EXPLORING INNOVATIVE INDICATORS FOR THE NEXT-GENERATION ENERGY PERFORMANCE CERTIFICATES FEATURES - SMART READINESS INDICATOR

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TABLE OF CONTENT

EXECUTIVE SUMMARY

Energy performance certificate (EPC) schemes have not evolved much since their first introduction in the Member States to meet the mandatory requirements of the Energy Performance of Buildings Directive (EPBD). Stakeholders have questioned their reliability but at the same time, they have been useful for the real estate industry. All the Member States have legislation in place and existing infrastructure or systems to run EPC schemes. These schemes require evolution with the changing needs of the built environment and requirements to look beyond the energy consumption of buildings to take in elements such as better indoor comfort, reducing air pollution and others. Public authorities view them as potential instruments to improve the performance of the existing and new building stock. Extending the functionalities of existing systems will create several pathways to update and manage next-generation EPCs.

This report presents the preliminary scoping and analysis of the five technical features related to developing innovative EPC indicators proposed within X-tendo[1]: (i) smart readiness, (ii) comfort, (iii) outdoor air pollution, (iv) real energy consumption, and (v) district energy. The outcome of this report is an initial mapping and selection of the suitable options of methods for developing indicators for these five features. The follow-up activities in the project will take forward this work to elaborate and provide technical specifications of the methodologies and concepts for the five features.

This report presents an overview of existing assessment approaches and methodologies for each feature that could be adopted in the indicator development for the EPCs. Details are provided of the most suitable existing methods that can be applied in the assessment of five technical indicators when integrated with EPCs. Their suitability and applicability to EPCs is analysed in a broader context, including building typologies and ranking/scoring techniques.

The report also evaluates existing links between these methods and the energy performance of a building/EPCs to determine how these can be integrated in the feature development. Since most of the assessment methods require some type of data related to end-users, therefore, their legal boundaries are also studied. Within the scoping and analysis, a ranking and SWOT analysis of several methods is presented to assess their suitability and feasibility of application in the development of the new features. Finally, a conceptual approach is proposed for the development of each of the five features. Findings are presented, highlighting the barriers, challenges and limitations of the assessment methods for the five features.

[1] In addition to these five features, X-tendo will also provide a set of five features dealing with innovative handling of EPC data.

Across all features, the following conclusions are made:

Indicators

- 'Smart readiness' approach presents a potential method for assessing the smartness of buildings with nine domains (e.g. lighting, ventilation, envelope, monitoring and control etc.)
- 'Comfort' approach incorporates four key indicators – thermal, visual and acoustic comfort and indoor air quality – to be assessed through checklists, on-site measurements and surveys
- 'Outdoor air pollution' approach addresses a building's impact on air by two methods: an outdoor air pollution contribution index and indoor air purity index
- 'Real energy consumption' approach outlines an assessment method based on operational ratings, with options for normalisation to allow for better inter-building comparison
- 'District energy' approach focuses on predicting the potential for future development for buildings via two methods: expected future performance of district heating and heat distribution and transfer system

Cross-cutting issues

- Technical challenges that constrain the application of existing methods such as assessment time, accuracy, normalisation process, variable definitions and emission factors could be overcome by certain modifications in approach
- Features should be aligned financially to increase market acceptance and cost-effective assessments during the development
- Legal and governance issues should be addressed by dealing with challenges such as development of universal methodologies, presence of multiple standards at Member State level, control of citizen data and privacy, and acceptance of future estimations by public authorities
- From a social perspective, user acceptance and public understating of the features are key issues and should be considered in feature development
- If these indicators are well integrated within EPCs, significant environmental benefits are anticipated
- Future implementation of indicators can be strengthened by addressing lack of industry readiness, understanding of anticipated benefits and enforcement issues

Certain limitations need to be overcome to implement these innovative indicators, such as variable levels of implementation in the Member States due to different local requirements and regulations. Some indicators require extensive monitoring and measurements, and a lack or absence of data is a barrier in the development and acceptance of these features within EPC schemes.

A concise overview of all the features is given in Figure 1. Overall, a promising picture is visible with the proposed conceptual approaches for features combining new ideas with existing methods to work towards developing innovative indicators that could be tested and integrated into the EPC schemes of the implementing countries within the X-tendo project.

Smart readiness

- Possible to embed SRI methodology in EPC scheme frameworks
- Data from EPCs can be used in the assessments of SRI
- Emphasis on smart-ready technologies for energy transition
- Tentative assessment method based on checklist criteria

Comfort

- Several methods exist for assessment of comfort indicators
- Limited measurements necessary for annual comfort evaluation
- Thermal comfort and indoor air quality are preferred comfort indicators
- Extensive assessment method requires skilled assessors

Outdoor air pollution

- Interference of buildings, outdoor air pollution and indoor air purity considered
- Standards classfications exists for fuel emissions and air quality
- Simple to set criteria based on readily available data
- Measurement-free approach used on assessment

Real energy consumption

- Multiple methods exists for real energy performance assessment
- Data available easily for good quality results
- Reduced energy performance gap and higher accuracy can be achieved
- Normalised energy consumption necessary for inter-building comparison

District energy

- Standards and calculation methods exist for energy factors
- Current state of indicator integrated in EPC systems will be advanced further
- Role of district heating utilities and authorities important in assessment
- Site visits necessary for evaluation of future potential of district energy

Figure 1: Overview of the five features

1 EXTENDING THE FUNCTIONALITIES OF EPCs WITH INNOVATIVE INDICATORS: SCOPING AND ANALYSIS

Energy performance certificates (EPCs) are the key source of information on the energy performance of the building stock [1]. Their role for the end-user and the real estate sector has mainly been limited to indicating and comparing the energy class of the building, helping to regulate property transaction prices and rents. They have also been attractive for end-users and builders in gaining access to funds and incentives to conduct energy efficiency improvements. EPCs have also been seen as an unreliable source of information by stakeholders in some Member States [2]. Weak enforcement, low public acceptance and awareness, quality of audits, qualifications of the auditors and widely varying certificate costs all influence the role of EPCs and how they can affect the real estate market.

Many Member States stepped up efforts in the last decade to improve their EPC frameworks after the introduction of the requirement of energy performance and assessment systems under the EPBD (2002/91/EC) and EPBD recast (2010/31/EU). The recent amendments in the EPBD (2018/844) further strengthened the existing provisions by setting out that Member States should provide information to owners and tenants on the purpose and objectives of EPCs, energy efficiency measures, and supporting financial instruments through accessible and transparent advisory tools such as direct advice and one-stop-shops.

In the current scenario, EPCs are viewed as instruments that can bring additional benefits to the end-user (e.g. property seller, buyer, or tenant) by being a vehicle for additional information other than energy efficiency.

1.1 Aim of the X-tendo project

The X-tendo project is developing a framework of 10 “next-generation EPC features”, aiming to improve compliance, usability, and reliability of the EPC. The X-tendo partners cover 10 countries or regions – Austria, Belgium (Flanders) Denmark, Estonia, Greece, Italy, Poland, Portugal, Romania, and the UK (Scotland) as displayed in Figure 2.

Figure 2: X-tendo consortium and target countries

The X-tendo project approaches next-generation EPCs by exploring 10 new features in addition to their existing functionalities (see Figure 3). The features that will be explored in the project fall into two broad categories:

- New technical features used within EPC assessment processes and enabling the inclusion of new indicators in EPCs
    1) Smart readiness
    2) Comfort
    3) Outdoor air pollution
    4) Real energy consumption
    5) District energy
- Innovative approaches to handle EPC data and maximise its value for building owners and other end-users.
    6) EPC databases
    7) Building logbook
    8) Tailored recommendations
    9) Financing options
    10) One-stop-shops

Figure 3: The X-tendo toolbox representing both innovative EPC indicators and novel ways of handling EPC data

Existing EPC schemes lack focussed vision. In order to become a catalyst for energy renovations, the next-generation EPC must provide an improved and more reliable service to the end-users. The key output of the project will be the X-tendo toolbox, a freely available online knowledge hub that will be continued beyond the project duration. For each feature, the toolbox would include (i) solution concepts and good practice examples, (ii) descriptions of methodological approaches, (iii) calculation tools, and (iv) implementation guidelines and recommendations.

1.2 Scope and objective of this report

The purpose of this report is to identify suitable methods and approaches to assess the five features (i) smart readiness, (ii) comfort, (iii) outdoor air pollution, (iv) real energy consumption, (v) district energy. Before developing individual methods for their assessment, a detailed review of the existing assessment and calculation methods is presented for developing the indicators for all the five features in this report. Although the goal of the next-generation EPC will be more holistic, the relation with energy performance remains a key boundary condition for the selected approaches presented in this report.

The identification of the suitable methods will consider the objective of the modular toolbox being developed specifically for EPC assessments. The results of the report will be an initial selection of options for methods and indicators for features 1-5. Findings of the scoping and analysis are gathered in this report for these indicators.

Table 1 lists the five innovative EPC indicators that could make EPCs more than just an informative tool. It also indicates the feature leads (VITO, BPIE, NAPE and e-think) who will develop the innovative indicators and organisations (EASt, DEA, TREA, CRES, ENEA, NAPE, ADENE, AAECR and EST) from implementing/expert partner countries that would support them in the development and testing of the indicators on several test projects.

Table 1: Innovative EPC indicators

	 Smart readiness	 Comfort	 Outdoor air pollution	 Real energy consumption	 District energy
Feature lead	*VITO*	*BPIE*	*NAPE*	*VITO*	*e-think*
EASt (Austria/Styria)	Implementer	Implementer		Implementer	
DEA (Denmark)	Implementer	Implementer			Expert
TREA (Estonia)	Implementer/ Expert			Implementer	
CRES (Greece)	Implementer	Implementer			
ENEA (Italy)				Implementer	Implementer
NAPE (Poland)			Implementer/ Expert		Implementer
ADENE (Portugal)		Implementer			
AAECR (Romania)	Implementer	Implementer		Implementer/ Expert	Implementer
EST (UK)				Implementer	

The EPCs can become much more useful for the end-users, public authorities and policymakers by providing more detailed information on the existing building stock and its performance. Next-generation EPCs can support the transition to a low-carbon building sector, provided they are revised considering new indicators, with effective mechanisms to ensure compliance and high quality, reliable certifications.

2 FEATURE 1: SMART READINESS

2.1 Overview of methods to assess the smartness of a building

Besides an important impact on the energy performance, smart buildings improve the quality of life for building users and owners through better comfort, increased safety and improved interaction. Far from the classical definition of a building as a shelter, modern buildings are complex concatenations of structures, systems and technology. Today, it is not enough **for a building to simply contain the systems that provide comfort, light and safety:** it is important to consider the building's impact on the grid and the global environment while continuing to adapt its services to the future needs of the occupants. To do this, a smart building relies on recent technology based on two pillars: connectivity and data. The Internet of Things (IoT) is seen as a way to bridge the gap between the two [3]. On the one hand, the goal of the smart building is to provide the user with the best possible facilities while optimising its resource consumption: obtaining accurate data about the needs of the occupants must be perfectly coupled with secure applications that allow the user to communicate their desires to the building. On the other, a smart building should also be able to play a role in wider energy systems and smart grids (see Figure 4).

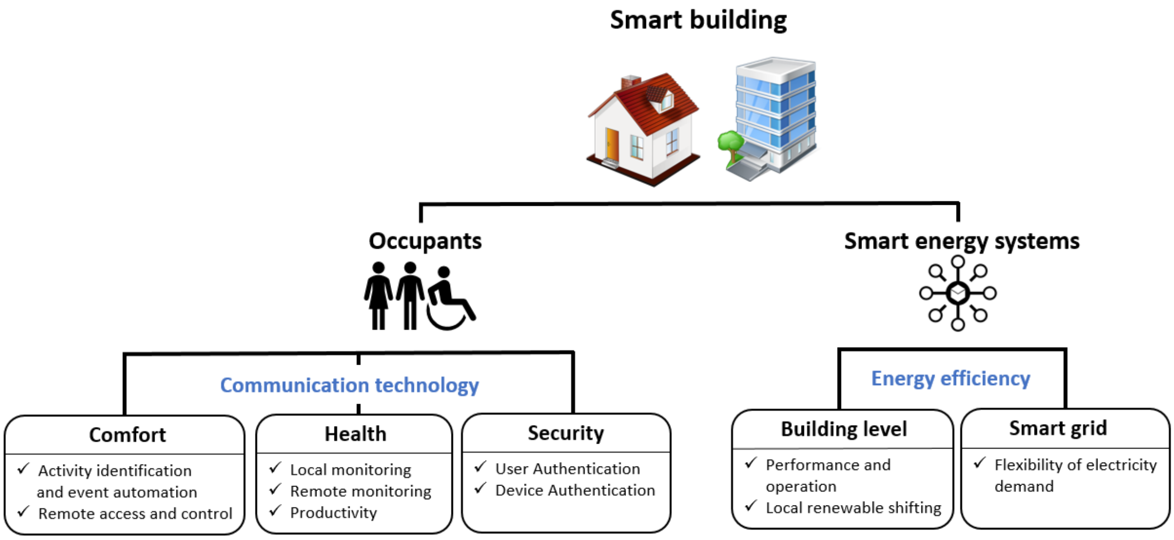

Figure 4: Smart building composition (adapted) [4]

Recent years have seen a large variety of smart building applications being launched on the market to improve building performance but also to satisfy human needs. While the concept and goals of a smart building are well defined [5], there is a growing need for a methodology to assess the degree of the smartness of a building.

As pointed out by Arditi et al. [4], measures regarding the building *modus operandi* are key elements to improve and assess the level of smartness of a building [6]. While some authors argue that the most important aspect to determine the smartness of a building is the ability to measure and monitor its services [7], others propose tangible indicators encompassing measures such as technological adaptability, individual comfort, environmental performance and organisation flexibility [8] or a more simple ratio between performance (in energy used or CO_2 emitted) and a reference building [9].

The Building Intelligence Quotient (BIQ) was proposed by the Continental Automated Building Association (CABA) [10] to rate automation systems in existing large office buildings and to support the implementation of new technologies. This includes measures such as the building automation environment, power distribution, voice and data systems, intelligent building systems features, facility management applications and subsystem operation in degraded mode. Although mainly conceived to evaluate sustainability issues, there are other well-known tools to assess building performance, such as the British Building Research Establishment Environmental Assessment Method (BREEAM), the American Leadership in Energy and Environmental Design (LEED, 2008) and the Hong Kong Building Environmental Assessment Method (HK-BEAM) [11]. Despite the strong similarity and comparable outputs amongst these three indicators [11], there exist some methodology differences between them. For instance, LEED bases its measurements on a direct points system whereas BREEAM weight factors between the distinct categories to calculate a relative target point. Yet performance levels of the baseline buildings are comparable, and less than 5% of buildings on the market receive an excellent score for energy performance for the three indicators.

None of these schemes directly consider the assessment of the capability of the building to communicate or adapt actively to changing situations. However, BREEAM considers new equipment and systems to optimise dynamically the use of energy within the building and a management plan to facilitate the operation of the building systems. Likewise, LEED promotes operational efficiency by including in its evaluation the presence of intelligent/automated technologies that contribute to reduce energy or water consumption.

Following the methodology of these schemes, other new systems have been developed to assess energy efficiency for specific building cases. The Labs21 Environmental Performance Criteria is a rating system to assess the environmental performance of laboratory facilities. Laboratories present a unique challenge for energy efficient and sustainable design, with their inherent complexity of systems and health and safety requirements. The typical laboratory is about five times as energy intensive as a typical office building and costs about three times as much per unit area [12].

More difficult still is the evaluation of the smartness of a building from an occupant point of view. A recent study used factor analyses to identify the features that makes a building smart from a user's perspective [13]. Results showed the existence of two diverse groups based on their reported perception of smart building functionalities. Group 1 was composed of professionals within "trading, banking and finance, engineering and construction" and Group 2 included professionals within the "information and communication" industry. While both groups chose technologies within the "smart building indoor environment" and "eco and social spaces" domains as essential parts of a smart building, Group 1 selected the "smart building skin" whereas Group 2 selected "intelligent information systems". This result is interesting because it shows that the smartness of a building as perceived by its users relies strongly on their background and experience. Furthermore, the results also show the privacy paradox of smart and sustainable buildings, with users rating "security systems" as the most important feature but indicating "an intelligent system which monitors people" as the least important [13].

Other wide-ranging building performance indicators are the European Level(s) [14], the Smartness Index (SI) [6], and the recent R2G scheme and DGNB system of awards [15]. The Level(s) scheme was developed as a common EU framework to evaluate the sustainability of office and residential buildings. It provides a set of indicators and common metrics for measuring the performance of buildings across their life cycle. It includes environmental performance, health and comfort, life-cycle cost and potential future risks to performance. The Smartness Index includes an experimental study in the construction industry in the US to identify several performance components across the economic, energy and occupant-related domains. The results of this work also suggested that designers and owners are more focused on energy issues than constructors and that professionals with fewer years of experience pay more attention to energy-related issues [6]. This is important because it illustrates the importance that the energy efficiency of a building is gaining over time.

The Ready2Grids (R2G) scheme was developed by the French Smart Building Alliance and the certifying body Certivéa to assess the level of services that a building can provide. This scheme stresses the need not only to cover the facilities inside a building but also its capacity to connect to other buildings in the grid. The R2G will include three complementary levels of performance, namely the capacity of the building (i) to communicate its consumption to the grid, (ii) to predict and communicate its energy needs and (iii) to adapt its services to the availability of energy in the grid. Finally, the DGNB 'Climate Positive' award is a recent initiative from the German Sustainable Building Council to reward buildings that make a positive contribution to achieving climate protection goals. To evaluate net values, the DGNB examines the absolute greenhouse gas emissions of a building in use, looking specifically at values for a period of one year [15].

Table 2 presents a benchmarking of the different schemes reviewed, highlighting the development of the concept of 'smartness' in buildings over the years.

Table 2: Benchmarking of different rating systems and schemes

	LEED	BREEAM	HKBEAM	BIQ	EPC-Labs21	SI	Level(s)	R2G	DGNB	SRI
Year	1998	1990	1996	2009	2002	2015	2017	*2018*	2019	*In progress*
Country	United States	United Kingdom	Hong Kong	Canada	United States	United States	EU	France	Germany	EU
Status of the scheme	In use	In use	In use	In use	In use	Study proposition	Testing phase	Testing phase	In use	Testing phase
Assessment method	Feature-specific criteria and energy cost budget method	Mixture of performance-based and feature-specific criteria	Performance-based and feature-specific criteria	Score system	Extension of LEED – Increased nbr of points (from 69 to 85)	Score system including economic, energy and occupant performance	System of scores by levels		System of points based on 3 energy efficiency indicators	Mixture of performance-based and feature-specific criteria
Type of assessment	On-site: US-GBC	On-site: Trained assessors	Online & On-site	Online	Online & On-site	Online & On-site			On-site	Online & On-site
Targeted building typology	Residential and non-residential	Residential and non-residential	Residential and non-residential	Office buildings	Laboratory buildings	Construction industry in the US	Residential and non-residential	Residential and non-residential	Residential and non-residential	Residential and non-residential
Age of building	New	New and existing	New and existing	New	New and existing	New	New and existing	New and existing	New and existing	New and existing
Strengths	No need for an assessor or training	Most largely implemented scheme (>250 000 buildings)	Different versions for new and old buildings	Easy implementation	Includes life-cycle costing processes	Includes economic performance	Considers value creation and risk factors	Grid flexibility	Award including occupant behaviour	Large scope (UE) and uniqueness of the solution
Weaknesses	US adapted	Cost	Lower inclusion criteria	Only targets existing office buildings	Only for laboratory facilities	US adapted	Not direct measure of "smartness" components	Specificity on the connectivity attribute	Reduced scope of application	Not launched yet

The development of a smart readiness indicator (SRI) in Europe

The revised EPBD (2018/844/EU) formalised the need for a common EU scheme for rating the smart readiness of buildings: the so called "smart readiness indicator" (SRI). The goal of the SRI is to provide a common methodology to assess the capacity of a building to use information and communication technologies and electronic systems to adapt its operation to the needs of the occupants and the grid and to improve the energy efficiency and overall performance of buildings. The SRI methodology is still under development and its approval agenda extends over the next two years [16]. Other European Commission funded projects relevant to the development of the SRI and future EPC schemes are: the U-Cert, a Dutch coordinated project started in 2019 intending to make the new certification schemes more practical and reliable via an holistic and user-centred approach; HOLISDER, a project coordinated in Spain and started at the end of 2017, focusing on the development of smart technologies at the building level to reduce energy consumption; and HOPE-ON, a small initiative developed by a local Swedish company in 2017 to create an holistic open platform to manage building appliances. Other EU projects indirectly affect the future of the SRI and EPC: BUILD UPON2, coordinated in Spain and started in 2019, intends to develop national strategies to improve the renovation rate across EU countries; IDEAS, started in Ireland in 2019, seeks to develop an innovative cost-effective building relying on renewable energy systems and adapted to the different European climate zones; and the NEWCOM and Fit-to-nZEB projects, coordinated in Austria and Bulgaria respectively, which aim at improving the qualification and certification of the blue-collar workers who inspect and control the buildings.

Most of these programmes are quite recent and are still ongoing. However, some of the first theoretical conceptualisation papers are promising and are already raising important questions for future building energy management systems. For instance, in an article written within the project HOLISDER, the authors described the need to involve final users to achieve good energy systems optimisation. They argue that smart home systems are insufficient to achieve desirable performances without a well-defined human-centric demand response programme supported by information [17].

2.2 Detailed SRI approach and calculation method

As discussed in the previous section most of the methods used in assessment and rating schemes fall far behind in 'smartness' aspects compared to the SRI method already being developed. Therefore, the focus of this and upcoming sections will be only on the SRI method and how it can be used for the development of the indicator for EPCs.

The SRI covers impacts related to the three pillars defined in the amended EPBD, namely (i) energy performance of the building, (ii) building users, and (iii) energy grid. During the revised version (2nd technical study) of the of the SRI methodology [16], nine relevant domains and seven impact criteria were identified:

Domains (see Figure 5)

1. **Heating:** thermal storage, emission control systems, generators and energy consumption for space heating
2. **Cooling:** thermal storage, emission control systems, generators and energy consumption for space cooling.
3. **Domestic hot water:** services dealing with the smarter control of generating, storing, and distributing potable hot water in a building.
4. **Controlled ventilation:** services for air flow control and indoor temperature control.
5. **Lighting:** electric lighting managed/controlled by a lighting system based on, for instance, time, daylight and occupancy.
6. **Dynamic building envelope:** control of openings and sun shading systems and/or windows.
7. **Electricity:** both on-site renewables and storage (and in the future, potentially plug loads).
8. **Electric vehicle charging:** technical services provided by buildings to electric vehicles (EV) through recharging points, e.g. for electric consumption management and storage capabilities.
9. **Monitoring and control:** sensor data which can be provided by technical building systems (TBS) and used by other services, and/or be combined into one overarching system such as a home energy management system (HEMS).

Figure 5: Visualisation of the nine domains covering the pillars defined in the amended EPBD

Impact criteria (see Figure 6)

1. **Energy efficiency** refers to the impacts of smart-ready services on energy saving capabilities. It is not the whole energy performance of buildings that is considered, but only the contribution made to this by smart technologies, e.g. energy savings resulting from better control of room temperature settings.
2. **Maintenance and fault prediction**: automated fault detection and diagnosis has the potential to significantly improve maintenance and operation of the TBS, eventually leading to better energy performance.
3. **Comfort** refers to the impacts of *services* on occupants' comfort, being the conscious and unconscious perception of the physical environment, including thermal comfort, acoustic comfort, and visual performance. This criterion differs from the 'comfort feature' in X-tendo as it focuses only on the systems/services of the building whereas the feature covers a broad range of assessments.
4. **Convenience** refers to the impacts of services on convenience for occupants, i.e. the extent to which services "make life easier" for the occupant, such as by requiring fewer manual interactions to control the TBS.

5. **Health and well-being** refer to the impacts of services on the well-being and health of occupants. Not being harmful in this respect is a strict boundary condition required of all services included in the SRI assessment. This category valourises the additional positive impact that some services could also provide, e.g. smarter controls could deliver an improved indoor air quality compared to traditional controls, thus raising occupants' well-being.
6. **Information to occupants** refers to the impacts of services on the provision of information on a building's operation to occupants.
7. **Energy flexibility and storage** refers to the impacts of services on the energy flexibility potential of a building.

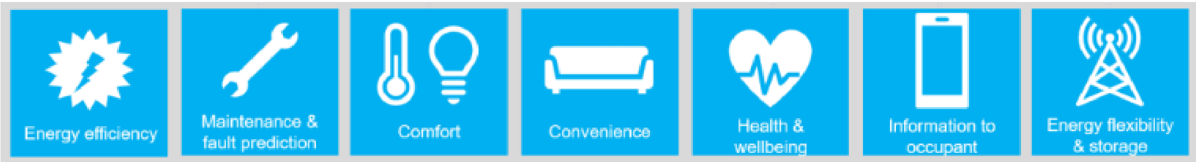

Figure 6: Visualisation of the seven impact criteria covering the pillars defined in the amended EPBD

NOTE: the development of certain smart readiness technologies within the building might be conditioned/strongly affected by the presence of smart metering technology. Smart meters will allow building users to engage with an in-home display which will provide real-time feedback on the effect of their behaviour on energy consumption and will support other forms of feedback and advice. Their presence has a direct impact on the availability of certain functionality levels for various domains. For instance, real consumption inputs are essential to provide users with daily information about their energy consumption.

2.2.1 How is the SRI calculated?

The smart readiness score of a building is a percentage that expresses how close (or far) the building is from maximal smart readiness. The higher the percentage is, the smarter the building. The total SRI score is based on the average of total scores on seven impact criteria and is measured as follows:

1. **Theoretical maximum calculation**: In a first step, an individual assessment calculates the theoretical maximum score that is achievable for each of the seven impact criteria in the building. The characteristics of each building mean that not every domain will be relevant in the score calculation of each impact criterion.
2. **Aggregated impact score per domain:** An aggregated impact score is then calculated for each of the nine domains as the ratio between individual scores and the theoretical maximum for that domain.
3. **Total impact score by impact criterion:** For each impact criterion, a total impact score is then calculated as a weighted sum of the domain impact scores. In this calculation, the weight of a given domain will depend on its relative importance for the impact being considered.
4. **Final SRI score:** The SRI score is then derived as a weighted sum of the seven total impact scores.

The SRI score is then calculated as:

$$N = A \times a + B \times b + C \times c + D \times d + E \times e + F \times f + G \times g$$

where:

- N is the total SRI score, weighted by domain
- A = the impact score (0–100) for energy savings on-site
- B = the impact score (0–100) for flexibility of the grid and storage
- C = the impact score (0–100) for comfort
- D = the impact score (0–100) for convenience
- E = the impact score (0–100) for health and well-being
- F = the impact score (0–100) for maintenance and fault prediction
- G = the impact score (0–100) for information to occupants
- a = the impact weighting (0–100%) for energy savings
- b = the impact weighting (0–100%) for flexibility of the grid and storage
- c = the impact weighting (0–100%) for comfort
- d = the impact weighting (0–100%) for convenience
- e = the impact weighting (0–100%) for health and well-being
- f = the impact weighting (0–100%) for maintenance and fault prediction
- g = the impact weighting (0–100%) for information to occupants.

The final aggregate score thus represents an overall percentage of the maximum score which the building could achieve (refer to Figure 7 to see how some of the non-eligible scores are marked as "-").

Given their nature, it is logical to deem that the different impact criteria have a specific weight. For example, the services in the heating domain might jointly account for 60% of the obtainable score for the "energy savings" impact category, whereas for other impacts such as "convenience" or "comfort", the relative weight of the heating domain is lower, e.g. 25%.

2.2.2 How are the weighting factors defined?

Following this idea, factors are weighted following a hybrid approach in which some have a fixed score and some a variable one:

For the impact criteria:

- Impact criteria "energy savings on-site", "maintenance and fault prediction", and "energy flexibility and storage" will be balanced based on their direct impact on the energy savings of the building.
- Since no objective sources are available yet, the impact criteria corresponding to the needs of occupants ("comfort", "convenience", "information to occupants", and "health and well-being") will follow an equal weighting.

For the domains:

- Since the contribution of the domain "monitoring and control" can be derived from the energy balance in all the domains, a fixed weighted value of 20% will be assigned to this domain over the seven impact criteria.
- Comparably, "dynamic envelope" will receive a fixed weighted value of 5% for all the impact criteria not related to the user's needs.

Figure 7 below shows a visual representation of the weighted approach. For example, for 'energy savings and operation' the weighting sums to 100% for two impact criteria (energy savings and maintenance & prediction) with energy balance method (75%), fixed weight (5%) and fixed weight (20%) in the respective domains in the left. By their nature, some domains have no effect on certain impact criteria. For example, "health and well-being" is only affected by the domains of ventilation, lighting, heating, cooling, and dynamic envelope, whereas the EV domain will not be assessed in the impact criteria of comfort or health and well-being.

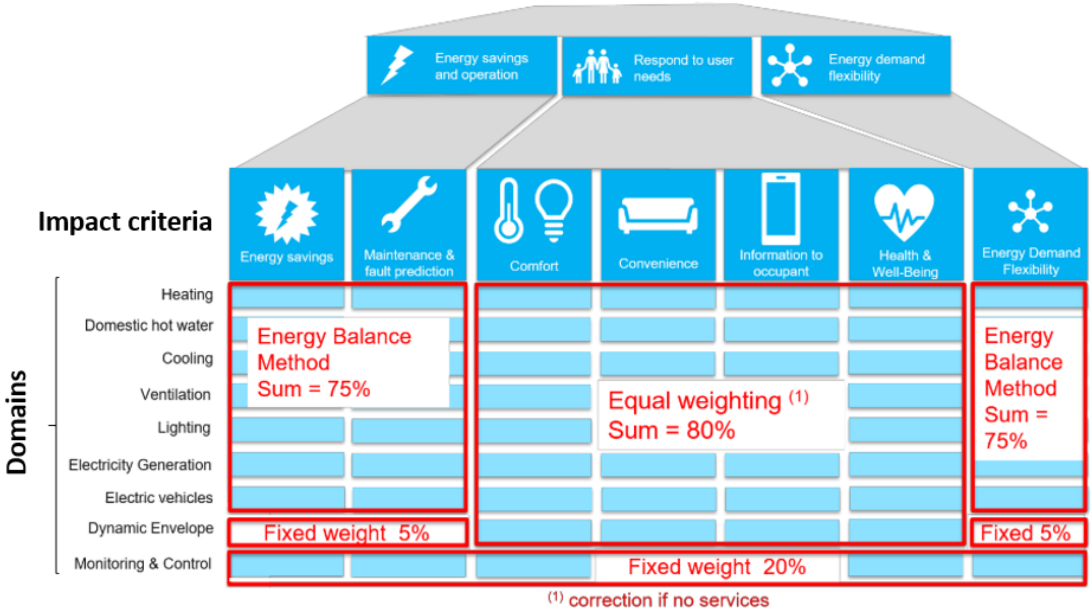

Figure 7: Visual representation of the weighted approach by impact criteria and domain

2.2.3 Which is the specific value of each impact criteria in the final SRI score?

When assigning the specific weight of the different impact criteria, we need to consider (i) the quantified degree of smartness related to the EPBD targets in terms of energy efficiency, and (ii) the ability to communicate these impact criteria to the public.

Taking these into account, equal weight was assigned for the three EPBD targets (33.3%) (see Figure 8):

- 33% for "energy savings and operation", divided into 16.7% each for "energy savings" and "maintenance & fault prediction".
- 33% for "user needs", divided into 8.3% each for "comfort", "convenience", "health and well-being" and "information to occupants"
- 33% for "energy flexibility and storage"

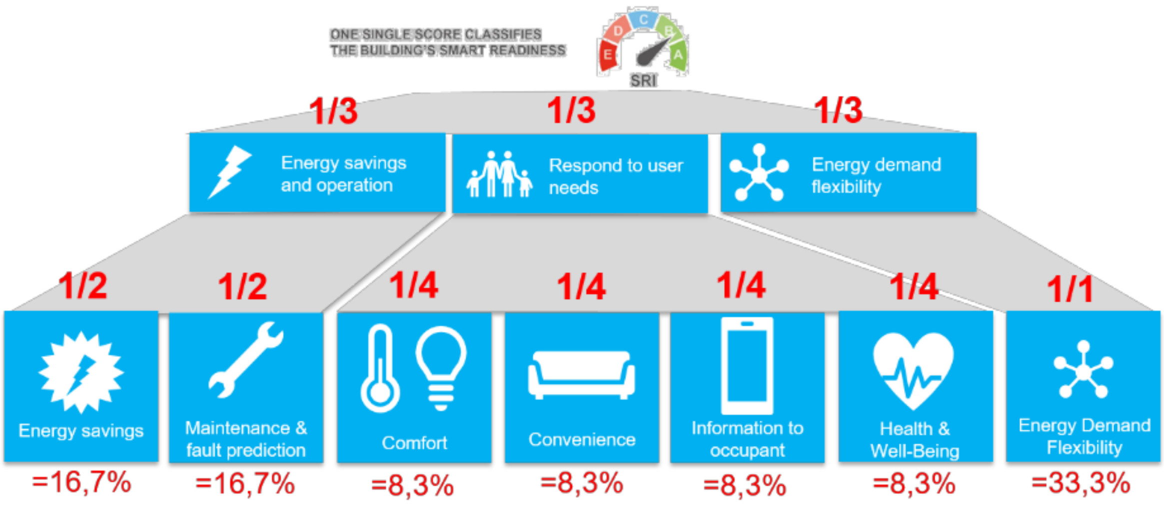

Figure 8: Aggregation of impact scores to a single score

Climate adjustment

Although still under discussion, the development of the SRI methodology includes tentative schemas to adjust the impact of the different domains to the diverse European climates: North, West, South, North-East and South-East. Based on systematic evidence, a weighted score is calculated for each of the domains separately for residential and non-residential buildings. Some domains, such as the dynamic envelope of the building or monitoring and control, have fixed values.

Selection of building-relevant domains: Triage

It is highly likely that due to local and site-specific contexts, some domains and services are not relevant, not applicable, or not desirable. For instance, the climate conditions can mean a building does not have a need for cooling, or the structural shape that it cannot support EV charging. The SRI methodology accommodates this by performing a triage process to identify the relevant services for a specific building, considering:

- The distinction between smart-ready (smart ready technologies (SRT) are already installed) and smart-possible (SRT can be installed) concepts
- The fact that the SRI should incentivise the uptake of SRTs
- The potential mutual exclusivity between some services
- The fact that some services might not be desirable from a policy perspective[2]
- Transparency of the assessed domains rather than comparability is preferred

[2] As a guiding principle, it could be considered that all services that are mandatory in a Member State's building code are mandatory in the SRI.

To this end, the solution communicates all the relevant scores (including the building score, the building maximum score and the theoretical maximum score; see Figure 9) and shows the domains not eligible for the building greyed out.

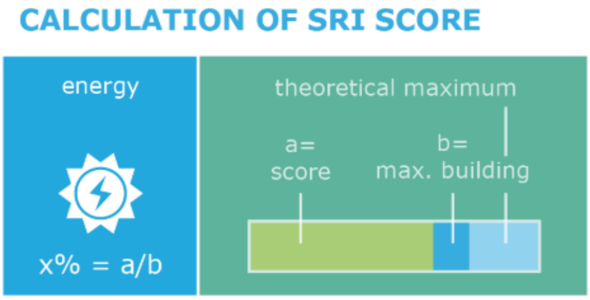

Figure 9: SRI score based on the maximum obtainable score per building

2.2.4 Proposed SRI assessment methods

Three methods are foreseen to assess SRI score (see Table 3). The scope of the methods is currently tentative. Additional guidelines may be developed by the EC and/or Member States to further specify the applicability and scope of the methods. Importantly, method C is not being developed currently, but is envisioned as a potential future evolution of the SRI methodology.

In the context of SRI feature in X-tendo the focus will be only on developing method A considering its suitability to the EPC schemes, as explained further in Section 2.8.

Table 3: Comparison of SRI assessment methods

	A – Simplified online quick-scan*	B – Expert SRI assessment	C – In-use smart building performance
Method	Checklist approach	Checklist approach	Measured / metered data
Means	Online	On-site inspection	In-use buildings
By whom	Self-assessment	Third-party qualified expert	TBS self-reporting their actual performance
Duration	15 minutes	Few hours	Data gathered over a long period (e.g. 1 year)
(tentative) scope	Residential buildings + non-residential	Non-residential + residential	Non-residential + residential (restricted occupied buildings)

NOTE: *With the aim to simplify method A and promote its use by the general public, the number of services to be assessed might be reduced from 54 to 27 (including items in the topics of "controllability and performance", "storage & connectivity" and "reporting of functionalities").*

2.3 Application of SRI assessment methods for the indicator

2.3.1 Use of methods for EPCs

The application of all the above-mentioned methods is independent of the EPC system, even when some of them share similar methodological calculations and could benefit from a parallel application (see Section 2.4 for more information). The experience of EPCs is not only relevant to the SRI with regard to the implementation but also to its methodology [16]. Indeed, both EPC and SRI stem from the EPBD so streamlining could work both ways. SRI could aim to leverage efforts made with existing schemes such as EPCs, HVAC inspectors, building inspectors, sustainability assessors etc. to make use of the existing training/accreditation and certification infrastructure to speed up the throughput and reduce the costs associated with establishing a pool of qualified assessors.

2.3.2 Applicability of methods to different building typologies

Most of the schemes in Table 2 consider the assessment of both new and existing buildings. The SRI is designed to be applicable to all building types (residential and non-residential), and to both new and existing buildings. At EU level, the indicator is not mandatory so far and its future applicability is expected to depend on each Member State [16]. Since the SRI relies on the use of new ICT and IoT, new buildings are likely to score better on this indicator. Nevertheless, new buildings represent only a small part of the EU building stock, so applying the SRI only to them would significantly limit its use; the SRI is designed to evaluate existing buildings as well. From a broad perspective, SRI could be used as an incentive to keep buildings up-to-date and motivate high quality and high energy efficiency renovation.

The SRI might be key to helping existing buildings to achieve the goal of becoming nearly zero-energy buildings (nZEBs) without adding excessive materials and equipment, as it relies on relevant information (sometimes cheap to install) to optimise the overall building energy consumption. Importantly, the ongoing second technical study of the SRI includes the definition of the SRI features and calculation methodology, as well as an analysis of the value proposition and potential implementation pathways [16]. However, final decisions regarding the scope of its application (new vs. existing buildings) and the updating procedure of the SRI are part of the implementation process, starting in 2020.

Although most of the schemes consider the assessment of both residential and non-residential buildings, there are some indicators which have been developed to apply to one specific type of building. This is the case of the BIQ for laboratory facilities or the BIQ for office buildings.

Table 2 shows a schematic view of the different targeted buildings assessed in each of the schemes. Regarding the SRI, its inherent automation makes it ideal to contribute to the efficient management of common use buildings such as offices, department stores, hospitals, schools or museums. Yet the dependency on personal information on which this technology relies makes it especially interesting in the context of private buildings, such as residential homes or retail premises. This is especially relevant when the collected data is properly processed and transmitted to the final user, which enables personalisation of services.

2.3.3 Presentation of the indicator

The images used and the structure of the SRI aim to provide direct and clear information about the building's smart-ready technology (SRT) while facilitating its understanding by the public (not only experts). The buildings EPC and the energy label for household appliances are positive examples of members of the public, not only experts, using information like this when it comes to purchasing decisions. This suggests that the visual organisation of the information will determine its success and impact. Mnemonics can be used to simplify the processing and retention of information as well as to enable a comparison, while colour ranking, number of stars or series of numbers are commonly employed. Given the wide scope of user needs and potential implementation pathways, it is likely that offering a spectrum of media to communicate the SRI assessment and hierarchical layers of informational depth will offer the most value to the target audiences. An SRI score of 100%, meaning ideal inclusion of SRT within the building, could be indicated by a dark green colour. Furthermore, the assessment of the SRI will present (1) a total score for each building, complemented by three sub-scores ("energy savings and operation", "respond to user needs" and "energy demand flexibility") including seven impact criteria (see Figure 10).

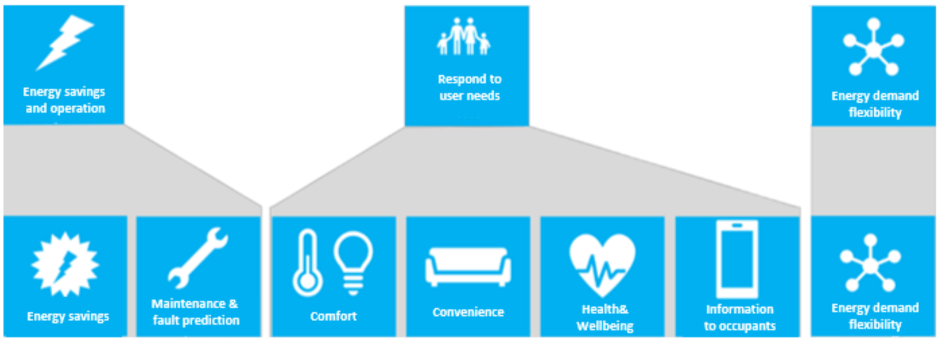

Figure 10: SRI sublabel and impact criteria

Each of the impact criteria is then assessed based on nine different domains gathering the diverse aspects a smart building needs to perform against. A 9x7 matrix containing the different scores per impact criteria/domain can be thus created (see Figure 11; "*note that SRI methodology is still under investigation and that the final format might be different").* This is important because SRI contains information that can be presented at multiple levels. Therefore, at the sub-aggregate level it contains information on intrinsically more tangible aspects such as the energy efficiency performance of a control solution for a specific technical building system, or the delivery of indoor air quality.

IMPACTS

DOMAINS	Energy efficiency	Maintenance and fault protection	Comfort	Convenience	Health and well-being	Information to occupants	Energy flexibility & storage	SRI
Total	39%	18%	60%	71%	48%	59%	51%	46%
Heating	32%	18%	62%	55%	24%	74%	100%	
Sanitary hot water	17%	0%	45%	70%	67%	83%	0%	
Cooling	65%	51%	78%	72%	61%	55%	0%	
Controlled ventilation	41%	0%	55%	60%	34%	44%	-	
Lighting	85%	14%	90%	100%	83%	15%	-	
Dynamic building envelope	10%	0%	31%	56%	22%	46%	-	
Electricity	10%	0%	-	-	-	68%	0%	
Electric vehicle charging	-	38%	-	82%	-	84%	25%	
Monitoring and control	52%	43%	62%	72%	45%	64%	14%	

Figure 11: SRI assessment matrix – impact criteria/domain

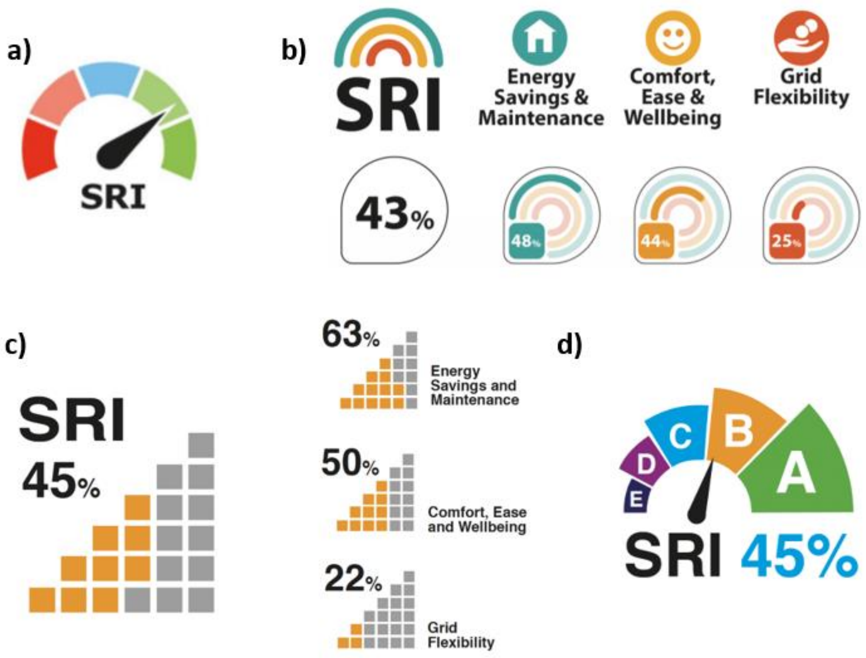

Figure 12: Sample SRI visualisation schemes being currently investigated

Multiple SRI visualisations are currently being tested with real users and its final form is still to be defined (see Figure 12). While some options include only the general SRI score (Figure 12a and c), others are presented together with the three sub-scores on each of the sub-categories (Figure 12b and c). Although the implementation pathways may depend on national conditions (e.g. the regulatory framework for energy supply varies across different EU members) and building typology, the aim of the SRI is to provide a common framework for all countries and building types. Notwithstanding this, the fact that some Member States already require independent commissioning of large non-residential buildings lets perfect room for tying SRI into that process.

Data including both EPC and SRI assessment in real cases is not yet available since SRI is still in a testing phase. Within the X-tendo frame, a parallel assessment of SRI is accounted for in EPCs.

2.4 Linking SRI assessment methods to energy performance and EPCs

In the context of the EPBD, the impact of smart-ready services and technologies on the energy consumption of buildings is evaluated as a first key performance indicator. Smart services and technologies may unlock energy savings both by improving the energy efficiency at building level and by allowing the optimisation of energy flows on an aggregated energy grid level. Both impacts on energy performance are thus separately accounted below.

Building level: The calculation method used in the interim report to assess the energy performance improvement of a building is computed by taking into account the overall energy savings related to the upgrade of SRI systems [16], such as improving the smartness of the heating system by one or more levels of smartness (calculation method in EN 15232: Energy Performance of Buildings — Impact of Building Automation, Controls and Building Management, see Figure 13 for an example).

As can be expected, estimations presented in the interim SRI report showed that the largest savings are obtained when increasing the system smartness from level D to A, with a resulting 25% total energy saving estimated [16]. The results show a clear dependence on the original energy demand of the building prior to installing the SRTs.

Grid level: The goal of the SRI is also to assess the impact of smart buildings in relation to the energy grids. The capacity of the building to offer demand-response services such as self-consumption, self-production or storage services is expected to increase the renewable capacity of the energy grid as well as the energy efficiency of the system. Based on a literature review conducted within the interim report, it is estimated that the first category of flexibility (i.e. SRI scores of D and C) result in an estimated 5% increase of self-consumption [16]. In contrast, buildings with smartness levels B and A are expected to reach self-consumption levels close to 25% increase.

Residential	
Climate region:	Western Europe
Building type:	Single family house
Construction period:	1960-1990
Retrofit level:	Renovated

SRI level	D	C (Reference)	B	A
Heating system				
BAC efficiency	1.09	1.00	0.88	0.81
Qheating	16433	15076	13267	12212
Cooling system				
BAC efficiency	1.09	1.00	0.88	0.81
Qcooling	214	197	173	159
Ventilation system				
BAC efficiency	1.08	1.00	0.93	0.92
Qventilation	902	835	777	768
Lighting system				
BAC efficiency	1.08	1.00	0.93	0.92
Qlighting	635	588	546	541
DHW system				
BAC efficiency	1.11	1.00	0.90	0.80
Qdhw	4460	4018	3616	3214

Saving	D->C	D->B	D->A	C->B	C->A	B->A
Heating	1357	3166	4221	1809	2865	1055
Cooling	18	41	55	24	37	14
Ventilation	67	125	134	58	67	8
Lighting	47	88	94	41	47	6
DHW	442	844	1246	402	804	402

Saving [%]	D->C	D->B	D->A	C->B	C->A	B->A
Heating	8%	19%	26%	12%	19%	8%
Cooling	8%	19%	26%	12%	19%	8%
Ventilation	7%	14%	15%	7%	8%	1%
Lighting	7%	14%	15%	7%	8%	1%
DHW	10%	14%	28%	10%	20%	11%
Total	**9%**	**19%**	**25%**	**11%**	**18%**	**8%**

Figure 13: Example of estimated energy performance improvement following the improvement of SRI for residential buildings in Western Europe

Smart-ready services contribute also to increasing energy security and the optimisation of flows in energy grids. Since the energy flexibility that can be offered by a building cannot be captured by a single-value indicator as it covers multiple dimensions (time, power, energy, rebound, etc.), the best way to assess the impact of this factor is to consider the reduction in GHG emissions and energy savings.

Detailed comparison between EPC and SRI schemes is required for the future development of a common assessment approach. Points of convergence and potential overlapping between the two assessment schemes can be summarised by theme:

Scope of application: There is a clear distinction between the implementation of EPC and SRI within Member States:

- For EPC, there is an outline of the methodology in the EPBD, but Member States can develop their own calculation methodology, software etc., so there is little comparability across Europe.
- For SRI, the calculation methodology is designed to be common to all countries. Member States can choose whether they implement the SRI or not, and whether they make it mandatory to all buildings, some buildings, or not mandatory at all.

There may be some national deviations (e.g. weighting factors) but in general the methodology will be identical across Europe.

Maturity: While EPCs are quite mature and their characteristics are well established (at least for some Member States), SRI is a new indicator

Scale: EPCs and SRI both cover the majority of the EU's building stock. With this high degree of coverage, a large target convergence between EPC and SRI can be expected.

Building assessments and site visits/inspections: Building assessments are included in both schemes and site visits and inspections could be correlated. Importantly, shared assessment costs might reduce overall assessment costs.

Target audience: Both SRI and EPC should address the same public audience including property owners, facility managers, investors and tenants. Establishing links between the indicators could increase the target audience interested.

Actors directly involved in delivery: Building assessors, building service engineers, HVAC engineers and qualified building professionals are likely to be involved at some level in the delivery of services within EPC and SRI schemes. For other more product-focused initiatives, such as cybersecurity certification or smart meter technology (necessary for the implementation of some SRI features), specific professionals such as electrical engineers working for distribution system operators or manufacturers operating at the single market level will be necessary.

Certification: The issuance of a certificate to denote that a building or service within it has had a qualified assessment will be common ground for both schemes. The use of both indicators could end up reinforcing the value proposition. Potential SRI implementation pathways will be sensitive to trigger points generated by EPC assessment (e.g. inspections, renovations, etc.).

Quality assurance: This is related to certification and likely regulated in different ways within the Member States. These indicators could be inserted in the future within a much larger building renovation passport.[3]

Mandate: The mandates applicable to the schemes encompass (1) governmental, legally binding initiatives (such as those related to the EPBD), (2) governmental voluntary initiatives, (3) private sector mandates operated through an association and (4) private sector project-specific.

Organisation: Again, highly dependent on the specific Member State, various schemes are possible within one of the following organizational frameworks:

[3] EU initiatives such as the digital logbook recently funded are expected to work on this during the upcoming years

- Government managed with private sector delivery at Member State level
- Voluntary framework open for use by building profession
- Voluntary framework open for use by product manufacturers
- Government regulated with private sector delivery
- Private sector managed

Governance: Both indicators are likely to fall under the same governmental objective, facilitating its implementation and providing a robust strategy to reach it. However, conflicts of interest exist within member states. Local governments are responsible for managing issues regarding the (potentially) combined implementation of EPC and SRI such as assessors' certification, private sector action outlines or the potential economic interests prompted by the common implementation of both indicators.

Methodology: Finally, EPC status might be used to calculate the weighted factors within the SRI impact criteria. For buildings that have (or are in the process of obtaining) an EPC, the SRI weighting factors for energy savings could be derived from the EPC calculation directly.

2.5 Legal boundaries or requirements of assessment methods

Regarding data privacy

During the assessment process, the assessor (or an automated system) collects data on the various smart services present in a building (e.g. temperature regulation, EV charging capabilities and provisions on automated solar shading control). This provides personal information about the smart services that are present or missing in the building, the functionality level of these services and the building usage. On top of this, additional information is also recorded, including technical information on specific technical building systems or pictures and notes taken by the assessors during on-site inspections. This data, potentially interesting for commercial purposes, must in all cases follow a security process to ensure compliance with the European General Data Protection Regulation (GDPR). The procedure is comparable to the one currently followed for EPC assessment. A smooth and secure process for retrieving previously entered SRI data will greatly support the efficiency of the SRI assessment and reduce its cost. This could be integrated within the regular update by the owner, facility manager or contractor every time the building receives an upgrade.

Cybersecurity risks

More potentially dangerous are the risks associated with the constant connectivity and data sharing which characterises several SRT. IoT deployments can lead to hackers entering into the building system to get personal data or to demand ransoms from residents.

2.6 Ranking of existing methods to evaluate the smartness levels

The different schemes reviewed in Section 2.1 and summarised in Table 2 are now evaluated based on the capacity to assess the smartness[4] of a building. Table 4 gives a ranking based on expert judgement and a brief explanation is provided. Although the other methods do not significantly include smartness aspects in their assessments, they are presented as a comparison to the SRI method. The SRI method is so far the only method that has been designed to consider all the smartness aspects of a building.

Table 4: Comparison of the reviewed assessment schemes based on their capacity to evaluate the smartness level of a building

Method	Ranking[5]	Comment on feasibility/ explanation
Building level of smartness		
LEED	**	Does not evaluate smart technology within the building and connection to the grid
BREEAM	**	Does not assess smart technology or connection to the grid
HKBEAM	**	Does not assess smart technology or connection to the grid
BIQ	****	Only for office buildings
EPC-Labs21	*	Specific to laboratory facilities, shares LEED's methodology
SI	***	Just a value proposition; not yet a standardised scheme
Level(s)	***	Includes new concepts such as resilience to climate change or risk factors, but lacks the evaluation of automation components
R2G	***	Promising indicator including connection to the grid but requires further development and case studies
DGNB	***	Powerful but with a reduced scope of application so far (award)
SRI	*****	Complete indicator designed to account for the diverse components making a building smart
Likert scale used for suitability: not at all (*), slightly (**), moderately (***), very (****), extremely (*****)		

[4] Smartness as defined in the EPBD EU directive

[5] Ranking scores are assigned based on the review in Section 3.1, but risk being subjective, based on the author's opinion

2.7 SWOT analysis of the SRI assessment method

The implementation frame of the SRI together with its methodology makes it possible to embed within the existing EPC assessment. For instance, the target audience (e.g. property owners, tenants, facility managers, investors) of both and the actors (e.g. EPC assessors) involved in their assessment are the same. EPC data could be valuable to help assess the SRI of the building, thus reducing the total assessment time of the indicator. Similarly, SRI information could be used to support the assessment process of the EPC for new and existing buildings. Despite the potential benefits of combining assessment of both indicators, it is important to be aware of possible drawbacks, including increased assessment time and the need to train certified assessors.

Table 5 summarises the strengths and weaknesses of including SRI assessment in the current EPC scheme with regard to the opportunities and threats in the construction market (SWOT analysis).

Table 5: SWOT analysis of the SRI assessment method

Strengths	Weakness
Rapid coverage of SRI assessments if made mandatory within the EPC	Increased EPC time and cost
Third-party assessment should maximise assessment quality and market value	Do not include in their methodology the potential to be assessed through portable devices
Third-party assessment allows issuance of a trustworthy certificate	It will lower EPC credibility; not always high with all market actors
Assessment can directly inform owner/occupier via targeted advice	Requires extra training of EPC assessors
Increases energy efficiency renovation potential as both provide complementary information	Does not influence the design phases of a building (yet)
Opportunities	**Threats**
Complements existing EPC assessment	EPC assessors may not be trained/accredited for SRI assessment -> risks reputational damage
Can emphasise the use of SRT as an opportunity for the energy transition	If enough qualified assessors are not available there may be a risk of slowing down EPC deployment due to added SRI burden
Could make use of EPC energy balance data	Greater time and cost of EPC/SRI assessment could create resentment against EPCs and reduce conformity with EPC requirements
Assessment could be linked to online tools which personalise the information of interest for the users regarding both EPC and SRI	Risk to data security such as data thefts or misuse for commercial purposes
Positive impact on real estate value	

2.8 Proposed approach to develop the feature

Although the scope of the methods is still tentative, three methods have been described so far to assess the SRI score [18]. Additional guidelines may be developed by the EC and/or Member States to further specify the applicability and scope of the methods. Importantly, method C is not being developed currently, but is envisioned as a potential future evolution of the SRI methodology. The most recent analysis (published in February 2020) showed that, despite the differences in assessing time, methods A and B present comparable assessment outputs.

For this reason, X-tendo partners agreed to use method A (abbreviated) in the testing to assess in parallel both SRI and EPC. Method A has an estimated assessment time of 15 minutes and covers both non-residential and residential buildings. It is based on a checklist and the assessment process does not require external experts (self-assessment). More details of the variables covered in method A can be seen in the 3rd interim report (Annex C; Table 69, pages 356-361) [18].

As explained within Section 2.2, different building parameters such as type, characteristics or geographical location will determine the specific theoretical maximums and weighted values of the "domain x impact criteria" matrices. As discussed, the weighting for different domains and impact criteria will vary between buildings: for example, for most buildings aspects such as the general heating domain might account for 60% of the possible score for the "energy savings" impact category, whereas EV charging will only be significant in buildings that have the capacity to include charging points. The final SRI score will be represented as a percentage, where 100% will represent the maximum score. This main score could be also split into three sub-scores: "energy savings & maintenance", "comfort, ease & well-being" and "grid flexibility". Figure 14 shows as schematic view of the scoring process.

Key messages:

- Method A will be considered as the reference SRI assessment method within the X-tendo project. This is because it has equivalent outputs when compared to the more detailed method B together with a reduced assessment time.
- Not all buildings are evaluated equally. Different building parameters (type, characteristics, geographical location) will determine the eligible assessment facets (theoretical maximum) as well as the weighted values of each.
- The final SRI score is provided in the form of a percentage and subdivided in three subcategories matching EPBD objectives: "energy savings & maintenance", "comfort, ease & well-being" and "grid flexibility".

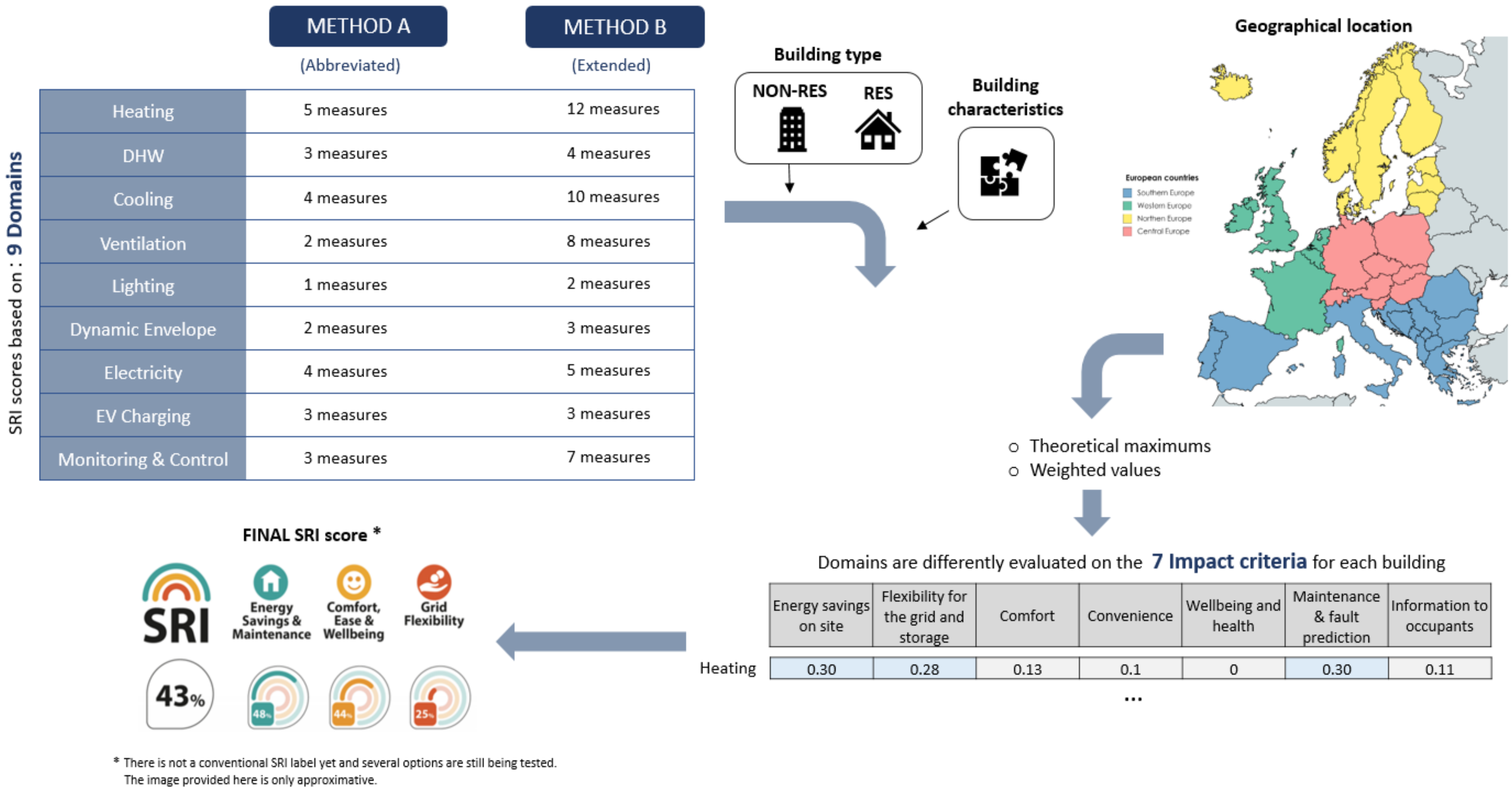

Figure 14: Indicative flow of SRI assessment approach

3 FINDINGS

This section presents a summary of key findings (Table 6) related to the indicators that will be developed for the five innovative features in the X-tendo toolbox. This summary will be a precursor for further work in WP3. The findings have been categorised into key barriers, challenges, limitations, delivery actors, presentation, target audience and link with energy performance.

Table 6: Key findings of the scoping and analysis of all features

	Feature 1: smart readiness	Feature 2: comfort	Feature 3: outdoor air pollution	Feature 4: real energy consumption	Feature 5: district energy
Key barriers					
Technical/ methodological	Dealing with differences in building services (heating, EV presence, etc.) and characteristics (age, type or geographical location) Weighted measures and theoretical building maximums need to be developed	Assessment methodology for different building typologies	Proper definition of outdoor air quality	Length of the monitoring duration	Implementation of a certification scheme for calculating future PEF, REF and CEF could be a major barrier for some countries
Financial /economic	Existence of several schemes (market saturation)	-	-	Normalisation for user behaviour financially	-
Legislative/ governance	Differences across MS in smart readiness levels	Various standards at MS level	-	Enforcement frame Accounting for bulked quantities	-
Social	Novelty of the indicator requires the presence of useful	Benefits are not well understood by public	-	Landlord/tenant split	-

	information for the majority of the public				
Environmental	ICT technology might have a significant environmenta l impact	-	-	Monitoring infrastructure cost in relation to benefits	Additional efforts and committing to values stated in EPCs might be a reason for district heating utilities to oppose these indicators
Industry	Potential lack of readiness of the industry to satisfy the demand of new ICT	Application of industry-based solutions in building sector	-	Strict enforcement is difficult or even not feasible	Implementati on of a certification scheme for calculating future PEF, REF and CEF could be a major barrier for some countries
Key challenges					
Technical/ methodological	Quick assessment -> Method A is created to reduce assessment time	Provision of single rank/score Accuracy of methods with or without measurement s	Estimation of filter classification for each county Proper definition of reference values of emission rates Scale of indexes and weights for each country	Development of suitable models for missing data (e.g. DHW energy consumption) Differentiatio n of method for various functions (especially non-residential) Normalisatio n versus maintaining the link with actual measured energy consumption Normalisatio n for indoor environmenta	Variable definitions of PEF, REF and CEF

				l quality and service provision	
Financial/ economic	Low cost and easy-to-use option	Developing cost-effective assessment criteria	-	Cost/accurac y or effectiveness balance	Estimation of data for future years for a district heating system (mainly plant capacities and full load hours)
Legislative/ governance	Universal methodology applicable to all MS (in contrast to EPC)	No reference for EPCs available from MS	Multiple standards and regulations in different MS	Minimising fraud GDPR (especially in the case of individual dwellings or buildings with low number of users) Citizen security and data privacy	Estimation of data for future years for the public electricity grid so that it is accepted by the district heating utilities and authorities
Social	Acceptability and appropriation	-	-	User acceptance; maintaining the link with energy billing/meteri ng information	Method for verification between roadmap of district heating utility and estimated data
Environmental	Benefits vs. costs understudied	Integration in decision-making for renovation measures	Integration of variable sources of emissions in different MS	Positive balance of environmenta l benefits of EPC method effectiveness improvement versus environmenta l impact	-
Industry	Demand satisfaction	Quantified benefits not well integrated in assessments	-	-	-

Limitations	Might work at the level of some MS but not all Higher smartness levels should reflect better quality of life for occupants and building performance	Reduction of measurements for cost-effectiveness Limited complexity to simplify training of experts	AQI data is required	For the design, calculation is still required; duration of measurement period (relevant for new/renovated buildings) Monitoring infrastructure roll-out may not be supported in all MS	-
Presentation	Well-developed presentation approach	Few examples of presentation available	Existing colourful scale exists	As part of EPC, printed, digital, as part of building logbook, complementary to current EPC information or replacing it.	-
Delivery actors	EPC assessors, qualified experts but also owners (self-assessment)	EPC assessors, qualified building professionals	EPC assessors, energy auditors	EPC assessors, qualified building professionals /experts Depending on data availability, potentially fully automated	EPC assessors, district heating utilities
Target audience	Whole building ecosystem: property owners, buyers, renters, tenants, facility managers, public authorities	Property owners, buyers, renters, tenants, facility managers	End-users, owners, occupants	Same as current EPC target audience, although focus is more user-oriented.	Property owners, buyers, renters, tenants, facility managers, research, public authorities responsible for planning heating and

					cooling
Link with energy performance	Monitoring and operation at the building level and improved interoperabili ty with the grid	Thermal comfort and indoor air quality have a strong link with energy performance	Pollutant emission and indoor air purity have a strong link with building thermal and installation characteristic s	Real energy consumption directly links with energy performance and additional operational (energy) performance Potentially contributes to mitigation of energy performance gap	All indicators have a strong link to the energy performance of the building

4 CONCLUSIONS

This report provides useful and crucial insights into working out the indicators for the five features during the X-tendo project. For all features, we have outlined details of the existing assessment/calculation methods in the context of EPCs. Their application domain, legal boundaries, and links with energy consumption and EPCs were also studied and evaluated. A SWOT analysis and ranking of methods were presented highlighting the best fits for each of the indicators. However, further work and adjustments to these methods would be required to make them available for real testing. A proposed approach for the development of each feature based on a preliminary concept for the indicator is also presented. Finally, across all features, key findings have been presented, leading to the following conclusions in two groups:

Indicators

- 'Smart readiness' approach presents a potential method for assessing the smartness of buildings with nine domains (e.g. lighting, ventilation, envelope, monitoring and control etc.)
- 'Comfort' approach incorporates four key indicators – thermal, visual and acoustic comfort and indoor air quality – to be assessed through checklists, on-site measurements and surveys
- 'Outdoor air pollution' approach addresses a building's impact on air by two methods: an outdoor air pollution contribution index and indoor air purity index
- 'Real energy consumption' approach outlines an assessment method based on operational ratings, with options for normalisation to allow for better inter-building comparison
- 'District energy' approach focuses on predicting the potential for future development for buildings via two methods: expected future performance of district heating and heat distribution and transfer system

Cross-cutting issues

- Technical challenges that constrain the application of existing methods such as assessment time, accuracy, normalisation process, variable definitions and emission factors could be overcome by certain modifications in approach
- Features should be aligned financially to increase market acceptance and cost-effective assessments during the development
- Legal and governance issues should be addressed by dealing with challenges such as development of universal methodologies, presence of multiple standards at Member

State level, control of citizen data and privacy, and acceptance of future estimations by public authorities

- From a social perspective, user acceptance and public understating of the features are key issues and should be considered in feature development
- If these indicators are well integrated within EPCs, significant environmental benefits are anticipated
- Future implementation of indicators can be strengthened by addressing lack of industry readiness, understanding of anticipated benefits and enforcement issues

Certain limitations need to be overcome to implement these innovative indicators, such as variable levels of implementation in the Member States due to different local requirements and regulations. Some indicators require extensive monitoring and measurements, and a lack or absence of data is a barrier in the development and acceptance of these features within EPC schemes.

A range of delivery actors was identified for all the features, including EPC assessors, qualified experts, building professionals, and auditors. It is especially important to focus on them while developing the features as they will directly affect the outcomes of the assessments. While developing the features, links with energy performance are being explored and studied with reference to interoperability with the grid, energy consumption, and operational energy performance. To successfully develop the indicators and their implementation in the EPC schemes of the Member States, the features should ensure compliance with the requirements of the target audience and the framework principles of the cross-cutting criteria in X-tendo.

GLOSSARY OF TERMS

Term/words	Meaning/definition
Air Quality Index (AQI)	Index used by government agencies to communicate to the public how polluted the air currently is or how polluted it is forecast to become
Building smartness	A building's capacity to communicate with its occupants and the grid and to monitor and regulate efficiently the use of energy and other resources. It exemplifies the ability of the building to adapt to internal and external situations, relies on information and connectivity, and requires an appropriate level of cybersecurity.
Carbon emission factor (CEF)	A coefficient which allows conversion of activity data (process/processes) into CO_2 emissions
Emission rate	The emission intensity of a given pollutant relative to the intensity of a specific activity, or an industrial production process; for example grams of carbon dioxide released per megajoule of energy produced, or the ratio of greenhouse gas emissions produced to gross domestic product (GDP)
Energy Performance of Buildings Directive (EPBD)	The EPBD covers a broad range of policies and supportive measures that will help national EU governments boost energy performance of buildings and improve the existing building stock
Expectable return temperature (ERT)	Average temperature to be expected in the return of a building's heat distribution system
Filtration	A physical, biological or chemical operation that separates solid matter and fluid from a mixture with a filter medium that has a complex structure through which only the fluid can pass
Final energy consumption	Final energy consumption is the total energy consumed by end users, such as households, industry and agriculture. It is the energy which reaches the final consumer's door and excludes that which is used by the energy sector itself.
Indoor environmental quality (IEQ)	IEQ encompasses the conditions inside a building – air quality, lighting, thermal comfort, acoustic conditions, ergonomics – and their effects on occupants or residents
Information and communication technologies (ICT)	Infrastructure and components that enable modern computing

Internet of Things (IoT)	Enabling of everyday devices to send and receive data through the internet
Low emission	Emission of combustion products of solid, liquid and gaseous fuels to the atmosphere from emission sources (emitters) located at a height of not more than 40 m
Nearly zero energy building (nZEB)	nZEBs have very high energy performance, and the low amount of energy they require comes mostly from renewable sources
Necessary supply line temperature (NST)	Maximum temperature that is necessary to be supplied to a building's heat distribution system in order to ensure that the heat load can be supplied to each part of the building on the coldest day of the year
Overheating risk	Situations where the indoor temperature of a home becomes uncomfortably or excessively warm
PM2.5/PM10	Particles with an aerodynamic diameter smaller than respectively 2.5 and 10 µm
Pollutant	A substance or energy introduced into the environment that has undesired effects, or adversely affects the usefulness of a resource
Primary energy factor (PEF)	A PEF connects primary and final energy by indicating how much primary energy is used to generate a unit of electricity or a unit of useable thermal energy
Primary energy consumption	Primary energy consumption measures the total energy demand of a country. It covers consumption of the energy sector itself, losses during transformation (for example, from oil or gas into electricity) and distribution of energy, and the final consumption by end users. It excludes energy carriers used for non-energy purposes (such as petroleum not used not for combustion but for producing plastics).
Primary resource factor (PRF)	The ratio between fossil energy supply and energy used in a building
Renewable energy factor (REF)	The share of renewable energy in the heat supplied by the district heating system
Sick building syndrome (SBS)	A condition affecting office workers, typically marked by headaches and respiratory problems, attributed to unhealthy or stressful factors in the working environment such as poor ventilation
Smart readiness indicator (SRI)	Measure of the capability of buildings to adapt their operation to the needs of the occupant, optimising energy efficiency and overall performance, and to adapt their operation in reaction to signals from the grid (energy flexibility)

Smog	An atmospheric phenomenon resulting from the mixing of fog with smoke and exhaust fumes
Volatile organic compounds (VOCs)	Organic chemicals that readily produce vapours at ambient temperatures and are therefore emitted as gases from certain solids or liquids. All organic compounds contain carbon, and organic chemicals are the basic chemicals found in all living things.

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