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Master's Programme in Automation and Electrical Engineering

Smart Readiness Indicator - Suitability to Finnish context

Evaluating the suitability of the SRI framework for the Finnish context based on a wider number of assessment results as part of the national SRI testing phase

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Abstract

Over the years, the European Union (EU) has progressively set increasingly stringent climate and energy targets in response to climate change having the head targets of reducing greenhouse gas emission, increasing the share of renewable energy, and promoting energy efficiency. The building sector has the greatest potential to meet energy efficiency targets since it accounts for a significant 42% of the final energy consumption in the EU. Recognizing the potential, the Energy Performance of Buildings Directive (EPBD) proposed the Smart Readiness Indicator (SRI) as a standardized building assessment tool for assessing a building's smart readiness, emphasizing interactions with building automation systems and enhancing energy efficiency.

This thesis explored the suitability of the SRI framework within the Finnish context based on the assessment results collected by Motiva company during the national SRI testing phase. The SRI evaluation encompasses approximately 100 individual assessments all over Finland. The large amount of real assessment results enables a comprehensive understanding of the current SRI framework and the direction of potential improvements. The analysis delves into the impacts of building types, construction years, and abnormal results, aiming to determine the framework's suitability for the Finnish environment. Additionally, practical considerations and feedback from assessors were also included, with an emphasis on providing valuable suggestions to improve the SRI assessment process. The study also considers factors like assessor training and guidance, ensuring a comprehensive assessment, using tools such as Excel, Power BI, and Jupyter Notebook.

Based on the analysis, the current SRI assessment method has aspects to be improved to apply to the Finnish context completely. Although the recent SRI framework is not standardized and suitable, some reasonable and indicative results were found, such as the correlations between impact scores, as well as development potential in the Energy Flexibility and Storage, and Electrical Vehicle Charging. These improvement suggestions could instruct the building owners and decision-makers to help meet the energy targets in the EU.

Keywords Smart readiness indicator, SRI, smart readiness

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Tiivistelmä

Euroopan unioni (EU) on vuosien mittaan asettanut asteittain yhä tiukempia ilmasto- ja energiatavoitteita vastauksena ilmastonmuutokseen, joiden päätavoitteena on vähentää kasvihuonekaasupäästöjä, lisätä uusiutuvan energian osuutta ja edistää energiatehokkuutta. Rakennusalalla on suuri potentiaali saavuttaa energiatehokkuustavoitteet, koska sen osuus EU:n energian loppukulutuksesta on merkittävä 42 prosenttia. Rakennusten energiatehokkuusdirektiivi (EPBD) tiedosti potentiaalin ja ehdotti rakennusten älyindikaattori (Smart Readiness Indicator) standardoiduksi rakennuksen arviointityökaluksi rakennuksen älykkään valmiuden arvioimiseen, korostaen kulutusjoustoa, huoltojen ja säätöjen ennakointia, sekä energiatehokkuuden parantamista.

Tässä opinnäytetyössä selvitettiin SRI-kehyksen soveltuvuutta Suomen ympäristössä arvioimalla Motiva-yhtiön kansallisen testausvaiheen aikana keräämiä noin 100 yksittäistä SRI arviointia eri puolilta Suomea. Suuri määrä todellista arviointitulosta mahdollistaa nykyisen älyindikaattorin kokonaisvaltaisen ymmärtämisen ja mahdollisten kehityssuuntien antamiseen. Analyysissä tarkastettiin eri muuttujien, kuten rakennustyyppien, rakennusvuosien ja poikkeavien tulosten vaikutuksia. Lisäksi mukana oli myös arvioitsijoiden palautetta arviointiprosessista, jotka loivat käytännönläheinen pohjan SRI-arviointiprosessin parantamiseksi. Työssä hyödynsi eri data käsittely työkaluja, kuten Exceliä, Power BI:tä ja Jupyter Notebookia.

Analyysin perusteella nykyisellä älyindikaattoriarviointimenetelmällä on parantamisen varaa soveltuakseen täysin suomalaiseen kontekstiin. Vaikka työssä käytetty älyindikaattori ei ole lopullinen versio, joitakin suuntaa antavia tuloksia saatiin, kuten energian joustavuuden ja varastoinnin sekä sähköajoneuvojen latauksen kehityspotentiaali. Nämä parannusehdotukset voisivat ohjata rakennusten omistajia ja päättäjiä auttamaan EU:n energiatavoitteiden saavuttamisessa.

Avainsanat Rakennusten älyvalmius, SRI-menetelmä, rakennuksen älyindikaattori

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Preface and acknowledgements

The end of one story marks the beginning of the new story. My journey with Aalto University commenced in the autumn of 2018 and concluded in the summer of 2024. I am grateful for the six wonderful years I spend at in Aalto University.

I would like to express my deepest gratitude to Professor Jaakko Ketomäki for his invaluable advice and guidance during the thesis process. From selecting the theme to finalizing the work, his patience and constructive feedback have not only made my journey smooth but also highly instructive. Moreover, the realization of this thesis would not have been possible without the Master Thesis Worker position in the Smart Buildings Department at Aalto University's School of Electrical Engineering, which allowed me to focus on my research without concerns about financial issues.

I would like to extend my sincere thanks to my family, classmates and friands for their unwavering emotional support and encouragement. I am also thankful to myself for all the effort and hard work invested during my university years.

Reflecting on the past, I have successfully overcome various challenges, marking the end of my student life. As I look to the future, I am committed to continuous learning at all stages of my life and aim to contribute meaningfully to society.

Espoo, 29.04.2024
Xueyan Li

Abbreviations

AI	Artificial Intelligence
BMS	Building Management System
EU	European Union
EPBD	Energy Performance of Building Directive
EPC	Energy Performance Certificate
HVAC	Heating, Ventilation, and Air Conditioning
IoT	Internet of Thing
NZEB	Nearly Zero-Energy Building
SRI	Smart Readiness Indicator

1 Introduction

Over the years, the European Union (EU) has progressively set increasingly stringent climate and energy targets in response to climate change [1]. The latest targets aim to reduce greenhouse gas emission by at least 55%, increase the share of renewable energy by at least 45%, and promote energy efficiency by decreasing energy consumption by at least 42% by 2030 compared to levels in 1990[1]. Energy efficiency plays a crucial role in achieving these goals, with the building sector accounting for a significant 42% of the final energy consumption in the EU, followed transportation (29%) and industry (25%)[2]. The building sector is recognized as one of the areas that shows the greatest potential in achieving the set targets.

Therefore, the building sector provides a significant opportunity for reaching the targets, as the EU member states are facing the challenging task of accelerating the transformation towards a more energy-efficient and sustainable, and cost-efficient building stock to meet the ambitious climate and energy targets, as well as to achieve benefits for both building owners and occupants [2]. This transformation is not only limited to newly constructed buildings; it must also extend to existing ones, as a substantial portion of the buildings standing today will still be present in 2050, and many existing buildings lack energy efficiency [3].

Recognizing the important role of the building sector, the Energy Performance of Buildings Directive (EPBD) underscores the development of smart buildings as a solution for reducing the energy consumption and enhancing energy efficiency [4]. This "smartness" is commonly known as the ability of a building to interact with different building systems, such as Heating, Ventilation, and Air Conditioning (HVAC) and energy management systems, to make the environment more comfortable, while managing the usage of energy more efficiently at the same time [5]. Achieving this smartness will require adopting various building automation technologies and building management systems which could be further linked to machine learning algorithms in order to maximise the smart readiness and automation level of buildings. To improve the transformation toward more smart buildings, the Smart Readiness Indicator (SRI) was introduced by EPBD and established as an official EU instrument [4].

The SRI is a common legislative building assessment framework at the EU level for rating the smart readiness level of the building and building units based in three functionalities: the ability to optimise building energy efficiency and performance, the ability to adjust building operation to meet the occupants' needs, and the ability to respond to signals from the grid, forming a flexibility energy usage [5]. Such a European-level standard also enhances understanding of the economic, political, and social factors influencing greenhouse gas emission reduction, thereby enabling the development of policies aimed at mitigating climate change [6]. However, because of Europe's heterogeneous building stock based on its diverse cultural landscapes, regulations related to the SRI are still in an optional implementation phase, granting EU member countries the autonomy to determine the level of implementation of these regulations. Thus, each member state may choose to implement the SRI across all building types or specific categories within their jurisdiction.

The adaptability and applicability of the SRI framework is presently undergoing a national testing phase in eight EU countries, with Finland being one of these participants [7]. Although little research has focused on analysing the feasibility of SRI in EU countries [6], [8], [9], [10], some case-studies have analysed the SRI in Italy [11] and Greece [12]. However, these studies have been based on a limited number of buildings, thus yielding only a few SRI assessments for evaluating the suitability of SRI. While several theses have explored case studies of adopting SRI in the Finnish residential rental property market [13] and using SRI as a guide for construction of buildings in Finland [14], the number of assessments results have also been limited, and the suitability of SRI has thus not been thoroughly evaluated yet.

Therefore, the aim of this thesis is to evaluate the current SRI framework based on a wider number of assessment results as part of the national SRI testing phase in Finland in order to determine its suitability for the Finnish environment. To achieve this goal, the thesis will use an in-depth analysis of the 93 individual SRI assessments collected by Motiva [15] for validating the possible impacts of building types, construction year, and any abnormal results. An additional aim is to investigate the potential improvements related to the assessment process, such as assessor training and guidance. The data will be analysed using tools such as excel, Power BI and Jupyter Notebook. A critical aspect of this analysis will involve possible feedback from the evaluators to avoid any misunderstanding or misinterpretations. To ensure the usefulness of the evaluation, the thesis will analyse different practical factors and then validate suggestions to property owners that might increase building's smart readiness. It is important to note that this thesis only focuses on evaluating the 93 SRI assessments based on Motiva's data, which have used version 4.5. of the SRI scheme introduced in the COMMISSION DELEGATED REGULATION (EU) 2020/2155 [16].

The rest of this thesis is divided into five chapters. Chapter 2 introduces the concepts of SRI and smart buildings, as well as reviews the literature on evaluating and applying SRI in European buildings. Chapter 3 outlines the methodology and methods for analysing the data. Chapter 4 presents and discusses the results obtained using the methodology, including data visualizations and SRI improvement suggestions. Chapter 5 concludes the thesis by discussing the suitability of the SRI for assessing smart readiness of Finnish buildings and suggesting further directions for developing the future SRI framework.

2 The Smart Readiness Indicator (SRI)

This chapter serves as a comprehensive review of smart building definitions, the development of the Smart Readiness Indicator (SRI) in the European Union (EU) strategy, the detailed SRI assessment structure, calculation methodology, and related studies on SRI.

2.1 Smart Buildings in the EU strategy

This section is a review of Smart Building in the EU strategy. The “green” and “smart” buildings are in a key role due to their promising impacts on energy efficiency, climate change mitigation and renewable energy generation [17]. In the European Union (EU), the building sector is responsible for over 42% of the total energy consumption, over 1/3 of the energy related greenhouse gas (GHG) emissions, and around 80% of the energy used in EU households is for heating, cooling and hot water [4].

While the energy saving potential is large in all sectors, there is a significant challenge relating to buildings, since around 85% of EU building stock has built before 2000, 75% of the existing EU’s building stock has a poor performance in energy efficiency, and only 1% of buildings have their performance improved through renovations each year [18].

In 2021, the European Commission adopted a set of ambitious targets aiming to reduce greenhouse gas emission by at least 55% by 2023 compared to 1990 levels that will enable reaching climate neutrality by 2050 [19]. To contribute this EU’s energy and climate goals, the Energy Performance of Building Directive (EPBD) together with the Energy Efficiency Directive (EED) promotes policies that will boost the energy performance of buildings and towards achieving a fully decarbonised building stock by 2050 [4].

Smart technologies and deep renovation of the building stock are the key enablers for reducing energy consumption as well as decarbonizing the energy system and increasing grid flexibility [4]. There are already a variety of smart technologies [20], [21], features and potentials [22] of smart buildings have been discovered in the literatures. The European Commission also strengthened the importance of smart buildings through the revised Directive 2023/1781/EU and 2018/844/EU [4], [18].

The Smart Readiness Indicator (SRI) stands as a pivotal tool in highlighting the advantages presented by smart building technologies, such as the automation of building functions and the electronic monitoring of systems like heating, hot water, ventilation, and lighting. It serves as an illustrative guide, offering insights into the anticipated benefits of incorporating smart technologies into building infrastructures [5].

Through the establishment of the SRI framework, the construction sector receives robust support for technological innovation. This not only fosters awareness but also acts as a compelling incentive for the seamless integration of cutting-edge smart technologies within buildings. In essence, the SRI becomes more than just an assessment tool; it emerges as a driving force propelling the adoption of advanced technologies, thereby reshaping, and enhancing the landscape of construction practices and building systems management [5].

2.2 What makes a building "smart"

This section discusses the recent smart building technologies. The interest in energy efficiency and energy-saving potentials within the building sector has grown in the EU in the last years. A variety of building automation technologies and smart services are already available in the market. The concept of "smart buildings" has gained substantial attentions not just in Europe but globally, due to its potential impact on more efficient energy usage, more comfortable indoor environment, and less energy consumption.

Despite the concept of smart buildings has been developed over the past three decades, there is not yet a clear definition of it. Buckman et al. have undertaken the task of gathering up diverse definitions and summarizing the smart buildings as a dynamic and user-centric approach to architecture and construction that aims to create more efficient, comfortable, and sustainable environment [23].

Smart buildings are based on sensors, actuators, and management systems to structure automated processes to control the building's operations such as lighting, heating, ventilation, air conditioning etc. The essential components of smart buildings are the hardware, software, and network [17]. The recent advances in smart building technologies, such as user centric controlling system and use of artificial neural network [20], creates new ways for building to interact with energy grid smartly and offers benefits in terms of more sustainable and more comfort environment to work and live [24], [25]. The EPBD defines "smartness" of a building as its ability to interact with different building systems, including sensing and interrupting the physical properties, and responding to them according to desired logics to make the environment more comfortable and energy efficient at the same time [5]. **Error! Reference source not found.**

Digitalization of the Smart Building

These recent smart technologies in buildings unlock variety of new possibilities to speed up their transition to more sustainable, comfort and energy efficient buildings. In the recent years, the five emerging information and communication technologies (ICT), that are 5G, internet of things (IoT), big data, artificial intelligence (AI) and blockchain, have been studied in the energy and building sectors [26]. The “smart buildings” brought new decarbonization and digitalization opportunities of the building stock.

An AI technique for Monitoring Systems in Smart Buildings (AIMA-SB) [20] in an energy efficient manner that aims to improve the energy distribution efficiency by ensuring fair utilization. The proposed solution relies on renewable energy source for optimal and seamless performance of the building by predicting the energy usage based on energy analysis to optimize energy consumption and utilize renewable energy production and recycling based on the predicted models.

To ensure a smooth and real-time interaction between different smart devices and systems, the smart buildings need a building management system (BMS) that is able to handle big data and give responses in real-time. The traditional BMS has limitations in handling real-time updates and big volume of data. To solve that, a case study has combed artificial intelligence with digital twin (DT) concept realizing A DT software system, equipped with real-time visual management and artificial intelligent diagnosis modules [27]. It is able to cover the wide range of real-time actions of all parameters, detecting and reporting any maintenance demands to whom should be informed, for instance the building owners, users, or property managers.

Building-to-grid ecosystem

The interaction with the energy grid could also be realized from residential building energy systems to realize economic and environmental benefits. For instance, integrating only a small-scale crossflow wind turbine (EFWT) into residential building could enhance flexible demand side energy usage while achieve maximum energy performance, reliability, and cost-effectiveness under certain conditions [28]. While the EPBD regulates that all new buildings need to be nearly zero energy buildings (NZEBs) by 2021, the researchers continue searching for the potential next steps. From building-to-grid interaction perspective, the integration of advanced smart technologies will improve the energy performance of smart buildings, from generating energy for their own use towards positive energy building that produce excess energy to the grid [29].

2.3 Smart Readiness Indicator in the EU strategy

This section delves into the role of SRI in the broader context of the EU strategy. In addition to advancements in smart technologies and innovations, a critical aspect of improving the energy efficiency in the building stock is to comprehend the current performance situation of buildings, thereby to identify the potential developments and adapt smart technologies to enhance the energy efficient performances. To improve the "smartness" in the building stock a reliable and accurate analysis together with a fit-for-purpose evaluation framework of different types of buildings is required. This framework should be able to measure the smartness of different building topologies and respond to each EU member states' local environment, climate conditions, and policies.

The EU recognized these needs and established primary legislative framework addressing smart readiness in buildings within the context of the 2030 energy efficiency targets. To make the value of buildings' smartness more concrete, highlighting the benefits and strengths of smart technologies for building owners, users, and stakeholders, the EPBD Directive 2018/844 introduced the Smart Readiness Indicator (SRI) as an optional common European Union scheme for rating the smart readiness of buildings [4]. The SRI plays an essential role in EU's targets to accelerate the renovation of existing buildings by 2050 and to support the digitalization of all buildings through the use of smart technologies such as artificial intelligence and cloud-based services [16].

Figure 1 illustrates some of the expected advantages that buildings could reach through the adaption of smart technologies. Key benefits include local energy storage and green energy production, contributing to enhanced energy flexibility, optimisation, and storage capabilities. The ability to forecast and predict energy usage is crucial for optimizing interactions with the energy grid. This predictive capability can be based on advanced technologies such as machine learning (ML), artificial intelligence (AI), or data analysis. The capacity to foresee future events is also advantageous in automatic diagnosis and maintenance processes, ultimately improving occupant comfort.

Figure 1. Expected advantages of smart technologies in buildings [30]

The SRI ensures an EU level consistent and comparable scheme to highlight the smart readiness of buildings across the EU but also leaves flexibility to adapt the calculation to specific conditions [16]. This methodology for rating the smart readiness of buildings should be used to measure the capacity of buildings to adapt information and communication technologies and electronic devices to manage the building's operation to meet the needs of the users and enable flexible grids, improve buildings energy efficiency and performance [4].

It is important to mention that the SRI is not a replacement but a complement tool for assessing other aspects of buildings, such as energy performance or sustainability. It should not be mistaken for an indicator of the energy performance of buildings, and the distinction between smart readiness and energy performance is emphasized. The goal is to inform building owners that these are separate considerations requiring distinct measures, although smart readiness can contribute to enhancing energy performance. The regulation encourages the use of available instruments for rating buildings in combination to provide a comprehensive understanding of building performance.

The framework for calculating the smart readiness is applicable to both existing and new buildings, and digital models, such as building information models or digital twins, can be used to facilitate its calculation. It aims to highlight additional benefits from advanced smart technologies. Considering the increased digitization and connectivity in buildings, the regulation recognizes cybersecurity and data protection risks. The smart readiness indicator is designed to inform building owners and users about these risks, thus contributing to awareness and preparedness in the face of potential cyber threats and misuse of personal data.

SRI implementation is also supposed to enhance the role of building into the energy infrastructure by integration of smart buildings, NZEBs and other energy efficient buildings promoting smart and flexible grid. The core idea of SRI is to evaluate a building's capacity to receive smart-ready services. The result of the SRI rating expresses how close the building is to the maximum smart readiness.

The SRI is designed to be a tool that could be used together with other building assessment indicators. It aims to provide a measurable assessment of a building's readiness to incorporate and benefit from smart technologies and solutions that enhance energy efficiency. The indicator is expected to assign a numerical value or rating based on specific criteria related to the integration of information and communication technologies (ICT), energy performance, and other relevant factors. The qualitative nature of the SRI allows policymakers, building owners, and stakeholders to have a clear, standardized metric to evaluate and compare the smart readiness of different buildings. By providing a numerical score, it facilitates the development and implementation of targeted strategies to improve energy efficiency and promote the adoption of smart technologies in buildings across the European Union.

2.4 SRI testing phase in Finland

This section delves into the developing testing phase across the EU. Since the scheme should also influence the national building performance standards, implementing a national level evaluation standard [4]. Such a European-level standard also enhances the understanding of the economic, political, and social factors influencing greenhouse gas emission reduction, thereby enabling the proposal of policies aimed at mitigating climate change [6].

To ensure the acceptability, usability and consistency of the SRI scheme in the EU member states, the regulation related to the SRI is still in an optional implementation phase where the Commission collaborates with wide range of stakeholders from different EU member states granting them the autonomy to determine its adoption status [16]. Each member state may choose to implement the SRI across all building types or specific categories within their jurisdiction.

Right now, the acceptability of the SRI framework is presently undergoing testing phase in 8 EU countries and Finland is one of these participants [7]. Testing SRI's suitability and applicability in different countries is important because every country has their unique building stock and environment.

The SRI applicability test project in Finland leading by Motiva has been started at the end of 2022. Figure 2 illustrates the plan of the testing project in Finland. The project was an important initiative to evaluate the SRI relevance and functionality in the Finnish context. One important feature of the SRI testing process is its focus on applicability to a regional context, even as it adheres to the formal EU level assessment procedure. Figure 2. The plan for SRI-testing project in Finland [15].It is noteworthy that, there is no official Finnish version of the SRI framework has been released by the EPBD. Despite this, Motiva has proactively taken the initiative to produce a translated version, which has been used throughout the testing phase.

Motiva's testing project has gained around 70 participators from a diverse group of professionals with various backgrounds in building construction and automation fields, and with different education levels from all over Finland. More detailed participant's information will be discussed in Section 4.3. Each participant has contributed by undertaking at least one SRI assessment, resulting in a comprehensive dataset to be analysed.

The overarching goals of the testing phase are multiangled, seeking to clarify the functionality of the SRI method within the Finnish context. One main objective is to find the potential forms of SRI that could find practical application in Finland. Another crucial goal is to gain insights into the types for which the SRI is most efficient. Understanding the specific construction phases where the SRI emerges as a valuable tool, offering the most significant benefits, is a nuanced aspect that this testing project aims to uncover. By delving into the applicability of the SRI at various stages of construction, the project contributes valuable data to guide decision-making processes in the building industry.

The final goal emphasizes the broader goal of assessing the suitability of SRI to the unique Finnish context. This requires an in-depth investigation of how well SRI meets the complexity of Finnish construction practices, regulatory frameworks, and societal expectations. The testing project thus functions as a comprehensive investigation of the suitability and integration of the SRI framework into the Finnish construction landscape.

In conclusion, the SRI testing project in Finland not only evaluates the functional aspects of the SRI method, but also aims to create a path for its practical application in the Finnish context. This project is a significant step forward in increasing our understanding of how SRI can be a transformative tool in promoting smart and energy efficient building practices in Finland.

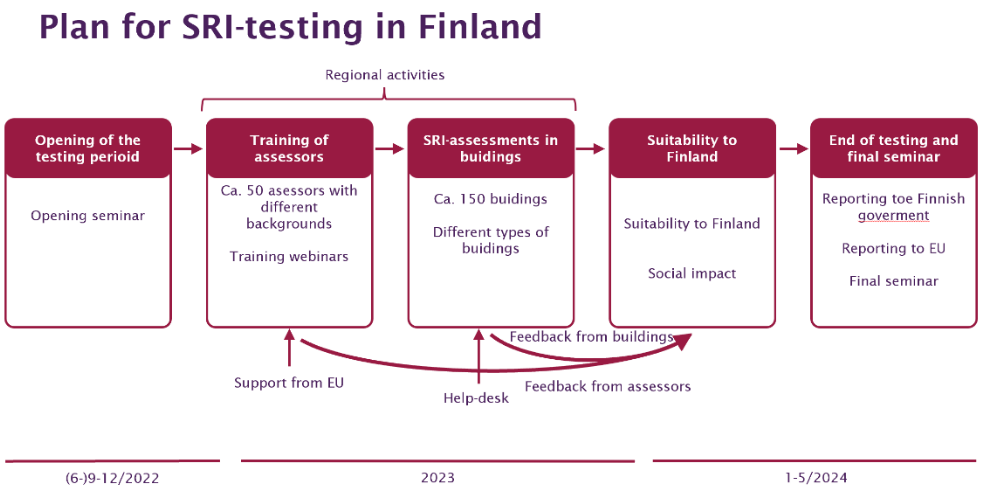


Figure 2. The plan for SRI-testing project in Finland [15].

2.5 SRI assessment structure

This section provides a detailed exploration of the structure of the SRI assessment scheme, which is built on the evaluation of different catalogues of “smart ready services”. Figure 3 illustrates the three key functionalities in smart readiness that has been highlighted in the Directive 2010/31/EU [31]. These functionalities are crucial components that define smart readiness and encompass:

1) **Response to the Needs of Occupants**: Occupant-centric considerations are integral to the SRI assessment. This functionality explores how well the building's smart features meet the needs and

preferences of its occupants. It involves assessing the responsiveness and adaptability of the building's systems to occupants' requirements.

2) **Energy Performance and efficient Operation**: This aspect focuses on evaluating the efficiency and operational aspects related to energy consumption and maintenance within the building. It delves into the building's performance concerning energy use and operational effectiveness.
3) **Energy Flexibility**: The ability of a building to flexibly respond to changes in energy demands and optimize its energy usage falls under this functionality. It encompasses features that enhance the building's adaptability to varying energy conditions and requirements.

Figure 3. Key functionalities of smart readiness in buildings. [30]

Since these key functionalities cover a wide range of different aspects, there were no simple rating systems that could perform well. Therefore, the three key functionalities have been further divided into seven distinct impact criteria, each focusing on specific aspect related to the building and its technical systems. The breakdown of these impact criteria is outlined in Figure 4Figure 6, as defined in the COMMISSION DELEGATED REGULATION (EU) 2020/2155 [16].

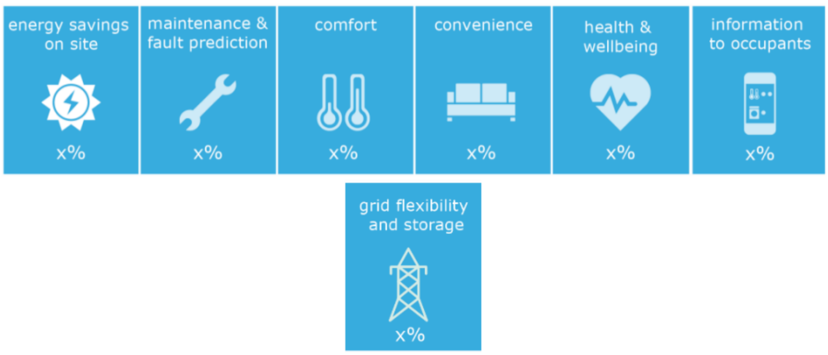


Figure 4. The structure os smart service impact criteria.

Under the key functionality “Response to the Needs of Occupants”, the SRI consider four impact criteria:

- **Comfort**: Evaluates the building's ability to provide a comfortable indoor environment for its occupants, considering factors like temperature, lighting, and air quality.
- **Convenience**: Assesses the convenience and ease of use of the building's technological systems, emphasizing user-friendly interfaces and accessibility.
- **Health, Well-being, and Accessibility**: Considers features that contribute to the occupants' health, well-being, and overall accessibility within the building.
- **Information to occupants**: Examines the building's capacity to provide relevant and real-time information to its occupants, promoting awareness and informed decision-making.

For the key functionality “Energy Performance and efficient Operation”, the SRI considers two impact criteria:

- **Energy Efficiency**: Evaluates the building's overall energy efficiency related technical systems, focusing on its ability to optimize energy consumption.
- **Maintenance and Fault Prediction**: Considers the building's capability to predict and address maintenance needs and faults in its technical systems.

The key functionality “Energy flexibility” is represented by a single impact criterion:

- **Energy Flexibility and Storage**: Assesses the building's capacity to manage the flexibility in energy usage and storage, contributing to overall grid stability, efficiency and building’s demand.

Such impacts are assessed against smart-ready services that are categorised into nine domains that are illustrated in Figure 5 below.

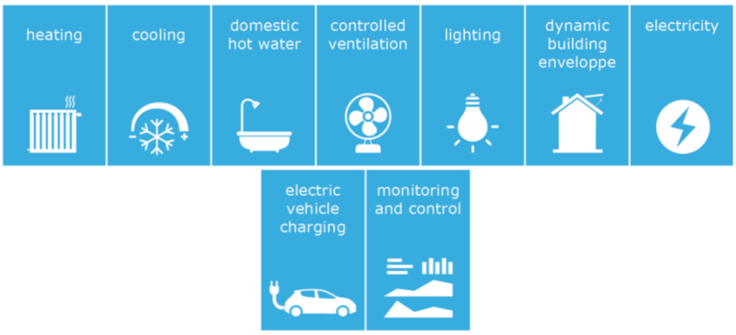


Figure 5. The structure of SRI domains.[30]

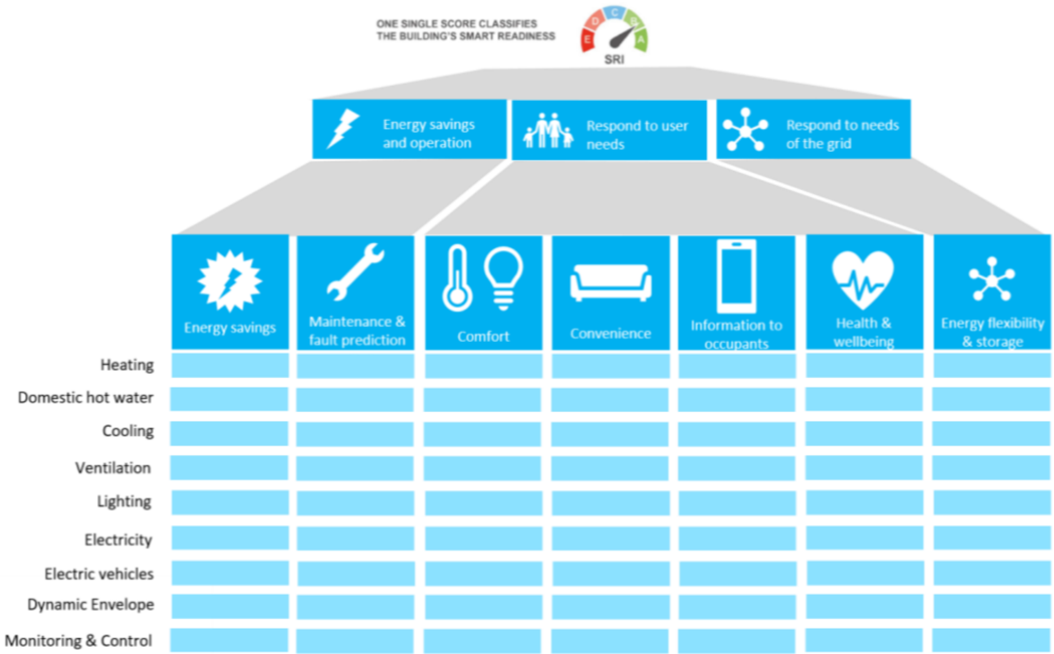


Figure 6. Structure of smart ready services (domain level and impact criteria) [30]

Figure 6 illustrates the complete SRI calculation framework. The calculation of these scores incorporates predetermined weighting factors that consider variables such as climatic conditions and building types. These factors play a crucial role in the assessment, ensuring a dedicated and context-specific evaluation of a building's smart readiness capabilities. Figure 7 illustrates the weighting distribution of the impact criteria to the three key functionalities.

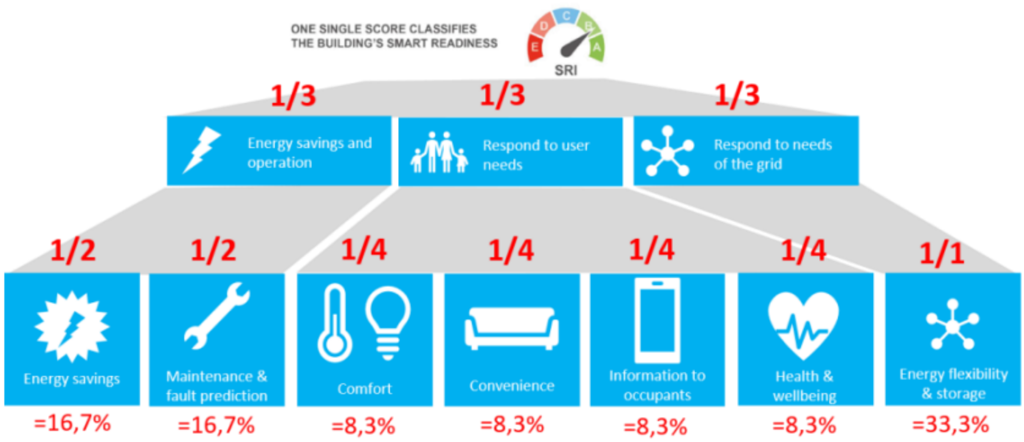


Figure 7. Aggregation of impact scores to key functionalities [30].

The impact criteria and domain level present sub-scoring and together with different weighting factors form an overall total SRI scoring. By organizing the assessment around three key functionalities, the SRI framework provides a structured and comprehensive evaluation of a building's smart readiness. Through a systematic breakdown, the SRI ensures a comprehensive evaluation of each building's smart readiness, taking into account various dimensions that collectively contribute to its overall performance, user satisfaction, and energy efficiency. This approach ensures that the assessment captures essential aspects related to energy efficiency, occupant comfort, and flexibility in energy management, contributing to an accurate understanding of a building's overall smart capabilities.

2.6 SRI assessment spreadsheet

This section provides a comprehensive overview of the calculation methodology employed for the SRI, detailed the calculation methodology of the SRI through detailed breakdown. The proposed SRI methodology aims to quantify the smart readiness of a building or unit, resulting in a total smart readiness score expressed as a percentage. This percentage score serves as a clear indicator of the building or unit's smart readiness in comparison to its maximum potential.

The interpretation of the score is straightforward: the higher the percentage, the smarter the building is to be. This quantitative approach offers a standardized and easily comprehensible metric for assessing and comparing the smart readiness of diverse building types or units. By summarizing the complex evaluation into a single percentage score, the SRI methodology facilitates a concise representation of a building's overall smart capabilities, contributing to the broader goal of enhancing the comparability of smart building assessments.

The SRI calculation spreadsheet used during the testing phase in Finland is version 4.5 that has been translated into Finnish by Motiva. The most important sheets of the calculation spreadsheet are building information sheet illustrated in Figure 8, SRI structure (Figure 6) based calculation sheet, and results sheet illustrated in Figure 9. The buildings are categorized according to their building type, net area, construction year and condition. The detailed categorization is shown on the following tables (Table 1, Table 2, Table 3, and Table 4).

Building Type	Residential	Non-Residential
	Single-family house	Office
	Small multi-family house	Educational
	Large multi-family house	Healthcare
	Other	Other

Table 1. Category of the building types.

Floor Area	M²
	<200
	200 - 500
	500 - 1 000
	1 000 - 10 000
	10 000 - 25 000
	>25 000

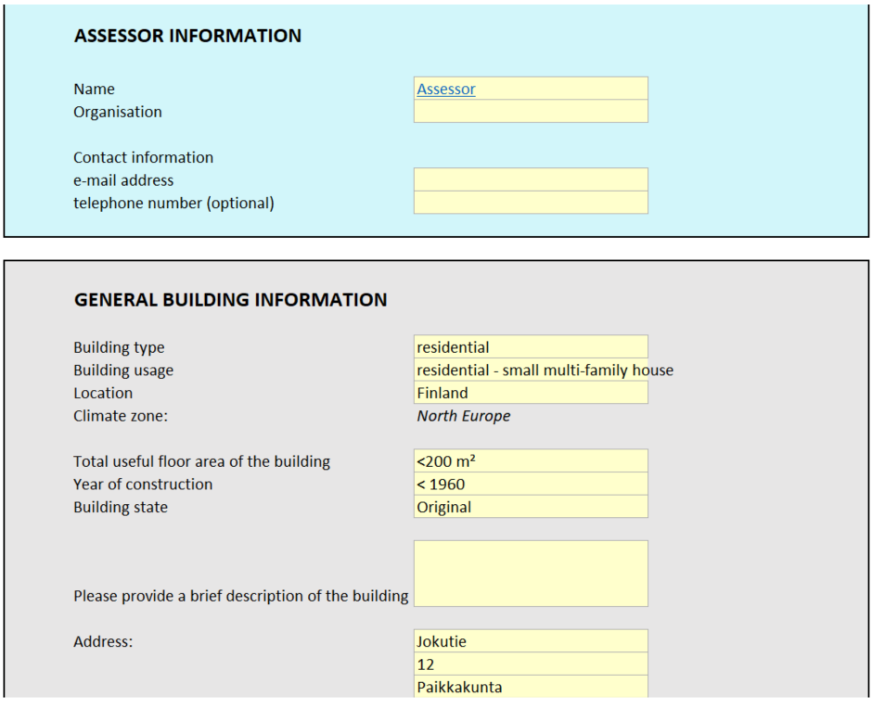
Table 2. Category of floor area.

Construction Year	
	<1960
	1960 – 1990
	1990 – 2010
	>2010
	Not constructed

Table 3. Category of the construction year.

Condition	
	Renovated
	Original

Table 4. Condition of the building.



ASSESSOR INFORMATION

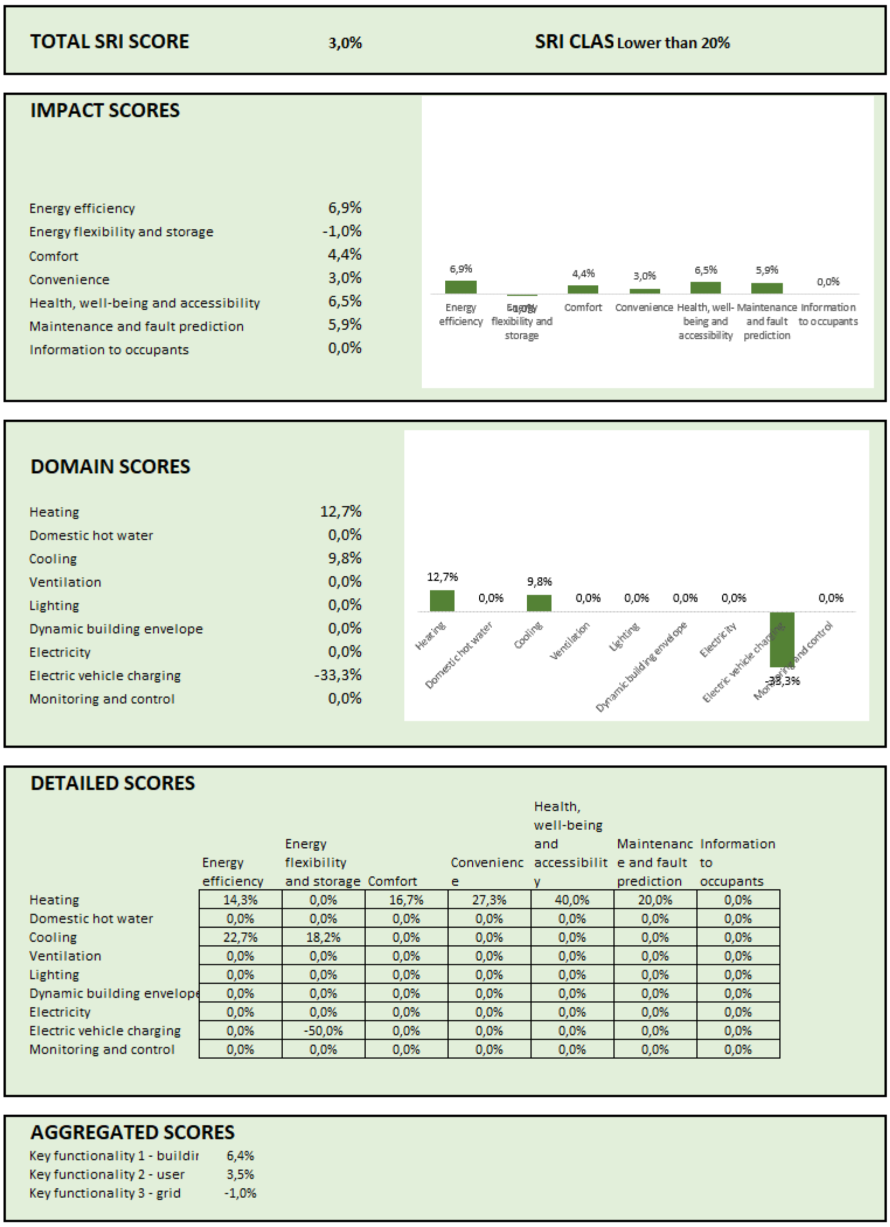
Name	Assessor
Organisation	
Contact information	
e-mail address	
telephone number (optional)	

GENERAL BUILDING INFORMATION

Building type	residential
Building usage	residential - small multi-family house
Location	Finland
Climate zone:	*North Europe*
Total useful floor area of the building	<200 m²
Year of construction	< 1960
Building state	Original
Please provide a brief description of the building	
Address:	Jokutie
	12
	Paikkakunta

Figure 8. Building information sheet from calculation sheet v4.5.

Upon completion of the calculation sheet, the results sheet compiles the scores, including sub-scoring (Impacts criteria and Domain level), forming the total SRI score, and the corresponding SRI class. The detailed categorization of the SRI total score and associated SRI class are shown in Table 5.



TOTAL SRI SCORE	3,0%	SRI CLAS Lower than 20%

IMPACT SCORES

Energy efficiency	6,9%
Energy flexibility and storage	-1,0%
Comfort	4,4%
Convenience	3,0%
Health, well-being and accessibility	6,5%
Maintenance and fault prediction	5,9%
Information to occupants	0,0%

DOMAIN SCORES

Heating	12,7%
Domestic hot water	0,0%
Cooling	9,8%
Ventilation	0,0%
Lighting	0,0%
Dynamic building envelope	0,0%
Electricity	0,0%
Electric vehicle charging	-33,3%
Monitoring and control	0,0%

DETAILED SCORES

	Energy efficiency	Energy flexibility and storage	Comfort	Convenienc e	Health, well-being and accessibilit y	Maintenanc e and fault prediction	Information to occupants
Heating	14,3%	0,0%	16,7%	27,3%	40,0%	20,0%	0,0%
Domestic hot water	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Cooling	22,7%	18,2%	0,0%	0,0%	0,0%	0,0%	0,0%
Ventilation	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Lighting	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Dynamic building envelope	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Electricity	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Electric vehicle charging	0,0%	-50,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Monitoring and control	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%

AGGREGATED SCORES

Key functionality 1 - buildir	6,4%
Key functionality 2 - user	3,5%
Key functionality 3 - grid	-1,0%

Figure 9. SRI results sheet from SRI calculation sheet (v4.5_FIN).

Sri Class	Total Sri Score
A	SRI > 90%
B	80% < SRI < 90%
C	65% < SRI < 80%
D	50% < SRI < 65%
E	35% < SRI < 50%
F	20% < SRI < 35%
G	SRI < 20%

Table 5. Total SRI scores and corresponding SRI classes.

2.7 SRI related studies

This section delves into studies related to SRI. Since SRI is a relatively new regulation in EU, only a limited number of studies applying the SRI scheme to case buildings and different climate zones exist currently [11], [12], [32], [33]. Existing research identifies methodological gaps, inconsistencies, and limitations in the SRI assessment across different residential and non-residential buildings. The assessors' subjective opinions and potential for different interpretations during the SRI assessment process raise concerns about the fairness of the current EU-level evaluation scheme. This subsection will discuss some of the existing studies in a chronological order according to their release year starting from 2019.

Janhunen et al. [32] analysed the applicability of the SRI for cold climate countries in Northern Europe, in this case in Finland. The study focuses on technological fit, comparing the smart ready service catalogue and selecting SRI relevant building services. Results indicate that, without adjustments, the current SRI framework may not be fully applicable to cold climate countries or encourage smart ready technology (SRT) implementation. In terms of technological fit, the SRI couldn't address properly the buildings that utilize mainly advanced districted heating (DH) systems to cover the large heating demand. Additionally, despite the SRI scheme's context-specific evaluation, the current form of the indicator struggles to recognize some cold climate country-specific technologies.

The study acknowledges limitations, such as the need for a more extensive sample of buildings for a comprehensive analysis of SRI applicability to cold climates to cover demand response capabilities of energy grids, including district heating. Additionally, the study highlights a practical implication: the subjective nature of the proposed process for selecting SRI-relevant building services raises concerns about the applicability of the SRI as a fair rating system across EU member states. [32]

Researchers Märzinger et al. [34] evident that a higher SRI value corresponds to higher flexibility in a building to store and release energy back to the grid when needed through the article. In other words, a higher SRI suggests that the building is more adept at managing and utilizing energy resources efficiently, contributing to a more responsive and dynamic role within the broader energy system. This aligns with the idea that buildings with a higher SRI are better equipped for storing and redistributing energy based on demand and grid conditions.

Vigna et al. [11] have implemented the SRI method where they focus on exploring the feasibility and applicability through practical application, particularly in the context of a nearly zero-energy (NZE) office building in Italy. The evaluation involves two distinct expert groups, one comprised of researchers and the other of technical building systems specialists, working in parallel. Using a two-step assessment approach, the groups initially work separately and then compare results, discussing discrepancies and identifying challenges in applying the methodology. Similarly to Janhunen et al., the research of Vigna et al. also outlined the impact of subjective decision makings in the selection of proper functionality levels and services during the assessment.

In addition to this, Vigna et al. [11] concluded with a set of recommendations aiming at broad and effective implementation of the SRI, emphasizing enhanced relevance, effectiveness, comparability, benchmarking, and integration with other measurable indicators, particularly those related to energy flexibility. For instance, they identified the initial challenge in the evaluation process was the difficulty in retrieving the necessary technical documentation for the detailed assessment due to the complex nature of the building, involving various stakeholders and technical systems. The analysis revealed that the source of information significantly influences the evaluation's accuracy, emphasizing the need for a defined source hierarchy to reduce uncertainties.

The study also highlighted the impact of assessor interpretation on the SRI evaluation, particularly in selecting relevant building services and functionality levels. The lack of a comprehensive guidance document describing smart services and their translation into specific functionalities contributes to this challenge. To address this, the paper suggests allowing Member States to define national guidelines tailored to their contexts, specifying functionality levels for commonly applied technologies. [11]

The paper recommends clarifying procedures for considering services relevant to building smartness based on factors such as floor area coverage, energy use, or user involvement. In terms of interpreting results, the impact scores for individual criteria were deemed more informative than the overall SRI score. The paper proposes introducing a classification of assessed scores for each criterion to aid stakeholders in decision-making for improving smartness levels. [11]

The methodology's current limitations include its ability to compare only buildings with similar smart technologies, making benchmark definition complex. To address this, the paper suggests providing clear benchmarks and acceptable smartness levels, making SRI results more relevant at a broader level. For enhanced relevance, the paper recommends defining criteria accurately and associating each with measurable parameters. Though the SRI is qualitative, introducing measurable parameters can facilitate performance comparison. Examples include using physical quantities like hours of thermal discomfort and indicators such as CO_2 concentration for criteria like 'Comfort' and 'Wellbeing and health.' [11]

The authors suggest that the SRI should primarily target key stakeholders in future energy distribution systems. The 'Energy flexibility and storage' criterion, crucial for grid operators, aggregators, and energy prosumers, could benefit from a qualitative indicator measuring the building's energy flexibility. This would support grid operators in handling energy demand fluctuations and enable cost-effective energy supply solutions based on renewable energy availability, providing valuable information for the future energy system. [11]

Fokaides et al [33] attempted to present and identify the gaps in the SRI assessment scheme evaluating a mixed-use building in Cyprus. The authors identified that the current SRI framework is not well tailored for small residential buildings that usually do not have BMS offering a central monitoring and control. Another significant gap identified is the lack of recognition of challenges in historic buildings, their potential smart applications, and the absence of a tailored assessment system for historical building intelligence. The researchers also emphasized the need for SRI to be tailored to different building types, considering varying user activities and system requirements.

Apostolopoulos et al. [12] employed the SRI assessment methodology in two common residential building types—Single-Family Houses and Multi-Family Houses—across five EU countries (Denmark, Czech Republic, Greece, Bulgaria, and Austria). The objective is to assess the retrofitting cost for enhancing building smartification and to evaluate the resulting SRI scores under different retrofitting scenarios. The assessment involves three steps: calculating the baseline SRI according to national minimum requirements, assessing SRI after retrofitting with market-available technologies toward Nearly Zero Energy Buildings, and evaluating a comprehensive retrofitting scenario toward Positive Energy Buildings.

They found that buildings constructed post the Energy Performance of Buildings Directive (EPBD) implementation show a relatively lower cost for increasing smartness compared to older buildings. However, their initial overall SRI score typically falls into the SRI Class G (0–20%), with strengths in "Health, well-being and accessibility" and "Comfort" impact categories. Retrofitting scenarios focusing on building automation and control measures can elevate these buildings to Class "C" (65–80%), particularly improving energy efficiency when retrofitting toward Nearly Zero Energy Buildings. Additionally, retrofitting scenarios with potential for energy positiveness primarily enhance building-grid interaction. [12]

3 Methodology

This chapter serves as the cornerstone of the thesis, providing an in-depth exploration of the methodological choices, their constraints, and the underlying principles that govern the study. It offers a comprehensive view of the research data, the approach to human subjects, the implementation of the research, and the methods employed. Throughout, the section not only elucidates the strengths of the research but also candidly discusses its limitations. Drawing from the practices of earlier researchers, this methodology is articulated to present a clear account of the undertaken study.

3.1 Research Design and Framework

In further elaborating on the research design and framework, it is crucial to underscore the significance of the SRI in broader context of building practices. This section presents the fundamental elements guiding the study's approach, outlining the design choices and conceptual framework that guide the study's approach. As detailed in section 2.3, the SRI plays a pivotal tool supporting building renovation, encouraging the adoption of smart technologies with the goal of promoting the energy efficiency within the EU. The SRI not only address immediate energy efficiency goals but also align with the broader sustainable goals.

Since its official introduced in 2018, it is undergoing a testing phase at the Member State. This testing phase is a testament to the commitment to ensuring the adaptability and utility of the SRI across diverse EU countries. In Finland, a country at the forefront of sustainable practices, this testing phase gains particular significance. The ongoing testing phase becomes an invaluable opportunity to evaluate the applicability of the recent SRI assessment scheme in the unique Finnish setting.

This thesis contributes to the ongoing testing phase in Finland by assessing the applicability of the recent SRI assessment scheme. The primary dataset utilized for in-depth statistical analysis is delivered from SRI case assessments collected by Motiva. These assessments were captured through various assessors from different building construction companies across Finland that provides a rich repository of information. Utilizing this dataset leverages the dedicate qualitative metrics that shape the effectiveness of the SRI framework.

The adoption of a quantitative analysis design aligns seamlessly with the structured and numerical nature of SRI assessments. It allows for a systematic examination of statistical data extracted from the SRI case assessments, emphasizing the need for precision and objectivity in the evaluation process. This approach allows for a robust evaluation of the SRI metrics and their relevance in the Finnish setting. To ensure a systematic and comprehensive evaluation, the research is divided into 3 steps:

- Data processing.
- Data analytics and visualization.
- Statistical data analytics.

The initial step involves data processing, addressing the complexity of the existing SRI case assessments collected by Motiva. They have used the most recent version calculation sheet 4.5. in their testing project. Despite the pre-existing dataset, the assessments were scattered across separate Excel files with multiple sheets. The overwhelming information required meticulous data cleaning, formatting, and extraction. This process aimed to enhance data clarity and extract key factors essential for subsequent analyses. The extracted factors were then compiled into an Excel spreadsheet, serving as the foundational data source for subsequent steps.

The second step engages data analytics and visualization, employing advanced tools such as Power BI and Jupyter Notebook with Python programming. Power BI is known for its capacity in statistical data management, transforms raw data into interactive visualizations. This capability facilitates the extraction of insights at both a high level and detailed drill-downs, offering a holistic understanding of the data. On the other hand, Jupyter Notebook provides a flexible platform for combining and modelling modular, that can be used repeatably, allowing for the customization of visualizations with specific plot settings. In the Jupyter Notebook, the searborn package was used to visualize correlation plots and violin plots, that shows the density of scores.

The last step was the statistical data analytics based on the visualisation results from the second step. The final step concentrates around statistical data analytics, building upon the insights gathered from the visualizations generated in the preceding step. This phase involves a thorough examination of data patterns and correlations revealed through Power BI and Jupyter Notebook, contributing to a thorough understanding of the applicability and relevance of the SRI framework in the specific context of Finland.

This methodological framework ensures a structured evaluation of the SRI assessment scheme, leveraging advanced tools and techniques to derive meaningful insights from the complex dataset. The stepwise approach allows for transparency and replicability, essential components of robust quantitative research. While the research is primarily focused on quantitative analysis, the consideration for qualitative analysis is noteworthy. The choice for a quantitative approach is driven by the feedback from assessors after the assessments, aligning with the research goals. However, recognizing the potentials of qualitative insights, qualitative aspects may be explored in future research to supplement the quantitative findings. This decision underscores a holistic approach to research, where both quantitative and qualitative perspectives are valued for a more comprehensive understanding of the subject matter.

3.2 Data collection procedure and Training

As section **Error! Reference source not found.** has explained, this thesis is built upon the research data collected by Jaakko Ketomäki's group during their SRI testing project. This section details the data collection procedure and participant training process crucial elements contributing to the robustness and reliability of the research findings. As the primary source of the dataset, Motiva played an important role in ensuring the accuracy of the information. Recognizing the sensitive nature of the data, the information related to assessors and assessed objects have been presented in a balance between the precision and anonymity. Personal details of assessor, including their name and building addresses, are treated anonymously in this work to meet the confidential requirements of Motiva.

Motiva provided initial training to a diverse group of voluntarily registered participants with different working and education backgrounds from various companies from building construction, energy assessment, and property management fields across Finland and some universities and cities are also actively participated. These participants underwent a comprehensive introducing process. The training was structured to be familiar with the most recent revised SRI assessment scheme and calculation sheet (version 4.5.) that was available when the testing project started. The Excel calculation sheet has multiple sheets and translated into Finnish.

Beside introducing the SRI assessment scheme, the calculation methodology in the Excel-based calculation sheet, there were also practical examples to illustrate the application of theoretical concepts. The collaborative aspect of the training was emphasized through case assessments conducted jointly with trainers and participants. This hands-on approach allowed participants to pose questions and seek clarification, ensuring a deeper understanding of the assessment process, and facilitating a uniform interpretation of the assessment criteria. The case assessments were done together with trainers and participants where the participants could ask assessment related questions.

Following the training session, assessors were responsible to independently evaluate different buildings over a specified timeframe. The voluntary nature of their involvement and the diverse backgrounds they represented added layers of authenticity to the assessment process. Around 70 participated in Motiva's testing project but a total of 51 assessors have been participated actively till the end, each contributing at least one assessment. The geographical distribution of SRI assessments shows the comprehensive nature of the testing process.

3.3 Data processing

This section outlines the comprehensive data processing procedure used to manage and extract valuable insights from diverse dataset received from Motiva. The dataset includes:

- SRI assessments
- Assessors' information
- Assessors' final feedback

The SRI assessments were done individually using Excel calculation sheets. To extract key data, a precise procedure was implemented, including the separation of information from each assessment. The extracted information from the datasets was categorized into three groups. The information extracted from SRI assessments was categorized into two main groups:

1. SRI-related information:
   - Scores, metrics directly associated with the Smart Readiness Indicator.
   - Technological aspects and functionalities assessed within the SRI framework.
2. Building-related information:
   - Building characteristics, such as size, construction year, and location.
   - Specific features and components evaluated within the context of the building.

The third information group was extracted from Assessors' information that was collected into an Excel spreadsheet.

3. Assessor-Related Information:
   - Information about the assessors involved in the evaluations.
   - Background, expertise, and skills of assessors contributing to the assessments.

The detailed data structure is illustrated below:

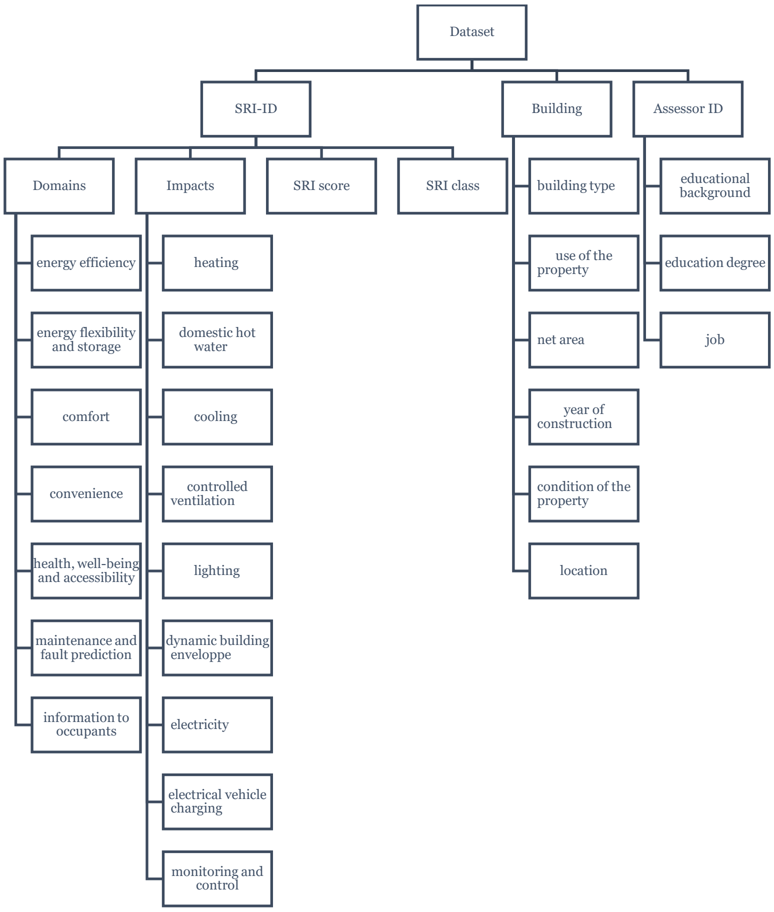


Figure 10. Structure of the dataset for analysis.

To capture the qualitative aspects of the assessments, the final feedback from assessors was collected through individual interviews by Motiva. The results of these interviews were systematically compiled into a Word file, providing a rich source of qualitative insights. The same approach was taken with the assessors' information, compiling details about the assessors' educational background, work experience, and specific skills related to the assessment process.

By combining quantitative data from the SRI assessments with qualitative information gathered from assessors' feedback, this data processing methodology ensures a comprehensive and multifaceted analysis. The structured extraction of information allows for a nuanced understanding of the interplay between SRI metrics, building characteristics, and assessor-related factors, contributing to a holistic evaluation of the Smart Readiness Indicator in the Finnish context.

This thorough data processing procedure lays the foundation for subsequent analyses, ensuring the accuracy and reliability of the insights derived from the diverse dataset provided by Motiva.

4 Results

This chapter delves into the findings of the study, offering insights that address the research questions formulated in the Introduction chapter.

4.1 SRI Data Processing and preliminary Findings

This section provides an exploration of the data cleaning and extraction process, discovering the initial insights gained from the comprehensive dataset collected during the SRI testing phase in Finland. The presentation of preliminary findings aims to offer an initial exploration of the empirical study's results and how they contribute to addressing the research questions outlined in the Introduction. This preliminary overview aims to initiate an understanding of the empirical study's outcomes, setting the stage for later critical reviews and interpretations.

The data processing applied to the dataset collected from 93 SRI assessments conducted by 51 trained assessors. The focus of this processing extends to both the diverse calculation factors and building characteristics assessed in the SRI evaluations, as well as the comprehensive information about the assessors. The analysis is focusing on the statistical approach and divers characteristics of assessed buildings, including location, building type, construction year, and size.

The resulting datasheet, structured as discussed in Section 3.3, categorizes information into SRI-related, Building-related, and Assessor-related components. This organizational framework facilitates a comprehensive understanding of the multifaceted aspects captured during the SRI assessments. The following four figures (Figure 11, Figure 12, Figure 13, Figure 14) illustrate the first five contents of the SRI assessments from the extracted datasheet. These figures serve as a preliminary exploration of the dataset, showcasing the diverse range of information gathered from the assessments. The compiled data reside in an Excel table sheet, serving as the foundational input for subsequent data analysis and visualization using tools like Power BI and Jupyter Notebook with Python programming.

	A	B	C	D	E	F	G	H	I	J
1	SRI-ID	energy efficiency	energy flexibility and storage	comfort	convenience	health, well-being and accessibility	maintenance and fault prediction	information to occupants	SRI score	SRI class
2	MOT-01-008	0,68	0,05	0,59	0,45	0,58	0,48	0,53	38,90	E
3	MOT-01-091	0,71	0,50	0,64	0,56	0,51	0,45	0,59	55,21	D
4	MOT-01-127	0,61	0,02	0,52	0,40	0,51	0,37	0,39	32,36	F
5	MOT-02-001	0,20	0,03	0,28	0,15	0,19	0,04	0,05	10,80	G
6	MOT-02-002	0,51	0,13	0,58	0,46	0,44	0,35	0,34	33,93	F

Figure 11. First five SRI-score, -class and impacts.

	A	K	L	M	N	O	P	Q	R	S
1	**SRI-ID**	**heating**	**domestic hot water**	**cooling**	**controlled ventilation**	**lighting**	**dynamic building enveloppe**	**electricity**	**electrical vehicle charging**	**monitoring and control**
2	MOT-01-008	0,37	0,67	0,00	0,82	0,57	0,00	0,21	0,07	0,49
3	MOT-01-091	0,64	0,37	0,00	0,65	0,37	0,00	0,15	0,42	0,66
4	MOT-01-127	0,31	0,23	0,00	0,70	0,22	0,00	0,53	-0,31	0,46
5	MOT-02-001	0,13	0,07	0,00	0,08	0,37	0,00	0,00	0,00	0,14
6	MOT-02-002	0,38	0,32	0,44	0,33	0,29	0,00	0,18	0,67	0,41

Figure 12. First five SRI domains.

	A	T	U	V	W	X	Y	Z	AA
1	**SRI-ID**	**building type**	**use of the property**	**net area**	**year of constructio n**	**condition of the property**	**location**	**Arvioitsija ID**	**education level**
2	MOT-01-008	**Non-residential building**	Educational institution	1000-10000	>2010	Original	Lahti	**AR-35**	university of
3	MOT-01-091	**Non-residential building**	Educational institution	500-1000	>2010	Original	Lappeenrant:	**AR-46**	university
4	MOT-01-127	**Non-residential building**	Other	1000-10000	>2010	Original	Jyväskylä	**AR-03**	university
5	MOT-02-001	**Residential building**	Apartment	1000-10000	1960-1990	Original	Vantaa	**AR-25**	university
6	MOT-02-002	**Residential building**	Apartment	1000-10000	>2010	Original	Helsinki	**AR-36**	university

Figure 13. First five Building information.

	A	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP
1	**SRI-ID**	**building engineering (elec)**	**building engineering (HVAC)**	**building engineering (automatic**	**construction technology**	**energy engineering**	**else educations**	**no edu information**	**assessor of energy certificate**	**energy auditor**	**electrical engineer**	**HVAC designer**	**building engineering expert**	**automation designer**	**else positions**	**no work information**
2	MOT-01-008	applied sciences					electrical and automation engineering						expert			
3	MOT-01-091					energy	environmental engineerin		assessor	auditor						
4	MOT-01-127		HVAC										expert		certified building health spec	
5	MOT-02-001					energy				auditor			expert			
6	MOT-02-002	elec													Doctoral student/ Smart Buil	

Figure 14. First five Assessors' information.

As discussed on this initial exploration, it is imperative to exercise critical caution regarding the significance of the results. While these preliminary findings offer a glimpse into the dataset, a thorough and critical review will be conducted in later sections, potentially in conjunction with the Conclusions chapter. By acknowledging the importance of data integrity and the meticulous processing undertaken, the study establishes a foundation for the subsequent critical analysis and interpretation of results. This section sets the stage for a deeper exploration of the empirical study's results, providing an initial overview of the processed data and laying the groundwork for subsequent critical discussions in later chapters.

As illustrated in Figure 15, the assessments covered nearly the entire country. While the northernmost part of Finland is an exception, the coverage otherwise spans diverse regions, providing a holistic view of the applicability of the SRI framework across different locales in Finland.

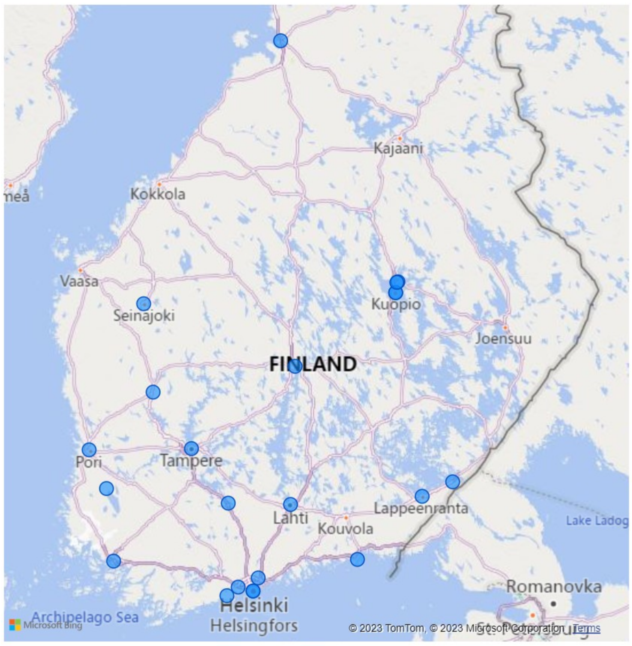


Figure 15. Locations of the assessments.

In Figure 16, the pie chart further illustrates the detailed number of assessments conducted in different cities. The concentration of results in Southern Finland, particularly in Helsinki (30%), Jyväskylä (~12%), and Turku (~10%), is noteworthy. This spatial distribution not only reflects the density of assessments but also offers insights into regional variations and preferences concerning smart readiness in buildings.

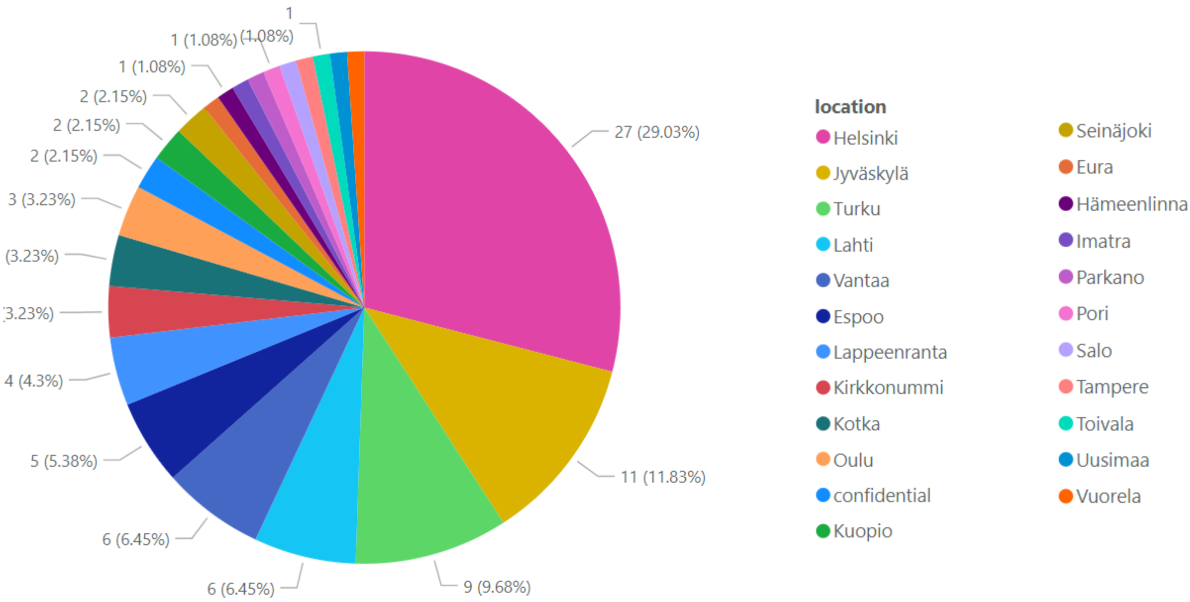


Figure 16. Number of assessments per city.

The pie chart in Figure 17 provides a visual representation of the distribution of different building types. Notably, non-residential buildings significantly outnumbered residential ones, constituting over 80% of the assessed buildings. Non-residential buildings encompassed diverse categories, including offices, educational institutions such as kindergartens, elementary schools, and university campuses, hospitals, and other non-residential structures without further categorization. On the other hand, residential buildings comprised apartments, single-family houses (in Finnish, "pientalo"), small multi-family houses (in Finnish, "rivitalo"), and other residential structures.

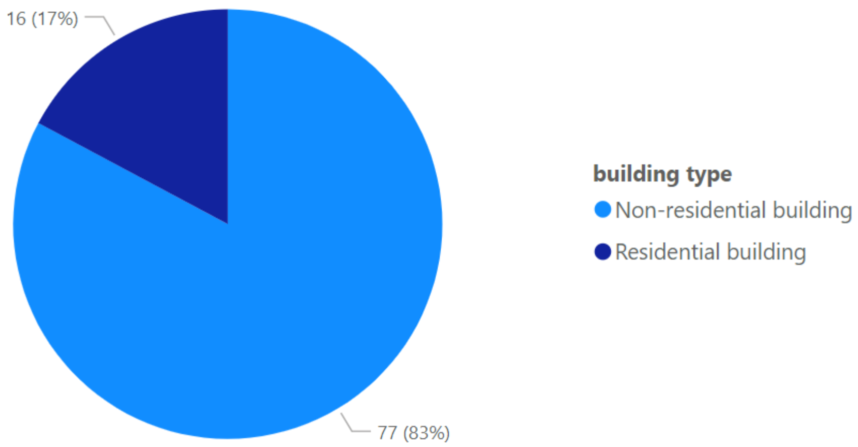


Figure 17. Number of assessments per building type.

Figure 18 shows the distribution of each use of buildings. Offices were assessed the most followed by educational institutions and the number of apartments was the largest within the residential buildings.

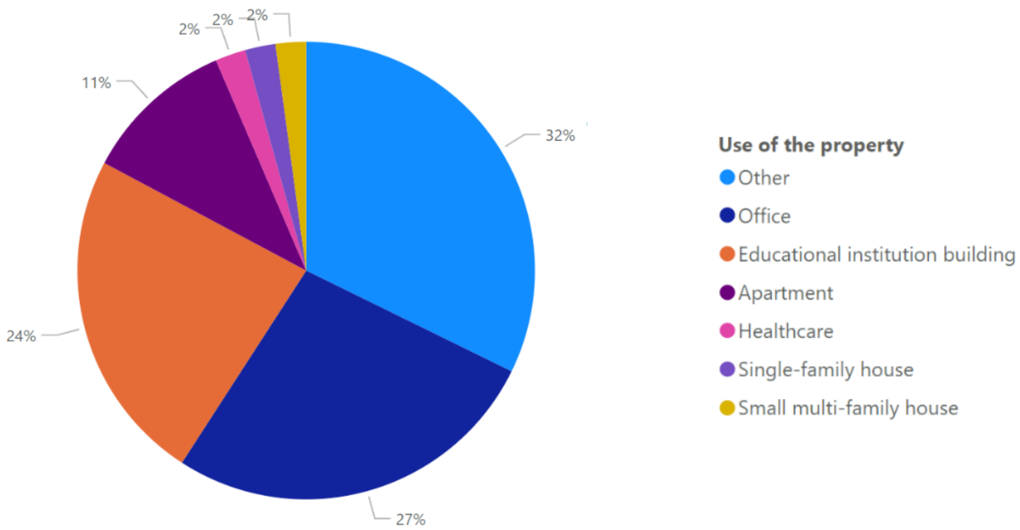


Figure 18. Use of the assessed buildings.

Figure 19 shows the distribution of each year of construction. The buildings constructed after 2010 (40%) had the significant portion following by buildings constructed in 1960-1990 (38%).

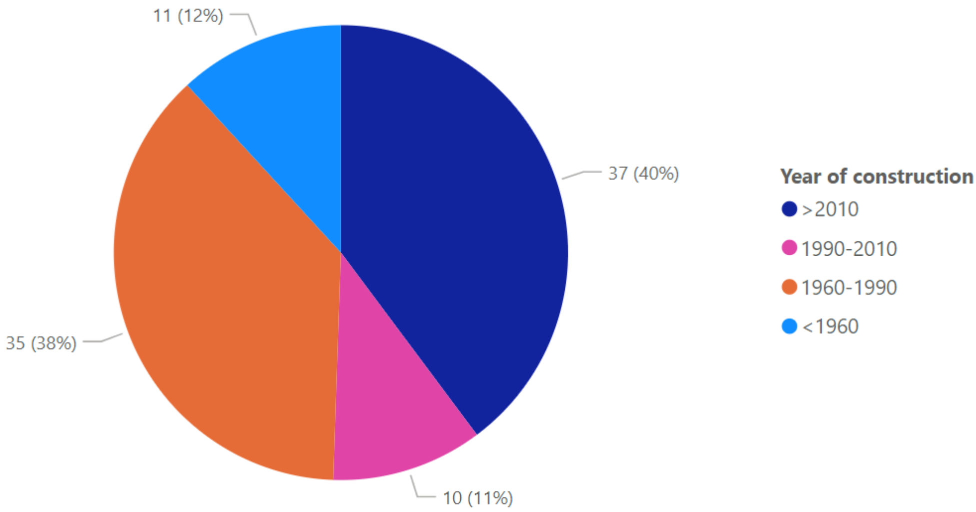


Figure 19. Number of assessments per year of construction.

The combination of construction year, building type and total SRI score is visually represented in Figure 20, providing a more comprehensive overview of the assessed buildings. The x-axis displays SRI scores as percentages, while the y-axis depicts the construction year. Different shapes of blue represent building types, with darker blue indicating residential buildings and lighter blue representing non-residential buildings. This visualization allows for a detailed understanding of how SRI scores vary across different construction years and building types.

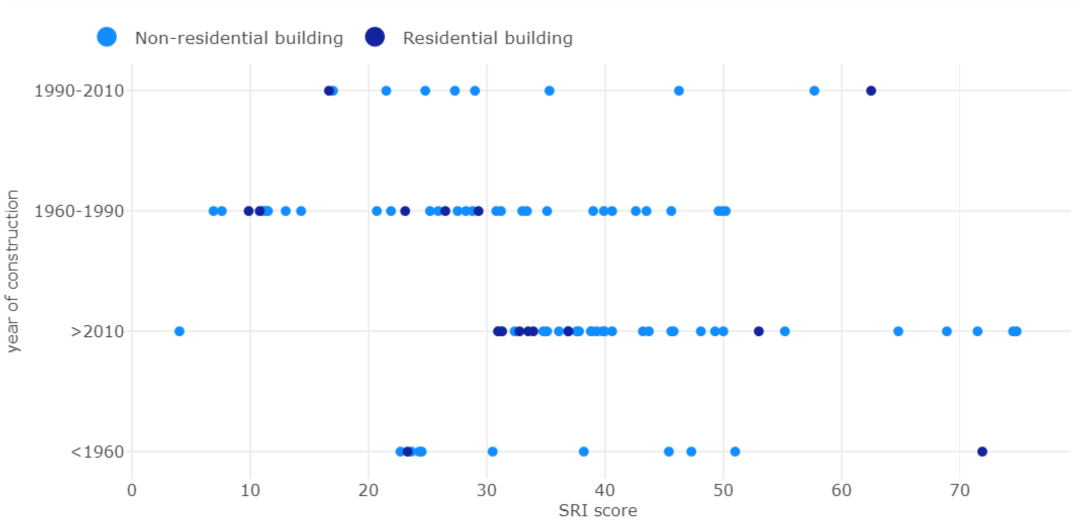


Figure 20. The building type of each building distributed in different construction year.

The assessed buildings have different conditions. The following histogram (Figure 21) illustrates the average of total SRI score by the year of construction and the condition of the building. The buildings constructed after 2010 have the highest average, following by buildings constructed before 1960.

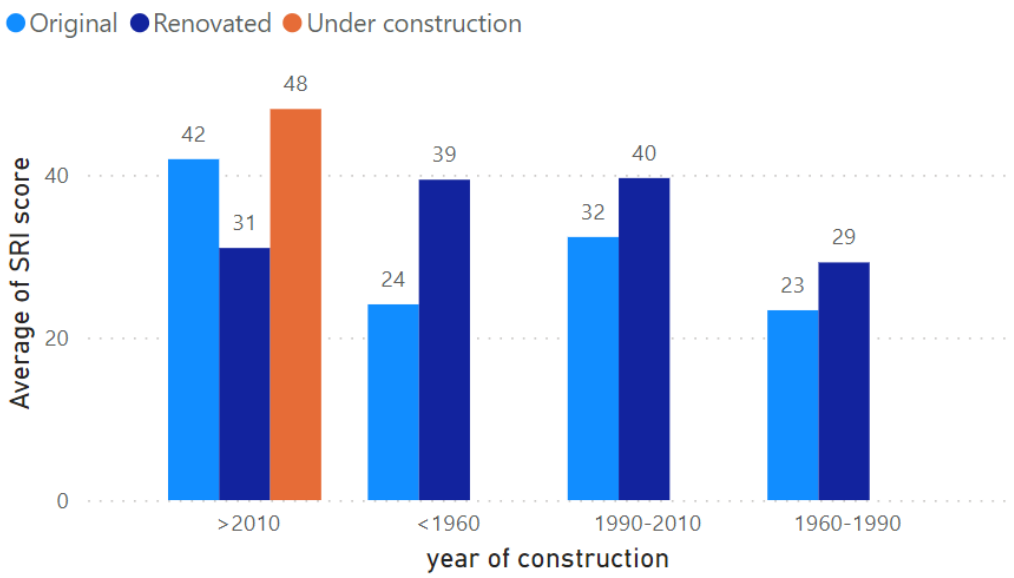


Figure 21. Average of total SRI score by year of construction and condition of the building.

Figure 23 shows the count of buildings by their year of construction and condition. The buidings constructed between 1990-2010 and after 2010 have significant low renovation rate. The buildings constructed between

1960-1990 have over 50% of the buildings renovated. The buildings constructed before 1960 are almost all renovated. The high renovation rate explains also the previous high average.

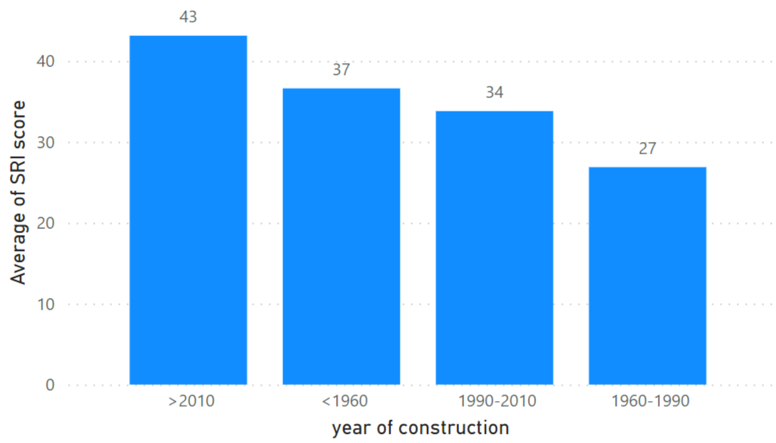


Figure 22. Average of total SRI score by year of construction.

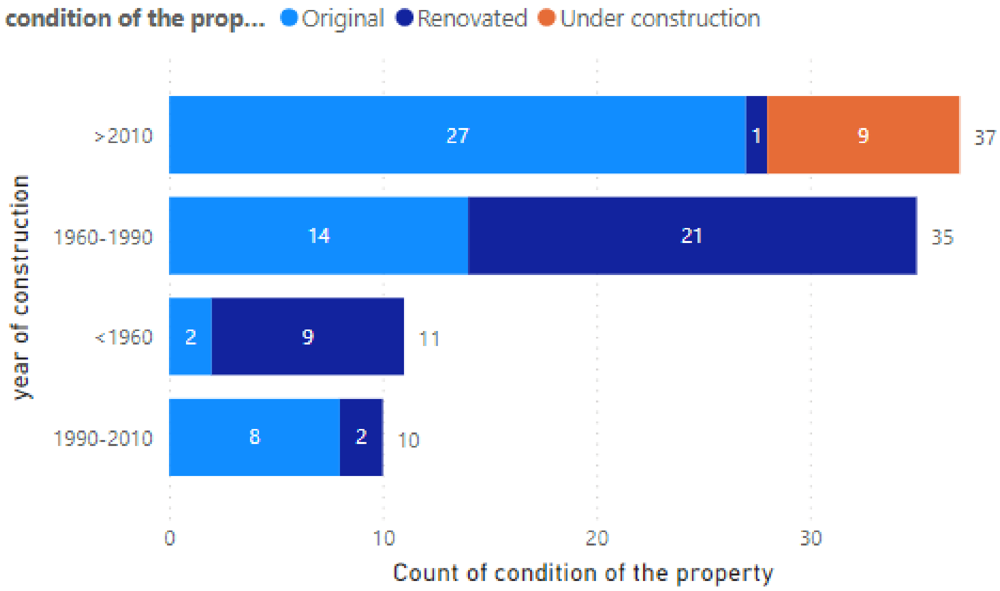


Figure 23. Count of buildings by their year of construction and condition.

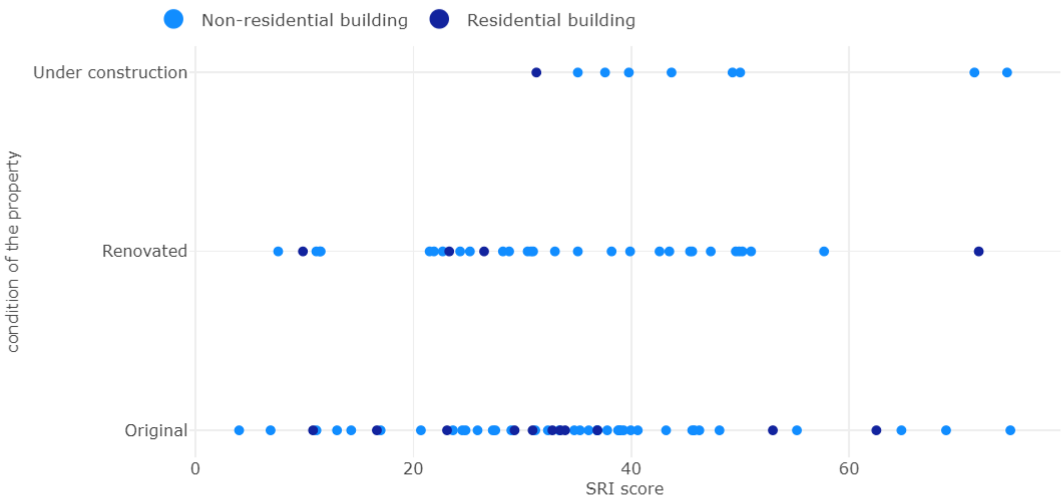


Figure 24. Condition of the building by total SRI score and building type.

4.2 Analysis of SRI assessments

This section includes the review of the visualisations and analysis of assessment results, focusing on the SRI scores and scores of building services. The correlations between different impacts and domains were also visualized to see the influencing factors and their correlations.

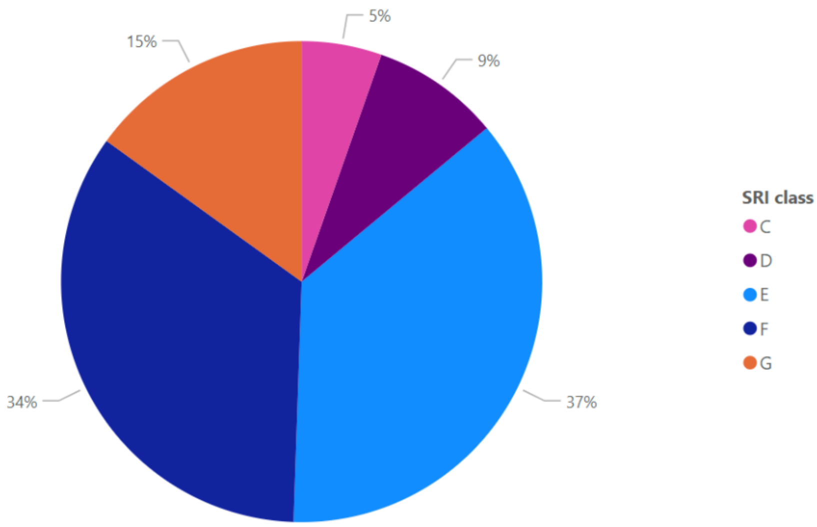


Figure 25. Distribution of buildings by the SRI classes.

The Figure 26 illustrates the distribution and density of the total SRI scores in different building types. X-axis shows the total SRI score and y-axis the density of the results. The orange line illustrates non-residential buildings and blue line residential ones. The highest density of the residential buildings locates in lower SRI score than non-residential ones.

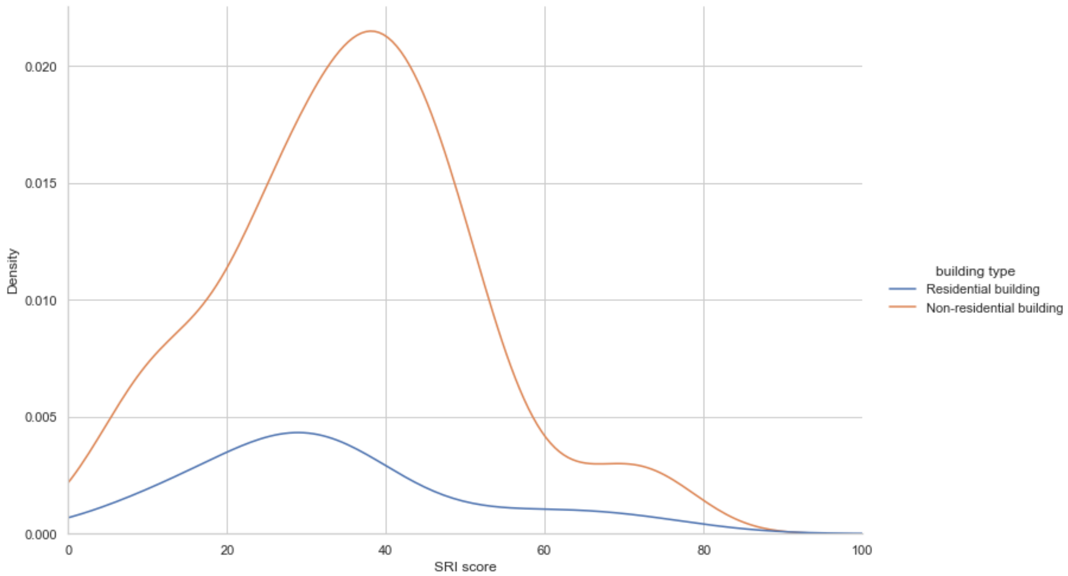


Figure 26. Distrubution and density of different building types by total SRI score.

Table 6 illustrates the average scores of the impact criterion, with 1.00 representing the maximum score. Notably, energy efficiency has achieved the highest score at 0.53, followed by comfort at 0.5, and health, well-being, and accessibility at 0.46. The visualization offers a clear overview of the performance of each impact category, providing valuable insights into the strengths and areas for improvement within the context of the SRI framework.

	Average
Energy efficiency	0.53
Energy flexibility and storage	0.16
Comfort	0.50
Convenience	0.39
Health-, well-being, and accessibility	0.46
Maintenance and fault prediction	0.39
Information to occupants	0.40

Table 6. Impact score averages.

Figure 27 shows violin plot to present the density of each impact criterion. The vertical height of each factor represents the range between the maximum and minimum scores, while the width illustrates the frequency of each score. A notable observation from the plot is that the impact criterion

"Energy Flexibility" appears to have the lowest scores, indicating potential challenges or areas requiring improvement in this specific aspect of the SRI assessment.

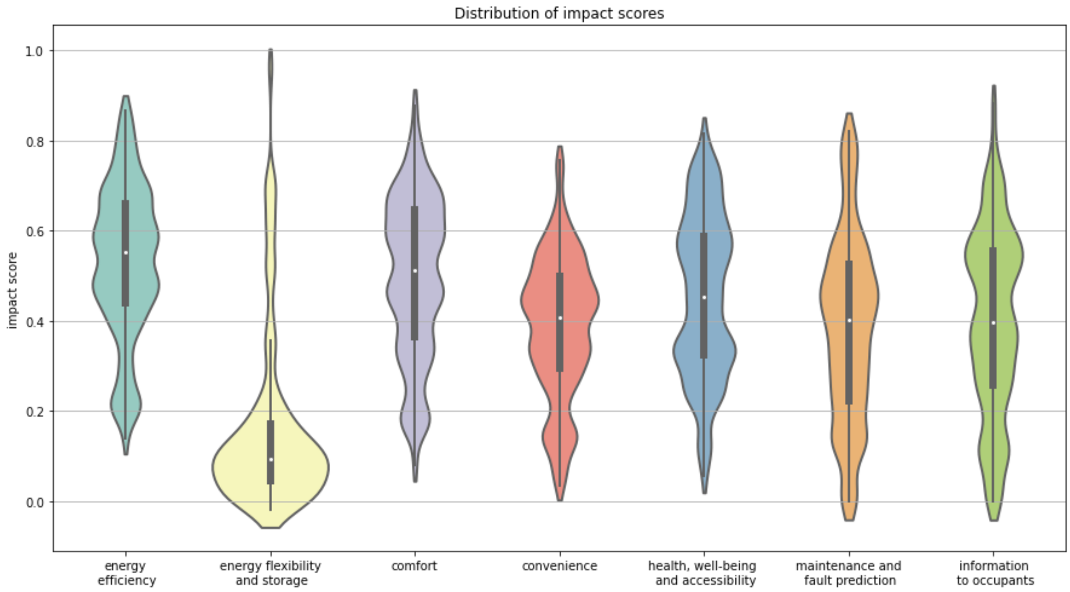


Figure 27. Distribution and density of impact scores.

Table 7 and Figure 28 illustrates the same results of domains. The “Dynamic Building Envelope” appear to have the lowest score followed by “Electrical Vehicle Charging”, indicating potential challenges or areas requiring improvement in this specific aspect of the SRI assessment.

	Average
Heating	0.41
Domestic hot water	0.42
Cooling	0.22
Controlled ventilation	0.50
Lighting	0.34
Dynamic building envelope	0.04
Electricity	0.18
Electrical vehicle charging	0.06
Monitoring and control	0.38

Table 7. Domain score averages.

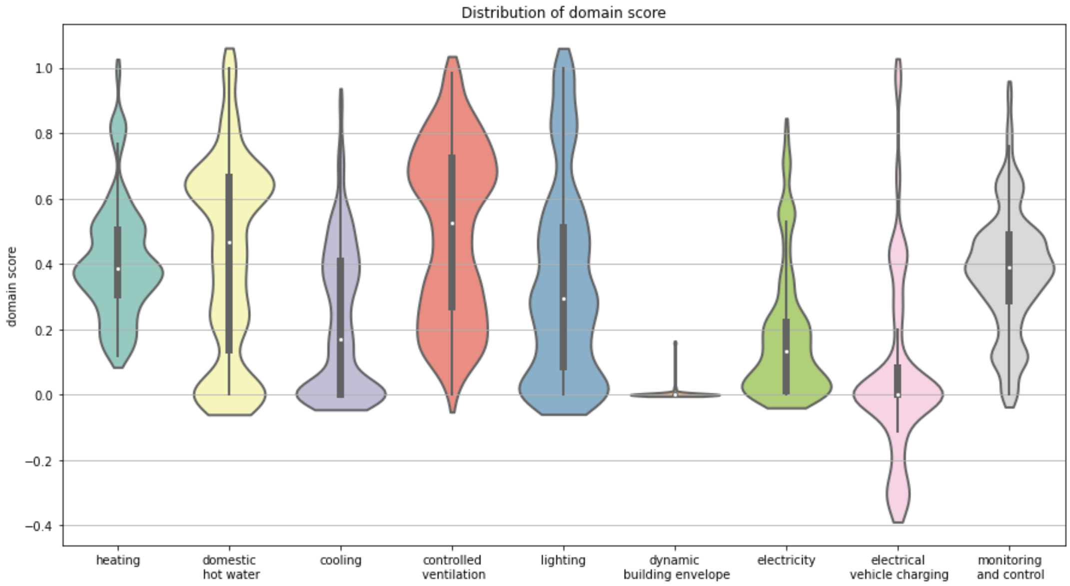


Figure 28. Distribution and density of domain scores.

Figure 29. Correlation plots between impacts and density histograms of each impact. Figure 29 and Figure 30 provide visual representations of the correlation between different impacts and domains, offering insights into the influences of various factors to another. In the correlation plots, each point corresponds to the impact and domain scores of individuals assessed buildings, contributing to the overall understanding of how these buildings perform in different aspects. The regression line across the plot signifies the correlation between each factor, indicating whether an increase or decrease in one factor corresponds to a similar change in another.

The diagonal histogram complements the plot by illustrating the density of scores along the diagonal axis. This histogram provides a distribution overview, helping to identify patterns and trends in the impact scores. By examining both the scatter plot and the histogram, it becomes possible to find the strength and direction of correlations, as well as the concentration or dispersion of scores within each impact and domain.

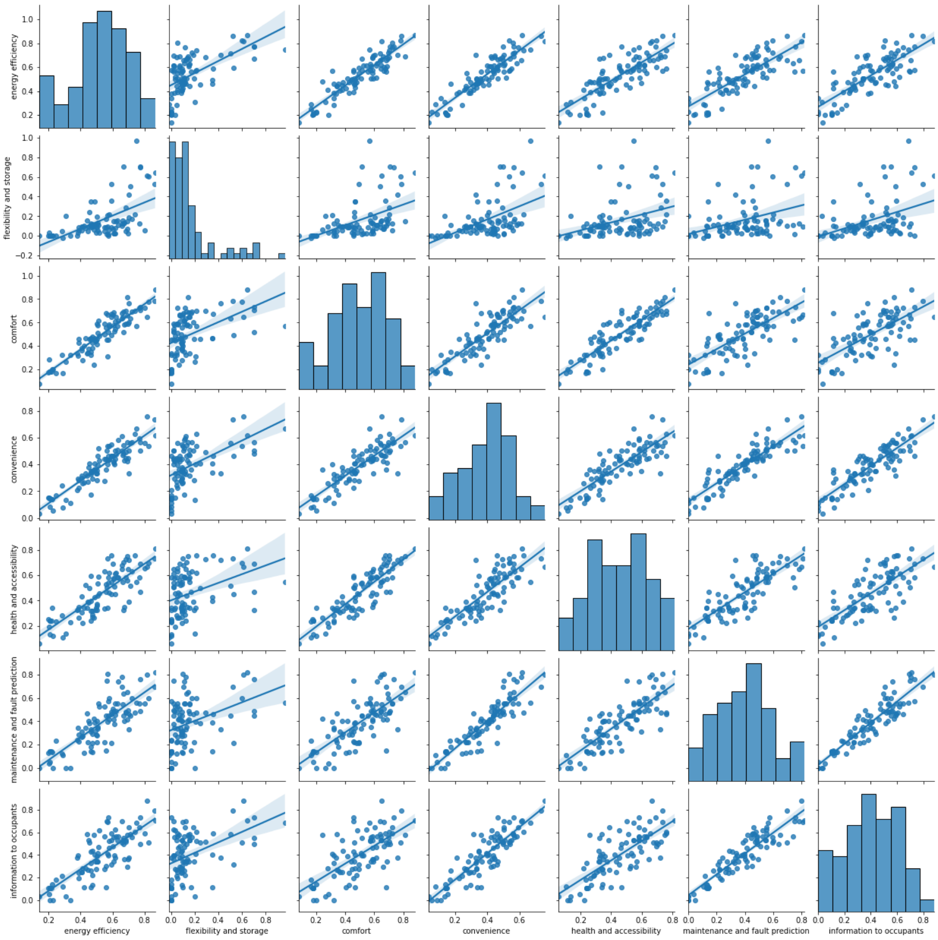


Figure 29. Correlation plots between impacts and density histograms of each impact.

Figure 29 effectively demonstrates a clear correlation pattern among impacts, as evident from the increasing regression lines indicating positive correlations. This implies that a high score in one impact is associated with good performance in other impacts. However, there is an exception observed in the case of Energy Flexibility and Storage, where the regression line deviates from the positive correlation trend.

Notably, the second histogram at the (2,2) and the scatter plots in the second row (2,:) and column (:,2) specifically highlight the challenges associated with Energy Flexibility and Storage. Across the board, every assessed building performed poorly in this category, as reflected in the clustered scores around 0.0. This concentration of scores indicates a common struggle among the buildings in achieving a satisfactory level of energy flexibility and storage, posing a notable area for improvement.

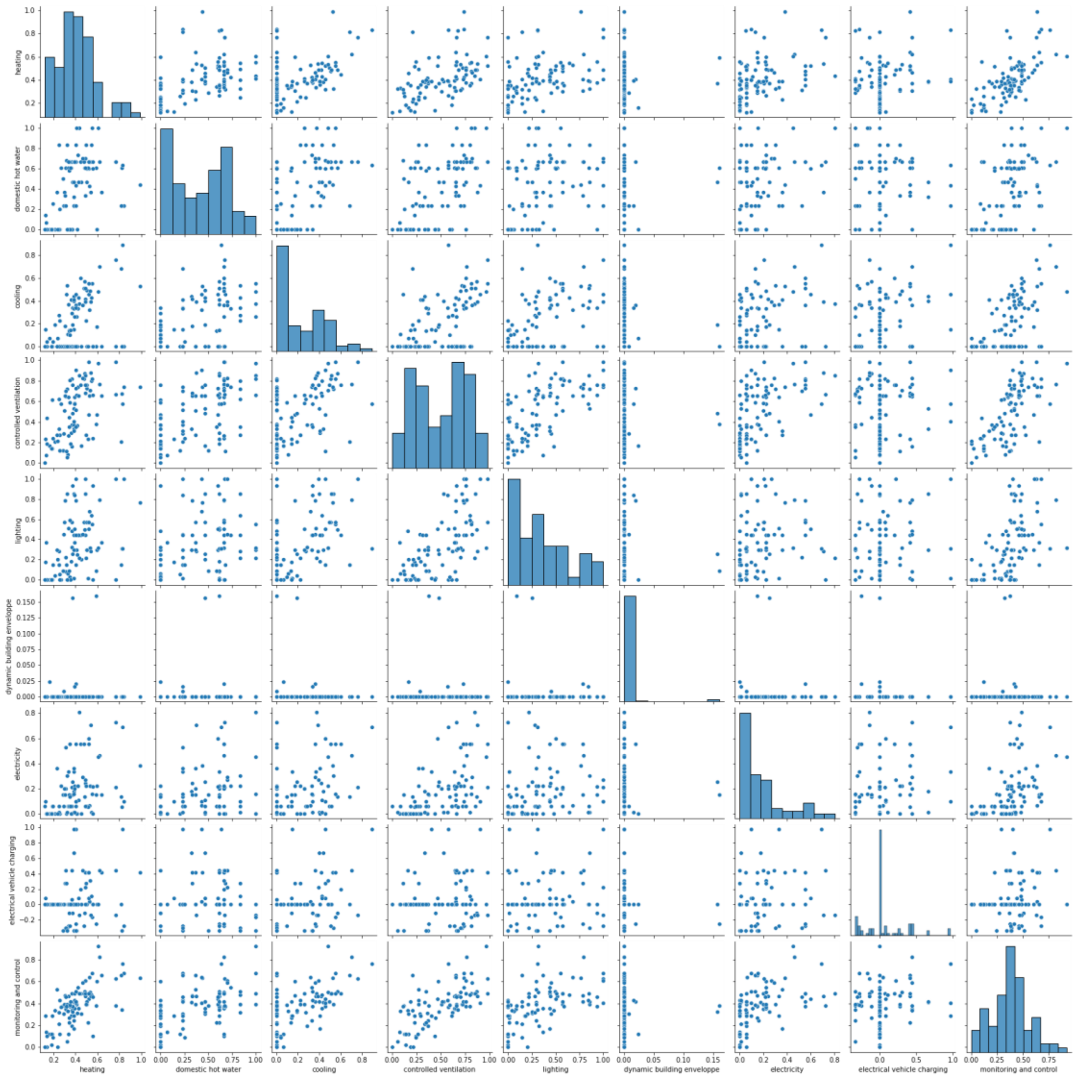


Figure 30. Correlation plots between domains and density histogram of each domain.

Figure 30 illustrates correlation plots between domains, showing a noteworthy distinction from impacts. Unlike impacts, domains do not exhibit any apparent correlations, aligning with expectations. The absence of correlations is logical, considering that strong performance in one domain, such as lighting, should not necessarily influence the performance in another, like heating or domestic hot water generation.

A specific domain worth highlighting is Dynamic Building Envelope, which consistently received low scores across almost all buildings. This outcome is rational, as dynamic building envelope technologies are not widely applied or utilized in Finland. The lack of relevance and implementation in the Finnish context contributes to the poor performance of this domain across the assessed buildings.

Similarly, Electrical Vehicle Charging emerges as another domain with suboptimal performance, as evidenced by the prominent density of 0.0 scores. The widespread occurrence of low scores in this domain indicates a common challenge among the assessed buildings in terms of electrical vehicle charging. This could be attributed to various factors, such as inadequate infrastructure or limited adoption of electrical vehicle charging technologies.

These observations underscore the importance of tailoring smart readiness assessments to the local context and considering the specific technologies and practices relevant to the region. Recognizing the unique characteristics and needs of the Finnish environment allows for a more accurate evaluation of building performance in the context of smart technologies and automation.

4.3 Assessors Background

This section provides insights into the diverse backgrounds of the individuals assessors of the SRI case assessments. Following figures (Figure 31, Figure 32, Figure 33) illustrate key information about the assessors, including their study background, work history, skills, and roles as energy assessors for Energy Performance Certificates. It's worth to mention that one assessor could have more than one education backgrounds, but for the clarification, only the highest education level was included.

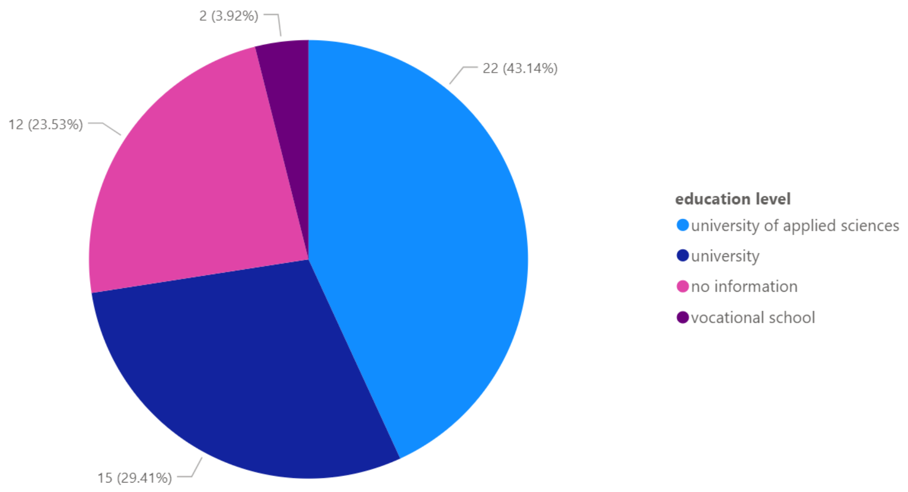


Figure 31. Number of assessors per education levels.

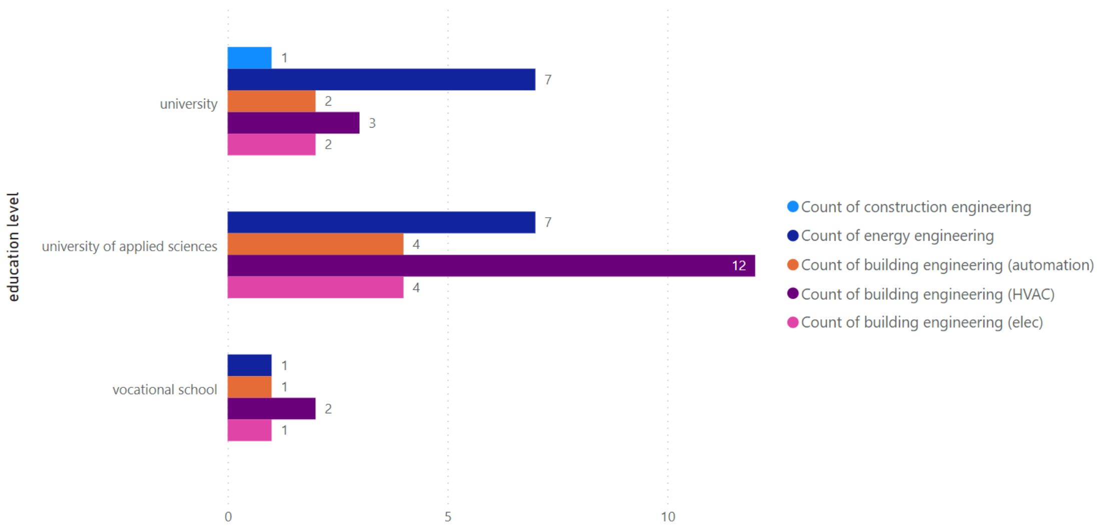


Figure 32. Assessors' study background.

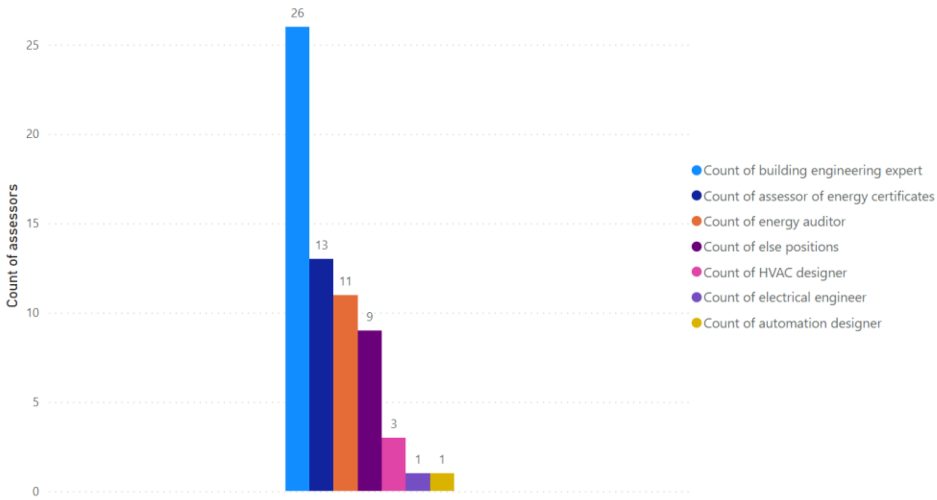


Figure 33. Assessors' work experiences.

4.4 Assessors' Feedback

This section delves into a detailed exploration of the key insights derived from the assessors' feedback, shedding light on their experiences, challenges encountered, and suggestions for refining the SRI assessments. The insights gathered from the assessors' feedback, offering a comprehensive understanding of their experiences and the challenges encountered during the SRI assessments. Approximately 53% of assessors actively participated in the final feedback session, enriching the study with diverse perspectives. The assessors brought attention to several noteworthy observations from their assessment experiences, that are detailed in the following subsections.

Assessors' Varied Experiences and Challenges

The feedback from assessors serves as a valuable source of information, offering detailed insights based on their experience with SRI assessments. It is noteworthy, that some assessors have asked help from construction, or automation professionals, and maintenance managers associated with the target property, such as instance property maintenance managers. Their participation into the assessment process added a layer of complexity and richness to assessors' observations.

Assessors shared varied experiences with different types of properties, including hotels, cultural centers, and educational buildings. A repeating challenge frequently highlighted by assessors was the difficulty in accurately assessing various automation system functionalities and their percentages within a building. Especially when automated systems covered only specific areas. There rises a question. When a property has some automated systems only in some areas, is it acceptable to generally rate that building's system based on that. This emphasizes the complexity of evaluating diverse building structures and functionalities.

Importance of On-Site Visits and Practical Experience

The significance of on-site visits for a comprehensive evaluation was emphasized, enabling assessors to gather firsthand information and insights. Positive experiences were noted when professionals from construction and automation teams actively participated in the assessment process. However, challenges existed, particularly in obtaining accurate information about a building's automation systems, especially in unfamiliar or technologically advanced structures.

Also, if the asked participants are not suitable, they might not give much help to the assessment process. In a case assessment, a property maintenance manager of the target building was involved, but since he didn't have enough understanding of building's automation systems, the assessment difficult. This underscores the necessity for a standardized approach to assessments, particularly in the field of automation.

Assessors collectively recognized the crucial role of practical experience in conducting successful SRI assessments. The suggestions were concentrated in setting and learning the common assessment method, for example through more case assessments. The feedback emphasizes the importance of additional training and expertise, particularly in the field of automation, indicating a continuous learning curve for professionals in this type of evaluation. This will also increase the suitability of assessors when reinforce the understanding of SRI methodology.

Addressing Questions on SRI

After the assessment, questions were raised regarding the perceived added value of SRI for property owners. Clarification on the tangible benefits of implementing SRI recommendations emerged as an ongoing need. The feedback suggested that while there might be limited added value of SRI for property owners, it could potentially serve as a valuable tool for consultants and professionals involved in property transactions. Discussions revolved around the relevance of SRI in influencing property-related decisions and negotiations.

Overall, the feedback collectively underscored the notion that SRI assessments may require more than basic information for accurate evaluation. The discussions touched on the complexity of systems, including automation and lighting, indicating the multifaceted nature of building readiness.

Assessors considered SRI within the wider context of energy efficiency and building management, emphasizing the need for ongoing development, training, and refinement of the SRI methodology to address challenges and enhance its practical applicability in diverse building scenarios. These insights contribute to a more comprehensive understanding of the assessors' experiences and highlight critical considerations for refining the SRI methodology for future applications in the dynamic domain of smart buildings.

5 Conclusions

This chapter concludes a comprehensive analysis of the Smart Readiness Indicator's (SRI) suitability in the Finnish environment, emphasizing the complexity of building readiness and unexpected trends in property characteristics. Assessors' feedback underscores the need for ongoing development and refinement of the SRI methodology. The SRI's benefits for property owners are highlighted, offering a clear understanding of a building's smart readiness. The discussion extends to the paradigm shift from traditional to smart building control systems, emphasizing the role of predictive capabilities. Future lines of inquiry focus on refining the SRI methodology and exploring opportunities in evolving smart technologies.

5.1 Impact of Building Characteristics

This section will discuss the impact of certain building characteristics on the total SRI scores. The visual representations of building information in the Chapter 4 have revealed noteworthy correlations and trends, particularly concerning the construction year and property condition.

The visualization, as illustrated in Figure 22, displays the average SRI scores of assessed properties categorized by different construction years. The histogram bars are arranged in descending order based on the averages. Surprisingly, the analysis indicates that buildings constructed after 2010 (>2010) obtained the highest average SRI score, followed by buildings constructed before 1960 (<1960), those constructed between 1990 and 2010 (1990-2010), and finally, buildings from the 1960-1990 period. The unexpected finding is that older buildings, especially those constructed before 1960, achieved a better average SRI score.

However, it is crucial to emphasize another influencing factor: the condition of the property. The renovation rate of buildings constructed before 1960 was nearly 82%. This high SRI score for older buildings might be attributed to the substantial rate of renovation incorporating modern building technologies. The use of contemporary building methods during renovations could significantly contribute to enhancing the overall smart readiness of these older structures.

Several aspects contribute to this positive trend. Notably, the focus on impacts:

- Maintenance and fault prediction
- Information to occupants

These means that the renovated buildings (<1960) performed better in forecasting, reporting, and addressing errors and informing the changes to occupants in heating efficiency and performance plays a pivotal role. The efficient utilization of warm water, along with effective cooling systems and automated ventilation, also contributes to higher SRI scores. Additionally, the implementation of good demand-side management practices further enhances the overall smart readiness of buildings.

The correlation between construction year and SRI scores challenges preconceptions about the relationship between building age and smart readiness. The findings underscore the importance of renovation and modernization efforts, especially in older structures, to align them with contemporary smart building standards. As the analysis unfolds, it becomes evident that a combination of construction year and property condition influences the SRI scores, emphasizing the need for a detailed understanding of these factors in the context of smart building assessments.

5.2 Improvement suggestions based on the analysis results

This section delves into the assessment results visualized in the results chapter and offers improvement suggestions based on the analysis. The objective is to enhance the Smart Readiness Indicator (SRI) scoring by focusing on factors with the most potential for improvement. The analysis of visualized results reveals clear distributions in impact and domain scores.

Figure 27. Distribution and density of impact scores. illustrates the distribution and density of impact scores, highlighting that energy efficiency and storage have the lowest average scores at 0.16, with 1.00 being the maximum. With the same logic, Figure 28 shows the distribution and density of domain scores, with dynamic building envelope having the lowest average at 0.04, followed by electrical vehicle charging at 0.06. These scores are clustered around 0.00, and electrical vehicle charging even has negative scoring due to its low smart level. The relevance of dynamic building envelope in the Finnish construction field is limited. However, with the ongoing transformation in the vehicle industry towards electric vehicles, increasing the relevance of electrical vehicle charging is necessary. Adding charger utilization information can enhance the smart readiness level further.

Smart building technologies encompass optimizing the performance of control systems, such as HVAC, lighting, and security. Buildings with low total SRI scores tend to employ traditional building technologies, where control systems operate mainly in building management with simple automation. Such buildings lack the capability to smartly control specific HVAC systems and face challenges in forecasting and predicting the usage of essential systems like heating or lighting. The SRI emphasizes the "smartness" of these systems, focusing on aspects such as energy consumption flexibility, forecasting based on data analytics, and human-building interaction.

Traditional buildings often lack smart control systems, hindering predictability. Integration of smart analysis, such as data analysis or AI-based learning methodologies, into management-level control is essential. This integration enables a sophisticated understanding of historical data, leading to improved predictability of future conditions and optimizing the performance of building systems.

Furthermore, energy flexibility and storage are commonly absent in traditional buildings. Predictability plays a crucial role in addressing energy flexibility, and incorporating more sensors, actuators, and advanced data analysis can enhance adaptability to changing energy demands. Buildings equipped with energy storage, local energy production, or HVAC control based on separate energy storage systems can benefit from predictive analytics to optimize energy flexibility. This involves making informed decisions about when to use stored energy, engage local energy production, or leverage HVAC controls to enhance energy efficiency and cost-effectiveness.

In essence, the transition from traditional building control systems to smart building control systems with predictive capabilities represents a paradigm shift. Smart technologies enable forecast and predictability, empowering buildings to respond intelligently to occupant needs, enhance system predictability, and maximize energy flexibility and storage. This shift is crucial for improving overall building performance, energy efficiency, and cost-effectiveness in the dynamic landscape of smart buildings.

5.3 Suitability of SRI assessment methodology

This section critically evaluates the Smart Readiness Indicator (SRI) assessment scheme, specifically its recent version (version 4.5) used in the testing phase in Finland. The purpose is to identify what aspects align well with the Finnish environment, what needs clarification, and areas requiring improvement. In the testing phase, the SRI calculation framework faced feedback from assessors, highlighting several points that require attention. The version utilized was 4.5., translated into Finnish by Motiva.

The following aspects of the SRI methodology were highlighted based on their suitability for the Finnish context:

- District Heating and Heat Control
- Cooling Generation
- Relevance of Technologies
- Dynamic Envelope and Window Control
- Local Energy Generation

One notable issue pertained to the main heating system in Finland, predominantly district heating. The SRI's heat control section did not account for district heating, leading to challenges in scoring. The current framework lacked clarity in scoring distributed heating and introduced confusion in the domestic hot water (DHW) storage aspect. In Finland, DHW comes from the grid, rendering DHW storage scores irrelevant, and this discrepancy needs addressing in the SRI methodology.

Similarly, cooling generation in Finland primarily relies on ventilation or air conditioning, differing from the SRI's chilled water cycle approach. Misalignments like these highlight the need for adjustments to make the SRI more applicable to the Finnish context. Additionally, aspects such as Thermally Activated Building Structures (TABS) and Thermal Energy Storage (TES) were deemed irrelevant in the Finnish environment.

The SRI's treatment of the dynamic envelope, primarily assessed from a window control perspective, raised confusions. While window shading control could be relevant in the future, the current assessment did not align with the Finnish context, where dynamic building envelope concepts are not yet commonplace. This indicates a potential area for future consideration as smart technologies evolve.

Local energy generation, though still in the early stages of development in Finland, holds promise for future energy flexibility control. Technologies like solar panels and geothermal heat, though not widely adopted at present, are expected to play a significant role in enhancing the smart readiness of buildings in Finland.

In conclusion, the SRI assessment methodology, particularly version 4.5, demonstrates both strengths and areas for improvement in the Finnish context. Adjustments are needed to align with the local heating and cooling systems, exclude irrelevant technologies, and better capture the detailed differences of the Finnish building environment. Additionally, considering the evolving landscape of local energy generation, incorporating these aspects into the SRI framework could enhance its relevance and applicability in the Finnish context.

5.4 Improvement suggestions to training process

This section addresses improvement suggestions for the training process of individuals involved in assessing SRI assessments. During the testing phase, assessors with diverse professional backgrounds participated in the evaluation after receiving training. Feedback from assessors highlighted certain challenges, such as difficulty in understanding some factors, room for different interpretations, and the need for more detailed explanations. The existing training mainly focused on the practical usage of Excel spreadsheets and some case analysis. To enhance common understanding and minimize subjective influences, a more comprehensive training process is proposed.

The suggested improvements involve incorporating more detailed case building analyses and assessments within small groups. Practical training, including site visits to assess buildings using the SRI, is recommended to provide assessors with hands-on experience. This approach ensures a more practical understanding of the assessment process and contributes to a standardized and generalized assessment.

While assessors can be trained, having a suitable background is deemed essential. A prerequisite for assessors includes knowledge in building automation technology, and familiarity with HVAC (Heating, Ventilation, and Air Conditioning) systems is considered beneficial. Work experience or knowledge spanning different decades can provide valuable insights. Individuals with expertise as upper-level energy performance certificate assessors, with additional training, may also be suitable for the SRI assessor role.

During assessments, having a consultant with expertise in building automation systems, such as a building automation manager, property manager, or someone from the construction team, is crucial. The consultant's knowledge complements the assessor's skills and ensures a more comprehensive evaluation of a building's smart readiness.

In conclusion, refining the training process by incorporating practical experiences, small group discussions, and site visits, along with ensuring a diverse skill set among assessors and their consultants, contributes to a more effective and reliable Smart Readiness Indicator assessment process.

5.5 SRI Assesment Guide

This section explores the potential benefits of utilizing assessment guides for SRI assessment in the Finnish context. The SRI assessment guides aim to provide comprehensive instructions to supports assessors during the SRI assessment. This section includes the Energy Performance Certification (EPC) evaluation as a comparison since it has already seen successful implementation in Finland.

The EU's Energy Performance of Buildings Directive (EPBD) [31] established regulations related to the EPC, emphasizing it as a mandatory and important standardized approach to building rating. In the Finnish context, the Ministry of the Environment has developed various instructions to facilitate the EPC evaluation process. These instructions contain regulations and principles relating to the EPC, along with guides that assist in evaluating a building's energy performance. The guidance includes evaluation models for typical building types, such as small family-house, apartment house, and office building covering various construction years. Also, some special heating systems, like heat pump, solar heat and energy production, are having detailed instructions.

The key aspect that the SRI could adopt from the EPC evaluation process is the utilization of guides. These guides serve as essential tools, offering detailed instructions and typical case building evaluations. By emulating this model, the SRI assessment can benefit from clear guidelines, aiding assessors in their preparation and evaluation processes. The guides would play a crucial role in ensuring a standardized and consistent approach to SRI assessments.

To further enhance the effectiveness of the SRI assessment, the guide could include specific instructions and examples tailored to different building characteristics. Case buildings representing typical building types, various construction years, and building automation systems could be incorporated into the guide. These case examples would serve as practical references, guiding assessors in understanding how different building attributes may influence SRI scores. The inclusion of diverse scenarios would contribute to the overall consistency and reliability of SRI assessment results.

In essence, the SRI Assessment Guide proposes a structured framework inspired by the successful practices of the EPC evaluation process. By incorporating detailed instructions, regulations, and case evaluations, the guide aims to empower assessors, ensuring a standardized and reliable approach to SRI assessments. The overarching goal is to enhance the clarity, consistency, and effectiveness of the SRI framework in evaluating the smart readiness of buildings in the Finnish context.

5.6 The benefits of the SRI assessment

This section details the possible benefits of the SRI assessments and sheds light to assessment timing during the construction phase to the end useage. The Smart Readiness Indicator (SRI) assessment offers property owners a valuable tool to gain a clearer understanding of their building's smart readiness level and overall performance. While there are widely used building sustainability rating systems like LEED (Leadership in Energy and Environmental Design) and BREEAM (Building Research Establishment Environmental Assessment Method), as well as Energy Performance Certification, each serving specific purposes, the SRI stands out as a distinct and compulsory tool focusing on a building's smart technologies and automation capabilities.

Conducting the SRI assessment alongside other evaluations allows a comprehensive overview of the entire building system. This integrated approach facilitates a thorough examination of various aspects, including energy efficiency, sustainability, and smart technologies. The SRI, focusing specifically on a building's smart readiness, adds a distinctive layer to the overall assessment, ensuring that the property owner gains insights into the building's capabilities in terms of automation and advanced technologies.

LEED and BREEAM focus primarily to the performance of building’s sustainable factors and environmental impacts across different categories such as indoor environment quality and sustainable sites. Meanwhile, Energy Performance Certification, regulated by the Energy Performance of Buildings Directive (EPBD) in the EU, focuses on rating a building's overall energy efficiency. In contrast, the SRI does not replace these existing rating tools; instead, it complements them by specifically evaluating a building's smart readiness and automation perspective.

As highlighted in previous discussions, the SRI serves a unique role, emphasizing the integration of smart technologies and automation in buildings. It provides a standardized metric to measure a building's capacity to incorporate and benefit from these technologies. The SRI aims to contribute to the reduction of CO_2 emissions in the building sector, aligning with broader environmental goals. By doing so, it assists property owners and occupants in creating a more efficient, comfortable, and convenient living environment.

The benefits of SRI assessments for property owners extend beyond environmental considerations. Property owners can leverage the insights gained from SRI assessments to make informed decisions about optimizing their building's performance. The assessment results offer a roadmap for enhancing energy efficiency, adjusting operations to meet occupants' needs, and responding to signals from the grid. This comprehensive understanding empowers property owners to implement improvements that not only align with environmental sustainability but also enhance the overall functionality and desirability of their buildings.

Moreover, incorporating the SRI assessment early in the construction design phase offers significant advantages. It becomes a valuable decision-making tool, providing crucial information for architects, builders, and property developers. The SRI score becomes instrumental in guiding decisions related to building systems. For instance, it can inform choices about incorporating AI-based forecasting and decision-making systems, integrating local energy production and storage solutions, and planning for features like electric car charging infrastructure.

The findings from the assessment of 93 buildings underscore key areas that can be improved. These include AI-based forecasting and decision-making systems, local energy production and storage, and facilities for electric car charging. By integrating the SRI assessment into the early stages of construction design, stakeholders can make informed decisions that align with the goal of enhancing a building's smart readiness. This proactive approach not only contributes to the building's overall efficiency but also ensures that it meets the evolving needs and expectations of occupants and property owners in the context of modern, technologically advanced living environments.

In conclusion, the SRI assessment serves as a tool that goes beyond standalone evaluations. Its compatibility with other assessments allows for a comprehensive understanding of building performance. Embracing the SRI in the construction design phase provides a roadmap for decision-making, enabling th e integration of cutting-edge technologies and smart solutions. As buildings continue to evolve and adapt to the demands of a changing world, the SRI proves to be an essential guide for creating smarter, more efficient, and technologically advanced living spaces.

5.7 Development of future SRI

This section will discuss the direction of developing the future SRI framework. Based on the Directive of the European Parliament and of The Council on energy performance of building (recast) that has been proposed at the end of 2023 [35], the development of the SRI is directed towards establishing a common Union scheme for rating the smart readiness of buildings. Article 13 [35] highlighted that the Commission is expected to submit a report on the testing and implementation of the SRI by June 2026, potentially leading to a mandatory application for non-residential buildings by June 2027. The ongoing evaluation and refinement of the SRI framework based on feedback from national test phases, research studies, and practical implementation experiences are important to be reported. Furthermore, the regular updates should be considered to address emerging technologies and changing building practices.

As outlined in Annex IV[35], the future SRI development will focus on features promoting enhanced energy savings, benchmarking, and flexibility through interconnected and intelligent devices. The methodology is expected to incorporate aspects like the existence of a digital twin of the building, smart meters, building automation systems, self-regulating devices, energy storage, and interoperability of these features. Furthermore, the development will consider factors like occupant privacy, data protection, and cybersecurity while ensuring alignment with existing national energy performance certification schemes.

The goal of the SRI development is to create a standardized, transparent, and easily understandable format that meets the needs of consumers, building owners, investors, and participants in demand-response markets. This includes features previously mentioned, such as occupant privacy, data protection, and cybersecurity. To achieve this goal, active involvement and feedback from stakeholders, including building owners, occupants, industry experts, and policymakers, are crucial. This collaborative approach will contribute to shaping a comprehensive, effective, and adaptable SRI framework that accommodates emerging technologies and changing building practices.

6 Summary

The primary aim of this thesis was to comprehensively analyse the suitability of SRI assessment scheme for the Finnish environment based on the data provided by Motiva as part of their SRI testing phase in Finland. To test the SRI scheme, the testing project included professionals from different fields related to building, such as construction, building automation and energy production field. The assessors also have variety study backgrounds including automation, energy and construction technologies, and work experiences, such as energy certificate assessors, energy auditors, automation designers, HVAC designers and energy designers. The detailed information of assessors was gone through in section 4.3.

The detailed distribution of SRI assessments was discussed in section 4.1. The assessed targets were both residential and non-residential buildings, including hotels, schools, shopping centres, libraries, office buildings, hospitals, and family houses. The use of the assessed properties was shown in Figure 18.

The SRI assessment and its calculation method were presented in the sections 2.5 and 2.6, as well as the methodology of the thesis in the chapter 3. To achieve the aim, the work deeply analysed the 93 SRI assessments, assessors' information and feedback from assessors, to answer following questions:

- Were the possible correlations between different factors reasonable and logical?
- What is the feasibility of the improvement suggestions based on the analysis results?
- How assessors survived from the assessments and who could be suitable role for assessment?
- What part of the recent SRI methodology could be improved to suit Finnish environment?

The total SRI scores of assessed properties varied between 4% - 75%. The overall results confirmed the relatively low total SRI scores, having the average of 35%. The majority of the assessed property had placed below 50%. The average total SRI score of residential buildings was 33% and non-residential buildings was 36%, which showed that there was only a little variation between different building types.

In the further analyses, the differences between different conditions of the building were found. Figure 21 shows that generally the renovated property gained better total SRI scores than original ones, except buildings constructed after 2010, where the original buildings gained better average scores. The buildings that are still under the construction (>2010), gained the best scores in average. Figure 22 illustrates that buildings that were constructed before 1960 gained better average scores than buildings that were constructed later (1960-1990, 1990-2010). This is logical because if the renovation included better and updated smart services and automation systems, the impact of the year of construction remains small.

There were clear potentials for smart readiness improvements in every technical domain and impact criteria based on the results. By improving the factor that has gained the lowest score shows the highest potential for improving the smart readiness. The conclusions were based on the correlations between them (Figure 29, Figure 30Figure 30) and their distribution and density shown in violin plots (Figure 27, Figure 28). The highest potential for improvements in technical domains is the Dynamic building envelope, but since this is not relevant in Finnish environment other suggestions are needed. Table 7 showed that after the Dynamic Building Envelope, the low averages have gained Electrical vehicle charging (0.18). For the impact criteria, Table 6 showed that the highest potential for improvement of impact criteria is the Energy Flexibility and Storage (0.16).

Although the SRI results could give proposal for potential improvements, but the concrete actions that could directly affect the result should be discovered and calculated in more detail. The SRI aims to highlight the benefits of smart technologies for building owners, users, and stakeholders, but the concrete benefits from cost-efficiency perspective is missing.

The noteworthy about the SRI is that it is not a replacement but a complementary tool for assessing other aspects of buildings, such as energy performance or sustainability. The SRI stands out as a pivotal tool, serving as an illustrative guide and fostering the integration of cutting-edge smart technologies within buildings. Furthermore, the SRI aims to highlight the benefits of smart technologies for building owners, users, and stakeholders. It is designed to provide a measurable assessment of a building's readiness to incorporate and benefit from smart technologies, contributing to the EU's targets to accelerate building renovations and support the digitalization of all buildings.

Based on the collective feedback, there existed still many problems with the recent SRI calculation method. During the assessment process, there were underscored that SRI assessments demand more than basic information for accurate evaluation. Moreover, the assessor's subjective impacts, potentials for misunderstanding and misinterpretations might directly affects the performance of the assessment and the final result. Discussions delved into the complexity of systems, particularly in automation and lighting, indicating the multifaceted nature of building readiness. Assessors positioned SRI within the broader context of energy efficiency and building management, emphasizing the necessity for ongoing development, training, and refinement of the SRI methodology.

In summary, while the SRI framework presents a valuable tool for assessing smart readiness, its alignment with specific characteristics of the Finnish environment requires careful consideration and potential adjustments. The feedback from assessors' sheds light on areas where the current methodology might not fully capture the nuances of the Finnish building landscape, signalling the need for ongoing refinement to ensure the SRI's effectiveness in diverse contexts.

References

[1] European Court of Auditors, “Special report 18/2023: EU climate and energy targets – 2020 targets achieved, but little indication that actions to reach the 2030 targets will be sufficient.” doi: 10.2865/105673.

[2] European Court of Auditors, “Special Report Energy efficiency in buildings: greater focus on cost-effectiveness still needed,” 2020. doi: 10.2865/996083.

[3] European Commision, “A Renovation Wave for Europe - greening our buildings, creating jobs, improving lives,” 2020. Accessed: Feb. 29, 2024. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0662

[4] Council of the European Union, “DIRECTIVE (EU) 2018/844 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency (Text with EEA relevance),” 2018. Accessed: Dec. 09, 2023. [Online]. Available: http://data.europa.eu/eli/dir/2018/844/oj

[5] European Commission, “What is the SRI?” Accessed: Sep. 19, 2023. [Online]. Available: https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/smart-readiness-indicator/what-sri_en

[6] T. Märzinger and D. Österreicher, “Supporting the smart readiness indicator-A methodology to integrate a quantitative assessment of the load shifting potential of smart buildings,” *Energies (Basel)*, vol. 12, no. 10, 2019, doi: 10.3390/en12101955.

[7] European Comission, “SRI test phase.” Accessed: Sep. 29, 2023. [Online]. Available: https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/smart-readiness-indicator/sri-test-phases_en

[8] E. Janhunen, L. Pulkka, A. Säynäjoki, and S. Junnila, “Applicability of the smart readiness indicator for cold climate countries,” *Buildings*, vol. 9, no. 4, Apr. 2019, doi: 10.3390/buildings9040102.

[9] P. A. Fokaides, C. Panteli, and A. Panayidou, “1How are the smart readiness indicators expected to affect the energy performance of buildings: First evidence and perspectives,” *Sustainability (Switzerland)*, vol. 12, no. 22, pp. 1–12, Nov. 2020, doi: 10.3390/su12229496.

[10] B. Ramezani, “Application of smart readiness indicator for Mediterranean buildings in retrofitting actions,” 2021. doi: 10.1016/j.enbuild.2021.111173.

[11] I. Vigna, R. Pernetti, G. Pernigotto, and A. Gasparella, “Analysis of the building smart readiness indicator calculation: A comparative case-study

with two panels of experts," *Energies (Basel)*, vol. 13, no. 11, 2020, doi: 10.3390/en13112796.

[12] V. Apostolopoulos, P. Giourka, G. Martinopoulos, K. Angelakoglou, K. Kourtzanidis, and N. Nikolopoulos, "Smart readiness indicator evaluation and cost estimation of smart retrofitting scenarios - A comparative case-study in European residential buildings," *Sustain Cities Soc*, vol. 82, Jul. 2022, doi: 10.1016/j.scs.2022.103921.

[13] S. Kaartinen, "The adoption of the Smart readiness indicator in the Finnish residential rental property market," 2023.

[14] Kyllönen Jaakob, "Rakennusten älyindikaattori rakentamisen ja korjaamisen ohjaajana liikekiinteistöissä," 2023.

[15] Motiva, "Rakennusten älyindikaattori - Motiva." Accessed: Dec. 19, 2023. [Online]. Available: https://www.motiva.fi/ratkaisut/ohjauskeinot/rakennusten_alyindikaattori

[16] "COMMISSION DELEGATED REGULATION (EU) 2020/2155 of 14 October 2020 supplementing Directive (EU) 2010/31/EU of the European Parliament and of the Council by establishing an optional common European Union scheme for rating the smart readiness of buildings," 2020. Accessed: Dec. 09, 2023. [Online]. Available: http://data.europa.eu/eli/reg_del/2020/2155/oj

[17] R. Rameshwar, A. Solanki, A. Nayyar, and B. Mahapatra, "Green and Smart Buildings: A Key to Sustainable Global Solutions," *Https://Services.Igi-Global.Com/Resolvedoi/Resolve.Aspx?Doi=10.4018/978-1-5225-9754-4.Ch007*, 2022.

[18] Office of the European Union, "DIRECTIVE (EU) 2023/1791 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 13 September 2023 on energy efficiency and amending Regulation (EU) 2023/955 (recast) (Text with EEA relevance)." Accessed: Dec. 09, 2023. [Online]. Available: http://data.europa.eu/eli/dir/2023/1791/oj

[19] EuropeanCommission, "(2019)_The European Green Deal", Accessed: Dec. 09, 2023. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52019DC0640

[20] R. Selvaraj, V. M. Kuthadi, and S. Baskar, "Smart building energy management and monitoring system based on artificial intelligence in smart city," *Sustainable Energy Technologies and Assessments*, vol. 56, 2023, doi: 10.1016/j.seta.2023.103090.

[21] H. Farzaneh, L. Malehmirchegini, A. Bejan, T. Afolabi, A. Mulumba, and P. P. Daka, "Artificial intelligence evolution in smart buildings for energy efficiency," *Applied Sciences (Switzerland)*, vol. 11, no. 2. 2021. doi: 10.3390/app11020763.

[22] B. K. Sovacool and D. D. Furszyfer Del Rio, “Smart home technologies in Europe: A critical review of concepts, benefits, risks and policies,” *Renewable and Sustainable Energy Reviews*, vol. 120. 2020. doi: 10.1016/j.rser.2019.109663.

[23] A. H. Buckman, M. Mayfield, and S. B. M. Beck, “What is a smart building?,” *Smart and Sustainable Built Environment*, vol. 3, no. 2, 2014, doi: 10.1108/SASBE-01-2014-0003.

[24] W. M. To, L. S. L. Lai, K. H. Lam, and A. W. L. Chung, “Perceived importance of smart and sustainable building features from the users’ perspective,” *Smart Cities*, vol. 1, no. 1, 2018, doi: 10.3390/smartcities1010010.

[25] N. Attoue, I. Shahrour, and R. Younes, “Smart building: Use of the artificial neural network approach for indoor temperature forecasting,” *Energies (Basel)*, vol. 11, no. 2, 2018, doi: 10.3390/en11020395.

[26] Z. Ma, A. Clausen, Y. Lin, and B. N. Jørgensen, “An overview of digitalization for the building-to-grid ecosystem,” *Energy Informatics*, vol. 4. 2021. doi: 10.1186/s42162-021-00156-6.

[27] Y. Peng, M. Zhang, F. Yu, J. Xu, and S. Gao, “Digital Twin Hospital Buildings: An Exemplary Case Study through Continuous Lifecycle Integration,” *Advances in Civil Engineering*, vol. 2020, 2020, doi: 10.1155/2020/8846667.

[28] Z. Sefidgar, A. Ashrafizadeh, and A. Arabkoohsar, “Techno–Economic Analysis and Multi-Objective Optimization of Cross-Flow Wind Turbines for Smart Building Energy Systems,” *Global Challenges*, vol. 7, no. 4, 2023, doi: 10.1002/gch2.202200203.

[29] M. Ala-juusela, H. U. Rehman, M. Hukkalainen, and F. Reda, “Positive energy building definition with the framework, elements and challenges of the concept,” *Energies (Basel)*, vol. 14, no. 19, 2021, doi: 10.3390/en14196260.

[30] Stijn. Verbeke *et al.*, “Final report on the technical support to the development of a smart readiness indicator for buildings : summary.” doi: 10.2833/600706.

[31] “Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings,” 2010. Accessed: Dec. 15, 2023. [Online]. Available: http://data.europa.eu/eli/dir/2010/31/oj

[32] E. Janhunen, L. Pulkka, A. Säynäjoki, and S. Junnila, “Applicability of the smart readiness indicator for cold climate countries,” *Buildings*, vol. 9, no. 4, 2019, doi: 10.3390/buildings9040102.

[33] P. A. Fokaides, C. Panteli, and A. Panayidou, “How are the smart readiness indicators expected to affect the energy performance of buildings: First evidence and perspectives,” *Sustainability (Switzerland)*, vol. 12, no. 22. 2020. doi: 10.3390/su12229496.

[34] T. Märzinger and D. Österreicher, “Supporting the smart readiness indicator-A methodology to integrate a quantitative assessment of the load shifting potential of smart buildings,” *Energies (Basel)*, vol. 12, no. 10, 2019, doi: 10.3390/en12101955.

[35] Council of the European Union, “DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the energy performance of buildings (recast),” 2023. Accessed: Feb. 22, 2024. [Online]. Available: https://www.europarl.europa.eu/meetdocs/2014_2019/plmrep/COMMITTEES/ITRE/DV/2024/01-15/11_AnnextoEPLetterEPBDfinaltext_EN.pdf

A. Detailed Results of the SRI Assessments

Table A 1. Detailed scoring of impact criteria and domains, total SRI score, as well as SRI class.

SRI ID	ENERGY EFFICIENCY	ENERGY FLEXIBILITY AND STORAGE	COMFORT	CONVENIENCE	HEALTH, WELL-BEING AND ACCESSIBILITY	MAINTENANCE AND FAULT PREDICTION	INFORMATION TO OCCUPANTS	TOTAL SRI SCORE	SRI CLASS	HEATING	DOMESTIC HOT WATER	COOLING	CONTROLLED VENTILATION	LIGHTING	DYNAMIC BUILDING ENVELOPE	ELECTRICITY	ELECTRICAL VEHICLE CHARGING	MONITORING AND CONTROL
NO. 1	0,48	0,07	0,24	0,36	0,26	0,42	0,58	**29,30**	**F**	0,35	0,61	0,14	0,19	0,00	0,00	0,06	0,00	0,41
NO. 2	0,44	0,16	0,34	0,32	0,34	0,47	0,59	**33,50**	**F**	0,30	0,37	0,00	0,51	0,57	0,00	0,20	0,00	0,39
NO. 3	0,31	0,20	0,26	0,14	0,13	0,00	0,03	**16,66**	**G**	0,20	0,25	0,04	0,24	0,15	0,00	0,06	0,00	0,09
NO. 4	0,46	0,35	0,47	0,34	0,40	0,14	0,11	**32,77**	F	0,46	0,47	0,00	0,17	0,20	0,00	0,00	0,00	0,30
NO. 5	0,56	0,17	0,68	0,36	0,47	0,14	0,11	**30,95**	F	0,42	0,00	0,00	0,36	0,25	0,00	0,00	0,00	0,31
NO. 6	0,51	0,11	0,61	0,52	0,59	0,55	0,47	**39,79**	**E**	0,39	0,47	0,40	0,53	0,85	0,00	0,01	0,67	0,41
NO. 7	0,60	0,07	0,66	0,46	0,69	0,51	0,47	**39,96**	**E**	0,40	0,43	0,45	0,90	1,00	0,00	0,10	0,97	0,40
NO. 8	0,46	0,11	0,35	0,17	0,32	0,18	0,26	**23,64**	**F**	0,56	0,67	0,00	0,24	0,00	0,00	0,00	0,00	0,10
NO. 9	0,25	0,00	0,17	0,17	0,23	0,24	0,18	**14,30**	**G**	0,26	0,20	0,00	0,12	0,06	0,00	0,00	0,00	0,12
NO. 10	0,61	0,15	0,69	0,41	0,57	0,42	0,34	**38,80**	**E**	0,43	0,47	0,43	0,65	0,44	0,00	0,11	0,08	0,35
NO. 11	0,39	0,05	0,46	0,23	0,26	0,22	0,19	**21,50**	**F**	0,25	0,00	0,00	0,33	0,15	0,00	0,01	0,00	0,21
NO. 12	0,34	0,00	0,32	0,11	0,23	0,00	0,00	**11,11**	**G**	0,24	0,00	0,07	0,21	0,20	0,00	0,00	0,00	0,00
NO. 13	0,14	0,00	0,08	0,03	0,06	0,00	0,03	**4,02**	**G**	0,12	0,00	0,00	0,00	0,00	0,00	0,06	0,00	0,00
NO. 14	0,29	-0,02	0,17	0,08	0,11	0,11	0,12	**9,87**	**G**	0,32	0,00	0,00	0,06	0,00	0,00	0,01	-0,33	0,05
NO. 15	0,22	0,00	0,20	0,05	0,12	0,00	0,00	**6,90**	**G**	0,14	0,00	0,00	0,19	0,00	0,00	0,00	0,00	0,00
NO. 16	0,22	0,00	0,20	0,14	0,34	0,13	0,14	**13,00**	**G**	0,14	0,00	0,04	0,44	0,00	0,00	0,00	0,00	0,10
NO. 17	0,47	0,09	0,38	0,35	0,32	0,29	0,44	**28,23**	**F**	0,39	0,23	0,15	0,40	0,01	0,00	0,33	0,97	0,29

NO. 18	0,61	0,02	0,52	0,40	0,51	0,37	0,39	**32,36**	**F**	0,31	0,23	0,00	0,70	0,22	0,00	0,53	-0,31	0,46
NO. 19	0,46	0,08	0,46	0,35	0,60	0,31	0,43	**31,00**	**F**	0,25	0,83	0,27	0,62	0,28	0,00	0,06	0,00	0,32
NO. 20	0,68	0,29	0,70	0,49	0,73	0,47	0,52	**49,30**	**E**	0,50	0,47	0,49	0,76	0,57	0,00	0,06	0,00	0,41
NO. 21	0,50	0,05	0,51	0,40	0,54	0,34	0,41	**31,30**	**F**	0,31	0,61	0,00	0,65	0,08	0,00	0,20	0,44	0,35
NO. 22	0,77	0,70	0,73	0,57	0,69	0,76	0,73	**71,50**	**C**	0,99	0,44	0,53	0,74	0,77	0,00	0,38	0,42	0,63
NO. 23	0,66	0,16	0,65	0,47	0,55	0,55	0,53	**43,70**	**E**	0,49	0,33	0,42	0,68	0,45	0,00	0,24	0,42	0,46
NO. 24	0,67	0,71	0,52	0,48	0,32	0,45	0,55	**57,70**	**D**	0,82	0,23	0,68	0,21	0,15	0,00	0,13	0,00	0,65
NO. 25	0,82	0,60	0,78	0,54	0,70	0,60	0,51	**64,80**	**D**	0,84	0,23	0,00	0,74	1,00	0,00	0,10	-0,28	0,68
NO. 26	0,58	0,06	0,59	0,44	0,46	0,41	0,46	**34,77**	**F**	0,39	0,67	0,00	0,64	0,37	0,00	0,22	0,00	0,36
NO. 27	0,72	0,17	0,70	0,57	0,63	0,60	0,56	**48,10**	**E**	0,49	0,61	0,51	0,85	0,85	0,00	0,06	0,00	0,49
NO. 28	0,63	0,11	0,62	0,58	0,58	0,74	0,56	**46,25**	**E**	0,53	0,67	0,48	0,70	0,32	0,00	0,22	0,31	0,50
NO. 29	0,67	0,13	0,69	0,54	0,71	0,64	0,50	**51,00**	**D**	0,50	0,60	0,00	0,72	0,29	0,00	0,06	0,00	0,39
NO. 30	0,69	0,15	0,81	0,56	0,75	0,65	0,58	**53,00**	**D**	0,56	0,60	0,00	0,66	0,93	0,00	0,22	0,00	0,46
NO. 31	0,87	0,65	0,88	0,62	0,81	0,82	0,71	**74,80**	**C**	0,77	0,67	0,76	0,98	1,00	0,00	0,21	-0,14	0,63
NO. 32	0,77	0,70	0,71	0,50	0,47	0,49	0,50	**62,50**	**D**	0,77	0,67	0,00	0,66	0,00	0,00	0,73	0,44	0,38
NO. 33	0,62	0,15	0,65	0,47	0,62	0,49	0,56	**42,60**	**E**	0,32	0,83	0,53	0,72	0,85	0,00	0,30	-0,31	0,39
NO. 34	0,59	0,09	0,65	0,55	0,55	0,48	0,53	**39,90**	**E**	0,49	0,70	0,39	0,76	1,00	0,00	0,27	0,22	0,61
NO. 35	0,58	0,00	0,46	0,46	0,58	0,57	0,73	**37,80**	**E**	0,35	0,67	0,00	0,80	0,59	0,00	0,56	0,00	0,37
NO. 36	0,82	0,61	0,65	0,76	0,67	0,80	0,88	**71,90**	**C**	0,60	1,00	0,48	0,97	0,31	0,00	0,45	0,00	0,92
NO. 37	0,74	0,22	0,70	0,63	0,76	0,48	0,60	**49,90**	**E**	0,46	0,70	0,36	0,82	0,45	0,00	0,29	0,44	0,59
NO. 38	0,56	0,09	0,56	0,44	0,53	0,45	0,30	**35,10**	**E**	0,30	0,33	0,18	0,65	0,79	0,00	0,15	0,28	0,47
NO. 39	0,58	0,22	0,57	0,54	0,62	0,60	0,53	**45,60**	**E**	0,53	0,43	0,32	0,65	0,68	0,00	0,06	0,04	0,64
NO. 40	0,20	0,03	0,28	0,15	0,19	0,04	0,05	**10,80**	**G**	0,13	0,07	0,00	0,08	0,37	0,00	0,00	0,00	0,14
NO. 41	0,39	0,08	0,43	0,28	0,35	0,28	0,24	**24,80**	**F**	0,26	0,00	0,22	0,27	0,00	0,00	0,00	0,00	0,43
NO. 42	0,70	0,19	0,61	0,50	0,39	0,46	0,65	**43,50**	**E**	0,52	0,60	0,46	0,47	0,50	0,00	0,60	0,08	0,44
NO. 43	0,57	0,21	0,31	0,40	0,34	0,40	0,41	**35,30**	**E**	0,50	0,83	0,22	0,27	0,21	0,00	0,22	0,28	0,39

NO. 44	0,49	0,10	0,44	0,37	0,32	0,32	0,34	**29,00**	**F**	0,36	0,61	0,41	0,29	0,18	0,00	0,00	0,00	0,29
NO. 45	0,47	0,10	0,43	0,29	0,27	0,14	0,13	**22,70**	**F**	0,34	0,58	0,14	0,35	0,09	0,00	0,06	0,00	0,23
NO. 46	0,41	0,06	0,38	0,32	0,43	0,26	0,25	**24,50**	**F**	0,19	0,00	0,00	0,61	0,00	0,00	0,06	0,00	0,29
NO. 47	0,70	0,42	0,76	0,33	0,72	0,33	0,38	**49,60**	**E**	0,83	0,61	0,00	0,68	0,31	0,00	0,05	-0,33	0,34
NO. 48	0,50	0,20	0,46	0,28	0,33	0,22	0,34	**30,50**	**F**	0,51	0,61	0,00	0,23	0,01	0,00	0,05	0,42	0,22
NO. 49	0,80	0,06	0,72	0,56	0,66	0,55	0,59	**45,60**	**E**	0,48	0,67	0,51	0,82	0,57	0,00	0,56	-0,28	0,49
NO. 50	0,68	0,05	0,59	0,45	0,58	0,48	0,53	**38,90**	**E**	0,37	0,67	0,00	0,82	0,57	0,00	0,21	0,07	0,49
NO. 51	0,77	0,12	0,72	0,59	0,58	0,55	0,64	**47,30**	**E**	0,45	0,67	0,60	0,76	0,44	0,00	0,56	0,20	0,49
NO. 52	0,51	0,13	0,58	0,46	0,44	0,35	0,34	**33,93**	**F**	0,38	0,32	0,44	0,33	0,29	0,00	0,18	0,67	0,41
NO. 53	0,41	0,09	0,36	0,30	0,31	0,31	0,24	**25,20**	**F**	0,29	0,23	0,00	0,29	0,45	0,01	0,06	0,00	0,30
NO. 54	0,69	0,07	0,66	0,42	0,56	0,41	0,29	**36,90**	**E**	0,39	0,23	0,34	0,57	0,84	0,02	0,01	0,00	0,43
NO. 55	0,59	0,53	0,49	0,46	0,45	0,21	0,32	**45,40**	**E**	0,60	0,00	0,17	0,47	0,29	0,00	0,22	0,00	0,60
NO. 56	0,50	0,04	0,45	0,34	0,34	0,29	0,27	**25,90**	**F**	0,37	0,00	0,29	0,37	0,32	0,00	0,06	0,00	0,20
NO. 57	0,70	0,02	0,59	0,45	0,65	0,49	0,36	**37,60**	**E**	0,38	0,00	0,34	0,76	0,93	0,00	0,15	-0,11	0,37
NO. 58	0,41	0,09	0,28	0,26	0,22	0,27	0,28	**23,10**	**F**	0,29	0,50	0,00	0,12	0,09	0,00	0,15	-0,33	0,38
NO. 59	0,38	0,03	0,32	0,30	0,33	0,35	0,40	**24,30**	**F**	0,34	0,00	0,14	0,45	0,01	0,00	0,15	-0,11	0,27
NO. 60	0,71	0,50	0,64	0,56	0,51	0,45	0,59	**55,21**	**D**	0,64	0,37	0,00	0,65	0,37	0,00	0,15	0,42	0,66
NO. 61	0,57	0,10	0,66	0,53	0,74	0,81	0,69	**48,10**	**E**	0,49	0,61	0,57	0,87	0,49	0,00	0,13	-0,11	0,51
NO. 62	0,43	0,08	0,47	0,33	0,53	0,34	0,28	**28,80**	**F**	0,35	0,00	0,10	0,59	0,03	0,00	0,13	-0,28	0,38
NO. 63	0,48	0,12	0,48	0,35	0,29	0,21	0,22	**26,50**	**F**	0,37	0,00	0,00	0,16	0,48	0,00	0,00	0,44	0,33
NO. 64	0,42	0,10	0,40	0,27	0,34	0,13	0,11	**21,90**	**F**	0,21	0,00	0,19	0,21	0,04	0,00	0,00	0,00	0,33
NO. 65	0,57	0,02	0,51	0,44	0,54	0,45	0,40	**33,40**	**F**	0,41	1,00	0,26	0,66	0,29	0,00	0,00	-0,33	0,39
NO. 66	0,46	0,12	0,32	0,33	0,24	0,33	0,33	**27,53**	**F**	0,32	0,68	0,45	0,11	0,15	0,00	0,00	0,28	0,37
NO. 67	0,61	0,03	0,58	0,42	0,58	0,48	0,56	**36,87**	**E**	0,55	1,00	0,55	0,82	0,55	0,00	0,16	-0,17	0,68
NO. 68	0,63	0,16	0,57	0,51	0,58	0,55	0,53	**43,20**	**E**	0,42	0,73	0,33	0,74	0,44	0,00	0,22	0,00	0,55
NO. 69	0,45	0,09	0,38	0,38	0,38	0,40	0,53	**31,20**	**F**	0,27	0,61	0,00	0,57	0,00	0,00	0,22	0,00	0,37

NO. 70	0,52	0,04	0,48	0,43	0,45	0,53	0,62	**35,10**	**E**	0,39	0,67	0,26	0,58	0,51	0,00	0,20	0,00	0,49
NO. 71	0,75	0,96	0,57	0,67	0,55	0,56	0,68	**74,50**	**C**	0,83	0,63	0,89	0,58	0,31	0,00	0,69	0,97	0,76
NO. 72	0,55	0,09	0,50	0,27	0,34	0,22	0,27	**27,30**	**F**	0,39	0,23	0,33	0,37	0,29	0,00	0,16	-0,33	0,24
NO. 73	0,20	0,00	0,18	0,15	*0,25*	0,13	0,10	**11,10**	**G**	0,16	0,00	0,07	0,16	0,00	0,02	0,00	*0,00*	0,12
NO. 74	0,21	0,00	0,18	0,14	0,24	*0,14*	0,10	**11,40**	**G**	0,18	0,00	0,00	0,14	0,00	*0,00*	0,00	0,00	0,12
NO. 75	0,21	0,00	0,18	0,09	*0,13*	0,05	0,00	**7,60**	**G**	0,18	0,00	0,00	0,14	*0,00*	0,00	0,00	0,00	0,02
NO. 76	0,67	0,14	0,59	0,43	0,35	0,41	0,36	**36,90**	**E**	0,59	0,61	0,00	0,38	0,09	0,16	0,15	-0,25	0,38
NO. 77	0,50	0,11	0,59	0,33	0,37	0,28	0,34	**33,00**	**F**	0,39	0,23	0,41	0,31	0,44	0,00	0,36	0,00	0,17
NO. 78	0,46	0,24	0,46	0,41	0,50	0,39	0,51	**39,00**	**E**	0,23	0,37	0,00	0,27	0,29	0,00	0,36	0,00	0,53
NO. 79	0,44	0,05	0,34	0,27	0,39	0,22	0,27	**23,30**	**F**	0,33	0,00	0,11	0,08	0,06	0,00	0,06	0,00	0,33
NO. 80	0,86	0,53	0,79	0,73	0,74	0,70	0,79	**68,90**	**C**	0,62	0,67	0,70	0,76	0,79	0,00	0,46	0,44	0,82
NO. 81	0,38	0,00	0,34	0,21	0,33	0,24	0,38	**20,70**	**F**	0,34	0,67	0,00	0,27	0,00	0,00	0,06	0,00	0,12
NO. 82	0,66	0,11	0,68	0,50	0,68	0,70	0,51	**45,80**	**E**	0,55	0,83	0,43	0,80	0,64	0,00	0,01	0,11	0,48
NO. 83	0,62	0,08	0,61	0,44	0,45	0,46	0,37	**36,10**	**E**	0,40	0,83	0,34	0,35	0,44	0,00	0,10	-0,33	0,51
NO. 84	0,50	0,09	0,42	0,36	0,36	0,40	0,39	**30,80**	**F**	0,37	0,47	0,19	0,48	0,25	0,16	0,25	0,00	0,32
NO. 85	0,28	0,05	0,32	0,24	0,28	0,12	0,21	**17,00**	**G**	0,12	0,14	0,14	0,23	0,18	0,00	0,10	0,08	0,29
NO. 86	0,62	0,02	0,55	0,50	0,61	0,55	0,62	**39,30**	**E**	0,41	0,67	0,36	0,73	0,79	0,02	0,56	-0,25	0,41
NO. 87	0,59	0,36	0,67	0,46	0,76	0,46	0,59	**50,20**	**D**	0,54	0,37	0,39	0,88	0,28	0,00	0,71	-0,14	0,47
NO. 88	0,49	0,35	0,47	0,41	0,43	0,39	0,41	**40,60**	**E**	0,41	0,23	0,00	0,51	0,15	0,00	0,06	0,00	0,41
NO. 89	0,55	0,05	0,59	0,44	0,63	0,53	0,56	**38,20**	**E**	0,34	0,61	0,37	0,64	0,51	0,00	0,33	-0,28	0,46
NO. 90	0,56	0,02	0,46	0,50	0,51	0,75	0,70	**40,60**	**E**	0,44	1,00	0,37	0,85	0,22	0,00	0,81	-0,14	0,49
NO. 91	0,66	0,13	0,64	0,61	0,65	0,78	0,70	**50,00**	**D**	0,52	0,67	0,55	0,98	0,57	0,00	0,56	0,42	0,49
NO. 92	0,21	0,00	0,18	0,14	0,24	0,14	0,10	**11,40**	**G**	0,18	0,00	0,00	0,14	0,00	0,00	0,00	0,00	0,12
NO. 93	0,22	0,00	0,18	0,14	*0,24*	0,14	0,10	**11,50**	**G**	0,19	0,00	0,00	0,14	*0,00*	0,00	0,00	0,00	0,12

Table A 2. Details of building information.

SRI ID	BUILDING TYPE	USE OF THE PROPERTY	NET AREA	YEAR OF CONSTRUCTION	CONDITION OF THE PROPERTY	LOCATION
NO. 1	**Residential building**	Small multi-family house	500-1000	1960-1990	Original	Espoo
NO. 2	**Residential building**	Apartment	1000-10000	>2010	Original	Helsinki
NO. 3	**Residential building**	Single-family house	<200	1990-2010	Original	confidential
NO. 4	**Residential building**	Apartment	1000-10000	>2010	Original	Helsinki
NO. 5	**Residential building**	Apartment	1000-10000	>2010	Original	Helsinki
NO. 6	**Non-residential building**	Office	10000-25000	>2010	Under construction	Helsinki
NO. 7	**Non-residential building**	Office	1000-10000	>2010	Original	Vantaa
NO. 8	**Non-residential building**	Other non-residential	1000-10000	<1960	Original	Helsinki
NO. 9	**Non-residential building**	Educational institution building	1000-10000	1960-1990	Original	Helsinki
NO. 10	**Non-residential building**	Office	1000-10000	>2010	Original	Toivala
NO. 11	**Non-residential building**	Other non-residential	1000-10000	1990-2010	Renovated	Vuorela
NO. 12	**Non-residential building**	Other non-residential	10000-25000	1960-1990	Original	Hämeenlinna
NO. 13	**Non-residential building**	Other non-residential	1000-10000	>2010	Original	Kirkkonummi
NO. 14	**Residential building**	Small multi-family house	1000-10000	1960-1990	Renovated	Parkano
NO. 15	**Non-residential building**	Other non-residential	<200	1960-1990	Original	Helsinki
NO. 16	**Non-residential building**	Other non-residential	500-1000	1960-1990	Original	Helsinki
NO. 17	**Non-residential building**	Other non-residential	10000-25000	1960-1990	Renovated	Jyväskylä
NO. 18	**Non-residential building**	Other non-residential	1000-10000	>2010	Original	Jyväskylä
NO. 19	**Non-residential building**	Educational institution building	10000-25000	>2010	Renovated	Helsinki
NO. 20	**Non-residential building**	Office	1000-10000	>2010	Under construction	Vantaa
NO. 21	**Residential building**	Apartment	1000-10000	>2010	Under construction	Turku
NO. 22	**Non-residential building**	Educational institution building	1000-10000	>2010	Under construction	Tampere
NO. 23	**Non-residential building**	Office	1000-10000	>2010	Under construction	Oulu
NO. 24	**Non-residential building**	Office	10000-25000	1990-2010	Renovated	Jyväskylä
NO. 25	**Non-residential building**	Educational institution building	1000-10000	>2010	Original	Jyväskylä
NO. 26	**Non-residential building**	Educational institution building	1000-10000	>2010	Original	Oulu
NO. 27	**Non-residential building**	Other non-residential	>25000	>2010	Original	Helsinki
NO. 28	**Non-residential building**	Office	1000-10000	1990-2010	Original	Espoo
NO. 29	**Non-residential building**	Healthcare	>25000	<1960	Renovated	Lahti
NO. 30	**Residential building**	Other residential	10000-25000	>2010	Original	Turku
NO. 31	**Non-residential building**	Educational institution building	>25000	>2010	Original	Helsinki
NO. 32	**Residential building**	Single-family house	200-500	1990-2010	Original	Kirkkonummi
NO. 33	**Non-residential building**	Educational institution building	1000-10000	1960-1990	Renovated	Imatra
NO. 34	**Non-residential building**	Other non-residential	500-1000	1960-1990	Renovated	Espoo
NO. 35	**Non-residential building**	Educational institution building	1000-10000	>2010	Original	Helsinki
NO. 36	**Residential building**	Other residential	>25000	<1960	Renovated	Helsinki
NO. 37	**Non-residential building**	Other non-residential	10000-25000	1960-1990	Renovated	Lahti
NO. 38	**Non-residential building**	Educational institution building	10000-25000	>2010	Under construction	Uusimaa
NO. 39	**Non-residential building**	Educational institution building	1000-10000	>2010	Original	confidential

NO. 40	**Residential building**	Apartment	1000-10000	1960-1990	Original	Vantaa
NO. 41	**Non-residential building**	Office	1000-10000	1990-2010	Original	Helsinki
NO. 42	**Non-residential building**	Educational institution building	10000-25000	1960-1990	Renovated	Pori
NO. 43	**Non-residential building**	Office	1000-10000	1990-2010	Original	Eura
NO. 44	**Non-residential building**	Office	1000-10000	1990-2010	Original	Kotka
NO. 45	**Non-residential building**	Other non-residential	1000-10000	<1960	Renovated	Kotka
NO. 46	**Non-residential building**	Other non-residential	500-1000	<1960	Original	Kotka
NO. 47	**Non-residential building**	Office	10000-25000	1960-1990	Renovated	Seinäjoki
NO. 48	**Non-residential building**	Office	1000-10000	<1960	Renovated	Seinäjoki
NO. 49	**Non-residential building**	Educational institution building	10000-25000	1960-1990	Renovated	Lahti
NO. 50	**Non-residential building**	Educational institution building	1000-10000	>2010	Original	Lahti
NO. 51	**Non-residential building**	Educational institution building	1000-10000	<1960	Renovated	Helsinki
NO. 52	**Residential building**	Apartment	1000-10000	>2010	Original	Helsinki
NO. 53	**Non-residential building**	Educational institution building	10000-25000	1960-1990	Renovated	Helsinki
NO. 54	**Non-residential building**	Office	1000-10000	>2010	Original	Lappeenranta
NO. 55	**Non-residential building**	Educational institution building	1000-10000	<1960	Renovated	Jyväskylä
NO. 56	**Non-residential building**	Office	1000-10000	1960-1990	Original	Jyväskylä
NO. 57	**Non-residential building**	Office	10000-25000	>2010	Under construction	Helsinki
NO. 58	**Residential building**	Apartment	1000-10000	1960-1990	Original	Lahti
NO. 59	**Non-residential building**	Office	1000-10000	<1960	Renovated	Lahti
NO. 60	**Non-residential building**	Educational institution building	500-1000	>2010	Original	Lappeenranta
NO. 61	**Non-residential building**	Educational institution building	10000-25000	>2010	Original	Turku
NO. 62	**Non-residential building**	Other non-residential	10000-25000	1960-1990	Renovated	Turku
NO. 63	**Residential building**	Apartment	1000-10000	1960-1990	Renovated	Turku
NO. 64	**Non-residential building**	Office	1000-10000	1960-1990	Renovated	Turku
NO. 65	**Non-residential building**	Office	1000-10000	1960-1990	Original	Vantaa
NO. 66	**Non-residential building**	Office	1000-10000	1960-1990	Original	Helsinki
NO. 67	**Non-residential building**	Other non-residential	10000-25000	>2010	Original	Helsinki
NO. 68	**Non-residential building**	Educational institution building	10000-25000	>2010	Original	Jyväskylä
NO. 69	**Non-residential building**	Educational institution building	1000-10000	1960-1990	Original	Jyväskylä
NO. 70	**Non-residential building**	Office	1000-10000	1960-1990	Renovated	Jyväskylä
NO. 71	**Non-residential building**	Other non-residential	10000-25000	>2010	Under construction	Espoo
NO. 72	**Non-residential building**	Office	1000-10000	1990-2010	Original	Oulu
NO. 73	**Non-residential building**	Other non-residential	1000-10000	1960-1990	Renovated	Helsinki
NO. 74	**Non-residential building**	Other non-residential	1000-10000	1960-1990	Renovated	Helsinki
NO. 75	**Non-residential building**	Other non-residential	500-1000	1960-1990	Renovated	Helsinki
NO. 76	**Residential building**	Apartment	1000-10000	>2010	Original	Jyväskylä
NO. 77	**Non-residential building**	Other non-residential	10000-25000	1960-1990	Renovated	Lappeenranta
NO. 78	**Non-residential building**	Other non-residential	1000-10000	1960-1990	Original	Lappeenranta
NO. 79	**Residential building**	Apartment	10000-25000	<1960	Renovated	Turku
NO. 80	**Non-residential building**	Office	1000-10000	>2010	Original	Turku
NO. 81	**Non-residential building**	Other non-residential	1000-10000	1960-1990	Original	Turku
NO. 82	**Non-residential building**	Office	1000-10000	>2010	Original	Kuopio

NO. 83	**Non-residential building**	Other non-residential	1000-10000	>2010	Original	Kuopio
NO. 84	**Non-residential building**	Educational institution building	10000-25000	1960-1990	Renovated	Helsinki
NO. 85	**Non-residential building**	Office	1000-10000	1990-2010	Original	Vantaa
NO. 86	**Non-residential building**	Office	>25000	>2010	Original	Helsinki
NO. 87	**Non-residential building**	Other non-residential	10000-25000	1960-1990	Renovated	Vantaa
NO. 88	**Non-residential building**	Other non-residential	1000-10000	1960-1990	Original	Espoo
NO. 89	**Non-residential building**	Educational institution building	1000-10000	<1960	Renovated	Jyväskylä
NO. 90	**Non-residential building**	Healthcare	10000-25000	>2010	Original	Kirkkonummi
NO. 91	**Non-residential building**	Other non-residential	1000-10000	>2010	Under construction	Salo
NO. 92	**Non-residential building**	Other non-residential	1000-10000	1960-1990	Renovated	Helsinki
NO. 93	**Non-residential building**	Other non-residential	1000-10000	1960-1990	Renovated	Helsinki