LAPPEENRANTA–LAHTI UNIVERSITY OF TECHNOLOGY LUT
LUT School of Energy Systems
Trilateral Master's Degree Programme in Energy Technology

Vilppu Eloranta

APPLICABILITY EVALUATION OF SMART READINESS INDICATOR FOR BUILDINGS

Examiners Professor, D.Sc. (Tech.) Risto Soukka
Associate Professor, D.Sc. (Tech.) Mika Luoranen

Reviewer Professor, Dr.-Ing. Bernard Nacke, Leibniz Universität Hannover

ABSTRACT

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Applicability Evaluation of Smart Readiness Indicator for Buildings

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78 pages, 19 figures, 20 tables, 7 equations and 2 appendices

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Keywords smart building, building rating system, building development, energy performance, energy flexibility

Buildings are a major energy consumer in the European Union, and only few existing buildings are classified as energy efficient. The EU has established energy directives to enhance energy performance and sustainability of the built environment, including through smart technologies. Therefore, the Smart Readiness Indicator (SRI) for Buildings method is being developed and expected to become a standard procedure to assess buildings based on their readiness to increase performance using smart technologies.

This master's thesis considers usage of SRI especially in the Nordic environment. The aims were to recognize benefits of the method and assess its applicability. The objectives were to classify and compare SRI with other building rating systems and analyse real SRI assessment results. Material was acquired in a case study, in which ten public buildings in South Karelia, Finland were SRI assessed.

SRI was found to support digitalization of buildings and to identify especially the flexibility required by future energy systems. Transparency and assessment simplicity were also considered advantages. However, the current version did not fully recognize all energy demand flexibility and storage methods, such as virtual power plant system controlling ventilation or heat storage capacity integrated in district heating networks. Additionally, some assessment domains were not considered relevant in the Nordic environment.

SRI was recognized as a potentially useful tool in building development activities, provided that the results are interpreted correctly and other assessments performed properly. To facilitate this, a tool was drafted, which would identify essential smartness deficiencies in the building and provide automatic suggestions for improvement.

TIIVISTELMÄ

Lappeenrannan–Lahden teknillinen yliopisto LUT
LUT School of Energy Systems
Trilateral Master’s Degree Programme in Energy Technology

Vilppu Eloranta

Rakennusten älyratkaisuvalmiusindikaattorin sovellettavuusarvio

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Tarkastajat	Professori, TkT Risto Soukka Tutkijaopettaja, TkT Mika Luoranen
Hakusanat	älykäs rakennus, rakennusten arviointijärjestelmä, rakennusten kehittäminen, energiatehokkuus, energiajousto

Rakennukset kuluttavat merkittävän osan energiasta Euroopan unionissa, ja vain pieni osa nykyisistä rakennuksista luokitellaan energiatehokkaiksi. EU:n energiadirektiiveillä pyritään parantamaan rakennetun ympäristön energiatehokkuutta ja kestävyyttä mm. älykkäiden teknologioiden avulla. Siksi rakennuksille on kehitteillä älyratkaisuvalmiusindikaattori Smart Readiness Indicator (SRI), jonka odotetaan muodostuvan rakennusten älyratkaisujen mahdollistamien suorituskykyparannusten arviointistandardiksi.

Tässä diplomityössä käsitellään SRI-menetelmän käyttöä erityisesti pohjoismaisessa ympäristössä. Tavoitteina oli tunnistaa menetelmän hyötyjä ja arvioida sen sovellettavuutta. Päämäärinä oli luokitella ja verrata SRI:tä muihin rakennusten arviointijärjestelmiin sekä tutkia todellisten SRI-arviointien tuloksia. Aineistoa hankittiin tapaustutkimuksessa, jossa SRI-arvioitiin kymmenen julkista rakennusta Etelä-Karjalassa.

SRI:n havaittiin tukevan rakennusten digitalisaatiota ja tunnistavan erityisesti tulevaisuuden energiajärjestelmien vaatimaa joustavuutta. Etuina pidettiin myös läpinäkyvyyttä ja arvioinnin yksinkertaisuutta. Nykyinen versio ei kuitenkaan täysin tunnistanut kaikkia energian kysyntäjousto- ja varastointimenetelmiä, kuten ilmanvaihtoa ohjaavaa virtuaalivoimalaitosjärjestelmää tai kaukolämpöverkkoon sisäänrakennettua varastointikapasiteettia. Lisäksi joitain arviointikohteita ei pidetty olennaisina pohjoismaisessa ympäristössä.

SRI:n tunnistettiin olevan mahdollisesti hyödyllinen työkalu rakennusten kehitystoiminnassa, kunhan tulokset tulkitaan oikein ja selvitykset tehdään asianmukaisesti. Tämän helpottamiseksi luonnosteltiin työkalu, joka tunnistaisi tarkasteltavan rakennuksen olennaisia älykkyyspuutteita ja tarjoaisi niille automaattisia parannusehdotuksia.

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Many thanks to Mika Luoranen and Risto Soukka at LUT for the frequent and fruitful feedback and brainstorming sessions. Time flies when you discuss and actually figure something out. I'd like to thank the whole South Karelian S3UNICA team and all specialists who participated in the remote SRI assessment meetings. Each session was an instructive experience for me and actually made the study possible.

University time has thrown me to interesting places, such as Hannover in Germany and St. Petersburg in Russia. Yet I have drawn the most important motivation from home – family and friends. Thank you for all the support and company. And, to indiscreetly quote a friend of mine, for the numerous cups of coffee.

Vilppu Eloranta
26th July 2020
Iitti, Finland

CONTENTS

NOMENCLATURE

Latin alphabet

E	calculated energy performance metric	kWh/m^2a
EP	overall energy performance indicator	
FL	service functionality level	
I	impact criterion point score	
N	number	
R	energy performance reference	
SR	smart readiness score	
w	weighting factor	

Subscripts

d	SRI domain
f	SRI function
i	SRI impact
s	SRI service

Abbreviations

AI	artificial intelligence
BAC	building automation and control
BACS	building automation and control system
BREEAM	Building Research Establishment Environmental Assessment Method
CED	cumulative energy demand
CO	carbon monoxide
CO_2	carbon dioxide
DE	dynamic building envelope
DH	district heating
DHW	domestic hot water
EED	Energy Efficiency Directive
elem.	elementary
EnB	energy baseline

EnMS	energy management system
EnPI	energy performance indicator
EPBD	Energy Performance of Buildings Directive
EPC	energy performance certificate
EU	European Union
EU-28	Member States of the European Union
EV	electric vehicle charging
GPP	Green Public Procurement
I/O	input/output
IAQ	indoor air quality
IoT	internet of things
LCA	life cycle analysis
LCC	life cycle cost
LEED	Leadership in Energy and Environmental Design
MC	monitoring and control
NO_2	nitrous dioxide
PDCA	plan-do-check-act
PM	particulate matter
PV	photovoltaic
PWM	pulse width modulation
SRI	Smart Readiness Indicator
SYK	University Properties of Finland Ltd (*Suomen Yliopistokiinteistöt Oy*)
TABS	thermally activated building system
TBM	technical building management
TBS	technical building system
TQA	total quality assessment
VOC	volatile organic compound
voc.	vocational
VPP	virtual power plant
WHO	World Health Organization

1 INTRODUCTION

In the whole European Union (EU), buildings account for 40 % of total energy consumption, which corresponds to 36 % of total greenhouse gas emissions. Approximately 75 % of buildings in the EU are energy inefficient and 35 % are over 50 years old. (European Commission 2019). There is therefore interest in improving energy efficiency of the whole building sector. European Commission (2019) estimates that renovation of existing buildings could lower the total EU energy consumption by 5–6 % and reduce carbon dioxide (CO_2) emissions accordingly. Hence, the European Union has set new regulations to improve building energy efficiency.

In the EU, developments include Energy Performance of Buildings Directive 2010/31/EU (EPBD) and Energy Efficiency Directive 2012/27/EU (EED). The directives were amended later in 2018 and 2019. Among other additions, the amended EPBD promotes smart technologies by requiring more advanced building automation and control devices. The additions also introduce an optional *smart readiness indicator* procedure. (European Commission 2019).

Based on the EPBD, the Smart Readiness Indicator (SRI) for Buildings project was launched. SRI is intended to become a standard procedure to assess buildings based on their technical readiness to increase energy performance using smart technologies, producing results comparable between EU member states. The development work is assigned to Verbeke et al. (2020), who report progress with interim reports and aim to provide the necessary technical specifications of SRI to the European Commission.

The first SRI technical support study was conducted in 2017–2018, in which smart ready building, service and methodology concepts were defined. Currently, the project is in the second technical support study phase, which aims to define the final SRI procedure. The study team has analysed a large number of stakeholder comments during the technical studies. (Verbeke et al. 2020, pp. 1–2).

Smart Readiness Indicator implementation pathways in individual EU member states have been compared by Verbeke et al. (2020, p. 154). Suggested pathways include:

- requiring SRI with the mandatory energy performance certificate (EPC)
- requiring SRI for new constructions and major renovations of buildings
- a voluntary non-obligating approach, possibly subsidized by state.

A combination of pathways could also be selected. In Finland, the national SRI implementation project has been launched aiming to produce implementation recommendations (Virtanen 2019). Furthermore, SRI applicability for cold climate countries has already been studied by Janhunen et al. (2019). They concluded that the SRI catalogue is not fully feasible for cold-climate countries because it, among other reasons, neglects energy storage potential and other advantages of district heating networks. Additionally, they noted that the assessor is able to manipulate results through ambiguous selections.

1.1 Energy consumption and sources

In Finland, approximate annual energy consumption for space heating is 79 TWh, which corresponds to 26 % of final energy consumption. More energy is consumed only by industry (46 %), while the rest is used in transport (16 %) and others (12 %). (Statistics Finland 2019). Annual gross inland energy consumption per capita is relatively high in most Northern European countries, and in Finland the value is over 6 toe compared to EU member state (EU-28) average of 3,3 toe (Eurostat 2017).

Building energy consumption per floor area in Finland compared to EU-28 is 35 % higher in residential and 16 % higher in non-residential buildings (European Commission 2016), which is naturally explained by the cold climate. Typical energy consumers in buildings are space heating, space cooling, domestic water heating and electricity use. Modelled energy consumption values of Finnish non-residential buildings according to building codes in different eras are presented in figure 1 (Möttönen, Vainio and Nissinen 2014).

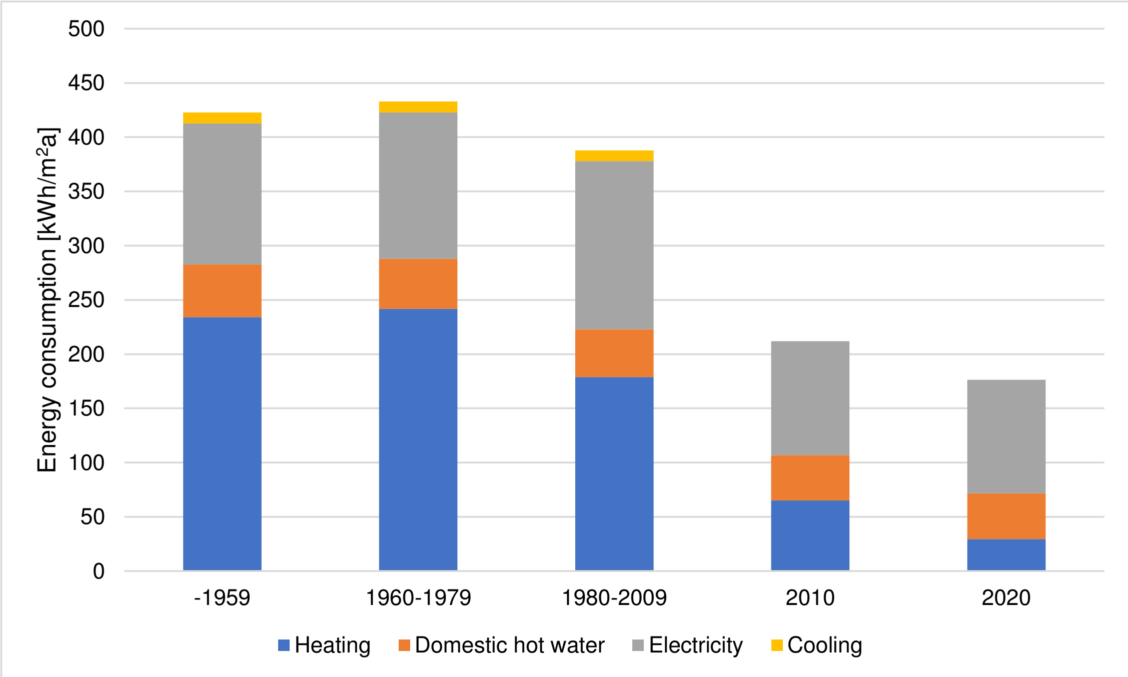


Figure 1. Modelled annual energy consumptions per floor area in Finnish non-residential buildings complying with then building codes (data from Möttönen, Vainio and Nissinen 2014).

As figure 1 visualizes, specific energy consumption in non-residential building complying with local building codes has already halved between 1980 and 2020. Traditionally, heating has been the largest energy consumer in buildings, while updated building codes with stricter insulation requirements have reduced it significantly. Cooling energy consumption has always been low due to limited cooling periods in northern climate. In new buildings, electricity use is the prominent energy consumer.

Building energy systems in different regions have their own characteristics. In countries with cold climates, district heating networks are usually well-developed and widespread due to their efficiency benefits (Janhunen et al. 2019). Also, compositions of energy sources differ due to availability, economic and political reasons. Energy sources of gross inland energy consumptions in Finland and EU-28 are compared in figure 2. (Eurostat 2017).

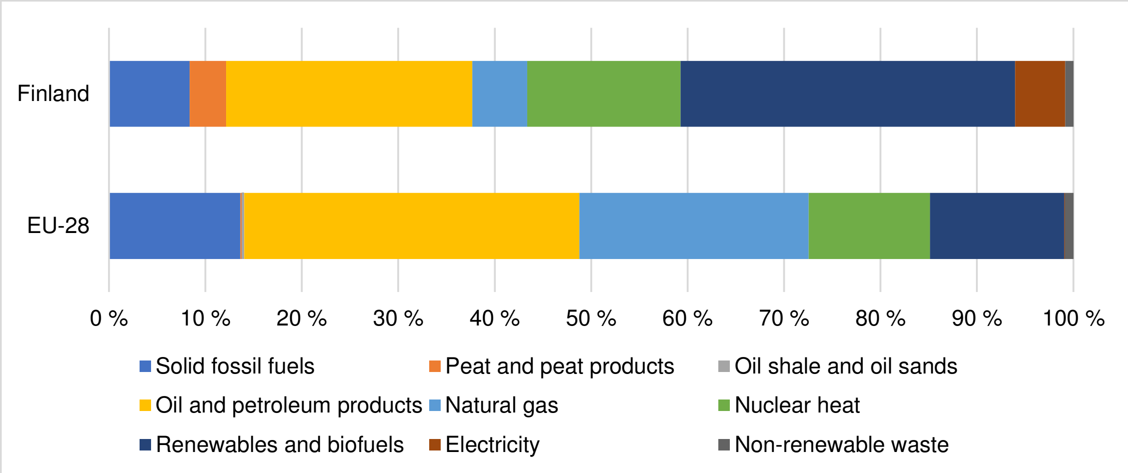


Figure 2. Energy sources of gross inland energy consumptions in Finland and EU-28 (data from Eurostat 2017).

Figure 2 clarifies that Finland and EU-28 average have essential energy source structure differences. For example, natural gas is commonly used in EU-28, while renewables, biofuels and controversial peat have notable shares in Finland. Comparing the smallest cumulative fossil fuel shares in EU-28, Finland ranks third at 40 %, behind Estonia (11 %) and Sweden (28 %). (Eurostat 2017).

The EU climate targets drive rapid increase of renewable energy sources (European Parliament 2018), and their adoption is boosted by the decreased prices of the technologies. However, intermittency of most renewable energy sources poses challenges in maintaining the constant balance between energy generation and consumption, and thus creates needs for energy storage and demand flexibility systems. (Vinokurov et al. 2018). Since buildings are a major energy consumer, integration of renewable energy sources, smart grids and smart-ready buildings has great potential (European Parliament 2018).

1.2 Smart buildings

There is no single commonly accepted definition for *smart* or *intelligent building*. Numerous, even partly conflicting definitions are suggested since 1988 and have evolved over time with technological advancements. (Ghaffarianhoseini et al. 2016). Three main categories for the definitions are pointed out by Ghaffarianhoseini et al. (2016):

1. Performance-based: emphasizes expectations and demands of users (occupants) with less attention to technological systems.
2. System-based: emphasizes technological systems as the most important part, while they are also linked to human needs.
3. Service-based: evaluates smartness based on service quality.

European Parliament (2018) defines smart capabilities as “capabilities of a building or building unit to adapt its operation to the needs of the occupant and the grid and to improve its energy efficiency and overall performance”. Hence, a smart building can be considered to contain one or several of these capabilities.

Smart capabilities in buildings are achieved through technology-neutral *smart services* that use technology-specific *smart technologies* to perform their functions (Verbeke et al. 2018, p. 32). These technologies can be described as interfaces between human, collective and artificial intelligence. For example, smart technologies could consist of networked sensors whose signals are processed and used to control mechanical-electrical systems. Ideally, the benefits include a healthier, more comfortable and energy efficient indoor environment. (Ghaffarianhoseini et al. 2016).

According to European Parliament (2018), connectivity targets and high-bandwidth communication networks are essential for digitalization of the building sector. The trend has already began materializing with internet of things (IoT) devices. IoT platforms and high-speed network connections enable the implementation of connected smart platforms, such as cloud-based energy prediction tools. Additionally, with sufficient performance resources, even machine learning and data mining techniques are feasible. (Yu et al. 2018).

European Parliament (2018) also encourages the deployment of flexible energy grids. Electricity power exchange Nord Pool, initially operating in the Nordics, has pioneered the deployment of modern power trading models and subsequently defined the target for European power markets. They respond to challenges of changing energy sources, system stability and service quality. In smart buildings, modern power markets enable the use of energy flexibility as an important tool to improve efficiency. (Rönnback 2019).

The smart building scene has attracted businesses to develop connected energy performance and flexibility solutions. For example, Siemens Finland has developed a virtual power plant (VPP) platform, which connects several buildings into a microgrid and allows them to sell power to the reserve market by controlling electrical loads such as ventilation or lighting systems. It reduces the need for traditional reserve power plants and hence has CO_2 reduction potential. Siemens already has several large VPP customers in Finland. (Siemens AG 2019).

Leanheat Oy (2019) offers a heating system control solution based on IoT and AI (artificial intelligence), claimed to offer up to 10–20 % heating energy savings and up to 30 % maintenance cost savings. The system monitors indoor conditions with sensors and controls HVAC systems optimally based on thermodynamic data. It also integrates energy flexibility and predictive problem detection capabilities.

Comfy (2017) has developed a smart building solution, which offers individual computer or smartphone-based temperature and airflow controls for occupants. It can proactively adjust HVAC settings after learning typical occupant behaviour and enhance energy efficiency by adjusting temperatures of unoccupied zones. The solution uses standard protocols and can be connected to any BACnet-compatible HVAC system.

1.3 Research in this thesis

In this thesis, the Smart Readiness Indicator methodology is tested by performing SRI assessments for buildings in South Karelia, Finland. It is assumed that SRI assessment results are utilizable and applicable for different purposes, such as building development and energy management functions.

To confirm the hypothesis, two studies are initiated. The first is a literature study to clarify how SRI relates to technical building systems (TBS) and other building rating systems. The second is a case study to acquire real-world experience of SRI usage and applicability. Results are synthesized from outcomes of both studies. Figure 3 illustrates the studies, including their aims, objectives, research questions, methods and desired results.

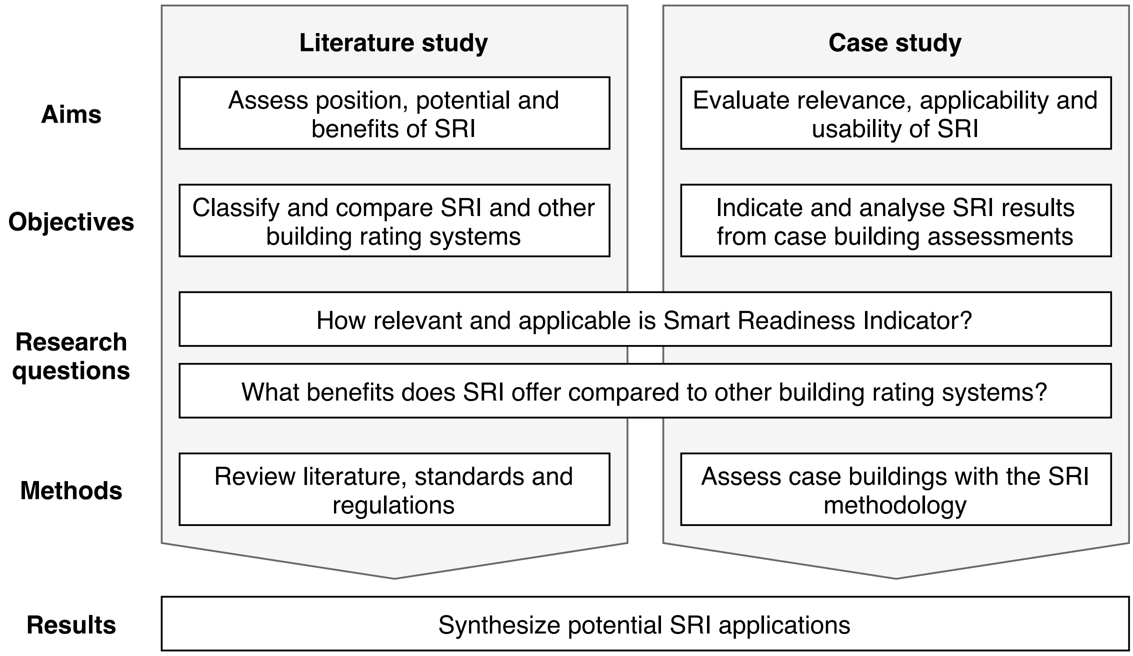


Figure 3. Visualization of the two studies in this thesis along with their drivers and results.

Structurally, this thesis is divided into parts. Sections 2–4 contain the literature study based on regulations, standards and statistics, and sections 5–7 the case study based on SRI case assessments. Overarching applicability conclusions are presented in section 8, while the whole research is summarized and concluded in section 9.

Because the case study in this research is performed for buildings in Finland, literature is reviewed primarily from national perspective. Furthermore, due to the campus project context, the case study is delimited to non-residential buildings in Finland. As the goal is to provide suggestions for SRI applications, detailed specification and development of the tools will remain for further research.

2 BUILDING SYSTEMS AND INDOOR ENVIRONMENT

This section provides background to adequately comprehend Smart Readiness Indicator and its applications. The topics include technical building systems, indoor environment, building automation and energy management functions, and are introduced mainly through building codes, decrees and standards.

Building energy balance can be represented as an interface with ingoing, outgoing and internal energy flows, of which figure 4 shows a general representation (Decree 1048/2017). Every building has an individual composition of energy balance components depending on its use, and thus may contain fewer or more components than the general example here.

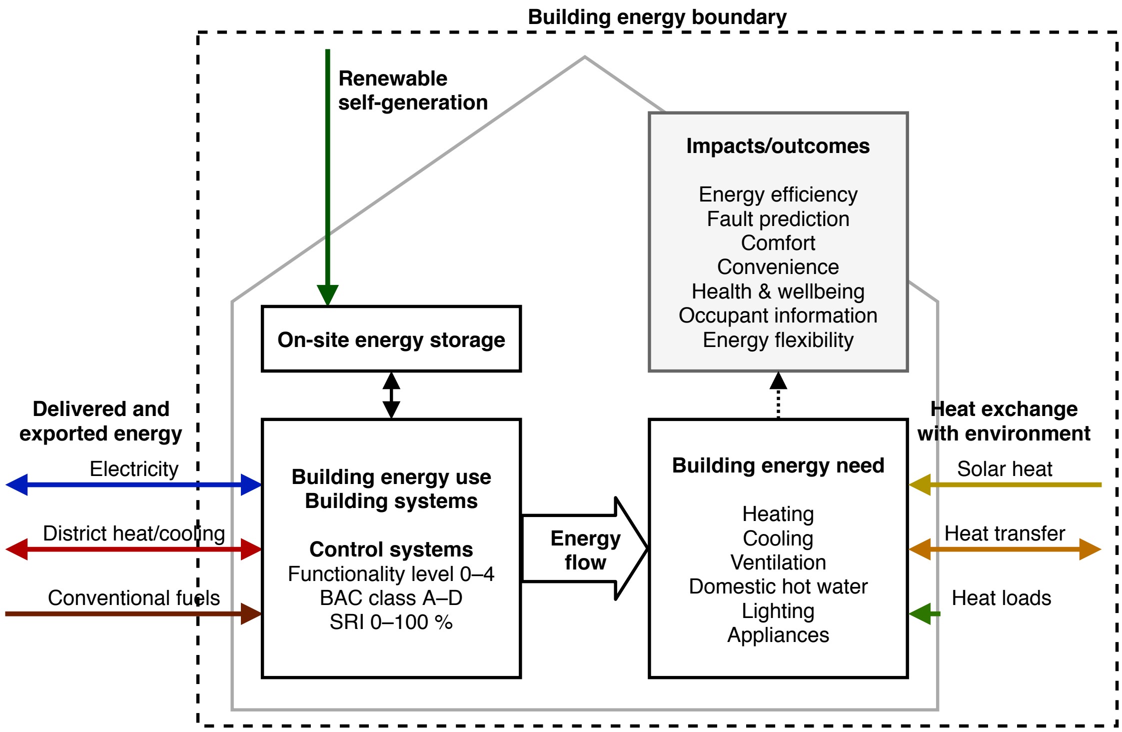


Figure 4. Building energy balance with consumers, self-generation and energy storage possibilities (based on Decree 1048/2017). Impacts represent the positive effects achieved with energy use and technical control systems (Verbeke et al. 2020).

Energy consumption of technical building systems is dependent on implemented control methods. In figure 4, control system functionality levels 0–1 generally represent current mandatory baseline and levels 2–4 more advanced optional capabilities. The latter usually positively impact building energy efficiency, comfort or other factors, and may have smart capabilities such as adapting to occupant needs or communicating with other systems. (SFS-EN 15232-1 2017). Benefits of advanced solutions may not be obvious today, however in the future they may gradually become mandatory in building directives and codes such as EPBD. Thus they are important when considering the entire life cycle of buildings (Vinokurov et al. 2018).

2.1 Indoor climate

Indoor climate is maintained by heating, cooling, ventilation and lighting systems. In the EU, building indoor heating and cooling corresponds to almost 40 % of final energy consumption (European Parliament 2018). For single residential reference buildings in EU-28, share of heating, cooling and ventilation energy use of total building energy use is 62–73 % depending on geographical area, and for non-residential buildings the share is 68–80 %. Indoor lighting consumes 1–5 % and 10–16 %, respectively. (Verbeke et al. 2020, p. 124). Therefore, maintaining indoor climate consumes the most energy in buildings everywhere in EU-28, while also being a major occupant comfort factor.

To achieve ideal indoor climate conditions, stable temperature and sufficient ventilation and air purity are required. International standardized design temperatures are defined in EN standard 15251. It divides indoor air quality into classes I–III and specifies minimum and maximum indoor temperatures for different classes and seasons. EN 7730 provides metrics to estimate thermal ergonomics. (Dodd, Garbarino and Gama Caldas 2016, pp. 111–113).

Studies have shown that sufficient indoor air quality might increase productivity. On the other hand, insufficient indoor air quality is as a severe risk for occupants and can cause "sick building syndrome" symptoms. Indoor CO_2 level should be monitored and controlled. Other contaminants include particulate matter (PM), carbon monoxide (CO), nitrous dioxide (NO_2), formaldehyde, benzene and naphthalene. They originate from outdoor air, materials, combustion, humidity or other sources. (Dodd, Garbarino and Gama Caldas 2016, pp. 116–117).

According to multiple studies, fine particulate matter is the most significant indoor pollutant (Dodd, Garbarino and Gama Caldas 2016, pp. 116–117). Burden of disease share of indoor particulate matter with a diameter less than 2,5 µm ($PM_{2.5}$) is 66 % for Finland and 78 % for EU26. For both, 16 % of these shares is $PM_{2.5}$ from indoor sources and the rest originates from outdoor air. (Hänninen and Asikainen 2013, p. 39).

To overcome indoor air quality challenges, standard EN 13779 describes ventilation system design guidelines which aim to maintain sufficient indoor air quality. Sufficient air quality is defined based on World Health Organization (WHO) recommendations or national standards. (Dodd, Garbarino and Gama Caldas 2016, p. 116).

2.2 Indoor climate standards in Finland

In Finland, national Decree 1009/2017 and Decree 545/2015 regulate limits for indoor temperatures, air pollutants and sufficient ventilation. Optional higher indoor climate classes S1 and S2 are independently defined by Finnish Society of Indoor Air Quality and Climate (2018) in co-operation with multiple Finnish organizations. Class S3 represents the minimum required design complying with local building codes, S2 is the common basic level for good indoor climate and S1 has even stricter quality requirements (Säteri 2008). Selected design values of indoor air classes S1, S2 and S3 are compared in table 1.

Table 1. Design values for Finnish indoor climate classes S1, S2 and S3 (Finnish Society of Indoor Air Quality and Climate 2018). S3 represents levels required by local building codes (Decree 1009/2017; Decree 545/2015). Values from the latter are in parenthesis.

Value	S1 (individual)	S2 (good)	S3 (satisfactory)	
Target temperature (heating) [°C]	21,5	21,5	21	(–)
Target temperature (cooling) [°C]	24,5	25,5	21	(–)
Max. temperature (heating) [°C]	23	23	25	(26)
Max. temperature (cooling) [°C]	27	27	27	(32)
Min. temperature [°C]	20	20	20	(18)
Max. additional CO_2 [ppm]	350	550	800	(1150)
Max. radon [Bq/m^3]	100	100	200	(–)
Max. $PM_{2.5}$ [µg/m^3]	10	10	–	(25)

In addition to values in table 1, the standard defines maximum indoor air velocity, acoustic proofing, smell characteristics and other criteria. There are additional requirements especially for the highest S1 class. For instance, room temperature must be individually adjustable. (Finnish Society of Indoor Air Quality and Climate 2018).

Indoor lighting is internationally standardized in EN 12464-1. It includes indoor work place lighting requirements and good practices for normal-sighted persons. The requirements are achieved throught natural and artificial lighting solutions. Main goals of sufficient lighting properties are visual comfort, visual performance and safety. Automatic switching or atmosphere creation functions are not specified or required. (SFS-EN 12464-1 2011).

Finnish indoor climate standards refer to the European standard EN 12464-1 in lighting design. However, in addition they have additional requirements for lighting adjustment capabilities. The highest indoor climate class S1 requires individually adjustable dimmable lighting and sun shading. (Finnish Society of Indoor Air Quality and Climate 2018).

In conclusion, the highest Finnish indoor climate class S1 defined by Finnish Society of Indoor Air Quality and Climate (2018) already has certain requirements for individual indoor climate adjustments. In figure 4, these requirements mostly correspond to advanced level 2–4 control solutions.

2.3 Building automation and control

Building automation and control systems (BACS) contained in the buildings systems block in figure 4 are used to automatically control building services, such as HVAC, lighting and electricity. BACS design process is standardized in series EN ISO 16484, and its four steps are identified as design, engineering, installation and completion. Main objectives of the system are to achieve sufficient indoor climate, energy conservation and efficiency. (SFS-EN ISO 16484-3 2006). BACS typically implements functions at the following levels (SFS-EN ISO 16484-3 2006, pp. 9–11):

- Management functions in software handle communications, data recording, statistical analysis and support functionalities.
- Processing functions are implemented in software to provide monitoring, interlocking, control and optimization tasks.

- Input/output (I/O) interfaces provide communications between hardware devices and BACS software.
- Field devices are hardware components, which handle actual switching, positioning, state monitoring and measuring functions.

Inputs and outputs can be either binary (digital, two possible states) or analogue (stepless, multi-state) depending on the use case and capabilities (SFS-EN ISO 16484-3 2006). Generally, advanced level 2–4 controls require more analogue measurement and control capabilities for more precise adjustments. For level 0–1, simple binary control or no control at all might be sufficient. (Verbeke et al. 2020, Annex D).

Typical advanced building automation and control (BAC) functions can be represented with a demand-based model plotted in figure 5, in which BAC functions control the energy source based on demands of the building or occupants. (SFS-EN 15232-1 2017).

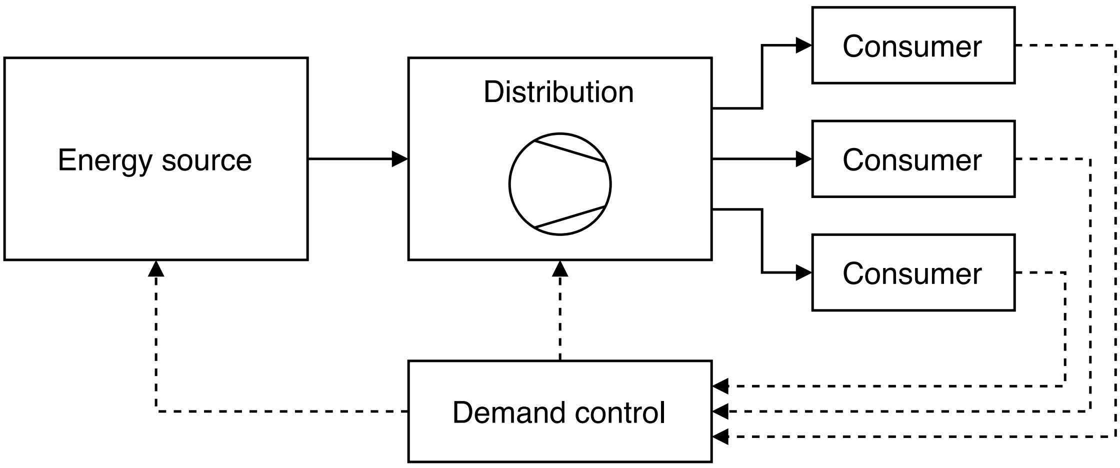


Figure 5. BAC demand control model for HVAC functions. Energy flows are marked with solid and measurement and control signals with dashed arrows (based on SFS-EN 15232-1 2017, figure 2).

Consumer blocks in figure 5 represent rooms or areas in the building with variable HVAC energy demands requiring BACS to adapt. The distribution block represents distribution networks with auxiliary equipment, and the energy source block includes a district heat exchanger or furnace with adjustable power. Demand-controlled BACS utilizes feedback signals such as temperature or CO_2 level measurements to control the source and distribution blocks. This enables high system efficiencies by minimizing supply and distribution losses while providing satisfactory occupant environment (SFS-EN 15232-1 2017).

2.4 BAC energy performance class

European standard EN 15232 defines a set of building automation and control (BAC) functions which influence the energy efficiency of buildings. The standard describes a BAC capability assessment system with numerous criteria for HVAC, DHW (domestic hot water), lighting and other functions. Capabilities are evaluated by selecting a functionality level 0–4 for each issue. As an example, functionality levels for “heat emission control” are (SFS-EN 15232-1 2017):

- Level 0: no automatic control
- Level 1: central automatic control
- Level 2: individual room control
- Level 3: individual room control with communication
- Level 4: individual room control with communication and occupancy detection.

Individual service levels are used to define the BACS energy performance class A–D. Class D does not comply with current requirements, whereas class A represents a system with advanced BAC and TBM (technical building management) functionalities. Requirements for each class are listed in the standard, and all conditions of a class must be met to achieve it. Available classes and required functionalities are presented in table 2. (SFS-EN 15232-1 2017).

Table 2. BACS energy performance classes and overview of their requirements (SFS-EN 15232-1 2017).

Class	Description	Requirements
D	Non-energy efficient	–
C	Standard	Minimum BAC functionality • Baseline automatic control • Scheduled operation of HVAC and lighting systems
B	Advanced	Class C and additional BAC functionality • More advanced automatic control • Room controller communication with BACS
A	High energy performance	Class B and additional TBM and BAC functionality • Readiness for HVAC demand control (figure 5) • Interoperation of several BAC services

Additionally, EN 15232 includes guidelines for including BACS in energy management systems, that enables its capabilities to be utilized in continuous energy performance improvement. They also contain recommendations about good documentation, history logging, regulation compliance and continuous system development. (SFS-EN 15232-1 2017, Annex E).

2.5 Energy management functions

Energy management system (EnMS) in a standardized framework supporting continuous energy performance improvement in organizations. EnMS implementation includes establishment of energy policy, objectives, targets and plans, and the process is based on plan-do-check-act (PDCA) model that supports continuous improvement and evaluation. In organizations, EnMS implementation responsibility is assigned to an energy management team, which can consist of one or multiple persons depending on size and type of the building. Figure 6 visualizes the continuous PDCA process, interaction with other parties and potential positive outcomes. (SFS-EN ISO 50001 2018).

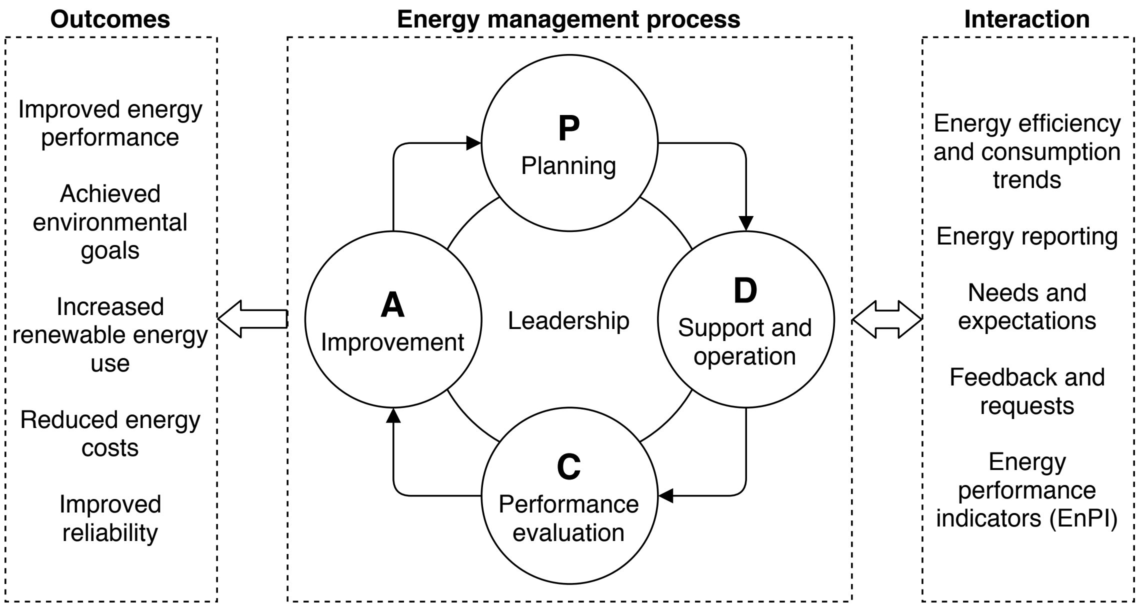


Figure 6. PDCA-based energy management process, including potential outcomes and interaction with the building, its occupants and other relevant parties (based on SFS-EN ISO 50001 2018).

In organizations managing large building masses, such as property management companies, energy management functions are often procured as a service. In this concept, an external service provider takes total responsibility of the energy performance, functionality and comfort of the properties. The service can consist of property manager persons on-site, remote supervision facilities and energy managers. It usually includes generation of personalized recommendations, plans and projects for constant energy performance improvement and indoor climate quality control. (Seeling 2015).

Energy performance developments are monitored with energy performance indicators (EnPI), that can be used as inputs in the energy management process. Relative energy performance improvements can be monitored through comparing EnPI values to energy baseline (EnB) values from real measurements. Since the standard does not suggest suitable EnPI or EnB parameters, selecting them is responsibility of the implementing organization. For instance, a simple numeric value such as energy consumption over a time period could be used. (SFS-EN ISO 50001 2018, p. 56).

3 SUSTAINABILITY RATING SYSTEMS FOR BUILDINGS

In this section, common building sustainability rating systems are overviewed to enable comparing them later. Sustainability rating systems can be categorized for instance into three types described by Berardi (2012):

- Cumulative energy demand (CED) systems are one-dimensional and quantitatively measure sustainability based on energy metrics, such as specific energy consumption of the building.
- Life cycle analysis (LCA) systems consider environmental and ignore social and economic factors. They usually quantitatively assess chemical emissions during the whole life cycle. LCA can be extended to include economic factors with life cycle cost (LCC) analysis.
- Total quality assessment (TQA) systems usually have a multi-parameter criteria set with qualitative and quantitative parameters. They consider environmental, economic and social factors.

However, many rating systems are hard to categorize or they fit into multiple categories (Berardi 2012). Technical building rating systems, such as BAC energy performance class (presented in subsection 2.4) and Smart Readiness Indicator (presented in section 4), primarily assess technical functionality, and thus they must be distinguished from sustainability rating systems. The sustainability rating systems considered in this section include:

- Energy performance certificate (EPC): internationally standardized and nationally implemented CED system that assesses specific energy consumption of buildings (SFS-EN 15217 2007). EPC is relevant in this study because one possible SRI implementation path is to link it to EPC (Verbeke et al. 2020, p. 154).
- Green Public Procurement (GPP) criteria for office building design, construction and management: TQA guideline compilation launched by European Commission for sustainable procurement of office buildings (European Commission 2020).
- Building Research Establishment Environmental Assessment Method (BREEAM): commercial TQA system from United Kingdom (BRE Global Ltd. 2016).

- Leadership in Energy and Environmental Design (LEED): another commercial TQA system from United States (U.S. Green Building Council 2020).

Nordic Swan Ecolabelling method exists for small house, apartment, school and pre-school buildings. It assesses several life cycle factors, such as energy consumption, product safety and indoor environment quality. (Nordic Ecolabelling 2020). However, no Swan Ecolabelling criteria currently exist for commercial or office buildings, and therefore it will not be discussed more specifically. Green Building Council Finland has also produced a “Life cycle indicators for buildings” method, which is a compilation of CED, LCA and LCC indicators with some TQA elements (Bruce et al. 2013). The method has not been updated since 2013 and is not very widespread, so it will not be included either.

Many similar sustainability rating systems as BREEAM and LEED exist, such as Japanese *Comprehensive Assessment System for Built Environment Efficiency* (CASBEE), German *Deutsche Gesellschaft für Nachhaltiges Bauen* (DNGB) and French *Haute Qualité Environnementale* (HQE) (Bernardi et al. 2017). They are less widespread and consider mostly similar topics as BREEAM and LEED, and are therefore omitted from this section.

LCA systems, such as international Common Carbon Metric by United Nations Environment Program’s Sustainable Buildings and Climate Initiative (UNEP-SBCI), enable building emission assessment and comparison through annual carbon dioxide emission metrics (Bernardi et al. 2017). Since GPP criteria and other TQA systems already contain methods for evaluating carbon emissions, LCA systems will not be addressed here.

In Finland, EPC is currently the only legally mandatory rating scheme of these considered here (Act 50/2013, 2–3 §). BAC energy performance requirements according to EN 15232 have already been mostly implemented in Finnish building codes and design practices, although the classification procedure is not required (Kangas et al. 2019, pp. 13–14). Other sustainability rating schemes are completely optional to implement.

3.1 Energy performance certificate

European standard EN 15217 defines a common energy performance certificate (EPC) scheme for buildings. Main objectives of the standardized scheme are to enable establishment of regulations and encourage to commonly improve energy performance of buildings. According to the standard, energy performance is described by an overall energy performance indicator *EP* which may represent primary energy, CO_2 emissions, net delivered energy or other suitable values. (SFS-EN 15217 2007).

In Finland, the owner or occupant of a building must ensure that an EPC exists for the property. Summer homes and other leisure buildings are exempt of this requirement. While selling or renting out buildings, their EPCs must generally be available for the buyer or tenant to see. An awarded EPC is valid for ten years. (Act 50/2013, 2–3 §).

National Decree 1048/2017 describes the method for calculating building energy performance for EPC. In addition to energy performance class, EPC includes suggestions to improve building energy performance. The decree specifies a metric E, which describes annual delivered net energy to the building weighted by energy source coefficients per heated net area. Energy fed back into grids is not considered and calculation of E value is based purely on calculative heat transfer coefficients. (Decree 1048/2017). The following physical parts of the building must be evaluated for E value calculation (Decree 1048/2017):

- outer walls, doors, windows, roof, floor and other structures
- heating system
- domestic water system
- ventilation system
- lighting
- cooling system
- additional electrical heating systems
- other systems affecting building energy usage.

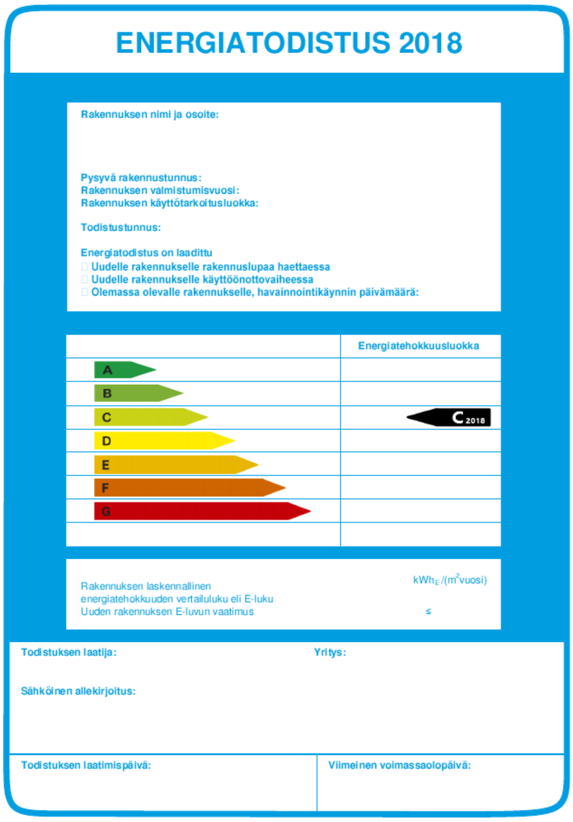
Energy source weighting coefficients for E values are regulated nationally; for example, currently for electricity the coefficient is 1,2 and for district heating 0,5. Energy sources in building surroundings (e.g. from sun or ground) do not have coefficients because they are not included in delivered energy. (Decree 1048/2017). Energy source coefficients complicate using E values for energy consumption comparisons between buildings with different energy sources. With same specific energy consumptions, an electrically heated apartment has higher E than a similar apartment connected to district heating.

Once the E value is calculated, the building energy performance class is defined with tables in Decree 1048/2017. Class boundary conditions are defined in SFS-EN 15217 (2007) with two reference values: energy performance regulation reference R_r and building stock reference R_s. R_r corresponds to value typical for new buildings fulfilling current requirements and R_s to the existing building stock median value. Table 3 displays EP limits defined with R_r and R_s (SFS-EN 15217 2007) alongside Finnish E value limits for office buildings (Decree 1048/2017).

Table 3. Energy performance class limits for EP (SFS-EN 15217 2007) and Finnish E value limits for office buildings (Decree 1048/2017).

EPC class	EP (standardized)	E [kWh/m^{2}a] (national)
A	$EP < 0{,}5R_r$	$E \leq 80$
B	$0{,}5R_r \leq EP < R_r$	$81 \leq E \leq 120$
C	$R_r \leq EP < 0{,}5(R_r + R_s)$	$121 \leq E \leq 170$
D	$0{,}5(R_r + R_s) \leq EP < R_s$	$171 \leq E \leq 200$
E	$R_s \leq EP < 1{,}25R_s$	$201 \leq E \leq 240$
F	$1{,}25R_s \leq EP < 1{,}5R_s$	$241 \leq E \leq 300$
G	$1{,}5R_s \leq EP$	$301 \leq E$

EP column in table 3 clarifies the relationship between EP and references of existing and new buildings. Buildings in class A have the highest energy performance and class G the lowest. R_r (regulation reference) is placed at the boundary between classes B and C and R_s (building stock reference) at the boundary between classes D and E. After the energy performance indicator is calculated, the building energy certificate may be assigned. (SFS-EN 15217 2007). A national template for energy certificate from Decree 1048/2017 is displayed in figure 7.


ENERGIATODISTUS 2018

Rakennuksen nimi ja osoite:

Pysyvä rakennustunnus:
Rakennuksen valmistumisvuosi:
Rakennuksen käyttötarkoitusluokka:

Todistustunnus:

Energiatodistus on laadittu
Uudelle rakennukselle rakennuslupaa haettaessa
Uudelle rakennukselle käyttöönottovaiheessa
Olemassa olevalle rakennukselle, havainnointikäynnin päivämäärä:

Energiatehokkuusluokka
A
B
C
D
E
F
G
C 2018

Rakennuksen laskennallinen energiatehokkuuden vertailuluku eli E-luku
Uuden rakennuksen E-luvun vaatimus
kWh$_E$/(m^{2}vuosi)
≤

Todistuksen laatija:
Yritys:
Sähköinen allekirjoitus:
Todistuksen laatimispäivä:
Viimeinen voimassaolopäivä:

Figure 7. Finnish template of energy performance certificate for buildings (Decree 1048/2017).

3.2 Green Public Procurement criteria

Green Public Procurement (GPP) criteria are voluntary guidelines launched by European Commission (2020) to support environmentally sustainable public procurement. GPP is defined as "a process whereby public authorities seek to procure goods, services and works with a reduced environmental impact throughout their life-cycle when compared to goods, services and works with the same primary function that would otherwise be procured" (European Commission 2020).

GPP criteria exist for several targets, such as buildings, wall panels and water taps. In this research, the criteria for office building design, construction and management by Dodd, Garbarino and Gama Caldas (2016) are relevant and will be abbreviated as "office GPP criteria". Office GPP criteria categories, subcategories and selected criterion examples are collected into table 4. (Dodd, Garbarino and Gama Caldas 2016, pp. 1, 9–10).

Table 4. Office GPP criterion categories, sub-categories and selected criteria (Dodd, Garbarino and Gama Caldas 2016, pp. 9–10).

Category	Sub-category or criterion
Project team competencies	Project manager, designers and contractors
Energy-related	Energy performance, commissioning and quality Lighting control system Building energy management system Low or zero carbon energy sources Energy management reporting and contracting
Resource efficient construction	Life cycle performance Recycled construction products Material transportation emissions Legal wood sourcing Demolition and site waste management plans
Other environmental	Waste recycling facilities Water saving installations
Office environmental quality	Thermal comfort conditions Daylighting and glare Ventilation system, air quality and materials

Office GPP criteria do not contain rating or scoring instructions, but rather they are procurement recommendations for existing and future buildings. As an example, criterion "thermal comfort conditions" is provided in table 5 (Dodd, Garbarino and Gama Caldas 2016, pp. 111–113). All GPP criteria include two levels: core and comprehensive. Core criteria include key points for easy and cost-effective application of the methodology, while comprehensive criteria broaden the scope and offer more extensive criteria to further enhance environmental performance. (European Commission 2020).

Table 5. Office GPP criteria "thermal comfort conditions" (Dodd, Garbarino and Gama Caldas 2016, pp. 111–113). Requirements are listed for both core and comprehensive levels.

Core criteria	Comprehensive criteria
Indoor temperature design values comply with category II (EN 15251).	Indoor temperature design values comply with category I (EN 15251).
Verification data must be available.	Verification data must be available.
–	Compliance must be demonstrated with a dynamic thermal simulation model according to EN ISO 13790.

Table 5 clarifies that in case of “thermal comfort conditions”, requirements for comprehensive level are stricter than for core level: indoor temperature design values should be designed to stricter standards and modelling is required to fulfil the comprehensive criteria. While in most criteria the core and comprehensive level definitions differ, in some cases (e.g. “commissioning of building energy systems”) they are equal (Dodd, Garbarino and Gama Caldas 2016).

3.3 BREEAM

Building Research Establishment Environmental Assessment Method (BREEAM) is a sustainability certification scheme launched in 1990 by Building Research Establishment based in United Kingdom (Bernardi et al. 2017, p. 8). It is the earliest sustainability rating method for built environment and over 530 000 buildings in over 70 countries have been certified with it. International versions of the methodologies are published by BRE Global Ltd. They include extensive life-cycle sustainability performance criteria for buildings, communities and infrastructure projects, including land use, materials and pollution. The most essential aims of BREEAM are to reduce life cycle impact, recognize environmental benefits, provide legible labelling and encourage demand and value creation for sustainable buildings and products. (BRE Global Ltd. 2016, p. 3).

There are multiple BREEAM standards for assessing different installations: infrastructure, communities, new construction, in-use and refurbishment. BREEAM certification is performed by a third party professional assessor and results in a rating benchmark of unclassified, pass, good, very good, excellent or outstanding. (BRE Global Ltd. 2016, pp. 4, 18). The assessments consider ten main challenge categories listed in table 6 (BRE Global Ltd. 2016, pp. 6–7).

Table 6. BREEAM assessment categories and considerations (BRE Global Ltd. 2016, pp. 6–7).

Category	Considerations
Management	Project design, life cycle planning, construction, commissioning, aftercare
Health and well-being	Visual comfort, indoor air quality, acoustic performance, water quality
Energy	Energy efficiency, carbon emissions, energy monitoring
Transport	Public and alternative transport accessibility, car parking capacity
Water	Consumption, monitoring, leak detection
Materials	Life cycle impact, responsible sourcing, durability, efficiency
Waste	Construction and operational waste management, functional adaptability
Land use and ecology	Site selection, biodiversity protection, impact minimization
Pollution	Pollutant, light, noise and water emissions
Innovation	Innovations exceeding standard credit criteria

BREEAM categories in table 6 are further divided into environmental assessment issues, for which the BREEAM assessor assigns credits (score points) based on target or benchmark accomplishment. BREEAM International New Construction 2016 contains 57 issues of which five examples are presented in table 7. (BRE Global Ltd. 2016).

Table 7. Examples of BREEAM assessment issues (BRE Global Ltd. 2016).

Credit	Description	Criteria summary
Hea 01	Visual comfort	Measures against glare Sufficient daylighting levels Adequate view out Flicker-less lighting systems Zoned lighting with occupant control
Ene 02a	Energy monitoring	Consumption figures available to users Sub-meters for high energy loads
Mat 03	Responsible sourcing of construction products	Sustainable procurement plan Responsibly sourced materials
LE 04	Enhancing site ecology	Enhancing ecological value of the site
Pol 05	Reduction of noise pollution	Reduction of noise from fixed installations

BREEAM score is defined through assessing each credit and filling them into a calculation tool. The overall score is provided as 0–100 % with benchmark levels corresponding to an unclassified, pass, good, very good, excellent or outstanding rating. (BRE Global Ltd. 2016). The calculation is performed as follows (BRE Global Ltd. 2016, p. 26):

1. Scope of the project is determined and BREEAM category (table 6) weightings are adjusted accordingly.
2. Credits are awarded for each issue (examples in table 7) and sum of scores for each category (table 6) is calculated.
3. Relative category scores are calculated [%].
4. Overall BREEAM score is calculated as a weighted sum of all categories [%].
5. Achieved score is compared to benchmark level requirements and if standards are met, the score is valid.
6. Innovation credits (up to 10 %) are added to the total score.

3.4 LEED

Leadership in Energy and Environmental Design (LEED) is a green building rating system launched in 1998 by U.S. Green Building Council based in United States (Bernardi et al. 2017, p. 11) with criteria comparable to BREEAM. Motivators for LEED certification process include economic, health and environmental benefits. LEED provides multiple green rating schemes for different projects, such as new constructions, interior fit-outs, existing buildings and entire cities. In the “building design and construction” scheme, credits are categorized as shown in table 8. (U.S. Green Building Council 2020).

Table 8. LEED v4.1 BD+C (building design and construction) credit categories and examples of criteria (U.S. Green Building Council 2020).

Category	Criteria examples
Integrative process (IP)	Integrative project planning and design
Location and transportation (LT)	Sensitive land protection, bicycle facilities, reduced parking footprint
Sustainable sites (SS)	Protect or restore habitat, rainwater management, light pollution reduction
Water efficiency (WE)	Water use reduction, water metering
Energy and atmosphere (EA)	Optimize energy performance, advanced energy metering, renewable energy
Materials and resources (MR)	Storage and collection of recyclables, waste management, building life-cycle impact reduction
Indoor environmental quality (EQ)	Indoor air quality assessment, thermal comfort, daylight, acoustic performance
Innovation (IN)	Additional results not recognized by other criteria
Regional priority (RP)	Regionally specific points

LEED certification level is defined by summing all assigned points and minimum 40 of 110 points is required to obtain the certificate. Successful buildings are awarded a certified (40–49), silver (50–59), gold (60–79) or platinum (80–) LEED rating. (U.S. Green Building Council 2020, p. 9).

4 SMART READINESS INDICATOR FOR BUILDINGS

Smart Readiness Indicator (SRI) is described in the 2018 amendment of EPBD (Energy Performance of Buildings Directive) as follows: "The smart readiness indicator should be used to measure the capacity of buildings to use information and communication technologies and electronic systems to adapt the operation of buildings to the needs of the occupants and the grid and to improve the energy efficiency and overall performance of buildings." (European Parliament 2018).

The main aims of SRI are to raise awareness of building automation and monitoring systems and the value and benefits they offer (European Parliament 2018). According to the EPBD, the methodology is based on three key building functions 1–3 and two optional functions 4–5 (European Parliament 2018, Annex Ia):

1. energy consumption adaptation based on renewable energy source output
2. operation mode adaptation based on occupant needs
3. electricity demand flexibility based on electric grid status
4. system interoperability between smart meters, building automation and appliances
5. utilization of available communication networks.

By raising awareness of smart technologies, SRI targets to increase motivation for investments and support overall technological innovation in the building sector. The methodology is applicable to all buildings regardless of their age. (Verbeke et al. 2018, p. 8). Three main audiences of SRI are recognized by Verbeke et al. (2018, p. 8):

- building occupants, owners and investors
- facility managers
- service providers: network operators, design, engineering, manufacturing and others.

SRI is defined as a simple, transparent and easily understandable indicator, and it must not interfere with existing national energy performance certifications. Furthermore, all privacy, data security and ownership principles of existing legislation must be taken into account. (European Parliament 2018, Annex Ia).

The power of creating and defining this indicator is assigned to the European Commission, and equal participation possibilities must be ensured for all member states (European Parliament 2018, Annex Ia). Responsibility of technical specification development is assigned to Verbeke et al. (2020). The current SRI development phase, technical support study, seeks to produce technical specifications to support the final definition stage. One main objective is to define the calculation methodology according to the EPBD, with the following additional requirements (Verbeke et al. 2020, p. 5):

- applicability, cost-effectiveness and efficiency
- technology-neutrality and fairness
- attention to cybersecurity concerns
- possibility for local calculation methodology adjustments.

Verbeke et al. (2018, p. 8) identify the SRI as an integrator of the building sector and forthcoming energy systems and markets. SRI does not directly measure energy efficiency of buildings, but rather describes their smartness-enabling technological readiness.

4.1 SRI service catalogue

The SRI methodology assesses smart ready services technology-neutrally. The assessment is performed with a checklist-based catalogue, which can be applied with self-assessment, external inspectors or equipment data collection. For each assessment issue (service), a functionality (smartness) level 0–4, which best describes the real functionality, is selected. (Verbeke et al. 2018, pp. 10–11).

In the SRI catalogue, technical services of buildings are categorized into domains and affect through impact criteria derived from the amended EPBD. The final SRI score is calculated with a multi-criteria assessment (weighted average) method, which additionally allows calculation of sub-scores. Domain and impact criteria definitions have been streamlined during the SRI methodology development and the current definitions with relevant abbreviations are shown in figure 8. (Verbeke et al. 2020, pp. 102–111).

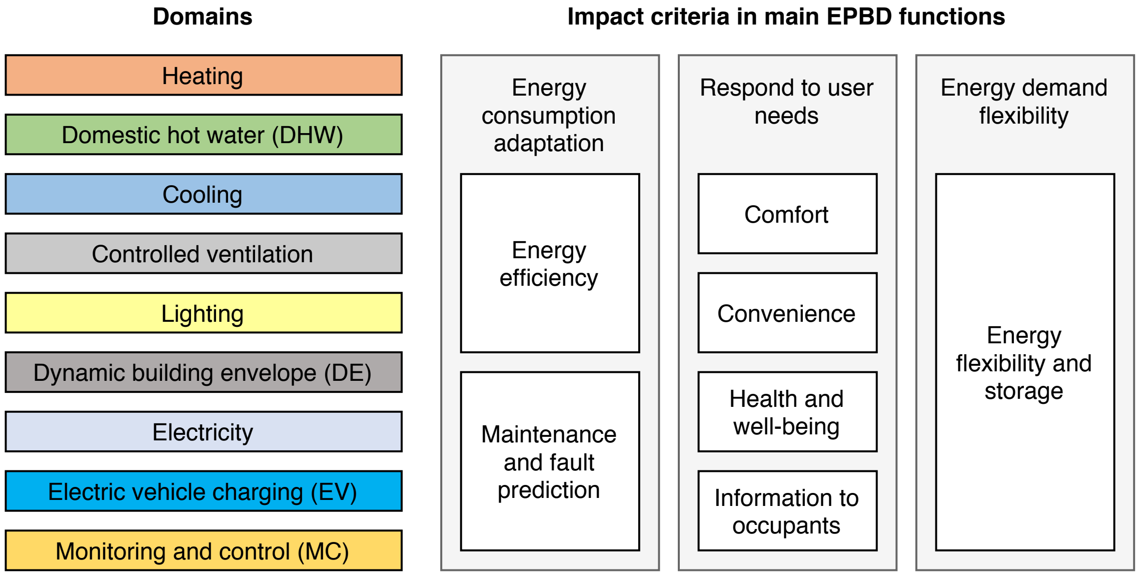


Figure 8. SRI domains (coloured), SRI impact criteria (white) and EPBD functions (grey) (Verbeke et al. 2020, pp. 102–108). Services are categorized in domains and their colours are derived from the official SRI catalogue.

SRI services are selected based on their relevance with the main EPBD functions and the main inclusion criterion is expected impact. They mostly represent established and widespread technologies, yet some emergent technologies are also included where relevant. (Verbeke et al. 2018, p. 34).

The SRI detailed method spreadsheet is provided with interim reports (Verbeke et al. 2020, Annex D). Currently, it contains 54 SRI services and provides a checklist-based SRI assessment template. Exemplary services from the catalogue are collected to table 9. Also, a simplified service catalogue with 27 SRI services is available mainly for self-assessment (Verbeke et al. 2020, Annex C).

Table 9. Service examples for each domain in the SRI catalogue (Verbeke et al. 2020, Annex D). "Min. level" corresponds to the lowest (level 0) and "max. level" the most advanced functionality (level 2–4, varies, shown in parentheses).

Service code and description	Min. level	Max. level
Heating-1a. Heat emission control	No automatic control	(4) Individual room control with communication and occupancy detection
DHW-3. Report information regarding domestic hot water performance	None	(4) Performance evaluation including forecasting, benchmarking, predictive management and fault detection
Cooling-1f. Avoiding simultaneous heating and cooling in the same room	No interlock	(2) Total interlock (control system prevents simultaneous heating and cooling)
Ventilation-1a. Supply air flow control at the room level	No ventilation system or manual control	(4) Local demand control based on air quality sensors (CO_2, VOC, …) and zone air flow dampers
Lighting-1a. Occupancy control for indoor lighting	Manual on/off	(3) Automatic detection (manual on, auto off/dimmed)
DE-1. Window solar shading control	No sun shading or manual operation	(4) Predictive blind control (e.g. based on weather forecast)
Electricity-4. Optimizing self-consumption of locally generated electricity	None	(3) Automated management of local electricity consumption based on current and predicted energy needs and renewable energy availability
EV-15. EV charging capacity	Not present	(4) More than half of parking spaces have recharging points
MC-4. Detecting faults of technical building systems and supporting fault diagnosis	No central indication of detected faults and alarms	(3) Central indication and diagnosis of detected faults and alarms for all relevant TBSs

Currently, most services (29 of 54, 54 %) in the SRI catalogue are sourced from the standard EN 15232 (presented in subsection 2.3), which describes the impact of BACS on building energy consumption (Verbeke et al. 2020, pp. 99–100). Some services are extended with additional levels not from the standard. Numbers of SRI services in total and sourced from EN 15232 are compared in figure 9.

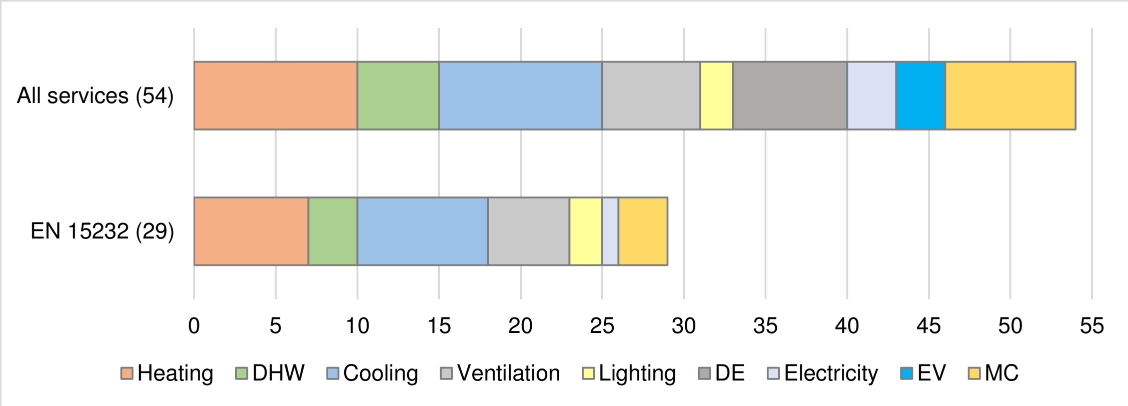


Figure 9. Numbers of SRI services in each domain. The lower bar shows only services sourced from the standard EN 15232.

Figure 9 confirms that the share of services derived from EN 15232 is notable in domains “heating”, “domestic hot water”, “cooling” and “lighting” (25 of 33, 76 %). However, only four services are sourced from it in domains “dynamic building envelope”, “electricity”, “electric vehicles” and “monitoring and control”. Apparently, no suitable standards exist for sourcing services in those domains.

4.2 SRI score calculation

The aggregated smart readiness score is determined with a step-by-step approach. Final SRI score is expressed as 0–100 % and describes relative smartness compared to a fully smart building. SRI assessment and score calculation are performed according to following steps (Verbeke et al. 2020, pp. 132–135):

Step 1. Relevant services in the specific building are identified and included, while non-relevant services are excluded from next steps to avoid penalizing buildings for non-existent or non-relevant domains and services. For example, if a building is heated with DH, it probably does not contain redundant combustion or heat pump heating systems, and therefore services concerning these systems are omitted. This step is called the *triage process*. (Verbeke et al. 2020, pp. 129–131).

Step 2. Relevant services are assessed by selecting functionality levels in range 0–4, level 0 being the baseline and level 4 the most advanced. Based on the selected levels, services affect one or several SRI impact criteria, which are assigned points in range $-3 \ldots 3$.

Service point distribution tables are included in the SRI catalogue. As an example, points for service “Ventilation-1a” are distributed according to table 10. Distributions are ideally based on standards, especially for the impact criterion “energy efficiency”. For other criteria, such as “convenience” or “information to occupants”, few or no standards are available, hence the distributions are at least partly based on subjective judgements. (Verbeke et al. 2020, p. 100).

Table 10. Impact criterion points $I_{s,d,i}$ awarded by service “Ventilation-1a. Supply air flow control at the room level” (Verbeke et al. 2020, Annex D). All services have individual point distributions.

		Impact criterion points						
Functionality level		Energy	Flexibility	Comfort	Convenience	Health	Maintenance	Information
Level 0	No ventilation system or manual control	0	0	0	0	0	0	0
Level 1	Scheduled control	1	0	1	1	1	0	0
Level 2	Occupancy detection control	1	0	2	2	2	0	0
Level 3	Central demand control based on air quality sensors (CO_2, VOC, humidity, ...)	2	0	3	3	3	0	0
Level 4	Local demand control based on air quality sensors and zone air flow dampers	3	0	3	3	3	0	0

Table 10 clarifies how functionality levels of service “Ventilation-1a” are connected to impact criteria. For some impact criteria, such as “energy flexibility and storage”, all levels assign zero points, hence the service does not affect these criteria at all. For other impact criteria, such as “energy efficiency”, maximum possible impact points are greater than zero (3 points at level 4) and thus the selected functionality level affects these impact criterion scores. After all services for a domain are assessed, the aggregation process is initiated in the next step as described by Verbeke et al. (2020, pp. 132–135).

Step 3. Impact criterion point score is calculated for each domain-impact combination with equation 1, by summing the relevant service points, ignoring services dropped in the first step. Points are calculated for seven impact criteria in nine domains, hence producing 63 point scores in total. Lowercase subscripts in the following equations represent numerical indexes of single services, domains, impact criteria and functions, while uppercase subscripts represent categories.

$$I_{d,i} = \sum_{s=1}^{N_{S,d}} I_{s,d,i} \tag{1}$$

where: $I_{d,i}$ = point score of impact criterion i in domain d; $I \in \mathbb{Z}$

$N_{S,d}$ = number of services in domain d; $N \in \mathbb{N}$

$I_{s,d,i}$ = point score of service s in domain d for impact criterion i

s, d, i = numerical index of service, domain or impact; $(s, d, i) \in \mathbb{N}$

Step 4. Maximum impact criterion point score $I_{d,i,\max}$ is calculated for each domain-impact combination, again with equation 1 by replacing the achieved service point scores $I_{s,d,i}$ with maximum achievable scores $I_{s,d,i,\max}$. The values can be obtained for example from the highest level 4 values in table 10.

Step 5. Smart readiness impact score is calculated for each of the seven impact criteria with equation 2. Numeric values of weighting factors w are described in subsection 4.3. Relative values are represented in decimal form 0–1.

$$SR_i = \frac{\sum_{d=1}^{N_D} w_{d,i}\, I_{d,i}}{\sum_{d=1}^{N_D} w_{d,i}\, I_{d,i,\max}} \tag{2}$$

where: SR_i = smart readiness score of impact criterion i; $0 \leq SR \leq 1$

N_D = number of domains; $N_D = 9$

$w_{d,i}$ = weight of domain d for impact criterion i; $0 \leq w \leq 1$

Step 6. Relative impact score is calculated for each of the three EPBD key functionalities with equation 3.

$$SR_f = \sum_{i=1}^{N_{\mathrm{I},f}} \frac{w_i}{w_f} SR_i \tag{3}$$

where: SR_f = smart readiness score of function f

$N_{\mathrm{I},f}$ = number of impact criteria in function f

w_i = weight of impact criterion i

w_f = weight of EPBD function f

Step 7. Finally, the total smart readiness score is calculated as a weighted average of the function scores or impact criterion scores, as shown in equation 4.

$$SR = \sum_{i=1}^{N_{\mathrm{I}}} w_i \, SR_i \tag{4}$$

where: SR = the total smart readiness score

N_{I} = number of impact criteria; $N_{\mathrm{I}} = 7$

Step 8. Optionally, relative smart readiness scores for each of the 63 domain-impact pairs can be calculated individually with equation 5.

$$SR_{d,i} = \frac{I_{d,i}}{I_{d,i,\max}} \tag{5}$$

where: $SR_{d,i}$ = smart readiness score of selected domain-impact pair

4.3 Weighting schemes

SRI calculation equations in subsection 4.2 contain weighting factors for domains $w_{d,i}$, impact criteria w_i and functions w_f. Although in principle they could be defined arbitrarily, the SRI methodology suggests schemes for each of these factors.

For defining domain weighting factors $w_{d,i}$, three conceptual alternatives were considered by Verbeke et al. (2020, pp. 112–113): equal weighting, predicted impact and energy balance method. Following discussions, a hybrid approach is selected, that utilizes available research and energy balance data when available, and equal or fixed weights if not.

Energy balance method weightings are primarily derived from statistical energy balances or alternatively from building-specific data, if desired. Fixed weightings are selected for impacts not present in energy balance (e.g. "monitoring and control"). For subjective impact criteria (e.g. "comfort" and "convenience"), no objective data sources for weighting can be found, and therefore equal weighting is used. (Verbeke et al. 2020, pp. 112–115).

Numerical domain weighting matrices are provided in the SRI catalogue spreadsheet (Verbeke et al. 2020, Annex D). Because building energy balances differ between climate regions and building use types, matrices are provided for both residential and non-residential buildings in several areas. Since this thesis concentrates on non-residential buildings in Northern Europe, the $w_{d,i}$ values for this category are provided in table 11 with used weighting methods (Verbeke et al. 2020, 115, Annex D).

Table 11. SRI domain weighting matrix containing $w_{d,i}$ [%] values for non-residential buildings in Northern Europe (Verbeke et al. 2020, Annex D). Colours indicate used weighting methods: blue is energy balance, green is equal and red is fixed. Empty cells signify that the services in the specific domain do not contribute to the impact criteria in question.

	Impact criteria						
Domain	Energy	Maintenance	Comfort	Convenience	Health	Information	Flexibility
Heating	31	35	16	10	16	11	49
DHW	5	6		10		11	8
Cooling	9	10	16	10	16	11	15
Ventilation	20	22	16	10	16	11	
Lighting	8		16	10	16		
Electricity	2	2		10		11	2
DE	5	5	16	10	16	11	
EV				10		11	5
MC	20	20	20	20	20	20	20

Some domain-impact weighting cells are empty in table 11, because the specific domains do not have any services that contribute points to the specific impact criteria. For instance, according to the SRI catalogue, domain “ventilation” cannot affect impact “energy flexibility and storage” at all. Rationality of these choices, however, is to be discussed.

For EPBD building function w_f and impact weights w_i, a hybrid weighting scheme presented in table 12 is used. The method is based on categorizing the seven SRI impact criteria to the three main EPBD building functions with mutual equal weights. (Verbeke et al. 2020, pp. 117–121).

Table 12. EPBD function and impact weightings for SRI [%]. All weights are presented as part of total. (Verbeke et al. 2020, p. 121).

EPBD functions	w_f	Impact criteria	w_i
Energy performance and operation	33,3	Energy efficiency	16,7
		Maintenance and fault prediction	16,7
Respond to user needs	33,3	Comfort	8,3
		Convenience	8,3
		Information to occupants	8,3
		Health and well-being	8,3
Energy demand flexibility	33,3	Energy flexibility and storage	33,3

As table 12 shows, impact criteria weightings differ depending on the EPBD function category. Consequently, the domain “energy flexibility and storage” has the most prominent effect on the final score, as it is has four times the weighting of “comfort” or “convenience”. This fact makes SRI results clearly sensitive on the energy flexibility functions.

4.4 Comparison with other rating systems

To clarify the position of SRI among other discussed building rating systems, and also to conclude the literature study part, table 13 is synthesized. The data is sourced from references in subsection 2.4 and sections 3 and 4, and describes the types and considerations included in the presented schemes.

Table 13. Type and criterion comparison of the discussed building rating systems. Legend: • yes, ∘ indirectly, ∗ possibly in the future.

	Type			Criteria								
System	Scoring or classification	Legally mandatory	Commercial	Technical functionality	Energy use	Indoor environmental quality	Resource use and emissions	Waste and recycling	Site location	Transport accessibility	Project management	Life cycle management
SRI	•	∗		•	∘	∘						
BAC efficiency class	∘	∘		•	∘							
EPC	•	•			•							
Office GPP criteria				∘	•	•	•	•	•		•	•
BREEAM			•	∘	•	•	•	•	•	•	•	•
LEED			•	∘	•	•	•	•	•	•	•	

Table 13 shows that TQA sustainability rating systems (office GPP criteria, BREEAM and LEED) include many sustainability factors, including energy use and various life-cycle criteria. EPC as a CED system includes narrow yet specific energy use and source criteria. Unlike TQA or CED systems, technical building rating systems SRI and BAC efficiency class primarily assess the building based on technical readiness. BAC efficiency class does not include any sustainability factors, such as energy use or indoor environmental quality, while SRI identifies positive health, comfort, convenience and information impacts in addition to technical functionality levels.

5 CASE STUDY METHODOLOGY

In this section, the case study part of this thesis is initiated. The main objective is to obtain case assessment data to support SRI applicability conclusions. Figure 10 outlines the study methodology arranged in four phases: preparation, assessment meetings, processing and results.

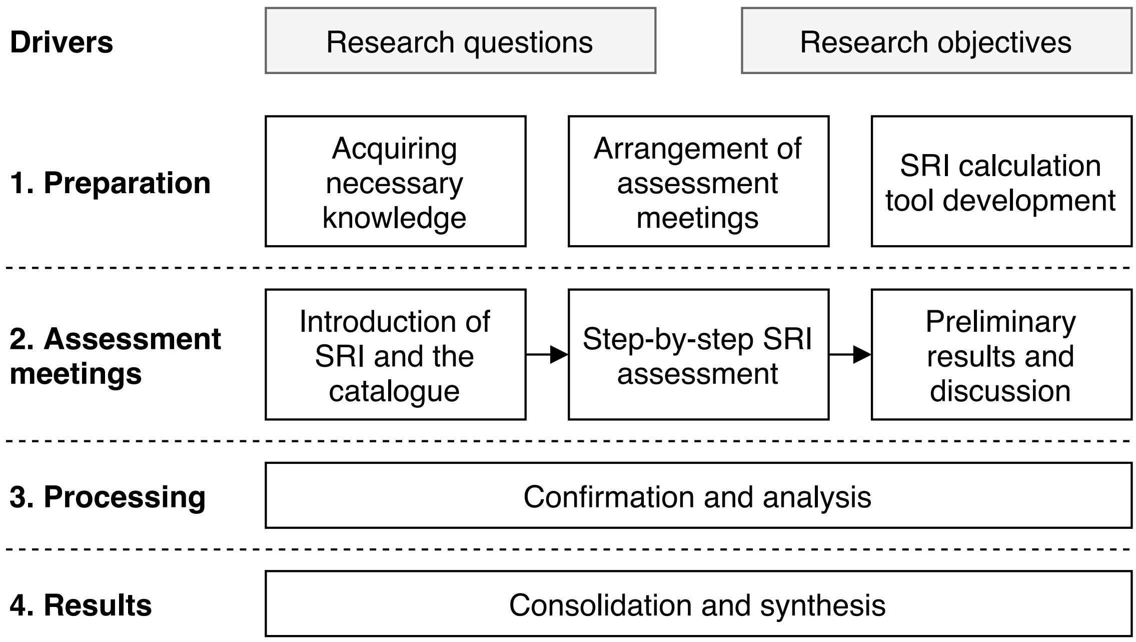


Figure 10. Drivers, phases and activities of the case study. Phases are separated with horizontal dashed lines.

The preparation phase supported the arrangement of assessment meetings. Specialist entities of BAC, HVAC and electricity systems of the building to be assessed were requested to participate in the meetings. Participants were briefed about SRI and given the opportunity to explore the latest detailed SRI service spreadsheet (Verbeke et al. 2020, Annex D) in advance. Due to the pandemic situation, meetings were arranged remotely with Microsoft Teams. Another activity in the preparation phase is development of a SRI calculation tool.

In the assessment meeting phase, the SRI spreadsheet was used as a checklist template. Participants were encouraged to be critical and comment at any point. Ambiguities and comments were documented for further processing. Because guidelines for building group assessments are not provided in the SRI methodology (Verbeke et al. 2020), a constant convention was decided: If the system functionalities differed one level, the level representing most devices was used, and if the system functionality levels differed two levels, the levels were averaged. This approach was considered a compromise to recognize partly implemented systems while providing sufficient result comparability.

The processing phase includes examination and confirmation of obtained SRI assessment results, and filtering and consolidation of observations from the assessments. The last results phase aims to answer set research questions and synthesize suggestions based on the gathered data.

5.1 SRI calculation tool

Because no publicly available SRI calculation tool was available at the time of making this study, a calculation tool was developed for obtaining aggregated SRI scores based on the SRI calculation methodology presented in subsection 4.2. Design of the calculation tool is visualized as a flowchart in figure 11.

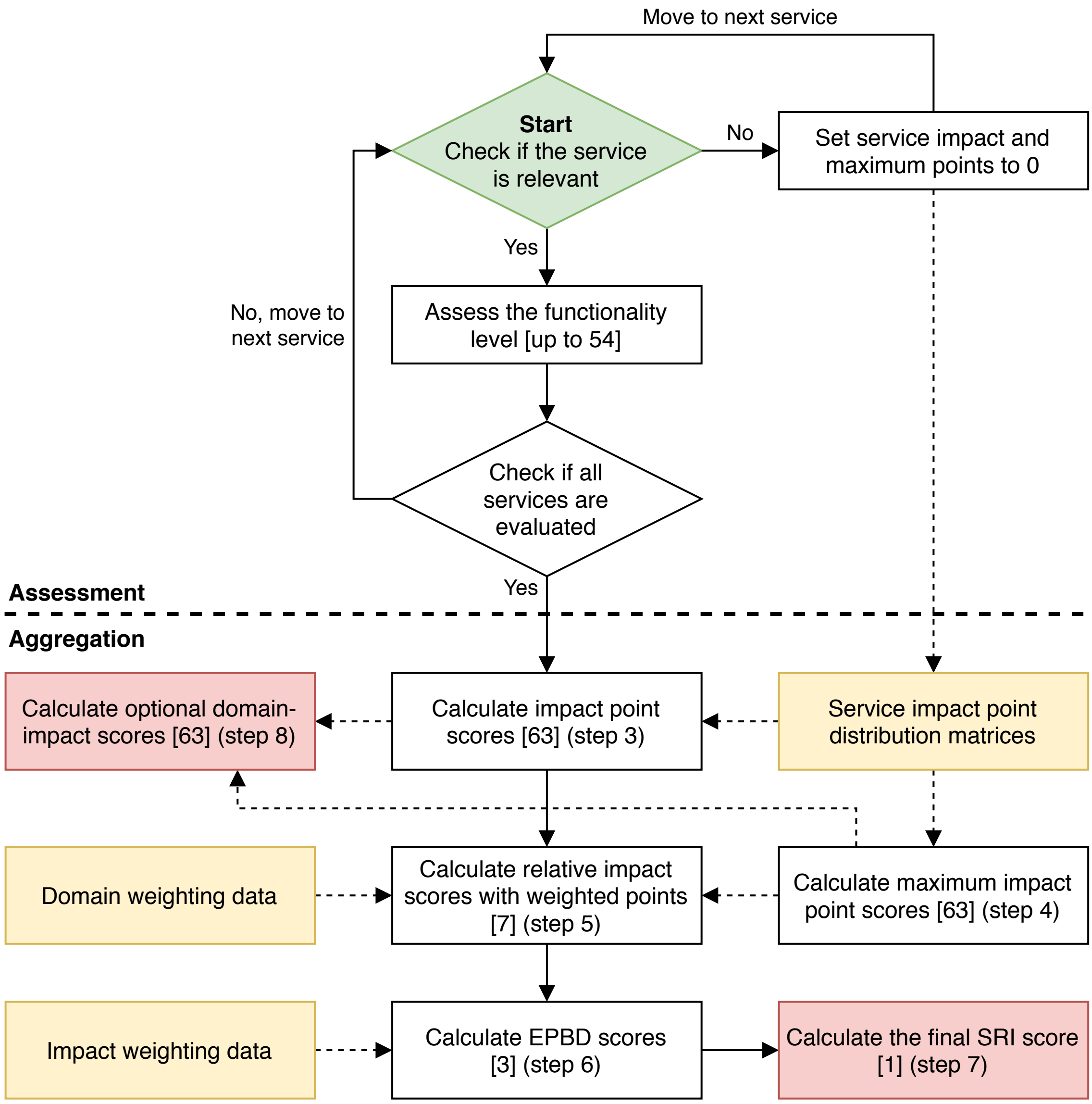


Figure 11. SRI calculation tool flowchart. Green: starting position, red: final result, yellow: initial data. Solid lines represent primary workflows, dashed lines auxiliary data flows. Brackets indicate numbers of derived values. Steps correspond with those presented in subsection 4.2.

The tool was decided to be built on the SRI detailed method spreadsheet, as the spreadsheet template already contained service definitions, impact criterion point distribution matrices and weighting matrices for several climate areas. Therefore, all necessary data could be fetched automatically without manual input. Additionally, the tool was designed to allow testing of modified service exclusion and calculation methods, which might be useful in sensitivity analysis. The extended overview sheet with assessment checklist and impact point calculation functionality is overviewed in figure 12.

Service	Level: Selected	Level: Maximum	Assigned impact points: Energy	Flexibility	Comfort	Convenience	Health	Maintenance	Information	Maximum impact points: Energy	Flexibility	Comfort	Convenience	Health	Maintenance	Information	Service score
Heating-1a	**2**	4	2	0	2	2	2	0	0	3	0	2	3	2	1	0	50 %
Heating-1b	**3**	3	2	0	2	3	2	1	1	2	0	2	3	2	1	1	100 %
Heating-1c	**1**	2	1	0	1	1	0	0	0	2	0	1	1	0	0	0	50 %
Heating-1d	**3**	4	2	0	0	0	0	0	0	2	0	0	0	0	0	0	75 %
Heating-1f																	
Heating-2a	**2**	2	2	0	2	0	0	0	0	2	0	2	0	0	0	0	100 %
Heating-2b																	
Heating-2d																	
Heating-3	**4**	4	1	0	0	1	0	3	3	1	0	0	1	0	3	3	100 %
Heating-4	**1**	4	1	0	1	1	0	0	0	2	3	3	3	1	0	0	25 %

Figure 12. First rows of the SRI assessment checklist and impact point calculator, showing only services in domain "heating". The real tool has all 54 services in the main view. The assessor fills selected functionality levels for each service, corresponding to steps 1 and 2 in subsection 4.2.

During the assessment, selected levels are inputted to the "selected level" column, and cells concerning non-relevant services are left blank. Other columns are filled and calculations performed automatically.

"Service scores" in figure 12 are calculated according to equation 6. They provide a simple method to assess smart readiness of individual services, and the scores can additionally be combined with a simple average.

$$SR_s = \frac{FL_s}{FL_{s,\max}} \tag{6}$$

where: SR_s = simple smart readiness score of service s; $0 \leq SR \leq 1$

FL_s = selected functionality level for service s; $0 \leq FL \leq 4$, $FL \in \mathbb{N}$

$FL_{s,\max}$ = maximum functionality level for service s

Calculated impact point data is migrated into a custom aggregation sheet, which calculates domain-specific point sums and aggregates them according to the SRI methodology steps presented in subsection 4.2. This sheet is displayed in figure 13.

Impact point scores *I_(d,i)* (step 3)

	Energy		User needs				Flex.
	Energy efficiency	Maintenance and fault prediction	Comfort	Convenience	Health and well-being	Information to occupants	Energy flexibility and storage
Heating	15	4	10	8	4	4	4
DHW	1	2	0	1	0	3	0
Cooling	13	2	6	5	2	3	1
Ventilation	13	1	10	8	9	2	0
Lighting	5	0	5	5	3	0	0
Electricity	3	2	0	2	0	6	2
DE	1	0	1	1	0	0	0
EV	0	0	0	5	0	3	2
MC	6	10	3	15	4	9	7
∑ *w_(d,i) I_(d,i)*	10,21	3,98	5,72	6,50	3,68	4,20	3,67

Maximum impact point scores *I_(d,i,max)* (step 4)

	Energy		User needs				Flex.
	Energy efficiency	Maintenance and fault prediction	Comfort	Convenience	Health and well-being	Information to occupants	Energy flexibility and storage
Heating	21	5	12	11	5	4	11
DHW	1	2	0	1	0	3	0
Cooling	15	4	8	8	3	3	6
Ventilation	14	2	10	8	9	3	0
Lighting	6	0	5	5	3	0	0
Electricity	4	4	0	9	0	6	9
DE	3	0	3	3	3	0	0
EV	0	0	0	6	0	3	4
MC	8	11	3	17	4	9	9
∑ *w_(d,i) I_(d,i)*	13,06	4,99	6,68	8,50	4,48	4,31	8,53

Domain-impact scores *SR_(d,i)* (step 8)

	Energy efficiency	Maintenance and fault prediction	Comfort	Convenience	Health and well-being	Information to occupants	Energy flexibility and storage	*SR_d*
Heating	71 %	80 %	83 %	73 %	80 %	100 %	36 %	65 %
DHW	100 %	100 %		100 %		100 %		100 %
Cooling	87 %	50 %	75 %	63 %	67 %	100 %	17 %	54 %
Ventilation	93 %	50 %	100 %	100 %	100 %	67 %		82 %
Lighting	83 %		100 %	100 %	100 %			93 %
Electricity	75 %	50 %		22 %		100 %	22 %	46 %
DE	33 %		33 %	33 %	0 %			27 %
EV				83 %		100 %	50 %	64 %
MC	75 %	91 %	100 %	88 %	100 %	100 %	78 %	86 %
SR_i (step 5)	78 %	80 %	86 %	76 %	82 %	97 %	43 %	
SR_f (step 6)	79 %		85 %				43 %	
SR (step 7)	69 %							

Figure 13. SRI score calculation sheet. Steps presented in subsection 4.2 are followed and calculations are performed automatically according to equations 1–5. Additionally, equation 7 is used for domain scores SR_d.

The domain-impact matrix containing $SR_{d,i}$ values is constructed for result interpretation according to step 8, even though it is optional and not necessary for the final score calculations. Additionally, domain scores SR_d are calculated from the $SR_{d,i}$ matrix rows according to equation 7, which ignores empty cells.

$$SR_d = \sum_{i=1}^{N_{\mathrm{I}'}} \frac{w_i}{w_{\mathrm{I}'}} SR_{d,i} \tag{7}$$

where: SR_d = smart readiness score of domain d; $0 \leq SR \leq 1$

$N_{\mathrm{I}'}$ = number of impact criteria in which $I_{d,i,\max} > 0$; $N \in \mathbb{N}$

w_i = weight of impact criterion i; $0 \leq w \leq 1$

$w_{\mathrm{I}'}$ = sum of weights of impact criteria in which $I_{d,i,\max} > 0$

$SR_{d,i}$ = smart readiness score of the specific domain-impact pair

6 CASE BUILDINGS AND ASSESSMENT RESULTS

In this section, the assessed case buildings and confirmed SRI results are presented. Each building is presented in separate subsection with concise overall and technical introductions. SRI assessment results are calculated and visualized in coloured tables containing individual domain-impact and aggregated impact, function and total scores. The representation is based on the detailed SRI result matrix suggestion by Verbeke et al. (2020, figure 31). Detailed functionality level selections made in the assessments are available in appendix 2.

6.1 LUT University campus

Lappeenranta LUT campus area contains seven university buildings constructed in several phases in 1975–2004. It also contains a university of applied sciences building (2011) and a student union building (1994), however they are not assessed in this study. Total floor area of the campus is approximately 70 000 m^2. (City of Lappeenranta 2018). LUT main entrance from the street is viewed in figure 14.

Figure 14. Curved LUT main entrance building 5 on the left and recently renovated building 1 in the background. Dark grey solar panels are visible on the wall behind the trees.

Figure 15 visualizes campus building boundaries on an aerial image (National Land Survey of Finland 2020). In Finland, public buildings are often owned by separate property management companies. LUT University Lappeenranta campus buildings 1–5 and 7 are owned and managed by University Properties of Finland Ltd (SYK), which is owned by the Finnish state and nine Finnish universities (including LUT University) outside the

Helsinki metropolitan area. In total, SYK owns 1 300 000 m^2 of campus properties in Finland and identifies as a campus developer emphasizing sustainability and responsibility. (University Properties of Finland Ltd 2020). Campus building 6 is owned by Lappeenrannan Tieto-Sähkötalo Oy.

Figure 15. Lappeenranta campus area (aerial image from National Land Survey of Finland 2020). Buildings 1–7: university buildings, LAB: university of applied sciences building, YO: student union building.

LUT Green Campus concept has driven the installation of local renewable energy generation. Hence, a solar power plant with over 500 kW maximum electric power and over 1700 photovoltaic (PV) modules has been installed on roofs and walls of the campus buildings. (LUT University 2020). In figure 15, solar panels can be seen especially on the roofs of building 3 and car parking facilities in the lower left corner.

Because the campus buildings are constructed in different eras, they contain separate technical systems with varying functionality levels. In this study, all seven campus buildings were assessed separately to obtain accurate results, while other approaches are also possible. All campus buildings have quite similar technical base functionalities:

- heating supplied by district heating (DH)
- central heating system with distribution fluid and radiators or floor heating in rooms
- central mechanical ventilation system with heat recovery capability
- cooling integrated into the controlled central ventilation system and some additional mechanical cooling devices
- domestic hot water heating with DH without storage
- HVAC system set-points adjusted with outdoor temperature compensation.

Buildings 1–5 and 7 participate in a virtual power plant system provided by Siemens. The system enables energy demand flexibility by controlling ventilation systems based on electricity grid signals while not negatively affecting indoor conditions. Thus, electricity consumption of the buildings can be automatically reduced to offer virtual reserve power to the markets, that reduces the need for real reserve power plants. (Siemens Osakeyhtiö 2020).

SRI case assessment for building 6 was performed in March 2020. After the assessment procedure was familiar, campus buildings 1–5 and 7 owned by SYK were assessed in May 2020 in a remote meeting. Energy, campus and property managers participated in the assessment. Consolidated SRI scores of the campus buildings are shown in table 14.

Table 14. Smart readiness impact, domain and total scores [%] for individual LUT University campus buildings and for the whole campus weighted by floor areas. Impact and domain scores are weighted according to the SRI methodology, and empty cells are due to excluded services.

	Impacts							Domains									
Building	Energy	Maintenance	Comfort	Convenience	Health	Information	Flexibility	Heating	DHW	Cooling	Ventilation	Lighting	Electricity	DE	EV	MC	Total
1	78	80	86	76	82	97	43	65	100	54	82	93	46	27	64	86	69
2	78	86	71	77	65	93	42	56	100	54	70	57	45	0		92	67
3	75	76	68	71	65	89	39	50	100	41	70	57	64	0		86	63
4	74	78	68	72	65	87	38	50	100	47	70	43	45	0		86	62
5	76	77	72	70	68	88	35	54	100	36	70	79	45	0	6	86	62
6	70	78	66	61	62	94	12	50	100	55	64	57	23	0	64	63	52
7	80	86	81	80	77	93	38	56	100	53	82	79	45	27		86	68
Tot.	77	81	76	75	72	93	38	57	100	51	75	72	46	13	26	85	66

Detailed assessment results for building 1 are presented in table 15 with aggregated impact, EPBD function and total scores. Some domain-impact scores are not defined because the services in the domain do not distribute any points to the impact or are not relevant. Full assessment result matrices for buildings 2–7 are included in appendix 1.

Table 15. Smart readiness score matrix for LUT University building 1 [%]. Cells are colour coded corresponding to scores. The rightmost column contains weighted domain scores. Impact criteria are abbreviated as EE (energy efficiency), M (maintenance and fault prediction), Cm (comfort), Cn (convenience), H (health and well-being), I (information to occupants) and EF (energy flexibility and storage).

	Energy		User needs				Flexibility	
Score	EE	M	Cm	Cn	H	I	EF	Domain
Heating	71	80	83	73	80	100	36	65
DHW	100	100		100		100		100
Cooling	87	50	75	63	67	100	17	54
Ventilation	93	50	100	100	100	67		82
Lighting	83		100	100	100			93
Electricity	75	50		22		100	22	46
DE	33		33	33	0			27
EV				83		100	50	64
MC	75	91	100	88	100	100	78	86
Impact	78	80	86	76	82	97	43	
Function	79		85				43	
Total	69							

6.2 Elementary school building

Construction of the assessed elementary school building was finished in 2017. As typical in Finland, district heating is used and therefore no on-site DHW storage is necessary. The central heating system is equipped with a distribution fluid network and utilizes floors as a thermally activated building system (TABS).

The central mechanical ventilation system is equipped with heat recovery capabilities, and airflows are controlled on room level with temperature and CO_2 level measurements. Because the building is unoccupied during the summer due to its use, mechanical cooling capabilities are not needed and are therefore not installed.

The building is equipped with a roof-mounted 50 kW solar power plant. It is also connected to a virtual power plant system enabling energy demand flexibility (Greenreality 2019) through ventilation system control, as most LUT campus buildings.

SRI assessment for the elementary school building was conducted in March 2020 as a remote meeting, in which its HVAC, electricity and automation specialists participated. With this composition, all SRI services were successfully assessed. The processed results are presented in table 16.

Table 16. Smart readiness score matrix for the elementary school building [%].

	Energy		User needs				Flexibility	
Score	EE	M	Cm	Cn	H	I	EF	Domain
Heating	79	60	80	73	80	100	0	51
DHW	100	50		0		100		67
Cooling								
Ventilation	86	50	90	88	78	33		70
Lighting	83		80	80	67			79
Electricity	50	25		22		67	22	33
DE	0		0	0	0			0
EV				0				0
MC	100	100	100	100	100	100	100	100
Impact	83	78	78	74	72	87	53	
Function	80		78				53	
Total	70							

6.3 Vocational school building

The assessed vocational school building group was built in 1954–1991, and its floor area is approximately 23 000 m^2. Even though latest partial renovation work was made in 2015, no complete renovation has been made. In the assessment meeting, specialists concluded that the building is in overall poor condition and some parts would need to be rebuilt, as typical renovation would not be sufficient to achieve satisfactory results. The vocational building group was considered as one entity and assessed once.

As in other case buildings, heat is supplied with district heating, and therefore no on-site DHW storage is necessary. As typical in Finland, the heating system is equipped with distribution fluid network and thermostats in radiators. The building has a retrofitted 30 kW solar power plant, dimensioned to partly produce the base load.

Because the building group contains technical building systems from different eras and functionality levels, functionality variance exists especially in the mechanical ventilation system. According to the assessment personnel, approximately two thirds of the air supply units are modern integrated units with pulse width modulation (PWM) controlled fans with external pressure measurement controls, while rest of the units are multi-stage controlled without external measurements.

Instead of cooling capabilities integrated in the mechanical ventilation system, cooling is provided on room level by independent heat pumps with no central coordination. The heat pump units also have heating capabilities, although they are not the primary heating source. The vocational school building group was assessed in May 2020 and the results are shown in table 17.

Table 17. Smart readiness score matrix for the vocational school building [%].

	Energy		User needs				Flexibility	
Score	EE	M	Cm	Cn	H	I	EF	Domain
Heating	71	25	70	38	67	100	17	44
DHW	100	50		0		100		67
Cooling	36	25	57	43	67	0	17	30
Ventilation	57	0	40	38	22	0		27
Lighting	0		0	0	0			0
Electricity	50	25		0		67	0	22
DE	0		0	0	0			0
EV				33				33
MC	38	44	33	43	25	50	20	33
Impact	55	31	42	31	28	54	17	
Function	43		38				17	
Total	33							

6.4 Office building

The assessed office building group was built on average in 1993, and its floor area is approximately 30 000 m^2. In this assessment, the whole building group was considered as one entity as the technical systems are largely similar in the individual buildings. Where variance was found, the case study methodology was followed and prevalent levels were selected. The technical systems are quite similar than in other assessed buildings, although the office building does not have local energy production nor flexibility capabilities. The assessment results are presented in table 18.

Table 18. Smart readiness score matrix for the office building [%].

	Energy		User needs				Flexibility	
Score	EE	M	Cm	Cn	H	I	EF	Domain
Heating	83	100	75	75	67	100	0	57
DHW	100	100		100		100		100
Cooling	73	100	71	71	67	100	17	60
Ventilation	86	100	100	100	100	100		96
Lighting	100		80	80	67			85
Electricity	67	50		0		100	0	33
DE	0		0	0	0			0
EV				83		100	50	64
MC	63	100	100	79	100	100	20	65
Impact	79	100	78	73	77	100	12	
Function	89		82				12	
Total	61							

7 RESULT ANALYSIS AND CONCLUSIONS

This section analyses the results and observations of the SRI case assessments, and presents discussion and conclusions. Even though the assessment meetings were held remotely due to the circumstances, they were considered successful. In total, over 10 specialists of the assessed buildings and their technical systems were interviewed in the meetings. Each assessment meeting took 2–4 hours depending on the building and participant composition, which is in line with expectations by Verbeke et al. (2020, p. 296).

During this study, ideas emerged to test bundling similar buildings together, which would potentially enable rough evaluation of several buildings with single SRI assessment. For tentative experimentation, a simple and easily available variable was selected: age of the building. Figure 16 visualizes the case assessment results as a function of construction or major renovation year, additionally with a linear regression.

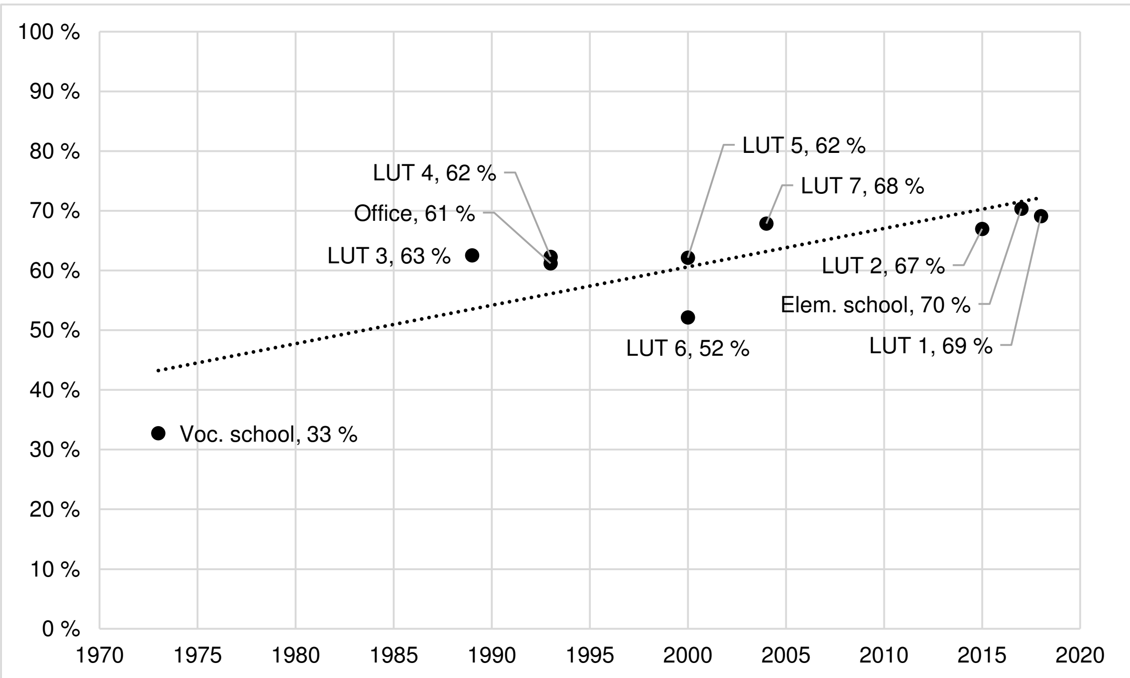


Figure 16. SRI case assessment results as a function of average construction or major renovation year of the building. A linear regression visualizes the overall smart readiness trend.

Figure 16 shows an ascending linear regression based on the smart readiness scores. On average, newer buildings achieved higher smart readiness values than older ones, although variance is significant. For example, LUT building 3 achieved higher score than over

10 years newer building 6. The preliminary observations seem promising, but reliable bundling would probably require more variables concerning also technical capabilities.

Overall, all scores settled in range 30–70 % and the best score 70 % was achieved by the elementary school building, which suggests that there is smart readiness improvement potential even in the highest rated building. For instance, none of the assessed buildings implemented heating energy demand flexibility. In case of elementary school building, energy demand flexibility functionality would improve the score 16 % points, resulting in total score of 86 %.

Nonetheless, research concludes that heating energy flexibility would not very profitable for the local DH provider at the moment (Timonen 2018), especially since DH networks have significant thermal energy storage capacity naturally built in (Janhunen et al. 2019). Thus it could be argued that heating energy flexibility or storage on building level is not even necessary in broad DH networks. Solution feasibility is not considered in the SRI methodology, however.

7.1 Number of assessed services

In SRI assessment step 1, non-relevant and non-existing services are excluded to make results from different buildings and environments comparable, which is called the *triage process* (Verbeke et al. 2020, pp. 129–131). In this study, inclusion preconditions in the service catalogue were followed, even for services not considered locally relevant. For instance, service “DE-1” was assessed if blinds were installed on windows, even though motorized blinds were not considered common or necessary in the regional conditions. Numbers of assessed services for each case building are compared in figure 17.

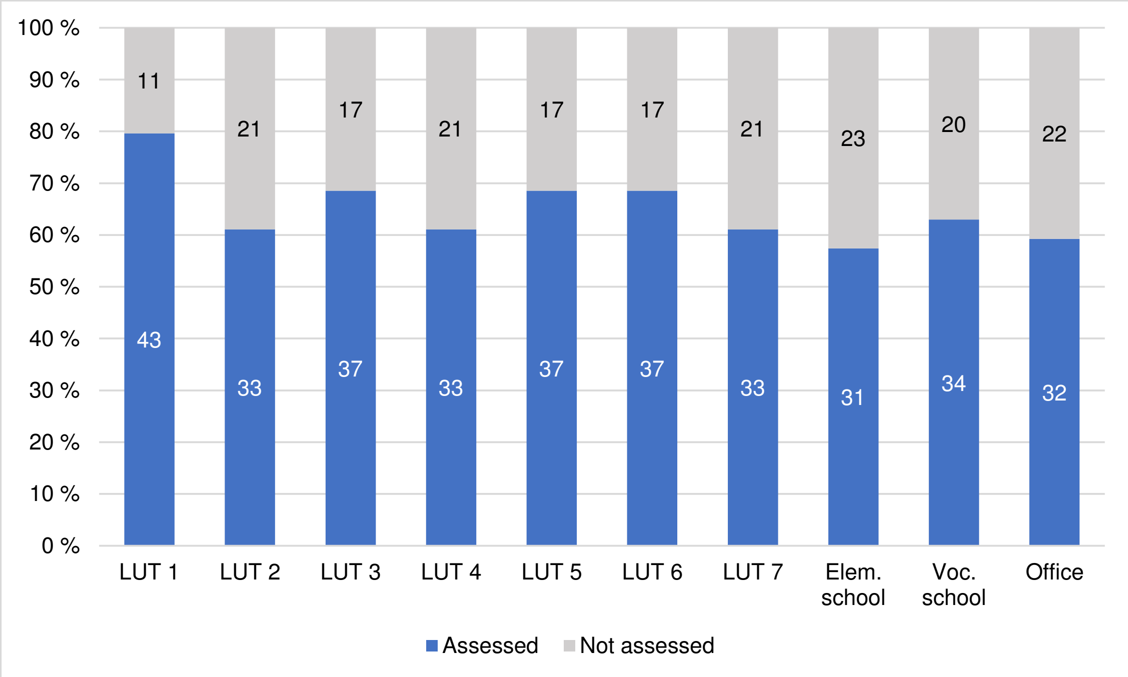


Figure 17. Numbers of assessed and not assessed SRI services in case assessments. Number of services in the SRI catalogue is 54.

Especially for the elementary school building, number of assessed services was low (31/54) because it did not contain a cooling system. Service inclusion preconditions in the catalogue (Verbeke et al. 2020, Annex D) are partly incomplete, and consistent decisions are therefore difficult. The triage process was already identified as problematic by Janhunen et al. (2019). Likewise, this study indicated that the assessor's judgement has a significant impact on the final score, that led to concerns of score consistency and comparability.

For example, service "Heating-4" distributes points especially to "energy flexibility and storage", which has a prominent weight on the final score. Unfortunately, the SRI catalogue does not impose clear preconditions for this service. In the elementary school building, removing the selected functionality level 1 and therefore excluding the service would have improved the final score 15 % points, and therefore results seem to be sensitive to even one questionable triaging choice. Similar results would have been achieved also with other buildings.

7.2 Calculation methodology variations

SRI scores for the case buildings were additionally calculated with two modified methodologies to evaluate effects on final scores, and the results are compared in figure 18. Following paragraphs explain the modifications and refer to SRI calculation steps explained in subsection 4.2.

No triage: Service triaging step 1 is removed from the assessment, while the following steps are performed normally. Hence, all services in the SRI catalogue are assessed and functionalities of non-relevant and non-existing services are rated as level 0. This modification is performed to assess result comparability issues due to questionable or inconsistent triaging choices, which have a major effect on final scores as noted in subsection 7.1.

Simplified: Simple functionality level scores SR_s are calculated for each service with equation 6. For instance, service functionality level 2/4 translates to a 50 % score. In this method, steps 3–8 are skipped completely, and the combined simplified smart readiness score is determined by averaging all relevant SR_s scores. Impact point or weighting matrices are not used, and therefore all services have equal weights in the combined score. This modification is performed to evaluate benefits of the SRI point aggregation system, and is additionally combined with the no triage modification to further assess result sensibility.

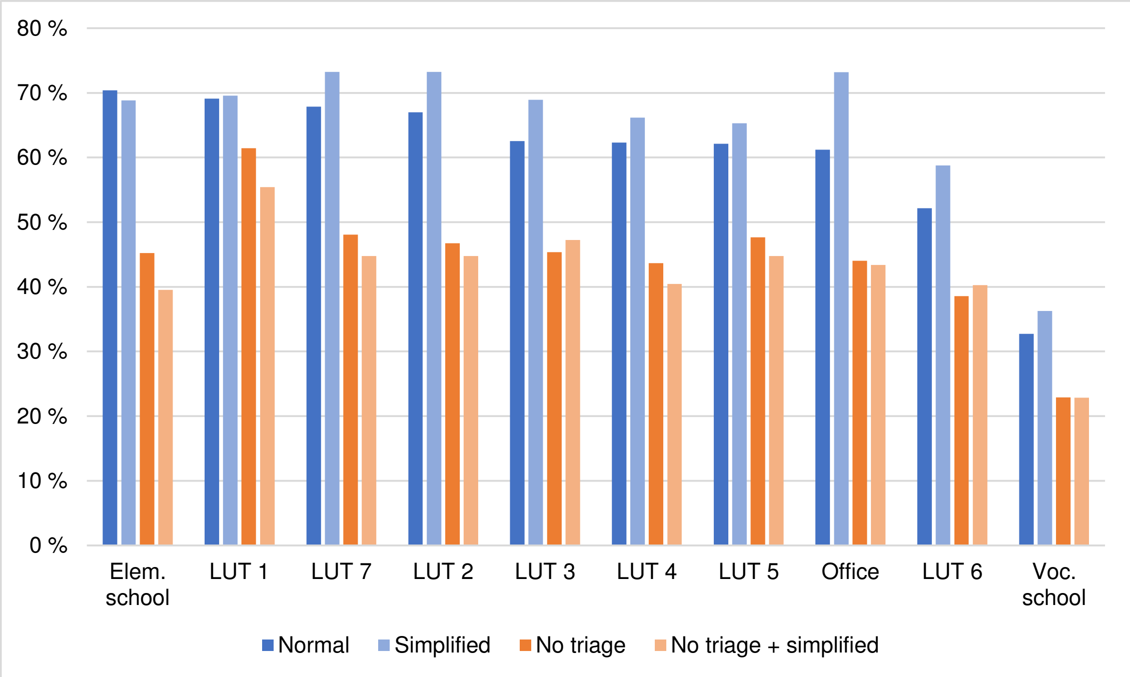


Figure 18. SRI case assessment results calculated with alternative methodologies. The buildings are sorted by normal scores, which correspond to those already presented in figure 16.

To compare reliability of different methodologies, results from figure 18 were sorted individually for each calculation method. This comparison is presented in table 19.

Table 19. Comparison of case building rankings based on SRI scores [%] obtained with normal and modified calculation methodologies.

Ranking	Normal		Simplified		No triage		NT + simplified	
1st	Elem. school	70	LUT 2	73	LUT 1	61	LUT 1	55
2nd	LUT 1	69	LUT 7	73	LUT 7	48	LUT 3	47
3rd	LUT 7	68	Office	73	LUT 5	48	LUT 5	45
4th	LUT 2	67	LUT 1	70	LUT 2	47	LUT 2	45
5th	LUT 3	63	LUT 3	69	LUT 3	45	LUT 7	45
6th	LUT 4	62	Elem. school	69	Elem. school	45	Office	43
7th	LUT 5	62	LUT 4	66	Office	44	LUT 4	40
8th	Office	61	LUT 5	65	LUT 4	44	LUT 6	40
9th	LUT 6	52	LUT 6	59	LUT 6	39	Elem. school	40
10th	Voc. school	33	Voc. school	36	Voc. school	23	Voc. school	23

Table 19 shows that the simplified method produced 20 % lower score than normal for the office building, while in other cases the difference was below 13 %. The results suggest that if approximate results are sufficient, this kind of simplified scoring could be used as a substitute for the rather complicated official SRI calculation method. It is fast, intuitive and easy to implement, as weightings or impacts do not need to be considered. However, since this method lacks impact level aggregation, only domain-level sub-scores are obtainable and further usability of the scores might thus be limited. Also comparability with normally scored buildings is implausible because of the totally different aggregation method.

No triage scores were lower than normal scores in all cases. As even non-existing systems are assessed as non-smart (level 0), no triage seems to be most disadvantageous for cases with many excluded services in the initial assessment. This can be noted especially for the school building, which initially had 31 assessed services and achieved 36 % lower score with this calculation variation. The building with the highest number of assessed services (LUT 1, 43 services) scored only 11 % lower than normally.

Combination of the no triage and simplified methods produced rather similar results than plain no triage in most cases, and largest difference was 13 % in the elementary school building. This method could be argued as the most neutral option, since there is no need to select any service exclusions or weightings. However, it does not have any mechanism to compensate for justified deficiencies, such as for unnecessary cooling systems in school buildings.

Overall, table 19 indicates that the calculation method modifications tested in this experiment produced notably different rankings for the assessed buildings. Rankings of the elementary school building varied from 1st to 9th, while the vocational school building was 10th in all variations. High variance could be partly explained by the narrow range of initial SRI scores, as 8 of 10 scores were in range 61–70 % and therefore even small score changes could easily change mutual rankings.

In conclusion, the findings suggest that a balance between neutrality and flexibility, providing sufficient comparability but still compensating for justified deficiencies, should be found. This could be achieved with good guidelines, such as common national weighting and service exclusion norms.

7.3 Comments on the SRI catalogue

During the case assessments, observations and comments on SRI services and functionality levels were made by the study team and participating specialists. They were later analysed, filtered and consolidated, and the most important points are listed in table 20. Most of the notes concern compatibility of SRI with regional technical building system features and designs, while some apply generally.

Table 20. Comments on the SRI catalogue made by the study team and external specialists during the assessment meetings.

Service	Observation
Heating-1a. Heat emission control	Variable room temperature based on occupancy detection was considered hard to implement in cold climates due to heat stored in building structures.
Heating-2a. Heat generator control (all except heat pumps)	Appears to be redundant in buildings with direct heat exchangers from DH supply to internal distribution network.
Heating-4. Flexibility and grid interaction	According to Timonen (2018), DH demand flexibility would not be profitable enough for the local DH operator at this time.
DHW-1a–2b. (Several)	Not assessed in any building because DHW storage is not necessary with DH (Finnish Energy 2014).
Ventilation. (Domain)	There is no service for ventilation energy demand flexibility, although functionality was implemented in several case buildings with virtual power plant services.
Ventilation-2c. Heat recovery control: prevention of overheating	The description was deemed unclear. Additionally, SFS-EN 15232-1 (2017) includes a criterion for heat recovery icing protection, which is considered relevant in cold climates but not included in SRI.
Ventilation-6. Reporting information regarding IAQ	Detailed real-time CO_2 level reporting to occupants was suspected to cause unnecessary concern.
DE-1. Window solar shading control	Automatic sun shading was considered unconventional and generally unnecessary in Finland.
DE-2. Window open/close control, combined with HVAC system	Opening windows in buildings with controlled ventilation was mentioned to be detrimental for indoor air quality, especially due to outdoor PM.
Electricity-3–4. (Several)	On-site storage and load optimization were considered unnecessary in all case buildings because local energy production capacity was below base load.

Service “Heating-2a” assesses heat generator control, and according to triaging guidelines in the SRI catalogue it should be assessed if district heating systems are present. However, buildings using DH usually have direct heat exchangers from network to internal heat distribution systems (Finnish Energy 2014). Because currently the DH network operator fully controls supply fluid temperatures, it is not possible to control off-site heat generation facilities from buildings. Thus, this service is considered redundant in buildings connected to broad DH networks.

Several case buildings had ventilation energy demand flexibility functionalities, which were not identified by SRI in the ventilation domain. Mechanical ventilation is the second largest energy consumer in Northern non-residential buildings (Verbeke et al. 2020, p. 124) and therefore has notable energy demand flexibility potential. This led to concerns that the obtained SRI scores do not reflect the true energy demand flexibility capabilities of the assessed buildings.

Additionally, concerns regarding unnecessary CO_2 level reporting were extended to other reporting functions. SRI services appear to be defined on the assumption that occupants should see as much real-time data as possible, which was suspected to cause unnecessary concern and confusion among occupants in some cases. Another option would be to provide only relevant information to occupants, while keeping all data available to building managers and technical personnel for diagnostics and maintenance. In case of CO_2 level reporting, the solution could be a simple “traffic light” indicator with sufficiently high but safe alert limits, which still provides the information occupants need.

8 FURTHER APPLICABILITY OF SRI

The case study provided means to assess whether SRI results could be further applied to other purposes, such as building energy performance development. The applicability analysis is performed through analysing how improvement possibilities could be identified from SRI results and which kind of tools would be needed. Ideally, SRI should encourage relevant and effective technical improvements that:

- improve functionality in the key EPBD functions (energy performance, adaptability to user needs and energy flexibility)
- tangibly improve energy, financial or environmental performance
- positively affect the achieved SRI score.

Essentially, SRI only assesses smartness of buildings and ignores more conventional yet important energy performance factors such as insulation quality and appliance efficiency. Thus, the most profitable energy performance investments might not be related to smartness at all, which is important to keep in mind.

Two potential SRI implementation paths are already identified as linking SRI to the currently mandatory energy performance certificate (EPC) system or to building construction and renovation work (Verbeke et al. 2020, p. 154). In these cases, SRI could be thought as a complement to EPC, extending specific energy demand evaluation to technical functionality. Presumably, SRI would become rather quickly widespread with any mandatory implementation (Verbeke et al. 2020, p. 183).

On the other hand, mandatory SRI assessment could lead to negative reception due to the associated cost and effort (Verbeke et al. 2020, p. 183), resulting in incomplete realization of its potential. Therefore, a voluntary scheme is considered a better option to allow the public to freely discover the benefits SRI offers. It could also create broader interest in using SRI as a building development tool, not only as a mandatory classification procedure.

8.1 SRI as a building development tool

Achieving long-term aims of SRI, especially measurable financial and environmental benefits (Verbeke et al. 2020), requires realization of investments. One effective route could be to use SRI as a voluntary building development tool.

The final SRI score was not seen as a sufficient basis for building energy performance development. Rather, its value was recognized as an indicative classification, comparison or marketing tool. In the building development context, more detailed examination of score components is needed, which can be performed using sub-score matrices. For more high-level analysis, aggregated impact or domain scores could be sufficient. The following approach is suggested as a starting point:

1. Observe the SRI domain-impact result matrix with sub-scores for each combination. If improvements in specific domains or impacts are desired, concentrate especially on those sub-scores. Otherwise, select domain-impact pairs with the lowest scores.
2. Using the SRI catalogue, trace which services affect scores of the selected pairs. The simplest method is to compare selected and maximum functionality levels in the overview sheet. A more advanced method would be to explore the impact criterion point matrices (as in table 10).
3. Evaluate SRI score improvement potential of the services by increasing their functionality levels. After each modification, observe effects in the scoring sheet.
4. If effects on scores are satisfactory, consider the technical improvements that should be made to fulfil the requirements of the selected functionality levels.

This approach is based on the assumption that technical solutions justifying SRI level improvements produce real financial and environmental effects. However, analysis of the case study suggests that this might not be the case in all services due to climatic or other factors, and therefore development suggestions derived from SRI results should always be subjected to further energy, financial and environmental evaluation. Moreover, estimating impacts of subjective impact criteria, such as “comfort” or “health and well-being” is more challenging especially in the short term.

Tracing the relevant services according to the approach could be made easier and faster by developing an interactive tool which identifies the services distributing points for chosen domain-impact sub-scores. Additionally, the tool could list development suggestions and illustrate their effects to scores. A draft of this kind of tool is presented in figure 19. However, actual development of the tool is outside the scope of this thesis.

	Energy efficiency	Maintenance and fault prediction	Comfort	Convenience	Health and well-being	Information to occupants	Energy flexibility and storage
Heating	71 %	80 %	83 %	73 %	80 %	100 %	36 %
DHW	100 %	100 %		100 %		100 %	
Cooling	87 %	50 %	75 %	63 %	67 %	100 %	17 %
Ventilation	93 %	50 %	100 %	100 %	100 %	67 %	
Lighting	83 %		100 %	100 %	100 %		
Electricity	75 %	50 %		22 %		100 %	22 %
DE	33 %		33 %	33 %	0 %		
EV				83 %		100 %	50 %
MC	75 %	91 %	100 %	88 %	100 %	100 %	78 %

Services affecting the selected score	**Level**	**Points**	
Control of Thermal Energy Storage (TES) operation	0/0	0/0	(not relevant)
Generator control for cooling	2/3	1/3	(a)
Sequencing of different cooling generators	0/0	0/0	(not relevant)
Flexibility and grid interaction	1/4	0/3	(b)

Development suggestions	**Point change**	**Score change**
Implement grid signal based control in cooling system	(a) 1/3 → 3/3 (b) 0/3 → 3/3	17 → 100 %
Implement self-learning cooling system control	(a) 0/3 → 1/3	17 → 33 %

Figure 19. Draft of a SRI point tracing tool based on the SRI domain-impact score matrix. Red gradient colouring is applied to focus attention on the lowest scores. Scores can be clicked to backtrace services affecting them. The view contains SRI catalogue-based development suggestions and their score improvement potentials.

In principle, the tool could also be extended to perform the subsequent energy, environmental and financial evaluations at least roughly. For instance, the tool could use current energy use and cost data to statistically estimate savings achievable with the suggestions. This approach would properly link technological capabilities to tangible benefits.

Finally, it must still be noted that SRI does not assess all available or installed energy performance functions. Rather, it describes the technical readiness potentially enabling better energy performance. Because improvements based purely on SRI scores without further evaluation could lead to ineffective results, SRI should be used as a steering device to suggest development areas to focus on.

8.2 SRI in energy management functions

In most assessed buildings, energy management functions were assigned to external energy managers who had constant energy performance improvement goals. Energy managers were often requested to deliver monthly energy reports to building managers or occupants. Because of the prevalence of energy management systems (EnMS), it is relevant to discuss whether SRI could be attached to them in some way, for example as an energy performance indicator (EnPI) introduced in figure 6.

EnPI is defined as measure or unit reflecting energy performance with a simple metric, ratio or model (SFS-EN ISO 50001 2018, p. 56). Technically, SRI score is a simple relative metric and thus fits the definition of EnPI. However, because SRI primarily assesses technical readiness instead of measurable energy performance, its direct feasibility as EnPI seems implausible.

Another option could be to consider that smart readiness has intrinsic value, in which case SRI could be directly applicable as EnPI, especially in the future. However, it is debatable which kind of benefits this approach would have, as some alleged benefits of SRI (energy, environmental and financial) can already be measured more reliably with sustainability indicators overviewed in section 3.

As inputs of EnMS can include factors such as occupant comfort or indoor air quality, some SRI sub-scores could therefore be used to measure them, effectively complementing subjective occupant feedback. Since SRI assessment is based entirely on technical functionality, it enables more systematic and possibly automated evaluation of these parameters. Confirmation of this approach, however, would require further research.

9 SUMMARY

In this thesis, Smart Readiness Indicator (SRI) for Buildings was overviewed, positioned and evaluated. Two main aims were defined in the introduction:

- assess position, potential and benefits of SRI
- evaluate relevance, applicability and usability of SRI.

To accomplish the aims, two research activities were performed: literature study and case study. Literature study aimed to position SRI among other building rating systems. Case study was performed to evaluate SRI result usability and applicability, and to reach the aim, ten buildings in Finland were assessed according to the current SRI methodology to enable further analysis and discussion.

In the literature study, SRI was recognized to support technological development, digitalization and connectivity on the building sector in the EU. Compared to other building rating schemes, SRI is uniquely profiled as a technical building capability indicator extended with occupant comfort, convenience, health and information factors. Advantages of SRI are simple and relatively fast assessment process, transparency and neutrality. Unlike commercial sustainability rating systems such as BREEAM and LEED, SRI does not directly consider sustainability aspects, nor does it measure energy consumption, environmental or cost savings.

Rather, SRI assesses technical means for achieving the measurable goals. It recognizes benefits of connected systems and energy flexibility needs, especially for forthcoming needs. Some functionalities represented in SRI may not have any obvious benefits today. For instance, maximum electric power output of local renewable energy generation is usually dimensioned to cover the base load of the building, as the feed-in tariff is not sufficient for profitable feed-in. Nevertheless, the situation may change with financial incentives once demands for renewable balancing power, energy storage and energy demand flexibility capabilities increase.

In the case study, SRI applicability was evaluated through case building assessments. Each assessment lasted 2–4 hours, depending on complexity. Some services in the SRI catalogue were not relevant for any assessed building because of regional factors. This was noted especially in the domain “dynamic building envelope”, which contains services related to sun shading with motorized blinds. Furthermore, some services were conflicting with local design conventions and indoor climate requirements, which was the case with services concerning automatic window opening systems, for example.

The case study also indicated that SRI does not fully identify advantages of typical Nordic building systems such as advanced district heating networks. Unfortunately, SRI penalizes individual buildings for functions that are implemented on network level or are not needed, which is the case with heating demand flexibility. In turn, energy demand flexibility in the ventilation domain was not recognized by SRI even though mechanical ventilation systems are a notable energy consumer based on energy balances.

Official SRI service inclusion preconditions were applied in the triage process whenever available, although some of them were considered ambiguous. It was proposed that results could be made more reliable and comparable by implementing national norms for weighting factors and triaging conditions. Additionally, some climate-specific services could be added to better represent regional features, especially in the heating and ventilation domains. Unfortunately, region-specific SRI catalogue additions would complicate international result comparability.

Value of SRI as a development tool was identified, as it can shift attention to areas where the building has technical improvement potential. To facilitate this process, a tracing tool was drafted, which would trace SRI scores back to individual services. This kind of tool would visualize SRI sub-score formation in easily understandable format and speed up result interpretation. However, actual development of the tool remains for further research.

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APPENDIX 1 DETAILED RESULTS FOR LUT BUILDINGS 2–7

(a) Building 2

	Energy		User needs				Flexibility	
Score	EE	M	Cm	Cn	H	I	EF	Domain
Heating	75	100	75	75	67	100	0	56
DHW	100	100		100		100		100
Cooling	87	50	75	63	67	100	17	54
Ventilation	79	50	80	75	78	67		70
Lighting	67		60	60	33			57
Electricity	33	0		50		67	67	45
DE	0		0	0	0			0
EV								
MC	88	91	100	94	100	100	89	92
Impact	78	86	71	77	65	93	42	
Function	82		77				42	
Total	67							

(b) Building 3

	Energy		User needs				Flexibility	
Score	EE	M	Cm	Cn	H	I	EF	Domain
Heating	75	75	75	63	67	100	0	50
DHW	100	100		100		100		100
Cooling	80	25	63	50	67	33	17	41
Ventilation	79	50	80	75	78	67		70
Lighting	67		60	60	33			57
Electricity	60	50		60		89	67	64
DE	0		0	0	0			0
EV								
MC	75	91	100	88	100	100	78	86
Impact	75	76	68	71	65	89	39	
Function	75		74				39	
Total	63							

(c) Building 4

	Energy		User needs				Flexibility	
Score	EE	M	Cm	Cn	H	I	EF	Domain
Heating	75	75	75	63	67	100	0	50
DHW	100	100		100		100		100
Cooling	80	50	75	63	67	33	17	47
Ventilation	79	50	80	75	78	67		70
Lighting	50		40	40	33			43
Electricity	33	0		50		67	67	45
DE	0		0	0	0			0
EV								
MC	75	91	100	88	100	100	78	86
Impact	74	78	68	72	65	87	38	
Function	76		73				38	
Total	62							

(d) Building 5

	Energy		User needs				Flexibility	
Score	EE	M	Cm	Cn	H	I	EF	Domain
Heating	79	80	80	73	80	100	0	54
DHW	100	100		100		100		100
Cooling	73	25	63	38	33	33	17	36
Ventilation	79	50	80	75	78	67		70
Lighting	83		80	80	67			79
Electricity	33	0		50		67	67	45
DE	0		0	0	0			0
EV				33		100	-25	6
MC	75	91	100	88	100	100	78	86
Impact	76	77	72	70	68	88	35	
Function	77		75				35	
Total	62							

(e) Building 6

	Energy		User needs				Flexibility	
Score	EE	M	Cm	Cn	H	I	EF	Domain
Heating	75	75	75	63	67	100	0	50
DHW	100	100		100		100		100
Cooling	73	75	63	63	67	100	17	55
Ventilation	71	50	70	63	67	67		64
Lighting	67		60	60	33			57
Electricity	50	25		0		83	0	23
DE	0		0	0	0			0
EV				83		100	50	64
MC	63	89	100	79	100	100	20	63
Impact	70	78	66	61	62	94	12	
Function	74		70				12	
Total	52							

(f) Building 7

	Energy		User needs				Flexibility	
Score	EE	M	Cm	Cn	H	I	EF	Domain
Heating	75	100	75	75	67	100	0	56
DHW	100	100		100		100		100
Cooling	80	50	75	63	67	100	17	53
Ventilation	93	50	100	100	100	67		82
Lighting	83		80	80	67			79
Electricity	33	0		50		67	67	45
DE	33		33	33	0			27
EV								
MC	75	91	100	88	100	100	78	86
Impact	80	86	81	80	77	93	38	
Function	83		83				38	
Total	68							

APPENDIX 2 SELECTED SERVICE FUNCTIONALITY LEVELS

1–7: LUT campus, E: elementary school, V: vocational school, O: office, M: max. level

Code	Service	1	2	3	4	5	6	7	E	V	O	M
Heating-1a	Heat emission control	2	3	2	2	2	2	3	3	2	3	/ 4
Heating-1b	Emission control for TABS (heating mode)	3	-	-	-	3	-	-	3	-	-	/ 3
Heating-1c	Control of distribution fluid temperature (supply or return air flow or water flow)	1	1	1	1	1	1	1	1	1	2	/ 2
Heating-1d	Control of distribution pumps in networks	3	3	3	3	3	3	3	4	4	4	/ 4
Heating-1f	Thermal Energy Storage (TES) for building heating (excluding TABS)	0	-	-	-	-	-	-	-	-	-	/ 3
Heating-2a	Heat generator control (all except heat pumps)	2	2	2	2	2	2	2	2	2	2	/ 2
Heating-2b	Heat generator control (for heat pumps)	3	-	-	-	-	-	-	-	2	-	/ 3
Heating-2d	Sequencing in case of different heat generators	2	-	-	-	-	-	-	-	-	-	/ 4
Heating-3	Report information regarding HEATING system performance	4	4	4	4	4	4	4	3	3	4	/ 4
Heating-4	Flexibility and grid interaction	1	1	1	1	1	1	1	1	0	1	/ 4
DHW-1a	Control of DHW storage charging (with direct electric heating or integrated electric heat pump)	-	-	-	-	-	-	-	-	-	-	/ 3
DHW-1b	Control of DHW storage charging (using hot water generation)	-	-	-	-	-	-	-	-	-	-	/ 3
DHW-1d	Control of DHW storage charging (with solar collector and supplementary heat generation)	-	-	-	-	-	-	-	-	-	-	/ 3
DHW-2b	Sequencing in case of different DHW generators	-	-	-	-	-	-	-	-	-	-	/ 4
DHW-3	Report information regarding domestic hot water performance	4	4	4	4	4	4	4	3	3	4	/ 4
Cooling-1a	Cooling emission control	3	3	2	3	1	2	3	-	3	3	/ 4
Cooling-1b	Emission control for TABS (cooling mode)	-	-	-	-	-	-	-	-	-	-	/ 3
Cooling-1c	Control of distribution network chilled water temperature (supply or return)	2	2	2	2	2	2	2	-	-	-	/ 2
Cooling-1d	Control of distribution pumps in networks	2	3	3	1	1	1	1	-	-	-	/ 4
Cooling-1f	Interlock: avoiding simultaneous heating and cooling in the same room	2	2	2	2	2	2	2	-	0	1	/ 2
Cooling-1g	Control of Thermal Energy Storage (TES) operation	-	-	-	-	-	-	-	-	-	-	/ 3
Cooling-2a	Generator control for cooling	2	2	2	2	2	2	2	-	2	2	/ 3
Cooling-2b	Sequencing of different cooling generators	-	-	-	-	-	-	-	-	-	-	/ 4
Cooling-3	Report information regarding cooling system performance	3	3	1	1	1	4	3	-	0	4	/ 4
Cooling-4	Flexibility and grid interaction	1	1	1	1	1	1	1	-	0	1	/ 4
Ventilation-1a	Supply air flow control at the room level	4	1	1	1	1	1	4	4	1	3	/ 4
Ventilation-1c	Air flow or pressure control at the air handler level	3	4	3	3	3	3	3	3	3	4	/ 4
Ventilation-2c	Heat recovery control: prevention of overheating	2	2	2	2	2	1	2	1	1	2	/ 2
Ventilation-2d	Supply air temperature control at the air handling unit level	3	3	3	3	3	3	3	3	3	3	/ 3
Ventilation-3	Free cooling with mechanical ventilation system	2	2	2	2	2	2	2	2	0	2	/ 3
Ventilation-6	Reporting information regarding IAQ	2	2	2	2	2	2	2	1	0	3	/ 3
Lighting-1a	Occupancy control for indoor lighting	2	2	2	1	2	2	2	2	0	3	/ 3
Lighting-2	Control artificial lighting power based on daylight levels	4	2	2	2	3	2	3	3	0	3	/ 4
DE-1	Window solar shading control	1	0	0	0	0	0	1	0	0	0	/ 4

Continued on next page…

Code	Service	1	2	3	4	5	6	7	E	V	O	M
DE-2	Window open/closed control, combined with HVAC system	-	-	-	-	-	-	-	-	-	-	/ 3
DE-4	Reporting information regarding performance of dynamic building envelope systems	-	-	-	-	-	-	-	-	-	-	/ 4
Electricity-2	Reporting information regarding local electricity generation	3	-	3	-	-	3	-	2	2	-	/ 4
Electricity-3	Storage of (locally generated) electricity	0	-	4	-	-	0	-	0	0	-	/ 4
Electricity-4	Optimizing self-consumption of locally generated electricity	0	-	1	-	-	0	-	0	0	-	/ 3
Electricity-5	Control of combined heat and power plant (CHP)	-	-	-	-	-	-	-	-	-	-	/ 2
Electricity-8	Support of (micro)grid operation modes	1	1	1	1	1	0	1	2	0	0	/ 3
Electricity-11	Reporting information regarding energy storage	-	-	4	-	-	-	-	-	-	-	/ 4
Electricity-12	Reporting information regarding electricity consumption	3	2	2	2	2	2	2	2	2	3	/ 4
EV-15	EV Charging Capacity	2	-	-	-	1	2	-	0	1	2	/ 4
EV-16	EV Charging Grid balancing	1	-	-	-	0	1	-	-	-	1	/ 2
EV-17	EV charging information and connectivity	2	-	-	-	2	2	-	-	-	2	/ 2
MC-3	Run time management of HVAC systems	2	2	2	2	2	2	2	3	1	2	/ 3
MC-4	Detecting faults of technical building systems and providing support to the diagnosis of these faults	3	3	3	3	3	3	3	3	1	3	/ 3
MC-9	Occupancy detection: connected services	1	1	1	1	1	1	1	2	0	2	/ 2
MC-13	Central reporting of TBS performance and energy use	3	3	3	3	3	3	3	3	2	3	/ 3
MC-25	Smart Grid Integration	1	2	1	1	1	0	1	2	0	0	/ 2
MC-28	Reporting information regarding demand side management performance and operation	2	2	2	2	2	-	2	2	-	-	/ 2
MC-29	Override of DSM control	4	4	4	4	4	-	4	4	-	-	/ 4
MC-30	Single platform that allows automated control & coordination between TBS + optimization of energy flow based on occupancy, weather and grid signals	3	3	3	3	3	2	3	3	2	2	/ 3