement the directive and to establish the definition of the SRI and the calculation methodology was delegated to the European Commission (EC). The powers regarding the modalities for its implementation were also conferred to the Commission. As preparatory work, a first SRI technical study had been requested by the EC to VITO, WSEE, ECOFYS, and OFFIS, including a preliminary definition of the SRI and calculation methodology, as well as an extensive stakeholder consultation. A second SRI technical study was later commissioned by VITO and WSEE for the finetuning of the definition and calculation methodology [2]. As a result, the Commission Delegated Regulation 2020/2155 [3] and the Commission Implementing Regulation (EU) 2020/2156 [4] were published.

The Delegated Regulation established a common definition and calculation methodology for the SRI. Consequently, the *smartness* of a building or building unit was defined as its ability to sense, interpret, communicate, and actively respond in an efficient manner to changing conditions in relation to the operation of technical building systems, the external environment, and demands from building occupants. The calculation methodology and smart readiness rating were described in annexes I to VIII; though striving for consistency and comparability of building ratings across the EU, flexibility to adapt the calculation to specific conditions is enabled. The SRI scheme was labeled as optional, leaving the decision for its implementation to the Member

States (MSs). The SRI calculation methodology enables the connection or integration of the SRI scheme with national EPB schemes, particularly EPCs.

Nevertheless, the SRI can never substitute, only complement, energy performance, and sustainability assessments. Furthermore, digital building models shall be allowed to be used to facilitate the calculation of a building's SRI. The SRI certificate was defined as the document for communicating the smart readiness indicator of a building or building unit. It was established that only qualified or accredited experts could issue SRI certificates. If implemented, the SRI ought to have an independent control system, which may be linked to that in place for the energy performance certification schemes.

The Implementing Regulation detailed the accreditation and qualification of SRI experts. It indicated that the experts accredited or qualified for issuing energy performance certificates, carrying out an inspection of heating, air conditioning, combined heating or air conditioning and ventilation systems under Directive 2010/31/EU, or performing energy audits under Directive 2012/27/EU, are also competent for issuing smart readiness indicator certificates. It posed that additional requirements may be set, particularly in relation to training. Regarding the validity of the SRI certificate, the Regulation indicated that it should not exceed ten (10) years. It indicated that self-assessment by building owners, users, and other interested stakeholders ought to be enabled. However, any smart readiness assessment without the intervention of an expert may not lead to the issue of a smart readiness indicator certificate. Article 9 outlines the details of the national testing of the smart readiness indicator scheme.

In 2021, the SRI support team was set up by VITO, WSEE, R2M Solution, and LIST. The objective is to provide technical assistance for the testing and implementation of the SRI. In 2022, some countries launched a voluntary test phase of the SRI.

2.1.2 SRI core methodology

As indicated by the Commission Delegated Regulation 2020/2155 [5], the smart readiness of a building or building unit is determined based on the assessment of **smart-ready services** present or planned in, or relevant for, the building or building unit and their **functionality level**. The smart readiness of a building or building unit is expressed by a rating that derives from a total smart readiness score expressed as a percentage and represents the ratio between the smart readiness of the building or building unit compared to the maximum smart readiness it could reach. Therefore, it assesses the effective capabilities of the building or building unit to adapt its operation to the needs of the occupants and the grid and to improve its energy efficiency and overall in-use performance compared to a given potential.

The SRI methodology is structured in **three key smart readiness functionalities** (f), as highlighted in point 2 of Annex Ia, to Directive 2010/31/EU, within which certain **impact criteria** exist (ic).

1. Energy performance and operation
    - Energy efficiency
    - Maintenance and fault prediction
2. Response to user needs
    - Comfort

  - Convenience
  - Health, well-being, and accessibility
  - Information to occupants
3. Energy flexibility
  - Energy flexibility and storage

The relevant impact criteria per key smart readiness functionality are depicted visually in **Figure 1**.

The SRI assesses **nine technical domains** (d), also defined by [5] are listed below and depicted in **Figure 2**.

1. Heating
2. Domestic hot water
3. Cooling
4. Ventilation
5. Lighting
6. Dynamic building envelope
7. Electricity
8. Electric vehicle charging
9. Monitoring and control

For each technical domain (d), **smart-ready services** $(S_{i,d})$ shall be defined by the MSs as part of smart-ready catalogs, including their related **functionality levels** $(FL(S_{i,d}))$, and corresponding individual scores for each impact criterion $(I_{ic}\left(FL(S_{i,d})\right))$. The smart-ready catalogs shall reflect the state-of-the-art of **smart-ready technologies**, which may be different among building types. Hence, several smart-ready catalogs may exist. The smart-ready service catalog shall define the maximum score of each technical domain for each impact criterion $(I_{max}(d, ic))$.

MSs shall define the respective **weighting factors** $(W_{d,ic})$ characterizing the influence of each technical domain (d) on each impact criterion (ic). Such factors ought to be expressed as a percentage, the sum of which ought to be 100% for each impact criterion. Weighting factors may be different between building types. As a result, it is possible to obtain the **smart readiness score for each impact criterion** (SR_{ic}).

MSs shall define the respective **weighting factors** $(W_{f,ic})$ of relevant impact criteria (ic) within each key functionality (f), which enables to obtain **smart readiness scores** (SR_f) along the three key functionalities. Next, the **weighting factor** (W_f) indicates the influence of each key functionality (f) on the **total smart readiness score** (SR). Ultimately, the ratio between the smart readiness of the building or building unit compared to the maximum smart readiness that it could reach results in the **smart readiness rating**. The ratio yields a rating based on the **seven-class scale**: 90-100%; 80-90%; 65-80%; 50-65%; 35-50%; 20-35%; <20%, ranging from highest to lowest smart readiness.

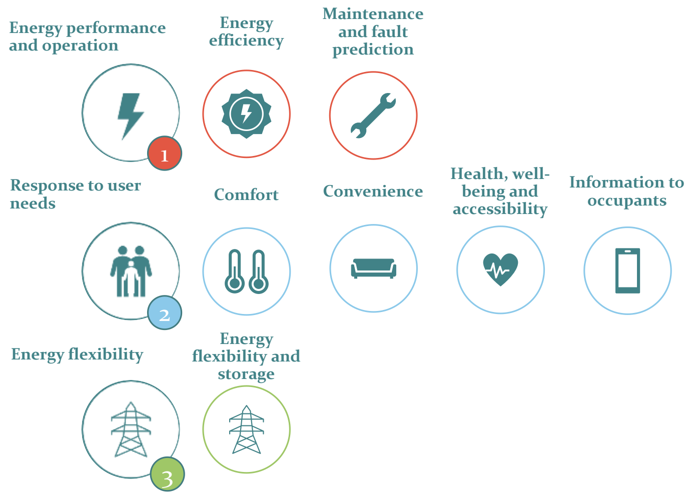

Figure 1: Relevant impact criteria per key functionality

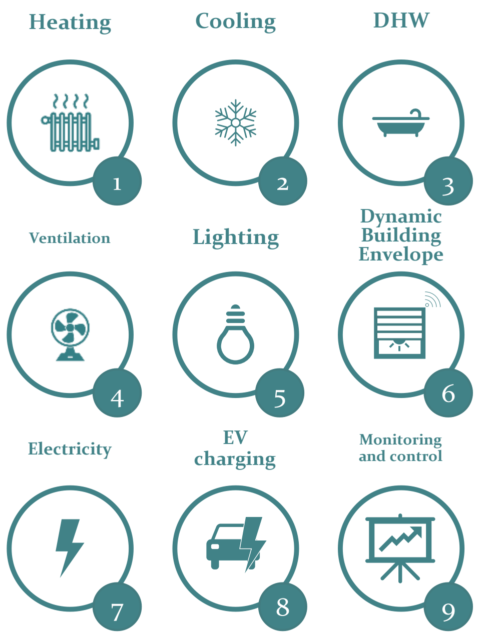

Figure 2: SRI technical domains

In the subsequent Sections of the document, when using the terms technical domains, service groups, smart ready services, and functionality levels in italics, they shall be understood as referred to their meaning within the SRI calculation methodology.

2.2 SRI certificate

The content of the smart readiness indicator certificate, as defined by Annex IX of the Commission Delegated Regulation 2020/2155 [5], includes the following:

- General certificate information
    - Unique ID of the certificate
    - Date of issue and date of expiration of the certificate
    - An informational text clarifies the smart readiness indicator's scope, particularly about energy performance certificates. Where available, the energy performance class of the building or building unit as specified by a valid energy performance certificate.
- General building or building unit information
    - Type of building or building unit
    - Surface area
    - Year of construction and, where relevant, of renovation
    - Location
- Smart readiness of the building
    - Smart readiness class of the building or building unit. Optionally, the total smart readiness score of the building or building units.

    - Smart readiness scores along the three key functionalities and per impact criterion. Optionally, scores of each technical domain for each impact criterion.

An informational text clarifying that the certificate reflects smart readiness at the date of issuance and that any significant modifications to the building and its systems would affect smart readiness and would therefore require an update of the information given on the certificate.

Optionally, additional information on the assumptions made in the calculation of scores, such as weighting factors of impact criteria used for calculating smart readiness scores for key functionalities.

- Where possible, available information on connectivity, in particular on the existence of high-speed-ready in-building physical infrastructure, such as the voluntary 'broadband ready' label. Also, where possible, available information on interoperability, cybersecurity of systems, and data protection, including where relevant on conformity to commonly agreed standards and information on related risks.
- Optionally, recommendations on improving the smart readiness of the building or building unit considering, where relevant, the heritage value.

Note how there is information in the SRI certificate that directly comes from input data retrieved by the assessor and specific to the assessed object (i.e., general building or building unit information, information on connectivity and in-building physical infrastructure, recommendations to improve the smart readiness of the building or building unit), general information to be provided by the assessor that is not explicitly linked to the assessed object (i.e., assessor identification, additional information on financial opportunities, etc.), and information related to the result of the assessment (i.e., smart readiness class, score, etc.). This situation is similar to that found in energy performance certificates.

2.2.1 Contextual adaptations

Service catalogs ought to be defined by the MSs. As a result, different *smart ready services* per technical domain may be considered among European countries.

The definition of **weighting factors** of *technical domains* per impact criterion is the prerogative of Mss as well. The standard approach defines the weighting factors of certain technical domains (i.e., *heating*, *domestic hot water*, *cooling*, *ventilation*, *lighting*, and *electricity*) as the energy balance per climatic zones. The remaining technical domains' weighting factors per impact criterion (i.e., *dynamic building envelope*, *electric vehicle charging*, and *monitoring and control*) are either fixed or equally distributed. For the calculation of the energy balance, energy performance in building assessments as per the energy performance certificates may be used. The climatic zones are defined by the MSs, and it is possible to have diverse sets of weighting factors depending on the building type. Approaches for the weighting factors definition that deviate from the standard approach are also possible.

MSs shall also define the **weighting factors** related to the influence of each *key functionality* in the total smart readiness score. To avoid unfairly penalizing a building or building unit, some smart-ready services may be omitted in the calculation of the smart readiness scores if those services are not relevant for that building or building unit. MSs shall define the conditions for allowing such adaptations of the calculation procedure. MSs may define additional considerations in terms of inclusiveness, connectivity, interoperability, cybersecurity, data protection, etc.

2.3 Data and parameters for SRI analysis

The SRI support team has produced the SRI assessment package (v4.5 being the latest) [6]. It is comprised of a practical guide for the SRI calculation framework and a calculation spreadsheet. The spreadsheet is a representation of the methodology for calculating the SRI based on the multi-criteria assessment method defined in the Commission Delegated Regulation 2020/2155 [5]. The spreadsheet is a tool to support SRI testing and implementation in EU MSs. It includes a default **service catalog** and **weighting factors** while enabling the use of customized values.

2.3.1 Service Catalog

The SRI assessment package produced by the SRI support team defines a **service catalog** in which each *technical domain* comprises several service groups containing *smart-ready services,* as in **Table 1**.

Table 1: Default service catalog - SRI assessment package (v4.5)

Technical domain	Service group	Smart-ready service
Heating	Heat control – demand side	Emission control
		Control of distribution fluid temperature
		Control of distribution pumps in networks
		TES for building heating, excluding TABS
	Heat control – supply side	Generator control
		Sequencing in the case of different generators
	Information to occupants and facility managers	Report regarding system performance
	Flexibility and grid interaction	
Domestic hot water	Heat control – supply side	Storage - generator control
		Sequencing in the case of different generators
	Information to occupants and facility managers	Report regarding system performance
Cooling	Cooling control – demand side	Emission control
		Control of distribution fluid temperature
		Control of distribution pumps in networks
		TES for building heating, excluding TABS
		Interlock avoiding
	Cooling control – supply side	Generator control
		Sequencing in the case of different generators
	Information to occupants and facility managers	Report regarding system performance
	Flexibility and grid interaction	
Ventilation	Air flow control	Supply air flow control at room level
		Supply air flow control at the air handling unit level
	Air temperature control	Heat recovery control
		Supply air temperature at the air handling unit level
	Free cooling	

	Information to occupants and facility managers	Report regarding system performance
Lighting	Artificial lighting control	Occupancy control for indoor lighting
	Control artificial lighting based on daylight levels	
Dynamic building envelope	Window control	Solar shading control
		Opening control, combined with an HVAC system
	Information to occupants and facility managers	Report regarding system performance
Electricity	Locally generated electricity storage	
	Locally generated electricity self-consumption optimization	
	Combined Heat and Power generation control	
	Demand Side Management	Support of (micro) grid operation
	Information to occupants and facility managers	Report regarding local electricity generation.
		Report regarding local electricity storage.
		Report regarding local electricity consumption
Electric vehicle charging	EV Charging	Capacity
		Grid balancing
		Connectivity
Monitoring and control	HVAC interaction control	Run time management of HVAC systems
	Fault detection	
	Technical building system interaction control	Occupancy detection
	Smart Grid integration	
	Information to occupants and facility managers	Report regarding demand side management performance and operation.
		Report regarding demand side management performance and operation.
	Override DSM control	
	Single platform that allows automated control, coordination between TBS, and optimization of energy flow	

Several incremental **functionality levels**, ranging from 0 to 4, are defined in a technology-neutral manner for each technical domain's smart-ready service. A higher functionality level reflects smarter performance. The SRI calculation spreadsheet enables user-defined *smart-ready services*.

2.3.2 Weighting factors

The SRI assessment package produced by the SRI support team defines default **weighting factors** for each technical domain per impact criterion for five (5) climatic zones in Europe (i.e., South-East Europe, North-East Europe, South Europe, West Europe, and North Europe). Such factors are different for residential and non-residential buildings; furthermore, the **weighting factors** of each *key functionality* in the total smart readiness score. The SRI calculation spreadsheet enables user-defined **weighting factors**.

2.4 SmartLivingEPC SRI Indicators

The final report of the second SRI technical study [8] investigated three potential SRI assessment methods (i.e., Method A, Method B, and Method C). Methods A and B are based on the assessment of the *smart-ready services* that are present or planned at the design stage and their *functionality level*. The assessment aims to determine with sufficient reliability what services are present or planned, and if so, the functionality level for each of those services. For this purpose, digital models of buildings, including building information models or digital twins, may be used when available. The main difference is that Method A considers a reduced **service catalog** and thus spans a subset of the *smart-ready services* considered in Method B. Consequently, Method A requires less effort, time, and potential expertise. By default, Method B would require an on-site inspection of the assessed object. Alternatively, Method C aims to be based on measured data, quantifying the operational *smartness* of in-use buildings.

Methods A and B are methodologies included in the SRI assessment package produced by the SRI support team, whereas Method C is considered a potential future evolution. The generic process of the SRI assessment following Method A or B is outlined in **Figure 3**.

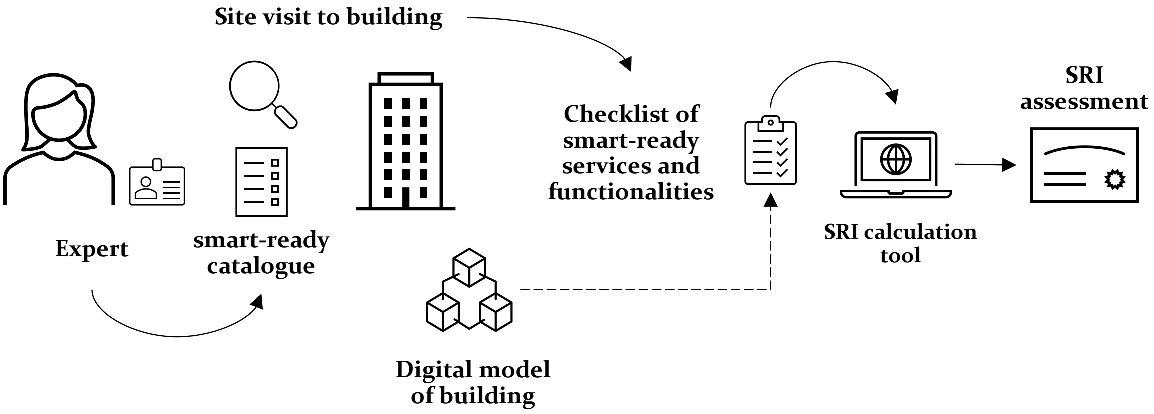

Figure 3: Generic SRI assessment process. Method A or B

The following sub-sections will explain the SRI assessment procedure taken as reference Method B and the default calculation methodology.

2.4.1 Input data

Performing an SRI assessment requires the identification of general information about the assessed object as well as retrieving the inputs needed for the calculations, similar to that required for the issue of energy performance certificates. The SRI assessment, as per the calculation spreadsheet developed by the SRI support team, requires the definition of certain input data, which can be structured according to the following:

- Assessor information.
- General building information.
- Methodology selection.
- Definition of applicability of smart-ready services and main functionality levels.
- Assessment date.

The input data regarding **assessor information**, the **methodology selection**, and the **assessment data** are trivial and, therefore, not of interest in this document. The **general building information** contains items that correlate with overarching preparation steps for EPB assessments [9]. The **definition of the applicability of smart ready**

service and main functionality level is the core calculation methodology for the SRI. Certain *functionality levels* may be defined for each *technical domain's smart-ready service*. Such *functionality levels* are enabled by certain smart-ready technologies either present or planned at the building or building unit. Depending on the applicable smart service catalog, the input data-gathering process may be variable in terms of time and effort needed. Furthermore, where they are available, digital models of buildings, including building information models or digital twins, may be used to increase reliability and reduce the time of the assessment.

2.4.1.1 Calculation

Once the main *functionality level* has been defined for each applicable *technical domain's smart-ready service*, the calculation proceeds as indicated in Section 2.1.2.

Each *smart-ready service* $(S_{i,d})$ has a certain *functionality level* $(FL(S_{i,d}))$, which is equivalent to a score for each *impact criterion* (ic). The scores $I_{ic}(FL(S_{i,d}))$ of each *technical domain* (d) and *impact criterion* are defined by **Equation 1**, as the sum of the scores of the *smart-ready services* within a given *technical domain*.

$$I(d, ic) = \sum_{i=1}^{Nd} I_{ic}\left(FL(S_{i,d})\right)$$

Equation 1.

The calculation is reproduced considering the maximum *functionality level* per applicable *smart-ready service* contained in the *smart-ready service catalog* $(FL_{max}(S_{i,d}))$. It is indicated in Equation 2.

$$I_{max}(d, ic) = \sum_{i=1}^{Nd} I_{ic}\left(FL_{max}(S_{i,d})\right)$$

Equation 2.

It is possible to produce the smart readiness score per *technical domain* and *impact criterion* following Equation 3.

$$SR_{d,ic} = \frac{I(d, ic)}{I_{max}(d, ic)} \cdot 100$$

Equation 3.

Next, the scores per *technical domain* are summed, considering their respective contribution to each *impact criterion*. The result is divided by the maximum possible score, resulting in the smart readiness score per *impact criterion* (SR_{ic}) as per Equation 4.

$$SR_{ic} = \frac{\sum_{d=1}^{N} W_{d,ic} \cdot I(d, ic)}{\sum_{d=1}^{N} W_{d,ic} \cdot I_{max}(d, ic)} \cdot 100$$

Equation 4.

The smart readiness per technical domain follows Equation 4.

$$SR_{d} = \frac{\sum_{ic=1}^{M} W_{d,ic} \cdot I(d, ic)}{\sum_{ic=1}^{M} W_{d,ic} \cdot I_{max}(d, ic)} \cdot 100$$

Equation 5.

The smart readiness score per *smart readiness functionality* (f) is obtained as the weighted addition of the scores per *impact criterion* as per Equation 6.

$$SR_{f} = \sum_{ic=1}^{M} W_{f}(ic) \cdot SR_{ic}$$

Equation 6.

Finally, the total smart readiness score is obtained as the weighted addition of the scores per *smart readiness functionality,* as in Equation 7.

$$SR = \sum W_f \cdot SR_f \qquad \textbf{Equation 7.}$$

The contextual adaptations outlined in Section 2.2.1 may have a significant impact on the calculation process. The total smart readiness score corresponds to a smart readiness rating (SR_{class}), expressed based on seven smart readiness classes; namely, 90-100%; 80-90%; 65-80%; 50-65%; 35-50%; 20-35%; <20%, ranging from highest to lowest smart readiness.

2.4.1.2 Output data

The results of the SRI assessment are included in the SRI certificate, as indicated in sub-Section 2.3.1. The output data of the calculations is depicted in **Table 2**.

Table 2: SRI assessment output data

Description	Symbol	Unit
Total smart readiness score	SR	%
Total smart readiness rating	SR_{class}	-
Smart readiness score, per key functionality Energy performance and operation Response to user needs Energy flexibility	SR_f	%
Smart readiness score, per impact criterion Energy efficiency Maintenance and fault prediction Comfort Convenience Health, well-being, and accessibility Information to occupants Energy flexibility and storage	SR_{ic}	%
Smart readiness score, per technical domain Heating Domestic hot water Cooling Ventilation Lighting Dynamic building envelope Electricity Electric vehicle charging Monitoring and control	SR_d	%

2.5 SmartLivingEPC SRI calculation

The SRI calculation within the SmartLivingEPC framework corresponds to UC3.2 as defined in SmartLivingEPC's Deliverable 1.2. The process consists virtually of the following:

1. The assessor logs into the **Web Platform**.
2. The required information for the calculation of the SRI is requested from the CIEM.
3. The available information retrieved fills as much as possible the input data needed.
4. The assessor validates the retrieved information and manually inputs the missing data.
5. The assessment is run through the Asset Rating Engine/SRI component.
6. The output of the assessment is stored both in the CIEM and the Digital Building Logbook.

In a basic situation the CIEM does not have any of the required input data for the SRI and the assessor is expected to manually provide all the inputs. Thus, the input data outlined in section 2.4.1 shall be provided.

The input data regarding *assessor information*, the *methodology selection*, and the *assessment date* is trivial and therefore not of interest in this section. The *general building information* contains items which correlate with overarching preparation steps for energy performance assessments in buildings, so it is considered as a familiar topic for assessors. The definition of applicability of *technical domain*'s *smart ready service* and main *functionality level* is the core calculation methodology for the SRI. Consequently, it is paramount that prospective SRI assessors are familiarised with the technological enablers of each *smart ready service* and *functionality levels*.

In a more favourable situation, an EPC or an inspection of heating, air-conditioning and combined heating or air-conditioning and ventilation systems has already taken place for the building or building unit before the SRI is attempted. Therefore, some of the input data needed for the SRI may be already in the CIEM, as it may have been requested for such complementary EPB assessments.

Ultimately, a digital model of the building or building unit of which the SRI is to be assessed may exist. In that case, SRI input data is subject to be retrieved and validated from a BIM model (as defined in UC1.1 in Deliverable 1.2).

The remainder of the subchapter is structured as follows. In section 2.5.1, a detailed overview of how each of the BAC and TBM functions as defined by the EPB Standards correlates with the *technical domains*, *smart ready services,* and *functionality levels*, as defined by the default SRI assessment, is presented. In section 2.5.2, the synergies regarding input data needs between the SRI and complementary EPB assessments is presented. Lastly, in section 2.5.3, the extraction of SRI input data from IFC literacy is discussed.

2.5.1 SRI vis-à-vis technological enablers

The *functionality levels* within each *technical domain*'s *smart-ready service* considered in the SRI assessment are enabled by certain smart-ready technologies. These technological enablers, as defined in the SRI calculation methodology, shall be installed, or foreseen to be installed, in the assessed building or building unit. Thus, identifying the presence of certain building elements related to the *technical domain's smart-ready services* is a crucial task when assessing the SRI. As indicated in the first technical study by the SRI Support Team many of the *smart ready services* (and related *functionality levels*) were sourced from standards related to smart buildings; notably EN 15323, superseded in December 2021 by EN ISO 52120 [9].

EN ISO 52120-1:2021 provides a "structured list of control, building automation and technical building management functions which contribute to the energy performance of buildings; functions have been categorised and structured according to building disciplines and building automation and control". Building, automation, and control (BAC) provide effective control functions for any building energy system leading to improve operational and energy efficiencies. Technical building management (TBM) provides information about operation, maintenance, services, and management of buildings, especially for energy management. Hence, the SRI technological enablers generally correlate with BAC and TBM functions as defined in European standards. This is particularly true for the *energy performance and operation* impact criteria.

Next, a detailed overview of how each of the BAC and TBM functions, as defined by the existing standards, correlates with the *technical domains*, *smart ready services,* and *functionality levels*, as defined by the SRI default assessment, is presented. Applicability considerations of the *technical domains* and *smart ready services*, when relevant, are included. Also, when possible, the BAC functions are detailed following the BAC function description from EN ISO 16484-3 [10] with a view to facilitate drafting of project specifications at the design phase for improving the *smartness* as well as for identifying the applicable *smart-ready services* and *functionality levels* of a building or building unit. In addition, when available, examples of vendor-unspecific technological enablers are indicated for each *technical domain*'s *smart ready service* included in the assessment.

2.5.1.1 *Introduction*

The BAC functions to be used are generally based on the energy demand-supply model for a building, as illustrated in Figure 4.

Rooms serve as the locus of energy demand, with generation supplying the requisite media in accordance with the energy demand, strategically aimed at minimizing distribution losses. Consequently, the orchestration of building automation and control functions commences at the room level, progressing hierarchically through distribution up to the generation sub-system. The most important control strategy is demand-oriented control in which, when comfort is reached in the emission area, the controller from therein informs the distribution controller to stop distributing energy.

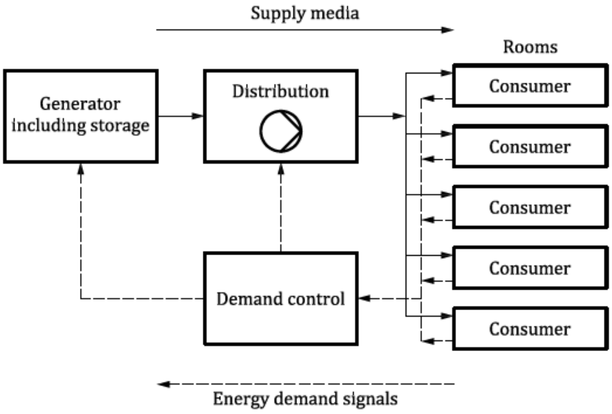

Figure 4. Energy demand-supply model. Reproduced from [11].

Then, such controller sends a message to the one overseeing the storage to either store the energy or to send the message to the generation controller to stop generating more energy. Therefore, in general, BAC functions capable of applying the control function closer to the emission area shall represent a higher *functionality level* than those operating upstream the energy flow.

2.5.1.2 *Heating*

In a generic space heating system (Figure 5) the BAC and TBM functions can be outlined as identified in Table 3. The alphanumeric codes depicted in the figure refer to those from the default *smart ready service catalogue*. Those in bold correspond to the BAC and/or TBM functions which are included in the current version of the default *smart service catalogue* of the SRI assessment but are not covered by European standards.

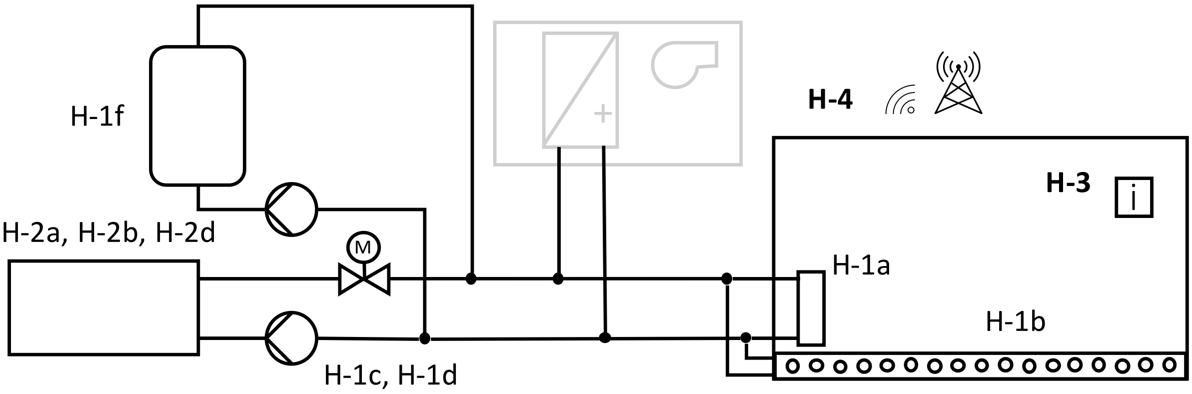

Figure 5. Space heating system. Adapted from [9].

As indicated in the EN ISO 52120-1 standard, air side system control of HVAC shall be treated as ventilation and air-conditioning control, separately from heat generators, chillers, terminal units and water and refrigerant side controls. Therefore, they are depicted in light gray in the schematic above.

Table 3. Standardised BAC and TBM functions. SRI's Heating technical domain.

BAC and TBM function description, adapted from European standards		SRI assessment (v4.5)		BAC function description as in EN 16484-3	Example of vendor-neutral technology enabler
		Smart ready service code	*Functionality level*		
Emission control	The **objective** is to adjust the heat delivered at room level, preferably by applying the control function to the heat emitter. *All heat emitters included, except for TABS.*	**H-1a**	-		
Control functions	No automatic control of the room temperature.		0	-	Manual on-off heat emitter control, without any automatic control of the room temperature. The emitter is manually controlled through human operation of the actuators linked to the equipment.
	Only central automatic control, indirectly controlling one or more rooms by acting either on the distribution or on the generation without consideration of local demand of different rooms. *The heat delivered at the room is adjusted by a control function non-exclusive of the room to be controlled. Thus, it assumes similar thermal demand in different parts of the building.*		1	-[a]	Thermostatic valve conforming to EN 215 [12] or non-communicating electronic controller for example conforming to EN 12098-1 [13] or EN 12098-3 [14], both at plant level.
	Individual automatic room control. *The heat delivered at the room is adjusted by a control function exclusive of the room to be controlled without any information exchange outside the controlled room.*		2	-[a] *The individual control may be combined with scheduler programs providing different operating modes.*	Thermostatic valve conforming to EN 215 [12] or non-communicating electronic controller, for example conforming to EN 15500-1 [15] at room level.
	Individual room control with communication between controllers and BACS. *The heat delivered at the room is adjusted by a control function exclusive of the room to be controlled with information exchange outside the controlled room.*		3	-[a]	Like the previous, but with communication functions. As indicated in [16], the communication functions shall enable exchange of setpoints, demand and other status information. To obtain energy demand for further use to control distribution and generators, keeping run time at minimum and setpoints optimal
	Individual room control with communication between controllers and BACS and demand detection-control. *The heat delivered at the room is adjusted by a control function, coupled with occupancy detection, exclusive of the room to be controlled with information exchange outside the controlled room.*		4	-[a]	Like the previous, but with occupancy sensing control functions. For example, as applied in [17] [18]. As indicated in [16], the occupancy sensing control function is usually not applied to any slow reacting heat emission systems with relevant thermal mass (e.g., floor heating, wall heating, etc.).
Emission control	The **objective** is to adjust the heat delivered at room level, preferably by applying the control function to the heat emitter. *Only applicable for TABS.*	**H-1b**	-		
Control functions	No automatic control of the room temperature.		0	-	Manual on-off heat emitter control, without any automatic control of the room temperature. The emitter is manually controlled through human operation of the actuators linked to the equipment.
	Central automatic control. *The heat delivered at the service area is adjusted by a control function non-exclusive of the room to be controlled, possibly based on the filtered outside temperature (e.g., the average of the previous 24h).*		1	-[a]	Outside temperature compensated supply water temperature control. For example, as applied in [19].
	Advanced central automatic control. *The heat delivered at the service area is adjusted by a control function non-exclusive of the room to be controlled, aiming to maintain the indoor temperature within the comfort range in all zones within the service area while minimising the energy demand (i.e., maintaining the indoor temperature as low as possible).*		2	-[a]	Room temperature feedback control. For example, as applied in [19].
	Advanced central automatic control with intermittent operation.		3	-[a]	

	The heat delivered at the service area is adjusted by a control function non-exclusive of the room to be controlled, aiming to maintain the indoor temperature within the comfort range while minimising the energy demand. Additionally, the circulating pump is switched off regularly to save electrical energy. Advanced central automatic control with room temperature feedback control. *The heat delivered at the service area is adjusted by a control function non-exclusive of the room to be controlled, aiming to maintain the indoor temperature within the comfort range while minimising the energy demand. Additionally, the supply water temperature is corrected to adapt to non-predictable day-to-day variation of the heat gain.*				Like the previous, but periodically switching off the circulation pump and/or correcting the supply water temperature to non-predictable variations of the heat gain. For example, pulse width modulation control as applied in [19].
Distribution temperature control	The **objective** is to reduce the distribution fluid temperature, either on the supply or return. *Not applicable in case of independent heating devices (e.g., electrical radiator, stove). Similar function can be applied to the control of direct electric heating networks.*	**H-1c**	-		
Control functions	No automatic control.		0	-	-
	Outside temperature compensated control. *The supply temperature is adjusted based on the outside temperature.*		1	-[a]	Outside temperature compensated supply water temperature control. Electronic controller for example conforming to EN 12098-1 [13] or EN 12098-3 [14].
	Demand-based control. *The supply temperature is adjusted based on the indoor temperature measurements.*		2	-[a]	Room temperature feedback control. Electronic controller, for example conforming to EN 15500-1 [15] at room level.
Distribution pumps control	The **objective** is to reduce the auxiliary energy demand of the pumps, by applying the control function to the pumps. The controlled pumps can be installed at different levels in the network. *Only applicable for hydronic heating systems.*	**H-1d**	-		
Control functions	No automatic control, only protection functions.		0	-[a]	-
	On/off control. *Pumps are automatically switched on and off. When on, they run at maximum speed.*		1	-[a]	As per the technical specifications of the distribution pumps. Single-stage pump(s) have a fixed number of impellers. The pump curve can't actively be modified.
	Multi-stage control. *Pumps are automatically switched on and off. When on, they may run at different speed based on fixed multistep.*		2	-[a]	As per the technical specifications of the distribution pumps. Multi-stage pump(s) have a series of impellers, each housed in its own stage, to gradually increase the pressure of the fluid as it passes through the pump. Depending on the required pressure or flow rate, the number of active stages is adjusted, modifying the pump curve.
	Variable speed pump control. *Pumps are automatically switched on and off. When on, they may run at different speed based on constant or variable Δp.*		3	-[a]	As per the technical specifications of the distribution pumps. Variable speed pump(s), also known as variable frequency drive, enable to alter the speed of the pump motor to control the flow rate and pressure of the pumped fluid.
	Advanced variable speed pump control. *Pumps are automatically switched on and off. When on, they may run at different speed based on variable Δp following an external demand signal.*		4	-[a]	Like the previous, but with communication capacities. As indicated in [20], the external demand signal may be based on e.g., hydraulic requirements, temperature difference, energy optimization or a demand evaluation to reduce the auxiliary energy demand of the pumps.
Generation control	The **objective** is to lower the generator temperature, by applying the control function to the heat generator. *Only for combustion and district heating generators.*	**H-2a**	-		
Contro	Constant temperature control.		0	-[a]	-

	The generator temperature is kept at a predefined constant temperature within a defined control deviation.				
	Variable temperature control depending on the outside temperature. *The generator temperature is modified based on the outside temperature. There is direct compensation, reducing the supply flow temperature with increasing ambient temperature.*		1	-[a] *When coupling it with generators providing both heating and hot water, interlocks are required to override the control when there is demand of domestic hot water to avoid the risk of Legionella.*	Non-communicating electronic controller for example conforming to EN 12098-1 [21] or EN 12098-3 [22], both at generator level. This is particularly easy to apply in boilers. *Care should be taken to avoid the direct compensation control to force the generator to provide water below the minimum temperature needed for any given operation mode (e.g., sanitary hot water production, fan coils, air-handling units, etc.). Also, in installations with large distribution systems, as there may be a too slow response.*
	Variable temperature control depending on the load. *The generator temperature is modified based on the load of the system.*		2	-[a]	Non-communicating electronic controller for example conforming to EN 12098-1 [21] or EN 12098-3 [22], both at generator level. The supply temperature may be characterised depending on supply water temperature setpoint.
Generation control	The **objective** is to maximise the heat generator efficiency, by applying the control function to the heat generator. *Only for heat pumps.*	**H-2b**	-		
Control functions	On/off control. *The compressor(s) is automatically switched on and off. When on, it runs at maximum speed.*		0	-[a]	As per the technical specifications of the heat pumps. The generator always tries to produce the maximum allowed temperature.
	Multi-stage control. *The compressor(s) is automatically switched on and off. When on, it may run at different speed based on fixed multistep.*		1	-[a]	As per the technical specifications of the heat pumps. As indicated in [16], for example depending on the load or demand the on/off several compressors could be actioned.
	Variable control. *The compressor(s) is automatically switched on and off. When on, it may run at different speed based on the load or demand.*		2	-[a]	As per the technical specifications of the heat pumps. As indicated in [16], for example depending on the load or demand the hot gas bypass or inverter frequency control could be actioned.
	Advanced variable control. *The compressor(s) is automatically switched on and off. When on, it may run at different speed based on the load or demand. In addition, it can also respond to signals from the grid.*		3	-[a]	Like the previous, but with communication capacities.
Sequencing of different generators	The **objective** is to prioritise the operation of various heat generators, by applying the control function to one or several eat generators. This control function only applies to a system with a set of different heat generators.	**H-2d**	-	This *smart-ready service* is related to function 4.3 "Switch over" in the BAC function list. It is to be combined with (e.g., time dependent switching, runtime totalisation limit, interlocks, and motor control, as required.	
Control functions	Priorities are only based on running time. *Each generator is assigned a priority seeking to equalise running times.*		0	-[a]	The nature of the control algorithm would need to be facilitated. The priority of each generator is modified periodically seeking to equalise running times to optimise maintenance. The priority does not change automatically.
	Control according to fixed priority. *Each generator is assigned an arbitrary fixed priority.*		1	-[a]	The nature of the control algorithm would need to be facilitated. A given generator in the priority list runs only if the generator(s) with higher priority run at full load. The priority does not change automatically.
	Control according to dynamic priority list.		2	-[a]	The nature of the control algorithm would need to be facilitated.

	Each generator is assigned a dynamic priority based on load, considering the instantaneous capacities of the generators.				A given generator in the priority list runs only if the generator(s) with higher priority run according to the dynamic rules (e.g., load, capacities, etc.). The priority does change automatically based on the overall system status, while avoiding too short cycle times.
	Control according to prediction based dynamic priority list. *Each generator is assigned a dynamic priority based on load, considering the instantaneous efficiencies of the generators.*		3	-[a]	The nature of the control algorithm would need to be facilitated. A given generator in the priority list runs only if the generator(s) with higher priority run according to the instantaneous efficiency. The priority does change automatically based on the overall system status, while avoiding too short cycle times.
	Control according to prediction based dynamic priority list. Also, control based on external signals from the grid. *Each generator is assigned a dynamic priority based on load, considering the instantaneous efficiencies of the generators and external grid signals.*		4	-[a]	The nature of the control algorithm would need to be facilitated. Like the previous, but with communication capacities. For example, establishing the dynamic priority based on timely energy price.
TES charging control	The **objective** is to manage the charging of thermal energy storage units with a view to reducing thermal losses. *TABS are not considered TES.*	**H-1f**	-		
Control functions	Continuous storage operation. *The TES charging is enabled all the time.*		0	-[a]	As per the technical specifications of the TES. Thermal energy storage is enabled for charging all the time independently of the expected load.
	Time-scheduled control. *The TES charging is enabled during the time defined by one or several schedules.*		1	This function related to function 6.4 “Time schedule control” in the BAC function list.	As per the technical specifications of the TES. Thermal energy storage is enabled for charging at certain times.
	Load-prediction control. *The TES charging is enabled all the time, but the state of charge is reduced when not needed based on load prediction.*		2	-[a]	As per the technical specifications of the TES. Thermal energy storage is enabled for charging all the time dependent of the expected load. Thus, the state of charge is reduced when storage is not needed.
	Flexible control through grid signals. *The TES charging is enabled all the time, but the charging is prioritised according to received signals from the grid.*		3	-[a]	As per the technical specifications of the TES. For example, as indicated in [23], in response to dynamic pricing or tariffs, price-responsive demand bidding, contractually obligated and voluntary curtailment, and direct load control/cycling.
Information to occupants and facility managers	The **objective** is to inform building occupants and facility managers on the heating system’s performance.	**H-3**	-		
Control functions	None.		0		-
	Central or remote reporting of current performance KPIs.		1	-[a]	As per the technical specifications of the information system.
	Central or remote reporting of current performance KPIs and historical data.		2	-[a]	As per the technical specifications of the information system.
	Central or remote reporting of performance KPIs, historical data and evaluation including forecasting and/or benchmarking.		3	-[a]	As per the technical specifications of the information system.
	Central or remote reporting of performance KPIs, historical data and evaluation including forecasting and/or benchmarking. Also including predictive management and fault detection.		4	-[a]	As per the technical specifications of the information system.
Flexibility and grid interaction	The **objective** is to provide flexibility services to or interact with the electricity grid, by applying the control function to one or several sub-systems or components of the heating system. The impact on the indoor comfort conditions shall be minimised.	**H-4**	-		

Control functions	None.		0	-	
	Scheduled operation of heating system. *The operation of the heating system may be scheduled, prioritising certain times, which may indirectly correlate with external grid signals.*		1	This function related to function 6.4 “Time schedule control” in the BAC function list.	The nature of the control algorithm would need to be facilitated. The availability of the system is enabled at certain times.
	Self-learning control of heating system. *The operation of the heating system may serve as parametrisation of the thermal response of the building or building unit, such information may be leveraged for adapting the operation of the heating system to external grid signals.*		2	-[a]	The nature of the control algorithm would need to be facilitated.
	Flexible control through grid signals. *The operation of the heating system may be modified based on external grid signals.*		3	-[a]	The nature of the control algorithm would need to be facilitated. For example, as indicated in [23], in response to dynamic pricing or tariffs, price-responsive demand bidding, contractually obligated and voluntary curtailment, and direct load control/cycling.
	Optimised control based on local predictions and grid signals. *The operation of the heating system may be modified based on external grid signals and predicted system performance.*		4	-[a]	The nature of the control algorithm would need to be facilitated. Like the previous but including predictions.

[a] The function is described by one row of the ISO 16484-3 BAC function list and a control schematic. Additional remarks ought to be included, if needed.

2.5.1.3 Domestic hot water

In a generic domestic hot water heating system (Figure 6) the BAC and TBM functions can be outlined as in Table 4. The alphanumeric codes depicted in the figure refer to those from the default *smart ready service catalogue*. Those in bold correspond to the BAC and/or TBM functions which are included in the current version of the default *smart service catalogue* of the SRI assessment but are not covered by European standards.

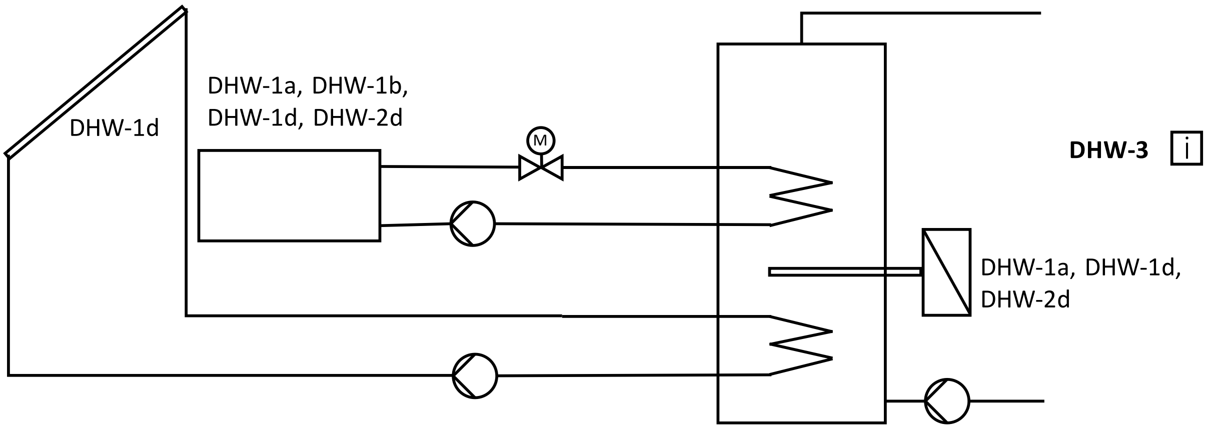

Figure 6. Domestic hot water heating system. Adapted from [9].

Table 4. Standardised BAC and TBM functions. SRI's DHW technical domain.

BAC and TBM function description, adapted from European standards		SRI assessment (v4.5)		BAC function description as in EN 16484-3	Example of vendor-neutral technology enabler
		Smart ready service	Functionality level		
Storage control	The **objective** is to lower the mean DHW storage temperature, preferably by applying the control function to the DHW storage charging. *Direct electric heating and integrated electric heat pump included.*	**DHW-1a**	-		
Control functions	Automatic on/off control.		0	-[a]	The DHW storage temperature is continuously kept at a predefined constant value within a defined control deviation.
	Automatic on/off control and scheduled charging enable. *The DHW storage charging is enabled at dedicated times, blocking the charging in the complementary time frames.*		1	This function related to function 6.4 "Time schedule control" in the BAC function list.	As per the technical specifications of the DHW storage charging unit. Thermal energy storage is enabled for charging at certain times.
	Automatic on/off control, scheduled charging enabler, and multi-sensor storage management. *The DHW storage charging is enabled at dedicated times, blocking the charging in the complementary time frames. In addition, the multi sensing detection identifies the remaining heat capacity of the buffer, avoiding early recharging.*		2	-[a]	As per the technical specifications of the DHW storage charging unit. Like the previous but considering the remaining heat capacity of the buffer to reduce the recharge cycles.
	Automatic control based on local availability of renewables or information from electricity grid. *The DHW storage charging is prioritised according to received signals from the grid.*		3	-[a]	As per the technical specifications of the DHW storage charging unit. Thermal energy storage is prioritised based on signals from the grid.
Storage control	The **objective** is to lower the mean DHW storage temperature, preferably by applying the control function to the DHW storage charging. *Hot water generation.*	**DHW-1b**	-	-	-
Control functions	Automatic on/off control.		0	-[a]	The DHW storage temperature is continuously kept at a predefined constant value within a defined control deviation.
	Automatic on/off control and scheduled charging enable. *The DHW storage charging is enabled at dedicated times, blocking the charging in the complementary time frames.*		1	-[a]	As per the technical specifications of the DHW storage charging unit. Thermal energy storage is enabled for charging at certain times.
	Automatic on/off control, scheduled charging enabler, and demand-based supply temperature control or multi-sensor storage management. *The DHW storage charging is enabled at dedicated times, blocking the charging in the complementary time frames. In addition, the multi sensing detection identifies the remaining heat capacity of the buffer, avoiding early recharging. Alternatively, supply water temperature information is provided to the heat generator.*		2	-[a]	As per the technical specifications of the DHW storage charging unit. Like the previous but considering the remaining heat capacity of the buffer to reduce the recharge cycles. Alternatively, considers demand information to control the storage temperature.
	Automatic control based on external signals (e.g., district heating network, etc.).		3	-[a]	As per the technical specifications of the DHW storage charging unit. For example, as indicated in [23], in response to dynamic pricing or tariffs, price-responsive demand bidding, contractually obligated and voluntary curtailment, and direct load control/cycling.

Storage control	The **objective** is to maximise the DHW storage charging via solar collectors, preferably by applying the control function to the DHW storage charging. *Solar collectors with supplementary DHW generation.*	**DHW-1d**	-	This *smart-ready service* is related to function 4.3 “Switch over” in the BAC function list. It is to be combined with (e.g., time dependent switching, runtime totalisation limit, interlocks, and motor control, as required.	-
Control functions	Manual selection control.		0	-[a]	
	Automatic control of solar storage charge (priority 1) and supplementary storage charge (priority 2). *The DHW storage charging is always enabled, preferring the solar to the supplementary DHW storage charging.*		1	-[a]	The nature of the control algorithm would need to be facilitated. The supplementary storage charge runs only if the solar charge is at full load. The priority does not change automatically.
	Automatic control of solar storage charge (priority 1) and supplementary storage charge (priority 2). Also, demand-based supply temperature control or multi-sensor storage management. *The DHW storage charging is always enabled, preferring the solar to the supplementary DHW storage charging. In addition, the multi sensing detection identifies the remaining heat capacity of the buffer, avoiding early recharging. Alternatively, supply water temperature information is provided to the heat generator.*		2	-[a]	As per the technical specifications of the DHW storage charging unit. Like the previous but considering the remaining heat capacity of the buffer to reduce the recharge cycles. Alternatively, considering supply demand information to control the storage temperature.
	Automatic control of solar storage charge (priority 1) and supplementary storage charge (priority 2). Also, demand-based supply and return temperature control and multi-sensor storage management. *The DHW storage charging is always enabled, preferring the solar to the supplementary DHW storage charging. In addition, the multi sensing detection identifies the remaining heat capacity of the buffer, avoiding early recharging. Also, supply and return water temperature information is provided to the heat generator.*		3	-[a]	As per the technical specifications of the DHW storage charging unit. Like the previous but also considering supply and return demand information to control the storage temperature.
Sequencing of different generators	The **objective** is to prioritise the operation of various heat generators, by applying the control function to one or several heat generators. This control function only applies to a system with a set of different heat generators without considering solar collectors.	**DHW-2b**	-	This *smart-ready service* is related to function 4.3 “Switch over” in the BAC function list. It is to be combined with (e.g., time dependent switching, runtime totalisation limit, interlocks, and motor control, as required.	-
Control functions	Priorities are only based on running time. *Each generator is assigned a priority seeking to equalise running times.*		0	-[a]	The nature of the control algorithm would need to be facilitated. The priority of each generator is modified periodically seeking to equalise running times to optimise maintenance. The priority does not change automatically.
	Control according to fixed priority. *Each generator is assigned an arbitrary fixed priority.*		1	-[a]	The nature of the control algorithm would need to be facilitated. A given generator in the priority list runs only if the generator(s) with higher priority run at full load. The priority does not change automatically.
	Control according to dynamic priority list. *Each generator is assigned a dynamic priority based on load, considering the instantaneous capacities of the generators.*		2	-[a]	The nature of the control algorithm would need to be facilitated. A given generator in the priority list runs only if the generator(s) with higher priority run according to the dynamic rules (e.g., load, capacities, etc.). The priority

					does change automatically based on the overall system status, while avoiding too short cycle times.
	Control according to prediction based dynamic priority list. *Each generator is assigned a dynamic priority based on load, considering the instantaneous efficiencies of the generators.*		3	-[a]	The nature of the control algorithm would need to be facilitated. A given generator in the priority list runs only if the generator(s) with higher priority run according to the instantaneous efficiency. The priority does change automatically based on the overall system status, while avoiding too short cycle times.
	Control according to prediction based dynamic priority list. Also, control based on external signals from the grid. *Each generator is assigned a dynamic priority based on load, considering the instantaneous efficiencies of the generators and external grid signals.*		4	-[a]	The nature of the control algorithm would need to be facilitated. Like the previous, but with communication capacities. For example, establishing the dynamic priority based on timely energy price.
Information to occupants and facility managers	The **objective** is to inform building occupants and facility managers on the domestic hot water system's performance.	**DHW-3**	-	-	-
Control functions	None.		0	-[a]	-
	Central or remote reporting of current performance KPIs.		1	-[a]	As per the technical specifications of the information system.
	Central or remote reporting of current performance KPIs and historical data.		2	-[a]	As per the technical specifications of the information system.
	Central or remote reporting of performance KPIs, historical data and evaluation including forecasting and/or benchmarking		3	-[a]	As per the technical specifications of the information system.
	Central or remote reporting of performance KPIs, historical data and evaluation including forecasting and/or benchmarking. Also including predictive management and fault detection		4	-[a]	As per the technical specifications of the information system.

[a] The function is described by one row of the ISO 16484-3 BAC function list and a control schematic. Additional remarks ought to be included, if needed.

2.5.1.4 Cooling

In a generic space cooling system (Figure 7) the BAC and TBM functions can be outlined as in Table 5. The numbers depicted in the figure refer to those in the first column of the table. The alphanumeric codes depicted in the figure refer to those from the default *smart ready service catalogue*. Those in bold correspond to the BAC and/or TBM functions which are included in the current version of the default *smart service catalogue* of the SRI assessment but are not covered by European standards.

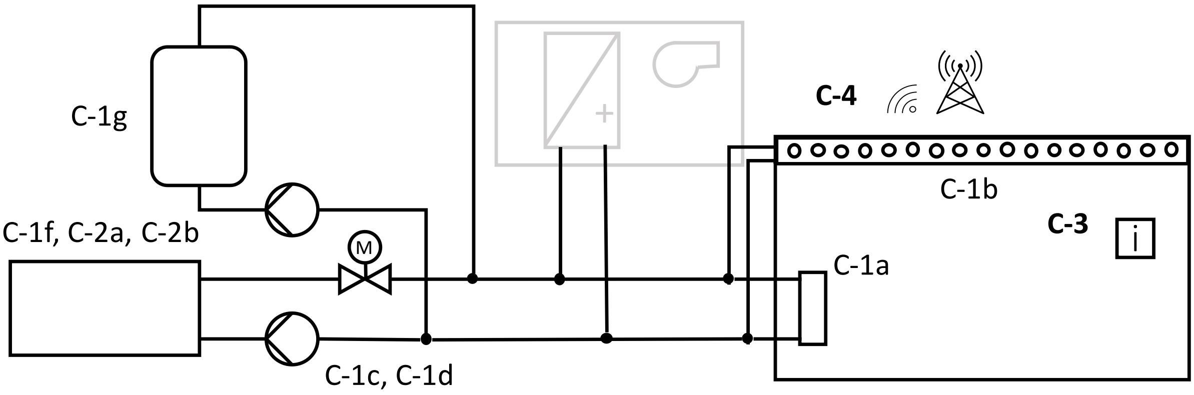

Figure 7. Space cooling system. Adapted from[9].

As indicated in the EN ISO 52120-1 standard, air side system control of HVAC shall be treated as ventilation and air-conditioning control, separately from heat generators, chillers, terminal units and water and refrigerant side controls. Therefore, they are depicted in light gray in the schematic above.

Table 5. Standardised BAC and TBM functions. SRI's Cooling technical domain.

BAC and TBM function description, adapted from European standards		SRI assessment (v4.5)		BAC function description as in EN 16484-3	Example of vendor-neutral technology or device
		Smart ready service code	*Functionality level*		
Emission control	The **objective** is to adjust the heat removed at room level, preferably by applying the control function to the cool emitter. *All chill emitters included, except for TABS.*	**C-1a**	-		
Control functions	No automatic control of the room temperature.		0	-	Manual on-off heat emitter control, without any automatic control of the room temperature. The emitter is manually controlled through human operation of the actuators linked to the equipment.
	Only central automatic control, indirectly controlling one or more rooms by acting either on the distribution or on the generation without consideration of local demand of different rooms. *The heat removed at the room is adjusted by a control function non-exclusive of the room to be controlled. Thus, it assumes similar thermal demand in different parts of the building.*		1	-[a]	Thermostatic valve conforming to EN 215 [12] or non-communicating electronic controller for example conforming to EN 12098-1 [13] or EN 12098-3 [14], both at plant level.
	Individual automatic room control without communication between controllers and BACS. *The heat removed at the room is adjusted by a control function exclusive of the room to be controlled without any information exchange outside the controlled room.*		2	-[a]	Thermostatic valve conforming to EN 215 [12] or non-communicating electronic controller, for example conforming to EN 15500-1 [15] at room level.
	Individual room control with communication between controllers and BACS. *The heat removed at the room is adjusted by a control function exclusive of the room to be controlled with information exchange outside the controlled room.*		3	-[a]	Like the previous, but with communication functions. As indicated in [16], the communication functions shall enable exchange of setpoints, demand and other status information. To obtain energy demand for further use to control distribution and generators, keeping run time at minimum and setpoints optimal
	Individual room control with communication between controllers and BACS and demand detection-control. *The heat removed at the room is adjusted by a control function, coupled with occupancy detection, exclusive of the room to be controlled with information exchange outside the controlled room.*		4	-[a]	Like the previous, but with occupancy sensing control functions. For example, as applied in [17] [18]. As indicated in [16], the occupancy sensing control function is usually not applied to any slow reacting chill emission systems with relevant thermal mass (e.g., chilled beam, etc.).
Emission control	The **objective** is to adjust the heat removed at room level, preferably by applying the control function to the cool emitter. *Only applicable for TABS.*	**C-1b**	-		
Control functions	No automatic control of the room temperature.		0	-	Manual on-off heat emitter control, without any automatic control of the room temperature. The emitter is manually controlled through human operation of the actuators linked to the equipment.
	Central automatic control. *The heat removed at the service area is adjusted by a control function non-exclusive of the room to be controlled, possibly based on the filtered outside temperature (e.g., the average of the previous 24h).*		1	-[a]	Outside temperature compensated supply water temperature control. For example, as applied in [19].
	Advanced central automatic control. *The heat removed at the service area is adjusted by a control function non-exclusive of the room to be controlled, aiming to maintain the indoor temperature within the comfort range*		2	-[a]	Room temperature feedback control. For example, as applied in [19].

	in all zones within the service area while minimising the energy demand (i.e., maintaining the indoor temperature as high as possible).				
	Advanced central automatic control with intermittent operation. *The heat removed at the service area is adjusted by a control function non-exclusive of the room to be controlled, aiming to maintain the indoor temperature within the comfort range while minimising the energy demand. Additionally, the circulating pump is switched off regularly to save electrical energy.*		3	-[a]	Like the previous, but periodically switching off the circulation pump and/or correcting the supply water temperature to non-predictable variations of the heat gain. For example, pulse width modulation control as applied in [19].
	Advanced central automatic control with room temperature feedback control. *The heat removed at the service area is adjusted by a control function non-exclusive of the room to be controlled, aiming to maintain the indoor temperature within the comfort range while minimising the energy demand. Additionally, the supply water temperature is corrected to adapt to non-predictable day-to-day variation of the heat gain.*				
Distribution temperature control	The **objective** is to adjust the distribution water temperature, preferably by applying the control function to the cool generator. *Only applicable for hydronic cooling systems.*	**C-1c**	-		
Control functions	No automatic control.		0	-	-
	Outside temperature compensated control. *The mean distributed water temperature is increased based on outside temperature compensation.*		1	-[a]	Outside temperature compensated supply water temperature control. Electronic controller for example conforming to EN 12098-1 [13] or EN 12098-3 [14].
	Demand-based control. *The mean distributed water temperature is increased based on indoor temperature measurements.*		2	-[a]	Room temperature feedback control. Electronic controller, for example conforming to EN 15500-1 [15] at room level.
Distribution pumps control	The **objective** is to reduce the auxiliary energy demand of the pumps, by applying the control function to the pumps. The controlled pumps can be installed at different levels in the network. *Only applicable for hydronic cooling systems.*	**C-1d**	-		
Control functions	No automatic control, only protection functions.		0	-[a]	-
	On/off control. *Pumps are automatically switched on and off. When on, they run at maximum speed.*		1	-[a]	As per the technical specifications of the distribution pumps. Single-stage pump(s) have a fixed number of impellers. The pump curve can't actively be modified.
	Multi-stage control. *Pumps are automatically switched on and off. When on, they may run at different speed based on fixed multistep.*		2	-[a]	As per the technical specifications of the distribution pumps. Multi-stage pump(s) have a series of impellers, each housed in its own stage, to gradually increase the pressure of the fluid as it passes through the pump. Depending on the required pressure or flow rate, the number of active stages is adjusted, modifying the pump curve.
	Variable speed pump control. *Pumps are automatically switched on and off. When on, they may run at different speed based on constant or variable Δp.*		3	-[a]	As per the technical specifications of the distribution pumps. Variable speed pump(s), also known as variable frequency drive, enable to alter the speed of the pump motor to control the flow rate and pressure of the pumped fluid.
	Advanced variable speed pump control. *Pumps are automatically switched on and off. When on, they may run at different speed based on variable Δp following an external demand signal.*		4	-[a]	Like the previous, but with communication capacities. As indicated in [20], the external demand signal may be based on e.g., hydraulic requirements, temperature

					difference, energy optimization or a demand evaluation to reduce the auxiliary energy demand of the pumps.
Interlock between heating and cooling control of emission and/or distribution	The **objective** is to avoid at the same time heating and cooling in the same room. It depends on the system principle.	**C-1f**	-		
Control functions	No interlock. *The two systems are controlled independently.*		0	-[a]	-
	Partial interlock. *The possibility of simultaneous heating and cooling is minimised.*		1	-[a]	As indicated in [16], when air conditioning is serving many rooms with one supply air temperature, but emission is controlled at room level, the setpoints for the centralised air supply may be changed towards lowering the interlock.
	Total interlock. *The control function enables to guarantee that there will be no simultaneous heating and cooling.*		2	-[a]	As indicated in [16], either hydraulic mechanical construction or total switchover on supply level impede simultaneous heating and cooling.
Generation control	The **objective** is to maximise the heat generator efficiency, by applying the control function to the cool generator. *Only for heat pumps.*	**C-2a**	-		
Control functions	On/off control. *The compressor(s) is automatically switched on and off. When on, it runs at maximum speed.*		0	-[a]	As per the technical specifications of the heat pumps. The generator always tries to produce the maximum allowed temperature.
	Multi-stage control. *The compressor(s) is automatically switched on and off. When on, it may run at different speed based on fixed multistep.*		1	-[a]	As per the technical specifications of the heat pumps. As indicated in [16], for example depending on the load or demand the on/off several compressors could be actioned.
	Variable control. *The compressor(s) is automatically switched on and off. When on, it may run at different speed based on the load or demand.*		2	-[a]	As per the technical specifications of the heat pumps. As indicated in [16], for example depending on the load or demand the hot gas bypass or inverter frequency control could be actioned.
	Advanced variable control. *The compressor(s) is automatically switched on and off. When on, it may run at different speed based on the load or demand, and external signals from the grid.*		3	-[a]	Like the previous, but with communication capacities.
Sequencing of different generators	The **objective** is to prioritise the operation of various cool generators, by applying the control function to one or several cool generators. This control function only applies to a system with a set of different heat generators.	**C-2b**	-	This *smart-ready service* is related to function 4.3 "Switch over" in the BAC function list. It is to be combined with (e.g., time dependent switching, runtime totalisation limit, interlocks, and motor control, as required.	
Control functions	Priorities are only based on running time. *Each generator is assigned a priority seeking to equalise running times.*		0	-[a]	The nature of the control algorithm would need to be facilitated. The priority of each generator is modified periodically seeking to equalise running times to optimise maintenance. The priority does not change automatically.

	Control according to fixed priority. *Each generator is assigned an arbitrary fixed priority.*		1	-[a]	The nature of the control algorithm would need to be facilitated. A given generator in the priority list runs only if the generator(s) with higher priority run at full load. The priority does not change automatically.
	Control according to dynamic priority list. *Each generator is assigned a dynamic priority based on load, considering the instantaneous capacities of the generators.*		2	-[a]	The nature of the control algorithm would need to be facilitated. A given generator in the priority list runs only if the generator(s) with higher priority run according to the dynamic rules (e.g., load, capacities, etc.). The priority does change automatically based on the overall system status, while avoiding too short cycle times.
	Control according to prediction based dynamic priority list. *Each generator is assigned a dynamic priority based on load, considering the instantaneous efficiencies of the generators.*		3	-[a]	The nature of the control algorithm would need to be facilitated. A given generator in the priority list runs only if the generator(s) with higher priority run according to the instantaneous efficiency. The priority does change automatically based on the overall system status, while avoiding too short cycle times.
	Control according to prediction based dynamic priority list. Also, control based on external signals from the grid. *Each generator is assigned a dynamic priority based on load, considering the instantaneous efficiencies of the generators and external grid signals.*		4	-[a]	The nature of the control algorithm would need to be facilitated. Like the previous, but with communication capacities. For example, establishing the dynamic priority based on timely energy price.
TES charging control	The **objective** is to manage the charging of thermal energy storage units. *TABS are not considered TES.*	**C-1g**	-		
Control functions	Continuous storage operation. *The TES charging is enabled all the time.*		0	-[a]	As per the technical specifications of the TES. Thermal energy storage is enabled for charging all the time independently of the expected load.
	Time-scheduled control. *The TES charging is enabled during the time defined by one or several schedules.*		1	This function related to function 6.4 “Time schedule control” in the BAC function list.	As per the technical specifications of the TES. Thermal energy storage is enabled for charging at certain times.
	Load-prediction control. *The TES charging is enabled all the time, but the state of charge is reduced when not needed based on load prediction.*		2	-[a]	As per the technical specifications of the TES. Thermal energy storage is enabled for charging all the time dependent of the expected load. Thus, the state of charge is reduced when storage is not needed.
	Flexible control through grid signals. *The TES charging is enabled all the time, but the charging is prioritised according to received signals from the grid.*		3	-[a]	As per the technical specifications of the TES. For example, as indicated in [23], in response to dynamic pricing or tariffs, price-responsive demand bidding, contractually obligated and voluntary curtailment, and direct load control/cycling.
Information to occupants and facility managers	The **objective** is to inform building occupants and facility managers on the cooling system’s performance.	**C-3**	-		
Control	None.		0		-

	Central or remote reporting of current performance KPIs.		1	-[a]	As per the technical specifications of the information system.
	Central or remote reporting of current performance KPIs and historical data.		2	-[a]	As per the technical specifications of the information system.
	Central or remote reporting of performance KPIs, historical data and evaluation including forecasting and/or benchmarking		3	-[a]	As per the technical specifications of the information system.
	Central or remote reporting of performance KPIs, historical data and evaluation including forecasting and/or benchmarking. Also including predictive management and fault detection		4	-[a]	As per the technical specifications of the information system.
Flexibility and grid interaction	The **objective** is to provide flexibility services to or interact with the electricity grid, by applying the control function to one or several sub-systems or components of the cooling system. The impact on the indoor comfort conditions shall be minimised.	**C-4**	-		
Control functions	None.		0		
	Scheduled operation of cooling system. *The operation of the cooling system may be scheduled, prioritising certain times, which may indirectly correlate with external grid signals.*		1	-[a]	The nature of the control algorithm would need to be facilitated.
	Self-learning control of cooling system. *The operation of the cooling system may serve as parametrisation of the thermal response of the building or building unit, such information may be leveraged for adapting the operation of the cooling system to external grid signals.*		2	-[a]	The nature of the control algorithm would need to be facilitated.
	Flexible control through grid signals. *The operation of the cooling system may be modified based on external grid signals.*		3	-[a]	The nature of the control algorithm would need to be facilitated. For example, as indicated in [23], in response to dynamic pricing or tariffs, price-responsive demand bidding, contractually obligated and voluntary curtailment, and direct load control/cycling.
	Optimised control based on local predictions and grid signals. *The operation of the cooling system may be modified based on external grid signals and predicted system performance.*		4	-[a]	The nature of the control algorithm would need to be facilitated. Like the previous but including predictions.

[a] The function is described by one row of the ISO 16484-3 BAC function list and a control schematic. Additional remarks ought to be included, if needed.

2.5.1.5 Ventilation

In a generic ventilation and air-conditioning system (Figure 8) the BAC and TBM functions can be outlined as in Table 6. The numbers depicted in the figure refer to those in the first column of the table. The numbers depicted in the figure refer to those in the first column of the table. The alphanumeric codes depicted in the figure refer to those from the default *smart ready service catalogue*. Those in bold correspond to the BAC and/or TBM functions which are included in the current version of the default *smart service catalogue* of the SRI assessment but are not covered by European standards.

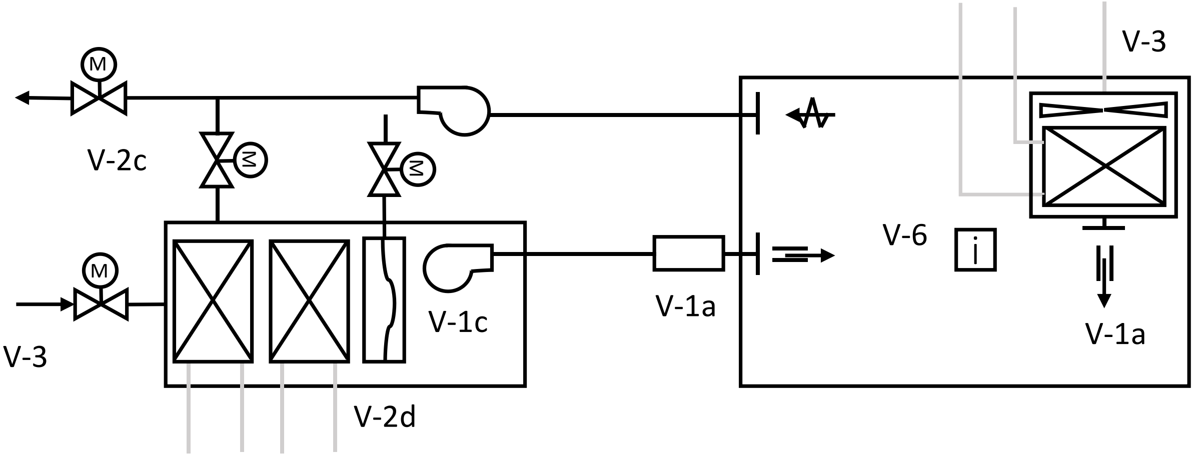

Figure 8. Ventilation and air-conditioning system. Adapted from [9].

As indicated in the EN ISO 52120-1 standard, heated and/or chilled water side system control of HVAC shall be treated as heating and cooling control, separately from air-side HVAC controls. Therefore, they are depicted in light gray in the schematic above.

The control functionalities within this section apply mainly to mechanical ventilation.

Table 6. Standardised BAC and TBM functions. SRI's Ventilation technical domain.

BAC and TBM function description, adapted from European standards		SRI assessment (v4.5)		BAC function description as in EN 16484-3	Example of vendor-neutral technology or device
		Smart ready service code	*Functionality level*		
Supply air flow control	The **objective** is to adjust the air flow supplied at the room level. The control function is applied to the fan, preferably at room level, based on the occupancy.	**V-1a**	-		
Control functions	No automatic control. *The system runs constantly or is controlled by a manually operated switch.*		0	-	-
	Time control. *The system runs according to a given schedule.*		1	This function related to function 6.4 "Time schedule control" in the BAC function list.	As per the technical specifications of the mechanical ventilation. The system runs at certain times. When it runs, it usually is at maximum speed.
	Occupancy-based control. *The system runs dependent on the occupancy. Occupancy may be sensed through a light switch, infrared sensors, etc.*		2	-[a]	As per the technical specifications of the mechanical ventilation. The system runs when there is occupation. When it runs, it usually is at maximum speed.
	Central demand-based control. *The system runs dependent on the central indoor air quality. Indoor air quality may be measured in terms of CO_2, VOC, etc.*		3	-[a]	As per the technical specifications of the mechanical ventilation. The system runs according to the overall demand of the service area. When it runs, it can be a variable speed proportional on the demand.
	Room demand-based control. *The system runs dependent on the local indoor air quality. Indoor air quality may be measured in terms of CO_2, VOC, etc.*		4	-[a]	As per the technical specifications of the mechanical ventilation. The system runs according to the demand of each zone of the service area. When it runs, it can be a variable speed proportional on the demand.
Air flow or pressure at air handler level	The **objective** is to adjust the air flow at the air handler level. The control function is applied to the air handler system.	**V-1c**	-		
Control functions	No automatic control. *The system continuously runs and supplies air flow at maximum load of all rooms.*		0		The system continuously runs and supplies air flow for a maximum load of all rooms.
	On/off time control. *The air handler fan is controlled via on/off time mechanism. During nominal occupancy time, the fan pressure is maximum.*		1	This function related to function 6.4 "Time schedule control" in the BAC function list.	As per the technical specifications of the air handler. The system runs at certain times. When it runs, it usually is at maximum speed.
	Multi-stage control. *The air handler fan is controlled via multi-step control mechanism. When on, the fan pressure can vary in predefined steps.*		2	-[a]	As per the technical specifications of the air handler. The system runs at certain times. When it runs, it may run at incremental multi-step speeds.
	Automatic flow or pressure control without pressure reset. *The air handler fan is controlled via air flow demand from the rooms. There is no pressure or critical zone reset carried out.*		3	-[a]	As per the technical specifications of the air handler. As indicated in [16], the fan is switched off when the sensed air quality is within the setpoints, which can be either constant or variable (i.e., dynamic).
	Automatic flow or pressure control with pressure reset. *The air handler fan is controlled via air flow demand from the rooms. There is pressure or critical zone reset carried out.*		4	-[a]	Like the previous, but with pressure or critical zone reset. For instance, as in [24].

Heat recovery control	The **objective** is to avoid overheating at the heat recovery unit. The control function is applied to the heat recovery unit.	**V-2c**			
Control functions	No overheating control.		0		-
	Overheating control. *The overheating control is applied based on temperature sensor(s) in air exhaust.*		1	-[a]	As per the technical specifications of the heat recovery unit. As indicated in [16], the overheating control may either stop, modulate, or by-pass the heat exchanger.
	Advanced overheating control. *The overheating control is applied based on temperature sensor(s) in several rooms or on predictive control.*		2	-[a]	As per the technical specifications of the heat recovery unit. As indicated in [16], the overheating control may either stop, modulate, or by-pass the heat exchanger.
Free mechanical cooling	The **objective** is to cool the building applying mechanical ventilation while in unoccupied mode. The control function is applied to the mechanical ventilation system.	**V-3**			
Control functions	No automatic control.		0		
	Night cooling. *The amount of outside air is set to its maximum during the unoccupied period provided that firstly the room temperature is above the setpoint for the comfort period, and secondly the difference between the room temperature and the outside temperature is above a given limit.*		1	This function relates to function 6.7 “Night cooling” in the BAC function list.	As per the technical specifications of the mechanical ventilation.
	Free cooling. *The amount of outdoor air and recirculation air are modulated during all periods of time to minimise the amount of mechanical cooling.* Calculation is performed on the basis of temperatures.		2	-[a]	As per the technical specifications of the mechanical ventilation.
	Enthalpy-based control. *The amount of outdoor air and recirculation air are modulated during all periods of time to minimise the amount of mechanical cooling.* Calculation is performed on the basis of temperatures and humidity (enthalpy).		3	This function relates to function 6.1 “h,x-directed control” in the BAC function list.	As per the technical specifications of the mechanical ventilation.
Supply air temperature control by AHU	The **objective** is to determine the supply air temperature setpoint at air handler level. The control function is applied preferably at the air handler level.	**V-2d**			
Control functions	No automatic control.		0		-
	Constant setpoint. *A control loop enables to control the supply air temperature, the setpoint is constant and can only be modified by a manual action.*		1	-[a]	As per the technical specifications of the air handling unit. The setpoint is constant and can only be modified by a manual action.
	Variable setpoint with outside temperature compensation. *A control loop enables to control the supply air temperature. The setpoint is a simple function of the outside temperature (e.g., linear function).*		2	-[a]	As per the technical specifications of the air handling unit. The setpoint is variable and can be modified automatically based on the outside temperature.
	Variable setpoint with load dependent compensation. *A control loop enables to control the supply air temperature. The setpoint is defined as a function of the loads in the room. This can normally only be achieved with an integrated control system enabling to collect the temperatures or actuator position in the different rooms.*		3	-[a]	As per the technical specifications of the air handling unit. The setpoint is variable and can be modified automatically based on the indoor temperature.

Information to occupants and facility managers	The **objective** is to inform building occupants and facility managers on the mechanical ventilation system's performance. Also, to reporting information regarding IAQ.	**V-6**			
Control functions	None.		0		-
	Central or remote reporting of current performance KPIs from air quality sensors and real time autonomous monitoring.		1	-[a]	As per the technical specifications of the information system.
	Central or remote reporting of current performance KPIs and historical data.		2	-[a]	As per the technical specifications of the information system.
	Central or remote reporting of performance KPIs, historical data and warning on maintenance needs or occupant actions.		3	-[a]	As per the technical specifications of the information system.
[a] The function is described by one row of the ISO 16484-3 BAC function list and a control schematic. Additional remarks ought to be included, if needed.					

2.5.1.6 *Lighting*

Table 7. Standardised BAC and TBM functions. SRI's Lighting technical domain.

BAC and TBM function description, adapted from European standards		SRI assessment (v4.5)		BAC function description as in EN 16484-3	Example of vendor-neutral technology or device
		Smart ready service code	*Functionality level*		
Occupancy control	The **objective** is to reduce the energy use of the lighting system, reducing the time it is on. The control function is applied to the lighting system.	**L-1a**	-	-	
Control functions	No automatic control. *The luminaire is switched on and off with a manual switch in the room.*		0	-[a]	-
	Manual on/off switch plus additional sweeping extinction signal. *The luminaire is switched on and off with a manual switch in the room. An automatic signal switches off the luminaire. At least once a day.*		1	This function relates to function 6.4 "Time schedule" in the BAC function list.	As per the technical specifications of the lighting system. Manual switches with central time control set based on building occupancy pattern. Specifically, the luminaire is switched on and off with a manual switch in the room. In addition, an automatic signal switches the luminaire off at least once per day, typically in the evening to avoid needless operation at night.
	Automatic detection. *The control system switches the luminaire(s) on whenever the illuminated area is occupied, and automatically switches it to a dimmed status or off after the last occupancy in the illuminated area.*		2	-[a]	As per the technical specifications of the lighting system. The lighting zone contain IR motion sensors linked to controllers that activate the lighting when occupants are detected and deactivate or reduce it if occupancy has not been detected for some time. Specifically, auto on/dimmed off: the control system switches the luminaire(s) automatically on whenever the illuminated area is occupied, and automatically switches them to a state with dimmed status after the last occupancy in the illuminated area.
	Advanced automatic detection. *The luminaire can only be switched on manually, and automatically switches it to a dimmed status or off after the last occupancy in the illuminated area.*		3	-[a]	As per the technical specifications of the lighting system. Like the previous, but with control set to manual initial activation. Specifically, - manual on/partial auto on/dimmed off: the luminaire(s) can only be switched on by means of a manual switch or automatically by occupancy detection sensor located in (or very close to) the area illuminated by the luminaires, and if not switched off manually, is/are automatically switched to a state with dimmed status after the last occupancy in the illuminated area. - manual on/ partial auto on/ auto off: the luminaire(s) can only be switched on by means of a manual switch or automatically by occupancy detection sensor.
Light level/daylight control	The **objective** is to reduce the energy use of the lighting system, maximising daylight harvesting. The control function is applied to the lighting system.	**L-2**	-		
Control functions	Manual central. *The luminaire is switched on and off with a centralised manual switch. There is no manual switch in the room.*		0	-[a]	As per the technical specifications of the lighting system. Centrally activated lighting with no room switch.
	Manual room.		1	-[a]	As per the technical specifications of the lighting system.

	The luminaire is switched on and off with a manual switch in the room.				Manual lighting switch in the room.
	Automatic switching. *The luminaires are automatically switched off when more than enough daylight is present to fully provide minimum illuminance required and switched on when there is not enough daylight.*		2	-[a]	As per the technical specifications of the lighting system. Luminaire control is driven by daylight sensors set to fully activate the luminaire(s) when daylight is below a threshold level and switch them off when it is above a threshold level. Daylight sensors may be within each luminaire or external to them.
	Automatic dimming. *The luminaires are dimmed down and finally fully switched off when daylight is available. The luminaires will be switched on again and dimmed up if the amount of daylight is decreasing.*		3	-[a]	As per the technical specifications of the lighting system. Like the previous, except the luminaire light output is dimmed in response to the detected daylight level to ensure a prescribed minimum light level is provided on the working area. If that level is detected without the need for artificial light the luminaires are deactivated.
	Advanced automatic dimming. *The luminaires are dimmed down and finally fully switched off, when daylight is available or when scene based light level control is applied. The luminaires will be switched on again and dimmed up if the amount of daylight is decreasing or when scene based light level control is applied.*		4	-[a]	As per the technical specifications of the lighting system. Like the previous but including scene-based light control, (during time-intervals dynamic and adapted lighting scenes are set in terms of illuminance level, different correlated colour temperature and the possibility to change the light distribution within the space according to e.g., design, needs, visual tasks, etc.). e.g. the light levels on task areas (such as desks) may be higher than in the areas in between.

[a] The function is described by one row of the ISO 16484-3 BAC function list and a control schematic. Additional remarks ought to be included, if needed.

2.5.1.7 *Dynamic building envelope*

In a generic building fabric, there are elements which have certain degree of dynamism or motion. In the standard EN ISO 52016-3, the *adaptative building envelope element* is defined as “building envelope or part of it with at least one layer having physical properties that can be adapted in a reversible way as a response to transient conditions or actively controlled to adjust to transient conditions or changing priorities”, examples of an adaptative building envelope element are *“a window or façade with dynamic solar shading (blind or shutter)”* [25]. Admittedly, operable windows are also considered adaptative building envelope elements [26].

Table 8. Standardised BAC and TBM functions. SRI’s Dynamic building envelope technical domain.

BAC and TBM function description, adapted from European standards		SRI assessment (v4.5)		BAC function description as in EN 16484-3	Example of vendor-neutral technology or device
		Smart ready service code	*Functionality level*		
Window control	The **objective** is to reduce the energy use for heating and cooling systems, modifying the solar gains through the windows. The control function is applied to the solar shading system.	**DE-1**	-	-	
Control functions	No sun shading or only manual operation.		0	-[a]	Manual operation requiring an effort or a force. For example, by crank or cord.
	Motorised operation with manual control. *Upon manual action, there is a motor that modifies the position of the solar shading device.*		1	-[a]	The operation is motorised but requires a manual activation. For example, by means of a remote or wall switch.
	Motorised operation with automatic control based on sensor data. *Automatic action of a motor that modifies the position of the solar shading device based on solar radiation sensing. The sensing can be done for each room or collectively by an outside solar sensor.*		2	-[a]	As per the technical specifications of the motorised solar shading device. The solar shading device is automatically moved into position to provide shading in response to solar radiation sensing signals. It usually allows a manual override by the occupants.
	Combined light-solar shading device-HVAC control. *The solar shading is controlled in coordination with HVAC and lighting controls for occupied and non-occupied rooms.*		3	-[a]	As per the technical specifications of the motorised solar shading device. Like the previous, but the control signal is also coordinated with HVAC and lighting controls.
	Predictive solar shading device control.		4	-[a]	As per the technical specifications of the motorised solar shading device. The solar shading device is automatically moved into position to provide shading in response to predictive information that helps optimise thermal/visual comfort and energy performance. Predictive information used to inform the control could concern forecast solar radiation levels with the related heat gains and glare; exterior temperatures; internal temperatures in response to HVAC set points and occupancy levels; and the interaction with building thermal response rates.
Window control	The **objective** is to reduce the energy use for heating and cooling systems, modifying the gains through the windows. The control function is applied to the window opening.	**DE-2**	-		
Control functions	Manual operation or only fixed windows.		0	-[a]	-
	Open/close detection with automatic action on heating and/or cooling systems.		1	-[a]	As per the technical specifications of the motorised windows.

					Based on its open/close status, automatic action is taken on HVAC systems. For example, automatically turning off HVAC when open.
	Open/close detection with automatic action on heating and/or cooling systems. In addition, automatised mechanical opening based on room sensor data.		2	-[a]	As per the technical specifications of the motorised windows. Like the previous, but also automatic opening based on indoor sensor data. For example, automatically opening the motorised windows when IAQ levels reach a certain threshold.
	Open/close detection with automatic action on heating and/or cooling systems. In addition, automatised mechanical opening based on room sensor data. Also, centralised coordination of operable windows.		3	-[a]	As per the technical specifications of the motorised windows. Like the previous, but with coordination of the motorised windows in the whole building.
Information to occupants and facility managers	The **objective** is to inform building occupants and facility managers on the dynamic building envelope system's performance.	**DE-4**			
Control functions	None.		0	-[a]	-
	Position of each product and fault detection		1	-[a]	As per the technical specifications of the information system.
	Position of each product, fault detection and predictive maintenance.		2	-[a]	As per the technical specifications of the information system.
	Position of each product, fault detection, predictive maintenance, and real-time sensor data.		3	-[a]	As per the technical specifications of the information system.
	Position of each product, fault detection, predictive maintenance, real-time and historical sensor data.		4	-[a]	As per the technical specifications of the information system.

[a] The function is described by one row of the ISO 16484-3 BAC function list and a control schematic. Additional remarks ought to be included, if needed.

2.5.1.8 *Electricity*

In a generic prosumer's electrical installation (Figure 9) the functional layers can be outlined as identified in Table 9. The alphanumeric codes depicted in the figure refer to those from the default *smart ready service catalogue*.

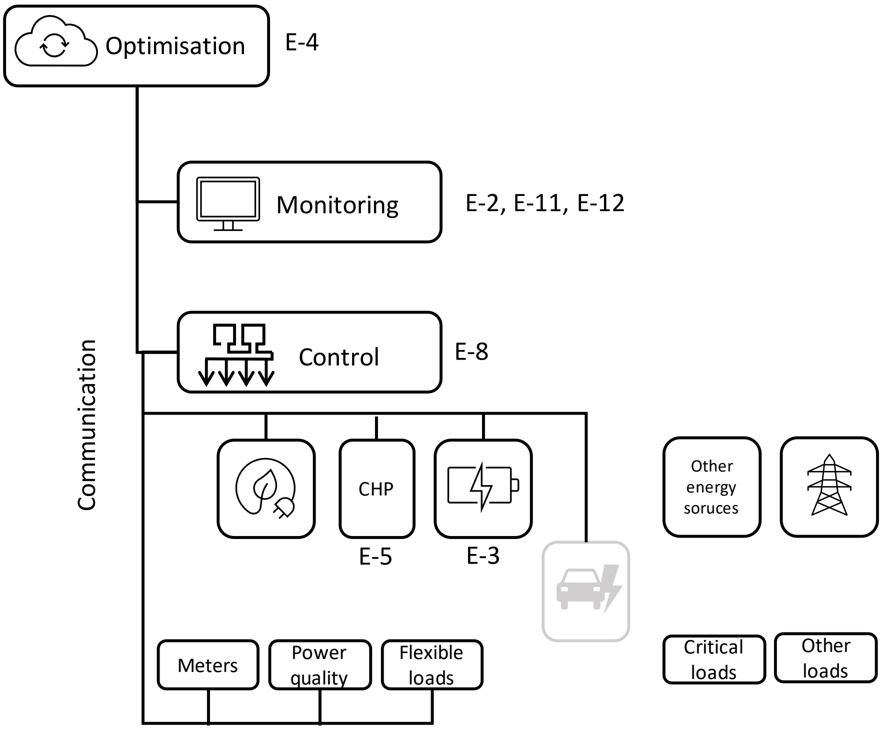

Figure 9. Prosumer's electrical installation. Adapted from [27].

As indicated in the IEC TS 60364-8-3 technical specification, the lower layer relates to the protection and metering, which comprises the equipment and devices in the installation for the purpose of safety, reliability, power, and energy management. The power supplies layer includes the connection to the distribution network and local power supplies, the electrical energy storage units and the electric vehicle charging stations. The latter is discussed in section 2.5.1.9. Therefore, it is depicted in light gray in the schematic above. The control layer is focused on the power and energy management. Data management and remote and local interfaces fall in the monitoring layer. Lastly, the optimisation layer performs the optimisation of services, analytics, and artificial intelligence.

The IEC TS 60364-8-1 [23]and IEC TS 60364-8-3 [27] technical specifications are not focused on the description of the automation, control, and management functions. However, they constitute the reference documents to attempt the description of such functions vis-à-vis the SRI electricity *technical domain*.

Table 9. Standardised BAC and TBM functions. SRI's Electricity technical domain.

BAC and TBM function description, adapted from European standards		SRI assessment (v4.5)		BAC function description as in EN 16484-3	Example of vendor-neutral technology or device
		Smart ready service code	*Functionality level*		
Local electricity production. Reporting information	The **objective** is to inform building occupants and facility managers on the local electricity production.	**E-2**	-	-	
Control functions	None		0	-[a]	-
	Central or remote reporting of real time generation data.		1	-[a]	As per the technical specifications of the information system.
	Central or remote reporting of real time generation and historical data.		2	-[a]	As per the technical specifications of the information system.
	Central or remote reporting of real time generation and historical data. Including performance evaluation with forecasting and/or benchmarking functionalities.		3	-[a]	As per the technical specifications of the information system.
	Central or remote reporting of real time generation and historical data. Including performance evaluation with forecasting and/or benchmarking functionalities. Also, predictive management and fault detection.		4	-[a]	As per the technical specifications of the information system.
Optimizing self-consumption of locally generated electricity.	The **objective** is to optimise local electricity consumption to maximise the consumption of locally produced electricity and/or minimise usage at peak power periods.	**E-4**			
Control functions	None.		0	-[a]	
	Scheduling electricity consumption		1	-[a]	Electricity use is enabled at certain times. It is usually focused on the flexible loads (e.g., plug loads, white goods, etc.).
	Automated management of local electricity consumption based on current renewable energy availability		2	-[a]	The nature of the control-optimisation algorithm would need to be facilitated. As indicated in [27], the utilization of the local sources may be optimized through the exchange of information and controlling signal with other systems such as weather forecasts, demand response, tariffs.
	Automated management of local electricity consumption based on current and predicted energy needs and renewable energy availability		3	-[a]	The nature of the control-optimisation algorithm would need to be facilitated. As indicated in [27], it involves configuration of the control and monitoring system for predicting power usage is based on power information for efficient use of power load in the installation.
Combined Heat and Power (CHP) generation control	The **objective** is to maximise the generator efficiency, by applying the control function to the CHP generator.	**E-5**		-[a]	
Control functions	CHP control based on scheduled runtime management and/or heat energy demand.		0	-[a]	CHP generation is enabled at certain times.
	CHP runtime control influenced by the fluctuating availability of renewables. *Overproduction is fed into the grid.*		1	-[a]	The nature of the control algorithm would need to be facilitated. CHP generation is prioritised based on signals from local renewable sources.

	CHP runtime control influenced by the fluctuating availability of renewables and grid signals.		2	-[a]	The nature of the control algorithm would need to be facilitated. Like the previous, but also with signals from the grid.
Electricity storage control	The **objective** is to maximise the use of local electricity by managing its storage. The control function is applied to the electricity storage system.	**E-3**	-		
Control functions	None		0	-[a]	
	On-site electricity storage.		1	-[a]	As indicated in [27], after supplying power to the current-using equipment from a distributed generation in the local system, the surplus power shall be stored in the electricity storage.
	On-site electricity storage with controller based on grid signals.		2	-[a]	The nature of the control algorithm would need to be facilitated. Electricity storage is controlled primarily based on signals from the grid. For example, to provide instantaneously any power fluctuation occurring from the difference between power generation and current-using equipment consumption in the island mode.
	On-site electricity storage with controller optimising the use of local electricity production.		3	-[a]	The nature of the control algorithm would need to be facilitated. Electricity storage is controlled seeking to maximise the use of local electricity production based on signals from the grid.
	On-site electricity storage with controller optimising the use of local electricity production. Also, possibility to feed back into the grid.		4	-[a]	The nature of the control algorithm would need to be facilitated. As indicated in [27], after supplying power to the current-using equipment from a distributed generation in the local system, the surplus power shall be stored in the electricity storage, and/or fed into the grid.
Electricity storage. Reporting information	The **objective** is to inform building occupants and facility managers on the electricity storage. *TES excluded.*	**E-11**			
Control functions	None.		0	-[a]	-
	Central or remote reporting of real time state-of-charge (SOC) data.		1	-[a]	As per the technical specifications of the information system.
	Central or remote reporting of real time state-of-charge (SOC) and historic data.		2	-[a]	As per the technical specifications of the information system.
	Central or remote reporting of real time state-of-charge (SOC) and historic data. Including performance evaluation with forecasting and/or benchmarking functionalities.		3	-[a]	As per the technical specifications of the information system.
	Central or remote reporting of real time state-of-charge (SOC) and historic data. Including performance evaluation with forecasting and/or benchmarking functionalities. Also, predictive management and fault detection.		4	-[a]	As per the technical specifications of the information system.

Demand side management control	The **objective** is to support micro-grid operation modes. *The prosumer's electricity installation may also interact with others or just distributed energy resources, to optimize the global energy usage and/or energy costs and/or produce services to the (micro)grid, typically under a contractual format.*	**E-8**			
Control functions	None.		0	-[a]	-
	Automated management of electricity consumption based on grid signals.		1	-[a]	The nature of the control algorithm would need to be facilitated. Electricity consumption and storage is controlled primarily based on signals from the (micro)grid.
	Automated management of electricity consumption and supply to (micro)grid		2	-[a]	The nature of the control algorithm would need to be facilitated. Like the previous but enabling local electricity production to be fed into the (micro)grid.
	Automated management of electricity consumption and supply to (micro)grid. Possibility of island mode operation.		3	-[a]	The nature of the control algorithm would need to be facilitated. Like the previous but enabling island mode operation.
Electricity consumption. Reporting information	The **objective** is to inform building occupants and facility managers on the electricity consumption.	**E-12**			
Control functions	None.		0	-[a]	-
	Central or remote reporting of real time electricity consumption data.		1	-[a]	As per the technical specifications of the information system.
	Central or remote reporting of real time electricity consumption data. Including benchmarking at building or building unit level.		2	-[a]	As per the technical specifications of the information system.
	Central or remote reporting of real time electricity consumption data. Including benchmarking at load level.		3	-[a]	As per the technical specifications of the information system.
	Central or remote reporting of real time electricity consumption data. Including benchmarking at load level. Also, provision of automated personalised recommendations.		4	-[a]	As per the technical specifications of the information system.

[a] The function is described by one row of the ISO 16484-3 BAC function list and a control schematic. Additional remarks ought to be included, if needed.

2.5.1.9 Electric vehicle charging

In a generic electric vehicle connection to a supply network (Figure 10) the functions necessary to condition voltage and/or current provided by the AC or DC supply network to assure the supply of electric energy to the EV can be outlined as identified in Table 10Table 9. The alphanumeric codes depicted in the figure refer to those from the default *smart ready service catalogue*.

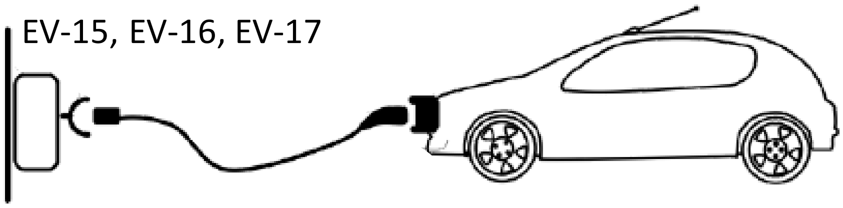

Figure 10. Electric vehicle supply equipment. Adapted from [28]**.**

The IEC 61851-1 [28], IEC 60364-7-722 [29], and ISO 15118-1 [30] international standards are not solely focused on the description of the automation, control, and management functions. However, they constitute the reference documents to attempt the description of such functions vis-à-vis the SRI EV charging *technical domain*.

Table 10. Standardised BAC and TBM functions. SRI's EV charging technical domain.

BAC and TBM function description, adapted from European standards		SRI assessment (v4.5)		BAC function description as in EN 16484-3	Example of vendor-neutral technology enabler
		Smart ready service code	*Smart ready service code*		
Electric Vehicle (EV) charging	The **objective** is to assess the EV supply equipment. *The EV supply equipment is the equipment or a combination of equipment, providing dedicated functions to supply electric energy from a fixed electrical installation or supply network to an EV for the purpose of charging.* *EV charging stations are the stationary parts of the EV supply equipment connected to the supply network. EV charging stations for public use shall be so designed as to facilitate easy access to the charging point regardless of where the vehicle inlet is located on the electric vehicle.*	**EV-15**	-	-	
Control functions	None		0	- [a]	-
	Ducting or simple socket-outlet available.		1	- [a]	Ducting for the EV supply equipment or regular socket outlet or, in the case of a fixed cable, connector, that may provide power to the EV, typically to be installed with the fixed wiring.
	<10% Parking spaces has recharging points.		2	- [a]	EV socket-outlet(s) or EV charging station(s).
	10-50% Parking spaces has recharging points.		3	- [a]	EV socket-outlets or EV charging stations.
	>50% Parking spaces has recharging points.		4	- [a]	EV socket-outlets or EV charging stations.
Electric Vehicle (EV) charging	The **objective** is to assess the EV charging modes and functions regarding energy transfer.	**EV-16**			
Control functions	None or uncontrolled charging.		0	- [a]	If applicable, equipment providing dedicated functions to supply electric power from an electrical installation or supply network to an EV for the purpose of charging.
	1-way controlled energy transfer. Charging only.		1	- [a]	Like the previous, but communication controller enabling communication between the vehicle and the user to support specific functions.
	2-way controlled energy transfer Charging and discharging.		2	- [a]	Like the previous but charging and discharging. As indicated in [30], vehicle to grid (V2G) plug-in Ev interaction with the electric grid, including charging as well as discharging and bi-directional communication interface.
EV charging	The **objective** is to assess the EV charging connectivity.	**EV-17**			
Control functions	No information available.		0	- [a]	-
	Central or remote reporting of EV charging status data.		1	- [a]	Messages are exchanged between the EV and the supply equipment communication controller to query and report on its system status. If an error occurs during checking of the system status, the energy transfer process shall be aborted.
	Central or remote reporting of EV charging status data. Also, automatic identification and authorisation of driver charging station.		2	- [a]	Like the previous, but with user authorisation procedure to verify if an EV is allowed to charge or discharge.

[a] The function is described by one row of the ISO 16484-3 BAC function list and a control schematic. Additional remarks ought to be included, if needed.

2.5.1.10 *Monitoring and control*

In a generic monitoring and control system (Figure 11) the functions necessary to control the usage of the energy consumed can be outlined as identified in Table 11. The alphanumeric codes depicted in the figure refer to those from the default *smart ready service catalogue*.

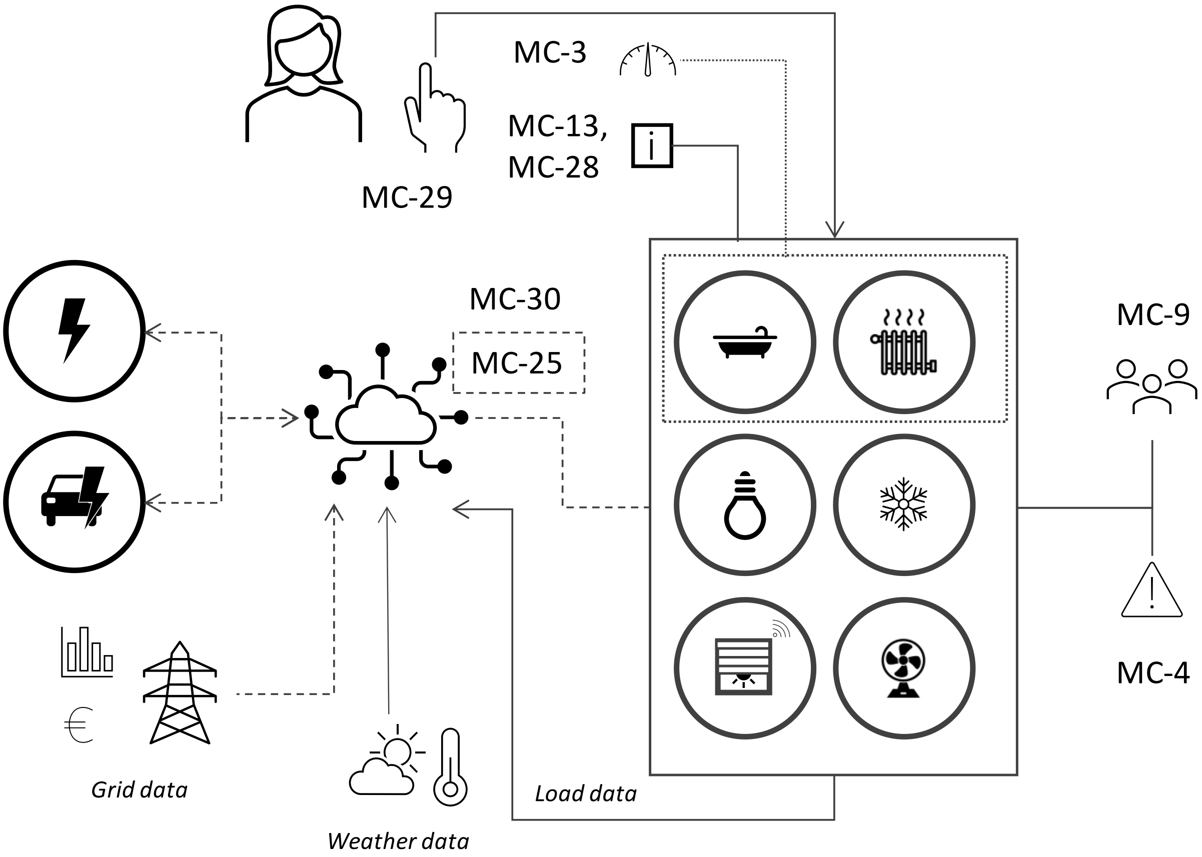

Figure 11. Monitoring and control system. Adapted from [23].

The IEC TS 60364-8-1 [23] technical specification is not focused on the description of the automation, control, and management functions. However, it constitutes the reference document to attempt the description of such functions vis-à-vis the SRI monitoring and control *technical domain*.

Table 11. Standardised BAC and TBM functions. SRI's monitoring and control technical domain.

BAC and TBM function description, adapted from European standards		SRI assessment (v4.5)		BAC function description as in EN 16484-3	Example of vendor-neutral technology enabler
		Smart ready service code	*Functionality level*		
Heating and cooling systems. Runtime control	The **objective** is to manage the runtime of the heating and cooling systems	**MC-3**	-	-	
Control functions	Manual setting.		0	-[a]	-
	Runtime setting of heating and cooling plants following a predefined time schedule.		1	This function related to function 6.4 "Time schedule control" in the BAC function list.	The system runs at certain times. When it runs, it usually is at maximum speed.
	Runtime setting of heating and cooling plants based on buildings loads.		2	-[a]	Sensors of temperature for the air of the indoor spaces of the building, with a proper coverage of the different thermal zones. These sensors must be connected to the control devices of the BAC systems, which must allow to define the setpoint values for the indoor spaces to switch on/off or to modulate the heating or cooling systems. If both sensible and latent thermal loads of the building are covered, in addition to the above ones, also relative humidity sensors can be present and connected to the BAC systems, to allow the automatic control of relative humidity values in the rooms and control functionalities related to moist air enthalpy.
	Runtime setting of heating and cooling plants based on predictive control and grid signals.		3	-[a]	Like the previous but with the presence of automatic predictive controls for heating and cooling systems, in the installed BAC systems or in a proper supervising management system (e.g., through statistical methods, or time series analysis, or artificial intelligence methods, etc.). In addition, also the possibility integration of external data sources, such as weather forecast or signals form the grid (like for example energy prices, thresholds of powers, availability of renewable energy, etc.).
Technical Building Systems (TBS). Fault detection	The **objective** is to detecting faults of technical building systems and providing support to the diagnosis of these faults.	**MC-4**			
Control functions	No central indication of detected faults and alarms.		0	-[a]	-
	With central indication of detected faults and alarms for at least 2 systems.		1	-[a]	As per the technical specifications of the information system. Graphical user interface of the BAC system allowing for the visualization of the faults, through proper warnings and messages.
	With central indication of detected faults and alarms for all relevant systems.		2	-[a]	As per the technical specifications of the information system. Graphical user interface of the BAC system allowing for the visualization of the faults, through proper warnings and messages.
	With central indication of detected faults and alarms for all relevant systems. In addition, diagnosing functions.		3	-[a]	As per the technical specifications of the information system. Like the previous, but with diagnosing functions.
Technical Building Systems (TBS). Occupancy detection	The **objective** is to adapt the operation of technical building systems based on occupancy detection.	**MC-9**			

Control functions	None.		0	-[a]	-
	Occupancy detection for individual systems.		1	-[a]	Sensors for occupancy in place in the considered spaces and connected to the considered individual systems. For example, sensor of occupancy connected to a mechanical ventilation system.
	Centralised occupant detection, capable of being fed into several systems.		2	-[a]	Sensors for occupancy in place in the considered spaces and connected to the BAC systems of the building, with the functionalities of control different technical building systems.
Technical Building Systems (TBS). Reporting information	The **objective** is to inform building occupants and facility managers on the of technical building systems performance and energy use.	**MC-13**	-		
Control functions	None		0	-[a]	-
	Central or remote reporting of real-time energy use per energy carrier.		1	-[a]	As per the technical specifications of the information system. Graphical user interface of the BAC system allowing for the visualization of the performance indicators.
	Central or remote reporting of real-time energy use per energy carrier, combining of TBS of at least 2 domains in one interface.		2	-[a]	As per the technical specifications of the information system. Like the previous, but more granularity of indicator.
	Central or remote reporting of real-time energy use per energy carrier, combining of TBS of all relevant domains in one interface.		3	-[a]	As per the technical specifications of the information system. Like the previous, but more granularity of indicator.
Smart grid interaction	The **objective** is to support the smart grid interaction and demand response.	**MC-25**			
Control functions	None. The building is operated independently from the grid.		0	-[a]	-
	Demand side management is possible for some TBS. There is no coordination between domains.		1	-[a]	The nature of the control algorithm would need to be facilitated. For example, as indicated in [23], some technical systems can be operated in response to dynamic pricing or tariffs, price-responsive demand bidding, contractually obligated and voluntary curtailment, and direct load control/cycling.
	Demand side management is possible for some TBS. There is coordination between domains.		2	-[a]	The nature of the control algorithm would need to be facilitated. Like the previous but with communication and coordination between systems, to maximise efficiency.
Demand Side Management (DSM). Reporting information	The **objective** is to inform building occupants and facility managers on the of Demand Side Management performance.	**MC-28**			
Control functions	None.		0	-[a]	-
	Reporting information on current time DSM status, including managed energy flows.		1	-[a]	As per the technical specifications of the information system. Graphical user interface of the BAC system allowing for the visualization of the real-time performance indicators.
	Reporting information on current time, historic, and predicted DSM status, including managed energy flows.		2	-[a]	As per the technical specifications of the information system. Like the previous but with historic and/or predicted features.

Demand Side Management (DSM). Override control	The **objective** is to override the of Demand Side Management by building occupants and facility managers.	**MC-29**			
Control functions	No DSM control.		0	-[a]	-
	DSM control without the possibility of override by the building occupant or facility manager.		1	-[a]	Provision of a manual override facility which enables the user to take control from the automatic functions.
	DSM control with the possibility of manual override and reactivation by the building occupant or facility manager.		2	-[a]	Like the previous, but with reactivation of the automatic mode based on certain routines.
	DSM control with the possibility of scheduled override and reactivation by the building occupant or facility manager.		3	-[a]	Like the previous, but with scheduling functionalities.
	DSM control with the possibility of scheduled override and reactivation by the building occupant or facility manager. In addition, it provides optimised control.		4	-[a]	Like the previous, but with optimised controls.
Single platform	The **objective** is to assess the presence of a single platform that allows automated control and coordination between TBS and optimisation of energy flow based on occupancy, weather, and grid signals.	**MC-30**			
Control functions	None.		0	-[a]	-
	Single platform that allows manual control of multiple TBS.		1	-[a]	As per the technical specifications of the platform. Graphical user interface of the BMS allowing for the control of several systems.
	Single platform that allows automatic control and coordination of multiple TBS.		2	-[a]	As per the technical specifications of the platform. Like the previous, but with automatic reaction of systems upon controlled action of other systems.
	Single platform that allows automatic control and coordination of multiple TBS. In addition, optimisation of energy flow based on occupancy, weather, and grid signals.		3	-[a]	As per the technical specifications of the platform. Like the previous, but considering dynamic pricing or tariffs, price-responsive demand bidding, contractually obligated and voluntary curtailment, and direct load control/cycling.

[a] The function is described by one row of the ISO 16484-3 BAC function list and a control schematic. Additional remarks ought to be included, if needed.

2.5.2 SRI vis-à-vis EPB assessments and certification schemes

As it was indicated in the Commission Implementing Regulation (EU) 2020/2156 [4], Member States that decide to implement the Smart Readiness Indicator (SRI) scheme may couple the issuing of its certificate with their energy performance certification scheme or with the inspection of heating, air-conditioning and combined heating or air-conditioning and ventilation systems under Directive 2010/31/ EU, or with their scheme for energy audits under Directive 2012/27/EU.

There are topical and procedural similarities between the SRI and EPB assessments. Particularly, the assessed object (i.e., building or building unit) is common, and there are some overlaps in the considered aspects (e.g., assessor information, building information, technical building systems, etc.). In addition, the expertise required to perform the assessment is similar, fostering that EPB assessors also issue SRIs. Other administrative synergies may exist, such as display of certificates, online availability in databases, independent control system, etc.

The concrete coupling mechanism of the SRI and the energy performance certification scheme will be different for each Member State, on account of each having its own procedure and methodology to issue energy performance certificates. Therefore, performing a comprehensive description of the synergies between the SRI assessment and each national EPB assessment and certification scheme is a titanic effort, out of the scope of the present document. Alternatively, a generic coupling mechanism is proposed relying on the taxonomy of the existing standards.

To assess the overall energy performance of a building, the European Commission has established a set of standards and accompanying technical reports to support the EPBD [31]. These standards are called the energy performance of buildings standards or “set of EPB standards”. They are aimed at the international harmonisation of the methodology for assessing the energy performance of buildings.

The set of EPB standards have a modular structure, which enables the identification of all required parts of the assessment procedure, the modules covered by the EPB standards, and the connection between the EPB standards. The overarching modular structure has the following four main areas.

- M1. Overarching standards.
- M2. Building as such.
- M3-M11. Technical Building Systems under EPB (M3-Heating, M4-Cooling, M5-Ventilation, M6-Humidification, M7-Dehumidification, M8-Domestic Hot Water, M9-Lighting, M10-Building Automation and Control, M11-Electriciy production).
- M12-M13. Other systems or appliances (non-EPB).

Each main module is divided into sub-modules, as indicated in Table 12. A comprehensive overview of the standards linked to each EPB Standards modules and submodules is presented in Annex B of the present document.

Table 12. EPB Standards modules and submodules. Reproduced from [32].

Main area	**Overarching**	**Building as such**	**Technical Building Systems**
Module	**M1**	**M2**	**M3-M11**
Submodule	**Description**		
1	General	General	General
2	Common terms and definitions; symbols; units and subscripts	Building Energy Needs	Needs
3	Applications	(Free) Indoor conditions without systems	Maximum load and power
4	Ways to Express Energy Performance	Ways to Express Energy Performance	Ways to Express Energy Performance
5	Building Functions and Building Boundaries	Heat Transfer by Transmission	Emission & control

6	Building Occupancy and Operating Conditions	Heat Transfer by Infiltration and Ventilation	Distribution & control
7	Aggregation of Energy Services and Energy Carriers	Internal Heat Gains	Storage & control
8	Building Zoning	Solar Heat Gains	Generation & control
9	Calculated Energy Performance	Building Dynamics (thermal mass)	Load dispatching and operating conditions
10	Measured Energy Performance		
11	Inspection		
12	Ways to Express Indoor Comfort		BMS
13	External Environment Conditions		
14	Economic Calculation		

As indicated in EN ISO 52000-1, all EPB standards provide a certain flexibility regarding the methods, the required input data, and references to other EPB standards, by the introduction of a normative template in Annex A and Annex B with informative default choices.

In general, the input data requested for each module can be of the following types:

- Product data.
- System design data.
- Operating data and boundary conditions.
- Other data.

The topical synergies between some modules and submodules of the EPB Standards and the SRI assessment methodology is remarkable, as depicted in Table 13.

Table 13. Topical synergies between SRI and EPB Standards

SRI			**EPB Standards**	
Technical domain	**Smart-ready service**	**Code**	**Module name**	**Module code**
Heating	Emission control	H-1a, H-1b	Emission & control	M3-5
	Storage and shifting of thermal energy	H-1c	Storage & control	M3-7
	Control of distribution pumps in networks	H-1d	Distribution & control	M3-6
	Thermal Energy Storage control	H-1f	Storage & control	M3-7
	Generation control	H-2a, H-2b	Generation & control	M3-8
	Sequencing of different generators	H-2d		
	Information to occupants and facility managers	H-3	Not covered	
	Flexibility and grid interaction	H-4	Not covered	
Domestic hot water	Storage charging control	DHW-1a, DHW-1b, DHW-1c,	Storage & control, Generation & control	M3-7, M3-8
	Sequencing of different generators	DHW-2b	Generation & control	M3-8

	Information to occupants and facility managers	DHW-3	Not covered	
Cooling	Emission control	C-1a, C-1b	Emission & control	M4-5
	Control of distribution network chilled water temperature	C-1c	Generation & control	M4-8
	Control of distribution pumps in networks	C-1d	Distribution & control	M4-6
	Interlock	C-1f		
	Thermal Energy Storage control	C-1g	Storage & control	M4-7
	Generation control	C-2a	Generation & control	M4-8
	Sequencing of different generators	C-2b		
	Information to occupants and facility managers	H-3	Not covered	
	Flexibility and grid interaction	H-4	Not covered	
Ventilation	Supply air flow control	V-1a	Emission & control	M5-5
	Air flow or pressure at air handler level	V-1c	Distribution & control	M5-6
	Heat recovery control	V-2c	Distribution & control, Generation & control	M5-6, M5-8
	Free mechanical cooling	V-3	Distribution & control, Generation & control	M5-6, M5-8
	Supply air temperature control by AHU	V-2d	Distribution & control, Generation & control	M5-6, M5-8
	Information to occupants and facility managers	V-6	Not covered	
Lighting	Occupancy control	L-1a	Emission & control[a]	M9-5
	Light level/daylight control	L-2	Emission & control[a]	M9-5
Dynamic building envelope	Window control	DE-1	Solar heat gains	M2-8
	Window control	DE-2	Heat transfer by infiltration and ventilation	M2-6
	Information to occupants and facility managers	DE-4	Not covered	
Electricity	Local electricity production. Reporting information	E-2	Not covered	
	Local electricity production. Optimisation	E-5	Generation & control	M11-8
	CHP generation control	E-5	Generation & control	M11-8

	Electricity storage	E-3		
	Electricity storage. Reporting information	E-11	Not covered	
	Demand side management control	E-8		
	Electricity consumption. Reporting information	E-12	Not covered	
Electric vehicle charging	EV charging	EV-15	Not covered	
	EV charging	EV-16	Not covered	
	EV charging	EV-17	Not covered	
Monitoring and control	Heating and cooling systems interaction control	MC-3	Not covered	
	Technical Building Systems. Fault detection	MC-4	Not covered	
	Technical Building Systems. Occupancy detection	MC-9	Not covered	
	TBS performance and energy use. Reporting information	MC-13	Not covered	
	Smart grid interaction	MC-25	Not covered	
	Demand side management. Reporting information.	MC-28	Not covered	
	Demand side management. Override control.	MC-29	Not covered	
	Single platform	MC-30	Not covered	

As indicated in [33], this submodule provides assessment approaches to control the electric lighting system. Methods to describe and rate constant illuminance control, presence detection systems and daylight dependent controls are provided.

Table 13 reveals the significant synergies between the SRI assessment and EPB assessments, as defined by the EPB Standards. The remainder of the section is structured as follows. Section 2.5.2.1 covers the contribution to the SRI from EPB assessments, and section 2.5.2.2 deals with the complementary information flow, from the SRI to EPB assessments and certification schemes.

2.5.2.1 Which SRI input data is covered by EPB assessments?

As indicated in section 2.2.1, the SRI assessment requires the identification of general information of the assessed object as well as retrieving the inputs needed for the calculations, similarly to that required for the issue of energy performance certificates. Particularly, the general building information, the presence of technical domains, and the definition of applicability of *technical domains*, *smart ready service,* and main *functionality level* as required by the calculation spreadsheet developed by the SRI support team [6] includes input data partially covered by the EPB Standards. Consequently, this section aims at revealing the potential for a semi-automatic SRI assessment based on a previous EPB assessment.

The synergies between SRI input data and the EPB standards are detailed below. In Table 14 for the general building information and the applicability of *technical domains*. In Table 15, for the presence of *technical domains* in the assessed object. In Table 16, for the applicability of each *smart-ready service* contained in the default service catalogue.

Table 14. SRI input data vis-à-vis the EPB Standards. General building information and technical domain applicability.

SRI – General building information		EPB Standards				
Input data	**Options**	**Module name**	**Module code**	**Step in assessment**	**Description**	**Options**[a]
Building type	**Value list** [residential, non-residential]	Overarching	M1-1	Overarching preparation steps	Building category [b]	Table A.4 in ISO 52000-1
Building usage	**Value list** [residential – single-family house, residential – small multi-family house, residential – large multi-family house, residential - other, non-residential – office, non-residential – educational, non-residential – healthcare, non-residential – other]					
Location	**Value list** [EU Countries] which defines the *Climate zone* as a **Value list** [North Europe, North-East Europe, East Europe, South-East Europe, South Europe, West Europe]	Overarching	M1-13	Overall calculation procedure	- [c]	ISO 52010-1
Total useful floor area of the building	**Value list** [<200 m^2, 200 - 500 m^2, 500 - 1.000 m^2, 1.000 - 10.000 m^2, 10.000 - 25.000 m^2, > 25.000 m^2]	Overarching	M2-2	Building energy needs assessment	- [d]	Table A.20 in ISO 52000-1
Year of construction	**Value list** [< 1960, 1960 – 1990, 1990 – 2010, > 2010, not yet constructed]	- [e]				
Building state	**Value list** [Renovated, Original]	Overarching	M1-1	Overarching preparation steps	Object type[f]	Table A.3 in ISO 52000-1

Applicable technical domain – Heating	**Value list** [0 – Domain absent and not mandatory, 1 – Domain present, 2 – Domain absent, but mandatory]	Overarching	M1-1	Overarching preparation steps	Type of combination of services [g]	Table A.10 and A.18 in ISO 52000-1
Applicable technical domain – DHW						
Applicable technical domain – Cooling						
Applicable technical domain – Ventilation						
Applicable technical domain – Lighting						
Applicable technical domain – Dynamic building envelope						
Applicable technical domain – Electricity						
Applicable technical domain – Electric vehicle charging						
Applicable technical domain – Monitoring and control						

[a] In the context of national or regional legal requirements, mandatory choices may be given at national or regional level for such specific applications following template of Annex A. Informative default choices are given in Annex B of each EPB Standard. The codification of the referenced options is the same, except for references to “A” and “B”.

[b] The concepts of “building type” and “usage” from the SRI are contained within that of “building category” in the EPB Standards, which is more detailed.

[c] The location of the assessed object is needed for the determination of the external climatic conditions.

[d] Area of the floor of a building needed as parameter to quantify specific conditions of use that are expressed per unit of floor area and for the application of the simplifications and the zoning and (re-)allocation rules.

[e] Usually required for applications of EPB assessments dealing with compliance requirements.

[f] The concept of “building state” from the SRI is contained within that of “object type” in the EPB Standards, which is more detailed.

[g] The applicable services that shall be taken into account in the assessment are linked to the combination of mandatory services, which may be different for different building or space categories. However, the definition of mandatory technical domains is the prerogative of the Member States; SRI assessors would only need to assess their presence in the assessed object.

The data included in Table 14 shows that many of the parameters that shall be defined as preparatory steps for the SRI assessment, correlate with those that shall be identified in preparation of the energy performance assessment, as indicated in EN ISO 52000-1. Consequently, the general building information needed for the SRI can be easily coordinated with EPB Assessments. As previously indicated, SRI *technical domains* significantly correlate with “building services” as defined in the EPB Standards. As per the EPB Standards, a combination of service types applies to EPB assessments, which may be different for different building or space categories. As a result, there is a national choice to be made regarding which building services are included in the energy performance calculations. The coordination of such selection of building services for EPB assessments with the related *technical domains* defined as “mandatory” for the SRI assessment could be fostered with a view to couple the issuing of the smart readiness indicator certificate with their energy performance certification scheme at national level.

The next step in the SRI assessment is to assess the presence of each *technical domain.* This generally based on the presence of certain elements at system or sub-system level. Again, this is susceptible of being aligned with EPB assessment procedures, as defined in Table 15.

Table 15. SRI input data vis-à-vis the EPB Standards. Methodology selection. Technical domain presence.

SRI – General building information		EPB Standards				
Input data	**Options**	**Module name**	**Module code**	**Step in assessment**	**Description**	**Options[a]**
Presence of technical domain – Heating	**Binary choice** [1, 0]	Heating	M3-1	Building energy needs assessment. Input data	Available heating power, per thermally conditioned zone	[0-∞]W[b]
Presence of technical domain – DHW		DHW	M8-1	Input data	Volume of water drawn per day	[0-∞]l[b]
Presence of technical domain – Cooling		Cooling	M4-1	Building energy needs assessment. Input data	Available cooling power, per thermally conditioned zone	[0-∞]W[b]
Presence of technical domain – Ventilation		Ventilation	M5-2	Building energy needs assessment. Input data	Supply temperature for each ventilation system air flow element entering a zone,	[0-50]°C[b]
Presence of technical domain – Lighting[c]		Lighting	M9-1	Building energy needs assessment. Input data	Specific internal heat flow rate due to lighting, per thermal zone	[0-∞]W/m^2 [b]

Presence of technical domain – Dynamic building envelope		Building (as such)	M2-5, M2-8	Building energy needs assessment. Input data	Properties per dynamic window, per state	Control levels in section 2.2.1.2 of Annex G in EN ISO 52016-1:2017
Presence of technical domain – Electricity		Electricity	M11	Input data	Total area of PV modules (without frame)	[+1-∞]m^2
Presence of technical domain – Electric vehicle charging		Not covered				
Presence of technical domain – Monitoring and control		Not covered				

[a] In the context of national or regional legal requirements, mandatory choices may be given at national or regional level for such specific applications following template of Annex A. Informative default choices are given in Annex B of each EPB Standard. The codification of the referenced options is the same, except for references to “A” and “B”.

[b] A not null value would suffice for the determination of the presence of the *technical domain*. Other parameters may also serve to identify the applicability of the *technical domain*.

[c] Always applicable, as per the calculation spreadsheet developed by the SRI support team

As indicated in EN 15316-1 [34], “the calculation direction is from the energy needs to the source”. Consequently, the consideration of the presence of each *technical domain* vis-à-vis EPB assessments starts at the energy needs. However, other data such as that related to emitters, generators, etc. could also be leveraged to assess it. This is the case for the electricity *technical domain*.

Next, for each applicable *technical domain*, the applicability of each *smart ready service* within shall be defined. This generally based on the presence of certain elements at system or sub-system level. Again, this is susceptible of being aligned with EPB assessment procedures, as defined in Table 16.

Table 16. SRI input data vis-à-vis the EPB Standards. Methodology selection. Smart ready service applicability.

SRI – General building information		**EPB Standards**				
Input data	**Options**	**Module name**	**Module code**	**Step in assessment**	**Description**	**Options**[a]
Heating – Emission control – [H-1a]- Applicability	**Binary choice** [1, 0][b]	Heating	M3-1, M3-5, M3-6, M3-7, M3-8	Input	Type of room emission system	Table 8 in EN 15316-2[c] [35]
Heating – Emission control – [H-1b]- Applicability						
Heating – Storage and shifting of thermal energy – [H-1c]- Applicability						

Heating – Distribution pumps control – [H-1d]- Applicability					Hydronic distribution system or else	Inferred from other data
Heating –Generation control – [H-2a]- Applicability					Type of generation system	EN 15316-4-1[c] [36], EN 15316-4-5[c] [37]
Heating –Generation control – [H-2b]- Applicability						EN 15316-4-2[c] [38]
Heating – Sequencing of different heat generators – [H-2d]- Applicability					Number of generation systems	-[c]
Heating – TES charging control – [H-1f]- Applicability					Product description data of storage unit	Table 5 in EN 15316-5 [39]
Heating – Information to occupants and facility managers – [H-3]- Applicability		Not covered				
Heating – Flexibility and grid interaction – [H-4]- Applicability		Not covered				
DHW – Storage control – [DHW-1a]- Applicability	**Binary choice** [1, 0][b]	DHW	M8-1, M8-6, M8-7, M8-8	Input	Product description data of storage unit	Table 5 in EN 15316-5 [39]
DHW – Storage control – [DHW-1b]- Applicability						
DHW – Storage control – [DHW-1d]- Applicability						Table 5 in EN 15316-5 [39], EN 15316-4-3[c] [40]
DHW – Sequencing of different generators – [DHW-2b]- Applicability					Number of generation systems	-[c]
DHW – Information to occupants and facility managers – [DHW-3]- Applicability		Not covered				
Cooling –Emission control – [C-1a]- Applicability	**Binary choice** [1, 0][b]	Cooling	M4-1, M4-5, M4-6, M4-7, M4-8	Input	Like *Presence of technical domain – Cooling* in Table 15	
Cooling –Emission control – [C-1b]- Applicability					Type of room emission system	Table 8 in EN 15316-2[c] [35]
Cooling – Distribution chilled water temperature control – [C-1c]- Applicability					Hydronic distribution system or else	Inferred from other data

Cooling – Distribution pumps control – [C-1d]- Applicability						
Cooling - Interlock between heating and cooling control of emission and/or distribution – [C-1f]- Applicability					Like *Presence of technical domain – Cooling* in Table 15	
Cooling - TES charging control – [C-1g]- Applicability					Product description data of storage unit	Table 5 in EN 15316-5 [39]
Cooling - Generation control – [C-2a]- Applicability					Like *Presence of technical domain – Cooling* in Table 15	
Cooling – Sequencing of different cool generators – [C-2b]- Applicability					Number of generation systems	-[c]
Cooling – Information to occupants and facility managers – [C-3]- Applicability		Not covered				
Cooling – Flexibility and grid interaction – [C-4]- Applicability		Not covered				
Ventilation – Supply air flow control – [V-1a]- Applicability	**Binary choice** [1, 0][b]	Ventilation	Always applicable as per [6]			
Ventilation – Air flow or pressure at air handler level – [V-1c]- Applicability			M5-1	Input	Type and configuration of ventilation system	Table 10 and 11 in EN 16798-3[c] [41]
Ventilation – Heat recovery control – [V-2c]- Applicability					Type and configuration of ventilation system	Table 11 in EN 16798-3[c] [41]
Ventilation – Free mechanical cooling – [V-3]- Applicability					Type and configuration of ventilation system	Table 10 and 11 in EN 16798-3[c] [41]
Ventilation – Supply air temperature control by AHU – [V-2d]- Applicability					Type and configuration of ventilation system	Table 11 in EN 16798-3[c] [41]
Ventilation – Information to occupants and facility managers – [V-6]- Applicability			Always applicable as per [6]			

Lighting – Occupancy control – [L-1a]- Applicability	**Binary choice** [1, 0][b]	Lighting	Always applicable as per [6]			
Lighting – Light level/daylight control – [L-2]- Applicability			Always applicable as per [6]			
Dynamic Building Envelope – Window control – [DE-1]- Applicability	**Binary choice** [1, 0][b]	Building (as such)	M2-5, M2-8	Input	Criteria for switching of shutters/blinds	Table 19 in ISO 52016-1 [26]
Dynamic Building Envelope – Window control – [DE-2]- Applicability					-	Control levels in section 2.2.1.2 of Annex G in EN ISO 52016-1:2017
Dynamic Building Envelope – Information to occupants and facility managers – [DE-4]- Applicability					Criteria for switching of shutters/blinds	Table 19 in ISO 52016-1 [26]
Electricity – Local electricity production. Reporting information – [E-2]- Applicability	**Binary choice** [1, 0][b]	Electricity	M11-8	Input	Total area of PV modules (without frame)	Table 21 in EN 15316-4-3 [40]
Electricity – Local electricity production. Optimisation – [E-4]- Applicability				Input	Total area of PV modules (without frame)	Table 21 in EN 15316-4-3 [40]
Electricity – CHP generation control– [E-5]- Applicability				Input	Total area of PV modules (without frame)	Table 21 in EN 15316-4-3 [40]
Electricity – Electricity storage control– [E-3]- Applicability					Power output at CHP100%+Sup100%	Table 8 in EN 15316-4-4 [42]
Electricity – Electricity storage. Reporting of information– [E-11]- Applicability		Not covered				
Electricity – Demand Side Management control– [E-8]- Applicability		Not covered				
Electricity – Electricity consumption. Reporting of information– [E-12]- Applicability		Electricity	Always applicable as per [6]			

[a] In the context of national or regional legal requirements, mandatory choices may be given at national or regional level for such specific applications following template of Annex A. Informative default choices are given in Annex B of each EPB Standard. The codification of the referenced options is the same, except for references to "A" and "B".

[b] Some smart ready services' applicability is interdependent. Thus, the applicability of one may influence the applicability of others.

[c] Not a choice in Annex A of the related standard. However, it is an information needed for the assessment.

The *smart-ready services* linked to the EV charging and Monitoring and control *technical domains* are not covered by EPB Standards.

Through Table 16 it is indicated that the assessment of *smart-ready services* for the SRI assessment can be linked with parameters that are requested by the EPB Standards when assessing the energy performance of a building or a building unit. Some of these parameters directly correlate with choices in the national annexes, and some others are indirectly considered in the input data to be provided by the assessor.

Lastly, for each applicable *smart ready service*, the main *functionality levels* shall be defined. Such *functionality levels* are enabled by certain smart-ready technologies either present or planned at the building or building unit (see section 2.5). In case more than one *functionality level* of a given *smart-ready service* is applicable, the share of applicability throughout the building of each shall be defined. In this case, the alignment with EPB assessment procedures is restricted to the BAC and TBM functions as defined in EN ISO 52120-1, which are extensively described in section 2.5.1. Notwithstanding, detailed information about the building, the HVAC systems and especially the type of automation, control and management functions is hardly ever available for EPB Assessments linked to most common applications (e.g., checking compliance with energy performance requirements, energy performance certification, and energy performance inspection). This is because most national EPB Assessments tend to overlook detailed contribution of BAC and TBM functions to the energy performance of buildings, although EN ISO 52120-1 contemplates the possibility.

EN ISO 52120-1 also defines a simplified factor-based method. It is intended for easily calculating a rough estimate of the impact of building automation, control, and management on the energy performance of a building based on a given energy performance (either a consumption metered, or a demand calculated) correlated to a certain BAC efficiency classification of the building. The efficiency class used for the BAC factor-based method, if previously existing for the assessed object, can be used to infer the *functionality levels* of each applicable *smart-ready services*. The equivalence between SRI *functionality levels* and the BAC efficiency classes defined in Table 6 of the EN ISO 52120-1:2021 is described in Annex C. The same rationale could be applied to other BAC efficiency classes set by Member States at national level.

2.5.2.2 How can the SRI support EPB assessments?

This section complements the previous by revealing the potential for influencing an EPB assessment based on a previous SRI assessment. The SRI assessment consists of a detailed characterization of the smart-ready technologies present or planned in, or relevant for, the building or building unit. These technological enablers, as defined in the default smart-ready service catalogue, strongly correlate with BAC and TBM functions (section 2.5.1). Consequently, the information contained in an SRI assessment may be used to modify the energy performance calculation to account for BAC contribution.

As anticipated in section 2.5.2.1, when there is a detailed method to account for the contribution of BAC to the energy performance calculation of buildings, the data contained in the SRI Assessment can be used as inputs for the relevant standards dealing with automation and control functions for each module of the calculation. In Table 7 in EN ISO 52120-1 a relation between the BAC and TBM functions and the related standards is indicated. This relation is further described in section 5.3.6 in ISO/TR 52120-2:2021.

Alternatively, the information contained in the SRI assessment can be used to infer the BAC efficiency classes applicable to the assessed object when using the simplified factor-based method to account for the contribution of BAC to the energy performance calculation of buildings. The equivalence between SRI *functionality levels* and the BAC efficiency classes defined in Table 6 of the EN ISO 52120-1:2021 is described in Annex C. The same rationale could be applied to other BAC efficiency classes set by Member States at national level.

2.5.3 IFC supported SRI assessment

The *functionality levels* within each *smart-ready service* considered in the SRI assessment are enabled by certain smart-ready technologies. These technological enablers, as defined in the SRI calculation methodology, shall be installed, or foreseen to be installed, in the assessed building or building unit. Thus, identifying the presence of certain building elements related to the *technical domain's smart-ready services* is a crucial task when assessing the SRI. Hence, where available, leveraging information contained in digital building models can ease the input data gathering process.

Building information modelling (BIM) represents the flagship initiative for the creation of digital building models through a myriad of ever-growing specialised software tools. The information contained in the digital building models can be structured through the Industry Foundation Classes (IFC), which is a standardised, digital description of the built environment. ISO 16739-1:2018 is an open, international standard, meant to be vendor-neutral and usable across a wide range of hardware devices, software platforms, and interfaces for many different use cases [43]. The IFC schema codifies in a logical way the identity and semantics, the characteristics or attributes and relationships of objects, abstract concepts, processes, and people. Leveraging such logic, it is possible to assess a given building design based on the configuration of objects, their relations, or attributes via rule-based systems [44]. This document intends to contribute to the existing body of research by defining a rule-based system for the semi-automatic assessment of the SRI via IFC literacy.

The remainder of the chapter is structured as follows. Section 2.5.3.1 introduces rule checking of building models. In section 2.5.3.2, the BIM model preparation guidelines for the semi-automatic SRI assessment are outlined, including a description of the IFC schema structure and the itemisation of the minimum modelling requirements. In section 2.5.3.4, the rule checking logical structuring is presented.

2.5.3.1 Introduction to rule checking of building models

Following C. Eastman, et al., *"rule-based systems apply rules, constraints, or conditions to a building design, with results such as 'pass', 'fail' or 'warning' or 'unknown' for cases where the needed data is incomplete or missing"*.

The rule checking process for digital building models can be structured into four stages as conceptualised in [44]:

1. Rule interpretation and logical structuring.
2. Building digital model preparation.
3. Rule execution phase.
4. Reporting of checking results.

Also indicated in [44], within the first three phases there must exist shared conventions so that the information contained in the building model can be coordinated with the coded rules. Thus, the building model ought to explicitly include the input for the rule checking or enable the derivation of the needed input from building model data.

2.5.3.2 BIM model preparation guidelines

Trade-offs exist between imposing documentation work on the building model designer and imposing greater inference capabilities to the rule checking process [44]. Consequently, modelling requirements must be carefully outlined. In this section, the IFC schema structure is presented as well as the modelling requirements for the semi-automatic assessment of SRI based on the IFC 4.0.2.1 schema [43].

2.5.3.2.1 IFC schema structure

The IFC schema enables a description of information that originates from the construction industry through a network of entities and their relationships. Within the IFC schema, an *entity* represents a class of information defined by common attributes and constraints as defined in ISO 10303-11. The *attributes* represent units of information within an *entity*, defined by a particular *type* or reference to a particular *entity*. The attributes may be subject to *constraints*. For example, mandatory and optional attributes. Values of mandatory attributes must be provided whereas values of optional attributes may be omitted. Attributes that are dynamically defined as a particular entity instance are called *properties*. Additionally, there are constructs that allow an attribute value to be one of multiple values identified by name. They are *enumerations*. *Quantities* refer to measurements of a scope-based metrics, specifically length, area, volume, weight, count, or time. *Relationships* are units of information describing an interaction between items.

In the IFC schema specifications, terms and concepts use the plain English words. Data items within the data specification use the following naming convention. Types, entities, rules, and functions start with the prefix “ifc” and continue with the English words in CamelCase naming convention. The attribute names within an entity follow the CamelCase naming convention with no prefix. The property set definitions that are part of this standard start with the prefix "Pset_" and continue with the English words in CamelCase naming convention. The quantity set definitions that are part of this standard start with the prefix "Qto_" and continue with the English words in CamelCase naming convention.

The data schema architecture of IFC defines four conceptual layers, each individual schema is assigned to exactly one conceptual layer.

- Resource layer — the lowest layer includes all individual schemas containing resource definitions, those definitions do not include a globally unique identifier and shall not be used independently of a definition declared at a higher layer;
- Core layer — the next layer includes the kernel schema and the core extension schemas, containing the most general entity definitions, all entities defined at the core layer, or above carry a globally unique id and optionally owner and history information;
- Interoperability layer — the next layer includes schemas containing entity definitions that are specific to a general product, process or resource specialization used across several disciplines, those definitions are typically utilized for inter-domain exchange and sharing of construction information;
- Domain layer — the highest layer includes schemas containing entity definitions that are specializations of products, processes, or resources specific to a certain discipline, those definitions are typically utilized for intra-domain exchange and sharing of information.

In the scope of building *smartness,* the IfcBuildingControlsDomain schema, which belongs to the Domain Layer, is of relevance. It defines concepts of building automation, control, instrumentation, and alarm. The distribution element IfcDistributionControlElement defines occurrence elements of a building automation control system that are used to impart control over elements of a distribution system, generalized in the ifcDistributionElement, described in the IfcHvacDomain and IfcElectricalDomain schemas. The ifcHvacDomain schema defines basic object concepts required for interoperability within the heating, ventilating, and air conditioning (HVAC) domain. The IfcElectricalDomain defines concepts of cabled systems where the cabling carries electrical supply, data, telephone signals or other forms of cable transmission.

The **ifcDistributionFlowElement** defines occurrence elements of a distribution system that facilitate the distribution of energy or matter, such as air, water, or power. The elements are then grouped into a system (i.e., a heating system). Below the entity, the following exist, also depicted in Figure 12

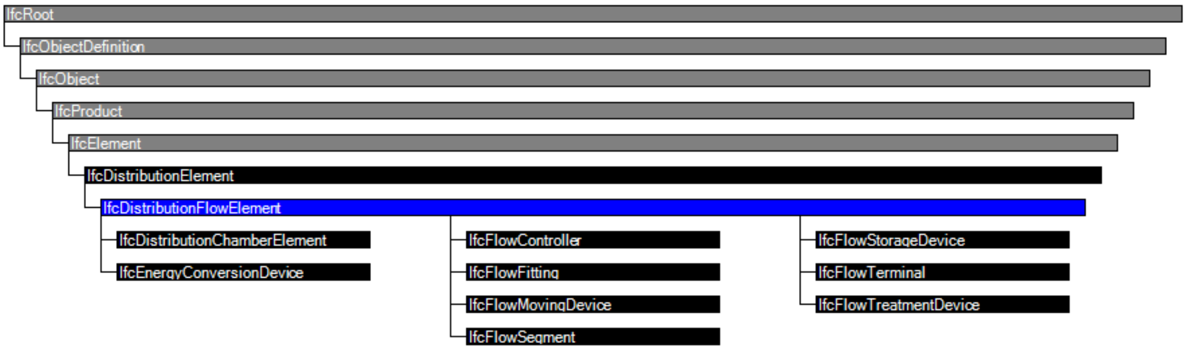

Figure 12. ifcDistributionFlowElement entity inheritance [45].

- **ifcDistributionChamberElement** which defines a place at which distribution systems and their constituent elements may be inspected or through which they may travel. An

IfcDistributionChamberElement is a formed volume used in a distribution system, such as a sump, trench, or manhole.

- **ifcEnergyConversionDevice** defines the occurrence of a device used to perform energy conversion or heat transfer and typically participates in a flow distribution system.
- **ifcFlowController** defines the occurrence of elements of a distribution system that are used to regulate flow through a distribution system. Examples include dampers, valves, switches, and relays.
- **IfcFlowFitting** defines the occurrence of a junction or transition in a flow distribution system, such as an elbow or tee.
- **IfcFlowMovingDevice** defines the occurrence of an apparatus used to distribute, circulate, or perform conveyance of fluids, including liquids and gases (such as a pump or fan), and typically participates in a flow distribution system.
- **IfcFlowSegment** defines the occurrence of a segment of a flow distribution system.
- **IfcFlowStorageDevice** defines the occurrence of a device that participates in a distribution system and is used for temporary storage (such as a tank).
- **IfcFlowTerminal** defines the occurrence of a permanently attached element that acts as a terminus or beginning of a distribution system (such as an air outlet, drain, water closet, or sink). A terminal is typically a point at which a system interfaces with an external environment.
- **IfcFlowTreatmentDevice** defines the occurrence of a device typically used to remove unwanted matter from a fluid, either liquid or gas, and typically participates in a flow distribution system.

The connections between the diverse elements are described by distribution ports through the **ifcDistributionPort** entity, which is linked to the distribution flow elements via the **ifcRelNests** entity. Distribution ports are defined by system type and flow direction such that for two ports to be connected, they must share the same system type and have opposite flow directions.

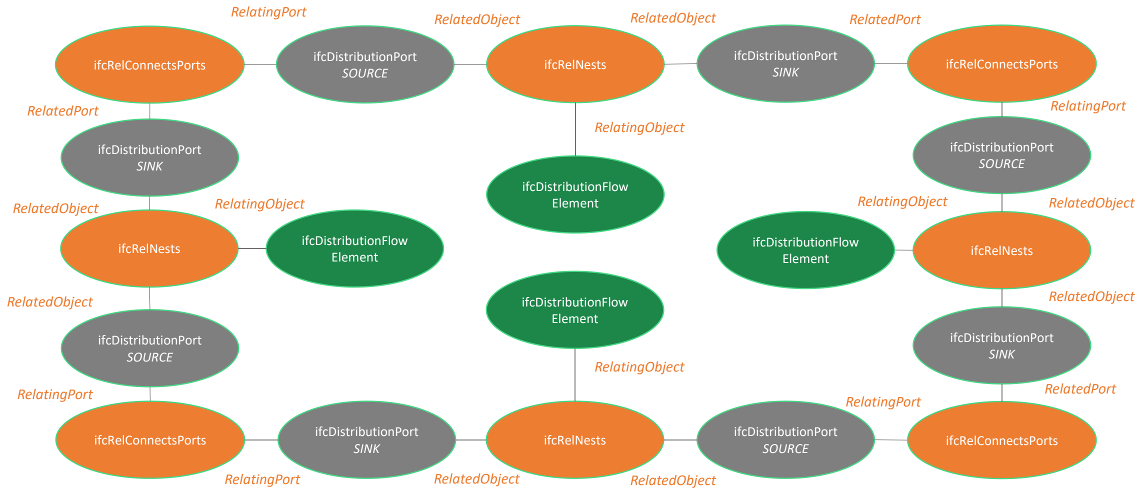

Figure 13. Example of the connection of ifcDistributionFlowElements.

See in Figure 13 an example of the use of ifcDistributionPort to connect ifcDistributionFlowElements. Note how the relationships ifcRelNests and ifcRelConnectsPorts are used, and how the ifcDistributionPorts have attributes outlining the direction of the flow. In this case all ifcDistributionPorts would have the *SystemType* attribute defined equally. If the ifcDistributionFlowElements were part of a heating system, then the *SystemType* attribute would be “HEATING”.

The **IfcDistributionControlElement** defines elements of a building automation control system. These are typically used to control distribution system elements to maintain variables such as temperature, humidity, pressure, flow, power, or lighting levels, through the modulation, staging or sequencing of mechanical or electrical devices. Below the entity, the following exist, also depicted in Figure 14.

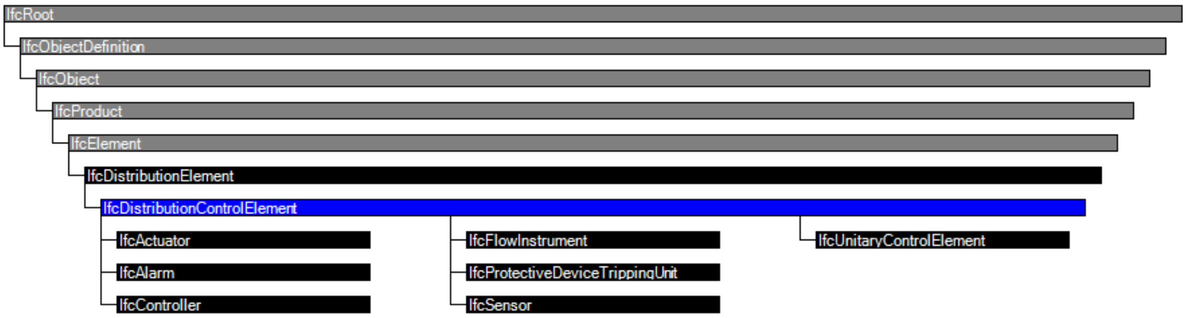

Figure 14. ifcDistributionControlElement entity inheritance [45]**.**

- **IfcActuator** defines a mechanical device for moving or controlling a mechanism or system. An actuator takes energy, usually created by air, electricity, or liquid, and converts that into some kind of motion.
- **IfcAlarm** defines a device that signals the existence of a condition or situation that is outside the boundaries of normal expectation or that activates such a device.
- **IfcController** defines a device that monitors inputs and controls outputs within a building automation system. A controller may be physical (having placement within a spatial structure) or logical (a software interface or aggregated within a programmable physical controller).
- **IfcFlowInstrument** defines a device that reads and displays the value of a particular property of a system at a point or displays the difference in the value of a property between two points. Instrumentation is typically for the purpose of determining the value of the property at a point in time. It is not the purpose of an instrument to record or integrate the values over time (although they may be connected to recording devices that do perform such a function). This entity provides for all forms of mechanical flow instrument (thermometers, pressure gauges etc.) and electrical flow instruments (ammeters, voltmeters etc.).
- **IfcProtectiveDeviceTrippingUnit** defines a device that breaks an electrical circuit at a separate breaking unit when a stated electric current that passes through the unit is exceeded.
- **IfcSensor** defines a device that measures a physical quantity and converts it into a signal which can be read by an observer or by an instrument.
- **IfcUnitaryControlElement** combines several control components into a single product, such as a thermostat or humidistat. A unitary control element provides a housing for an aggregation of control or electrical distribution elements that, in combination, perform a singular (unitary) purpose. Each item in the aggregation may have its own geometric representation and location.

The three general functional categories of control elements are as follows:

- Impart control overflow control elements (**IfcFlowController**) in a distribution system such as dampers, valves, or relays, typically with actuation (**IfcActuator**).
- Sensing elements (**IfcSensor**) that measure changes in the controlled variable such as temperature, humidity, pressure, or flow.
- Controllers (**IfcController**) typically classified according to the control action they seek to perform and generally responsible for making decisions about the elements under control.

The distribution control elements (i.e., IfcDistributionControlElement types and subtypes) typically relate to many different distribution flow elements (i.e., IfcDistributionFlowElement types and subtypes). The objectified relationship **IfcRelFlowControlElements** relates control and flow elements. This relationship implies a sensing or controlling relationship. A generic way in which the control elements connect with each other is depicted in Figure 15. If elements are merely connected without any control relationship, then IfcRelConnectsElements should be used.

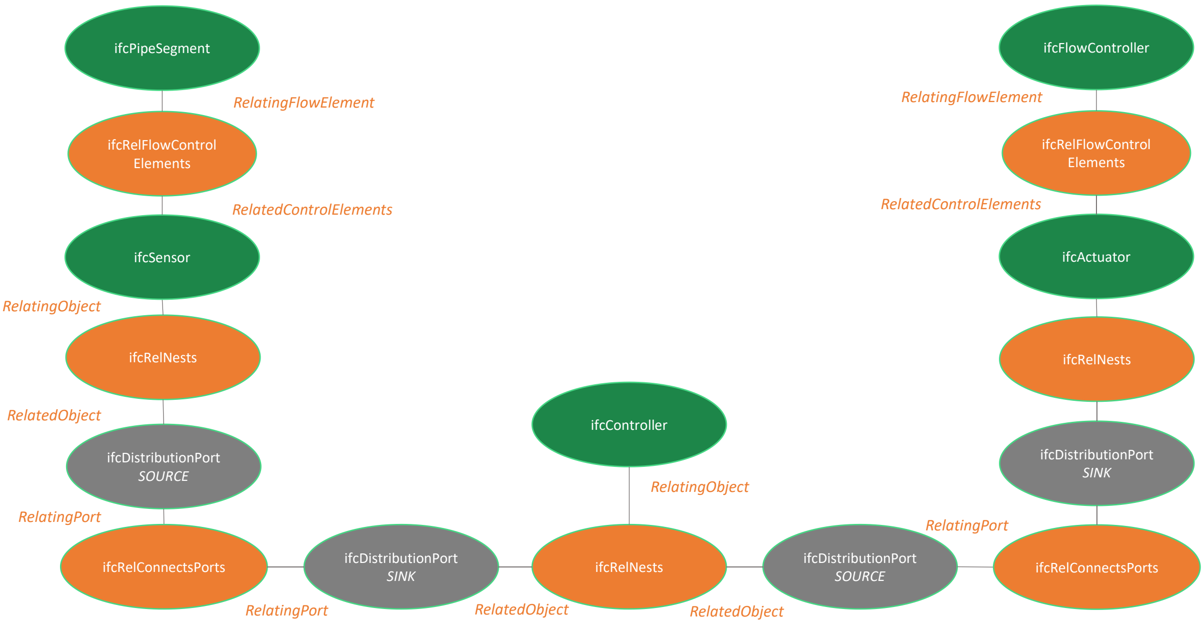

Figure 15. Example of the connection of ifcDistributionControlElements.

The key distinction between IfcDistributionFlowElement and IfcDistributionControlElement is whether it is internal or external to the flow system, respectively. A physical device that connects within the flow system in which it measures (having inlet/outlet pipes for the measured substance) follows the IfcDistributionFlowElement hierarchy. Otherwise, if it monitors/controls but does not connect inline within the flow system (it is external or is a component of another device), then it follows the IfcDistributionControlElement hierarchy.

Note how, in terms of hierarchy as depicted in Figure 12 and Figure 14, both IfcDistributionFlowElement and IfcDistributionControlElement are contained within IfcProduct, which is an abstract representation of any object that relates to a geometric or spatial context. Also contained within IfcElement, which is a generalization of all components that make up an AEC (i.e., Architecture Engineering and Construction) product.

2.5.3.3 Modelling requirements

As outlined in [44], many trade-offs exist in rule checking implementation approaches as the burden of the data provision for rule checking can be put on the designer, through a definition of stringent modelling requirements, or on the rule checking environment, by imposing greater inference capabilities to the rule checking application. Regardless of the ambition of the rule checking software, there are some limitations when reusing information contained in an IFC model [46].

On the one hand, there may be a limited expression range within the required domains or disciplines. Markedly, commonly used BIM software in the design phase of buildings do not allow describing the control functions of HVAC systems with the needed detail for subsequent phases (e.g., commissioning, maintenance, energy performance assessment, etc.). This may be the case for the comprehensive SRI assessment as well. Consequently, additional work is required to extend the information regarding the control functions available in the model. This information enhancement can be made on the BIM model [47] or directly in the specialised software (i.e., SmartLivingEPC Web Platform). The latter is the applicable case as indicated in section 2.5.

On the other hand, when the expression range is enough for one specific purpose, it may be relevant to limit the information available to a specific user to maintain the efficiency and quality in the collaborative workflow BIM fosters. Also, since the IFC schema enables users to define generic objects with user defined set of attributes as well as relying on predefined enumerations, it may occur that the same information is described in multiple ways. This may constitute a difficulty when extracting information from IFC literacy [46]. In this regard, human intervention, apart from being required by regulation for the SRI assessment [3], is expected to always be needed from the technical point of view. At least to validate and, in most cases, to complement the SRI input data automatically retrieved from digital building model.

As initially outlined, the modelling requirements for BIM models shall be in accordance with the ambition of the rule checking process. In the scope of this chapter, the modelling requirements for MEP models are defined in accordance with the rule checking for SRI assessment from section 2.5.3.4.

The modelling requirements are restricted to the use of entities whose supertype is *ifcDistributionElement*. This is entities within *ifcDistributionFlowElement* and *ifcDistributionControlElements* classes, which is consistent with previous work [48] [49]. Additionally, their internal connections must be defined through the relationship class *IfcRelNests* and *ifcDistributionPort* entity. The port attributes 8, 9 and 10 (i.e., *FlowDirection*, *PredefinedType*, and *SystemType*) shall be specified. Furthermore, the link between entities within the ifcDistributionFlowElement and ifcDistributionControlElement classes shall be defined via the relationship class *ifcRelFlowControlElements*. This is a novel approach that, to the authors knowledge improves the existing state of the art on the topic.

The distribution port's attribute options are determined by the relevant enumeration. For the *FlowDirection*, the *ifcFlowDirectionEnum* (e.g., source, sink, sourceandsink); for the *PredefinedType*, the *ifcDistributionPortTypeEnum* (e.g., cable, cablecarrier, duct, pipe); for the *SystemType* (e.g., airconditioning, chilledwater, domestichotwater, heating, ventilation, electrical, lighting, control).

Not abiding by these modelling requirements may impede the complete application of the rule checking process. However, it is still possible to find a balance between a not too stringent BIM modelling and the usefulness of a subset of rules. For example, some rules apply only to distribution flow elements, whereas others do to distribution flow control elements. Therefore, if only the former is defined, the subset of related rules may still be applicable. In any case, the provision of input data for the SRI assessment from IFC literacy intends to ease the process by the SRI assessor not to deem the SRI assessor superfluous. As indicated in section 2.5, manual provision of SRI input data shall always be possible.

2.5.3.4 Rule checking for SRI assessment

Many initiatives have developed applications capable of parsing IFC files, interpreting and leveraging the information therein for many purposes (e.g., energy performance assessments, compliance with building codes, etc.) [46]. However, leveraging IFC literacy for the purpose of the SRI assessment has only been attempted, to the authors knowledge, by the D^{2}EPC project[1] [50] [48] and the EPC Recast project[2] [49]. In [50], the assessment on whether physical objects, relationships and configurations needed for the definition of the control functions linked to the SRI could be defined through IFC entities within the IfcBuildingControlDomain from the latest version of IFC4 schema was performed. It was found that although a significant number of *functionality levels* were not addressed, the identification of the applicability of some *technical domains* could be performed by identifying the presence of certain entities. The remainder of the information needed for the SRI assessment shall be manually inserted by the SRI assessor [48]. In [49], a basic ontological alignment between the basic IFC schema concepts (i.e., IfcDistributionElemement and IfcDistributionControlElement sub-classes) and the SRI technical domains was outlined using the Web Ontology Language (OWL).

In this section the logic structuring of the rule checking process for the partial assessment of SRI leveraging data from IFC models is presented. The rules are represented as IF-THEN-ELSE statements. The IF condition is assessed to elements from the IFC schema defined as modelling requirements in section 2.5.3.3, and the THEN-ELSE consequence is applied to the SRI assessment. Markedly, the rule checking procedure presented here can not consider the definition of customised entities and/or attributes. Therefore, it presumes, for most cases, that the distribution flow elements' type is left to one of the predefined options.

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[1] Funded by the European Union's Horizon 2020 research and innovation programme under the grant agreement number 892984.

[2] Funded by the European Union's Horizon 2020 research and innovation programme under the grant agreement number 893118.

In the next subsections, the logic structuring of the rule checking process is presented. The rationale of the rule execution phase is the following:

- To assess the presence of each SRI *technical domain*, the existence of a distribution element at system or sub-subsystem level related to each *technical domain* is proposed.
    - This would be equivalent to filling cells G48:G56 in "Building Information" tab in the SRI calculation spreadsheet (v4.5).
- To assess the applicability of each SRI *technical domain*'s *smart-ready service*, the presence of a distribution element at sub-subsystem level related to each *technical domain* is proposed.
    - This would be equivalent to filling cells I6:I104 in "Calculation" tab in the SRI calculation spreadsheet (v4.5).
- To assess each *technical domain's smart-ready service functionality level*, the presence of control elements at sub-system level is proposed.
    - This would be equivalent to filling cells J6:J104 in "Calculation" tab in the SRI calculation spreadsheet (v4.5).

The rule checking is presented divided in the above steps. Nevertheless, when being implemented into a fully-fledged software they should be merged seeking programming efficiency. Such programming is out of the scope of this chapter and is left to be performed by future work within WP5. The rule checking has been defined seeking the simplest formulation.

2.5.3.4.1 Technical domain presence

The following rules are defined for checking the applicability of the *technical domains* in the building or building unit. The general approach is to first identify the presence of distribution networks specific of a *technical domain*. Then, if applicable, to contemplate the possibility of standalone devices that relate to a *technical domain* without a distribution network (i.e., when the emitter and the generator are the same device).

<u>The rules identified in this section enable to ascertain the presence of all the *technical domains*, except for the Electric Vehicle Charging and the Monitoring and Control</u>.

- **Heating**.

```
IF
  an ifcDistributionPort is found
    whose SystemType attribute = "HEATING"
  OR
    an ifcSpaceHeater is found
  OR
    an ifcElectricAppliance is found
    whose PredefinedType attribute = "FREESTANDINGELECTRICHEATER"
  OR
    an ifcBurner is found
THEN
  The HEATING technical domain is applicable
ELSE
  The HEATING technical domain is not applicable.
```

- **Domestic hot water**.

```
IF
  an ifcDistributionPort is found
    whose SystemType attribute = "DOMESTICHOTWATER"
THEN
  The DOMESTIC HOT WATER technical domain is applicable
ELSE

  The DOMESTIC HOT WATER technical domain is not applicable
```

- **Cooling**.

```
IF
  an ifcDistributionPort is found
```

```
      whose SystemType attribute = "CHILLEDWATER"
      OR
      whose SystemType attribute = "AIRCONDITIONING"
  THEN
    The COOLING technical domain is applicable
  ELSE
    The COOLING technical domain is not applicable.
```

- **Ventilation**.

```
  IF
    an ifcDistributionPort is found
      whose SystemType attribute = "VENTILATION"
    OR
      an ifcElectricAppliance is found
      whose PredefinedType attribute = "FREESTANDINGFAN"
  THEN
    The VENTILATION technical domain is applicable
  ELSE
    The VENTILATION technical domain is not applicable.
```

- **Lighting**. The Lighting *technical domain* will generally be applicable to residential buildings or building units.

```
  IF
    an ifcDistributionPort is found
      whose SystemType attribute = "LIGHTING"
  THEN
    The LIGHTING technical domain is applicable
  ELSE
    The LIGHTING technical domain is not applicable.
```

- **Dynamic Building Envelope**. The Dynamic Building Envelope *technical domain* will generally be applicable to residential buildings or building units.

```
  IF
    an ifcWindow is found
  THEN
    The DYNAMIC BUILDING ENVELOPE technical domain is applicable
  ELSE
    The DYNAMIC BUILDING ENVELOPE technical domain is not applicable.
```

- **Electricity**.

```
  IF
    an ifcDistributionPort is found
      whose SystemType attribute = "POWERGENERATION"
    OR
      an ifcElectricGenerator is found
      whose PredefinedType attribute = "CHP"
  THEN
    The ELECTRICITY technical domain is applicable
  ELSE
    The ELECTRICITY technical domain is not applicable.
```

- **Electric Vehicle Charging**.

The Electric Vehicle Charging *technical domain* is not covered by the IFC4 schema.

- **Monitoring and control**.

The Monitoring and Control *technical domain* is not covered by the IFC4 schema.

As indicated in section 2.5.3.3, the definition of every distribution flow element shall include the detail on the distribution ports, which, in turn, define the system type. Therefore, it is possible to identify the presence of a heating system in the IFC building model. Leveraging the attributes of the *ifcDistributionPort* entities within the model is an improvement of [50], where the presence of a heating system was correlated with the presence of a finite set of entities (e.g., *ifcUnitaryEquipment*, *ifcBoiler*, *ifcSpaceHeater*, *ifcCoil*, *ifcElectricAppliance*). That approach, albeit of significant value, incurred in some imprecision. For example, and as outlined in [49], the presence of the *ifcBoiler* entity does not imply unequivocally the presence of a heating system, as it could also be related to a domestic hot water installation. This is also true for the *ifcUnitaryEquipment* and *ifcCoil*.

2.5.3.4.2 Smart-ready service applicability

The following rules are defined for checking the applicability of the *technical domains' smart-ready services* in the building or building unit. The focus is in assessing the applicability of the *smart-ready services* that are mutually exclusive[3]. For example, as per the SRI assessment default service catalogue, the heat emission control can be either TABS or every other option. In addition, special attention shall be paid to other *smart-ready services* whose lowest *functionality level* implies the presence of the related *smart-ready service*. For example, for the control of combined heat and power plant (CHP) *smart-ready service*, the lowest *functionality level* indicates "CHP control based on scheduled runtime management and/or current heat energy demand". This implies the presence of CHP.

The general approach is to first identify the presence of distribution networks elements specific of a *technical domain*, provided that the applicability of the given *technical domain* has been proven as indicated in section 2.5.3.4.1. The *smart-ready services* not assessed at this stage of the rule checking process are assumed to be applicable with a default *functionality level* of zero. In the subsequent subsections the rules defined for each *technical domain* are presented.

The rules identified in this section enable to ascertain the presence of all most *smart-ready services* (Table 17).

Table 17. *Smart-ready services* covered by the rule checking on IFC

Technical domain	Smart-ready services covered by the rule-checking on IFC		
	SRI Code	Share of total	Comments
Heating	H-1a, H-1b, H-1c, H-1d, H-1f, H-2a, H-2b, H-2d	80%	H-3, H-4 are not covered as their presence can't be assessed based on distribution flow elements.
DHW	DHW-1a, DHW-1b, DHW-1d, DHW-2b	80%	DHW-3 is not covered as their presence can't be assessed based on distribution flow elements.
Cooling	C-1a, C-1b, C-1c, C-1d, C-1g, C-2b	60%	C-1f, C-2a, C-3, C-4 are not covered as their presence can't be assessed based on distribution flow elements.
Ventilation	V-1c, V-2c	60%[a]	V-2d, V-3, V-6 are covered as their presence can't be assessed based on distribution flow elements.
Lighting	-	0%[b]	None of the *smart-ready services* are covered as their presence can't be assessed based on distribution flow elements.

---

[3] From a methodological perspective, two *smart-ready services* for the same service (i.e., heat emission) could coexist in different parts of the building. However, from the practical stance, the SRI spreadsheet (v4.5) does not enable it. See column M (i.e., M4 and M5) in "overview_of_services" tab for further details.

Dynamic Building Envelope	-	0%	None of the *smart-ready services* are covered as their presence can't be assessed based on distribution flow elements.
Electricity	E-2, E-3, E-4, E-5, E-8, E-11	100%[c]	E-12 is not covered as their presence can't be assessed based on distribution flow elements.
EV charging	*Technical domain* is not covered by the IFC4 schema		
Monitoring and Control	*Technical domain* is not covered by the IFC4 schema		

[a] As per the SRI calculation sheet (v4.5), V-1a shall always be assessed.

[b] As per the SRI calculation sheet (v4.5), L-1a and L2 shall always be assessed.

[c] As per the SRI calculation sheet (v4.5), E-12 shall always be assessed.

2.5.3.4.2.1 Heating

- **Heating emission control.** H-1a, H-1b.

As indicated in section 2.5.1.2, the applicability of H-1a or H-1b is based on the emission sub-system of type TABS or not. Consequently, the main objective is to discern whether the heat emitter is TABS or else. However, as there is not a distribution flow element specific for TABS emission sub-system it is not possible to unequivocally identify whether H-1a or H-1b applies for the SRI assessment solely based on the information available in the IFC model.

The predefined distribution element to be used for defining TABS is **ifcCoil** ("*coils may be used for non-airflow cases such as embedded in a floor slab*" [45]) but it is not exclusive ("*A coil is a device used to provide heat transfer between non-mixing media. A common example is a cooling coil, which utilizes a finned coil in which circulates chilled water, antifreeze, or refrigerant that is used to remove heat from air moving across the surface of the coil. A coil may be used either for heating or cooling purposes by placing a series of tubes (the coil) carrying a heating or cooling fluid into an airstream*" [45]).

The available information in the IFC4 schema allow to define the following:

```
IF
    an ifcCoil is found embedded in a building structural element
    whose ifcDistributionPort's SystemType attribute = "HEATING"
THEN
  The smart-ready service H-1b is applicable and H-1a is not.
ELSE
  The smart-ready service H-1a is applicable and H-1b is not.
```

- **Control of distribution fluid temperature** and **pumps in networks**. H-1c, H-1d.

Distribution sub-systems don't apply for standalone devices.

The available information in the IFC4 schema allow to define the following:

```
IF
  an ifcDistributionPort is found
    whose SystemType attribute = "HEATING"
THEN
  The smart-ready service H-1c and H-1d are applicable
ELSE
  The smart-ready service H-1c is not applicable
```

In addition, control of pumps is only relevant for hydronic systems.

```
IF
  an ifcPump is found
    whose ifcDistributionPort's SystemType attribute = "HEATING"
THEN
  The smart-ready service H-1d is applicable
ELSE
  The smart-ready service H-1d is not applicable
```

- **Thermal Energy Storage (TES) for heating**. H-1f.

The available information in the IFC4 schema allow to define the following:

```
IF
  an ifcTank is found
    whose PredefinedType attribute = "STORAGE"
    AND
    whose ifcDistributionPort's SystemType attribute = "HEATING"
THEN
  The smart-ready service H-1f is applicable
ELSE
  The smart-ready service H-1f is not applicable
```

- **Heating generation control.** H-2a, H-2b.

As indicated in section 2.5.1.2, the applicability of H-2a or H-2b is based on the generation sub-system of type heat pump or not. Consequently, the main objective is to discern whether the heat generator is a heat pump or else.

The available information in the IFC4 schema allow to define the following:

```
IF
    an ifcUnitaryEquipment is found
THEN
  The smart-ready service H-2b is applicable and H-2a is not.
ELSE
  The smart-ready service H-2a is applicable and H-2b is not.
```

- **Sequencing of different heat generators**. H-2d.

The available information in the IFC4 schema allow to define the following:

```
IF
  More than an ifcEnergyConversionDevice is found
    whose ifcDistributionPort's SystemType attribute = "HEATING"
THEN
  The smart-ready service H-2d is applicable
ELSE
  The smart-ready service H-2d is not applicable
```

2.5.3.4.2.2 Domestic Hot Water

- **Control of DHW storage charging.** DHW-1a, DHW-1b.

As indicated in section 2.5.1.2, the applicability of DHW-1a or DHW-1b is based on the generation sub-system of type direct electrical heating or using hot water generation. Consequently, the main objective is to discern whether the heat generator is direct electrical heating or integrated electric heat pump.

The available information in the IFC4 schema allow to define the following:

```
IF
  an ifcTank is found
    whose PredefinedType attribute = "STORAGE"
    AND
    whose ifcDistributionPort's SystemType attribute = "DOMESTICHOTWATER"
    AND
```

```
    whose ifcDistributionPort's PredefinedType attribute = "CABLE"
THEN
  The smart-ready service DHW-1a is applicable and DHW-1b is not.
ELSE
  The smart-ready service DHW-1b is applicable and DHW-1a is not.
```

- **Control of DHW storage charging.** DHW-1c.

As indicated in section 2.5.1.2, the applicability of DHW-1a or DHW-1b is based on the generation sub-system of type direct electrical heating or using hot water generation. Consequently, the main objective is to discern whether the heat generator is direct electrical heating or integrated electric heat pump.

The available information in the IFC4 schema allow to define the following:

```
IF
  an ifcSolarDevice is found
    whose PredefinedType attribute = "SOLARCOLLECTOR"
    AND
    whose ifcDistributionPort's SystemType attribute = "DOMESTICHOTWATER"
THEN
  The smart-ready service DHW-1c is applicable.
ELSE
  The smart-ready service DHW-1c is not applicable.
```

- **Sequencing of different DHW generators**. DHW-2d.

The available information in the IFC4 schema allow to define the following:

```
IF
  More than an ifcEnergyConversionDevice is found
    whose ifcDistributionPort's SystemType attribute = "DOMESTICHOTWATER"
THEN
  The smart-ready service DHW-2d is applicable
ELSE
  The smart-ready service DHW-2d is not applicable
```

2.5.3.4.2.3 Cooling

- **Cooling emission control.** C-1a, C-1b.

As indicated in section 2.5.1.2, the applicability of C-1a or C-1b is based on the emission sub-system of type TABS or not. Consequently, the main objective is to discern whether the heat emitter is TABS or else. However, as there is not a distribution flow element specific for TABS emission sub-system it is not possible to unequivocally identify whether C-1a or C-1b applies for the SRI assessment solely based on the information available in the IFC model.

The predefined distribution element to be used for defining TABS is **ifcCoil** ("*coils may be used for non-airflow cases such as embedded in a floor slab*" [45]) but it is not exclusive ("*A coil is a device used to provide heat transfer between non-mixing media. A common example is a cooling coil, which utilizes a finned coil in which circulates chilled water, antifreeze, or refrigerant that is used to remove heat from air moving across the surface of the coil. A coil may be used either for heating or cooling purposes by placing a series of tubes (the coil) carrying a heating or cooling fluid into an airstream*" [45]).

The available information in the IFC4 schema allow to define the following:

```
IF
    an ifcCoil is found embedded in a building structural element
    whose ifcDistributionPort's SystemType attribute = "CHILLEDWATER"

THEN
  The smart-ready service C-1b is applicable and C-1a is not.
ELSE
  The smart-ready service C-1a is applicable and C-1b is not.
```

- **Control of distribution fluid temperature** and **pumps in networks**. C-1c, C-1d.

Distribution sub-systems don't apply for standalone devices.

The available information in the IFC4 schema allow to define the following:

```
IF
  an ifcDistributionPort is found
    whose SystemType attribute = "CHILLEDWATER"
THEN
  The smart-ready service C-1c and C-1d are applicable
ELSE
  The smart-ready service C-1c is not applicable
```

In addition, control of pumps is only relevant for hydronic systems.

```
IF
  an ifcPump is found
    whose ifcDistributionPort's SystemType attribute = "CHILLEDWATER"
THEN
  The smart-ready service C-1d is applicable
ELSE
  The smart-ready service C-1d is not applicable
```

- **Thermal Energy Storage (TES) for heating**. C-1g.

The available information in the IFC4 schema allow to define the following:

```
IF
  an ifcTank is found
    whose PredefinedType attribute = "STORAGE"
    AND
    whose ifcDistributionPort's SystemType attribute = "CHILLEDWATER"
THEN
  The smart-ready service C-1g is applicable
ELSE
  The smart-ready service C-1g is not applicable
```

- **Sequencing of different chill generators**. C-2b.

The available information in the IFC4 schema allow to define the following:

```
IF
  More than an ifcEnergyConversionDevice is found
    whose ifcDistributionPort's SystemType attribute = "CHILLEDWATER"
    OR
    whose ifcDistributionPort's SystemType attribute = "AIRCONDITIONING"
THEN
  The smart-ready service C-2b is applicable
ELSE
  The smart-ready service C-2b is not applicable
```

2.5.3.4.2.4 Ventilation

As per the SRI calculation sheet (v4.5), V-1a shall always be assessed.

- **Air flow or pressure control at the air handler level** V-1c.

The available information in the IFC4 schema allow to define the following:

```
IF
  an ifcDistributionPort is found
    whose SystemType attribute = "VENTILATION"
THEN
  The smart-ready service V-1c is applicable
ELSE
  The smart-ready service V-1c is not applicable
```

- **Heat recovery control**. V-2c.

The available information in the IFC4 schema allow to define the following:

```
IF
  an ifcAirToAirHeatRecovery is found
    whose ifcDistributionPort's SystemType attribute = "VENTILATION"
THEN
  The smart-ready service V-2c is applicable
ELSE
  The smart-ready service V-2c is not applicable
```

2.5.3.4.2.5 Lighting

The available information in the IFC4 schema does not allow to assess the applicability of any of the *smart-ready services*.

2.5.3.4.2.6 Dynamic building envelope

The available information in the IFC4 schema does not allow to assess the applicability of any of the *smart-ready services*.

2.5.3.4.2.7 Electricity

- **Reporting information regarding local electricity generation**. E-2.
- **Storage of locally generated electricity**. E-3.
- **Optimising self-consumption of locally generated electricity**. E-4.

The available information in the IFC4 schema allow to define the following:

```
IF
  an ifcSolarDevice is found
    whose PredefinedType attribute = "SOLARPANEL"
  OR
  an ifcElectricGenerator is found
    whose PredefinedType attribute = "CHP"

THEN
  The smart-ready service E-2, E-3 and E-4 are applicable
ELSE
  The smart-ready service E-2, E-3 and E-4 are not applicable
```

- **Control of combined heat and power plant**. E-5.

The available information in the IFC4 schema allow to define the following:

```
IF
  an ifcElectricGenerator is found
    whose PredefinedType attribute = "CHP"

THEN
  The smart-ready service E-5 is applicable
ELSE
  The smart-ready service E-5 is not applicable
```

- **Support of microgrid operation modes**. E-8.
- **Reporting information regarding energy storage**. E-11.

The available information in the IFC4 schema allow to define the following:

```
IF
  an ifcElectricFlowStoringDevice is found
    whose PredefinedType attribute = "BATTERY"

THEN
  The smart-ready service E-8 and E-11 are applicable
ELSE
  The smart-ready service E-8 and E-11 are not applicable
```

2.5.3.4.2.8 Electric vehicle charging

The available information in the IFC4 schema does not allow to assess the applicability of any of the *smart-ready services*.

2.5.3.4.2.9 Monitoring and control

The available information in the IFC4 schema does not allow to assess the applicability of any of the *smart-ready services*.

2.5.3.4.3 Functionality level applicability

Additional rules could be defined for assessing the *technical domains' smart-ready services' functionality level* in the building or building unit. The general approach shall be to identify the presence of related distribution control elements linked to specific *smart-ready services*, provided that the applicability of the given *smart-ready service* has been proven as indicated in section 2.5.3.4.2. Nevertheless, this last step of the rule-checking process is not defined in this document. The main reason is because of the existing limitations of defining SRI *functionality levels* relying on the limited expression range of the IFC schema. Consequently, rather than imposing additional work to the assessor to extend the information regarding the control functions available in the model [47], it's preferred for him/her to provide the missing input data via the SmartLivingEPC Web Platform.

2.6 Case Studies

In this section, the results of the SRI assessment, following the default methodology produced by the SRI Support team [6] is presented. A brief extract of the descriptive information for each case study, as defined in SmartLivingEPC's Deliverable 1.2, is included for context.

Note that as the national implementation regarding the SRI scheme has not taken place, contextual adaptations on the calculation methodology (e.g., service catalogue) have been made by the partners in charge of each case study to the best of their ability.

2.6.1 Pilot #1 nZEB Smart House

2.6.1.1 Description

This pilot is a living lab of the Centre for Research and Technology Hellas (CERTH). Although constructively is a duplex single-family building, it is generally used as an office during working hours and eventually as a laboratory. It is a two-story building with over 300 m^2. It was constructed in 2016.

The building is equipped with many sensors (e.g., temperature, humidity, and CO_2 at room level; dedicated luminance sensors, and outdoor weather station) which feed information to the building management system (BMS) and Smart Home IoT platform. This, in turn, enables remote operation of some of the technical systems. The heating and cooling services are provided by the same facility. It is a variable refrigerant flow (VRF) installation, with at least one terminal unit in each room, and one outdoor unit per floor. The system is connected to a building management system (BMS), enabling the temperature control of each room. The domestic hot water (DHW) service is by design provided by an air-to-water heat pump coupled with a solar thermal installation (i.e., 2.5 m^2 of collector area and 200 l storage tank). Due to the nature of the building, the service is in practice not provided in the building. In addition, ventilation is only provided by natural means. Lighting is provided by many luminaries installed throughout the building. All of them are controlled by room manual switches. The windows in the building are manually operated; some are motorised. There is 0.85 kWp photovoltaic generation located on the roof, which supplies on-site renewable electricity to the whole building. In addition, there are two units of 12 V battery storage with capacity of 180 Ah each. In addition, there is a vertical axis wind turbine coupled with a 24-pole permanent-magnet synchronous electric generator with a nominal power of 1.75 kVA. Lastly, the building is coupled with a 1-way controlled EV charging station.

2.6.1.2 SRI results

Upon Method B application, the building obtains a total SRI score of 51.2%. Per key functionality, the scores are Energy performance and operation 56.1%, Response to user needs 55%, and Energy flexibility 42.6%. The impact and domain scores are shown in Figure 16 and Figure 17.

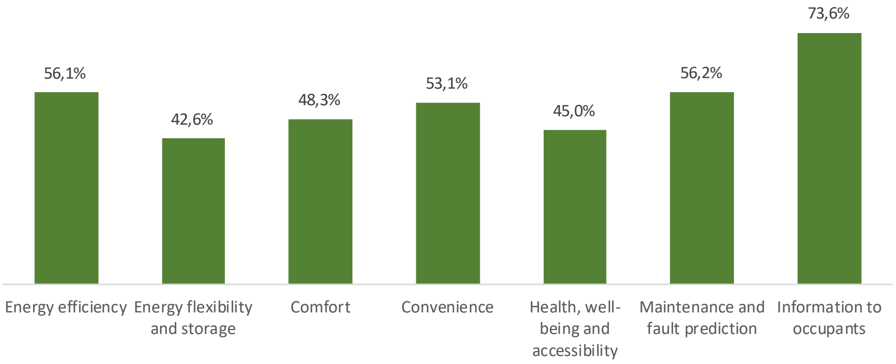

Figure 16. SRI Impact Scores. Pilot #1

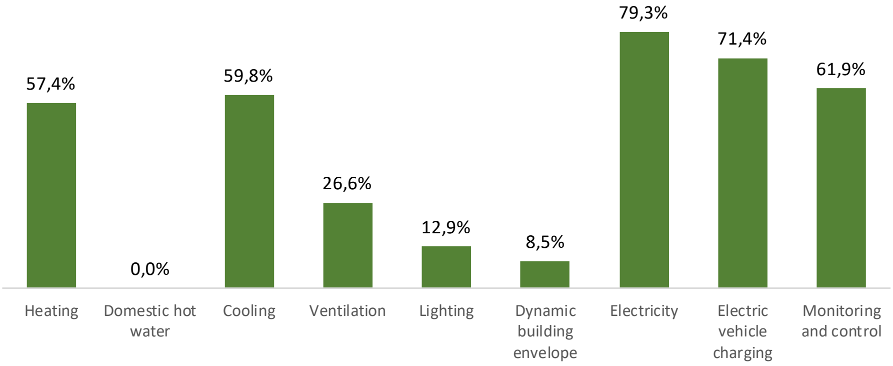

Figure 17. SRI Domain Scores. Pilot #1

2.6.2 Pilot #2 Frederick's University Main Building

2.6.2.1 *Description*

This pilot is a building of the Frederick University. It comprises classrooms, computer and engineering laboratories, administration and faculty offices, a large cafeteria, among others. It is a four-story building with over 4,021 m^2. It was constructed in 1996 and the last floor was added in 2021.

The building is equipped with some dedicated sensors, apart from those provided by the manufacturers of existing technical building systems. There are four units to gather data on indoor environment (e.g., temperature, humidity, occupancy, illuminance, barometric pressure, and CO_2). These units are distributed throughout the building. In addition, there are several data points for energy monitoring. The heating and cooling services are provided by the same facility. It is a central variable refrigerant flow (VRF) installation, with at least one terminal unit in each room, and one outdoor unit per floor. The domestic hot water (DHW) service, which is only related to the cafeteria and toilets, is by design provided by solar thermal collectors coupled with electric water heaters. In addition, mechanical ventilation is supplied only to the second floor, also with mechanical exhaust. There are heat recovery units. On the remaining floors, ventilation is provided by natural means. Lighting is provided by many luminaries installed throughout the building. Those in common areas are controlled based on central switches, while the rest of them are controlled by room manual switches. The windows in the building are manually operated. At the moment there is no on-site electricity production.

2.6.2.2 *SRI results*

Upon Method B application, the building obtains a total SRI score of 28%. Per key functionality, the scores are Energy performance and operation 36,7%, Response to user needs 36,5%, and Energy flexibility 9,6%. The impact and domain scores are shown in Figure 18 and Figure 19.

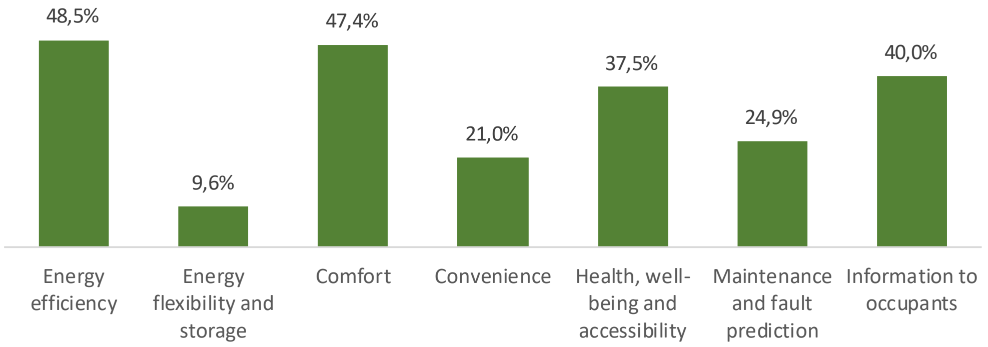

Figure 18. SRI Impact Scores. Pilot #2

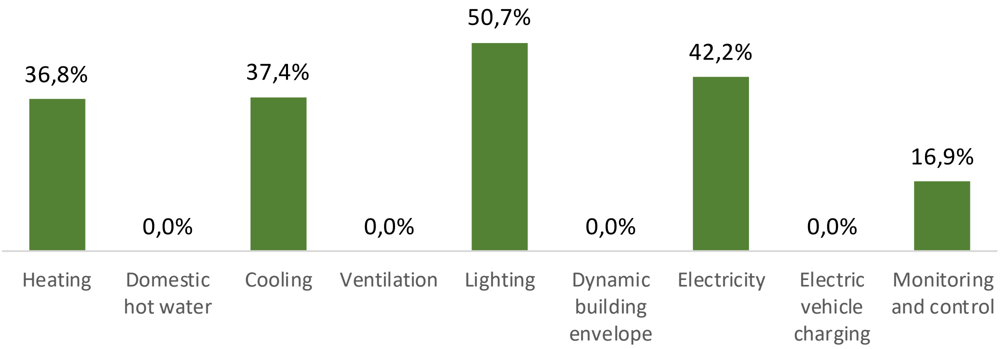

Figure 19. SRI Domain Scores. Pilot #2

2.6.3 Pilot #3 Ehituse Mäemaja

2.6.3.1 Description

This pilot is an office and laboratory building of the Tallin University of Technology (TalTech). It is a four-story building with over 300 m^2. It was constructed in 2021.

The building is equipped with comprehensive BMS capable of monitoring, logging, and controlling the installed systems. The platform is accessible online. This, in turn, enables remote operation of some of the technical systems, while allowing for physical panels throughout the building. Manual settings from physical panels are reset at the end of each workday. The heating and domestic hot water service is provided by connection to a district heating network. The cooling service is provided by a central chiller, coupled with a 2 m^3 thermal energy storage tank. As terminal units, there are radiators for heating and chilled beams for cooling. Mechanical supply-exhaust ventilation with heat recovery guarantees the Indoor Air Quality (IAQ) in the building through demand control valves linked to CO_2 and temperature sensors. Air handling is provided at neutral conditions, allowing for fan control, hydronic heating and cooling control. Indoor built-in lighting in common areas is centrally controlled during working hours and triggered by passive infrared sensors outside of working hours. In the offices, classrooms, laboratories, and other non-common areas the lighting is turned on by manual switches. There is 63.5 kWp photovoltaic generation located on the roof, which supplies on-site renewable electricity to the whole building.

2.6.3.2 SRI results

Upon Method B application, the building obtains a total SRI score of 50,4%. Per key functionality, the scores are Energy performance and operation 65,3%, Response to user needs 65,9%, and Energy flexibility 20%. The impact and domain scores are shown in Figure 20 and Figure 21.

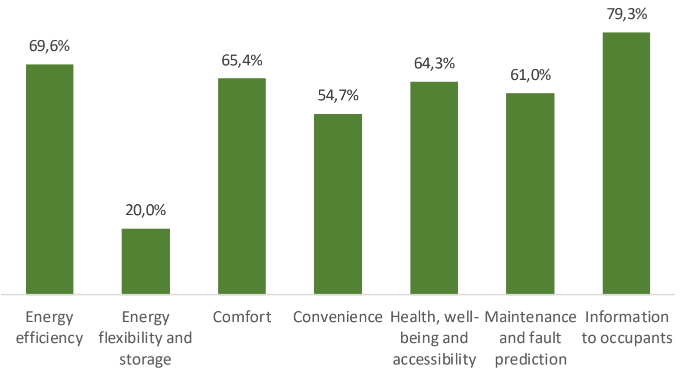

Figure 20. SRI Impact Scores. Pilot #3

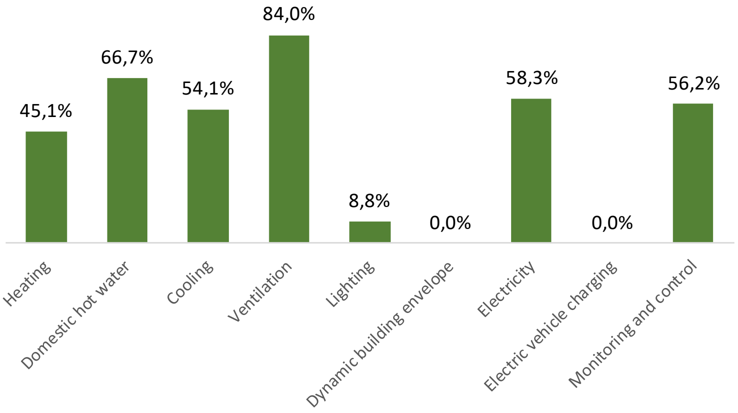

Figure 21. SRI Domain Scores. Pilot #3

2.6.4 Pilots #4 Single-family. Complex of Leitza.

2.6.4.1 Description

This pilot is a detached single-family house. It is a three-story building with over 340 m^2. It was constructed in 2001. It participates in the project as the building complex of Leitza, in Spain.

The building does not have any kind of BMS or complex BACS, the only BAC functions are those provided by the manufacturer of the technical systems existing in the building. This is a condensing gas boiler for domestic hot water production and space heating. The operation of the heating sub-system is controlled by a single thermostat. This system is coupled with a heat exchanger and storage tank to capture some of the heat from a wood fireplace which only operated during the winter. Space cooling is not provided in the building, and ventilation is only natural. The operation of the lighting system and dynamic building envelope elements is completely manual. There is no renewable electricity production on-site.

2.6.4.2 SRI results

Upon Method B application, the building obtains a total SRI score of 18,5%. Per key functionality, the scores are Energy performance and operation 20,0%, Response to user needs 30,5%, and Energy flexibility 5,0%. The impact and domain scores are shown in Figure 22 and Figure 23.

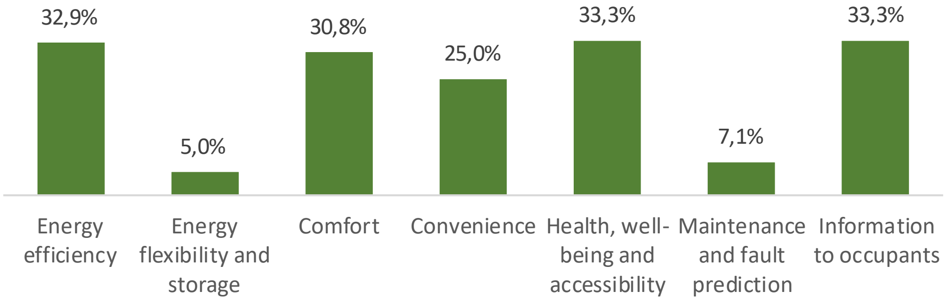

Figure 22. SRI Impact Scores. Pilot #4

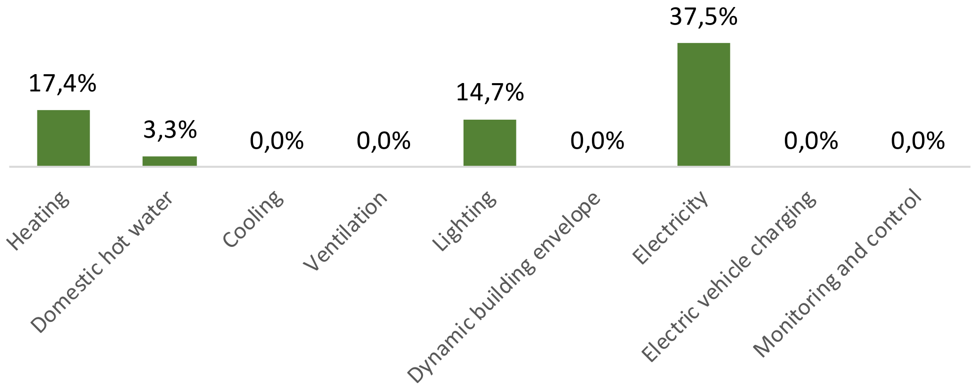

Figure 23. SRI Domain Scores. Pilot #4

2.6.5 Pilots #5 Private flat. Complex of Leitza.

2.6.5.1 *Description*

This pilot is a ground-floor apartment from a residential multi-family building. The building is composed by three flats, one in each story. The pilot building unit has an area of over 92 m^2. It was constructed in 1985. It participates in the project as the building complex of Leitza, in Spain.

The building does not have any kind of BMS or complex BACS, the only BAC functions are those provided by the manufacturer of the technical systems existing in the building. This is a condensing gas boiler for domestic hot water production and space heating. The operation of the heating sub-system is controlled by a single thermostat. In addition, there is a wood fireplace which is only operated during the winter. Space cooling is not provided in the building, and ventilation is only natural. The operation of the lighting system and dynamic building envelope elements is completely manual. There is no renewable electricity production on-site.

2.6.5.2 *SRI results*

Upon Method B application, the building obtains a total SRI score of 13,7%. Per key functionality, the scores are Energy performance and operation 10,7%, Response to user needs 24,3%, and Energy flexibility 6,2%. The impact and domain scores are shown in Figure 24 and Figure 25.

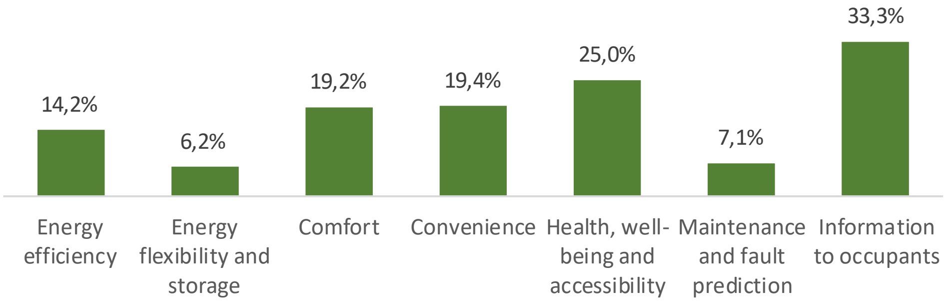

Figure 24. SRI Impact Scores. Pilot #5

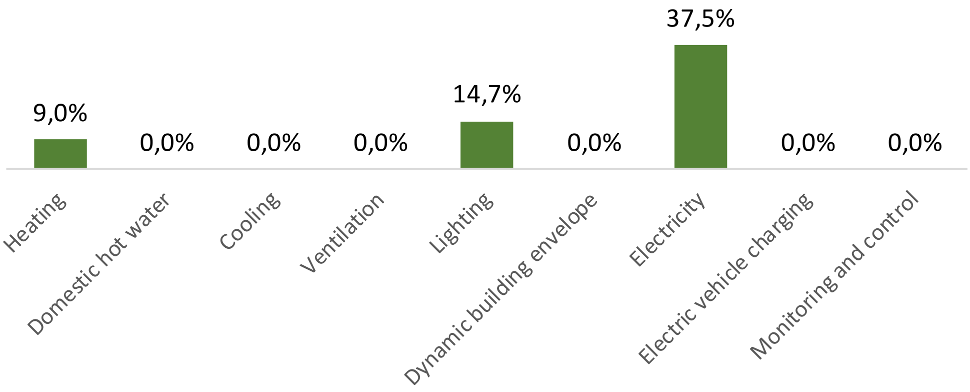

Figure 25. SRI Domain Scores. Pilot #5

2.6.6 Pilots #6 Mixed-use building. Complex of Leitza.

2.6.6.1 Description

This pilot is a mixed-use building; on the ground floor there is a store, while the first and second floor are devoted to residential use. The pilot building has an area of over 305 m^2. It was constructed in 1860. It participates in the project as the building complex of Leitza, in Spain.

The building does not have any kind of BMS or complex BACS, the only BAC functions are those provided by the manufacturer of the technical systems existing in the building, which are different per each building use. Space heating and cooling at the store is provided by an air-to-air heat pump, which is continuously operating on account of maintaining the products being sold (i.e., chocolate). The domestic hot water is provided by a 50-liter electric water heater. The two dwellings share a centralised biomass boiler with hot water radiators as terminal units. In addition, each unit has an individual LPG boiler for domestic hot water and lack space cooling systems. Ventilation is only natural. The operation of the lighting system and dynamic building envelope elements is completely manual. There is no renewable electricity production on-site.

2.6.6.2 SRI results

Upon Method B application, the building obtains a total SRI score of 10,9%. Per key functionality, the scores are Energy performance and operation 9,8%, Response to user needs 17,7%, and Energy flexibility 5,2%. The impact and domain scores are shown in Figure 26 and Figure 27.

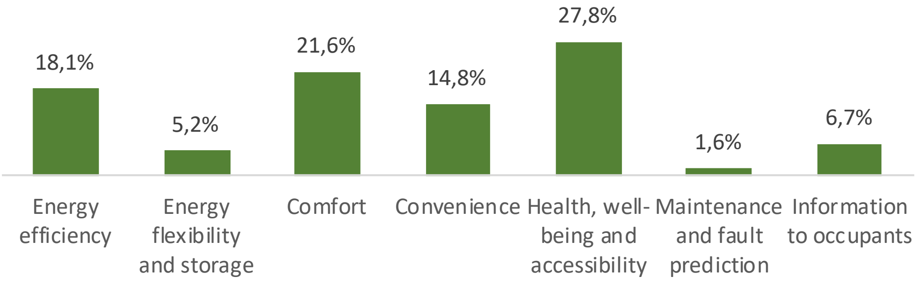

Figure 26. SRI Impact Scores. Pilot #6

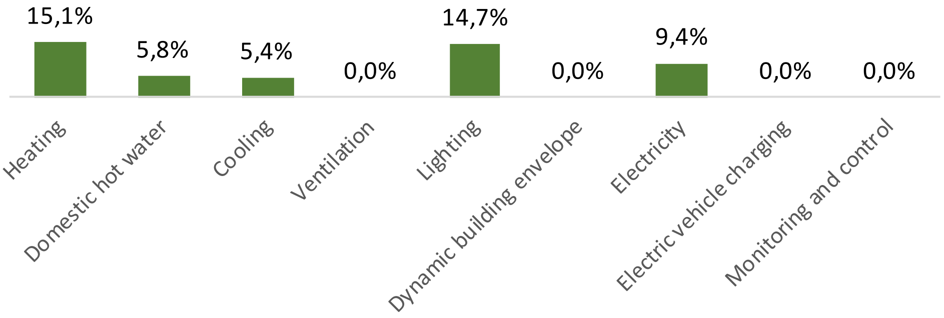

Figure 27. SRI Domain Scores. Pilot #6

2.6.7 Pilots #7 Town hall. Complex of Leitza.

2.6.7.1 Description

This pilot is the municipality's town hall with multiple uses (e.g., offices, court of justice, archives, radio station, school, etc.). The pilot building has an area of over 305 m2 and three stories. It was constructed in 1917, and the roof was completely renovated in 2018. It participates in the project as the building complex of Leitza, in Spain.

The building does not have any kind of BMS or complex BACS, the only BAC functions are those provided by the manufacturer of the technical systems existing in the building. Space heating is provided by a low temperature gas boiler. The ground and first floors have aluminium radiators as terminal units, while the third floor has fan coils. Each floor is a service area controlled by its own thermostat. The domestic hot water needs are very low on account of the use of the building. Hence, there is only a 50-liter electric water heater mostly used for cleaning purposes.

Ventilation is only natural. The operation of the lighting system and dynamic building envelope elements is completely manual. There is a 4.23 kWp photovoltaic installation on the roof.

2.6.7.2 SRI results

Upon Method B application, the building obtains a total SRI score of 17,2%. Per key functionality, the scores are Energy performance and operation 22,8%, Response to user needs 27,6%, and Energy flexibility 1,2%. The impact and domain scores are shown in Figure 28 and Figure 29.

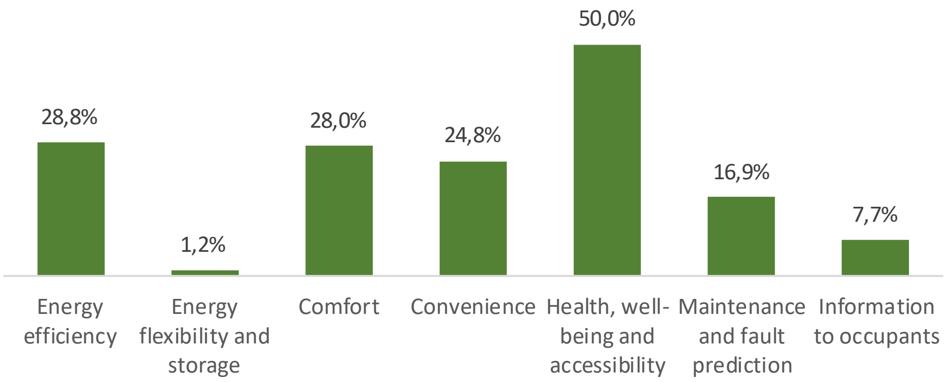

Figure 28. SRI Impact Scores. Pilot #7

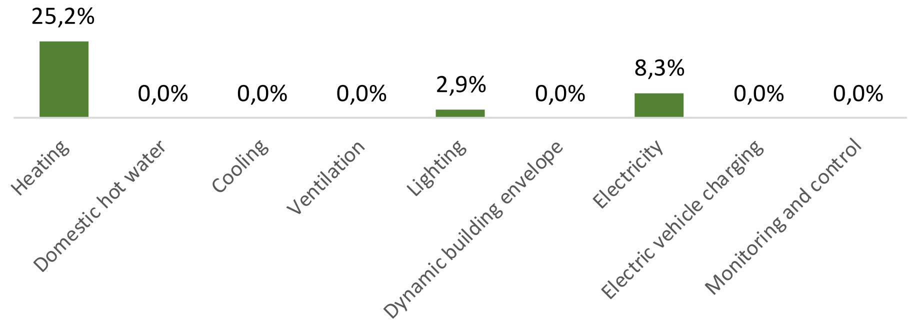

Figure 29. SRI Domain Scores. Pilot #7

2.6.8 Pilots #8 Erleta School. Complex of Leitza.

2.6.8.1 *Description*

This pilot is the school. The pilot site is composed of two interconnected buildings: the main block, built in 1968, and the annex, built in 1979. The main structure is composed by ground floor and 4 additional ones; the annex has one floor less. The total area of the building is a bit short of 4,000 m^2. It participates in the project as the building complex of Leitza, in Spain.

The building does not have any kind of BMS or complex BACS, the only BAC functions are those provided by the manufacturer of the technical systems existing in the building. Space heating is provided by a condensing gas boiler, with cast iron radiators as terminal units. Domestic hot water is generated by two independent installations. The one in the kitchen has a natural gas boiler, while in the changing rooms there is a 600-liter electric water heater. Ventilation is only natural. The operation of the lighting system and dynamic building envelope elements is completely manual.

2.6.8.2 *SRI results*

Upon Method B application, the building obtains a total SRI score of 12,8%. Per key functionality, the scores are Energy performance and operation 16,2%, Response to user needs 22,2%, and Energy flexibility 0%. The impact and domain scores are shown in Figure 30 and Figure 31.

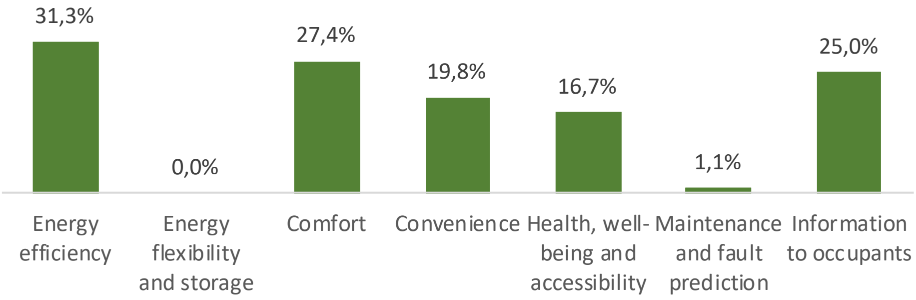

Figure 30. SRI Impact Scores. Pilot #8

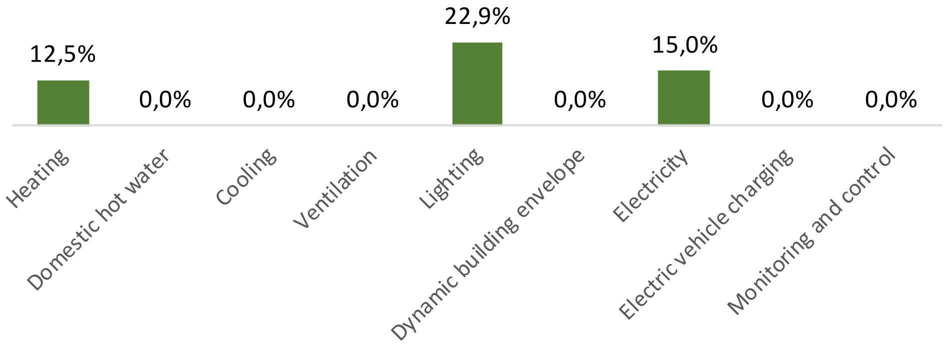

Figure 31. SRI Domain Scores. Pilot #8

2.6.9 Pilots #9 Amazabal Sports Centre. Complex of Leitza.

2.6.9.1 Description

This pilot is the municipality's sports centre. It was built in 2001, with a deep envelope renovation in 2016. The main structure is composed by two plus ground floors. The court is double-height space. The total area of the building is a bit short of 2,200 m^2. It participates in the project as the building complex of Leitza, in Spain.

The building does not have any kind of BMS or complex BACS, the only BAC functions are those provided by the manufacturer of the technical systems existing in the building. Space heating is provided by an oil boiler and an air-duct network coupled with a centralised thermostat. In addition, there are two individual air-to-air heat pumps located in the gymnasium, which are controlled by room thermostats. Domestic hot water is generated by an independent oil boiler, coupled with a 1000-liter storage tank. Ventilation is only natural. The operation of the lighting system and dynamic building envelope elements is completely manual or fixed.

2.6.9.2 SRI results

Upon Method B application, the building obtains a total SRI score of 5,2%. Per key functionality, the scores are Energy performance and operation 4,8%, Response to user needs 10,8%, and Energy flexibility 0%. The impact and domain scores are shown in Figure 32 and Figure 33.

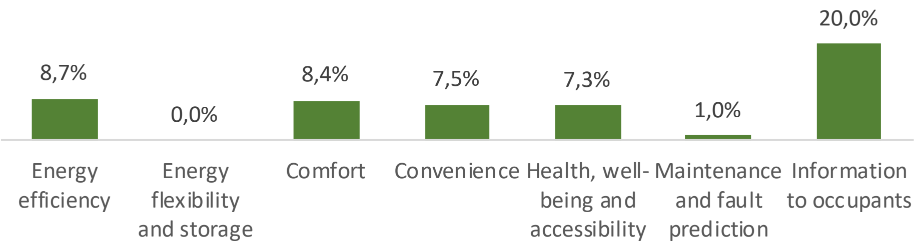

Figure 32. SRI Impact Scores. Pilot #9

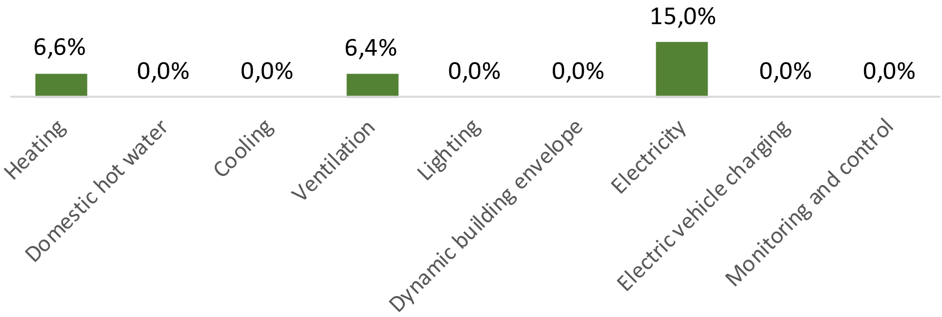

Figure 33. SRI Domain Scores. Pilot #9

3 Energy and non-energy resources analysis and integration to SmartLivingEPC

3.1 Current technical documentation for a joint asset-based methodology

Building Energy Simulation (BES) is a reliable computational tool for calculating a building's energy consumption accurately. It estimates energy consumption based on several factors, including building geometry, orientation, envelope properties, HVAC systems, lighting systems, and occupancy patterns. BES can predict energy consumption under different operating conditions and can simulate a building's energy performance over its entire life cycle. BES's ability to model complex systems and interactions and its adaptability to specific building types, climates, and operating conditions make it a valuable tool for building owners and designers to make informed decisions about a building's energy efficiency and identify energy-saving opportunities. Non-energy assessment evaluates aspects that impact the comfort and quality of life in a building, such as indoor air quality, acoustics, thermal comfort, lighting, accessibility, and functionality.

The state of the environment throughout buildings is known as indoor environmental quality (IEQ). Poor indoor environmental quality has been associated with respiratory problems, allergies, headaches, and fatigue. IEQ is affected by things including air, lighting, sound, and temperature. IEQ may be enhanced by ensuring adequate ventilation, air filtration, lighting, acoustics, and thermal comfort. Multiple factors influence indoor environmental quality (IEQ), including the ventilation system, window type, building location, building occupancy, and building use. Improvements in occupant health and productivity may be achieved by increasing attention to IEQ factors including natural light and noise levels.

The design and layout of a building may influence the health, productivity, and satisfaction of the people who live there. Important non-energy factors that contribute to IEQ include things like air quality, temperature, illumination, and noise. Important non-energy issues include safety, radon danger, earthquake potential, accessibility, flexibility, and ecological sustainability. A structure's carbon footprint may be further reduced by using sustainable building materials, installing rainwater collecting systems, installing green roofs, and installing solar panels. Noise may be reduced in buildings without sacrificing the comfort or productivity of their occupants via the use of sound-absorbing materials and strategic wall placement. As a whole, a building's usefulness, security, and comfort may benefit by attending to these non-energy elements.

The entire asset calculation engine is based on a rating from I to IV (categories) for non-energy parameters and A to G for energy parameters or CO_2 emissions. The recommended color scheme, consisting of the same RGB colors as proposed in the project, proves to be the most suitable choice as it aptly embodies the distinctive essence of the project’s undertaking.

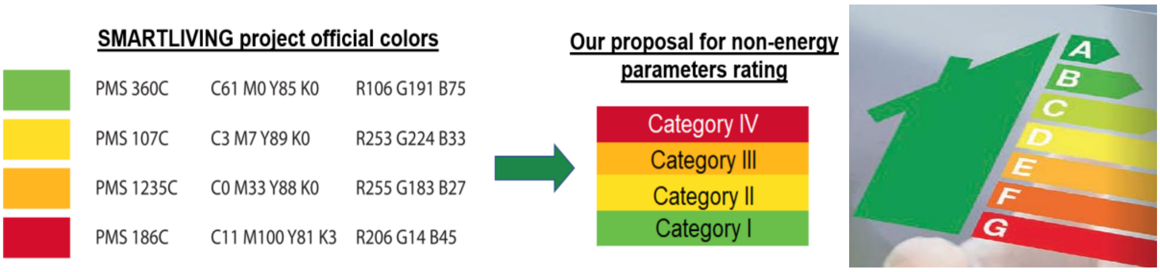

Figure 34: a) Proposed colour scheme for non-energy parameters (e.g. IEQ or other) b) energy scheme from SmartLivingEPC proposed for energy scale

In the present-day context of heightened awareness of climate change and the need to minimize energy use, energy efficiency has become an increasingly important factor in the design and construction of buildings. Certification programs that analyze and score buildings based on specified energy characteristics are one technique to encourage energy efficiency in buildings. In order to better understand the energy efficiency of their buildings, both owners and tenants may benefit from these certification schemes.

One of the most important parts of the asset calculation is the energy consumption of the buildings, including the calculation of heating, domestic hot water, lightning, ventilation and air conditioning. The calculation is based on the EPBD standards with the following parts: EPB standards ISO 52000-1, 52003-1, 52010-1, 52016-1 and 52018-1.

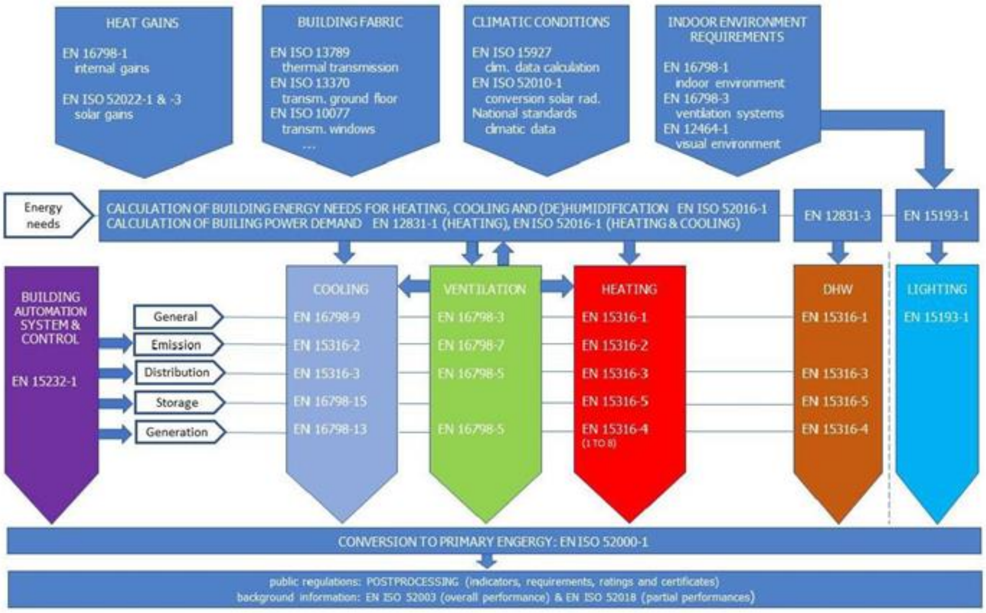

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Figure 35: Logical scheme of energy calculation using EN ISO standards [https://epb.center/]

It is generally agreed that the most precise way to estimate a building's energy usage is via the use of Building Energy Simulation (BES). BES is a computer method for modelling the energy efficiency of buildings. The geometry, orientation, envelope qualities, heating, ventilation, and air conditioning (HVAC), lighting, and occupancy patterns of a structure are only some of the variables that might affect an estimate of its energy consumption. One of BES's key benefits is its capacity to foretell a building's energy usage under various scenarios. In this way, architects and building owners can evaluate the relative energy efficiency of several design possibilities. It is essential for long-term planning and decision-making to be able to simulate a building's energy performance across its full life cycle, and BES makes this possible.

Another advantage of BES is that it may replicate complicated systems and interactions, such as those between the envelope and HVAC systems of a building. Improved energy consumption forecasts and the potential for new energy-saving strategies are the consequences of this approach. Because of their flexibility and configurability, BES tools may be adapted to meet the needs of a wide variety of buildings and environments. Because of this, they may be installed in a wide variety of buildings, from residences to factories.

When estimating a building's energy usage, Building Energy Simulation (BES) provides the best precision. It is a useful tool for building owners and designers since it can anticipate energy consumption under varied operating situations, simulate complicated systems and relationships, and be adapted to specific building types. BES provides owners and architects with data on a building's energy use so they may make educated choices about how to improve efficiency and save costs.

For the rating the following energy parameters are proposed based on the new EPBD standards:

- **Final energy consumption of a building (kWh/m^2/year)**
  1. Heating
  2. Cooling
  3. Domestic Hot Water
  4. Lighting
  5. Ventilation
- **Primary energy consumption of a building (kWhep/m^2/year)**
  1. Heating
  2. Cooling
  3. Domestic Hot Water
  4. Lighting
  5. Ventilation
- **Renewable energy production of a building (kWh/m^2/year) and share by utilities and total (%)**
  1. Heating
  2. Cooling
  3. Domestic Hot Water
  4. Lighting (e.g. from photovoltaic energy)
  5. Ventilation (similar to d.)
- **Exported energy (kWh/m^2/year)**
  1. Thermal energy

2. Electric energy
3. Thermal energy from renewable sources
4. Electric energy from renewable sources

3.2 Collection of performance data generated over the building's life cycle concerning the consumption of non-energy resources

A building's design and layout may have a significant impact on the wellness, fulfilment, and productivity of its residents. Buildings may be described using a wide range of metrics, not only energy-related ones like energy efficiency and carbon emissions. Indoor environmental quality, safety, radon risk, earthquake potential, ease of access, adaptability of design, lifetime of construction materials, and ecological sustainability are all factors to consider.

The comfort, health, and productivity of building occupants may also be affected by indoor environmental quality (IEQ), an important non-energy parameter. The term "indoor environmental quality" (IEQ) is used to describe the state of a building's air, temperature, lighting, and levels of background noise. Health concerns including asthma flare-ups, migraines, and exhaustion may result from inadequate IEQ. The use of high-quality materials, appropriate ventilation, and temperature and humidity management are all ways in which building owners may improve indoor environmental quality.

The safety of the building's inhabitants and the structure itself makes security a significant non-energy component. Access control systems, video cameras, and locked doors are just some of the security features that may be built into a building to keep unwanted visitors out. Security systems in buildings may safeguard their residents from more than just physical injury; they can also deter criminal activity like theft and vandalism.

The radon threat is an additional important non-energy component that may impact the occupant's health. Accumulated radon gas poses health hazards, including an increased risk of lung cancer recognized by WHO as the second source after smoking. The location and geology of the building site, as well as the building's construction and ventilation systems, may all affect the chance of being exposed to radon. Radon testing and, if required, the installation of radon mitigation solutions by building owners will reduce radon risk.

The possibility of earthquakes is another non-energy factor that should be considered when assessing a building's resilience. Seismic bracing or reinforced foundations are two examples of how buildings in earthquake-prone areas may be made safer for residents. Seismic retrofitting is an option for building owners looking to increase their structures' resilience to earthquakes. Thus, an important non-energy parameter may be represented by the seismic risk class (SR1 to SR4).

One further non-energy factor that might impact a building's functionality and acceptability to the public is its level of accessibility. The term "accessibility" refers to the convenience with which visitors and residents may use the building's facilities. Buildings that are accessible to all users, including those with physical limitations, tend to have more fulfilled and productive occupants.

The longevity and usefulness of a structure may also be affected by another non-energy factor: adaptability. The capacity of a structure to accommodate its occupants' and the building's changing requirements through time is what is meant by the term "adaptability." Owners might avoid spending a lot of money on costly upgrades and retrofits by designing their buildings to be flexible.

Materials used in construction and long-term upkeep are two more crucial factors outside of energy use. Recycled or low-emission materials are only two examples of the types of sustainable construction supplies that might lessen a structure's negative influence on the environment. Sustainable elements, such as rainwater collection systems, green roofs, and solar panels, may help building owners further reduce their carbon footprint.

The above-mentioned energy-related criteria aren't the only ones that may be utilized to characterize a structure. Buildings may be constructed with features like sound-absorbing materials or smart wall placement to decrease noise, for instance, which can have a significant impact on occupant comfort and productivity. Natural light, vistas, and colour schemes are all examples of aesthetic and design aspects that might improve tenant pleasure.

Security, radon danger, seismic risk, IEQ, ADA compliance, adaptability, sustainable materials, acoustics, and aesthetics are just a few of the numerous non-energy factors that may be used to characterize a structure. Addressing these factors and designing places that satisfy the demands of users over the long term may enhance the functioning, safety, and comfort of buildings. In the following chapters we will present each of these along with the asset assessment method.

3.3 Non-energy resources assessment

When people talk about how they feel inside a building, they often talk about the indoor environmental quality (IEQ) [10]. Numerous adverse health effects, including respiratory issues, allergies, headaches, and weariness, have been linked to low IEQ [11].

- IEQ is determined by a number of variables [12], including but not limited to air quality, illumination, sound, and temperature.
- Poor indoor air quality has been linked to decreased lung and brain function [13].
- Indoor air pollution is often caused by things like cigarette smoke, cleaning chemicals, and materials used in construction [14].
- Indoor air quality may be enhanced and health risks mitigated with the aid of proper ventilation and air filtration [15].
- IEQ is affected not just by the air quality but also by the amount of light. Poor lighting may cause discomfort to the eyes, head, and body [16].

- The mental and physical well-being of building residents may also be affected by the acoustics, or level of noise, within the structure.
- Too much noise may be stressful and inhibit work output, while too little can lead to feelings of isolation and a breakdown in communication [17].
- Comfort and efficiency may also be affected by the building's thermal comfort, which includes the temperature and humidity levels within.
- High humidity encourages the formation of mold and other indoor air pollutants [18], while very high temperatures may be uncomfortable and impair mental performance.

Thus, indoor environmental quality (IEQ) is vital to the well-being of building occupants. A healthy interior environment is the result of several factors coming together, including proper ventilation, air filtration, lighting, acoustics, and thermal comfort [19]. In the asset assessment have been considered the 4 main parts of the IEQ thus we have the following schematic diagram that includes also the proposed non-energy parameters for each part:

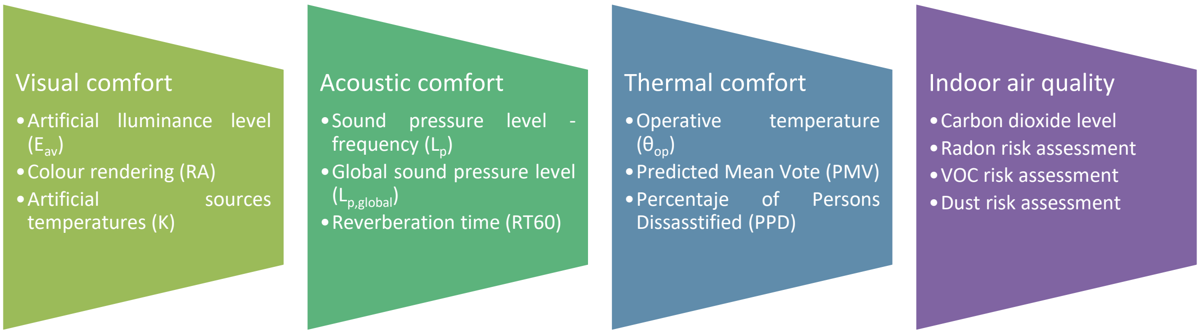


Figure 36: Main non-energy parameters for IEQ

The IEQ level varies widely throughout a building based on a number of factors. The ventilation system of a building is a key factor since it modulates the amount of outside air brought in and removes contaminants. Moreover, the window type and frame may increase or decrease air infiltration and thus impact the air quality. IEQ may also be affected by other factors, such as where in the building you happen to be. It's possible, for instance, that upper-floor residents will be subjected to higher temperatures and more intense solar radiation than ground-floor residents. In addition, the interior air quality may be lower for those who are closer to sources of indoor air pollutants such as photocopiers (e.g., ozone production) or cleaning chemicals (higher VOC levels). Occupant density is another factor that might affect IEQ. IEQ may also be affected by the kind of occupancy and the actions (metabolic rate) that occur inside it. The presence of natural light has been shown to improve the mood, productivity, and energy efficiency of building occupants. A building's interior may be divided into several zones, with those closest to windows getting more natural light than those furthest from the windows. Natural lighting may also be difficult to provide in buildings with deep floor plates or narrow floor designs. IEQ may also be affected by other crucial factors, like noise level. Occupant comfort, focus, and productivity may all take a hit when noise levels are too high.

External noise levels in a building may be affected by its proximity to a ***busy road*** or an industrial region, while *inside noise levels may be affected by HVAC systems or elevators*. Daylight and noise levels are two crucial elements that might affect the indoor environmental quality (IEQ) of a building. The health and productivity of the building's residents depend on these factors being properly addressed.

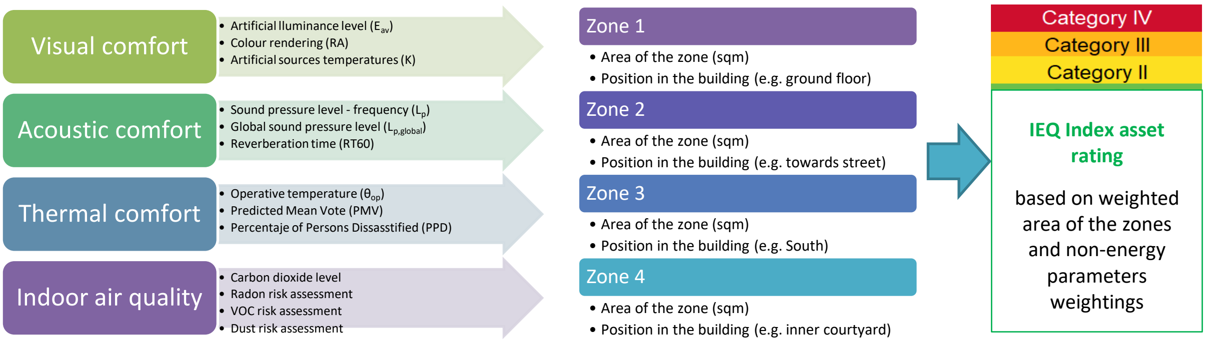


Figure 37: Analysis of indoor environmental quality throughout an entire building based on four reference zones

In previous research conducted during the last years the indoor parameters can vary considerably within the same building and thus it is important to choose reference zones that describe the best the destination of the studied building. In the example below we can observe the variation of temperature and illuminance for different rooms and floors for the same building.

More details about the paper are found here: https://www.rric.ro/reviste/articole/vol4nr3art7.pdf

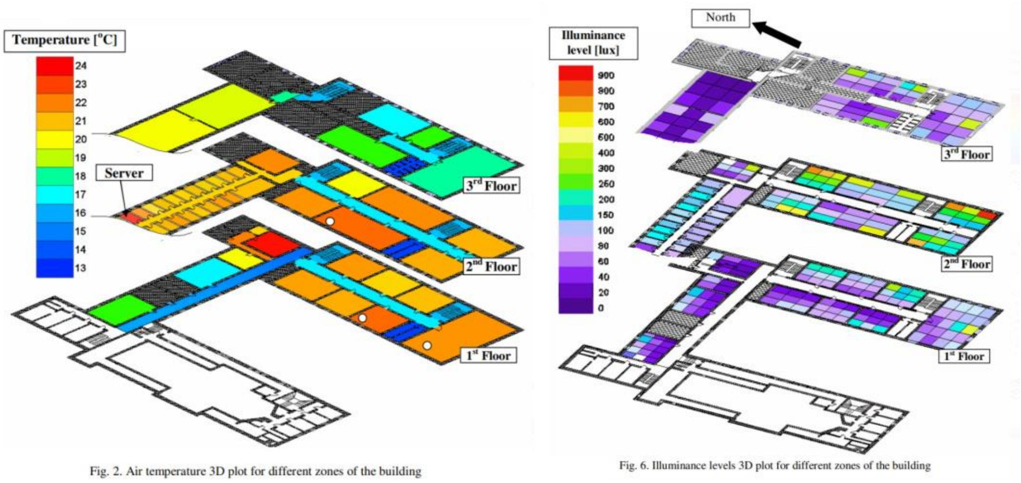


Fig. 2. Air temperature 3D plot for different zones of the building

Fig. 6. Illuminance levels 3D plot for different zones of the building

Figure 38: Variation of air temperature and daylight illuminance within the same building

Considering the above data, we consider it mandatory to rate a building in terms of IEQ based on at least four reference zones. For the following assessment procedure, all the calculations are based on four reference zones.

3.3.1 Thermal comfort

Thermal comfort, which refers to a person's degree of satisfaction with the thermal environment they reside in, is an important component of IEQ. It is a complex process that is impacted by several variables, including radiant temperature, air temperature, humidity, and air velocity. The health, productivity, and well-being of building inhabitants depend on maintaining thermal comfort [20][21].

Research has repeatedly shown that the temperature within buildings has a substantial impact on the well-being and satisfaction of individuals [22][23]. Unfavourable interior thermal conditions, including extreme heat or cold, may impair comfort, raise stress, and impair cognitive performance [24]. According to the World Health Organization (WHO), exposure to very high temperatures may result in several health issues, such as heat stroke, dehydration, and cardiovascular illnesses [25]. Therefore, it is essential to control interior temperatures to maintain the comfort and safety of inhabitants.

Variations in temperature may also affect how comfortable occupants are. According to Kim et al. (2019), office employees' ratings of thermal comfort were strongly impacted by changes in air temperature [26]. Like this, Choi et al.'s research from 2019 found that temperature variation might cause pain and dissatisfaction among building inhabitants [27]. These results underline how crucial it is to keep interior temperatures stable to increase occupant wellbeing and comfort.

Thermal comfort, as a crucial component of IEQ, has a substantial influence on the health, productivity, and well-being of occupants. Understanding all the variables that affect interior thermal conditions is essential to achieving and sustaining thermal comfort. Building owners and facility managers may guarantee resident satisfaction by controlling interior temperatures and reducing temperature variability.

In order to evaluate people's thermal comfort in enclosed spaces, the Predicted Mean Vote (PMV) model is often utilized. It is a tool that assesses how people perceive the thermal environment and offers a thermal comfort index based on a variety of environmental and individual characteristics. PMV is generally acknowledged and regularly used in research applications, HVAC systems, and building design. The calculating method for PMV and its importance in foretelling human thermal comfort will be covered in this work.

Measuring environmental variables such as air temperature, mean radiant temperature, air velocity, humidity, and garment insulation, which is measured in Clo units, is one of many phases in the PMV calculation technique [28] [29]. The PMV model predicts an individual's thermal experience using these metrics together with personal elements like metabolic rate, degree of clothing, and personal preferences. The PMV is a scale with a 0 signifying a neutral temperature feeling and a range from -3 (cold) to +3 (hot).

The PMV model has been verified by several experiments, which demonstrate its potency in forecasting thermal comfort [30] [31]. Additionally, studies have shown that the PMV model is a superior thermal comfort indicator than other models [32] [33]. The PMV model, however, has certain drawbacks, such as the inability to take into account individual variances and variations in thermal sensitivity [34]. Additionally, psychological elements like light, sound, and air quality that may affect thermal comfort are not taken into consideration by the PMV model. Despite these drawbacks, the PMV model continues to be a popular tool for HVAC system design and gives a quantitative evaluation of thermal comfort. Additionally, it enables engineers and designers to evaluate how well various HVAC systems and architectural designs affect how comfortable occupants are.

We have considered a non-energy parameter the PMV model as it provides a trustworthy method for estimating people's thermal comfort in enclosed spaces and it is mentioned in multiple EN standards. The PMV model is still a commonly used tool in building design and HVAC systems since it has been well proven in multiple research. The PMV model, despite its drawbacks, is nevertheless a useful tool for designers, engineers, and researchers for evaluating and enhancing occupant thermal comfort and thus can be proposed for our project.

How the procedure was prepared

The key PMV components that are utilized to forecast an individual's thermal perception are environmental and personal characteristics. Air temperature, mean radiant temperature, air velocity, humidity, and clothing insulation are all environmental influences. Metabolic rate, degree of clothing, and personal preferences are all personal aspects. To anticipate an individual's thermal feeling, these parameters are integrated using the PMV computation process. Several assumptions and simplifications were necessary for the procedure.

Air temperature

The PMV model relies heavily on the indoor air temperature as a predictor of thermal comfort [29]. According to the PMV model, the average temperature of the air around people is what constitutes the "indoor air temperature". The model works on the assumption that there is no appreciable change in air temperature with elevation. Consequently, effective thermal comfort in buildings requires precise monitoring and management of internal air temperatures. Keeping the temperature of the indoor air between 20 and 23 degrees Celsius is advised for sedentary work [34]. According to EN 16798-1:2019 the conventional heating set-point temperature depends on the building category and room destination (e.g., residential buildings: living area and bedroom, the air temperature is 20^{o}C, office is also 20^{o}C, classrooms the air temperature is 18^{o}C, hospital rooms 22^{o}C, hotels 20^{o}C, commercial non-food 18^{o}C and 15^{o}C for commercial food).

Mean radiant temperature

The average surface temperature across all objects in an area is known as the Mean Radiant Temperature (MRT). Walls, ceilings, flooring, and even furniture may all fall within this category. Since MRT influences the rate at which heat is transferred to and from the human body, it is an essential factor in establishing thermal comfort. The human body loses heat to the environment through radiation, convection, and evaporation, making this heat exchange crucial. The MRT is accounted for in the PMV model's computation of heat exchange between the human body and the environment, which is extensively used to forecast thermal comfort. The asymmetry factor, which indicates the discrepancy between the operative temperature and the MRT, is also calculated from the MRT inside the model. Optimal thermal comfort in buildings requires precise MRT measurement and regulation. Achieving an equilibrium between the air temperature and MRT and improving thermal comfort in buildings may be accomplished via the employment of strategies such as radiant heating and cooling systems. The key to thermal comfort is keeping the air temperature and MRT in equilibrium.

Operative temperature

The operative temperature of a zone is a measure of what temperature the air and surfaces are, on average. It is commonly utilized in the design and evaluation of buildings because of its importance in determining occupant thermal comfort. By **averaging the air temperature and the mean radiant temperature**, we can get the operational temperature, which is representative of what a human would feel if they were placed in an environment with the same heat transfer properties. Different kinds of rooms have varying thermal comfort needs, hence, European standards for IEQ divide the operational temperature into a number of categories. The following are examples of categories defined by EN standards:

Category I ("comfort zone") refers to the optimal temperature range in which an individual may work without excessive sweating or shivering. Example: for residential buildings at 1 clo the $\theta_{op,min}$ is 21°C while for summer period for 0.5 clo is $\theta_{op,max}$ is 25.5°C.

Category II ("acceptable zone") is the range of working temperatures within which a person has only little discomfort. Example: for residential buildings at 1 clo the $\theta_{op,min}$ is 20°C while for summer period for 0.5 clo is $\theta_{op,max}$ is 26°C.

Category III ("border zone") is the temperature gray area where a person may need supplemental heating or cooling to feel comfortable. Example: for residential buildings at 1 clo the $\theta_{op,min}$ is 18°C while for summer period for 0.5 clo is $\theta_{op,max}$ is 27°C.

Category IV ("critical zone") the temperature range where workers may experience symptoms of thermal stress, which may have serious health consequences. Example: for residential buildings at 1 clo the $\theta_{op,min}$ is less than 18°C while for summer period for 0.5 clo is $\theta_{op,max}$ is higher than 27°C.

Air velocity

The speed and direction of airflow are what we call its "air velocity." Because it impacts how quickly heat is transported from the body to the environment, it is a crucial aspect in establishing a person's level of thermal comfort. One of the factors used to determine thermal comfort in the Predicted Mean Vote (PMV) model is air velocity. Convective heat loss from the skin accelerates in response to an increase in air velocity, making one feel cold and even chilly. However, low air velocities may make people feel stuffy and slow down the pace at which they cool down via evaporation, leading to discomfort and even heat stress.

According to the thermal comfort needs of various locations, the European standards for indoor environmental quality divide air velocity into a number of distinct classes. The following are examples of categories defined by EN 15251 and EN16798-1 in three categories (v_{air_max}=0.1 m/s, v_{air_max}=0.16 m/s, v_{air_max}=0.21 m/s for winter case and (v_{air_max}=0.12 m/s, v_{air_max}=0.19 m/s, v_{air_max}=0.24 m/s for summer case).

A person's thermal comfort zone is the range of air velocities at which they experience only mild discomfort. The tolerance zone is broader than the comfort zone and includes a range of acceptable air velocities.

This zone of air velocities is the limit beyond which a human would experience thermal discomfort and may need extra ventilation or air conditioning to reach a state of thermal comfort. In this range of air velocities, a human may experience thermal stress, which may lead to serious health issues.

Clothing level

As concerns the clothing factor in various seasons, maintaining thermal comfort requires the right clothes. People often dress in lightweight, breathable clothes in the summer when the temperature is high, with a recommended clothing level of 0.5 clo (where 1clo is equivalent to 0.155 m2·°C/W). In contrast, people dress in warmly in insulating clothes during the winter when the air is cold. The degree of clothing that is suggested for winter is 1 clo. It is important to note that suggested clothing levels may change based on individual parameters including age, gender, and amount of physical activity. To maintain thermal comfort in various seasons inside a heated/cooled building, the basic rule of thumb **of 0.5 clo for summer** and **1 clo for winter** is a suitable starting point.

Metabolic rate

The Predicted Mean Vote (PMV) of thermal sensation is calculated using the metabolic rate which primarily measures how much heat the human body produces. Most widely accepted standards provide the metabolic rates for different activities. The unit "Met" is often used to quantify the metabolic rate, also known as human body heat or power generation. One Met is the metabolic rate of a calm, sitting individual. Table 18 lists typical metabolic rates for various popular activities:

Table 18 - Metabolic rates included in the procedure

Activity	W/m^2	CO2 exhalation (m^3/h)	Met
Resting	46	0.013	0.8
Light activity	70	0.02	1.2
Moderate activity	93	0.1	1.6
Heavy activity	116	0.33	2

Calculation of PMV

To estimate how most individuals in a specific area would feel about the thermal comfort the Predicted Mean Vote (PMV) takes into account individual and environmental variables. To determine PMV, one uses the following formula:

$$\begin{aligned}\mathrm{PMV} = (0.303e^{0.303} + 0.028)\{(\mathrm{M}-\mathrm{W}) - 3.05\,[5.37 - 0.007\,(\mathrm{M}-\mathrm{W}) - \,\mathrm{p_a}] \\ - 0.42\,[(\mathrm{M}-\mathrm{W}) - 58.15] - 0.0173\mathrm{M}\,(5.87 - \mathrm{p_a}) \\ - 0.0014\mathrm{M}\,(34 - \mathrm{t_a}) - 3.96 \\ * 10^{-8}\mathrm{f_{cl}}[(\mathrm{t_{cl}} + 273)^4 - \,(\mathrm{t_{mr}} + 273)^4] - \mathrm{f_{cl}}\mathrm{h_c}(\mathrm{t_{cl}} - \mathrm{t_a})\}\end{aligned}$$

Equation 8.

$$\begin{aligned} t_{cl} = 35.7 - 0.0275(M - W) - I_{cl}\{(M - W) \\ - 3.05\,[5.73 - 0.007(M - W) - p_a] \\ - 0.42\,[(M - w) - 58.15] - 0.0173M\,(5.87 - p_a) \\ - 0.0014M\,(34 - t_a)\} \end{aligned}$$

Equation 9.

$$PPD = 100 - 95\exp[-(0.003353PMV^4 + 0.29179PMV^2)]$$

Equation 10.

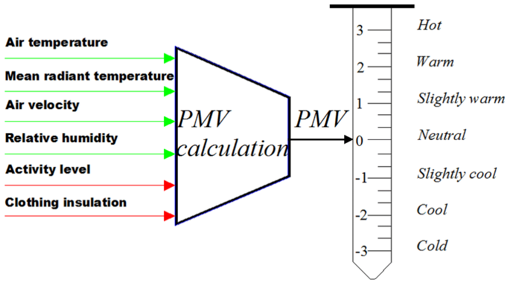
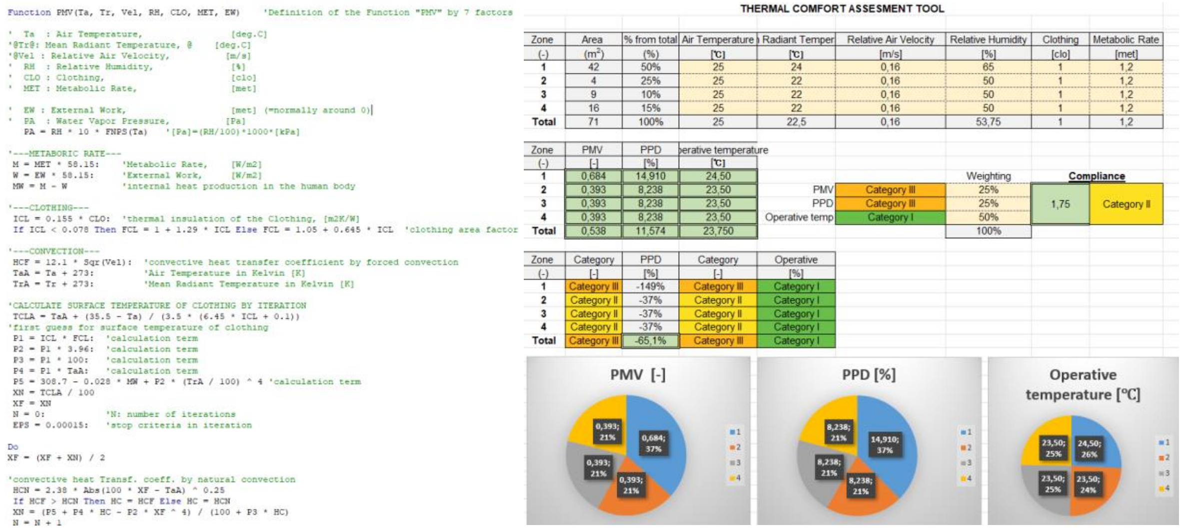


Figure 39: Calculation formulas/factors and value scale of PMV and PPD [35]

Calculation of the PMV and PPD was realized under VBA code in Excel based on the reference proposed by Takahiro Sat [245], thus below a part of the code and on the right is the proposed assessment of thermal comfort based on 3 non-energy parameters (PMV, PPD, Operative temperature).



```
Function PMV(Ta, Tr, Vel, RH, CLO, MET, EW)    'Definition of the Function "PMV" by 7 factors

'  Ta  : Air Temperature,                [deg.C]
'@Tr@: Mean Radiant Temperature, @    [deg.C]
'@Vel : Relative Air Velocity,          [m/s]
'  RH  : Relative Humidity,              [%]
'  CLO : Clothing,                       [clo]
'  MET : Metabolic Rate,                 [met]

'  EW  : External Work,                  [met] (=normally around 0)
'  PA  : Water Vapor Pressure,          [Pa]
   PA = RH * 10 * FNPS(Ta)    '[Pa]=(RH/100)*1000*[kPa]

'---METABORIC RATE---
 M = MET * 58.15:     'Metabolic Rate,     [W/m2]
 W = EW * 58.15:      'External Work,      [W/m2]
 MW = M - W           'internal heat production in the human body

'---CLOTHING---
 ICL = 0.155 * CLO:  'thermal insulation of the Clothing, [m2K/W]
 If ICL < 0.078 Then FCL = 1 + 1.29 * ICL Else FCL = 1.05 + 0.645 * ICL  'clothing area factor

'---CONVECTION---
 HCF = 12.1 * Sqr(Vel):  'convective heat transfer coefficient by forced convection
 TaA = Ta + 273:         'Air Temperature in Kelvin [K]
 TrA = Tr + 273:         'Mean Radiant Temperature in Kelvin [K]

'CALCULATE SURFACE TEMPERATURE OF CLOTHING BY ITERATION
 TCLA = TaA + (35.5 - Ta) / (3.5 * (6.45 * ICL + 0.1))
'first guess for surface temperature of clothing
 P1 = ICL * FCL:  'calculation term
 P2 = P1 * 3.96:  'calculation term
 P3 = P1 * 100:   'calculation term
 P4 = P1 * TaA:   'calculation term
 P5 = 308.7 - 0.028 * MW + P2 * (TrA / 100) ^ 4 'calculation term
 XN = TCLA / 100
 XF = XN
 N = 0:           'N: number of iterations
 EPS = 0.00015:   'stop criteria in iteration

Do
XF = (XF + XN) / 2

'convective heat Transf. coeff. by natural convection
 HCN = 2.38 * Abs(100 * XF - TaA) ^ 0.25
 If HCF > HCN Then HC = HCF Else HC = HCN
 XN = (P5 + P4 * HC - P2 * XF ^ 4) / (100 + P3 * HC)
 N = N + 1
```

THERMAL COMFORT ASSESMENT TOOL

Zone	Area	% from total	Air Temperature	Radiant Temper	Relative Air Velocity	Relative Humidity	Clothing	Metabolic Rate
(-)	(m^2)	(%)	[℃]	[℃]	[m/s]	[%]	[clo]	[met]
1	42	50%	25	24	0,16	65	1	1,2
2	4	25%	25	22	0,16	50	1	1,2
3	9	10%	25	22	0,16	50	1	1,2
4	16	15%	25	22	0,16	50	1	1,2
Total	71	100%	25	22,5	0,16	53,75	1	1,2

Zone	PMV	PPD	erative temperature
(-)	[-]	[%]	[℃]
1	0,684	14,910	24,50
2	0,393	8,238	23,50
3	0,393	8,238	23,50
4	0,393	8,238	23,50
Total	0,538	11,574	23,750

		Weighting	Compliance	
PMV	Category III	25%	1,75	Category II
PPD	Category III	25%		
Operative temp	Category I	50%		
		100%		

Zone	Category	PPD	Category	Operative
(-)	[-]	[%]	[-]	[%]
1	Category III	-149%	Category III	Category I
2	Category II	-37%	Category II	Category I
3	Category II	-37%	Category II	Category I
4	Category II	-37%	Category II	Category I
Total	Category III	-65,1%	Category III	Category I

Figure 40: a) VBA code calculation for PMV/PPD and b) proposed calculation sheet for Thermal Comfort Rating and weighting (example)

Future parameters that are to be implemented: overheating hours if no cooling, mean radiant temperature estimation based on regression models.

3.3.2 Visual comfort

Visual comfort is a crucial element of building design that can impact occupant productivity and well-being. The term "visual comfort" describes the nature of the visual environment, which includes elements like illumination, glare, and colour. While good visual comfort can increase occupant satisfaction and performance, poor visual comfort can cause eye strain, headaches, and fatigue [36]. Lighting is a crucial component of visual comfort. Comfort, mood, and productivity of occupants can be impacted by lighting levels and quality. High-quality illumination can increase clarity of vision, lessen strain on the eyes, and increase attentiveness. Lighting systems should be created to offer adequate illumination without producing glare or other unpleasant visual effects [37]. Glare is another factor in visual comfort. Glare occurs when the visual environment has an excessive amount of brightness or contrast, which causes pain to the eyes and reduces visibility. Direct sunlight, reflection off of surfaces, and poorly positioned lighting fixtures are all potential sources of glare. The incidence of glare can be decreased through proper building fenestration and shading systems, while glare from artificial lighting can be diminished through the installation of light fixtures with proper shielding [38].

Another crucial element for visual comfort is colour. Colour can influence perception and mood; some hues encourage relaxation while others encourage energy and production. When choosing colours for a structure, designers should consider both the intended purpose of the area and the inhabitant experience [39].

The daylight factor quantifies the quantity of daylight that enters a structure during the course of a typical day. Under an overcast sky, it is defined as the comparison of the indoor illuminance of a horizontal surface to the outside illuminance of the same surface. To determine how well a building takes advantage of its natural lighting, architects and designers might utilize the daylight factor [40].

Orientation, window size and placement, shading devices, and glazing characteristics are only a few of the variables that might affect the daylight factor in a building. High-performance glazing, such as low-e glass, can improve a building's energy efficiency by allowing more natural light inside while keeping the inside cooler and decreasing glare [41]. Depending on the room's function, a different amount of natural light is ideal. The daylight component in circulation areas may just need to be 2%, whereas in offices it may ideally be between 5% and 10% [42]. Building occupants can obtain numerous benefits from well-designed daylighting systems, including enhanced visual comfort, enhanced productivity, and decreased energy use. Daylighting systems, which let in outside light during the day, can save a lot of money on electricity by reducing the need for artificial lighting [42].

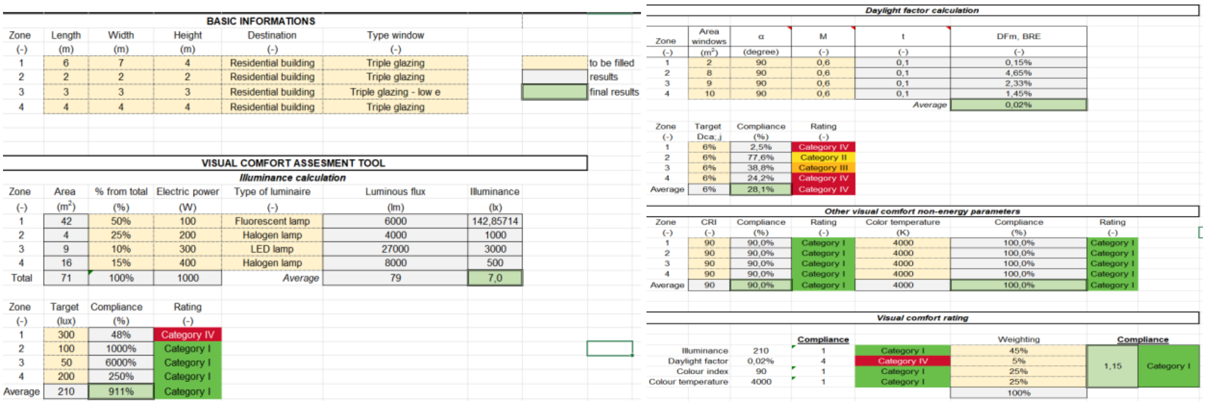
The daylight factor is an essential indicator of how well a building makes use of its natural sunlight. There are numerous energy savings and occupant benefits that can result from well-designed daylighting systems. In order to create efficient shading and daylighting systems, architects and designers of buildings should take into account the recommended daylight factor for the planned use of each room. Thus, visual comfort is a crucial non-energy parameter of building design that can have an impact on occupant satisfaction and efficiency. For inhabitants, places can be made that are both useful and enjoyable with the help of good lighting design, glare reduction, and colour selection.

We have prepared a calculation sheet with the following parameters:

- Illuminance level (lx)
- Daylight factor (%)
- Colour Rendering Index (CRI)
- Colour temperature

Based on the destination of the building, type of window, electric consumption, type of luminaire, target of illuminance from international norms (e.g. 300 lx), area of windows, angle of visible sky from the mid-point of the window, maintenance factor, target Dca;j, CRI target (e.g. 90), Colour temperature target (e.g. 4000 K) the compliance and rating was possible.

It must be mentioned that users can modify the weighting scheme for the 4 non-energy parameters available for visual comfort. Below are presented some of the screenshots from the calculation sheet:



BASIC INFORMATIONS

Zone	Length	Width	Height	Destination	Type window
(-)	(m)	(m)	(m)	(-)	(-)
1	6	7	4	Residential building	Triple glazing
2	2	2	2	Residential building	Triple glazing
3	3	3	3	Residential building	Triple glazing - low e
4	4	4	4	Residential building	Triple glazing

🟨 to be filled
⬜ results
🟩 final results

VISUAL COMFORT ASSESMENT TOOL

Illuminance calculation

Zone	Area	% from total	Electric power	Type of luminaire	Luminous flux	Illuminance
(-)	(m^2)	(%)	(W)	(-)	(lm)	(lx)
1	42	50%	100	Fluorescent lamp	6000	142,85714
2	4	25%	200	Halogen lamp	4000	1000
3	9	10%	300	LED lamp	27000	3000
4	16	15%	400	Halogen lamp	8000	500
Total	71	100%	1000	*Average*	79	7,0

Zone	Target	Compliance	Rating
(-)	(lux)	(%)	(-)
1	300	48%	Category IV
2	100	1000%	Category I
3	50	6000%	Category I
4	200	250%	Category I
Average	210	911%	Category I

Daylight factor calculation

Zone	Area windows	α	M	t	DFm, BRE
(-)	(m^2)	(degree)	(-)	(-)	(-)
1	2	90	0,6	0,1	0,15%
2	8	90	0,6	0,1	4,65%
3	9	90	0,6	0,1	2,33%
4	10	90	0,6	0,1	1,45%
				Average	0,02%

Zone	Target Dca;,j	Compliance	Rating
(-)		(%)	(-)
1	6%	2,5%	Category IV
2	6%	77,6%	Category II
3	6%	38,8%	Category III
4	6%	24,2%	Category IV
Average	6%	28,1%	Category IV

Other visual comfort non-energy parameters

Zone	CRI	Compliance	Rating	Color temperature	Compliance	Rating
(-)	(-)	(%)	(-)	(K)	(%)	(-)
1	90	90,0%	Category I	4000	100,0%	Category I
2	90	90,0%	Category I	4000	100,0%	Category I
3	90	90,0%	Category I	4000	100,0%	Category I
4	90	90,0%	Category I	4000	100,0%	Category I
Average	90	90,0%	Category I	4000	100,0%	Category I

Visual comfort rating

		Compliance		Weighting	**Compliance**	
Illuminance	210	1	Category I	45%	1,15	Category I
Daylight factor	0,02%	4	Category IV	5%		
Colour index	90	1	Category I	25%		
Colour temperature	4000	1	Category I	25%		
				100%		

Figure 41: Proposed calculation sheet for Visual Comfort Rating and weighting (example)

3.3.3 Acoustic comfort

Acoustic comfort is a crucial component of IEQ that may significantly affect building occupants' productivity and general well-being. It deals with the volume of sound or noise in a place and how its inhabitants react to it [43]. High noise levels might interfere with communication and focus, increase tension, and make speech less understandable. On the other side, a place that is completely silent or without sound may also be unsettling and confusing [44]. Depending on the way the room will be used, different acoustic comfort levels are advised. For instance, a school could need less noise than a restaurant or a mall [43].

Structure materials, room acoustics, HVAC systems, and outside noise sources are just a few of the elements that might influence how comfortable it is to hear within a structure. Noise levels may be decreased and acoustic comfort can be increased by thoughtfully arranging the design of acoustic systems such as walls, ceilings, and floors [45].

Furthermore, using sound-absorbing furnishings like carpets, curtains, and acoustic panels may decrease noise levels and enhance acoustic comfort [46]. In conclusion, acoustic comfort is a crucial component of IEQ that may have an impact on building occupants' productivity and general well-being. Building designers should take into account the appropriate levels of acoustic comfort for each space's intended usage when designing efficient acoustic systems to lower noise levels and enhance acoustic comfort.

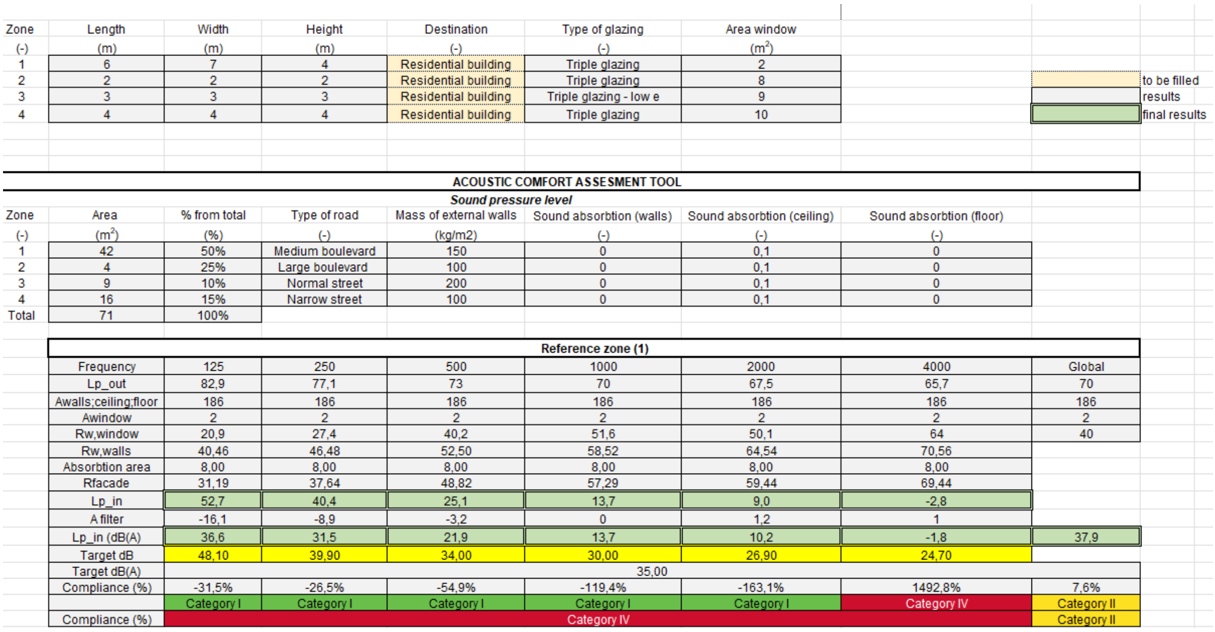
In the proposed procedure, we have proposed 3 non-energy parameters:

1) Global Sound pressure level (dB(A))
2) Noise curve compliance – sound pressure by frequency (dB)
3) Reverberation time RT60

The analyzed frequencies were 125 Hz to 4000 Hz. The input data is the destination, type of glazing, area of the windows, type of road – noise exposure (e.g., large boulevard), mass of external walls, sound absorption coefficient and area for walls, ceiling, and floor. The calculation formula for the theoretical assessment of sound attenuation of walls is presented below:

$$R = 20 * log_{10}(f) + 20 * log_{10}(p_{s)} - 45$$ **Equation 11.**

Below is presented a screenshot from the calculation sheet:



Zone	Length	Width	Height	Destination	Type of glazing	Area window
(-)	(m)	(m)	(m)	(-)	(-)	(m^2)
1	6	7	4	Residential building	Triple glazing	2
2	2	2	2	Residential building	Triple glazing	8
3	3	3	3	Residential building	Triple glazing - low e	9
4	4	4	4	Residential building	Triple glazing	10

🟨	to be filled
⬜	results
🟩	final results

ACOUSTIC COMFORT ASSESMENT TOOL

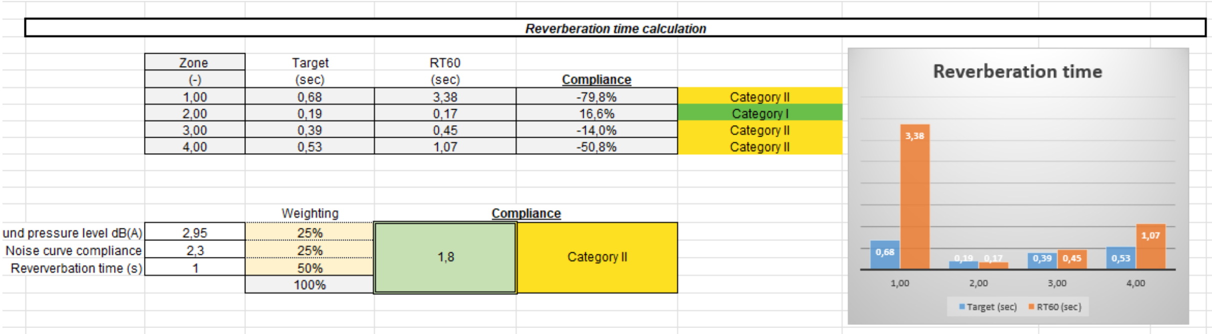
Sound pressure level

Zone	Area	% from total	Type of road	Mass of external walls	Sound absorbtion (walls)	Sound absorbtion (ceiling)	Sound absorbtion (floor)
(-)	(m^2)	(%)	(-)	(kg/m2)	(-)	(-)	(-)
1	42	50%	Medium boulevard	150	0	0,1	0
2	4	25%	Large boulevard	100	0	0,1	0
3	9	10%	Normal street	200	0	0,1	0
4	16	15%	Narrow street	100	0	0,1	0
Total	71	100%					

Reference zone (1)

Frequency	125	250	500	1000	2000	4000	Global
Lp_out	82,9	77,1	73	70	67,5	65,7	70
Awalls;ceiling;floor	186	186	186	186	186	186	186
Awindow	2	2	2	2	2	2	2
Rw,window	20,9	27,4	40,2	51,6	50,1	64	40
Rw,walls	40,46	46,48	52,50	58,52	64,54	70,56	
Absorbtion area	8,00	8,00	8,00	8,00	8,00	8,00	
Rfacade	31,19	37,64	48,82	57,29	59,44	69,44	
Lp_in	52,7	40,4	25,1	13,7	9,0	-2,8	
A filter	-16,1	-8,9	-3,2	0	1,2	1	
Lp_in (dB(A)	36,6	31,5	21,9	13,7	10,2	-1,8	37,9
Target dB	48,10	39,90	34,00	30,00	26,90	24,70	
Target dB(A)	35,00						
Compliance (%)	-31,5%	-26,5%	-54,9%	-119,4%	-163,1%	1492,8%	7,6%
	Category I	Category I	Category I	Category I	Category I	Category IV	Category II
Compliance (%)	Category IV						Category II

Figure 42: proposed calculation sheet for Acoustic Comfort Rating



Reverberation time calculation

Zone (-)	Target (sec)	RT60 (sec)	**Compliance**	
1,00	0,68	3,38	-79,8%	Category II
2,00	0,19	0,17	16,6%	Category I
3,00	0,39	0,45	-14,0%	Category II
4,00	0,53	1,07	-50,8%	Category II

		Weighting	**Compliance**	
und pressure level dB(A)	2,95	25%	1,8	Category II
Noise curve compliance	2,3	25%		
Reververbation time (s)	1	50%		
		100%		

Figure 43: Proposed calculation sheet for Reverberation time calculation and weighting of the non-energy parameters (example)

3.3.4 Indoor air quality

Indoor air quality (IAQ) is the state of the air within the building and how it affects the health and comfort of the people who are housed there [47]. Problems with breathing, allergies, and headaches are only some of the outcomes of low levels of IAQ [48]. Pollutants in the air may originate either from outside or within, including in construction materials, cleaning products, combustion appliances, and traffic exhaust [49]. Locating and removing the origins of IAQ-detrimental contaminants is essential. Ventilation, filtering, and eliminating the original source are all viable options for doing this [50]. Ventilation is the process of bringing in fresh air from outside to mix with the stale air within. Natural ventilation, mechanical ventilation, or a mix of the two may all provide adequate ventilation [51]. Cleaning using non-toxic materials and reducing the amount of cooking and heating done indoors are two examples of source control measures that may be taken to improve IAQ [53].

Carbon dioxide (CO_2) levels within buildings have been demonstrated to adversely affect the well-being and health of people. Symptoms like this may be brought on by excessive amounts of CO_2 [54].

Indoor CO_2 levels may be controlled in part via ventilation. By leaving the windows and doors open, as well as using other naturally occurring ventilation approaches, IAQ is enhanced. On the other hand, mechanical ventilation involves the use of mechanical components like fans and air handlers to transport and condition the air within a building [55].

Natural ventilation has been proven to be an efficient method of reducing CO_2 concentrations within buildings. A Swedish research showed that opening classroom windows for only 10 minutes each hour may cut CO_2 emissions by 40-50% [56]. In buildings where natural ventilation is impractical or insufficient, mechanical ventilation systems may be an efficient alternative for maintaining safe indoor CO_2 levels. Researchers at an Italian hospital discovered that CO_2 levels were considerably lower in-patient rooms when mechanical ventilation was used [57].

Maintaining secure amounts of carbon monoxide within buildings benefits the health and satisfaction of everyone inside. Building-specific and occupant-specific factors should inform the decision between natural and mechanical ventilation for CO_2 management. IAQ is an essential non-energy parameter of IEQ since it may have a direct impact on people's health and comfort within a structure. The risk of health issues caused by indoor air pollutants may be greatly reduced by maintaining adequate IAQ by proper ventilation, filtration, and source management.

The proposed procedure takes into account the air infiltration rate based on the type of windows, building exposure to wind, destination, target CO_2, etc.

Using the calculation procedure, we are also able to predict the air infiltration rate of the zones. For that, we have used the **Table 19** (valid in general for residential buildings at a pressure difference of 4 Pa):

Table 19: Buildings' calculation procedure (Romanian methodology)

Table 2.14b. Took from Mc 001 /2022, Romanian Methodology																				
			Carpentry category																	
			Wood						Metal					PVC				Aluminium		
Building category	Exposure class	Shelter class	W1	W2	W3	W4	W5	W6	M1	M2	M3	M4	M5	P1	P2	P3	P4	A1	A2	A3
Individual buildings (single-family, coupled, strung together)		NS	0,50	0,69	0,88	1,21	1,48	1,74	0,50	0,76	1,18	1,59	2,00	0,50	0,50	0,73	1,03	0,50	0,84	1,06
		MS	0,50	0,65	0,80	1,06	1,25	1,44	0,50	0,69	1,03	1,40	1,70	0,50	0,50	0,65	0,88	0,50	0,73	0,88
		S	0,50	0,61	0,73	0,91	1,03	1,14	0,50	0,61	0,88	1,18	1,40	0,50	0,50	0,58	0,73	0,50	0,61	0,73
Multiple apartments buildings	DE	NS	0,50	0,58	0,73	0,99	1,21	1,40	0,50	0,65	0,95	1,29	1,63	0,50	0,50	0,61	0,84	0,50	0,80	0,88
		MS	0,50	0,54	0,65	0,88	1,03	1,18	0,50	0,58	0,84	1,12	1,40	0,50	0,50	0,54	0,73	0,50	0,69	0,76
		S	0,50	0,50	0,61	0,76	0,84	0,95	0,50	0,50	0,73	0,95	1,18	0,50	0,50	0,50	0,61	0,50	0,58	0,65
	ME	NS	0,50	0,50	0,65	0,91	1,10	1,25	0,50	0,58	0,88	1,21	1,51	0,50	0,50	0,54	0,76	0,50	0,73	0,84
		MS	0,50	0,50	0,61	0,80	0,95	1,06	0,50	0,54	0,76	1,03	1,29	0,50	0,50	0,50	0,65	0,50	0,65	0,73
		S	0,50	0,50	0,58	0,69	0,76	0,88	0,50	0,50	0,65	0,84	1,06	0,50	0,50	0,50	0,58	0,50	0,55	0,61
	SE	NS	0,50	0,50	0,61	0,84	1,03	1,21	0,50	0,54	0,84	1,14	1,44	0,50	0,50	0,54	0,73	0,50	0,65	0,80
		MS	0,50	0,50	0,58	0,76	0,88	0,99	0,50	0,50	0,73	0,99	1,25	0,50	0,50	0,50	0,61	0,50	0,60	0,69
		S	0,50	0,50	0,54	0,65	0,73	0,80	0,50	0,50	0,61	0,80	0,99	0,50	0,50	0,50	0,54	0,50	0,54	0,58

Some of the tables used depend on the exposure to wind:

- No other buildings around (town building or holiday house)
- Few buildings around (building at city's border).
- Many buildings around (downtown, adjacent building or inside forest)

Type of carpentry and frame type (PVC, metal, wood, Aluminium)

- New carpentry with sealing gasket
- Good carpentry (without seal or slightly degraded)
- Old carpentry without seal

Operation scenarios for occupational period:

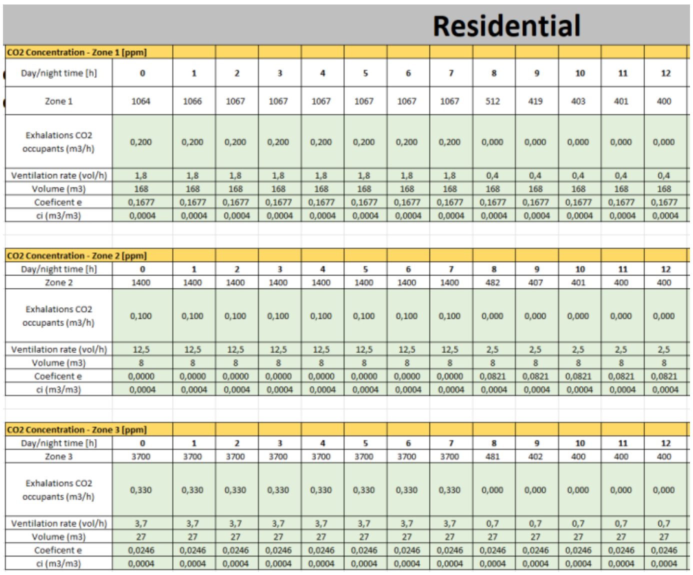
- Residential (24h)
- Office (8-17h, 5 days/week)
- Restaurant (8-22h, 7days/week)
- Hospital (24h)

The CO_2 concentration level was considered as our non-energy parameter that define the IAQ quality thus using the following formula:

$$\mathrm{c} = \left(\frac{\mathrm{q}}{\mathrm{n\ V}}\right)\left[1 - \left(\frac{1}{e^{n\,t}}\right)\right] + (c_0 - c_i)\left(\frac{1}{e^{n\,t}}\right) + c_i$$

Equation 12.

Based on CO_2 exhalation rate, volume, air change rate, time of calculation, c0 – concentration of 0 moment, ci – variable CO_2 level.



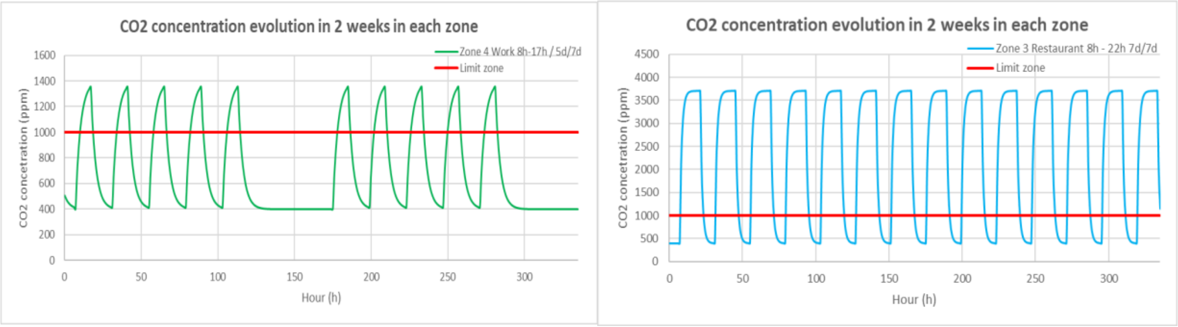
Residential

CO2 Concentration - Zone 1 [ppm]													
Day/night time [h]	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Zone 1	1064	1066	1067	1067	1067	1067	1067	1067	512	419	403	401	400
Exhalations CO2 occupants (m3/h)	0,200	0,200	0,200	0,200	0,200	0,200	0,200	0,200	0,000	0,000	0,000	0,000	0,000
Ventilation rate (vol/h)	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8	0,4	0,4	0,4	0,4	0,4
Volume (m3)	168	168	168	168	168	168	168	168	168	168	168	168	168
Coeficent e	0,1677	0,1677	0,1677	0,1677	0,1677	0,1677	0,1677	0,1677	0,1677	0,1677	0,1677	0,1677	0,1677
ci (m3/m3)	0,0004	0,0004	0,0004	0,0004	0,0004	0,0004	0,0004	0,0004	0,0004	0,0004	0,0004	0,0004	0,0004

CO2 Concentration - Zone 2 [ppm]													
Day/night time [h]	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Zone 2	1400	1400	1400	1400	1400	1400	1400	1400	482	407	401	400	400
Exhalations CO2 occupants (m3/h)	0,100	0,100	0,100	0,100	0,100	0,100	0,100	0,100	0,000	0,000	0,000	0,000	0,000
Ventilation rate (vol/h)	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5	2,5	2,5	2,5	2,5	2,5
Volume (m3)	8	8	8	8	8	8	8	8	8	8	8	8	8
Coeficent e	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0821	0,0821	0,0821	0,0821	0,0821
ci (m3/m3)	0,0004	0,0004	0,0004	0,0004	0,0004	0,0004	0,0004	0,0004	0,0004	0,0004	0,0004	0,0004	0,0004

CO2 Concentration - Zone 3 [ppm]													
Day/night time [h]	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Zone 3	3700	3700	3700	3700	3700	3700	3700	3700	481	402	400	400	400
Exhalations CO2 occupants (m3/h)	0,330	0,330	0,330	0,330	0,330	0,330	0,330	0,330	0,000	0,000	0,000	0,000	0,000
Ventilation rate (vol/h)	3,7	3,7	3,7	3,7	3,7	3,7	3,7	3,7	0,7	0,7	0,7	0,7	0,7
Volume (m3)	27	27	27	27	27	27	27	27	27	27	27	27	27
Coeficent e	0,0246	0,0246	0,0246	0,0246	0,0246	0,0246	0,0246	0,0246	0,0246	0,0246	0,0246	0,0246	0,0246
ci (m3/m3)	0,0004	0,0004	0,0004	0,0004	0,0004	0,0004	0,0004	0,0004	0,0004	0,0004	0,0004	0,0004	0,0004

Figure 44: Example of calculation sheet for 3 zones (period 0-12 hours) – the proposed method takes into account 2-week period



Zone	Target (ppm)	**Compliance**		**Compliance**	
1	1000	109,20%	Category I	74,3%	Category III
2	1000	71,58%	Category III		
3	1000	28,69%	Category IV		
4	1000	87,57%	Category II		

Figure 45: a) Example for an office zone (mechanical ventilation) and b) Restaurant (only air infiltration – windows and doors) calculated with the propose worksheet

For all the zones the category of IAQ based on EN16798-1 (Cat I - CO2 level <=400 + $CO_{2\_outdoor}$, Cat II - CO2 level between 400-600 + $CO_{2\_outdoor}$, Cat II - CO2 level between 600-1000 + $CO_{2\_outdoor}$, Cat IV - CO2 level > 1000 + $CO_{2\_outdoor}$). For the 4 analyzed zones:

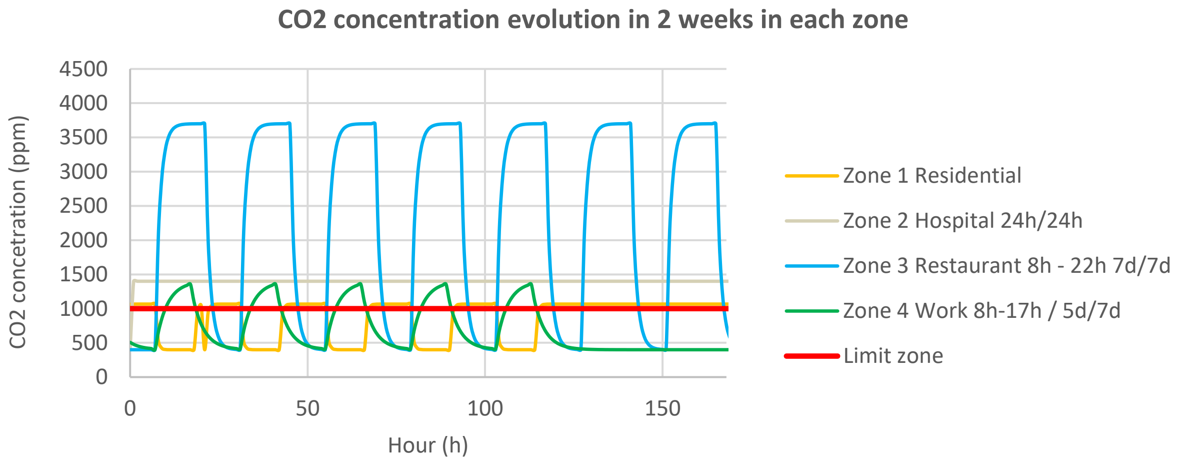


Figure 46: Example of a graphical representation of the CO_2 evolution for 168 hours (theoretical) based on multiple input data (e.g. occupants, exhalation rate – activity, type of air sealing – window, wind exposure, building type, fresh air flow – HVAC system, scenario of occupation)

3.3.4.1 Indoor Environmental quality Index

Calculating the IEQ of a building or interior space is rarely an easy task, given that the designer has to deal with numerous theoretical equations and simulation software for each of the IEQ parameters (operative temperature, illuminance and sound level) [58]. In addition, depending on what the occupants have highlighted, certain weights have to be given to the individual parameters. The ensuing weighting schemes attempt to combine the interrelated IEQ categories, into one performance model that can be used for ranking purposes. While there maybe value in combined indices for benchmarking and rating purposes, according to some studies there is also a loss of information and consequently a danger of misinterpretation. Many factors influence the relative importance of IEQ categories and that is why devising a universal weighting scheme that applies to all buildings at all times would seem difficult and unlikely. However, this should not deter the current study or further research dealing with weighting schemes from being pursued. While indeed some researchers argue that one-to-one comparisons of individual environmental parameters provide more information and are less likely to result in a conclusion that is inconsistent with occupant responses, the current study went forth with the holistic approach. An important remark has to be made when using the weighting values found in literature. These were derived especially for office buildings and their usability can thus be limited when applied to educational facilities. One key difference between the two building types comes from the importance placed on aural comfort. Whilst it is evident that office workers will place more emphasis on having a quiet working environment, school children will rank thermal comfort higher. A similar comment can be made for the lighting comfort.

Although no one discredits the importance of adequate light levels, survey respondents tend to crudely assess this aspect. It appears that a certain threshold exists below which insufficient lighting becomes bothersome depending on the activity employed. From one of our previous paper we have extracted the following weighting schema for the four non-energy parts of the IEQ (acoustic, IAQ, Visual, and Thermal).

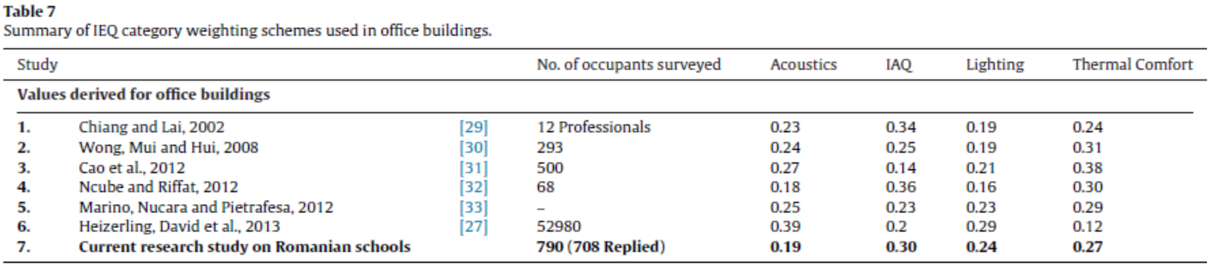
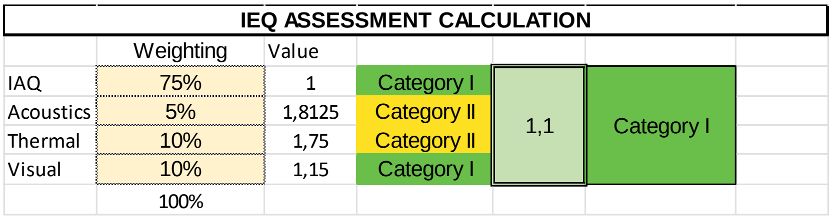


Table 7
Summary of IEQ category weighting schemes used in office buildings.

Study			No. of occupants surveyed	Acoustics	IAQ	Lighting	Thermal Comfort
Values derived for office buildings							
1.	Chiang and Lai, 2002	[29]	12 Professionals	0.23	0.34	0.19	0.24
2.	Wong, Mui and Hui, 2008	[30]	293	0.24	0.25	0.19	0.31
3.	Cao et al., 2012	[31]	500	0.27	0.14	0.21	0.38
4.	Ncube and Riffat, 2012	[32]	68	0.18	0.36	0.16	0.30
5.	Marino, Nucara and Pietrafesa, 2012	[33]	–	0.25	0.23	0.23	0.29
6.	Heizerling, David et al., 2013	[27]	52980	0.39	0.2	0.29	0.12
7.	**Current research study on Romanian schools**		**790 (708 Replied)**	**0.19**	**0.30**	**0.24**	**0.27**



IEQ ASSESSMENT CALCULATION						
	Weighting	Value				
IAQ	75%	1	Category I	1,1	Category I	
Acoustics	5%	1,8125	Category II			
Thermal	10%	1,75	Category II			
Visual	10%	1,15	Category I			
	100%					

Figure 47: Proposed calculation sheet for IEQ Index (example)

3.3.5 Radon risk assessment

Radon is a radioactive gas that occurs naturally and is often found inside, particularly in poorly ventilated structures. Research has connected radon exposure to lung cancer, and it is thought to be the second largest cause of mortality from lung cancer in the United States, after smoking [59]. Indoor radon levels may change based on things like soil type, building age and construction, and ventilation practices. The World Health Organization (WHO) advises that indoor radon levels not go over 100 Bq/m3 [60]. Building owners and occupants can take a number of steps to reduce radon levels in indoor environments, including increasing ventilation rates, sealing foundation and wall cracks and openings, and installing radon mitigation systems like active soil depressurization and ventilation systems [61]. Research shows that by taking these steps, indoor radon levels may be drastically lowered. In a British school, for instance, radon levels were found to drop from an average of 300 Bq/m3 to less than 10 Bq/m3 when a radon mitigation system was installed [62]. Radon poses a significant threat to human health in enclosed spaces, and steps should be taken to minimize exposure by both building owners and tenants. Reducing radon levels inside may be accomplished by improved ventilation, the sealing of cracks and crevices, and the installation of radon mitigation equipment.

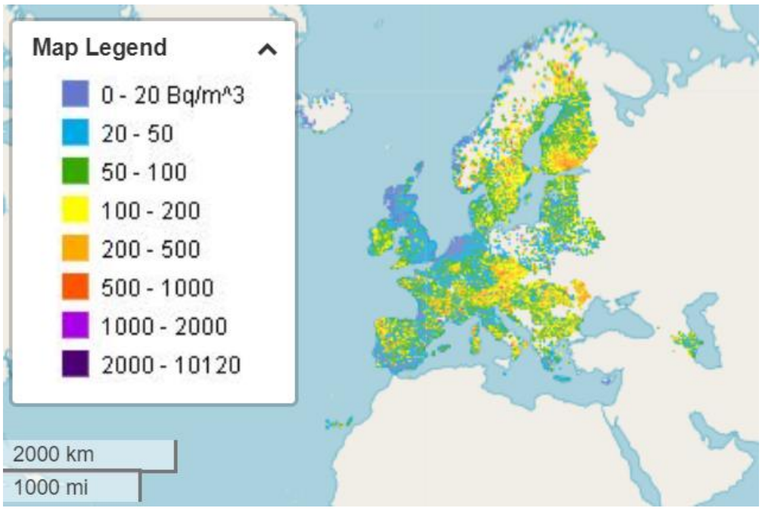


Figure 48: Indoor radon concentration averaged levels for a part of EU map (https://remap.jrc.ec.europa.eu/Atlas.aspx?layerID=3)

It can be seen that with this map we can identify with a resolution of 10 x 10 km the are that are most likely with the highest risk of radon problems inside a building.

A four-category risk assessment of radon exposure may be provided based on the European Indoor Radon Map, which offers data on indoor radon concentrations throughout Europe at a resolution of 10 km by 10 km.

Category I: Low risk- less than 100 Bq/m3

Indoor radon levels below 100 Bq/m3 are deemed safe for habitation. However, regular radon monitoring by residents is still advised to guarantee that the gas never rises over acceptable levels.

Category II: Moderate risk **–** levels within 100–300 Bq/m^3

Indoor radon levels between 100 and 300 Bq/m3 are considered a moderate concern for occupants of a building. Increased ventilation, sealing of cracks and holes, and radon mitigation devices are some of the actions that tenants may take to lower radon levels.

Category III – High risk levels within 300–1000 Bq/m3

High-risk regions include structures with indoor radon concentrations of 300 to 1000 Bq/m3. Residents should immediately begin taking action to lower radon levels, such as those described for category 2 or even relocate to a safer area if required.

Category IV – Very high risk (above 1000 Bq/m3) Radon levels within a building are considered very dangerous if they are more than 1000 Bq/m3. Urgent steps are needed to lower radon levels, and residents may want to look elsewhere for shelter.

The European Indoor Radon Map's four-category radon risk assessment may be used by building owners and occupants to determine the degree of radon risk in their building and take the necessary steps to minimize it.

3.3.6 Earthquake risk assessment

Europe is not a very seismic zone, although it does experience the occasional tremor. Considering both anticipated ground motion and the features of structures, Eurocode 8 sets standards for seismic design in Europe [63]. Several elements, including Europe's tectonic setting, geology, and seismicity history, affect the continent's seismic danger [64].

Seismic activity is highest in the Mediterranean and Balkan regions [63] [64], and severe earthquakes are more likely to occur there. Some of the most devastating earthquakes in modern European history have occurred in Italy, Greece, and Turkey [63]. Therefore, these nations have improved the seismic resilience of structures by establishing norms and laws [63] [65].

Europe's seismic hazard maps are created alongside the building rules to assist pinpoint high-risk locations and educate on earthquake-proof construction. These maps predict the potential for ground motion in various places by taking into account historical earthquake data, geological data, and seismological information [63] [64]. The most recent seismic hazard model for Europe, SHARE (Seismic Hazard Harmonization in Europe), was created as a joint effort between various European nations and offers a standardized hazard assessment for the area [64].

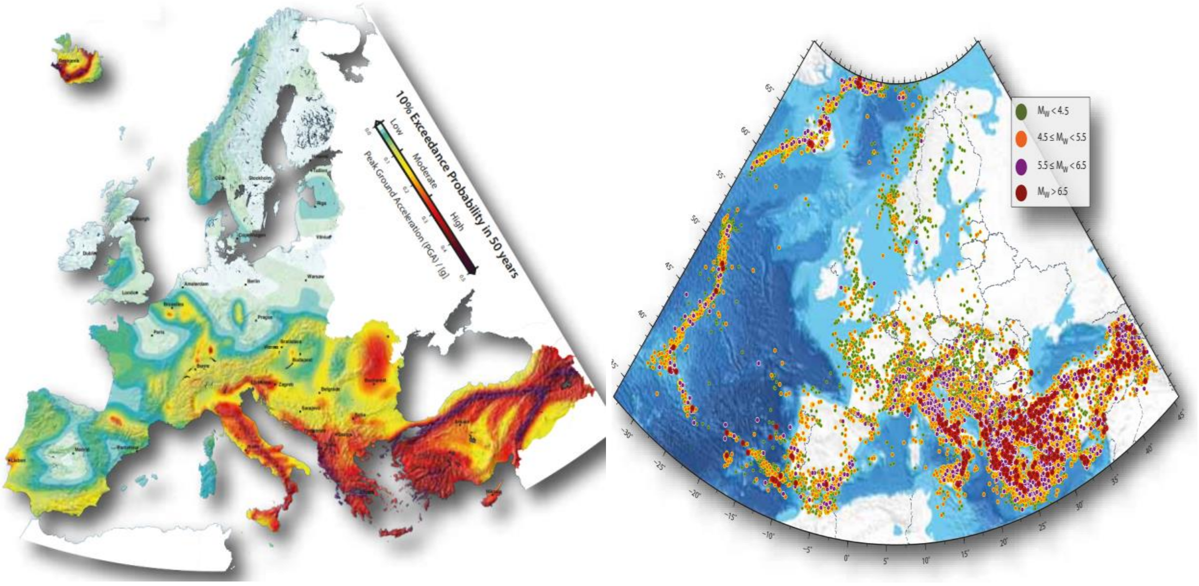


Figure 49: European Seismic Hazard Map (ESHM) displays the ground motion and b) earthquakes in Europe (major disasters in Italy, Greece, Romania or Turkey) – http://www.share-eu.org/sites/default/files/SHARE_Brochure_public.web_.pdf

Although Europe as a whole is not particularly prone to earthquakes, the danger varies from area to region. In Europe, designing and constructing structures that can withstand earthquakes requires the use of certain instruments, such as building rules, laws, and seismic hazard maps [63] [64] [65].

Any surveyed building falls into one of the following four risk classes:

- **R1** Class Rs I, which includes buildings with a high risk of collapse at the design earthquake corresponding to the ultimate limit state;
- **R2** Class Rs II, which includes buildings that are likely to suffer major structural degradation under the design earthquake but where loss of stability is unlikely;
- **R3** Class Rs III, which comprises buildings that under the effect of the design earthquake, may show structural degradation that does not significantly affect structural safety, but in which non-structural degradation may be significant;
- **R4** Class Rs IV, corresponding to constructions in which the expected seismic response is similar to that obtained in constructions designed on the basis of the requirements in force.

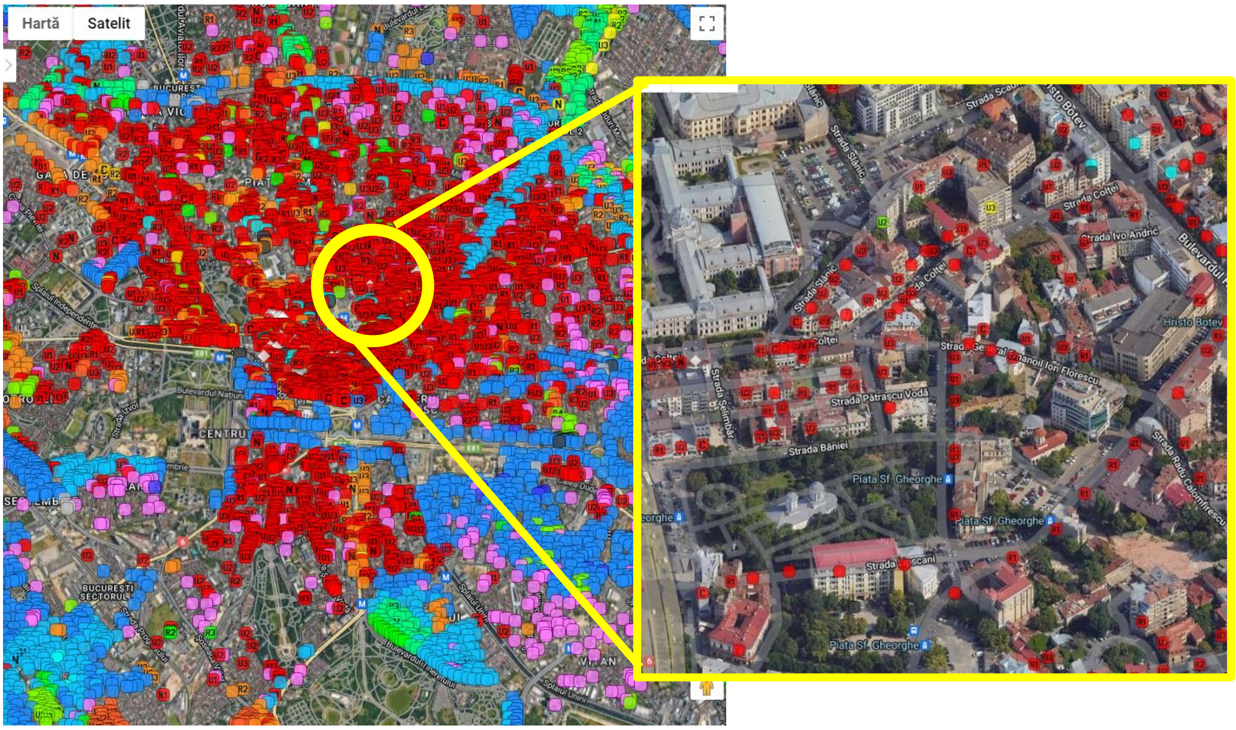


Figure 50: Seismic Risk (example for Bucharest, Romania) and zoom on a certain area with multiple building rated at earthquake hazard

Thus, it is proposed as a **non-energy parameter to measure the seismic risk of a building**.

3.3.7 Security assessment

Regarding the safety of people within and outside of the building, security measures must be taken very seriously. Access control systems, security cameras, and intrusion detection systems are just a few of the components that go into the construction of safe buildings. Whether the threat is real or digital, these systems can help you identify it and take action [66].

Authorized staff are the only ones who can enter restricted areas thanks to access control systems. Swipe cards, biometric scanners, and personal identification numbers are all viable options for this system. Cameras for monitoring the premises are another vital component of any adequate security system. They allow for constant surveillance of the building's inside and outside and may discourage illegal behaviour [67].

Perimeter-based and area-based intrusion detection systems are also viable options. All unlawful attempts to enter the building are detected by the perimeter-based security system. However, area-based systems may monitor a specific region within the structure for suspicious activity [68].

The safety of occupants is paramount throughout the construction and maintenance of any structure. Access control systems, security cameras, and intrusion detection systems are just a few of the components that go into the construction of safe buildings. Whether the threat is real or digital, these systems can help you identify it and take action. Protecting against cyber threats is another important function of a building's security system.

Based on the current security measures, a four-tiered risk assessment may be presented. Following is a breakdown of the classes:

Category I: A high-security facility is one that uses sophisticated security measures, such as a 24-hour security guard, surveillance cameras in all public areas, keypad-accessible automated doors, and other similar methods.

Category II: Moderately secure facilities include basic security features like staffed security during business hours, security cameras at strategic locations, automatic doors that need a key card to open, and so on.

Category III: Low-security buildings are those that only have the most fundamental security features, such as simple locks and no security cameras at the major entrances.

Category IV: No-security buildings are those that lack any kind of security, whether it be in the form of security cameras, guards, automated doors, or anything else.

All of the above-mentioned security measures, taken together, may increase or decrease a building's overall degree of security. Automatic doors may limit access to particular areas and prevent unwanted entrance, while security cameras can dissuade attackers and provide proof in the event of an incident. Manned security guards may serve as a visible deterrent by just being there. The value of the assets or information housed in a facility, as well as its location and the kind of operations conducted there, determine the degree of protection required. Banks, data centers, and other buildings storing valuable assets, as well as government and other sensitive sites, often demand a greater security level. Buildings may be categorized according to their degree of security using the results of a risk assessment, which are divided into four categories. Proposed rating of this non-energy parameter

Security, Lower-Level (Low Risk)

- No cameras (-), some cameras (-1) or full coverage (2-points) for security purposes. (2)
- Guards for Safety (out of a possible two points): None (-), Part-Time (1), and Full-Time (2) (2)
- Zero-Point-One-Point Automatic Doors: Absent (), Present (1)
- Access Restriction Levels: Restricted (-) or Full (+1) (1)

Second-Rate Protection (Moderate Risk)

- Score Security Cameras from 0 to 3: 0 = no cameras, 3 = some cameras, and 5 = all cameras. (5)
- Guards for Safety (from -3) to (3-5): None, Part-Time, and Full-Time (5)
- Zero-Point-One-Point Automatic Doors: Absent (), Present (1)
- Access Restriction Levels: Restricted (-) or Full (+1) (1)

Third-Grade Protection (High Risk)

- No cameras (-), few cameras (-6), or extensive coverage (--8): security cameras. (8)
- No security (-8 points), reduced security (-6 points), and full-time security (-8 points) (8)
- Zero-Point-One-Point Automatic Doors: Absent (), Present (1)
- Access Restriction Levels: Restricted (-) or Full (+1) (1)

Security, Level 4 (Very High Risk)

- No cameras (-), some cameras (9), or all cameras (10 points) for security. (10)

- None (-10 points), Part-Time (9), and Full-Time (10 points) (10)
- Zero-Point-One-Point Automatic Doors: Absent (), Present (1)
- Assorted (out of ten): Restricted access (-), Full authorization (1)

Each of the four aspects of security is given a score out of a possible 10, and the result is averaged. A higher score indicates a greater potential for breaching security measures. Low-risk structures have a total score of 0-2; moderate-risk structures have a score of 3-5; high-risk structures have a score of 6-8; and extremely high-risk structures have a score of 9-10. The weights assigned to each consideration may be modified to fit the needs of a certain structure.

3.4 Subject of SmartLivingEPC methodology regarding the energy performance of buildings

The methodology is used to assess and certify the energy performance of:

- New buildings and new sections/units of existing buildings;
- Existing buildings and their sections/units
- The SmartLivingEPC calculation methodology can be applied to the following building categories:
- Single-family houses;
- Multi-residential buildings;
- Office buildings;
- Educational buildings;
- Hospitals;
- Hotels and restaurants;
- Buildings for sport activities;
- Buildings for the provision of wholesale and retail services;

For mixed use buildings, provisions related for each category shall be applied separately to the respective parts of the building.

3.5 Normative references

Normative references are listed here below

Table 20 - Normative references

Nr.crt.	Number	Standard Title
	EN ISO 52000-1	Energy performance of buildings — Overarching EPB assessment — Part 1: General framework and procedures
	EN ISO 52003-1	Energy performance of buildings — Indicators, requirements, ratings and certificates —Part 1:General aspects and application to the overall energy performance
	EN ISO 52016-1	Energy performance of buildings - Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads - Part 1: Calculation procedures
	EN ISO 52017-1	Energy performance of buildings — Sensible and latent heat loads and internal temperatures —Part 1:Generic calculation procedures
	EN ISO 52018-1	Energy performance of buildings — Indicators for partial EPB requirements related to thermal energy balance and fabric features — Part 1:Overview of options
	EN ISO 13789	Thermal performance of buildings. Heat transfer coefficients through transmission and ventilation.
	EN 15316–1	Energy performance of buildings - Method for calculation of system energy requirements and system efficiencies - Part 1: General and Energy performance expression
	EN 15316–2	Energy performance of buildings - Method for calculation of system energy requirements and system efficiencies - Part 2: Space emission systems (heating and cooling)

Nr.crt.	Number	Standard Title
	EN 15316–3	Energy performance of buildings - Method for calculation of system energy requirements and system efficiencies - Part 3: Space distribution systems (DHW, heating and cooling)
	EN 15316–5	Energy performance of buildings - Method for calculation of system energy requirements and system efficiencies - Part 5: Space heating and DHW storage systems (not cooling)
	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)
	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
	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
	EN 15316-4-8	Energy performance of buildings - Method for calculation of system energy requirements and system efficiencies - Part 4-8: Space heating generation systems, air heating and overhead radiant heating systems, including stoves (local)
	EN 16798–9	Energy performance of buildings - Part 09: Ventilation for buildings - Module M4-1, M4-4, M4-9 - Calculation methods for energy requirements - Calculation methods for energy requirements of cooling systems - General
	EN 16798–15	Energy performance of buildings - Part 15: Module M4-7 - Calculation of cooling systems - Storage
	EN 16798–13	Energy performance of buildings - Part 13: Module M4-8 - Calculation of cooling systems - Generation
	EN 16798–5–1 și EN 16798–5–2	Energy performance of buildings - Modules M5-6, M5-8, M6-5, M6-8, M7-5, M7-8 - Ventilation for buildings - Calculation methods for energy requirements of ventilation and air conditioning systems - Part 5-1: Distribution and generation - method 1 Energy performance of buildings - Modules M5-6.2, M5-8.2 - Ventilation for buildings - Calculation methods for energy requirements of ventilation systems - Part 5-2: Distribution and generation - Method 2
	EN 12831–3	Energy performance of buildings - Method for calculation of the design heat load - Part 3: Domestic hot water systems heat load and characterisation of needs
	EN 15193–1	Energy performance of buildings - Energy requirements for lighting - Part 1: Specifications.
	EN ISO 6946	Construction parts and elements. Thermal resistance and thermal transmission coefficient. Calculation method
	EN ISO 7345	Thermal insulation. Physical quantities and definitions

3.6 Overview of the calculation procedure of the energy performance of buildings

The energy performance of a building is calculated according to the following sequential steps[4]:

Step 1: Identify the location of the building and select the appropriate climatic data

Step 2: Determine the boundary of the assessed building and the envelope of the conditioned area.

Step 3: If necessary, divide the conditioned space into thermal zones and service areas of for the calculations

Step 4: Determine input data for the calculations: internal conditions for the calculations, the inner climate and other input data relating to the environment.

Step 5: Determine the geometric and thermal properties of the building and of the building elements.

Step 6: For each calculation interval, calculate the energy need, the recoverable heat losses, the electric energy use and the required delivered energy for the DHW, taking into account the contribution of any installed thermal solar system.

Step 7: For each calculation interval, calculate the adjusted ODA ventilation flow rates, taking into account natural and/or mechanical ventilation and any installed heat recovery. Calculate electric energy use for mechanical ventilation.

Step 8: For each calculation interval, calculate the energy need for heating and cooling, taking into account recoverable losses from domestic hot water system as gains and adjusted ODA ventilation flow rates.

Step 9: For each calculation interval, repeat the calculation of energy needs for space heating and cooling, without the contribution of recoverable losses, to qualify the building envelope.

Step 10: For each calculation interval, calculate the electricity use for indoor lighting.

Step 11: For each calculation interval, calculate the on-site electricity production and the building electricity energy balance.

Step 12: For each calculation interval, calculate the total delivered energy per energy carrier and per service.

Step 13: For each calculation interval, calculate the primary energy and CO_2 emissions (weighted energy performance), in accordance with Section 3.9

Step 14: Select the appropriate energy conservation measures and calculate the new energy performance, the new class, the cost of the measures and the simple payback.

Step 15: Prepare the energy performance certificate.

The schematic overview of the calculation procedure of the energy indicators of a building is described in the flow diagrams in figures 51 to 56.

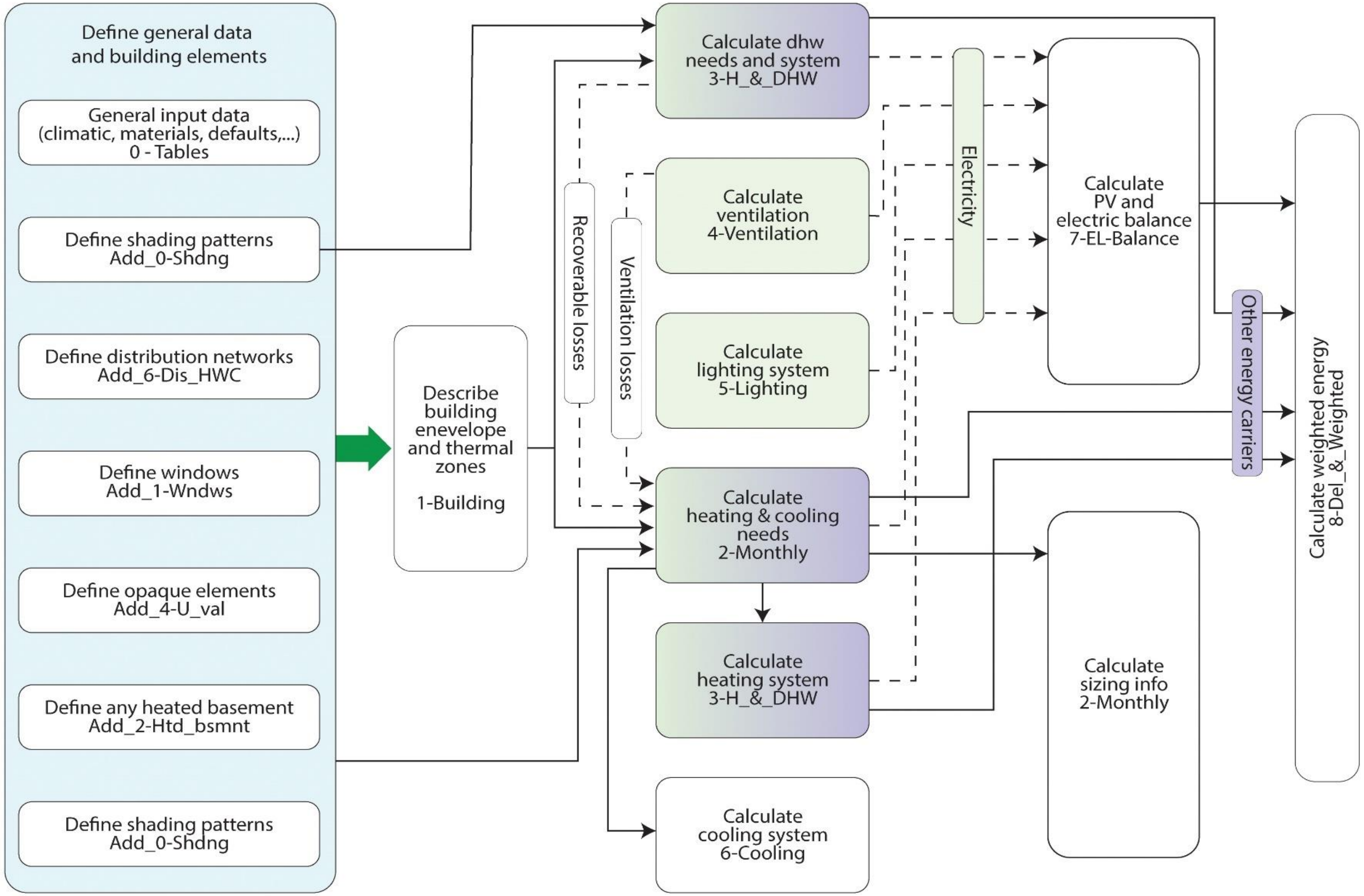


Figure 51 - General calculation flow diagram

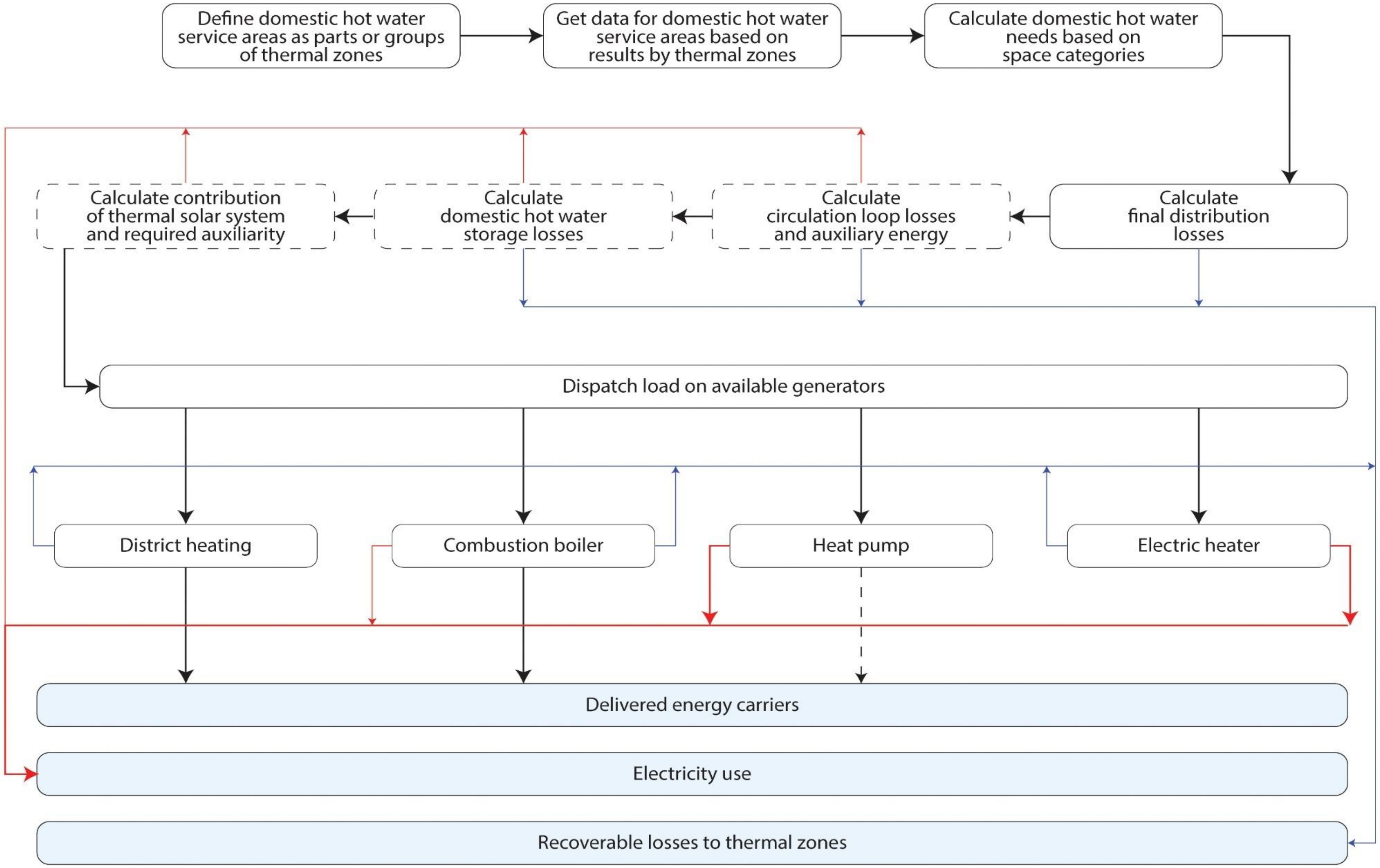


Figure 52 - Logical scheme for calculating the domestic hot water system

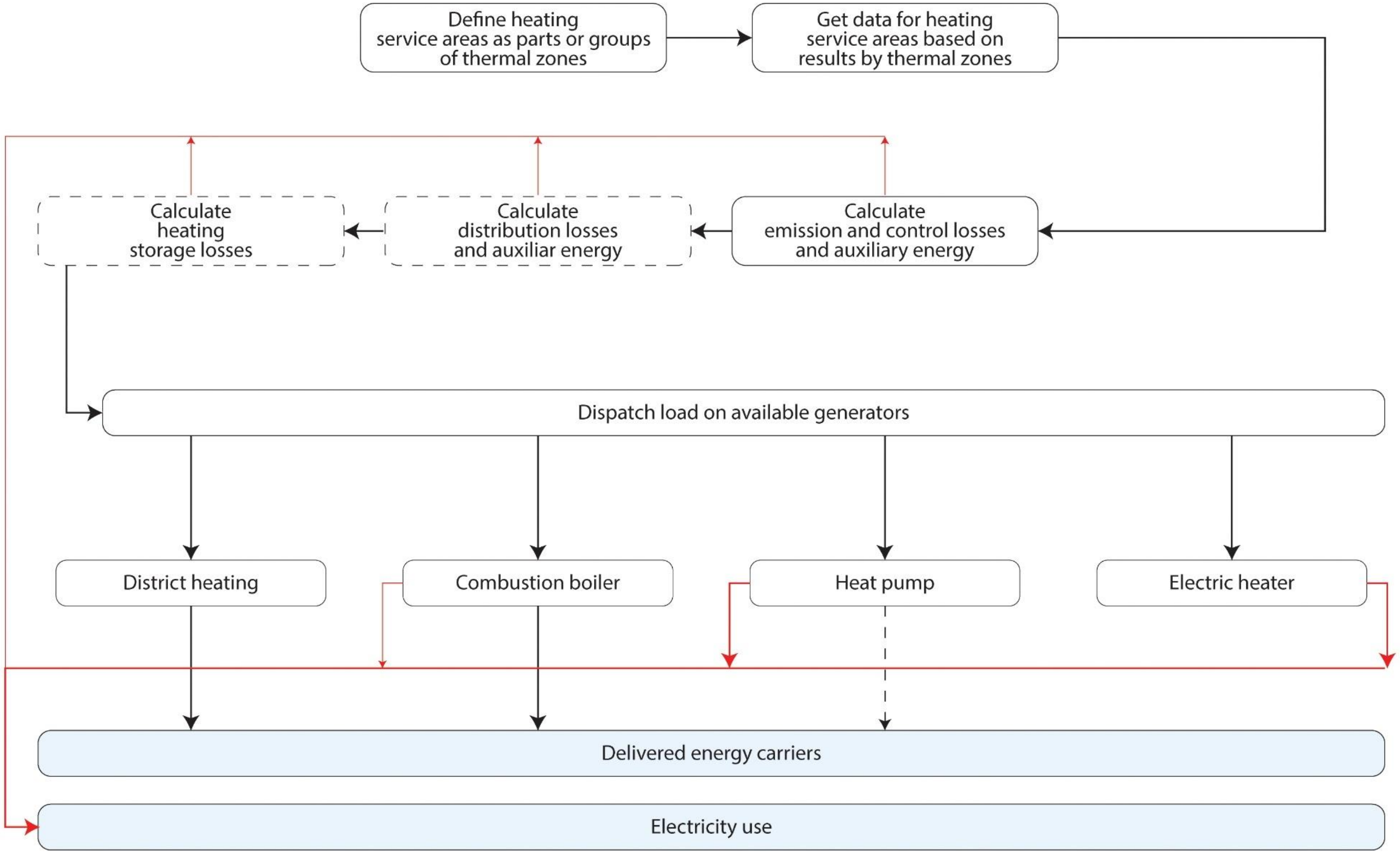


Figure 53 - Logical scheme for calculating the space heating system

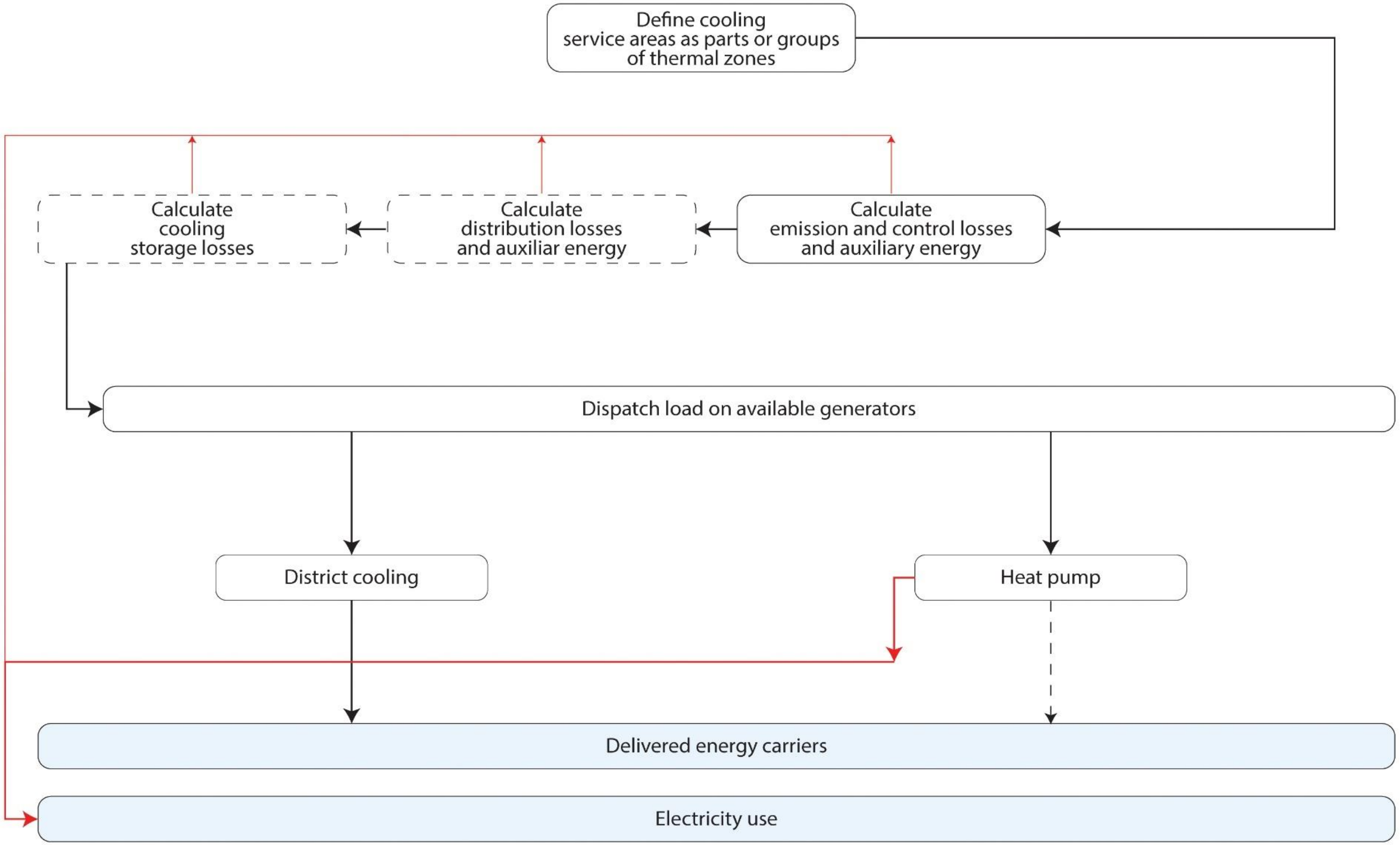


Figure 54 - Logical scheme for calculating the cooling system

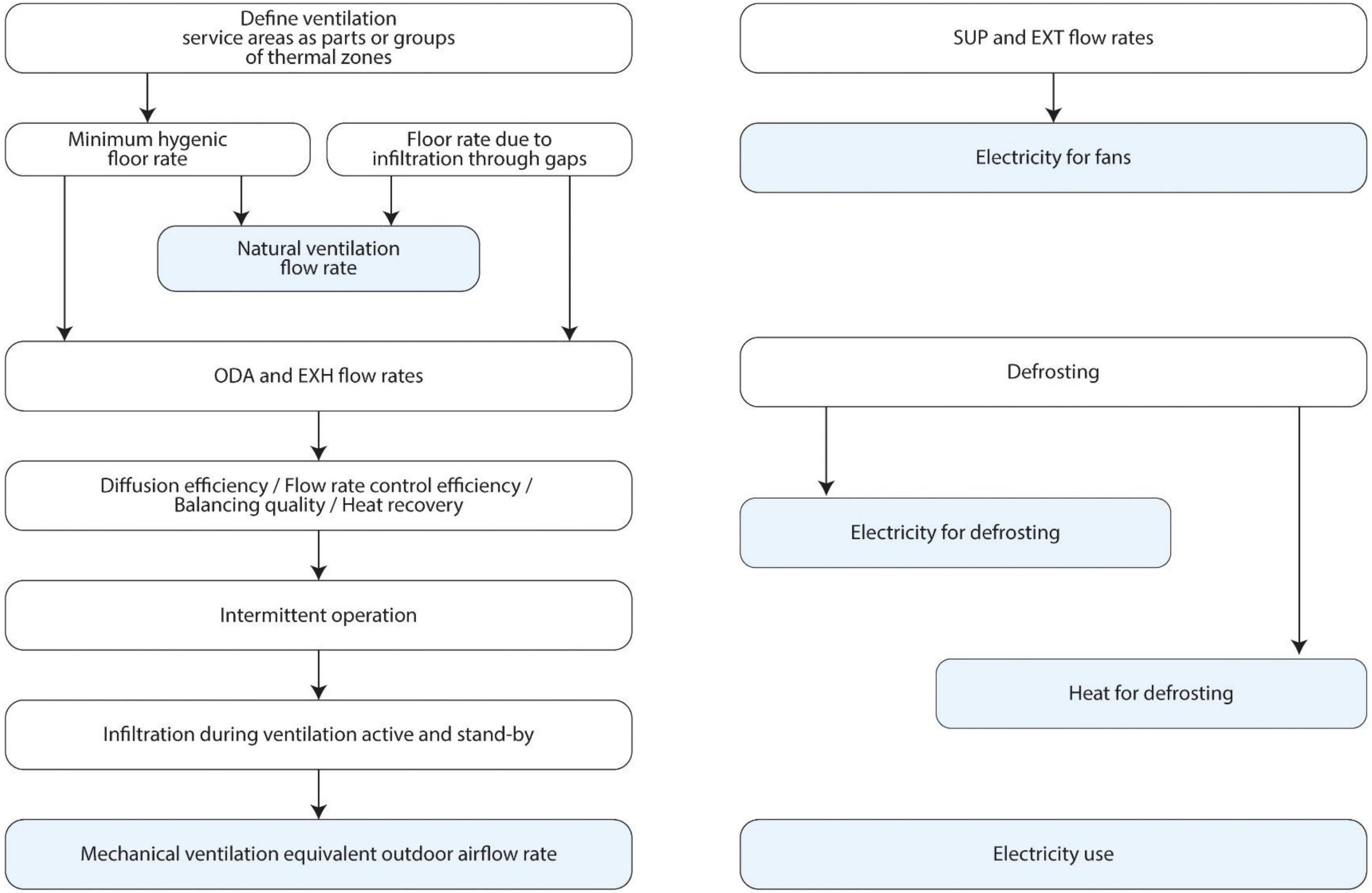


Figure 55 - Logical scheme for calculating the energy use for natural mechanical ventilation

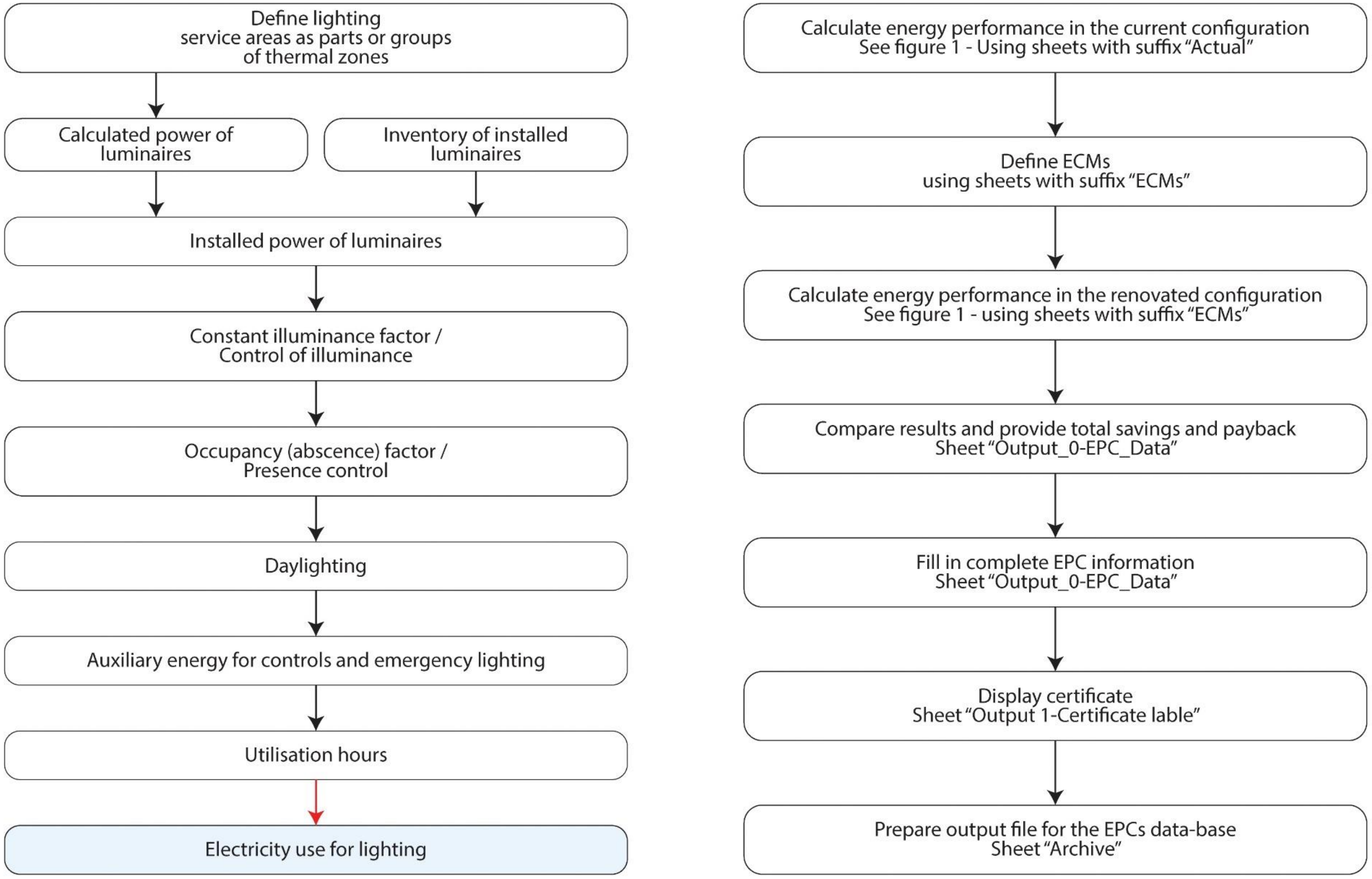


Figure 56 - Logical schemes for calculating the energy use for lighting and for applying energy conversion measures and preparing the certificate.

3.7 Definition of the input data for the calculation

3.7.1 Thermal zones and service areas of a building

General

To calculate the energy performance of the building it may be necessary to divide the building into several parts.

Thermal zones are related to the calculation of heating and/or cooling needs of the building envelope.

Service areas are related to the calculation of the different parts of the technical systems.

This regulation is in accordance with the general principles for zoning and service areas given in EN ISO 52000-1.

3.7.1.1 Thermal zones

Thermal zones are part of the building that share the balance of losses and gains to calculate heating and cooling needs.

The boundary of a thermal zone consists of the external surface all the structural elements that separate the conditioned space of the thermal zone from:

- The external environment (air, soil or water);
- Adjacent unconditioned spaces;
- Other thermal zones of the same building;
- Other buildings.

Division of a building into several thermal zones is required when:

- There are parts of the building of different space categories and sub-categories whose total area do exceed 10% of the whole building area.
- There are spaces with very different values of the gains/losses ration (e.g. South rooms with large windows);
- There are spaces whose conditions (energy balance) are dominated by specific thermal processes (such as an indoor swimming pool, a room for computers / servers or kitchen in the restaurant);
- A certificate or an indicator is required per building unit. For this case, each building unit shall be considered as a thermal zone;
- There are parts of the building served by different heating and/or cooling systems. Thermal zones may be defined according to the respective service areas.
- If one or more of the conditions a) to g) applies, then the building is divided into several heating and cooling thermal zones so that none of these conditions applies to each thermal zone.
- No thermal interaction between thermal zones is taken into account.

Depending on the conditions previously listed:

- The entire building can be modelled as a single thermal zone if there is no requirement to have several thermal zones;
- The building has to be divided into several thermal zones (multi-zone calculation).

3.7.1.2 Service areas

The service area is part of a building which is served by one unique technical system.

If there are several technical systems serving a building or only part of the building, an independent calculation is performed for each service area.

3.7.1.3 Data transfer between thermal zones and service areas

The following general rules apply for the date transfer between thermal zones and service areas.

If a service area covers several thermal zones, the relevant information from the thermal zones is summed or averaged according to the thermal zone areas.

Example A heating system serving several thermal zones: the heating needs of the thermal zones are are summed.

If a technical systems service area covers several thermal zones, the relevant results for the thermal zones, such as recoverable heat, that are not bound to a specific thermal zone shall be distributed according to the floor areas served in each thermal zone by the service area.

Example 1 The recoverable heat losses of an equipment or component which is located in a well defined thermal zone are taken into account in that thermal zone

Example 2 The recoverable heat losses which are not located in a well-defined thermal zone (like final distribution losses of a domestic hot water system serving several zones), the share of recoverable losses in that thermal zone are proportional to the area served by the system in that thermal zone.

If a thermal zone is supplied by several heating/cooling installations, the heating and/or cooling needs for the entire thermal zone may be distributed proportionally to the building floor area served by the different heating / cooling plants.

Example A building with a single thermal zone served by two heating and/or cooling systems.

Detailed rules for the connection of service areas to thermal zones are given in the relevant parts of the calculation procedure.

3.7.2 Floor area and volumes of the conditioned space

The reference floor area A_B and volume V_B of the entire building are the gross area and gross volume of the conditioned rooms in that building.

To determine the conditioned area and volume of the building, **the external dimensions are used**.

To determine the reference area and volume of each thermal zone, the boundary between thermal zones shall be in the middle of the dividing building element, so that the sum of the reference areas and volumes of the thermal zone equals the reference area and volume of the building.

The net floor area and the net volume of a thermal zone are given by the respective gross values multiplied by a default factor depending on the space category. The default factors are given in the following table.

Table 21 - Net Gross ratio

Category	**Net to gross ration, area** $k_{ng;A}$	**Net to gross ration, volume** $k_{ng;V}$
Single-family houses	0,80	0,75
Apartment buildings	0,80	0,75
Office buildings	0,80	0,75
Educational buildings	0,80	0,75
Hospitals	0,80	0,75
Hotels	0,80	0,75
Restaurants	0,80	0,75
Sport buildings	0,80	0,75
Commercial, wholesale and retail	0,80	0,75

The net floor area and the net volume of a building are given by the sum of the respective values for the thermal zones.

3.7.2.1 Principle of the calculation

Each “distribution network” consists of a set of pipes.

The properties of each pipe are defined individually.

A distribution network is attributed to each relevant distribution subsystem.

Total losses and recoverable losses are calculated taking into account:

- the properties of the pipes belonging to the distribution network;
- the operating temperature of the relevant distribution subsystem.

3.7.2.2 Required input data

For each pipe, the data listed in the following table are collected.

Table 22 - Input data to characterise pipes

Symbol	Unit	Description
DIS_PIPE_ID	ID	Pipe identifier
DIS_NET_ID	ID	Distribution network to which the pipe belongs
D_{ext}	M	Pipe external diameter
D_{int}	M	Pipe internal diameter
L	M	Length of the pipe
		Installation type
z	M	For buried pipes: depth within wall
λ_G	W/(m·K)	For buried pipes: environment conductivity
e	M	For couple of pipes buried: distance between axis of pipes
		Insulation material
d_{ins}	M	Insulation thickness
		Installation room temperature

3.7.3 Building envelope and thermal zones

Input data

The general data about the building listed in the following table shall be collected.

Table 23 – General data of the building

Symbol	Unit	Description
	String	Building name
	String	Building description
	String	Address: street and number
	String	Address: city
	String	Cadastral information
		Latitude
		Longitude
z		Elevation above sea level

	ID	Building main category
V_B	m^3	Gross volume of the building
A_B	m^2	Gross area of the building
$N_{B;fl}$	-	Number of floors
		Type of thermal bridges

Calculated data

The gross height of a typical floor $h_{B;fl}$ is given by:

$$\mathrm{h}_{\mathrm{B;fl}} = \frac{V_B}{A_B} \qquad (13)$$

The air density ρ_a at the building elevation is given by:

$$\rho_{\mathrm{a}} = 1{,}204 \cdot \left(1 - \left(0{,}00651 \cdot \frac{z}{288}\right)^{4{,}255}\right) \qquad (14)$$

The additional transmittance of building elements ΔU_{tb} due to thermal bridges is given in the following table according to the insulation type

Table 24 – Default values of ΔU_{tb} as a function of the insulation type

Insulation type	**Increase of transmittance ΔU_{tb} W/(m²·K)**
Continuous insulation	0,05
Other structure	0,1
Very heavy	370000

For each thermal zone ztc,j, the effective internal heat capacity $C_{m;int;eff;ztc,j}$ is given by

$$\mathrm{C}_{\mathrm{m;int;eff;ztc,j}} = \mathrm{A}_{\mathrm{ztc,j}} \cdot \mathrm{c}_{\mathrm{m;int;eff;ztc,j}} \qquad (1)$$

3.7.3.1 Building envelope description

Input data

For each building element that is separating the conditioned space from the external environment, from unheated spaces and from other buildings, the data listed in the following table shall be collected.

Table 25 – Data of building elements

Symbol	Unit	Description
	ID	Orientation of the element
	ID	Name of the element
	ID	Thermal zone to which it belongs
N_k	-	Number of items

A_k	m²	Area of each building element
	ID	The shading pattern, for elements towards exterior environment

Calculated data

The shape factor S/V is given by

$$S/V = \frac{\sum_k (A_k \cdot N_k)}{V_B} \tag{15}$$

3.7.4 Domestic hot water system

General

There can be several domestic hot water systems in a building.

Each domestic hot water system shall be calculated independently. The domestic hot water service area is the part of a building where domestic hot water is provided by the individual domestic hot water system.

Each domestic hot water system includes:

- A final distribution, that are the final pipes that connect the distribution loop or the domestic hot water generator to each tapping device, without permanent circulation.
- An optional domestic hot water circulation loop;
- An optional storage;

A generation system that may include one or several of the following:

- A thermal solar system;
- A district heating connection;
- A combustion boiler;
- A heat pump;
- A direct electric heater.

Depending on the building and installations set-up, a domestic hot water service area:

can cover an entire building which is of a single category and with a unique thermal zone; Example: single family house.

can cover a part of building encompassing several thermal zones; Example: a centralised domestic hot water system serving a large building with restaurant and shops on the ground floor, offices on the first floor and apartments on the upper floors.

can cover only a part of a single thermal zone of a building Example: an individual domestic hot water system in a flat inside an apartment block with centralised heating system.

Input data

For each domestic hot water service area Wsa,j, the following data shall be specified:

Table 26 -Data required to define a domestic hot water service area

Symbol	Unit	Description
$A_{Wsa,j;ztc,k}$	m²	Gross area of thermal zone ztc,k which is served by domestic hot water service area Wsa,j

3.7.5 Thermal solar systems

Required data

If a thermal solar system is connected to the domestic hot water storage of service area Wsa,j, the following data shall be specified.

Table 27 – Data required to define a domestic hot water thermal solar system

Symbol	Unit	Description
	ID	Type of domestic hot water need coverage
$k_{W;sol;aux;Wsa,j}$	-	Auxiliary energy as a fraction of heat output

3.7.6 Heat pump

Required data

For each heat pump domestic hot water generation system k, the following data shall be specified.

Table 28 -Data required for district heating domestic hot water generation

Symbol	Unit	Description
	ID	Heat pump type
	ID	Main energy carrier

3.7.7 Combustion boiler

Required data

For each combustion boiler for domestic hot water generation system blr,k, the following data shall be specified.

Table 29 - Data required for district heating domestic hot water generation

Symbol	Unit	Description
		Main energy carrier
		Type of boiler and application
		Thermal zone where installed
		Position of the boiler with respect to the thermal zone
$k_{W;blr,k;aux;Wsa,j}$		Auxiliary energy fraction
$k_{W;blr,k;ls;tot;rbl;Wsa,j}$		Recoverable fraction of total boiler losses (fraction through the envelope, the rest is to the chimney and is not recoverable)

The default value of the fraction of auxiliary energy $k_{W;blr,k;aux;Wsa,j}$ of the boiler k for domestic hot water generation for service area Wsa,j, is 0,04.

The default value of the fraction of total boiler losses that are recoverable $k_{W;blr,k;ls;tot;rbl;Wsa,j}$ of the boiler k for domestic hot water generation for service area Wsa,j, is 0,15.

3.7.8 Ventilation

Overview

This clause covers:

- The calculation of the total outdoor air flow rate, for both natural and mechanical ventilation, for inclusion in the energy balance of the relevant thermal zones;
- The calculation of electric energy use for mechanical ventilation.
- For buildings with natural ventilation, the assumed outdoor air flow rate is the maximum of:
- Minimum average hygienic flow rate $q_{v;0;av}$
- Infiltration flow rate due to joints in the opening elements $q_{v;gap}$
- The minimum hygienic flow rate is calculated:
- Based on air exchange rate on the net volume, for residential buildings
- Based on occupancy and area for non-residential buildings
- For building with a ventilation system, the outdoor air flow rate is an adjusted average values that takes into account
- During mechanical ventilation operation, the sum of
- Maximum of actual air handling unit (ahu) oda flow rate and minimum hygienic flow rate
- Infiltration flow rate with ventilation system on;
- During mechanical ventilation stand-by;
- Infiltration flow rate with ventilation system off.

Ventilation service areas

General

In a building, there can be areas with natural ventilation and areas served by mechanical ventilation systems.

A ventilation service area is a part of a building where there is either only natural ventilation or it is served by an individual mechanical ventilation system.

Each ventilation service area shall be calculated independently.

If more than 90% of the floor area of an existing building is served by the same ventilation setting, then it is assumed that the rest of the building is served by the same ventilation setting.

NOTE This condition of 90% applies only to existing buildings and is included to avoid situations when it is necessary to define additional zones in order to allow for smaller rooms such as corridors and utility room with different ventilation conditions.

Depending on the building and installations set-up, a ventilation service area:

Can cover an entire building which is of a single category and with a unique thermal zone; Example: single family house with natural ventilation or mechanical ventilation.

Can cover a part of building encompassing several thermal zones;

Example: a centralized ventilation system serving restaurant and shops on the ground floor and offices on the first floor of a large building with apartments without mechanical ventilation on the upper floors.

Can cover only a part of a single thermal zone of a building

Example: a mechanical ventilation system serving only a large meeting room in an office.

Input data

For each ventilation service area Vsa,j, the following data shall be specified:

Table 30 - Data required to define a ventilation area

Symbol	Unit	Description

$A_{Vsa,j;ztc,k}$	m²	Gross area of thermal zone k which is served by ventilation service area j

3.7.9 Energy needs for heating and cooling

General

Energy needs for space heating and space cooling are calculated with the following procedure, which complies with the monthly method according to EN ISO 52016-1:2017.

The calculation procedure is summarized in the following steps.

1. Determine the external and internal operating conditions and the heating and cooling seasons;
2. Calculate the heat transfer characteristics by transmission;
3. Calculate the heat transfer characteristics by ventilation;
4. Calculate the internal heat gains;
5. Calculate the solar heat gain through transparent and opaque elements;
6. Calculate the dynamic parameters;
7. Calculate the effect of intermittency;
8. Repeat the calculation with and without the domestic hot water recoverable losses to assess respectively the required heating and cooling system output and the energy needs of the building envelope without the influence of systems.

3.7.10 Heating system

Heating system service areas

General

There can be several space heating systems in a building.

Each space heating system shall be calculated independently. The space heating service area Hsa,j is the part of a building where space heating is provided by the heating system j.

Each space heating system includes the following subsystems:

- An emission and control sub-system
- A distribution sub-system;
- An optional storage sub-system;
- A generation sub-system that may include one or several of the following:
- A district heating connection;
- A combustion boiler;
- A heat pump;

Depending on the building and installations set-up, a space heating service area:

- Can cover an entire building which is of a single category and with a unique thermal zone; Example: single family house.
- Can cover a part of building encompassing several thermal zones; Example: a centralized heating system serving a large building with restaurant and shops on the ground floor, offices on the first floor and apartments on the upper floors.
- Can cover only a part of a single thermal zone of a building Example: an individual heating system in a flat inside an apartment block.

Input data

For each space heating service area Hsa,j, the following data shall be specified:

Table 31 - Data required to define a space heating service area

Symbol	Unit	Description
$A_{Hsa,j;ztc,k}$	m²	Gross area of thermal zone ztc,k which is served by space heating service area Hsa,j

Heating distribution

Input data

For each space heating service area Hsa,j, the following data shall be specified:

Table 32 - Data required to define a space heating distribution

Symbol	Unit	Description
Ψ_k	W/(m·K)	Linear transmittance of each pipe k belonging to the distribution
l_k	m	Length of each pipe k belonging to the distribution
		Installation position of each pipe k belonging to the distribution
		Type of circulation pump and pump control
$k_{H;dis;aux;rvd}$	-	Recovery factor of auxiliary energy

3.7.11 Heating storage

Required data

For each space heating storage, the following data shall be specified.

Table 33 – Data required to define a space heating storage

Symbol	Unit	Description
$Q_{H;sto;ls;ref;day;Hsa,j}$	kWh	Reference daily heat loss of storage device
		Storage position with respect to the thermal zone

If the reference daily heat losses are not known from the product label, then the following data are required.

Table 34 - Additional data required to calculate the reference losses of a space heating storage

Symbol	Unit	Description
$V_{H;sto;Hsa,j}$	m³	Volume of storage vessel
$h_{H;sto;Hsa,j}$	m	Height of storage vessel
$s_{H;sto;Hsa,j}$	mm	Insulation thickness
		Insulation material

3.7.12 Heat pump

Required data

For each heat pump hp,k for space heating generation, the following data shall be specified

Table 35 - Data required for heat pump space heating generation

Symbol	Unit	Description
	ID	**Heat pump type**
	ID	**Main energy carrier**
$P_{H;hp,k;aux}$		**Power of auxiliaries not included in the COP.** **This includes e.g. primary pumps and pumps of the source loop**
		Type of auxiliary energy use: constant power / load dependent

3.7.13 Combustion boiler

Required data

For each combustion boiler for space heating generation system blr,k, the following data shall be specified.

Table 36 - Data required for combustion boiler space heating generation

Symbol	Unit	Description
		Main energy carrier
		Type of boiler and application
		Thermal zone where installed
		Position of the boiler with respect to the thermal zone
$k_{H;blr,k;aux;Hsa,j}$		**Auxiliary energy fraction**
$k_{H;blr,k;ls;tot;rbl;Hsa,j}$		**Recoverable fraction of total boiler losses (fraction through the envelope, the rest is to the chimney and is not recoverable)**

The default value of the fraction of auxiliary energy $k_{H;blr,k;aux;Hsa,j}$ of the boiler blr,k for space heating generation for service area Hsa,j, is 0,04.

The default value of the fraction of total boiler losses that are recoverable $k_{H;blr,k;ls;tot;rbl;Hsa,j}$ of the boiler blr;k for space heating generation for service area Hsa,j, is 0,15.

3.7.14 Cooling system

Cooling system service areas

General

There can be several space cooling systems in a building.

Each space cooling system shall be calculated independently. The space cooling service area Csa,j is the part of a building where space cooling is provided by the cooling system j.

Each space cooling system includes the following subsystems:

- An emission and control sub-system
- A distribution sub-system;
- An optional storage sub-system;
- A generation sub-system that may include one or several chillers or heat pumps.
- Depending on the building and installations set-up, a space cooling service area:
- Can cover an entire building which is of a single category and with a unique thermal zone; example: single family house.

- Can cover a part of building encompassing several thermal zones; example: a centralized cooling system serving restaurant and shops on the ground floor as well as offices on the first floor.
- Can cover only a part of a single thermal zone of a building example: an individual cooling system in a flat inside an apartment block.

Input data

For each space cooling service area Csa,j, the following data shall be specified

Table 37 - Data required to define a space cooling service area

Symbol	Unit	Description
$A_{Csa,j;ztc,k}$	m²	Gross area of thermal zone ztc,k which is served by space cooling service area Csa,j

3.7.15 Cooling emission and control

Input data

For each cooling service area Csa,j, the data on emission and control subsystem listed in the following table shall be specified:

Table 38 - Data required to define a space cooling emission and control subsystem

Symbol	Unit	Description
$A_{Csa,j;em;k}$	m²	Area or percentage of area served by each group em,k of cooling terminals
		Type of cooling terminals of the group (panel/air/fan-coil)
		Balancing factor for panels
		Operation type for panels
		Type of panel
		Panel back insulation
		Control efficiency (for each terminal) and recovered fraction of recoverable losses
		Recovered fraction of auxiliary energy

3.7.16 Cooling distribution

Input data

For each space cooling service area Csa,j, the following data shall be specified:

Table 39 - Data required to define a space cooling distribution

Symbol	Unit	Description
Ψ_k	W/(m·K)	Linear transmittance of each pipe k, belonging to the distribution
l_k	m	Length of each pipe k belonging to the distribution
		Installation position of each pipe k belonging to the distribution
		Type of circulation pump and pump control
$k_{C;dis;aux;rvd}$	-	Recovery factor of auxiliary energy

3.7.17 Cooling storage

Required data

For each space cooling storage, the following data shall be specified.

Table 40 - Data required to define a space cooling storage

Symbol	**Unit**	**Description**
$Q_{C;sto;ls;ref;day;Csa,j}$	**kWh**	**Reference daily heat loss of storage device**
		Storage position with respect to the thermal zone

If the reference daily heat losses are not known from the product label, then the following data are required.

Table 41 - Additional data required to calculate the reference losses of a space cooling storage

Symbol	Unit	Description
$V_{C;sto;Csa,j}$	m³	Volume of storage vessel
$h_{C;sto;Csa,j}$	m	Height of storage vessel
$s_{C;sto;Csa,j}$	mm	Insulation thickness
		Insulation material

3.7.18 Heat pump (chiller)

Required data

For each heat pump hp,k for space cooling generation, the following data shall be specified.

Table 42 - Data required for heat pump space cooling generation

Symbol	**Unit**	**Description**
	ID	**Chiller or heat pump type**
	ID	**Energy carrier**
$P_{C;hp,k;aux}$		**Power of auxiliaries not included in the EER. This includes e.g. primary pumps and pumps of the heat rejection loop**
		Type of auxiliary energy use: constant power / load dependent

Spaces without a cooling system

For each month m,i in the cooling season, the electric energy that would be required for the cooling of spaces without a cooling system $E_{C;gen;in;el;nC;m,i}$ is given by

$$\mathrm{E_{C;gen;in;el;nC;m,i}} = \frac{\mathrm{Q_{C;hp,k;out;Csa,j;m,i}}}{\eta_{C;ctr;nC} \cdot \eta_{C;dis;nC} \cdot EER_{C;gen;nC}} \qquad (16)$$

where the default efficiencies of the fictive cooling system are given in the following table

Table 43 - Default efficiencies of the fictive cooling system

Description	Symbol	Value
Emission and control efficiency	$\eta_{C;ctr;nC}$	0,75

Distribution efficiency	$\eta_{C;dis;nC}$	1,00
Generation efficiency	$EER_{C;gen;nC}$	2,50

3.7.19 Lighting

General

A lighting service area is a part of the building with uniform properties concerning lighting energy performance calculation. If there are parts of the building with different lighting properties, they shall be identified as separated “lighting service areas” and calculated independently.

By default, there shall be one lighting service area for each thermal zone, since the space category associated to each thermal zone determines the operating conditions of the lighting.

There can be part of a thermal zone with different lighting properties, such as different control properties and/or different daylighting conditions. In that case the thermal zone shall be divided into several lighting service areas.

Depending on the building and installations set-up, a lighting service area:

- Can cover an entire building which is of a single category and with a unique thermal zone; Example: single family house.
- Can cover an entire thermal zone of a building divided into several thermal zones; Example: the lighting of the ground floor shops on a mixed use building.
- Can cover only a part of a single thermal zone of a building Example: the part of an office where an automatic control of lighting has been installed. Another service area will be defined to cover the rest of the office.

A lighting service area cannot extend over multiple thermal zones.

Input data

For each lighting service area Lsa,j, the following data shall be specified:

Table 44 - Data required to define a lighting service area

Symbol	Unit	Description
$A_{Lsa,j}$	m^2	Gross area served by domestic hot water service area Lsa,j
$ztc_{Lsa,j}$		Thermal zone covered by the lighting service area

3.7.20 Photovoltaic and electricity balance

General

The photovoltaic (PV) systems can be considered if they are permanently installed

- Either directly on the building;
- Or within the building site (e.g. On a garage attached to the building on the same land lot)

and the produced energy is used in the building.

Input data

For each installed photovoltaic system PV,j, the following data shall be specified.

Table 45 - Data required to define the façade daylight factor

Symbol	**Unit**	**Description**
$P_{PV,j;pk}$		**Peak power of the installed PV panels: the electrical power output of a PV system with a given area under a solar irradiance of 1 kW/m² on its surface at 25 °C**

		Orientation of the PV panels
		Tilt angle of the PV panels
		Installation type

For each installed photovoltaic system PV,j and for each month m,i, the solar radiation $H_{sol;or;tlt;m,i;PV,j}$ as a function of orientation and tilt is given in the following table.

For each installed photovoltaic system PV,j, the system performance factor $f_{perf;PV,j}$ is given in the following table.

Table 46 - Day time and night time utilisation hours of lightingDay time and night time utilisation hours of lighting

Installation type	**System performance factor** f_{perf} -
Unventilated modules (embedded)	**0,76**
Moderately ventilated modules	**0,80**
Strongly ventilated modules or forced ventilation	**0,82**

The reference solar irradiation $I_{sol;ref}$ is equal to 1,0 kW/m²

3.7.21 Electricity balance

Used electricity

For each month m,i and for each service X,k, the used electricity $E_{EPus;el;X,k;m,i}$ is the sum of all electricity main inputs for all generators and of all auxiliary energy uses for service X,k.

$$\mathrm{E}_{\mathrm{EPus;el;X,k;m,i}} = \sum\nolimits_{gen,j} E_{X,k;gen,j;in;el;m,i} + \sum\nolimits_{Y,j} W_{X,k;Y,j;aux;m,i} \tag{4}$$

where

X,1=H for space heating service

X,2=W for domestic hot water service

X,3=Cfor space cooling service

X,4=Vfor ventilation service

X,5=L for lighting service

Y,j is any subsystem like emission, distribution, control, generation, etc.

For each month m,i and for each service X,k, the fraction $k_{EPus;el;X,k;m,i}$ of used electricity by service X,k is given by.

$$\mathrm{k}_{\mathrm{EPus;el;X,k;m,i}} = \frac{\mathrm{E}_{\mathrm{EPus;el;X,k;m,i}}}{\sum_{X,j} \mathrm{E}_{\mathrm{EPus;el;X,j;m,i}}} \tag{517}$$

For each month m,i, the used electricity $E_{EPus;el;m,i}$ is the sum of electricity used for all services X,k and is given by:

$$\mathrm{E}_{\mathrm{EPus;el;m,i}} = \sum\nolimits_{X,k} \mathrm{E}_{\mathrm{EPus;el;X,k;m,i}} \tag{6}$$

Produced electricity

For each month m,i, the produced electricity $E_{pr;el;m,i}$ is the sum of the electricity production from all installed electricity generation systems Y,j and is given by:

$$\mathrm{E}_{\mathrm{pr;el;m,i}} = \sum_{Y,j} E_{pr;el;Y,j;m,i} \tag{7}$$

NOTE: for the moment there is no cogeneration.

If added the energy produced by cogeneration shall be added.

For each month m,i, the total weighted produced electricity $E_{we;el;pr;m,i}$ is given by:

$$\mathrm{E}_{\mathrm{Pnren;el;pr;m,i}} = \sum_{Y,j} \mathrm{E}_{\mathrm{Pnren;el;pr;Y,j;m,i}} \tag{8}$$

$$\mathrm{E}_{\mathrm{Pren;el;pr;m,i}} = \sum_{Y,j} \mathrm{E}_{\mathrm{Pren;el;pr;Y,j;m,i}} \tag{9}$$

$$\mathrm{M}_{\mathrm{CO2;el;pr;m,i}} = \sum_{Y,j} \mathrm{M}_{\mathrm{CO2;el;pr;Y,j;m,i}} \tag{10}$$

where Y,j are the electricity production systems in the building.

NOTE Y may be PV for photovoltaic and cgn for cogeneration

For each month m,i, the weighting factors of produced electricity $f_{we;el;pr;m,i}$ is given by:

$$\mathrm{f}_{\mathrm{Pnren;el;pr;m,i}} = \frac{\mathrm{E}_{\mathrm{Pnren;el;pr;m,i}}}{\mathrm{E}_{\mathrm{pr;el;m,i}}} \tag{11}$$

$$\mathrm{f}_{\mathrm{Pren;el;pr;m,i}} = \frac{\mathrm{E}_{\mathrm{Pren;el;pr;m,i}}}{\mathrm{E}_{\mathrm{pr;el;m,i}}} \tag{12}$$

$$\mathrm{f}_{\mathrm{CO2;el;pr;m,i}} = \frac{\mathrm{M}_{\mathrm{CO2;el;pr;m,i}}}{\mathrm{E}_{\mathrm{pr;el;m,i}}} \tag{13}$$

Self used electricity

For each month m,i, the ration $x_{m;i}$ of produced and used electricity is given by

$$\mathrm{x}_{\mathrm{m,i}} = \frac{\mathrm{E}_{\mathrm{pr;el;m,i}}}{\mathrm{E}_{\mathrm{EPus;el;m,i}}} \tag{14}$$

For each month m,i, the matching factor $f_{match;m,i}$ of produced and used electricity is given by

$$\mathrm{f}_{\mathrm{match;m,i}} = \frac{x_{m,i}{}^{n} + \frac{1}{x_{m,i}{}^{n}}}{x_{m,i}{}^{n} + \frac{1}{x_{m,i}{}^{n}} + k} \tag{15}$$

where

n=1 coefficient controlling sharpness of matching factor

k=1,3 coefficient controlling the minimum value of matching factor

For each month m,i, the self-used part for EPB purpose of produced electricity $E_{pr;el;used;EPus;m,i}$ is given by

$$\mathrm{E}_{\mathrm{pr;el;used;EPus;m,i}} = \mathrm{f}_{\mathrm{match;m,i}} \cdot min\left[\mathrm{E}_{\mathrm{EPus;el;m,i}}; \mathrm{E}_{\mathrm{pr;el;m,i}}\right] \tag{16}$$

Delivered and exported energy

For each month m,i, the electricity exported to the grid $E_{exp;m,i}$ is given by

$$\mathrm{E}_{\mathrm{exp;el}} = \mathrm{E}_{\mathrm{pr;el;m,i}} - \mathrm{E}_{\mathrm{pr;el;used;EPus;m,i}} \tag{17}$$

For each month m,i, the electricity delivered from the grid $E_{del;el;m,i}$ is given by

$$\mathrm{E}_{\mathrm{del;el}} = \mathrm{E}_{\mathrm{EPus;el;m,i}} - \mathrm{E}_{\mathrm{pr;el;used;EPus;m,i}} \tag{18}$$

Weighted electricity balance

For each month m,i, the weighted exported energy at step A (evaluated according to the resource used to produce it) $E_{we;exp;el;m,i;A}$ is given by:

$$\mathrm{E}_{\mathrm{Pnren;exp;el;m,i;A}} = \mathrm{E}_{\mathrm{exp;el;m,i}} \cdot f_{\mathrm{Pnren;el;pr;m,i}} \tag{19}$$

$$\mathrm{E}_{\mathrm{Pren;exp;el;m,i;A}} = \mathrm{E}_{\mathrm{exp;el;m,i}} \cdot f_{\mathrm{Pren;el;pr;m,i}} \tag{20}$$

$$\mathrm{M}_{\mathrm{CO2;exp;el;m,i;A}} = \mathrm{E}_{\mathrm{exp;el;m,i}} \cdot f_{\mathrm{CO2;el;pr;m,i}} \tag{21}$$

NOTE index "we" for "weight" may be replaced by any type of weighting per energy carrier, such primary energy, CO_2 emissions, cost and more.

For each month m,i, the weighted delivered energy at step A $E_{we;exp;el;m,i;A}$ is given by:

$$\mathrm{E}_{\mathrm{Pnren;del;el;m,i;A}} = \mathrm{E}_{\mathrm{del;el;m,i}} \cdot f_{\mathrm{Pnren;el}} \tag{22}$$

$$\mathrm{E}_{\mathrm{Pren;del;el;m,i;A}} = \mathrm{E}_{\mathrm{del;el;m,i}} \cdot f_{\mathrm{Pren;el}} \tag{23}$$

$$\mathrm{M}_{\mathrm{CO2;del;el;m,i;A}} = \mathrm{E}_{\mathrm{del;el;m,i}} \cdot f_{\mathrm{CO2;el}} \tag{24}$$

For each month m,i, the weighted energy performance for electricity at step A $E_{we;el;m,i;A}$ is given by:

$$\mathrm{E}_{\mathrm{Pnren;el;m,i;A}} = \mathrm{E}_{\mathrm{Pnren;del;el;m,i;A}} - \mathrm{E}_{\mathrm{Pnren;exp;el;m,i;A}} + \mathrm{E}_{\mathrm{Pnren;el;pr;m,i}} \tag{25}$$

$$\mathrm{E}_{\mathrm{Pren;el;m,i;A}} = \mathrm{E}_{\mathrm{Pren;del;el;m,i;A}} - \mathrm{E}_{\mathrm{Pren;exp;el;m,i;A}} + \mathrm{E}_{\mathrm{Pren;el;pr;m,i}} \tag{26}$$

$$\mathrm{M}_{\mathrm{CO2;el;m,i;A}} = \mathrm{M}_{\mathrm{CO2;del;el;m,i;A}} - \mathrm{M}_{\mathrm{CO2;exp;el;m,i;A}} + \mathrm{M}_{\mathrm{CO2;el;pr;m,i}} \tag{27}$$

For each month m,i, the potential effect of inclusion of exported energy in the weighted energy performance for electricity $E_{we;el;exp;m,i;AB}$ is given by:

$$\mathrm{E}_{\mathrm{Pnren;el;exp;m,i;AB}} = \mathrm{E}_{\mathrm{exp;el;m,i}} \cdot \left(f_{\mathrm{Pnren;el;pr;m,i}} - f_{\mathrm{Pnren;el}}\right) \tag{28}$$

$$\mathrm{E}_{\mathrm{Pren;el;exp;m,i;AB}} = \mathrm{E}_{\mathrm{exp;el;m,i}} \cdot \left(f_{\mathrm{Pren;el;pr;m,i}} - f_{\mathrm{Pren;el}}\right) \tag{29}$$

$$\mathrm{M}_{\mathrm{CO2;el;exp;m,i;AB}} = \mathrm{E}_{\mathrm{exp;el;m,i}} \cdot \left(f_{\mathrm{CO2;el;pr;m,i}} - f_{\mathrm{CO2;el}}\right) \tag{30}$$

For each month m,i, the weighted energy performance for electricity $E_{we;el;m,i}$ is given by:

$$\mathrm{E}_{\mathrm{Pnren;el;m,i}} = \mathrm{E}_{\mathrm{Pnren;el;m,i;A}} + k_{exp} \cdot \mathrm{E}_{\mathrm{Pnren;el;exp;m,i;AB}} \tag{31}$$

$$\mathrm{E}_{\mathrm{Pren;el;m,i}} = \mathrm{E}_{\mathrm{Pren;el;m,i;A}} + k_{exp} \cdot \mathrm{E}_{\mathrm{Pren;el;exp;m,i;AB}} \tag{32}$$

$$\mathrm{M}_{\mathrm{CO2;el;m,i}} = \mathrm{M}_{\mathrm{CO2;el;m,i;A}} + k_{exp} \cdot \mathrm{M}_{\mathrm{CO2;el;exp;m,i;AB}} \tag{33}$$

For each month m,i, the weighting factors of used electricity $f_{we;el;m,i}$ are given by:

$$\mathrm{f_{Pnren;el;us;m,i}} = \frac{\mathrm{E_{Pnren;el;m,i}}}{\mathrm{E_{EPus;m,i}}} \quad (34)$$

$$\mathrm{f_{Pren;el;us;m,i}} = \frac{\mathrm{E_{Pren;el;m,i}}}{\mathrm{E_{EPus;m,i}}} \quad (35)$$

$$\mathrm{f_{Ptot;el;us;m,i}} = \frac{\mathrm{E_{Pnren;el;m,i}} + \mathrm{E_{Pren;el;m,i}}}{\mathrm{E_{EPus;m,i}}} \quad (36)$$

$$\mathrm{f_{CO2;el;us;m,i}} = \frac{\mathrm{M_{CO2;el;m,i}}}{\mathrm{E_{EPus;m,i}}} \quad (37)$$

3.8 Energy performance indicators

Input data

The values of the weighting factors for the delivered energy carriers are given in the following table

Table 47 – Examples of values of the weighting factors of energy carriers – must be adapted to each SLE pilot (country)

Energy carrier	Code	f_{Pnren} kWh/kWh	f_{Pren} kWh/kWh	f_{Ptot} kWh/kWh	f_{CO2} kg_{CO2}/kWh
Electricity	El	2,300	0,200	2,500	420
Natural gas	Gas	1,100	0,000	1,100	220
Light oil	Oil_l	1,100	0,000	1,100	290
Wood	Wood	0,200	1,000	1,200	40
Photovoltaic	PV	0,000	1,000	1,000	0
Thermal solar	Slr	0,000	1,000	1,000	0
Environment	Env	0,000	1,000	1,000	0
District heat	DH	1,300	0,000	1,300	260
Coal	Coal	1,400	0,000	1,400	433

The exported energy is evaluated with k_{exp}=0:

- only self-used produced electricity is included in the energy performance of the building;
- exported energy is not part of the energy performance of the building.

Energy use per service and per energy carrier

For each service X,k, for each month m,i and for each energy carrier cr,j except for electricity and photovoltaic, the energy use $\mathrm{E_{EPus;cr,j;X,k;m,i}}$ is given by:

$$\mathrm{E_{EPus;cr,j;X,k;m,i}} = \sum_{gen,l} E_{X,k;gen,l;in;cr,j;m,i} \quad (38)$$

where

X,1=H for space heating service

X,2=W	for domestic hot water service
X,3=C	for space cooling service
X,4=V	for ventilation service
X,5=L	for lighting service
gen,l	are the generation sub-systems for service X,k using carrier cr,j during month m,i

For each service X,k and for each energy carrier cr,j except for electricity and photovoltaic, the yearly energy use $E_{EPus;cr,j;X,k}$ is given by:

$$\mathrm{E}_{\mathrm{EPus;cr,j;X,k}} = \sum_{m,i} \mathrm{E}_{\mathrm{EPus;cr,j;X,k;m,i}} \tag{39}$$

For each service X,k and for each month m,i, the electricity use $E_{EPus;el;X,k;m,i}$ is given by equation (4) at clause 0.

For each service X,k the yearly electricity use $E_{EPus;el;X,k}$ is given by

$$\mathrm{E}_{\mathrm{EPus;el;X,k}} = \sum_{m,i} \mathrm{E}_{\mathrm{EPus;el;X,k;m,i}} \tag{40}$$

To avoid double counting, all energy carriers used to produce electricity such as:

- photovoltaic production;
- share of cogeneration fuel input allocated to electric energy production;

shall not be counted as separate used energy carrier because their use is already covered by the electricity use.

NOTE The equivalent alternative would be counting the photovoltaic and the cogeneration fuel input allocated to electric energy production but discard the use of the produced electricity

Delivered and exported energy carriers per service

For each service X,k, for each month m,i and for each energy carrier cr,j except for electricity and photovoltaic, the delivered energy $E_{del;cr,j;X,k;m,i}$ is given by:

$$\mathrm{E}_{\mathrm{del;cr,j;X,k;m,i}} = \mathrm{E}_{\mathrm{EPus;cr,j;X,k;m,i}} \tag{41}$$

For each service X,k and for each energy carrier cr,j except for electricity and photovoltaic, the yearly delivered energy $E_{del;cr,j;X,k}$ is given by:

$$\mathrm{E}_{\mathrm{del;cr,j;X,k}} = \sum_{m,i} \mathrm{E}_{\mathrm{del;cr,j;X,k;m,i}} \tag{42}$$

For each service X,k and for each month m,i, the delivered grid electricity $E_{del;el;X,k;m,i}$ is given by:

$$\mathrm{E}_{\mathrm{del;el;X,k;m,i}} = \mathrm{E}_{\mathrm{del;el;m,i}} \cdot k_{EPus;el;X,k;m,i} \tag{43}$$

For each service X,k, the yearly delivered grid electricity $E_{del;el;X,k;m,i}$ is given by:

$$\mathrm{E}_{\mathrm{del;el;X,k}} = \sum_{m,i} \mathrm{E}_{\mathrm{del;el;X,k;m,i}} \tag{44}$$

For each service X,k and for each month m,i, the delivered photovoltaic electricity $E_{del;PV;X,k;m,i}$ is given by:

$$\mathrm{E}_{\mathrm{del;PV;X,k;m,i}} = \mathrm{E}_{\mathrm{pr;el;PV;m,i}} \cdot k_{EPus;el;X,k;m,i} \tag{45}$$

For each service X,k, the yearly delivered photovoltaic electricity $E_{del;PV;X,k}$ is given by:

$$\mathrm{E}_{\mathrm{del;PV;X,k}} = \sum_{m,i} \mathrm{E}_{\mathrm{del;PV;X,k;m,i}} \tag{46}$$

For each service X,k and for each month m,i, the exported electricity $E_{exp;el;X,k;m,i}$ is given by:

$$\mathrm{E_{exp;el;X,k;m,i}} = \mathrm{E_{exp;el;m,i}} \cdot k_{EPus;el;X,k;m,i} \tag{47}$$

For each service X,k, the yearly exported electricity $\mathrm{E_{exp;el;X,k}}$ is given by:

$$\mathrm{E_{exp;el;X,k}} = \sum_{m,i} \mathrm{E_{exp;el;X,k;m,i}} \tag{48}$$

Total delivered and exported energy carriers

For each month m,i and for each energy carrier cr,j, the delivered energy $\mathrm{E_{del;cr,j;m,i}}$ is given by:

$$\mathrm{E_{del;cr,j;m,i}} = \sum_{X,k} \mathrm{E_{del;cr,j;X,k;m,i}} \tag{49}$$

For each energy carrier cr,j, the yearly delivered energy $\mathrm{E_{del;cr,j}}$ is given by:

$$\mathrm{E_{del;cr,j}} = \sum_{m,i} \mathrm{E_{del;cr,j;m,i}} \tag{50}$$

For each month m,i, the exported electric energy $\mathrm{E_{del;el;m,i}}$ is given by:

$$\mathrm{E_{del;el;m,i}} = \sum_{X,k} \mathrm{E_{del;el;X,k;m,i}} \tag{51}$$

The yearly exported electric energy $\mathrm{E_{exp;el}}$ is given by:

$$\mathrm{E_{exp;el}} = \sum_{m,i} \mathrm{E_{exp;el;m,i}} \tag{52}$$

3.9 Weighted energy performance

Non renewable primary energy

For each service X,k, for each month m,i and for each used energy carrier cr,j except for electricity, the non-renewable primary energy use $\mathrm{E_{Pnren;cr,j;X,k;m,i}}$ is given by:

$$\mathrm{E_{Pnren;cr,j;X,k;m,i}} = \mathrm{E_{EPus;cr,j;X,k;m,i}} \cdot f_{Pnren;cr,j} \tag{53}$$

For each service X,k and for each energy carrier cr,j except for electricity, the yearly non-renewable primary energy use $\mathrm{E_{Pnren;cr,j;X,k}}$ is given by:

$$\mathrm{E_{Pnren;cr,j;X,k}} = \sum_{m,i} \mathrm{E_{Pnren;cr,j;X,k;m,i}} \tag{54}$$

For each service X,k and for each month m,i, the non-renewable primary energy use $\mathrm{E_{Pnren;el;X,k;m,i}}$ due to electricity use is given by:

$$\mathrm{E_{Pnren;el;X,k;m,i}} = \mathrm{E_{EPus;el;X,k;m,i}} \cdot f_{Pnren;el;us;m,i} \tag{55}$$

For each service X,k, the yearly non-renewable primary energy use $\mathrm{E_{Pnren;el;X,k}}$ due to electricity use is given by:

$$\mathrm{E_{Pnren;el;X,k}} = \sum_{m,i} \mathrm{E_{Pnren;el;X,k;m,i}} \tag{56}$$

For each service X,k and for each month m,i, the non-renewable primary energy use $\mathrm{E_{Pnren;X,k;m,i}}$ is given by:

$$\mathrm{E_{Pnren;X,k;m,i}} = \sum_{cr,j} \mathrm{E_{Pnren;cr,j;X,k;m,i}} \tag{57}$$

where the sum is extended to all used energy carriers, including electricity

For each service X,k and the yearly non-renewable primary energy use $\mathrm{E_{Pnren;X,k}}$ is given by:

$$\mathrm{E_{Pnren;X,k}} = \sum_{m,i} \mathrm{E_{Pnren;X,k;m,i}} \tag{58}$$

where the sum is extended to all used energy carriers, including electricity

Note For lighting and ventilation there is only electricity use, no other energy carrier is used

For each month m,i, the non-renewable primary energy use $E_{Pnren;m,i}$ is given by:

$$\mathrm{E_{Pnren;m,i}} = \sum_{X,k} \mathrm{E_{Pnren;X,k;m,i}} \tag{59}$$

The yearly non-renewable primary energy use E_{Pnren} is given by:

$$\mathrm{E_{Pnren}} = \sum_{m,i} \mathrm{E_{Pnren;m,i}} \tag{60}$$

Renewable primary energy

For each service X,k, for each month m,i and for each used energy carrier cr,j except for electricity, the renewable primary energy use $E_{Pren;cr,j;X,k;m,i}$ is given by:

$$\mathrm{E_{Pren;cr,j;X,k;m,i}} = \mathrm{E_{EPus;cr,j;X,k;m,i}} \cdot f_{Pren;cr,j} \tag{61}$$

For each service X,k and for each energy carrier cr,j except for electricity, the yearly renewable primary energy use $E_{Pren;cr,j;X,k}$ is given by:

$$\mathrm{E_{Pren;cr,j;X,k}} = \sum_{m,i} \mathrm{E_{Pren;cr,j;X,k;m,i}} \tag{62}$$

For each service X,k and for each month m,i, the renewable primary energy use $E_{Pren;el;X,k;m,i}$ due to electricity use is given by:

$$\mathrm{E_{Pren;el;X,k;m,i}} = \mathrm{E_{EPus;el;X,k;m,i}} \cdot f_{Pren;el;us;m,i} \tag{63}$$

For each service X,k, the yearly renewable primary energy use $E_{Pren;el;X,k}$ due to electricity use is given by:

$$\mathrm{E_{Pren;el;X,k}} = \sum_{m,i} \mathrm{E_{Pren;el;X,k;m,i}} \tag{64}$$

For each service X,k and for each month m,i, the renewable primary energy use $E_{Pren;X,k;m,i}$ is given by:

$$\mathrm{E_{Pren;X,k;m,i}} = \sum_{cr,j} \mathrm{E_{Pren;cr,j;X,k;m,i}} \tag{65}$$

where the sum is extended to all used energy carriers, including electricity

For each service X,k and the yearly renewable primary energy use $E_{Pren;X,k}$ is given by:

$$\mathrm{E_{Pren;X,k}} = \sum_{m,i} \mathrm{E_{Pren;X,k;m,i}} \tag{66}$$

where the sum is extended to all used energy carriers, including electricity

Note For lighting and ventilation there is only electricity use, no other energy carrier is used

For each month m,i, the renewable primary energy use $E_{Pren;m,i}$ is given by:

$$\mathrm{E_{Pren;m,i}} = \sum_{X,k} \mathrm{E_{Pren;X,k;m,i}} \tag{67}$$

The yearly renewable primary energy use E_{Pren} is given by:

$$\mathrm{E_{Pren}} = \sum_{m,i} \mathrm{E_{Pren;m,i}} \tag{68}$$

Total primary energy

For each service X,k, for each month m,i and for each used energy carrier cr,j except for electricity, the total primary energy use $E_{Ptot;cr,j;X,k;m,i}$ is given by:

$$\mathrm{E_{Ptot;cr,j;X,k;m,i}} = \mathrm{E_{EPus;cr,j;X,k;m,i}} \cdot f_{Ptot;cr,j} \tag{69}$$

For each service X,k and for each energy carrier cr,j except for electricity, the yearly total primary energy use $E_{Ptot;cr,j;X,k}$ is given by:

$$\mathrm{E}_{\mathrm{Ptot;cr,j;X,k}} = \sum_{m,i} \mathrm{E}_{\mathrm{Ptot;cr,j;X,k;m,i}} \tag{70}$$

For each service X,k and for each month m,i, the total primary energy use $\mathrm{E}_{\mathrm{Ptot;el;X,k;m,i}}$ due to electricity use is given by:

$$\mathrm{E}_{\mathrm{Ptot;el;X,k;m,i}} = \mathrm{E}_{\mathrm{EPus;el;X,k;m,i}} \cdot f_{Ptot;el;us;m,i} \tag{71}$$

For each service X,k, the yearly total primary energy use $\mathrm{E}_{\mathrm{Ptot;el;X,k}}$ due to electricity use is given by:

$$\mathrm{E}_{\mathrm{Ptot;el;X,k}} = \sum_{m,i} \mathrm{E}_{\mathrm{Ptot;el;X,k;m,i}} \tag{72}$$

For each service X,k and for each month m,i, the total primary energy use $\mathrm{E}_{\mathrm{Ptot;X,k;m,i}}$ is given by:

$$\mathrm{E}_{\mathrm{Ptot;X,k;m,i}} = \sum_{cr,j} \mathrm{E}_{\mathrm{Ptot;cr,j;X,k;m,i}} \tag{73}$$

where the sum is extended to all used energy carriers, including electricity

For each service X,k and the yearly total primary energy use $\mathrm{E}_{\mathrm{Ptot;X,k}}$ is given by:

$$\mathrm{E}_{\mathrm{Ptot;X,k}} = \sum_{m,i} \mathrm{E}_{\mathrm{Ptot;X,k;m,i}} \tag{74}$$

where the sum is extended to all used energy carriers, including electricity

Note For lighting and ventilation there is only electricity use, no other energy carrier is used

For each month m,i, the total primary energy use $\mathrm{E}_{\mathrm{Ptot;m,i}}$ is given by:

$$\mathrm{E}_{\mathrm{Ptot;m,i}} = \sum_{X,k} \mathrm{E}_{\mathrm{Ptot;X,k;m,i}} \tag{75}$$

The yearly total primary energy use $\mathrm{E}_{\mathrm{Ptot}}$ is given by:

$$\mathrm{E}_{\mathrm{Ptot}} = \sum_{m,i} \mathrm{E}_{\mathrm{Ptot;m,i}} \tag{76}$$

CO$_2$ emission

For each service X,k, for each month m,i and for each used energy carrier cr,j except for electricity, the CO$_2$ emission $\mathrm{M}_{\mathrm{CO2;cr,j;X,k;m,i}}$ is given by:

$$\mathrm{M}_{\mathrm{CO2;cr,j;X,k;m,i}} = \mathrm{E}_{\mathrm{EPus;cr,j;X,k;m,i}} \cdot f_{\mathrm{CO2};cr,j} \tag{77}$$

For each service X,k and for each energy carrier cr,j except for electricity, the yearly CO$_2$ emission $\mathrm{M}_{\mathrm{CO2;cr,j;X,k}}$ is given by:

$$\mathrm{M}_{\mathrm{CO2;cr,j;X,k}} = \sum_{m,i} \mathrm{M}_{\mathrm{CO2;cr,j;X,k;m,i}} \tag{78}$$

For each service X,k and for each month m,i, the CO$_2$ emission $\mathrm{M}_{\mathrm{CO2;el;X,k;m,i}}$ due to electricity use is given by:

$$\mathrm{M}_{\mathrm{CO2;el;X,k;m,i}} = \mathrm{E}_{\mathrm{EPus;el;X,k;m,i}} \cdot f_{\mathrm{CO2};el;us;m,i} \tag{79}$$

For each service X,k, the yearly CO$_2$ emission $\mathrm{M}_{\mathrm{CO2;el;X,k}}$ due to electricity use is given by:

$$\mathrm{M}_{\mathrm{CO2;el;X,k}} = \sum_{m,i} \mathrm{M}_{\mathrm{CO2;el;X,k;m,i}} \tag{80}$$

For each service X,k and for each month m,i, the CO$_2$ emission $\mathrm{M}_{\mathrm{CO2;X,k;m,i}}$ is given by:

$$\mathrm{M}_{\mathrm{CO2;X,k;m,i}} = \sum_{cr,j} \mathrm{M}_{\mathrm{CO2;cr,j;X,k;m,i}} \tag{81}$$

where the sum is extended to all used energy carriers, including electricity

For each service X,k and the yearly CO$_2$ emission $\mathrm{M}_{\mathrm{CO2;X,k}}$ is given by:

$$\mathrm{M}_{\mathrm{CO2;X,k}} = \sum\nolimits_{m,i} \mathrm{M}_{\mathrm{CO2;X,k;m,i}} \tag{82}$$

where the sum is extended to all used energy carriers, including electricity

Note For lighting and ventilation there is only electricity use, no other energy carrier is used

For each month m,i, the total CO2 emission $\mathrm{M}_{\mathrm{CO2;m,i}}$ is given by:

$$\mathrm{M}_{\mathrm{CO2;m,i}} = \sum\nolimits_{X,k} \mathrm{M}_{\mathrm{CO2;X,k;m,i}} \tag{83}$$

The yearly CO2 emission $\mathrm{M}_{\mathrm{CO2}}$ is given by:

$$\mathrm{M}_{\mathrm{CO2}} = \sum\nolimits_{m,i} \mathrm{M}_{\mathrm{CO2;m,i}} \tag{84}$$

3.10 Specific energy indicators

3.10.1.1 Energy needs

For space heating, space cooling and domestic hot water preparation, the specific energy need indicator in kWh/(m²·yr) $\mathrm{Q}_{\mathrm{X;nd;A}}$ is given by:

$$\mathrm{Q}_{\mathrm{X;nd;A}} = \frac{\mathrm{Q}_{\mathrm{X;nd}}}{A_B} \tag{85}$$

where X is H, C and W for space heating, space cooling and domestic hot water preparation respectively.

3.10.1.2 Weighted energy

For each service X,k, the specific weighted energy indicator $\mathrm{EP}_{\mathrm{we;X,k}}$ expressed in kWh/(m²·yr) or $\mathrm{kg}_{\mathrm{CO2}}$/(m²·yr) is given by:

$$\mathrm{EP}_{\mathrm{Pnren;X,k}} = \frac{\mathrm{E}_{\mathrm{Pnren;X,k}}}{A_B} \tag{86}$$

$$\mathrm{EP}_{\mathrm{Pren;X,k}} = \frac{\mathrm{E}_{\mathrm{Pren;X,k}}}{A_B} \tag{87}$$

$$\mathrm{EP}_{\mathrm{Ptot;X,k}} = \frac{\mathrm{E}_{\mathrm{Ptot;X,k}}}{A_B} \tag{88}$$

$$\mathrm{m}_{\mathrm{CO2;X,k}} = \frac{\mathrm{M}_{\mathrm{CO2;X,k}}}{A_B} \tag{89}$$

and the corresponding total values for the building are given by:

$$\mathrm{EP}_{\mathrm{Pnren}} = \sum\nolimits_{X,k} \mathrm{EP}_{\mathrm{Pnren;X,k}} \tag{90}$$

$$\mathrm{EP}_{\mathrm{Pren}} = \sum\nolimits_{X,k} \mathrm{EP}_{\mathrm{Pren;X,k}} \tag{91}$$

$$\mathrm{EP}_{\mathrm{Ptot}} = \sum\nolimits_{X,k} \mathrm{EP}_{\mathrm{Ptot;X,k}} \tag{92}$$

$$\mathrm{m_{CO2}} = \sum\nolimits_{X,k} \mathrm{m_{CO2;X,k}} \tag{93}$$

3.10.1.3 Renewable energy ratio RER

For each service X,k, the renewable energy ratio $\mathrm{RER_{X,k}}$ is given by:

$$\mathrm{RER_{X,k}} = \frac{\mathrm{E_{Pren;X,k}}}{\mathrm{E_{Ptot;X,k}}} \tag{94}$$

and the overall RER value is given by

$$\mathrm{RER} = \frac{\mathrm{E_{Pren}}}{\mathrm{E_{Ptot}}} \tag{95}$$

3.10.1.4 System efficiency

For space heating, space cooling and domestic hot water preparation, the system efficiency $\eta_{\mathrm{X;sys}}$ is given by:

$$\eta_{\mathrm{X;sys}} = \frac{\mathrm{Q_{X;nd}}}{E_{Pnren;X}} \tag{96}$$

where X is H, C and W for space heating, space cooling and domestic hot water preparation respectively.

4 Environmental life-cycle assessment and integration to SmartLivingEPC

4.1 Review of the sustainability performance of buildings

Life cycle assessment (LCA) is a relatively new field of study, having a history of only 50 years but having seen significant research and application within the past 30 years. Over the course of decades, the technique and applications have progressed to the point that there is now a consensus among scientists and established guidelines for how to conduct an LCA. In many countries, including the European Union (EU), Australia, Japan, Korea, the United States of America (USA), Canada, and, in developing economies such as India and, more recently, China, LCA is emerging as an essential component of climate change policy or voluntary actions. In the 1970s, LCA expanded from being simply an energy overview to an extensive investigation of the environmental burden of a product. In the 1980s and 1990s, complete LCA assessment and life cycle costing (LCC) concepts were initiated. During the first decade of the 21st century, social-LCA (SLCA) and — in particular, consequential LCA gained a foothold. Despite the fact that LCA provides us with the extremely valuable potential of selecting the most eco-efficient means of providing a particular feature or service, this framework does have some significant constraints when it comes to ensuring that a system is sustainable from an environmental perspective.

Life-cycle-oriented methodologies have been developed for the environmental characterization of products in response to rising awareness of environmental degradation, as well as a lack of energy and raw materials. LCA enables the assessment of the environmental impact of any system throughout its life cycle by considering the system's required input and associated output resources. LCA is frequently utilized in the decision-making process when actions extending either close or long into the future are at issue. Nonetheless, the typical technique for LCA needs to be modified in order to accommodate future and change-oriented aims. However, even so, there is not yet a standardized approach to accomplishing this goal.

Some of the critical moments in the history of LCA are outlined in **Table 48**.

Table 48: Moments in LCA history (selective)

Event	Year	Reference
Possibly the first-oriented LCA study concerning Energy requirements for the manufacturing of chemical intermediates and products	1963	World Energy Conference, Harold Smith
Coca-Cola Company conducts its very first investigation into the various types of beverage containers.	1969	Unpublished
The cornerstone of the methodological approach for environmentally extended input/output analysis is constructed.	1970	Leontief [69]
First LCA publications appeared, describing methodology & data sets	1972	
First computer program funded by MRI client	1973	
Resource and Environmental Profile Analysis of Nine Beverage Container Alternatives, the first publicly available and peer-reviewed LCA report commissioned by the US EPA.	1974	US EPA [70]

EPA decided REPA/LCA was impractical as a regulatory tool (EPD)	1975	Hunt, Franklin, et al. [71] (1996)
Franklin Associates was established (first LCA company)	1975	Founded by William E. Franklin and Marjorie A. Franklin
Coca Cola published their LCA study (1969) in Science Magazine	1976	Baumann and Tillman [72] (2004)
Goodyear Tire and Rubber Company LCA on PET drink containers	1978	Unpublished
The first impact assessment method based on critical volumes introduced	1984	BUS (1984)
GaBi, which went on to become the first widely used commercial LCA program, had its first version launched.	1989	Thinkstep [73] (2016)
International forum by The Conservation Foundation debated role of REPA	1990	
The First edition of the commercial LCA program SimaPro was launched.	1990	PRé [74] (2016)
The concept of a "life cycle assessment" was initially conceived.	1990	SETAC [75] (1991)
Establishment of a variety of LCI databases, each of which is overseen by a separate organization	Early 1990s	
Franklin Associates published first methodology of LCA article	1992	Curran and Young [76] (1996)
EPA developed guidance manual for conducting and evaluating life cycle inventory	1992	Vigon et al. [77] (1993)
CML92, the first approach to impact assessment with a focus on environmental themes.	1992	Heijungs et al. [78]
The LCA framework, nomenclature, and methodology were standardized by the publication of the SETAC Code of Practice.	1993	SETAC [79]
The International Journal of Life Cycle Assessment, an academic journal devoted entirely to LCA, was established.	1996	IJLCA [80]
ISO 14040 standard on LCA principles and framework released	1997	ISO 14040 [81]
ISO 14041 standard on goal and scope definition released	1998	ISO 14041 [82]
Eco-indicator 99, methodology based on the extent of the damage appears	1999	Goedkoop and Spriensma [83] (2000)
ISO 14042 standard on life cycle impact assessment released	2000	ISO 14042
ISO 14043 standard on life cycle interpretation released	2000	ISO 14043
UNEP/SETAC Life Cycle Initiative launched	2002	UNEP [84]
The LCI database Ecoinvent version 1.01 is available	2003	Ecoinvent [85] (2016)
Through the use of ISO 14040 and ISO 14044, a broad methodological framework and guidelines for LCA were established	2006	
A framework for Life Cycle Sustainability Analysis was proposed	2008	Klöpffer [86]
“Guidelines to S-LCA", the first and most important steps towards standardization produced by the UNEP-SETAC Life Cycle Initiative	2009	UNEP/SETAC
International Reference Life Cycle Data System (ILCD) handbook released	2010	EC [87]
PAS 2050 standard on the assessment of the life cycle greenhouse gas emissions of goods and services	2011	World Resource Institute and World Business Council for Sustainable Development [88]

PEF and OEF guidelines launched	2012 and later	
ISO 14071 standard on critical review processes and reviewer competencies	2014	ISO 14071 [89]
ISO 14072 standard on requirements and guidelines for organizational LCA	2014	ISO 14072 [90]
Level(s); the European Commission's first-ever framework to improve the sustainability of buildings.	2021	EC [91]

4.2 Overview of the current state of LCA

4.2.1 LCA conception

In the 1960s, when concerns about environmental deterioration and, more specifically, scarce resources began to surface, the concept of LCA was established. It was in the 1960s and 1970s that researchers first began looking at the effects that consumer goods had on the natural world [92]. More specifically, at the World Energy Conference in 1963, Harold Smith presented his "cumulative energy concept," which is credited with laying the groundwork for LCAs. The idea spread into environmental impacts in the 1970s in the US with "Resource and Environmental Profile Analysis," followed by the 1980s in Europe with the concepts of Ecobalances and industrial ecology, which demonstrated the increasing waste problem as a potential resource [93]. Both of these ideas contributed to the expansion of the concept. During this period, in which environmental issues like saving energy and resources, controlling pollution, and cutting down the use of waste and other unnecessary materials became important to the broader public, the earliest investigations, which were later classified as (partial) LCAs, were published [94]. There was an absence of uniformity and harmonization in the methodologies tended to fluctuate with public concerns. International forums for scholarly discourse and exchange around LCA were clearly lacking. There was a pause in the activity of the scientific community throughout the 1970s; LCAs were conducted without a unified conceptual perspective and using various methodologies. Even though the study's objectives were essentially the same, the acquired results varied substantially, which hindered LCA from being an even more widely recognized and used analysis method [95]. At the beginning of the 1980s and continuing throughout the 1990s, there was a marked increase in the development of new methodologies, as well as increased international coordination and collaboration. Thus, in the 1980s and 1990s, product life cycle management emerged as a critical concern. This gave rise to the concept of LCA, which is translated as the systematic gathering and analysis of information about a product system's inputs, outputs, and possible environmental implications [81] [96].

At the beginning of this era, companies commissioned the majority of the research, employed it internally, and shared relatively little of it with outside parties.

Materials and energy accountancy were early approaches that were influenced by material flow accountancy and tallied up each industrial process's resources and energy requirements (crude oil, steel, etc.), emissions, and solid waste. The Midwest Research Institute (MRI) undertook one of the earliest (unpublished) studies estimating the resource needs, pollutant load conditions, and waste streams of various beverage containers in 1969 for the

Coca-Cola Company. Instead of openly sharing study results with consumers, they were mostly utilized for internal decision-making purposes, such as advising on the mitigation of life cycle consequences. The MRI referred to this type of study as Resource and Environmental Profile Analysis (REPA), involved analyzing the entire production process, "from cradle-to-grave", for the products under examination [92].

LCA attracted the attention of the government as well. For instance, a follow-up investigation to this study was carried out in 1974 for the United States Environmental Protection Agency (US EPA) by the same institute, with the intention of contributing to the formation of packaging regulations [97] [98]. A comparable study carried out by Basler and Hofman [99] in Switzerland is often seen as the impetus for the growth of LCA as we currently understand it. More widespread use of LCA was spurred by a study issued in 1984 by the Swiss Federal Laboratories for Materials Testing and Research (EMPA) [100]. This paper included a thorough list of the data required for LCA research [94]. The United Nations World Commission on Environment and Development released its report Our Common Future in 1987; this document is often known as the Brundtland Report in honor of its chairperson, Gro Harlem Brundtland [101]. Although the International Union for the Conservation of Nature first used the phrase "sustainable development" in 1980, it was not until the release of Our Common Future that the concept gained wider attention and received its most well-known description: "… development that meets the needs of the present without compromising the ability of future generations to meet their own needs". The notion of sustainable growth provides a foundation for conceiving of these two increasingly urgent global crises as one tremendously powerful word by combining the concerns of current and future generations [102].

4.2.2 LCA standardization

Before LCA became commonplace in the 1990s, we had the development of the first life-cycle-oriented methods through a joint effort between academics and businesses in the 1960s. These analyses were known as Resource and Environmental Profile Analysis (REPA) [103] or Ecobalances or else as the precursors of today's LCA. For reasons including the need to protect proprietary data and the intricacy of translating technical findings into layman's terms, many of the earliest studies commissioned by businesses were never made public.

In spite of the fact that this decade is predominately one of convergence, it also represents a time of scientific inspection, investigation of LCA's theoretical underpinnings, and investigation of its synergies with other fields. Several life cycle inventory databases spanning various industries were also established in the early 1990s; these were administered by various institutes and associations. However, due to data specifications and quality discrepancies, databases may report vastly different amounts of resources used and emissions produced by the same industrial activity [104]. There are a number of well-known life cycle impact assessment methodologies that originated during this time period. These include environmental topic approaches [78] [105], end point or destruction approaches [106] [107], and the now-standard multidimensional practice [108] [109] of evaluating potential human and ecotoxic pollutants [110].

There was a significant increase in research and coordinating efforts across the globe in the 1990s (12-17), as seen by the proliferation of seminars, conferences, and LCA manuals and handbooks (18-25) published in the field. The international Journal of LCA (the first scholarly publication that is solely devoted to LCA); Resources, Conservation, and Recycling; Environmental Science & Technology; Journal of Industrial Ecology; Journal of Cleaner Production; and other journals also began publishing the first papers in their scientific series during this era. One of the most important outcomes of a coordinated effort to bring LCA specialists, clients, and academics together for the purpose of improving and harmonizing the LCA concept, nomenclature, and methods was the SETAC "Code of Practice" [111]. Since 1994, ISO has worked in conjunction with SETAC to advance LCA. Over the course of the years, ISO drafted and published four standards — principles and framework (ISO 14040), goal and scope definition (ISO 14041), life cycle impact assessment (ISO 14042), and life cycle interpretation (ISO 14043). The last three were incorporated in the ISO 14044 standard in 2006 as part of a revision that detailed the guidelines and specifications. This revision did not alter any of the provisions that were included in the standards. Since the introduction of the ISO 14040 series of standards for LCA, it has become standard procedure for businesses to disseminate LCA reports that have undergone peer review in order to substantiate their environmental claims. However, the complete revelation of source data remains uncommon due to confidentiality considerations. Instead of focusing on process validation and harmonization, as SETAC working groups did, ISO has taken on the formal responsibility of standardizing techniques and processes. The applicable standards will be analyzed in detail in the relevant sub-section. Due to SETAC's coordination and ISO's standardization operations, which provided a defined framework and nomenclature as well as a space for discussion and unification of LCA methodologies, the years 1990-2000 might be considered an era of convergence [92]. Furthermore, LCA was also incorporated into several policy documents and pieces of legislation, which had as their primary focus the legislation pertaining to packaging.

It was not until about 1990 that the first versions of SimaPro and GaBi, two popular LCA software, were produced. This requirement arose from the modeling of incredibly challenging product systems, as well as the expansion of LCI information and impact analysis methodology [73] [74]. CML92 was the first impact assessment technique to include a full spectrum of modern intermediate effect classifications [78]. It was released by Leiden University's Institute of Environmental Sciences in 1992. The Swedish EPS methodology [112] [113], which examined the damages, adopted a different tack by emphasizing human health and environmental harm instead of financial impacts; the Dutch Eco-indicator 99 method, introduced in 1999, fell into line by adopting a rather more science-based perspective to risk analysis [83]. To remedy this, in 2003, the first version of the Ecoinvent database (v1.01) was released, encompassing all major industries and seeking uniform data quality and standards [85]. The introduction of the EDIP2003 technique [114] with geographically heterogeneous impact assessment methodologies addressing non-global impacts reflects the recognition that there might be quite considerable disparities in the vulnerability of the environment enduring the consequences. In the 2000s and 2010s, much work will be done on methodologies for impact assessment of extraction-related effects such as water consumption and land use. In order to combine the best features of process-based and input/output-focused inventory classification, hybrid LCA will arise [104]. For the purpose of conducting assessments, a life cycle sustainability assessment (LCSA) framework will evolve, with the overarching goal of factoring in the environmental, social, and financial aspects of sustainability.

4.2.3 LCA elaboration

Although there is a growing need for LCA, the contemporary era is marked by a variety of different approaches. During the time that the ISO standardization process was taking place in the 1990s, LCA methodology was still infancy and rather immature. As a direct consequence, the standards that were produced of this process are not particularly thorough on certain methodological approaches; rather, they are mainly concentrated on the structure and the underlying values of LCA. Due to the wide range of interpretations that could be taken from the ISO standards, the Institute for Environment and Sustainability at the EU Commission's Joint Research Centre created a thorough guideline for LCA that describes scientific options left undetermined by the ISO standards [104].

Due to the absence of a consistent approach, different evaluations of the same material could provide inconsistent findings based on the specific technical decisions that were made. The American Center for LCA [115] and the Australian LCA Network [116], both of which were founded in 2001, are only two examples of the many national LCA networks that have since been launched. During the same time span, environmental policy is becoming more life-cycle-focused everywhere in the world (e.g., [117] [118] [119]). The Life Cycle Initiative [120] was first introduced in 2002 by the Society for Environmental Toxicology and Chemistry (SETAC) and the United Nations Environment Program (UNEP). Conforming to the definition provided in the ISO standard [81], LCA is the process of compiling and analyzing the inputs, outputs, and potential negative consequences on the environment that a product system has during its entire lifespan.

Using a life cycle thinking (LCT) approach, LCA can effectively evaluate and promote environmentally responsible production and consumption by providing comprehensive and balanced data concerning the environmental efficiency of products and services. LCT is a conceptual framework that refers to the requirements of analyzing the burdens of products, sectors, and projects using a holistic and all-encompassing viewpoint, beginning with the extraction of raw materials and ending with product disposal, and it is often seen as being crucial for assisting in the process of better-incorporating sustainability into policy decisions [121] [122]. Putting LCT into reality and enhancing the supporting instruments through solid information and metrics were established as the key goals of the Life Cycle Initiative. In anticipation of the European Integrated Product Policy (IPP) to be enacted at the EU level in 2003 with national policies such as environmental product declarations, ecolabels, green public procurements, and the incorporation of sustainability issues into standardization, multiple European countries established national product-oriented environmental initiatives employing LCA as the scientific basis. The European Commission emphasized the significance of LCA and the necessity of encouraging the implementation of life cycle thinking among the many parties involved in IP [123]. In 2005, the European Union (EU) established the European Platform on LCA [124] with the goal of increasing access to and use of high-quality LCA knowledge, methodologies, and research in order to better inform public policy and commercial actions. The United States Environmental Protection Agency (EPA) began advocating for LCA's adoption in the country [125]. The European Commission's Joint Research Centre (EC-JRC) deserves special recognition for its efforts to provide this policy encouragement through a variety of programs and actions dating all the way back to 2004.

Building efficiency can be improved by including LCA alongside integrated project delivery (IPD) and Building Information Modeling (BIM) [126] [127] [128]. When properly integrated, BIM models can become part of building automation systems, providing the building operator with a comprehensive picture of all the building's systems. Through the implementation of LCT, which improves both IPD and BIM, puts people, profits, and the environment at the forefront of decision-making so that all three can be considered simultaneously. The essential parts of the IPD and LCA process are broken down and illustrated in **Figure 57** [129] [130].

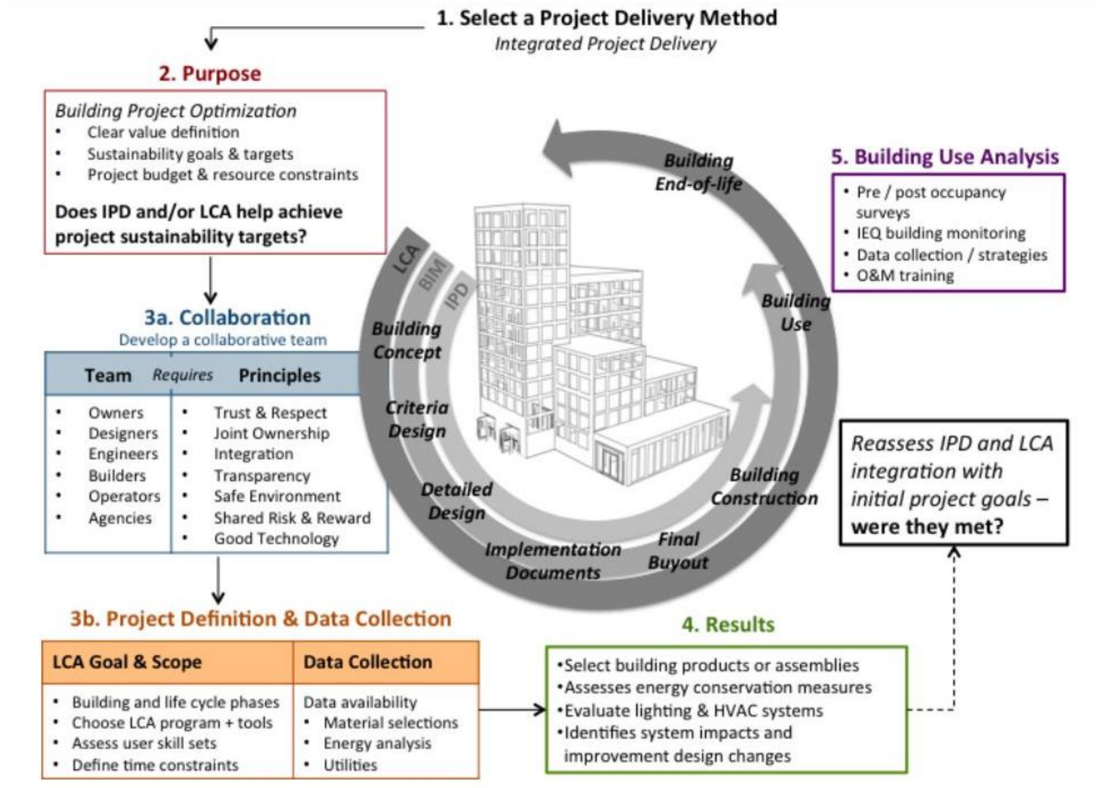


Figure 57: IPD and LCA structure [131]

As a result of using LCT at the inception of a construction project, all phases of the endeavor are guided by a comprehensive perspective. However, LCA's lack of comprehensiveness in answering all the concerns that a building owner needs to consider before making a decision is one of its few drawbacks. In particular in the construction sector, the LCA application business can benefit from extending the function of conventional LCAs through the use of a wider range of tools and approaches. As can be seen in **Figure 58**, an exploratory approach in the form of a decision tree was designed to assist users in selecting an optimal LCA enhancement strategy for their specific endeavors [92]. The IPD team will keep improving project life cycle thinking and increasing effect consciousness by utilizing the decision tree to identify the most relevant LCA optimization approach. The decision tree is meant to graphically connect how several LCA techniques can be combined to achieve a certain objective, like product choice or energy usage.

Since the International Organization for Standardization (ISO) never intended to define LCA methodologies in depth, and due to the lack of consensus on how to perceive parts of the ISO standards, many approaches have been created with regard to system boundaries and allocation methods [132]. These include risk-based LCA [133] [134] [135] [136], dynamic LCA [137] [138] [139] [140], hybrid LCA [131] [141] [142], and spatially differentiated LCA [143] [144]. The term LCC refers to a financial evaluation that factors in all agreed-upon predicted major and pertinent cost flows across the time of the study. The estimated expenditures are those expected to be incurred to accomplish the desired performance goals (such as those related to reliability, safety, and availability) [145]. Further, methods for social life cycle assessment (SLCA) [146] and life cycle costing (LCC) [147] have been suggested and/or implemented that might be inconsistent with environmental LCA with respect to temporal perspectives, system boundaries, calculation methodologies, etc. [143] [148]. Each of these methods addresses a unique set of questions and builds on the life-cycle foundation in unique ways. In 2006, in response to this challenge, the European Commission initiated the Co-ordination Action for innovation in Life Cycle Analysis for Sustainability (CALCAS) [149] initiative in order to standardize the wide variety of LCA methods and establish research priorities and directions.

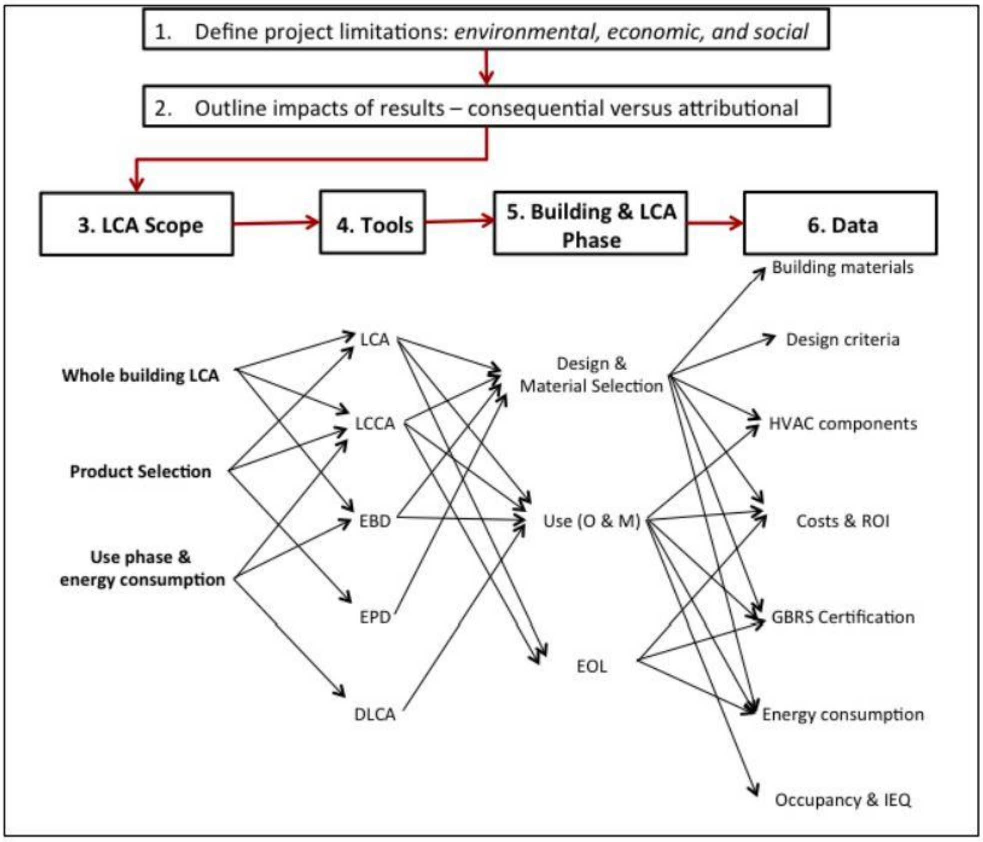


Figure 58: Decision tree of optimal LCA enhancement strategy [150]

In 2008, the European Commission launched its Sustainable Consumption and Production and Sustainable Industrial Policy (SCP/SIP) Action Plan [151], marking a watershed moment in the development of LCA for policy support. As a result, LCA emerged as the scientific core alongside IPP and resource and waste management policies from the past, but without the micromanagement legislative extent investigated by the US EPA in the 1980s. Following the publication of the guidelines for ILCD [152] in 2012, the EU Commission issued recommendations for Product Environmental Footprint (PEF) [153] and Organizational Environmental Footprint (OEF) [154]. The European Platform on LCA (EPLCA) [155] is an important resource in this context; the platform's stated mission is to enhance life cycle thinking in the industry and policy decisions in the EU, and it has been instrumental in the growth of both PEF and OEF [156] by ensuring adequate data and methodologies.

4.2.4 LCA sustainability

Since the beginning of this millennium, efforts have been made to broaden the scope of the LCA framework so that it takes into account the effects of the product or system on social entities like workers, consumers, and communities. This is being done in order to be able to provide a more in-depth evaluation of the ability to contribute that a product or system makes to the concept of sustainability. S-LCA is the abbreviation for Social Life Cycle Assessment (SLCA), which refers to this augmentation of LCA.

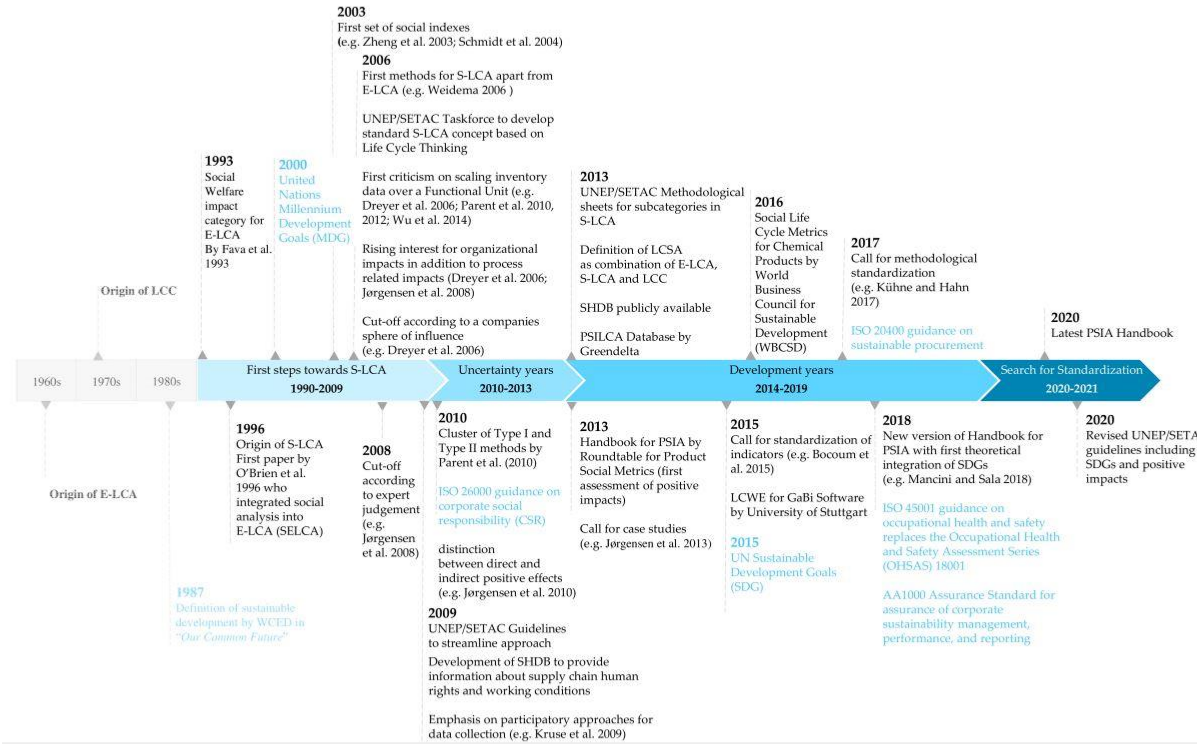


Figure 59: S-LCA progress 1996-2020 (adapted by [159] [160] [161] [162] [163] [164])

S-LCA is still developing. Thus, a wide range of strategies for the aforementioned methodological stages are presented in the extant S-LCA literature. As a result, it would be inaccurate to refer to it as a consistent and unanimous process. The "Guidelines to S-LCA" developed under the UNEP-SETAC Life Cycle Initiative represent the most significant step towards standardization to date and can be seen as a backbone for future research on S-LCA [157]. Early S-LCA development was heavily inspired by LCA, with the research community presuming that S-LCA could analyze social implications in the same manner that LCA could examine environmental ones. A comprehensive history of the developments and turning points that led to the present-day situation of SLCA has been laid forth. Accordingly, Huarachi et al. [158] broad classification of S-LCA history under four periods was refined and supported by scientific, political, and social benchmarks (**Figure 59**).

The main objective of an S-LCA is to determine how different aspects of a product or system influence human well-being at different points during its life cycle [165] [166] [167]. In light of this, S-LCA should offer a way that allows not only recognizing the social alterations generated by a product or system yet also for characterizing them and assessing them in terms of how they lead to a certain collective human wealth. If a person's welfare is in any way influenced by an action taken at any point in the product's life cycle, then that action must be accounted into the S-LCA [168]. This means that any impacted individual is regarded as a stakeholder, be it workers throughout the life cycle, local or regional people impacted by the various phases of the product life cycle, consumers [156], as well as interested parties who have the potential to influence or be influenced by decisions made during the product's life cycle, such as other decision-makers or business owners [169].

Figure 60: Impact areas identified by UNEP/SETAC [169]

According to Pollok et al. [169], all categories suggested by the methodology sheets have been employed in certain studies when evaluating them at the sub-category level, however their use is quite uneven. It is worth noting that UNEP/SETAC has not released a new set of methodology sheets at this time. Consequently, **Figure 60** does not include the evaluation of the new subcategories indicated by the Guideline 2020. One of the most significant flaws of the S-LCA paradigm is that it risks glossing over crucial distinctions between social and environmental concerns. Nevertheless, it cannot avoid its objective as a life cycle-oriented approach that aims for social evaluation, irrespectively of whether it will successfully incorporate essential values from the social sciences.

To incorporate social and economic sustainability dimensions into product life cycle analyses alongside environmental ones (three pillars), LCA has been recommended to be expanded into LCSA [170] [171]. It shifts the focus from challenges at the production level to those at the industry level and beyond, potentially albeit at the economic growth level. This way of thinking became more popular when Elkington [172] came up with the idea of the "Triple bottom line". He said that enterprises should control the environmental, social, and financial elements of sustainability in the same quantifiable manner that they actually manage the financial implications. The LCSA is rather a structure for the synthesis of concepts that span multiple disciplines. The main difficulty, then, lies in organizing, choosing, and making available the multiplicity of models in regard to various sorts of life cycle sustainability concerns.

Consequently, Kloepffer [170] presented the subsequent plan for LCSA, where LCSA necessitates that all three aspects of sustainability be evaluated in the same context, taking into account the same aspects of a product's life cycle in each evaluation.

$$\text{LCSA} = \text{LCA} + \text{LCC} + \text{SLCA} \qquad \textbf{Equation 18.}$$

4.2.5 LCA further development

The EU has been at the forefront of incorporating LCA into product design and application to a considerably larger degree compared to any other part of the world [122] [173]. Over the course of the next ten years, it is believed that LCA will be developed further in a wide range of ways. Additionally, it is possible that LCSA will have matured enough to provide a conceptual model for questions spanning multiple product, sector, and economic levels, as well as for tackling these issues across the entire sustainability scope (citizens, earth, and wealth) and with a more comprehensive set of processes.

Since the release of ISO 14040 [174], EN 15978 [175], which explains LCA methodology for structures, and, more recently, Level(s) [91], which is a reporting tool for assessing building sustainability, the implementation of LCA within the built environment has seen tremendous growth over the course of the past years [176]. Challenges remain to LCA's extensive industry implementation. This is partially because traditional LCA requires a lot of time and resources [177] [178]; thus, it is usually performed after a design has been agreed on [179] [180]. Life cycle thinking and assessment are making their way from academic applications and ad hoc deployments (mainly in-house in large corporations) to complex applications in the community as a whole [181]. This shift is occurring gradually. "Responsible consumption and production" is the focus of Sustainable Development Goal (SDG) (**Figure 61**) number 12 of the United Nations Agenda 2030, and the LCT is at the center of this goal. This objective intends to encourage individuals to embrace more environmentally friendly lifestyles by the year 2030, and accomplishing this objective will require a significant amount of attention on the supply chain, from primary producers to final consumers [182].

According to the findings of the review by Roberts et al. [184], LCA is typically applied later in the design phase when it is already too belated to have a significant contribution to the design. Despite the progress that has been made, the analysis showed that LCA still has a long way to go before it can effectively guide early-stage design decisions and significantly improve the built environment's performance. When designing a structure, it is important to consider how our choices will affect the building's carbon footprint over its lifetime. Considering the estimation that the built environment is responsible for over 40% of global greenhouse gas emissions [185], there is considerable space for improvement in this area [186]. Recommendations for achieving a net-zero carbon-built environment by 2050 have been released by the World Green Building Council (WorldGBC) [187]. Following applicable policies, the term carbon is commonly used to refer to all anthropogenic greenhouse gases equivalent to carbon dioxide [188].

LCA is frequently used in the decision-making process when addressing operations that will actually occur in the near or far future during every stage of the manufacturing, usage, and eventual disposal of products [189] [190]. Despite their differences, foresight approaches may provide valuable insights into a range of issues associated with future-oriented LCAs. However, the conventional technique for LCA needs to be modified for the prospective and change-oriented aims; even so, a standardized approach has not yet been developed to accomplish this goal. The term "prospective" or "future-oriented" LCA is used to describe a methodical evaluation of forthcoming events and developments that takes into account potential changes in the product system (and/or functional unit), its socioeconomic structures, and policy decisions that could have a consequence for the environment in the future. The LCA of upcoming technologies will yield a number of responses rather than "the" solution.

Figure 61: Links of Sustainable Development Goals [183]

LCA, a similar tool or a suite of tools, appears likely to expand in the near future due to the variety of policy variables and implications on stakeholder choices [191]; this is an interesting and promising period for the method [92] [192]. The expected mediating feedback mechanisms between methodology and policy are depicted in **Figure 62.**

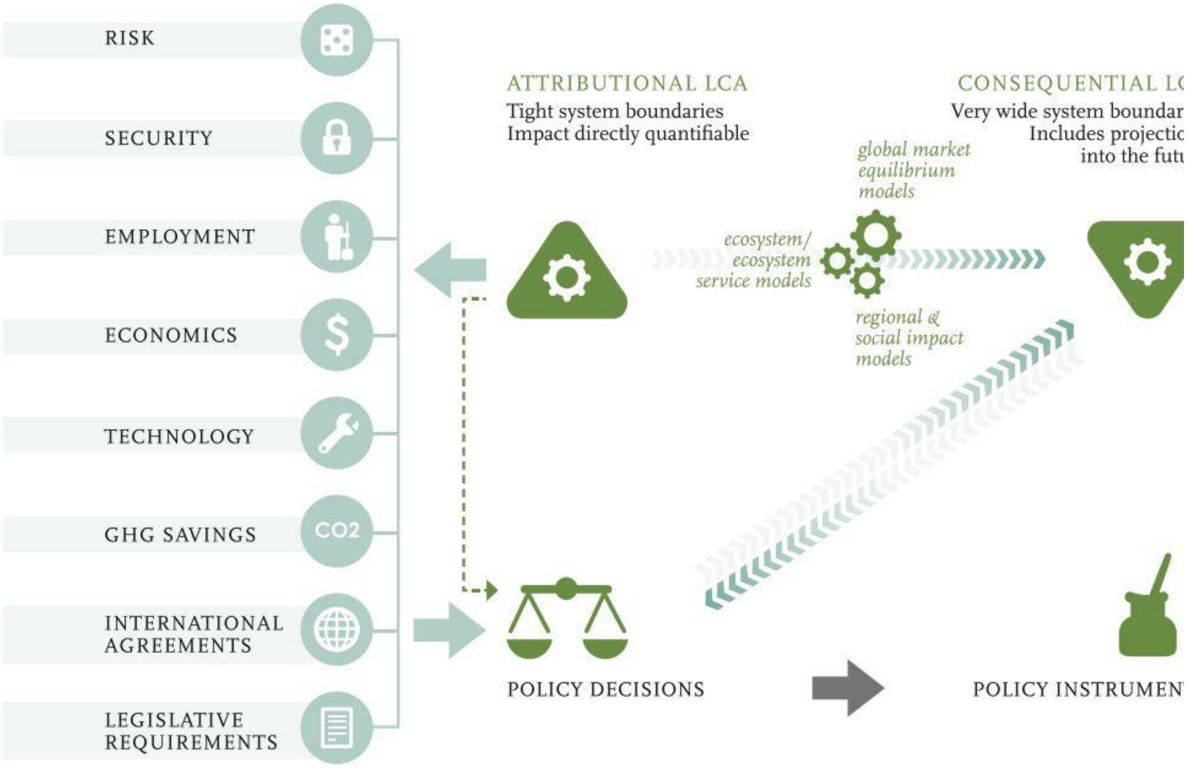


Figure 62: Feedback mechanisms between methodology and policy [193]

There are commonalities to be seen between LCSA and the field of integrated assessment (IA). When it comes to particular concerns of sustainability, risk assessment (RA) is very relevant and should either be performed in addition to or instead of LCSA tools. IA is an interdisciplinary method that combines, analyzes, and distributes knowledge from several scientific fields in such a manner that the entire cause-effect sequence of a challenge can be assessed. This definition comes from Van der Sluijs [194], who describes IA as thus. As such, LCSA can be understood as the reincarnation of IA inside the life-cycle context. The international scientific community and international political agencies have a formidable challenge in developing the LCSA framework; effective international cooperation is essential if we are not to return to an impasse of the multiplicity of various theories and techniques.

Pomponi and Moncaster [195] showed that the use and end-of-life stages of a building are commonly left out of embodied carbon LCA research. This highlights the importance of focusing on the impacts that buildings have when they are initially constructed. All of the effects that occur before the materials exit the plant or processing facility are included in the cradle-to-gate emissions [196]. According to the findings, more research is required to offer designers with context-specific knowledge to make informed judgments about all aspects that can be modified by design and management, which vary depending on time and location [197]. The incorporation of LCA into the design phase will be of tremendous assistance to designers in meeting the targets for 2030 and 2050 [198] concerning (i) guaranteeing that designs will be able to contribute to the establishment of a built environment with a net-zero carbon footprint, (ii) having knowledge of the environmental effects that will be caused by constructions prior to their building, and (iii) enabling designers to get rid of undesired influences at any point in the design phase [185] [199]. Whole-life carbon analysis is an analogous approach that also incorporates elements from LCA theory and practice; however, it narrows its attention to a specific concern, namely the potential for global warming, which is more commonly known as the carbon footprint [200] [201].

Finally, the Masterplan to Limiting Building Life Cycle Hazards, depicted in Figure 63: Masterplan to Limiting Building Life Cycle Hazards [202] can be utilized to determine which critical steps should be taken and which major design milestones should be reached at each phase of a building's development.

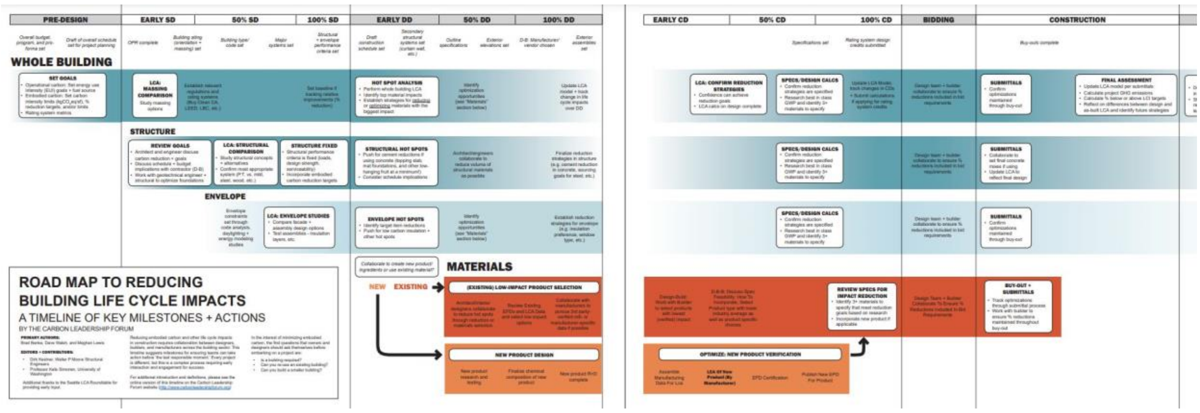


Figure 63: Masterplan to Limiting Building Life Cycle Hazards [202]

4.3 Overview of existing BIM to LCA

Since there is a growing interest in integrating LCA and BIM to steer the building sector toward environmental sustainability, the BIM-based LCA methods are analyzed to propose a workflow based on data input, data analysis, and data output that would support a holistic approach to buildings while minimizing wasted time and effort. The goal is to provide professionals with cutting-edge methods for assessing environmental implications, such as energy analysis, cost estimation, and green building certifications.

There have been multiple attempts to categorize BIM and LCA [203] [204] [205] [206]. Anton and Diaz [204] proposed two different ways in which BIM and LCA could be combined. First, data from building information models (BIMs) is used directly in environmental performance calculations—the second kind requests that environmental attributes be incorporated into the BIM objects. Wastiels and Decuypere [206] put forward the most exhaustive taxonomy. A total of five subtypes focused on the medium via which data is exchanged between BIM and LCA tools were identified; the Bill of Quantities report, the IFC format, BIM viewer tools, LCA plug-ins, and attribute values.

In the most recent studies, there were found to be three distinct ways of handling the interchange of data between BIM and LCA (**Figure 64**). Using a third-party tool, Type I combines information from BIM and LCA to provide carbon results. Material amounts can be included in models made with BIM programs like Autodesk Revit [207] [208], ArchiCAD [209], and Rhinoceros [210], and then exported to be integrated with carbon emission values found in numerous LCA databases [211] [212]. Excel spreadsheets and other custom tools written in programming languages [213] [214] [215] are commonly used to perform calculations. Despite being easy to implement and providing immediate results, this method can only be used for very basic forms of LCA. Type II integrates carbon emission variables into the BIM system through the creation of plug-ins and APIs (APIs) [216] [217] [218]. The data mapping process between carbon emission components and BIM objects is still time-consuming due to differences in material characteristics like units, types, and names, but this method makes effective use of BIM technology as a data repository and visualization platform [219] [220]. Professionally and reliably, Type III has the overwhelming advantage since it imports the essential BIM data into specialized LCA software tools, resulting in an accurate and thorough LCA. Since it connects the relevant BIM model to expert LCA implementation and offers sufficient LCA information with in-tool databases, this strategy should receive more attention.

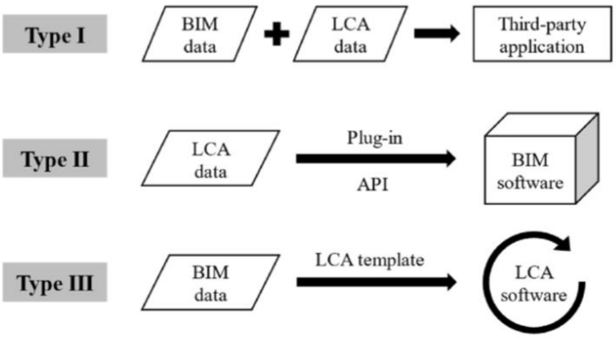


Figure 64: Three BIM-integrated LCA data-flow methodologies [221]

Construction design makes Revit the most popular BIM tool. Athena Impact Estimator, eBalance, openLCA, and SimaPro are other LCA tools. Revit, SketchUp, Tekla, and ArchiCAD are just a few of the available various BIM software packages that allow for property modification and IFC export. SimaPro, one of the best LCA software programs, can pull in data from numerous LCA databases, including the widely-used Ecoinvent, ETH-ESU 96, and US LCI, to generate accurate estimates of carbon emissions from raw materials and energy use [222]. There are also various licensed, automated LCA-BIM software, such as OneClickLCA [223].

A BIM-integrated LCA approach (Figure 65) was created in the Xu et al. [224] study, incorporating three components: (i) BIM data preprocessing, (ii) information extraction and incorporation, and (iii) embodied carbon evaluation. Pan et al. [225] propose a five-level analytical framework that divides buildings into (i) materials, like concrete and steel, (ii) components, like prefabricated concrete surfaces or staircases, (iii) assemblies, like non-volumetric precast facades, (iv) flats, like a residential unit, and (v) whole buildings.

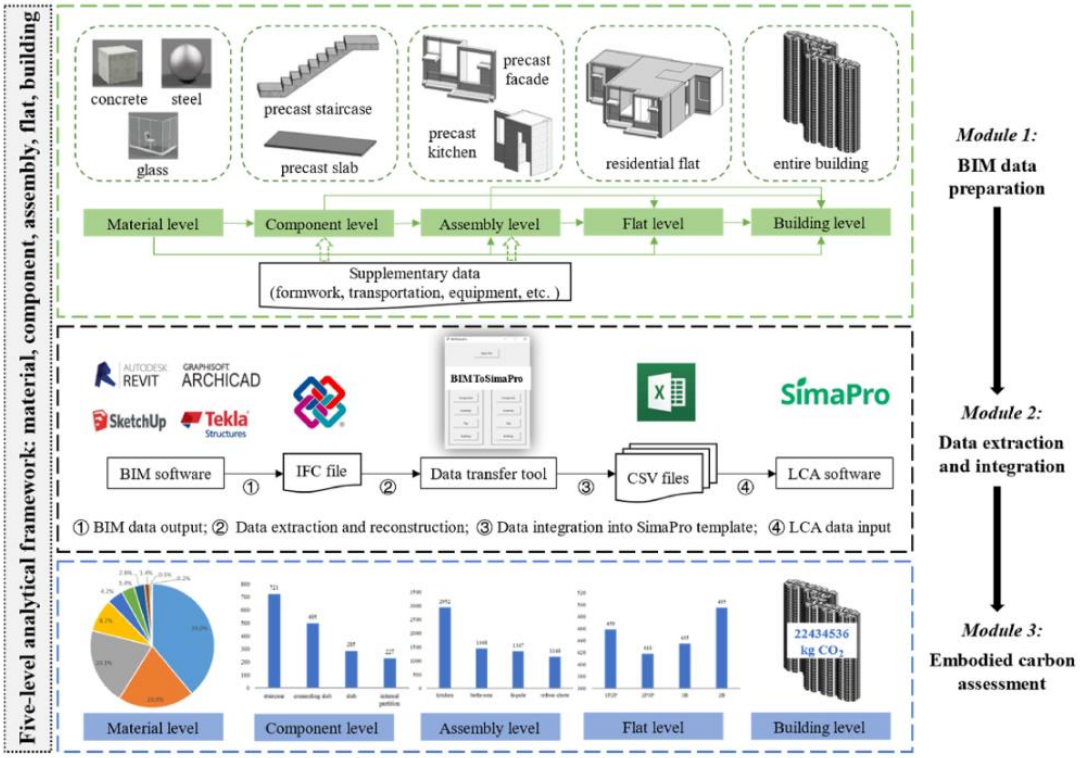


Figure 65: The framework of the developed BIM-integrated LCA solution [224]

In the future, it will be impossible to disregard the need to incorporate LCA and BIM in the process of decision-making at an early stage. The incorporation and LCA hold great promise for the building industry's long-term sustainability. When all relevant building data is combined with existing LCA databases, the possible environmental influence of building professionals' actions becomes clear. The methodological difficulties and restrictions of currently available LCA-BIM technologies demonstrate the seemingly limitless potential for the creation of new assessment tools and approaches. Once the integration is established, information-based building modeling will ensure that LCA is performed continually in real-time throughout all phases of construction planning.

The challenges with BIM-LCA development and sustainability (Table 49) leading to inefficiency [226] include, among others, the lack of a uniform database platform and the employment of databases that are too different from one another. Using the same or similar databases offers more consistent outcomes [227]. Although relative tools have been developed, they are still not widely used, and it is not common practice for engineers at the design stage to also perform LCA. Region-specific databases are useful since some of them provide automated material classification, which is essential for assigning and measuring potential environmental consequences. Some of these difficulties can be traced to an absence of management or standardization of the concepts in regard to LCA; for example, the most frequently cited barriers have been pointed out to be the absence of a method for extracting quantities, specifications for the input of material data, and high-quality models at the time they necessitate them for LCA. Consequently, the necessary collaborative modeling effort is not being undertaken since there is no motivation to model for quantity take-off.

Table 49: BIM and sustainability assessment: opportunities and constraints for discussion [228] [229]

Challenges	Comments	
Improper administration of construction models in a collaborative process	▪ Time-consuming	▪ No minimum demands for LOD on material information
	▪ Model not designed by users	▪ Inability to edit models
	▪ Lack of responsibility for the quantities in models	▪ No standardization for extraction of quantities
	▪ Late commencement of models	
Modelling errors	▪ Errors in the model	▪ Wrong mensuration from modelling errors
	▪ Wrong dimension of elements	▪ Double modelling
	▪ No reinforcement in concrete elements	
Manual workflow and large models	▪ Too much information	▪ Extracting quantities/checking data is the most time-consuming process
	▪ Time consuming with manual BIM–LCA workflow	
Workflow errors	▪ Paint areas are wrong if the suspended ceiling is not accounted for	▪ Difficult to check models for errors by third parties
	▪ Human error when manually typing	▪ Inability to detect missing quantities in Revit quantities extraction
Data exchange and matching model data with LCIA data	▪ Matching quantities with LCIA data from LCA by creating generic plug-in scripts for all models	▪ Difficulty using quantity outputs units from models for LCA
	▪ Issues with stability and workflow	▪ Difficulty in future workflow prediction to user-friendly tools
Variations in the structure of models	▪ Difference in modelling across nations	▪ Structurally different models
Lack of data availability and quality in models	▪ Incorrect modelling	▪ Difficulty in extracting correct quantities from the models
	▪ Incorrect quantities	▪ Materials are not in the models
	▪ Varying details	▪ Not all materials are modelled in the model
	▪ Data in models is not good enough	▪ Varying models quality
	▪ MEP model is not used for the LCA because it is not good enough	▪ Insufficient details in models
	▪ Getting information from the right source	▪ Incomplete data availability in Revit
	▪ Information is not in the Revit model; only geometry	▪ Incorrect models in terms of extracting quantities

4.4 Data and Parameters for Environmental Analysis

In the context of the SmartLivingEPC project, **Figure 67** demonstrates the process of extracting LCA results for a building's environmental indicators, encompassing various stages such as construction materials, transportation, construction/installation, and deconstruction. These results are obtained from a BIM file and are informed by the environmental indicators outlined in Level(s) guidelines.

The comprehensive analysis conducted reveals detailed values for the environmental indicators during distinct stages of the building's life cycle (Figure 66): (a) the phase involving construction materials, (b) transportation of materials to the site, (c) the construction and installation process, and (d) the end-of-life phase. Additionally, the total values for each indicator are provided. As a result of this analysis, the environmental footprint associated with each construction material and structural element category can be discerned.

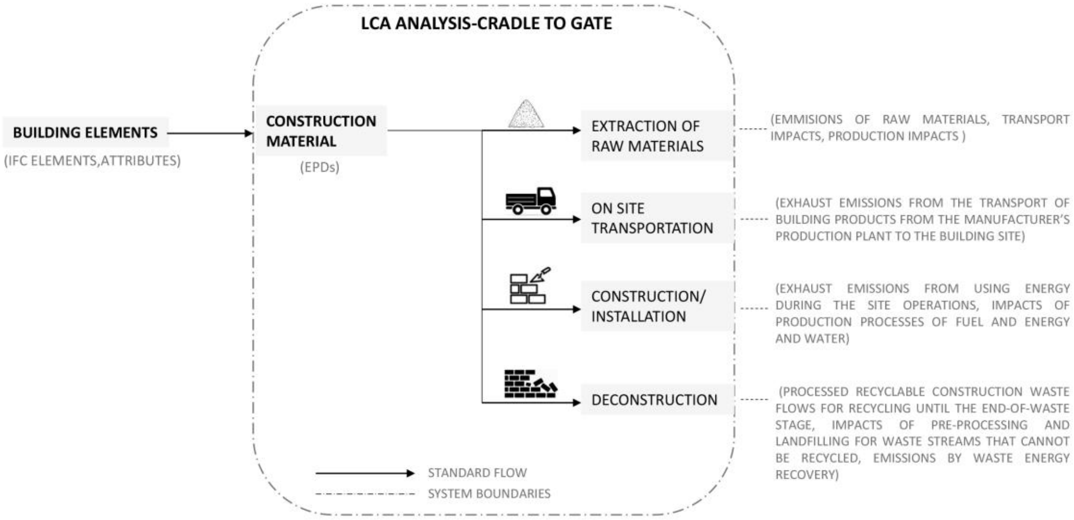


Figure 66: System's boundaries for the LCA analysis materials

4.4.1 Methodology

The SmartLivingEPC project aims to incorporate a comprehensive set of indicators concerning the environmental aspects of buildings. This endeavor underscores the significance of integrating LCA methodologies into the efficient energy design of buildings. The EPCs primarily cater to pertinent stakeholders, practicing engineers, and EPC assessors, with the ultimate goal of implementing the principles of SmartLivingEPC in building certification processes.

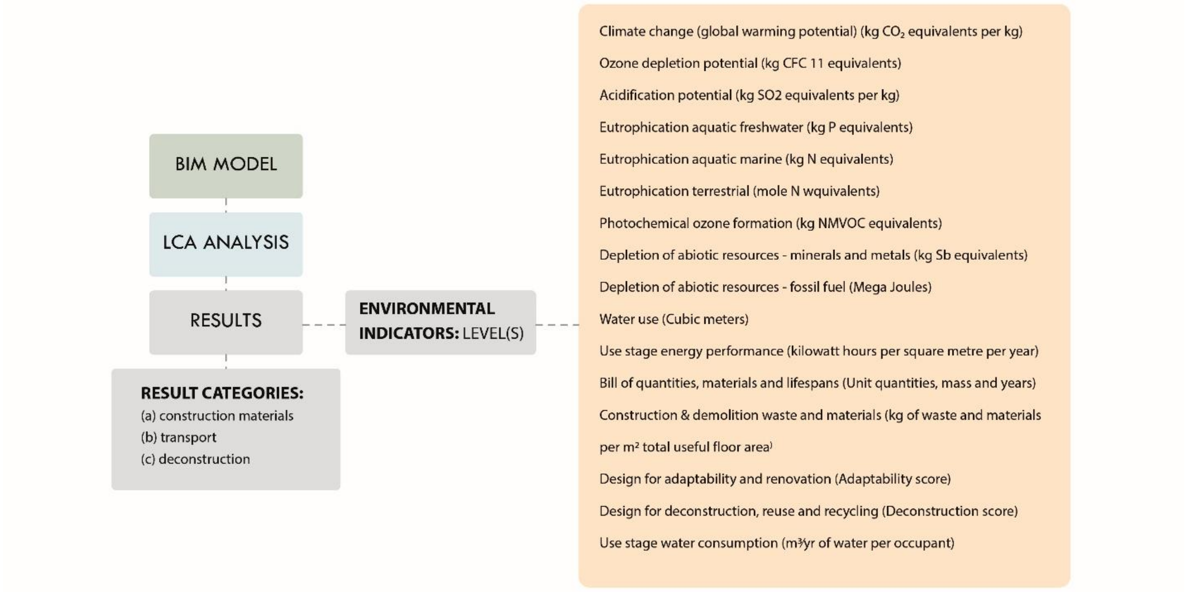


Figure 67: Environmental indicators extraction

The development of environmental indicators for SmartLivingEPC is rooted in the Level(s) scheme, which serves as the European Union's framework for assessing and reporting on the sustainability performance of buildings across their entire life cycle. The Level(s) approach aligns its evaluations with European sustainability objectives and employs existing standards, thereby providing a cohesive platform for quantifying, analyzing, and comprehending the life cycle of buildings. This approach targets various circularity aspects and furnishes indicators that offer valuable insights into enhancing building functionality. Consequently, Level(s) constitutes a constructive framework devoted to bolstering environmental performance, optimizing resource utilization, and diminishing the overall impact of the built environment on global resources.

4.5 SmartLivingEPC Environmental Indicators

4.5.1 Level(s) scheme indicators

Level(s) offers a comprehensive framework of indicators and standardized metrics aimed at assessing the environmental efficacy of buildings throughout their entire life cycle. In addition to gauging environmental performance, the methodology facilitates the evaluation of other crucial facets pertaining to building performance, such as health and comfort indicators, life cycle cost analysis, and the anticipation of potential future performance risks.

Level(s) endeavors to establish a comprehensive lexicon of sustainability concerning edifices. This universally accepted terminology is intended to facilitate the implementation of measures at the individual building scale, which can effectively align with and support overarching environmental policy imperatives within the European context. The framework of Level(s) is organized as in Figure 68.

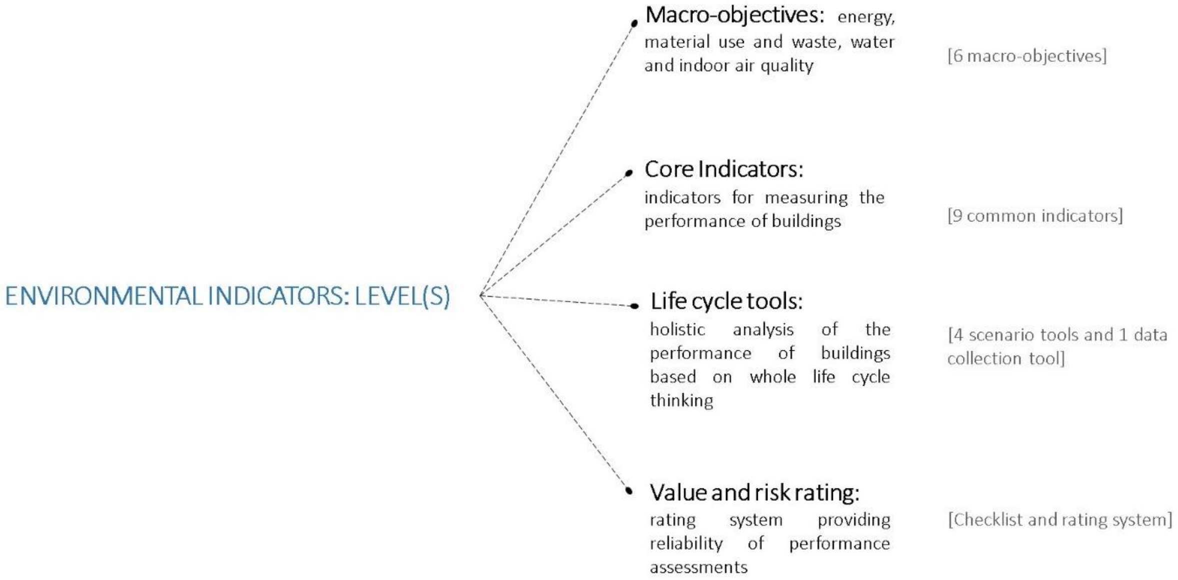


Figure 68: Diagram of Level(s) objectives

Moreover, the Level(s) framework endeavors to foster life cycle thinking by directing users to progress from a preliminary concentration on discrete facets of building performance to a more comprehensive outlook. The ultimate objective lies in its potential to attain broader adoption of Life Cycle Assessment (LCA) and Life Cycle Cost Assessment (LCCA) practices throughout Europe. The indicators are explained in more detail below:

Climate change (global warming potential) (kg CO_2 equivalents per kg): Indicator of potential global warming due to air emissions of greenhouse gases. Climate change is defined as the impact of human emissions on the radiative forcing (i.e., heat radiation absorption) of the atmosphere. This may, in turn, have adverse impacts on ecosystem health, human health, and material welfare. Most of these emissions enhance radiative forcing, causing the temperature at the earth's surface to rise, i.e., the greenhouse effect. The areas of protection are human health, the natural environment, and the man-made environment.

Ozone depletion potential (kg CFC 11 equivalents): Indicator of air emissions that causes the destruction of the stratospheric ozone layer.

Acidification potential (kg SO_2 equivalents per kg): Decrease in the pH-value of rainwater and fog measure, which has the effect of ecosystem damage due to, for example, nutrients being washed out of soils and increased solubility of metals into soils. Acidifying pollutants have a wide variety of impacts on soil, groundwater, surface waters, biological organisms, ecosystems, and materials (buildings). The major acidifying pollutants are SO_2, NO_x, and NH_x. Areas of protection are the natural environment, the man-made environment, human health, and natural resources.

Eutrophication aquatic freshwater (kg P equivalents): Excessive growth measurement of aquatic plants or algal blooms due to high levels of nutrients in freshwater. Freshwater ecotoxicity refers to the impacts of toxic substances on freshwater aquatic ecosystems.

Eutrophication aquatic marine (kg N equivalents): marine ecosystem reaction measurement to excessive availability of a limiting nutrient.

Eutrophication terrestrial (mole N equivalents): increased nutrient availability measurement in the soil as a result of the input of plant nutrients.

Photochemical ozone formation (kg NMVOC equivalents): emissions of nitrogen oxides (NOx) and non-methane volatile organic compounds (NMVOC) measurement and consequent effects on the 'Human Health' and 'Terrestrial ecosystems' areas of protection. The photo-oxidant formation is the formation of reactive chemical compounds such as ozone by the action of sunlight on certain primary air pollutants. These reactive compounds may be injurious to human health, and ecosystems may also damage crops. The relevant areas of protection are human health, the man-made environment, the natural environment, and natural resources.

Depletion of abiotic resources - minerals and metals (kg Sb equivalents): Indicator of the depletion of natural non-fossil resources. "Abiotic resources" are natural sources (including energy resources) such as iron ore, crude oil, and wind energy, which are regarded as non-living. Abiotic resource depletion is one of the most frequently discussed impact categories, and there is consequently a wide variety of methods available for characterizing contributions to this category. To a large extent, these different methodologies reflect differences in problem definition. Depending on the definition, this impact category includes only natural resources, or natural resources, human health, and the natural environment, among its areas of protection.

Depletion of abiotic resources – fossil fuel (Mega Joules): Indicator of the depletion of natural fossil fuel resources.

Water use (Cubic meters): Indicator of the amount of water required to dilute toxic elements emitted into water or soil.

Use stage energy performance (kilowatt-hours per square meter per year): 'operational energy consumption': primary energy demand measurement of a building in the use stage, generation of low-carbon or renewable energy.

Life cycle Global Warming Potential (kg CO_2 equivalents per square meter per year): 'carbon footprint assessment' or 'whole life carbon measurement': building's contribution to greenhouse gas (GHG) emissions measurement associated with earth's global warming or climate change.

Bill of quantities, materials, and lifespans (Unit quantities, mass, and years): The quantities and mass of construction products and materials, as well as the estimation of the lifespan measurements necessary to complete defined parts of the building.

Construction & demolition waste and materials (kg of waste and materials per m^2 of total useful floor area): The overall quantity of waste and materials generated by construction, renovation, and demolition activities; used to calculate the diversion rate to reuse and recycling, in line with the waste hierarchy.

Design for adaptability and renovation (Adaptability score): Building design extent assessment of facilitation future adaptation to changing occupier needs and property market conditions; a building proxy capacity to continue to fulfill its function and for the possibility to extend its useful service life into the future.

Design for deconstruction, reuse, and recycling (Deconstruction score): Building design extent assessment of facilitation future recovery of materials for reuse or recycling, including assessment of the disassembly for a minimum scope of building parts ease, followed by the reuse and recycling for these parts and their associated sub-assemblies and materials ease.

Use stage water consumption (m^3/yr of water per occupant): The total consumption of water measurement for an average building occupant, with the option to split this value into potable and non-potable supplied water, as well as support measurement of the identification of the water-scarce location.

The findings pertain to the various **life stages of the building**, encompassing: (a) A1-A3, involving construction materials; (b) A4, concerning transportation to the construction site; (c) A5, encompassing the construction/installation process; (c) B1, during the utilization phase; (d) B3, involving repair activities; (e) B4-B5, encompassing material replacement and refurbishment; (f) B6, pertaining to energy consumption; (g) B7, involving water usage; and (h) C1-C4, during the end-of-life stage. By employing a specialized process for the computation of environmental indicators, the results primarily pertain to the following four life stages of the building: (1) A1-A3, concerning construction materials; (2) A4, relating to transportation to the site; (3) B5, encompassing construction and installation; and (4) C1-C4, during the end-of-life phase. A comprehensive account of the principal life cycle stages and the scope of analysis is furnished in the accompanying Table 50.

Table 50: Table of life-cycle stages description [OneClick LCA]

Life-cycle stages	Description
A1-A3 Construction Materials	Raw material supply (A1) includes emissions generated when raw materials are taken from nature transported to industrial units for processing, and processed. Loss of raw material and energy are also taken into account. Transport impacts (A2) include exhaust emissions resulting from the transport of all raw materials from suppliers to the manufacturer's production plant as well as impacts on the production of fuels. Production impacts (A3) cover the manufacturing of the production materials and fuels used by machines, as well as the handling of waste formed in the production processes at the manufacturer's production plants until the end-of-waste state.
A4 Transportation to the site	A4 includes exhaust emissions resulting from the transport of building products from the manufacturer's production plant to the building site as well as the environmental impacts of the production of the used fuel.
A5 Construction/installation process	A5 covers the exhaust emissions resulting from using energy during the site operations, the environmental impacts of production processes of fuel and energy and water, as well as handling of waste until the end-of-waste state.
B1-B5 Maintenance and material replacement	The environmental impacts of maintenance and material replacements (B1-B5) include environmental impacts from replacing building products after they reach the end of their service life. The emissions cover impacts from raw material supply, transportation, and production of the replacing new material as well as the impacts from manufacturing the replacing material as well as handling of waste until the end-of-waste state.
B6 Energy use	The considered use phase energy consumption (B6) impacts include exhaust emissions from any building-level energy production as well as the environmental impacts of production processes of fuel and externally produced energy. Energy transmission losses are also taken into account.
B7 Water use	The considered use phase water consumption (B7) impacts include the environmental impacts of the production processes of fresh water and the impacts from wastewater treatment.
C1-C4 Deconstruction	The impacts of deconstruction include impacts for processing recyclable construction waste flows for recycling (C3) until the end-of-waste stage or the impacts of pre-processing and landfilling for waste streams that cannot be recycled (C4) based on the type of material. Additionally, deconstruction impacts include emissions caused by waste energy recovery.
D External impacts/end-of-life benefits	The external benefits include emission benefits from recycling recyclable building waste. Benefits for re-used or recycled material types include the positive impact of replacing virgin-based material with recycled material and benefits for materials that can be recovered for energy cover positive impact for replacing other energy streams based on average impacts of energy production.

In the context of the SmartLivingEPC project, the LCA Level(s) tool is employed for the purpose of conducting assessments. Within this framework, a comprehensive compilation of seventeen distinct data result terms is meticulously outlined in Annex A.5. These environmental indicators primarily constitute asset indicators, amenable to computation through the amalgamation of the materials bill of quantities derived from a BIM document, along with the pertinent Environmental Product Declarations (EPDs) of the building materials under consideration.

4.6 Environmental LCA indicators calculation

This task involves developing a Python-based service designed for calculating and storing environmental Life Cycle Assessment (LCA) indicators in a MySQL database. The service gets an ifc file as input, which includes details about a building's structure and components. After the extraction of building materials, the service proceeds to calculate the total mass for each material respectively. The next step of the process is fetching the corresponding material data, i.e. only the materials of the corresponding building, to compute the product of material mass and indicator values for each life cycle stage. The management of materials and indicators is implemented in an external REST API service. Additionally, the application provides users the flexibility to add material-indicator records individually or in bulk by uploading an Excel file. Below is represented the architecture of the system and the methodology that is followed.

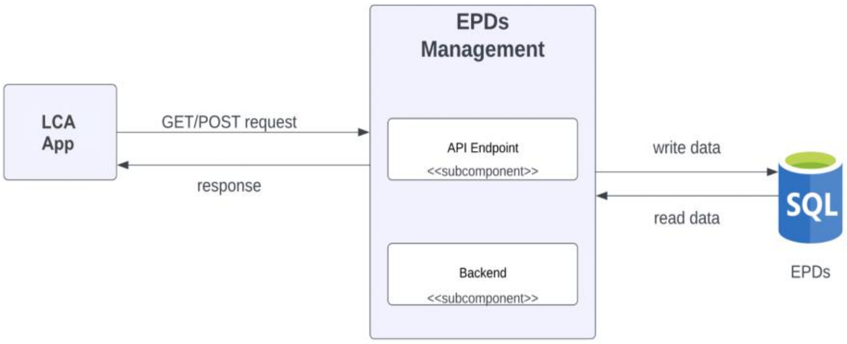


Figure 69 - LCA Service Architecture

Materials and Indicators storage

For the materials and indicators management, a REST API service is created, which be analyzed after the database schema discussion. Materials have a unique id and the indicators as well. This design's purpose is allowing independence between materials and indicators, in case materials are not associated with all indicators. Consequently, an entity named EPD exists for combining materials, indicators, and life cycle stages. The table below shows the included indicators in the database and follows the Entity Relationship Diagram (ERD) of the database context.

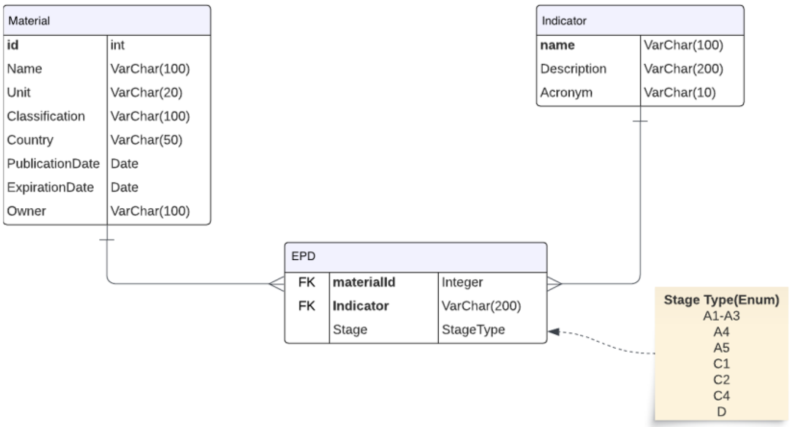


Figure 70 - Database ER Diagram

REST API for Data Management

In the following table are shown the REST API's endpoints:

Table 51 - API Endpoint Reference for Environmental Product Declarations and Materials Management

Request Type	Request Format	Description
GET	/api/epd/	List all EPDs
GET	/api/epd/int:id/	Get details of a specific epd by ID
POST	/api/epd/	Create new EPD record
PUT	/api/epd/edit/int:id/	Edit details of a specific epd by ID
DELETE	/api/epd/delete/int:id/	Delete a specific EPD record by ID
GET	/api/materials/	List all materials
GET	/api/materials/int:id/	Get details of a specific material by ID
PUT	/api/materials/edit/int:id/	Edit details of a specific material by ID
DELETE	/api/materials/delete/int:id/	Delete a specific material record by ID

IFC Parser

The IFC parser, as suggested using the ifcopenshell library in the code, is a crucial component for extracting and processing building information modeling (BIM) data. Following is the process of the ifc parser in steps:

- **Opening IFC Files:** The parser begins by opening an IFC file using ifcopenshell.open(), creating an object model representing the building.
- **Element Type Filtering:** It filters elements by type (e.g., IfcWall, IfcRoof) to process different categories of building elements separately. This is essential for targeted analysis, such as calculating the material mass for walls or roofs specifically.

- **Property Extraction:** For each element, the parser navigates its property sets to extract relevant data, such as material layers, thicknesses, areas, and densities. This involves traversing relationships defined in the IFC schema, like IsDefinedBy or RelatingPropertyDefinition.
- **Material Analysis:** The parser calculates derived properties, such as material volumes and masses, by applying the extracted dimensions and densities.
- **Mass Calculation:** In this step calculates the total mass of each material.

LCA Indicators Calculation

When a user selects a stage within the application and the product of mass and environmental indicator is calculated. Stages could include raw material supply (A1), transport (A2), manufacturing (A3), use (B1-B7), disposal (C1-C4), and potential for reuse, recovery or recycling (D). Continuing with retrieving all the EPDs from database using the respective endpoint. After that we extract only the parsed materials and their EPDs for the selected life cycle stage. Following, the environmental impact of each material is calculated by multiplying the total mass of the material used in the construction by its corresponding environmental indicator value.

4.6.1 Cyprus – FRC pilot

This section includes a sample of the service, where "Limassol Building" is used for the Ifc Parser and LCA indicators calculation testing. Before showing test's results, the table below shows the indicators and their units.

Following are all the extracted results from Limassol Building, i.e the environmental impact for each material in categories, roofs, walls and coverings respectively. The cells that contain "-", is result of the lack of the corresponding EPD. Also, it is notable that materials for floor category do not exist. In each category, the mass of each material is given in the beginning of the section. The environmental impact, as it is aforementioned, is results of the product of mass and material corresponding indicator value.

Table 52 - LCA Indicators Table

Indicator	Acronym	Unit
Global Warming Potential	GWP	kg CO2-Eq
Depletion Potential of the Stratospheric Ozone Layer	ODP	kg CFC11-Eq.
Acidification potential of land and water	AP	kg SO2-Eq.
Eutrophication potential	EP	kg (PO4) 3- -Eq.
Formation potential of tropospheric ozone photochemical oxidants	POCP	Kg EthenEq.
Abiotic depletion potential for non-fossil resources ADPE-ADPM	ADPE	kgSbEq.
Abiotic depletion potential for fossil resources	ADPF	MJ

Roof Materials

Material	Asphalt, Bitumen	Roofing Felt	Rigid insulation	Vapour Retarder	Concrete, Sand/Cement Screed	Concrete, Cast In Situ
Mass [kg]	4.09E+07	0	1.01E+06	0	1.01E+08	3.53E+08

Life Cycle Stage A1-A3:

Material	GWP	ODP	AP	EP	POCP	ADPE	ADPF
Asphalt, Bitumen	-	-	-	-	-	-	-
Roofing Felt	0	0	0	0	0	0	0
Rigid insulation	5.86E+06	5.05E-01	2.73E+04	4.34E+03	2.42E+03	2.12E+02	1.21E+08
Vapour Retarder	0	0	0	0	0	0	0
Concrete, Sand/Cement Screed	9.21E+08	1.05E+01	1.61E+06	4.59E+05	6.96E+04	1.23E+02	4.99E+09
Concrete, Cast In Situ	3.22E+09	3.68E+01	5.62E+06	1.60E+06	2.44E+05	4.31E+02	1.75E+10

Life Cycle Stage A4(Transport from the gate to the site):

Material	**GWP**	**ODP**	**AP**	**EP**	**POCP**	**ADPE**	**ADPF**
Asphalt, Bitumen	-	-	-	-	-	-	-
Roofing Felt	0	0	0	0	0	0	0
Rigid insulation	1.41E+05	2.42E-02	5.35E+02	1.31E+02	2.63E+01	7.07E-01	2.12E+06
Vapour Retarder	-	-	-	-	-	-	-
Concrete, Sand/Cement Screed	4.53E+07	7.07E-09	1.05E+05	2.55E+04	-3.52E+04	3.22E+00	6.14E+08
Concrete, Cast In Situ	1.59E+08	2.47E-08	3.68E+05	8.91E+04	-1.23E+05	1.13E+01	2.15E+09

Life Cycle Stage A5(Assembly):

Material	**GWP**	**ODP**	**AP**	**EP**	**POCP**	**ADPE**	**ADPF**
Asphalt, Bitumen	-	-	-	-	-	-	-
Roofing Felt	0	0	0	0	0	0	0
Rigid insulation	1.21E+07	8.08E-01	6.16E+04	3.74E+04	6.56E+03	2.12E+02	1.41E+08
Vapour Retarder	-	-	-	-	-	-	-
Concrete, Sand/Cement Screed	-	-	-	-	-	-	-
Concrete, Cast In Situ	-	-	-	-	-	-	-

Life Cycle Stage C1(De-construction demolition):

Material	GWP	ODP	AP	EP	POCP	ADPE	ADPF
Asphalt, Bitumen	-	-	-	-	-	-	-
Roofing Felt	0	0	0	0	0	0	0
Rigid insulation	3.03E+05	4.65E-02	3.94E+03	2.12E+02	2.22E+02	1.62E-02	6.16E+06
Vapour Retarder	0	0	0	0	0	0	0
Concrete, Sand/Cement Screed	2.33E+05	0	6.95E+04	1.73E+04	6.06E+03	0	0
Concrete, Cast In Situ	8.17E+05	0	2.43E+05	6.04E+04	2.12E+04	0	0

Life Cycle Stage C2(Transport)

Material	GWP	ODP	AP	EP	POCP	ADPE	ADPF
Asphalt, Bitumen	-	-	-	-	-	-	-
Roofing Felt	0	0	0	0	0	0	0
Rigid insulation	2.73E+05	4.44E-02	1.21E+03	3.43E+02	1.11E+02	9.90E-01	4.04E+06
Vapour Retarder	0	0	0	0	0	0	0
Concrete, Sand/Cement Screed	1.21E+07	2.02E-09	2.81E+04	6.79E+03	-9.40E+03	8.58E-01	1.64E+08
Concrete, Cast in Situ	4.24E+07	7.07E-09	9.83E+04	2.38E+04	-3.29E+04	3.00E+00	5.73E+08

Life Cycle Stage C3 (Waste processing)

Material	GWP	ODP	AP	EP	POCP	ADPE	ADPF
Asphalt, Bitumen	-	-	-	-	-	-	-
Roofing Felt	0	0	0	0	0	0	0
Rigid insulation	-	-	-	-	-	-	-
Vapour Retarder	0	0	0	0	0	0	0
Concrete, Sand/Cement Screed	1.21E+07	1.01E-09	4.32E+04	1.05E+04	4.04E+03	4.30E-01	8.21E+07
Concrete, Cast In Situ	4.24E+07	3.53E-09	1.51E+05	3.68E+04	1.41E+04	1.51E+00	2.87E+08

Life Cycle Stage C4 (Disposal)

Material	GWP	ODP	AP	EP	POCP	ADPE	ADPF
Asphalt, Bitumen	-	-	-	-	-	-	-
Roofing Felt	0	0	0	0	0	0	0
Rigid insulation	1.62E+05	9.39E-04	4.34E+01	6.67E+02	3.53E+01	5.86E-03	1.01E+05

Vapour Retarder	0	0	0	0	0	0	0
Concrete, Sand/Cement Screed	9.18E+06	1.21E-08	2.80E+04	5.35E+03	-4.86E+03	7.04E-01	1.25E+08
Concrete, Cast In Situ	3.21E+07	4.24E-08	9.79E+04	1.87E+04	-1.70E+04	2.46E+00	4.38E+08

Life Cycle Stage D (Reuse-Recovery-Recycling-potential)

Material	**GWP**	**ODP**	**AP**	**EP**	**POCP**	**ADPE**	**ADPF**
Asphalt, Bitumen	-	-	-	-	-	-	-
Roofing Felt	0	0	0	0	0	0	0
Rigid insulation	-	-	-	-	-	-	-
Vapour Retarder	0	0	0	0	0	0	0
Concrete, Sand/Cement Screed	-8.49E+06	-1.03E-07	-4.66E+04	-8.69E+03	-4.22E+03	-1.53E+00	-1.08E+08
Concrete, Cast In Situ	-2.97E+07	-3.61E-07	-1.63E+05	-3.04E+04	-1.48E+04	-5.34E+00	-3.78E+08

Covering Materials

Material	Metal Stud Layer	ACT[5]	Concrete, Sand/Cement Screed	Paint
Mass [kg]	2.43E+05	2.52E+07	1.14E+05	0

Life Cycle Stage A1-A3:

Material	**GWP**	**ODP**	**AP**	**EP**	**POCP**	**ADPE**	**ADPF**
Metal Stud Layer	5.07E+05	9.77E+00	1.20E+03	1.24E+02	5.48E-01	1.13E-01	4.97E+06
ACT	-	-	-	-	-	-	-
Concrete, Sand/Cement Screed	1.04E+06	1.18E-02	1.81E+03	5.16E+02	7.83E+01	1.39E-01	5.61E+06
Paint	-	-	-	-	-	-	-

Life Cycle Stage A4 (Transport from the gate to the site):

Material	**GWP**	**ODP**	**AP**	**EP**	**POCP**	**ADPE**	**ADPF**
Metal Stud Layer	8.63E+01	0	6.38E-01	1.07E-01	3.42E-02	8.61E-06	1.13E+03
ACT	-	-	-	-	-	-	-

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[5] ACT: ACT - Armstrong Ceilings - 24" x 24" - ULTIMA Health Zone AirAssure - Mineral Fiber - Bev Tegular 9/16" x 3/4" - 1351 - White with SUPRAFINE XL 9/16" Exposed Tee Suspension System

Concrete, Sand/Cement Screed	5.10E+04	7.95E-12	1.18E+02	2.86E+01	-3.97E+01	3.62E-03	6.91E+05
Paint	-	-	-	-	-	-	-

Life Cycle Stage A5(Assembly):

Material	GWP	ODP	AP	EP	POCP	ADPE	ADPF
Metal Stud Layer	2.79E+04	4.90E-01	6.55E+01	6.60E+00	1.05E+01	5.02E-02	2.74E+05
ACT	-	-	-	-	-	-	-
Concrete, Sand/Cement Screed	-	-	-	-	-	-	-
Paint	-	-	-	-	-	-	-

Life Cycle Stage C1(De-construction demolition):

Material	GWP	ODP	AP	EP	POCP	ADPE	ADPF
Metal Stud Layer	1.07E+03	0	1.34E+00	2.06E-01	1.54E-01	3.13E-05	1.42E+04
ACT	-	-	-	-	-	-	-
Concrete, Sand/Cement Screed	2.62E+02	0	7.82E+01	1.94E+01	6.82E+00	0	0
Paint	-	-	-	-	-	-	-

Life Cycle Stage C2(Transport):

Material	GWP	ODP	AP	EP	POCP	ADPE	ADPF
Metal Stud Layer	5.55E+02	0	2.22E+00	5.58E-01	8.83E-02	4.58E-05	7.54E+03
ACT	-	-	-	-	-	-	-
Concrete, Sand/Cement Screed	1.36E+04	2.27E-12	3.16E+01	7.64E+00	-1.06E+01	9.66E-04	1.84E+05
Paint	-	-	-	-	-	-	-

Life Cycle Stage C3(Waste processing):

Material	GWP	ODP	AP	EP	POCP	ADPE	ADPF
Metal Stud Layer	5.21E+02	2.43E-12	3.66E+00	8.78E-01	4.05E-01	5.92E-04	1.01E+04
ACT	-	-	-	-	-	-	-
Concrete, Sand/Cement Screed	1.36E+04	1.14E-12	4.86E+01	1.18E+01	4.54E+00	4.84E-04	9.24E+04
Paint	-	-	-	-	-	-	-

Life Cycle Stage C4(Disposal)

Material	GWP	ODP	AP	EP	POCP	ADPE	ADPF
Metal Stud Layer	5.41E+02	2.43E-12	3.18E+00	3.59E-01	2.59E-01	1.89E-04	7.03E+03
ACT	-	-	-	-	-	-	-
Concrete, Sand/Cement Screed	1.03E+04	1.36E-11	3.15E+01	6.02E+00	-5.47E+00	7.92E-04	1.41E+05
Paint	-	-	-	-	-	-	-

Life Cycle Stage D (Reuse-Recovery-Recycling-potential):

Material	GWP	ODP	AP	EP	POCP	ADPE	ADPF
Metal Stud Layer	-2.98E+05	-1.03E+01	-5.77E+02	-4.03E+01	-1.39E+02	-5.09E+00	-2.81E+06
ACT	-	-	-	-	-	-	-
Concrete, Sand/Cement Screed	-9.56E+03	-1.16E-10	-5.24E+01	-9.77E+00	-4.75E+00	-1.72E-03	-1.22E+05
Paint	-	-	-	-	-	-	-

Wall Materials

Material	Concret, Sand/Cement Screed	Brick	Gypsum Wall Board	Wood Sheathing, Chipboard	Rock Wool	Concrete, C25/30	Concrete, Cast In Situ	White	Brick, Light Blend, Soldier	Metal Stud Layer
Mass [Kg]	2.31E+08	5.86E+08	5.93E+07	3.38E+07	2.81E+07	1.91E+08	2.77E+06	7.70E+06	1.71E+07	3.23E+04

Life Cycle Stage A1-A3 (Raw material supply):

Material	GWP	ODP	AP	EP	POCP	ADPE	ADPF
Paint	-	-	-	-	-	-	-
Concrete, Sand/Cement Screed	2.11E+09	2.40E+01	3.67E+06	1.05E+06	1.59E+05	2.82E+02	1.14E+10
Brick, Common	5.82E+10	8.32E+02	1.27E+09	1.99E+08	5.70E+07	2.69E+05	4.99E+11
Gypsum Wall Board	1.68E+08	1.19E+00	3.75E+05	1.73E+05	2.64E+04	1.68E+02	2.78E+09
Wood Sheathing, Chipboard	4.40E+09	8.69E+00	2.84E+07	2.47E+06	5.71E+08	-	8.45E+10
Rock Wool	3.40E+07	5.36E-02	1.48E+05	2.06E+04	8.51E+03	7.05E+00	3.45E+08
Concrete, C25/30	1.74E+09	1.98E+01	3.03E+06	8.65E+05	1.31E+05	2.32E+02	9.41E+09

Concrete, Cast In Situ	2.53E+07	2.88E-01	4.41E+04	1.26E+04	1.91E+03	3.38E+00	1.37E+08
White	-	-	-	-	-	-	-
Brick, Light Blend, Soldier	1.70E+09	2.43E+01	3.70E+07	5.81E+06	1.67E+06	7.87E+03	1.46E+10
Default Wall	-	-	-	-	-	-	-
Polyrey B187 Blue Moon	-	-	-	-	-	-	-
Metal Stud Layer	6.75E+04	1.30E+00	1.60E+02	1.66E+01	7.30E-02	1.50E-02	6.62E+05

Life Cycle Stage A4 (Transport from the gate to the site):

Material	GWP	ODP	AP	EP	POCP	ADPE	ADPF
Paint	-	-	-	-	-	-	-
Concrete, Sand/Cement Screed	1.04E+08	1.62E-08	2.40E+05	5.82E+04	-8.06E+04	7.37E+00	1.40E+09
Brick, Common	1.89E+09	3.28E-07	1.38E+06	2.75E+05	-2.20E+04	1.48E+02	2.56E+10
Gypsum Wall Board	2.75E+06	5.93E-10	1.10E+04	2.68E+03	4.02E+02	3.66E-02	3.83E+07
Wood Sheathing, Chipboard	2.51E+09	8.93E+01	1.66E+07	1.91E+06	4.83E+08	-	3.18E+10
Rock Wool	1.59E+07	1.12E-09	4.83E+03	9.80E+02	-2.06E+01	5.08E-01	8.34E+07
Concrete, C25/30	8.55E+07	1.33E-08	1.98E+05	4.80E+04	-6.65E+04	6.08E+00	1.16E+09
Concrete, Cast In Situ	1.25E+06	1.94E-10	2.88E+03	6.99E+02	-9.68E+02	8.85E-02	1.69E+07
White	-	-	-	-	-	-	-
Brick, Light Blend, Soldier	5.54E+07	9.60E-09	4.05E+04	8.06E+03	-6.45E+02	4.32E+00	7.49E+08
Default Wall	-	-	-	-	-	-	-
Polyrey B187 Blue Moon	-	-	-	-	-	-	-
Metal Stud Layer	1.15E+01	0	8.50E-02	1.42E-02	4.55E-03	1.15E-06	1.51E+02

Life Cycle Stage A5 (Assembly):

Material	GWP	ODP	AP	EP	POCP	ADPE	ADPF

Paint	-	-	-	-	-	-	-
Concrete, Sand/Cement Screed	-	-	-	-	-	-	-
Brick, Common	2.28E+09	1.59E-06	1.85E+06	2.50E+05	6.04E+04	3.66E+01	5.18E+09
Gypsum Wall Board	1.20E+07	5.93E-02	2.56E+04	9.55E+03	2.81E+03	1.21E+02	1.83E+08
Wood Sheathing, Chipboard	-	-	-	-	-	-	-
Rock Wool	3.03E+06	4.24E-03	3.54E+03	6.94E+02	2.59E+02	1.23E-01	1.03E+07
Concrete, C25/30	-	-	-	-	-	-	-
Concrete, Cast In Situ	-	-	-	-	-	-	-
White	-	-	-	-	-	-	-
Brick, Light Blend, Soldier	6.67E+07	4.65E-08	5.40E+04	7.32E+03	1.77E+03	1.07E+00	1.52E+08
Default Wall	-	-	-	-	-	-	-
Polyrey B187 Blue Moon	-	-	-	-	-	-	-
Metal Stud Layer	3.72E+03	6.53E-02	8.72E+00	8.79E-01	1.39E+00	6.69E-03	3.65E+04

Life Cycle Stage C1 (De-construction demolition):

Material	**GWP**	**ODP**	**AP**	**EP**	**POCP**	**ADPE**	**ADPF**
Paint	-	-	-	-	-	-	-
Concrete, Sand/Cement Screed	5.34E+05	0	1.59E+05	3.95E+04	1.39E+04	0	0
Brick, Common	0	0	0	0	0	0	0
Gypsum Wall Board	2.29E+06	5.93E-10	8.07E+03	4.69E+02	5.41E+02	5.70E-02	2.85E+07
Wood Sheathing, Chipboard	-	-	-	-	-	-	-
Rock Wool	0	0	0	0	0	0	0
Concrete, C25/30	4.40E+05	0	1.31E+05	3.26E+04	1.14E+04	0	0
Concrete, Cast In Situ	6.41E+03	0	1.91E+03	4.74E+02	1.66E+02	0	0
White	-	-	-	-	-	-	-

Brick, Light Blend, Soldier	0	0	0	0	0	0	0
Default Wall	-	-	-	-	-	-	-
Polyrey B187 Blue Moon	-	-	-	-	-	-	-
Metal Stud Layer	1.42E+02	0	1.79E-01	2.75E-02	2.05E-02	4.17E-06	1.90E+03

Life Cycle Stage C2 (Transport):

Material	GWP	ODP	AP	EP	POCP	ADPE	ADPF
Paint	-	-	-	-	-	-	-
Concrete, Sand/Cement Screed	2.77E+07	4.62E-09	6.42E+04	1.55E+04	-2.15E+04	1.96E+00	3.74E+08
Brick, Common	1.44E+09	2.52E-07	1.05E+06	2.09E+05	-1.68E+04	1.13E+02	1.95E+10
Gypsum Wall Board	1.25E+06	5.93E-10	5.06E+03	1.29E+03	2.07E+02	1.08E-01	1.69E+07
Wood Sheathing, Chipboard	-	-	-	-	-	-	-
Rock Wool	8.45E+04	0	7.27E+01	1.52E+01	-2.80E+00	7.02E-03	1.15E+06
Concrete, C25/30	2.29E+07	3.81E-09	5.30E+04	1.28E+04	-1.77E+04	1.62E+00	3.09E+08
Concrete, Cast In Situ	3.33E+05	5.55E-11	7.71E+02	1.86E+02	-2.58E+02	2.36E-02	4.49E+06
White	-	-	-	-	-	-	-
Brick, Light Blend, Soldier	4.22E+07	7.37E-09	3.09E+04	6.12E+03	-4.90E+02	3.29E+00	5.71E+08
Default Wall	-	-	-	-	-	-	-
Polyrey B187 Blue Moon	-	-	-	-	-	-	-
Metal Stud Layer	7.40E+01	0	2.96E-01	7.43E-02	1.18E-02	6.11E-06	1.00E+03

Life Cycle Stage C3 (Waste processing):

Material	GWP	ODP	AP	EP	POCP	ADPE	ADPF
Paint	-	-	-	-	-	-	-
Concrete, Sand/Cement Screed	2.77E+07	2.31E-09	9.89E+04	2.40E+04	9.24E+03	9.84E-01	1.88E+08

Brick, Common	4.13E+08	7.03E-08	1.24E+06	2.88E+05	1.28E+05	3.23E+01	5.61E+09
Gypsum Wall Board	0	0	0	0	0	0	0
Wood Sheathing, Chipboard	-	-	-	-	-	-	-
Rock Wool	0	0	0	0	0	0	0
Concrete, C25/30	2.29E+07	1.91E-09	8.15E+04	1.98E+04	7.62E+03	8.12E-01	1.55E+08
Concrete, Cast In Situ	3.33E+05	2.77E-11	1.19E+03	2.88E+02	1.11E+02	1.18E-02	2.26E+06
White	-	-	-	-	-	-	-
Brick, Light Blend, Soldier	1.21E+07	2.06E-09	3.62E+04	8.43E+03	3.75E+03	9.46E-01	1.64E+08
Default Wall	-	-	-	-	-	-	-
Polyrey B187 Blue Moon	-	-	-	-	-	-	-
Metal Stud Layer	6.95E+01	3.23E-13	4.88E-01	1.17E-01	5.39E-02	7.88E-05	1.35E+03

Life Cycle Stage C4 (Disposal):

Material	GWP	ODP	AP	EP	POCP	ADPE	ADPF
Paint	-	-	-	-	-	-	-
Concrete, Sand/Cement Screed	2.10E+07	2.77E-08	6.40E+04	1.22E+04	-1.11E+04	1.61E+00	2.86E+08
Brick, Common	8.14E+07	4.45E-07	4.87E+05	5.53E+04	3.74E+04	8.20E+00	1.11E+09
Gypsum Wall Board	8.19E+06	4.57E-08	4.66E+04	5.28E+03	3.84E+03	2.78E+00	1.09E+08
Wood Sheathing, Chipboard	-	-	-	-	-	-	-
Rock Wool	3.51E+05	1.97E-09	2.26E+03	2.54E+02	1.70E+02	1.36E-01	5.00E+06
Concrete, C25/30	1.73E+07	2.29E-08	5.28E+04	1.01E+04	-9.16E+03	1.33E+00	2.36E+08
Concrete, Cast In Situ	2.52E+05	3.33E-10	7.68E+02	1.47E+02	-1.33E+02	1.93E-02	3.44E+06
White	-	-	-	-	-	-	-
Brick, Light Blend, Soldier	2.38E+06	1.30E-08	1.42E+04	1.62E+03	1.09E+03	2.40E-01	3.24E+07

Default Wall	-	-	-	-	-	-	-
Polyrey B187 Blue Moon	-	-	-	-	-	-	-
Metal Stud Layer	7.20E+01	3.23E-13	4.23E-01	4.78E-02	3.46E-02	2.52E-05	9.37E+02

Life Cycle Stage D (Reuse-Recovery-Recycling-potential):

Material	GWP	ODP	AP	EP	POCP	ADPE	ADPF
Paint	-	-	-	-	-	-	-
Concrete, Sand/Cement Screed	-1.94E+07	-2.36E-07	-1.06E+05	-1.99E+04	-9.66E+03	-3.49E+00	-2.47E+08
Brick, Common	-1.87E+09	-2.75E-05	-6.50E+06	-1.29E+06	-6.27E+05	-3.60E+02	-2.49E+10
Gypsum Wall Board	2.84E+04	5.93E-10	1.36E+02	3.50E+01	1.34E+01	9.61E-01	3.25E+05
Wood Sheathing, Chipboard	-	-	-	-	-	-	-
Rock Wool	-1.30E+06	-4.46E-07	-3.06E+03	-3.15E+02	-3.45E+02	-2.54E-01	-2.63E+07
Concrete, C25/30	-1.60E+07	-1.94E-07	-8.78E+04	-1.64E+04	-7.96E+03	-2.88E+00	-2.04E+08
Concrete, Cast In Situ	-2.33E+05	-2.83E-09	-1.28E+03	-2.39E+02	-1.16E+02	-4.19E-02	-2.97E+06
White	-	-	-	-	-	-	-
Brick, Light Blend, Soldier	-5.47E+07	-8.04E-07	-1.90E+05	-3.79E+04	-1.83E+04	-1.05E+01	-7.29E+08
Default Wall	-	-	-	-	-	-	-
Polyrey B187 Blue Moon	-	-	-	-	-	-	-
Metal Stud Layer	-3.97E+04	-1.37E+00	-7.69E+01	-5.36E+00	-1.86E+01	-6.78E-01	-3.75E+05

Life Cycle Stage A1 (Raw material supply):

Material	GWP	ODP	AP	EP	POCP	ADPE	ADPF
Paint	-	-	-	-	-	-	-
Concrete, Sand/Cement Screed	2.11E+09	2.40E+01	3.67E+06	1.05E+06	1.59E+05	2.82E+02	1.14E+10
Brick, Common	5.82E+10	8.32E+02	1.27E+09	1.99E+08	5.70E+07	2.69E+05	4.99E+11

Gypsum Wall Board	1.68E+08	1.19E+00	3.75E+05	1.73E+05	2.64E+04	1.68E+02	2.78E+09
Wood Sheathing, Chipboard	4.40E+09	8.69E+00	2.84E+07	2.47E+06	5.71E+08	-	8.45E+10
Rock Wool	3.40E+07	5.36E-02	1.48E+05	2.06E+04	8.51E+03	7.05E+00	3.45E+08
Concrete, C25/30	1.74E+09	1.98E+01	3.03E+06	8.65E+05	1.31E+05	2.32E+02	9.41E+09
Concrete, Cast In Situ	2.53E+07	2.88E-01	4.41E+04	1.26E+04	1.91E+03	3.38E+00	1.37E+08
White	-	-	-	-	-	-	-
Brick, Light Blend, Soldier	1.70E+09	2.43E+01	3.70E+07	5.81E+06	1.67E+06	7.87E+03	1.46E+10
Default Wall	-	-	-	-	-	-	-
Polyrey B187 Blue Moon	-	-	-	-	-	-	-
Metal Stud Layer	6.75E+04	1.30E+00	1.60E+02	1.66E+01	7.30E-02	1.50E-02	6.62E+05

Life Cycle Stage A4 (Transport from the gate to the site):

Material	GWP	ODP	AP	EP	POCP	ADPE	ADPF
Paint	-	-	-	-	-	-	-
Concrete, Sand/Cement Screed	1.04E+08	1.62E-08	2.40E+05	5.82E+04	-8.06E+04	7.37E+00	1.40E+09
Brick, Common	1.89E+09	3.28E-07	1.38E+06	2.75E+05	-2.20E+04	1.48E+02	2.56E+10
Gypsum Wall Board	2.75E+06	5.93E-10	1.10E+04	2.68E+03	4.02E+02	3.66E-02	3.83E+07
Wood Sheathing, Chipboard	2.51E+09	8.93E+01	1.66E+07	1.91E+06	4.83E+08	-	3.18E+10
Rock Wool	1.59E+07	1.12E-09	4.83E+03	9.80E+02	-2.06E+01	5.08E-01	8.34E+07
Concrete, C25/30	8.55E+07	1.33E-08	1.98E+05	4.80E+04	-6.65E+04	6.08E+00	1.16E+09
Concrete, Cast In Situ	1.25E+06	1.94E-10	2.88E+03	6.99E+02	-9.68E+02	8.85E-02	1.69E+07
White	-	-	-	-	-	-	-
Brick, Light Blend, Soldier	5.54E+07	9.60E-09	4.05E+04	8.06E+03	-6.45E+02	4.32E+00	7.49E+08
Default Wall	-	-	-	-	-	-	-

Polyrey B187 Blue Moon	-	-	-	-	-	-	-
Metal Stud Layer	1.15E+01	0	8.50E-02	1.42E-02	4.55E-03	1.15E-06	1.51E+02

Life Cycle Stage A5 (Assembly):

Material	GWP	ODP	AP	EP	POCP	ADPE	ADPF
Paint	-	-	-	-	-	-	-
Concrete, Sand/Cement Screed	-	-	-	-	-	-	-
Brick, Common	2.28E+09	1.59E-06	1.85E+06	2.50E+05	6.04E+04	3.66E+01	5.18E+09
Gypsum Wall Board	1.20E+07	5.93E-02	2.56E+04	9.55E+03	2.81E+03	1.21E+02	1.83E+08
Wood Sheathing, Chipboard	-	-	-	-	-	-	-
Rock Wool	3.03E+06	4.24E-03	3.54E+03	6.94E+02	2.59E+02	1.23E-01	1.03E+07
Concrete, C25/30	-	-	-	-	-	-	-
Concrete, Cast In Situ	-	-	-	-	-	-	-
White	-	-	-	-	-	-	-
Brick, Light Blend, Soldier	6.67E+07	4.65E-08	5.40E+04	7.32E+03	1.77E+03	1.07E+00	1.52E+08
Default Wall	-	-	-	-	-	-	-
Polyrey B187 Blue Moon	-	-	-	-	-	-	-
Metal Stud Layer	3.72E+03	6.53E-02	8.72E+00	8.79E-01	1.39E+00	6.69E-03	3.65E+04

Life Cycle Stage C1 (De-construction demolition)

Material	GWP	ODP	AP	EP	POCP	ADPE	ADPF
Paint	-	-	-	-	-	-	-
Concrete, Sand/Cement Screed	5.34E+05	0	1.59E+05	3.95E+04	1.39E+04	0	0
Brick, Common	0	0	0	0	0	0	0

Gypsum Wall Board	2.29E+06	5.93E-10	8.07E+03	4.69E+02	5.41E+02	5.70E-02	2.85E+07
Wood Sheathing, Chipboard	-	-	-	-	-	-	-
Rock Wool	0	0	0	0	0	0	0
Concrete, C25/30	4.40E+05	0	1.31E+05	3.26E+04	1.14E+04	0	0
Concrete, Cast In Situ	6.41E+03	0	1.91E+03	4.74E+02	1.66E+02	0	0
White	-	-	-	-	-	-	-
Brick, Light Blend, Soldier	0	0	0	0	0	0	0
Default Wall	-	-	-	-	-	-	-
Polyrey B187 Blue Moon	-	-	-	-	-	-	-
Metal Stud Layer	1.42E+02	0	1.79E-01	2.75E-02	2.05E-02	4.17E-06	1.90E+03

Life Cycle Stage C2 (Transport):

Material	GWP	ODP	AP	EP	POCP	ADPE	ADPF
Paint	-	-	-	-	-	-	-
Concrete, Sand/Cement Screed	2.77E+07	4.62E-09	6.42E+04	1.55E+04	-2.15E+04	1.96E+00	3.74E+08
Brick, Common	1.44E+09	2.52E-07	1.05E+06	2.09E+05	-1.68E+04	1.13E+02	1.95E+10
Gypsum Wall Board	1.25E+06	5.93E-10	5.06E+03	1.29E+03	2.07E+02	1.08E-01	1.69E+07
Wood Sheathing, Chipboard	-	-	-	-	-	-	-
Rock Wool	8.45E+04	0	7.27E+01	1.52E+01	-2.80E+00	7.02E-03	1.15E+06
Concrete, C25/30	2.29E+07	3.81E-09	5.30E+04	1.28E+04	-1.77E+04	1.62E+00	3.09E+08
Concrete, Cast In Situ	3.33E+05	5.55E-11	7.71E+02	1.86E+02	-2.58E+02	2.36E-02	4.49E+06
White	-	-	-	-	-	-	-
Brick, Light Blend, Soldier	4.22E+07	7.37E-09	3.09E+04	6.12E+03	-4.90E+02	3.29E+00	5.71E+08
Default Wall	-	-	-	-	-	-	-

Polyrey B187 Blue Moon	-	-	-	-	-	-	-
Metal Stud Layer	7.40E+01	0	2.96E-01	7.43E-02	1.18E-02	6.11E-06	1.00E+03

Life Cycle Stage C3 (Waste processing):

Material	GWP	ODP	AP	EP	POCP	ADPE	ADPF
Paint	-	-	-	-	-	-	-
Concrete, Sand/Cement Screed	2.77E+07	2.31E-09	9.89E+04	2.40E+04	9.24E+03	9.84E-01	1.88E+08
Brick, Common	4.13E+08	7.03E-08	1.24E+06	2.88E+05	1.28E+05	3.23E+01	5.61E+09
Gypsum Wall Board	0	0	0	0	0	0	0
Wood Sheathing, Chipboard	-	-	-	-	-	-	-
Rock Wool	0	0	0	0	0	0	0
Concrete, C25/30	2.29E+07	1.91E-09	8.15E+04	1.98E+04	7.62E+03	8.12E-01	1.55E+08
Concrete, Cast In Situ	3.33E+05	2.77E-11	1.19E+03	2.88E+02	1.11E+02	1.18E-02	2.26E+06
White	-	-	-	-	-	-	-
Brick, Light Blend, Soldier	1.21E+07	2.06E-09	3.62E+04	8.43E+03	3.75E+03	9.46E-01	1.64E+08
Default Wall	-	-	-	-	-	-	-
Polyrey B187 Blue Moon	-	-	-	-	-	-	-
Metal Stud Layer	6.95E+01	3.23E-13	4.88E-01	1.17E-01	5.39E-02	7.88E-05	1.35E+03

Life Cycle Stage C4 (Disposal):

Material	GWP	ODP	AP	EP	POCP	ADPE	ADPF
Paint	-	-	-	-	-	-	-
Concrete, Sand/Cement Screed	2.10E+07	2.77E-08	6.40E+04	1.22E+04	-1.11E+04	1.61E+00	2.86E+08
Brick, Common	8.14E+07	4.45E-07	4.87E+05	5.53E+04	3.74E+04	8.20E+00	1.11E+09

Gypsum Wall Board	8.19E+06	4.57E-08	4.66E+04	5.28E+03	3.84E+03	2.78E+00	1.09E+08
Wood Sheathing, Chipboard	-	-	-	-	-	-	-
Rock Wool	3.51E+05	1.97E-09	2.26E+03	2.54E+02	1.70E+02	1.36E-01	5.00E+06
Concrete, C25/30	1.73E+07	2.29E-08	5.28E+04	1.01E+04	-9.16E+03	1.33E+00	2.36E+08
Concrete, Cast In Situ	2.52E+05	3.33E-10	7.68E+02	1.47E+02	-1.33E+02	1.93E-02	3.44E+06
White	-	-	-	-	-	-	-
Brick, Light Blend, Soldier	2.38E+06	1.30E-08	1.42E+04	1.62E+03	1.09E+03	2.40E-01	3.24E+07
Default Wall	-	-	-	-	-	-	-
Polyrey B187 Blue Moon	-	-	-	-	-	-	-
Metal Stud Layer	7.20E+01	3.23E-13	4.23E-01	4.78E-02	3.46E-02	2.52E-05	9.37E+02

Life Cycle Stage D (Reuse-Recovery-Recycling-potential)

Material	GWP	ODP	AP	EP	POCP	ADPE	ADPF
Paint	-	-	-	-	-	-	-
Concrete, Sand/Cement Screed	-1.94E+07	-2.36E-07	-1.06E+05	-1.99E+04	-9.66E+03	-3.49E+00	-2.47E+08
Brick, Common	-1.87E+09	-2.75E-05	-6.50E+06	-1.29E+06	-6.27E+05	-3.60E+02	-2.49E+10
Gypsum Wall Board	2.84E+04	5.93E-10	1.36E+02	3.50E+01	1.34E+01	9.61E-01	3.25E+05
Wood Sheathing, Chipboard	-	-	-	-	-	-	-
Rock Wool	-1.30E+06	-4.46E-07	-3.06E+03	-3.15E+02	-3.45E+02	-2.54E-01	-2.63E+07
Concrete, C25/30	-1.60E+07	-1.94E-07	-8.78E+04	-1.64E+04	-7.96E+03	-2.88E+00	-2.04E+08
Concrete, Cast In Situ	-2.33E+05	-2.83E-09	-1.28E+03	-2.39E+02	-1.16E+02	-4.19E-02	-2.97E+06
White	-	-	-	-	-	-	-
Brick, Light Blend, Soldier	-5.47E+07	-8.04E-07	-1.90E+05	-3.79E+04	-1.83E+04	-1.05E+01	-7.29E+08

Default Wall	-	-	-	-	-	-	-
Polyrey B187 Blue Moon	-	-	-	-	-	-	-
Metal Stud Layer	-3.97E+04	-1.37E+00	-7.69E+01	-5.36E+00	-1.86E+01	-6.78E-01	-3.75E+05

4.6.2 Specific audit standards

The report focuses on the following inspection standards for HVAC systems:

- EN 15378-1:Energy performance of buildings - Heating systems and DHW in buildings - Part 1: Inspection of boilers, heating systems and DHW, Module M3-11, M8-11
- EN 16798-17:Energy performance of buildings. Ventilation for buildings Guidelines for inspection of ventilation and air conditioning systems (Module M4-11, M5-11, M6-11, M7- 11)

And:

- EN 16798-1:Energy performance of buildings - Ventilation for buildings - Part 1: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting, and acoustics - Module M1-6.

Later editions will include the standard:

- Energy Performance of Buildings - Inspection of Automation, Controls and Technical Building Management - Part 1: Module M10-11

5 Technical audits and inspections integration to SmartLivingEPC

5.1 Introduction

Noting that the objective of this Section is to facilitate the integration of information derived from energy performance inspections/audits of HVAC systems (such as those conducted under the auspices of the EPBD Article 14 and 15 provisions) into the SmartLivingEPC asset rating's calculation methodology, both at the building and complex level. In broad terms, the methodology entails:

- Conducting an analysis of the inputs and findings (outputs) of the technical inspection audits for building systems, such as the EN 15378, the EN 16798, the EN 16946, and the EN 16947 standards series.
- Identifying and listing the main findings from the technical inspection audits which can be used for the energy classification
- Developing the necessary procedures and methodology, to enable the utilization of the findings of building systems periodic audits in the process of calculating the asset energy class of buildings, complementing Tasks T2.1, T2.2, and T2.3.

Noting that the scope is focused on the inspections/audits applied when assessing HVAC systems in line with the EPBD article 14 and 15 provisions, for each primary HVAC TBS, the methodology comprises the following steps:

- Acquisition and review of relevant TBS audit standards for HVAC TBS
- Clarification of the generic EPB EPC asset methodology per EN standards for each related HVAC type that has an audit standard
- Mapping of inputs/outputs of the EN TBS inspection/audit standards against the generic EPC asset assessment methodology – identification within each specific case where the EN audit standards:
    - produce inputs (or outputs) that could be used in the generic EPC asset methodology
    - where they do not and could not be adapted to do so
    - where they do not but could be adapted to do so
    - for the latter case, propose potential adaptations in procedure and method
- Note that this is to be done for each inspection level (per the annexes in the audit standards)
- Reporting of findings.

This is complemented by an additional step that considers how the inspection findings could be used as inputs into the SmartLivingEPC asset methodology and the proposal of procedures for how to do so.

5.1.1 Specific HVAC calculation standards

The principal HVAC calculation standards and their relationship to the EPB EPC calculation methodology are shown in **Figure 71**.

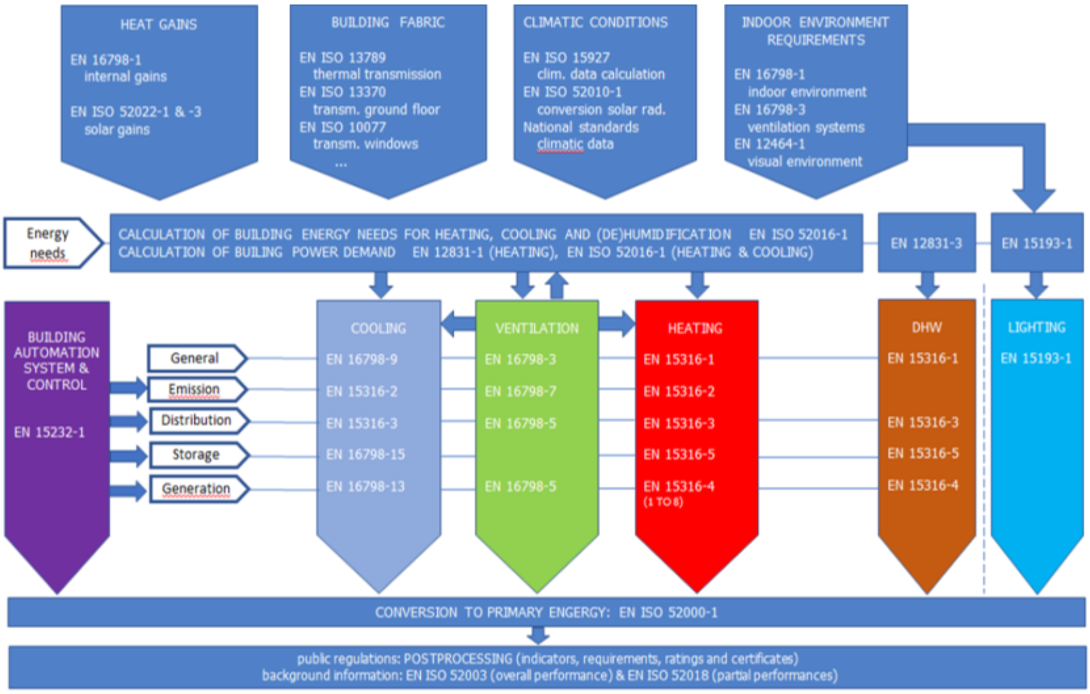


Figure 71: HVAC, BACS & lighting within the EPB calculation framework [230]

5.1.2 Respecting copyright

Drafting Section 5 is challenging due to the copyright of the EN standards. The mapping analysis underpinning this work is very detailed and hence necessarily includes the content of the standards in analytical mapping matrices (TBS inspection procedure steps and outputs mapped to inputs/outputs of the EPC asset assessment methodologies). Putting this into a public report (unless as a less meaningful synthesis) carries copyright risk. The text in this Section aims to avoid any copyright breach by only relaying synthetic tables in EPB standards that are of types already widely in the public domain, such as those on public view within the EPB center documents. Moreover, by summarising relevant outputs of the standards and (when relevant) their main objectives. At no stage does it report any details of the methodologies used to conduct the assessments except in the most general terms. Thus, the IP in the standards is fully protected.

5.2 Methodology

Noting that the objective of this document is to facilitate the integration of information derived from energy performance inspections/audits of HVAC systems (such as those conducted under the auspices of the EPBD Article 14 and 15 provisions) into the SmartLivingEPC asset rating's calculation methodology, both at the building and complex level. In broad terms the methodology entails:

- Conducting an analysis of the inputs and findings (outputs) of the technical inspection audits for building systems, such as the EN 15378, the EN 16798 the EN 16946 and the EN 16947 standards series
- Identifying and listing the main findings from the technical inspection audits which can be used for the energy classification

- Developing the necessary procedures and methodology, to enable the utilization of the findings of building systems periodic audits, in the process of calculating the asset energy class of buildings, complementing the Tasks T2.1, T2.2 and T2.3.

Noting that the scope is focused on the inspections/audits applied when assessing HVAC systems in line with the EPBD article 14 and 15 provisions, for each of primary HVAC TBS the methodology comprises the following steps:

- Acquisition and review of relevant TBS audit standards for HVAC TBS
- Clarification of the generic EPB EPC asset methodology per EN standards for each related HVAC type that has an audit standard
- Mapping of inputs/outputs of the EN TBS inspection/audit standards against the generic EPC asset assessment methodology – identification within each specific case where the EN audit standards:
    - produce inputs (or outputs) that could be used in the generic EPC asset methodology
    - where they don't and couldn't be adapted to do so
    - where they don't but could be adapted to do so
    - for the latter case propose potential adaptations in procedure and method
- Note this is to be done for each inspection level (per the annexes in the audit standards)
- Reporting of findings.

This is complemented by an additional step that considers how the inspection findings could be used as inputs into the SmartLivingEPC asset methodology and the proposal of procedures for how to do so.

5.3 Audits of technical building systems under the EPBD

5.3.1 Context

To boost energy performance of buildings, the EU established a legislative framework that includes the Energy Performance of Buildings Directive 2010/31/EU . The Directive amending the Energy Performance of Buildings Directive (2018/844/EU) (the so-called EPBD recast) introduced new elements and sent a strong political signal on the EU's commitment to modernise the buildings sector in light of technological improvements and to increase building renovations.

In October 2020, the Commission presented its Renovation wave strategy, as part of the European Green Deal. It contains an action plan with concrete regulatory, financing and enabling measures to boost building renovation. Its objective is to at least double the annual energy renovation rate of buildings by 2030 and to foster deep renovation. A revision of the Energy Performance of Buildings Directive is one of its key initiatives. A revision of the Energy Performance of Buildings Directive is one of its key initiatives.

Some of the key provisions in the original EPBD of direct relevance to the SmartLivingEPC project and the work reported in this task on inspections/audits include:

- Article 3, Adoption of a methodology for calculating the energy performance of buildings
- Article 8 Technical building systems
- Article 11 Energy performance certificate
- Article 14 Inspection of heating systems
- Article 15 Inspection of air-conditioning systems
- Article 16 Reports on the inspection of heating and air-conditioning systems.

5.3.2 Measures introduced in the 2018 EPBD recast

The amending directive (2018/844/EC) covers a broad range of policies and support measures that will help national EU governments boost energy performance of buildings and improve the existing building stock.

EU countries must for example establish strong **long-term renovation strategies**, aiming at decarbonising the national building stocks by 2050, with indicative milestones for 2030, 2040 and 2050. The strategies should contribute to achieving the national energy and climate plans (NECPs) energy efficiency targets.

The directive also requires that EU countries set cost-optimal **minimum energy performance requirements** for new buildings, for existing buildings undergoing major renovation, and for the replacement or retrofit of building elements like heating and cooling systems, roofs and walls.

As of 2021, all new buildings must be nearly zero-energy buildings (NZEB) and since 2019, all new public buildings should be NZEB. When a building is sold or rented, energy performance certificates must be issued and inspection schemes for heating and air conditioning systems must be established.

The directive supports **electro-mobility** by introducing minimum requirements for car parks over a certain size and other minimum infrastructure for smaller buildings.

There is also an optional European scheme for rating the smart readiness of buildings and **smart technologies** are promoted. The directive introduced requirements on the installation of building automation and control systems, and on devices that regulate temperature at room level. It addresses health and well-being of building users, for instance through the consideration of air quality and ventilation.

5.3.3 Proposal for a revision of the directive

In December 2021, the Commission proposed a revision of the directive (COM(2021) 802 final). It upgrades the existing regulatory framework to reflect higher ambitions and more pressing needs in climate and social action, while providing EU countries with the flexibility needed to take into account the differences in the building stock across Europe.

It also sets out how Europe can achieve a zero-emission and fully decarbonised building stock by 2050. The proposed measures will increase the rate of renovation, particularly for the worst-performing buildings in each country. The revised directive will modernise the building stock, making it more resilient and accessible. It will also support better air quality, the digitalisation of energy systems for buildings and the roll-out of infrastructure for sustainable mobility. Crucially, the revised directive facilitates more targeted financing to investments in the building sector, complementing other EU instruments supporting vulnerable consumers and fighting energy poverty.

In order to make sure that buildings are fit for the enhanced climate ambition, as presented in the 2030 Climate Target Plan and reflected in the "Delivering the European Green Deal Package" in July 2021, the Commission's new proposal aims to contribute to reaching the target of at least -60% emission reductions by 2030 in the building sector in comparison to 2015 and achieve climate neutrality by 2050. It will work hand in hand with other initiatives of the European Green Deal package, in particular with the review of the proposed new emissions trading system for fuels used in buildings, the Energy Efficiency Directive, the Renewable Energy Directive, as well as the Alternative Fuels Infrastructure Regulation.

The main measures in the new proposal are:

- the gradual introduction of minimum energy performance standards to trigger renovation of the worst performing buildings
- a new standard for new buildings and a more ambitious vision for buildings to be zero-emission
- enhanced long-term renovation strategies, to be renamed national Building Renovation Plans
- increased reliability, quality and digitalisation of Energy Performance Certificates; with energy performance classes to be based on common criteria
- a definition of deep renovation and the introduction of building renovation passports

- modernisation of buildings and their systems, and better energy system integration (for heating, cooling, ventilation, charging of electric vehicles, renewable energy)

The proposed revision of the directive is now being considered by the Council and the European Parliament.

5.4 Inspection provisions in the EPBD

5.4.1 EPBD provisions on inspections of HVAC

The Energy Performance of Buildings Directive[6] sets out the following provisions with regard to the inspection of heating and cooling systems (including ventilation) and their reporting:

> Article 14 Inspection of heating systems
>
> 1. Member States shall lay down the necessary measures to establish regular inspections of the accessible parts of heating systems or of systems for combined space heating and ventilation, with an effective rated output of over 70 kW, such as the heat generator, control system and circulation pump(s) used for heating buildings. The inspection shall include an assessment of the efficiency and sizing of the heat generator compared with the heating requirements of the building and, where relevant, consider the capabilities of the heating system or of the system for combined space heating and ventilation to optimise its performance under typical or average operating conditions.
>
> Where no changes have been made to the heating system or to the system for combined space heating and ventilation or to the heating requirements of the building following an inspection carried out pursuant to this paragraph, Member States may choose not to require the assessment of the heat generator sizing to be repeated.
>
> 2. Technical building systems that are explicitly covered by an agreed energy performance criterion or a contractual arrangement specifying an agreed level of energy efficiency improvement, such as energy performance contracting, or that are operated by a utility or network operator and therefore subject to performance monitoring measures on the system side, shall be exempt from the requirements laid down in paragraph 1, provided that the overall impact of such an approach is equivalent to that resulting from paragraph 1.
>
> 3. As an alternative to paragraph 1 and provided that the overall impact is equivalent to that resulting from paragraph 1, Member States may opt to take measures to ensure the provision of advice to users concerning the replacement of heat generators, other modifications to the heating system or to the system for combined space heating and ventilation and alternative solutions to assess the efficiency and appropriate size of those systems.
>
> Before applying the alternative measures referred to in the first subparagraph of this paragraph, each Member State shall, by means of submitting a report to the Commission, document the equivalence of the impact of those measures to the impact of the measures referred to in paragraph 1.
>
> Such a report shall be submitted to the Commission as part of the Member States' integrated national energy and climate plans referred to in Article 3 of Regulation (EU) 2018/1999.
>
> 4. Member States shall lay down requirements to ensure that, where technically and economically feasible, non-residential buildings with an effective rated output for heating systems or systems for

---

[6] Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency, https://eur-lex.europa.eu/eli/dir/2018/844/oj

combined space heating and ventilation of over 290 kW are equipped with building automation and control systems by 2025.

The building automation and control systems shall be capable of:

(a) continuously monitoring, logging, analysing and allowing for adjusting energy use;

(b) benchmarking the building's energy efficiency, detecting losses in efficiency of technical building systems, and informing the person responsible for the facilities or technical building management about opportunities for energy efficiency improvement; and

(c) allowing communication with connected technical building systems and other appliances inside the building, and being interoperable with technical building systems across different types of proprietary technologies, devices and manufacturers.

5. Member States may lay down requirements to ensure that residential buildings are equipped with:

(a) the functionality of continuous electronic monitoring that measures systems' efficiency and informs building owners or managers when it has fallen significantly and when system servicing is necessary; and

(b) effective control functionalities to ensure optimum generation, distribution, storage and use of energy.

6. Buildings that comply with paragraph 4 or 5 shall be exempt from the requirements laid down in paragraph 1.

Article 15 Inspection of air-conditioning systems

1. Member States shall lay down the necessary measures to establish regular inspections of the accessible parts of air-conditioning systems or of systems for combined air-conditioning and ventilation, with an effective rated output of over 70 kW. The inspection shall include an assessment of the efficiency and sizing of the air-conditioning system compared with the cooling requirements of the building and, where relevant, consider the capabilities of the air-conditioning system or of the system for combined air-conditioning and ventilation to optimise its performance under typical or average operating conditions.

Where no changes have been made to the air-conditioning system or to the system for combined air-conditioning and ventilation or to the cooling requirements of the building following an inspection carried out pursuant to this paragraph, Member States may choose not to require the assessment of the sizing of the air-conditioning system to be repeated.

Member States that maintain more stringent requirements pursuant to Article 1(3) shall be exempt from the obligation to notify them to the Commission.

2. Technical building systems that are explicitly covered by an agreed energy performance criterion or a contractual arrangement specifying an agreed level of energy efficiency improvement, such as energy performance contracting, or that are operated by a utility or network operator and therefore subject to performance monitoring measures on the system side, shall be exempt from the requirements laid down in paragraph 1, provided that the overall impact of such an approach is equivalent to that resulting from paragraph 1.

3. As an alternative to paragraph 1 and provided that the overall impact is equivalent to that resulting from paragraph 1, Member States may opt to take measures to ensure the provision of advice to users concerning the replacement of air-conditioning systems or systems for combined air-conditioning and ventilation, other modifications to the air-conditioning system or system for combined air-conditioning and ventilation and alternative solutions to assess the efficiency and appropriate size of those systems.

Before applying the alternative measures referred to in the first subparagraph of this paragraph, each Member State shall, by means of submitting a report to the Commission, document the equivalence of the impact of those measures to the impact of the measures referred to in paragraph 1.

Such a report shall be submitted to the Commission as part of the Member States' integrated national energy and climate plans referred to in Article 3 of Regulation (EU) 2018/1999.

4. Member States shall lay down requirements to ensure that, where technically and economically feasible, non-residential buildings with an effective rated output for systems for air-conditioning or systems for combined air-conditioning and ventilation of over 290 kW are equipped with building automation and control systems by 2025.

The building automation and control systems shall be capable of:

(a) continuously monitoring, logging, analysing and allowing for adjusting energy use;

(b) benchmarking the building’s energy efficiency, detecting losses in efficiency of technical building systems, and informing the person responsible for the facilities or technical building management about opportunities for energy efficiency improvement; and

(c) allowing communication with connected technical building systems and other appliances inside the building, and being interoperable with technical building systems across different types of proprietary technologies, devices and manufacturers.

5. Member States may lay down requirements to ensure that residential buildings are equipped with:

(a) the functionality of continuous electronic monitoring that measures systems’ efficiency and informs building owners or managers when it has fallen significantly and when system servicing is necessary, and

(b) effective control functionalities to ensure optimum generation, distribution, storage and use of energy.

6. Buildings that comply with paragraph 4 or 5 shall be exempt from the requirements laid down in paragraph 1.

Article 16 Reports on the inspection of heating and air-conditioning systems

1. An inspection report shall be issued after each inspection of a heating or air-conditioning system. The inspection report shall contain the result of the inspection performed in accordance with Article 14 or 15 and include recommendations for the cost-effective improvement of the energy performance of the inspected system.

The recommendations may be based on a comparison of the energy performance of the system inspected with that of the best available feasible system and a system of similar type for which all relevant components achieve the level of energy performance required by the applicable legislation.

2. The inspection report shall be handed over to the owner or tenant of the building.

Thus, in summary, regular mandatory inspection of HVAC systems of 70kW or greater heating (or cooling) capacity is required using a standardised inspection process, unless Member States put in place alterative measures that will produce equivalent energy savings. In addition, Member States shall lay down requirements to ensure that, where technically and economically feasible, non-residential buildings with an effective rated output for systems for air-conditioning or systems for combined air-conditioning and ventilation of over 290 kW are equipped with building automation and control systems by 2025.

5.5 Technical Audits for building systems analysis

5.5.1 Audits of space heating (and hot water) systems

This Section sets out the information on the inspections/audits of space heating and hot water systems and considers the outputs that could be integrated into the SmartLivingEPC asset methodology.

5.5.1.1 Standards and assessment procedures

This sub-section cites the standards that are used to calculate the energy performance of space heating and hot water systems when determining building energy performance via an EPC asset methodology and also cites the standards that are used to conduct audits/inspections of the space heating and hot water systems. It also reports the standards that are relevant to the EPBD Article 8(1) TBS measures.

5.5.1.2 Space heating and hot water within the overall EPB standards framework

Space heating is the largest contributor to building energy use in Europe, and domestic hot water heating is the second largest contributor, so collectively, their assessment is critical to the determination of any building's primary energy consumption and performance under an EPC rating. The assessment methods applicable to them sit within the following broad building energy performance evaluation framework.

Thus, from the left, a set of standards exists to determine the boundary conditions with regard to the indoor/outdoor conditions and the component and product characteristics. Another set of standards builds into these to determine the energy needs of the building (including the space heating and hot water). The energy use is determined for this energy need by applying calculation standards, 12 of which apply to space heating and domestic hot water. Then all the results from across all the technical building systems (including space heating and hot water) are aggregated to determine the primary energy use, which then allows the energy performance class under an EPC to be established. The energy calculations under the EPB standards asset assessment methodological framework are shown in **Figure 73**.

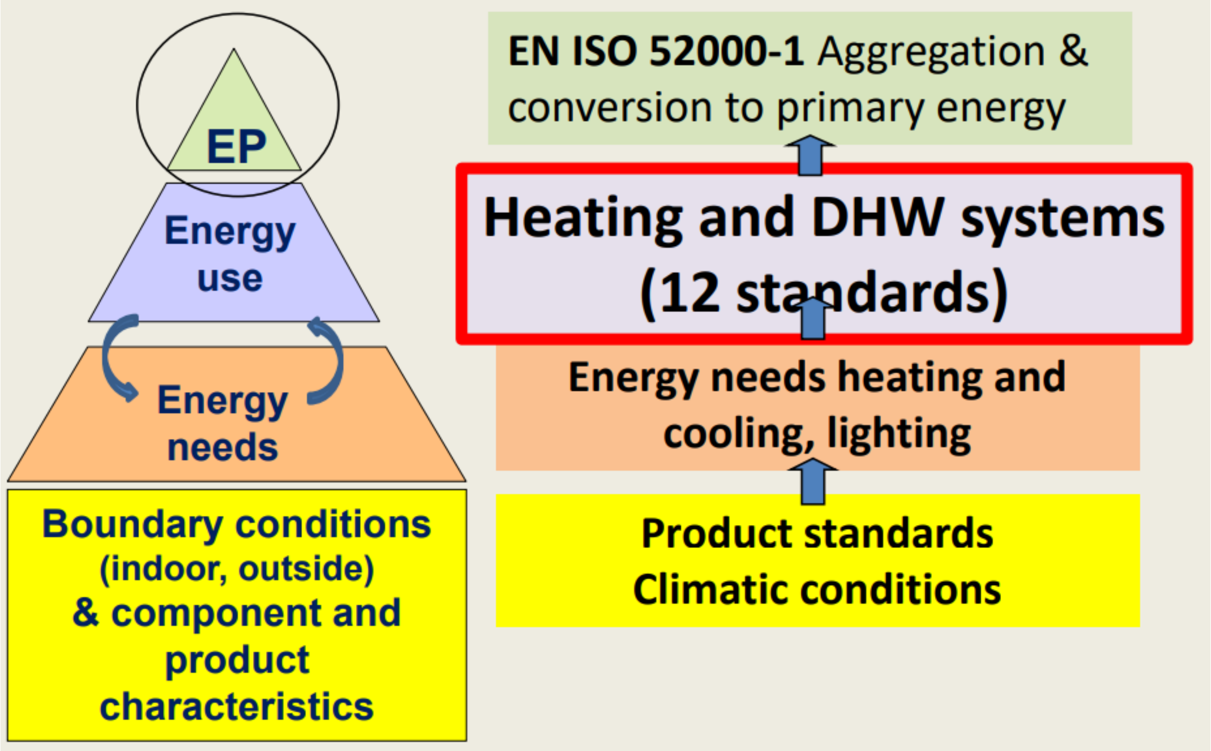


Figure 72: Space heating and hot water within the EPB calculation framework [243]

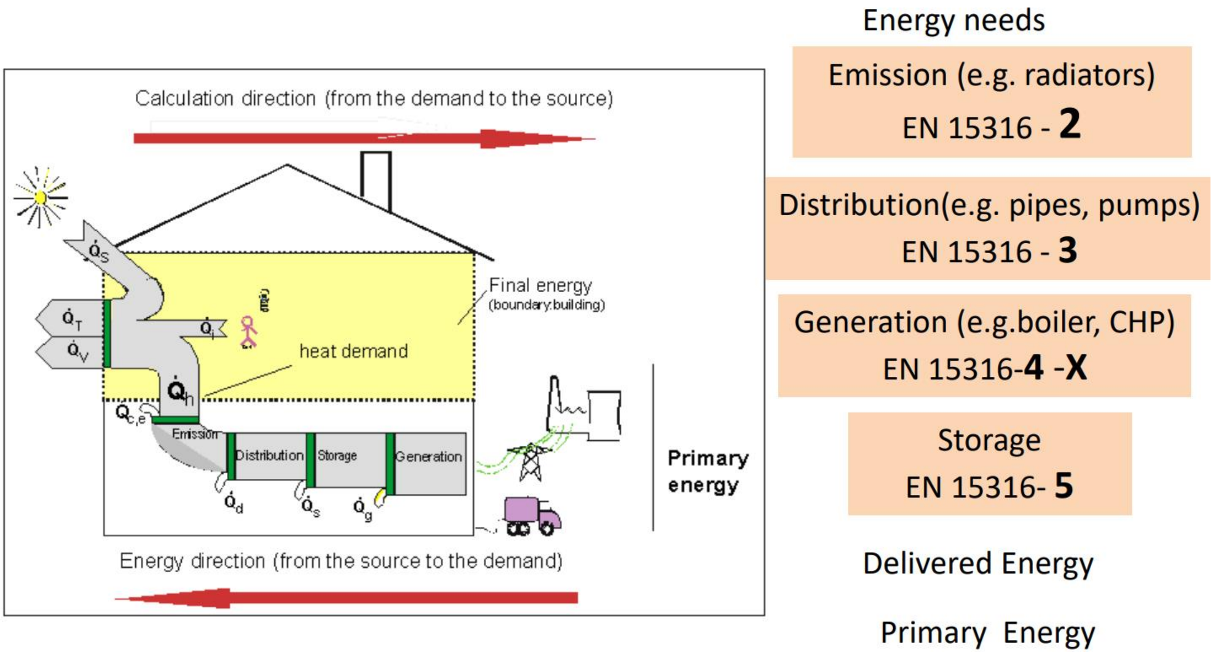


Figure 73: Energy calculation: General structure of heating and DHW standards - EN 15316 – series [243]

The following standards are concerned:

- EN 15316–1 Energy performance of buildings – Method for calculation of system energy requirements and system efficiencies – Part 1: General and Energy performance expression, Module M3–1, M3–4, M3–9, M8–1, M8–4
- EN 15316–2 Energy performance of buildings – Method for calculation of system energy requirements and system efficiencies – Part 2: Space emission systems (heating and cooling), Module M3–5, M4–5
- EN 15316–3 Energy performance of buildings – Method for calculation of system energy requirements and system efficiencies – Part 3: Space distribution systems (DHW, heating, and cooling), Module M3–6, M4–6, M8–6
- EN 15316–4-1 (heat. & DHW generation, combust. systems) 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 and M 8–8-1
- EN 15316–4-2 (heat. & DHW generation, heat pump systems) 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
- EN 15316–4-3 (heat generation, th. solar & PV systems) 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
- EN 15316–4-4 (heating generation, cogen systems) Energy performance of buildings – Method for calculation of system energy requirements and system efficiencies – Part 4–4: Heat generation systems, building-integrated cogeneration systems, Module M8–3-4, M8–8-4, M8–11-4
- EN 15316–4-5 (heating generation, district H&C) 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
- EN 15316–4-8 (heating generation, air heat. & ovhead rad. systems) Energy performance of buildings – Method for calculation of system energy requirements and system efficiencies – Part 4–8: Space heating generation systems, air heating and overhead radiant heating systems, including stoves (local), Module M3–8-8
- EN 15316–5 (heating and DHW storage systems) Energy performance of buildings – Method for calculation of system energy requirements and system efficiencies – Part 5: Space heating and DHW storage systems (not cooling), Module M3–7, M8–7

And additionally:

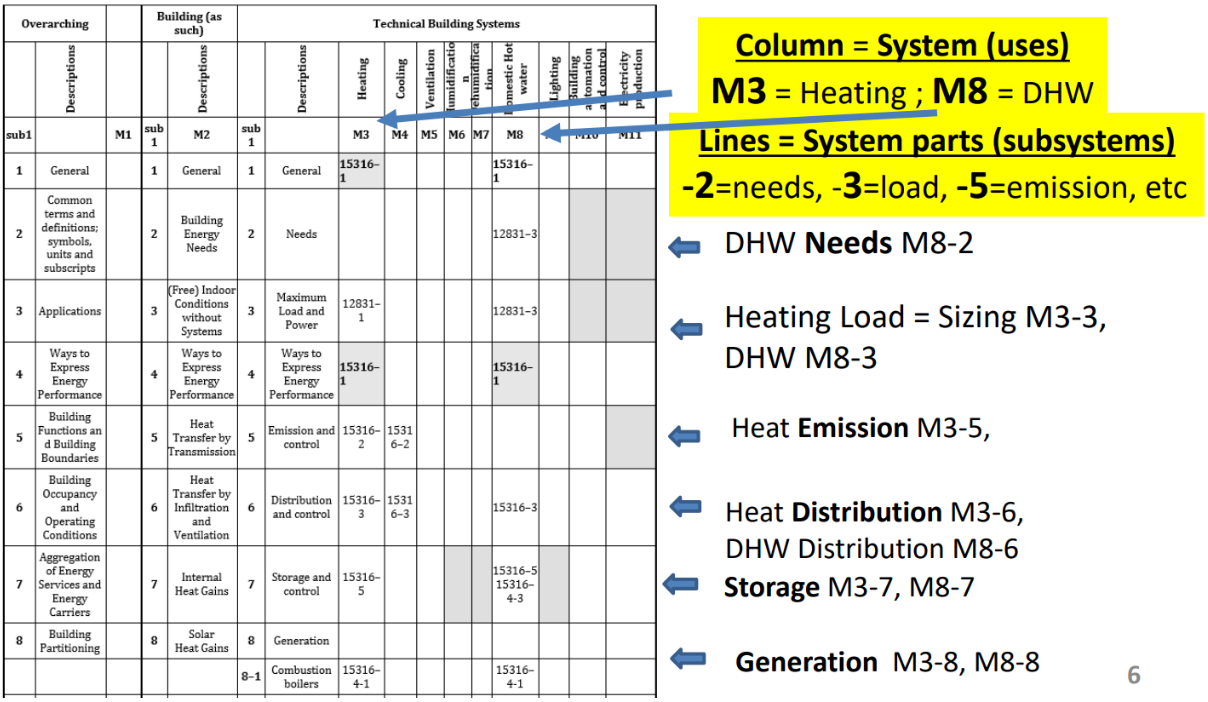
- CEN/TR 15316-6-1 (technical report)
- CEN/TR 15316-6-2 (technical report)
- CEN/TR 15316-6-3 (technical report)
- CEN/TR 15316-6-4 (technical report)
- CEN/TR 15316-6-5 (technical report)
- CEN/TR 15316-6-7 (technical report)
- CEN/TR 15316-6-8 (technical report)
- CEN/TR 15316-6-9 (technical report)
- CEN/TR 15316-6-10 (technical report)
- EN 12831–1 (heat. design load)

- CEN/TR 15316-6-6 (technical report)
- CEN/TR 12831-2 (technical report)

The following calculation standards are applicable:

- EN 15316-1: M3 Space heating: general
- EN 15316-1: M8 DHW: general
- EN 12831-3: M8-2 DHW: needs
- EN 12831-1: M3-3 Space heating: needs (sizing)
- EN 12831-3: M8-3 DHW: needs (sizing)
- EN 15316-2: M3-5 Space heating: emission and control
- EN 15316-3: M3-6 Space heating: Distribution and control
- EN 15316-5: M3-7 Space heating: Storage and control
- EN 15316-5: M8-7 DHW: Storage and control
- EN 15316-4-1: M3-8 Space heating: generation
- EN 15316-4-1: M8-8 DHW: generation

The relationship between these and the EPB methodological framework is shown in **Figure 74**.



Overarching			Building (as such)		Technical Building Systems										
	Descriptions			Descriptions		Descriptions	Heating	Cooling	Ventilation	umidification	ehumidification	omestic Hot water	Lighting	uilding automation and control	Electricity production
sub1		M1	sub 1	M2	sub 1		M3	M4	M5	M6	M7	M8		M10	M11
1	General		1	General	1	General	**15316-1**					**15316-1**			
2	Common terms and definitions; symbols, units and subscripts		2	Building Energy Needs	2	Needs						12831-3			
3	Applications		3	(Free) Indoor Conditions without Systems	3	Maximum Load and Power	12831-1					12831-3			
4	Ways to Express Energy Performance		4	Ways to Express Energy Performance	4	Ways to Express Energy Performance	**15316-1**					**15316-1**			
5	Building Functions and Building Boundaries		5	Heat Transfer by Transmission	5	Emission and control	15316-2	15316-2							
6	Building Occupancy and Operating Conditions		6	Heat Transfer by Infiltration and Ventilation	6	Distribution and control	15316-3	15316-3				15316-3			
7	Aggregation of Energy Services and Energy Carriers		7	Internal Heat Gains	7	Storage and control	15316-5					15316-5 15316-4-3			
8	Building Partitioning		8	Solar Heat Gains	8	Generation									
					8-1	Combustion boilers	15316-4-1					15316-4-1			

Column = System (uses)
M3 = Heating ; **M8** = DHW
Lines = System parts (subsystems)
-2=needs, -**3**=load, **-5**=emission, etc

DHW **Needs** M8-2

Heating Load = Sizing M3-3,
DHW M8-3

Heat **Emission** M3-5,

Heat **Distribution** M3-6,
DHW Distribution M8-6
Storage M3-7, M8-7

Generation M3-8, M8-8

Figure 74: Relationships between EPB energy calculation standards for space heating and hot water [243]

It should be noted that while most MS use monthly calculation methods in their EPCs, the new EN standards support hourly calculations. Using an hourly calculation interval enables several new possibilities, including:

- it is easier to determine and handle priorities when dealing with several generators, e.g., determining the load to the next generator in the sequence - the monthly method necessitates a "turn-around" such as calculating critical generators like heat pumps with monthly bins to check if they can fulfill the load
- the ability to take into account storage and thermal solar dynamics
- in connection with EN ISO 52016, taking into account the effect of intermittent operation and limited power.

There are also the following additional aspects to consider when defining the comfort schedule and operation schedule:

- comfort schedule: at what time a certain level of comfort is required to achieve a standard service i.e. the reference to evaluate a discomfort
- system operation schedule: at what time the system is turned on, e.g., the set-point is set on comfort level. This has to anticipate the comfort schedule to enable recovery of comfort conditions.

However, the EPB space heating and DHW standards are not only energy calculation standards but also include EN 15378-1-Inspection of boilers, heating systems, and DHW, M3-11, M8-11 with the aim of:

- supporting transposition of the EPBD article 14 and 15 requirements on inspection
- supporting transposition of EPBD requirement on economic feasibility via EN 15459 Economic evaluation procedure for energy systems, M1_14
- supporting measured energy performance via EN 15378-3 Measured energy performance, Module M3-10, M8-10
- helping to close the gap between measured and calculated energy.

Commission guidance on the interpretation of Article 8(1) measures

When setting Article 8(1) requirements, it is helpful to consider the Commission's guidance [244] on the possible interpretation of system requirements for space heating, as shown in **Table 53**. In principle, energy inspections and audits inform the extant situation of heating systems with regard to each of these aspects.

Table 53: Commission Article 8(1) guidance for space heating

Type of requirement	A possible interpretation for space heating	Useful references
Overall energy performance	In this context, overall performance refers to the performance of the whole process of energy transformation in heat generators, heat distribution across the building, heat emission in individual rooms or spaces of the building, and, where applicable, heat storage. In particular, it is not limited to the performance of heat generators and can include requirements that affect other parts of the system (e.g. insulation of distribution piping network).	▪ EN 15316 standard series e.g. ▪ EN 15316-1 ▪ EN 15316-2 ▪ EN 15316-3 ▪ EN 15316-4-1 ▪ EN 15316-4-2 ▪ EN 15316-4-5 ▪ EN 15316-4-8 ▪ EN 15316-5 ▪ EN 15316-4-8 ▪ EN 15316-5
Appropriate dimensioning	For heating systems, 'appropriate dimensioning' would refer to determining heating needs, taking into account relevant parameters (in particular, intended usage of the building and its spaces), and translating these requirements into design specifications for heating systems.	▪ EN 12831-1, EN 12831–3 ▪ Module M8–2, M8–3EN 12828 ▪ EN 14337 ▪ EN 1264-3:2009
Proper installation	Proper installation refers to the need to ensure the system can operate according to design specifications. Ensuring proper installation can rely e.g., on national technical guidelines, product manufacturer documentation, and certification of installers.	▪ EN 14336 ▪ EN 1264-4 ▪ EN 14337
Adjustment	The adjustment refers here to the test and fine-tuning of the system under real-life conditions, in particular, to check and possibly adjust system functions that can impact performance (e.g., control capabilities – see below).	▪ EN 15378-1 ▪ EN 14336 ▪ EN 15378–3

Appropriate control	Concerns control capabilities that heating systems can include in order to optimize performance, e.g., automatic adaptation of heat output of emitters in individual rooms or spaces, the adaptation of system temperature based on outside temperature ('weather compensation'), or time schedules, dynamic and static hydronic balancing, system operation monitoring, adjustment of water/air flow depending on needs, etc.	▪ EN 15500-1 ▪ EN 15316-2 ▪ EN 15232, space heater energy labeling regulations

Applicable inspection standards

The applicable inspection (audit) standard for space heating and hot water systems is:

- EN 15378-1: Energy performance of buildings - Heating systems and DHW in buildings - Part 1: Inspection of boilers, heating systems and DHW, Module M3-11, M8-11

For operational ratings, the following calculation standard is used:

- EN 15378-3: Energy performance of buildings - Heating and DHW systems in buildings - Part 3: Measured energy performance, Module M3-10, M8-10

In addition, the EN 153780-1 standard sets out procedures to inspect:

- Heat generator inspection procedure
- Heating system inspection procedure.

Elements to be inspected

The heat generator inspection procedure includes inspection methods and procedures on:

- Heat generator inspection level identification
- Heat generator identification
- Document identification
- Heat generator visual inspection
- Heat generator functionality check
- Heat generator maintenance status
- Heat generator controls, sensors, and indicators
- Meter readings
- Heat generator performance evaluation
- Heat generator inspection report and advice
- Heat generator performance advice

The heating system inspection procedure includes the following steps, which comprise the actions, in order, that could be included in an inspection.

- Heating system inspection level identification
- Heating system inspection preparation
- Heating system and inspection identification
- Document collection and system identification
- Heating system functionality check
- Heating system maintenance status
- Heating system central controls, sensors, and indicators
- Meter readings
- Energy ware consumption
- Space heating emission subsystem
- Space heating emission control subsystem
- Space heating distribution subsystem
- Generation subsystem
- Storage subsystem
- Generation subsystem sizing
- Heating system global efficiency or rating
- Domestic hot water systems
- Heating system inspection report and advice

Elements to be inspected as a function of the designated inspection level

The standard proposes that a set of "inspection levels" be determined (ostensibly by inspection mandating authorities) that determine what should be inspected as a function of the level. The implicit notion is that the inspection level would depend on the nature of the building and heating/hot water system, such that higher energy-using systems with higher savings potentials from inspection would be subject to more comprehensive inspections than those with lower saving potentials.

While the standard leaves it up to the user (practically the inspection mandating authorities) to decide what items should be inspected using the standard through the establishment of inspection levels; however, it includes an informative annex that identifies three optional inspection levels according to the following cases:

- if the property is: a) single-family house or b) any other building type
- the nature of the heating/hot water system i.e., a) autonomous system, b) autonomous system per building unit, c) centralized system

Combinations of the above lead to three inspection levels, two basic and one detailed as follows:

- Basic 1(a) is for single-family homes
- Basic 1(b) for all other properties with an autonomous heating/hot water system per building unit
- Detailed is for all other properties (than single-family homes) but with a centralized heating/hot water system.

5.5.1.3 Mapping audit outputs with EPC inputs

From the inspection content reported in Section 5.2.2, the following key space energy heater performance aspects can be reported (depending on the level of inspection adopted)

- Sizing of the space heat generator (specifically the degree of oversizing in relation to the need)
- Seasonal efficiency of the space heat generator
- Correct positioning of the heat emitters
- Quality of insulation of the distribution system piping
- Information on the characteristics/energy performance of the pumping system
- Information on the spatial resolution of the control of the heat emitters
- Information on the appropriateness of the positioning of the sensors
- Information on the amount and appropriate sizing of the hot water storage
- Information on the insulation quality of the hot water storage

Table 54: Inclusion of heating and hot water elements within an inspection as a function of the informative inspection level per EN 15378-1

A/A	Subject of inspection	Inspection Level		
		Basic - 1 Single Family Home	Basic - 1 Other (autonomous)	Detailed - 2 Other – (centralized)
1.	Heating system inspection level identification	Y	Y	Y
2.	Heating system inspection preparation	Y	Y	Y
3.	Heating system and inspection identification			
	▪ Collect and record the information on inspection, building (i.e. address, location), and heating system identification as specified in the inspection level definition.	Y	Y	Y
	▪ Identify the service(s) provided by the heating system	Y	Y	Y
4.	Document collection and system identification			
	▪ If required by the inspection level, collect and identify available relevant documents according to inspection-level specifications.	Y	Y	Y
5.	Heating system functionality check	N	N	Y
6.	Heating system maintenance status	Y	Y	Y
	Heating system central controls, sensors, and indicators	N	N	Y
	Meter readings	Y	Y	Y
	Energyware consumption	N	N	Y
	Space heating emission subsystem	Y	Y	Y
	Space heating emission control subsystem	Y	Y	Y
	Space heating distribution subsystem	Y	Y	Y
	Generation subsystem	Y	Y	Y
	Heat generators identification	Y	Y	Y
	Heat generators inspection			
	1. Boiler inspection	Y	Y	Y
	1. Thermal solar inspection	Y	Y	Y
	2. Heat pump inspection	N	N	Y
	3. Heat exchangers	N	N	Y
	4. Other generation sub-systems	N	N	Y
	5. Generation subsystem control inspection	N	N	Y
	Storage subsystem	Y	Y	Y
	Generation subsystem sizing	Y	Y	Y
	▪ Other generators sizing	N	N	N
7.	Heating system global efficiency or rating	N	N	N
8.	Domestic hot water systems	Y	Y	Y
9.	Heating system inspection report and advice	Y	Y	Y

For the DHW system:

- type and size of heat generator used for domestic hot water production
- sizing, thermal insulation, temperature levels, and control strategy of any storage vessel
- sizing, performance (including fouling and scaling), thermal insulation, and temperature control of the heat exchanger
- auxiliary energy requirements (e.g. circulation pump)
- temperature levels, operation timing, and control strategy of circulation lines

Each of the above can be mapped to corresponding parameters in the EPB asset-based energy performance calculation standards, which will be shown in the M22 version of this report (subject to clarification of the issues mentioned in Section 5.2.3). Thus, they can be used to adjust and improve the accuracy of heating and hot water energy performance calculations used to generate EPCs providing the EPCs are generated in accordance with the EPB calculation standards.

5.5.2 Mapping audit outputs with SRI inputs

The SRI methodology B, as set out in the service catalogue V4.5, includes ten smart services for space heating, as detailed in Table 55 (which also shows the various smart functionality levels). Also shown are the services/functionalities that map to the information obtainable from audits as shown in Section 4.1.5. Note, a colour coding of the table cells is used as follows:

- Dark green indicates an SRI function that could be determined while doing a space heating audit (or vice versa) but that are fully aligned
- Olive green indicates an SRI function that could be determined while doing a space heating audit (or vice versa) but that are also somewhat aligned
- Yellow indicates an SRI function that could be determined while doing a space heating audit (or vice versa) but that are not otherwise aligned

Table 55. SRI Methodology B space heating services, functionality levels and related standards

Domain	Code	Service group	Related standard	Smart ready service	Functionality level 0 (as non-smart default)	Functionality level 1	Functionality level 2	Functionality level 3	Functionality level 4
Heating	H-1a	Heat control - demand side	EN15232 EN ISO 52120-1 EN 16798-9 EN 16947-1 Function 1	Heat emission control	No automatic control	Central automatic control (e.g. central thermostat)	Individual room control (e.g. thermostatic valves, or electronic controller)	Individual room control with communication between controllers and to BACS	Individual room control with communication and occupancy detection
Heating	H-1b	Heat control - demand side	EN15232 EN ISO 52120-1 EN 16947-1 Function 1	Emission control for TABS (heating mode)	No automatic control	Central automatic control	Advanced central automatic control	Advanced central automatic control with intermittent operation and/or room temperature feedback control	
Heating	H-1c	Heat control - demand side	EN15232 EN ISO 52120-1	Control of distribution fluid temperature (supply or return air flow or water flow) - Similar function can be applied to the control of direct electric heating networks	No automatic control	Outside temperature compensated control	Demand based control		
Heating	H-1d	Heat control - demand side	EN15232 EN ISO 52120-1	Control of distribution pumps in networks	No automatic control	On off control	Multi-Stage control	Variable speed pump control (pump unit (internal) estimations)	Variable speed pump control (external demand signal)
Heating	H-1f	Heat control - demand side	EN15232 EN ISO 52120-1 EN 16947-1 Function 5	Thermal Energy Storage (TES) for building heating (excluding TABS)	Continuous storage operation	Time-scheduled storage operation	Load prediction based storage operation	Heat storage capable of flexible control through grid signals (e.g. DSM)	
Heating	H-2a	Control heat production facilities	EN15232 EN ISO 52120-1 EN 16947-1 Function 2	Heat generator control (all except heat pumps)	Constant temperature control	Variable temperature control depending on outdoor temperature	Variable temperature control depending on the load (e.g. depending on supply water temperature set point)		

Domain	Code	Service group	**Related standard**	Smart ready service	Functionality level 0 (as non-smart default)	Functionality level 1	Functionality level 2	Functionality level 3	Functionality level 4
Heating	H-2b	Control heat production facilities	EN ISO 52120-1 EN 16947-1 Function 2	Heat generator control (for heat pumps)	On/Off-control of heat generator	Multi-stage control of heat generator capacity depending on the load or demand (e.g. on/off of several compressors)	Variable control of heat generator capacity depending on the load or demand (e.g. hot gas bypass, inverter frequency control)	Variable control of heat generator capacity depending on the load AND external signals from grid	
Heating	H-2d	Control heat production facilities	EN15232 EN ISO 52120-1 EN 16947-1 Function 3	Sequencing in case of different heat generators	Priorities only based on running time	Control according to fixed priority list: e.g. based on rated energy efficiency	Control according to dynamic priority list (based on current energy efficiency, carbon emissions and capacity of generators, e.g. solar, geothermal heat, cogeneration plant, fossil fuels)	Control according to dynamic priority list (based on current AND predicted load, energy efficiency, carbon emissions and capacity of generators)	Control according to dynamic priority list (based on current AND predicted load, energy efficiency, carbon emissions, capacity of generators AND external signals from grid)
Heating	H-3	Information to occupants and facility managers	EN ISO 52120-1	Report information regarding heating system performance	None	Central or remote reporting of current performance KPIs (e.g. temperatures, submetering energy usage)	Central or remote reporting of current performance KPIs and historical data	Central or remote reporting of performance evaluation including forecasting and/or benchmarking	Central or remote reporting of performance evaluation including forecasting and/or benchmarking; also including predictive management and fault detection
Heating	H-4	Flexibility and grid interaction	EN ISO 52120-1 EN 16947-1 Function 6	Flexibility and grid interaction	No automatic control	Scheduled operation of heating system	Self-learning optimal control of heating system	Heating system capable of flexible control through grid signals (e.g. DSM)	Optimized control of heating system based on local predictions and grid signals (e.g. through model predictive control)

In summary, eight of the ten SRI space heating services could be assessed while doing a space heating energy audit and two of these are somewhat aligned with current EN 15378-1 audit checks (in that similar information is being gathered).

The specific mapping is shown in Table 5.

Table 56. Mapping of SRI services to space heating audit checks under EN 15378-1

SRI service	Audit parameter	Notes
H-1a: Heat emission control	Checks under EN 15378-1: 11) Space heating emission control subsystem Correct positioning of the heat emitters	Either could be determined while assessing the other The control checks are relatively consistent
H-1c: Control of distribution fluid temperature (supply or return air flow or water flow) - Similar function can be applied to the control of direct electric heating networks	Checks under EN 15378-1: 12) Space heating distribution subsystem Pump control type	Either could be determined while assessing the other
H-1d: Control of distribution pumps in network	Checks under EN 15378-1: 12) Space heating distribution subsystem Pump control type	Either could be determined while assessing the other The control checks are relatively consistent
H-2a: Heat generator control (all except heat pumps)	Checks under EN 15378-1: 7) Heating system central controls, sensors and indicators	Either could be determined while assessing the other
H-2b: Heat generator control for heat pumps	Checks under EN 15378-1: 7) Heating system central controls, sensors and indicators	Either could be determined while assessing the other
H-2d: Sequencing in case of different heat generators	Checks under EN 15378-1: 7) Heating system central controls, sensors and indicators	Either could be determined while assessing the other
H-3: Report information regarding heating system performance	Checks under EN 15378-1: 8) Meter readings 9) Energyware consumption	Either could be determined while assessing the other

5.5.3 Other mapping synergies

This section will explore the reverse mapping e.g. how EPC asset data, SRI data or ErP product data could inform audits. Information on such synergies for space heating systems that are identified in the course of the SmartLivingEPC project will be added in this section for the version of this report due in M31.

5.5.4 Audits of air conditioning systems

This Section sets out the information on the inspections/audits of air conditioning systems and considers the outputs that could be integrated into the SmartLivingEPC asset methodology.

5.5.4.1 Standards and assessment procedures

This sub-section cites the standards that are used to calculate the energy performance of air conditioning systems when determining building energy performance via an EPC asset methodology and also cites the standards that are used to conduct audits/inspections of the air conditioning systems. It further reports the standards that are relevant to the EPBD Article 8(1) TBS measures.

The applicable audit standards for air conditioning/cooling systems are:

- EN 16798-17: Energy performance of buildings. Ventilation for buildings Guidelines for inspection of ventilation and air conditioning systems (Module M4-11, M5-11, M6-11, M7- 11), and
- EN 16798-1: Energy performance of buildings - Ventilation for buildings - Part 1: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting, and acoustics - Module M1-6

For asset ratings, the following calculation standards are used:

- EN 16798–9 Energy performance of buildings. Ventilation for buildings Calculation methods for energy requirements of cooling systems (Modules M4-1, M4-4, M4-9). General
- CEN/TR 16798-10 Energy performance of buildings – Ventilation for buildings – Part 10: Interpretation of the requirements in EN 16798-9 – Calculation methods for energy requirements of cooling systems (Module M4-1, M4-4, M4-9) – General
- EN 16798–13 Energy performance of buildings. Ventilation for buildings Calculation of cooling systems (Module M4-8). Generation
- CEN/TR 16798-14 Energy performance of buildings – Ventilation for buildings - Part 14: Interpretation of the requirements in EN 16798-13 – Calculation of cooling systems (Module M4-8) – Generation
- EN 16798–15 Energy performance of buildings. Ventilation for buildings Calculation of cooling systems (Module M4-7). Storage
- CEN/TR 16798-16 Energy performance of buildings – Ventilation for buildings – Part 16: Interpretation of the requirements in EN 16798-15 – Calculation of cooling systems (Module M4-8) – Storage

Table 57: Relationships between EPB energy calculation standards for space cooling

Overarching		Building (as such)		Technical Building Systems										
	Descriptions		Descriptions		Descriptions	Heating	**Cooling**	Ventilation	Humidification	Dehumidification	Domestic Hot water	Lighting	Building automation and control	PV, wind, ..
sub1	M1	sub1	M2	sub1		M3	**M4**	M5	M6	M7	M8	M9	M10	M11
1.	General	1.	General	1.	General									
2.	Common terms and definitions; symbols, units, and subscripts	2.	Building Energy Needs	2.	Needs								▨	▨
3.	Applications	3.	(Free) Indoor Conditions without Systems	3.	Maximum Load and Power								▨	▨
4.	Ways to Express Energy Performance	4.	Ways to Express Energy Performance	4.	Ways to Express Energy Performance									
5.	Building Functions and Building Boundaries	5.	Heat Transfer by Transmission	5.	Emission and control									▨
6.	Building Occupancy and Operating Conditions	6.	Heat Transfer by Infiltration and Ventilation	6.	Distribution and control									
7.	Aggregation of Energy Services and Energy Carriers	7.	Internal Heat Gains	7.	Storage and control				▨	▨		▨		
8.	Building Partitioning	8.	Solar Heat Gains	8.	Generation and control									
9.	Calculated Energy Performance	9.	Building Dynamics (thermal mass)	9.	Load dispatching and operating conditions				▨	▨		▨		▨

10.	Measured Energy Performance	10.	Measured Energy Performance	10.	Measured Energy Performance									
11.	Inspection	11.	Inspection	11.	Inspection									
12.	Ways to Express Indoor Comfort			12.	BMS									
13.	Outdoor Environment Conditions													
14.	Economic Calculation													

Commission guidance on the interpretation of Article 8(1) measures

When setting Article 8(1) requirements, it is helpful to consider the Commission's guidance[3] on the possible interpretation of system requirements for space cooling, as shown in **Table 58**. In principle, energy inspections and audits inform the extant situation of cooling systems with regard to each of these aspects.

Table 58: Commission Article 8(1) guidance for space cooling

Type of requirement	A possible interpretation for space cooling	Useful references
Overall energy performance	In this context, overall performance refers to the performance of the whole process of energy transformation in cooling generators, cooling distribution across the building, cooling emission in individual rooms or spaces of the building, and, where applicable, cool storage. In particular, it is not limited to the performance of cooling generators but can include requirements that affect other parts of the system (e.g. insulation of distribution piping network).	▪ EN 16798 standard series on cooling systems, e.g. ▪ EN 16798–9, ▪ EN 16798–13 ▪ EN 16798–15
Appropriate dimensioning	Dimensioning refers to the optimal sizing of the cooling system with regard to the cooling needs of the building and its spaces.	▪ EN 1264-3:2009
Proper installation	Proper installation refers to the need to ensure the system can operate according to design specifications. Ensuring proper installation can rely e.g. on national technical guidelines, product manufacturer documentation, and certification of installers.	▪ EN 1264-4
Adjustment	The adjustment refers here to the test and fine-tuning of the system under real-life conditions (6), in particular to check and possibly adjust system functions that can impact performance (e.g. control capabilities – see below).	▪ EN 16798–17
Appropriate control	Concerns control capabilities that systems for space cooling can include in order to optimize performance, e.g. automatic adaptation of cooling output of emitters in individual rooms or spaces.	▪ EN 15500-1 ▪ EN 15316-2 ▪ EN 15232

Applicable inspection standards

The applicable inspection (audit) standard for cooling systems is:

- EN 16798-17: Energy performance of buildings. Ventilation for buildings Guidelines for inspection of ventilation and air conditioning systems (Module M4-11, M5-11, M6-11, M7- 11)

For asset ratings, the following calculation standard is used:

- EN 16798-1:Energy performance of buildings - Ventilation for buildings - Part 1: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting, and acoustics - Module M1-6

The EN 16798-17 standard sets out procedures to inspect:

- Method 2 – Air conditioning systems

The inspection's principal purpose is to advise building operators and owners on reducing their energy consumption while maintaining acceptable indoor environmental conditions. Accordingly, each inspection should produce an inspection report explaining the advantages gained from implementing the recommendations.

The inspection report includes:

- recommendations for improvements with an indication of their probable cost-effectiveness and any other benefits
- an assessment of the system's efficiency, including maintenance and controls
- an assessment of the sizing compared to the cooling and ventilation requirements of the building
- characteristics of the air conditioning and/or ventilation system that can be compared to design specifications or inputs of energy calculations.

Elements to be inspected

The air conditioning system inspection procedure includes inspection methods and procedures on:

1) refrigeration equipment
2) pump and chilled water pipework
3) outdoor heat rejection devices
4) water and refrigerant-based terminal units
5) mechanical ventilation
6) building systems controls and parameters
7) metering.

The refrigeration equipment inspection procedure is specified in CEN/TR 16798-18:20.

The pumps and chilled water pipework inspection procedure includes steps on:

1) condition and operation of chilled water pipework and its insulation
2) signs of leakage from the pipe work

3) pumps and valves for the distribution of water as an energy carrier.

The outdoor heat rejection devices inspection procedure includes steps on:

1) location, condition, and operation of the outdoor heat rejection devices
2) condition and operation of water pipework and its insulation
3) signs of leakage from the pipe work and casing of the heat rejection device
4) pumps and valves for the distribution of water as an energy carrier
5) fans
6) cleanliness of the heat exchanger.

The water and refrigerant-based terminal units include steps on:

1) condition and operation of water and refrigerant-based terminal units.

The mechanical ventilation inspection procedure includes steps on:

1) externally or internally mounted air transfer devices
2) ductwork
3) air handling unit
4) air filters
5) heat exchanger
6) exhaust opening
7) outdoor air intake.

The building systems controls and parameters inspection procedure includes steps:

1) All controls, sensors, and indicators relevant to energy performance, as well as the Building Management System, shall be identified. If the air conditioning system provides ventilation, the controls shall be inspected as a whole, taking into account the requirements for ventilation systems
2) Guidance per EN15232 may be given on: location; function; settings; operating time.

Elements to be inspected as a function of the designated inspection level

The standard sets out a set of three “inspection levels” (**Table 59**) to be determined (ostensibly by inspection mandating authorities) that determine what should be inspected as a function of the level. The implicit notion is that the inspection level would depend on the nature of the building and ventilation system, such that higher energy-using systems with higher savings potentials from inspection would be subject to more comprehensive inspections than those with lower saving potentials.

Table 59: Inspection levels for air conditioning systems per EN 16798-17

Inspection level	Type of inspection	Description

1	Pre-inspection and functional checks	This basic level of inspection has two purposes, to: ▪ gather all relevant documentation on the system type and size and to identify any priority inspection areas where the design, installation, or operation of the system departs from good practice in a manner likely to affect its energy consumption; ▪ non-intrusively identify on-site (normally visually) features of system operation that are wasteful of energy. It does not include measurements.
2	Functional measurements	This level requires measurements in addition to level 1 to check that the system is operating as intended and to identify sources of energy wastage. These can include, for example, specified design conditions and set points.
3	Special measurements	This level requires, in addition to levels 1 and 2, additional measurements to provide more detailed assessments of system performance. Such measurements can, for example, cover extended periods of time or technical aspects such as *in situ* component performance.

Aspects to be included in the inspection report as a function of the designated inspection level

Table 60 shows the elements to be included in the cooling system inspection reports as a function of the designated inspection level.

Table 60: Contents of the cooling system inspection report per EN 16798-17

Information	Method		Part
	1	2	
General			
Name, address, and status of the person and organization in charge of the inspection	X	X	—
Official designation and address of the property	X	X	—
Name and address of the building owner	X	X	—
Date of the inspection	X	X	—
Parts of the system that could not be inspected	X	X	5.4
Pre-inspection / Compliance with design documentation			
Status of the documentation or information, including identification of lacking and outdated documentation	X	X	5.3.6
Priority areas for the collection of missing information during the inspection on site	X	X	5.3.6
Priority areas for the inspection where the design installation appears to depart from good practice in a manner likely to affect its performance	X	X	5.3.6
Any difference between documentation and actually installed components	X	X	6.3, 7.3
Any difference between working or as-installed drawings and the actual system	X	X	6.3, 7.3
Aspects of the inspections simplified or reduced because of clear evidence that a good practice program of maintenance is being carried out	X	X	6.4.1.1, 7.4.2
Check the system			
Evidence showing why parts could not be checked because they were not accessible	X	X	5.4
Building parts and components inspected and number of measurements performed	X	X	5.5
In case of the presence of specific ventilation systems for the reduction in the concentration of specific gas (e.g. radon), the operation or not of these specific ventilation systems during the inspection	X	NA	6.4.1.4
State, integrity, and cleanliness of the ductwork (including observations)	X	NA	6.4.1.5,

			6.4.2.2
Total air flow rate extracted and/or supplied by the air handling unit	X	NA	6.2, 6.4.2.3
Electrical power consumed by the fan(s)	X	NA	6.2, 6.4.2.3
In the case of a central system, the pressure before and after the unit and the air filter	X	NA	6.4.2.3
Missing, blocked, damaged air filters and blanking plates in place	X	NA	6.4.2.4
Frequency of air filter changing or cleaning, and time elapsed since the last change or cleaning, as well as discrepancies between written records of air filter changes and visual evidence	X	NA	6.4.2.4
In the case of the use of manometers or magnehelic gauges to monitor pressure drop across the air filter, their condition and issues. Presence and conditions of air filter change warning devices or control systems (if existing).	X	NA	6.4.2.4
Condition and cleanliness of the heat exchangers	X	X	6.4.2.5

Information	**Method**		**Part**
	1	2	
Any evidence that occupants find the air delivery arrangement unacceptable	X	NA	6.4.2.6
Cleanliness and correct functioning of the air inlets and outlets	X	NA	6.4.2.6
The adequacy of air inlets and outlets, according to 6.4.2.6	X	NA	6.4.2.6
If air flow rate measurements are performed, guidance to the selection of air inlets/exhausts to be measured	X	NA	6.4.2.6
Results of the comparison of the settings of control that limit the operation of the ventilation systems with the periods when the building is in use	X	NA	6.4.2.8
In cases where the ventilation system is considered to be producing excessive noise or vibration, or allowing cross-talk between spaces, the probable cause	X	NA	6.4.2.10.1
Assessment of the system			
The specific cooling load	NA	X	7.2
The specific cooling capacity	NA	X	7.2
Assessment of the air-conditioning efficiency	NA	X	7.2
Assessment of the sizing compared to the cooling and ventilation requirements of the building	X	X	5.1, 7.2
Assessment of the system efficiency, including maintenance and controls	X	X	5.1
Characteristics of the air conditioning and/or ventilation system that can be compared to design specifications or inputs of energy calculations	X	X	5.1
Information on any parameters suspected to be useful to measure concerning the energy efficiency of the refrigerator	NA	X	7.4.2
Measurements carried out	X	X	—
Comments on faults found	X	X	—
Recommendations and advice			
Advice to keep any documentation determined in 5.3, any survey or calculation in a file so they are available for subsequent inspections	X	X	5.3.5

Advice to the building manager on issues to address when developing a plan to complete the documentation	X	X	5.3.6
Advice regarding the cleaning of exhaust and supply systems to ensure a good air quality	X	NA	6.4.1.5
Advice for improvement, including the adjustments to be made to ensure that it agrees with the design	X	X	6.5, 7.5
Proposals to improve the results in terms of energy impact, including possible replacement of the system, subsystems, or components and the economic justification of choices	X	X	6.5, 7.5
Advice on location, function, and settings of controls, sensors, and indicators	NA	X	7.4.7
Advice to the owner to reduce energy consumption if energy consumption recordings show that the equipment in not running in accordance with the use of the building	NA	X	7.4.8
Advice to record meter readings on a regular basis if meters are installed but no consumption records are available	NA	X	7.4.8
Advice on the use of shading devices	NA	X	7.5
Final comment about the system's performance	X	X	—

5.5.4.2 Mapping audit outputs with EPC inputs

From the inspection content reported in Section 5.5.1, the following key air conditioner system energy performance aspects can be reported (depending on the level of inspection adopted):

- The specific cooling load
- The specific cooling capacity
- Assessment of the air-conditioning efficiency
- Assessment of the sizing compared to the cooling and ventilation requirements of the building
- Assessment of the system’s efficiency, including maintenance and controls
- Characteristics of the air conditioning and/or ventilation system that can be compared to design specifications or inputs of energy calculations
- Information on any parameters suspected to be useful to measure concerning the energy efficiency of the refrigerator

Each of the above can be mapped to corresponding parameters in the EPB asset-based energy performance calculation standards, which will be shown in the M22 version of this report (subject to clarification of the issues mentioned in Section 5.2.3). Thus, they can be used to adjust and improve the accuracy of air conditioning energy performance calculations used to generate EPCs, provided the EPCs are generated in accordance to the EPB calculation standards.

Furthermore, the following advice may improve the system's energy performance:

- Advice on location, function, and settings of controls, sensors, and indicators
- Advice to the owner to reduce energy consumption if energy consumption recordings show that the equipment is not running in accordance with the use of the building

- Advice to record meter readings on a regular basis if meters are installed but no consumption records are available
- Advice on the use of shading devices.

5.5.4.3 Mapping audit outputs with SRI inputs

The SRI methodology B, as set out in the service catalogue V4.5, includes ten smart services for air conditioning, as detailed in Table 9 (which also shows the various smart functionality levels). Also shown are the services/functionalities that map to the information obtainable from audits as shown in section 5.1.5. Note, a colour coding of the table cells is used as follows:

- Dark green indicates an SRI function that could be determined while doing an air conditioning audit (or vice versa) but that are fully aligned
- Olive green indicates an SRI function that could be determined while doing an air conditioning audit (or vice versa) but that are also somewhat aligned
- Yellow indicates an SRI function that could be determined while doing an air conditioning audit (or vice versa) but that are not otherwise aligned

It is relevant to note that EN16978-17 explicitly references EN15232:2017 *Energy Performance of Buildings - Energy performance of buildings - Part 1: Impact of Building Automation, Controls and Building Management - Modules M10-4,5,6,7,8,9,10* which is at the core of the SRI methodology (especially for energy performance) although it is technically supplanted by EN ISO 52120:2021, which is almost identical to EN 15232:2017.

Table 61. SRI Methodology B space cooling services, functionality levels and related standards

Domain	Code	Service group	Related standard	Smart ready service	Functionality level 0 (as non-smart default)	Functionality level 1	Functionality level 2	Functionality level 3	Functionality level 4
Cooling	C-1a	Cooling control - demand side	EN15232 EN ISO 52120-1/ EN 16798-9 EN 16947-1 Function 1	Cooling emission control	No automatic control	Central automatic control	Individual room control	Individual room control with communication between controllers and to BACS	Individual room control with communication and occupancy detection
Cooling	C-1b	Cooling control - demand side	EN15232 EN ISO 52120-1 EN 16947-1 Function 1	Emission control for TABS (cooling mode)	No automatic control	Central automatic control	Advanced central automatic control	Advanced central automatic control with intermittent operation and/or room temperature feedback control	
Cooling	C-1c	Cooling control - demand side	EN15232 EN ISO 52120-1	Control of distribution network chilled water temperature (supply or return)	Constant temperature control	Outside temperature compensated control	Demand based control		
Cooling	C-1d	Cooling control - demand side	EN15232 EN ISO 52120-1	Control of distribution pumps in networks	No automatic control	On off control	Multi-Stage control	Variable speed pump control (pump unit (internal) estimations)	Variable speed pump control (external demand signal)
Cooling	C-1f	Cooling control - demand side	EN15232 EN ISO 52120-1 EN 16947-1 Function 5	Interlock: avoiding simultaneous heating and cooling in the same room	No interlock	Partial interlock (minimising risk of simultaneous heating and cooling e.g. by sliding setpoints)	Total interlock (control system ensures no simultaneous heating and cooling can take place)		
Cooling	C-1g	Cooling control - demand side	EN15232 EN ISO 52120-1 EN 16947-1 Function 5	Control of Thermal Energy Storage (TES) operation	Continuous storage operation	Time-scheduled storage operation	Load prediction based storage operation	Cold storage capable of flexible control through grid signals (e.g. DSM)	

Domain	Code	Service group	Related standard	Smart ready service	Functionality level 0 (as non-smart default)	Functionality level 1	Functionality level 2	Functionality level 3	Functionality level 4
Cooling	C-2a	Control cooling production facilities	EN15232 EN ISO 52120-1	Generator control for cooling	On/Off-control of cooling production	Multi-stage control of cooling production capacity depending on the load or demand (e.g. on/off of several compressors)	Variable control of cooling production capacity depending on the load or demand (e.g. hot gas bypass, inverter frequency control)	Variable control of cooling production capacity depending on the load AND external signals from grid	
Cooling	C-2b	Control cooling production facilities	EN15232 EN ISO 52120-1 EN 16947-1 Function 3	Sequencing of different cooling generators	Priorities only based on running times	Fixed sequencing based on loads only: e.g. depending on the generators characteristics such as absorption chiller vs. centrifugal chiller	Dynamic priorities based on generator efficiency and characteristics (e.g. availability of free cooling)	Load prediction based sequencing: the sequence is based on e.g. COP and available power of a device and the predicted required power	Sequencing based on dynamic priority list, including external signals from grid
Cooling	C-3	Information to occupants and facility managers	EN ISO 52120-1	Report information regarding cooling system performance	None	Central or remote reporting of current performance KPIs (e.g. temperatures, submetering energy usage)	Central or remote reporting of current performance KPIs and historical data	Central or remote reporting of performance evaluation including forecasting and/or benchmarking	Central or remote reporting of performance evaluation including forecasting and/or benchmarking; also including predictive management and fault detection
Cooling	C-4	Flexibility and grid interaction	EN 16947-1 Function 6	Flexibility and grid interaction	No automatic control	Scheduled operation of cooling system	Self-learning optimal control of cooling system	Cooling system capable of flexible control through grid signals (e.g. DSM)	Optimized control of cooling system based on local predictions and grid signals (e.g. through model predictive control)

In summary, eight of the ten SRI cooling services could be assessed while doing a air conditioning energy audit and one of these are somewhat aligned with current 16798-17 audit checks (in that similar information is being gathered).

The specific mapping is shown in Table 10.

Table 62. Mapping of SRI services to cooling audit checks under EN 15378-1

SRI service	Audit parameter	Notes
C-1a: Cooling emission control	Checks under EN 16798-17: 5.1) Assessment of the system efficiency including maintenance and controls 7.4.7) Advice on location, function and settings of controls, sensors and indicators	Either could be determined while assessing the other The control checks are relatively consistent
C-1c: Control of distribution network chilled water temperature (supply or return)	Checks under EN 16798-17: 5.1) Assessment of the system efficiency including maintenance and controls 7.4.7) Advice on location, function and settings of controls, sensors and indicators	Either could be determined while assessing the other
C-1d: Control of distribution pumps in network	Checks under EN 16798-17: 5.1) Assessment of the system efficiency including maintenance and controls 7.4.7) Advice on location, function and settings of controls, sensors and indicators	Either could be determined while assessing the other
C-1f: Interlock: avoiding simultaneous heating and cooling in the same room	Checks under EN 16798-17: 5.1) Assessment of the system efficiency including maintenance and controls 7.4.7) Advice on location, function and settings of controls, sensors and indicators	Either could be determined while assessing the other
C-1g: Control of Thermal Energy Storage (TES) operation	Checks under EN 16798-17: 5.1) Assessment of the system efficiency including maintenance and controls 7.4.7) Advice on location, function and settings of controls, sensors and indicators	Either could be determined while assessing the other

C-2a: Generator control for cooling	Checks under EN 16798-17: 5.1) Assessment of the system efficiency including maintenance and controls 7.4.7) Advice on location, function and settings of controls, sensors and indicators	Either could be determined while assessing the other
C-2d: Sequencing of different cooling generators	Checks under EN 16798-17: 5.1) Assessment of the system efficiency including maintenance and controls 7.4.7) Advice on location, function and settings of controls, sensors and indicators	Either could be determined while assessing the other
C-3: Report information regarding cooling system performance	Checks under EN 15378-1: 8) Meter readings 9) Energyware consumption	Either could be determined while assessing the other

5.5.4.4 Other mapping synergies

This section will explore the reverse mapping e.g. how EPC asset data, SRI data or ErP product data could inform audits. Information on such synergies for cooling systems that are identified in the course of the Smart Living EPC project will be added in this section for the version of this report due in M31.

5.5.5 Audits of ventilation systems

This Section sets out the information on the inspections/audits of ventilation systems and considers the outputs that could be integrated into the SmartLivingEPC asset methodology.

5.5.5.1 Standards and assessment procedures

This sub-section cites the standards used to calculate the energy performance of ventilation systems when determining building energy performance via an EPC asset methodology and also cites the standards used to conduct audits/inspections of the ventilation systems. It further reports the standards that are relevant to the EPBD Article 8(1) TBS measures.

Table 63: Relationships between EPB energy calculation standards for ventilation systems

Overarching		**Building (as such)**		**Technical Building Systems**										
	Descriptions		Descriptions		Descriptions	Heating	Cooling	**Ventilation**	Humidification	Dehumidification	Domestic Hot water	Lighting	Building automation and control	PV, wind, ..
sub1	M1	sub1	M2	sub1		M3	M4	**M5**	M6	M7	M8	M9	M10	M11
1.	General	1.	General	1.	General									
2.	Common terms and definitions; symbols, units, and subscripts	2.	Building Energy Needs	2.	Needs									
3.	Applications	3.	(Free) Indoor Conditions without Systems	3.	Maximum Load and Power									
4.	Ways to Express Energy Performance	4.	Ways to Express Energy Performance	4.	Ways to Express Energy Performance									
5.	Building Functions and Building Boundaries	5.	Heat Transfer by Transmission	5.	Emission and control									
6.	Building Occupancy and Operating Conditions	6.	Heat Transfer by Infiltration and Ventilation	6.	Distribution and control									

7.	Aggregation of Energy Services and Energy Carriers	7.	Internal Heat Gains	7.	Storage and control									
8.	Building Partitioning	8.	Solar Heat Gains	8.	Generation and control									
9.	Calculated Energy Performance	9.	Building Dynamics (thermal mass)	9.	Load dispatching and operating conditions									
10.	Measured Energy Performance	10.	Measured Energy Performance	10.	Measured Energy Performance									
11.	Inspection	11.	Inspection	11.	Inspection									
12.	Ways to Express Indoor Comfort			12.	BMS									
13.	Outdoor Environment Conditions													
14.	Economic Calculation													

When setting Article 8(1) requirements, it is helpful to consider the Commission's guidance on the possible interpretation of system requirements for ventilation, as shown in **Table 64**.

Table 64: Commission Article 8(1) guidance for ventilation

Type of requirement	A possible interpretation for space heating	Useful references
Overall energy performance	The energy performance of the ventilation system as a whole, taking into account e.g. fans' energy efficiency, the characteristics of the ventilation duct network, heat recovery, etc.	▪ EN 16798–3 ▪ EN 16798–5–1 ▪ EN 16798–5–2
Appropriate dimensioning	Dimensioning refers to the optimal sizing of the ventilation system with regard to the ventilation needs of the building and its spaces.	▪ EN 16798-7 ▪ CEN/TR 14788 ▪ CR 1752
Proper installation	Proper installation refers to the need to ensure the system can operate according to design specifications. Ensuring proper installation can rely e.g. on national technical guidelines, product manufacturer documentation, and certification of installers.	N/A
Adjustment	The adjustment refers here to the test and finetuning of the system under real-life conditions (8), in particular, to check and possibly adjust system functions that can impact performance (e.g. control capabilities – see below).	▪ EN 12599 ▪ EN 16798-17 ▪ EN 14134

Appropriate control	Concerns control capabilities that ventilation systems can include in order to optimize performance, e.g. airflow modulation	▪ EN 15232 ▪ EN 15500-1

Applicable inspection standards

The applicable inspection (audit) standard for ventilation systems is:

- EN 16798-17: Energy performance of buildings. Ventilation for buildings Guidelines for inspection of ventilation and air conditioning systems (Module M4-11, M5-11, M6-11, M7- 11)

For asset ratings, the following calculation standard is used:

- EN 16798-1:Energy performance of buildings - Ventilation for buildings - Part 1: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting, and acoustics - Module M1-6

The EN 16798-17 standard sets out procedures to inspect:

- Method 1 – Ventilation-only systems

The inspection's principal purpose is to advise building operators and owners on reducing their energy consumption while maintaining acceptable indoor environmental conditions. Accordingly, each inspection should produce an inspection report explaining the advantages gained from implementing the recommendations.

The inspection report includes:

- recommendations for improvements with an indication of their probable cost-effectiveness and any other benefits
- an assessment of the system's efficiency, including maintenance and controls
- an assessment of the sizing compared to the cooling and ventilation requirements of the building
- characteristics of the air conditioning and/or ventilation system that can be compared to design specifications or inputs of energy calculations.

Elements to be inspected

The ventilation system inspection procedure for Mechanical exhaust and/or supply systems includes inspection methods and procedures on:

- ductwork
- air handling unit or fan
- air filters
- heat exchangers and heat recovery
- externally or internally mounted air transfer device/supply or exhaust in rooms
- air intakes and air exhaust openings of the system
- controls and settings
- recirculated air
- noise vibration

There are also inspection procedures for balanced systems, those using natural ventilation, and those using hybrid systems.

Elements to be inspected as a function of the designated inspection level

The standard sets out a set of three "inspection levels", see the table below, to be determined (ostensibly by inspection mandating authorities) that determine what should be inspected as a function of the level. The implicit notion is that the inspection level would depend on the nature of the building and ventilation system, such that higher energy-using systems with higher savings potentials from inspection would be subject to more comprehensive inspections than those with lower saving potentials.

Table 65: Inspection levels for ventilation systems per EN 16798-17

Inspection level	Type of inspection	Description
1	Pre-inspection and functional checks	This basic level of inspection has two purposes, to: ▪ gather all relevant documentation on the system type and size and to identify any priority inspection areas where the design, installation, or operation of the system departs from good practice in a manner likely to affect its energy consumption; ▪ non-intrusively identify on-site (normally visually) features of system operation that are wasteful of energy. It does not include measurements.
2	Functional measurements	This level requires measurements in addition to level 1 to check that the system is operating as intended and to identify sources of energy wastage. These can include, for example, specified design conditions and set points.
3	Special measurements	This level requires, in addition to levels 1 and 2, additional measurements to provide more detailed assessments of system performance. Such measurements can, for example, cover extended periods of time or technical aspects such as *in situ* component performance.

Aspects to be included in the inspection report as a function of the designated inspection level

Table 66 shows the elements to be included in the ventilation system inspection reports as a function of the designated inspection level.

Table 66: Contents of the ventilation system inspection report per EN 16798-17

Information	Method		Part
	1	2	
General			
Name, address, and status of the person and organization in charge of the inspection	X	X	—
Official designation and address of the property	X	X	—
Name and address of the building owner	X	X	—
Date of the inspection	X	X	—
Parts of the system that could not be inspected	X	X	5.4
Pre-inspection / Compliance with design documentation			
Status of the documentation or information, including identification of lacking and outdated documentation	X	X	5.3.6
Priority areas for the collection of missing information during the inspection on site	X	X	5.3.6
Priority areas for the inspection where the design installation appears to depart from good practice in a manner likely to affect its performance	X	X	5.3.6
Any difference between documentation and actually installed components	X	X	6.3, 7.3

Any difference between working or as-installed drawings and the actual system	X	X	6.3, 7.3
Aspects of the inspections simplified or reduced because of clear evidence that a good practice program of maintenance is being carried out	X	X	6.4.1.1, 7.4.2
Check the system			
Evidence showing why parts could not be checked because they were not accessible	X	X	5.4
Building parts and components inspected and number of measurements performed	X	X	5.5
In case of the presence of specific ventilation systems for the reduction in the concentration of specific gas (e.g. radon), the operation or not of these specific ventilation systems during the inspection	X	NA	6.4.1.4
State, integrity, and cleanliness of the ductwork (including observations)	X	NA	6.4.1.5, 6.4.2.2
Total air flow rate extracted and/or supplied by the air handling unit	X	NA	6.2, 6.4.2.3
Electrical power consumed by the fan(s)	X	NA	6.2, 6.4.2.3
In the case of a central system, the pressure before and after the unit and the air filter	X	NA	6.4.2.3
Missing, blocked, damaged air filters and blanking plates in place	X	NA	6.4.2.4
Frequency of air filter changing or cleaning, and time elapsed since the last change or cleaning, as well as discrepancies between written records of air filter changes and visual evidence	X	NA	6.4.2.4
In the case of the use of manometers or magnehelic gauges to monitor pressure drop across the air filter, their condition and issues. Presence and conditions of air filter change warning devices or control systems (if existing).	X	NA	6.4.2.4
Condition and cleanliness of the heat exchangers	X	X	6.4.2.5

Information	**Method**		**Part**
	1	2	
Any evidence that occupants find the air delivery arrangement unacceptable	X	NA	6.4.2.6
Cleanliness and correct functioning of the air inlets and outlets	X	NA	6.4.2.6
The adequacy of air inlets and outlets, according to 6.4.2.6	X	NA	6.4.2.6
If air flow rate measurements are performed, guidance to the selection of air inlets/exhausts to be measured	X	NA	6.4.2.6
Results of the comparison of the settings of control that limit the operation of the ventilation systems with the periods when the building is in use	X	NA	6.4.2.8
In cases where the ventilation system is considered to be producing excessive noise or vibration, or allowing cross-talk between spaces, the probable cause	X	NA	6.4.2.10.1
Assessment of the system			
The specific cooling load	NA	X	7.2
The specific cooling capacity	NA	X	7.2
Assessment of the air-conditioning efficiency	NA	X	7.2
Assessment of the sizing compared to the cooling and ventilation requirements of the building	X	X	5.1, 7.2
Assessment of the system efficiency, including maintenance and controls	X	X	5.1

Characteristics of the air conditioning and/or ventilation system that can be compared to design specifications or inputs of energy calculations	X	X	5.1
Information on any parameters suspected to be useful to measure concerning the energy efficiency of the refrigerator	NA	X	7.4.2
Measurements carried out	X	X	—
Comments on faults found	X	X	—
Recommendations and advice			
Advice to keep any documentation determined in 5.3, any survey or calculation in a file so they are available for subsequent inspections	X	X	5.3.5
Advice to the building manager on issues to address when developing a plan to complete the documentation	X	X	5.3.6
Advice regarding the cleaning of exhaust and supply systems to ensure a good air quality	X	NA	6.4.1.5
Advice for improvement, including the adjustments to be made to ensure that it agrees with the design	X	X	6.5, 7.5
Proposals to improve the results in terms of energy impact, including possible replacement of the system, subsystems, or components and the economic justification of choices	X	X	6.5, 7.5
Advice on location, function, and settings of controls, sensors, and indicators	NA	X	7.4.7
Advice to the owner to reduce energy consumption if energy consumption recordings show that the equipment is not running in accordance with the use of the building	NA	X	7.4.8
Advice to record meter readings on a regular basis if meters are installed but no consumption records are available	NA	X	7.4.8
Advice on the use of shading devices	NA	X	7.5
Final comment about the system's performance	X	X	—

5.5.5.2 Mapping audit outputs with EPC inputs

From the inspection content reported in Section 5.3.3, the following key ventilation system energy performance aspects can be reported (depending on the level of inspection adopted)

- Assessment of the sizing compared to the cooling and ventilation requirements of the building
- Assessment of the system efficiency, including maintenance and controls
- Characteristics of the air conditioning and/or ventilation system that can be compared to design specifications or inputs of energy calculations
- Electrical power consumed by the fan(s)

Each of the above can be mapped to corresponding parameters in the EPB asset-based energy performance calculation standards, which will be shown in the M20 version of this report (subject to clarification of the issues mentioned in Section 5.2.3). Thus, they can be used to adjust and improve the accuracy of heating and hot water energy performance calculations used to generate EPCs providing the EPCs are generated in accordance with the EPB calculation standards.

Furthermore, the following advice may improve the system's energy performance:

- Proposals to improve the results in terms of energy impact, including
- possible replacement of the system, subsystems, or components and the economic justification of choices
- Advice on location, function, and settings of controls, sensors, and indicators
- Advice to the owner to reduce energy consumption if energy consumption recordings show that the equipment is not running in accordance with the use of the building
- Advice to record meter readings on a regular basis if meters are installed but no consumption records are available
- Advice on the use of shading devices.

In addition, the following aspects have relevance for the IAQ and IEQ of the ventilation system:

- State, integrity, and cleanliness of the ductwork (including observations)
- Total air flow rate extracted and/or supplied by the air handling unit
- In case of the presence of specific ventilation systems for the reduction in the concentration of specific gas (e.g. radon), the operation or not of these specific ventilation systems during the inspection
- In the case of a central system, the pressure before and after the unit and the air filter
- Missing, blocked, damaged air filters and blanking plates in place
- Frequency of air filter changing or cleaning, and time elapsed since the last change or cleaning, as well as discrepancies between written records of air filter changes and visual evidence
- Any evidence that occupants find the air delivery arrangement unacceptable
- Cleanliness and correct functioning of the air inlets and outlets.

Furthermore, the following advice may improve the IAQ/IEQ:

- Advice regarding the cleaning of exhaust and supply systems to ensure a good air quality
- Advice for improvement, including the adjustments to be made to ensure that it agrees with the design.

5.5.5.3 Mapping audit outputs with SRI inputs

The SRI methodology B, as set out in the service catalogue V4.5, includes ten smart services for ventilation, as detailed in Table 14 (which also shows the various smart functionality levels). Also shown are the services/functionalities that map to the information obtainable from audits as shown in section 6.1. Note, a colour coding of the table cells is used as follows:

- Dark green indicates an SRI function that could be determined while doing a ventilation system audit (or vice versa) but that are fully aligned
- Olive green indicates an SRI function that could be determined while doing a ventilation system audit (or vice versa) but that are also somewhat aligned
- Yellow indicates an SRI function that could be determined while doing a ventilation system audit (or vice versa) but that are not otherwise aligned

It is relevant to note that EN16978-17 explicitly references EN15232:2017 *Energy Performance of Buildings - Energy performance of buildings - Part 1: Impact of Building Automation, Controls and Building Management - Modules M10-4,5,6,7,8,9,10* which is at the core of the SRI methodology (especially for energy performance) although it is technically supplanted by EN ISO 52120:2021, which is almost identical to EN 15232:2017.

Table 67. SRI Methodology B ventilation services, functionality levels and related standards

Domain	Code	Service group	Related standard	Smart ready service	Functionality level 0 (as non-smart default)	Functionality level 1	Functionality level 2	Functionality level 3	Functionality level 4
Ventilation	V-1a	Air flow control	EN15232 EN ISO 52120-1 Function 4.1 partial alignment with extra differentiation for levels 3 and 4	Supply air flow control at the room level	No ventilation system or manual control	Clock control	Occupancy detection control	Central Demand Control based on air quality sensors (CO2, VOC, humidity, ...)	Local Demand Control based on air quality sensors (CO2, VOC,...) with local flow from/to the zone regulated by dampers
Ventilation	V-1c	Air flow control	EN15232 EN ISO 52120-1 Function 4.5	Air flow or pressure control at the air handler level	No automatic control: Continuously supplies of air flow for a maximum load of all rooms	On off time control: Continuously supplies of air flow for a maximum load of all rooms during nominal occupancy time	Multi-stage control: To reduce the auxiliary energy demand of the fan	Automatic flow or pressure control without pressure reset: Load dependent supplies of air flow for the demand of all connected rooms.	Automatic flow or pressure control with pressure reset: Load dependent supplies of air flow for the demand of all connected rooms (for variable air volume systems with VFD).
Ventilation	V-2c	Air temperature control EN 16947-1 Function 5	EN15232 EN ISO 52120-1 Function 4.9 partial alignment	Heat recovery control: prevention of overheating	Without overheating control	Modulate or bypass heat recovery based on sensors in air exhaust	Modulate or bypass heat recovery based on multiple room temperature sensors or predictive control		
Ventilation	V-2d	Air temperature control	EN15232 EN ISO 52120-1	Supply air temperature control at the air handling unit level	No automatic control	Constant setpoint: A control loop enables to control the supply air temperature, the setpoint is constant and can only be modified by a manual action	Variable set point with outdoor temperature compensation	Variable set point with load dependant compensation. A control loop enables to control the supply air temperature. The setpoint is defined as a function of the loads in the room	

In summary, all four of the SRI ventilation services could be assessed while doing a ventilation system energy audit and one of these are somewhat aligned with current 16798-17 audit checks (in that similar information is being gathered).

The specific mapping is shown in Table 38.

Table 68. Mapping of SRI services to ventilation system audit checks under EN 15378-1

SRI service	Audit parameter	Notes
V-1a: Supply air flow control at the room level	Checks under EN 16798-17: 5.1) Assessment of the system efficiency including maintenance and controls 7.4.7) Advice on location, function and settings of controls, sensors and indicators	Either could be determined while assessing the other The control checks are relatively consistent
V-1c: Air flow or pressure control at the air handler level	Checks under EN 16798-17: 5.1) Assessment of the system efficiency including maintenance and controls 7.4.7) Advice on location, function and settings of controls, sensors and indicators	Either could be determined while assessing the other
V-2c: Heat recovery control: prevention of overheating	Checks under EN 16798-17: 5.1) Assessment of the system efficiency including maintenance and controls 7.4.7) Advice on location, function and settings of controls, sensors and indicators	Either could be determined while assessing the other
V-2d: Supply air temperature control at the air handling unit le	Checks under EN 16798-17: 5.1) Assessment of the system efficiency including maintenance and controls 7.4.7) Advice on location, function and settings of controls, sensors and indicators	Either could be determined while assessing the other

5.5.5.4 Other mapping synergies

This section will explore the reverse mapping e.g. how EPC asset data, SRI data or ErP product data could inform audits. Information on such synergies for ventilation systems that are identified in the course of the SmartLivingEPC project will be added in this section for the version of this report due in M31.

5.5.6 Definition of building systems periodic audits procedures and methodology

To boost the energy performance of buildings [2031], the EU established a legislative framework that includes the Energy Performance of Buildings Directive 2010/31/EU [232]. The Directive amending the Energy Performance of Buildings Directive (2018/844/EU) [233] (the so-called EPBD recast) introduced new elements and sent a strong political signal on the EU's commitment to modernize the building sector in light of technological improvements and to increase building renovations.

In October 2020, the Commission presented its Renovation wave strategy [234] as part of the European Green Deal [235]. It contains an action plan with concrete regulations, financing, and enabling measures to boost building renovation. Its objective is to at least double the annual energy renovation rate of buildings by 2030 and to foster deep renovation. A revision of the Energy Performance of Buildings Directive is one of its key initiatives. A revision of the Energy Performance of Buildings Directive is one of its key initiatives.

Some of the key provisions in the original EPBD of direct relevance to the SmartLivingEPC project and the work reported in this task on inspections/audits include:

- Article 3, Adoption of a methodology for calculating the energy performance of buildings
- Article 8 Technical building systems
- Article 11 Energy performance certificate
- Article 14 Inspection of heating systems
- Article 15 Inspection of air-conditioning systems
- Article 16 Reports on the inspection of heating and air-conditioning systems.

5.5.6.1 Measures introduced in the 2018 EPBD recast

The amending directive (2018/844/EC) covers a broad range of policies and support measures that will help national EU governments boost the energy performance of buildings and improve the existing building stock. EU countries must, for example, establish strong **long-term renovation strategies**, aiming at decarbonizing the national building stocks by 2050, with indicative milestones for 2030, 2040, and 2050. The strategies should contribute to achieving the national energy and climate plans (NECPs) energy efficiency targets. The directive also requires that EU countries set cost-optimal **minimum energy performance requirements** for new buildings, for existing buildings undergoing a major renovation, and for replacing or retrofitting building elements like heating and cooling systems, roofs, and walls.

As of 2021, all new buildings must be nearly zero-energy buildings (NZEB) [236], and since 2019, all new public buildings should be NZEB. When a building is sold or rented, energy performance certificates must be issued, and inspection schemes for heating and air conditioning systems must be established. The directive supports **electro-mobility** by introducing minimum requirements for car parks over a certain size and other minimum infrastructure for smaller buildings. There is also an optional European scheme for rating the smart readiness of buildings, and **smart technologies** are promoted. The directive introduced requirements for the installation of building automation and control systems and devices that regulate temperature at room level. It addresses the health and well-being of building users, for instance, by considering air quality and ventilation.

5.5.6.2 Proposal for a revision of the directive

In December 2021, the Commission proposed a revision of the directive (COM(2021) 802 final). It upgrades the existing regulatory framework to reflect higher ambitions and more pressing needs in climate and social action while providing EU countries with the flexibility needed to take into account the differences in the building stock across Europe.

It also sets out how Europe can achieve a zero-emission and fully decarbonized building stock by 2050. The proposed measures will increase the rate of renovation, particularly for the worst-performing buildings in each country. The revised directive will modernize the building stock, making it more resilient and accessible. It will also support better air quality, the digitalization of energy systems for buildings, and the roll-out of infrastructure for sustainable mobility. Crucially, the revised directive facilitates more targeted financing to investments in the building sector, complementing other EU instruments supporting vulnerable consumers and fighting energy poverty.

In order to make sure that buildings are fit for the enhanced climate ambition, as presented in the 2030 Climate Target Plan and reflected in the "Delivering the European Green Deal Package" [237] in July 2021, the Commission's new proposal aims to contribute to reaching the target of at least -60% emission reductions by 2030 in the building sector in comparison to 2015 and achieve climate neutrality by 2050. It will work hand in hand with other initiatives of the European Green Deal package, in particular with the review of the proposed new emissions trading system for fuels used in buildings, the Energy Efficiency Directive, the Renewable Energy Directive, as well as the Alternative Fuels Infrastructure Regulation.

The main measures in the new proposal are:

- the gradual introduction of minimum energy performance standards to trigger renovation of the worst-performing buildings
- a new standard for new buildings and a more ambitious vision for buildings to be zero-emission
- enhanced long-term renovation strategies [238], to be renamed national Building Renovation Plans
- increased reliability, quality, and digitalization of Energy Performance Certificates [239], with energy performance classes to be based on common criteria
- a definition of deep renovation and the introduction of building renovation passports
- modernization of buildings and their systems, and better energy system integration (for heating, cooling, ventilation, charging of electric vehicles, renewable energy)

The Council and the European Parliament are now considering the proposed revision of the directive.

5.5.7 Inspection provisions

5.5.7.1 EPBD provisions on inspections of HVAC

The Energy Performance of Buildings Directive [240] sets out the following provisions with regard to the inspection of heating and cooling systems (including ventilation) and their reporting:

Article 14: Inspection of heating systems

1. Member States shall lay down the necessary measures to establish regular inspections of the accessible parts of heating systems or systems for combined space heating and ventilation, with an effective rated output of over 70 kW, such as the heat generator, control system, and circulation pump(s) used for heating buildings. The inspection shall include an assessment of the efficiency and sizing of the heat generator compared with the heating requirements of the building and, where relevant, consider the capabilities of the heating system or the system for combined space heating and ventilation to optimize its performance under typical or average operating conditions.

Where no changes have been made to the heating system or to the system for combined space heating and ventilation or to the heating requirements of the building following an inspection carried out pursuant to this paragraph, MSs may choose not to require the assessment of the heat generator sizing to be repeated.

2. Technical building systems that are explicitly covered by an agreed energy performance criterion or a contractual arrangement specifying an agreed level of energy efficiency improvement, such as energy performance contracting, or that are operated by a utility or network operator and therefore subject to performance monitoring measures on the system side, shall be exempt from the requirements laid down in paragraph 1, provided that the overall impact of such an approach is equivalent to that resulting from paragraph 1.

3. As an alternative to paragraph 1 and provided that the overall impact is equivalent to that resulting from paragraph 1, Member States may opt to take measures to ensure the provision of advice to users concerning the replacement of heat generators, other modifications to the heating system or to the system for combined space heating and ventilation and alternative solutions to assess the efficiency and appropriate size of those systems.

Before applying the alternative measures referred to in the first subparagraph of this paragraph, each Member State shall, by submitting a report to the Commission, document the equivalence of those measures' impact to the measures referred to in paragraph 1. Such a report shall be submitted to the Commission as part of the Member States' integrated national energy and climate plans referred to in Article 3 of Regulation (EU) 2018/1999.

4. Member States shall lay down requirements to ensure that, where technically and economically feasible, non-residential buildings with an effective rated output for heating systems or systems for combined space heating and ventilation of over 290 kW are equipped with building automation and control systems by 2025. The building automation and control systems shall be capable of:

- continuously monitoring, logging, analyzing, and allowing for adjusting energy use;

- benchmarking the building's energy efficiency, detecting losses in efficiency of technical building systems, and informing the person responsible for the facilities or technical building management about opportunities for energy efficiency improvement; and
- allowing communication with connected technical building systems and other appliances inside the building and being interoperable with technical building systems across different types of proprietary technologies, devices, and manufacturers.

5. Member States may lay down requirements to ensure that residential buildings are equipped with:
   - the functionality of continuous electronic monitoring that measures systems' efficiency and informs building owners or managers when it has fallen significantly and when system servicing is necessary; and
   - effective control functionalities to ensure optimum energy generation, distribution, storage, and use.
   - Buildings that comply with paragraph 4 or 5 shall be exempt from the requirements laid down in paragraph 1.

Article 15: Inspection of air-conditioning systems

1. Member States shall lay down the necessary measures to establish regular inspections of the accessible parts of air-conditioning systems or systems for combined air-conditioning and ventilation with an effective rated output of over 70 kW. The inspection shall include an assessment of the efficiency and sizing of the air-conditioning system compared with the cooling requirements of the building and, where relevant, consider the capabilities of the air-conditioning system or the system for combined air-conditioning and ventilation to optimize its performance under typical or average operating conditions.

Where no changes have been made to the air-conditioning system or the system for combined air-conditioning and ventilation or to the cooling requirements of the building following an inspection carried out under this paragraph, MSs may choose not to require the assessment of the sizing of the air-conditioning system to be repeated. MSs that maintain more stringent requirements according to Article 1(3) shall be exempt from the obligation to notify them to the Commission.

2. Technical building systems that are explicitly covered by an agreed energy performance criterion or a contractual arrangement specifying an agreed level of energy efficiency improvement, such as energy performance contracting, or that are operated by a utility or network operator and therefore subject to performance monitoring measures on the system side, shall be exempt from the requirements laid down in paragraph 1, provided that the overall impact of such an approach is equivalent to that resulting from paragraph 1.

3. As an alternative to paragraph 1 and provided that the overall impact is equivalent to that resulting from paragraph 1, MSs may opt to take measures to ensure the provision of advice to users concerning the

replacement of air-conditioning systems or systems for combined air-conditioning and ventilation, other modifications to the air-conditioning system or system for combined air-conditioning and ventilation and alternative solutions to assess the efficiency and appropriate size of those systems.

Before applying the alternative measures referred to in the first subparagraph of this paragraph, each MS shall, by means of submitting a report to the Commission, document the equivalence of the impact of those measures to the impact of the measures referred to in paragraph 1. Such a report shall be submitted to the Commission as part of the Member States' integrated national energy and climate plans referred to in Article 3 of Regulation (EU) 2018/1999.

4. MSs shall lay down requirements to ensure that, where technically and economically feasible, non-residential buildings with an effective rated output for systems for air-conditioning or systems for combined air-conditioning and ventilation of over 290 kW are equipped with building automation and control systems by 2025. The building automation and control systems shall be capable of:

- continuously monitoring, logging, analyzing, and allowing for adjusting energy use;
- benchmarking the building’s energy efficiency, detecting losses in efficiency of technical building systems, and informing the person responsible for the facilities or technical building management about opportunities for energy efficiency improvement; and
- allowing communication with connected technical building systems and other appliances inside the building and being interoperable with technical building systems across different types of proprietary technologies, devices, and manufacturers.

5. MSs may lay down requirements to ensure that residential buildings are equipped with:

- the functionality of continuous electronic monitoring that measures systems’ efficiency and informs building owners or managers when it has fallen significantly and when system servicing is necessary, and
- effective control functionalities to ensure optimum energy generation, distribution, storage, and use.
- buildings that comply with paragraph 4 or 5 shall be exempt from the requirements laid down in paragraph 1.

Article 16: Reports on the inspection of heating and air-conditioning systems

1. An inspection report shall be issued after each heating or air-conditioning system inspection. The inspection report shall contain the result of the inspection performed in accordance with Article 14 or 15 and include recommendations for the cost-effective improvement of the energy performance of the inspected system.

The recommendations may be based on a comparison of the energy performance of the system inspected with that of the best available feasible system and a system of a similar type for which all relevant components achieve the level of energy performance required by the applicable legislation.

2. The inspection report shall be handed over to the owner or tenant of the building. Thus, a regular mandatory inspection of HVAC systems of 70 kW or greater heating (or cooling) capacity is required using a standardized inspection process unless MSs put in place alternative measures that will produce equivalent energy savings. In addition, MSs shall lay down requirements to ensure that, where technically and economically feasible, non-residential buildings with an effective rated output for systems for air-conditioning or systems for combined air-conditioning and ventilation of over 290 kW are equipped with building automation and control systems by 2025.

5.5.7.2 EPBD provisions on technical building systems under Article 8(1) and 8(9)

Technical building systems (TBS) are defined in the Energy Performance of Buildings Directive (EPBD) as ‘technical equipment for space heating, space cooling, ventilation, domestic hot water, built-in lighting, building automation and control, on-site electricity generation, or a combination thereof, including those systems using energy from renewable sources of a building or building unit’ (Article 2(3)). Inspections and audits of technical building systems are a key aspect of determining their energy performance, as will be made clear in the later text; however, here, the characteristics and linkages to EPB standards will be made clear as this explains the policy and standardization context that links the Article 14 and 15 HVAC inspections/audits to the other EPBD measures that address HVAC (Article 8 TBS, the EPC measures and the minimum energy performance standards measures).

The main function of the TBS in a building is to provide a comfortable, healthy, and functional indoor environment when the building is occupied. There can be large differences in energy performance between TBSs designed to deliver the same functionality. These performance differences arise, for example, by the extent to which: the overshooting of comfort temperature or air quality set points is minimized, energy demand is reduced by matching service delivery with occupancy, hydronic heating or cooling distribution system losses are minimized, and heat or cold generation efficiency is optimized. Therefore, the energy efficiency community and related policy-making process need to be aware that very significant energy savings in buildings can be obtained by measures that improve the performance of technical building systems (TBS). Furthermore, the rate at which TBS is renewed or retrofitted is greater than that of building fabric renovation and/or new construction, and thus, measures that target TBS can access a much greater proportion of the building stock in any given period than those that concern major renovation.

The performance of technical building systems has a very significant impact on the overall building energy performance and therefore needs to be a major focus of building energy performance policy measures. For this reason, the 2018[1] amendment of the EPBD strengthened the measures applicable to TBS. In particular:

- Article 8(1) of the EPBD requires MSs to set system requirements for overall energy performance, proper installation, appropriate dimensioning, adjustment, and control of technical building systems.

- Article 8(9) of the EPBD requires MSs to ensure that when a technical building system is installed, replaced, or upgraded, the overall energy performance of the altered part or (where relevant) of the complete altered system is assessed.

These provisions are very relevant to the SmartLivingEPC framework because the SmartLivingEPC methodology can be designed to help speed up the recognition of the Article 8(1)/(9) impacts within EPCs, as is explained later in this report.

5.5.7.3 Article 8(1) provisions

Article 8(1) specifies requirements as set out in the sub-sections below:

5.5.7.3.1 Appropriate dimensioning

Article 8(1) requires MSs to set appropriate TBS dimensioning requirements because oversized systems will often operate far from the optimal efficiency level and create unnecessary energy wastage. In practice, this requires obligations to be imposed on system designers and installers to conduct an adequate dimensioning assessment according to specified procedures and to document the outcome. The dimensioning assessment needs to determine the realistic (not overly inflated) maximum load based on the actual characteristics of the building, its occupants and how it is to be used, and climate. It also needs to determine the system's efficiency in delivering that load so it can be sized accordingly.

For thermal systems (space heating and cooling), the sizing requirements should be based on specified design temperatures. For example, Spain requires space heating systems to be sized to deliver a 21°C indoor temperature and space cooling systems to be sized to deliver a 25°C indoor temperature and requires the outdoor temperature to be based on the 99% most extreme thermal conditions [241].

5.5.7.3.2 Proper installation

The quality of installation often has a significant impact on the delivered performance of a TBS; thus, Article 8(1) requires MSs to set proper system installation requirements to minimize the risk of poor installation outcomes.

As an example, Flanders, Belgium [242], apply installation correction factors to the overall system performance requirements for ventilation for:

- the airtightness of the air group, e.g., of the Air Handling Unit
- the airtightness of the ducts
- the insulation of the ducts.

These correction factors penalize poor adjustment practices and reward good practices, thereby creating an incentive to implement higher-quality system adjustment practices.

5.5.7.3.3 Adjustment

Many/most TBS's require proper adjustment to perform at or near their optimal operational levels; thus, Article 8(1) requires Member States to set adjustment requirements.

For example, Flanders applies correction factors to the overall system performance requirements for space heating for adjustment for:

- the control of boiler temperature
- the regulation of a normal regimen
- self-regulating equipment
- hydraulic balancing.

These correction factors penalize poor adjustment practices and reward good practices, thereby creating an incentive to implement higher-quality system adjustment practices.

5.5.7.3.4 Control

The quality of system control has a very large impact on the TBS energy consumption and quality of service provision. Accordingly, Article 8(1) requires MSs to set TBS control requirements. The system boundary at which the control provisions apply can have a large bearing on the energy-saving impact, as can the sophistication of the control requirements.

Many of the largest energy savings opportunities for system operation concern control, and to a large degree, these options are applicable at a system boundary level that is not captured by control provisions in product policy instruments such as Ecodesign for TBS components and energy labeling for space and water heating.

5.5.7.3.5 Relation to inspections/audits

In principle, TBS inspections and audits (specifically the HVAC-related ones of Articles 14 and 15) inform the understanding of the extant situation of HVAC systems with regards to each of these aspects and thus can help with the implementation of Article 8(1) measures. As discussed later, in principle, this information could also be reflected within a dynamic "living" EPC in the spirit of the SmartLivingEPC concept.

5.5.7.3.6 Need for a meaningful Article 8(1)

All building energy is consumed in technical building systems, and space heating alone accounts for by far the largest share of primary energy use in EU buildings (~65% of the total). Whole building minimum energy performance measures only affect new buildings or major renovations, while Ecodesign and energy labeling apply to components or part of the system but do not address much of the savings opportunity from optimization of the technical building system as a whole. In the case of space heating, it is estimated that the adoption of comprehensive Article 8(1) requirements could reduce total EU building primary energy consumption in 2040 by between 6.5% and 16%, in addition to the savings triggered by the other policy measures. Therefore, MSs are required to set such measures for space heating systems with regard to overall performance, dimensioning, installation, adjustment, and control to abide by the terms of Article

8(1).

5.5.7.4 Article 8(9) provisions

Article 8(9) specifies 3.2.3 Performance assessment and documentation provisions as set out below.

Article 8(9) of the EPBD stipulates that:

> “Member States shall ensure that, when a technical building system is installed, replaced or upgraded, the overall energy performance of the altered part, and where relevant, of the complete altered system, is assessed. The results shall be documented and passed on to the building owner so that they remain available and can be used for the verification of compliance with the minimum requirements laid down pursuant to paragraph 1 of this Article and the issue of energy performance certificates. Without prejudice to Article 12, Member States shall decide whether to require the issuing of a new energy performance certificate.”
>
> The European Commission’s guidance [14] states:
>
> “Article 8(9) of the EPBD requires that the results of the assessment of the system (or of an altered part of it) performance are documented and passed on to the building owner. Member States are free to determine the form and content of this documentation, which can vary depending on the type of intervention considered. However, in this context, Member States should ensure that the documentation covers the scope of the assessment performed and can be useful for the verification of compliance with the minimum requirements on energy performance laid down pursuant to Article 8(1) of the EPBD and for energy performance certification (see next paragraph). Member States are also free to determine how the documentation is to be passed on to the building owner.
>
> The obligations in Article 8(9) of the EPBD on documenting system (or altered part) performance aim to ensure that up-to-date information on technical building system performance is made available to building owners. Such information can be used, for instance, for energy performance certification or to verify compliance with minimum energy performance requirements (e.g., when a building undergoes a major renovation). It is up to MSs to decide whether a new energy performance certificate (EPC) will have to be issued as a result of the energy performance assessment of the technical building system (or an altered part of it).”

Thus, it is up to the MSs to define in their national legislation the cases where it is relevant to assess the performance of the whole system, as opposed to those where only the assessment of the performance of the altered part is required. Noting that the following cases can be defined:

- a new system is installed

- a whole system is replaced
- a part or parts of a system undergo a major upgrade that can significantly affect the overall performance of the system.

5.6 Implications for use of audit data within SLEPC

In principle HVAC and BACS audit data, gathered through audits implemented under Articles 14 and 15 of the EPBD, could help to inform the energy parameters for the SmartLivingEPC asset methodology listed in the table below.

Table 69. Mapping of SmartLivingEPC KPIs to findings from HVAC audits

Energy parameters					**Asset (retroactive)**	**Operational (periodically)**
1 -energy rating 2 – Level(s) 3 – Other (non-energy/on-site audit) - 4 - SRI	1	2	3	4	Calculated	Measured
Heating consumption [kWh]			√		YES	YES
Specific heating consumption [kWh/m²]			√		YES	NO
DHW consumption [kWh]			√		YES	YES
Specific DWH consumption [kWh/m²]			√		YES	NO
Ventilation consumption [kWh]			√		YES	YES
Specific ventilation consumption [kWh/m²]			√		YES	NO
Cooling consumption [kWh]			√		YES	YES
Specific cooling consumption [kWh/m²]			√		YES	NO

The audits would return information on the actual sizing and efficiency of heating and ventilation systems, as operated, in the buildings subject to inspection and hence would tend to occur in a different sequence to a conventional EPC assessment and calculation.

In the case of BACS the audit data could be applied to determine the BACS factors under EN ISO 52120-1:2022 which could then be applied to adjust the calculated primary energy values per TBS concerned; which could lead to substantial improvement in the quality of EPC asset calculations and the help lower the performance gap that is often referenced between asset and operational EPC ratings.

To understand the importance of this in the case of BACS it is pertinent to see how the BACS factors affect a buildings overall thermal energy demand as a function of the class of the BACS (on a scale of D to A, where C is typical of new BACS and A is highest energy performance class), as shown in the tables below.

Table 70. Overall BAC efficiency factors for thermal energy – Non-residential buildings (EN ISO 52120-1:2022)

Non-residential buildings	Overall BAC efficiency factors $f_{\mathrm{BAC,th}}$			
	D	C Reference	B	A
	Non energy efficient	Standard	Advanced	High energy performance
Offices	1,51	1	0,80	0,70

Lecture hall	1,24	1	0,75	0,5[a]
Education buildings (schools)	1,20	1	0,88	0,8
Hospital	1,31	1	0,91	0,86
Hotels	1,31	1	0,85	0,68
Restaurants	1,23	1	0,77	0,68
Wholesale and retail trade service buildings	1,56	1	0,73	0,6[a]
Other types: - Sport facilities - Storage - Industrial buildings - Etc.		1		
[a]These values highly depend on heating /cooling demand for ventilation.				

Note that overall BAC efficiency factors are not available for “Other types”.

Table 71. Overall BAC efficiency factors for thermal energy – Residential buildings (EN ISO 52120-1:2022)

Residential building types	Overall BAC efficiency factors $f_{\text{BAC,th}}$			
	D	C Reference	B	A
	Non energy efficient	Standard	Advanced	High energy performance
Single family houses Apartment block Other residential buildings or similar residential buildings	1,10	1	0,88	0,81

Thus, from this it is apparent that moving from Class C to Class A BACS will result in a difference in thermal energy demand of up to 50% for non-residential buildings and 19% for residential buildings. Furthermore, the savings are much larger again if moving from class D to A. Noting, that the pending EPBD revision includes measures for TBS performance but also requirements to upgrade the least efficient part of the building stock, phasing out inefficient BACS, as identified via inspections, would seem to be an excellent opportunity to meet the provisions with minimum cost and disruption to the building stock.

5.7 Procedures for the use of audit data within SLEPC

HVAC audits are currently required under Articles 14/15 of he EPBD for buildings with certain characteristics. The frequency with which mandatory HVAC audits are conducted are set at the Member State level but they are likely to be more frequent than the issuance of an EPC in most cases. Nor do the audits generally occur at the same time as an EPC assessment, calculation and certificate is issued. In part for this reason the audit information is not currently made use of in EPCs. This is a waste as in principle the information these audits contain could be used to refine the EPC HVAC performance calculations. Doing do would make the audit information more salient as it could affect the EPC rating and building owners (and the market in general) are known to place value on higher EPC ratings.

For the above to happen from a procedural perspective the EPC would need to be amendable in the light of the information gathered from the audit as shown in the following figure.

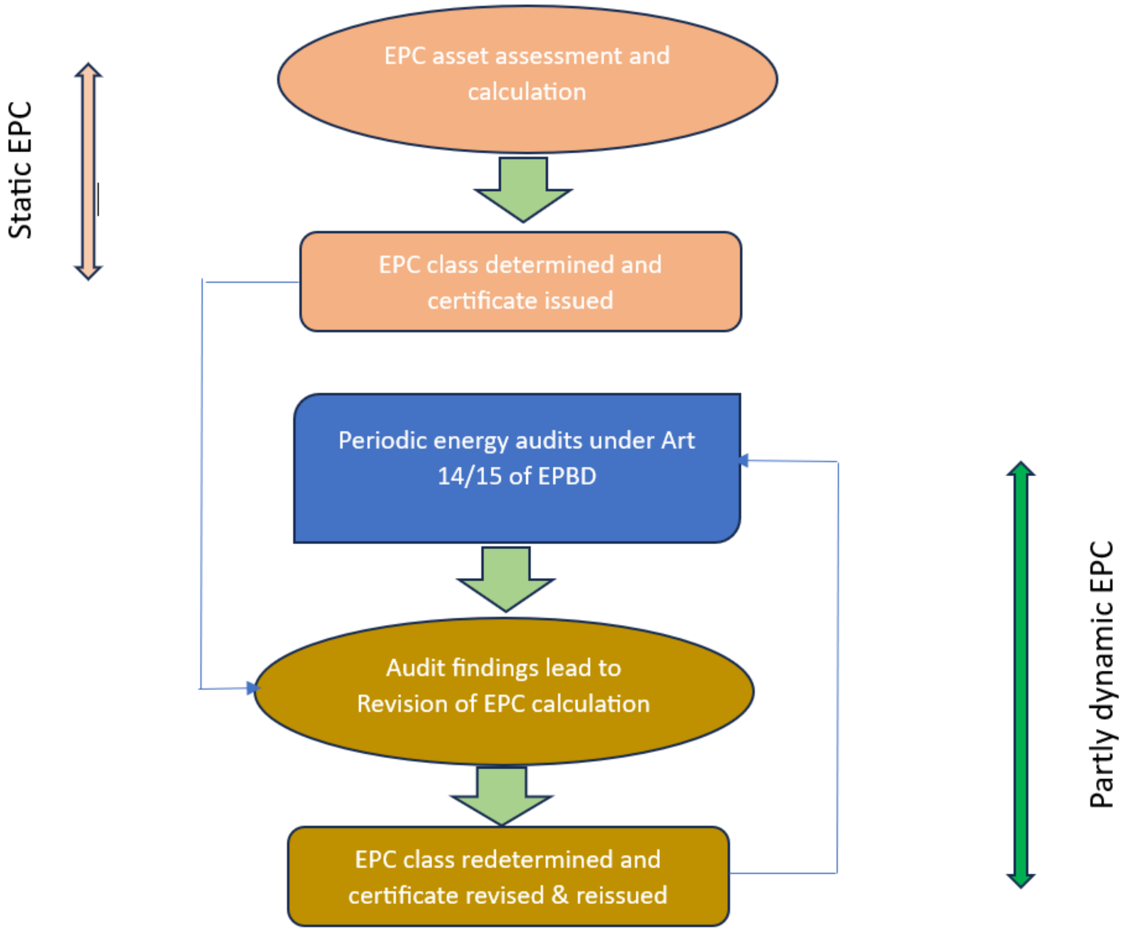


Figure 75. Energy calculation: General structure of heating and DHW standards - EN 15316 - series

Under this schematic if an EPC has been calculated using a standard asset calculation methodology (e.g. aligned with the EN ISO asset calculation methodology for the energy performance of buildings), then the EPC would need to be capable of being updated each time an HVAC and BACS energy performance audit is conducted to reflect the additional information contained within the audit.

Permitting this to happen would be beneficial for the following reasons:

- The HVAC is the dominant part of almost all building’s energy use and thus EPC ratings are sensitive to the performance attributed to it
- The EPBD asset methodology makes a number of assumptions about how the HVAC is operated that may be inaccurate – inclusion of the HVAC audit data would allow the actual performance characteristic to be captured leading to more accurate EPC
- Furthermore if BACS are also audited in line with EN ISO 52120-1 it would allow derivation of simple BAC factors that could be applied within each the EPC asset calculations for each TBS to take into account of the importance of control on their energy use – which is a major gap in most current EPCs

and may be a significant explanatory factor behind the performance gap between asset and operational EPC methodologies

- HVAC systems performance can be adjusted (especially in response to audit recommendations) which would alter the real energy efficiency of the building
- HVAC systems are likely to be upgraded or replaced much more rapidly than the building fabric thus are inherently more dynamic – significant changes in the HVAC characteristics can lead to significant changes in the real energy efficiency of a building and EPCs ought to be better at reflecting (and hence encouraging) upgrades
- Such upgrades or replacements should also be subject to EPBD Article 8(1) and 8(9) requirements regarding the energy performance of technical building systems, thus the audit could both serve as a means of determining the impact that such measures have had while acting as a means of verifying that they have been respected
- Electronic EPC registration systems are already in use in some Member States and in principle such systems could be structured to allow EPCs to be recalculated and reissued (electronically) every time significant changes in the buildings energy performance are reported into the system
- Were such systems to already include the default EPC asset information for the HVAC systems then it would be possible to adapt the data in the system to reflect the audit findings each time an audit is conducted – this would encourage building owners/managers to act upon audit recommendations as doing so would lead to an improved EPC rating
- Such a system would also encourage the owners/managers of buildings subject to periodic HVAC audits to consider upgrading the HVAC system (perhaps through a replacement of all or part of the system) faster than may otherwise be the case as the impact on the EPC rating would be reported at the frequency of the audit. This could be an important stimulus for building owners looking to upgrade the performance to meet minimum EPC rating requirements (now under consideration in the EPBD recast proposals), or simply to demonstrate faster progress in the energy performance of a portfolio of buildings.

For all of the above reasons it makes sense to leverage the value of the HVAC and BACS audits and to use them to both enable a more dynamic (and hence valuable) EPC rating and also to allow audits and EPCs to support the critical Article 8 objectives which are one of the key mechanisms to accelerate the transformation of Europe’s buildings to higher energy efficiency levels. On top of this, the potential value of such audits in reflecting real service delivered and in particular informing insights into the quality of ventilation delivered can also be leveraged through the SmartLivingEPC IAQ/IEQ KPIs. The experience of the Covid19 pandemic has demonstrated how critical IAQ is to minimizing transmission of viruses and hence to health and productivity, and hence the value of this aspect alone is very significant and should be a big motivating factor towards both more common and frequent audits and dynamic EPCs.

6 Conclusions

This version of Deliverable 2.4 highlights the outcomes from the SmartLivingEPC project pilots, demonstrating substantial advancements in assessing energy performance within the built environment. The updated SmartLivingEPC framework now includes an expanded set of results from SRI and LCA for the project's pilots, underscoring the project's innovative approach to energy and non-energy indicators. By integrating a broad spectrum of evaluation parameters, the framework offers a more comprehensive and unified energy performance certification (EPC) system.

The novel EPC framework goes beyond traditional energy consumption metrics by incorporating advanced practices that address multiple dimensions affecting building performance. The inclusion of SRI analysis enhances our understanding of a building's broader environmental, social, and governance impacts. This promotes not only sustainable practices but also responsible resource management across the building's lifecycle. The incorporation of LCA tools allows for a detailed analysis of environmental impacts from the initial construction phase to the end of life, facilitating informed decision-making concerning materials, energy sources, and waste management. This supports the transition toward a lower-carbon future. Furthermore, the framework emphasizes non-energy factors like indoor air quality, thermal comfort, and occupant well-being.

A significant innovation introduced in this deliverable is the application of the EPC framework at the building level. This approach, leads to more precise evaluations of collective energy performance and sustainability attributes. The enhanced use of digital tools and data from BIM, energy audits, and technical inspections facilitates the issuance of smart EPCs, highlighting the project's capability to streamline certification processes and enhance assessment accuracy through digital technologies, including IoT and AI. This version emphasizes the practical implementation of audit recommendations and the potential for audits to be conducted voluntarily, which can significantly extend the impact of the HVAC audits.

Firstly, the integration of diverse evaluation parameters in the SmartLivingEPC framework has led to a comprehensive and harmonized rating system. Unlike traditional energy rating systems that focus solely on energy consumption, the SmartLivingEPC framework incorporates cutting-edge practices and embraces multiple aspects that significantly influence a building's performance. The inclusion of SRI analysis allows for a more holistic understanding of a building's environmental, social, and governance implications, promoting sustainable practices and responsible resource utilization.

Secondly, the adoption of Life Cycle Assessment (LCA) tools within the SmartLivingEPC framework enables a more thorough examination of a building's environmental impact throughout its entire life cycle. By considering factors in cradle-to-gate boundaries, stakeholders can make informed decisions regarding building materials, energy sources, and waste management, contributing to a low-carbon future.

Thirdly, the incorporation of non-energy aspects, such as indoor air quality, thermal comfort, and occupant well-being, underscores the project's commitment to a people-centric approach to building assessment. Recognizing that buildings are spaces for human occupancy, the SmartLivingEPC framework places occupant satisfaction and well-being at the forefront, aiming to enhance the overall quality of life for building users.

The possibility of using audit data to inform and improve EPC ratings would encourage building owners to implement the audit recommendations (thereby raising the impact of the audits), as well as audits to be undertaken voluntarily, i.e., independently of the Article 14/15 requirements, therefore expanding the number of buildings that have such audits and thus again increasing the market transformational effect. The digitalization of the EPC issuance process and the use of data retrieved from BIM, energy audits, and technical inspections have proven to be instrumental in generating smart EPCs. By leveraging digital tools, sensor data, smart meters, and innovations related to the Internet of Things (IoT) and Artificial Intelligence (AI), the SmartLivingEPC project has demonstrated the potential for streamlining the certification procedure and improving the accuracy of assessments.

7 References

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Annex

A.1 Smart Readiness Indicators

A.1.1 Total SRI readiness indicators

Indicator name	**Total smart readiness**	
	Score	Rating
Description	This indicator displays the overall smart readiness score	This indicator displays the overall smart readiness rating
Input	Refer to input data from Section 2.4.1.2	
Sensors	None	
Algorithm	Refer to calculation from Section 2.4.1.2	
Output	Value in %	Value within 7-step scale
Worked example	Refer to calculation from Section 2.4.1.2	
References	SRI assessment package (v4.5) [6].	

A.1.2 SRI readiness score, per technical functionality

Indicator name	**Smart readiness score**, per technical functionality		
	per Energy performance and operation	per Response to user needs	per Energy flexibility
Description	This indicator displays the smart readiness score for the *technical functionality*		
Input	Refer to input data from Section 2.4.1.2		
Sensors	None		
Algorithm	Refer to calculation from Section 2.4.1.2		
Output	Value in %		
Worked example	Refer to calculation from Section 2.4.1.2		
References	SRI assessment package (v4.5) [6].		

A.1.3 SRI readiness score, per impact criterion

Indicator name	**Smart readiness score**, per impact criterion						
	per Energy efficiency	per Maintenance and fault prediction	per Comfort	per Convenience	per Health, well-being, and accessibility	per Information to occupants	per Energy flexibility and storage
Description	This indicator displays the smart readiness score for the *impact criterion*						
Input	Refer to input data from Section 2.4.1.2						
Sensors	None						
Algorithm	Refer to the calculation from Section 2.4.1.2						
Output	Value in %						
Worked example	Refer to the calculation from Section 2.4.1.2						
References	SRI assessment package (v4.5) [6].						

A.1.4 SRI readiness score per technical domain

Indicator name	**Smart readiness score**, per technical domain							
	per Heating	per Domestic Hot Water	per Cooling	per Ventilation	per Lighting	per Dynamic building envelope	per Electricity	per Electric vehicle charging
Description	This indicator displays the smart readiness score for the *technical domain*							
Input	Refer to input data from Section 2.4.1.2							
Sensors	None							
Algorithm	Refer to the calculation from Section 2.4.1.2							
Output	Value in %							

Worked example	Refer to the calculation from Section 2.4.1.2
References	SRI assessment package (v4.5) [6].

A.2 BACS function list

The BAC functions of a BACS are, in general, structured into three functional levels: **management**, **processing functions** for automation and control, and the **interface to field devices**, providing inputs and outputs. Additionally, there are the **operator functions**, which are not assigned to any functional level.

The **management** functions are performed by the software of a BACS. They are used to provide data for storage, evaluation, and display of information. In addition, they are used for definition and selection of data point information from processing functions. They include functionalities such as: communication with devices of the control network and for shared data points; communications for data exchange with dedicated special systems; recording, archiving, and statistical analysis; and decision support.

The **processing functions** are performed by controllers and automation stations. The groups of processing functions are:

The **input and output functions**, which are divided into:

- **Physical input and output functions**. Include all necessary software programs and engineering/commissioning services for recognizing the state and value of inputs and command of outputs. All other processing functions rely on the information provided by these.
- **Shared input and output functions**. Include software and engineering/commissioning services, but not the communication protocol, for data point address, value, state, and status, etc. These functions' information is available for further processing by other functions.

The rest of processing functions, which include:

- **Monitoring functions**. These processing functions are used to monitor input and output functions or the result of other processing functions. Any other function can use their results as virtual data points.
- **Interlock functions**. They require logic (e.g., AND, OR, XOR, NOT) to derive output signals as a combination in input signals.
- **Closed loop control functions**. They process input and output and virtual functions through algorithms (e.g., P, PI, PID) that require feedback from the control medium. Each closed control loop includes one setpoint.
- **Calculation functions**. They are used to calculate derived values for other functions and to provide complex data to a user.
- **Optimisation functions**. They are used for cross plant or cross system energy management to reduce energy consumption and operating costs. For adaptation to varying application needs, the optimisation functions must be provided with adjustable parameters to give flexibility to trained users.
- **Room control functions**. They are used for individual zone control. This is to be developed in EN ISO 16484-4, which is currently under development within ISO/TC 205 WG3 and CEN/TC 247[7].

The **field devices** are generally sensors and actuators, coupling units and local override/indication devices that are connected to input/output interfaces of controllers and automation stations. Field devices can be connected to controllers via field network or direct wiring. The field devices perform connection to the physical items of plant providing the necessary information about the conditions, states and values of the processes and effect the programmed operations.

The **operator functions** refer to human system interface for supervision, alarms, state monitoring and human interaction for operation.

The plant specific functions can be documented in control schematics (following the graphical symbols for diagrams in IEC 60617) and the BACS function list (following the template outlined in EN ISO 16484-3's Annex A and reproduced in this document's Annex A). The BACS function list allows a supplier-independent description

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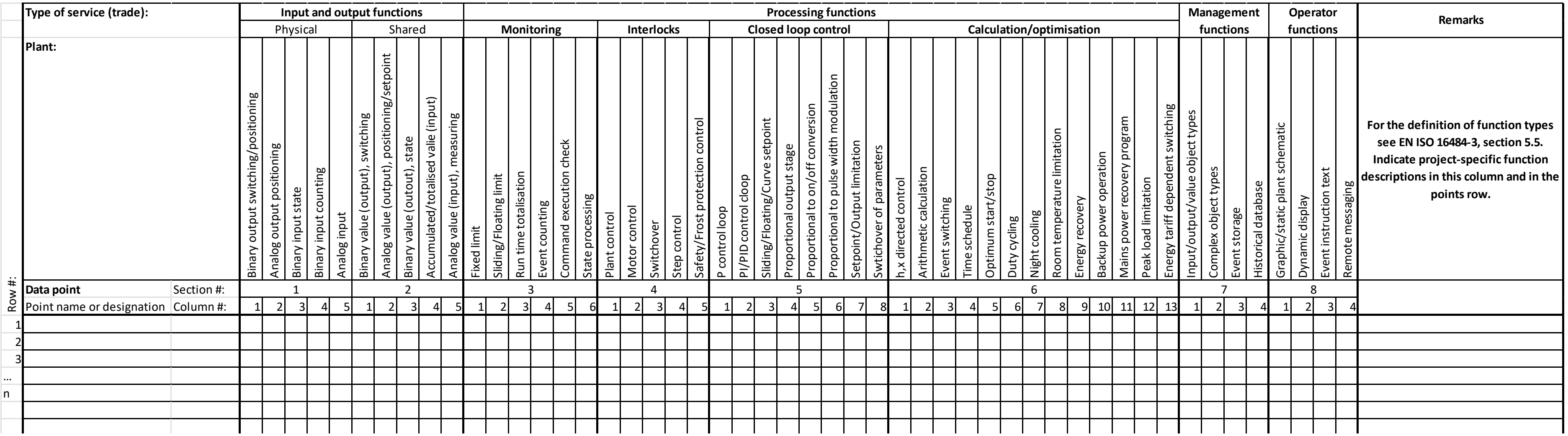
of the control requirements. Some complex projects and/or sophisticated control algorithms for optimal control performance require additional information and methods to describe the requirements in detail.

The BACS function list is a spreadsheet used to document and add up functions. The BACS function list is structured as in Figure 76. The first column corresponds to the data point description or designation. The following columns correspond to the functional levels as introduced in section 2.5.1.1 of this document and further detailed in section 5.5 of EN ISO 16484-3 standard. In the last column, remarks for further description of the function types are included.

The basis for working with the BACS function list is the plant control schematic and, if required, a control flow chart diagram. A recommended method of use is to follow the flow of the main medium (e.g., air, water) in the schematic and fill in the rows with control related plant items for inputs and outputs. Thus, there is a clear correspondence between the data point description or designation in the schematic and in the BACS function list.



	Type of service (trade):		Input and output functions										Processing functions																																Management functions				Operator functions				Remarks
			Physical					Shared					Monitoring						Interlocks					Closed loop control								Calculation/optimisation																					
	Plant:		Binary output switching/positioning	Analog output positioning	Binary input state	Binary input counting	Analog input	Binary value (output), switching	Analog value (output), positioning/setpoint	Binary value (outout), state	Accumulated/totalised valie (input)	Analog value (input), measuring	Fixed limit	Sliding/Floating limit	Run time totalisation	Event counting	Command execution check	State processing	Plant control	Motor control	Switchover	Step control	Safety/Frost protection control	P control loop	PI/PID control cloop	Sliding/Floating/Curve setpoint	Proportional output stage	Proportional to on/off conversion	Proportional to pulse width modulation	Setpoint/Output limitation	Swtichover of parameters	h,x directed control	Arithmetic calculation	Event switching	Time schedule	Optimum start/stop	Duty cycling	Night cooling	Room temperature limitation	Energy recovery	Backup power operation	Mains power recovery program	Peak load limitation	Energy tariff dependent switching	Input/output/value object types	Complex object types	Event storage	Historical database	Graphic/static plant schematic	Dynamic display	Event instruction text	Remote messaging	For the definition of function types see EN ISO 16484-3, section 5.5. Indicate project-specific function descriptions in this column and in the points row.
Row #:	Data point	Section #:	1					2					3						4					5								6													7				8				
	Point name or designation	Column #:	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	6	1	2	3	4	5	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	9	10	11	12	13	1	2	3	4	1	2	3	4	
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Figure 76. BACS function list template. Extracted from EN ISO 16484-3

To describe plant control, processing functions must be combined by filling in the number of functions required in the appropriate column and row of the BACS function list, as combining function blocks. The data points' functionality is given by the type(s) and number of the required functions. It may be necessary to use several columns to convey a particular application function.

A.3 EPB Standard modules

In this section, the EPB standards' modular structure and references from ISO/TR 52010-2 is reproduced.

Table 72. EPB Standards modules and submodules. Reproduced from [32].

Main area	Overarching		Building as such		Technical Building Systems									
					Description	Heating	Cooling	Ventilation	Humidification	Dehumidification	Domestic Hot Water	Lighting	Building automation & control	Electricity production
Module	M1		M2			M3	M4	M5	M6	M7	M8	M9	M10	M11
Submodule	Desc.	Std	Desc.	Std		Std								
1	General	ISO 52000-1 ISO/TR 52000-2	General	-	General	EN 15316-1	EN 16798-9 CEN/TR 16798-4	EN 16798-3 (EN 13779 rev.) CEN/TR 16798-4	EN 16798-3 (EN 13779 rev.) CEN/TR 16798-4	EN 16798-3 (EN 13779 rev.) CEN/TR 16798-	EN 15316-1	EN 15193-1	EN 15232-1 CEN/TR 15232-2	
2	Common terms and definitions; symbols; units and subscripts	ISO 52000-1 ISO/TR 52000-2	Building Energy Needs	ISO 52016-1 ISO 52017-1 ISO/TR 52016-2	Needs						EN 12831-3	prEN 15193-1		
3	Applications	ISO 52000-1 ISO/TR 52000-2	(Free) Indoor conditions without systems		Maximum load and power	EN 12831-1	ISO 52016-1 ISO/TR 52016-2				EN 12831-3			
4	Ways to Express Energy Performance	ISO 52003-1 ISO 52003-2	Ways to Express Energy Performance	ISO 52018-1 ISO/TR 52018-2	Ways to Express Energy Performance	EN 15316-1	EN 16798-9 CEN/TR 16798-10	EN 16798-3 (EN 13779 rev.) CEN/TR 16798-4	EN 16798-3 (EN 13779 rev.) CEN/TR 16798-4	EN 16798-3 (EN 13779 rev.) CEN/TR 16798-4	EN 15316-1	EN 15193-1 CEN/TR 15193-2	EN 15232-1 CEN/TR 15232-2	

5	Building Functions and Building Boundaries	ISO 52000-1 ISO/TR 52000-2	Heat Transfer by Transmission	ISO 13789 ISO 13370 ISO 6946 ISO 10211 ISO 14683 ISO/TR 52019-2 ISO 10077-1 ISO 10077-2 ISO 12631	Emission & control	EN 15316-2 EN 1500 CEN/TR 15500 EN 12098-1 CEN/TR 12098-1 EN 12098-3 CEN/TR 12098-3 EN 12098-5 CEN/TR 12098-5	15316-2 EN 15500 CEN/TR 15500	EN 16798-7CEN/TR 16798-8 EN 15500 CEN/TR 15500	EN 16798-5-1 EN 16798-5-2 CEN/TR 16798-6-1 CEN/TR 16798-6-2	EN 16798-5-1 EN 16798-5-2 CEN/TR 16798-6-1 CEN/TR 16798-6-2			EN 15232-1 CEN/TR 15232	
6	Building Occupancy and Operating Conditions	EN 16798-1 CEN/TR 16798-2 [ISO 17772-1, ISO/TR 17772-2 (to be published)]	Heat Transfer by Infiltration and Ventilation	ISO 13789	Distribution & control	EN 15316-3 EN 12098-1 CEN/TR 12098-1 EN 12098-3 CEN/TR 12098-3 EN 12098-5 CEN/TR 12098-5	EN 15316-3	EN 16798-5-1 EN 16798-5-2 CEN/TR 16798-6-1 CEN/TR 16798-6-2			EN 15316-3		EN 15232-1 CEN/TR 15232-2	
7	Aggregation of Energy Services and Energy Carriers	ISO 52000-1 ISO/TR 52000-2	Internal Heat Gains	See M1-6	Storage & control	EN 15316-5 EN 12098-1 CEN/TR 12098-1 EN 12098-3 CEN/TR 12098-3 EN 12098-5 CEN/TR 12098-5	EN 16798-15 CEN/TR 16798-16				EN 15316-5 EN 15316-4-3		EN 15232-1 CEN/TR 15232-2	

8	Building Zoning	ISO 52000-1 ISO/TR 52000-2	Solar Heat Gains	ISO 52022-3ISO 52022-1ISO/TR 52022-2	Generation & control	EN 12098-1 CEN/TR 12098-1 EN 12098-3 CEN/TR 12098-3 EN 12098-5 CEN/TR 12098-5 EN 15316-4-1 EN 15316-4-2 EN 15316-4-3 EN 15316-4-4 EN 15316-4-5 EN 15316-4-6 EN 15316-4-8	EN 16798-13CEN/TR 16798-14 EN 15316-4-2 EN 15316-4-5	EN 16798-5-1 EN 16798-5-2 CEN/TR 16798-6-1 CEN/TR 16798-6-2	EN 16798-5-1 EN 16798-5-2 CEN/TR 16798-6-1 CEN/TR 16798-6-2	EN 16798-5-1 EN 16798-5-2 CEN/TR 16798-6-1 CEN/TR 16798-6-22	EN 15316-4-1 EN 15316-4-2 EN 15316-4-3 EN 15316-4-4 EN 15316-4-5 EN 15316-4-6		EN 15232-1 CEN/TR 15232-2	EN 15316-4-3 EN 15316-4-4 EN 15316-4-5 EN 15316-4-7
9	Calculated Energy Performance	ISO 52000-1 ISO/TR 52000-2	Building Dynamics (thermal mass)	ISO 13786	Load dispatching and operating conditions								EN 15232-1 CEN/TR 15232-2	
10	Measured Energy Performance	ISO 52000-1 ISO/TR 52000-2	Measured Energy Performance		Measured Energy Performance	EN 15378-3					EN 15378-3	EN 15193-1 CEN/TR 15193-2	EN 15232-1 CEN/TR 15232-2	
11	Inspection		Inspection	(existing standards on IR inspection, airtightness, ...)	Inspection	EN 15378-1	EN 16798-17 CEN/TR 16798-18	EN 16798-17 CEN/TR 16798-18	EN 16798-17 CEN/TR 16798-18	EN 16798-17 CEN/TR 16798-18	EN 15378-1	EN 15193-1 CEN/TR 15193-2	WI 00247092	
12	Ways to Express Indoor Comfort	EN 16798-1CEN/TR 16798-2(ISO 17772-1, ISO/TR 17772-2)			BMS								WI 00247093	
13	External Environment Conditions	ISO 52010-1ISO/TR 52010-2												
14	Economic Calculation	EN 15459-1												

A.4 SRI functionality levels assignment to BAC efficiency classes

In this section, an adaptation of Table 3 in EN ISO 52120-1 is introduced, outlining the equivalence of the SRI *functionality levels* with BAC efficiency classes.

Table 73. Adaptation of function list and assignment to BAC efficiency class. SRI's Heating technical domain.

BAC and TBM function description, adapted from European standards		SRI assessment (v4.5)		Efficiency class definition	
		Smart ready service code	***Functionality level***	**Residential buildings**	**Non-residential buildings**
Emission control	The **objective** is to adjust the heat delivered at room level, preferably by applying the control function to the heat emitter. *All heat emitters included, except for TABS.*	**H-1a**	-	-	-
Control functions	No automatic control of the room temperature.		0	D	D
	Only central automatic control, indirectly controlling one or more rooms by acting either on the distribution or on the generation without consideration of local demand of different rooms. *The heat delivered at the room is adjusted by a control function non-exclusive of the room to be controlled. Thus, it assumes similar thermal demand in different parts of the building.*		1	D	D
	Individual automatic room control. *The heat delivered at the room is adjusted by a control function exclusive of the room to be controlled without any information exchange outside the controlled room.*		2	C	C
	Individual room control with communication between controllers and BACS. *The heat delivered at the room is adjusted by a control function exclusive of the room to be controlled with information exchange outside the controlled room.*		3	B	B
	Individual room control with communication between controllers and BACS and demand detection-control. *The heat delivered at the room is adjusted by a control function, coupled with occupancy detection, exclusive of the room to be controlled with information exchange outside the controlled room.*		4	A	A

A.5 Environmental life-cycle Indicators

Indicator Name	Indicator Description	Units
Climate change (global warming potential)	Indicator denoting the potential global warming resulting from the discharge of greenhouse gases into the atmosphere. Climate change is the consequence of human-induced emissions on atmospheric radiative forcing, specifically heat radiation absorption, which has been identified as a subject of paramount concern. Subsequently, this phenomenon may yield adverse ramifications on vital components such as ecosystem health, human well-being, and material welfare. The majority of these emissions have been observed to accentuate radiative forcing, leading to an elevation in surface temperatures on Earth, commonly acknowledged as the greenhouse effect. Consequently, this indicator emphasizes the imperative areas of safeguarding, namely human health, the natural environment, and the built environment.	kg CO_2 equivalents per kg [kg CO_2 eq / kg]
Ozone depletion potential	Indicator of emissions to air that causes the destruction of the stratospheric ozone layer.	kg CFC 11 equivalents [kg CFC 11 eq]
Acidification potential	In the realm of environmental phenomena, a reduction in the pH level of rainwater and fog measurements ensues, subsequently eliciting adverse consequences for ecosystems. Such effects manifest in the leaching of soil nutrients and heightened metal solubility into the soil matrix. The ramifications of acidifying pollutants extend across diverse domains, including soil quality, groundwater, surface waters, living organisms, ecosystems, and even the integrity of constructed materials such as buildings. Among the chief contributors to acidification are emissions of sulfur dioxide (SO_2), nitrogen oxides (NOx), and ammonia compounds (NHx). Areas warranting particular	mole H+ equivalents [mol H+ eq.] kg SO_2 equivalents per kg [kg CO_2 eq / kg]

	concern and protection encompass both the natural environment and the constructed urban landscape, as well as human health and the safeguarding of vital natural resources.	
Eutrophication aquatic freshwater	In the realm of freshwater ecosystems, an observable phenomenon emerges in the form of amplified growth measurements of aquatic plants or the proliferation of algal blooms, both of which can be attributed to the elevated presence of nutrients. This influx of nutrients contributes to a state of excessive enrichment, resulting in the exacerbation of aquatic plant growth or the burgeoning of algal populations. Such a scenario warrants scholarly attention, as it pertains to the subject of freshwater ecotoxicity, which delves into the repercussions of toxic substances on the delicate balance and functionality of these vital aquatic environments.	kg P equivalents [kg P eq.]
Eutrophication aquatic marine	Marine ecosystem reaction measurement to excessive availability of a limiting nutrient.	kg N equivalents [kg N eq.]
Eutrophication terrestrial	Enhanced quantification of nutrient accessibility within the soil consequent to the infusion of botanical fertilizers.	mole N equivalents [mol N eq.]
Photochemical ozone formation	Indicator delving into the measurement and subsequent effects of nitrogen oxides (NOx) and non-methane volatile organic compounds (NMVOC) on the domains of 'Human Health' and 'Terrestrial Ecosystems' protection. Emphasizing photo-oxidant formation, which engenders the generation of reactive chemical species such as ozone through solar irradiation on specific primary air pollutants, the research explores the potential deleterious consequences of these reactive compounds on human health and the environment, including detrimental effects on crops. The pertinent areas of protection under scrutiny encompass human health, the built environment, the natural habitat, and essential natural resources.	kg NMVOC equivalents [kg NMVOC eq.]

Depletion of abiotic resources - minerals and metals	Indicator delving into the concept of "abiotic resource depletion," an essential metric for measuring the exhaustion of natural non-fossil resources. Abiotic resources encompass diverse natural sources, such as iron ore, crude oil, and wind energy, which are characterized by their non-living origin. This indicator holds significant prominence within sustainability discussions, and consequently, various methodologies have emerged to characterize contributions to this domain. The divergent approaches adopted in these methodologies often stem from disparities in problem definitions. As a result, the scope of this indicator may encompass solely natural resources or extend to encompass human health and the natural environment, thereby warranting comprehensive consideration.	kg Sb equivalents [kg Sb eq.]
Depletion of abiotic resources – fossil fuel	Indicator of the depletion of natural fossil fuel resources.	Mega Joules [MJ]
Water use	Indicator of the amount of water required to dilute toxic elements emitted into water or soil.	Cubic meters [m^3]
Use stage energy performance	“Operational energy consumption”: primary energy demand measurement of a building in the use stage, generation of low carbon or renewable energy.	kilowatt-hours per square meter per year (kWh/m^2 /yr)
Life cycle Global Warming Potential	“Carbon footprint assessment” or “whole life carbon measurement”: building’s contribution to greenhouse gas (GHG) emissions measurement associated with earth’s global warming or climate change.	kg CO_2 equivalents per square meter per year (kg CO_2 eq./m^2/yr
Bill of quantities, materials, and lifespans	The quantities and mass of construction products and materials, as well as estimation of the lifespans measurement necessary to complete defined parts of the building.	Unit quantities, mass, and years

Construction & demolition waste and materials	In the context of construction, renovation, and demolition activities, the aggregate volume of waste and materials produced serves as the basis for computing the diversion rate pertaining to reuse and recycling, adhering to the principles outlined in the waste hierarchy.	kg of waste and materials per m^2 total useful floor area
Design for adaptability and renovation	Building design extent assessment of facilitation future adaptation to changing occupier needs and property market conditions; a building proxy capacity to continue to fulfill its function and for the possibility to extend its useful service life into the future.	Adaptability score
Design for deconstruction, reuse, and recycling	In the realm of architectural design, the evaluation of the potential for future material recovery and reuse, encompassing disassembly considerations to optimize the ease of deconstructing essential building components, is imperative. This entails a comprehensive assessment of the feasibility of reutilizing and recycling said components, along with their associated sub-assemblies and constituent materials.	Deconstruction score
Use stage water consumption	The comprehensive quantification of water utilization for an average building inhabitant, encompassing the ability to distinguish between potable and non-potable water supplies, as well as facilitating the identification of regions facing water scarcity.	m^3/yr of water per occupant

HE Grant Agreement Number: 101069639
Document ID:
WP2/D2.4

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This project has received funding from the European Union's Horizon Europe research and innovation programme under the grant agreement number 101069639. The European Union is not liable for any use that may be made of the information contained in this document, which is merely representing the authors' view.