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Smart-Ready Buildings:

EPBD Policy Updates, National Implementation & Research Breakthroughs

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REHVA OFFICE:
Washington Street 40
1050 Brussels, Belgium
Tel: +32-2-5141171
info@rehva.eu, www.rehva.eu

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The EPBD recast boosts smart-ready buildings

PABLO CARNERO MELERO
Technical and EU Project Officer
REHVA
pcm@rehva.eu

FRANCESCO ROBIMARGA
Policy and Advocacy Officer
REHVA
fr@rehva.eu

Pablo Carnero Melero is working as a consultant for REHVA since February 2023, balancing the role of Technical and EU Project Officer with the secretariat of the Technology Research Committee. His research and practice have traditionally been linked to energy performance and decarbonisation of existing buildings, integrating more recently the topic building smartness. Beyond his technical background, he is passionate about the social and economic aspect of energy access and use. He has collaborated in the past with local initiatives in the field of energy poverty and has been involved in educational programs for the upskilling of architects in dwelling energy renovation. He is based in València (Spain).
https://www.linkedin.com/in/pcarnerom/

Francesco Robimarga is a qualified lawyer with an LL.M. in European Law and Policies from LUISS University. With a strong foundation in Constitutional and Parliamentary Law gained from a Juris Doctor degree at Sapienza Università di Roma. He has developed a deep passion for parliamentary democracy, EU integration, public affairs, and human rights. He has also gained practical experience as a Political Group Trainee at the European Parliament and as an Academic Assistant at the Chair of Parliamentary Law at Sapienza Università di Roma. A keen follower of national, EU, and global politics, he is dedicated to advancing the principles of constitutional law and parliamentary democracy.
https://www.linkedin.com/in/francesco-robimarga-27462420b/

Important dates for national implementation of stringent requirements and a new rating scheme for smart readiness in buildings.

Achieving ambitious carbon-neutrality goals necessitates the integration of smart, active technologies in the building sector, serving as a crucial complement to renovations in areas like insulation and electrification. Smart technologies, such as smart thermostats that adjust the temperature in each room and can save up to 30% of energy, and occupancy detection sensors that optimize energy use when integrated with ventilation and lighting systems, offer significant benefits in energy efficiency, comfort, and convenience for building occupants. Beyond individual buildings, these technologies play a crucial role in the broader energy landscape. As renewable and intermittent energy sources like solar and wind expand, electricity systems face greater challenges, making it increasingly important for buildings to provide flexibility services to help balance the grid.

The Energy Performance of Building Directive – Directive (EU) 2024/1275 of the European Parliament and of the Council – was published in the Official Journal of the European Union on 24 April 2024. The recast includes several recitals and dedicated provisions, aiming to boost the smart readiness of buildings further supporting the European Green Deal.

The Smart Readiness Indicator (SRI), firstly introduced in the 2018 amendment of Directive 2010/31/EU, is confirmed as the common Union scheme for rating the smart readiness of buildings and developed in Article 15 of the EPBD recast. Albeit defined as an optional scheme, it is expected that by 30 June 2027, the European Commission shall adopt an implementing act detailing the technical arrangements for the effective implementation of the application of the SRI to non-residential buildings with an effective rated output for heating systems, air-conditioning systems, systems for combined space heating and ventilation, or systems for combined air-conditioning and ventilation of over 290 kW. Consequently, the ground is ripe for service engineers, building owners, and Member States to get acquainted with this new scheme which is soon to be implemented. There are several EU-funded research projects and initiatives that are developing supporting materials particularly to that end.

For now, 12 Member States are undergoing non-committal test phases of the SRI scheme, testing the calculation methodology proposed by the European Commission. France and Denmark concluded the test phases in 2024 and are in the early stages of implementation, seeking to coordinate the new common Union scheme with existing assessments and procedures at national level, such as those related to energy performance certification schemes.

Beyond the provisions related to the SRI, Member States are mandated to begin setting requirements regarding smart-ready technologies by the end of 2024. Particularly regarding building automation and control systems (BACS), automatic lighting controls, and infrastructure for electric vehicles. The minimum capabilities for such smart-ready technologies are described in Article 13 and 14, respectively. An overview of the important dates for national implementation of the smart-ready technology requirements are depicted in the **tables** below.

The EPBD also strives for Member States to promote effective installation and operation of low temperature heating systems in new or renovated buildings, as well as self-regulating devices. In addition, Member States are also mandated to ensure building owners, tenants and managers to have direct access to the building system's data, being able to make it available to a third party, without additional costs. By 31 December 2025, the Commission shall adopt implementing acts detailing interoperability requirements and non-discriminatory and transparent procedures for access to the data.

We were already aware that building smartness was an effective means to healthier and more comfortable buildings with lower energy use and carbon emissions, while facilitating the integration of renewable energy sources into the energy system. Now the EPBD recast is mandating Member States to integrate the smart dimension into national building codes and regulations. As a result, a market is emerging for skilled professionals capable of checking the compliance with smart-ready requirements, inspecting related systems, and performing smart readiness assessments in buildings. The challenge is clear, buildings shall be able 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. Will the stakeholders across the value chain be up to the task? ■

Building type		Condition for application	Scope of Requirement	
		Effective rated output of the HVAC systems	BACS[a]	Automatic lighting controls
Non-residential buildings	All types	>290 kW	31 December 2024	31 December 2027
		>70 kW	31 December 2029	31 December 2029
Residential buildings	Newly built	-	29 May 2026	-

Building type		Condition for application	Scope of Requirement[a]	
		Car parking spaces	Infrastructure for electric vehicles	
			Recharging points	Pre-cabling and ducting
Non-residential buildings	Newly built and majorly renovated	>5	Promptly[b]	
	All types	>20	1 January 2027	
	Owned or occupied by public bodies	-	-	1 January 2033
Residential buildings	Newly built and majorly renovated	>3	-	Promptly[b]

[a] Member States may decide not to apply them to specific building categories under specific circumstances described in Article 14 (5)
[b] Pursuant the principle of sincere cooperation between Member states and the Union laid down in art. 4(3) TEU

The new rating for building smart readiness: the Smart Readiness Indicator

The EPBD recast confirms the Smart Readiness Indicator (SRI) as the common EU scheme to rate the smart readiness of buildings. This article analyses the specific provisions outlined in Directive (EU) 2024/1275, and related legal acts. It describes the calculation methodology and other elements, which shall be implemented at national level in the coming years.

Keywords: Smart Readiness Indicator (SRI); Energy Performance of Buildings Directive (EPBD); calculation methodology; technical framework; smart-ready buildings

PABLO CARNERO MELERO
Technical and EU Project Officer
REHVA
pcm@rehva.eu

The Smart Readiness Indicator (SRI), firstly introduced in the 2018 amendment of Directive 2010/31/EU, is confirmed as the common Union scheme for rating the smart readiness of buildings and developed in Article 15 of the EPBD recast.

Each of the dimensions of the SRI framework depicted in **Figure 1** are described in detail in the next sections.

Calculation methodology

The Delegated Regulation 2020/2155 established the binding and technical provisions regarding the calculation methodology of the common Union scheme for rating the smart readiness of buildings. The methodology for calculating the SRI is based on the assessment of smart-ready services present or planned at design stage in a building or building unit, and of smart-ready services that are considered relevant for that building or building unit.

The SRI calculation shall be structured in 3 key functionalities, with related impact criteria. The assessment evaluates a building's ability to optimize energy efficiency and overall in-use performance, including maintenance and fault prediction; their capacity to adapt operations to meet occupants' needs, focusing on comfort, convenience, health (particularly air quality), and promoting virtuous behaviours through information provision; and their responsiveness to grid signals to offer energy flexibility services. Also, the SRI includes 9 technical domains based on which a building's smart readiness is assessed, similarly to how energy performance certificates do with energy performance. However, it expands the traditional scope of heating, cooling, domestic hot water, ventilation, lighting and electricity, to include also the dynamic building envelope, electric vehicle charging, monitoring and control. A schematic representation of the SRI calculation methodology is depicted in **Figure 2**.

In addition, Member States shall define the respective weighting factors of relevant impact criteria and of technical domains for each impact criterion. The latter may differ between building types and categories. In addition, Member States ought to make available at least one smart-ready service catalogue, which shall describe the smart-ready services included in the assessment. Additional may be devised, for instance for different building types.

The main indicator of the SRI assessment is a single score, expressed as a percentage, which combines the key functionalities and technical domains. This smartness score is transferred to a rating scale to deliver a smartness class. Also, secondary indicators are provided for each of the three key functionalities, and technical domains.

To facilitate the national implementation of such provisions, the European Commission has produced a default smart-ready service catalogue and weighting factors. As a result, a SRI self-assessment tool can be provided upon request by the SRI support team, acting on behalf of European Commission, by filling out this form: https://ec.europa.eu/eusurvey/runner/SRI-assessment-package.

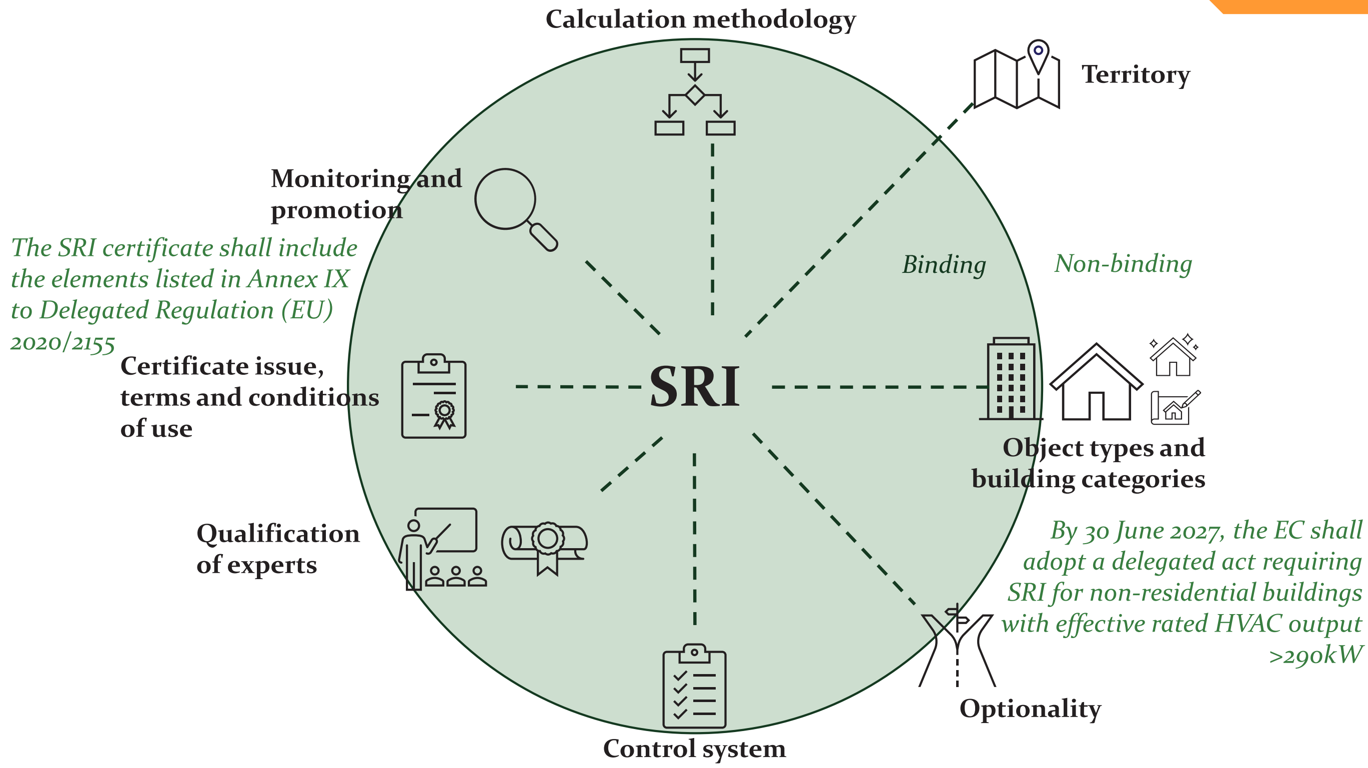


Figure 1. SRI framework overview.

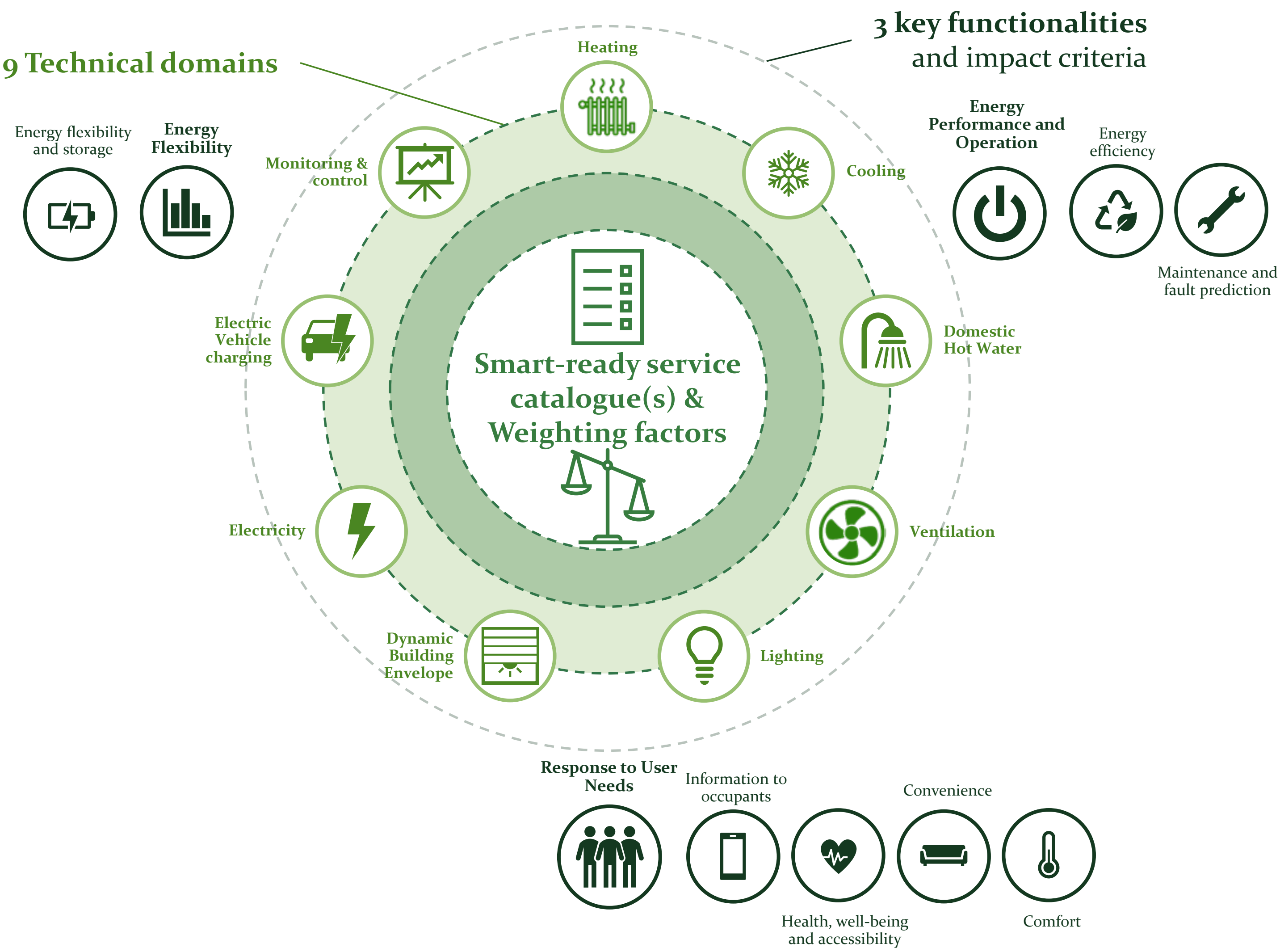


Figure 2. SRI calculation methodology overview.

- In addition, many EU-funded research projects are implementing supporting tools for the SRI assessment. For example, the open access web app developed by Smart Square or the online tool coupled with e-learning materials in many EU languages resulting from SRI2market, among others.

Territory

The Delegated Regulation established that Member States shall decide if the SRI scheme is implemented in their national territory, or parts thereof.

> Many countries are in the process of undergoing a non-committal test phase. Check the SRI Observatory to learn more about the status of test phase across Europe!

Object types and building categories

The Delegated Regulation established that Member States may decide to implement the SRI scheme only to certain categories of buildings.

Optionality

Member States that implement the SRI scheme may choose to apply it on a voluntary or mandatory basis for buildings or building units located on their territory. Member States that decide to implement, modify, adapt, or terminate the implementation of the scheme needn't provide any justification, but shall notify the Commission.

> By 30 June 2027, the European Commission shall adopt a delegated act requiring the application of the common Union scheme for rating the smart readiness of buildings, in accordance with Annex IV, to non-residential buildings with an effective rated output of HVAC systems over 290 kW.

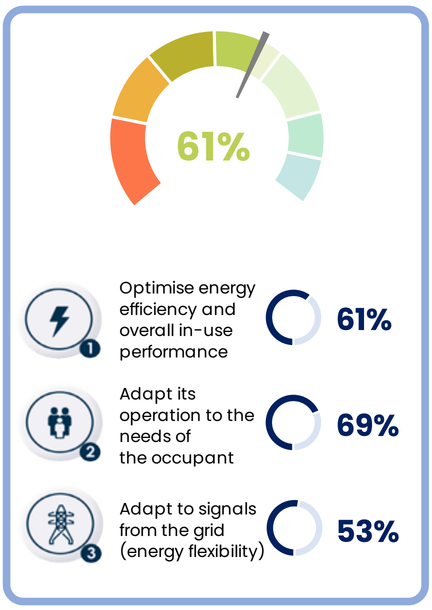
Control system

The Delegated Regulation states that Member States that decide to implement the SRI scheme shall establish an independent control system for SRI certificates, which shall ensure the validity of the SRI certificates issued on the territory.

> Where relevant, those Member States may rely on the independent control systems that are already in place, such as those for energy performance certification schemes.

Qualification of experts

The Delegated Regulation states that Member States that decide to implement the SRI scheme shall ensure that the assessment of the smart readiness of buildings or building units with a view to issuing a smart readiness certificate is carried out by experts that are qualified or accredited. Consequently, Member States shall lay down requirements on the qualification or accreditation of smart readiness indicator experts and ensure that those requirements include competence criteria, including in the ICT field. Member States



DOMAINS	IMPACTS: 1 Energy efficiency	1 Maintenance & fault prediction	2 Comfort	2 Convenience	2 Health, well-being & accessibility	2 Information to occupants	3 Energy flexibility & storage	SRI
Total	72%	49%	74%	63%	70%	68%	53%	61%
Heating	81%	40%	75%	73%	80%	50%	45%	58%
Domestic hot water	82%	50%	0%	86%	0%	67%	55%	88%
Cooling	82%	20%	70%	55%	80%	50%	45%	26%
Ventilation	57%	50%	80%	75%	78%	67%	-	21%
Lighting	67%	0%	60%	60%	33%	0%	-	42%
Dynamic building enveloppe	80%	50%	60%	50%	50%	67%	-	48%
Electricity	57%	33%	-	-	-	67%	64%	49%
Electric vehicle charging	-	0%	-	83%	-	67%	25%	61%
Monitoring & control	50%	64%	100%	53%	75%	78%	67%	67%

Figure 3. SRI scoring. Example.

shall make available to the public information on the qualifications of experts in charge of the smart readiness assessment, as per the Implementing Regulation 2020/2156.

> In addition, the Commission Implementing Regulation indicates that where Member States decide to implement the smart readiness indicator scheme, they may decide that experts accredited or qualified for issuing energy performance certificates, or for carrying out inspection of heating, air- conditioning, combined heating or air-conditioning and ventilation systems under Directive 2010/31/EU, or for performing energy audits under Directive 2012/27/EU, are also competent for issuing smart readiness indicator certificates.

In that case, Member States may decide to set additional requirements for those experts in order to qualify for issuing smart readiness indicator certificates, in particular in relation to their training. Where relevant, Member States may make available to the public either regularly updated lists of qualified or accredited experts or regularly updated lists of accredited companies that offer the services of such experts. Member States may use for this purpose the same means as for experts for energy performance certification and inspections under Article 17 of Directive 2010/31/EU.

> Many EU-funded projects are developing training materials to promote the upskilling of building professionals.

Certificate issue, terms and conditions of use

The Implementing Regulation states that any economic operator may request from a qualified experts an SRI assessment and certificate for the building or building unit in question. The expert shall verify the reliability of the information collected for the assessment of the smart readiness of the building or building unit and for the issue of the SRI certificate. An SRI certificate shall only be issued based on an assessment performed by a qualified or accredited expert. The issue of an SRI certificate may be coordinated with that of an energy performance certificate.

> Many EU-funded projects are developing supporting tools and guidelines to facilitate the issue of SRI certificates.

The SRI certificate shall include the elements listed in Annex IX to Delegated Regulation.

The validity of the SRI certificate shall not exceed 10 years. However, where there is a significant change in a building or building unit that would have had an impact on the initial assessment of smart readiness, a new certificate shall be recommended.

Monitoring and promotion

The Implementing Regulation states that where Member States decide to implement the SRI scheme, experts that operate in the respective Member State's or Member States' territory shall report data on the SRI certificates they issue to the national or, where applicable, the regional authorities of the respective Member States, in accordance with the Annex to this Regulation. They may rely on their energy performance certificate database, where available.

Member States that decide to implement the SRI scheme shall report annually to the Commission the number of smart readiness indicator certificates issued on their territory and related statistics, as set out in the Annex to this Regulation.

Conclusion

Building smartness is increasingly recognized as a key factor in creating healthier, more comfortable buildings with reduced energy consumption and carbon emissions, while also supporting the integration of renewable energy sources into the broader energy system. The Smart Readiness Indicator (SRI) is designed to raise awareness among building owners and occupants about the benefits of building automation and electronic monitoring of technical systems. It also aims to instil confidence in the actual energy savings delivered by these advanced functionalities.

While the decision on whether and how to implement the SRI scheme remains the prerogative of individual Member States, there is a strong determination within the EU to promote its widespread adoption as a common Union-wide scheme in the coming years. Many Member States have already taken steps to test the implementation pathways of the SRI, preparing for its potential mandatory application to non-residential buildings in the near future. The European institutions are committed to avoiding the fragmented implementation that occurred with Energy Performance Certificates, striving instead for a harmonized approach across all Member States.

As the SRI gains traction, it is becoming evident that a market is emerging for skilled professionals who can integrate smartness assessments into their existing practices of energy audits and energy performance evaluations. ■

The SRI – from an experimental to a regulatory instrument

SOPHIE DOURLENS-QUARANTA
Managing Partner
– R2M Solution France
& SRI Support Team
sophie.dourlens@r2msolution.com

RÉGIS DECORME
Managing Partner French
Branch – R2M Solution France
& SRI Support Team
regis.decorme@r2msolution.com

CÉCILE BARRÈRE
EU Project Manager and Business
Developer – R2M Solution France
& SRI Support Team
cecile.barrere@r2msolution.com

The Smart Readiness Indicator (SRI), introduced by the Energy Performance of Buildings Directive (EPBD) in 2018, is still an experimental instrument. Currently being tested in several EU countries, it is expected to become formally adopted as a regulatory instrument from 2027.

Keywords: EPBD, SRI, Smartness, Smart Building, Flexibility, Performance, EPC, Monitoring, Energy efficiency, Return on investment

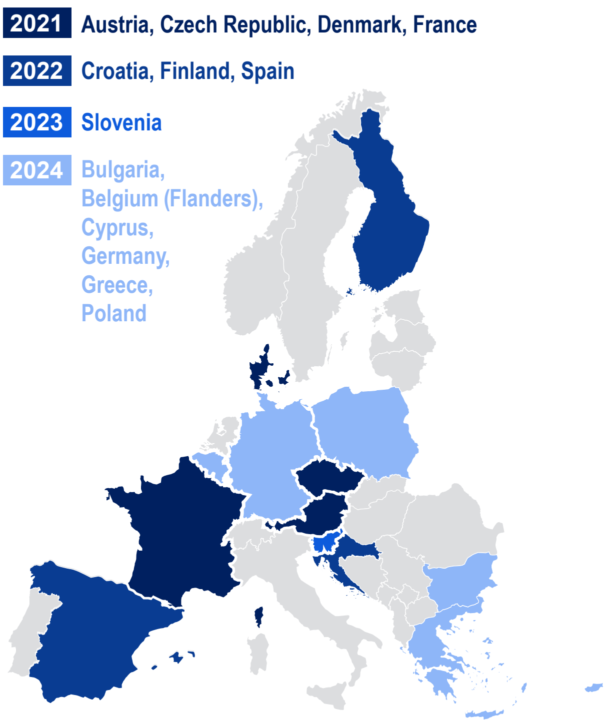
Experimentation of the SRI in EU countries

Launch of test phases at national level

The SRI is currently being tested in half of the EU countries. The *European Commission's webpage on the SRI* [1] provides the most up-to-date information about the national test phases and training materials available in national languages. Relevant information can also be found on the SRI Observatory [2].

These test phases allow for the examination of concrete aspects of the instrument:

- **Evaluators:** How should they be recruited and trained to conduct SRI assessments? What feedback do they provide regarding the practical implementation of the SRI methodology? What are the main obstacles they encounter during SRI assessments?
- **Building owners:** What value do they perceive in the SRI compared to EPCs? Does the result of the SRI evaluation of their building meet their expectations?
- **Smart Building professionals**: How will the SRI interact with existing regulatory frameworks, scores, and labels?



Countries where an official SRI test phase has been launched, with launch year.

Early test phases with different and complementary approaches

National authorities have implemented various and complementary approaches for their test phases.

In 2021, the initial test phases conducted by Member State authorities were supported by technical partners, such as universities, research centres, or consultancies). For instance: In *Austria*, the research centre AEE - Institute for Sustainable Technologies (AEE INTEC) [3] and the University of Natural Resources and Life Sciences Vienna (BOKU) [4] supported the test phase. In the *Czech Republic*, the Department of Environmental and Building Services Engineering of the Czech Technical University in Prague [5] was involved. In *Denmark*, the Danish Technological Institute (DTI) [6] provided support. In these three countries, the SRI evaluations were carried out directly by the technical partners, facilitating the rapid delivery of preliminary results.

Main issues reported:

- **For evaluators:**
  - **Data availability**: There can be challenges due to the high number of smart services that need to be assessed.
  - **Service availability**: Some services may be '*not applicable*' (e.g., services related to heat pumps when the building uses a boiler) and thus not assessed. Conversely, some services may be '*not available*' (e.g., lack of performance reporting), which can affect the score. Distinguishing between 'not applicable' and 'not available' can be challenging.
  - **Service relevance**: Certain services, such as *cloud-based apps*, may be more relevant to building owners or occupants rather than the building itself, which requires clarification.
- **For building owners:**
  - **Expectations vs. results**: Owners of buildings expected to be highly smart were sometimes surprised by their *relatively low SRI scores*.
  - **Recommendations**: Most building owners desire *recommendations on how to improve their SRI score* cost-effectively, though this feature is not yet integrated into the current SRI assessment tools.

Some countries, like *France*, recruited and trained external assessors from among accredited EPC experts, HVAC system inspectors, and energy auditors, with support from the research centre CEREMA [7]. This approach provided insights into various aspects of the process:

- **Competence and contractual issues**: Some assessors faced difficulties with the contractual aspects of SRI evaluations due to the instrument's novelty.
- **Facility manager support**: Evaluations often required input from facility managers to address operational questions and finalise assessments during site visits.
- **Service catalogue adaptation**: The Monitoring & Control domain services need simplification for better understanding by French evaluators. Explanations and illustrations are also necessary to facilitate accurate assessments.

Towards larger-scale test phases

The early test phases mentioned above assessed a limited number of buildings. To validate and expand on the initial findings, further testing is required. The European Commission, through the LIFE programme, is co-funding several projects to support the successful implementation and market uptake of the SRI in EU countries [8].

One of the 56 fiches prepared by SRI2MARKET, available in 7 languages.

One such project, SRI2MARKET, has enabled *Croatia* and *Spain* to launch official test phases, and allowed *Austria* and *France* to expand their initial test phases with a target of several hundred buildings. The project provides tailored training materials in national languages [9] to address issues encountered in earlier phases. These materials include detailed fiches on each smart-ready service, with illustrations of different functionality levels, examples, and pictures.

In *Bulgaria*, the SRI-ENACT project [10] supports the national adaptation of the SRI methodology, including the SRI assessment toolkit, auditor training courses, and pilot buildings. The SmartSquare project [11] is evaluating the payback of SRI improvement measures, capacity building, and information dissemination.

In *Cyprus* and *Greece*, several projects have collaborated to support the launch of test phases. In countries without a LIFE project, test phases have been initiated directly by national or regional authorities with support from national stakeholders (e.g., *Belgium-Flanders*, *Finland*, *Germany*, *Poland*, *Slovenia*).

A future regulatory instrument

According to the latest revision of the EPBD (adopted in April 2024), the use of the SRI is expected to become *mandatory for tertiary buildings with an effective rated output for HVAC systems of over 290 kW* by June 2027. Until then, it will remain optional for other buildings.

In the coming years, the test phases and projects will contribute to a report that the European Commission will submit to the European Parliament and the Council in 2026. This report will compile key findings and recommendations from the SRI's experimental phase and is anticipated to support the large-scale implementation of the instrument.

The SRI is therefore expected to become a new regulatory instrument alongside *EPCs*. While distinct in scope, both instruments are likely to be implemented by the same stakeholders (assessors, training organisations, quality control bodies). To prepare for *coordinated implementation of EPCs and the SRI*, three LIFE projects (SmarterEPC, tunES and iEPB) [12] are working together.

Another important area of research is developing *recommendations and prioritising actions to improve SRI scores post-assessment*. Building owners are interested in enhancing their building's smartness and understanding the *return on investment* for such improvements. This is complex, and monetising

Illustration of the need for recommendations following an SRI assessment. (By R2M Solution, from Carle van Loo - Spanisches Konzert)

benefits like comfort, convenience, and health, is less straightforward compared to energy efficiency. Projects like EVELIXIA [13], co-funded by Horizon Europe, are addressing these issues.

All these projects conclude between 2026 and 2027, the timing will be ideal for the large-scale deployment of the SRI in EU countries in 2027!

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Smart Readiness Indicator certification pathways and EPC systems

JOÃO CLETO
Project Manager at ADENE – Agência para a Energia, the Portuguese Energy Agency
joao.cleto@adene.pt

The current recast of the EPBD directive reinforces the role of a common EU scheme to classify the readiness of buildings for smart technologies: the smart readiness indicator (SRI). This article explores SRI certification pathways and its synergies with Energy Performance Certification (EPC) systems, developed within the SRI2MARKET LIFE project.

Keywords: Smart Readiness Indicator, Energy Performance of Buildings Directive, building performance certification, Smart Buildings

The Smart Readiness Indicator (SRI) and the new EPBD

SRI2MARKET - Paving the way for the adoption of the SRI into national regulation and market

There are several ongoing and past European (EU) funded projects working on the development of the SRI methodology, its implementation at the policy level, creating new features and tools related to the SRI as part of the LIFE Clean Energy Transition program [1]. The SRI2MARKET is one such project and aims at supporting six targeted Member States (MS): Austria, Croatia, Cyprus, France, Portugal, and Spain, in introducing the SRI into their national regulation. Two tools already developed by the project should be highlighted and are freely available by signing up at https://learning.sri2market.eu. These include an e-learning course on the SRI and an SRI assessment tool. Both tools are available in English, German, Spanish, French, Croatian, Portuguese, and Greek.

Within the SRI2MARKET project, an assessment is being made on the possible certification pathways in the targeted countries. Preliminary results of this assessment are presented in this article with detailed analysis and final output to be published early 2025. The purpose of this assessment is to evaluate alternative implementation paths for SRI certification and the costs and benefits from introducing combined EPC/SRI assessments and alternative options regarding the way SRI certificates could be issued.

EPC and SRI certification

EPC certification processes in targeted countries

Even though all MS follow the framework defined within the EPBD and have common features such as the trigger points for issuing EPC (e.g., selling, renting, new buildings and major renovations) and the use of Energy Performance of Buildings standards as reference, there is a myriad of different approaches in terms of calculation methods, energy performance classes, experts' qualification, training and inspections procedures, management structures and certificate design options. These different approaches are visible in the layouts for EPC´s as depicted in **Figure 1**.

This quite different landscape implies that the SRI certification pathways and possible integration with the EPC should be carefully evaluated per country and there is no one-size-fits-all solution.

SRI certificates – EU regulatory framework

Under the SRI delegated and implementing acts (EU) 2020/2156 [2] and (EU) 2020/2155 [3], there are already some provisions on the process and contents of SRI certification. The SRI certificate must be issued by a qualified expert, has a maximum validity of 10 years but should be renewed when there are significant changes in the building, and it can be coupled with EPC certification, the inspection of heating, air-conditioning and combined heating or air-conditioning and ventilation systems or the energy audits scheme. An independent control system must be set up and, if coupled with one of the mentioned systems/schemes, it can rely on the already existing control system. The certificate itself must include information such as a unique ID, date of issuing and expiry, relation to the EPC and energy performance class, general information on the building, smart readiness class and scores (in each of the three key functionalities and per impact criterion). Optionally, it can include the total smart readiness score and for each technical domain and impact criterion, recommendations for SRI upgrades and additional information on assumptions for calculation, available information on interoperability, cybersecurity of systems and data protection and connectivity.

The EU SRI regulation foresees seven labelling classes related to smart readiness scores as follows: 90–100%; 80–90%; 65–80%; 50–65%; 35–50%; 20–35%; <20%. It is up to the MS to define if they want to assign these seven classes to specific naming conventions.

The EPBD recast also defines a template for EPC which has related information with the SRI such as the mandatory information on whether the building has a capacity to react to external signals and adjust the energy consumption and, optionally, a yes/no indication if an SRI assessment has been performed for the building and the SRI value.

SRI certificates design

In 2020, a European Commission study [4] evaluated the SRI regulatory framework, but also the format and the SRI certificate design. Using consumer focus groups, it concluded that 1) a blend of physical and virtual certificate/platform would add most value (a one-page certificate with a QR code for additional detail could serve the purpose), 2) the scores disaggregation should be presented by domain and impact criterion, 3) a common EU graphic layout could be used as a basis and 4) there were no obstacles to EPC integration or other building rating, labelling or certification schemes. Some countries have also conducted test phases and produced their own SRI certificates based on this premises as is the case of France. Some of these graphic proposals are presented in **Figure 2**.

SRI and EPC input data overlap

The SRI and EPC input data overlaps were analysed to check to which extent the SRI assessment is an addition to the EPC (i.e. providing extra information but also requiring additional assessment time) or are fully compatible with current EPC systems. This type of analysis has already been performed in E-Panacea and X-Tendo projects [7], [8], and the findings seemed to indicate there was little overlap. SRI2MARKET approach addresses the same issue but refined the scope by checking differences between three building typologies (residential, non-residential <290 kW, non-residential >290 kW effective rated output) and by analysing potential overlaps. This means that, besides strict input data compatibility, the potential was also evaluated in cases where:

1. technical system/services are evaluated but not totally in terms of control/functionalities.
2. it is only applicable in some buildings.
3. the evaluation exists but is not mandatory.

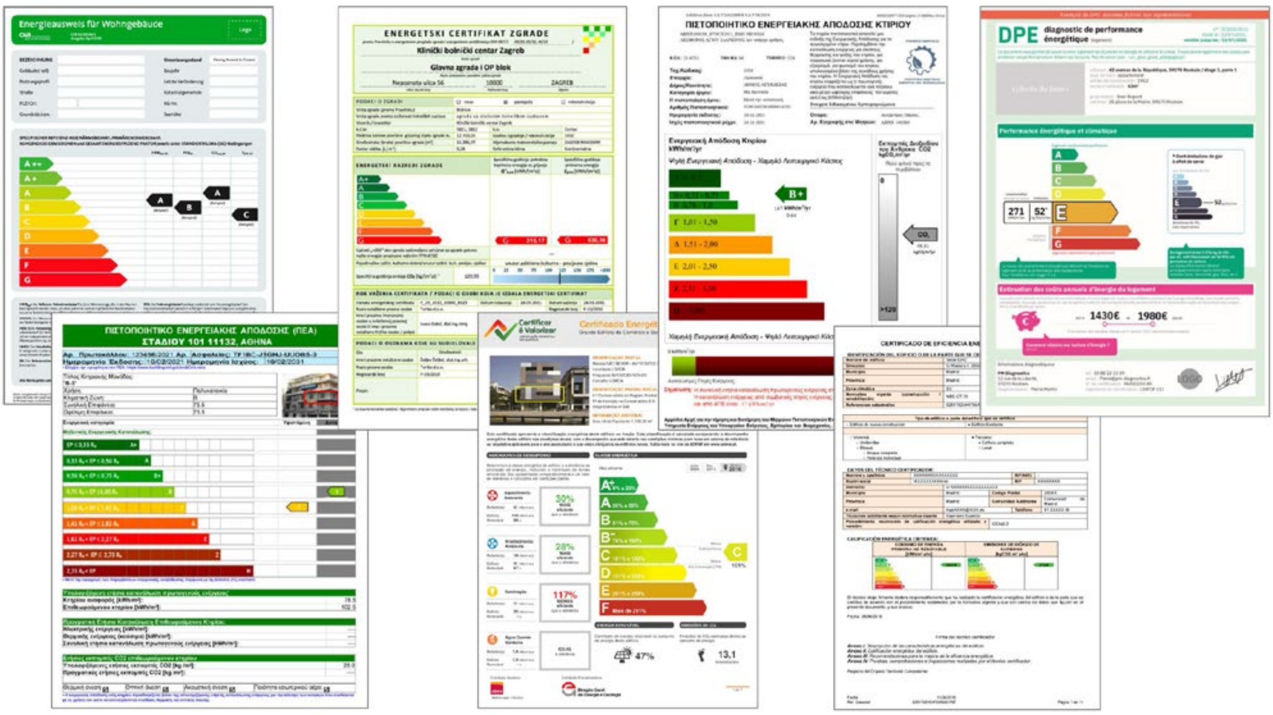

Figure 1. A myriad of different approaches to EPC certification highlighted in EPC certificates in SRI2MARKET countries (From left to right: Austria, Greece, Croatia, Portugal, Cyprus, Spain and France).

The result of this analysis is summed up in **Figure 3** and reveals a new insight on overlap from the previous works.

It is clear that, except for Greece, the strict overlap between parameters is low (on average 25% independent of the building type). A more detailed analysis revealed they are strongly correlated with general building data used on EPC and SRI and very little on actual smart ready services analysed. When evaluating the overlap potential, the picture changes, and a higher correlation is evident. This becomes obvious in non-residential buildings with and effective rated output >290 kW and in countries such as Spain and Portugal although for different reasons. The common practice of using centralized automation and control systems in new buildings as well as the positive implication these systems have on inspection procedures and the higher potential for cost-effective energy reduction impact, partially explains these results. In the case of Spain, the higher correlation is explained using some assessment methods (software) for EPC issuing which include the evaluation of several SRI related services. It is therefore mainly a voluntary assessment option some assessors use. The case of Portugal is quite different as there are mandatory BACS requirements for new buildings with an effective rated output >290 kW which are strictly related to the “Energy performance of buildings - Contribution of building automation, controls and building management” standard (EN ISO 52120-1:2022). In practical terms this means that a full SRI pre-assessment is almost made, and little effort is needed to perform a full SRI assessment.

SRI certification pathways

With the information available on the SRI2MARKET target countries on EPC certification systems and potential input parameters overlap, together with feedback gathered from national stakeholders and, in some cases, feedback from ongoing or finished test phases, a simplified multicriteria evaluation was performed for each country by national experts. It implied rating the importance of 49 different features/characteristics/criteria along three different SRI certification implementation scenarios according to its EPC system integration level:

- **Scenario I - Fully integrated** - SRI is fully embedded in EPC certification system and is part of the EPC certificate.
- **Scenario II - Mildly integrated** - Features of SRI are integrated in the EPC system. For instance, some information might be part of the certificate, qualification of experts and quality control systems are the same. But SRI can be assessed independently.
- **Scenario III – Solo** - There is a national framework for the SRI certificate, but its market implementation is fully independent of EPC system on all stages. Some information for SRI can still be placed in the EPC, if it exists

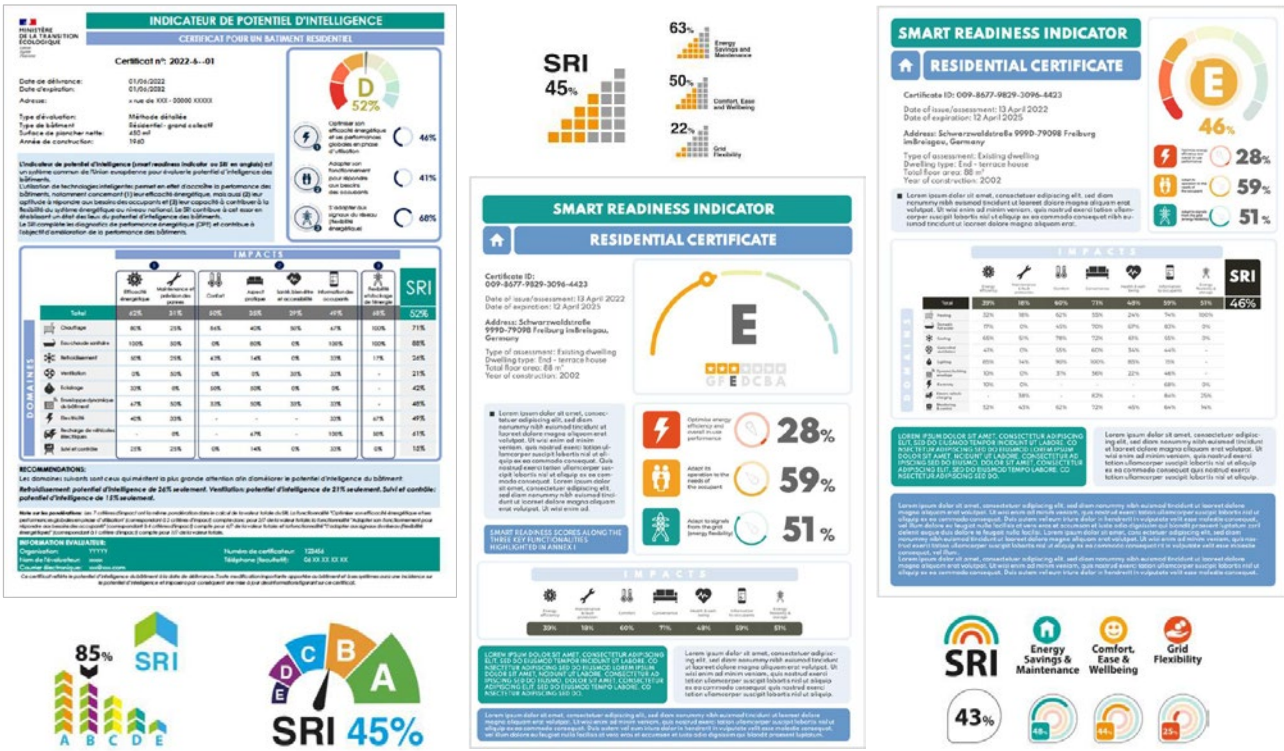

Figure 2. Several graphical layout and design proposals for SRI logos and certificates (Sources: [4], [5], [6]).

The preliminary results hint at some general conclusions:

1. Despite the differences between countries, the overall evaluation already points to a strong preference for a pathway that follows scenario I - fully integrated or Scenario II - mildly integrated.
2. Regardless of the scenario, there are topics that seem to be critical to the SRI certification process, namely: impact on energy and emissions reductions, the certificate format and contents, and the overall costs of implementing and running the scheme.
3. On the other hand, the alignment or complementarity with other market-based building certification systems was not considered very relevant for the definition of the certification pathway.

Going into more detail, there are specific features that have been commonly rated has very high importance irrespective of the scenario and country, namely:

1. Information from the buildings EPC or information from the national EPC database should influence the weighing factors for technical domains across impact criteria.
2. SRI relies on additional information from EPC databases and provides additional outputs to the EPC databases.
3. Display and visual appearance of the SRI certificate contents.
4. If the preferred pathway is scenario I - fully integrated or scenario II - mildly integrated with the EPC system, then SRI certificate visual identity should be linked to EPC visual identity.

This means a strong effort should be placed on the final format and graphic layout of the SRI certificate, effective, it not common, communication platforms and data exchange between SRI and EPC systems should be put in place and the visual identity of the SRI should follow has much as possible the EPC visual identity.

References

[1] European Comission (2023). LIFE projects supporting SRI. [Online]. Available: https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/smart-readiness-indicator/life-projects-supporting-sri_en. [Accessed 03 09 2024].

[2] European Union (2020). EUR-Lex. Document 32020R2156. [Online]. Available: https://eur-lex.europa.eu/eli/reg_impl/2020/2156/oj. [Accessed 03 09 2024].

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[4] Verbeke, S. et al (2020). Final report on the technical support to the development of a smart readiness indicator for buildings – Summary. Publications Office, 2020.

[5] SRI Platform Plenary #3. (2023). [Online]. Available: https://circabc.europa.eu/ui/group/54384127-eb1d-445e-9b6e-ef5ef14fe429/library/10f207e9-fee0-4386-966f-d20613b3d8ac?p=1&n=10&sort=modified_DESC. [Accessed 03 09 2024].

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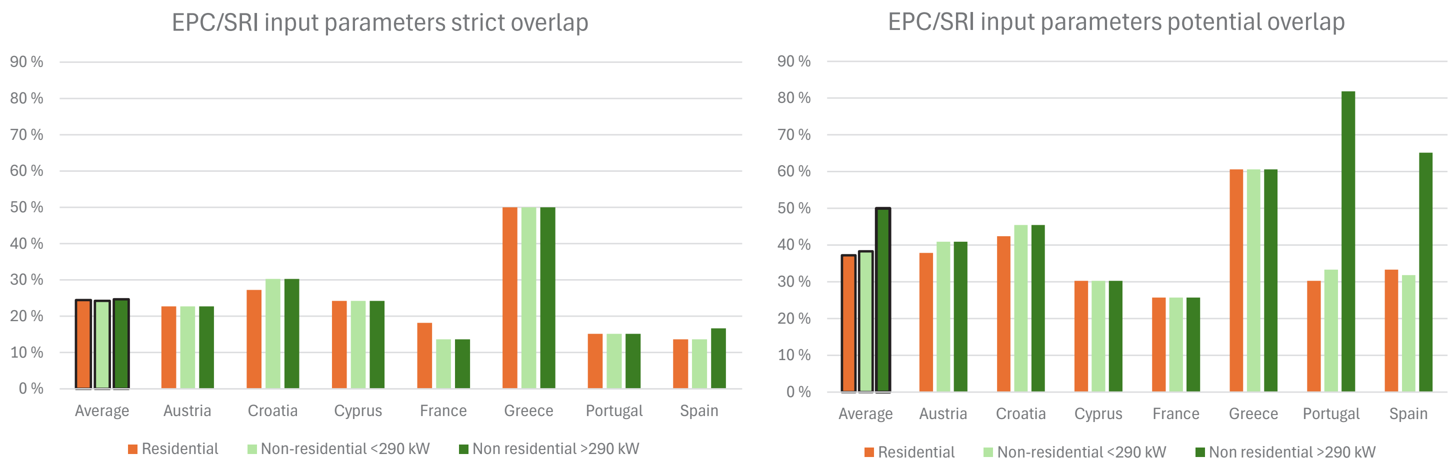

Figure 3. SRI input parameters strict and potential overlap with EPC input parameters across SRI2MARKET countries in 3 different building typologies.

Preliminary Insights of SRI assessments supported by SRI2market

MIGUEL ÁNGEL PASCUAL
PhD, CEO at Efinovatic, Spain

MARÍA FERNÁNDEZ BONETA
Research Project Manager at CENER (National Renewable Energy Centre), Spain

The global goal of zero net emissions by 2050 requires improvements in energy efficiency, electrification of end users and increased penetration of renewable energy generation. In this scenario, the building sector becomes a critical element in overcoming current challenges, with the ability to produce, consume, store, sell and buy energy. However, in order to unlock its full potential, the current smartness of the EU building stock needs to be assessed, monitored and upgraded. The common EU framework based on the Smart Readiness Indicator and related ongoing projects can contribute significantly to this goal. Some preliminary results are presented in this article.

Keywords: Smart readiness indicator (SRI), demand response, energy flexibility, smart buildings, technical building system, building automation and control systems

The global goal of zero net emissions by 2050 requires improvements in energy efficiency, electrification of energy services and increased penetration of renewable energy generation. The revised Renewable Energy Directive (RED) 1 adopted in 2023, raises the EU's binding renewable energy target for 2030 to a minimum of 42.5%. But then, the intermittency of renewable energy and the increasing use of these distributed energy resources will put additional pressure on existing grids. In this scenario, the building sector becomes a critical element in addressing today's challenges. With the ability to produce, consume, store, sell and buy energy, buildings become active participants in the buildings-to-grid ecosystem. Building-to-Grid (B2G) practices, based on digitalisation and ICT technologies, create an opportunity for buildings to generate new value streams with energy services. Emerging technologies such as IoT, artificial intelligence, big data, blockchain and 5G enable new approaches such as distributed resources including demand response, distributed generation, storage, and renewable generation, which enable consumers to provide energy flexibility.

The revised Energy Performance of Buildings Directive (EPBD) 2, emphasises the use of smart technologies and control systems (BACS) to improve the energy performance of buildings, including a common general framework in its Article 15 and Annex IV (Smart readiness of buildings).

In this scenario, the current intelligence of existing buildings needs to be assessed and building professionals and end users need methodologies and tools to carry out this assessment, diagnosis and proposal of the most appropriate measures to improve such indicators and then upgrade the intelligence of buildings according to market needs.

Context

The Smart Readiness Indicator (SRI) is a common EU methodology that rates the smart readiness of buildings (or building units) for their capability to perform three key functionalities: (KF1) 'optimisation of energy performance and operation', (KF2) 'response to the needs of the occupants', and (KF3) 'adaptation of operation to provide energy flexibility', including the ability of the building or building unit to enable participation in demand response. The SRI was introduced in the EPBD as a way to emphasize the role of smart building technologies – such as technologies for building automation, control and monitoring of equipment operation – in improving the energy efficiency of buildings and their capability to be active components of the future EU energy system.

The SRI scheme incorporates a calculation framework defined in the SRI delegated Regulation, which includes the assessment of smart technologies present in a building, classified into nine technical domains:

heating, cooling, domestic hot water, ventilation, lighting, dynamic building envelope, electricity, electric vehicle charging, and monitoring and control. Each service (e.g., heating emission) is rated according to its ability to impact on seven different impact criteria: energy efficiency, maintenance and fault prediction, comfort, convenience, health, wellbeing and accessibility, occupant information, and energy flexibility and storage.

Each service included in a National Service Catalogue (i.e., at Member State level) contains a list of functionality levels, from least to most smart, to cover the associated service. Each functionality level is described as an individual functionality, which in practice is associated with a physical installation that may include sensors, actuators, other control hardware, software and visual interfaces.

Finally, the calculation framework includes the weighted sum of all scores to provide a final SRI score, as well as aggregated scores per impact, domain and key functionality.

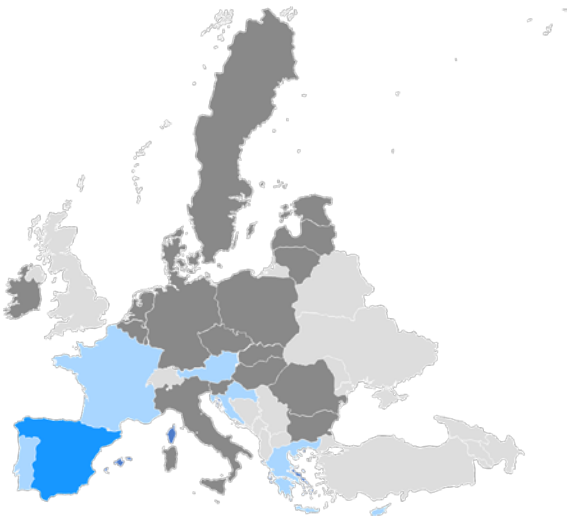

Figure 1. Focus countries of the SRI2Market project.

The SRI is based on a self-referencing system, which means that the indicator expressed as a percentage (%) is the score relative to the same building with the highest possible score.

The SRI2MARKET project aims to support Member States in successfully planning the introduction of SRI into their national regulations and markets. In particular, SRI2MARKET is working on specific Member States and with general objectives that are differentiated; Austria, France, Portugal, Spain, Croatia, Greece and Cyprus (**Figure 1**).

SRI training

The SRI2MARKET project has developed online learning and assessment tools based on the SRI calculation methodology. In particular, the SRI2MARKET e-learning programme (available in seven languages at https://learning.sri2market.eu) establishes a graded learning system to ensure proper training of building professionals and other interested end-users, while at the same time enabling a quality control system to curate the SRI2MARKET database.

The learning path is made up of three stages or levels, closely linked to access to the assessment platform, which is protected by login details: Level 1 - SRI User, Level 2 - SRI Beginner and Level 3 - SRI Expert. In order to achieve each level, it is mandatory to complete specific tasks as shown in **Figure 2** below and at the same time, each level grants different access to the assessment platform. Specifically, the achievement of "Level 2" will automatically provide access to the assessment platform (https://sri2market.eu) and the achievement of "Level 3" will differentiate the user account and classify the corresponding projects according to these criteria, making them valid for advanced monitoring of SRI scores.

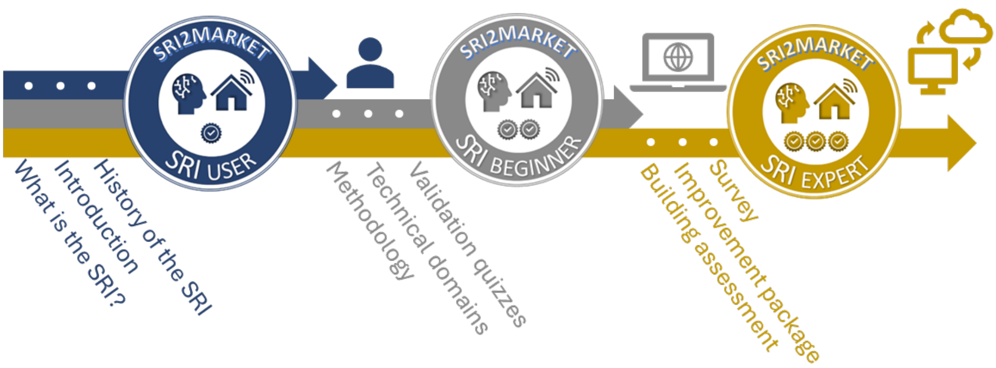

Figure 2. SRI2MARKET training programme.

The structure (**Figure2**) ensures that the SRI2Market database is populated with high quality and trustworthy input data in order to extrapolate aggregated and consolidated conclusions regarding the SRI test phases.

The SRI training platform is currently being used by more than 800 trainees with the aim of becoming 'SRI experts' (i.e. achieving level 3 SRI expertise). Most of them (around 600) are currently taking the SRI course in Spain as part of the Spanish test phase.

SRI monitoring and preliminary results

The SRI2Market database, which can be consulted at https://sri2market.eu/sri/powerBi/, includes 172 EU buildings assessed so far, 80 from these located in Spain. This tool offers the possibility to display results with different segmentations: user level, building type, building size or construction year.

The database will continue to be populated during the rest of year 2024 and most of 2025, when the advanced benchmarking provided by the project database and visualisation interface will be used to submit the corresponding report to the European Commission at the end of the official SRI test phases such as the Spanish test phase.

Some preliminary results of the advanced benchmarking and monitoring tools based on the current sample of buildings are shown in the following figures. These figures can answer a first list of questions that are useful for defining roadmaps and supporting policy decisions.

Figure 3 shows a comparison of the current state scores and the scores for the improvement proposals, for Spain and the European Union. It can be seen that the Spanish results follow the same tendency as the rest of the European Union, with most of the cases in the bin for SRI scores between 0% and 10% with a mean SRI score of 20%.

The histogram for the cases with improvement proposals shows that most of the cases are in the bin for SRI scores between 30% and 40%, with an average total SRI score of 39.5%.

In the right column of the **Figure 3** we have the results for the main functionalities. As can be seen, the least present functionality in the existing building stock is energy flexibility.

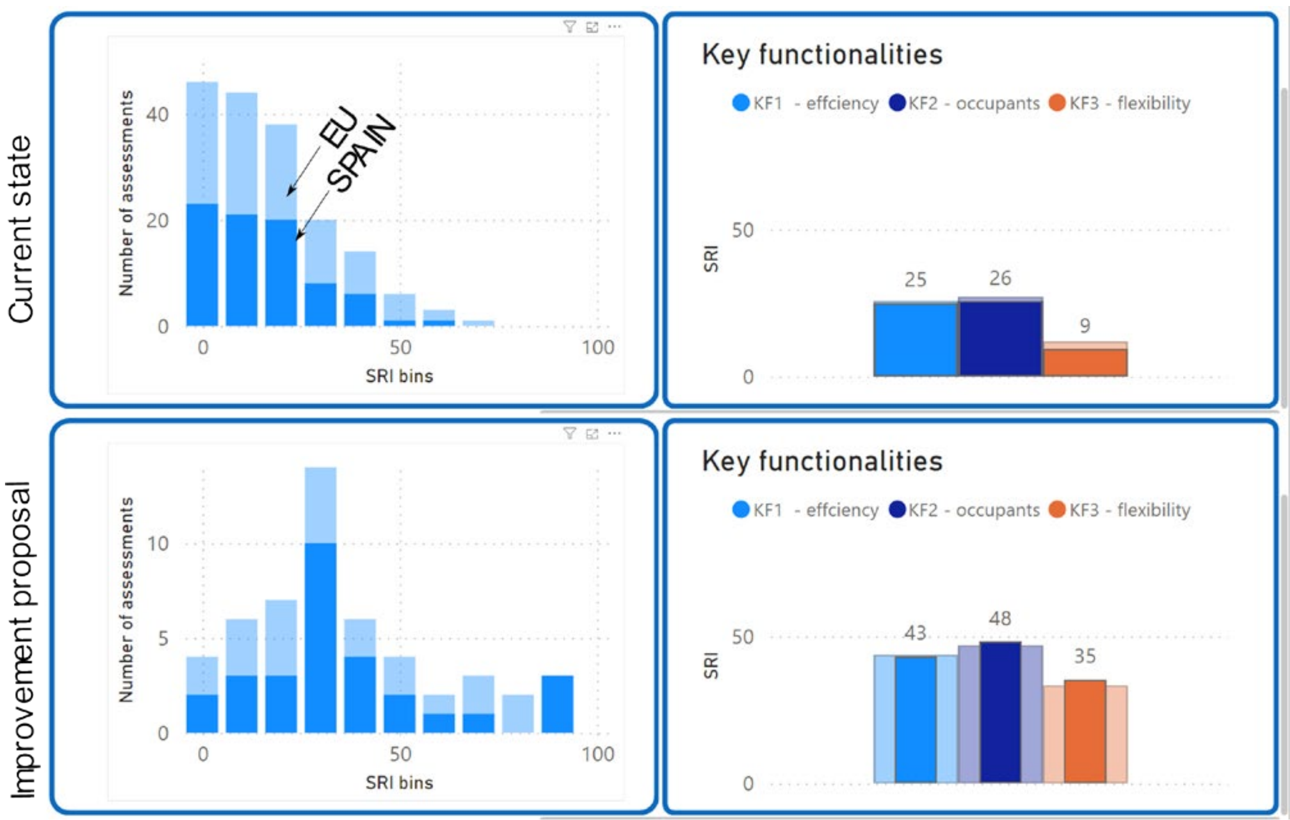

Figure 3. Left column: histogram with SRI distribution (for EU and Spain). Right column: Key functionalities scores. First row: current state assessments. Second row: improvement proposal assessments.

Energy Performance Certificate class

Figure 4 shows the mean overall SRI for each EPC class. The EPC class is not a mandatory input in the platform, so it is not known for all assessments. The results of this graph are inconclusive due to the small sample size so far, but there is a slight tendency for better SRI scores to be associated with better EPC labels.

Key functionalities

Figure 5 analyses the correlation between the three key functionalities. Each point is an SRI assessment, placed on the graph with the coordinates of the corresponding key functionality scores. There is a clear correlation between energy performance (KF1) and responsiveness to occupant needs (KF2). This can be interpreted as BACS improving energy efficiency will also improve occupant comfort.

On the other hand, Key Functionality 3 (i.e. energy flexibility) is not related to the other two.

Building construction year

Figure 6 shows the overall SRI score related to the year of construction of the building. There is no clear trend, but it seems that modern buildings can achieve a higher SRI.

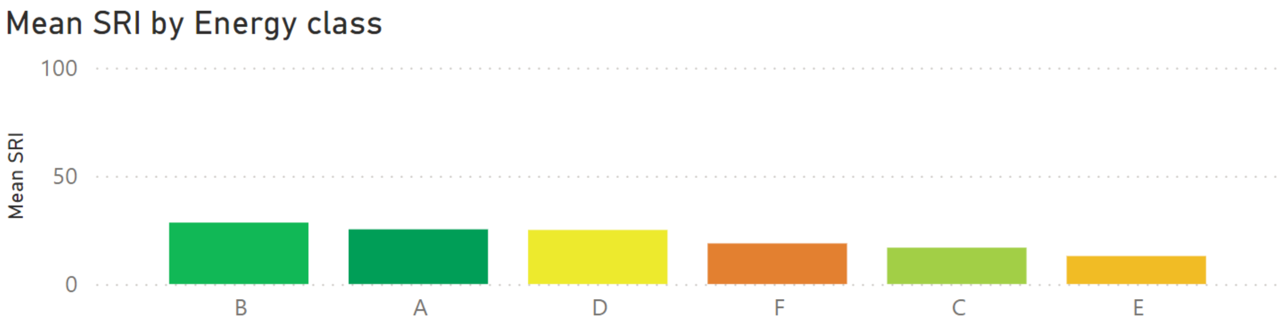

Figure 4. Mean SRI score versus EPC class.

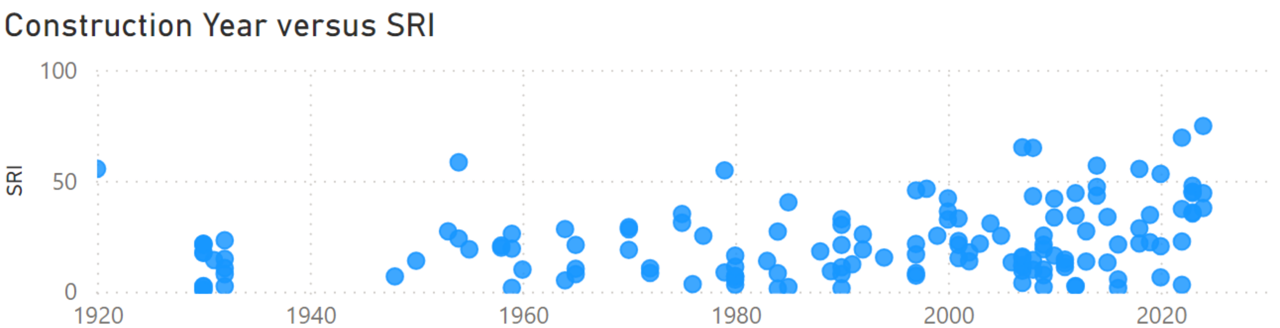

Figure 5. Key Functionality scores correlations.

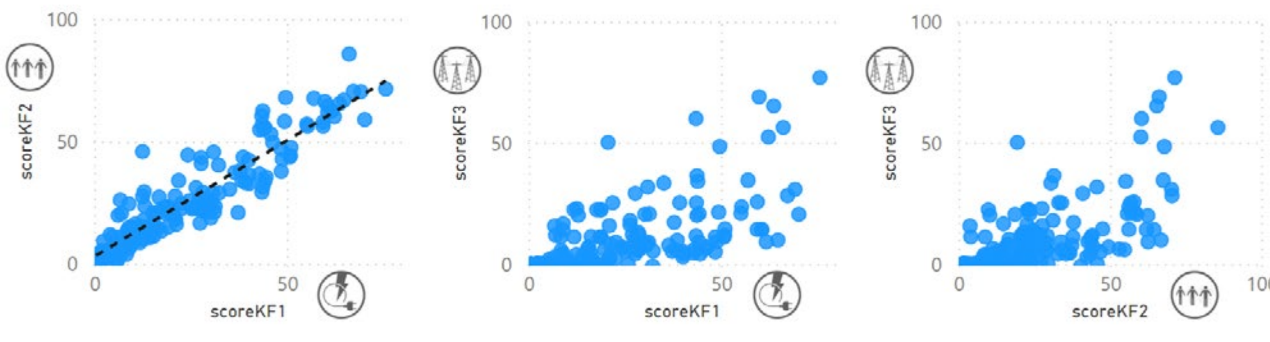

Figure 6. SRI versus year of construction.

Catalogues

Figure 7 shows several graphs representing the results obtained with both catalogues (i.e. the simplified catalogue for Method A and the detailed catalogue for Method B). Almost half of the buildings have been assessed using each catalogue. So far, the simplified Catalogue for Method A has achieved a better score, especially for key functionality 3 (energy flexibility).

ISO 52120

The SRI2MARKET assessment platform includes an ISO 52120 assessment approach. **Figure 8** shows that most cases fall into the D class, with an average SRI score of 24. Those that reach the B class have an average score of 39 and those that reach the A class have an average score of 43.

Conclusions

The sample size is not large enough to be highly representative, so no conclusions can be drawn. However, the following trends can be identified:

- The expected total SRI score for the existing building stock is between 0 and 20%.
- The key functionality that is less present in the existing building stock is KF3 - Energy Flexibility.
- There is a slight correlation between the energy certification class and the SRI score.
- The functionalities KF1 - Energy Efficiency and KF2 - Response to Occupants are highly correlated.
- It is found that buildings assessed with the simplified Catalogue A achieve a higher average SRI score than those assessed with the detailed Catalogue B.
- Most of the buildings assessed will fall into the D category of ISO 52120.

Links

[1] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L_202302413.

[2] https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en.■

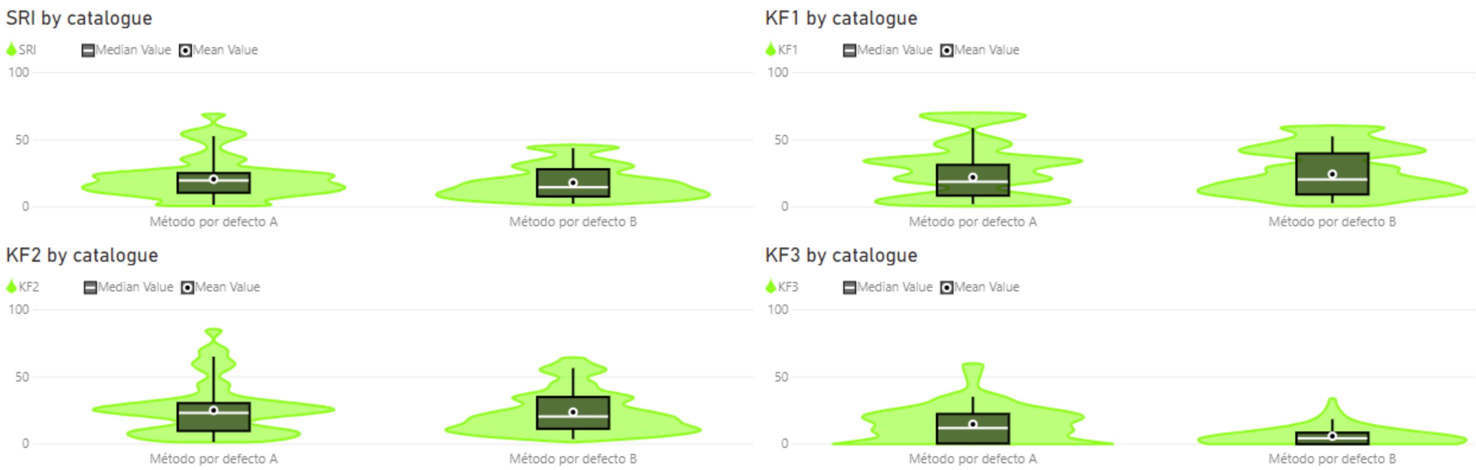

Figure 7. SRI scores according to both default catalogues (A and B).

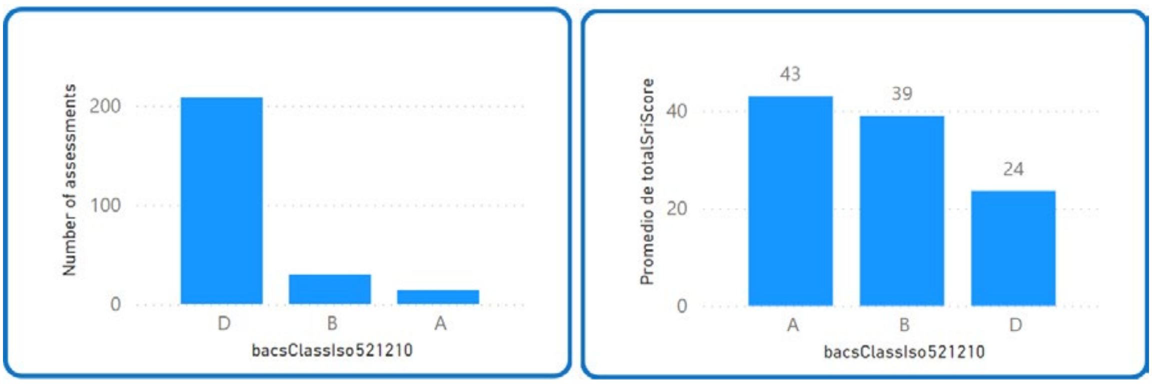

Figure 8. Relationship between ISO 52120 and SRI score.

The Smart by Powerhouse & SRI Framework: Towards a Smarter Norwegian Building Stock



ITALO ALDO CAMPODONICO AVENDANO
Norwegian University of Science and Technology (NTNU), Department of Ocean Operations and Civil Engineering, Norway

KAMILLA HEIMAR ANDERSEN
SINTEF Community, Department of Architectural Engineering, Norway

SILVIA ERBA
Politecnico di Milano, Department of Architecture and Urban Studies, Italy



AMIN MOAZAMI
SINTEF Community, Department of Architectural Engineering, Norway

MOHAMMADREZA AGHAEI
Norwegian University of Science and Technology (NTNU), Department of Ocean Operations and Civil Engineering, Norway

BEHZAD NAJAFI
Politecnico di Milano, Department of Energy, Italy

The focus on enhancing the interaction between buildings, users, and the grid is a cornerstone of the green energy transition. By evaluating the smartness in existing buildings, their legacy systems can be identified and targeted for potential upgrades. This process can lead to the development of new criteria for assessing smartness in buildings.

Keywords: Smart Readiness Indicator, Smart by Powerhouse, Smart buildings, Building stock, Energy use, Norway, Non-residential buildings, Digitalization

Motivations

Recently, the focus on solutions for the green energy transition is attracting attention across various sectors. The building sector is far behind, but stakeholders, policymakers, and users are looking to adopt solutions that can enhance the sector's efficiency without interfering with the satisfaction, health and well-being of the end users. Moreover, the building sector's focus on smarter solutions is not only motivated by the user experience and energy efficiency. A smarter interaction with the electrical grid can indeed boost the electrification of the demand sector, allowing the deployment of renewable generation at a large scale [1]. On a neighbourhood scale, it can lead to an increase in social welfare since smart buildings and grid interaction help alleviate the grid [2].

On the global scale, 30% of the end energy usage is in the building sector [3]. In Norway, only the non-industrial building sector uses a share of 55% of the electricity use [4]. The latter and considering that the heating system of up to 80% of the households is electrified [5], shows the level of electrification on the demand side, which can be mirrored in the future in other European countries to comply with the clean energy transition targets.

The current benefits of deploying smart solutions, such as "digitalization" and "IoT device integration", can only be fully understood when a thoughtful analysis of the smartness of the existing building stock is performed. With those purposes, the authors proposed [6] a benchmarking framework that joints together the Smart Readiness Indicator (SRI) [7], developed under the umbrella of the European Union (UE), and the Smart by Powerhouse assessment [8], created by a Norwegian consortium of stakeholders focused on developing future proof climate buildings.

Framework Development

The proposed framework contemplates the use of the SRI for measuring smart readiness and the Smart by Powerhouse (hereon known as the Smart assessment) for assessing the smartness of a building (see **Figure 1**). By using these tools, stakeholders (e.g., building managers, building owners) or energy policers can gain an overall understanding of the smartness of a portfolio of buildings and present the potential for improving the buildings' capacities based on their own limitations.

Buildings in Norway are used as a study case due to the presence of highly electrified buildings; thus, modifications in the assessments were proposed to truly represent the characteristics of Norway's building stock. In these adjustments the focus has firstly been put on the SRI assessment, where the scoring methodology is based on two main items: building category and geographical location. With these two inputs, the weights utilized for calculating the scores are defined, and they are mainly calculated based on the energy usage per domain (heating, cooling, etc.). However, the lack of specific energy-related data led the SRI's developers to provide a simplified classification of these two inputs for dealing with this issue. Hence, the building category is subsequently split into residential and non-residential categories, while the geographic location is limited to large sub-continental zones in Europe, with Norway placed in "North Europe". Consequently, the first modification proposed in the SRI methodology is the involvement of dedicated energy data for non-residential buildings in Norway. In **Figure 2**, the adaptation of the weights is presented.

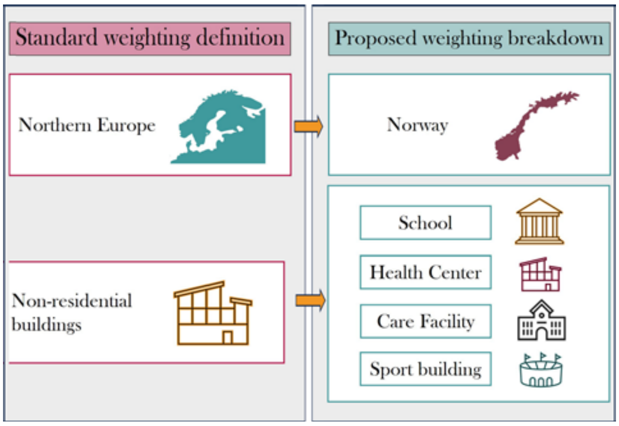

Figure 2. Proposed adaptation of the weighting factors for the SRI assessment considering the local conditions of energy use and variance in the non-residential building categories [6].

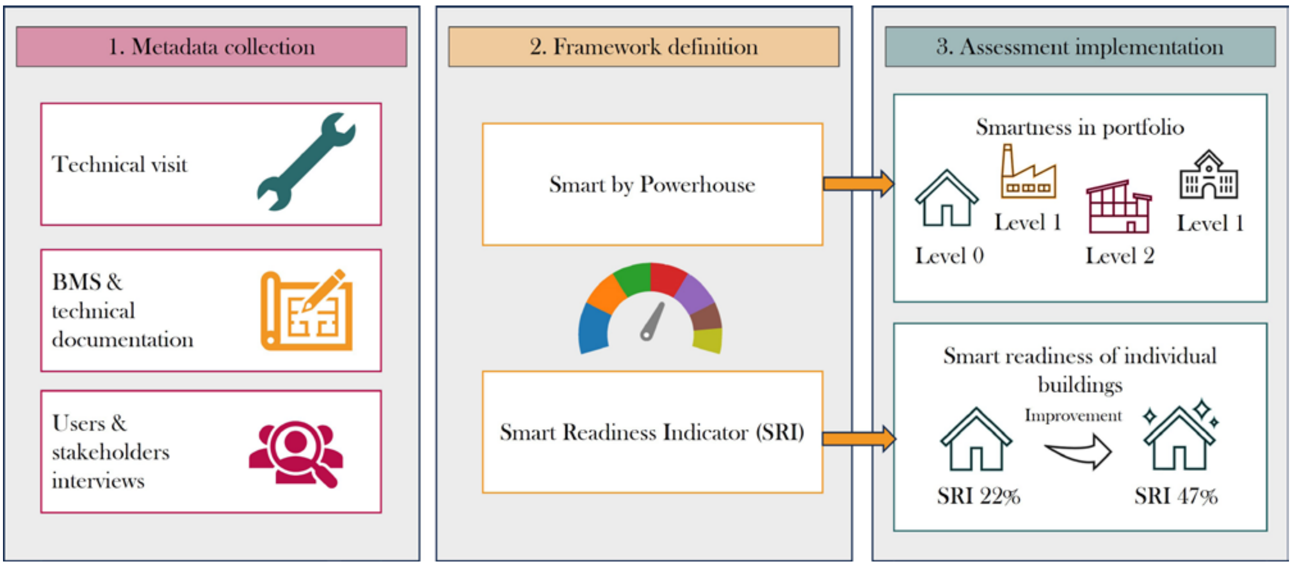

Figure 1. Assessment methodology for the proposed framework [6].

Next, the energy balance weights that influence the calculations for domains such as heating, cooling, and ventilation also provide the weights for the impact of "Energy flexibility and storage". Under the highly electrified building stock, the importance of this impact needs to be redefined to highlight the importance of the building/grid interaction. Moreover, "flexibility" corresponds to an active operational measure; thus, it should be seen in that context and not calculated based on yearly energy usage. Consequently, a new "Power balance" is proposed (see **Figure 3**) to account for the hourly impact of the different domains, which represent some characteristics of energy flexibility such as "power curtailment" or "grid congestion".

The second assessment part of the framework, the Smart by Powerhouse, was originally developed to measure commercial buildings' smartness at the design stage. This involved updating the definition of the functional requirements to make it applicable to general non-residential buildings and extending its use to already constructed buildings. In order to enhance the comprehensiveness of the assessment, a new scoring system was implemented. Additionally, two new levels of technological smartness were defined as "No Technological Equipment" and "Pre-Automated." These levels augment the existing ones: "Automated", "Smart Ready", "Smart Standard", "Smart Predictive", and "Smart Cognitive".

Smartness and Smart Readiness Assessment in Non-Residential Norwegian Buildings

The framework was tested in ten non-industrial pilot buildings ("Care facility", "Sport building", "School", and "Health centre") in Ålesund, Norway, provided by Ålesund Commune as part of the COLLECTiEF project [9]. These buildings were selected to represent a diverse range of energy systems and construction dates.

The proposed modifications of the SRI assessment are represented by the results of the SRI and aggregated scores presented in **Table 1**. The results show that using dedicated building category data for the specific country, as well as modifying the "flexibility" related calculation weights, results in a negative variation of the SRI score, ranging between 0% and 3.4%. Moreover, energy-related aggregated scores mostly led to negative variations but highlighted the larger variations in the "Grid" score, indicating that the importance of "flexibility" was addressed.

For the general assessment, a comparison between the Smart by Powerhouse and the overall SRI score is shown in **Figure 4**. The results indicate that the complete sample of buildings is located just above the "Automatized" level of smartness. The same sample shows an overall performance for the SRI in the range of 20-35%, where 100% indicates a total smart-ready building.

Conclusion

The study proposed a novel framework by jointly assessing the smart readiness (SRI) and smartness (Smart by Powerhouse) in buildings with a modified version of the SRI and Smart by Powerhouse assessments, respectively. The proposed modifications led to a more building- and country-specific SRI assessment by highlighting a dedicated representation of energy usage and the importance of "flexibility" participation. Next, the results of applying the framework in the building samples indicate a low smartness and smart readiness in the buildings independently of

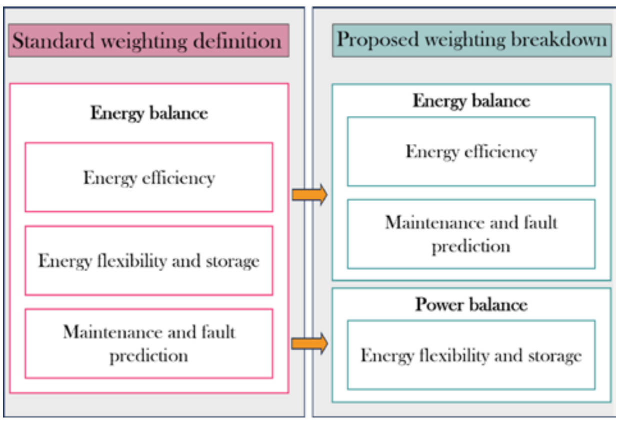

Figure 3. Proposed changes in the energy balance weighting factors for the SRI assessment [6].

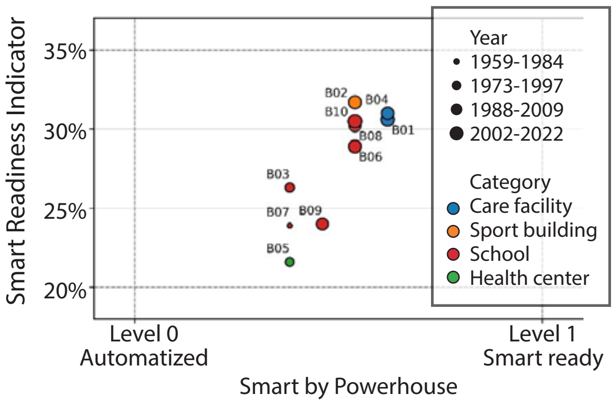

Figure 4. Overall score for the Smart/SRI framework [6].

Table 1. Overall SRI scores. The difference between the calculated SRI with the customized weights and the SRI based on the original weights defined for non-residential buildings in Northern Europe is presented in parenthesis [6].

Building		B01	B02	B03	B04	B05	B06	B07	B08	B09	B10
SRI Score		30.6% (−3.4%)	31.7% (−0.2%)	26.3% (−0.6%)	31.0% (−0.1%)	21.6% (−0.9%)	28.9% (−0.3%)	23.9% (−1.5%)	30.2% (−1.3%)	24.0% (0.0%)	30.5% (−2.3%)
Aggregated Score	Building	45.6% (−2.8%)	42.3% (−1.3%)	42.3% (−0.2%)	44.3% (−1.3%)	34.6% (−2.8%)	42.0% (−2.1%)	38.9% (−3.5%)	45.4% (−2.4%)	38.9% (1.0%)	44.5% (−2.9%)
	User	42.1% (0.0%)	38.3% (0.0%)	28.6% (0.0%)	35.7% (0.0%)	26.1% (0.0%)	37.7% (0.0%)	28.9% (0.0%)	37.4% (0.0%)	26.6% (0.0%)	38.1% (0.0%)
	Grid	4.2% (−7.5%)	14.5% (0.7%)	7.9% (−1.6%)	13.0% (0.9%)	4.1% (0.2%)	7.0% (1.1%)	4.0% (−1.1%)	7.9% (−1.6%)	6.7% (−0.9%)	8.9% (−4.2%)

the corresponding category (sport buildings, health centres etc.). Moreover, the building sample shows that physical tools such as sensors, actuators, and data collection exist in the buildings; thus, the buildings present the potential to become "Smart buildings". Similarly, the low "Grid" aggregated scores indicate that the interaction between buildings and the grid needs to be addressed by updating the legacy systems in the buildings.

Acknowledgment

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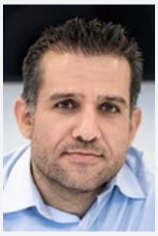
Standardized On-Site Smart Readiness Indicator (SRI) Audits

Enhancing Building Smartness through Structured Assessment



PARIS FOKAIDES
Senior Researcher at Sustainable Energy Research Group, Chief Researcher at Kaunas University of Technology, Associate Professor at Frederick University
p.fokaides@frederick.ac.cy

In a rapidly evolving energy landscape, the Smart Readiness Indicator (SRI) plays a crucial role in evaluating and improving building smartness. This article outlines the standardized approach to on-site SRI audits, emphasizing the practical implications and findings relevant to engineers involved in building management and energy efficiency.

Keywords: Smart Readiness Indicator (SRI); Energy Performance of Buildings Directive (EPBD); audit; standardisation; CEN; smart readiness

Introduction

The growing integration of smart technologies in buildings represents a significant shift in the way we manage energy, enhance occupant comfort, and optimize operational efficiency. As buildings become increasingly complex, the need for standardized assessments to measure their smart readiness has never been more critical. The Smart Readiness Indicator (SRI), established by the European Union, provides a comprehensive framework to evaluate a building's capability to adapt to advanced technologies and interact with energy grids efficiently [1].

This article presents the standardized approach to conducting on-site SRI audits, as outlined in the CEN Workshop Agreement (CWA) [2], as initiated by Smart Square project [3]. These audits are designed to assess a building's smart readiness across multiple domains, including technical building systems, grid interaction, and energy performance. By adhering to a structured methodology, engineers and building managers can obtain reliable insights into the smart capabilities of their buildings, enabling informed decisions for upgrades and improvements.

The focus of this article is to provide a practical guide to the SRI audit process, with an emphasis on the key findings and implications for practitioners. Through this, we aim to highlight how SRI audits can drive the development of smarter, more efficient, and sustainable buildings.

Framework for On-Site SRI Audits

The Smart Readiness Indicator (SRI) framework is a crucial tool for assessing a building's ability to integrate and optimize advanced technologies [4][5]. Developed as part of the European Union's energy efficiency initiatives, the SRI framework provides a standardized method for evaluating smart readiness, ensuring consistency and reliability across different building types and regions. There is a significant gap between the adoption of the SRI methodology and the implementation of onsite audits, as existing guidelines lack detailed procedures for this purpose; the CWA effectively bridges this gap by providing a comprehensive framework for standardized onsite SRI assessments.

The CEN Workshop Agreement provides a standardized framework for conducting on-site Smart Readiness Indicator (SRI) audits, ensuring consistency and reliability in assessing a building's smart capabilities. Developed through collaboration among experts, the CWA integrates best practices and existing standards to create a comprehensive methodology for evaluating and enhancing building smartness. This framework is designed to evaluate buildings in a holistic manner, covering key areas such as technical building systems (TBS), grid interaction, and energy performance. The aim is to provide a comprehensive assessment that not only measures current capabilities but also identifies potential areas for improvement.

The framework for SRI on-site audits is structured around several key components:

1. Assessment Principles: Establishes the fundamental criteria for conducting SRI audits, ensuring uniformity in the evaluation process. This includes defining the scope of the audit, identifying relevant stakeholders, and setting the objectives for the assessment.
2. Audit Methodology: Provides a detailed, step-by-step approach to performing on-site SRI audits. This methodology incorporates best practices from existing standards, such as the EN 16247 energy audit standard, and adapts them to focus on smart readiness [6].
3. Documentation and Reporting: Outlines the necessary documentation and reporting requirements, ensuring that audit findings are recorded comprehensively and communicated effectively. This includes data collection protocols, performance evaluations, and the generation of a final SRI report.
4. Quality Assurance and Compliance: Defines the standards and procedures for ensuring the accuracy and integrity of the SRI audit process. This includes guidelines for auditor training, data verification, and compliance with relevant regulations.

By adhering to this structured framework, practitioners can conduct thorough and reliable SRI audits, providing valuable insights that support the development of smarter, more energy-efficient buildings.

Methodology of On-Site SRI Audits

Conducting an on-site SRI audit involves a structured, methodical approach designed to thoroughly evaluate a building's smart capabilities. The audit process, as defined by the CWA, ensures that the assessment is comprehensive, accurate, and relevant to the building's specific context. The following outlines the step-by-step methodology for performing an on-site SRI audit:

Preliminary Contact and Start-Up Meeting

The audit process begins with the preliminary contact, where the objectives, scope, and depth of the audit are established. During this phase, the SRI auditor engages with the building's stakeholders to clarify expectations, allocate resources, and set a timeline for the audit. This is followed by a start-up meeting, which involves the nomination of key personnel, the finalization of the site visit schedule, and a detailed discussion on the necessary data and documentation. This preparatory phase is crucial as it ensures that all parties are aligned and that the audit can proceed smoothly.

Data Collection

Data collection is the backbone of the SRI audit, focusing on gathering detailed information about the building's technical systems and their smart capabilities. The auditor collects data on several key aspects, including:

- Building Information: Details such as building size, age, usage, and location are documented.
- Technical Building Systems (TBS): Information on heating, cooling, ventilation, lighting, and other relevant systems is gathered, with a focus on their automation and control functionalities.
- Grid Interaction and Flexibility: Data on the building's interaction with the energy grid, including demand-side management and integration with renewable energy sources, is collected.
- Performance Data: Historical and current data on energy consumption and system performance is recorded.

This comprehensive data collection process ensures that the auditor has all the necessary information to accurately assess the building's smart readiness.

Data Analysis

Once the data is collected, the auditor proceeds with the analysis phase, where the functionality levels of the various technical building systems are evaluated. This involves comparing the current state of the systems with the ideal functionality levels across the nine SRI domains, which include aspects such as energy efficiency, occupant control, and grid interaction. The analysis also involves benchmarking the building's performance against industry standards and historical data, identifying trends, inefficiencies, and opportunities for improvement. The goal is to generate a Smart Readiness Indicator score that reflects the building's current smart capabilities and highlights areas for enhancement.

Final Report and Meeting

The findings from the analysis are compiled into a comprehensive SRI audit report. This report provides a detailed assessment of the building's smart readiness, including the SRI score and impact scores for each of the nine domains. The report also includes recommendations for improving the building's smart capabilities, offering practical pathways for enhancement. The audit process concludes with a final meeting where the auditor presents the report to the stakeholders, discussing the findings, the building's smart readiness level, and potential strategies for improvement.

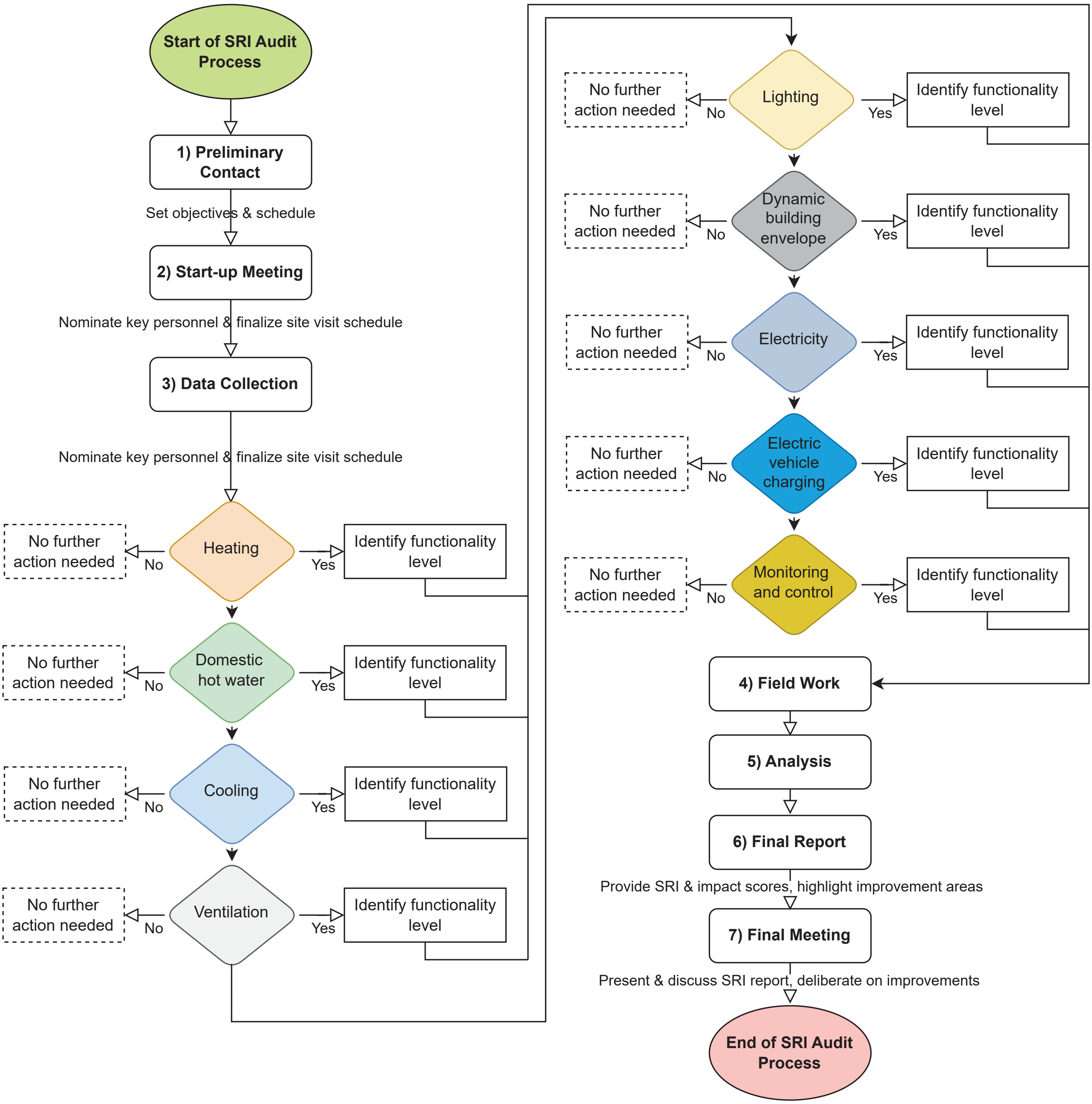


Figure 1. Step by step on-site SRI Audit Procedure.

Practical Implications

The implementation of standardized on-site Smart Readiness Indicator (SRI) audits brings significant practical benefits to building management and operations. By evaluating a building's capability to integrate smart technologies, SRI audits provide actionable insights that can lead to enhanced energy efficiency, improved occupant comfort, and optimized operational performance.

SRI audits are transformative tools for building owners, managers, and operators. By identifying the strengths and weaknesses in a building's smart readiness, these audits allow stakeholders to make informed decisions about upgrades and improvements. For instance, an SRI audit might reveal that a building's heating system is not optimized for energy efficiency due to outdated control mechanisms. Armed with this information, building managers can prioritize the integration of advanced control systems, such as smart thermostats or automated heating controls, which can lead to significant energy savings and enhanced occupant comfort.

Moreover, SRI audits support compliance with evolving regulations and standards, particularly those related to energy efficiency and sustainability. As regulatory frameworks increasingly emphasize smart technologies, having a clear understanding of a building's smart readiness through an SRI audit becomes essential for meeting compliance requirements and avoiding potential penalties.

While the benefits of SRI audits are clear, challenges do arise during their implementation. Common obstacles include insufficient data availability, the complexity of integrating new technologies with legacy systems, and the need for skilled auditors who understand both building operations and smart technologies. To overcome these challenges, best practices include early stakeholder engagement, thorough data collection, and the use of advanced tools such as the Smart-Ready-Go! Platform [7], which streamlines data analysis and reporting.

Conclusion

The Smart Readiness Indicator audit framework offers a structured and effective approach to assessing and enhancing the smart capabilities of buildings. As smart technologies become increasingly integral to building management, SRI audits provide critical insights that help building owners, managers, and operators make informed decisions about upgrades and improvements. By standardizing the audit process, the CEN Workshop Agreement ensures that assessments are consistent, transparent, and actionable across different building types and regions. The practical implications of SRI audits are profound, leading to significant improvements in energy efficiency, occupant comfort, and operational performance. Case studies have demonstrated how targeted interventions based on SRI findings can result in substantial energy savings and enhanced interaction with the energy grid. Looking ahead, the role of SRI audits is likely to grow as regulatory frameworks, and market demands increasingly emphasize smart technologies and energy efficiency. For practitioners, staying ahead of these developments and leveraging the insights from SRI audits will be key to maintaining competitive and sustainable building portfolios.

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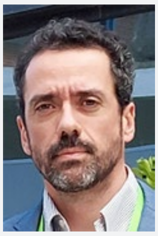
The PHOENIX solution – A versatile upgrading tool for making buildings smart

ARISTOTELIS NTAFALIAS
Motor Oil Hellas S.A, Greece

PANAGIOTIS PAPADOPOULOS
Motor Oil Hellas S.A, Greece



ALFONSO P. RAMALLO-GONZÁLEZ
Faculty of Computer Science, Campus de Espinardo, Universidad de Murcia, Spain
alfonsop.ramallo@um.es

ANTONIO F. SKARMETA-GÓMEZ
Faculty of Computer Science, Campus de Espinardo, Universidad de Murcia, Spain

JUAN SÁNCHEZ-VALVERDE
Faculty of Computer Science, Campus de Espinardo, Universidad de Murcia, Spain

MARIA C. VLACHOU
Kataskevastiki Makedonias, Thessaloniki, Greece

RAFAEL MARÍN-PÉREZ
Department of Research and Innovation, Odin Solutions, Spain

ALFREDO QUESADA-SÁNCHEZ
Department of Research and Innovation, Odin Solutions, Spain

FERGAL PURCELL
Arden Energy LTD, Dublin, Ireland

STEPHEN WRIGHT
Arden Energy LTD, Dublin, Ireland

The increase in energy efficiency in buildings has become a critical necessity in recent years, requiring the optimization and reduction of energy consumption to achieve this goal. ICT tools and innovations offer a promising approach to achieve this objective; however, they may entail significant costs in the renovation of legacy appliances. In this work, the authors present a solution based on an IoT platform that enables the integration of legacy equipment such as HVACs, CHP systems, etc., which, when complemented with machine learning algorithms, can be intelligently managed to meet energy efficiency targets. Smart services such as demand flexibility are enabled by this platform, allowing for a reduction in energy costs and an increase in efficiency. The proposed solution has been validated and tested in various demonstration sites located in Ireland and Greece, addressing the different challenges specific to each country. In Ireland, the proposed solution was employed for the management of a residential water heater and a commercial CHP unit, achieving a reduction in consumption of up to 39% and 61%, respectively. In Greece, the demand flexibility service executed in a residential building enabled a reduction in consumption by up to 86% during peak hours and 60% overall, leading to a 10% reduction in costs. In the Greek commercial building, daily energy-consumption savings of 6.9 kWh (4.6%) were achieved, resulting in a 22% reduction in monthly energy costs.

Keywords: Machine learning, Smart buildings, Legacy equipment, Energy consumption reduction, Internet of Things.

Introduction

Addressing energy cost reduction has become increasingly vital in the building sector due to the escalating demand for sustainable and efficient energy management [1], [2]. Conventional strategies for reducing energy costs often involve replacing energy-intensive appliances with more efficient alternatives, incorporating renewable energy systems, or enhancing the building's insulation and structure [3], [4]. Although these methods are effective and can lead to substantial energy savings, they usually require significant investment [5]. Moreover, concentrating on improving individual systems or components might not fully capitalise on the potential for energy optimisation, as it may reduce the benefits that arise from the interaction between various systems [6].

To maximise energy efficiency and achieve greater cost savings, more sophisticated approaches can be adopted such as shifting energy consumption from periods of high electricity prices to times when prices are lower. These strategies typically use advanced technologies and data analytics, including the prediction of energy use and electricity prices, to enhance overall energy efficiency [7], [8].

In this paper we show how PHOENIX solution integrates existing legacy equipment—such as heating, ventilation, and air conditioning (HVAC), or water boilers, and combined heat and power (CHP) units—with an advanced Internet of Things (IoT) platform. The proposed solution employs cutting-edge machine learning (ML) algorithms to precisely predict consumption trends and forecast day-ahead electricity prices, allowing users to benefit from the platform's flexibility services, thereby lowering their energy costs. The study presents specific case studies from Ireland and Greece to evaluate the practicality and effectiveness of this solution in different regional contexts. Additionally, it discusses the potential for scalability and adaptation of this approach to other geographic areas, considering the unique challenges and energy market conditions of each location.

Authors contribution

This paper presents the PHOENIX platform, a cutting-edge ICT solution that uses the integration of legacy equipment to an IoT environment to integrate and optimise energy consumption in both residential and commercial buildings. The platform incorporates a suite of algorithms within the Pycaret tool, which are specifically developed for time series forecasting. These algorithms identify patterns and select the most suitable algorithm or combination of algorithms, such as ARIMA, ANN, or curve fitting, to make accurate predictions. The key contributions to optimizing energy use in buildings with existing legacy equipment includes the development of a platform that effectively integrates legacy systems, employs machine learning for data analysis and trend recognition, and offers innovative services to building occupants aimed at reducing energy usage and associated costs. The PHOENIX platform is introduced in Section II, with its implementation detailed in Section III, the results discussed in Section IV, and the conclusions outlined in Section V.

PHOENIX platform

PHOENIX is an advanced ICT solution designed to make buildings smart, connected environments by integrating older systems, smart devices, and building management systems (BMS) with external sources like energy market prices and weather forecasts. This integration aims to improve energy efficiency, reduce costs, enhance occupant well-being, and support grid stability.

The use cases illustrate how extensively buildings are integrated within the PHOENIX platform, providing valuable insights into energy performance, environmental factors, equipment control, and relevant external data. The platform uses semantic data modelling and knowledge graphs for detailed data analysis and supports multiple communication protocols to efficiently manage data from various devices and sensors.

The PHOENIX architecture (**Figure 1**) emphasizes the integration of older devices within the platform. Pilot implementations have successfully demonstrated seamless access to various assets. This standardisation allows for uniform management of equipment from different manufacturers, enabling the development of smart services to control devices for both energy efficiency and comfort.

Use cases in Ireland and Greece

A. Irish commercial and domestic buildings

The Irish use case involves both domestic and commercial sites integrated within the PHOENIX platform. The domestic sites, located in southeast Dublin, were connected using a portal solution and an MQTT interface. The commercial site is the Rediscovery Centre, which features a BMS and various energy sources like solar thermal, solar PV, CHP, and a heat pump. The authors of [9] explored how CHP systems can optimize their usage based on day-ahead prices. Integration required connecting legacy equipment to the PHOENIX platform. Domestic site gateways with APIs for remote access were selected, and the BMS was upgraded for connectivity.

In the domestic site, the PHOENIX flexibility engine was tested with a domestic hot water boiler and an EV charger, utilizing dynamic pricing for demand shifting. By forecasting hot water demand and using day-ahead market pricing, the platform optimized activation times for the water heater. This resulted in an average load shift of 5.5 kWh/day (39% of total load), saving €0.19/day (equivalent to 12%).

In the commercial site, the Rediscovery Centre's CHP unit operation was optimized using the flexibility engine. Forecasting heat demand and market prices allowed the engine to determine optimal CHP operating times. Peak demand reduction was significant, with a 61% decrease in peak load. The load shifted was 5.5 kWh/day, representing 4% of the total daily consumption of 126 kWh, saving €0.30/day. Smart bills generated from these trials showed participants the cost benefits of optimized

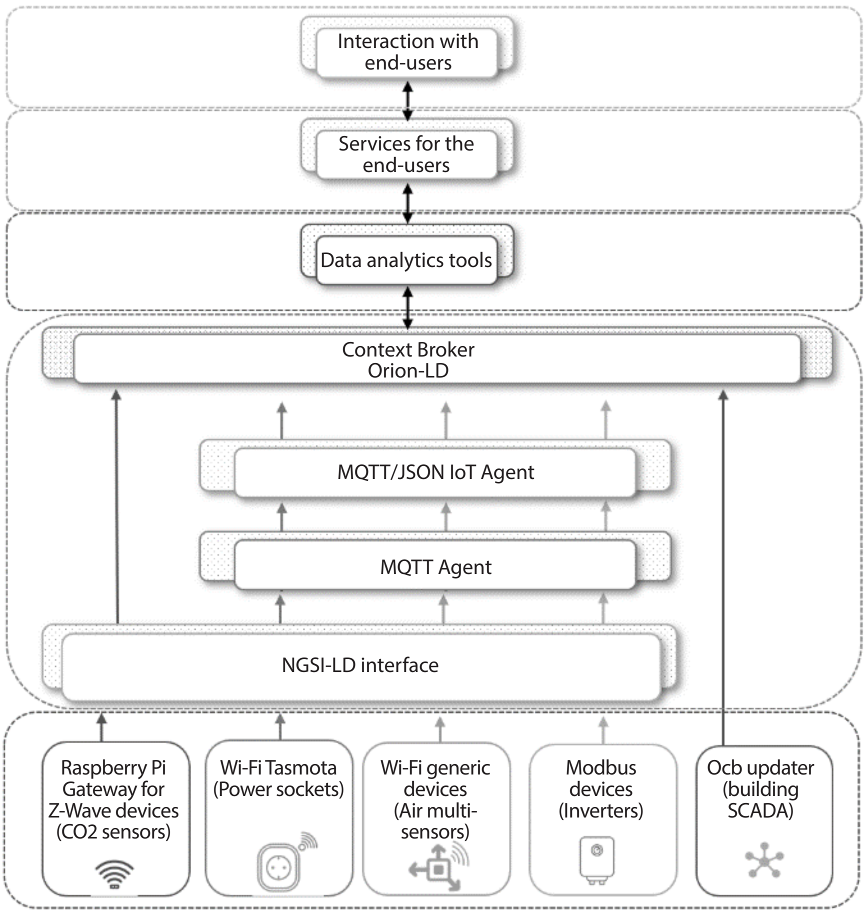


Figure 1. PHOENIX platform's representation.

energy use and dynamic tariffs. **Figure 2** shows the total active power input during the test day in the commercial building in kW.

B. Greek commercial and domestic buildings

The Greek pilot site tested PHOENIX grid flexibility services in both residential and commercial buildings, involving direct and indirect device control triggered by day-ahead dynamic energy prices. These prices do not yet exist for consumers in Greece [10], so realistic simulated prices were used. The residential building includes 8 apartments, each about 80 m² of floor area. Direct control involved a 5.1 kWh battery paired with a 6 kW hybrid inverter and a 4.95 kWp PV installation. PHOENIX simulated energy prices for the next day and identified the most expensive hour. Using energy production and consumption forecasts, the battery was charged either from the grid during low-priced periods or from solar energy if surplus was predicted. The battery then discharged during high-priced periods to reduce costs. Two tests showed energy savings of 3.66 kWh (86%) and 3.53 kWh (60%) during high-price periods, reducing costs by €2.48 (5.1%) and €1.64 (5.7%), respectively. **Figure 3** depicts the typical hourly consumption patterns for the entire building over a period of five days.

The second service indirectly controlled high-consumption devices like heat pumps, kitchens, and washing machines by notifying residents to adjust usage during expensive periods. During the tests, consumption was shifted from high-prices hours to cheaper ones. Across the building, this service shifted 3.26 kWh of consumption, saving about €0.60 per day, or €0.09 per apartment per day, with savings ranging from 1.7% to 10.1% per apartment, or an average of 5.8 %.

The commercial site, a newly constructed office building of 800 m², tested direct control using a 10 kW hybrid inverter linked to a 10.92 kWp PV installation. The battery, charged from solar excess, was controlled the flexibility service and used during the highest-priced periods. This approach optimises energy use and reduces costs shifting consumption to more economical periods. On the first day, 6.91 kWh supplied during 17:00-18:00 saved €1.26 (27% of the day's cost). On the second day, 6.91 kWh during 18:00-19:00 saved €1.00 (20%), as shown in **Figure 3**. On the third day, 6.84 kWh during 16:00-19:00 saved €1.08 (16%). The battery provided about 6.9 kWh of savings per day, significantly reducing costs by about €33 per month, or 16-27% of the total bill.

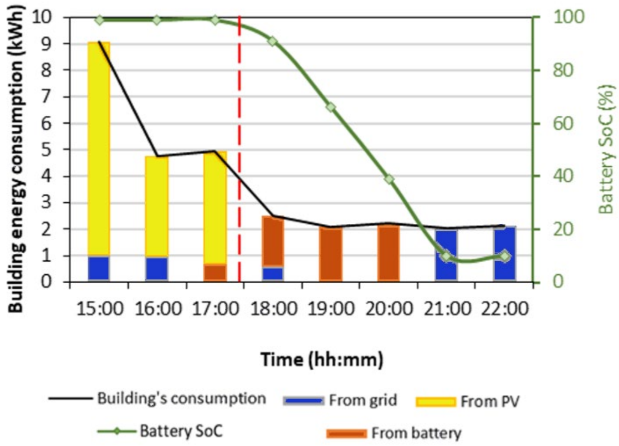


Figure 3. Building's energy sources and battery's state of charge during grid flexibility event.

Conclusion

The PHOENIX solution presents a promising approach with the potential to significantly reduce both energy consumption and costs. The findings from the pilot studies discussed in this paper illustrate the service's effectiveness across various contexts.

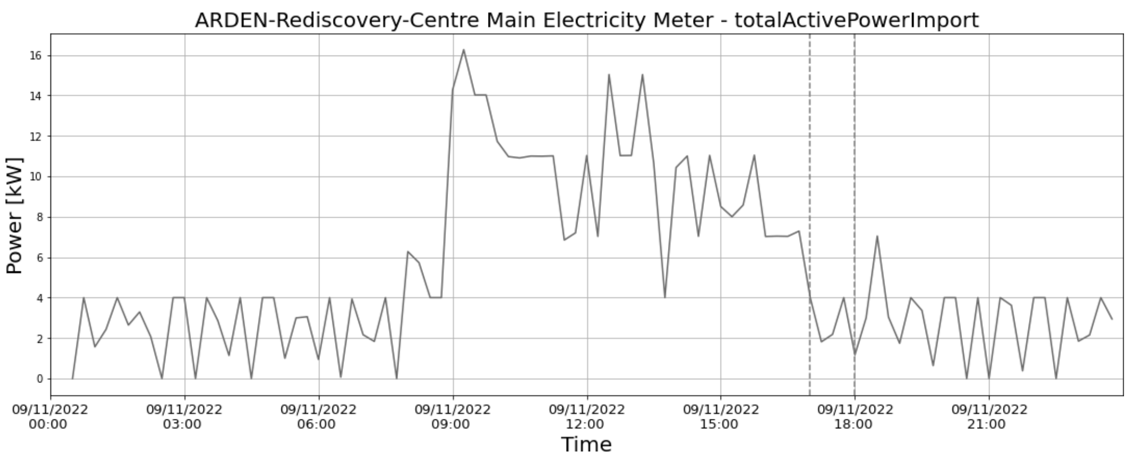


Figure 2. Power consumption on commercial site during trial day.

In the Irish pilot, the service was applied to a water heater and a CHP unit. Results indicated that, in the residential building, the service reduced energy consumption by up to 12% for the water heater, with an average load shift of approximately 39%. In the commercial building, the service's implementation on the CHP unit led to a 4% reduction in total daily energy consumption and a significant 61% decrease in peak load. These outcomes demonstrate the service's ability to optimize energy use for specific devices, resulting in notable cost savings for users.

In the Greek pilot, the service managed a battery system in both a residential and a commercial building. The residential application achieved up to an 86% reduction in energy consumption during peak hours and an overall reduction of up to 60%. Participants also experienced substantial cost savings, with daily savings averaging 10% of their monthly electricity bill. In the commercial building, the service provided an average daily energy savings of 6.9 kilowatt-hours (kWh), accounting for 4.6% of total consumption and leading to a 22% reduction in the monthly electricity bill. These results underscore the service's effectiveness in managing energy consumption during periods of high demand, yielding significant cost reductions for users

The approach used in this study emphasized the development of a highly organized platform, structured into multiple interconnected layers. A critical aspect of this approach was the adoption of a common information model, which has greatly simplified the integration and flow of data throughout the system. This methodology has been notably effective, allowing for the creation of innovative solutions like the demand flexibility service, which has been successfully implemented to achieve significant reductions in energy costs across various scenarios. Additionally, the incorporation of data analytics and advanced algorithms has been vital in processing the substantial amounts of data gathered by the platform.

The technology components created for the energy demand modification scenarios outlined in this paper are built on a modern, scalable design. The proposed architecture has proven its effectiveness by ensuring efficient resource management and quickly adapting to changing user demands. To ensure the developed components are both reliable and high-quality, comprehensive availability and performance tests were conducted. These tests were made possible through the use of the Jenkins framework, which streamlined the automation and management of the testing procedures.

Energy efficiency and sustainability are becoming increasingly crucial in the building industry. While replacing outdated, inefficient appliances can be expensive, advancements in AI and ML present new opportunities for optimising energy use. This paper introduces an IoT platform that leverages ML algorithms to forecast energy demands and predict day-ahead electricity prices, offering tenants flexibility services to lower energy costs while ensuring comfort. Pilot studies conducted in Ireland and Greece demonstrated notable reductions in energy consumption, particularly during peak times. The platform efficiently manages energy demand, optimizes the use of appliances, and addresses periods of high demand, leading to substantial cost savings. Although further large-scale research is necessary, these initial studies indicate that the PHOENIX solution holds significant promise for reducing energy expenses in smart buildings.

Acknowledgment

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Integrating Submetering and NILM for Building Smart Readiness



BILAL MOHAMMED
Integrated System Technologies Ltd and Nottingham Trent University
bilal.mohammed02@ntu.ac.uk

GEOFF ARCHENHOLD
Integrated System Technologies Ltd
geoffarchenhold@istl.com

YANGANG XING
Nottingham Trent University
yangang.xing@ntu.ac.uk

This article examines how submetering (Intrusive Load Monitoring- ILM) and Non-Intrusive Load Monitoring (NILM) can enhance smart readiness in residential buildings. Submetering provides precise data on energy use across different zones or systems, enabling detailed audits, cost allocation, and performance optimisation, though it often requires costly infrastructural changes. NILM offers a more scalable alternative by using a single meter and advanced algorithms to estimate energy use by individual appliances, though its accuracy can be challenged by complex loads. The proposed framework introduces both methods, allowing for a step-by-step increase in monitoring complexity as needed. By enabling finer control of individual loads in a building, this framework contributes to achieving smart readiness [1] in residential buildings for more sustainable and intelligent living environments by optimising energy efficiency, operational performance, and occupant engagement while reducing costs.

Keywords: Internet of Things (IoT), Intrusive Load Monitoring (ILM), Non-intrusive Load monitoring (NILM), Machine Learning.

Introduction

This article examines how submetering (i.e., Intrusive Load Monitoring- ILM) and Non-Intrusive Load Monitoring (NILM) enhance smart readiness in residential buildings. A framework is developed that can gradually increase monitoring complexity. There are various types of energy monitoring technologies. For example, ILM submetering provides precise data on energy usage across different zones or systems, enabling detailed audits, cost allocation, and performance optimization. However, it often requires costly infrastructural changes. NILM offers a more scalable alternative by using a single meter and advanced algorithms to estimate energy use by individual appliances, though its accuracy can be challenged by complex loads. The proposed framework combines both methods, allowing for a step-by-step increase in monitoring complexity as needed. Initial machine learning (ML) results from a residential case study show significant improvements in energy disaggregation accuracy. By optimising energy efficiency, operational performance, and occupant engagement while reducing costs, this framework offers a practical path to achieving smart readiness [1] in residential buildings, contributing to more sustainable and intelligent living environments.

To address climate change, governments worldwide are increasingly prioritising energy efficiency and reduction to lower global greenhouse gas emissions, with the goal of limiting global temperature rise to below 2°C [2]. Building operations are a significant contributor to rising CO_2 emissions, which have increased by 5.4% since 2015. This has prompted global policy shifts, including stricter emission standards for new buildings, such as the net-zero mandates detailed in the revised Energy Performance and Buildings Directive (EPBD) [3]. While smart readiness has become a focal point in optimising building performance, enhancing occupant comfort, and supporting sustainability goals [1], discussions on the importance of load monitoring remains limited.

Appliances in residential and commercial buildings account for an increasing amount of energy consumption with plug and process loads accounting for majority of total energy consumption in commercial buildings [4]. Significant energy savings could be actualised through effective load management through personalised recommendation and appliance usage feedback may result in more than 12% energy savings [4]. For example, highlighting the largest contributors to their total energy usage. Furthermore, energy suppliers can utilise this information to maintain grid stability through peak load management and demand response management through a better understanding of consumer behavioural patterns. An Intelligent Load Analytics framework can be utilised to provide fine-grained control over appliances in buildings, provide detailed insights on energy consumption and methods to reduce it. An overview of Intelligent Load Analytics framework (as shown in **Figure 1**) proposed in this paper consists of 3 modules: Load Monitoring, Intelligent Analysis and Feedback modules. Their application is shown in **Figure 2**.

Load Monitoring Module

The purpose of load monitoring is to identify the appliances drawing power in a building and collect information about their power consumption. There are two approaches to monitoring power consumption of appliances: Non-Intrusive Load Monitoring (NILM) or Intrusive Load Monitoring (ILM). Introduced by Hart in 1992 [5], NILM techniques aim to separate aggregate data into individual loads where the NILM problem formulation is summarized by Equation (1):

$$Y(t) = \sum_{n=1}^{M} y_n(t) + \varepsilon(t) \qquad \text{Eq. (1)}$$

Where $Y(t)$ is the aggregate signal which consists of a sum of M individual appliance loads and the ε noise and approximation error.

Aggregate data is collected through a custom sensor installed directly to the main supply or data extracted through existing smart meters. NILM research has been popular due to lower installation and maintenance costs associated with single-point sensing. Additionally, this

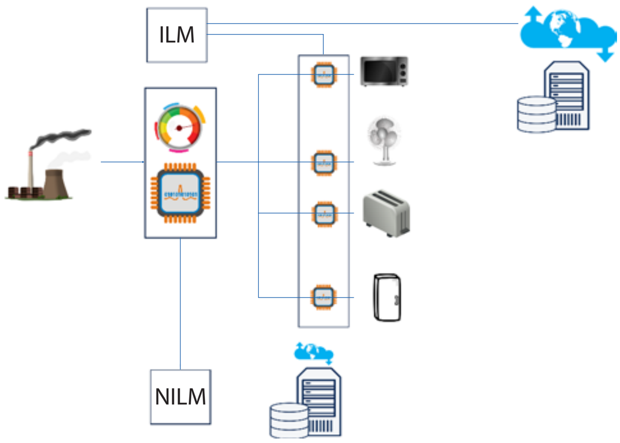

Figure 2. Diagram displaying ILM and NILM implementations and subsequent edge or cloud processing.

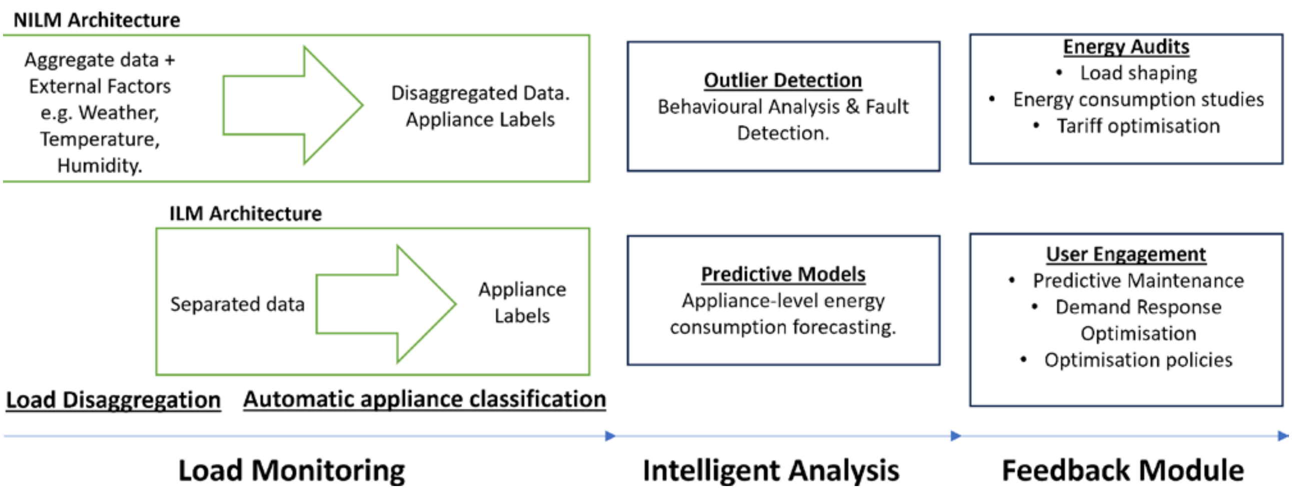

Figure 1. Intelligent Load Analytics framework.

reduces the intrusion experienced by occupants in residential settings, improving consumer buy-in. Despite this, NILM suffers from significant downsides. Due to the complexity of the disaggregation problem, NILM research struggles to deal with a wide range of appliances, especially when multiple appliances of the same type are utilized simultaneously [6]. Low frequency NILM research often struggles to identify low powered appliances [7]. This is problematic in commercial buildings where there are many similar appliances with overlapping power profiles such as computers, laptops, and printers.

On the other hand, ILM systems circumvent disaggregation using direct sensing, using smart plugs or additional circuitry, to submetering to a specific zone, plug or appliance. Increasing abundance in higher resolution smart plugs in the market has made it more viable to retrofit ILM to existing infrastructure resulting in a surge in their use in home automation. Direct access to a plug or appliance simplifies appliance classification as there is less noise and offers a whole suite of advantages such as increased localisation and low latency. This offers a method that is scalable to a wide range of appliances and effective for appliances of the same type. However, the cost of installing sensors or smart plugs into households rapidly scales in both residential and commercial settings where the former often struggles with consumer buy-in due to its intrusive nature.

Modern smart plug solutions offer up to 1Hz sampling frequency capable of enhanced control of individual appliances and real-time monitoring. A scalable solution would involve applying machine learning and deep learning models for automatic appliance classification that can be updated OTA (Over-The-Air) to reduce setup and maintenance costs. **Figure 3** shows a confusion matrix describing the performance of a lightweight random forest model that segments real-time power data into 60 second windows utilising statistical and frequency-based features from raw power data. The prediction of microwave and toaster has a lower performance due to the similarity of their power signals, but this can be resolved by utilising additional features such as power factor or apparent power data and utilising data of a higher sampling frequency.

To train these models, the datasets must be applicable to the target market. Using a dataset from a different country introduces challenges due to differences in electrical infrastructure and household appliance usage patterns driven by cultural behaviours. Electrical infrastructure often differs in voltage standards and grid stability. Furthermore, appliance types might have different power consumption characteristics and daily routines based on mealtimes and leisure activities, climate effect temporal aspects of data. All these factors may reduce generalization to different areas but may benefit from combining datasets by supplementing local data or using domain adaptation. For example, US homes use 120V compared to 230V in the UK with larger homes, prevalent use of air conditioning and different cooking habits on average compared to the UK. Indian homes often experience power outages and voltage fluctuations compared to UK homes. EU countries might have similar voltage standards but may differ in appliance types and energy efficiency regulations. Unfortunately, there are only few publicly available datasets that have appliance level data. The most prevalent UK datasets with appliance level data include UKDALE [7] and IDEAL [8] both of which have sampling rates larger than 5 seconds.

The choice between ILM, NILM and their respective techniques relies on the downstream application and the data available to train the model. The decision hinges on the latency required from the down-stream application and temporal resolution of the training data which are often inter-linked. The latency can be broken down into real-time or near real time and batch processing. The former is important for time-sensitive tasks such as an outlier detection for catastrophic failure or unauthorized access to an appliance or zone which benefits from ILM infrastructure. Batch processing is effective in NILM due to the added disaggregation task in NILM which introduces additional complexity.

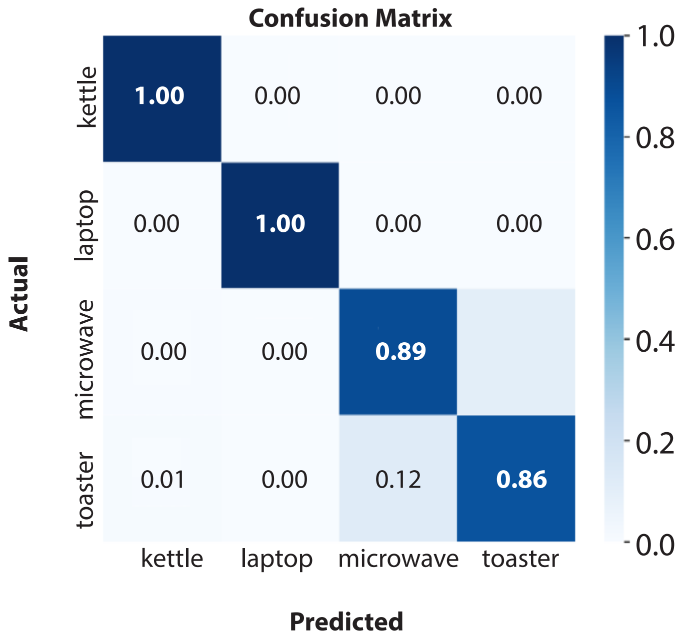

Figure 3. Confusion matrix displaying the performance of a random-forest model that automatically classifies raw power data to appliance labels. The diagonal highlights the accuracy of the model for each appliance.

Intelligent Analysis Module

The purpose of this module is to collect data for insights, detect anomalies and optimize the framework. Appliance data collected can be used to train outlier detection models that can be used to identify anomalies in appliances that may indicate inefficiencies or faults that can trigger notifications to inform corrective actions. For example, load monitoring of appliances has also been shown to be a possible avenue for the early prevention of dementia by classifying activity levels and detecting outliers [9] and detecting and isolating electrical faults in shipboard appliances enabling early intervention to prevent costly maintenance and failure [10].

Moreover, statistical analysis can be performed on the data to create energy audits that can inform control algorithms that adjust appliance activation or usage based on either manually specified policies or policy configurations. Additionally, optimisation algorithms such as demand response, load forecasting and energy storage management can be utilised to predict, analyse and optimise existing processes in a building and the grid.

Feedback Module

This module helps tune and retrain existing models and provides actionable insights, recommendations and automated responses to improve efficiency. For example, dashboards for real-time monitoring can help reduce energy usage in buildings and provide custom reports to different stakeholders for optimisation. Automated feedback loops can be integrated with building management systems to automatically adjust settings such as lighting, HVAC, electric heaters or fans to build a continuous learning system that adapts to feedback from users.

Conclusion

Adopting ILM and NILM has and will advance energy management by changing behavioural patterns in consumers through actionable feedback, providing fine-grained control to building management systems and improving grid optimisation through detailed insights on consumption patterns. Nevertheless, smart load monitoring, through ILM and NILM, offers detailed insights into energy usage patterns, enabling precise optimisation of building systems for efficiency and sustainability. By providing granular data on individual appliance consumption, these technologies lay a strong foundation for future smart readiness by facilitating targeted energy management and integration with intelligent building systems. Looking forward, NILM's current capabilities are limited by dataset availability and model complexity however ongoing advancements in model architectures suggest that it could eventually close the gap between ILM and NILM where NILM could be most dominant technology offering both comprehensive coverage and precision.

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How does building technology enable robust sustainability reports (ESG) for buildings?

The article shows the necessity of ESG and how this is possible with the SRI required in the EPBD

ALFRED FREITAG
Senior Consultant European Relations,
Belimo Automation AG, Switzerland
alfred.freitag@belimo.ch

The construction and real estate sectors are increasingly under pressure from legislators, investors, and society to provide transparent information on energy efficiency, safety, and comfort, key factors in Environmental, Social, and Governance (ESG) reporting. Numerous standards and labels exist, but their relevance to ESG goals remains a critical question. The Smart Readiness Indicator (SRI), introduced in the 2024 amendment of the EU Energy Performance of Buildings Directive (EPBD), emerges as a key tool for supporting ESG compliance, particularly in the building technology sector. This paper outlines the development of SRI, its role in enhancing transparency, and its potential to help consulting engineers and building stakeholders align with ESG criteria, ensuring future-proof and sustainable buildings. Additionally, it highlights the challenges and opportunities that arise from implementing EPBD regulations in the context of broader sustainability initiatives like the EU Green Deal and the Corporate Sustainability Reporting Directive (CSRD).

Keywords: Smart Readiness Indicator (SRI); Energy Performance of Buildings Directive (EPBD); ESG reporting; Building technology; Energy efficiency; EU Green Deal; Corporate Sustainability Reporting Directive (CSRD); Sustainable buildings; HVAC systems; Indoor air quality

Construction project clients and building owners are increasingly required by legislators and the public sphere to provide transparent information regarding energy efficiency, safety, and comfort. Many labels and standards exist, but how relevant are they when it comes to ESG?

The Smart Readiness Indicator (SRI) required by the 2024 amendment of the EU Energy Performance of Buildings Directive (EPBD) is a Europe-wide indicator demanded by EU member states that ideally supports ESG reporting.

In the following, we will explain how ESG reporting came about and how the SRI helps the building technology sector achieve greater transparency, and consulting engineers in their roles as client trustees.

The challenges

The United Nations addressed the problems of climate change, resource scarcity, and the role of mankind back in 2000 and developed the Millennium Development Goals (MDGs). The resulting 17 SDGs (Sustainable Development Goals) were adopted in 2015 and included in the 2030 Agenda, which now calls for implementation at the global, national, and local levels. Many standards, such as ISO 14001, and decarbonization initiatives, such as the Paris Agreement 2 and the Science-Based Targets (SBTs), followed.

The expectations and requirements placed on companies by civil society, investors, business partners, and customers, consumers and employees, benchmarks and ratings, as well as legislators are constantly increasing. **The construction and real estate sector need to take this into account in order to maintain both its own marketability and the value of real estate.**

In 2019, the EU launched the Green Deal, which aims to reduce net greenhouse gas emissions in the EU to zero. It, therefore, defines the EU's political framework for environmentally friendly and sustainable measures. Its application is intended to drastically reduce greenhouse gas emissions and promote environmental and sustainability objectives. The EU Taxonomy Regulation was formulated in the interest of a clear definition of green, sustainable, and environmentally friendly economic activity. It can be used within the EU to determine whether an economic activity can be classified as environmentally sustainable.

Requirements with direct influence on the construction and real estate sector

Various directives have been and are being issued by the EU to achieve the objectives of the Green Deal. These directives also have and will continue to have a direct impact on the construction and real estate sector.

Corporate Sustainability Reporting Directive

The Corporate Sustainability Reporting Directive (CSRD) has been in force since early 2023, and the EU member states are required to translate it into national law. Particularly, EU companies or non-EU companies with EU subsidiaries that meet two of the following three criteria must implement CSRD reporting for the financial year 2025: more than 250 employees, over €20 million in total assets, exceeding €40 million in sales.

Article 4 of the CSRD applies from 1 January 2024 to financial years beginning on or after such date. Companies must comply with the European Sustainability Reporting Standards (ESRS) for environmental, social, and governance (ESG) aspects. The relevant ESRS must be applied based on the significance of the sustainability topics. This makes the accurate recording and management of ESG key figures even more important than ever before. Key figures from buildings such as energy consumption are also part of this effort.

Corporate Sustainability Due Diligence Directive

The Corporate Sustainability Due Diligence Directive (CSDDD) has been in force since 25 July 2024 and the EU member states are required to translate it into national law within a period of two years. It applies to:

- EU companies that have more than 1,000 employees and annual net sales of more than €450 million;
- Foreign companies that generate more than €450 million net sales per year in the European Union.

Companies are obliged to exercise due diligence in the context of their activities, those of their subsidiaries, and those of their business partners in the respective value chains regarding respecting human rights and ecological standards.

The construction and real estate sector significantly influence health and safety in buildings, such as indoor air quality and fire protection. This fact has to be taken into account throughout the entire life cycle of a building.

Health and Safety at the workplace

- Right to health
- Right to fair and dignified working conditions
- Right to safe and healthy working conditions

Environmental, Social, Governance (ESG)

Companies and investors use ESG criteria to assess environmental impact, social responsibility, and governance practices. Compliance with these criteria can encourage companies and financial institutions to invest in sustainable business and construction projects in line with the EU taxonomy.

The **E** in ESG stands for the description of a company's impact on the environment. Aspects such as compliance with climate protection measures or containment of environmental pollution, in addition to a company's energy efficiency, resource consumption, and waste management practices, all have a role to play here. The **S** stands for the relationship a company has with its employees, customers, suppliers, communities, and other stakeholders. And finally, the **G** stands for ethical principles, integrity, transparency, composition of the steering committees, an independent audit, and compliance with regulations and laws.

Companies practice their business activities in rooms and buildings. These spaces influence all three ESG criteria. For that reason, they must be equipped to allow the company to achieve a corresponding ESG rating. The question of **How can building technology affect ESG criteria?** arises.

Energy Performance of Buildings Directive (EPBD) 2024

To achieve the goals of the Green Deal, the EPBD of 2018 had to be revised in what is called the "Recast," which was, in turn, approved in 2024. This Directive has been in force since 28 May 2024, and the EU member states are required to translate it into national law within two years.

In addition to the previous energy issues, Article 13 now addresses the safety and health of building users. Beyond that, Article 15 defines the assessment of the smart readiness of buildings. It is prescribed for non-residential buildings with a rated output for a heating system, an air-conditioning system, a combined space heating and ventilation system, or a combined air-conditioning and ventilation system of more than 290 kW.

By 30 June 2026, the EU Commission will submit a report to the European Parliament and the Council on the review and implementation of the Smart Readiness Indicator (SRI). Based on this report, a delegated act will be issued by 30 June 2027.

Smart Readiness Indicator (SRI)

The "Smart Readiness Indicator" (SRI) prescribed in the EPBD is a common EU scheme for assessing the degree of technical readiness of buildings. The indicator provides information as to how smart/intelligent a building is. It provides a common basis for building stakeholders (owners, consulting engineers, solution providers, policymakers, etc.) to discuss how buildings can be made smarter and what benefits can be expected.

The SRI assesses the smart readiness of buildings or building units with respect to their capability of fulfilling three key functions:

- Optimization of energy efficiency and overall performance during utilization
- Adaptation of the operation to the needs of residents
- Adaptation to signals from the power grid (e.g. energy flexibility)

These smart readiness functions are broken down into seven impact, and nine technical domain scores.

Impact of the EPBD on ESG reporting

The EPBD requires independent control systems from the Member States to identify overall energy performance (Appendix Vl), the renovation passports in accordance with Article 12, the smart readiness indicator, and the inspection reports for heating, ventilation, and air-conditioning systems.

For the criteria prescribed in ESG reporting, information on overall energy efficiency can be used as a source for the energy consumption criterion **E**. The smart readiness indicator SRI is suitable for proof of the indoor climate, which is important for the safety and health criterion **S**. Once the buildings and rooms are equipped with a building automation system as required by Article 13 (§ 9-11) of the EPBD, data will then be available for verification of the indoor climate, as is required by the legislator (Labor Act) in criterion **G**.

Exemplary depiction of the application of SRI for ESG reporting

The third floor at Belimo Headquarters in Hinwil, which is exclusively devoted to offices and meeting rooms, has been renovated. The conversion was identified as an optimum opportunity to research the connection between building technology and compliance with the ESG targets in one's own company.

A great deal was invested in technology with the aim of achieving high indoor air quality and energy efficiency. Belimo Energy Valves were installed for permanent hydronic balancing, and the radiators were fitted with tight-closing, blocking-proof ball valves with electric actuators. Indoor air quality in the zones is demand-controlled using variable air volume (VAV) and is ensured by corresponding room controllers.

An SRI expert assessment, according to Method B, resulted in an SRI of 58%. In the three main functions, 70% was achieved for energy efficiency and maintenance, 71% for comfort, and 11% for power grid flexibility. In addition, varied results are obtained for the domain scores.

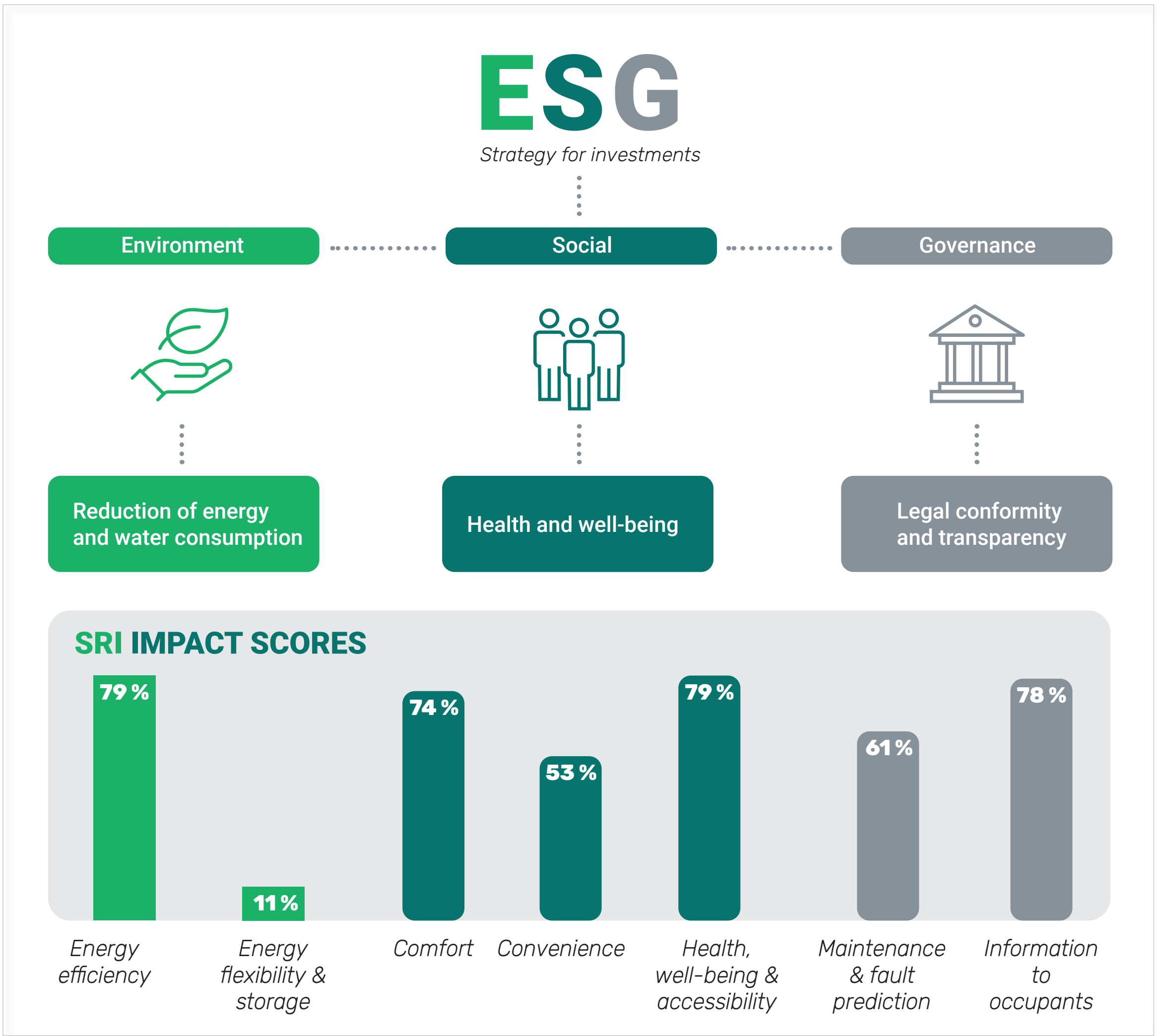
It should be considered that only one of the building floors was assessed. No water treatment or charging stations for electric vehicles or photovoltaic systems on the floor were evaluated.

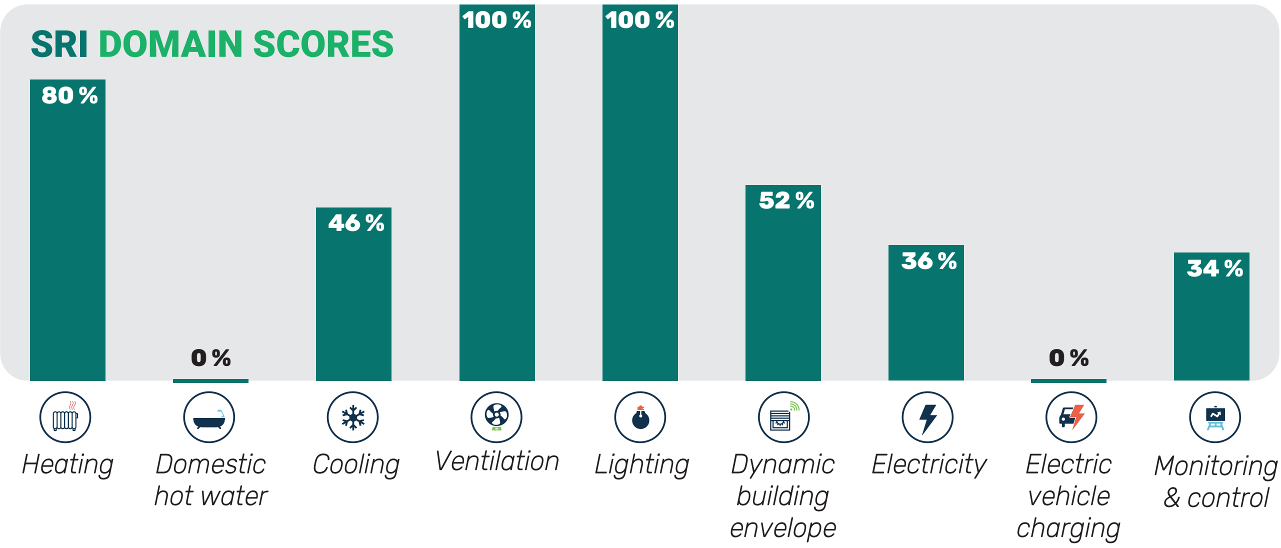
The resulting graphs and detailed results can be applied to sustainability reporting.

The SRI indicates potential for smart readiness improvement, in order to increase the value of a building. However, it also indicates whether the building is future proof with respect to the requirements for 2030/2050.

A sustainability report requires statements on compliance with laws such as the Labor Act. The corresponding reporting is needed to accomplish this. The SRI assessment shows whether the relevant services and functionalities are available. The SRI can be used for sustainability reporting in accordance with the Global Real Estate Sustainability Benchmark (GRESB). Should proof of compliance with labor laws be provided, the building technology needs functionalities required in EN ISO 52120-1 Class A/B, including a corresponding monitoring and reporting system.

EN ISO 52120, EPBD 2024, and the SRI are effective ESG-compliant building technology planning instruments.





Conclusion

The EU standards have been highly effective in helping companies meet ESG requirements set by legislators, such as the EPBD, CSRD, and CSDDD, while also addressing public demands for energy efficiency, safety, comfort, and transparency. However, it's crucial not to overlook the available funding that supports these efforts. Implementing these standards offers multiple benefits, including legal compliance, transparent reporting that attracts investment, reduced energy and management costs, more attractive workplaces that provide a competitive edge in talent recruitment, and an enhanced company image. ■

Results from the application of smart-ready technologies

Results from real-life application of artificial intelligence building service technology to HVAC systems in a medium-scale pilot building in Italy


THOMAS MESSERVEY
R2M Solution


MARCO PIETROBON
R2M Solution


LORENZO CIFARIELLO
R2M Solution


ALESSANDRO LODIGIANI
R2M Solution


MARTIN GRUBER
Brainbox AI

thomas.messervey@r2msolution.com | marco.pietrobon@r2msolution.com | lorenzo.cifariello@r2msolution.com | alessandro.lodigiani@r2msolution.com | m.gruber@brainboxai.com

Within the framework of the European Project "Smart Square," artificial intelligence building service technology has been applied to HVAC systems in a medium-scale pilot building. Energy efficiency results, before and after SRI assessments, the platform for conducting SRI assessment and concept of smart ready communities is presented and discussed.

Keywords: Artificial Intelligence, SRI, Smart Buildings, Smart Ready Go, Energy Efficiency, Case Study

The project

This case study falls within the context of the European Project "Smart Tools for Smart Buildings: Enhancing the Intelligence of buildings in Europe" (Smart Square [1]) which is part of the LIFE Programme, and one of the four LIFE CET SMART-READY projects aimed to support the successful uptake of the Smart Readiness Indicator [2]. Project objectives, amongst others, include the development of tools and services that boost the uptake of the SRI scheme amongst the member states of the European Union and the rollout of ICT smart ready technologies including Artificial Intelligence (AI) and Internet of Things (IoT) for enhanced building performance and overall smartness. The presented pilot is one of a set of project pilot buildings that contributes to the realization and demonstration of the project objectives.

The pilot site

La Forgiatura is a unique business park located in the north-western part of Milan consisting of 10 mixed-use buildings (offices, restaurant, common areas, green spaces, underground parking and other facilities) covering 24 300 m² of floor area. The site is the result of a €28 million renovation and urban renewal of a former metallurgy industrial complex carried out by RealStep and Engineer Carlo Bossi, as technical supervisor, and designed by Architect Giuseppe Tortato in 2013 to create the first 100% carbon-free corporate campus in Milan [3]. The transformation featured natural lighting, carbon free technologies, renewables, and on-site water use and optimization. The buildings and complex are in their operational phase (e.g. occupied and in use). Since 2013, the whole site is under the facility management by Engineer Daniele Bossi from Studio Bossi engineering firm.

Technical systems at La Forgiatura include systems for heating, cooling and mechanical ventilation, in addition to the other common energy consumers such as domestic hot water, lighting, and electrical appliances. A large central heating and cooling system is present which consists of 4 polyvalent heat pumps feeding two water loops forming a kind of local district heating and cooling for much of the campus.

The HVAC systems are controlled by a Building Management System (BMS). Beginning in 2022, R2M Solution and Brainbox AI have been working with RealStep to install, integrate and optimize BrainBox AI solutions to the installed HVAC components applying AI-based algorithms, automatic optimization rules, automatic control, and continuous monitoring. The reach of the AI-driven systems and number of algorithms employed is increasing each year with the next expansion of the deployed systems scheduled for 2025.

Smart Tools for Smart Buildings (Smart Square Project)

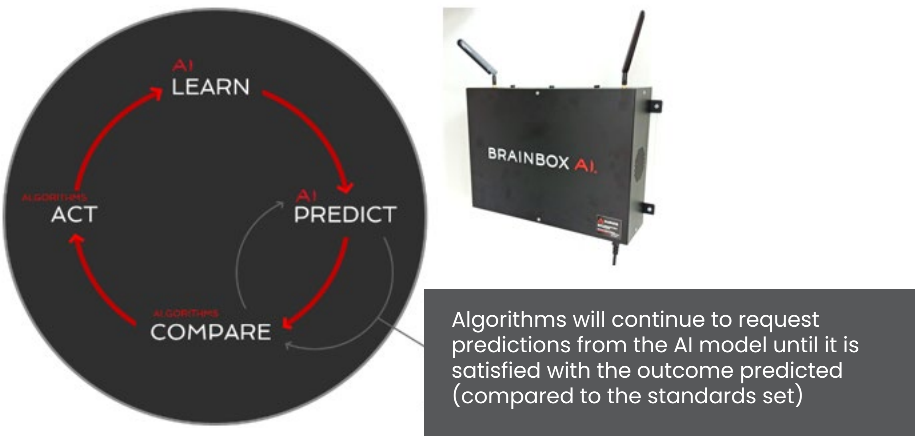
La Forgiatura, Milan – From metal works to carbon-free business park.

The smart-ready technologies: Brainbox AI and Smart Ready Go!

Brainbox AI provides AI solutions for various building typologies and use cases via a series of hardware and software solutions to conduct deep learning, cloud-based and local computing, algorithms and a proprietary process to support a 24/7 self-operating buildings [4]. The system communicates with the BMS, integrates other datapoints that can enrich analysis, pre-processes various data sets and communicates with Brainbox AI cloud services to receive back control actions to be sent to the BMS. In this way, BrainBox AI solutions integrate learned building performance, building occupancy and usage patterns with external data streams (weather, grid or other) to forecast and deliver pre-emptive controls in a dynamic and automatic way without human intervention that deliver energy savings and increased comfort to the indoor environment. With over 20 million square meters under management in 70 cities worldwide (2024), a wide set of algorithms are trained, validated and ready for use for various building typologies, use case scenarios, and diverse levels of pre-existing building smartness.

The BrainBox AI edge device can be easily installed and connected to the existing BMS network through a simple Ethernet LAN cable. This allows the analysis of data which are gathered by the BMS components and the deployment of the BrainBox AI's proprietary algorithms for the automatic control of the HVAC system. BrainBox AI also provides a user dashboard for the visualization of the benefits in terms of energy savings, environmental emissions reduction, and indoor comfort improvements. The dashboard also allows for functionalities related to monitoring of the controls of the system components and of the operation of the AI algorithms. The installation and operational process allows for continuous communication with the customer and facility management team who can select the AI-based algorithms to deploy and in what priority they are applied in collaboration with Brainbox AI. Brainbox AI solutions can be also applied to buildings with no BMS, like multi-site retail buildings, where BrainBox AI can communicate with the thermostats and the available controllers connected to cloud serves via a gateway that allows the HVAC system and specifically the rooftop HVAC system (present on most retailers) to be AI-enabled.

Smart Ready Go! [5] is a web-based platform for building assessors and real estate managers for the conduct, management and delivery of SRI assessments that has been developed within the Smart Square Project. It is based on the technical framework developed at European level by the European Commission [6], through the SRI Support Team, and has been successfully assessed and validated according to them across a wide set of calibration/validation scenarios. The Smart Ready Go! software environment allows for the easy implementation of the SRI calculation for simplified Method A, the more detailed Method B (appropriate for non-residential / large buildings) and a proprietary Call Centre approach which makes the SRI assessment process accessible to non-technical users via a set of interview questions that correspond to Method A and which can be used to open conversations on the SRI and building smartness. Each user has a distinct profile / user dashboard and functionalities are present to guide the users through assessment processes, to visualize the results, and to save, manage and deliver the performed assessments of the considered buildings.



Brainbox AI Process and Gateway.

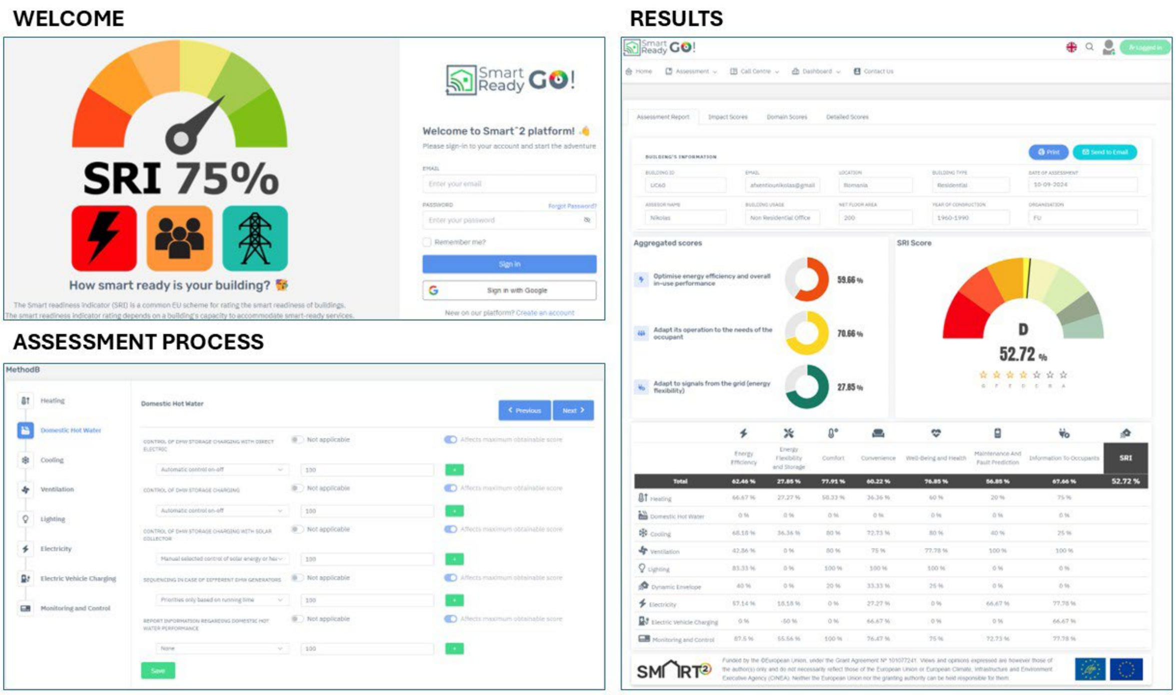
Application of Brainbox AI and Results

Nine buildings in the La Forgiatura campus are currently being driven or partially driven by Brainbox AI solutions. First installations and training of select buildings began late 2021 with the connection and integration of the Brainbox AI gateway to the existing BMS and customization of the dashboard for the building manager and maintenance team. The system subsequently went into full operational mode in February 2022. The BrainBox AI implementation did not require any investments in terms of upgrade of the existing systems or further interventions on the BMS already in place. In collaboration with the facility manager and according to the features of the HVAC systems present / controls layout, two AI-based algorithms were selected for implementation from the full set of the algorithms available through BrainBox AI. Specifically, they are called Optimus and Water-Clock.

Optimus' objective is to save as much energy as possible by managing optimal start and stop for the HVAC system. It uses the AI's temperature predictions as well as checking the outdoor air temperature condition and building conditions to decide when the optimal time is to start and stop the systems. The algorithm Optimus in La Forgiatura is controlling the air handling units and the fan coil units.

Water-Clock is an AI-based algorithm which modulates chillers and boilers delivery temperatures in accordance with the present and the predictive outdoor air temperature as well as the predicted building thermal load. In the La Forgiatura campus, it controls the supply water temperatures for heating and cooling at the base of each of the nine buildings under the BrainBox AI control thus managing the percentage of openings of the supply water valves for heating and cooling, the velocity of the corresponding pumps, and consequently the thermal energy demand for each building. Since AI-based algorithms consider in continuous way the data measured in the indoor spaces, the comfort conditions, and the set points of the room temperatures, set by the users, are always satisfied.

The application and expansion of the facilities under control for Optimus and Water-Clock has been a synergic work across time between the facility management team and Brainbox AI. The other control functionalities remain, as they were, to the existing BMS and to the tasks which the O&M team wanted to continue doing. The AI algorithms can also be turned off and turned back on through a simple step on the dashboard, when the O&M responsible or the facility managers need it, for example when a specific maintenance task is foreseen, and they need to have the full control of the involved components. This increases trust and confidence in the Brainbox AI solution as one of the key aspects driving the results and expansion of system capabilities at La Forgiatura as the O&M team directly sees the results in terms of savings and



Screenshots from the Smart Ready Go! SRI assessment platform.

of systems optimizations, which would be impossible through manual optimizations, because they could not be continuous, dynamic, and automatically data-driven like with the AI.

Year	Savings (kWh)	% HVAC Savings	Economic Value
2022	26 950	12.9%	€6 710
2023	100 954	31.4%	€25 137
2024 YTD (7 Mo.)	55 937	32.5%	€13 928
Total	**183 300**	**26.1%**	**€45 775**

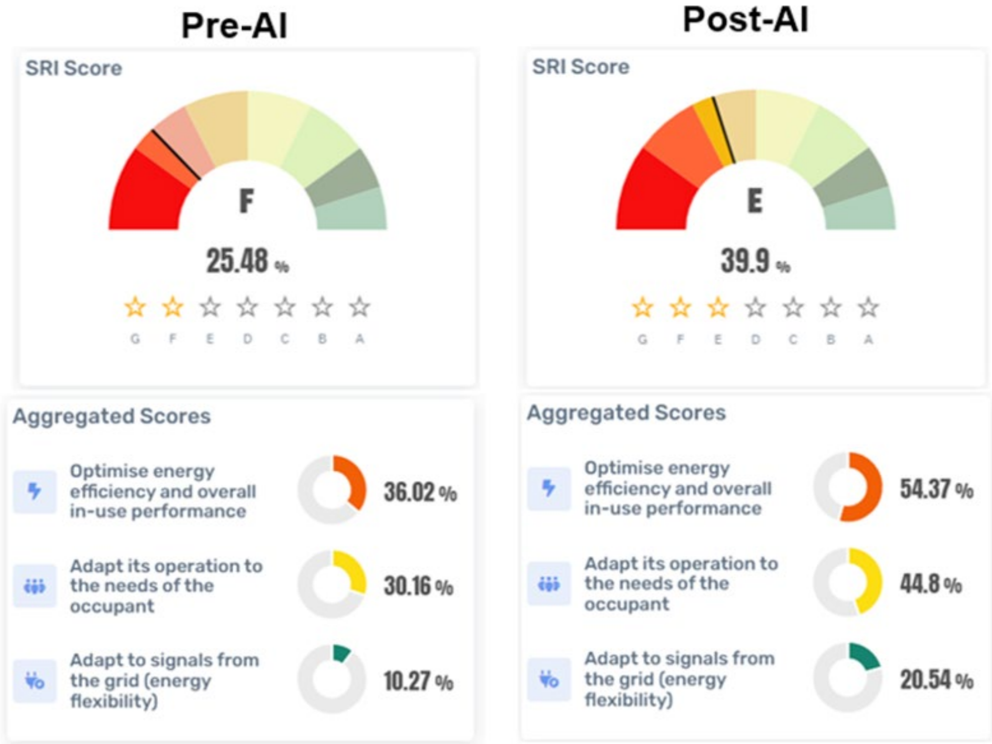
Thanks to the operation of BrainBox AI, from February 2022 to August 2024, a savings of more than 26% of electricity has been achieved on the equipment controlled by BrainBox AI, corresponding to 183 300 kWh of electricity savings and more than 45 000 € of energy costs savings (considering the average tariff of electricity of 0,248 €/kWh). The AI algorithms were not enabled 100% of the time but used increasingly across time with increased confidence in the system and disabled for planned or unplanned interruptions, maintenance, or other activities. In addition, more savings have been achieved in terms of lower demand of thermal energy for heating and cooling to the central polyvalent heat pumps, which are not included in the values above, but they were reached also in terms of further savings of electricity for the heat pumps. It can also be considered that the implementation of BrainBox AI allows for better capabilities of monitoring, data analysis, and feedback to the customers, which allowed the identification of faulty sensors or undesired behaviours of certain components, which otherwise would be very difficult to find through the human and manual activities also of expert and careful maintenance staff. These functionalities, thanks to the visualization of data trends, also allowed further considerations on optimization of the systems, for example to avoid too high thermal energy demand in specific period and to optimize the peak load of all the heat pumps installed. This also delivered concrete improvements in energy savings, in optimized operation of the components avoiding interruptions and issues, and in the indoor comfort conditions for the occupants. Over time, equipment efficiency also results in longer equipment lifespans and reduced maintenance costs. A final value also not quantified relates to brand, image, innovation capacity, the consideration of the environment and the comfort of building occupants. Several of these aspects are considered and quantified using the Smart Readiness Indicator.

Smart readiness improvement

Before and after SRI assessments have been conducted on the main campus building following the technical framework from the European Commission and following the SRI auditing process developed in the Smart Square Project proposed for standardization within the framework of an ongoing CEN workshop agreement. Building features, systems present, control capabilities and related functionality levels have been identified from the technical documentation (such as MEP drawings and data sheets of the components) and from analysis of the BMS graphical interface and functionalities it provides. In addition, a site inspection has been conducted to see further features and check the gathered information. It has been seen that the technical information in the documentation was consistent and up to date with the actual situation at the field. Final checks and feedback have also gathered directly from the building manager and from the responsible person for the system maintenance. A checklist printed out from the Smart Ready Go! Environment was used to take all the necessary information for the SRI assessment during the field visit and afterwards the information was entered into the Smart Ready Go! tool for this specific project and enabling calculation of the SRI score and visualization of the results. The SRI has been calculated according to the Method B, which is described in the reference document as "expert SRI assessment" and considers a more detailed analysis and an extended version of the catalogue of services (systems and subsystems) and their functionality levels.

Pre-AI, the building shows interesting levels of control functionalities, particularly related to the control of indoor temperature in the different rooms, to the operation of the heating and cooling systems, to the control of the hydraulic pumps, and for the presence of a BMS which some functionalities of monitoring and coordination between the systems. The rating of 25.48% is a good score considering the current assessment framework, weighting factors, and relative comparison against other building assessments. Post-AI, further control and optimization capabilities provided by the BrainBox AI solution, raise the assessment level of several of the smart ready service domains to 39.9% which is an excellent rating with respect to the current assessment framework and relative comparison.

In greater detail, the AI algorithms improved the functionality levels in the following assessment criteria of various smart ready services: providing predictive management and fault detection for reporting of KPIs and performance to the users; allowing for higher



Before and after SRI assessments at La Forgiatura.

energy flexibility levels with self-learning optimal control; improving the control of distribution fluid temperatures for heating and cooling with demand based control; providing predictive controls for the run time management of HVAC systems; allowing for automatic detection of faults; providing a platform for coordination and optimization of the HVAC systems; and providing the chance to optimize the systems based on weather. The attained results provided a new way to communicate and valorise the benefits of using a smart ready technology to the building owner and facility management team.

Conclusions and Future Work

There is robust set of existing and emerging smart-ready technologies. They work and are without doubt a part of meeting sustainability targets. Within this context, the Smart Readiness Indicator provides a common methodology and assessment for stakeholders to assess and have conversations about building smartness, smart-ready technologies and potentially to what buildings they can be applied first. This case study featured a pilot implementation from the Smart Square project at the business park La Forgiatura in Milan. Artificial intelligence solutions for HVAC provided building services by connecting to an existing BMS over a multi-year period and SRI assessments were facilitated by the software platform Smart Ready Go!.

Pilot results are promising, not only for the energy savings, but for the processes unlocked and lessons learned developed between the facility managers, Brainbox AI and R2M Solution as the system was deployed, integrated, and expanded over time both in terms of functionalities provided, buildings covered and amount of time in autonomous self-driving mode. A clear improvement in the SRI assessment was delivered by the integration of artificial intelligence and recommendations are in progress for feedback to the assessment methodology on how smart ready assessment criteria could better adapt to the emerging functionalities provided by AI. Building assessors were facilitated by the SRI assessment platform Smart Ready Go! and appreciated mostly that the platform provided a structure to conduct evaluations, store results for future use and to provide results and insights to the building owners and facility management teams.

Links

[1] https://www.smartsquare-project.eu/

[2] LIFE Projects Supporting the SRI

[3] https://realstep.it/case-study/la-forgiatura/

[4] https://brainboxai.com/en/

[5] https://www.smart-ready-go.eu/

[6] https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/smart-readiness-indicator_en ■

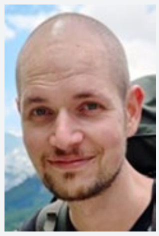
Development and Evaluation of a Multi-Zone VAV HVAC System with Demand-Controlled Ventilation for Energy-Efficient Homes

ALIREZA AFSHARI
Department of Built Environment, Aalborg University, Denmark

SAMIRA RAHNAMA
Department of Built Environment, Aalborg University, Denmark

GÖRAN HULTMARK
Department of Built Environment, Aalborg University, Denmark

KLEMEN RUPNIK
Department of Built Environment, Aalborg University, Denmark



PIERRE VOGLER-FINCK
Neogrid Technologies Aps, Denmark

This study develops and evaluates a multi-zone Variable Air Volume (VAV) HVAC system with demand-controlled ventilation (DCV) for efficient climate control in residential buildings. Traditional systems often fail to maintain optimal conditions in highly insulated homes. The novel system uses heat valves, VAV dampers, and sensors to adjust airflow and temperature based on each room's specific needs. In laboratory tests, the system-maintained temperature set points with minimal deviation (±0.3°C), adapted to heating demand changes, and reduced energy consumption by up to 30% compared to conventional systems. Future research will focus on field testing and humidity control integration.

Keywords: Variable Air Volume (VAV) system; Demand-controlled ventilation (DCV); HVAC system; Energy efficiency; Residential buildings; Climate control; Multi-zone

HVAC systems are essential for maintaining indoor climate control and ensuring thermal comfort and air quality across residential, commercial, and industrial buildings. These systems have evolved to meet the increasing energy-efficiency demands driven by stricter building codes and sustainability goals. In well-insulated residential buildings, where energy requirements for heating and cooling are minimized, traditional HVAC systems often struggle to provide optimal climate control across all rooms, leading to inefficiencies and discomfort (Georges et al., 2014; Berge & Mathisen, 2015).

HVAC systems are generally classified into all-air, all-water, and air-water categories. All-air systems, commonly used in residential buildings, offer a cost-effective solution for low thermal demand settings by providing heating and cooling via conditioned air. However, systems using Constant Air Volume (CAV) often rely on a single temperature reference zone, resulting in unsatisfactory climate control in other rooms like bedrooms and kitchens with differing thermal preferences (Seyam, 2018; Berge et al., 2016).

The demand for independent temperature control across different zones in homes has risen with the development of high-performance, insulated buildings. Traditional CAV systems are inadequate for such zoning because they cannot independently adjust airflow and temperature for each room, leading to inefficient energy use (Berge et al., 2017). Variable Air Volume (VAV) systems, which allow individual control of airflow and temperature in each room, provide a more energy-efficient alternative for residential HVAC systems. VAV systems adjust airflow according to the heating or cooling needs of specific zones, offering flexibility and improved energy efficiency (Rismanchi et al., 2019). Although traditionally used in commercial buildings, VAV systems are becoming more feasible in residential applications due to advances in affordable control technology like Internet of Things (IoT) devices (Lee et al., 2020).

A key innovation in residential HVAC systems has been the integration of demand-controlled ventilation (DCV) with VAV strategies. These systems use sensors to monitor occupancy and environmental conditions such as temperature and CO_2 levels, adjusting heating or cooling accordingly. This approach improves energy

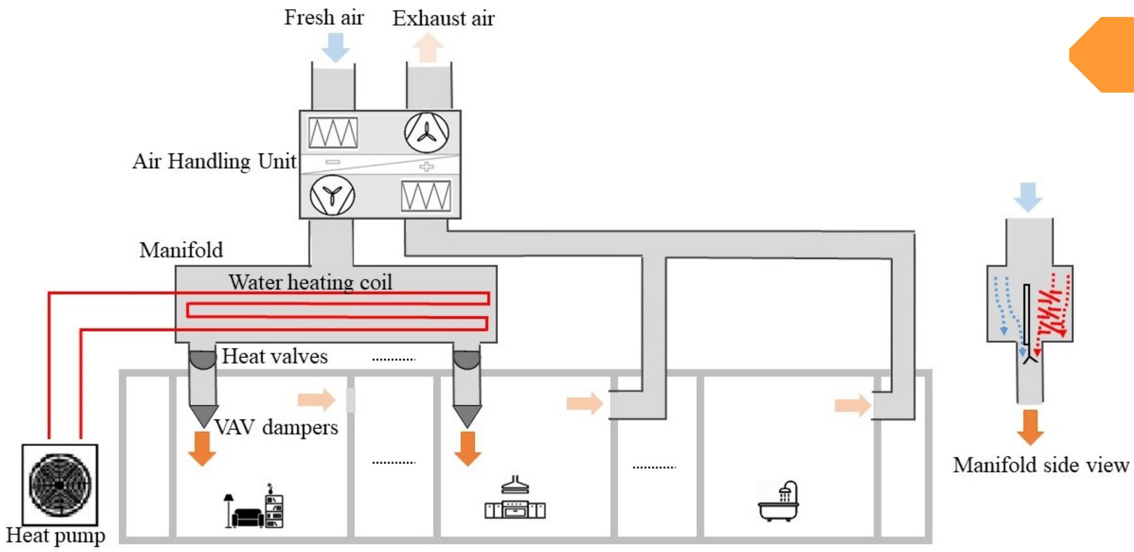


Figure 1. Novel-designed air heating and ventilation system, so-called HVV system: Overall design (left) and the manifold side view (right).

efficiency while maintaining comfort, making it ideal for residential buildings with low heating or cooling loads (Anand et al., 2019; Vindel et al., 2021).

A limitation of earlier VAV systems is their focus on single-zone control without addressing the need for room-specific temperature regulation. Polak et al. (2020) addressed this gap by introducing the Heat Valve Ventilation (HVV) system, which controls room-level temperature without energy-intensive local reheating. The HVV system adjusts both airflow and temperature based on the specific heating or cooling demand in each room, ensuring comfort while minimizing energy use.

The present study develops control logic for a novel multi-zone VAV HVAC system for residential buildings. The system integrates DCV and room-based temperature and airflow regulation, ensuring efficient operation and individualized comfort across all zones.

Study Objectives:

1. Develop control logic for room-based temperature and airflow regulation in a multi-zone VAV system.
2. Evaluate the system's performance in maintaining thermal comfort and air quality in a laboratory environment.
3. Assess the energy-saving potential of the proposed system compared to conventional HVAC systems.

The following sections describe the methodology used for testing the control logic, present the experimental results, and discuss the system's performance in terms of comfort and energy efficiency.

Methodology

This study focuses on developing, implementing, and evaluating a novel multi-zone VAV HVAC system with demand-controlled ventilation (DCV) to provide independent room-level climate control in residential buildings. The following summarizes the system design, experimental setup, and evaluation framework.

System Design

The system is based on the Heat Valve Ventilation (HVV) system developed by Polak et al. (2020), integrating heating and ventilation through an air-handling unit (AHU). It uses heat valves (HVs) to regulate air temperature and VAV dampers to control airflow to individual rooms, improving energy efficiency by eliminating the need for local reheat coils.

Key components include:

- AHU: Supplies conditioned air for heating and ventilation.
- Heat Valves (HVs): Adjust the air temperature by controlling the bypass around the heating coil.
- VAV Dampers: Control airflow to rooms based on real-time heating or cooling needs.
- Temperature and CO_2 Sensors: Monitor and adjust air quality and temperature in real-time (Anand et al., 2019).

The system uses a DCV algorithm to adjust airflow and temperature based on room occupancy and thermal needs, prioritizing energy efficiency while maintaining thermal comfort (Rismanchi et al., 2019).

Laboratory Setup

A full-scale prototype was tested in a controlled laboratory simulating six residential zones: two bedrooms, an office, a living room, a kitchen, and a large bedroom. Heating loads varied, with the largest load of 505 W in the living room and the smallest at 187 W in Bedroom 1. The setup included independent cooling loads and simulated real-life occupancy and humidity conditions to test the system's response (Polak et al., 2020; Executive Order on Building Regulations, 2018), see **Figure 1**.

Control Logic Development

The system's control logic focused on energy efficiency while maintaining room-specific set-points and air quality. Key features include:

1. Temperature Control: HVs adjust air temperature, and if necessary, VAV dampers increase airflow (Rismanchi et al., 2019).
2. Airflow Control: VAV dampers respond to temperature or CO_2 concentration exceeding set thresholds (Anand et al., 2019).
3. Critical Zone Reset: Fan speed is adjusted based on the most demanding zone to reduce energy use (Rahnama et al., 2017).
4. Humidity Control: While not tested, provisions are included for high-humidity zones like bathrooms (Berge et al., 2017).

Data Collection and Performance Metrics

The system's performance was measured using several key metrics:

- Temperature Stability: Sensors tracked how well-set points (±0.3°C) were maintained.
- Airflow Rates: The airflow in each zone was monitored to ensure indoor air quality per Danish regulations (Executive Order on Building Regulations, 2018).
- Energy Consumption: Recorded to compare the novel VAV system's efficiency against traditional CAV systems (Berge & Mathisen, 2015).
- System Stability: Monitored to ensure no overshoot or instability in temperature or airflow (Rahnama et al., 2017).

Experimental Procedure

The 36-hour experiment tested the system's response to varying temperature set points and heating demands across the six zones. Adjustments in set points were made to simulate real-world changes, such as increasing the living room set point from 21°C to 24°C during the experiment. Data were collected regularly to evaluate the system's ability to maintain comfort, efficiency, and air quality (Polak et al., 2020).

Results and Discussion

The system successfully maintained temperature set points across all six zones, with minimal deviations (±0.3°C). For example, Bedroom 1 remained between 20.8°C and 21.2°C with a set-point of 21°C, while the living room (46 m^2) maintained a 24°C set-point with a deviation of 0.2°C (Polak et al., 2020). The system adapted well to heating demand fluctuations, adjusting airflow and temperature dynamically. In high-demand zones like the kitchen and living room, it managed significant temperature variations caused by activities such as cooking. The dual strategy of adjusting both airflow and temperature helped maintain comfort without excessive energy use.

When set points were adjusted mid-experiment, such as raising the living room from 21°C to 24°C and lowering the kitchen from 23°C to 21°C, the system responded quickly and accurately. The living room reached its new set point within 15 minutes without overshoot, while the kitchen stabilized within 10 minutes (Rismanchi et al., 2019). This fast and stable response highlights the system's ability to adapt to frequent changes in set points, a common issue in conventional CAV systems.

Airflow rates were dynamically adjusted based on occupancy and heating demands, keeping airflow as low as possible while meeting ventilation requirements per Danish building codes (BR18). For example, Bedroom 1 maintained the minimum airflow rate of 4.5 ℓ/s, while the living room fluctuated between 12.4 ℓ/s and 18.6 ℓ/s depending on the heating load. The system's prioritization of temperature control over unnecessary airflow adjustments reduced energy consumption and prevented discomfort from excessive airflow (Berge & Mathisen, 2015).

The VAV system demonstrated significant energy savings, reducing fan energy use by up to 30% compared to conventional CAV systems. By modulating fan speed based on demand and adjusting airflow only, when necessary, the system operated at reduced speeds during low-demand periods, further lowering energy consumption (Anand et al., 2019; Polak et al., 2020).

The system maintained stable temperature and airflow, responding smoothly to fluctuations in heating demand and set-point changes without overshooting or instability. It managed simultaneous temperature adjustments across multiple zones, a significant improvement over conventional systems that struggle with complex multi-zone environments (Polak et al., 2020).

However, the controlled lab setting limits real-world applicability. Future research should focus on field testing in occupied homes to assess performance under varying occupancy and daily activities. Additionally, the system's humidity control, untested in the lab, should be evaluated in real environments, particularly in high-humidity zones like kitchens and bathrooms, see **Figure 2**.

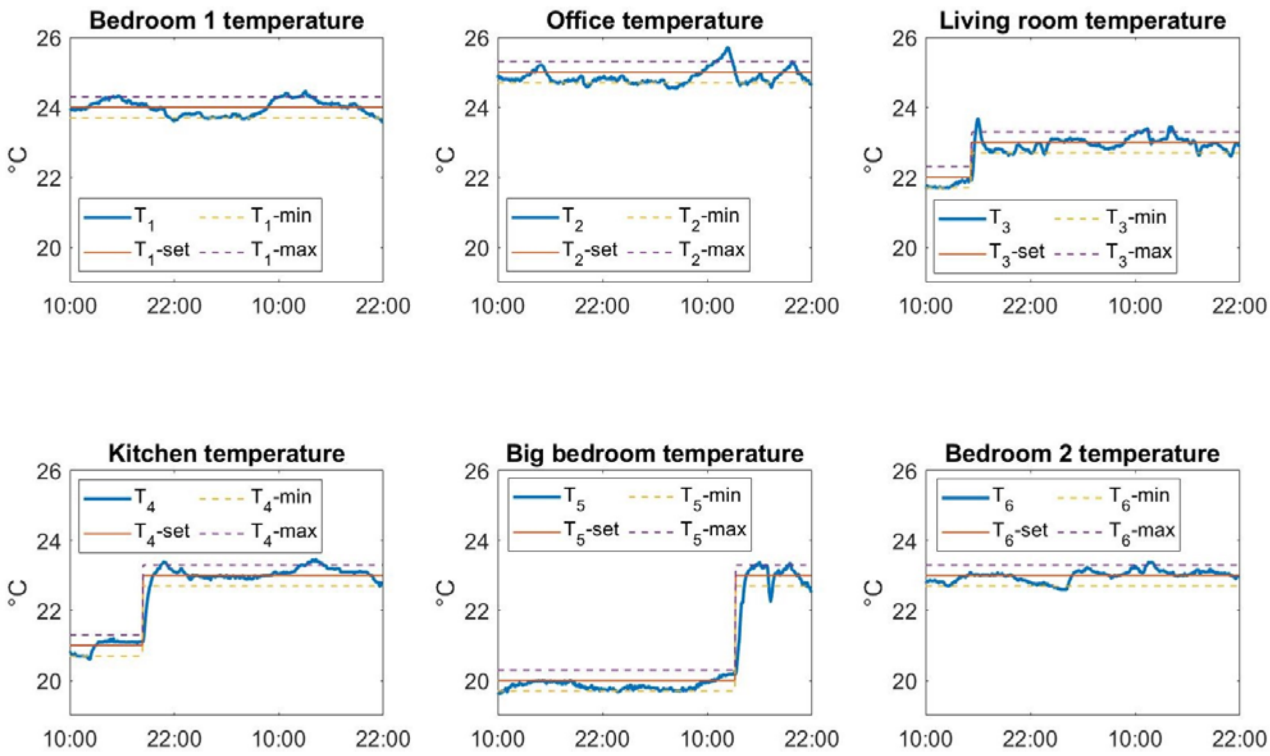


Figure 2. HVV prototype — Supply zones temperature together with the temperature set-point, the minimum, and the maximum temperature limits.

Conclusion

The experimental results confirm the effectiveness of the novel VAV HVAC system in maintaining individualized thermal comfort, improving indoor air quality, and reducing energy consumption in residential buildings. The system's ability to regulate both temperature and airflow at the room level, combined with its demand-controlled ventilation strategy, ensures that energy use is minimized without sacrificing comfort. While further field testing is needed, the findings from this study suggest that the system offers a promising solution for modern, energy-efficient residential buildings.*

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ARTICLES

Preparing the ground for an effective SRI

– 6 lessons from early test phases

MARTA MAIA
Senior communication expert, Institute of European Energy and Climate Policy
marta@ieecp.org

Summary of a roundtable between representatives of France, Portugal, Cyprus, Spain, and Croatia about tools, anticipation, customisation, training and market adoption of the upcoming Smart Readiness Indicator.

Keywords: Smart Readiness Indicator (SRI); Training; Tool Integration; Decision Making

As the European Commission's SRI platform gathered for the 5th plenary meeting in October, the SRI2MARKET project took the opportunity to lead a roundtable with seven representatives from six European countries. By exploring the different stages where each country stands in the testing of the Smart Readiness Indicator, the session brought to light several learnings, challenges, and expectations for the roll out of the indicator across Europe, while also reflecting on the impact of EU-funded research performed in parallel with pre-implementation activities.

The session was co-organised by the EU-funded projects SRI2MARKET, SRI-Enact, EasySRI, and Smart Square, and supported by DG ENER and CINEA. The dialogue engaged **Sabine Kamill** (Federal Ministry for Climate Protection, Environment, Energy, Mobility, Innovation, and Technology, Austria), **Vesna Bukarica** (Energy Institute Hrvoje Pozar, Croatia), **Soulla Karra** (Cyprus Energy Agency, Cyprus), **Sandro Silva Pereira** (Directorate General of Energy and Geology, Portugal), **Aitor Domínguez** (Institute for the Diversification and Saving of Energy, Spain), **Cécile Barrère** (R2M Solution, France), and **Pascal Torres** (Osmose, France), with moderation of **Pablo Carnero** (REHVA). Some key messages emerged from the fruitful discussion:

EU funded projects are providing crucial tools for national agencies to take action

The tools, databases, and training programs developed by EU-funded SRI projects are proving to be gamechangers as countries progress with their testing phases. While Soulla Karra stated that the Cyprus Energy Agency "always uses" projects' educational materials to train the future SRI assessors, Cécile Barrère explained that the time dedicated by projects to the translation of contents into several European languages made a big difference: "it's very useful to reach national stakeholders" in an interaction that "is not unilateral", she stated, adding that the smooth communication facilitates the collection of "difficulties on the ground".

Anticipation is already producing benefits

The SRI test phase at national level aims to allow countries to identify challenges in advance and be able to address them before the indicator comes into force. In the case of Austria, the test phase has provided a picture of the impact of the SRI in the national building stock, evincing the need to engage not only building owners and auditors, but also energy providers, electricians, and stakeholders alike who play a role in the design, construction, and monitoring of the building. Spain uncovered the need for a consolidation and subsequent deep understanding of the SRI

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calculation methodology, which are crucial for assessors to feel comfortable with the new system and not reject it. After engaging residential and non-residential buildings in the test phase, Portugal is also analysing how the implementation of the SRI will differ across building types.

Only many sizes will fit many

Test phases across countries are revealing that there will be no one-size-fits-all in the SRI. Croatia, for example, has different climate conditions in the coast and inland; France deals with buildings where certain technologies – such as cooling – may not make sense. All countries agree that not every family house will benefit from investing in EV charging stations and other similar commodities. Therefore, all speakers agreed that a flexible approach to the calculation methodology of the SRI – where certain domains can be excluded depending on the needs and context of the buildings and their users – would avoid overequipping and unfairly low scores.

Stakeholders demand integration of tools

Following a suggestion from the audience about the development of an EU-wide, open-source calculation engine for all countries to further customise to their context, all speakers acknowledged that such approach would be useful. However, there was unanimous concern about the timing for development – as the legislation for the SRI will be enforced soon – and the lack of integration with other existing tools for energy efficiency.

EPC assessors are not automatically SRI assessors

Due to the complexity of the SRI calculation methodology and domains, it is not granted that an EPC assessor will be immediately able to perform SRI assessments. Speakers agreed that intensive training will be required – but also that professionals with other knowledge backgrounds more connected to technology should be considered for the role of SRI assessors.

Motivation is also an issue. The French case evinced that only those looking for a competitive differentiation in the market engaged actively with the SRI trainings. On the contrary, the mass of assessors (in energy and automation) seemed to regard the new indicator and required trainings as additional workload with benefits still to be clear.

SRI tools are good to support market decision making

When asked about the market receptiveness to the SRI tools, Pascal Torres explained that market actors could use such tools to support their decision making, not only because their assessment results are easy to understand, but also because the reports allow for useful comparisons. Being able to predict the indirect impacts of an intervention, but also to compare the benefits of improving different buildings was highlighted as an attractive feature for investors and multi-building owners. ■

SRI2MARKET

The SRI2MARKET thanks the support of the DG ENER and CINEA in the organisation of this session, as well as the projects SRI-Enact, EasySRI, SmartSquare, Velixia, SmartEEStory, SmarterEPC, SmartLiving EPC, tunES, iEPB, REPowerE(d)U, and BuildON for participating in the discussions and in the projects' exhibition fair.

Interview with Richard de Dear by Lada Hensen Centnerová

Alliesthesia is used to differentiate thermal pleasure from thermal neutrality and acceptability

For over four decades Professor **Richard de Dear** has focused his research career on defining what occupants want and need from their built environments, and assessing the performance of buildings in terms of meeting those requirements. He is currently the most highly cited active researcher in thermal comfort, with over 230 peer-reviewed papers in the SCOPUS database, as well as several monographs on the subject. Within that body of research, it is his adaptive model of thermal comfort that's had the greatest impact, not just on the research community but also on the design and operation of actual buildings.

His adaptive model was in 2004 incorporated in ASHRAE Standard 55 and in 2007 in EN 15251 (from 2019 – EN 16789-1). In June 2024 he was awarded the Pettenkofer Gold Medal by ISIAQ in recognition of his outstanding contribution to our understanding of thermal comfort in the built environment.

LHC: You and Gail Brager (from the University of California in Berkeley, USA) developed an adaptive model of thermal comfort [1], which was later included in standards (ASHRAE 55 in 2004 and EN 15251* in 2007). Could you explain what does it mean 'adaptive thermal comfort'?

RdD: I can explain it by saying what it's not. It is not PMV (Predicted Mean Vote), the invention of an engineer's mind, with energy inputs balanced against energy outputs.

Human perception is not so deterministic, it's not linear, it's circular. It's a feedback loop. If we feel something that we don't enjoy or don't like, we will kind of respond to it, do something to adapt. This response will change the physics of the heat balance. We can adapt clothing or metabolic heat production, but we also adjust our expectations. This feedback loop is what I'm referring to and that's what we mean by adaptive comfort. We adapt to the thermal situation. We don't just sit there passively and suffer an uncomfortable environment.

LHC: You speak about adaptation. There are three main adaptation types: physiological, behavior and psychological. Which one do you think is the most important?

RdD: Psychological. First, I thought the physiological one would be much bigger. Physiologist call it acclimatization. In your first interview [2] Wouter (van Marken Lichtenbelt) talked about it. In my experience of thermal comfort, expectation is the most important thing of all. And I get reminded of it as I travel around the world. And I still get surprised at what people call comfortable and acceptable, in disparate places like India, China, Sweden, for example.

LHC: OK. So, if we inform users of each building what they can expect and what they can do to adapt themselves, would that solve all our problems with discomfort claims?

RdD: It is the $64 million question how to nudge comfort expectations. I'm using the language of behavioral economists here, and we actually wrote a paper about it.

LHC: Yes, I know 'Nudging the adaptive thermal comfort model' in Energy and Buildings [3]. So, how to nudge people?

RdD: I don't have all the answers other than to say that indeed it is possible to shift comfort expectations. The best example in my travels was in Japan. Cool Biz, have you heard that expression?

LHC: Yes, of course. Japanese Prime Minister in shorts in the office.

RdD: That's exactly it. Koizumi was the Prime Minister (in 2005) and in a last-ditch effort to get Japan to meet its Kyoto Protocol commitments, he

* EN15251 withdrawn and replaced by EN 16798-1:2018

recognized that probably the most efficient strategy would be just to shift set points in air-conditioned buildings during summer. And so, they really pushed the limits up to 28°C. They had a campaign in which the Prime Minister and the Minister of Environment were telling office workers what they could do to adapt, and clothing was their focal point. It was hugely successful, but perhaps not100% successful. Later they pulled it back from 28 to 27 degrees.

Result of Cool Biz Campaign (source: Wikipedia): After web-based questionnaire survey on September 30, 2005, survey results indicated that 95,8% of respondents knew Cool Biz and 32,7% respondents answered that their offices set the air conditioner thermostat higher than in previous year. Based on these figures, Ministry of Environment estimated that the campaign resulted in a 460,000-ton reduction in CO_2 emission. The results for 2006 were even better, the estimation was 1.14 million-ton reduction in CO_2 emission.)

LHC: Did they change their standards?

RdD: From what I remember, I don't think it's a part of a standard, but it is still practiced every summer. They have a winter-time counterpart now too – "Warm Biz" – with wintertime heating setpoints dropping well below levels that we normally find in the Anglosphere.

LHC: In your paper about 'nudging' you write in the abstract: "We present evidence that adaptive comfort processes are relevant to the occupants of all buildings, including those that are air-conditioned". Could you elaborate more on this?

RdD: Yes, this is something we've learned about the adaptive comfort model in the 20 years of its existence as a standard. ASHRAE 55 had to be built on strong empirical evidence and because we had the evidence mostly from naturally ventilated spaces, it was said that we didn't have enough evidence to generalize beyond naturally ventilated buildings.

In this paper that you're referring to, 20 years after the original ASHRAE adaptive comfort standard, we did the analysis in a different way, on a vastly enlarged database, and instead of using mean monthly ***outdoor*** temperature we took the mean ***indoor*** temperature as the X-variable instead. And we did that for all of the buildings we had data from – naturally ventilated, air-conditioned and even mix-mode buildings. Building type became a parameter in the regression model and the data just lined up beautifully, even more strongly when it did for when we used outdoor temperature as the predictor (X-variable). And so, the implication is that actually it's the ***indoor*** temperature that we're exposed to that actually driving our comfort expectations. We are indoor creatures after all! (**Figure 1** (reprint from [3])).

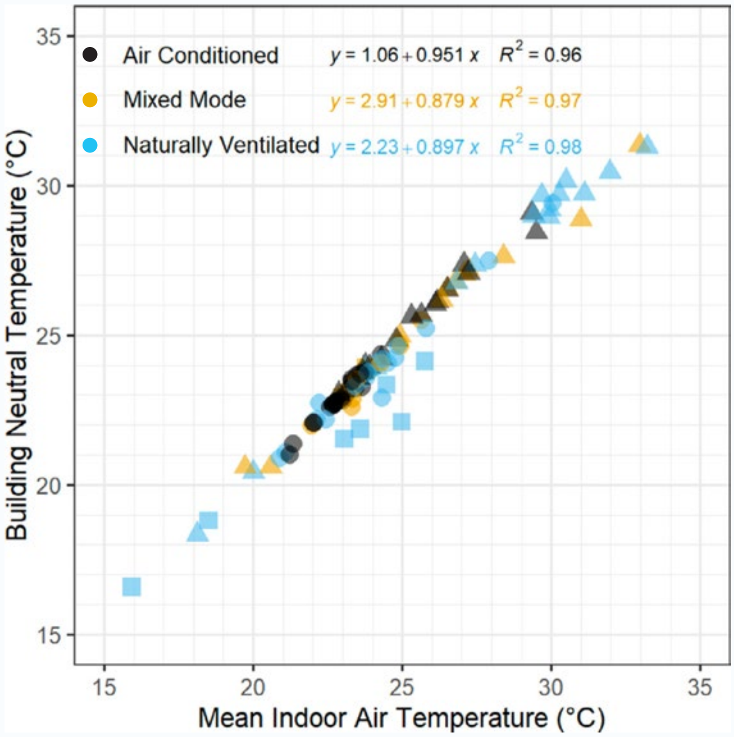

Figure 1. Plot shows the very clear relationship between the mean temperature inside a building and the temperature that people find most comfortable in that building. Each dot represents a building comfort study. These studies have been done in hundreds of buildings all over the world over the last couple of decades, and this graph is a meta-analysis of a database of building comfort studies. A building comfort study consists of a sample of people inside a building filling in a comfort questionnaire while the indoor climate of their room was simultaneously measured. When the questionnaire has been completed by a large enough sample of building occupants across a period of time (often a month), we can analyse the results and statistically identify the optimally comfortable temperature for that particular building for that month in that specific city - we call it "neutral temperature". The graph shows that, when a building is warm (x-axis), the temperature that its occupants regard as neutral (Y-axis) is also warm, and vice versa; cool buildings tend to have cool neutral temperatures. The most remarkable aspect of the graph is that this dependence of optimally comfortable temperatures on the average temperatures prevailing inside the building occurs in A/C buildings, free running buildings, and mixed-mode buildings.

LHC: This should be easy to use. If we know that summer is coming, the indoor temperatures can go slowly up, then people will get used to it (they will adapt their expectation) and will feel comfortable even at 27°C.

RdD: It's so logical and you are absolutely right, but it's not the way air-conditioned buildings are operated, at last not here. They just have a single set point here in Sydney, and it's the same set point ***all year around*** because it's too complicated for facilities managers to adjust their delicately balanced building's controls. Crazy I know!

LHC: What can we do to change this? Nowadays, with all that smart technology, it shouldn't be a problem.

RdD: It is inevitable this was going to happen. I have to bring 'the gender wars' into the discussion now. Women are much more adaptive in their clothing behaviour. It's been demonstrated over and over again. If it's hot outside, they will dress more lightly (wearing lighter clo-values). Men are not so responsive, and especially in the finance sector. Men are all wearing suits because they think they look more professional, more credible (stifled laughter).

LHC: In other words, the constant indoor temperature is for men in suits.

RdD: Exactly! Huge amounts of greenhouse gas go into the atmosphere so that men can wear their business suits. That's a very cynical interpretation, but it's probably closer to the truth than we'd like to admit.

LHC: This bring us to another (not scientific) article of yours 'Why the perfect office temperature is a myth' [4]. Could you explain that?

RdD: I wrote it together with a colleague here in Australia, Fan Zhang, and a psychologist in Florida, Peter Hancock. There was a 10 questions paper published in Building and Environment in 2017 [5] which said that people can adapt to their comfort expectations across wide-ranging temperatures, but the costs in terms of lost productivity will be enormous. On that logic the authors asserted that we must keep indoor temperature at 22 degrees.

Peter Hancock is a very famous psychologist - authoritive voice on cognitive performance, and he has mountains of empirical evidence that people are comfortable across a wide range of temperatures and productive as well. So, in that conversation piece you are referring to, we were arguing that there are no serious effects on productivity until you get to the edges of the fairly broad adaptive comfort temperature range.

LHC: As a worldwide recognized expert on thermal comfort, could you explain the difference between thermal comfort and thermal sensation?

RdD: That's a question I've received many times. To be honest, thermal comfort is almost a meaningless word. It means different things to different people. A lot of people think that thermal sensation is thermal comfort. I kind of regard comfort as an all-encompassing word that includes thermal sensation, thermal preferences, thermal pleasure, thermal acceptability. It's just a research domain that includes all of those different dimensions. But once we get inside the domain of thermal comfort, we can start splitting it down into pleasure, acceptability, satisfaction, preference, and lastly, thermal sensation, which is the one that everybody knows about, because that's what Fanger wrote about. When we say something is slightly cool, it doesn't say anything about whether we like it or not. Thermal sensation is not synonymous with thermal acceptability or thermal preference. They are really different. And thermal pleasure is the trickiest of them all. That's where alliesthesia comes in.

LHC: What is alliesthesia?

RdD: First, let me tell you how I first came across it. I was a PhD student (early 1980s). My supervisor prof. Andreas Auliciems, had been to a conference in Copenhagen (organized by Fanger) and he came back with proceedings (those days in hardcover). I avidly read all the papers and there was one paper by French Canadian physiologist, Michel Cabanac, on human thermal perception and alliesthesia. I read it, I knew it was important, but I couldn't quite make out what to make of it, so I kind of ignored it and so did everybody else apparently. And then, many years later I rediscovered it through my own experience. Suddenly, I felt what alliesthesia is all about. And the context was very memorable.

You know the Sydney Opera House. In summertime, they often have concerts on the forecourt, at the back of the house. Everybody sits on the steps of the Opera House to listen to classical music (**Figure 2**). And then it happened. I was there and it was a perfect summer evening. The temperature was perfectly balmy, the sunset behind the Harbour Bridge was perfect. I was thinking to myself, I know the music, I've heard this piece before, ***inside*** the Opera House, where the acoustics are supposedly much better, but this outdoor concert was next level. I realized that it's not just the music I'm enjoying, it's the whole package, the whole 'vibe' was perfect, including the bats in the night sky, and of course summer breeze – goosebump stuff! This wonderful gentle, warm breeze coming in off the harbour. And then it came to me; this is what Michel Cabanac was telling us about all those years ago. Thermal pleasure, a million miles away from neutral!

There are layers of thermal perception. The most basic layer is thermal sensation. It's cool, it's warm. And then there are other layers that we don't often deal with because it gets a bit complicated. And thermal pleasure is being completely ignored.

LHC: Fascinating. In your paper 'Revisiting an old hypothesis on human thermal perception: alliesthesia' [6] you write that alliesthesia is the feeling of change and it can be positive or negative. So, if you want to reach thermal pleasure, alliesthesia, you have to start from discomfort, right? How can this be used in real buildings?

RdD: It's a reasonable point you make. Let's look at a cold climate example. The ambient temperature there might be lower than neutral and then you use some localized heating and that gives you thermal pleasure. Most of the personalized comfort systems are really alliesthesia devices in my mind.

There are also some traditional ones, like an open fire, where you feel the radiation but also aromatic smells, and you hear and see the flames, but of course can be problematic in relation to air quality. In eastern cultures, for example in Japan, they're very familiar with personal comfort systems. The Japanese vernacular architecture is very lightweight, but Japanese winters can be quite cold. They don't heat the whole house but they have traditional, localized heating sources, which don't provide a thermally neutral environment, but they provide a thermally pleasant environment. The contrast is where the pleasure resides.

Figure 2. The Sydney Opera House. (https://www.boudist.com/news/2013/documentary-photography/sydney-opera-house-40th-anniversary)

I think the conventional wisdom in HVAC engineering is to homogenize everything and I think it's high time to seriously question that. I think variability is not such a bad thing after all. Variability can be through time. Like when we enter a space from outdoors (or vice versa). That's what we call temporal alliesthesia, with the change through time. That's what we enjoy.

In most standards is a section called local discomforts. One of them is vertical temperature gradient – cold feet, warm head. And actually, if you flip the gradient, it's not uncomfortable at all. It's quite pleasant – cool head and warm feet. That is what we call spatial alliesthesia (change through space instead of time). You can keep it going for much longer time exposures than temporal alliesthesia.

LHC: The last question. Research about light and its influence on people's behavior and health speaks about circadian rhythm, about the change of the color of light (temperature) during the day. Do you think that circadian rhythm could be important also for thermal sensation?

RdD: It's conflicting. There's not a really clear picture, but I believe it's true. And one of the realms in which it could be applied very effectively is in so-called "ultra-long-haul" air travel. They're now talking about Sydney to London, Sydney to New York non-stop flights. It is very interesting but that's a whole other topic.

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November 2024

18-19 November 2024	REHVA Brussels Summit (rehva.eu)	Brussels, Belgium
25-26 November 2024	ATMOSphere Europe Summit 2024 (rehva.eu)	Prague Congress Centre

December 2024

11-13 December 2024	55th International HVAC&R Congress and Exhibition (rehva.eu)	Belgrade, Serbia

2025

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8-12 February 2025	ASHRAE 2025 Winter Conference (ashrae.org)	Orlando,USA

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2-3 June 2025	REHVA Annual meeting 2024 (rehva.eu)	Milano, Italy
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24-26 September 2025	45th AIVC & ASHRAE 2025 IEQ joint Conference (ashrae.org)	Montreal, Canada

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dimitris@ieecp.org

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