Energy & Buildings 314 (2024) 114234

Contents lists available at ScienceDirect

Energy & Buildings

journal homepage: www.elsevier.com/locate/enb

A novel framework for assessing the smartness and the smart readiness level in highly electrified non-residential buildings: A Norwegian case study

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ARTICLE INFO

Keywords:
SRI
Smart by Powerhouse
Smart buildings
Building stock
Energy use
Norway
Non-residential buildings
Digitalization

ABSTRACT

This work presents a new operational framework to measure the smartness and smart readiness of highly electrified buildings. The framework seeks to enhance legacy systems and controls of existing buildings and establish minimum criteria for future constructions to ensure they interact effectively with users and the grid, aiming for a clean energy transition. To this end, we develop two modified complementary assessments, one based on the method indicated by the Smart Readiness Indicator (SRI), proposed by the European Union (EU), and the other following the Smart by Powerhouse scheme, introduced by a Norwegian consortium of stakeholders focused on developing future proof climate buildings. The proposed structure is implemented in ten non-residential buildings in Norway with different energy systems, typologies, and construction dates. The results of this study demonstrate that energy flexibility quantification plays a crucial role in correctly implementing the framework in highly electrified buildings. Therefore, the dynamic impact of having Electric Vehicle Charging (EVC) and other electrical-dependent loads must be considered in the assessment. With the proposed modifications, the EVC weight in the flexibility score now varies from 24.0 to 43.6%, up from the original 5%. Overall, the pilot buildings have a smart readiness level between 21.6% and 31.7%, with mostly automated smartness levels. Nevertheless, the study also emphasizes the need to differentiate current HVAC (Heating, Ventilation, and Air Conditioning) technologies and their efficiencies.

1. Introduction

The concept of “Smart Building” has attracted growing attention from end-users, market participants, and policymakers in the last few years. Enabling smart solutions such as the remote monitoring of energy use in heating, cooling, and ventilation, the adoption of smart lighting solutions in line with occupancy, the controls integrated with automated blinds, or the integration of local energy production and storage proved to maximize energy savings, flexibility, occupants’ comfort, and safety [1].

The potential of smart technologies in the building sector was underlined in the 2018 revision of the “Energy Performance of Buildings Directive (EPBD)” [2], which introduced an optional framework to assess the digitalization and the capabilities of the buildings to decrease their energy consumption and interact with users and grids, making the path for adopting the Smart Readiness Indicator (SRI), developed by EnergyVille and VITO [3]. This project was initiated to meet the demand for faster building renovation investments and to incorporate advanced Internet and communication technologies (ICT) to enhance energy efficiency while being able to interact and adapt their operation based on the needs of the building’s occupants and the grid. In December 2021, the European Commission proposed revising the directive 2018/844 as part of the Fit for 55 package to reflect higher ambitions and more pressing needs in climate and social action [4]. The amended proposal, adopted by the European Parliament on 14 March 2023 [5], strengthens the importance of rating the smart readiness of buildings for large non-residential buildings, proposing in Article 13 the adoption of a delegated

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https://doi.org/10.1016/j.enbuild.2024.114234
Received 15 January 2024; Received in revised form 26 April 2024; Accepted 30 April 2024
Available online 3 May 2024

Nomenclature

Symbol

α	Alpha factor for energy balance
β	Beta factor for energy intensity balance
δ	Binary variable
f	Weight factor for SRI

Acronyms

AHU	Air handling units
BMS	Building management system
BSO	Building stock observatory
CAV	Constant Air Volume
DBE	Dynamic building envelope
DG	Distributed generation
DHW	Domestic hot water
EE	Energy efficiency
EF&S	Energy flexibility and storage
EPBD	Energy performance of buildings directive
EV	Electric vehicle
EVC	Electric vehicle charging
GEB	Grid-interactive efficient building
HP	Heat pump
HVAC	Heating, ventilation, and air conditioning
HW&A	Health, well-being and accessibility
Q	Primary energy usage [kWh/year/m^2]
$\overline{Q}$	Average hourly primary energy [kWh/h/m^2]
$r_{surface}$	Building surface vs. total surface of non-residential buildings ratio
IB	Intelligent building
ICT	Internet and communication technologies
IEQ	Indoor environmental quality
IoT	Internet-of-thing
KPI	Key performance indicator
M&FP	Maintenance and Fault Prediction
MC	Monitoring and control
nZEB	Nearly zero energy building
PV	Photovoltaic
RES	Renewable energy source / renewable energy produced on-site
SB	Smart building
SDG	Sustainable development goals
SRI	Smart readiness indicator
VAV	Variable air volume
WH	Working hours

act by 31 December 2024 amending the directive by "requiring the mandatory application, by the same date, of the common Union scheme for rating the smart readiness of buildings to non-residential buildings with an effective rated output for heating systems, air-conditioning systems, and systems for combined space heating, air-conditioning and ventilation of over 290 kW. From 1 January 2030, the common Union scheme shall apply to non-residential buildings with an effective rated output of 70 kW." Further, the new article 14 supports the diffusion of smart buildings and smart building technologies, emphasizing the role of "data exchange", which ensures that the building owners, tenants, and managers can have direct access to their building systems data. The article also underlines the importance that the aggregated and anonymized building systems data are made publicly available.

Globally, 30 % of the total final energy is used by the building sector [6] while 75 % of the European Union (EU) buildings are energy inefficient [7]. In Norway, according to Statistics Norway (December 2023) [8], the building stock consists of 4.3 million buildings, out of which 2.7 million are non-residential. Non-industrial buildings account for 55 % [9] of the electricity use, with 70–80 % directly associated with household heating services [10]. In addition, fossil fuel-based heating systems were banned in the country in 2016, as well as heating oil in 2020, extending the electrification process in the country [11]. Consequently, the building sector plays a crucial role in plans for the future decarbonization of the grid [12,13]. However, a need still exists to benchmark the sector's real capabilities and raise awareness of the benefits of smarter building technologies by making their added value more tangible for building users, owners, tenants, and smart service providers.

1.1. How did the Smart buildings definition emerge?

Throughout the years, there have been various definitions of intelligent (IB) or smart building (SB). One of the primary definitions was given by "The Intelligent Building Institution" in Washington back in 1988 [14,15,16]. The definition stated the following: "An intelligent building seamlessly integrates multiple systems to efficiently manage resources, allowing for maximum occupant performance, investment and operating cost savings, and flexibility". Furthermore, in 1997, Derek and Clements-Croome [16] extended the concept of intelligent building to include a human-centric perspective, aiming to remark the importance of human needs in a short- and long-term view at the same time that they cope with the social and technological changes. In addition, continuing the importance of the human-centric approach, Nguyen and Aiello [17] suggested that "intelligent buildings need to adapt their usage by recognizing human activity and responding to environmental changes to enhance energy savings". Newer definitions for intelligent buildings were given by the US Department of Energy [18], where they defined them as "buildings that possess a high level of smartness, being capable of load management for energy/costs efficiency and flexibility". Moreover, they redefined that intelligent buildings should consider the users' needs and external grid signals such as price, CO_2 emissions, or grid congestion, among others, as Grid-Interactive Efficient Buildings (GEBs). Another suggestion for a definition of an intelligent building was proposed by Locatee and Memoor [19] where seven essential features that an intelligent building should have were defined, including controlling facilities and operations, conserving resources, finding people and assets, optimizing services and space utilization, personalizing comfort and workplace experience, communicating with building users and staff, and securing people and assets.

Nevertheless, in recent years, there was a shift towards using the term "Smart building" rather than an "Intelligent building". An example is the Norwegian definition provided by Smart by Powerhouse, which suggests a functionality framework for describing smart buildings based on the needs and expected benefits related to five categories and five levels. It includes functionalities that create value for the users, tenants, building owners, and society [20]. Additionally, the IEA EBC Annex 81 (Smart data-driven buildings) [21] proposed the following concept of a"Data-Driven Smart Building", which involves the following: "Optimizing building operations using digital technology to improve factors such as site energy use, indoor environmental quality (IEQ), and occupant experience. A well-connected and integrated smart building can adapt to external factors and changing conditions, remember past events, anticipate future impacts, and make informed decisions to achieve higher-level objectives." Furthermore, the Buildings Performance Institute Europe (BPIE) provides the following definition [22]: "A smart building is highly energy efficient and covers its very low energy demand to a large extent by on-site or district-system-driven renewable energy sources. A smart building (i) stabilizes and drives faster decarbonization of the energy system through energy storage and demand-side flexibility; (ii) empowers its users and occupants with control over the energy flows; (iii) recognizes and reacts to users' and occupants' needs in terms of comfort, health, indoor air quality, safety as well as operational requirements." The most recent definition gaining attention is provided about the novel SRI, which rates the smart readiness of buildings in their capability to perform 3 key functionalities: (i) optimize energy efficiency and overall in-use performance; (ii) adapt their operation to the needs of the occupant; (ii) adapt to signals from the grid (for example energy flexibility). The 'smartness' of a building is thus related to "its ability to sense, interpret, communicate and actively respond in an efficient manner to changing conditions in relation to i) The operation of technical building systems, ii) The external environment (including energy grids) and ii) Demands from building occupants" [23].

This terminology shift may be due to more indicative trends in language and marketing rather than a significant evolution or improvement in the actual technology or infrastructure of the buildings, as the terms are used interchangeably. Both the IB and SB have similar traits and are difficult to distinguish. The term "Smart buildings" is becoming more popular, perhaps due to its modern appealing connotations rather than any substantial change in the building management systems themselves [24].

1.2. Related Smart readiness indicator studies

Up to date, only a few studies were done on applying the SRI to assess the smartness in buildings and likewise to show the actual applicability of the tool. Canale et al. [25] presented a detailed study of typical residential blocks in Italy and possible retrofit scenarios. The results show, at a national level, a smartness score that varies between 5 % and 27 %. Apostolopoulos et al. [26]showed an extended study of the application of SRI for retrofitting in five different climatic zones in Europe, considering single and multi-family houses. This work concludes that buildings constructed after the revised implementation of the EPBD in 2010 can increase their SRI score at a lower cost and more straightforward than older buildings, even when their current scores are low (0–20 %). In addition, the retrofit scenario where automation of HVAC is considered shows the most promising results, achieving scores up to 70 %. Moreover, Ramezani et al. [27] conducted a study that considers retrofit for non-residential buildings located in the Mediterranean climatic zone. They conclude that SRI can generally recognize the characteristics and properties of the buildings and their systems, but still needs to revise the weighting factors since they fail to show the actual energy performance. Additionally, retrofitting actions to improve energy efficiency and thermal comfort were studied for the buildings, indicating that the SRI score did not improve as was initially expected. Becchio et al. [28] present the SRI assessment in an energy center in Turin, Italy. Using energy simulation and digital models of the building, different retrofitting scenarios of energy management and control were conducted in order to evaluate their impact on the SRI score. The study performed by Horák et al. [29] in a group of residential and non-residential buildings in the Czech Republic highlights the simplified and good quality information about the technical systems, but it also reflects some of the issues SRI has. For example, it is not possible to properly consider two different heating sources, as well as some domains, such as "Health, well-being and accessibility", can easily reach the maximum score given the lack of included services. Similarly, Vigna et al. [30], using as a study case a nearly zero energy building (nZEB) office in Bolzano, Italy, concluded that the SRI methodology enables the comparison of different buildings when technologies are similar, but with the need for the SRI to improve the cases when different buildings and systems need to be compared. Additionally, they proposed that domains such as "Comfort" and "Health, well-being and accessibility" could be improved by adding tangible quantities such as "hours of comfort" or "CO_2 levels" to level up the interpretation of the results. Nevertheless, the authors propose including valuable information for stakeholders and grid operators in the SRI evaluation, as could be the yearly costs in the "Convenience" criterion or the flexibility potential in the "Energy flexibility and storage" criterion. Including a quantitative SRI was the focus of the study by Märzinger and Österreicher for smart buildings [31] and smart grids in general [32]. Here, it is proposed that the implementation of a quantitative approach to the SRI based on the load-shifting potential and the interaction with the grids (electrical, thermal, and natural gas) allows the quantitative and objectivity of the results since the current SRI relies on a subjective judgment of the assessor.

Considering educational buildings, Plienaitis et al. [33] show that the proposed case study located in Lithuania reached 26 % in the SRI score. Moreover, by modernizing the heating system and implementing cutting-edge engineering technologies, the SRI score can reach up to 67 %. Nevertheless, they conclude that implementing the SRI "as it is" cannot reach its maximum achievable score in buildings dependent on centralized district heating services since the retrofitting level, in most cases, is outside the stakeholders' boundaries. Accordingly, Martínez et al. [33] present a case study based in a university building in Zaragoza, Spain, where they remark on the potential of integrating Internet-of-thing (IoT) devices to meet the Sustainable Development Goals (SDG) using a key performance indicator (KPI), such as SRI.

Janhunen et al. [34] conducted a study on the applicability of SRI assessment in northern countries with cold climates. They found that while SRI was designed to be applicable across the EU, the unique conditions of northern countries, such as significant energy efficiency potential and different market-specific technologies, require methodological changes to the framework. However, it could serve as a baseline for developing country-specific frameworks.

While still in development and not officially adopted as a standard by UE, Fokaides et al. [35] outline some of the guidelines SRI should follow to be adopted. SRI's indicators should be integrated with other energy-efficient assessment processes and tuned explicitly to each building category, building up future minimum standards that can be adopted in new constructions.

A summary of the researched studies related to the SRI is presented in Table 1.

1.3. Related buildings' smartness studies in Norway

The definition of *smartness* according to Cambridge Dictionary states: *"the quality of being intelligent, or able to think quickly or intelligently in difficult situations"* [37]. However, as this definition is related to people, the authors propose to define smartness in the context of buildings as the level of smart technologies available, or how smart the building is in the degree of smartness. In Norway, only a handful of studies have investigated related smartness in buildings, using all the Smart by Powerhouse assessment [20]. Lien et al. [38] presented a study where the flexibility potential for eight non-residential buildings (offices, schools, warehouses, and sports halls) is estimated in Norway. One of the conclusions reached in the study is, besides the common belief of public opinion, the buildings represented in this study have a low level of smartness based on Smart by Powerhouse classification. The report shows that only the relatively new buildings show the minimum smartness levels (on a scale from 0 to 4), meaning that even if they have a proper control system able to provide comfort to the end user, it does not have an optimization algorithm capable of enhancing the operation of the building. Nevertheless, the oldest building presented negative scores, indicating no advanced control systems exist. In a more extensive study, Andersen et al. [39] interviewed digitalization and HVAC experts and stakeholders to understand the extension of the digitalization and smartness of building management system (BMS) in current buildings. The interviewed stakeholders' buildings comprised more than 15 million square meters, of which 5,000 were commercial buildings and 68 % counted with centralized systems. Using the Smart score, the study

Table 1
Summary of the SRI-related works.

Author	Year	Country	Climatic Region	Building type	Building usage	Buildings	Purpose
[25]	2021	Italy	Southern Europe	Residential	Multi-family houses and single-family houses	7	National-level benchmarking and retrofit scenarios
[26]	2022	Denmark, Czechia, Greece, Bulgaria, and Austria	North, North-East, South, South-East, and West Europe	Residential	Multi-family houses and single-family houses	10 (5 in each category)	Retrofitting scenarios
[27]	2021	Portugal	SouthernEurope	Non-residential	Educational	2	SRI benchmarking and retrofitting scenarios
[28]	2021	Italy	SouthernEurope	Non-residential	Educational	1	SRI benchmarking and retrofitting scenarios
[29]	2019	Czechia	North-Eastern Europe	Residential and non-residential	Multi-family houses, single-family houses, and educational	3	SRI benchmarking
[30]	2020	Italy	SouthernEurope	Non-residential	Offices	1	SRI benchmarking
[31,32]	2019–20	–	–	–	–	–	SRI improvements
[33]	2023	Lithuania	North-Eastern Europe	Non-residential	Educational	1	Retrofitting scenarios
[35]	2021	Spain	Southern Europe	Non-residential	Educational	3	Retrofitting scenarios
[34]	2019	Finland	Northern Europe	Non-residential	Educational and offices	3 (2 and 1)	SRI benchmarking
[36]	2020	Cyprus	Southern Europe	Non-residential	Educational	1	SRI Review, improvements, and study case

shows that 25 % of the studied buildings are classified as"smart ready" (level score 1)[20], while the rest present an automated or lower smartness levels. Additionally, the study identified the infrastructure, business models, data security, implementation, and users' physiological factors as the main barriers to the buildings' digitalization and smartness.

Further information on Smart by Powerhouse and its score system can be found in Section 3.1.

1.4. Contributions of this article

This work aims to present a novel framework to perform a joint assessment based on a comparative analysis of the smartness level of a portfolio of buildings complemented by an individual analysis to assess the smart readiness of each building. With this framework, the stakeholder or any interested party will be provided with an assessment tool that can smooth the digitalization process and level up the buildings' smartness. In this research, the Smart by Powerhouse assessment is utilized to evaluate the smartness level of buildings, given its widespread use in Norway while the SRI is used to determine the smart readiness of buildings.

While the SRI score is starting to expand its application in the EU, to the best of the authors' knowledge, it has not been applied in Norway, yet. Therefore, its implementation requires a consequential analysis to identify strengths and weaknesses, especially in highly electrified countries. Furthermore, this analysis will establish new guidelines for adapting the SRI to these new circumstances, by modifying the domain weights used in the score calculation. Oppositely, the Smart by Powerhouse assessment does not provide a quantification scale since it was designed to establish the ambition level of users and stakeholders. Thus, this work will propose a point-based system to label the smartness status to support its implementation to assess the smartness level of buildings in the framework.

The framework will be applied to evaluate ten non-residential buildings in Norway, which were selected based on their diversity of use and construction.

1.5. Article structure

After the introduction, the article is organized in the following manner. Section 2 shows the methodology followed in the development of this work. Here, are included case studies and the presentation of the joint framework with SRI and Smart by Powerhouse. Section 3 introduces the calculation methods of both assessments, as well as the proposed modifications utilized in this work. Section 4 shows the results of the individual assessments in the pilots, while Section 5 discusses the synergies of the proposed framework. Finally, conclusions and future works are expressed in Section 6.

2. Methodology

The current section presents the methodology conducted in this work. First, a description of case studies and the information supporting their choice is given. Next, the possible improvements that can be implemented in both assessments, the Smart by Powerhouse and SRI, are discussed. Finally, how the integration process will take place is explained.

2.1. Case studies

Ten large buildings in Ålesund, Norway, were selected to rate their Smart Readiness using the SRI assessment methodology and their Smartness using the Smart by Powerhouse framework [20]. The city's climate is temperate oceanic (CFB in the Köppen system), with mild temperatures throughout the year and regular rainfall. These buildings are part of a complex owned and managed by Ålesund Municipality, including municipal schools, care/health facilities, and one sports hall. The complex includes seven buildings that are part of the COLLECTiEF project [40]. The BMS provider correspond to the same actor in all the pilots. Information on the conditioned surface and year of construction is displayed in Table 2. The selected samples range in the gross conditioned floor area from 2,000 to 7,000 [m^2], and they represent a variety of construction ages, including buildings constructed around 1980, renovated buildings, new constructions, and constructions that are less than 20 years old. The table also reports the energy performance certificate of the buildings which is mandatory in Norway since 2010 for any building constructed, sold, or rented out [41]. The certification provides, in [kWh/m^2], the energy performance of the facility, where this can be rated in a scale between A and G, where *A* indicates a high efficiency and *G* indicates a low energy efficiency in the facility. With the implementation of the energy labeling, it is expected that the facilities built before the 2010 technical regulation are rated *C or lower,* while low energy buildings and passive houses are expected to be certified with *A* and *B* [42].

Various systems with different technologies and levels of smartness are offered by the diverse range of building categories, sizes, and ages

Table 2
Metadata of the sample buildings used for the SRI assessment.

Building	Description	
B01[a]	• ***Category:*** Care facility • ***Gross conditioned floor area:*** 7,038 [m^2] • ***Year of construction (renovation):*** 2017 • ***Energy Performance:*** “-“	
B02[a]	• ***Category:*** Sport building • ***Gross conditioned floor area:*** 2,516 [m^2] • ***Year of construction (renovation):*** 2015 • ***Energy Performance:*** “G”	
B03[a]	• ***Category:*** School • ***Gross conditioned floor area:*** 3,308 [m^2] • ***Year of construction (renovation):*** 1984 • ***Energy Performance:*** “G”	
B04[a]	• ***Category:*** Care facility • ***Gross conditioned floor area:*** 5,770 [m^2] • ***Year of construction (renovation):*** 2012 • ***Energy Performance:*** “B”	
B05[a]	• ***Category:*** Health center • ***Gross conditioned floor area:*** 2,580 [m^2] • ***Year of construction (renovation):*** 1979 • ***Energy Performance:*** “-”	
B06[a]	• ***Category:*** School • ***Gross conditioned floor area:*** 6,676 [m^2] • ***Year of construction (renovation):*** 2015 • ***Energy Performance:*** “-”	

(*continued on next page*)

Table 2 (*continued*)

Building	Description	
B07[a]	• ***Category:*** School • ***Gross conditioned floor area:*** 2,200 [m^2] • ***Year of construction (renovation):*** 1959 (2002) • ***Energy Performance:*** "-"	
B08[b]	• ***Category:*** School • ***Gross conditioned floor area:*** 5,153 [m^2] • ***Year of construction (renovation):*** 2006 • ***Energy Performance:*** "D"	
B09[b]	• ***Category:*** School • ***Gross conditioned floor area:*** 3,514 [m^2] • ***Year of construction (renovation):*** 2007 • ***Energy Performance:*** "D"	
B10[c]	• ***Category:*** School • ***Gross conditioned floor area:*** 3,156 [m^2] • ***Year of construction (renovation):*** 2022 • ***Energy Performance:*** "-"	

[a] Picture retrieved online from: COLLECTiEF. (n.d.). Alesund, Norway | COLLECTiEF. Retrieved April 15, 2024, from https://collectief-project.eu/pilots/alesund-norway.

[b] Picture retrieved online from: EMSystemer. (2023, October 18). Forside | Tilbyr moderne egenutviklede SD-anlegg - EM Systemer. EM Systemer. Retrieved April 15, 2024, from https://emsystemer.no/.

[c] Picture retrieved online from: Ålesund kommune. (n.d.). Skole og SFO - Ålesund kommune. Retrieved April 15, 2024, from https://alesund.kommune.no/kommunen/alle-einingar/kommunalomrade-oppvekst/skole-og-sfo/.

used in these case studies, providing a wide understanding of the application of SRI. The description of the technical systems in each pilot is presented in Appendix A: Buildings' technical information. Considering the heating systems, in Norway there is a tendency to use electric equipment, which includes air/water-to-water heat pumps (HPs) in relatively new constructions (B01, B02, and B04), electric boilers for older ones (B03 and B09), and, in some cases, stand-alone electric radiators and radiative floor systems (B05, B07, and B08). Additionally, two of the recently constructed buildings (B06 and B10) are connected to district heating services. However, it is common practice to use centralized equipment with air handling units (AHU) to deliver heating and cooling services to zones at a neutral temperature while controlling the desired indoor temperature through decentralized electrical equipment. Overall, the presence of AHU provides heat recovery and 100 % external air, while air by-pass is present in some cases. Modern buildings, such as B01, B02, B04, B06, B08 and B10, include CO_2 concentration measurements in some spaces to regulate the airflow supply with Variable Air Volume (VAV) and Constant Air Volume (CAV) dampers. Given the mild temperatures of the zones, the cooling requirements are not as large enough as in Mediterranean countries; thus, its application is dedicated, in this case, to only the care and health center facilities. Nevertheless, a frequent practice in buildings with water-to-water heat pumps (B01 and B02) is"free-cooling" by pumping water from the boreholes to the cooling coil in AHU. Regarding domestic hot water (DHW), most buildings use centralized equipment directly connected to the heating circuit and one or more storage with electric coils and thermostatic valves to control the supply temperature. The centralized systems have as a common characteristic the presence of on/off pumps and fans, whose behavior is conducted by calendars and indoor temperature setpoints. However, the thermostatic valves and the temperature setpoints for the generation equipment are based on an outdoor climatic curve. Building B01 is the only facility where one-way electric vehicle charging (EVC) and photovoltaic (PV) systems without storage are available. However, the building's control systems do not possess optimal control to grid flexibility. The only possible action the BMS provides is the random load curtailment to avoid the maximum energy consumed in one hour. Regarding the lighting system, an automatic detection system can be found in newer buildings (B01, B02, B06, B10). Complementary, manual lighting systems without dimming are present in the older facilities. Only building B08 has a dynamic building envelope with on/off control and presence in the centralized BMS system. Accordingly, the BMS presents a corrective fault detection and alarm system that is only accessible by the stakeholder and does not include any predicting algorithm. Finally, the smart electric meters and energy counters dataflows, as well as setpoints, calendars, and indoor setpoints are available for the stakeholder through the BMS provider's webpage. At the same time, the historical metered electricity usage can be found on a third-party website for all the buildings. Nevertheless, no access to smart meter data is provided for buildings' users.

It is noteworthy to mention that the information compiled for the assessment of the pilots was done with on-place visits with the energy manager to the pilots and by gathering technical information of the systems from documentation and a constant interaction with the BMS provider and building manager. The assessment was carried out mainly by the author with initials IACA but supported by information gathered previously by the authors AM, SE, and MA.

2.2. Assessment implementations and a new framework definition

In the current work, two assessments were conducted: the first targeted to calculate the buildings' smartness through the Smart by Powerhouse scheme and the second one to rate the smart readiness of the buildings, following the procedure outlined by the Smart Readiness Indicator. These assessments are selected due to the complementary qualities that allow them to be implemented as a joint assessment to provide valuable knowledge regarding the smartification level in one or more buildings.

The Smart by Powerhouse scheme was born as a tailor-made tool for the Norwegian commercial building stock. However, its implementation can be extended to other categories of non-residential buildings due to its general assessment procedure that is independent of the buildings' usage. The advantage of its implementation is that it allows horizontal measuring of the smartness in buildings, making the comparison of the smart status of a portfolio of buildings possible. On the contrary, the SRI was developed to measure the smart readiness of individual buildings and, therefore, it shows only the capabilities of the building to improve its own smart readiness. By doing the assessment separately, a stakeholder with multiple assets cannot easily define which building should be improved or if the improvement made has a tangible impact on the overall smartness of the assets. Therefore, when the objective is improving the overall smartness of the portfolio of buildings, the implementation of SRI and the Smart by Powerhouse can help to define if the smartification of a system in a building will improve within its own capacities, and if the selected asset was chosen correctly compared with other assets from same portfolio.

Some modifications must first be made to apply both assessments under the new framework. In the case of the Smart by Powerhouse, it does not include a scoring system to quantify the overall smartness level of the building, but it provides the level for each functionality level defined in the assessment individually. In addition, the assessment also assumes that the building possesses at least some level of automation. Therefore, modifications in the level of smartness will be added to assess older buildings or buildings that do not include a BMS. For the SRI, extended modifications are needed. The large adoption of electric-based heating in the country, as well as the penetration of EVC, shows the need first to observe if the existing calculation methodology of the assessment is correctly adapted to the Norwegian context or if changes in weights' definition need to be applied in order to be considered a tool that can represent the particular characteristics of the country.

Finally, based on the proposed modifications, the assessments will be deployed in the portfolio of buildings presented in the case study section. An overview of the applied methodology is shown in Fig. 1.

3. Assessment calculation methods

The methodology for applying the Smart by Powerhouse and the Smart Readiness Indicator assessment are presented in this section.

3.1. Smart by Powerhouse

Smart by Powerhouse was created as an interpretable tool for designing, communicating, and developing smart commercial buildings while considering mainly the effect of the digitalization and smartification process on users' comfort and stakeholders' perspectives, values, and ambitions.

Five different domains are assessed with Smart by Powerhouse: "Enabling technologies", "Indoor climate and working environments", "Energy and resource utilization", "Safety, security and reliability", and "Adaptivity". Each domain possesses different requirements of specific functions or operations that meaningfully complement the functioning of the domains. These requirements are then called "functionality levels". In total, there are twenty-nine different functionality levels covered under these topics. The number of functionality levels applicable to the case studies analyzed in this article is thirteen. They are distributed under the domains as reported in Table 3.

Table 3
Domains, the total number of functionality levels, and the applicable functionality levels present in the Smart by Powerhouse assessment for the study cases.

Domains	*Total*	*Applicable to the study cases*
Enabling technologies	9	4
Indoor climate and working environment	5	3
Energy and resource utilization	5	4
Safety, security and reliability	7	2
Adaptivity	3	0

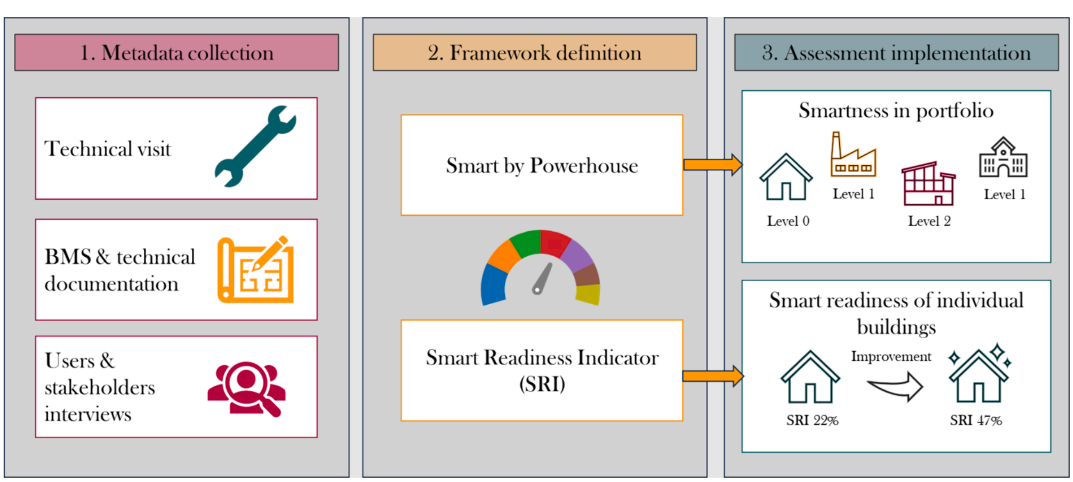

Fig. 1. Assessment methodology for the proposed framework.

Five ambition levels of smartness can be chosen when selecting a functionality level. An explanation for each level is provided in the next section:

- ***Level 0 – Automatized***: The buildings are built under the regulatory frame and contain the minimum level of automatization.
- ***Level 1 – Smart ready***: The necessary technical infrastructure exists to improve the smartness of the buildings, as well as the required communication protocols and access to data to simplify the operation of the systems.
- ***Level 2 – Smart standard***: Buildings can interact with users to provide guidance and to identify usage patterns. Open APIs are expected to improve the data-sharing process.
- ***Level 3 – Smart predictive***: Buildings can adapt their loads and working patterns based on data-driven forecasting based on the availability of different sensors.
- ***Level 4 – Smart cognitive***: The operation and management of the building are based on self-learning mechanisms supported by machine learning and active data flows. Additionally, the facilities should be capable of interacting within the neighborhood and surrounding spaces.

The requirements to select one or another ambition level are also defined specifically for each domain. By its definition, the assessment establishes that the building under evaluation has a minimum automatization level of the systems; thus, to extend its applicability, two additional ambition levels defined by Andersen et al. [39] are added in this work:

- ***Level −2 – No technological equipment***: Buildings built before 1980 with little or no renovation, no integration of technical systems and no monitoring. Additionally, there is no automatic interaction of the systems with the users.
- ***Level −1 – Pre-automated***: Buildings built after 1980, including renovation and upgrading. Exists separate control for different technical systems, but no interaction between them.

Smart by Powerhouse does not define a scoring strategy since it is considered as a tool to define the ambition in the design/renovation process more than an assessment tool. Nevertheless, the characteristic of the tool allows its implementation as an assessment scheme of the smartness and digitalization level of the building by proposing a point-based scoring system to give an overall score based on the predefined seven ambition levels. The calculation methodology is explained in the following point:

The domains and functionality levels are specified if they apply to the assessment. If not, no points will be assigned and will not be considered in the calculation process.

(1) For each functionality level, an incremental point system based on the ambition level associated with that functionality level is established. The lowest ambition level (−2) receives one point, while the maximum level (4) receives seven points, incrementing gradually by one point in each intermediate level.
(2) Next, the points assigned at each functionality level are grouped by sum in each domain and then weighted based on the available functionality level per topic.
(3) The final point of the building is the sum of the five domains' scores, and the ambition level of the building based on the weight points is presented in Table 4. In the current assessment, thirteen of the twenty-nine functionality levels are applied in the scope of this work. The selection of the functionality levels is decided based on the similarity of the information compiled for the SRI assessment of the buildings.
(4) The ambition level of the building is calculated as follows:

Table 4
Ambition level score of the building considering total and applicable functionality levels.

Level name	Level	Total point range	Applicable point range in this study[a]
No technological equipment	−2	29–43	13–19
Pre-automated	−1	44–72	20–32
Automated	0	73–10	33–45
Smart ready	1	102–130	46–58
Smart standard	2	131–159	59–71
Smart predictive	3	160–188	72–84
Smart cognitive	4	189–203	85–91

[a] The present implementation of the *Smart by Powerhouse* assessment is done in the current portfolio of building considering only the information compiled for the SRI assessment. Therefore, the applicable functionality levels are reduced from 29 to 13.

$$y = \frac{(x - x_{min})}{(x_{max} - x_{min})} \cdot (y_{max} - y_{min}) + y_{min} \quad (1)$$

where x corresponds to the calculated points, x_{min} and x_{max} are the minimum and maximum achievable points in the assessment, and y_{min} and y_{max} are the minimum (−2, "No technological equipment") and maximum (4, "Smart cognitive") achievable levels in the assessment.

3.2. Smart readiness indicator (SRI)

The present section provides an overview of the Smart readiness indicator scheme, including the assessment methodology, weights and score definitions, and the proposed modifications for its implementation in the Norwegian context.

3.2.1. Assessment methodology

The SRI assessment includes a list of fifty-four smart services that can be applied to a building. These services fall under nine categories representing the systems that can apply to a building. Table 5 displays the categories and the number of services available in each of them.

The SRI assessment starts by defining the metadata of the building, including typology, built surface, year of construction/renovation, and localization. Among these parameters, the localization of the buildings plays a crucial role in the calculations since it directly influences the predefined energetic weights. The building category, the built surface, and the year of construction/renovation do not affect the final calculations in the current SRI spreadsheet (V4.5) [43].

The SRI allows selecting between three preferred services catalogs: (1) catalog A, (2) catalog B, and (3) catalog C. Catalogue A corresponds to a simplified version of the services (27 instead of 54), allowing a more straightforward but simplified assessment of the building, and it is mostly applied in residential buildings. Catalog B uses all the possible services, and its application requires a longer assessment time and more technical knowledge. Finally, Catalog C is presented as a customizable version of the SRI assessment, allowing the inclusion or removal of

Table 5
Domains and the number of services currently present in the SRI assessment.

Code	Domain	Services
H	*Heating*	10
DHW	*Domestic hot water*	5
C	*Cooling*	10
V	*Ventilation*	6
L	*Lighting*	2
DBE	*Dynamic building envelope*	3
E	*Electricity*	7
EVC	*Electric vehicle charging*	3
MC	*Monitoring and control*	8

services in the function of the scope defined by the assessor. Catalog B is utilized in the scope of this study.

Next, the presence of the technical domains or the need for the presence of the technical domain should be specified to include the weights of their services in the SRI calculation process. Once the technical domains are selected, the presence or need for a service must be indicated. For each selected service, the functionality or smartness level is specified, varying in most cases between 0 and 4, where 0 represents no smartness and four indicates the maximum achievable smartness in the service. The functionality level can contain a maximum of two shared smartness levels, that are defined by a complementary fraction. Otherwise, the fraction remains 100 % if the functionality level considers only one smartness level. The SRI score is determined by calculating the weighted sum of the aggregated scores for "Building", "User", and "Grid" (as shown in Fig. 2). The "Building" score represents how well the building optimizes its energy efficiency and overall performance. The "User" score establishes the capacities of the building to adapt its operation to the users' needs. The "Grid" aggregated score reflects the ability of the building to interact with the grid (energy flexibility). As a previous step for calculating the SRI and Aggregated scores, the assessment defines seven impact criteria that represent in a more detailed manner the various aspects that define a smart building. The building score combines the "Energy Efficiency (EE)" and "Maintenance and Fault Prediction (M&FP)" impact scores. In contrast, the User score is a combination of the "Convenience", "Comfort", "Health, Well-being and Accessibility (HW&A)" and "Information to occupants" impact scores. The Grid score only considers the "Energy Flexibility and Storage (EF&S)" impact score.

Finally, the level of smartness of a building or SRI score is defined on a scale between 0 % and 100 %, where 0 % means that the building is not smart-ready. In comparison, 100 % implies that the building has achieved its maximum smartness potential. The defined ranges used to classify the SRI score, as well as the aggregated scores, are presented in Fig. 3.

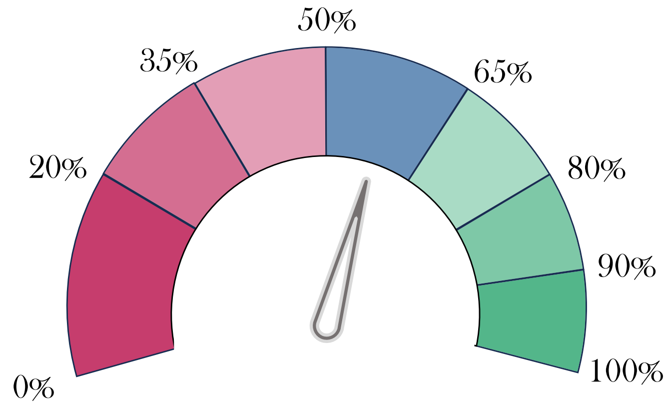

Fig. 3. Levels of smartness defined by the SRI score and aggregated scores. 100% indicates the highest smartness level, and 0% indicates no smartness in the building.

3.2.2. *Weighting factors definition*

The SRI assessment uses three types of weights related to technical domains and impact criteria for defining the smart readiness of the assets: fixed weights, equal weights, and energy balance weights. The energy balance weights are established by defining the major geographical area (e.g., Northen Europe), and differencing between residential and non-residential buildings, while the fixed and equal weights do not change based on these conditions. The approach for calculating the energy balance weights takes into account the annual energy consumption of each domain. However, in the current SRI, there is a lack of specific information on the energy usage of different building categories in European countries. This led to grouping the weights in larger geographical areas and not breaking down the buildings into subcategories. Therefore, in this study, precise information on energy usage for the categories that the pilots fall into is considered. Moreover, a more specific calculation of the weighting factors is included, with a focus on Norway (as shown in Fig. 4).

Once the location and the categories of buildings utilized in this work are established, the next step is to define the new weights in correspondence with these conditions. In addition, a new weighting method for the impact EF&S is proposed to consider the power impact of the assets in the grid. With this, is expected to provide a more accurate representation of the building's flexibility considering that the presence of EVC, distributed generation (DG), and HVAC systems can cause grid congestion when the load is not correctly managed. A graphical explanation of the main changes in the weighting factor calculation is presented in Fig. 5.

In the following subsection, first, the current weighting calculation methodology is explained. Next, the proposed changes and the new calculation methodology are presented.

3.2.2.1. Current SRI weighting factors calculation methodology. Three types of weight factors (*f*) are defined in the "Assessment Package: Practical Guide SRI Calculation Framework V4.5″ [43]: fixed weights, equal weights, and energy balance weights. The fixed weights and the equal weights are not dependent on the geographical location of the building as well as the building type. Nevertheless, the SRI technical department recommends not changing these values when alternative weighting factors are used for the SRI assessment.

Starting with fixed weights established in the practical guide [43], all impact criteria in MC domain are assigned a fixed weight value of 20 %. Additionally, EE and M&FP are given 5 % fixed weight value each in the "dynamic building envelope" domain. Lastly, EVC domain is assigned a weight of 5 % for its impact on "energy flexibility and storage.".

Next, the impact criteria of "comfort", "convenience", "health, wellbeing and accessibility", and "information for occupants" are given equal weight through the following equation:

$$f_{domain,impact} = \frac{\left(1 - f_{MC,impact}\right)}{relevant\ domains} \tag{2}$$

Where the "relevant domains" refers to the number of domains where a

Fig. 2. Aggregated and impact classes.

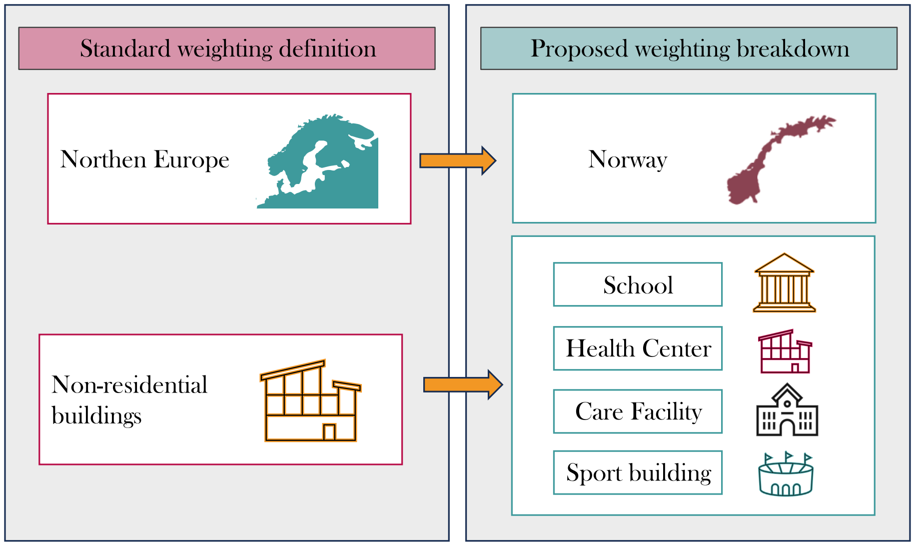

Fig. 4. Proposed adaptation of the weighting factors for the SRI assessment considering the local conditions of energy use and variance in the non-residential building categories.

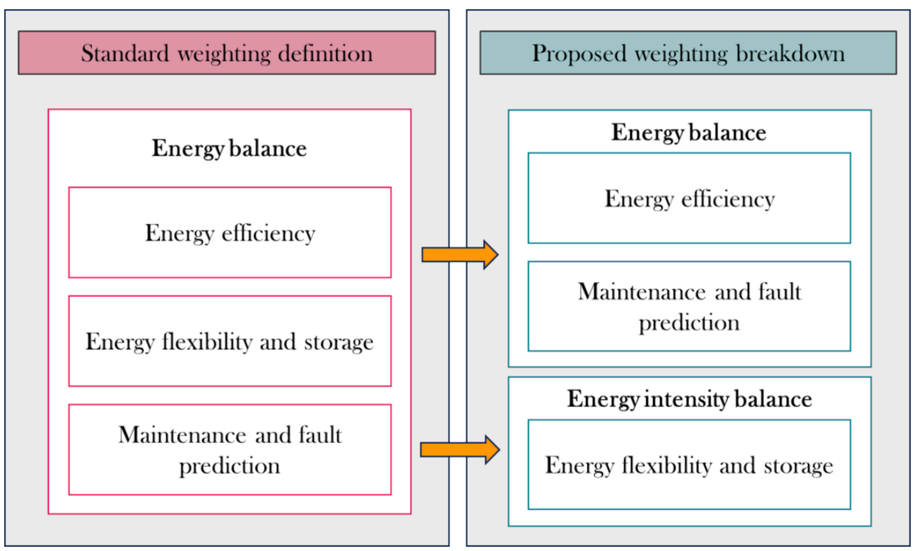

Fig. 5. Proposed changes in the energy balance weighting factors.

weighting factor needs to be calculated, while "impact" refers to the target impact criteria.

When it comes to building type and location, which for this work is based on North Europe, the estimation of energy balance weights is the main point of differentiation. These weights are assigned to impact criteria such as EE, MC, and EF&S in domains where they were not previously assigned. The calculation of energy balance weights is done using the following equation:

$$f_{domain,impact} = \alpha_{impact} \cdot \left(1 - f_{DBE,impacts} - f_{EVC,impacts} - f_{MC,impacts}\right) \quad (3)$$

Nonetheless, the $\alpha_{domain,impact}$ factor depends directly on an energy balance based on the location and typology of the building.

In first instance, the SRI technical department considered the yearly primary energy usage in the domains "heating", "domestic hot water", "cooling", "ventilation", "lighting" and "renewable energy produced onsite (RES)" (RES is directly utilized to calculate the weight factor for the "electricity" domain) based on the data provided by the EU Building Stock Observatory (BSO). The energy balance can be expressed in the following manner:

$$Q_{total} = Q_{heating} + Q_{DHW} + Q_{cooling} + Q_{ventilation} + Q_{lighting} + Q_{RES} \quad (4)$$

However, the gathered information for the SRI is limited to "heating space", "cooling space", "water heating", and "lighting". Hence, the primary use of heating and ventilation was estimated based on transmission and ventilation loss coefficient assumed by geographical location. Additionally, the break-down per building usage and country is not completely done, limiting in this way the calculation of the energy factors based on grouped larger geographical locations (north, west, south, north-east, and south-east of Europe) and the building types "residential" and "non-residential". Then, the $\alpha_{domain,impact}$ factor is calculated using the following equation:

$$\alpha_{domain,impact} = \frac{\sum \delta_{domain} \cdot Q_{domain}}{Q_{total}} \quad (5)$$

Where δ corresponds to a binary variable that indicates if the referred domain is part ($\delta_{domain} = 1$) is considered in the impact, of it is not

($\delta_{domain} = 0$).

This work presents the utilized α factors and the weights for non-residential buildings in Norway (northern Europe) in Table 6 and Table 7, respectively.

3.2.2.2. Proposed changes in SRI weighting factors calculation methodology. When considering digitalization and smartness assessment, comparing Norway to other northern European nations such as Denmark, Sweden, and others may need to be reconsidered. Accordingly, Janhunen et al. [34] remark that the SRI is inappropriate for measuring the smart readiness in a building in cold-climate countries. For instance, the degree of digitalization incorporating market-present technologies in the countries mentioned, like district heating, which accounts for over 50 % of heating production [44], is not influenced by building stakeholders but rather by the district manager. As a result, the authors highlight the impossibility of evaluating these outcomes using the SRI assessment. However, this statement is given from a regional point of view that differs from the Norwegian context, in which the generation is primarily on-site and highly electrified [45]. Some other differences exist on the generation side. Norway and Sweden are based mostly on programmable hydroelectric generation, while Denmark and Finland produce their electricity mainly by wind and nuclear power, respectively [11,46]. For instance, these variations can affect the significance and flexibility of the grid interaction before computing the weighting factors.

In addition, is also essential to consider how governmental policies can re-shape the needs while assessing the smartness in buildings. Since the beginning of the 1990 s, the Norwegian government is offering incentives for buying and using hybrid and electric cars [47,48,49,50]. The decision aligns with the National Transport Plan 2018–2029 [48], which aims to achieve net-zero emissions in new sales of passenger cars and light vehicles by 2025. This goal is reaffirmed in the current National Transport Plan 2022–2033 [49]. These incentives have resulted in exponential growth since the new incentives were established in 2012 [51], with a current stock (June 2023) of 872,623 units (28.48 % of the total vehicle stock) [52] and an expected increase to 1.5 million units by 2030 [53]. Nowadays, in Norway, electric vehicles account for 88 % of new car sales, making the country a leader in adopting new electric cars [54]. These statistics significantly affect the energy use and grid interaction of the buildings where these electric vehicles are parked. A study conducted by Flataker et al. [55] reveals that 90 % of electric vehicle owners charge their cars at home several times a week. On the other hand, only 16 % charge their vehicles at their workplace at least once a week.

To accurately assess the SRI of Norwegian buildings, three key changes are proposed to adjust the calculation weight based on the previously provided information.

Following the same methodology expressed by the SRI Guidelines, the first modification consists of using the information regarding the primary energy use in non-residential Norwegian buildings for calculating the weight factors, which is gathered from the document "Analyse av energibruk i yrkesbygg" (in English: Analysis of energy use in commercial buildings) [56], developed by the Norwegian Water Resources and Energy Directorate (NVE acronym in Norwegian). Here, the primary energy use for non-residential buildings is broken down by the different typologies of the buildings and for six energy uses: heating, domestic heat water, ventilation, lighting, cooling, and other internal electrical loads. Since the heating, cooling, and ventilation loads are given separately in the NVE statistics [56], there is no need to disaggregate the ventilation from heating and cooling loads, as it is performed in the SRI calculation framework [43]. The energy generated on-site is obtained from the NVE statistics [57], representing the average yearly use of the last three years. However, the on-site generation is not given by building category; thus, the fraction of on-site generation is assigned based on the fraction of the total built area per building category [58].

The second proposed modification includes the internal loads for calculating the energy balance in the "electricity" domain, given the possibilities of using them to provide energy efficiency and demand-side flexibility measures. This modification can gain importance in the service "Support of (micro) grid operation modes" (E-8). Then, the energy balance can be expressed as follows:

$$Q_{electricity} = Q_{internalloads} + Q_{RES} \tag{6}$$

$$Q_{total} = Q_{heating} + Q_{DHW} + Q_{cooling} + Q_{ventilation} + Q_{lighting} + Q_{electricity} \tag{7}$$

The annual average primary energy use and the α factor for the non-residential category investigated in the paper are presented in Table 8.

As presented in Table 7, EVC is included in the SRI assessment as equal or fixed weights. Therefore, this strategy does not allow the SRI score to differentiate and observe the impact that EVC can have in countries with a more considerable number of electric vehicles (EVs), such as the Netherlands, Sweden, and, specifically, Norway. Additionally, its inclusion in the energy balance weight is unsuitable given the larger annual energy requirement that domains such as heating will use in comparison with EVC. Hence, EVC's impact should be seen from a "power" perspective since the load is focused on specific hours, producing grid congestion and power peaks if the charging process is not "smart" enough. Accordingly, the EF&S weights are calculated using a power balance based on the average hourly energy use [kWh/h/m^2], as presented in the following equation:

$$\overline{Q_{total}} = \overline{Q_{heating}} + \overline{Q_{DHW}} + \overline{Q_{cooling}} + \overline{Q_{electricity}} + \overline{Q_{EVC}} \tag{8}$$

For the purposes of this work, the average hourly energy is used as a measure of power since it is the smallest metering frequency that can be obtained from the literature, and it can be calculated using the subsequent formulation for the heating, DHW, cooling, and electricity domains.

$$\overline{Q_{domain}} = \frac{Q_{domain}\left[\frac{kWh}{m^2 \cdot year}\right]}{\mathrm{WH}\left[\frac{h}{year}\right]} \tag{9}$$

For a more accurate estimation, the average hourly energy is calculated considering the average yearly working hours (WH) [59] per building category.

The average hourly energy of the EVC needs to be determined by factoring in the current number of EVs, the percentage that are charged at work (15 %, according to reference [53]), and the expected minimum standard size of electric vehicle chargers (7.2 [kW], according to reference [60]). To distribute the EV stock proportionally among the different building categories, the ratio ($r_{surface}$) between the building surface and the total surface of non-residential buildings in Norway [58] is used. The proposed equation is shown next.

$$\overline{Q}_{EVC} = \%charge\ at\ work \cdot EVstock \cdot P_{charger} \cdot r_{surface} \tag{10}$$

Then, the average hourly energy balance leads to the calculation of a β factor related to EF&S impact, which is calculated similarly to the energy balance:

$$\beta_{domain,EF\&S} = \frac{\sum \delta \cdot \overline{Q_{domain}}}{\overline{Q_{total}}} \tag{11}$$

Next, the corresponding weight factors for the EF&S impact are calculated using the next equation, and the results are displayed in Table 9.

Table 6
α factors used in the SRI assessment for non-residential buildings in north Europe and selected methodology B.

Domain	*Heating*	*DHW*	*Cooling*	*Ventilation*	*Lighting*	*Electricity*
α	0.42	0.07	0.12	0.26	0.10	0.02

Table 7
Current domain weights for the SRI assessment for non-residential buildings in Norway and selected methodology B. In green are presented the fixed weights, in orange are given the equal weights, and in blue are shown the energy balance weights.

Domains \ Impacts	Energy efficiency	Energy flexibility and storage	Comfort	Convenience	Health, well-being and accessibility	Maintenance and fault prediction	Information to occupants
Heating	31.3 %	49.4 %	16.0 %	10.0 %	16.0 %	35.0 %	11.4 %
Domestic hot water	5.4 %	8.5 %	-	10.0 %	0.0 %	6.0 %	11.4 %
Cooling	9.4 %	14.8 %	16.0 %	10.0 %	16.0 %	10.5 %	11.4 %
Ventilation	19.6 %	-	16.0 %	10.0 %	16.0 %	21.9 %	11.4 %
Lighting	7.8 %	-	16.0 %	10.0 %	16.0 %	-	-
Electricity	1.5 %	2.4 %	-	10.0 %	-	1.7 %	11.4 %
Dynamic building envelope	5.0 %	-	16.0 %	10.0 %	16.0 %	5.0 %	11.4 %
Electric vehicle charging	-	5.0 %	-	10.0 %	-	-	11.4 %
Monitoring and control	20.0 %	20.0 %	20.0 %	20.0 %	20.0 %	20.0 %	20.0 %

Table 8
Average primary energy and α factor detailed by domain for Norway's four non-residential buildings categories. The calculation of the α_{EE} factor considers the six domains presented in table, while $\alpha_{M\&FP}$ does not considers the "Lighting" domain.

Category	Item \ Domain	Heating	DHW	Ventilation	Lighting	Electricity	Cooling	Total
School	Primary energy Q [kWh/year/m^2]	99	6	13	26	27	0	*171*
	$\alpha_{domain,EE}$	0.58	0.04	0.08	0.15	0.16	0.00	*1.00*
	$\alpha_{domain,M\&FP}$	0.68	0.04	0.09	0.00	0.19	0.00	*1.00*
Health center	Primary energy Q [kWh/year/m^2]	125	32	34	60	77	52	*380*
	$\alpha_{domain,EE}$	0.33	0.08	0.09	0.16	0.20	0.14	*1.00*
	$\alpha_{domain,M\&FP}$	0.39	0.10	0.11	0.00	0.24	0.16	*1.00*
Care facility	Primary energy Q [kWh/year/m^2]	136	26	31	27	39	1	*260*
	$\alpha_{domain,EE}$	0.52	0.10	0.12	0.10	0.15	0.00	*1.00*
	$\alpha_{domain,M\&FP}$	0.58	0.11	0.13	0.00	0.17	0.00	*1.00*
Sport building	Primary energy Q [kWh/year/m^2]	85	24	32	35	37	23	*236*
	$\alpha_{domain,EE}$	0.52	0.10	0.12	0.10	0.15	0.00	*1.00*
	$\alpha_{domain,M\&FP}$	0.58	0.11	0.13	0.00	0.17	0.00	*1.00*

Table 9
Total built surface (m^2) at country level by category and in parenthesis the ratio compared with all the non-residential buildings' surface, average working hours (h/year), average hourly energy [GWh/h] and β factor detailed by domain for four categories of non-residential buildings in Norway.

Category	Total surface [m^2]	Working hours [h/year]	Item \ Domain	Heating	DHW	Electricity	Cooling	EV	Total
School	253 818 (5.5 %)	3 030	$\overline{Q}$[kWh/h/m^2]	0.03	0.00	0.01	0.00	0.05	*0.10*
			$\beta_{domain,EF\&S}$	0.34	0.02	0.09	0.00	0.55	*1.00*
Health center	90 504 (2.0 %)	7 373	$\overline{Q}$[kWh/h/m^2]	0.02	0.00	0.01	0.01	0.02	*0.06*
			$\beta_{domain,EF\&S}$	0.30	0.08	0.18	0.12	0.32	*1.00*
Care facility	54 162 (1.2 %)	7 373	$\overline{Q}$[kWh/h/m^2]	0.02	0.00	0.00	0.00	0.01	*0.04*
			$\beta_{domain,EF\&S}$	0.50	0.08	0.12	0.00	0.30	*1.00*
Sport building	142 746 (3.1 %)	3 760	$\overline{Q}$[kWh/h/m^2]	0.02	0.01	0.01	0.01	0.03	*0.07*
			$\beta_{domain,EF\&S}$	0.30	0.09	0.13	0.08	0.39	*1.00*

$$f_{domain,EF\&S} = \left(1 - f_{MC,EF\&S}\right) \cdot \beta_{domain,EF\&S} \tag{11}$$

Finally, the final weights utilized for the SRI estimation for the "School", "Health facility", "Care facility" and "Sport building" categories of non-residential buildings are shown in Table 10. Moreover, the calculated weights only present modifications in EE, M&FP, and EF&S impact categories.

4. Results

This section presents and discusses the results of implementing the Smart by Powerhouse and the SRI assessment in the ten Norwegian pilots. As previously mentioned, both assessments are deployed due to their complementary behavior to measure the smartness and the smart readiness of the buildings, respectively.

4.0.1. Smart by Powerhouse assessment

The “Smart by Powerhouse” assessment utilized twenty-nine functionality levels and four domains complementary to the SRI assessment. The characteristics of “Smart” match well with its implementation in a group of buildings from the same stakeholder and BMS provider, which is the case of the portfolio of buildings from this study. In Table 11 are presented the results of the assessment.

Based on the assumption previously made, the buildings being part of the same stakeholder and BMS provider will likely have similar overall results since the present technologies of the systems and control are related. For this research, in all the cases, the maximum achievable points were ninety-one, while the group of buildings obtained between 0.38 and 0.62, representing the inflection point between an automatized (level 0) and a smart ready (level 1) building. These results are in accordance with the study carried out by Andersen et al. [39], where only 25 % of the studied sample of Norwegian building stock achieved level 1. In contrast, the others were level 0 or below, supporting the fact that the Norwegian building stock possesses a high level of digitalization but still needs to boost its smart capabilities.

From the buildings that obtained higher scores, B01 and B04 share that both are relatively new care facilities with partially implemented CO_2 control for ventilation. The main differences are in the “Indoor environment and work environment” and “Energy and resource utilization”. First, all the building’s setpoints are based on calendars and climatic curves for valves and HVAC systems, making the only difference in the presence of CO_2 sensors for ventilation control. In the case of “Energy and resource utilization”, the flexibility provided by RES in B01 and the energy performance labeling of the buildings represent the inflection point. For “Enabling technologies,” it is observable that the ten buildings have obtained the same results, meaning that the integration of the control systems, the access to data, and the maturity of the digital twin are technically equivalent; thus, an improvement in this section can be implemented in the entire portfolio. Similarly, the domain “Safety and reliability” shows comparable results in the portfolio, with strengths in the deployed maintenance and alert system. The lowest overall scores are observed in buildings B03, B05 and B07, which are the oldest building stock in the portfolio, with the lowest or no present energy assessment that induce to a lower score, automated (level 0), in “Energy and resource utilization”, compared with other buildings. In addition, presence of manual lighting decreased the score, near to pre-automated (level −1), in “Indoor environment and work environment”.

4.0.2. SRI assessment results

The present section provides the results of the smart readiness indicator’s assessment for ten sample buildings in Ålesund, Norway. Overall, the carried-out assessment corresponds to its first application in Norway, and it is expected to provide a first evaluation of buildings in a highly electrified region. SRI is applied in this context to showcase its versatility in adapting to the changing conditions that are likely to emerge throughout Europe. This is crucial as the shift towards clean energy is heavily reliant on electrification.

The proposed SRI has modifications in the calculation weights to first differentiate between general non-residential building and the broken-down sub-categories and, secondly, to adapt its application into the Norwegian context. This differentiation can make a difference in the energetic behavior from other Nordic countries such as Denmark and Finland since in Norway exists a large adoption of EV and the primary energy source is mainly based on distributed electricity rather than district heating. Therefore, the main domain weight changes are done in the impact scores that are calculated based on energy balance and the fixed score related to the EVC domain in the impact EF&S, leaving the other fixed and equal domain weights out of the scope of this work. The impacts that are modified correspond to EE, EF&S, and M&FP. Nevertheless, the impact weights were not changed. Next, considering the Northern European context, even when the energy usage could be similar among the different countries due to the cold climate, distributed heating generation, and the quota of EVC that are present privately and publicly in Norway makes the necessity of shifting the calculation approach for the EF&S from an energy-based to an power-based calculation, primarily due to the reason that EVC has a disruptive and

Table 10
Proposed domain weights for the SRI assessment for four non-residential building categories in Norway and selected methodology B. In green are presented the fixed weights, in blue are shown the energy balance weights, and in yellow are presented the average hourly energy weights.

Domains \ Impacts	Energy efficiency	Energy flexibility and storage	Maintenance and fault prediction	Energy efficiency	Energy flexibility and storage	Maintenance and fault prediction
	School			***Health facility***		
Heating	43.5 %	27.3 %	51.3 %	24.7 %	23.6 %	29.3 %
Domestic hot water	2.6 %	1.7 %	3.1 %	6.3 %	6.0 %	7.5 %
Cooling	0.0 %	0.0 %	0.0 %	10.3 %	9.8 %	12.2 %
Ventilation	5.7 %	-	6.7 %	6.7 %	-	8.0 %
Lighting	11.4 %	-	-	11.8 %	-	-
Electricity	11.8 %	7.4 %	13.9 %	15.2 %	14.6 %	18.1 %
Dynamic building envelope	5.0 %	-	5.0 %	5.0 %	-	5.0 %
Electric vehicle charging	-	43.6 %	-	-	25.9 %	-
Monitoring and control	20.0 %	20.0 %	20.0 %	20.0 %	20.0 %	20.0 %
	Care facility			***Sport building***		
Heating	39.2 %	39.7 %	43.7 %	27.0 %	24.3 %	31.6 %
Domestic hot water	7.5 %	6.4 %	8.4 %	7.6 %	6.9 %	8.9 %
Cooling	0.3 %	0.2 %	0.3 %	7.3 %	6.6 %	8.6 %
Ventilation	8.9 %	-	10.0 %	10.1 %	-	11.9 %
Lighting	7.8 %	-	-	11.1 %	-	-
Electricity	11.3 %	9.6 %	12.6 %	11.9 %	10.7 %	13.9 %
Dynamic building envelope	5.0 %	-	5.0 %	5.0 %	-	5.0 %
Electric vehicle charging	-	24.0 %	-	-	31.6 %	-
Monitoring and control	20.0 %	20.0 %	20.0 %	20.0 %	20.0 %	3.0 %

Table 11
Smart by Powerhouse ambition level calculated based on the applicable functionality levels. In parenthesis, the normalized level between 0% and 100%, where 0% indicates an ambition level −2, while 100% indicates a fully deployed ambition level 4..

Building	Enabling technologies	Indoor environment and work environment	Energy and resource utilization	Safety and reliability	Adaptability	Total
B01	1.25 (54.17 %)	0.00 (33.33 %)	0.25 (37.50 %)	1.00 (50.00 %)	− (−)	**0.62 (43.59 %)**
B02	1.25 (54.17 %)	0.00 (33.33 %)	0.00 (33.33 %)	1.00 (50.00 %)	− (−)	**0.54 (42.31 %)**
B03	1.25 (54.17 %)	−0.67 (22.22 %)	0.00 (33.33 %)	1.00 (50.00 %)	− (−)	**0.38 (39.74 %)**
B04	1.25 (54.17 %)	0.00 (33.33 %)	0.25 (37.50 %)	1.00 (50.00 %)	− (−)	**0.62 (43.59 %)**
B05	1.25 (54.17 %)	−0.67 (22.22 %)	0.00 (33.33 %)	1.00 (50.00 %)	− (−)	**0.38 (39.74 %)**
B06	1.25 (54.17 %)	0.00 (33.33 %)	0.00 (33.33 %)	1.00 (50.00 %)	− (−)	**0.54 (42.31 %)**
B07	1.25 (54.17 %)	−0.67 (22.22 %)	0.00 (33.33 %)	1.00 (50.00 %)	− (−)	**0.38 (39.74 %)**
B08	1.25 (54.17 %)	−0.33 (27.78 %)	0.25 (37.50 %)	1.00 (50.00 %)	− (−)	**0.54 (42.31 %)**
B09	1.25 (54.17 %)	−0.67 (22.22 %)	0.25 (37.50 %)	1.00 (50.00 %)	− (−)	**0.46 (41.03 %)**
B10	1.25 (54.17 %)	0.00 (33.33 %)	0.00 (33.33 %)	1.00 (50.00 %)	− (−)	**0.54 (42.31 %)**

stressing effect in the grid at certain hours.

Table 7 shows the original weights defined in the SRI for non-residential buildings in Northern Europe, while Table 10 shows the utilized weights considering the sub-category of non-residential buildings and using the new weight calculation method. For the “Energy efficiency” impact, separating between sub-categories shows a better representation of some domains, such as cooling, which, for example, it is not widespread in schools. However, it is widespread in health and sports facilities; thus, it is represented in the new weight scores. Similarly, the categories with higher ventilation requirements present larger weights in that domain and smaller in heating. In contrast, buildings with smaller needs, such as schools, present larger weights in the heating domain rather than ventilation. Moreover, including plug-in loads has increased the share of the electricity domain in all categories.

Table 12 presents the overall SRI scores and the aggregated score for the portfolio of buildings. Based on the proposed weights, the ten selected buildings fall in the smart readiness range between 20–35 %, with buildings B02 and B04 reaching the highest scores of the portfolio. Compared with the default scores, obtained using the original weights defined for non-residential buildings in Northern Europe, eight out of ten buildings reduced their overall score, being the most noticeable case of building B01, where its score was reduced by 3.4 percentual points. In the aggregated scores, no changes were observed in the “User” category since the changes in the weights did not affect the impacts that are part of this aggregation. The major changes affected the “Building” and “Grid” aggregated scores, where for the first, an overall decrease is seen but still with the score between 35 % to 50 %. For the “Grid” aggregated score, more variance is present with noticeable low smart readiness, overall below 20 %. Moreover, it is evident that there is a significant decrease in the “Grid” score for building “B01″ (−7.5 %).

Table 12
Overall SRI scores. Between parenthesis is presented 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.

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

Next, Fig. 6 presents the disaggregated impact score. As was previously mentioned, “Comfort”, “Convenience”, “Health, well-being and accessibility”, and “Information to occupants” do not present any changes based on the modified domain weights. Considering these impact scores, it is noteworthy to mention similarities of the sensors, management, and control from the buildings’ systems due to the same BMS provider and installer. The scores for all these categories in most of the buildings are in the range of 35–50 % but with lower scores for buildings B03, B05, B07, and B09. The main difference is due to the presence of CO_2 sensors used for ventilation control. Moreover, the data and information provided are similar in all the pilots; thus, “Information to occupants” presents scores of around 30 % in all the pilots. Next, M&FP presents scores that mostly fall between 35 % and 50 % since the overall BMS presents an alert system with central indication for the HVAC systems. The lack of predictiveness and detailed identification prevents the results from being higher. The “Energy efficiency” impact score is the one that presents overall higher scores but also a general reduction in the scores compared with the default weights. Among the different buildings, the heating domain has one the most significant variance between the samples in reference to the new domain weights presented in Table 10. However, lighting and electricity have gained weight compared to the customized domain weights. Building B05 presents the lowest score (34.4 %) for “Energy efficiency”, since it is the only sample that presents cooling services with a chiller unit. In contrast, others have HP with dual generation or free cooling from the borehole’s water. Finally, the domain weights modification significantly influences the EF&S impact. The cooling fraction was in overall reduced to its minimum. At the same time, EVC and the Electricity domain have gained weight over the heating domain due to their capabilities for interacting with the grid. The most notable case is building B01, which is the only one in the sample with EVC and on-site generation. The lack of smartness in the charging process and the non-interactive generation/storage with the grid’s necessities have diminished the score by 7.5 percentual points, resulting in a major reduction in the overall SRI score.

In Fig. 7 domain scores are presented, and since the impact scores are not modified, there is no variation by changing the domain weights. Starting with the “Heating” domain, five sample buildings fall in the range of 20–35 %, while the rest are in the range of 35–50 %, with 35 % included. Based on the results, a significant variance exists in the scores, primarily independent of the technology (HP, DH, or electric boiler). However, the buildings with decentralized heating generation (B05 and B07) reach the lowest scores. In the case of DHW, the scores are within the range of 35–65 %, mainly because of the independence of the water heaters. The higher scores (range 50–65 %) are reached by the systems with a supplementary heat source, such as buildings B02, B04, B06, and B10. For the “Cooling” domain, only two buildings have cooling systems directly. Here, the difference in the control system and the configuration of the circuits provides a higher score for building B04. For the

Fig. 6. Impact score results for the selected portfolio of buildings. Between parenthesis, the difference between the calculated impact scores with the custom weights and the impact scores based on the original weights defined for non-residential buildings in Northern Europe are presented.

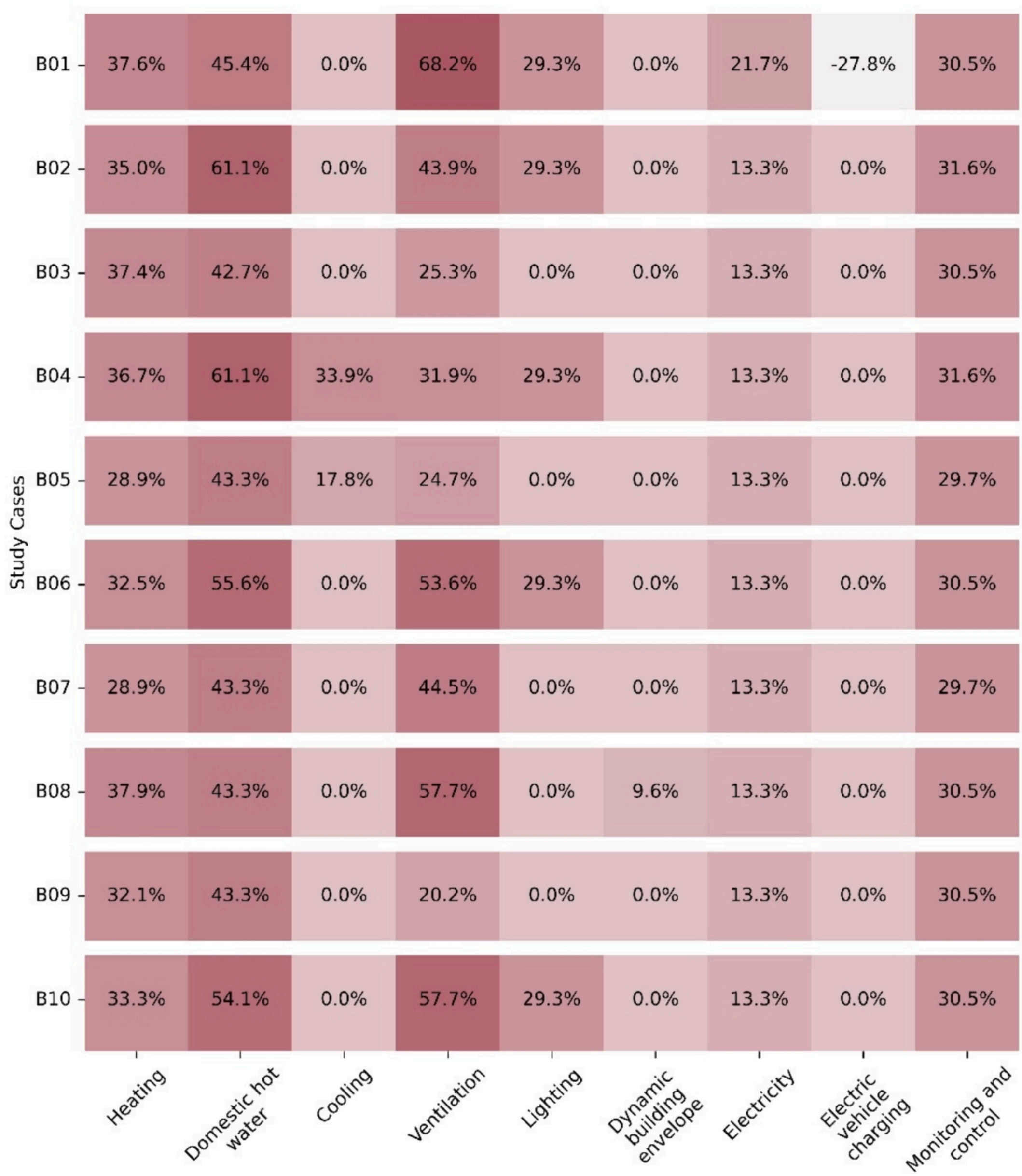

Fig. 7. Domain score results for the selected portfolio of buildings.

"Ventilation" impact score, three buildings (B06, B08, B10) reached 50–65 %, and one sample (B01) reached 65–80 %. Compared to the other buildings, the main difference in these buildings is the control based on CO_2, free cooling, and the dedicated flow control at zone and room level. In "Lighting" impact, the scores are within the range of 20–35 % for buildings B01, B02, B04, B06 and B10 since all these samples have similar automatic on/off systems based on sensors for the lights. The rest of the samples obtained a zero score since they only present manual lighting. Next, the "Electricity" domain presents a low smart readiness (13.3 %) due to its low score in nine of the ten buildings. This result represents the null implementation of demand-side flexibility with the grid. However, the presence of on-site generation in building B01 improves this impact score to 21.7 %, but the lack of storage still does not allow interaction with the grid, producing imbalances when a surplus in the generation exists. Similarly, the presence of one-way EVC in building B01 produces a similar effect to on-site generation since the loads can produce imbalances in the grid due to the uncontrollable charging process, which is represented in its impact score. For DBE, manual shading is recurrent in all the buildings, as well as the not reporting the status of the windows (on and off). However, the only non-zero obtained score (9.6 %) is in building B08, which counts with motorized shading. Finally, the "Monitoring and control" domain score is evenly distributed around 30 %. This result shows the similarities in the BMS in terms of control for energy efficiency and grid interaction, as well as for fault prediction and data processing and visualization.

5. Discussion

This section discussed the modifications in the weight calculation method for the SRI and its implication in the integration with the Smart by Powerhouse assessment.

The first step to adapt the SRI in the Norwegian context is the utilization of dedicated energy data of the country for each building subcategory. Through observation of the changes in the weight domains, it is possible to understand how their change affect the different building categories. As was expected due to the climatic conditions, heating services play an essential role in the overall balance of all the buildings. However, services such as cooling are not widespread in all categories but can still be considered for hospitals or sports facilities. In that context, the share of the cooling weight for the "Energy efficiency" impact is noticeably reduced compared with the default scores. At the same time, the heating domain's weight varies depending on the category. Another meaningful change is the inclusion of the internal plug-in loads in the energy balance, which has provoked an increase in the share of the electricity domain weight, besides the low penetration of distributed generation in the country. In the case of the ventilation, the more detailed information for the Norwegian case compared with the calculated methodology utilized in SRI has led to a decrease of around 10 % for all the categories in the "Energy efficiency" impact.

For this portfolio of buildings, which represents an important share of the non-residential Norwegian stock, different technologies for heating and cooling are observable along the categories, with a clear correlation to the construction year. Newer buildings are based on district heating and water-to-water heat pumps. The option of water-to-water over air-to-water HP is done to take advantage of the cold water in the boreholes in the summer months to provide free cooling due to the low cooling needs. The technologies in older buildings, such as B05, are mainly based on resistance heating through electric boilers, electric coils, or distributed electric radiators. In accordance, SRI does not consider the difference in technologies; thus, the final score does not represent the importance of having a more efficient technology besides the applicable control. However, Smart by Powerhouse considers this aspect since the energy labeling is considered part of the overall smartness assessment and shows independence on the existent technology.

Implementing EVCs in residential and non-residential buildings in Norway is becoming a natural part of their systems. Accordingly, SRI is seen as an accurate standard to estimate the EVC's influence on the building's flexibility. However, by default, the domain weights related to EVC in the "Energy flexibility and storage" impact are fixed to 5 % independent of the category and geographic location, which can underestimate its influence on the demand-side flexibility over other domains such as heating or cooling services. Therefore, understanding the influence of the EVC as a dynamic weight can cope with this issue. Moreover, the impact of the non-smart EVC and power-to-heat/cooling systems generally have more impact at peak than base hours. Hence, it is necessary to calculate the weights of the domains for "Energy Flexibility and Storage" in a manner that enables the identification of overlapping services during specific and shorter periods (grid congestion), as proposed in this work. The implementation of EVC in buildings is not part of the Smart assessment, but it is widely covered in the SRI assessment.

The above-mentioned measures in the SRI calculation have a visible impact on the overall scores. The most significant changes are observed in B01, with a decrease of 3.4 %, with a prevalent tendency in all buildings to decrease the scores. However, when considering aggregated scores such as "Building" and "Grid," it is possible to obtain more information on how the specification of weights for country and building typology is differentiated. For the "Building" score, the differences range from a decrease of 3.5 % (B07) to an increase of 1 % (B09). Meanwhile, in the "Grid" score, the range is extended, with a decrease of 7.5 % in B01 and an increase of 1.1 % in B06. Upon analyzing specific cases, it is observed that scores such as B01 or B05 had a similar variation (−2.8 %) in the "Building" score. However, in the "Grid" score, B01 shows a larger variation (−7.5 %) than B05, which did not vary. This is due to the increased importance of flexibility, which is a unique characteristic of Norway compared to other North European countries.

The Smart by Powerhouse assessment is incorporated into the framework to address the limitations of the SRI in comparative analysis across a building portfolio. This tool complements and enhances the SRI by providing a relative measure of smart readiness that aids portfolio managers in prioritizing improvements effectively. This dual-assessment approach offers a more holistic tool for decision-making regarding smart upgrades. This assessment can complement the SRI by covering the areas where it falls short or where it was not intended to assess. SRI is presented as a control-oriented assessment that primarily focuses on gathering information at the system level. However, the delivery, presentation, treatment, and security of information are not compromised, all of which are extensively covered in the Smart assessment. Moreover, Smart by Powerhouse strongly emphasizes resource utilization in a building's environment, including spaces, waste management, acoustics, and other factors beyond the scope of the SRI. Hence, implementing Smart by Powerhouse can thoroughly evaluate the level of digitalization and intelligence of the building. Nevertheless, Smart by Powerhouse presents a detailed but general assessment that can be easily extrapolated among buildings due to its focus on the interactivity and interaction of the building with the user and grid.

Fig. 8 displays the overall scores of the Smart by Powerhouse and SRI assessments for the studied portfolio. The proposed framework shows a correlation between the scores obtained for the smartness (Smart by Powerhouse) and smart readiness (SRI) assessments. First, older buildings generally show lower scores, while newer buildings tend to present higher scores in both assessments. As previously mentioned, "Care facilities" include CO_2 measurement that allows the implementation of more sophisticated control strategies for ventilation systems, which positively impacts the assessment scores. Next, the "School" category shows the most dispersed results but tending to an increase in both scores for newer buildings. Apart from the particular results, the application of the Smart by Powerhouse assessment exposes a similar level of smartness in the buildings, in a middle point between "Automatization" and "Smart Ready" levels; thus, leaving the smart readiness score as the inflection point in the decision-making process for smarten up the group of buildings. As a result, there is a significant difference between older and newer buildings (and technologies) even when their SRI scores fall in the same range. This difference leads to the formation of two distinct clusters when the SRI is compared to Smart by Powerhouse, as illustrated in Fig. 8. These clusters are created as a result of differences in how CO2-based control and lighting systems impact the "Indoor climate and working environment" scores in the Smart by Powerhouse assessment. Additionally, the energy labeling of the building affects the domain "Energy and resource utilization" for Smart by Powerhouse but does not have any effect on the SRI. Therefore, the horizontal separation is overemphasized.

The SRI assessment can provide additional information to estimate the potential improvement in smartness, while Smart by Powerhouse can provide an overall overview of the group of buildings. Based on these assessments, buildings B03, B05, B07, and B09 are targeted for having lower smartness in the portfolio and significant room for improvement. Therefore, these buildings are proposed as the first bildings cluster in the portfolio to be smartened up.

6. Conclusion and future work

The building stock in Norway possesses unique characteristics in terms of electrification, while the country is undergoing a profound transition towards the full deployment of electric vehicles under the umbrella of their almost 100 % renewable energy grid. Besides the climatic conditions that make the heating services the priority over the cooling systems, Norway represents the future and what the other countries should be aiming for; thus, it is reasonable that the tools utilized to measure the smartness and smart readiness in buildings are adapted to this specific scenario, providing a higher accuracy that can help in the decision-making process for the involved parties. Under this scope, a novel framework that utilizes SRI and Smart by Powerhouse assessment to quantify smartness and smart readiness in highly electrified buildings was presented in this work.

In first instance, the SRI was adapted to consider the energy use of different sub-categories of non-residential buildings based on their disaggregated energy usage. Based on these changes, the study cases have shown that the pre-defined weights for the non-residential buildings in Northern Europe do not represent the actual performance of each

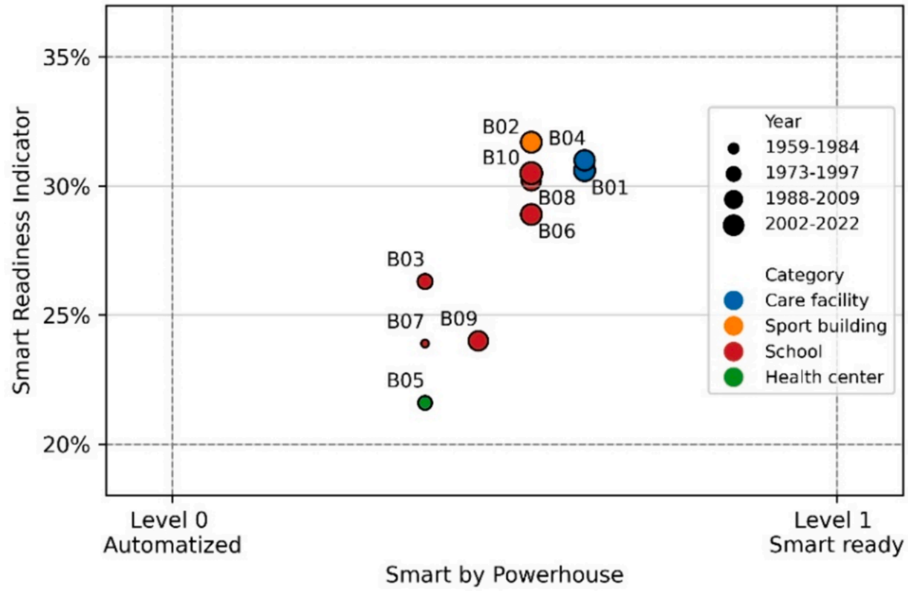

Fig. 8. Scatter plot corresponding to the overall modified versions of the SRI and Smart by Powerhouse scores, grouped by building categories.

individual category, outweighing the use of cooling and ventilation and underestimating the inner electrical loads. Similarly, changes in the domain calculation weights for the “Energy flexibility and storage” impact were proposed to provide dynamic weights to simultaneous power usage that could positively or negatively affect the congestion in the grid. The driving force of this change was the proliferation of EVC in Norwegian buildings since its weight remained constant for the different geographical locations and building categories. In overall, the proposed customized weights for the SRI shown an increase of up to 7.5 % for the aggregated grid score, up to 3.5 % for the building score, and up to 3.4 % on the overall SRI score, compared to the SRI based on the original weights.

Utilizing the SRI by itself has led to three fundamental issues: the comparison of its score only within the same building (smart readiness), it focuses mainly on energy systems and does not consider the efficiency of the installed technology. The first issue represents a disadvantage when a tenant or stakeholder owns a portfolio and needs to decide which building to target when they need to increase the smartness of one of them. In that sense, SRI can only show how smart-ready the building is, but not if that building is the one with lower or higher smartness. By focusing primarily on the energetic system, SRI left out essential topics in digitalization, such as security and connectivity, and the smartness of the building with the users, as it is the smart use of spaces, waste management, and noise pollution. Next, one of the main obstacles of the SRI is the lack of differentiation in the energy performance in buildings. This case study showed that facilities with different technologies in terms of efficiency and configuration (e.g., heat pumps and electric boilers) can reach similar scores regardless of their energy performance. In addition, two technologies with similar scores directly transfer the facility of upgrading the system to achieve a higher score in the SRI, penalizing in that sense more complicated systems that require higher efforts for their update. Nevertheless, these drawbacks can be smoothly compensated using Smart by Powerhouse. By utilizing Smart, the smartness of the portfolio of buildings was calculated by considering the technical and non-technical systems of the buildings and by considering their energy performance. Consequently, it can lead to an overall estimation of the smartness of the buildings, differentiate the technologies utilized in the technical systems, and focus on the smartness of the building in the hands of the users.

In future works, it is important to develop a complementary study considering the disaggregated energy usage and the technology used for generation. This will provide more accurate data for defining the energy-based domain weights, which can also be extended to the residential building stock. Similarly, more accurate data on the Electric Vehicle Chargers (EVCs) that are already installed in the buildings can complement the average hourly energy weights for “Energy flexibility and storage”. Furthermore, this framework can be implemented in various geographical locations, making it a standard tool to quantify the smartness of buildings for the clean electrification process of different countries.

CRediT authorship contribution statement

Italo Aldo Campodonico Avendano: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation. **Kamilla Heimar Andersen:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis. **Silvia Erba:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Formal analysis, Conceptualization. **Amin Moazami:** Writing – review & editing, Validation, Supervision, Methodology, Formal analysis, Conceptualization. **Mohammadreza Aghaei:** Writing – review & editing, Validation, Supervision, Project administration, Methodology, Conceptualization. **Behzad Najafi:** Writing – review & editing, Validation, Supervision, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgment

This work has been written with the LifeLine-2050 project, funded by the Faculty of Engineering (IV) at the Norwegian University of Science and Technology (NTNU). The LifeLine-2050 project is a flagship project with the NTNU’s Centre for Green Shift in the Built Environment

(Green2050). The authors gratefully acknowledge the support of Green2050's partners and the encouragement of the innovation committee of IV faculty at NTNU.

The authors acknowledge the COLLECTiEF project that has received research funding from European Union's H2020 research and innovation programme under Grant Agreement No 101033683.

The authors wish to thank Ålesund Kommunale Eigedom (ÅKE) and EM Systemer for providing access to the pilot buildings and data.

Appendix A:. Buildings' technical information

Building	Topic	Systems
B01	*Heating*	Water-to-water heat pump (HP) for neutral air and thermal valves, supported by an electric boiler. Decentralized electric radiators and solar collectors.
	Cooling	Free cooling from borehole provided by ventilation.
	DHW	Connected to HP and helped by the electric coil in storage.
	Ventilation	Centralized air handling unit (AHU) with external air, heat recovery and heating/cooling coil.
	Generation/ EV	PV System and one-way electric vehicle charging (EVC)
	Control	BMS to control centralized HVAC. Thermostatic valves are controlled based on outdoor temperature, while pumps/fans (on/off) and temperature setpoints are based on calendars. CO2-based control in some of the zones for ventilation. Electric and energy meter is available on time. Historical electrical data is presented on a third-party web.
B02	*Heating*	Water-to-water HP is used for ventilation, hydronic radiators, and radiant floor systems. Includes thermal valves supported by an electric boiler.
	Cooling	Free cooling from borehole provided by ventilation.
	DHW	Connected to HP and helped by the electric coil in storage.
	Ventilation	AHU with external air, heat recovery and heating/cooling coil.
	Generation/ EV	–
	Control	BMS to control centralized HVAC. Thermostatic valves are controlled based on outdoor temperature, while pumps/fans (on/off) and temperature setpoints are based on calendars. CO2-based control in some of the zones for ventilation. Electric and energy meter is available on time. Historical electrical data is presented on a third-party web.
B03	*Heating*	Electric boiler for neutral air. Includes thermal valves and decentralized electric radiators.
	Cooling	–
	DHW	Connected to the heating system and helped by the electric coil in storage.
	Ventilation	AHU with external air, heat recovery and heating coil.
	Generation/ EV	–
	Control	BMS to control centralized HVAC. Thermostatic valves are controlled based on outdoor temperature, while pumps/fans (on/off) and temperature setpoints are based on calendars. Electric and energy meter is available on time. Historical electrical data is presented on a third-party web.
B04	*Heating*	Air-to-water HP for ventilation and radiant floor systems. Includes thermal valves supported by an electric boiler.
	Cooling	Air-to-water HP for ventilation and fan coils in some zones.
	DHW	Connected to HP and helped by the electric coil in storage.
	Ventilation	Centralized AHU with external air, heat recovery and heating/cooling coil.
	Generation/ EV	–
	Control	BMS to control centralized HVAC. Thermostatic valves are controlled based on outdoor temperature, while pumps/fans (on/off) and temperature setpoints are based on calendars. Electric and energy meter is available on time. Historical electrical data is presented on a third-party web.
B05	*Heating*	Decentralized electric radiators and electric radiant floor system.
	Cooling	Chiller for one ventilation unit.
	DHW	Storage with an electric coil.
	Ventilation	AHU has heat recovery, an electric heating coil, and one unit with a cooling coil.
	Generation/ EV	–
	Control	BMS to control centralized HVAC. Thermostatic valves and electric coils are controlled based on outdoor temperature, while pumps/fans (on/off) and temperature setpoints are based on calendars. The electric meter is available on time. Historical electrical data is presented on a third-party web.
B06	*Heating*	District heating (DH) is for ventilation, hydronic radiators, and hydronic radiant floor systems. Includes thermostatic valves.
	Cooling	–
	DHW	Connected to DH and helped by the electric coil in storage.
	Ventilation	Centralized AHU with external air, heat recovery and heating coil.
	Generation/ EV	–
	Control	BMS to control centralized HVAC. Thermostatic valves are controlled based on outdoor temperature, while pumps/fans (on/off) and temperature setpoints are based on calendars. The electric meter is available on time. Historical electrical data is presented on a third-party web.
B07	*Heating*	Decentralized electric radiators.
	Cooling	–
	DHW	Storage with an electric coil.
	Ventilation	Centralized AHU with external air, heat recovery and electric heating coil.
	Generation/ EV	–
	Control	BMS to control centralized HVAC. Electric coils are controlled based on outdoor temperature, while fans (on/off) and temperature setpoints are based on calendars. The electric meter is available on time. Historical electrical data is presented on a third-party web.
B08	*Heating*	Decentralized electric radiators and electric radiant floor system.
	Cooling	–
	DHW	Storage with an electric coil.
	Ventilation	AHU with external air, heat recovery and electric heating coil.
	Generation/ EV	–
	Control	BMS to control decentralized HVAC. Thermostatic valves are controlled based on outdoor temperature, while pumps/fans (on/off) and temperature setpoints are based on calendars. CO2-based control in some of the zones for ventilation. Electric and energy meter is available on time. Centralized indoor and outdoor lighting (calendar). Historical electrical data is presented on a third-party web.

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(*continued*)

Building	Topic	Systems
B09	*Heating*	Electric boiler for neutral air, hydronic radiators, and hydronic radiant floor heating. Includes thermal valves.
	Cooling	–
	DHW	Connected to the heating system and helped by the electric coil in storage.
	Ventilation	Centralized AHU with external air, heat recovery and heating coil.
	Generation/ EV	–
	Control	BMS to control centralized HVAC. Thermostatic valves are controlled based on outdoor temperature, while pumps/fans (on/off) and temperature setpoints are based on calendars. Electric and energy meter is available on time. Historical electrical data is presented on a third-party web.
B10	*Heating*	DH is for ventilation, hydronic radiators, and hydronic radiant floor systems. Includes thermostatic valves.
	Cooling	–
	DHW	Connected to DH and helped by the electric coil in storage.
	Ventilation	AHU with external air, heat recovery and heating coil.
	Generation/ EV	–
	Control	BMS to control centralized HVAC. Thermostatic valves are controlled based on outdoor temperature, while pumps/fans (on/off) and temperature setpoints are based on calendars. CO2-based control is some of the zones for ventilation. Centralized outdoor lighting and shading (calendar). Electric and energy meter is available on time. Historical electrical data is presented on a third-party web.

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